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USERS' GUIDE TO FOUR-BODY AND THREE-BODY TRAJECTORY OPTIMIZATION PROGRAMS

by

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USERS' GUIDE

to

Four-Body and Three-Body Trajectory Optimization Programs

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C. L. Pu and T. N. Edelbaum

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ABSTRACT

This users' guide documents a collection of computer programs and subroutines written in FORTRAN to calculate 4-body (sun-earth-moon space) and 3-body (earth-moon space) optimal trajectories. The programs incorporate a new variable step integration technique and a new quadrature formula to correct single step errors. These new features have resulted in significant improvement in efficiency and accuracy.

The programs provide capability to solve initial value problem, two point boundary value problem of a transfer from a given initial position to a given final position in fixed time, optimal 2-impulse transfer from an earth parking orbit of given inclination to a given final position and velocity in fixed time and optimal 3-impulse transfer from a given position to a given final position and velocity in fixed time.

INTRODUCTION

This users' guide documents a collection of computer programs and subroutines written in FORTRAN to calculate 4-body optimal trajectories under the combined influence of the sun, earth, and moon. Additional programs and subroutines have been provided so that 3-body optimal trajectories can be computed without the influence of the sun.

The method used in the extrapolation of the state vector and the solution of boundary value problems is essentially the same as presented in Ref. (1) and (2). However, the present programs incorporate a new variable step integration technique and a new quadrature formula to correct single step errors. These changes have resulted in significant improvement in efficiency and accuracy. The 4-body as well as the 3-body state extrapolation subroutine automatically determines the step size that will yield a fixed estimate of the single step position and velocity errors. The quadrature formula developed by T. N. Edelbaum is based on the 4th derivatives of the position error estimates at the beginning of a step and the second derivatives of the Stumpff-Weiss position errors at the end of the step.

In addition, two subroutines have been provided to compute target position and velocity in a Halo orbit about the L_1 libration point on the sun-earth line or one of the libration points on the earth-moon line. State vectors are now available also in rotating frames similar to the familiar barycentric frame commonly used in the restricted 3-body problem. These new features will be described in some detail.

PROGRAM ORGANIZATION

The 4-body and 3-body programs consist of 4 options. The name of a 3-body program is given in parenthesis following the name of a corresponding 4-body program.

Option 1: Program TRAJ (TRAJ3)
This option is a trajectory integration program to solve initial value problems.

Option 2: Program EXLAM (EXLAM3)
This option is a program to solve two point boundary value problem of a transfer from a given initial position to a given final position in fixed time using Newton-Raphson method.

Option 3: Program ETP2I (ETP2I3)
This option determines the optimal 2-impulse transfer from an earth parking orbit of given inclination to a given final position and velocity in fixed time. It employs an accelerated gradient projection method using Davidon's Variance algorithm.

Option 4: Program PTP3I (PTP3I3)
This option computes the optimal 3-impulse transfer from a given initial position to a given final position and velocity in fixed time. It uses an accelerated gradient method (Davidon's Variance algorithm) in the outer-loop and Newton-Raphson method in the second leg of the inner loop.

These 4 main programs call one or more of the following subroutines.

Subroutine	Function
FOURBY (THRBDY)	State extrapolation.
TWOBDY	2-body state extrapolation.
CSTEP (CSTEP3)	Computes single step size and error estimate at beginning of step.
DELRV (DELRV3)	Computes corrections by quadrature formula.
LAMB (LAMB3)	Solves Lambert problem.
CTAR (CTAR3)	Computes target position and velocity on a Halo orbit about a libration point. Called by ETP2I (ETP2I3).
COMIC (COMIC3)	Transforms input parameters with respect to earth into states with respect to sun (4-body) or earth (3-body).
COMFG (COMFG3)	Computes function and gradient in ETP2I (ETP2I3).

COMAUG	Forms augmented function and gradient in ETP2I (ETP2I3)
COMDX	Computes changes in independent variables in ETP2I (ETP2I3).
COMF (COMF3)	Computes function in PTP3I (PTP3I3).
COMG	Computes gradient in PTP3I (PTP3I3).
PVEC	Advances primer vectors and monitor its magnitude in FOURBY (THRBDY).
RVEMV	Computes state vectors in FOURBY. Not used in 3-body.
UPX	Updates variables and functions in ETP2I (ETP2I3).
DISP (DISP3)	Computes states in rotating coordinates for display.
PTRAJ (PTRAJ3)	Prints trajectory.
FDATA (FDATA3)	Files data for further processing outside of the program.

The main programs and the above mentioned subroutines will be described in some detail in the sections to follow. In addition, there are a number of service subroutines, which performs standard mathematical operations.

Service Subroutines	Function
MXV	Multiplication of a vector by a matrix, $\bar{a} = M\,\bar{b}$.
VVT	Outer product of a vector, $M = \bar{a}\,\bar{a}^T$.
DOT	Dot product of 2 vectors, $\bar{c} = \bar{a}^T\,\bar{b}$.
VMAG	Magnitude of a vector.
INVERT	Inversion of a matrix
UNITV	Unit vector of a vector
VXV	Cross product of 2 vectors, $\bar{a} = \bar{b} \times \bar{c}$.
MTRANS	Transpose a matrix, $N = M^T$.
MXM	Multiplication of 2 matrices, $C = M\,N$

These service subroutines will be listed but not discussed further.

A tabulation of the subroutines called by the main programs is given in Table 1.

Table 1 PROGRAMS AND SUBROUTINES

Program / Subroutine	TRAJ (TRAJ3)	EXLAM (EXLAM3)	ETP2I (ETP2I3)	PTP3I (PTP3I3)
FOURBY(THRBDY)	X	X	X	X
TWOBDY	X	X	X	X
CSTEP (CSTEP3)	X	X	X	X
DELRV (DELRV3)	X	X	X	X
COMIC (COMIC3)	X	X	X	
COMFG (COMFG3)			X	
COMF (COMF3)				X
COMG				X
LAMB (LAMB3)		X		X
COMAUG			X	
COMDX			X	
CTAR (CTAR3)			X	
UPX			X	
(1) RVEMV	X	X	X	X
PVEC	X	X	X	X
DISP (DISP3)	X	X	X	X
PTRAJ (PTRAJ3)	X	X	X	X
FDATA (FDATA3)	X	X	X	X
MXV	X	X	X	X
VVT	X	X	X	X
DOT	X	X	X	X
VMAG	X	X	X	X
INVERT		X	X	X
UNITV	X	X	X	X
VXV	X	X	X	X
MTRANS			X	X
MXM	X	X	X	X

Note: 1 Not used in 3-body programs.

COORDINATES SYSTEMS

The position or velocity vector of a body with respect to another body may be expressed in different coordinates systems at different stages of computation. These coordinates systems are described below.

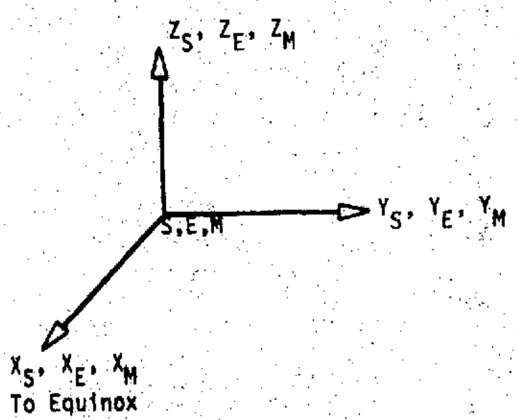
Coordinate Systems	Definition
S-frame (Basic computation frame in 4-body programs)	An inertial frame centered at the sun in which state extrapolation is performed. Since it is likely that input ephemerides will be obtained from JPL tapes, the X_S-Y_S plane will be the Ecliptic-Equinox plane of 1950.0, with the X_S-axis pointing in the Equinox direction.
E-frame (4-body)	An inertial frame centered at the earth parallel to S-frame.
M-frame (4-body)	An inertial frame centered at the moon parallel to S-frame.
e-frame (Basic computation frame in 3-body programs)	An inertial frame centered at the earth. The X_e-Y_e plane is the Equator-Equinox plane of 1950.0 with X_e pointing in the Equinox direction.
m-frame (3-body)	An inertial frame centered at the moon parallel to e-frame.
L-frame (4-body)	A rotating frame centered at the L_1 libration point used to define a target on a Halo orbit about L_1. The X_L-axis is along the line from the sun to the earth-moon barycenter. The Z_L-axis is along the total angular momentum vector of the earth and moon about the sun.
ℓ-frame (3-body)	A rotating frame centered at either L_1 or L_2 libration point to define a target on a Halo orbit. The X_ℓ-axis is along the line from the earth to the moon. The Z_ℓ-axis is along the angular momentum vector of the moon about the earth.

O-frame	An inertial frame centered at the earth. The X_O-Y_O plane is the parking orbit plane of an inclination i. The X_O-axis is along the line of ascending node.
D-frame (4-body)	A rotating frame centered at the earth used for display purpose. This frame is the equivalent of the rotating barycentric frame in a restricted 3-body problem. The X_D-axis is along the line from the sun to the earth. The Z_D-axis is along the angular momentum vector of the earth about the sun.
d-frame (3-body)	A rotating frame centered at the moon used for display purpose. The X_d-axis is along the line from the earth to the moon. The Z_d-axis is along the angular momentum vector of the moon about the earth.

These frames are shown in Figure 1.

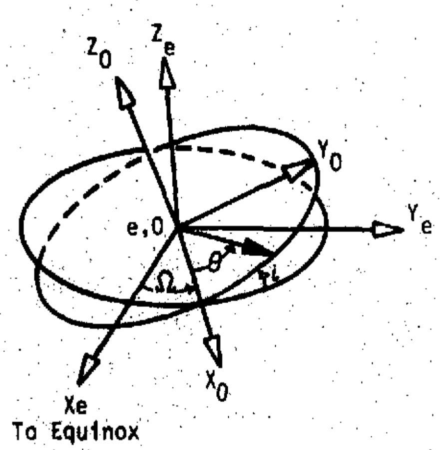
In general, when there is no ambiguity, a vector of a body A with respect to another body B will be written with subscripts BA. For example, $\overline{R}_{SV}$ will be a position vector of the vehicle with respect to the sun in the S-frame. Sometimes, it is necessary to add a superscript to indicate the frame in which the components are resolved. Thus, $\overline{\omega}_{SL}{}^S$ is the angular velocity of the L-frame with respect to the S-frame with components in the S-frame.

A transformation matrix will be denoted by a subscript and a superscript. It will transform a vector from the frame indicated by the subscript to the frame indicated by the superscript. For example $\overline{R}^L = C_S{}^L \, \overline{R}^S$ transforms $\overline{R}$ in S-frame to $\overline{R}$ in L-frame.



X-Y Plane parallel to Ecliptic-Equinox plane of 1950.0.

Figure 1a Inertial S, E, and M Frames



X_e-Y_e: Equator-Equinox plane of 1950.0.

Figure 1b Inertial e and O Frames

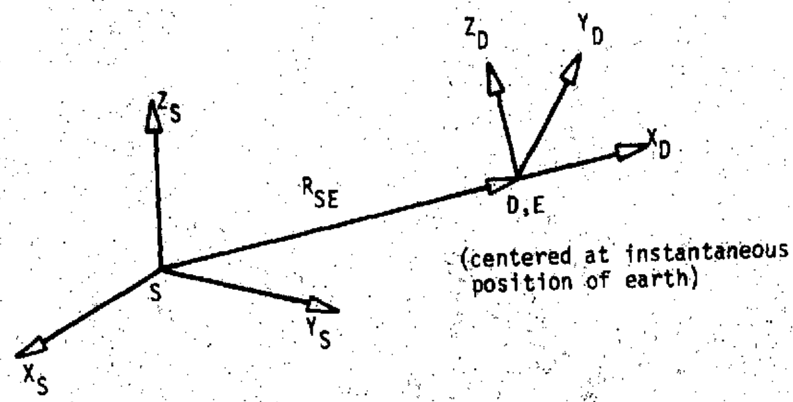


Figure 1c D-Frame

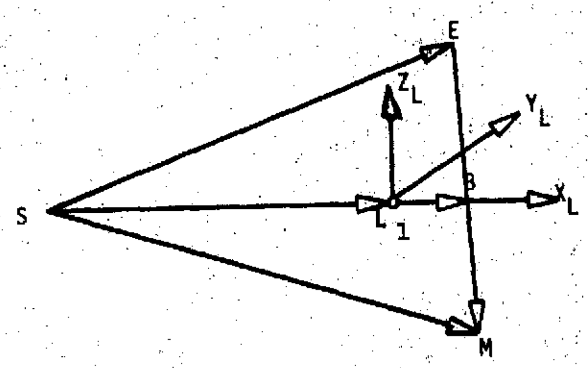


Figure 1d L-Frame

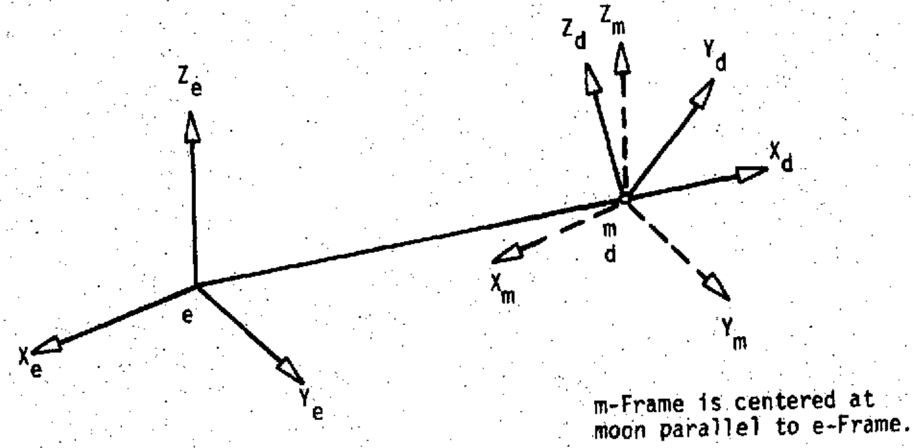


Figure 1e m and d Frames

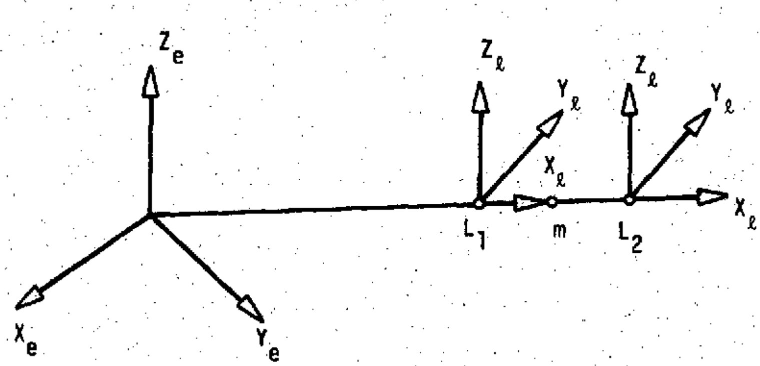


Figure 1f ℓ Frame

VARIABLE STEP INTEGRATION

The variable step integration technique used in subroutine FOURBY (THRBDY) is summarized here. The computation of step size and estimates of position errors, which is performed in subroutine CSTEP (CSTEPS), is an extension of D'Amario's derivation for the 3-body problem (Ref. 4). Let

$\bar{R}'(t+h)$ = approximate vehicle position determined by Stumpff-Weiss method

$\bar{R}(t+h)$ = true vehicle position

The position error at the end of a single step is

$$\bar{\epsilon}(t+h) = \bar{R}(t+h) - \bar{R}'(t+h) \tag{1}$$

Expanding Eq. (1) in Taylor series at t we obtain

$$\bar{\epsilon}(t+h) = \bar{\epsilon}(t) + \dot{\bar{\epsilon}}(t)h + \frac{1}{2}\ddot{\bar{\epsilon}}(t)\,h^2 + \frac{1}{6}\dddot{\bar{\epsilon}}(t)\,h^3 + \frac{1}{24}\ddddot{\bar{\epsilon}}(t)\,h^4 + O(h^5) \tag{2}$$

By definition,

$$\bar{\epsilon}(t) = 0 \tag{3}$$

It can be shown that

$$\dot{\bar{\epsilon}}(t) = \ddot{\bar{\epsilon}}(t) = \dddot{\bar{\epsilon}}(t) = 0 \tag{4}$$

The first non-zero term is the 4th derivative term. Neglecting all higher derivative terms the position error is given by

$$\bar{\epsilon}(t+h) \cong \ddddot{\bar{\epsilon}}(t)\,\frac{h^4}{24} \tag{5}$$

Let

$$\begin{aligned} |\bar{\epsilon}(t+h)| &= \epsilon_{max} \\ &= \text{allowable single step position error} \end{aligned} \tag{6}$$

Then, an estimate of step size is given by

$$h = \left(24\,\frac{\epsilon_{max}}{\ddddot{\bar{\epsilon}}(t)}\right)^{1/4} \tag{7}$$

In CSTEP we compute $\overline{\ddddot{\epsilon}}_{RSV}$ to estimate step size h and also $\overline{\ddddot{\epsilon}}_{RSE}$ and $\overline{\ddddot{\epsilon}}_{RSM}$ for for use in DELRV to compute error corrections. If we make the following definitions in a 4-body space,

$$
\begin{aligned}
G_{SV} &= \frac{\partial}{\partial \bar{R}_{SV}} \left[- \mu_S \frac{\bar{R}_{SV}}{R_{SV}^3} \right] = \frac{\partial}{\partial \bar{R}_{SV}} \left[\ddot{\bar{R}}_{SV} \right] \\
G_{EV} &= \frac{\partial}{\partial \bar{R}_{EV}} \left[- \mu_E \frac{\bar{R}_{EV}}{R_{EV}^3} \right] = \frac{\partial}{\partial \bar{R}_{EV}} \left[\ddot{\bar{R}}_{EV} \right] \\
G_{SE} &= \frac{\partial}{\partial \bar{R}_{SE}} \left[- \left(\mu_S + \mu_E \right) \frac{\bar{R}_{SE}}{R_{SE}^3} \right] = \frac{\partial}{\partial \bar{R}_{SE}} \left[\ddot{\bar{R}}_{SE} \right] \\
G_{MV} &= \frac{\partial}{\partial \bar{R}_{MV}} \left[- \mu_M \frac{\bar{R}_{MV}}{R_{MV}^3} \right] = \frac{\partial}{\partial \bar{R}_{MV}} \left[\ddot{\bar{R}}_{MV} \right] \\
G_{SM} &= \frac{\partial}{\partial \bar{R}_{SM}} \left[- \left(\mu_S + \mu_M \right) \frac{\bar{R}_{SM}}{R_{SM}^3} \right] = \frac{\partial}{\partial \bar{R}_{SM}} \left[\ddot{\bar{R}}_{SM} \right]
\end{aligned}
\tag{8}
$$

$$
\begin{aligned}
\delta \bar{g}_{SV} &= \overline{\ddot{R}}_{SV} - \left[\overline{\ddot{R}}_{SV} \right] \\
\delta \bar{g}_{EV} &= \overline{\ddot{R}}_{EV} - \left[\overline{\ddot{R}}_{EV} \right] \\
\delta \bar{g}_{SE} &= \overline{\ddot{R}}_{SE} - \left[\overline{\ddot{R}}_{SE} \right] \\
\delta \bar{g}_{MV} &= \overline{\ddot{R}}_{MV} - \left[\overline{\ddot{R}}_{MV} \right] \\
\delta \bar{g}_{SM} &= \overline{\ddot{R}}_{SM} - \left[\overline{\ddot{R}}_{SM} \right]
\end{aligned}
\tag{9}
$$

we can express the estimated errors by

$$
\begin{aligned}
\bar{\epsilon}_{RSV}(t+h) &= \Big\{ G_{SV}\,\delta\bar{g}_{SV} + G_{EV}\,\delta\bar{g}_{EV} + \frac{\mu_E}{\mu_S + \mu_E}\, G_{SE}\,\delta\bar{g}_{SE} \\
&\quad + G_{MV}\,\delta\bar{g}_{MV} + \frac{\mu_M}{\mu_S + \mu_M}\, G_{SM}\,\delta\bar{g}_{SM} \Big\} \frac{h^4}{24} + O(h^5) \\
\bar{\epsilon}_{RSE}(t+h) &= \Big\{ G_{SE}\,\delta\bar{g}_{SE} - \frac{\mu_M}{\mu_E + \mu_M}\, G_{EM}\delta\bar{g}_{EM} \\
&\quad + \frac{\mu_M}{\mu_S + \mu_M}\, G_{SM}\,\delta\bar{g}_{SM} \Big\} \frac{h^4}{24} + O(h^5) \\
\bar{\epsilon}_{RSM}(t+h) &= \Big\{ G_{SM}\,\delta\bar{g}_{SM} + \frac{\mu_E}{\mu_E + \mu_M}\, G_{EM}\,\delta\bar{g}_{EM} \\
&\quad + \frac{\mu_E}{\mu_S + \mu_E}\, G_{SE}\,\delta\bar{g}_{SE} \Big\} \frac{h^4}{24} + O(h^5)
\end{aligned}
\tag{10}
$$

In CSTEP3 we compute $\overline{\ddddot{\epsilon}_{REV}}$ to determine h and the error may be expressed by

$$
\overline{\epsilon_{REV}}(t+h) = \Big\{ G_{EV}\,\delta\bar{g}_{EV} + G_{MV}\,\delta\bar{g}_{MV} \Big\} \frac{h^4}{24} + O(h^5) \tag{11}
$$

Note that $\overline{\ddddot{\epsilon}_{REM}} = 0$ in a 3-body space.

CORRECTION OF ERRORS BY QUADRATURE FORMULAS

The quadrature formulas proposed by T. N. Edelbaum and used in subroutine DELRV (DELRV3) to compute a single step position and velocity corrections are presented here.

Assume the second derivative of the position error in a single step is given by

$$\ddot{\epsilon} = \frac{t^2}{2}\,(\bar{a} + \bar{b}\,t) \tag{12}$$

where

$$\bar{a} = \ddddot{\epsilon}(0) = \ddddot{\epsilon}_0 \tag{13}$$

Then the second derivative of the position error at the end of a singl step is given by

$$\ddot{\epsilon}_1 = \frac{h^2}{2}\,(\bar{a} + \bar{b}\,h) \tag{14}$$

Solving Eq. (14) and using Eq. (13),

$$\bar{b} = \frac{2\ddot{\epsilon}_1}{h^3} - \frac{\ddddot{\epsilon}_0}{h} \tag{15}$$

Integrating Eq. (12)

$$\dot{\epsilon} = \frac{\bar{a}\,t^3}{6} + \frac{\bar{b}\,t^4}{8} \tag{16}$$

$$\bar{\epsilon} = \frac{\bar{a}\,t^4}{24} + \frac{\bar{b}\,t^5}{40} \tag{17}$$

Using Eqs.(13) and (15) in (16) and (17), we obtain the following corrections at the end of a single step,

$$\dot{\epsilon}_1 = \frac{h}{4}\left(\ddddot{\epsilon}_0\,\frac{h^2}{6} + \ddot{\epsilon}_1\right) \tag{18}$$

$$\bar{\epsilon}_1 = \frac{h^2}{20}\left(\ddddot{\epsilon}_0\,\frac{h^2}{3} + \ddot{\epsilon}_1\right) \tag{19}$$

$\ddddot{\epsilon}_0$ is the 4th derivative of position error estimate at the beginning of a step and $\ddot{\epsilon}_1$ is the second derivative of Stumpff-Weiss error estimate at the end of the step.

INPUT PARAMETERS

The following input parameters are required for all 4 options.

Parameters	Symbol or Definition	Suggested Value
4-Body Programs:		
GL1	γ_{L1}	1.001098×10^{-2}
AUM	1 unit of distance in meters	$1.49597893 \times 10^{11}$ m
UTIME	1 unit of time in days	58.1323577631 days
UVELM	1 m/s in dimensionless velocity	$3.35742409867 \times 10^{-5}$
MS	μ_S (sun)	$9.99996959568 \times 10^{-1}$
ME	μ_E (earth)	$3.00348453188 \times 10^{-6}$
MM	μ_M (moon)	$3.69431224671 \times 10^{-8}$
RSE0	$\overline{R_{SE}}(t_o)$	
VSE0	$\overline{V_{SE}}(t_o)$	
RSM0	$\overline{R_{SM}}(t_o)$	
VSM0	$\overline{V_{SM}}(t_o)$	
3-Body Programs (Ref. 4 and 5)		
GAMMA	γ	$\gamma_{L1} = 0.150935$ $\gamma_{L2} = -0.167833$
UDM	1 unit of distance in meters	3.8441×10^{8} m
UTIME	1 unit of time	104.362/24 days
UVELM	1 m/s in dimensionless velocity	1/1023.17 m/s

ME	μ_E (earth)	.9878493
MM	μ_M (moon)	.0121507
REM0	$\overline{R_{EM}}(t_o)$	
VEM0	$\overline{V_{EM}}(t_o)$	

<u>Common to both 4- and 3-Body Programs:</u>

IPV	Flag to compute primer vector	IPV = 0, no 1, yes
IPTRAJ (IPTJX)	Flag to print trajectory each time step	IPTRAJ (IPTJX) = 0, no 1, yes
IFILEX (IFILE)	Flag to file data each time step	IFILEX (IFILE) = 0, no 1, yes
ERRMXM	Allowable single step position error in meters	150 m or higher
ERRMAX	Dimensionless ERRMXM	10^{-9} or higher
TDAY0	Starting time in days from reference date	
TRIPD	Trip time in days	

The following input parameters are required for Davidon's variance algorithm used in ETP2I (ETP2I3) and PTP3I (PTP3I3). See Ref. 2, Appendix A.

EPS	ϵ	10^{-11} for ETP2I (ETP2I3) 10^{-3} for PTP3I (PTP3I3)

V	V	Davidon's Variance matrix. If ICOMV = 1, this input is not needed and the program will compute an estimate. Once a working V matrix has been developed through iterations, it should be used in a new run to continue iteration.
ICOMV		Flag to compute V. ICOMV = 0, no (input V) 1, yes
EPSV		Small number to scale down V matrix if ICOMV = 1. It specifies the magnitude of the first step in the gradient direction. A typical value is about 10^{-5}.

PROGRAM TRAJ (TRAJ3)

A. Input Parameters

Parameters	Symbol	Definition/Value
IMODE		Mode to select input IMODE = 1, 2, or 3
	IMODE = 1	
REVMAG	$\lvert\bar{R}_{EV}(t_o)\rvert$	$4.38739157152 \times 10^{-5}$ for 100 n.m. parking orbit.
VEVMAG	$\lvert\bar{V}_{EV}{}^{+}(t_o)\rvert$	Estimate of departure velocity magnitude with respect to earth.
OINCD	i (deg)	Inclination of earth parking orbit.
OBLD (not used in 3-body)	OBL (deg)	Obliquity angle = 23.44578743018259 deg between E-frame and e-frame.
THED	θ (deg)	Position of vehicle from ascending node in orbital plane.
LOND	Ω (deg)	Longitude of ascending node.
	IMODE = 2	
REV0	$\bar{R}_{EV}(t_o)$	
VEV0P	$\bar{V}_{EV}{}^{+}(t_o)$	
	IMODE = 3	
RSV0	$\bar{R}_{SV}(0)$	
VSVI	$\bar{V}_{SV}{}^{+}(0)$	

B. Computation

Inputs of IMODE = 1 or 2 are converted into position and velocity of vehicle in S-frame or e-frame. The initial states are propagated to the final time using subroutine FOURBY (THRBDY).

C. Output Parameters

Terminal states are printed out. States at each time step will be printed out if IPTRAJ = 1 and they will be filed if IFILE = 1.

PROGRAM EXLAM (EXLAM3)

A. Input Parameters

Parameters	Symbol/Unit	Definition/Value
IMODE		Mode to select input IMODE = 1 or 2

Same inputs for IMODE = 1, 2 as shown under PROGRAM TRAJ (TRAJ3)

Parameters	Symbol/Unit	Definition/Value
ERRMIN	ϵ_{MIN}	Allowable error for stopping Newton-Raphson method (10^{-10})
KNR		Initial estimate of change in initial velocity magnitude (1)
ITLMAX		Maximum number of iterations (50)
RSVTAR	$\bar{R}_{SV}(t_f)$	Target position
IPTJX		Flag to compute and print trajectory after convergence IPTJX = 0, no 1, yes
IFILEX		Flag to compute and file trajectory after convergence IFILEX = 0, no 1, yes

B. Computation

Program calls subroutine LAMB (LAMB3) to solve the boundary value problem.

C. Output Parameters

Outputs are given under subroutine LAMB (LAMB3). If either IPTJX = 1 or IFILEX = 1, the trajectory after convergence will be printed or filed or both.

PROGRAM ETP2I (ETP2I3)

A. Input Parameters

Parameter	Symbol	Definition
ITAR		Flag to input or compute target ITAR = 0, compute 1, input
REVMAG	$\|\bar{R}_{EV}(t_o)\|$	
OINCD	ι (deg)	
OBLD	OBL (deg)	
TDAY0	t_o (deg)	
TTRIPD		$t_f - t_o$ (day)
VEVMAG	$\|\bar{V}_{EV}(t_o)\|$	
LOND	Ω (deg)	
THED	θ (deg)	
KDX		Initial value of constraint restoration parameter (start with KDX = 1)
EPSV		V-matrix scaling
EPSTSI		Allowable constraint violation (10^{-10})
ITERMX		Max. No. of iterations
ITAR = 0:		Parameter to define target on Halo orbit.
AYM	A_y(m)	$A_y = 2 \times 10^5$ km
AZM	A_z(m)	$A_z = 1 \times 10^5$ km
ATARD	A_{TAR} (deg)	A_{TAR} = Target position measured from X_L or X_ℓ axis.
4-Body:		
RSE0	$\bar{R}_{SE}(t_o)$	
VSE0	$\bar{V}_{SE}(t_o)$	
RSM0	$\bar{R}_{SM}(t_o)$	
VSM0	$\bar{V}_{SM}(t_o)$	

ITAR = 1:

RSVTAR	$\overline{R}_{SVTAR}(t_f)$
VSVTAR	$\overline{V}_{SVTAR}(t_f)$

3-Body:

REM0	$\overline{R}_{EM}(t_o)$
VEM0	$\overline{V}_{EM}(t_o)$

ITAR = 1:

REVTAR	$\overline{R}_{EVTAR}(t_f)$
VEVTAR	$\overline{V}_{EVTAR}(t_f)$

B. Computation

See Ref. 2 appendix, program listing and flow chart.

C. Internal Parameters

ALPHA, BETA	Davidon algorithm parameters
ALPHAM, BETAM	Davidon algorithm parameters

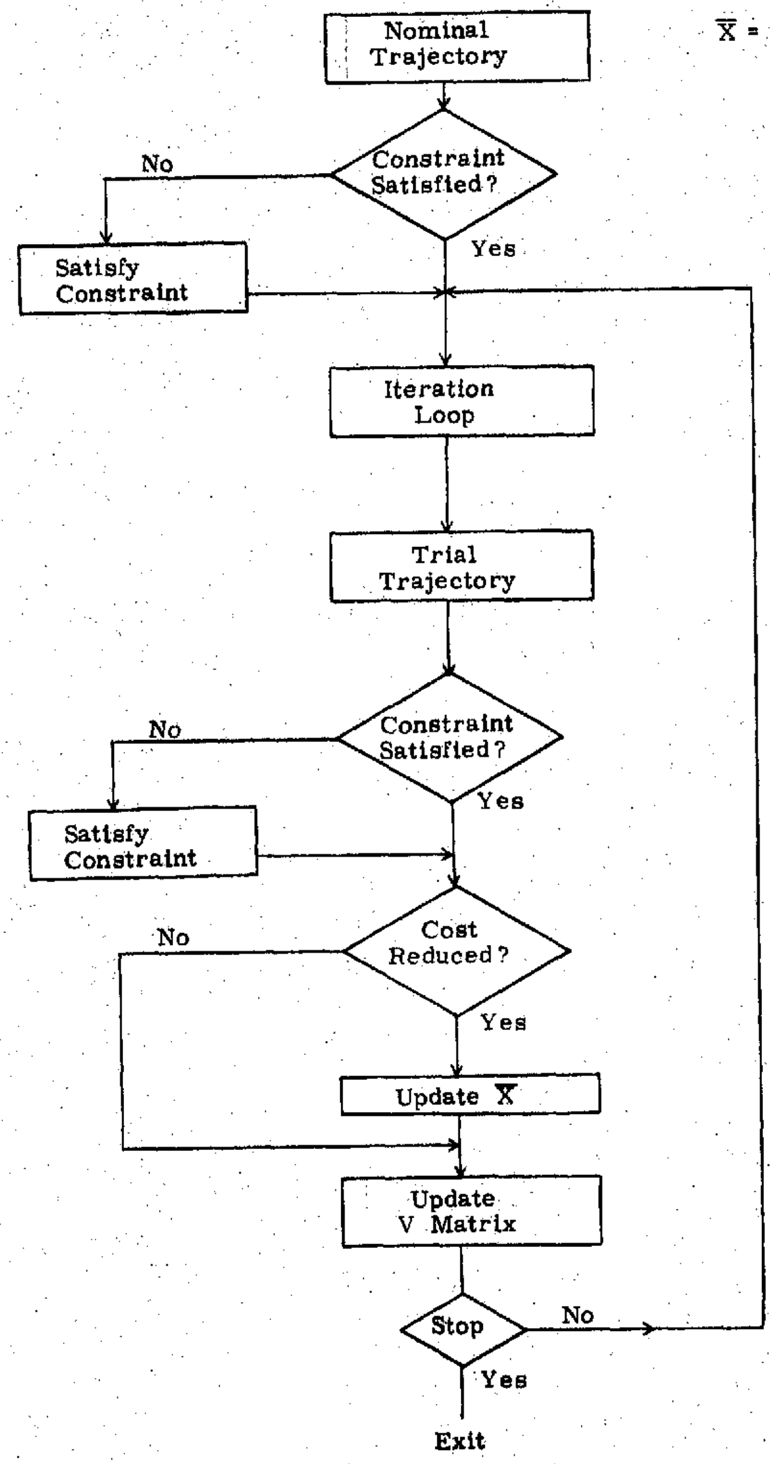
Current Variables	Trial Variables	Dummy Variables	
X	XS	XD	Independent variables
F	FS	FD	Cost
G	GS	GD	Cost gradient
FG	FGS	FGD	Augmented cost
TSI	TSIS	TSID	Constraint violation
LT	LTS	LTD	Constraint gradient
GG	GGS	GGD	Augmented cost gradient
TESTR	TESTRS	TESTRD	Magnitude of constraint violation
KDX			Constraint restoration scaling (internally adjusted)

KV	V matrix internal scaling (internally determined)
R	Parameters to compute quantities to update V matrix
P	Estimate of twice the excess of cost above its minimum value. If P < EPS, the problem is considered to be converged.

Program ETP21 and ETP213

$\overline{X}$ = Independent Variables

$\overline{X} = \left(|\overline{V}_{EV}(t_o)|, \ \Omega, \ \theta \right)$



PROGRAM PTP3I (PTP3I3)

A. Input Parameters

Parameters	Symbol	Definition
4-Body:		
RSV0	$\overline{R}_{SV}(t_o)$	
VSV0	$\overline{V}_{SV}^{-}(t_o)$	Velocity before initial impulse
VSVI	$\overline{V}_{SV}^{+}(t_o)$	Velocity after initial impulse
RSE0	$\overline{R}_{SE}(t_o)$	
VSE0	$\overline{V}_{SE}(t_o)$	
RSM0	$\overline{R}_{SM}(t_o)$	
VSM0	$\overline{V}_{SM}(t_o)$	
VSVMP	$\overline{V}_{SM}^{+}(t_m)$	Velocity after interior impulse
TM	t_m	Time of interior impulse
RSVTAR	$\overline{R}_{SVTAR}(t_f)$	Target position
VSVTAR	$\overline{V}_{SVTAR}(t_f)$	Target velocity
3-Body:		
REV0	$\overline{R}_{EV}(t_o)$	
VEV0	$\overline{V}_{EV}^{-}(t_o)$	Velocity before impulse
VEV0P	$\overline{V}_{EV}^{+}(t_o)$	Velocity after impulse
REM0	$\overline{R}_{EM}(t_o)$	
VEM0	$\overline{V}_{EM}(t_o)$	
VEVMP	$\overline{V}_{EV}^{+}(t_m)$	Velocity after interior impulse
TM	t_m	Time of interior impulse

Common to 4-Body and 3-Body:

ITLMAX	Maximum number of Lambert iterations
ILINC	Number of increments to solve Lambert problem
ITDMAX	Maximum number of Davidon iterations
FMINM	Estimated minimun value of ΔV (m/s)
KNR	Lambert iteration parameter (use KNR = 1 to start)
ERRMIN	Allowable constraint violation (10^{-10})

B. Computation

See Ref. 2, program listing and flow chart.

C. Internal Parameters

SG	Projection of cost gradient on search direction.
ALPHA	Step size in search direction
SGS	Projection of trial point cost gradient on search direction. Its sign is used to determine whether as interpolation or a reduction of interval is to be made.
R, RC	Parameters to update V matrix. R used in trial step. RC used in interpolation.
ALPHAC	Step size in search direction determined by cubic interpolation.
P, PC	Parameters to update V matrix. P used in trial step. PC used in interpolation

EPS	If magnitude of cost gradient is less then EPS, the problem is considered to be converged.
F	Cost
GMAG	Magnitude of cost gradient.
GSMAG	Magnitude of cost gradient of a trial point.
GCMAG	Magnitude of cost gradient of an interpolated point.
RMAG	Magnitude of R.
RCMAG	Magnitude of RC.
FS	Cost of a trial point.
FC	Cost of an interpolated point.
DG	Difference in cost gradient.
DX	Change in independent variable to compute a trial point.
DXC	Change in independent variable to compute an interpolated point.
PVMMAG, PVPMAG	See subroutine COMG

D. Stopping Options

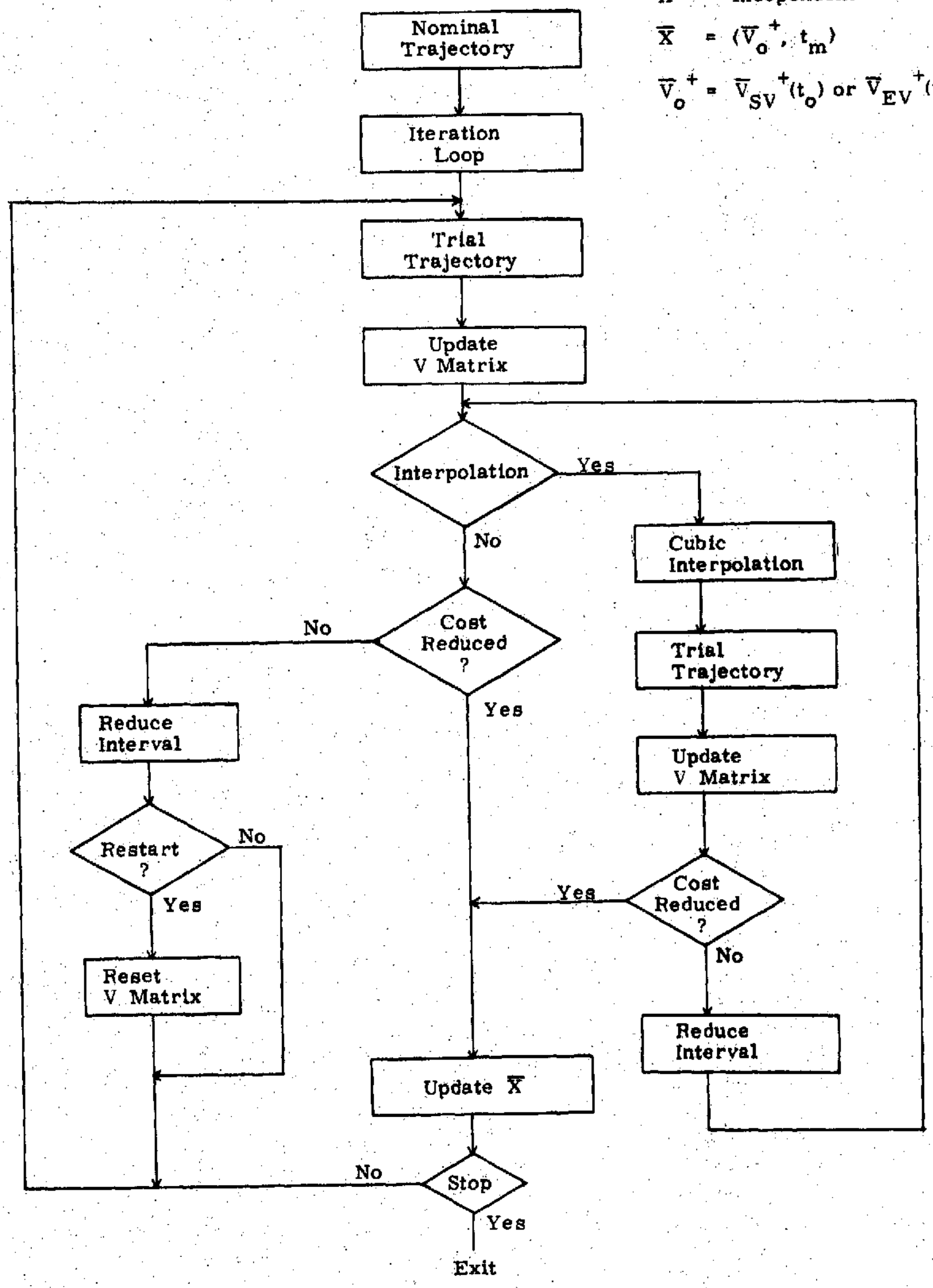
The programmed stopping condition is when GMAG is reduced to less than EPS. However, one should stop the iteration if F is not decreasing significantly from one iteration to the next. On the other hand, it may be necessary to continue iteration to satisfy the condition that PVMMAG is nearly equal to PVPMAG. (See comment in Ex. 4.)

Program PTP3I and PTP313

$\overline{X}$ = Independent Variables

$\overline{X} = (\overline{V}_o^+, t_m)$

$\overline{V}_o^+ = \overline{V}_{SV}^+(t_o)$ or $\overline{V}_{EV}^+(t_o)$



INPUT DATA DECKS

Program TRAJ

Card No.	Format	Parameters
1	4D20.11	GL1, AUM, UTIME, UVELM
2	3D20.11	MS, ME, MM
3	4I5	IMODE, IPV, IPTRAJ, IFILE
4	4D20.11	RSE0(1), RSE0(2), RSE0(3), VSE0(1)
5	4D20.11	VSE0(2), VSE0(3), RSM0(1), RSM0(2)
6	4D20.11	RSM0(3), VSM0(1), VSM0(2), VSM0(3)
7	3D20.11	TDAY0, TRIPD, ERRMXM

The above 7 input cards are needed for all modes. The following 2 cards depend on the mode selected

IMODE = 1

8	4D20.11	REVMAG, VEVMAG, OINCD, OBLD
9	2D20.11	LOND, THED

IMODE = 2

8	4D20.11	REV0(1), REV0(2), REV0(3), VEV0P(1)
9	2D20.11	VEV0P(2), VEV0P(3)

IMODE = 3

8	4D20.11	RSV0(1), RSV0(2), RSV0(3), VSVI(1)
9	2D20.11	VSVI(2), VSVI(3)

The following 2 input cards are needed if IPV = 1

10	4D20.11	PV0(1), PV0(2), PV0(3), PV0(4)
11	2D20.11	PV0(5), PV0(6)

Program TRAJ3

Card No.	Format	Parameters
1	4D20.11	GAMMA, UDM, UTIME, UVELM
2	2D20.11	ME, MM
3	4D20.11	IMODE, IPV, IPTRAJ, IFILE
4	4D20.11	REM0(1), REM0(2), REM0(3), VEM0(1)
5	2D20.11	VEM0(2), VEM0(3)
6	3D20.11	TDAY0, TRIPD, ERRMXM

The above 6 input cards are needed for all modes. The following 2 cards depend on the mode selected.

IMODE = 1

7	4D20.11	REVMAG, VEVMAG, OINCD, LOND
8	1D20.11	THED

IMODE = 2

7	4D20.11	REV0(1), REV0(2), REV0(3), VEV0P(1)
8	2D20.11	VEV0P(2), VEV0P(3)

The following 2 cards are needed if IPV = 1

9	4D20.11	PV0(1), PV0(2), PV0(3), PV0(4)
10	2D20.11	PV0 (5), PV0(6)

Program EXLAM

Card No.	Format	Parameters
1	4D20.11	GL1, AUM, UTIME, UVELM
2	3D20.11	MS, ME, MM
3	4I5	IMODE, ITLMAX, IPTJX, IFILEX
4	4D20.11	RSE0(1), RSE0(2), RSE0(3), VSE0(1)
5	4D20.11	VSE0(2), VSE0(3), RSM0(1), RSM0(2)
6	4D20.11	RSM0(3), VSM0(1), VSM0(2), VSM0(3)
7	3D20.11	TDAY0, TRIPD, ERRMXM
8	4D20.11	RSVTAR(1), RSVTAR(2), RSVTAR(3), ERRMIN
9	1D20.11	KNR

The above 9 cards are needed for all modes. The following cards depend on the mode selected.

IMODE = 1

10	4D20.11	REVMAG, VEVMAG, OINCD, OBLD
11	2D20.11	LOND, THED

IMODE = 2

10	4D20.11	REV0(1), REV0(2), REV0(3), VEV0P(1)
11	2D20.11	VEV0P(2), VEV0P(3)

IMODE = 3

10	4D20.11	RSV0(1), RSV0(2), RSV0(3), VSVI(1)
11	2D20.11	VSVI(2), VSVI(3)

Program EXLAM3

Card No.	Format	Parameters
1	4D20.11	GAMMA, UDM, UTIME, UVELM
2	2D20.11	ME, MM
3	4I5	IMODE, ITLMAX, IPTJX, IFILEX
4	4D20.11	REM0(1), REM0(2), REM0(3), VEM0(1)
5	2D20.11	VEM0(2), VEM0(3)
6	3D20.11	TDAY0, TRIPD, ERRMXM
7	4D20.11	REVTAR(1), REVTAR(2), REVTAR(3), ERRMIN
8	1D20.11	KNR

The above 8 cards are needed for all modes. The following cards depend on the mode selected.

IMODE = 1

9	4D20.11	REVMAG, VEVMAG, OINCD, LOND
10	1D20.11	THED

IMODE = 2

9	4D20.11	REV0(1), REV0(2), REV0(3), VEV0P(1)
10	2D20.11	VEV0P(2), VEV0P(3)

Program ETP2I

Card No.	Format	Parameters
1	4D20.11	GLI, AUM, UTIME, UVELM
2	3D20.11	MS, ME, MM
3	4D20.11	REVMAG, OINCD, OBLD, ERRMXM
4	2D20.11	TDAY0, TTRIPD
5	3D20.11	VEVMAG, LOND, THED
6	4D20.11	RSE0(1), RSE0(2), RSE0(3), VSE0(1)
7	4D20.11	VSE0(2), VSE0(3), RSM0(1), RSM0(2)
8	4D20.11	RSM0(3), VSM0(1), VSM0(2), VSM0(3)
9	4D20.11	EPS, EPSTSI, KDX, EPSV
10	4I5	ICOMV, ITERMX, IFILEX, ITAR

The next 1 or 2 cards depend on ITAR.

ITAR = 0

11	3D20.11	AYM, AYZ, ATARD

ITAR = 1

11	4D20.11	RSVTAR(1), RSVTAR(2), RSVTAR(3), VSVTAR(1)
12	2D20.11	VSVTAR(2), VSVTAR(3)

The following 3 cards are needed only if ICOMV = 0.

13	4D20.11	V(1, 1), V(1, 2), V(1, 3), V(2, 1)
14	4D20.11	V(2, 2), V(2, 3), V(3, 1), V(3, 2)
15	4D20.11	V(3, 3)

Program ETP213

Card No.	Format	Parameters
1	4D20.11	GAMMA, UDM, UTIME, UVELM
2	2D20.11	ME, MM
3	3D20.11	REVMAG, OINCD, ERRMXM
4	2D20.11	TDAY0, TTRIPD
5	3D20.11	VEVMAG, LOND, THED
6	4D20.11	REM0(1), REM0(2), REM0(3), VEM0(1)
7	2D20.11	VEM0(2), VEM0(3)
8	4D20.11	EPS, EPSTSI, KDX, EPSV
9	4I5	ICOMV, ITERMX, IFILEX, ITAR

The next 1 or 2 cards depend on ITAR.

ITAR = 0

10	3D20.11	AYM, AZM, ATARD

ITAR = 1

11	4D20.11	REVTAR(1), REVTAR(2), REVTAR(3), VEVTAR(1)
12	2D20.11	VEVTAR(2), VEVTAR(3)

The following 3 cards are needed only if ICOMV = 0.

13	4D20.11	V(1, 1), V(1, 2), V(1, 3), V(2, 1)
14	4D20.11	V(2, 2), V(2, 3), V(3, 1) V(3, 2)
15	4D20.11	V(3, 3)

Program PTP3I

Card No.	Format	Parameters
1	4D20.11	GL1, AUM, UTIME, UVELM
2	3D20.11	MS, ME, MM
3	3D20.11	TSTART, TM, TEND
4	4D20.11	RSE0(1), RSE0(2), RSE0(3), VSE0(1)
5	4D20.11	VSE0(2), VSE0(3), RSM0(1), RSM0(2)
6	4D20.11	RSM0(3), VSM0(1), VSM0(2), VSM0(3)
7	4D20.11	RSV0(1), RSV0(2), RSV0(3), VSV0(1)
8	2D20.11	VSV0(2), VSV0(3)
9	4D20.11	VSVI(1), VSVI(2), VSVI(3), VSVMP(1)
10	2D20.11	VSVMP(2), VSVMP(3)
11	4D20.11	RSVTAR(1), RSVTAR(2), RSVTAR(3), VSVTAR(1)
12	2D20.11	VSVTAR(2), VSVTAR(3)
13	3D20.11	KNR, ERRMIN, ERRMXM
14	3D20.11	FMINM, EPS, EPSV
15	5I5	ICOMV, ITLMAX, ILINC, ITDMAX, IFILEX

The following 4 cards are needed only if ICOMV = 0.

Card No.	Format	Parameters
16	4D20.11	V(1, 1), V(1, 2), V(1, 3), V(1, 4)
17	4D20.11	V(2, 1), V(2, 2), V(2, 3), V(2, 4)
18	4D20.11	V(3, 1), V(3, 2), V(3, 3), V(3, 4)
19	4D20.11	V(4, 1), V(4, 2), V(4, 3), V(4, 4)

Program PTP3I3

Card No.	Format	Parameters
1	4D20.11	GAMMA, UDM, UTIME, UVELM
2	2D20.11	ME, MM
3	3D20.11	TSTART, TM, TEND
4	4D20.11	REM0(1), REM0(2), REM0(3), VEM0(1)
5	2D20.11	VEM0(2), VEM0(3)
6	4D20.11	REV0(1), REV0(2), REV0(3), VEV0(1)
7	2D20.11	VEV0(2), VEV0(3)
8	4D20.11	VEV0P(1), VEV0P(2), VEV0P(3), VEVMP(1)
9	2D20.11	VEVMP(2), VEVMP(3)
10	4D20.11	REVTAR(1), REVTAR(2), REVTAR(3), VEVTAR(1)
11	2D20.11	VEVTAR(2), VEVTAR(3)
12	3D20.11	KNR, ERRMIN, ERRMXM
13	3D20.11	FMINM, EPS, EPSV
14	5I5	ICOMV, ITLMAX, ILINC, ITDMAX, IFILEX

The following 4 cards are needed only if ICOMV = 0.

Card No.	Format	Parameters
15	4D20.11	V(1, 1), V(1, 2), V(1, 3), V(1, 4)
16	4D20.11	V(2, 1), V(2, 2), V(2, 3), V(2, 4)
17	4D20.11	V(3, 1), V(3, 2), V(3, 3), V(3, 4)
18	4D20.11	V(4, 1), V(4, 2), V(4, 3), V(4, 4)

PROGRAM PRINTOUT DESCRIPTION

ALPHA	Step size in search direction or Davidon algorithm parameter
ALPHAC	Step size in cubic interpolation
ANGE	Subtended angle at earth (deg)
ANGM	Subtended angle at moon (deg)
ANGS	Subtended angle at sun (deg)
ANGV	Subtended angle at spacecraft (deg)
ATARD	Parameter to define Halo orbit (deg)
AUM	1 Unit of distance in meters (4-body)
AYM	Parameter to define Halo orbit (meter)
AZM	Parameter to define Halo orbit (meter)
BETA	Davidon algorithm parameter
DG	Cost gradient difference
DELX	Change in independent variables
DGC	Cost gradient difference
DRM	Change in interior impulse position
DUVI	Primer vector derivative at initial time
DUVMM	Primer vector derivative before interior impulse
DUVMP	Primer vector derivative after interior impulse
DV	Cost
DVI	Impulse at initial time
DVIMAG	Magnitude of initial impulse
DVM	Interior impulse
DVMMAG	Magnitude of interior impulse

DVMPX	Change in interior impulse
DVF	Impulse at terminal time
DVFMAG	Magnitude of terminal impulse
DVFMPS	Cost of terminal impulse (MPS)
DVIMPS	Cost of initial impulse (MPS)
DVMPS	Total cost (MPS)
DVMMPS	Cost of interior impulse (MPS)
DX	Change in independent variables
DXC	Change in independent variables
EPS	Parameter to terminate Davidon iterations
EPSTSI	Allowable terminal constraint violation
EPSV	Factor to scale down variance matrix
ERR	Constraint violation in Lambert iteration
ERRMAX	Allowable single step position error
ERRMIN	Allowable Lambert constraint violation
ERRMXM	Allowable single step position error (meter)
F	Cost
FC	Cost in cubic interpolation
FD	Cost
FG	Augmented cost
FGS	Augmented cost
FMINM	Estimated cost (MPS)
FS	Cost
G	Cost gradient

GAMMA	Parameter to define libration point (3-body)
GC	Cost gradient in cubic interpolation
GCMAG	Magnitude of cost gradient
GD	Cost radient
GG	Augmetned cost gradient
GGS	Augmented cost gradient
GL1	Parameter to define L1 libration point (4-body)
GMAG	Magnitude of cost gradient
GS	Cost gradient
GSMAG	Magnitude of cost gradient
H	Computed step size in state extrapolation
HDAY	Step size in days
ICOMV	Flag to compute variance matrix
IFILE	Flag to file trajectory data
IFILEX	Flag to file trajectory data
ILINC	Number of Lambert increments
IMODE	Flag to select mode of initial condition
IMTX	Flag to compute state transition matrix
IPTJX	Flag to print trajectory
IPTRAJ	Flag to print trajectory
IPV	Flag to compute primer vector
IPVTM	Flag to monitor primer vector magnitude history
ISTEP	Number of integration steps
ITAR	Flag to compute target position and velocity on Halo orbit

ITDMAX	Maximum number of Davidon iterations
ITER	Number of iteration in Lambert routine
ITERD	Number of Davidon iterations
ITERL	Number of Lambert increment
ITERMX	Maximum of Davidon iterations
ITLMAX	Maximum number of Lambert iterations
KDX	Parameter to scale independent variables in constraint restoration
KNR	Parameter to scale independent variables in Lambert iteration
KV	Parameter to scale variance matrix
LDM	Derivative of primer vector magnitude
LDTM	Derivative of maximum primer vector magnitude
LOND	Longitude of ascending node (deg)
LM	Magnitude of primer vector
LT	Constraint gradient matrix
LTM	Maximum primer vector magnitude
ME	Gravitational constant of earth
MM	Gravitational constant of moon
MS	Gravitational constant of sun
OBLD	Obliquity angle (deg)
OINCD	Orbital inclination (deg)
P	Davidon algorithm parameter (iteration stops if P is less than EPS in ETP2I or ETP2I3)
PC	Davidon algorithm parameter
PV	Primer vector and derivative
PVO	Primer vector and derivative at initial time

PVMMAG	Projection of primer vector derivative on primer vector before interior impulse
PVPMAG	Projection of primer vector derivative on primer vector after interior impulse
R	Davidon algorithm parameters
RC	Davidon algorithm parameters in cubic interpolation
RCMAG	Magnitude of RC
RDED	Position of earth in rotating coordinates
RDL1D	Position of L1 libration point in rotating coordinates
RDMD	Position of moon in rotating coordinates
RDSD	Position of sun in rotating coordinates
RDVD	Position of spacecraft in rotating coordinates
REL	Position of libration point wrt earth
REM	Position of moon wrt earth
REMO	Position of moon wrt earth at initial time
REMF	Position of moon wrt earth at terminal time
REV	Position of spacecraft wrt earth
REVF	Position of spacecraft wrt earth at terminal time
REVM	Position of spacecraft wrt earth at interior impulse time
REVMAG	Distance of spacecraft to earth
REVMX	Change of position of spacecraft wrt earth at interior impulse time
REVO	Position of spacecraft wrt earth at initial time
REVMD	Position of spacecraft wrt earth at interior impulse time
REVTAR	Target position wrt earth

RLTARL	Target position wrt libration point
RMAG	Magnitude of R
RMV	Position of spacecraft wrt moon
RMVF	Position of spacecraft wrt moon at terminal time
RMVMAG	Distance of spacecraft to moon
RSE	Position of earth wrt sun
RSEO	Position of earth wrt sun at initial time
RSEF	Position of earth wrt sun at terminal time
RSL1	Position of L1 libration point wrt sun
RSM	Position of moon wrt sun
RSMO	Position of moon wrt sun at initial time
RSMF	Position of moon wrt sun at terminal time
RSV	Position of spacecraft wrt sun
RSVO	Position of spacecraft wrt sun at initial time
RSVF	Position of spacecraft wrt sun at terminal time
RSVM	Position of spacecraft wrt sun at interior impulse time
RSVMAG	Distance of spacecraft to sun
RSVMD	Position of moon wrt sun at interior impulse time
RSVMX	Spacecraft position wrt sun at interior impulse
RSVTAR	Target position wrt sun
RTM	Position of spacecraft at maximum primer vector magnitude
S	Davidon algorithm search direction
SG	Projection of cost gradient on search direction
SGS	Projection of cost gradient on search direction

T	Time
TO	Initial time
TDAY	Time in day
TDAYO	Initial time in day
TDAYF	Terminal time in day
TEND	Terminal time
TESTR	Magnitude of constraint violation
TESTRD	Magnitude of constraint violation
TESTRS	Magnitude of constraint violation
TF	Terminal time
THED	Position of spacecraft from line of node (deg)
TM	Interior impulse time
TRIPD	Trip time in day
TSI	Constraint violation
TSID	Constraint violation
TSIS	Constraint violation
TSTART	Initial time
TTM	Time of maximum primer vector magnitude
TTRIP	Trip time
TTRIPD	Trip time in day
UDM	1 Unit of distance in meters (3-body)
UTIME	1 Unit of time in days
UVELM	1 MPS in dimensionless velocity
UVF	Unit vector of terminal impulse

UVI	Unit vector of initial impulse
UVM	Unit vector of interior impulse
V	Variance matrix
VDED	Velocity of earth in rotating coordinates
VDL1D	Velocity of L1 libration point in rotating coordinates
VDMD	Velocity of moon in rotating coordinates
VDSD	Velocity of sun in rotating coordinates
VDVD	Velocity of spacecraft in rotating coordinates
VEL	Velocity of libration point wrt earth
VEM	Velocity of moon wrt earth
VEMO	Velocity of moon wrt earth at initial time
VEMF	Velocity of moon wrt earth at terminal time
VEV	Velocity of spacecraft wrt earth
VEVO	Velocity of spacecraft wrt earth at initial time before impulse
VEVOP	Velocity of spacecraft wrt earth after initial impulse
VEVMP	Velocity of spacecraft wrt earth after interior impulse
VEVMPX	Spacecraft velocity wrt earth after interior impulse
VEVF	Velocity of spacecraft wrt earth at terminal time
VEVMAG	Magnitude of spacecraft velocity wrt earth
VEVMPD	Velocity of spacecraft wrt earth after interior impulse
VEVMPS	Magnitude of spacecraft velocity wrt earth in MPS
VEVTAR	Target velocity wrt earth
VIT	Initial velocity in Lambert iteration
VLTARL	Velocity of target wrt libration point

VMV	Velocity of spacecraft wrt moon
VMVF	Velocity of spacecraft wrt moon at terminal time
VSE	Velocity of earth wrt sun
VSEO	Velocity of earth wrt sun at initial time
VSEF	Velocity of earth wrt sun at terminal time
VSL1	Velocity of L1 libration point wrt sun
VSM	Velocity of moon wrt sun
VSMO	Velocity of moon wrt sun at initial time
VSMF	Velocity of moon wrt sun at terminal time
VSV	Velocity of spacecraft wrt sun
VSVI	Velocity of spacecraft wrt sun after initial impulse
VSVMPX	Spacecraft velocity wrt sun after interior impulse
VSVF	Velocity of spacecraft wrt sun at terminal time
VSVMP	Velocity of spacecraft wrt sun after interior impulse
VSVMPD	Velocity of spacecraft wrt sun after interior impulse
VSVO	Velocity of spacecraft wrt sun at initial time before impulse
VSVTAR	Target velocity wrt sun
VTM	Velocity of spacecraft at maximum primer vector magnitude
X	Independent variables in Davidon iterations
XC	Independent variables in cubic interpolation.
XD	Independent variables
XS	Independent variables

Subroutine FOURBY

A. Input Parameters

Parameter	Symbol	Definition
XT0	t_o	
XTF	t_f	
RSV0	$\overline{R}_{SV}(t_o)$	
VSV0	$\overline{V}_{SV}(t_o)$	
RSE0	$\overline{R}_{SE}(t_o)$	
VSE0	$\overline{V}_{SE}(t_o)$	
RSM0	$\overline{R}_{SM}(t_o)$	
VSM0	$\overline{V}_{SM}(t_o)$	
PV0	$\overline{\lambda}(t_o)$, $\dot{\overline{\lambda}}(t_o)$	Primer vector and derivative

B. Output Parameters

RSVD	$\overline{R}_{SV}(t_f)$	
VSVD	$\overline{V}_{SV}(t_f)$	
RSED	$\overline{R}_{SE}(t_f)$	
VSED	$\overline{V}_{SE}(t_f)$	
RSMD	$\overline{R}_{SM}(t_f)$	
VSMD	$\overline{V}_{SM}(t_f)$	
S11, S12, S21, S22	$\varphi\ (t_f, t_o)$	State transition matrix

C. Computation

Step 1. Initialize running variables equal to input states.

Step 2. Call RVEMV to compute $\overline{R}_{EV}$, $\overline{V}_{EV}$, $\overline{R}_{MV}$, $\overline{V}_{MV}$, $\overline{R}_{EM}$, V_{EM}.

Step 3. Call CSTEP to compute step size h, $\overline{\overset{....}{\epsilon}}_{RSV}$, $\overline{\overset{....}{\epsilon}}_{RSE}$, $\overline{\overset{....}{\epsilon}}_{RSM}$ and J.

Step 4. Call DISP

Step 5. If IPV = 1, call PVEC.
If IFILE = 1, call FDATA.
If IPTRAJ = 1, call PTRAJ.

Step 6. Call TWOBDY to compute 6 conics:

$$\left[\overline{R}_{SV}, \overline{V}_{SV}\right]$$

$$\left[\overline{R}_{SE}, \overline{V}_{SE}\right]$$

$$\left[\overline{R}_{SM}, \overline{V}_{SM}\right]$$

$$\left[\overline{R}_{EV}, \overline{V}_{EV}\right]$$

$$\left[\overline{R}_{MV}, \overline{V}_{MV}\right]$$

$$\left[\overline{R}_{EM}, \overline{V}_{EM}\right]$$

Step 7. Compute 3 perturbation vectors. Let

$\left[\overline{R}_{i,\, j}\right]$ = CONIC of j with respect to i

$\overline{R}_{i,\, j}$ = reference trajectory of j with respect to i.

$$d\overline{R}_{SV} = \left[\overline{R}_{SV}\right] - \overline{R}_{SV}(0) - h\,\overline{V}_{SV}(0)$$

$$d\overline{V}_{SV} = \left[\overline{V}_{SV}\right] - \overline{V}_{SV}(0)$$

$$d\overline{R}_{SE} = \left[\overline{R}_{SE}\right] - \overline{R}_{SE}(0) - h\,\overline{V}_{SE}(0)$$

$$d\overline{V}_{SE} = \left[\overline{V}_{SE}\right] - \overline{V}_{SE}(0)$$

$$d\overline{R}_{SM} = \left[\overline{R}_{SM}\right] - \overline{R}_{SM}(0) - h\,\overline{V}_{SM}(0)$$

$$d\overline{V}_{SM} = \left[\overline{V}_{SM}\right] - \overline{V}_{SM}(0)$$

$$d\overline{R}_{EV} = \left[\overline{R}_{EV}\right] - \overline{R}_{EV}(0) - h\,\overline{V}_{EV}(0)$$

$$d\overline{V}_{EV} = \left[\overline{V}_{EV}\right] - \overline{V}_{EV}(0)$$

$$d\overline{R}_{MV} = \left[\overline{R}_{MV}\right] - \overline{R}_{MV}(0) - h\,\overline{V}_{MV}(0)$$

$$d\overline{V}_{MV} = \left[\overline{V}_{MV}\right] - \overline{V}_{MV}(0)$$

$$d\overline{R}_{EM} = \left[\overline{R}_{EM}\right] - \overline{R}_{EM}(0) - h\,\overline{V}_{EM}(0)$$

$$d\overline{V}_{EM} = \left[\overline{V}_{EM}\right] - \overline{V}_{EM}(0)$$

Approximate perturbations

$$\overline{P}_{RSV} = \frac{\mu_E}{\mu_S + \mu_E}\, d\overline{R}_{SE} + d\overline{R}_{EV} + \frac{\mu_M}{\mu_S + \mu_M}\, d\overline{R}_{SM} + d\overline{R}_{MV}$$

$$\overline{P}_{VSV} = \frac{\mu_E}{\mu_S + \mu_E}\, d\overline{V}_{SE} + d\overline{V}_{EV} + \frac{\mu_M}{\mu_S + \mu_M}\, d\overline{V}_{SM} + d\overline{V}_{MV}$$

$$\overline{P}_{RSE} = \frac{\mu_M}{\mu_S + \mu_M}\, d\overline{R}_{SM} - \frac{\mu_M}{\mu_E + \mu_M}\, d\overline{R}_{EM}$$

$$\overline{P}_{VSE} = \frac{\mu_M}{\mu_S + \mu_M}\, d\overline{V}_{SM} - \frac{\mu_M}{\mu_E + \mu_M}\, d\overline{V}_{EM}$$

$$\overline{P}_{RSM} = \frac{\mu_E}{\mu_S + \mu_E}\, d\overline{R}_{SE} + \frac{\mu_E}{\mu_E + \mu_M}\, d\overline{R}_{EM}$$

$$\overline{P}_{VSM} = \frac{\mu_E}{\mu_S + \mu_E}\, d\overline{V}_{SE} + \frac{\mu_E}{\mu_E + \mu_M}\, d\overline{V}_{EM}$$

Step 8. Compute reference trajectories

$$\overline{R}_{SV} = \left[\overline{R}_{SV}\right] + \overline{P}_{RSV}$$

$$\overline{V}_{SV} = \left[\overline{V}_{SV}\right] + \overline{P}_{VSV}$$

$$\overline{R}_{SE} = \left[\overline{R}_{SE}\right] + \overline{P}_{RSE}$$

$$\overline{V}_{SE} = \left[\overline{V}_{SE}\right] + \overline{P}_{VSE}$$

$$\overline{R}_{SM} = \left[\overline{R}_{SM}\right] + \overline{P}_{RSM}$$

$$\overline{V}_{SM} = \left[\overline{V}_{SM}\right] + \overline{P}_{VSM}$$

$$\overline{R}_{EV} = - \overline{R}_{SE} + \overline{R}_{SV}$$

$$\overline{V}_{EV} = - \overline{V}_{SE} + \overline{V}_{SV}$$

$$\overline{R}_{MV} = - \overline{R}_{SM} + \overline{R}_{SV}$$

$$\overline{V}_{MV} = - \overline{V}_{SM} + \overline{V}_{SV}$$

$$\overline{R}_{EM} = - \overline{R}_{SE} + \overline{R}_{SM}$$

$$\overline{V}_{EM} = - \overline{V}_{SE} + \overline{V}_{SM}$$

$$t = t + h$$

Step 9. Call DELRV to compute corrections.

Step 10. Correct state vectors.

Step 11. If IMTX = 1, update state transition matrix.

Step 12. Call DISP

Step 13. If IPV = 1, call PVEC.
If IFILE = 1, call FDATA.
If IPTRAJ = 1, call PTRAJ

Step 14. If $t \geq t_f$, exit.

Step 15. Call CSTEP.
Go to Step 6.

Subroutine THRBDY

A. Input Parameters

Parameters	Symbol	Definition
XTO	t_o	
XTF	t_f	
REV0	$\overline{R}_{EV}(t_o)$	
VEV0	$\overline{V}_{EV}(t_o)$	
REM0	$\overline{R}_{EM}(t_o)$	
VEM0	$\overline{V}_{EM}(t_o)$	
PV0	$\overline{\lambda}, \overline{\dot{\lambda}}$	

B. Output Parameters

REVD	$\overline{R}_{EV}(t_f)$	
VEVD	$\overline{V}_{EV}(t_f)$	
REMD	$\overline{R}_{EM}(t_f)$	
VEMD	$\overline{V}_{EM}(t_f)$	
S11, S12, S21, S22	$\varphi(t_f, t_o)$	State transition matrix

C. Computation

Step 1. Initialize running variables equal to input states.

Step 2. Call CSTEP3 to compute step size h, $\overline{\dddot{\epsilon}}_{REV}$ and J.

Step 3. Call DISP3

Step 4. If IPV = 1, call PVEC
If IFILE = 1, call FDATA3
If IPTRAJ = 1, call PTRAJ3.

Step 5. Call TWOBDY to compute 3 conics:

$$\left[\overline{R}_{EV}, \overline{V}_{EV}\right]$$

$$\left[\overline{R}_{EM}, \overline{V}_{EM}\right]$$

$$\left[\overline{R}_{MV}, \overline{V}_{MV}\right]$$

Step 6. Compute perturbation vector

$$\overline{P}_{REV} = \left[\overline{R}_{MV}\right] - \overline{R}_{MV}(0) - h\,\overline{V}_{MV}(0)$$

$$\overline{P}_{VEV} = \left[\overline{V}_{MV}\right] - \overline{V}_{MV}(0)$$

Step 7. Compute reference trajectories

$$\overline{R}_{EV} = \left[\overline{R}_{EV}\right] + \overline{P}_{REV}$$

$$\overline{V}_{EV} = \left[\overline{V}_{EV}\right] + \overline{P}_{VEV}$$

$$\overline{R}_{EM} = \left[\overline{R}_{EM}\right]$$

$$\overline{V}_{EM} = \left[\overline{V}_{EM}\right]$$

$$\overline{R}_{MV} = -\overline{R}_{EM} + \overline{R}_{EV}$$

$$\overline{V}_{MV} = -\overline{V}_{EM} + \overline{V}_{EV}$$

$$t = t + h$$

Step 8. Call DELRV3 to compute corrections.

Step 9. Correct state vectors.

Step 10. If IMTX = 1, update state transition matrix.

Step 11. Call DISP3

Step 12. If IPV = 1, call PVEC.
If IFILE = 1, call FDATA3.
If IPTRAJ = 1, call PTRAJ3.

Step 13. If $t \geq t_f$, exit.

Step 14. Call CSTEP3.
Go to Step 5.

Subroutine TWOBDY

A. Input Parameters

Parameters	Symbol	Definition
XRO	$\overline{R}(t)$	
XVO	$\overline{V}(t)$	
TAU	h	Step size
MU	μ	Gravitational constant
PSI	ψ	Generalized eccecntric anomaly
IMTX	I_{MTX}	Flag to compute state transition matrix: I_{MTX} = 0, no 1, yes

B. Output Parameters

XRF	$\overline{R}(t+h)$	
VRF	$\overline{V}(t+h)$	
PSI	ψ	
P	φ (t+h, t)	State transition matrix

C. Computation

See Ref. (3).

Subroutine CSTEP

A. Input Parameters

Parameters	Symbol	Definition
ERRMAX	ϵ_{max}	Allowable single step position error
REV	$\bar{R}_{EV}(t)$	
RSE	$\bar{R}_{SE}(t)$	
RSV	$\bar{R}_{SV}(t)$	
RMV	$\bar{R}_{MV}(t)$	
RSM	$\bar{R}_{SM}(t)$	
REM	$\bar{R}_{EM}(t)$	
TGO	tgo	$t_f - t$

B. Output Parameters

H	h	Step size
DR4RSV	$\overline{\ddddot{\epsilon}}_{RSV}(t)$	4th Derivative of position error estimates
DR4RSE	$\overline{\ddddot{\epsilon}}_{RSE}(t)$	
DR4R5M	$\overline{\ddddot{\epsilon}}_{RSM}(t)$	
BIGJ	J	$J = \begin{pmatrix} I_3 & hI_3 \\ O_3 & I_3 \end{pmatrix}$

C. Computation

$$\ddddot{\epsilon}_{RSV}(t) = \mu_S \mu_E \Big[\frac{1}{R_{SV}^3}\left(I - 3\,\overline{u}_{SV}\,\overline{u}_{SV}^T\right)\left(\frac{\overline{R}_{EV}}{R_{EV}^3} + \frac{\overline{R}_{SE}}{R_{SE}^3}\right)$$

$$+ \frac{1}{R_{EV}^3}\left(I - 3\,\overline{u}_{EV}\,\overline{u}_{EV}^T\right)\left(\frac{\overline{R}_{SV}}{R_{SV}^3} - \frac{\overline{R}_{SE}}{R_{SE}^3}\right)\Big]$$

$$+ \mu_S \mu_M \Big[\frac{1}{R_{SV}^3}\left(I - 3\,\overline{u}_{SV}\,\overline{u}_{SV}^T\right)\left(\frac{\overline{R}_{MV}}{R_{MV}^3} + \frac{\overline{R}_{SM}}{R_{SM}^3}\right)$$

$$+ \frac{1}{R_{MV}^3}\left(I - 3\,\overline{u}_{MV}\,\overline{u}_{MV}^T\right)\left(\frac{\overline{R}_{SV}}{R_{SV}^3} - \frac{\overline{R}_{SM}}{R_{SM}^3}\right)\Big]$$

$$+ \mu_E \mu_M \Big[\frac{1}{R_{EV}^3}\left(I - 3\,\overline{u}_{EV}\,\overline{u}_{EV}^T\right)\left(\frac{\overline{R}_{MV}}{R_{MV}^3} + \frac{\overline{R}_{EM}}{R_{EM}^3}\right)$$

$$- \frac{1}{R_{SE}^3}\left(I - 3\,\overline{u}_{SE}\,\overline{u}_{SE}^T\right)\left(\frac{\overline{R}_{EM}}{R_{EM}^3} - \frac{\overline{R}_{SM}}{R_{SM}^3}\right)$$

$$+ \frac{1}{R_{MV}^3}\left(I - 3\,\overline{u}_{MV}\,\overline{u}_{MV}^T\right)\left(\frac{\overline{R}_{EV}}{R_{EV}^3} - \frac{\overline{R}_{EM}}{R_{EM}^3}\right)$$

$$+ \frac{1}{R_{SM}^3}\left(I - 3\,\overline{u}_{SM}\,\overline{u}_{SM}^T\right)\left(\frac{\overline{R}_{EM}}{R_{EM}^3} + \frac{\overline{R}_{SE}}{R_{SE}^3}\right)\Big]$$

$$h = \left(24\,\frac{\epsilon_{max}}{\ddddot{\epsilon}_{RSV}}\right)^{1/4}$$

$$\overline{u}_{SV} = \text{UNIT}\,(\overline{R}_{SV})$$

$$\overline{u}_{EV} = \text{UNIT}\,(\overline{R}_{EV})$$

$$\overline{u}_{MV} = \text{UNIT}\,(\overline{R}_{MV})$$

$$\overline{u}_{SE} = \text{UNIT}\,(\overline{R}_{SE})$$

$$\overline{u}_{SM} = \text{UNIT}\,(\overline{R}_{SM})$$

$$\ddddot{\epsilon}_{RSE}(t) = -\frac{\left(\mu_S + \mu_E\right)}{R_{SE}^3}\mu_M\left(I - 3\,\overline{u}_{SE}\,\overline{u}_{SE}^T\right)\left(\frac{\overline{R}_{EM}}{R_{EM}^3} - \frac{\overline{R}_{SM}}{R_{SM}^3}\right)$$

$$- \frac{\mu_M\,\mu_S}{R_{EM}^3}\left(I - 3\,\overline{u}_{EM}\,\overline{u}_{EM}^T\right)\left(\frac{\overline{R}_{SM}}{R_{SM}^3} - \frac{\overline{R}_{SE}}{R_{SE}^3}\right)$$

$$+ \frac{\mu_M\,\mu_E}{R_{SM}^3}\left(I - 3\,\overline{u}_{SM}\,\overline{u}_{SM}^T\right)\left(\frac{\overline{R}_{EM}}{R_{EM}^3} + \frac{\overline{R}_{SE}}{R_{SE}^3}\right)$$

$$\ddddot{\epsilon}_{RSM}(t) = \frac{\left(\mu_S + \mu_M\right)}{R_{SM}^3}\mu_E\left(I - 3\,\overline{u}_{SM}\,\overline{u}_{SM}^T\right)\left(\frac{\overline{R}_{EM}}{R_{EM}^3} + \frac{\overline{R}_{SE}}{R_{SE}^3}\right)$$

$$+ \frac{\mu_E\,\mu_S}{R_{EM}^3}\left(I - 3\,\overline{u}_{EM}\,\overline{u}_{EM}^T\right)\left(\frac{\overline{R}_{SM}}{R_{SM}^3} - \frac{\overline{R}_{SE}}{R_{SE}^3}\right)$$

$$- \frac{\mu_E\,\mu_M}{R_{SE}^3}\left(I - 3\,\overline{u}_{SE}\,\overline{u}_{SE}^T\right)\left(\frac{\overline{R}_{EM}}{R_{EM}^3} - \frac{\overline{R}_{SM}}{R_{SM}^3}\right)$$

All quantities are evaluated at the beginning of an integration step. If h is greater than tgo, it is set to tgo for the last step.

Subroutine CSTEP3

A. Input Parameters

Parameters	Symbols	Definition
ERRMAX	ϵ_{max}	Allowable single step position error
REV	$\overline{R}_{EV}(t)$	
RMV	$\overline{R}_{MV}(t)$	
TGO	tgo	Terminal time - present time

B. Output Parameters

H	h	Step size
DR4REV	$\overline{\ddddot{\epsilon}}_{REV}(t)$	4th Derivative of position error estimate
BIGJ	J	$J = \begin{pmatrix} I_3 & hI_3 \\ O_3 & I_3 \end{pmatrix}$

C. Computation

$$\overline{\ddddot{\epsilon}}_{REV}(t) = \mu_E \mu_M \left\{ \frac{1}{R_{EV}^3} \left(I - 3\,\overline{u}_{EV}\,\overline{u}_{EV}^T \right) \left(\frac{\overline{R}_{MV}}{R_{MV}^3} + \frac{\overline{R}_{EM}}{R_{EM}^3} \right) + \frac{1}{R_{MV}^3} \left(I - 3\,\overline{u}_{MV}\,\overline{u}_{MV}^T \right) \left(\frac{\overline{R}_{EV}}{R_{EV}^3} - \frac{\overline{R}_{EM}}{R_{EM}^3} \right) \right\}$$

$$\overline{\ddddot{\epsilon}}_{REM}(t) = 0$$

$$h = \left(24 \frac{\epsilon_{max}}{\overline{\ddddot{\epsilon}}_{REV}} \right)^{1/4}$$

$$\overline{u}_{EV} = \mathrm{UNIT}\,(\overline{R}_{EV})$$

$$\overline{u}_{MV} = \mathrm{UNIT}\,(\overline{R}_{MV})$$

All quantities are evaluated at the beginning of an itegration step. If h is greater then tgo, it is set to tgo for the last step.

Subroutine DELRV

A. Input Parameters

Parameters	Symbol	Definition
H	h	Step size
RSV	$\overline{R}_{SV}(t+h)$	Conics plus perturbations at end of step.
REV	$\overline{R}_{EV}(t+h)$	
RMV	$\overline{R}_{MV}(t+h)$	
RSE	$\overline{R}_{SE}(t+h)$	
RSM	$\overline{R}_{SM}(t+h)$	
REM	$\overline{R}_{EM}(t+h)$	
CRSV	$\left[\overline{R}_{SV}(t+h)\right]$	Conics at end of step
CREV	$\left[\overline{R}_{EV}(t+h)\right]$	
CRMV	$\left[\overline{R}_{MV}(t+h)\right]$	
CRSE	$\left[\overline{R}_{SE}(t+h)\right]$	
CRSM	$\left[\overline{R}_{SM}(t+h)\right]$	
CREM	$\left[\overline{R}_{EM}(t+h)\right]$	
DR4RSV	$\overline{\ddot{\ddot{\epsilon}}_{RSV}}(t)$	4th derivative of position error estimates at beginning of step.
DR4RSE	$\overline{\ddot{\ddot{\epsilon}}_{RSE}}(t)$	
DR4RSM	$\overline{\ddot{\ddot{\epsilon}}_{RSM}}(t)$	

B. Output Parameters

Parameters	Symbol	Definition
RRSV	$d\overline{R}_{SV}(t+h)$	Position and velocity corrections computed by quadrature formula.
RVSV	$d\overline{V}_{SV}(t+h)$	
RRSE	$d\overline{R}_{SE}(t+h)$	
RVSE	$d\overline{V}_{SE}(t+h)$	
RRSM	$d\overline{R}_{SM}(t+h)$	
RVSM	$d\overline{V}_{SM}(t+h)$	

C. **Computation**

Define

$$\bar{s}_{i,\,j} = \frac{\left[\bar{R}_{i,\,j}(t+h)\right]}{\left|\left[\bar{R}_{i,\,j}(t+h)\right]\right|} - \frac{\bar{R}_{i,\,j}}{\left|\bar{R}_{i,\,j}\right|}$$

$$(i,\ j) = (SV,\ EV,\ MV,\ SE,\ SM,\ EM)$$

The second derivatives of Stumpff-Weiss position errors are given by

$$\ddot{\epsilon}_{1,\ RSV} = \mu_S\,\mu_M\,\bar{s}_{SV} + \mu_E\left(\bar{s}_{SE} + \bar{s}_{EV}\right) + \mu_M\left(\bar{s}_{SM} + \bar{s}_{MV}\right)$$

$$\ddot{\epsilon}_{1,\ RSE} = \left(\mu_S + \mu_E\right)\bar{s}_{SE} + \mu_M\left(\bar{s}_{SM} - \bar{s}_{EM}\right)$$

$$\ddot{\epsilon}_{1,\ RSM} = \left(\mu_S + \mu_M\right)\bar{s}_{SM} + \mu_E\left(\bar{s}_{SE} + \bar{s}_{EM}\right)$$

The position and velocity corrections are computed by quadrature formulas below.

$$d\bar{R}_{SV} = \frac{h^2}{20}\left(\ddddot{\epsilon}_{RSV}\,\frac{h^2}{3} + \ddot{\epsilon}_{1,\ RSV}\right)$$

$$d\bar{V}_{SV} = \frac{h}{4}\left(\ddddot{\epsilon}_{RSV}\,\frac{h^2}{6} + \ddot{\epsilon}_{1,\ RSV}\right)$$

$$d\bar{R}_{SE} = \frac{h^2}{20}\left(\ddddot{\epsilon}_{RSE}\,\frac{h^2}{3} + \ddot{\epsilon}_{1,\ RSE}\right)$$

$$d\bar{V}_{SE} = \frac{h}{4}\left(\ddddot{\epsilon}_{RSE}\,\frac{h^2}{6} + \ddot{\epsilon}_{1,\ RSE}\right)$$

$$d\bar{R}_{SM} = \frac{h^2}{20}\left(\ddddot{\epsilon}_{RSM}\,\frac{h^2}{3} + \ddot{\epsilon}_{1,\ RSM}\right)$$

$$d\bar{V}_{SM} = \frac{h}{4}\left(\ddddot{\epsilon}_{RSM}\,\frac{h^2}{6} + \ddot{\epsilon}_{1,\ RSM}\right)$$

Subroutine DELRV3

A. Input Parameters

Parameters	Symbol	Definition
H	h	Step size
REV	$\bar{R}_{EV}(t+h)$	Conics plus perturbations at end of step.
RMV	$\bar{R}_{MV}(t+h)$	
CREV	$\left[\bar{R}_{EV}(t+h)\right]$	Conics at end of step.
CRMV	$\left[\bar{R}_{MV}(t+h)\right]$	
DR4REV	$\overline{\ddddot{\epsilon}}_{REV}(t)$	4th derivative of position error estimate at beginning of step

B. Output Parameters

RREV	$d\bar{R}_{EV}(t+h)$	Position and velocity corrections computed by quadrature formula
RVEV	$d\bar{V}_{EV}(t+h)$	

C. Computation

Define

$$\bar{s}_{i,\,j} = \frac{\left[\bar{R}_{i,\,j}(t+h)\right]}{\left|\left[\bar{R}_{i,\,j}(t+h)\right]\right|}$$

$$(i,\, j) = (EV,\ MV)$$

The second derivative of Stumpff-Weiss position errors is given by

$$\ddot{\bar{\epsilon}}_{1,\ REV} = \mu_E\, \bar{s}_{EV} + \mu_M\, \bar{s}_{MV}$$

The position and velocity corrections by quadrature formula are

$$d\bar{R}_{EV} = \frac{h^2}{20}\left(\overline{\ddddot{\epsilon}}_{REV}\,\frac{h^2}{3} + \ddot{\bar{\epsilon}}_{1,\ REV}\right)$$

$$d\bar{V}_{EV} = \frac{h}{4}\left(\overline{\ddddot{\epsilon}}_{REV}\,\frac{h^2}{6} + \ddot{\bar{\epsilon}}_{1,\ REV}\right)$$

Note that there is no error in moon's position and velocity in a 3-body space.

Subroutine COMIC

A. Input Parameters

Parameters	Symbol	Definition
REVMAG	r_o	$\lvert \overline{R}_{EV}(t_o) \rvert$
VEVMAG	v_o	$\lvert \overline{V}_{EV}{}^{+}(t_o) \rvert$
LON	Ω (rad)	Longitude of ascending node
THE	θ (rad)	Position of vehicle from ascending line of node in orbital plane.
OINC	i (rad)	Orbital inclination
OBL	OBL (rad)	Obliquity angles
RSE0	$\overline{R}_{SE}(t_o)$	
VSE0	$\overline{V}_{SE}(t_o)$	

B. Output Parameters

REV0	$\overline{R}_{EV}(t_o)$	
VEV0	$\overline{V}_{EV}{}^{-}(t_o)$	
RSV0	$\overline{R}_{SV}(t_o)$	
VSV0	$\overline{V}_{SV}{}^{-}(t_o)$	Velocity before impulse
VSVI	$\overline{V}_{SV}{}^{+}(t_o)$	Velocity after impulse

C. Computation

Matrix to transform a vector from O-frame to e-frame:

$$C_O^e = \begin{pmatrix} \cos\Omega & -\sin\Omega & 0 \\ \sin\Omega & \cos\Omega & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos i & -\sin i \\ 0 & \sin i & \cos i \end{pmatrix} \begin{pmatrix} \cos\theta & -\sin\theta & 0 \\ \sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

Matrix to transform a vector from e-frame to E-frame:

$$C_e^E = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(OBL) & \sin(OBL) \\ 0 & -\sin(OBL) & \cos(OBL) \end{pmatrix}$$

$$\overline{R}_{EV}(t_o) = C_e^E \, C_O^e \begin{pmatrix} r_o \\ 0 \\ 0 \end{pmatrix}$$

$$\overline{V}_{EV}{}^{+}(t_o) = C_e^E \, C_O^e \begin{pmatrix} 0 \\ v_o \\ 0 \end{pmatrix}$$

$$\overline{R}_{SV}(t_o) = \overline{R}_{SE}(t_o) + \overline{R}_{EV}(t_o)$$

$$\overline{V}_{SV}{}^{+}(t_o) = \overline{V}_{SE}(t_o) + \overline{V}_{EV}{}^{+}(t_o)$$

$$\overline{V}_{EV}{}^{-}(t_o) = \text{UNIT}\left(V_{EV}{}^{+}(t_o)\right) \sqrt{\frac{\mu_E}{r_o}}$$

$$\overline{V}_{SV}{}^{-}(t_o) = \overline{V}_{SE}(t_o) + \overline{V}_{EV}{}^{-}(t_o)$$

Subroutine COMIC3

A. Input Parameters

Parameter	Symbol	Definition
REVMAG	r_o	$\lvert \overline{R}_{EV}(t_o) \rvert$
VEVMAG	v_o	$\lvert \overline{V}_{EV}^{+}(t_o) \rvert$
LON	Ω (rad)	Longitude of ascending node
THE	θ (rad)	Position of vehicle from ascending node in orbital plane
OINC	i (rad)	Orbital inclination

B. Output Parameters

REV0	$\overline{R}_{EV}(t_o)$
VEV0	$\overline{V}_{EV}^{-}(t_o)$
VEV0P	$\overline{V}_{EV}^{+}(t_o)$

C. Computation

C_O^e = matrix to transform a vector from O-frame to e-frame (given in COMIC)

$$\overline{R}_{EV}(t_o) = C_O^e \begin{pmatrix} r_o \\ 0 \\ 0 \end{pmatrix}$$

$$\overline{V}_{EV}^{+}(t_o) = C_O^e \begin{pmatrix} 0 \\ v_o \\ 0 \end{pmatrix}$$

$$\overline{V}_{EV}^{-}(t_o) = \text{UNIT}\left(\overline{V}_{EV}^{+}(t_o)\right) \sqrt{\frac{\mu_E}{r_o}}$$

Subroutine COMFG

A. Input Parameters

Parameters	Symbol	Definition
TSTART	t_o	
TEND	t_f	
REVMAG	r_o	$\lvert\overline{R}_{EV}(t_o)\rvert$
VEVMAG	v_o	$\lvert\overline{V}_{EV}{}^{+}(t_o)\rvert$
LON	Ω (rad)	Longitude of ascending node
THE	θ (rad)	Position of vehicle from ascending node in orbital plane
OINC	i (rad)	Orbital inclination
OBL	OBL (rad)	Obliquity angle
RSE0	$\overline{R}_{SE}(t_o)$	
VSE0	$\overline{V}_{SE}(t_o)$	
RSM0	$\overline{R}_{SM}(t_o)$	
VSM0	$\overline{V}_{SM}(t_o)$	

B. Output Parameters

Parameters	Symbol	Definition
FD	ΔV	$\Delta V = \lvert\overline{V}_{SVTAR} - V_{SV}(t_f)\rvert$
TESTRD	ϵ	$\epsilon = \lvert\overline{\psi}\rvert$
GD	$\overline{g}$	$\overline{g} = \dfrac{\partial \Delta V}{\partial (v_o, \Omega, \theta)}$
TSID	$\overline{\psi}$	$\overline{\psi} = \overline{R}_{SV}(t_f) - \overline{R}_{SVTAR}$
LTD	L^T	$L^T = \dfrac{\partial \overline{\psi}}{\partial (v_o, \Omega, \theta)}$
S11, S12, S21, S22	$\varphi(t_f, t_o)$	$\varphi = \dfrac{\partial\left(\overline{R}_{SV}(t_f), \overline{V}_{SV}(t_f)\right)}{\partial\left(\overline{R}_{SV}(t_o), \overline{V}_{SV}(t_o)\right)}$
UVI	$\overline{u}_{VI}$	$\overline{u}_{VI} = \text{UNIT}\left(\overline{V}_{SV}{}^{+}(t_o) - \overline{V}_{SV}{}^{-}(t_o)\right)$

UVF $\quad \bar{u}_{VF} \quad \bar{u}_{VF} = \text{UNIT}\left(\bar{V}_{SVTAR} - \bar{V}_{SV}(t_f)\right)$

C. Computation

$$\bar{x} = (v_o, \Omega, \theta)$$

Call COMIC to compute $\bar{R}_{SV}(t_o)$, $\bar{V}_{SV}^-(t_o)$, $\bar{V}_{SV}^+(t_o)$.

Call FOURBY to advance states to t_f and compute φ.

For the first iteration, call CTAR to compute $\bar{R}_{SVTAR}$, $\bar{V}_{SVTAR}$.

$$\Delta\bar{v}_o = \bar{V}_{SV}^+(t_o) - \bar{V}_{SV}^-(t_o)$$

$$\bar{u}_{VI} = \text{UNIT}(\Delta\bar{V}_o)$$

$$\Delta\bar{V}_f = \bar{V}_{SVTAR} - \bar{V}_{SV}(t_f)$$

$$\bar{u}_{VF} = \text{UNIT}(\Delta\bar{V}_f)$$

$$\Delta V = |\Delta\bar{V}_f|$$

$$\bar{g} = \frac{\partial\Delta V}{\partial\bar{x}} = -\frac{\Delta\bar{V}_f^T}{\Delta V}\left(\varphi_{21}\frac{\partial\bar{R}_{SV}(t_o)}{\partial\bar{x}} + \varphi_{22}\frac{\partial\bar{V}_{SV}(t_o)}{\partial\bar{x}}\right)$$

$$\bar{\psi} = \bar{R}_{SV}(t_f) - \bar{R}_{SVTAR}$$

$$L^T = \frac{\partial\bar{\psi}}{\partial\bar{x}} = \varphi_{11}\frac{\partial\bar{R}_{SV}(t_o)}{\partial\bar{x}} + \varphi_{12}\frac{\partial\bar{V}_{SV}(t_o)}{\partial\bar{x}}$$

$$\bar{R}_{SV}(t_o) = \bar{R}_{SE}(t_o) + \bar{R}_{EV}(t_o)$$

$$\bar{V}_{SV}(t_o) = \bar{V}_{SE}(t_o) + \bar{V}_{EV}^+(t_o)$$

$$\frac{\partial\bar{R}_{SV}(t_o)}{\partial\bar{x}} = \frac{\partial\bar{R}_{EV}(t_o)}{\partial\bar{x}} = A$$

$A(1, 1) = 0$

$A(1, 2) = r_o (-\sin \Omega \cos \theta - \cos \Omega \cos i \sin \theta)$

$A(1, 3) = r_o (-\cos \Omega \sin \theta - \sin \Omega \cos i \cos \theta)$

$A(2, 1) = 0$

$A(2, 2) = r_o \cos (OBL) (\cos \Omega \cos \theta - \sin \Omega \cos i \sin \theta)$

$A(2, 3) = r_o [\cos (OBL) (-\sin \Omega \sin \theta + \cos \Omega \cos i \cos \theta)$

$\quad + \sin (OBL) \sin i \cos \theta]$

$A(3, 1) = 0$

$A(3, 2) = - r_o \sin (OBL) (\cos \Omega \cos \theta - \sin \Omega \cos i \sin \theta)$

$A(3, 3) = r_o [-\sin (OBL) (-\sin \Omega \sin \theta + \cos \Omega \cos i \cos \theta)$

$\quad + \sin (OBL) \sin i \cos \theta]$

$$\frac{\partial \overline{V}_{SV}(t_o)}{\partial \overline{x}} = \frac{\partial \overline{V}_{EV}{}^{+}(t_o)}{\partial \overline{x}} = B$$

$B(1, 1) = - \cos \Omega \sin \theta - \sin \Omega \cos i \cos \theta$

$B(1, 2) = v_o (\sin \Omega \sin \theta - \cos \Omega \cos i \cos \theta)$

$B(1, 3) = v_o (- \cos \Omega \cos \theta + \sin \Omega \cos i \sin \theta)$

$B(2, 1) = \cos (OBL) (-\sin \Omega \sin \theta + \cos \Omega \cos i \cos \theta)$

$\quad + \sin (OBL) \sin i \cos \theta$

$B(2, 2) = v_o \cos (OBL) (-\cos \Omega \sin \theta - \sin \Omega \cos i \cos \theta)$

$B(2, 3) = v_o [\cos (OBL) (-\sin \Omega \cos \theta - \cos \Omega \cos i \sin \theta)$

$\quad - \sin (OBL) \sin i \sin \theta]$

$$B(3,\ 1) = -\sin(OBL)\,(-\sin\Omega\sin\theta + \cos\Omega\cos i\cos\theta)$$

$$+ \cos(OBL)\sin i\cos\theta$$

$$B(3,\ 2) = -v_o\sin(OBL)\,(-\cos\Omega\sin\theta - \sin\Omega\cos i\cos\theta)$$

$$B(3,\ 3) = v_o\,[-\sin(OBL)\,(-\sin\Omega\cos\theta - \cos\Omega\cos i\sin\theta)$$

$$- \cos(OBL)\sin i\sin\theta]$$

Subroutine COMFG3

A. Input Parameters

Parameters	Symbol	Definition
TSTART	t_o	
TEND	t_f	
REVMAG	r_o	$\lvert \overline{R}_{EV}(t_o) \rvert$
VEVMAG	v_o	$\lvert \overline{V}_{EV}^{+}(t_o) \rvert$
LON	Ω (rad)	Longitude of ascending node
THE	θ	Position of vehicle from ascending node in orbital plane
OINC	i (rad)	Orbital inclination
REM0	$\overline{R}_{EM}(t_o)$	
VEM0	$\overline{V}_{EM}(t_o)$	

B. Output Parameters

FD	ΔV	$\Delta V = \lvert \overline{V}_{EVTAR} - \overline{V}_{EV}(t_f) \rvert$
TESTRD	ϵ	$\epsilon = \lvert \overline{\psi} \rvert$
GD	$\overline{g}$	$\overline{g} = \dfrac{\partial \Delta V}{\partial (v_o, \Omega, \theta)}$
TSID	$\overline{\psi}$	$\overline{\psi} = \overline{R}_{EV}(t_f) - \overline{R}_{EVTAR}$
LTD	L^T	$L^T = \dfrac{\partial \overline{\psi}}{\partial (v_o, \Omega, \theta)}$
S11, S12, S21, S22	$\varphi\ (t_f, t_o)$	$\varphi = \dfrac{\partial\left(\overline{R}_{EV}(t_f), \overline{V}_{EV}(t_f)\right)}{\partial\left(\overline{R}_{EV}(t_o), \overline{V}_{EV}(t_o)\right)}$
UVI u	$\overline{u}_{VI}$	$\overline{u}_{VI} = \text{UNIT}\left(\overline{V}_{EV}^{+}(t_o) - \overline{V}_{EV}^{-}(t_o)\right)$
UVF	$\overline{u}_{VF}$	$\overline{u}_{VF} = \text{UNIT}\left(\overline{V}_{EVTAR} - \overline{V}_{EV}(t_f)\right)$

C. Computation

Call COMIC3 to compute $\overline{R}_{EV}(t_o)$, $\overline{V}_{EV}^{-}(t_o)$, $\overline{V}_{EV}^{+}(t_o)$.

Call THRBDY to advance states to t_f and compute φ.

For the first iteration, call CTAR3 to compute $\overline{R}_{EVTAR}$ and $\overline{V}_{EVTAR}$.

Equations are same as in COMFG with cos (OBL) = 1 and sin (OBL) = 0.

Subroutine COMAUG

A. Input Parameters

Parameters	Symbol	Definition
F	f	ΔV
G	$\overline{g}$	$\overline{g} = \frac{\partial \Delta V}{\partial (v_o, \Omega, \theta)}$
L^T	L^T	Constraint gradient transposed $L^T = \frac{\partial \overline{\psi}}{\partial (v_o, \Omega, \theta)}$
V	V	Davidon's Variance matrix
TSI	$\overline{\psi}$	Constraint violation $\overline{\psi} = \overline{R}(t_f) - \overline{R}_{fd}$ $\overline{R}_{fd} = \overline{R}_{SVTAR}$ or $\overline{R}_{EVTAR}$

B. Output Parameters

L	L	$L = (L^T)^T$
FG		$f + \overline{\nu}^T \overline{\psi}$
GG		$\overline{g} + L \overline{\nu}$

C. Computation

$$L = (L^T)^T$$

$$\overline{\nu} = - [L^T V L]^{-1} L^T V \overline{g}$$

$$FG = f + \overline{\nu}^T \overline{\psi}$$

$$GG = \overline{g} + L \overline{\nu}$$

Subroutine CTAR

A. Input Parameters

Parameters	Symbol	Definition
RSEF	$\overline{R}_{SE}(t_f)$	
VSEF	$\overline{V}_{SE}(t_f)$	
RSMF	$\overline{R}_{SM}(t_f)$	
VSMF	$\overline{V}_{SM}(t_f)$	
REMF	$\overline{R}_{EM}(t_f)$	
VEMF	$\overline{V}_{EM}(t_f)$	
AY	Ay	Parameters to define a point on a Halo orbit.
AZ	Az	
ATAR	A_{TAR}	

B. Output Parameters

RSVTAR	$\overline{R}^S_{SVTAR}$	
VSVTAR	$\overline{V}^S_{SVTAR}$	

C. Computation

Position and velocity of L_1 in S-frame:

$$\overline{R}_{SL1}{}^S = (1 - \gamma_{L1}) \left(\overline{R}_{SE}{}^S + \frac{\mu_M}{\mu_E + \mu_M} \overline{R}_{EM}{}^S\right)$$

$$\overline{V}_{SL1}{}^S = (1 - \gamma_{L1}) \left(\overline{V}_{SE}{}^S + \frac{\mu_M}{\mu_E + \mu_M} \overline{V}_{EM}{}^S\right)$$

If both A_y and A_z are zero, the following computation is omitted and target position and velocity are set equal to that of L_1. Define L-frame unit vectors.

$$\overline{u}_{XL}{}^S = \text{UNIT}\left(\overline{R}_{SL1}{}^S\right)$$

$$\overline{u}_{ZL}{}^S = \text{UNIT}\left(\mu_E \overline{R}_{SE}{}^S \times \overline{V}_{SE}{}^S + \mu_M \overline{R}_{SM}{}^S \times \overline{V}_{SM}{}^S\right)$$

$$\bar{u}_{YL}{}^{S} = \bar{u}_{ZL}{}^{S} \times \bar{u}_{XL}{}^{S}$$

The matrix to transform a vector from S-frame to L-frame is given by

$$C_S{}^L = \left(\left(\bar{u}_{XL}{}^{S}\right)^T, \left(\bar{u}_{YL}{}^{S}\right)^T, \left(\bar{u}_{ZL}{}^{S}\right)^T\right)$$

The angular velocity of L-frame with respect to S-frame in S-frame is defined by

$$\bar{\omega}_{SL}{}^{S} = \bar{u}_{ZL}{}^{S} \left(\bar{u}_{YL}{}^{S} \cdot \frac{\bar{V}_{SL1}{}^{S}}{|\bar{R}_{SL1}{}^{S}|}\right)$$

The target position and velocity in L-frame are defined by

$$\bar{R}_{L1TAR}{}^{L} = \begin{pmatrix} k & Ay & \sin A_{TAR} \\ & Ay & \cos A_{TAR} \\ & Az & \sin A_{TAR} \end{pmatrix}$$

$$\bar{V}_{L1TAR}{}^{L} = \begin{pmatrix} k & \omega_n & Ay & \cos A_{TAR} \\ - & \omega_n & Ay & \sin A_{TAR} \\ & \omega_n & Az & \cos A_{TAR} \end{pmatrix}$$

where

$$\omega_n = \sqrt{1 - \frac{B_L}{2} + \sqrt{\left(\frac{3B_L}{2}\right)^2 - 2\,B_L}}$$

$$B_L = \frac{1-\mu}{(1-\gamma_{L1})^3} + \frac{\mu}{\gamma_{L1}{}^3}$$

$$\mu = \frac{\mu_E + \mu_M}{\mu_S + \mu_E + \mu_M}$$

$$k = \frac{2\,\omega_n}{\omega_n{}^2 + (2B_L + 1)}$$

The target position and velocity in S-frame are then given by

$$\bar{R}_{SVTAR}{}^{S} = \bar{R}_{SL1}{}^{S} + \left(C_S{}^L\right)^T \bar{R}_{L1TAR}{}^{L}$$

$$\bar{V}_{SVTAR}{}^{S} = \bar{V}_{SL1}{}^{S} + \left(C_S{}^L\right)^T \bar{V}_{L1TAR}{}^{L} + \bar{\omega}_{SL}{}^{S} \times \left(C_S{}^L\right)^T \bar{R}_{L1TAR}{}^{L}$$

Subroutine CTAR3

A. Input Parameters

Parameters	Symbol	Definition
REMF	$\overline{R}_{EM}(t_f)$	In e-frame
VEMF	$\overline{V}_{EM}(t_f)$	
AY	Ay	
AZ	Az	Parameters to define a point on a Halo orbit
ATAR	A_{TAR}	

B. Output Parameters

REVTAR	$\overline{R}_{EVTAR}{}^{e}$
VEVTAR	$\overline{V}_{EVTAR}{}^{e}$

C. Computation

Position and velocity of libration point in e- frame

$$\overline{R}_{EL}{}^{e} = (1 - \gamma)\, \overline{R}_{EM}{}^{e} \qquad \gamma > 0 \text{ for } L_1$$

$$\overline{V}_{EL}{}^{e} = (1 - \gamma)\, \overline{V}_{EM}{}^{e} \qquad < 0 \text{ for } L_2$$

If both Ay and Az are zero, the following computation is omitted and target position and velocity are set equal to that of the libration point. Define ℓ-frame by unit vectors:

$$\overline{u}_{XL}{}^{e} = \text{UNIT}\left(\overline{R}_{EL}{}^{e}\right)$$

$$\overline{u}_{ZL}{}^{e} = \text{UNIT}\left(\overline{R}_{EM}{}^{e} \times \overline{V}_{EM}{}^{e}\right)$$

$$\overline{u}_{YL}{}^{e} = \overline{u}_{ZL}{}^{e} \times \overline{u}_{XL}{}^{e}$$

The matrix to transform a vector from e-frame to ℓ-frame is given by

$$C_e^{\ell} = \left(\left(\overline{u}_{XL}{}^{e}\right)^{T}, \left(\overline{u}_{YL}{}^{e}\right)^{T}, \left(\overline{u}_{ZL}{}^{e}\right)^{T}\right)$$

The angular velocity of ℓ-frame with respect to e-frame in e-frame is defined by

$$\overline{\omega}_{EL}^{\ e} = \overline{u}_{ZL}^{\ e} \left(\overline{u}_{YL}^{\ e} \cdot \frac{\overline{V}_{EL}^{\ e}}{|\overline{R}_{EL}^{\ e}|} \right)$$

The target position and velocity in ℓ-frame are defined by

$$\overline{R}_{LTAR}^{\ \ell} = \begin{pmatrix} k & Ay & \sin A_{TAR} \\ & Ay & \cos A_{TAR} \\ & Az & \sin A_{TAR} \end{pmatrix}$$

$$\overline{V}_{LTAR}^{\ \ell} = \begin{pmatrix} k & \omega_n & Ay & \cos A_{TAR} \\ - & \omega_n & Ay & \sin A_{TAR} \\ & \omega_n & Az & \cos A_{TAR} \end{pmatrix}$$

where

$$\omega_n = \sqrt{1 - \frac{B_L}{2} + \sqrt{\left(\frac{3B_L}{2}\right)^2 - 2\ B_L}}$$

$$B_L = \frac{1 - \mu}{(1 - \gamma)^3} + \frac{\mu}{\gamma^3}$$

$$\mu = \frac{\mu_M}{\mu_E + \mu_M}$$

$$k = \frac{2\ \omega_n}{\omega_n^{\ 2} + (2B_L + 1)}$$

The target position and velocity in e-frame are then given by

$$\overline{R}_{EVTAR}^{\ e} = \overline{R}_{EL}^{\ e} + \left(C_e^{\ \ell}\right)^T \overline{R}_{LTAR}^{\ \ell}$$

$$\overline{V}_{EVTAR}^{\ e} = \overline{V}_{EL}^{\ e} + \left(C_e^{\ \ell}\right)^T \overline{V}_{LTAR}^{\ \ell} + \overline{\omega}_{EL}^{\ e} \times \left(C_e^{\ \ell}\right)^T \overline{R}_{LTAR}^{\ \ell}$$

Subroutine COMDX

A. Input Parameters

Parameters	Symbol	Definition
LTS	L^T	$\dfrac{\partial \overline{\psi}}{\partial (v_o, \Omega, \theta)}$
LS	L	
TSIS	ψ	$\overline{\psi} = \overline{R}(t_f) - \overline{R}_{fd}$ $\overline{R}_{fd} = \overline{R}_{SVTAR}$ or $\overline{R}_{EVTAR}$

B. Output Parameters

DX	$d\overline{x}$	$d\overline{x} = (dv_o, d\Omega, d\theta)$

C. Computation

$$d\overline{x} = - L (L^T L)^{-1} \overline{\psi}$$

Subroutine RVEMV

A. Input Parameters

Parameters	Symbol	Definition
RSV	$\overline{R}_{SV}(t)$	
VSV	$\overline{V}_{SV}(t)$	
RSE	$\overline{R}_{SE}(t)$	
VSE	$\overline{V}_{SE}(t)$	
RSM	$\overline{R}_{SM}(t)$	
VSM	$\overline{V}_{SM}(t)$	

B. Output Parameters

REV	$\overline{R}_{EV}(t)$	
VEV	$\overline{V}_{EV}(t)$	
RMV	$\overline{R}_{MV}(t)$	
VMV	$\overline{V}_{MV}(t)$	
REM	$\overline{R}_{EM}(t)$	
VEM	$\overline{V}_{EM}(t)$	

C. Computation

$$\overline{R}_{EV} = -\overline{R}_{SE} + \overline{R}_{SV}$$

$$\overline{V}_{EV} = -\overline{V}_{SE} + \overline{V}_{SV}$$

$$\overline{R}_{MV} = -\overline{R}_{SM} + \overline{R}_{SV}$$

$$\overline{V}_{MV} = -\overline{V}_{SM} + \overline{V}_{SM}$$

$$\overline{R}_{EM} = -\overline{R}_{SE} + \overline{R}_{SM}$$

$$\overline{V}_{EM} = -\overline{V}_{SE} + \overline{V}_{SM}$$

This subroutine is used in 4-body program only.

Subroutine UPX

A. Input Parameters

Parameters	Symbol	Definition
XD	$\overline{X}_d$	
FD	f_d	
TESTRD	$\lvert\overline{\psi}_d\rvert$	
GD	$\overline{g}_d$	
TSID	$\overline{\psi}_d$	
LTD	$(L^T)_d$	
LD	L_d	
FGD		$(f + \overline{\nu}^T \overline{\psi})_d$
GGD		$(\overline{g} + L\overline{\nu})_d$
S11D, S12D, S21D, S22D	$\varphi_d(t_f, t_o)$	
UVID, UVFD	$\overline{\lambda}_d(t_o), \overline{\lambda}_d(t_f)$	

B. Output Parameters

Same as input parameters relabelled as X, F, TESTR G, TSI, LT, L FG, GG, S11, S12, S21, S22, UVI, UVF.

C. Computation

Set output parameters = input parameters with new names.

Subroutine LAMB

A. Input Parameters

Parameters	Symbol	Definition
T0	t_o	
TF	t_f	
RSV	$\overline{R}_{SV}(t_o)$	
VSV	$\overline{V}_{SV}(t_o)$	Initial estimate
RSE	$\overline{R}_{SE}(t_o)$	
VSE	$\overline{V}_{SE}(t_o)$	
RSM	$\overline{R}_{SM}(t_o)$	
VSM	$\overline{V}_{SM}(t_o)$	
KNR		Lambert iteration parameter
ITLMAX		Maximum number of iterations
ERRMIN		Convergence criterion
RSVTAR	$\overline{R}_{SVTAR}$	

B. Output Parameters

Parameters	Symbol	Definition
RSVF	$\overline{R}_{SV}(t_f)$	
VSVF	$\overline{V}_{SV}(t_f)$	
RSEF	$\overline{R}_{SE}(t_f)$	
VSEF	$\overline{V}_{SE}(t_f)$	
RSMF	$\overline{R}_{SM}(t_f)$	
VSMF	$\overline{V}_{SM}(t_f)$	
VSV	$\overline{V}_{SV}(t_o)$	Final solution
S11, S12, S21, S22	$\varphi(t_f, t_o)$	State transition matrix

C. Computation

Call FOURBY to advance states to t_f. Newton-Raphson method is used which iterates on $\overline{V}_{SV}(t_o)$ until terminal constraint violation is less then ERRMIN or the number of iteration exceeds ITERL. The desired change in initial velocity is given by

$$d\overline{V} = -(\varphi_{12})^{-1}\left(\overline{R}_{SVTAR} - \overline{R}_{SV}(t_f)\right)$$

The subroutine has a built-in safeguard against inversion of a singular matrix when the transfer is 2-dimensional.

D. Internal Parameters

VIV	Dummy iteration variables of initial velocity.
ERR	Error vector of terminal constraint violation
TESTR	Magnitude of ERR.

Subroutine LAMB3

A. Input Parameters

Parameters	Symbol	Definition
T0	t_o	
TF	t_f	
REV	$\overline{R}_{EV}(t_o)$	
VEV	$\overline{V}_{EV}(t_o)$	Initial estimate
REM	$\overline{R}_{EM}(t_o)$	
VEM	$\overline{V}_{EM}(t_o)$	
KNR		
ITLMAX		
ERRMIN		
REVTAR		

B. Output Parameters

REVF	$\overline{R}_{EV}(t_f)$	
VEVF	$\overline{V}_{EV}(t_f)$	
REMF	$\overline{R}_{EM}(t_f)$	
VEMF	$\overline{V}_{EM}(t_f)$	
VEV	$\overline{V}_{EV}(t_o)$	Final Solution
S11, S12, S21, S22	$\varphi\ (t_f,\ t_o)$	

C. Computation

Call THRBDY to advance states to t_f. Use Newton-Raphson method to iterate on $\overline{V}_{EV}(t_o)$ until terminal constraint violation is less then ERRMIN or the number of iteration exceeds ITERL.

The desired change in initial velocity is given by

$$d\overline{V} = -(\varphi_{12})^{-1}(\overline{R}_{EVTAR} - \overline{R}_{EV}(t_f))$$

The subroutine has a built-in safeguard against inversion of a singular matrix when the transfer is 2-dimensional.

D. <u>Internal Parameters</u>

Same as listed under LAMB.

Subroutine COMF

A. Input Parameters

Parameter	Symbol	Definition
TSTART	t_o	Starting time
TM	t_m	Interior impulse time
TEND	t_f	Terminal time
RSV0	$\overline{R}_{SV}(t_o)$	
VSVI	$\overline{V}_{SV}^{+}(t_o)$	
VSV0	$\overline{V}_{SV}^{-}(t_o)$	
RSE0	$\overline{R}_{SE}(t_o)$	
VSE0	$\overline{V}_{SE}(t_o)$	
RSM0	$\overline{R}_{SM}(t_o)$	
VSM0	$\overline{V}_{SM}(t_o)$	
ERRMIN		Allowable position error
ILINC		Number of increments in solving Lambert problem
KNRSAV		Lambert iteration parameter
ITERD		Outer loop iteration number
ITLMAX		Maximum number of Lambert iterations
VSVMPD	$\overline{V}_{SV}^{+}(t_m)$, OLD	
RSVMD	$\overline{R}_{SV}(t_m)$, OLD	
RSVTAR	$\overline{R}_{SVTAR}$	Target position
VSVTAR	$\overline{V}SVTAR$	Target velocity
S11D	$\varphi_{11}(t_f, t_m)_{OLD}$	
S12D	$\varphi_{12}(t_f, t_m)_{OLD}$	

B. Output Parameters

RSVM	$\overline{R}_{SV}(t_m)$	
VSVMP	$\overline{V}_{SV}^{+}(t_m)$	
VSVMM	$\overline{V}_{SV}^{-}(t_m)$	
DV	ΔV	
UVI	$\overline{u}_{VI}$	
UVM	$\overline{u}_{VM}$	
UVF	$\overline{u}_{VF}$	
SMI11 SMI12 SMI21 SMI22	$\varphi(t_m, t_o)$	State transition matrix from t_o to t_m.
SFM11 SFM12 SFM21 SFM22	$\varphi(t_f, t_m)$	State transition matrix from t_m to t_f.

C. Computation

Step 1. Call FOURBY to advance states from t_o to t_m.

Step 2. If ITERD $\neq$ 0, go to step 4.

Step 3. Set $\overline{V}_{SVX}^{+}(t_m) = \overline{V}_{SV}^{+}(t_m)$

$\overline{R}_{SVX}(t_m) = \overline{R}_{SV}(t_m)$

Go to step 6.

Step 4. Solve second leg Lambert problem in increments

$\overline{R}_{SVX}(t_m) = \overline{R}_{SV}(t_m)_{OLD}$

$\overline{V}_{SVX}^{+}(t_m) = \overline{V}_{SV}^{+}(t_m)_{OLD}$

$d\overline{R}_m = (\overline{R}_{SV}(t_m) - \overline{R}_{SV}(t_m)_{OLD})/\text{ILINC}$

Set $\varphi_{11}(t_f, t_m) = \varphi_{11,\ OLD}$

$\varphi_{12}(t_f, t_m) = \varphi_{12,\ OLD}$

ITERL = 0

Step 5. $d\overline{V}_m = -\varphi_{12}(t_f, t_m)^{-1}\varphi_{11}(t_f, t_m)\, d\overline{R}_m$

$\overline{R}_{SVX}(t_m) = \overline{R}_{SVX}(t_m) + d\overline{R}_m$

$\overline{V}_{SVX}{}^{+}(t_m) = \overline{V}_{SVX}{}^{+}(t_m) + d\overline{V}_m$

Step 6. Call LAMB

ITERL = ITERL + 1

If ITERL < ILINC, go to step 5.

Step 7. $\overline{V}_{SV}{}^{+}(t_m) = \overline{V}_{SVX}{}^{+}(t_m)$

Step 8. $\Delta\overline{V}_o = \overline{V}_{SV}{}^{+}(t_o) - \overline{V}_{SV}{}^{-}(t_o)$

$\Delta\overline{V}_m = \overline{V}_{SV}{}^{+}(t_m) - \overline{V}_{SV}{}^{-}(t_m)$

$\Delta\overline{V}_f = \overline{V}_{SVTAR} - \overline{V}_{SV}(t_f)$

$\overline{u}_{VI} = \text{unit}\,(\Delta\overline{V}_o)$

$\overline{u}_{VM} = \text{UNIT}\,(\Delta\overline{V}_m)$

$\overline{u}_{VF} = \text{UNIT}\,(\Delta\overline{V}_f)$

$\Delta V = |\Delta\overline{V}_o| + |\Delta\overline{V}_m| + |\Delta\overline{V}_f|$

Step 9. EXIT

Subroutine COMF3

A. Input Parameters

Parameters	Symbol	Definition
TSTART	t_o	
TM	t_m	
TEND	t_f	
REV0	$\overline{R}_{EV}(t_o)$	
VEV0P	$\overline{V}_{EV}^{+}(t_o)$	
VEV0	$\overline{V}_{EV}^{-}(t_o)$	
REM0	$\overline{R}_{EM}(t_o)$	
VEM0	$\overline{V}_{EM}(t_o)$	
ERRMIN		Allowable position error
ILINC		Number of increments to solve Lambert problem
KNRSAV		Lambert iteration parameter
ITERD		Iteration number of outer loop
ITLMAX		Maximum Lambert iterations
VEVMPD	$\overline{V}_{EV}(t_m)_{OLD}$	
REVMD	$\overline{R}_{EV}(t_m)_{OLD}$	
REVTAR	$\overline{R}_{EVTAR}$	
VEVTAR	$\overline{V}_{EVTAR}$	
S11D	$\varphi_{11}(t_f, t_m)_{OLD}$	
S12D	$\varphi_{12}(t_f, t_m)$ OLD	

B. Output Parameters

REVM	$\overline{R}_{EV}(t_m)$
VEVMP	$\overline{V}_{EV}^{+}(t_m)$
VEVMM	$V_{EV}^{-}(t_m)$
DV	ΔV
UVI	$\overline{u}_{VI}$
UVM	$\overline{u}_{VM}$
UVF	$\overline{u}_{VF}$
SMI11, SMI12, SMI21, SMI22	$\varphi\,(t_m, t_o)$
SFM11, SFM12, SFM21, SFM22	$\varphi\,(t_f, t_m)$
DVM	$\Delta\overline{V}_m$

C. Computation

Step 1. Call THRBDY to advance states from t_o to t_m.

Step 2. If ITERD $\neq 0$, go to step 4.

Step 3. Set $\overline{V}_{EVX}^{+}(t_m) = \overline{V}_{EV}^{+}(t_m)$

$$\overline{R}_{EVX}(t_m) = \overline{R}_{EV}(t_m)$$

Go to step 6.

Step 4. Solve second leg Lambert problem

$$\overline{R}_{EVX}(t_m) = \overline{R}_{EV}(t_m)_{OLD}$$

$$\overline{V}_{EVX}^{+}(t_m) = \overline{V}_{EV}^{+}(t_m)_{OLD}$$

$$d\overline{R}_M = (\overline{R}_{EV}(t_m) - \overline{R}_{EV}(t_m)_{OLD})/\text{ILINC}$$

Set $\varphi_{11}\,(t_f, t_m) = \varphi_{11,\ OLD}$

$$\varphi_{12}\,(t_f, t_m) = \varphi_{12,\ OLD}$$

ITERL = 0

Step 5. $d\overline{V}_m = -\varphi_{12}(t_f, t_m)^{-1}\varphi_{11}(t_f, t_m)\, d\overline{R}_m$

$\overline{R}_{EVX}(t_m) = \overline{R}_{EVX}(t_m) + d\overline{R}_m$

$\overline{V}_{EVX}^{+}(t_m) = \overline{V}_{EVX}^{+}(t_m) + d\overline{V}_m$

Step 6. Call LAMB3

ITERL = ITERL + 1

If ITERL < ILINC, go to step 5.

Step 7. $\overline{V}_{EV}^{+}(t_m) = \overline{V}_{EVX}^{+}(t_m)$

Step 8. $\Delta\overline{V}_o = \overline{V}_{EV}^{+}(t_o) - \overline{V}_{EV}^{-}(t_o)$

$\Delta\overline{V}_m = \overline{V}_{EV}^{+}(t_m) - \overline{V}_{EV}^{-}(t_m)$

$\Delta\overline{V}_f = \overline{V}_{EVTAR} - \overline{V}_{EV}(t_f)$

$\overline{u}_{VI} = \text{unit}\,(\Delta\overline{V}_o)$

$\overline{u}_{VM} = \text{unit}\,(\Delta\overline{V}_m)$

$\overline{u}_{VF} = \text{unit}\,(\Delta\overline{V}_f)$

$\Delta V = |\Delta\overline{V}_o| + |\Delta\overline{V}_M| + |\Delta\overline{V}_f|$

Step 9. EXIT

Subroutine COMG

A. Input Parameters

Parameters	Symbol	Definition
SMI11	$\varphi_{11}(t_m, t_o)$	
SMI12	$\varphi_{12}(t_m, t_o)$	
SMI21	$\varphi_{21}(t_m, t_o)$	
SMI22	$\varphi_{22}(t_m, t_o)$	
SFM11	$\varphi_{11}(t_f, t_m)$	
SFM12	$\varphi_{12}(t_f, t_m)$	
SFM21	$\varphi_{21}(t_f, t_m)$	
SFM22	$\varphi_{22}(t_f, t_m)$	
UVI	$\bar{u}_{VI}$	
UVM	$\bar{u}_{VM}$	
UVF	$\bar{u}_{VF}$	
VTMM	$v^-(t_m)$	
VTMP	$v^+(t_m)$	

B. Output Parameter

G	$\bar{g}$	Cost gradient $g = \dfrac{\partial \Delta V}{\partial (V^+(t_o), t_m)}$
DUVI	$\dot{\bar{\lambda}}(t_o)$	
DUVMM	$\dot{\bar{\lambda}}^-(t_m)$	
DUVMP	$\dot{\bar{\lambda}}^+(t_m)$	

C. Computation

$$\dot{\bar{\lambda}}(t_o) = \varphi_{mo,\,12}^{-1}(\bar{u}_{VM} - \varphi_{mo,\,11}\,\bar{u}_{VI})$$

$$\dot{\bar{\lambda}}^-(t_m) = \varphi_{mo,\ 21}\,\bar{u}_{VI} + \varphi_{mo,\ 22}\,\dot{\bar{\lambda}}(t_o)$$

$$\dot{\bar{\lambda}}^+(t_m) = \varphi_{fm,\ 12}^{-1}\,(\bar{u}_{VF} - \varphi_{fm,\ 11}\,\bar{u}_{VM})$$

$$\frac{d}{dt}\,|\dot{\bar{\lambda}}_m^-| = \dot{\bar{\lambda}}_m^- \cdot \bar{u}_{VM}$$

$$\frac{d}{dt}\,|\dot{\bar{\lambda}}_m^+| = \dot{\bar{\lambda}}_m^+ \cdot \bar{u}_{VM}$$

$$\frac{\partial \Delta V}{\partial \bar{V}_o} = \varphi_{mo,\ 12}^{T}\left(\dot{\bar{\lambda}}_m^+ - \dot{\bar{\lambda}}_m^-\right)$$

$$\frac{\partial \Delta V}{\partial t_m} = -\dot{\bar{\lambda}}_m^+ \cdot (V_m^+ - V_M^-)$$

$$\bar{g} = \left(\frac{\partial \Delta V^T}{\partial \bar{V}_o},\ \frac{\partial \Delta V}{\partial t_m}\right)$$

NOTE: In addition to the output parameters the following parameters are also printed out after each iteration.

Parameter	Symbol
PVMMAG	$\frac{d}{dt}\,\lvert\dot{\bar{\lambda}}_m^-\rvert$
PVPMAG	$\frac{d}{dt}\,\lvert\dot{\bar{\lambda}}_m^+\rvert$

Subroutine PVEC

A. Input Parameters

Parameters	Symbol	Definition
T	t	
R	R	
V	V	
PV0	$\overline{PV}(t_o)$	
STM	$\varphi\ (t,\ t_o)$	State transition matrix
IPVTM		IPVTM = 0, Advance PV only 1, Also monitor max. value of primer vector magnitude.

B. Output Parameters

PV	PV(t)	$PV(t) = (\bar{\lambda}(t),\ \dot{\bar{\lambda}}(t))$
LM	$\lvert\bar{\lambda}\rvert$	
LDM	$\frac{d}{dt}\lvert\bar{\lambda}\rvert$	

The following parameters are transmitted through COMMON/CTM/.

TTM	t_m	Time of maximum $\lvert\bar{\lambda}\rvert$
RTM	$\bar{R}(t_m)$	
VTM	$\bar{V}(t_m)$	
LTM	$\lvert\bar{\lambda}\ (t_m)\rvert$	
LDTM	$\frac{d}{dt}\lvert\bar{\lambda}\ (t_m)\rvert$	
PVTM	$\bar{\lambda}\ (t_m)$	
PVDTM	$\dot{\bar{\lambda}}\ (t_m)$	
STNTM	$\varphi(t_m{}',\ t_o)$	$t_m{}'$ = time when the primer vector magnitude is maximum.

C. <u>Computation</u>

$$\begin{pmatrix} \overline{\lambda}\,(t) \\ \dot{\overline{\lambda}}\,(t) \end{pmatrix} = \varphi(t,\ t_o) \begin{pmatrix} \overline{\lambda}\,(t_o) \\ \dot{\overline{\lambda}}\,(t_o) \end{pmatrix}$$

If IPVTM $\neq 0$, monitor $|\overline{\lambda}\,(t)|$ to determine maximum value.

Subroutine DISP

Both input and output parameters are transmitted through COMMON/TDATA/.

A. Input Parameters

Parameters	Symbol	Definition
RSV	$\overline{R}_{SV}{}^{S}$	
VSV	$\overline{V}_{SV}{}^{S}$	
REV	$\overline{R}_{EV}{}^{E}$	
VEV	$\overline{V}_{EV}{}^{E}$	
RMV	$\overline{R}_{MV}{}^{M}$	
VMV	$\overline{V}_{MV}{}^{M}$	
RSE	$\overline{R}_{SE}{}^{S}$	
VSE	$\overline{V}_{SE}{}^{S}$	
RSM	$\overline{R}_{SM}{}^{S}$	
VSM	$\overline{V}_{SM}{}^{S}$	
REM	$\overline{R}_{EM}{}^{E}$	
VEM	$\overline{V}_{EM}{}^{E}$	

B. Output Parameters

Parameters	Symbol	Definition
RSL1	$\overline{R}_{SL1}{}^{S}$	
VSL1	$\overline{V}_{SL1}{}^{S}$	
RDVD	$\overline{R}_{DV}{}^{D}$	Position and velocity of vehicle in D-frame
VDVD	$\overline{V}_{DV}{}^{D}$	
RDSD	$\overline{R}_{DS}{}^{D}$	
VDSD	$\overline{V}_{DS}{}^{D}$	

RDMD	$\overline{R}_{DM}{}^{D}$	
VDMD	$\overline{V}_{DM}{}^{D}$	
RDL1D	$\overline{R}_{DL1}{}^{D}$	
VDL1D	$\overline{V}_{DL1}{}^{D}$	
ANGV	ANG_V	Angle at vehicle between LOS to sun and earth
ANGE	ANG_E	Angle at earth between LOS to sun and vehicle
ANGS	ANG_S	Angle at sun between LOS to vehicle and earth

C. <u>Computation</u>

The position and velocity of 4-body L_1 point in S-frame are computed by

$$\overline{R}_{SL1} = (1 - \gamma_{L1}) \left(\overline{R}_{SE} + \frac{\mu_M}{\mu_E + \mu_M} \overline{R}_{EM}\right)$$

$$\overline{V}_{SL1} = (1 - \gamma_{L1}) \left(\overline{V}_{SE} + \frac{\mu_M}{\mu_E + \mu_M} \overline{V}_{EM}\right)$$

An earth centered rotating frame (D-frame) for display is used to suppress the motion of the earth which is significant due to its orbital eccentricity around the sun and the presence of the moon.

Define:

$$\bar{u}X_D{}^S = \text{unit}\ (\overline{R}_{SE})$$

$$\bar{u}Z_D{}^S = \text{unit}\ (\overline{R}_{SE} \times \overline{V}_{SE})$$

$$\bar{u}Y_D{}^S = \bar{u}Z_D{}^S \times \bar{u}X_D{}^S$$

The transformation from the inertial S-frame to a frame parallel to the rotating D-frame is given by the matrix

$$C_S{}^D = \left(\left(\bar{u}X_D{}^S\right)^T, \left(\bar{u}Y_D{}^S\right)^T, \left(\bar{u}Z_D{}^S\right)^T\right)$$

The D-frame rotates with respect ot S-frame with an angular velocity defined by

$$\overline{\omega}_{SD}{}^{S} = \overline{u}Z_{D}{}^{S}\left(\overline{u}Y_{DS}{}^{S} \cdot \overline{V}_{SE}\right)/|\overline{R}_{SE}|$$

The transformating from S-frame to D-frame for typical position and velocity vectors are as follows:

$$\overline{R}_{SD}{}^{S} = \overline{R}_{SE}{}^{S}$$

$$\overline{V}_{SD}{}^{S} = \overline{V}_{SE}{}^{S}$$

$$\overline{R}_{DV}{}^{D} = C_{S}{}^{D}\,\overline{R}_{DV}{}^{S} = C_{S}{}^{D}\left(\overline{R}_{SV}{}^{S} - \overline{R}_{SD}{}^{S}\right)$$

$$\overline{V}_{DV}{}^{D} = C_{S}{}^{D}\left(\overline{V}_{SV}{}^{S} - \overline{V}_{SD}{}^{S} - \overline{\omega}_{SD}{}^{S} \times \overline{R}_{DV}{}^{S}\right)$$

The angles at the vehicle, sun and earth are computed by

$$\overline{u}R_{SE} = \mathrm{UNIT}\ (\overline{R}_{SE})$$

$$\overline{u}R_{EV} = \mathrm{UNIT}\ (\overline{R}_{EV})$$

$$\overline{u}R_{SV} = \mathrm{UNIT}\ (\overline{R}_{SV})$$

$$ANG_{V} = \cos^{-1}\left(\overline{u}R_{EV} \cdot \overline{u}R_{SV}\right)/DTR$$

$$ANG_{E} = \cos^{-1}\left(-\overline{u}R_{SE} \cdot \overline{u}R_{EV}\right)/DTR$$

$$ANG_{S} = 180 - (ANG_{V} + ANG_{E})$$

DTR = Degree to radian conversion

Subroutine DISP3

Both input and output parameters are transmitted through COMMON/TDATA3/.

A. Input Parameters

Parameters	Symbol	Definition
REV	$\bar{R}_{EV}^{e}$	
VEV	$\bar{V}_{EV}^{e}$	
RMV	$\bar{R}_{MV}^{m}$	
VMV	$\bar{V}_{MV}^{m}$	
REM	$\bar{R}_{EM}^{e}$	
VEM	$\bar{V}_{EM}^{e}$	

B. Output Parameters

Parameters	Symbol	Definition
REL	$\bar{R}_{EL}^{e}$	
VEL	$\bar{V}_{EL}^{e}$	
RDVD	$\bar{R}_{DV}^{d}$	
VDVD	$\bar{V}_{DV}^{d}$	
RDED	$\bar{R}_{DE}^{d}$	
VDED	$\bar{V}_{DE}^{d}$	
RDLD	R_{DL}^{D}	
VDLD	V_{DL}^{D}	
ANGV	ANG_{V}	
ANGE	ANG_{E}	
ANGM	ANG_{M}	

C. Computation

The position and velocity of 3-body libration point L in e-frame are computed by

$$\overline{R}_{EL} = (1 - \gamma)\,\overline{R}_{EM}$$

$$\overline{V}_{EL} = (1 - \gamma)\,\overline{V}_{EM}$$

where $\gamma > 0$ for L_1 and $\gamma < 0$ for L_2.

A moon centered rotating frame (d-frame) for display is used to suppress the motion of the moon. Define

$$\overline{u}_{XD}^{\,e} = \text{UNIT}\left(\overline{R}_{EM}^{\,e}\right)$$

$$\overline{u}_{ZD}^{\,e} = \text{unit}\left(\overline{R}_{EM}^{\,e} \times \overline{V}_{EM}^{\,e}\right)$$

$$\overline{u}_{YD}^{\,e} = \overline{u}_{ZD}^{\,e} \times \overline{u}_{XD}^{\,e}$$

The transformation from the inertial e-frame to a frame parallel to the rotating d-frame is given by the matrix

$$C_e^{\,d} = \left(\left(\overline{u}_{XD}^{\,e}\right)^T, \left(\overline{u}_{YD}^{\,e}\right)^T, \left(\overline{u}_{ZD}^{\,e}\right)^T\right)$$

The d-frame rotates with respect to the e-frame with an angular velocity

$$\overline{\omega}_{ed}^{\,e} = \overline{u}_{ZD}^{\,e}\left(\overline{u}_{YD}^{\,e} \cdot \frac{\overline{V}_{EM}^{\,e}}{|\overline{R}_{EM}^{\,e}|}\right)$$

The transformations from the e-frame to d-frame for typical position and velocity vectors are as follows:

$$\overline{R}_{ED}^{\,e} = \overline{R}_{EM}^{\,e}$$

$$\overline{V}_{ED}^{\,e} = \overline{V}_{EM}^{\,e}$$

$$\overline{R}_{DV}^{\,d} = C_e^{\,d}\,\overline{R}_{DV}^{\,e} = C_e^{\,d}\left(\overline{R}_{EV}^{\,e} - \overline{R}_{ED}^{\,e}\right)$$

$$\overline{V}_{DV}^{\,d} = C_e^{\,d}\left(\overline{V}_{EV}^{\,e} - \overline{V}_{ED}^{\,e} - \overline{\omega}_{ed}^{\,e} \times \overline{R}_{DV}^{\,e}\right)$$

The angles at the vehicle, earth and moon are computed by:

$$\bar{u}R_{MV} = \text{UNIT}\ (\bar{R}_{MV})$$

$$\bar{u}R_{EM} = \text{UNIT}\ (\bar{R}_{EM})$$

$$\bar{u}R_{EV} = \text{UNIT}\ (\bar{R}_{EV})$$

$$ANG_V = \cos^{-1}(\bar{u}R_{MV} \cdot \bar{u}R_{EV})/DTR$$

$$ANG_M = \cos^{-1}(-\bar{u}R_{EM} \cdot \bar{u}R_{MV})/DTR$$

$$ANG_E = 180 - (ANG_V + ANG_M)$$

DTR = Degree to radian conversion

Subroutine PTRAJ

Input parameters are transmitted through COMMON/TDATA/. If IPTRAJ = 1, the following parameters are printed at each time step.

T	T(DAY)	H	$\lvert\bar{R}SV\rvert$	$\lvert\bar{R}EV\rvert$	$\lvert\bar{R}MV\rvert$

$\bar{R}_{SV}{}^{S}$ $\quad$ $\bar{V}_{SV}{}^{S}$

$\bar{R}_{EV}{}^{E}$ $\quad$ $\bar{V}_{EV}{}^{E}$

$\bar{R}_{MV}{}^{M}$ $\quad$ $\bar{V}_{MV}{}^{M}$

$\bar{R}_{SE}{}^{S}$ $\quad$ $\bar{V}_{SE}{}^{S}$

$\bar{R}_{SM}{}^{S}$ $\quad$ $\bar{V}_{SM}{}^{S}$

$\bar{R}_{EM}{}^{E}$ $\quad$ $\bar{V}_{EM}{}^{E}$

$\bar{R}_{SL1}{}^{S}$ $\quad$ $\bar{V}_{SL1}{}^{S}$

$\bar{R}_{DV}{}^{D}$ $\quad$ $\bar{V}_{DV}{}^{D}$

$\bar{R}_{DS}{}^{D}$ $\quad$ $\bar{V}_{DS}{}^{D}$

$\bar{R}_{DM}{}^{D}$ $\quad$ $\bar{V}_{DM}{}^{D}$

$\bar{R}_{DL1}{}^{D}$ $\quad$ $\bar{V}_{DL1}{}^{D}$

ANG_V $\quad$ ANG_E $\quad$ ANG_S $\quad$ H(DAY)

If IPV = 1, the primer vector history below is printed.

$\bar{\lambda}$ $\quad$ $\dot{\bar{\lambda}}$

$|\bar{\lambda}|$ $\quad$ $\frac{d}{dt}|\bar{\lambda}|$

Subroutine PTRAJ3

Input parameters are transmitted through COMMON/TDATA3/. If IPTRAJ = 1, the following parameters are printed at each time step.

T	TDAY	H	H(DAY)	$\lvert\overline{R}_{EV}\rvert$	$\lvert\overline{R}_{MV}\rvert$
$\overline{R}_{EV}{}^{e}$			$\overline{V}_{EV}{}^{e}$		
$\overline{R}_{MV}{}^{m}$			$\overline{V}_{MV}{}^{m}$		
$\overline{R}_{EM}{}^{e}$			$\overline{V}_{EM}{}^{e}$		
$\overline{R}_{EL}{}^{e}$			$\overline{V}_{EL}{}^{e}$		
$\overline{R}_{DV}{}^{d}$			$\overline{V}_{DV}{}^{d}$		
$\overline{R}_{DE}{}^{d}$			$\overline{V}_{DE}{}^{d}$		
$\overline{R}_{DL}{}^{d}$			$\overline{V}_{DL}{}^{d}$		
ANG_V	ANG_E	ANG_M			

If IPV = 1, the primer vector history is printed

$\overline{\lambda}$		$\dot{\overline{\lambda}}$
$\lvert\overline{\lambda}\rvert$	$\frac{d}{dt}\lvert\overline{\lambda}\rvert$	

Subroutine FDATA

Input parameters are transmitted through COMMON/TDATA/. If IFILEX or IFILE is position nonzero the following double precision parameters are filed sequentially in unformatted form.

Parameter	File Location	Parameter	File Location
t	+1	$\overline{V}_{DS}{}^{D}$	54 - 56
h	2	$\overline{R}_{DM}{}^{D}$	57 - 59
$\overline{R}_{SV}$	3 - 5	$\overline{V}_{DM}{}^{D}$	60 - 62
$\overline{V}_{SV}$	6 - 8	$\overline{R}_{DL1}{}^{D}$	63 - 65
$\overline{R}_{EV}$	9 - 11	$\overline{V}_{DL1}{}^{D}$	66 - 68
$\overline{V}_{EV}$	12 - 14	$\overline{\lambda}, \dot{\overline{\lambda}}$	69 - 74
$\overline{R}_{MV}$	15 - 17	$\lvert\overline{\lambda}\rvert$	75
$\overline{V}_{MV}$	18 - 20	$\frac{d}{dt}\lvert\overline{\lambda}\rvert$	76
$\overline{R}_{SE}$	21 - 23	ANG_V	77
$\overline{V}_{SE}$	24 - 26	ANG_E	78
$\overline{R}_{SM}$	27 - 29	ANG_S	79
$\overline{V}_{SM}$	30 - 32	$\lvert\overline{R}_{SV}\rvert$	80
$\overline{R}_{EM}$	33 - 35	$\lvert\overline{V}_{SV}\rvert$	81
$\overline{V}_{EM}$	36 - 38	$\lvert\overline{R}_{EV}\rvert$	82
$\overline{R}_{SL1}$	39 - 41	$\lvert\overline{V}_{EV}\rvert$	83
$\overline{V}_{SL1}$	42 - 44	$\lvert\overline{R}_{MV}\rvert$	84
$\overline{R}_{DV}{}^{D}$	45 - 47	$\lvert\overline{V}_{MV}\rvert$	85
$\overline{V}_{DV}{}^{D}$	48 - 50	Blank	86 - 100
$\overline{R}_{DS}{}^{D}$	51 - 53	Total	100

Subroutine FDATA3

Input parameters are transmitted through COMMON/TDATA3/. If IFILEX or IFILE is positive nonzero, the following double precision parameters are filed sequentially in unformatted form.

Parameter	File Location	Parameter	File Location
t	+1	$\overline{V}_{DL}{}^{d}$	42 - 44
h	2	$\overline{\lambda}, \dot{\overline{\lambda}}$	45 - 50
$\overline{R}_{EV}$	3 - 5	$\lvert\overline{\lambda}\rvert$	51
$\overline{V}_{EV}$	6 - 8	$\frac{d}{dt}\lvert\overline{\lambda}\rvert$	52
$\overline{R}_{MV}$	9 - 11	ANG_V	53
$\overline{V}_{MV}$	12 - 14	ANG_E	54
$\overline{R}_{EM}$	15 - 17	ANG_M	55
$\overline{V}_{EM}$	18 - 20	$\lvert\overline{R}_{EV}\rvert$	56
$\overline{R}_{EL}$	21 - 23	$\lvert\overline{V}_{EV}\rvert$	57
$\overline{V}_{EL}$	24 - 26	$\lvert\overline{R}_{MV}\rvert$	58
$\overline{R}_{DV}{}^{d}$	27 - 29	$\lvert\overline{V}_{MV}\rvert$	59
$\overline{V}_{DV}{}^{d}$	30 - 32	$\lvert\overline{R}_{EM}\rvert$	60
$\overline{R}_{DE}{}^{d}$	33 - 35	$\lvert\overline{V}_{EM}\rvert$	61
$\overline{V}_{DE}{}^{d}$	36 - 38	Blank	62 - 75
$\overline{R}_{DL}{}^{d}$	39 - 41	Total	75

TROUBLE SHOOTING

In this section we list a number of common troubles, their causes and suggested corrective actions.

Trouble	Diagnosis	Action
Integration too slow.	Allowable single step position error too small. Input error.	Increase ERRMAX or ERRMXM. Check input.
TWOBDY fails to converge or gives strange answers.	Bad input state vector or gravitational constants.	Check input.
FOURBY (THRBDY) gives strange answers.	Bad input to TWOBDY.	Check input.
Slow to satisfy constraint.	Allowable terminal error too small.	Increase ERRMIN or EPSTSI.
LAMB (LAMB3) fails to converge.	Bad nominal trajectory.	Search for new nominal closer to satisfy constraint. Reduce KNR.
ETP21 (ETP213) fails to satisfy constraint.	Bad nominal trajectory.	Search for new nominal closer to satisfy constraint. Reduce KDX.
ETP21 (ETP213) fails to reduce ΔV.	Bad V-matrix.	Reduce EPSV. Try new estimate of independent variables.
PTP31 (PtP3I3) fails to reduce ΔV.	Bad V-matrix.	Reduce EPSV. Try new estimate of independent variables.

Helpful Suggestions

1. It pays to search for a nominal trajectory which comes close to satisfy terminal constraint. This is not so important in a short transfer, which will converge even if the nominal trajectory misses the target badly. For long transfer, a bad nominal trajectory will prolong iterations due to increased nonlinearity, which reduces permissable changes in the independent variables.

2. A capability to plot trajectory is very helpful to show whether a nominal trajectory is heading in the right direction. It is not difficult to adjust the independent variables properly after examining a plot of the trajectory but it is very difficult to determine what action to take by looking at a printout.

3. It is generally better to run the programs by a succession of short runs instead of a single long run. The pauses between short runs enable the user to interpret the results and make necessary changes. It is not possible nor practical to fully automate a program to take into account all possible contingencies.

4. When a run is continued, use the current independent variables, V-matrix, KDX, KNR, etc. to maintain continuity.

EXAMPLE 1

A. Purpose

This example may be used to check out Program TRAJ and associated subroutines. It is a 4-body transfer from noon July 4, 1978 from a 100 n. mi. earth parking orbit to L_1 in 36 days.

B. Input Parameters

Card No.	Format	Parameter	Value
1	4D20.11	GL1	1.001098D-02
		AUM	1.49597893D+11
		UTIME	5.81323577632D+01
		UVELM	3.35742409867D-05
2	3D20.11	MS	9.99996959568D-01
		ME	3.00348453188D-06
		MM	3.69431224671D-08
3	4I5	IMODE	1
		IPV	1
		IPTRAJ	1
		IFILE	0
4	4D20.11	RSE0(1)	1.98930090999D-01
		(2)	-9.97050589850D-01
		(3)	6.79027012471D-05
		VSE0(1)	9.64906589348D-01
5	4D20.11	(2)	1.92157060597D-01
		(3)	-1.47749626270D-05

		RSM0 (1)	1.99125783494D-01
		(2)	-9.94358817445D-01
6	4D20.11	(3)	-1.68002571823D-04
		VSM0 (1)	9.32348120275D-01
		(2)	1.95028878329D-01
		(3)	-2.62545160637D-04
7	3D20.11	TDAY0	1.099D+03
		TTRIPD	3.6D+01
		ERRMXM	1.524D+02
8	4D20.11	REVMAG	4.38739157152D-05
		VEVMAG	3.69220795569D-01
		OINCD	2.85D+01
		OBLD	2.34457874302D+01
9	2D20.11	LOND	3.59181042981D+02
		THED	-3.51880454048D+01
10	4D20.11	λ(1)	5.86468563221D-01
		(2)	8.06463656568D-01
		(3)	7.53060089751D-02
		$\dot{\lambda}$(1)	-3.43647891554D+03
11	2D20.11	(2)	2.47056772744D+03
		(3)	3.04177095939D+02

C. Output Parameters

A printout of the trajectory at each time step is submitted with this guide in a separate package. The state vectors at the terminal time is

RSV(1)	7.17957115972D-01
(2)	-7.01342803746D-01
(3)	4.27257573439D-05
VSV(1)	6.79829811710D-01
(2)	7.15967885505D-01
(3)	-6.21512714224D-04

The vehicle intercepts the L_1 point after 36 days. The trajectories with respect to earth and moon are shown in Figures 2a to 2f. The primer vector magnitude history is shown in Figure 2g. The ΔV of this transfer is 354.57 m/s. Note that the initial earth parking orbit has an inclination of 28.5 deg. If this restriction is removed, the ΔV of the same transfer of 36 days is about 288 m/s (Ref. 2).

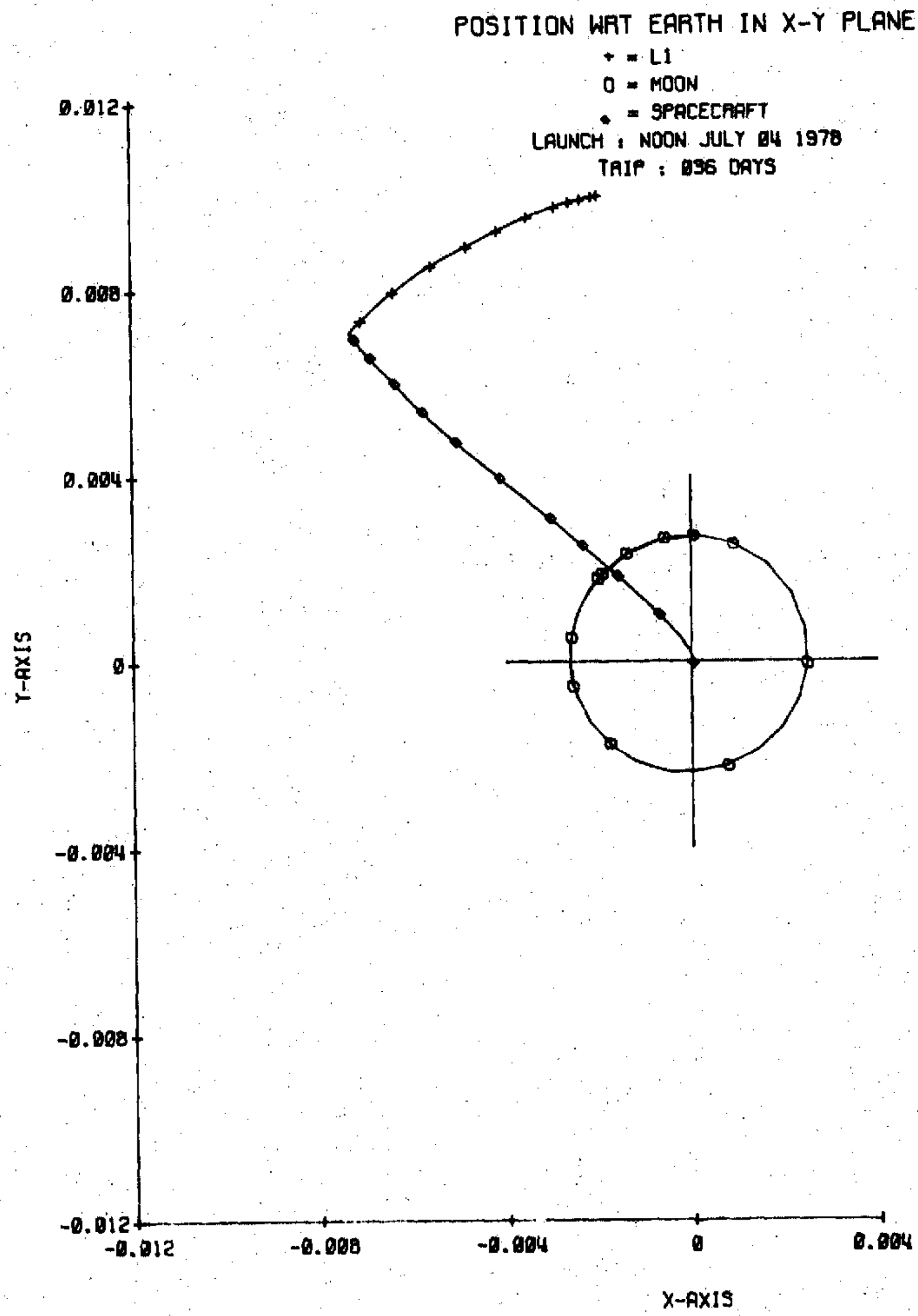


Figure 2a 2-Impulse Transfer (Example 1)

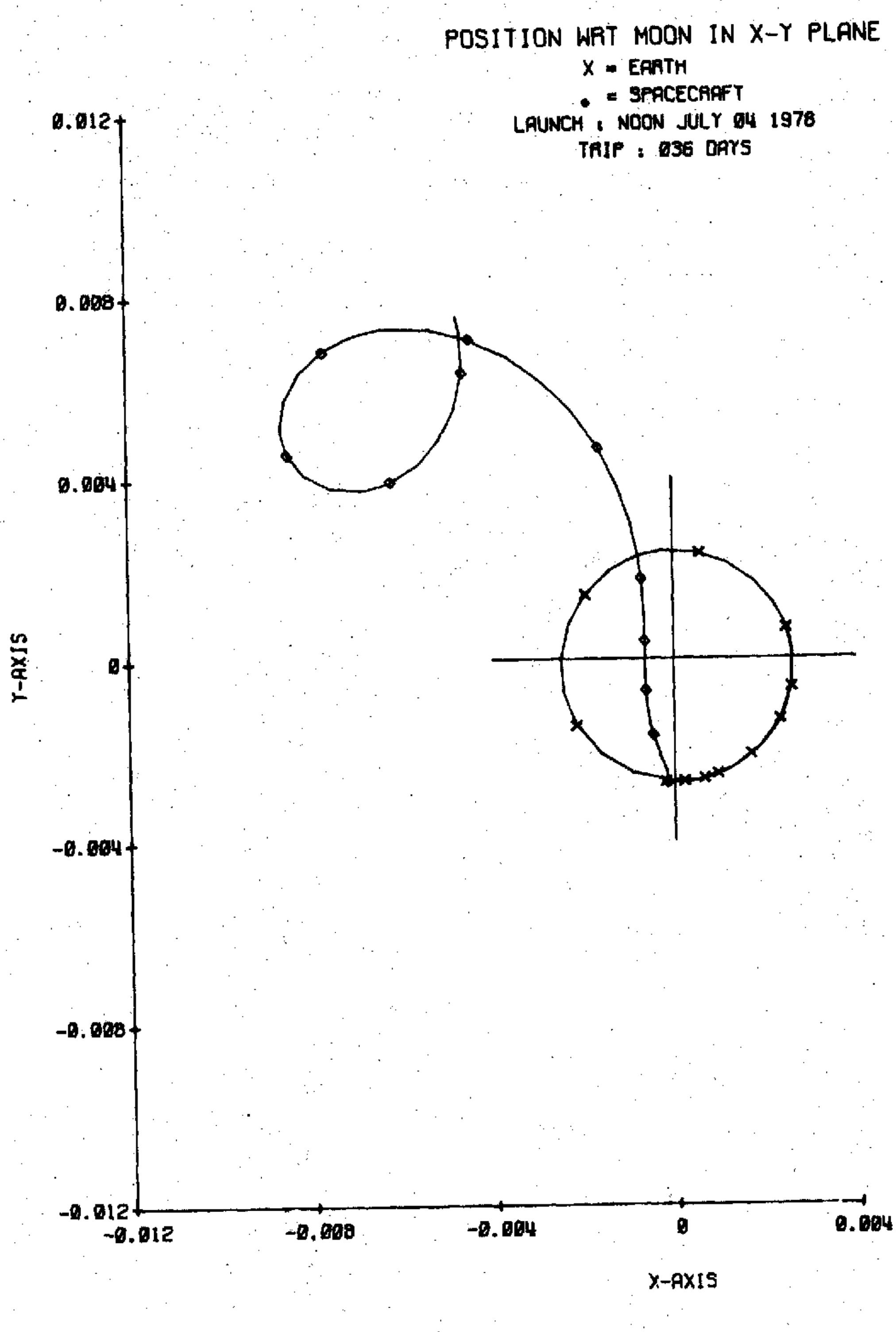


Figure 2b 2-Impulse Transfer (Example 1)

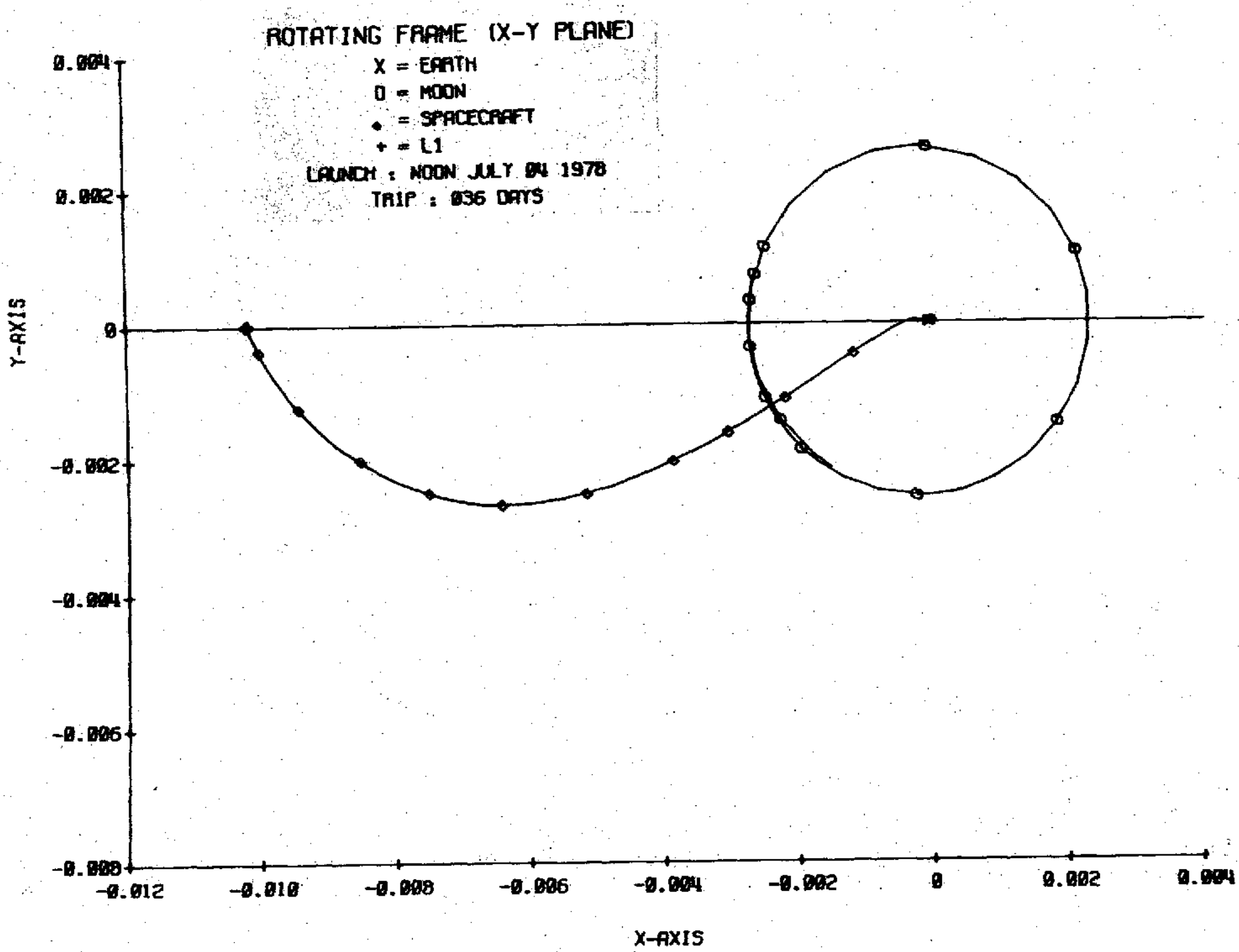


Figure 2c 2-Impulse Transfer (Example 1)

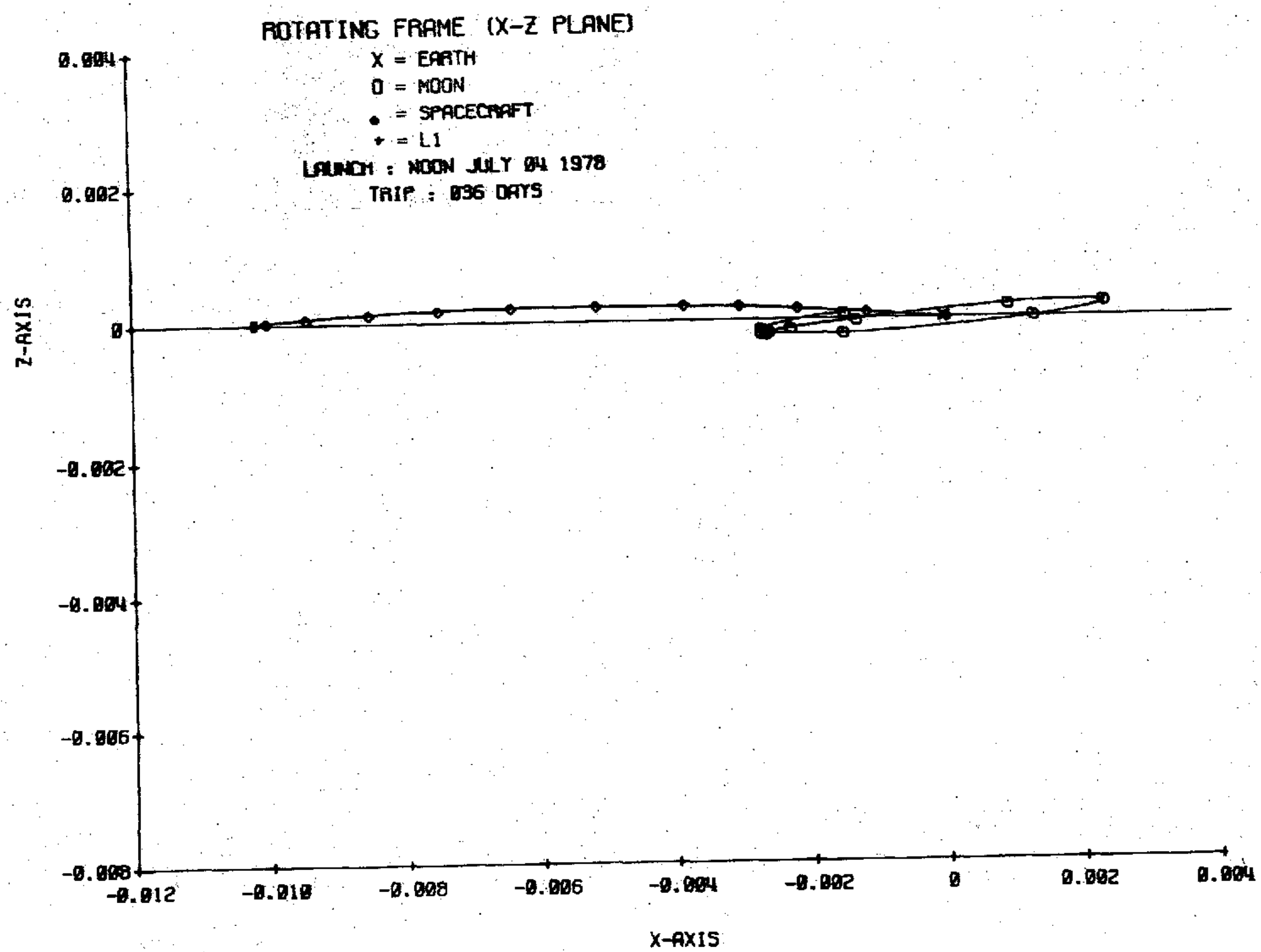


Figure 2d 2-Impulse Transfer (Example 1)

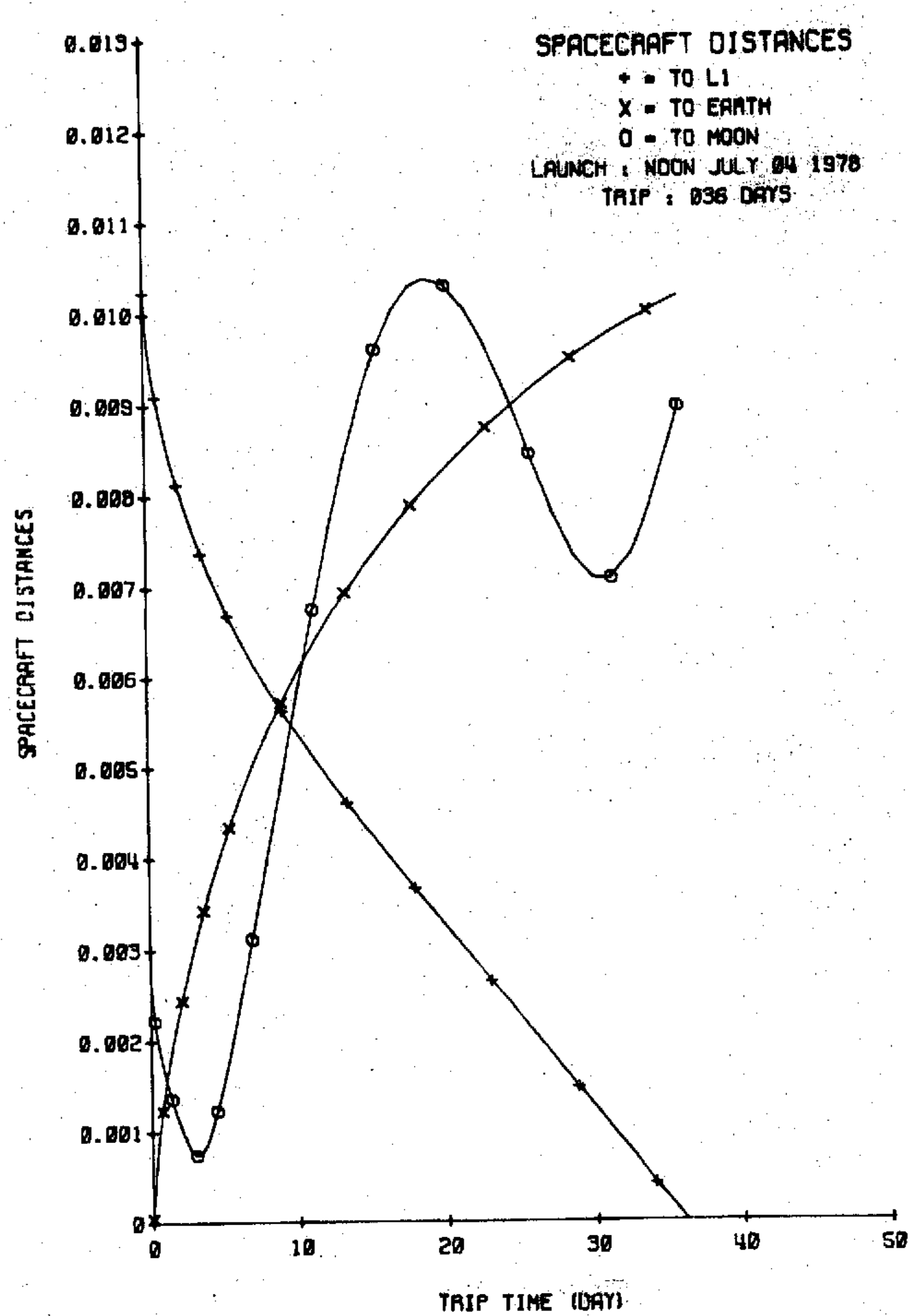


Figure 2e 2-Impulse Transfer (Example 1)

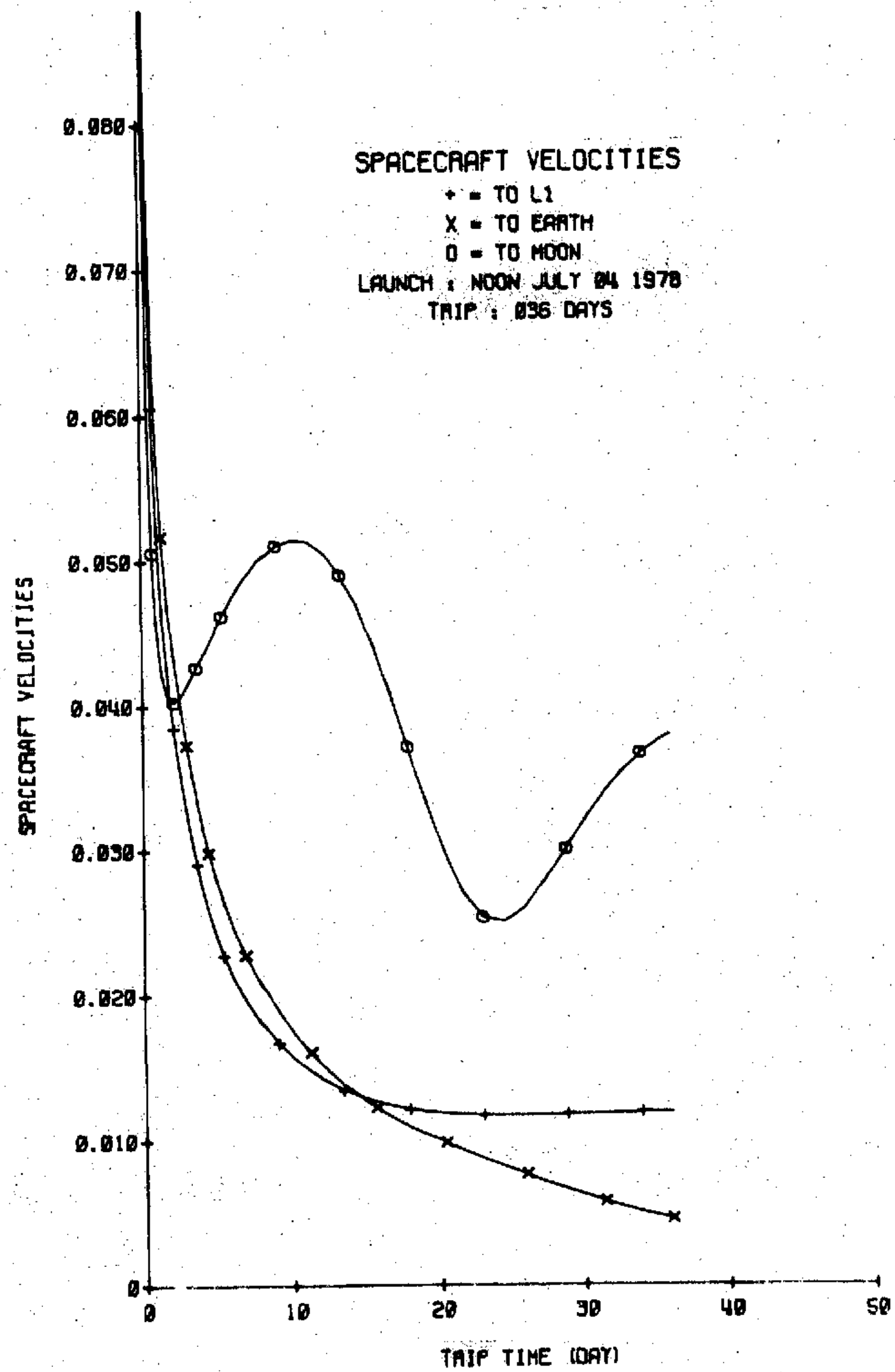


Figure 2f   2-Impulse Transfer (Example 1)

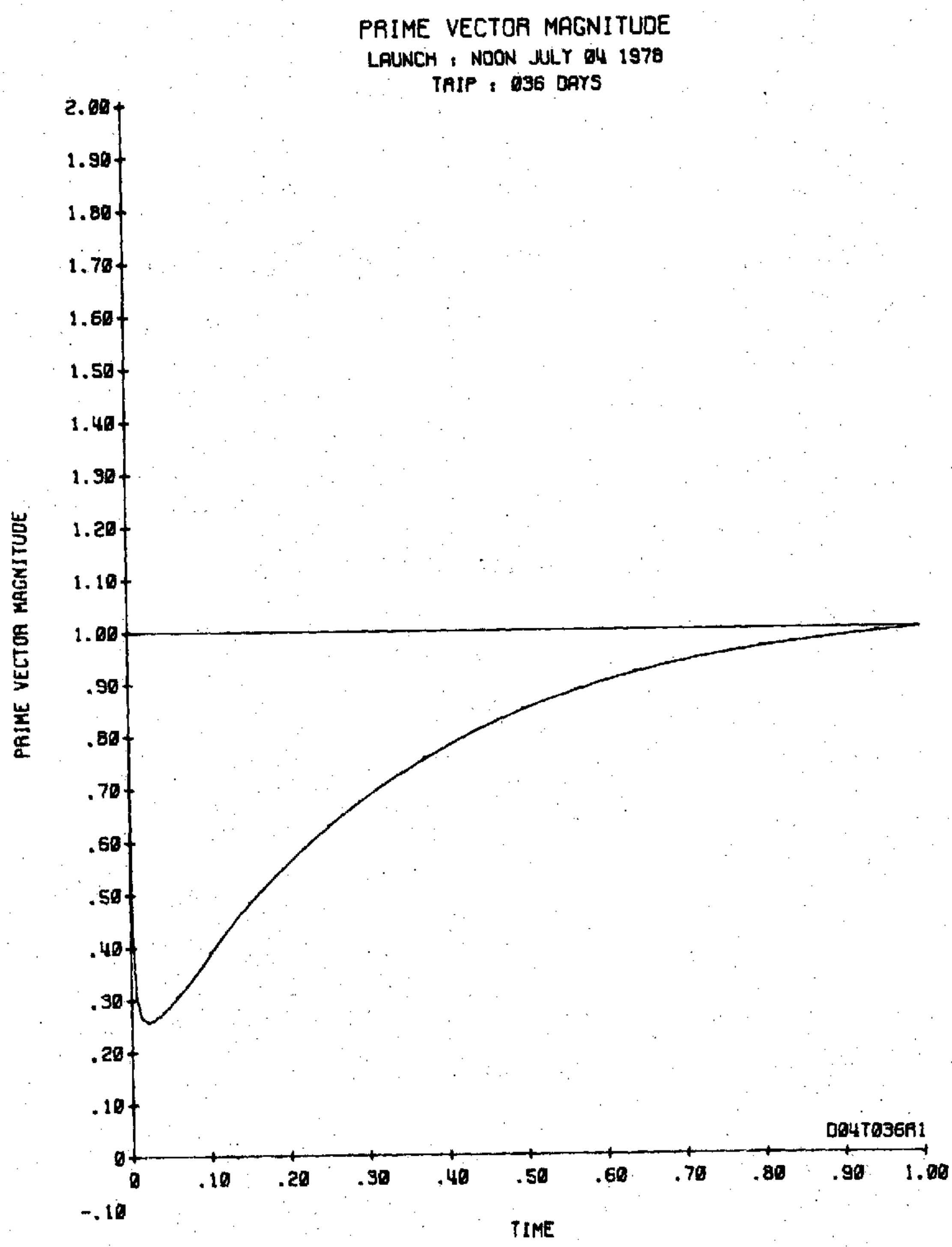


Figure 2g 2-Impulse Transfer (Example 1)

EXAMPLE 2

A. Purpose

This example may be used to check out Program EXLAM and associated subroutines. It is a 4-body transfer from noon July 4, 1978 from a given position at earth to a given point in space in 36 days.

B. Input Parameters

* Same as in Ex. 1

Card No.	Format	Parameter	Value
1	4D20.11	GL1	*
		AUM	*
		UTIME	*
		UVELM	*
2	3D20.11	MS	*
		ME	*
		MM	*
3	4I5	IMODE	2
		ITLMAX	50
		IPTJX	0
		IFILEX	0
4	4D20.11	RSE0 (1)	1.98930091D-01
		(2)	-9.97050589850D-01
		(3)	6.79027012471D-05
		VSE0 (1)	9.64906589348D-01
5	4D20.11	(2)	1.92157060597D-01
		(3)	-1.47749626270D-05

		RSM0 (1)	1.99125783494D-01
		(2)	-9.94358817445D-01
6	4D20.11	(3)	-1.68002571823D-04
		VSM0 (1)	9.32348120275D-01
		(2)	1.95028878329D-01
		(3)	-2.62545160637D-04
7	3D20.11	TDAY0	1.099D+03
		TRIPD	3.6D+01
		ERRMXM	1.524D+02
8	4D20.11	RSVTAR	7.17957115972D-01
			-7.01342803746D-01
			4.27257573439D-05
		ERRMIN	1.0D-10
9	1D20.11	KNR	1.0D+00
10	4D20.11	REV0 (1)	3.55098760149D-05
		(2)	-2.56858251705D-05
		(3)	-2.05123643240D-06
		VEV0P(1)	2.16833393469D-01
11	2D20.11	(2)	2.97557757082D-01
		(3)	2.76469306727D-02

C. Output Parameters

A printout of Lambert iterations is submitted with this guide in a separate package. The initial state vector is:

RSV0 (1)	1.98965600875D-01
(2)	-9.97076275675D-01
(3)	6.58514648147D-05
VSVI(1)	1.18173998282D+00
(2)	4.89714817679D-01
(3)	2.76321557101D-02

The iteration history is as follows:

ITER	Error(|ψ|)
1	3.9725 D-05 initial miss
2	1.6349D-04
3	3.4139D-05
4	2.0172D-05
5	1.7986D-05
6	1.6351D-05
7	9.6429D-09
8	6.1105D-12 < ERRMIN

The converged solution is

VSVI(1)	1.18164961297D+00
(2)	4.89491098961D-01
(3)	3.06148929077D-02

EXAMPLE 3

A. Purpose

This example may be used to check out Program ETP2I and associated subroutines. It is a 4-body transfer from noon July 4, 1978 to L_1 in 44 days. The earth parking orbit has an inclination of 28.5 deg.

B. Output Parameters

* Same as in Ex. 1

** Same as in Ex. 2

Card No.	Format	Parameter	Value
1	4D20.11	GL1	*
		AUM	*
		UTIME	*
		UVELM	*
2	3D20.11	MS	*
		ME	*
		MM	*
3	4D20.11	REVMAG	*
		OINCD	*
		OBLD	*
		ERRMXM	*
4	2D20.11	TDAY0	*
		TTRIPD	4.40D+01
5	3D20.11	VEVMAG	3.69195894918D-01
		LOND	3.40D+02
		THED	0.D+00

6	4D20.11	RSE0 (1)	*
		(2)	*
		(3)	*
		VSE0 (1)	*
7	4D20.11	(2)	*
		(3)	*
		RSM0 (1)	*
		(2)	*
8	4D20.11	(3)	*
		VSM0 (1)	*
		(2)	*
		(3)	*
9	4D20.11	EPS	1.0D-11
		EPSTSI	1.0D-10
		KDX	1.0D+00
		EPSV	1.0D-03
10	I4	ICOMV	1
		ITERMX	50
		IFILEX	0
		ITAR	0
11	3D20.11	AYM	0
		AZM	0
		ATARD	0

C. Output Parameters

The state vector at the terminal time is:

RSV(1)	8.04147100281D-01
(2)	-5.98272665021D-01
(3)	3.54443603861D-05
VSV(1)	5.80886320061D-01
(2)	8.02081814322D-01
(3)	-4.43809910137D-04

The converged initial conditions are:

VEVMAG	10997.18 m/s
LOND	358.32 deg
THED	-23.43 deg

The costs are:

$\lvert\Delta V_o\rvert$	3204.20 m/s
$\lvert\Delta V_f\rvert$	377.80 m/s
	3582.00

Ref. 2 indicates that $\lvert\Delta V_f\rvert$ is 263.31 m/s for the 44 day transfer without the inclination angle costraint.

A printout of the iterations together with the trajectory at each time step is submitted in a separate package.

The trajectory is shown in Figure 3a to 3f. The primer vector history is shown in Figure 3g.

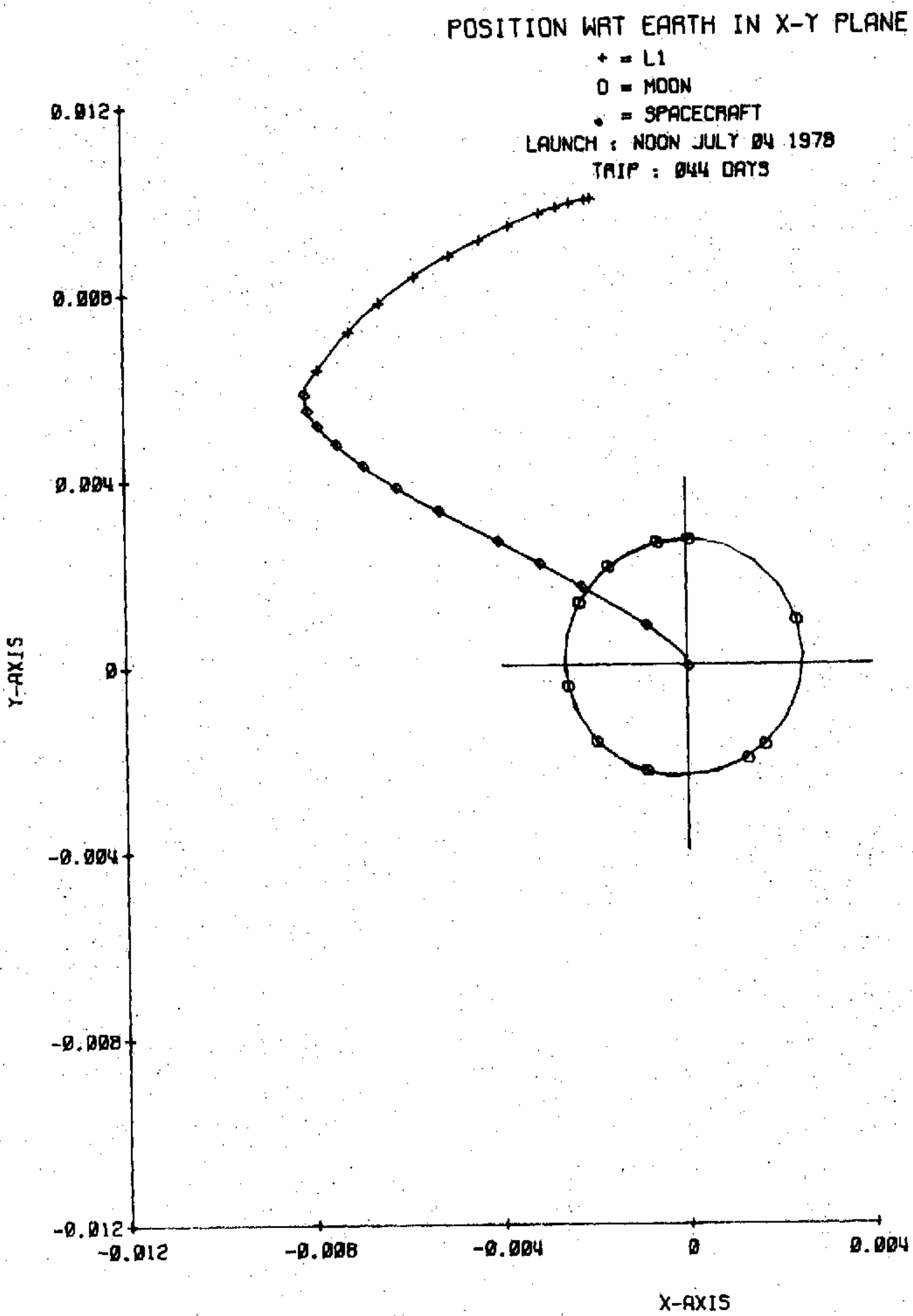


Figure 3a 2-Impulse Transfer (Example 3)

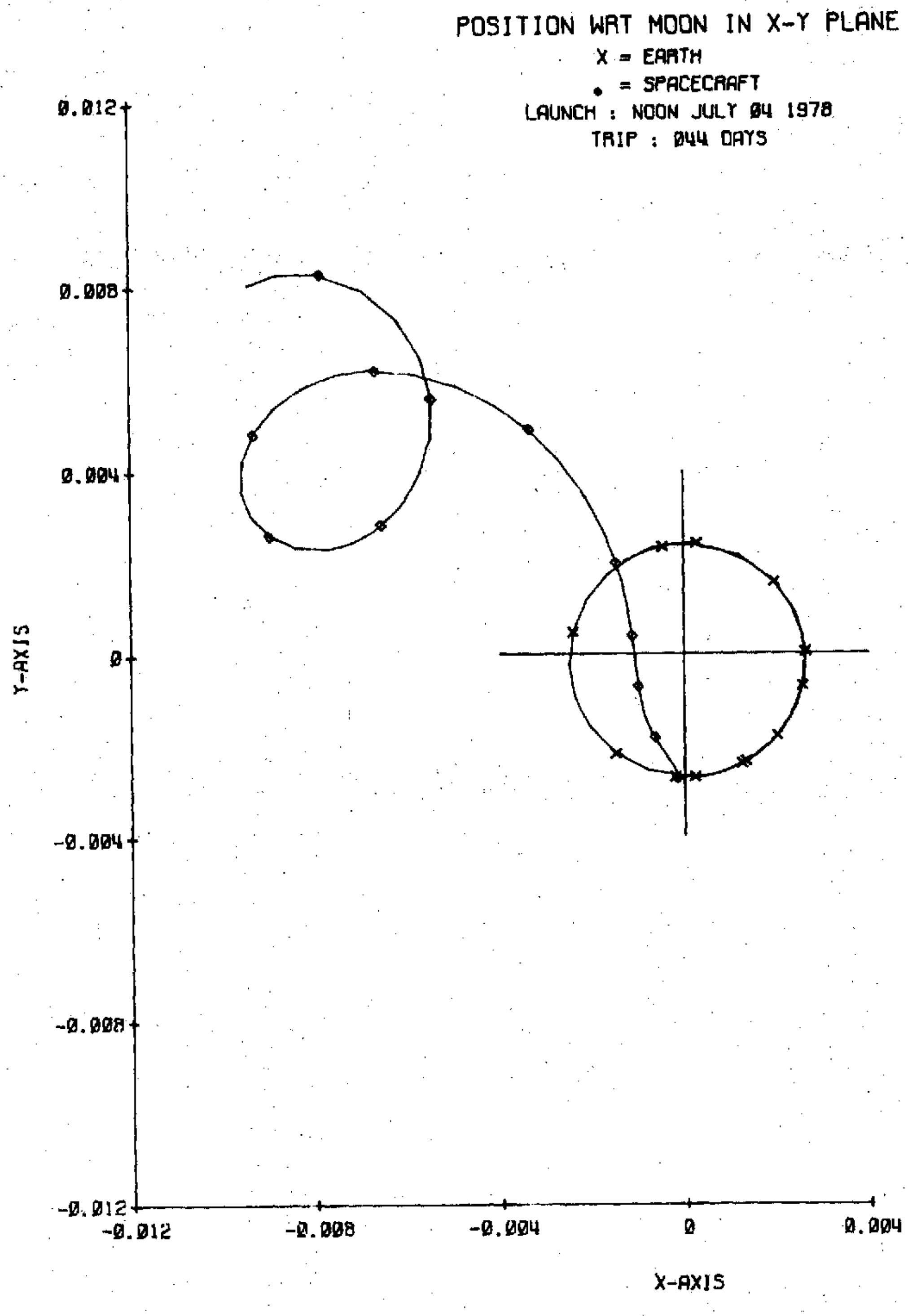


Figure 3b 2-Impulse Transfer (Example 3)

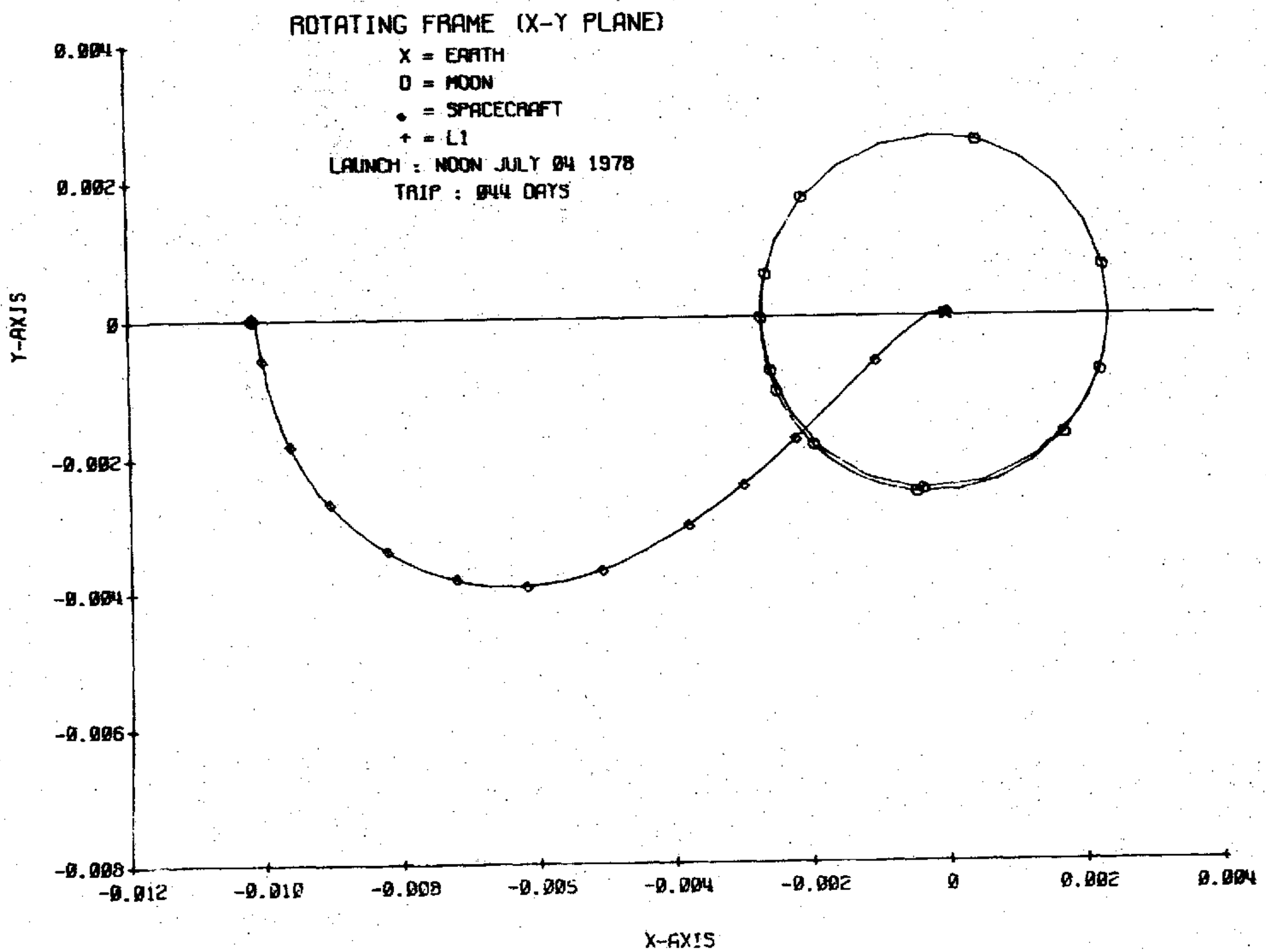


Figure 3c 2-Impulse Transfer (Example 3)

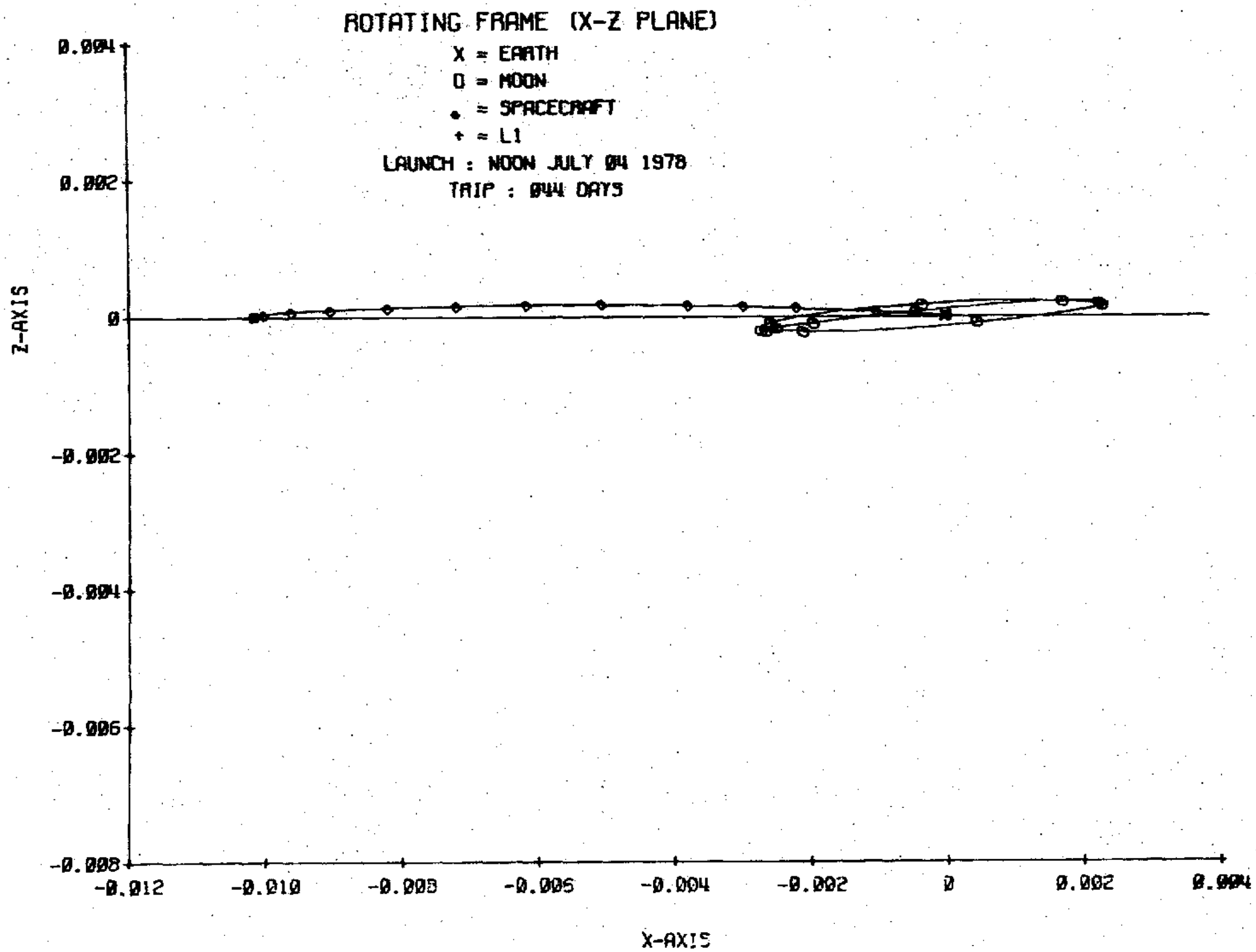


Figure 3d 2-Impulse Transfer (Example 3)

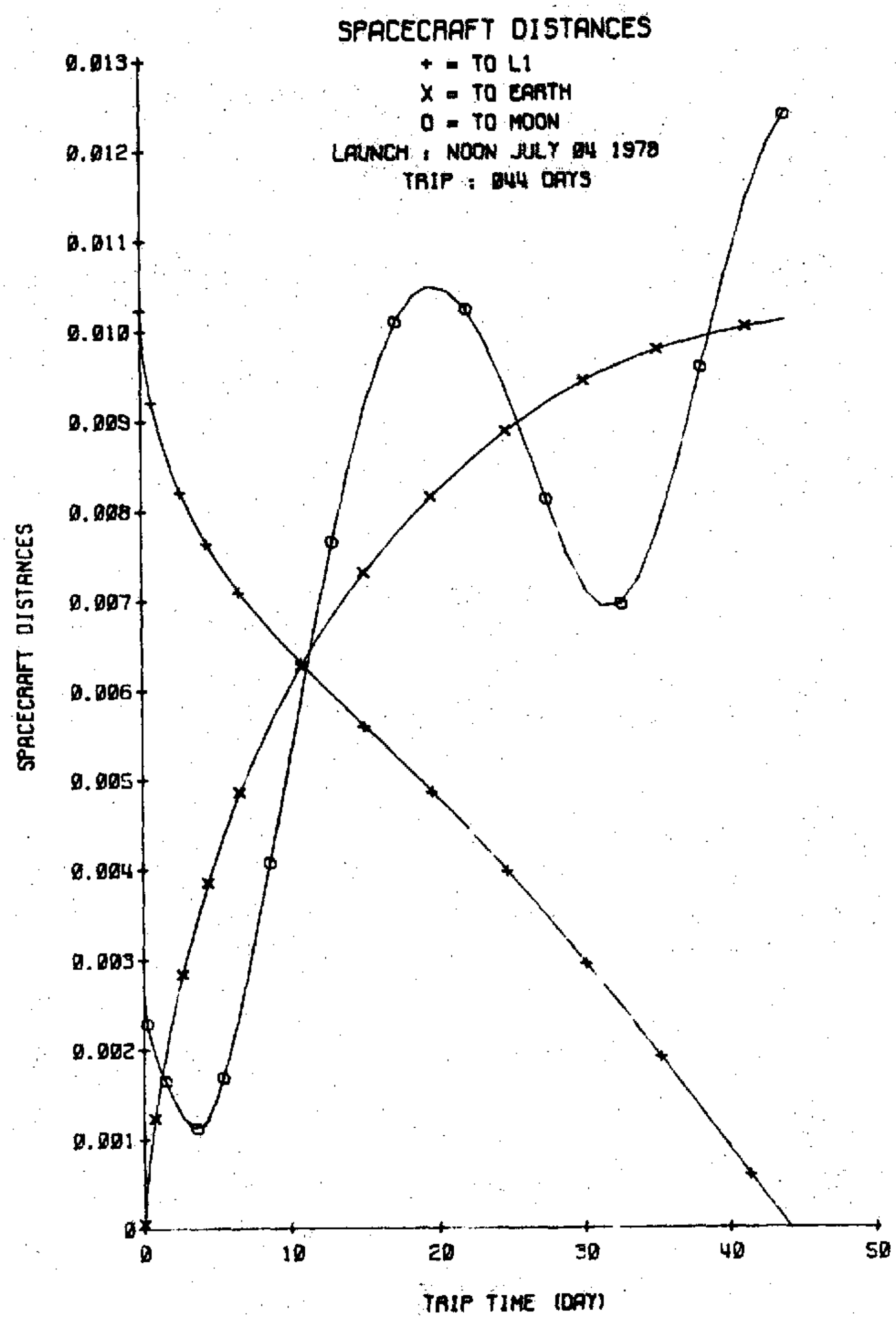


Figure 3e   2-Impulse Transfer (Example 3)

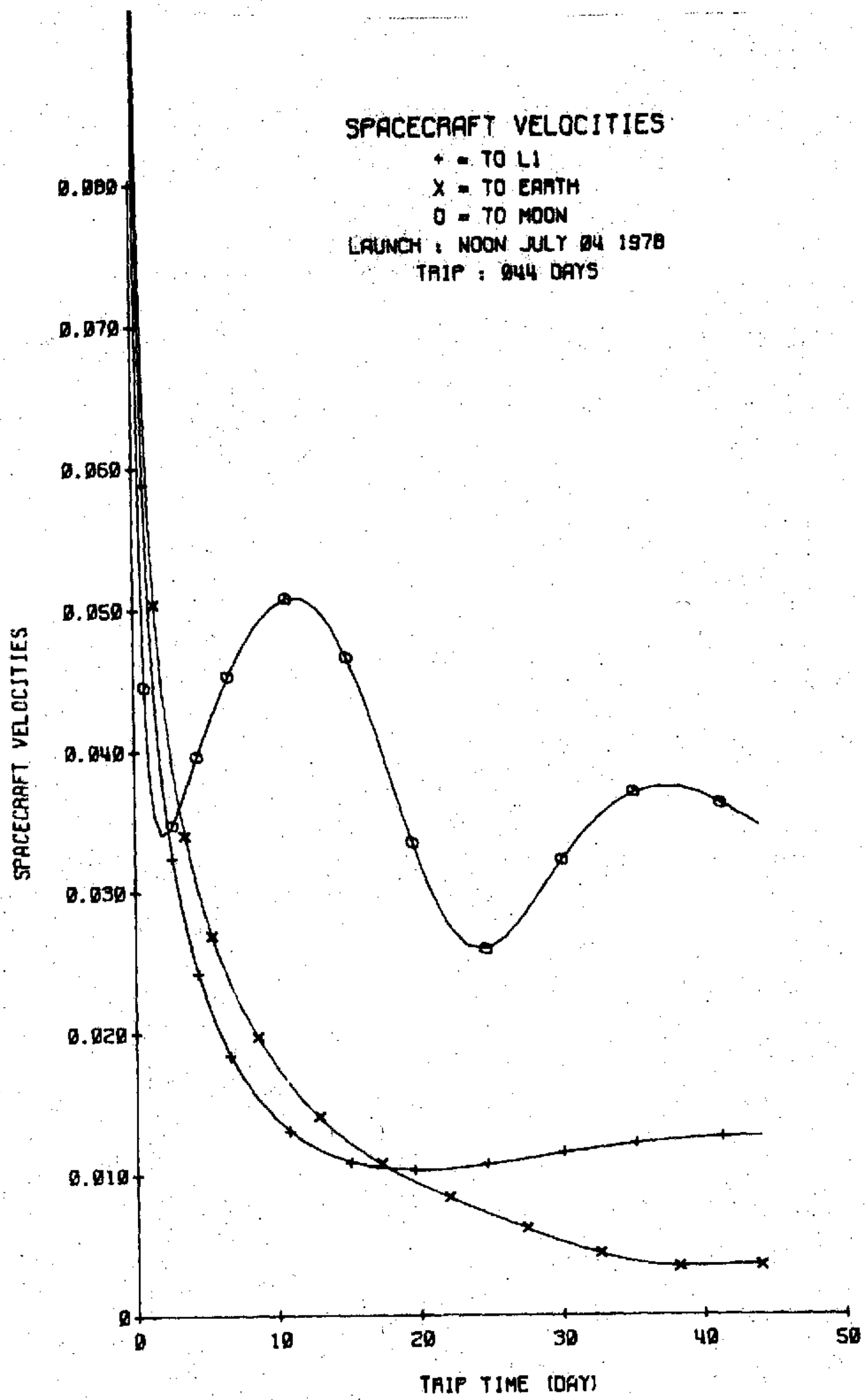


Figure 3f 2-Impulse Transfer (Example 3)

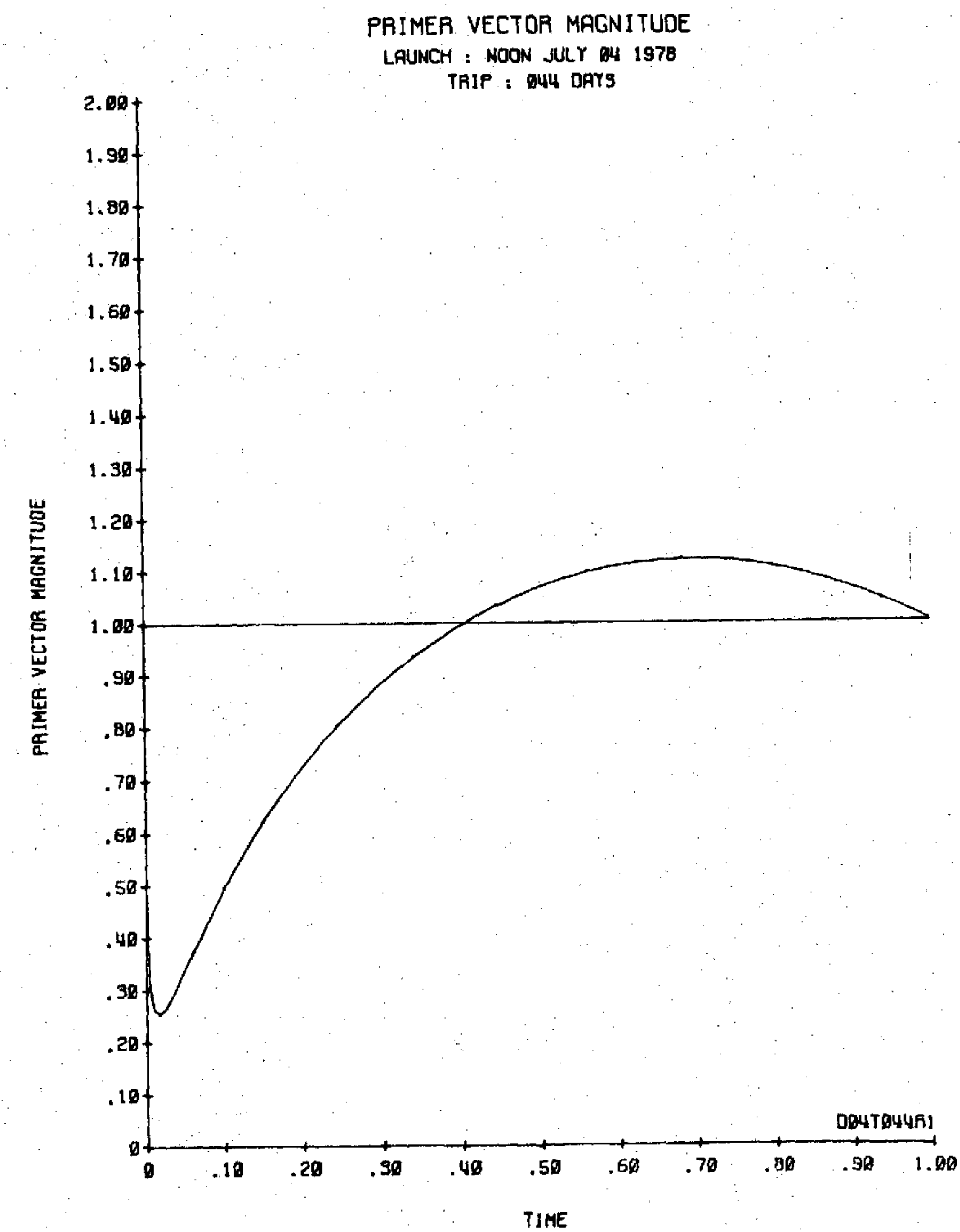


Figure 3g 2-Impulse Transfer (Example 3)

EXAMPLE 4

A. Purpose

This example may be used to check out Program PTP3I and associated subroutines. It is a 4-body 3-impulse transfer from noon July 4, 1978 to L_1 in 44-days. The 2-impulse transfer shown in Ex. 3 was used as the reference.

B. Input Parameters

* Same as in Ex. 1.

The starting independent variables ($\bar{v}_o$, t_m) shown here are values near the end of a sequence of computer runs.

Card No.	Format	Parameter	Value
1	4D20.11	GL1	*
		AUM	*
		UTIME	*
		UVELM	*
2	3D20.11	MS	*
		ME	*
		MM	*
3	3D20.11	TSTART	1.89051337719D+01
		TM	1.96168629221D+01
		TEND	1.96620272076D+01
4	4D20.11	RSE0(1)	*
		(2)	*
		(3)	*
		VSE0(1)	*
5	4D20.11	(2)	*
		(3)	*

		RSM0(1)	*
		(2)	*
6	4D20.11	(3)	*
		VSM0(1)	*
		(2)	*
		(3)	*
7	4D20.11	RSV0(1)	1.98969880525D-01
		(2)	-9.97069044391D-01
		(3)	6.68331499258D-05
		VSV0(1)	1.07508453453D+00
8	2D20.11	(2)	4.28411625788D-01
		(3)	2.23856828208D-02
9	4D20.11	VSVI(1)	1.12559555237D+00
		(2)	5.23005315320D-01
		(3)	3.22363348080D-02
		VSVMP(1)	6.12270768134D-01
10	2D20.11	(2)	7.70222061894D-01
		(3)	-3.40110040616D-04
11	4D20.11	RSVTAR(1)	8.04147100222D-01
		(2)	-5.98272665036D-01
		(3)	3.54443659015D-05
		VSVTAR(1)	5.74883737675D-01
12.	2D20.11	(2)	7.90914481955D-01
		(3)	-5.54211553533D-05

13	3D20.11	KNR	1.0D+00
		ERRMIN	1.0D-10
		ERRMXM	1.524D+02
14	3D20.11	FMINM	3.4D+03
		EPS	1.0D-02
		EPSV	1.0D-04
15	I5	ICOMV	0
		ITLMAX	100
		ILINC	2
		ITDMAX	100
		IFILEX	0
16	4D20.11	V(1, 1)	1.50704497134D-04
		V(1, 2)	1.08127195736D-04
		V(1, 3)	-1.88527012972D-03
		V(1, 4)	-1.33164676422D-01
17	4D20.11	V(2, 1) = V(1, 2)	
		V(2, 2)	-1.72891113995D-04
		V(2, 3)	1.25136470933D-03
		V(2, 4)	1.00119585112D-01
18	4D20.11	V(3, 1) = V(1, 3)	
		V(3, 2) = V(2, 3)	
		V(3, 3)	-3.48824401009D-03
		V(3, 4)	-3.68585896226D-01

19	4D20.11	V(4, 1) = V(1, 4)	
		V(4, 2) = V(2, 4)	
		V(4, 3) = V(3, 4)	
		V(4, 4)	-3.32401335566D+01

C. Output Parameters

The trajectory is shown in Figure 4a to 4f. The primer vector history is shown in Figure 4g. The interior impulse applied at about 41.9 days is nearly at the end of the 44-day transfer. The costs are

Initial impulse	3207.35 m/s
Interior impulse	273.44 m/s
Terminal impulse	97.64
	3578.43

The 3-impulse transfer costs about 3.50 m/s less than the 2-impulse transfer.

D. Comment

The 3-impulse transfer is difficult to generate, especially when the 2-impulse transfer is nearly optimal. First, the difficulty is to break away from the 2-impulse transfer. Secondly, the cost gradient must be reduced several orders of magnitude lower than necessary in order to satisfy the condition

$$\dot{\bar{\lambda}}_m^{\,+} \cdot \bar{\lambda}_m \approx \dot{\bar{\lambda}}_m^{\,-} \cdot \bar{\lambda}_m$$

while the cost remains practically unchanged. To accomplish this it may be necessary to reduce the single step allowable position error by an order of magnitude.

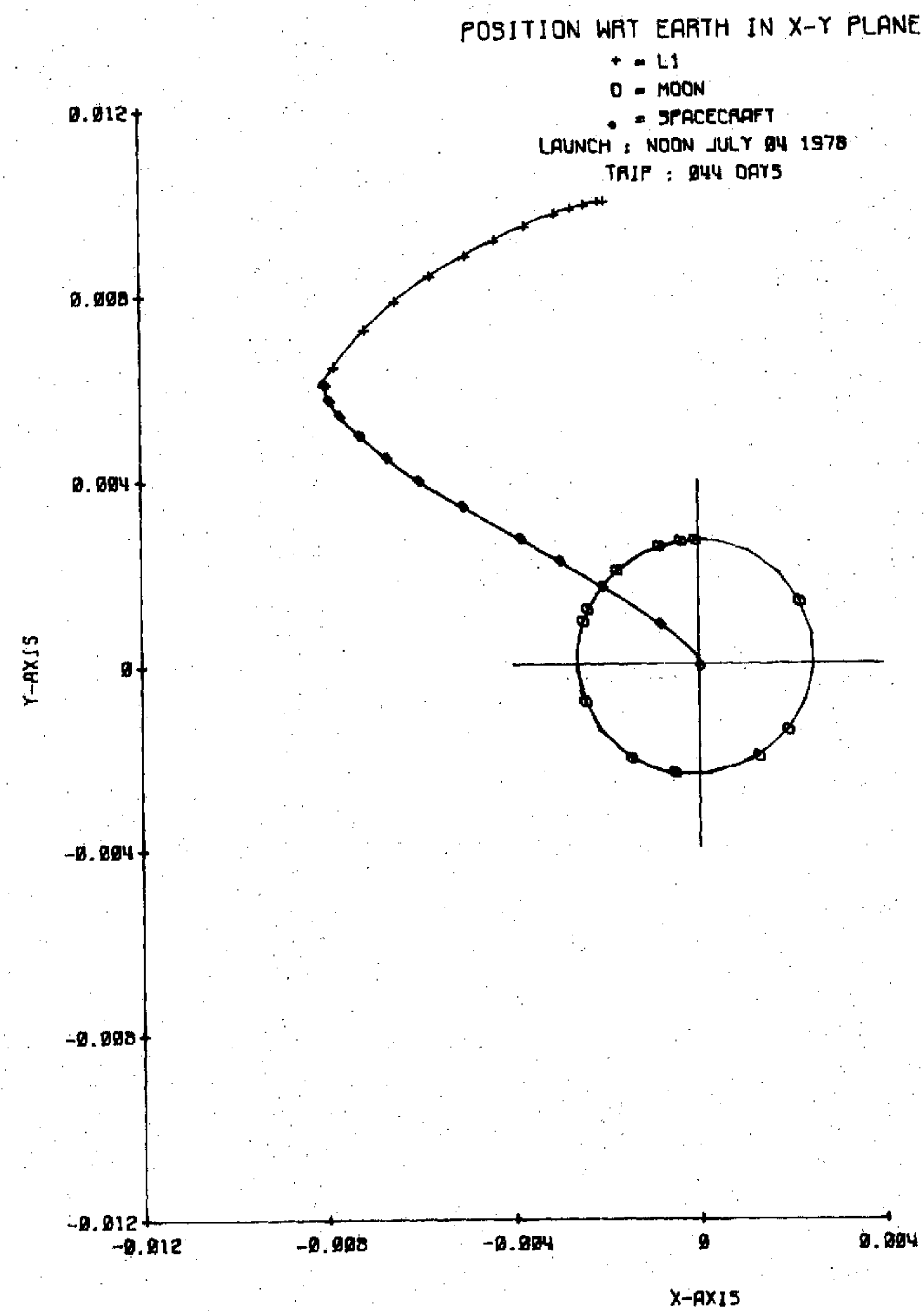


Figure 4a 3-Impulse Transfer (Example 4)

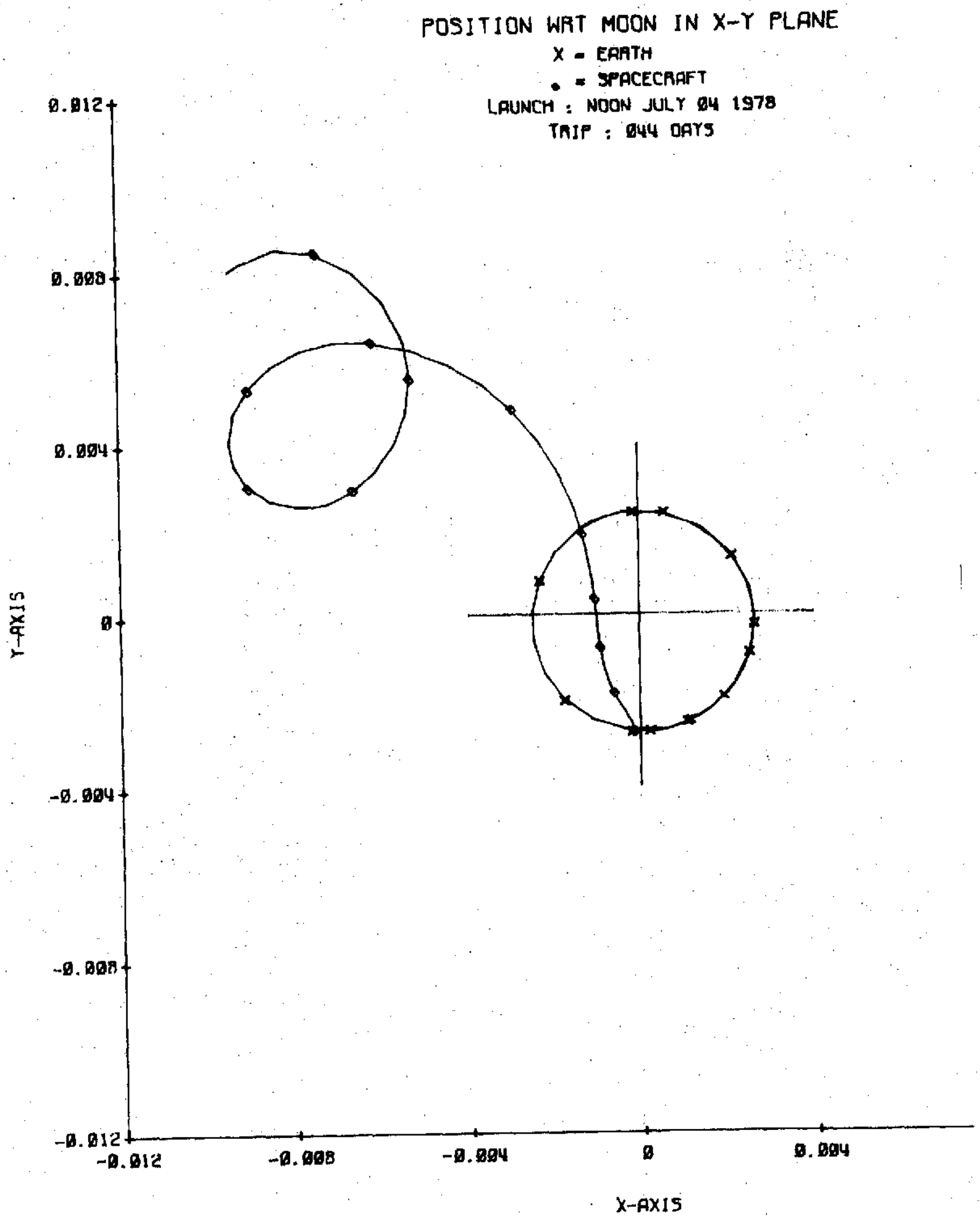


Figure 4b 3-Impulse Transfer (Example 4)

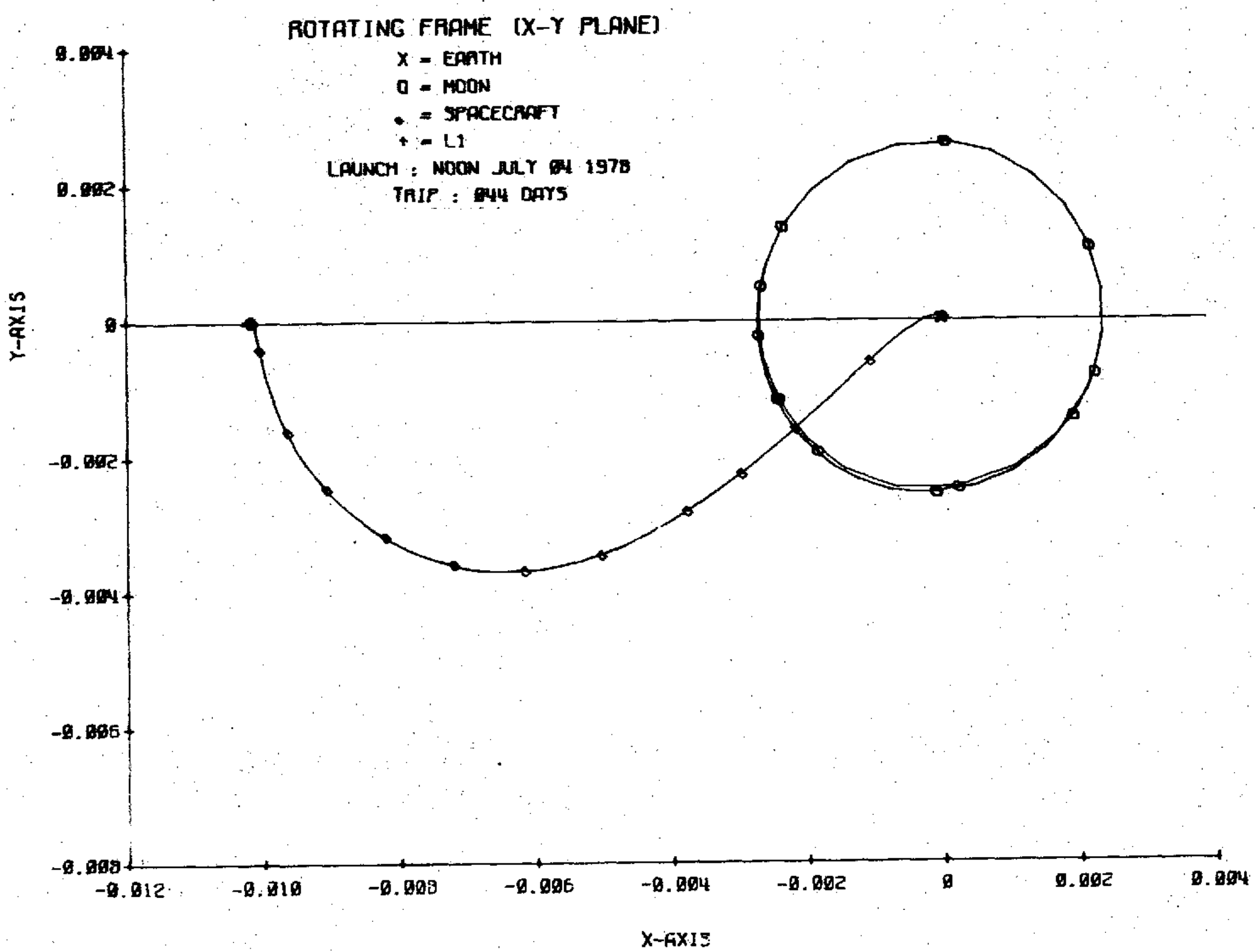


Figure 4c 3-Impulse Transfer (Example 4)

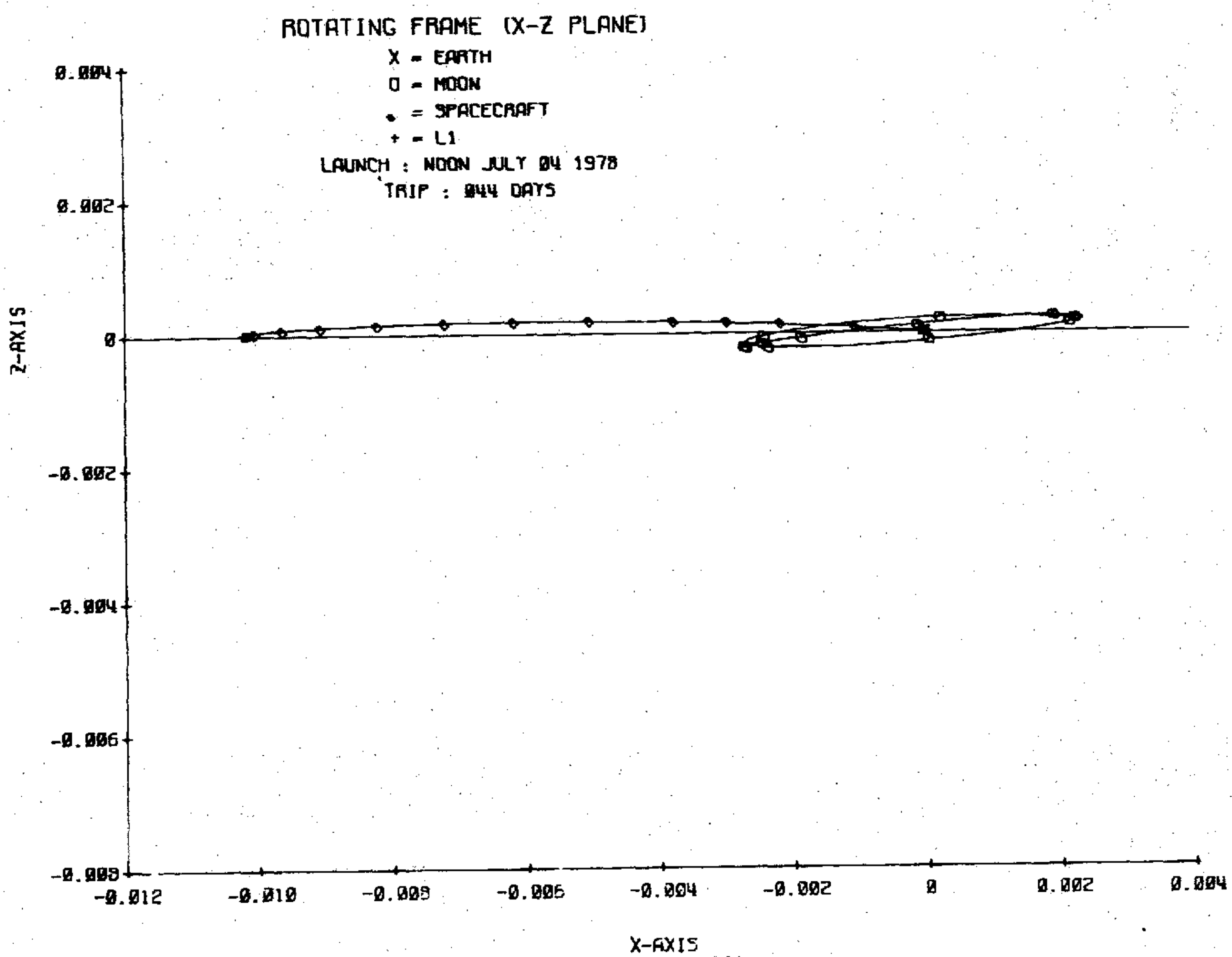


Figure 4d 3-Impulse Transfer (Example 4)

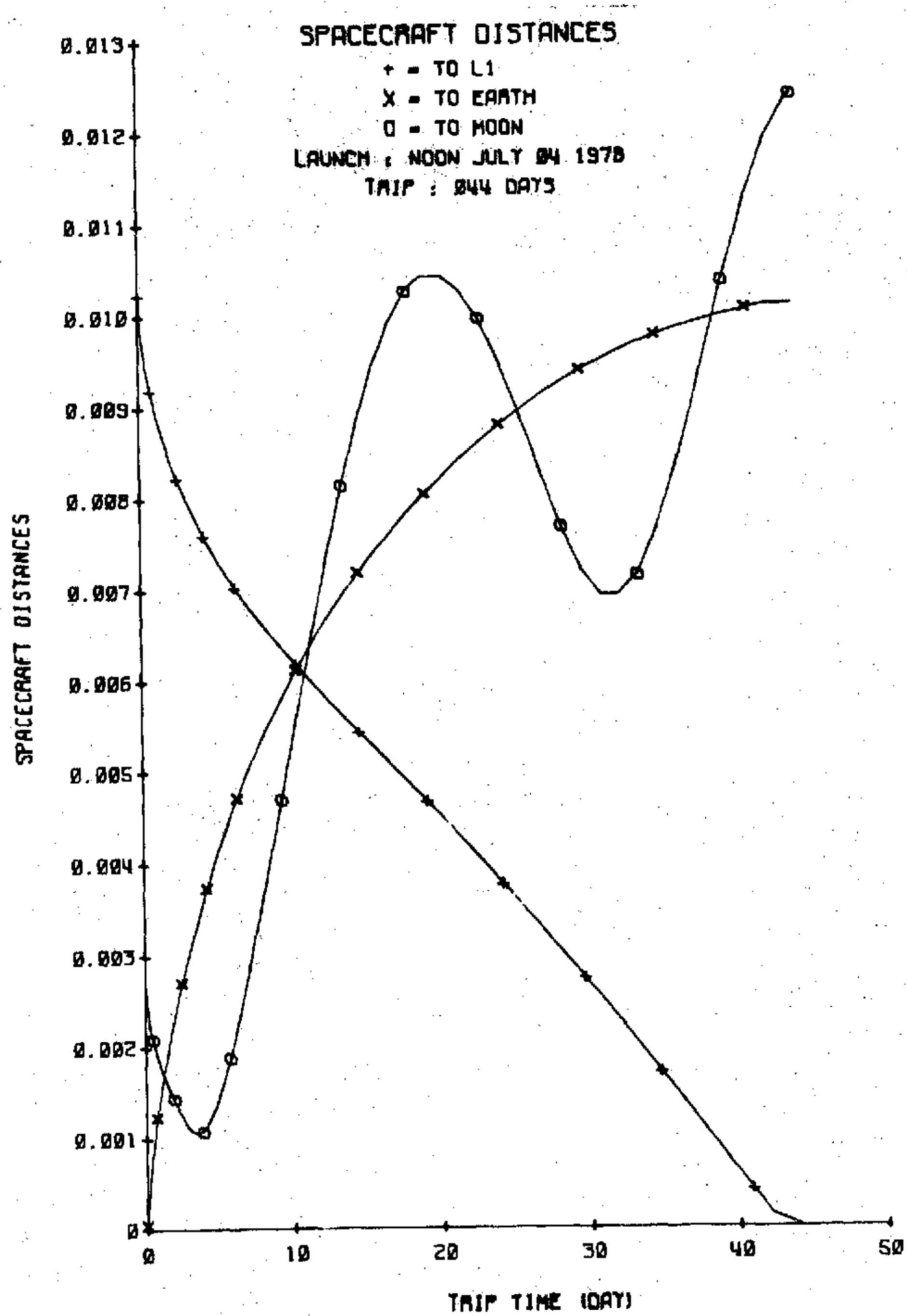


Figure 4e 3-Impulse Transfer (Example 4)

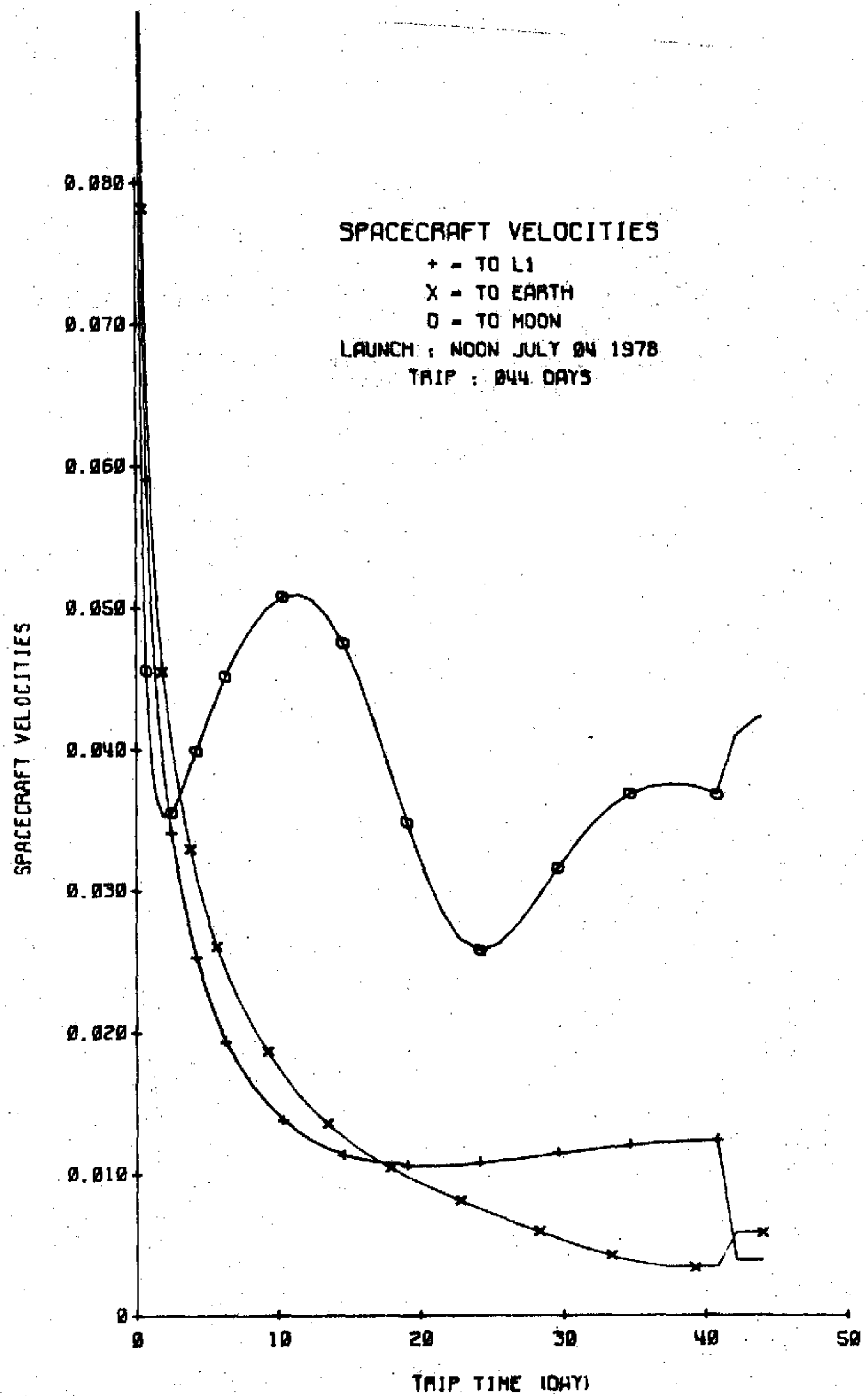


Figure 4f 3-Impulse Transfer (Example 4)

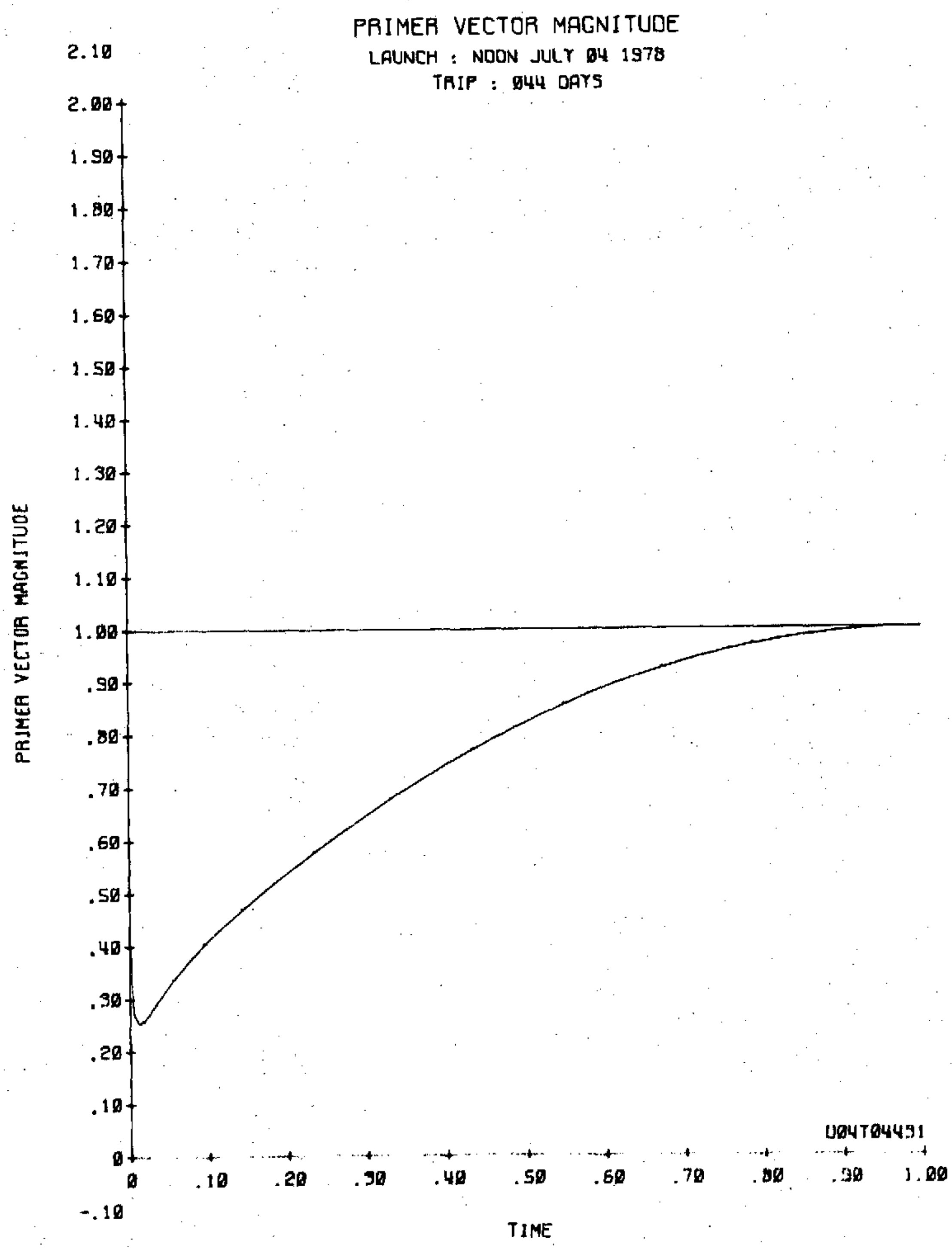


Figure 4g 3-Impulse Transfer (Example 4)

PROGRAM AND SUBROUTINE LISTING

TRAJ

TRAJ3

EXLAM

EXLAM3

ETP2I

ETP2I3

PTP3I

PTP3I3

FOURBY

THRBDY

TWOBDY

CSTEP

CSTEP3

DELRV

DELRV3

COMIC

COMIC3

COMFG

COMFG3

COMF

COMF3

COMG

CTAR

CTAR3

LAMB

LAMB3

DISP

DISP3

PTRAJ

PTRAJ3

FDATA

FDATA3

COMAUG

COMDX

UPX

PVEC

RVEMV

MXV

VVT

DOT

VMAG

INVERT

UNITV

VXV

MTRANS

MXM

```
C     PROGRAM TRAJ
C     PROGRAM PROPAGATES GIVEN STATES FROM TSTART TO TEND
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION RSEO(3),VSEO(3),RSMO(3),VSMO(3),REVO(3),VEVO(3),
     1RSVO(3),VSVO(3),VSVI(3),VEVOP(3),PVO(6),RSVF(3),VSVF(3),RSEF(3),
     2VSEF(3),RSMF(3),VSMF(3),S11(3,3),S12(3,3),S21(3,3),S22(3,3)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      READ(5,100)GL1,AUM,UTIME,UVELM
      READ(5,100)MS,ME,MM
      READ(5,101)IMODE,IPV,IPTRAJ,IFILE
      READ(5,100)RSEO,VSEO,RSMO,VSMO
      READ(5,100)TDAYO,TRIPD,ERRMXM
      DTR=1.7453292519943296D-2
      ERRMAX=ERRMXM/AUM
      TDAYF=TDAYO+TRIPD
      TSTART=TDAYO/UTIME
      TEND=TDAYF/UTIME
      IMTX=0
      IPVTM=0
      ITER=0
      WRITE(6,102)GL1,AUM,UTIME,UVELM,ERRMXM,ERRMAX,MS,ME,MM
      WRITE(6,103)TDAYO,TRIPD,TDAYF,TSTART,TEND
      WRITE(6,105)RSEO,VSEO,RSMO,VSMO
      GO TO(1,2,3),IMODE
    1 READ(5,100)REVMAG,VEVMAG,OINCD,OBLD,LOND,THED
      OINC=DTR*OINCD
      OBL=DTR*OBLD
      LON=DTR*LOND
      THE=DTR*THED
      CALL COMIC(REVMAG,VEVMAG,LON,THE,OINC,OBL,RSEO,VSEO,
     1REVO,VEVO,RSVO,VSVO,VSVI)
      WRITE(6,106)REVMAG,VEVMAG,OINCD,OBLD,LOND,THED
      GO TO 6
    2 READ(5,100)REVO,VEVOP
      DO 201 I=1,3
      RSVO(I)=RSEO(I)+REVO(I)
  201 VSVI(I)=VSEO(I)+VEVOP(I)
      WRITE(6,107)REVO,VEVOP
      GO TO 6
    3 READ(5,100)RSVO,VSVI
    6 WRITE(6,108)RSVO,VSVI
      IF(IPV.EQ.0) GO TO 7
      READ(5,100)PVO
      IMTX=1
      IPVTM=1
      WRITE(6,109)PVO
    7 WRITE(6,104)IMODE,IPTRAJ,IFILE,IMTX,IPV,IPVTM
      CALL FOURBY(TSTART,TEND,RSVO,VSVI,RSEO,VSEO,RSMO,VSMO,
     1PVO,RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,S11,S12,S21,S22)
      WRITE(6,110)RSVF,VSVF,RSEF,VSEF,RSMF,VSMF
  100 FORMAT(4D20.11)
  101 FORMAT(4I5)
  102 FORMAT(1H ,40X,'FOUR-BODY TRAJECTORY'/1H0,T8,'GL1',T28,'AUM',
     1T48,'UTIME',T68,'UVELM',T88,'ERRMXM',T108,'ERRMAX'/1H ,
     21P6D20.11/1H ,T8,'MS',T28,'ME',T48,'MM'/1H ,1P3D20.11)
  103 FORMAT(1H0,T8,'TDAYO',T28,'TRIPD',T48,'TDAYF',T68,'TSTART',
```

```
   1T88,'TEND'/1H ,1P5D20.11)
104 FORMAT(1H0,T8,'IMODE',T28,'IPTRAJ',T48,'IFILE',T68,'IMTX',T88,
   1'IPV',T108,'IPVTM'/1H ,I10,5I20)
  5 FORMAT(1H0,T8,'RSEO',T68,'VSEO'/1H ,1P6D20.11/1H ,T8,'RSMO',
   1T68,'VSMO'/1H ,1P6D20.11)
106 FORMAT(1H0,T8,'REVMAG',T28,'VEVMAG',T48,'OINCD',T68,'OBLD',
   1T88,'LOND',T108,'THED'/1H ,1P6D20.11)
107 FORMAT(1H0,T8,'REVO',T68,'VEVOP'/1H ,1P6D20.11)
108 FORMAT(1H0,T8,'RSVO',T68,'VSVI'/1H ,1P6D20.11)
109 FORMAT(1H0,T8,'PVO'/1H ,1P6D20.11)
110 FORMAT(1H0,T8,'RSVF',T68,'VSVF'/1H ,1P6D20.11/1H ,T8,'RSEF',
   1T68,'VSEF'/1H ,1P6D20.11/1H ,T8,'RSMF',T68,'VSMF'/1H ,1P6D20.11)
    RETURN
    END
```

```
C     PROGRAM TRAJ3
C     PROGRAM PROPAGATES GIVEN STATES FROM TSTART TO TEND IN
C     EARTH-MOON-VEHICLE SPACE.
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION REMO(3),VEMO(3),REVO(3),VEVO(3),VEVOP(3),REVF(3),
     1VEVF(3),REMF(3),VEMF(3),S11(3,3),S12(3,3),S21(3,3),S22(3,3)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      READ(5,100)GAMMA,UDM,UTIME,UVELM
      READ(5,100)ME,MM
      READ(5,101)IMODE,IPV,IPTRAJ,IFILE
      READ(5,100)REMO,VEMO
      READ(5,100)TDAYO,TRIPD,ERRMXM
      DTR=1.7453292519943296D-2
      ERRMAX=ERRMXM/UDM
      TDAYF=TDAYO+TRIPD
      TSTART=TDAYO/UTIME
      TEND=TDAYF/UTIME
      IMTX=0
      IPVTM=0
      ITER=0
      WRITE(6,102)GAMMA,UDM,UTIME,UVELM,ERRMXM,ERRMAX,ME,MM
      WRITE(6,103)TDAYO,TRIPD,TDAYF,TSTART,TEND
      WRITE(6,105)REMO,VEMO
      GO TO (1,2),IMODE
    1 READ(5,100)REVMAG,VEVMAG,OINCD,LOND,THED
      OINC=DTR*OINCD
      LON=DTR*LOND
      THE=DTR*THED
      CALL COMIC3(REVMAG,VEVMAG,LON,THE,OINC,REVO,VEVO,VEVOP)
      WRITE(6,106)REVMAG,VEVMAG,OINCD,LOND,THED
      GO TO 3
    2 READ(5,100)REVO,VEVOP
    3 WRITE(6,107)REVO,VEVOP
      IF(IPV.EQ.0) GO TO 4
      READ(5,100)PVO
      IMTX=1
      IPVTM=1
      WRITE(6,108)PVO
    4 WRITE(6,104)IMODE,IPTRAJ,IFILE,IMTX,IPV,IPVTM
      CALL THRBDY(TSTART,TEND,REVO,VEVOP,REMO,VEMO,PVO,REVF,VEVF,
     1REMF,VEMF,S11,S12,S21,S22)
      WRITE(6,109)REVF,VEVF,REMF,VEMF
  100 FORMAT(4D20.11)
  101 FORMAT(4I5)
  102 FORMAT(1H ,40X,'THREE-BODY TRAJECTORY'/1H0,T8,'GAMMA',T28,
     1'UDM',T48,'UTIME',T68,'UVELM',T88,'ERRMXM',T108,'ERRMAX'/1H ,
     21P6D20.11/1H ,T8,'ME',T28,'MM'/1H ,1P2D20.11)
  103 FORMAT(1H0,T8,'TDAYO',T28,'TRIPD',T48,'TDAYF',T68,'TSTART',
     1T88,'TEND'/1H ,1P5D20.11)
  104 FORMAT(1H0,T8,'IMODE',T28,'IPTRAJ',T48,'IFILE',T68,'IMTX',
     1T88,'IPV',T108,'IPVTM'/1H ,I10,5I20)
  105 FORMAT(1H0,T8,'REMO',T68,'VEMO'/1H ,1P6D20.11)
  106 FORMAT(1H0,T8,'REVMAG',T28,'VEVMAG',T48,'OINCD',T68,'LOND',
     1T88,'THED'/1H ,1P5D20.11)
  107 FORMAT(1H0,T8,'REVO',T68,'VEVOP'/1H ,1P6D20.11)
  108 FORMAT(1H0,T8,'PVO'/1H ,1P6D20.11)
```

```
109 FORMAT(1H0,T8,'REVF',T68,'VEVF'/1H ,1P6D20.11/1H0,T8,'REMF',
   1T68,'VEMF'/1H ,1P6D20.11)
    RETURN
    END
```

```
C     PROGRAM EXLAM
C     PROGRAM SOLVES 2-POINT BOUNDARY VALUE PROBLEM OF TRANSFER FROM
C     A GIVEN INITIAL POSITION TO A GIVEN FINAL POSITION IN FIXED TIME.
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION RSEO(3),VSEO(3),RSMO(3),VSMO(3),REVO(3),VEVO(3),
     1RSVO(3),VSVO(3),VSVI(3),VEVOP(3),RSVF(3),VSVF(3),RSEF(3),
     2VSEF(3),RSMF(3),VSMF(3),S11(3,3),S12(3,3),S21(3,3),S22(3,3),
     3RSVTAR(3),PVO(6)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      READ(5,100)GL1,AUM,UTIME,UVELM
      READ(5,100)MS,ME,MM
      READ(5,101)IMODE,ITLMAX,IPTJX,IFILEX
      READ(5,100)RSEO,VSEO,RSMO,VSMO
      READ(5,100)TDAYO,TRIPD,ERRMXM
      READ(5,100)RSVTAR,ERRMIN
      READ(5,100)KNR
      DTR=1.7453292519943296D-2
      ERRMAX=ERRMXM/AUM
      TDAYF=TDAYO+TRIPD
      TSTART=TDAYO/UTIME
      TEND=TDAYF/UTIME
      IMTX=1
      IPV=0
      IPVTM=0
      IPTRAJ=0
      IFILE=0
      WRITE(6,102)GL1 AUM,UTIME,UVELM,ERRMXM,ERRMAX,MS,ME,MM,ERRMIN,
     1KNR
      WRITE(6,103)TDAYO,TRIPD,TDAYF,TSTART,TEND
      WRITE(6,104)IMODE,ITLMAX,IPTJX,IFILEX,IPTRAJ,IFILE
      WRITE(6,105)RSEO,VSEO,RSMO,VSMO,RSVTAR
      GO TO (1,2,3),IMODE
    1 READ(5,100)REVMAG,VEVMAG,OINCD,OBLD,LOND,THED
      OINC=DTR*OINCD
      OBL=DTR*OBLD
      LON=DTR*LOND
      THE=DTR*THED
      CALL COMIC(REVMAG,VEVMAG,LON,THE,OINC,OBL,VCIR,RSEO,VSEO,
     1REVO,VEVO,RSVO,VSVO,VSVI)
      WRITE(6,106)REVMAG,VEVMAG,OINCD,OBLD,LOND,THED
      GO TO 6
    2 READ(5,100)REVO,VEVOP
      DO 201 I=1,3
      RSVO(I)=RSEO(I)+REVO(I)
  201 VSVI(I)=VSEO(I)+VEVOP(I)
      WRITE(6,107)REVO,VEVOP
      GO TO 6
    3 READ(5,100)RSVO,VSVI
    6 WRITE(6,108)RSVO,VSVI
      CALL LAMB(TSTART,TEND,RSVO,VSVI,RSEO,VSEO,RSMO,VSMO,KNR,ITLMAX,
     1ERRMIN,RSVTAR,RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,S11,S12,S21,S22)
      IPTRAJ=IPTJX
      IFILE=IFILEX
      IMTX=0
      IF(IPTRAJ.GT.0) GO TO 7
      IF(IFILE.GT.0) GO TO 7
```

```
      GO TO 8
    7 CALL FOURBY(TSTART,TEND,RSVO,VSVI,RSEO,VSEO,RSMO,VSMO,PVO,
     1RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,S11,S12,S21,S22)
    8 CONTINUE
  100 FORMAT(4D20.11)
  101 FORMAT(4I5)
  102 FORMAT(1H ,40X,'FOUR-BODY LAMBERT PROBLEM'/1H0,T8,'GL1',T28,
     1'AUM',T48,'UTIME',T68,'UVELM',T88,'ERRMXM',T108,'ERRMAX'/1H ,
     21P6D20.11/1H ,T8,'MS,',T28,'ME',T48,'MM',T68,'ERRMIN',T88,
     3'KNR'/1H ,1P5D20.11)
  103 FORMAT(1H0,T8,'TDAYO',T28,'TRIPD',T48,'TDAYF',T68,'TSTART',
     1T88,'TEND'/1H ,1P5D20.11)
  104 FORMAT(1H ,T8,'IMODE',T28,'ITLMAX',T48,'IPTJX',T68,'IFILEX',
     1T88,'IPTRAJ',T108,'IFILE'/1H ,I10,5I20)
  105 FORMAT(1H0,T8,'RSEO',T68,'VSEO'/1H ,1P6D20.11/1H ,T8,'RSMO',
     1T68,'VSMO'/1H ,1P6D20.11/1H ,T8,'RSVTAR'/1H ,1P3D20.11)
  106 FORMAT(1H0,T8,'REVMAG',T28,'VEVMAG',T48,'OINCD',T68,'OBLD',
     1T88,'LOND',T108,'THED'/1H ,1P6D20.11)
  107 FORMAT(1H0,T8,'REVO',T68,'VEVOP'/1H ,1P6D20.11)
  108 FORMAT(1H0,T8,'RSVO',T68,'VSVI'/1H ,1P6D20.11)
      RETURN
      END
```

```
      PROGRAM EXLAM3
C     PROGRAM SOLVES 2-POINT BOUNDARY VALUE PROBLEM OF TRANSFER FROM
C     A GIVEN INITIAL POSITION TO A GIVEN FINAL POSITION IN FIXED
C     TIME.
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION REMO(3),VEMO(3),REVTAR(3),REVO(3),VEVO(3),VEVOP(3),
     1REVF(3),VEVF(3),REMF(3),VEMF(3),S11(3,3),S12(3,3),S21(3,3),
     2S22(3,3),PVO(6)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      READ(5,100)GAMMA,UDM,UTIME,UVELM
      READ(5,100)ME,MM
      READ(5,101)IMODE,ITLMAX,IPTJX,IFILEX
      READ(5,100)REMO,VEMO
      READ(5,100)TDAYO,TRIPD,ERRMXM
      READ(5,100)REVTAR,ERRMIN
      READ(5,100)KNR
      DTR=1.7453292519943296D-2
      ERRMAX=ERRMXM/UDM
      TDAYF=TDAYO+TRIPD
      TSTART=TDAYO/UTIME
      TEND=TDAYF/UTIME
      IMTX=1
      IPV=0
      IPVTM=0
      IFILE=0
      WRITE(6,102)GAMMA,UDM,UTIME,UVELM,ERRMXM,ERRMAX,ME,MM,ERRMIN,KNR
      WRITE(6,103)TDAYO,TRIPD,TDAYF,TSTART,TEND
      WRITE(6,104)IMODE,ITLMAX,IPTJX,IFILEX
      WRITE(6,105)REMO,VEMO,REVTAR
      GO TO (1,2),IMODE
    1 READ(5,100)REVMAG,VEVMAG,OINCD,LOND,THED
      OINC=DTR*OINCD
      LON=DTR*LOND
      THE=DTR*THED
      CALL COMIC3(REVMAG,VEVMAG,LON,THE,OINC,REVO,VEVO,VEVOP)
      WRITE(6,106)REVMAG,VEVMAG,OINCD,LOND,THED
      GO TO 3
    2 READ(5,100)REVO,VEVOP
    3 WRITE(6,107)REVO,VEVOP
      CALL LAMB3(TSTART,TEND,REVO,VEVOP,REMO,VEMO,KNR,ITLMAX,ERRMIN,
     1REVTAR,REVF,VEVF,REMF,VEMF,S11,S12,S21,S22)
      WRITE(6,108)REVF,VEVF,REMF,VEMF
      IPTRAJ=IPTJX
      IFILE=IFILEX
      IMTX=0
      IF(IPTRAJ.EQ.0) GO TO 4
      IF(IFILE.EQ.0) GO TO 4
      GO TO 5
    4 CALL THRBDY(TSTART,TEND,REVO,VEVOP,REMO,VEMO,PVO,REVF,VEVF,
     1REMF,VEMF,S11,S12,S21,S22)
    5 CONTINUE
  100 FORMAT(4D20.11)
  101 FORMAT(4I5)
  102 FORMAT(1H ,40X,'3-BODY LAMBERT PROBLEM'/1H0,T8,'GAMMA',T28,
     1'UDM',T48,'UTIME',T68,'UVELM',T88,'ERRMXM',T108,'ERRMAX'/1H ,
     21P6D20.11/1H ,T8,'ME',T28,'MM',T48,'ERRMIN',T68,'KNR'/1H ,
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```
   31P4D20.11)
103 FORMAT(1H0,T8,'TDAYO',T28,'TRIPD',T48,'TDAYF',T68,'TSTART',
   1T88,'TEND'/1H ,1P5D20.11)
p4 FORMAT(1H ,T8,'IMODE',T28,'ITLMAX',T48,'IPTJX',T68,'IFILEX'/
   11H ,I10,3I20)
105 FORMAT(1H0,T8,'REMO',T68,'VEMO'/1H ,1P6D20.11/1H ,T8,'REVTAR'/
   11H ,1P3D20.11)
106 FORMAT(1H0,T8,'REVMAG',T28,'VEVMAG',T48,'OINCD',T68,'THED'/1H ,
   11P4D20.11)
107 FORMAT(1H0,T8,'REVO',T68,'VEVOP'/1H ,1P6D20.11)
108 FORMAT(1H0,T8,'REVF',T68,'VEVF'/1H ,1P6D20.11/1H ,T8,'REMF',
   1T68,'VEMF'/1H ,1P6D20.11)
    RETURN
    END
```

```
C     PROGRAM ETP2I
C     PROGRAM COMPUTES FUEL OPTIMAL 2-IMPULSE TRANSFER FROM A PARKING
C     ORBIT OF GIVEN INCLINATION TO A GIVEN FINAL POSITION AND VELOCITY
C     IN FIXED TIME.
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION RSE0(3),VSE0(3),RSM0(3),VSM0(3),XD(3),X(3),XS(3),
     1RSVTAR(3),VSVTAR(3),V(3,3),GS(3),TSIS(3),LTS(3,3),LS(3,3),
     2S11S(3,3),S12S(3,3),S21S(3,3),S22S(3,3),GGS(3),VSAV(3,3),G(3),
     3TSI(3),LT(3,3),L(3,3),GG(3),S11(3,3),S12(3,3),S21(3,3),
     4S22(3,3),DX(3),DELX(3),UVI(3),UVF(3),TEMP(3,3),DUM(3),UVID(3)
      DIMENSION R(3),RMV0(3),VMV0(3),RSV0(3),VSVI(3),UVIS(3),UVFS(3),
     1GD(3),TSID(3),LTD(3,3),LD(3,3),S11D(3,3),S12D(3,3),S21D(3,3),
     2S22D(3,3),RSVF(3),VSVF(3),RSEF(3),VSEF(3),RSMF(3),VSMF(3),
     3DUVI(3),REV0(3),VEV0(3),UVFD(3),PV0(6),GGD(3),VSV0(3)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/TARG/AY,AZ,ATAR,RSVTAR,VSVTAR
      READ(5,100)GL1,AUM,UTIME,UVELM
      READ(5,100)MS,ME,MM
      READ(5,100)REVMAG,OINCD,OBLD,ERRMXM
      READ(5,100)TDAY0,TTRIPD
      READ(5,100)VEVMAG,LOND,THED
      READ(5,100)RSE0,VSE0,RSM0,VSM0
      READ(5,100)EPS,EPSTSI,KDX,EPSV
      READ(5,101)ICOMV,ITERMX,IFILEX,ITAR
      IF(ITAR.GT.0) GO TO 21
      READ(5,100)AYM,AZM,ATARD
      GO TO 22
   21 READ(5,100)RSVTAR,VSVTAR
   22 IF(ICOMV.GT.0) GO TO 19
C     OPTION TO INPUT VARIANCE MATRIX (ICOMV=0)
      READ(5,100)((V(I,J),J=1,3),I=1,3)
      GO TO 1
   19 DO 20 I=1,3
      DO 20 J=1,3
      V(I,J)=0.
      IF(I.EQ.J) V(I,J)=1.0
   20 CONTINUE
    1 IPV=0
      IPVTM=0
      IPTRAJ=0
      IFILE=0
      IMTX=1
      ITER=0
      ITERD=0
      DTR=1.7453292519943296D-2
      ERRMAX=ERRMXM/AUM
      IF(ITAR.GT.0) GO TO 23
      AY=AYM/AUM
      AZ=AZM/AUM
      ATAR=DTR*ATARD
   23 TDAYF=TDAY0+TTRIPD
      TTRIP=TTRIPD/UTIME
      TSTART=TDAY0/UTIME
      TEND=TDAYF/UTIME
      ALPHA=1.0D-3
      BETA=10.
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      ALPHAM=ALPHA/(1.-ALPHA)
      BETAM=BETA/(BETA-1.)
      WRITE(6,102)
      WRITE(6,103)GL1,AUM,UTIME,UVELM,ERRMXM,ERRMAX
      WRITE(6,104)MS,ME,MM,OINCD,OBLD
      WRITE(6,105)TDAYO,TTRIPD,TDAYF,TSTART,TTRIP,TEND
      WRITE(6,106)RSEO,VSEO
      WRITE(6,107)RSMO,VSMO
      WRITE(6,108)VEVMAG,LOND,THED,REVMAG
      WRITE(6,109)ALPHA,BETA,EPS,EPSTSI,KDX,EPSV
      WRITE(6,110)ICOMV,ITERMX,IFILEX,ITAR
      IF(ITAR.GT.0) GO TO 24
      WRITE(6,124)AYM,AZM,ATARD
      GO TO 25
   24 WRITE(6,125)RSVTAR,VSVTAR
   25 LON=DTR*LOND
      THE=DTR*THED
      OINC=DTR*OINCD
      OBL=DTR*OBLD
      XS(1)=VEVMAG
      XS(2)=LON
      XS(3)=THE
C     COMPUTE INITIAL NOMINAL TRAJECTORY
      CALL COMFG(TSTART,TEND,REVMAG,XS,OINC,OBL,RSEO,VSEO,RSMO,VSMO,
     1FS,TESTRS,GS,TSIS,LTS,S11S,S12S,S21S,S22S,UVIS,UVFS)
      ITER=1
      CALL COMAUG(FS,GS,TSIS,LTS,V,LS,FGS,GGS)
      IF(ICOMV.EQ.0) GO TO 200
C     OPTION TO COMPUTE TRIAL VARIANCE MATRIX (ICOMV=1)
      GGSMAG=VMAG(GGS)
      DO 2 I=1,3
      DO 2 J=1,3
      V(I,J)=V(I,J)*EPSV/GGSMAG
    2 CONTINUE
  200 WRITE(6,111)((V(I,J),J=1,3),I=1,3)
C     SAVE VARIANCE MATRIX
      DO 3 I=1,3
      DO 3 J=1,3
    3 VSAV(I,J)=V(I,J)
      KV=1.
      KDXSAV=KDX
      IF(TESTRS.GT.EPSTSI)GO TO 8
C     UPDATE VARIABLES
      CALL UPX(XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,S21S,
     1S22S,UVIS,UVFS,X,F,TESTR,G,TSI,LT,L,FG,GG,S11,S12,S21,S22,
     2UVI,UVF)
      WRITE(6,112)X,F,FG,TESTR
      WRITE(6,113)TSI,G
      WRITE(6,114)LT
      WRITE(6,115)GG
C      ACCELERATED GRADIENT PROJECTION ITERATION LOOP
    4 ITERD=ITERD+1
    5 DO 501 I=1,3
      DO 501 J=1,3
  501 V(I,J)=KV*VSAV(I,J)
    6 CALL MXV(V,GG,R,3,3)
      P=DOT(GG,R,3)
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      IF((P-2.*FG).LE.EPS) GO TO 7
      LAM=2.*FG/P
      CALL VVT(R,TEMP,3)
      DO 601 I=1,3
      DO 601 J=1,3
  601 VSAV(I,J)=V(I,J)+(LAM-1.)*TEMP(I,J)/P
      GO TO 5
    7 CALL MXV(V,GG,DX,3,3)
C     FORM TRIAL NEW INDEPENDENT VARIABLES
      DO 701 I=1,3
  701 XS(I)=X(I)-DX(I)
      WRITE(6,116)ITERD,DX
      WRITE(6,117)XS,KV
      WRITE(6,111)((V(I,J),J=1,3),I=1,3)
      CALL COMFG(TSTART,TEND,REVMAG,XS,OINC,OBL,RSEO,VSEO,RSMO,VSMO,
     1FS,TESTRS,GS,TSIS,LTS,S11S,S12S,S21S,S22S,UVIS,UVFS)
      CALL COMAUG(FS,GS,TSIS,LTS,V,LS,FGS,GGS)
      IF(TESTRS.LT.EPSTSI) GO TO 11
C     CONSTRAINT RESTORATION
    8 WRITE(6,118)
  801 CALL COMDX(LTS,LS,TSIS,DX)
      WRITE(6,119)DX
    9 DO 901 I=1,3
      DELX(I)=KDX*DX(I)
  901 XD(I)=XS(I)+DELX(I)
      WRITE(6,120)KDX,DELX
      CALL COMFG(TSTART,TEND,REVMAG,XD,OINC,OBL,RSEO,VSEO,RSMO,VSMO,
     1FD,TESTRD,GD,TSID,LTD,S11D,S12D,S21D,S22D,UVID,UVFD)
      IF(TESTRD.LT.TESTRS) GO TO 10
      KDX=KDX/10.
      WRITE(6,126)
      GO TO 9
   10 CALL COMAUG(FD,GD,TSID,LTD,V,LD,FGD,GGD)
      CALL UPX(XD,FD,TESTRD,GD,TSID,LTD,LD,FGD,GGD,S11D,S12D,S21D,
     1S22D,UVID,UVFD,XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,
     2S21S,S22S,UVIS,UVFS)
      KDX=2.*KDX
      IF(KDX.GT.1.0)KDX=1.0
      IF(TESTRS.GT.EPSTSI) GO TO 801
      KDX=KDXSAV
      IF(ITERD.EQ.0) GO TO 11
      IF(FS.LT.F) GO TO 11
      KV=KV/2.
      GO TO 5
C     CONSTRAINT RESTORED
   11 IF(ITERD.LT.ITERMX)GO TO 300
      WRITE(6,127)
      GO TO 17
  300 IF(ITERD.EQ.0)GO TO 16
C     UPDATE VARIANCE MATRIX
      CALL MXV(V,GGS,R,3,3)
      P=DOT(GGS,R,3)
      WRITE(6,121)FS,TESTRS,FGS,TSIS
      WRITE(6,122)GS,GGS
      WRITE(6,123)P
      IF(P.LT.EPS) GO TO 17
      GAMMA=-DOT(GG,R,3)/P
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      IF(GAMMA.EQ.(-1.)) GO TO 12
      IF(GAMMA.GE.ALPHAM)GO TO 13
      LAM=ALPHA
      GO TO 14
   12 IF(GAMMA.LE.(-BETAM)) GO TO 13
      LAM=BETA
      GO TO 14
   13 LAM=GAMMA/(GAMMA+1.)
   14 CALL VVT(R,TEMP,3)
      DO 15 I=1,3
      DO 15 J=1,3
   15 V(I,J)=V(I,J)+(LAM-1.)*TEMP(I,J)/P
      IF(FGS.LT.FG) GO TO 16
      GO TO 6
   16 KV=1.
      CALL UPX(XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,S21S,
     1S22S,UVIS,UVFS,X,F,TESTR,G,TSI,LT,L,FG,GG,S11,S12,S21,S22,
     2UVI,UVF)
      IF(ITERD.EQ.0) GO TO 4
      DO 161 I=1,3
      DO 161 J=1,3
  161 VSAV(I,J)=V(I,J)
      GO TO 4
   17 CALL UPX(XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,S21S,
     1S22S,UVIS,UVFS,X,F,TESTR,G,TSI,LT,L,FG,GG,S11,S12,S21,S22,
     2 UVI,UVF)
C     COMPUTE PRIMER VECTOR DERIVATIVE
      CALL MXV(S11,UVI,DUM,3,3)
      CALL INVERT(S12,TEMP)
      DO 18 I=1,3
   18 DUM(I)=UVF(I)-DUM(I)
      CALL MXV(TEMP,DUM,DUVI,3,3)
      DO 400 I=1,3
      PVO(I)=UVI(I)
  400 PVO(I+3)=DUVI(I)
      IPV=1
      IPVTM=1
      IPTRAJ=1
      IFILE=IFILEX
C     GENERATE OPTIMAL TRAJECTORY AND PRIMER VECTOR HISTORY
      VEVMAG=X(1)
      LON=X(2)
      THE=X(3)
      CALL COMIC(REVMAG,VEVMAG,LON,THE,OINC,OBL,RSEO,VSEO,REVO,VEVO,
     1RSVO,VSVO,VSVI)
      CALL FOURBY(TSTART,TEND,RSVO,VSVI,RSEO,VSEO,RSMO,
     1VSMO,PVO,RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,S11,S12,S21,S22)
  100 FORMAT(4D20.11)
  101 FORMAT(4I5)
  102 FORMAT(1H ,T8,'4-BODY 2-IMPULSE OPTIMAL TRANSFER FROM EARTH'/
     11H ,T8,'TO HALO TARGET AT L1. ITERATE ON VELOCITY MAGNITUDE'/
     21H ,T8,',LONGITUDE OF NODE AND ORBITAL ANGLE FROM NODE USING'/
     31H ,T8,'ACCELERATED GRADIENT PROJECTION AND DAVIDON VARIANCE'/
     41H ,T8,'METHOD')
  103 FORMAT(1H0,T8,'GL1',T28,'AUM',T48,'UTIME',T68,'UVELM',T88,
     1'ERRMXM',T108,'ERRMAX'/1H ,1P6D20.11)
  104 FORMAT(1H ,T8,'MS',T28,'ME',T48,'MM',T68,'OINCD',T88,'OBLD'/
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    11H ,1P5D20.11)
105 FORMAT(1H ,T8,'TDAYO',T28,'TTRIPD',T48,'TDAYF',T68,'TSTART',
    1T88,'TTRIP',T108,'TEND'/1H ,1P6D20.11)
  6 FORMAT(1H ,T8,'RSEO',T68,'VSEO'/1H ,1P6D20.11)
 07 FORMAT(1H ,T8,'RSMO',T68,'VSMO'/1H ,1P6D20.11)
108 FORMAT(1H ,T8,'VEVMAG',T28,'LOND',T48,'THED',T68,'REVMAG'/
    11H ,1P4D20.11)
109 FORMAT(1H ,T8,'ALPHA',T28,'BETA',T48,'EPS',T68,'EPSTSI',T88,
    1'KDX',T108,'EPSV'/1H ,1P6D20.11)
110 FORMAT(1H ,T8,'ICOMV',T28,'ITERMX',T48,'IFILEX',T68,'ITAR'/
    11H ,I10,3I20)
111 FORMAT(1H0,T8,'V'/1H ,1P6D20.11/1H ,1P3D20.11)
112 FORMAT(1H0,T8,'X',T68,'F',T88,'FG',T108,'TESTR'/1H ,1P6D20.11)
113 FORMAT(1H ,T8,'TSI',T68,'G'/1H ,1P6D20.11)
114 FORMAT(1H ,T8,'LT'/1H ,1P6D20.11/1H ,1P3D20.11)
115 FORMAT(1H ,T8,'GG'/1H ,1P3D20.11)
116 FORMAT(1H1,T8,'ITERD',T28,'DX'/1H ,I10,10X,1P3D20.11)
117 FORMAT(1H ,T8,'XS',T68,'KV'/1H ,1P4D20.11)
118 FORMAT(1H0,T8,'CONSTRAINT RESTROATION')
119 FORMAT(1H0,T8,'DX'/1H ,1P3D20.11)
120 FORMAT(1H ,T8,'KDX',T28,'DELX'/1H ,1P4D20.11)
121 FORMAT(1H ,T8,'FS',T28,'TESTRS',T48,'FGS',T68,'TSIS'/1H ,
    11P6D20.11)
122 FORMAT(1H ,T8,'GS',T68,'GGS'/1H ,1P6D20.11)
123 FORMAT(1H ,T8,'P'/1H ,1PD20.11)
124 FORMAT(1H0,T8,'AYM',T28,'AZM',T48,'ATARD'/1H ,1P3D20.11)
125 FORMAT(1H0,T8,'INPUT TARGET'/1H0,T8,'RSVTAR',T68,'VSVTAR'/
    11H ,1P6D20.11)
126 FORMAT(1H0,T8,'--------------------')
127 FORMAT(1H0,T8,'NO. OF DAVIDON ITERATIONS HAS REACHED MAXIMUM')
    RETURN
    END
```

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C     PROGRAM ETP213
C     PROGRAM COMPUTES FUEL OPTIMAL 2-IMPULSE TRANSFER FROM A PARKING
C     ORBIT OF GIVEN INCLINATION TO A GIVEN FINAL POSITION AND VELOCITY
C     IN FIXED TIME IN EARTH-MOON-VEHICLE SPACE.
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION REMO(3),VEMO(3),XD(3),X(3),XS(3),REVTAR(3),VEVTAR(3),
     1V(3,3),GS(3),TSIS(3),LTS(3,3),LS(3,3),S11S(3,3),S12S(3,3),
     2S21S(3,3),GGS(3),VSAV(3,3),G(3),TSI(3),LT(3,3),L(3,3),GG(3),
     3S11(3,3),S12(3,3),S21(3,3),S22(3,3),DX(3),DELX(3),UVI(3),UVF(3),
     4TEMP(3,3),DUM(3),UVID(3),S22S(3,3),PV0(6),GGD(3)
      DIMENSION R(3),REV0(3),VEV0(3),VEVOP(3),UVIS(3),UVFS(3),UVFD(3),
     1GD(3),TSID(3),LTD(3,3),LD(3,3),S11D(3,3),S12D(3,3),S21D(3,3),
     2S22D(3,3),REVF(3),VEVF(3),REMF(3),VEMF(3),DUVI(3)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      COMMON/TARG/AY,AZ,ATAR,REVTAR,VEVTAR
      READ(5,100)GAMMA,UDM,UTIME,UVELM
      READ(5,100)ME,MM
      READ(5,100)REVMAG,OINCD,ERRMXM
      READ(5,100)TDAY0,TTRIPD
      READ(5,100)VEVMAG,LOND,THED
      READ(5,100)REMO,VEMO
      READ(5,100)EPS,EPSTSI,KDX,EPSV
      READ(5,101)ICOMV,ITERMX,IFILEX,ITAR
      IF(ITAR.GT.0) GO TO 21
      READ(5,100)AYM,AZM,ATARD
      GO TO 22
   21 READ(5,100)REVTAR,VEVTAR
   22 IF(ICOMV.GT.0) GO TO 19
C     OPTION TO INPUT VARIANCE MATRIX (ICOMV=0)
      READ(5,100) ((V(I,J),J=1,3),I=1,3)
      GO TO 1
   19 DO 20 I=1,3
      DO 20 J=1,3
      V(I,J)=0.
      IF(I.EQ.J) V(I,J)=1.0
   20 CONTINUE
    1 IPV=0
      IPVTM=0
      IPTRAJ=0
      IFILE=0
      IMTX=1
      ITER=0
      ITERD=0
      DTR=1.745329251994329 6D-2
      ERRMAX=ERRMXM/UDM
      IF(ITAR.GT.0) GO TO 23
      AY=AYM/AUM
      AZ=AZM/AUM
      ATAR=DTR*ATARD
   23 TDAYF=TDAY0+TTRIPD
      TTRIP=TTRIPD/UTIME
      TSTART=TDAY0/UTIME
      TEND=TDAYF/UTIME
      ALPHA=1.0D-3
      BETA=10.
      ALPHAM=ALPHA/(1.-ALPHA)
```

```
      BETAM=BETA/(BETA-1.)
      WRITE(6,102)
      WRITE(6,103)GAMMA,UDM,UTIME,UVELM,ERRMXM,ERRMAX
      WRITE(6,104)ME,MM,OINCD
      WRITE(6,105)TDAYO,TTRIPD,TDAYF,TSTART,TTRIP,TEND
      WRITE(6,106)REMO,VEMO
      WRITE(6,108)VEVMAG,LOND,THED,REVMAG
      WRITE(6,109)ALPHA,BETA,EPS,EPSTSI,KDX,EPSV
      WRITE(6,110)ICOMV,ITERMX,IFILEX,ITAR
      IF(ITAR.GT.0) GO TO 24
      WRITE(6,124)AYM,AZM,ATARD
      GO TO 25
   24 WRITE(6,125)REVTAR,VEVTAR
   25 LON=DTR*LOND
      THE=DTR*THED
      OINC=DTR*OINCD
      XS(1)=VEVMAG
      XS(2)=LON
      XS(3)=THE
C     COMPUTE INITIAL NOMINAL TRAJECTORY
      CALL COMFG3(TSTART,TEND,REVMAG,XS,OINC,REMO,VEMO,FS,TESTRS,GS,
     1TSIS,LTS,S11S,S12S,S21S,S22S,UVIS,UVFS)
      ITER=1
      CALL COMAUG(FS,GS,TSIS,LTS,V,LS,FGS,GGS)
      IF(ICOMV.EQ.0) GO TO 200
C     OPTION TO COMPUTE TRIAL VARIANCE MATRIX (ICOMV=1)
      GGSMAG=VMAG(GGS)
      DO 2 I=1,3
      DO 2 J=1,3
      V(I,J)=V(I,J)*EPSV/GGSMAG
    2 CONTINUE
  200 WRITE(6,111) ((V(I,J),J=1,3),I=1,3)
C     SAVE VARIANCE MATRIX
      DO 3 I=1,3
      DO 3 J=1,3
    3 VSAV(I,J)=V(I,J)
      KV=1.
      KDXSAV=KDX
      IF(TESTRS.GT.EPSTSI)GO TO 8
C     UPDATE VARIABLES
      CALL UPX(XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,S21S,
     1S22S,UVIS,UVFS,X,F,TESTR,G,TSI,LT,L,FG,GG,S11,S12,S21,S22,
     2UVI,UVF)
      WRITE(6,112)X,F,FG,TESTR
      WRITE(6,113)TSI,G
      WRITE(6,114)LT
      WRITE(6,115)GG
C      ACCELERATED GRADIENT PROJECTION ITERATION LOOP
    4 ITERD=ITERD+1
    5 DO 501 I=1,3
      DO 501 J=1,3
  501 V(I,J)=KV*VSAV(I,J)
    6 CALL MXV(V,GG,R,3,3)
      P=DOT(GG,R,3)
      IF((P-2.*FG).LE.EPS) GO TO 7
      LAM=2.*FG/P
      CALL VVT(R,TEMP,3)
```

```
      DO 601 I=1,3
      DO 601 J=1,3
  601 VSAV(I,J)=V(I,J)+(LAM-1.)*TEMP(I,J)/P
      GO TO 5
    7 CALL MXV(V,GG,DX,3,3)
C     FORM TRIAL NEW INDEPENDENT VARIABLES
      DO 701 I=1,3
  701 XS(I)=X(I)-DX(I)
      WRITE(6,116)ITERD,DX
      WRITE(6,117)XS,KV
      WRITE(6,111) ((V(I,J),J=1,3),I=1,3)
      CALL COMFG3(TSTART,TEND,REVMAG,XS,OINC,REMO,VEMO,FS,TESTRS,GS,
     1TSIS,LTS,S11S,S12S,S21S,S22S,UVIS,UVFS)
      CALL COMAUG(FS,GS,TSIS,LTS,V,LS,FGS,GGS)
      IF(TESTRS.LT.EPSTSI) GO TO 11
C     CONSTRAINT RESTORATION
    8 WRITE(6,118)
  801 CALL COMDX(LTS,LS,TSIS,DX)
      WRITE(6,119)DX
    9 DO 901 I=1,3
      DELX(I)=KDX*DX(I)
  901 XD(I)=XS(I)+DELX(I)
      WRITE(6,120)KDX,DELX
      CALL COMFG3(TSTART,TEND,REVMAG,XD,OINC,REMO,VEMO,FD,TESTRD,GD,
     1TSID,LTD,S11D,S12D,S21D,S22D,UVID,UVFD)
      IF(TESTRD.LT.TESTRS) GO TO 10
      KDX=KDX/10.
      GO TO 9
   10 CALL COMAUG(FD,GD,TSID,LTD,V,LD,FGD,GGD)
      CALL UPX(XD,FD,TESTRD,GD,TSID,LTD,LD,FGD,GGD,S11D,S12D,S21D,
     1S22D,UVID,UVFD,XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,
     2S21S,S22S,UVIS,UVFS)
      KDX=2.*KDX
      IF(KDX.GT.1.) KDX=1.
      IF(TESTRS.GT.EPSTSI) GO TO 801
      KDX=KDXSAV
      IF(ITER.EQ.0) GO TO 11
      IF(FS.LT.F) GO TO 11
      KV=KV/2.
      GO TO 5
C     CONSTRAINT RESTORED
   11 IF(ITERD.LT.ITERMX)GO TO 300
      WRITE(6,126)
      GO TO 17
  300 IF(ITERD.EQ.0)GO TO 16
C     UPDATE VARIANCE MATRIX
      CALL MXV(V,GGS,R,3,3)
      P=DOT(GGS,R,3)
      WRITE(6,121)FS,TESTRS,FGS,TSIS
      WRITE(6,122)GS,GGS
      WRITE(6,123)P
      IF(P.LT.EPS) GO TO 17
      GAMMA=-DOT(GG,R,3)/P
      IF(GAMMA.EQ.(-1.)) GO TO 12
      IF(GAMMA.GE.ALPHAM)GO TO 13
      LAM=ALPHA
      GO TO 14
```

```
  12 IF(GAMMA.LE.(-BETAM)) GO TO 13
     LAM=BETA
     GO TO 14
  13 LAM=GAMMA/(GAMMA+1.)
  14 CALL VVT(R,TEMP,3)
     DO 15 I=1,3
     DO 15 J=1,3
  15 V(I,J)=V(I,J)+(LAM-1.)*TEMP(I,J)/P
     IF(FGS.LT.FG) GO TO 16
     GO TO 6
  16 KV=1.
     CALL UPX(XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,S21S,
    1S22S,UVIS,UVFS,X,F,TESTR,G,TSI,LT,L,FG,GG,S11,S12,S21,S22,
    2UVI,UVF)
     IF(ITERD.EQ.0) GO TO 4
     DO 161 I=1,3
     DO 161 J=1,3
 161 VSAV(I,J)=V(I,J)
     GO TO 4
  17 CALL UPX(XS,FS,TESTRS,GS,TSIS,LTS,LS,FGS,GGS,S11S,S12S,S21S,
    1S22S,UVIS,UVFS,X,F,TESTR,G,TSI,LT,L,FG,GG,S11,S12,S21,S22,
    2 UVI,UVF)
C     COMPUTE PRIMER VECTOR DERIVATIVE
     CALL MXV(S11,UVI,DUM,3,3)
     CALL INVERT(S12,TEMP)
     DO 18 I=1,3
  18 DUM(I)=UVF(I)-DUM(I)
     CALL MXV(TEMP,DUM,DUVI,3,3)
     DO 400 I=1,3
     PVO(I)=UVI(I)
 400 PVO(I+3)=DUVI(I)
     IPV=1
     IPVTM=1
     IPTRAJ=1
     IFILE=IFILEX
C     GENERATE OPTIMAL TRAJECTORY AND PRIMER VECTOR HISTORY
     VEVMAG=X(1)
     LON=X(2)
     THE=X(3)
     CALL COMIC3(REVMAG,VEVMAG,LON,THE,OINC,REVO,VEVO,VEVOP)
     CALL THRBDY(TSTART,TEND,REVO,VEVOP,REMO,VEMO,PVO,REVF,VEVF,
    1REMF,VEMF,S11,S12,S21,S22)
 100 FORMAT(4D20.11)
 101 FORMAT(4I5)
 102 FORMAT(1H ,T8,'3-BODY 2-IMPULSE OPTIMAL TRANSFER FROM EARTH'/
    11H ,T8,'TO HALO ORBIT AT L1 OR L2. ITERATE ON VELOCITY'/
    21H ,T8,'MAGNITUDE, LONGITUDE OF NODE AND ORBITAL ANGLE FROM'/
    31H ,T8,'NODE USING ACCELERATED GRADIENT PROJECTION AND '/
    41H ,T8,'DAVIDON VARIANCE METHOD')
 103 FORMAT(1H0,T8,'GAMMA',T28,'UDM',T48,'UTIME',T68,'UVELM',T88,
    1'ERRMXM',T108,'ERRMAX'/1H ,1P6D20.11)
 104 FORMAT(1H ,T8,'ME',T28,'MM',T48,'OINCD'/
    11H ,1P5D20.11)
 105 FORMAT(1H ,T8,'TDAYO',T28,'TTRIPD',T48,'TDAYF',T68,'TSTART',
    1T88,'TTRIP',T108,'TEND'/1H ,1P6D20.11)
 106 FORMAT(1H ,T8,'REMO',T68,'VEMO'/1H ,1P6D20.11)
 108 FORMAT(1H ,T8,'VEVMAG',T28,'LOND',T48,'THED',T68,'REVMAG'/
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   11H ,1P4D20.11)
109 FORMAT(1H ,T8,'ALPHA',T28,'BETA',T48,'EPS',T68,'EPSTSI',T88,
   1'KDX',T108,'EPSV'/1H ,1P6D20.11)
110 FORMAT(1H ,T8,'ICOMV',T28,'ITERMX',T48,'IFILEX',T68,'ITAR'/
   11H ,I10,3I20)
111 FORMAT(1H0,T8,'V'/1H ,1P6D20.11/1H ,1P3D20.11)
112 FORMAT(1H0,T8,'X',T68,'F',T88,'FG',T108,'TESTR'/1H ,1P6D20.11)
113 FORMAT(1H ,T8,'TSI',T68,'G'/1H ,1P6D20.11)
114 FORMAT(1H ,T8,'LT'/1H ,1P6D20.11/1H ,1P3D20.11)
115 FORMAT(1H ,T8,'GG'/1H ,1P3D20.11)
116 FORMAT(1H1,T8,'ITERD',T28,'DX'/1H ,I10,10X,1P3D20.11)
117 FORMAT(1H ,T8,'XS',T68,'KV'/1H ,1P4D20.11)
118 FORMAT(1H0,T8,'CONSTRAINT RESTROATION')
119 FORMAT(1H0,T8,'DX'/1H ,1P3D20.11)
120 FORMAT(1H ,T8,'KDX',T28,'DELX'/1H ,1P4D20.11)
121 FORMAT(1H ,T8,'FS',T28,'TESTRS',T48,'FGS',T68,'TSIS'/1H ,
   11P6D20.11)
122 FORMAT(1H ,T8,'GS',T68,'GGS'/1H ,1P6D20.11)
123 FORMAT(1H ,T8,'P'/1H ,1PD20.11)
124 FORMAT(1H0,T8,'AYM',T28,'AZM',T48,'ATARD'/1H ,1P3D20.11)
125 FORMAT(1H0,T8,'INPUT TARGET'/1H0,T8,'REVTAR',T68,'VEVTAR'/1H ,
   11P6D20.11)
126 FORMAT(1H0,T8,'NO. OF DAVIDON ITERATIONS HAS REACHED MAXIMUM')
    RETURN
    END
```

```
C     PROGRAM PTP3I
C     PROGRAM COMPUTES FUEL OPTIMAL 3-IMPULSE TRANSFER FROM A GIVEN
C     INITIAL POSITION TO A GIVEN FINAL POSITION AND VELOCITY IN
C     FIXED TIME.
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION X(4),G(4),V(4,4),XS(4),GS(4),R(4),DX(4),RSVO(3),
     1VSVO(3),RSEO(3),VSEO(3),RSMO(3),VSMO(3),VSVI(3),
     2TEMP1(4,4),SFM11S(3,3),SFM12S(3,3),SFM21S(3,3),SFM22S(3,3),
     3SMI11S(3,3),SMI12S(3,3),SMI21S(3,3),SMI22S(3,3),RSVM(3),
     4VSVMP(3),RSVMS(3),VSVMPS(3),DUVIS(3),DUVMMS(3),
     5DUVMPS(3),DG(4),VS(4,4),DXC(4),XC(4),RSVMC(3),VSVMPC(3),
     6UVIC(3),UVMC(3),UVFC(3),DUVIC(3),DUVMMC(3),DUVMPC(3),RC(4),
     7SMI11C(3,3),SMI12C(3,3),SMI21C(3,3),SMI22C(3,3),SFM11C(3,3),
     8SFM12C(3,3),SFM21C(3,3),SFM22C(3,3),RSVMD(3),VSVMPD(3),UVIS(3),
     9UVMS(3),UVFS(3),S(4),SFM11(3,3),SFM12(3,3),SFM21(3,3),
     1SFM22(3,3),UVI(3),UVM(3),UVF(3),DUVI(3),DUVMM(3),DUVMP(3),
     2SMI11(3,3),SMI12(3,3),SMI21(3,3),SMI22(3,3),PVO(6),PVM(6),
     3RSVTAR(3),VSVTAR(3),SFM11D(3,3),SFM12D(3,3)
      DIMENSION VSVMM(3),RSEM(3),VSEM(3),RSMM(3),VSMM(3),
     1RSVF(3),VSVF(3),RSEF(3),VSEF(3),RSMF(3),VSMF(3)
      DIMENSION DGC(4),VC(4,4),GC(4),VSVMMS(3),VSVMMC(3)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      READ(5,100)GL1,AUM,UTIME,UVELM
      READ(5,100)MS,ME,MM
      READ(5,100)TSTART,TM,TEND
      READ(5,100)RSEO,VSEO,RSMO,VSMO
      READ(5,100)RSVO,VSVO
      READ(5,100)VSVI,VSVMP
      READ(5,100)RSVTAR,VSVTAR
      READ(5,100)KNR,ERRMIN,ERRMXM
      READ(5,100)FMINM,EPS,EPSV
      READ(5,101)ICOMV,ITLMAX,ILINC,ITDMAX,IFILEX
      IF(ICOMV.GT.0)GO TO 190
C     OPTION TO INPUT VARIANCE MATRIX(ICOMV=0)
      READ(5,100) ((V(I,J),J=1,4),I=1,4)
      GO TO 1
  190 DO 200 I=1,4
      DO 200 J=1,4
      V(I,J)=0.
      IF(I.EQ.J) V(I,J)=1.0
  200 CONTINUE
    1 DTR=1.745329251994329 6D-2
      ERRMAX=ERRMXM/AUM
      FMIN=FMINM*UVELM
      KNRSAV=KNR
      ALPMIN=1.0D-8
      WRITE(6,102)GL1,AUM,UTIME,UVELM,ERRMXM,ERRMAX,MS,ME,MM
      WRITE(6,103)TSTART,TM,TEND,RSVO,VSVO,RSEO,VSEO,RSMO,VSMO
      WRITE(6,104)VSVI,VSVMP,RSVTAR,VSVTAR
      WRITE(6,105)KNR,ERRMIN,FMINM,EPS,EPSV
      WRITE(6,106)ICOMV,ITLMAX,ILINC,ITDMAX,IFILEX
      IPV=0
      IPVTM=0
      IFILE=0
      IPTRAJ=0
      IMTX=1
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```
      ITERD=0
      DO 2 I=1,3
    2 X(I)=VSVI(I)
      X(4)=TM
C     COMPUTE INITIAL NOMINAL TRAJECTORY
      CALL COMF(TSTART,TM,TEND,RSVO,VSVO,VSVI,RSEO,VSEO,RSMO,VSMO,
     1ERRMIN,ILINC,KNRSAV,ITERD,ITLMAX,RSVMD,VSVMPD,RSVTAR,VSVTAR,
     2SFM11D,SFM12D,RSVM,VSVMM,VSVMP,F,UVI,UVM,UVF,SMI11,
     3SMI12,SMI21,SMI22,SFM11,SFM12,SFM21,SFM22)
      CALL COMG(SMI11,SMI12,SMI21,SMI22,SFM11,SFM12,VSVMP,VSVMM,UVI,
     1UVM,UVF,DUVI,DUVMM,DUVMP,G)
      GMAG=DSQRT(DOT(G,G,4))
      WRITE(6,108)F,G,GMAG
      DO 3 I=1,3
      RSVMD(I)=RSVM(I)
      VSVMPD(I)=VSVMP(I)
      DO 3 J=1,3
      SFM11D(I,J)=SFM11(I,J)
    3 SFM12D(I,J)=SFM12(I,J)
      IF(ICOMV.EQ.0) GO TO 40
C     OPTION TO COMPUTE TRIAL VARIANCE MATRIX (ICOMV=1)
      DO 4 I=1,4
      DO 4 J=1,4
      V(I,J)=V(I,J)*EPSV/GMAG
    4 CONTINUE
   40 WRITE(6,107) ((V(I,J),J=1,4),I=1,4)
C     ACCELERATED GRADIENT ITERATION LOOP
    5 ITERD=ITERD+1
      WRITE(6,109)ITERD
      CALL MXV(V,G,S,4,4)
      DO 50 I=1,4
   50 S(I)=-S(I)
      SG=DOT(S,G,4)
      WRITE(6,110)S,SG
      IF(SG.LT.0.)GO TO 51
      DO 52 I=1,4
   52 S(I)=-S(I)
      SG=-SG
      WRITE(6,111)S,SG
   51 ALP=(FMIN-F)/SG
      ALPHA=DMIN1(1.0D+0,ALP)
    6 DO 61 I=1,4
      DX(I)=ALPHA*S(I)
   61 XS(I)=X(I)+DX(I)
      DO 62 I=1,3
   62 VSVI(I)=XS(I)
      WRITE(6,112)DX,ALPHA,XS
      CALL COMF(TSTART,XS(4),TEND,RSVO,VSVO,VSVI,RSEO,VSEO,RSMO,VSMO,
     1ERRMIN,ILINC,KNRSAV,ITERD,ITLMAX,RSVMD,VSVMPD,RSVTAR,VSVTAR,
     2SFM11D,SFM12D,RSVMS,VSVMMS,VSVMPS,FS,UVIS,UVMS,UVFS,SMI11S,
     3SMI12S,SMI21S,SMI22S,SFM11S,SFM12S,SFM21S,SFM22S)
      CALL COMG(SMI11S,SMI12S,SMI21S,SMI22S,SFM11S,SFM12S,VSVMPS,
     1VSVMMS,UVIS,UVMS,UVFS,DUVIS,DUVMMS,DUVMPS,GS)
      GSMAG=DSQRT(DOT(GS,GS,4))
      WRITE(6,113)FS,GS,GSMAG
      DO 701 I=1,4
  701 DG(I)=GS(I)-G(I)
```

```
      CALL MXV(V,DG,R,4,4)
      DO 71 I=1,4
   71 R(I)=R(I)-DX(I)
      RMAG=DSQRT(DOT(R,R,4))
      P=DOT(DG,R,4)
      PMAG=DABS(P)
      SGS=DOT(S,GS,4)
      WRITE(6,114)DG,P,SGS,R,RMAG
    8 CALL VVT(R,TEMP1,4)
      DO 81 I=1,4
      DO 81 J=1,4
   81 V(I,J)=V(I,J)-TEMP1(I,J)/P
   82 IF(SGS.GT.0.)GO TO 83
      IF(FS.LT.F)GO TO 14
      ALPHA=ALPHA/10.0
      IF(ALPHA.LT.ALPMIN)GO TO 84
      GO TO 6
   84 DO 840 I=1,4
      DO 840 J=1,4
      V(I,J)=0.
      IF(I.EQ.J)V(I,J)=1.
  840 V(I,J)=V(I,J)*EPSV/GMAG
      WRITE(6,122)
      GO TO 40
   83 CONTINUE
C     CUBIC INTERPOLATION BETWEEN X AND XS
      Z=3.*(F-FS)/ALPHA+SG+SGS
      W2=Z*Z-SG*SGS
      IF(W2.LE.0.)GO TO 13
      W=DSQRT(W2)
      ALPHAC=ALPHA*(1.-(SGS+W-Z)/(SGS-SG+2.*W))
      DO 9 I=1,4
      DXC(I)=ALPHAC*S(I)
    9 XC(I)=X(I)+DXC(I)
      DO 901 I=1,3
  901 VSVI(I)=XC(I)
      WRITE(6,115)DXC,ALPHAC,XC
      CALL COMF(TSTART,XC(4),TEND,RSVO,VSVO,VSVI,RSEO,VSEO,RSMO,VSMO,
     1ERRMIN,ILINC,KNRSAV,ITERD,ITLMAX,RSVMD,VSVMPD,RSVTAR,VSVTAR,
     2SFM11D,SFM12D,RSVMC,VSVMMC,VSVMPC,FC,UVIC,UVMC,UVFC,SMI11C,
     3SMI12C,SMI21C,SMI22C,SFM11C,SFM12C,SFM21C,SFM22C)
      CALL COMG(SMI11C,SMI12C,SMI21C,SMI22C,SFM11C,SFM12C,VSVMPC,
     1VSVMMC,UVIC,UVMC,UVFC,DUVIC,DUVMMC,DUVMPC,GC)
      GCMAG=DSQRT(DOT(GC,GC,4))
      WRITE(6,116)FC,GC,GCMAG
      DO 902 I=1,4
  902 DGC(I)=GC(I)-G(I)
      DO 91 I=1,3
      RSVMD(I)=RSVMC(I)
      VSVMPD(I)=VSVMPC(I)
      DO 91 J=1,3
      SFM11D(I,J)=SFM11C(I,J)
   91 SFM12D(I,J)=SFM12C(I,J)
      CALL MXV(V,GC,RC,4,4)
      DO 92 I=1,4
   92 RC(I)=RC(I)-DXC(I)
      RCMAG=DSQRT(DOT(RC,RC,4))
```

```
      PC=DOT(DGC,RC,4)
      CALL VVT(RC,TEMP1,4)
      DO 93 I=1,4
      DO 93 J=1,4
   93 V(I,J)=V(I,J)-TEMP1(I,J)/PC
      WRITE(6,117)DGC,PC,RC,RCMAG
      IF(FS.GT.F)GO TO 11
      IF(FC.GT.FS)GO TO 14
   10 DO 20 I=1,4
      X(I)=XC(I)
   20 G(I)=GC(I)
      DO 201 I=1,3
      UVI(I)=UVIC(I)
      UVM(I)=UVMC(I)
      DUVI(I)=DUVIC(I)
      DUVMM(I)=DUVMMC(I)
      DUVMP(I)=DUVMPC(I)
      RSVMD(I)=RSVMC(I)
      VSVMPD(I)=VSVMPC(I)
      DO 201 J=1,3
      SFM11D(I,J)=SFM11C(I,J)
  201 SFM12D(I,J)=SFM12C(I,J)
      F=FC
      GMAG=GCMAG
      GO TO 16
   11 IF(FC.LT.F)GO TO 10
C     FC GRTHN F. REPEAT INTERPOLATION IN REDUCED INTERVAL.
      FS=FC
      ALPHA=ALPHAC
      DO 250 I=1,3
      XS(I)=XC(I)
      GS(I)=GC(I)
      RSVMS(I)=RSVMC(I)
      VSVMPS(I)=VSVMPC(I)
      UVIS(I)=UVIC(I)
      UVMS(I)=UVMC(I)
      DUVIS(I)=DUVIC(I)
      DUVMMS(I)=DUVMMC(I)
      DUVMPS(I)=DUVMPC(I)
      DO 250 J=1,3
      SFM11S(I,J)=SFM11C(I,J)
  250 SFM12S(I,J)=SFM12C(I,J)
      SGS=DOT(S,GS,4)
      WRITE(6,121)SGS
      GO TO 82
   13 IF(FS.GT.F)GO TO 15
   14 F=FS
      GMAG=GSMAG
      DO 140 I=1,4
      X(I)=XS(I)
  140 G(I)=GS(I)
      DO 141 I=1,3
      UVI(I)=UVIS(I)
      UVM(I)=UVMS(I)
      DUVI(I)=DUVIS(I)
      DUVMM(I)=DUVMMS(I)
      DUVMP(I)=DUVMPS(I)
```

```
      RSVMD(I)=RSVMS(I)
      VSVMPD(I)=VSVMPS(I)
      DO 141 J=1,3
      SFM11D(I,J)=SFM11S(I,J)
  141 SFM12D(I,J)=SFM12S(I,J)
   15 CONTINUE
   16 DO 161 I=1,3
      RSVM(I)=RSVMD(I)
      VSVMP(I)=VSVMPD(I)
      DO 161 J=1,3
      SFM11(I,J)=SFM11D(I,J)
  161 SFM12(I,J)=SFM12D(I,J)
      WRITE(6,118)X,F,GMAG,G,RSVMD,VSVMPD
      WRITE(6,107)((V(I,J),J=1,4),I=1,4)
      IF(GMAG.LT.EPS)GO TO 18
      IF(ITERD.LT.ITDMAX)GO TO 5
      WRITE(6,119)
   18 IPV=1
      IPTRAJ=1
      IFILE=IFILEX
      WRITE(6,120)
C     GENERATE OPTIMAL TRAJECTORY AND PRIMER VECTOR HISTORY
      DO 30 I=1,3
      PVO(I)=UVI(I)
      PVO(I+3)=DUVI(I)
      PVM(I)=UVM(I)
      PVM(I+3)=DUVMP(I)
   30 VSVI(I)=X(I)
      CALL FOURBY(TSTART,X(4),RSVO,VSVI,RSEO,VSEO,
     1RSMO,VSMO,PVO,RSVM,VSVMM,RSEM,VSEM,RSMM,VSMM,SMI11,SMI12,
     2SMI21,SMI22)
      CALL FOURBY(X(4),TEND,RSVM,VSVMP,RSEM,VSEM,RSMM,VSMM,
     1PVM,RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,SFM11,SFM12,SFM21,SFM22)
  100 FORMAT(4D20.11)
  101 FORMAT(6I5)
  102 FORMAT(1H0,40X,'4-BODY 3-IMPULSE BOUNDARY VALUE PROBLEM'/
     11H0,T8,'GL1',T28,'AUM',T48,'UTIME',T68,'UVELM',T88,'ERRMXM',
     2T108,'ERRMAX'/1H ,1P6D20.11/1H ,T8,'MS',T28,'ME',T48,'MM'/1H ,
     31P3D20.11)
  103 FORMAT(1H ,T8,'TSTART',T28,'TM',T48,'TEND'/1H ,1P3D20.11/1H ,
     1T8,'RSVO',T68,'VSVO'/1H ,1P6D20.11/1H ,T8,'RSEO',T68,'VSEO'/
     21H ,1P6D20.11/1H ,T8,'RSMO',T68,'VSMO'/1H ,1P6D20.11)
  104 FORMAT(1H0,T8,'VSVI',T68,'VSVMP'/1H ,1P6D20.11/1H ,T8,'RSVTAR',
     1T68,'VSVTAR'/1H ,1P6D20.11)
  105 FORMAT(1H0,T8,'KNR',T28,'ERRMIN',T48,'FMINM',T68,'EPS',T88,
     1'EPSV'/1H ,1P5D20.11)
  106 FORMAT(1H0,T8,'ICOMV',T28,'ITLMAX',T48,'ILINC',T68,'ITDMAX',T88,
     1'IFILEX'/1H ,I10,4I20)
  107 FORMAT(1H0,T8,'V'/1H ,1P6D20.11/1H ,1P6D20.11/1H ,1P4D20.11)
  108 FORMAT(1H ,T8,'F',T28,'G',T108,'GMAG'/1H ,1P6D20.11)
  109 FORMAT(1H1,T8,'ITERD'/1H ,I10)
  110 FORMAT(1H0,T8,'S',T88,'SG'/1H ,1P5D20.11)
  111 FORMAT(1H0,T8,'SIGNS OF S AND SG REVERSED'/1H ,T8,'S',T88,'SG'/
     11H ,1P5D20.11)
  112 FORMAT(1H0,T8,'DX',T88,'ALPHA'/1H ,1P5D20.11/1H ,T8,'XS'/1H ,
     11H ,1P4D20.11)
  113 FORMAT(1H ,T8,'FS',T28,'GS',T108,'GSMAG'/1H ,1P6D20.11)
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114 FORMAT(1H ,T8,'DG',T88,'P',T108,'SGS'/1H ,1P6D20.11/1H ,T8,
   1'R',T88,'RMAG'/1H ,1P5D20.11)
115 FORMAT(1H0,T8,'CUBIC INTERPOLATION BETWEEN X AND XS'/1H0,T8,
   1'DXC',T88,'ALPHAC'/1H ,1P5D20.11/1H ,T8,'XC'/1H ,1P4D20.11)
116 FORMAT(1H ,T8,'FC',T28,'GC',T108,'GCMAG'/1H ,1P6D20.11)
117 FORMAT(1H ,T8,'DGC',T88,'PC'/1H ,1P5D20.11/1H ,T8,'RC',T88,
   1'RCMAG'/1H ,1P5D20.11)
118 FORMAT(1H0,T8,'OUTPUT OF THIS ITERATION'/1H0,T8,'X',T88,'F',
   1T108,'GMAG'/1H ,1P6D20.11/1H ,T8,'G'/1H ,1P4D20.11/1H ,T8,
   2'RSVMD',T68,'VSVMPD'/1H ,1P6D20.11)
119 FORMAT(1H0,T8,'NO. OF DAVIDON ITERATIONS HAS REACHED MAXIMUM')
120 FORMAT(1H1)
121 FORMAT(1H0,T8,'SGS'/1H ,1P1D20.11)
122 FORMAT(1H0,T8,'RESTART WITH IDENTITY V MATRIX SCALED BY EPSV')
    RETURN
    END
```

```
C     PROGRAM PTP3I3
C     PROGRAM COMPUTES FUEL OPTIMAL 3-IMPULSE TRANSFER FROM A GIVEN
C     INITIAL POSITION TO A GIVEN FINAL POSITION AND VELOCITY IN
C     FIXED TIME.
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION X(4),G(4),V(4,4),XS(4),GS(4),R(4),DX(4),REVO(3),
     1VEVO(3),REMO(3),VEMO(3),VEVOP(3),TEMP1(4,4),SFM11S(3,3),
     2SFM12S(3,3),SFM21S(3,3),SFM22S(3,3),SMI11S(3,3),SMI12S(3,3),
     3SMI21S(3,3),SMI22S(3,3),REVM(3),VEVMP(3),REVMS(3),VEVMPS(3),
     4DUVIS(3),DUVMMS(3),DUVMPS(3),DG(4),VS(4,4),DXC(4),XC(4),
     5REVMC(3),VEVMPC(3),UVIC(3),UVMC(3),UVFC(3),DUVIC(3),DUVMMC(3),
     6DUVMPC(3),RC(4),SMI11C(3,3),SMI12C(3,3),SMI21C(3,3),SMI22C(3,3),
     7SFM11C(3,3),SFM12C(3,3),SFM21C(3,3),SFM22C(3,3),REVMD(3),
     8VEVMPD(3),UVIS(3),UVMS(3),UVFS(3),S(4),SFM11(3,3),SFM12(3,3),
     9SFM21(3,3),SFM22(3,3),UVI(3),UVM(3),UVF(3),DUVI(3),DUVMM(3),
     1DUVMP(3),SMI11(3,3),SMI12(3,3),SMI21(3,3),SMI22(3,3),PVO(6),
     2PVM(3),REVTAR(3),VEVTAR(3),SFM11D(3,3),SFM12D(3,3),DGC(4),
     3VC(4,4),GC(4),VEVMM(3),REMM(3),VEMM(3),REVF(3),VEVF(3),REMF(3),
     4VEMF(3),VEVMMS(3),VEVMMC(3)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      READ(5,100)GAMMA,UDM,UTIME,UVELM
      READ(5,100)ME,MM
      READ(5,100)TSTART,TM,TEND
      READ(5,100)REMO,VEMO
      READ(5,100)REVO,VEVO
      READ(5,100)VEVOP,VEVMP
      READ(5,100)REVTAR,VEVTAR
      READ(5,100)KNR,ERRMIN,ERRMXM
      READ(5,100)FMINM,EPS,EPSV
      READ(5,101)ICOMV,ITLMAX,ILINC,ITDMAX,IFILEX
      IF(ICOMV.GT.0)GO TO 190
C     OPTION TO INPUT VARIANCE MATRIX(ICOMV=0)
      READ(5,100)((V(I,J),J=1,4),I=1,4)
      GO TO 1
  190 DO 200 I=1,4
      DO 200 J=1,4
      V(I,J)=0.
      IF(I.EQ.J)V(I,J)=1.0
  200 CONTINUE
    1 DTR=1.745329251994329 6D-2
      ERRMAX=ERRMXM/UDM
      FMIN=FMINM*UVELM
      KNRSAV=KNR
      ALPMIN=1.0D-8
      WRITE(6,102)GAMMA,UDM,UTIME,UVELM,ERRMXM,ERRMAX,ME,MM
      WRITE(6,103)TSTART,TM,TEND,REVO,VEVO,REMO,VEMO
      WRITE(6,104)VEVOP,VEVMP,REVTAR,VEVTAR
      WRITE(6,105)KNR,ERRMIN,FMINM,EPS,EPSV
      WRITE(6,106)ICOMV,ITLMAX,ILINC,ITDMAX,IFILEX
      IPV=0
      IPVTM=0
      IFILE=0
      IPTRAJ=0
      IMTX=1
      ITERD=0
      DO 2 I=1,3
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    2 X(I)=VEVOP(I)
      X(4)=TM
C     COMPUTE INITIAL NOMINAL TRAJECTORY
      CALL COMF3(TSTART,TM,TEND,REVO,VEVO,VEVOP,REMO,VEMO,ERRMIN,
     1ILINC,KNRSAV,ITERD,ITLMAX,REVMD,VEVMPD,REVTAR,VEVTAR,SFM11D,
     2SFM12D,REVM,VEVMM,VEVMP,F,UVI,UVM,UVF,SMI11,SMI12,SMI21,SMI22,
     3SFM11,SFM12,SFM21,SFM22)
      CALL COMG(SMI11,SMI12,SMI21,SMI22,SFM11,SFM12,VEVMP,VEVMM,UVI,
     1UVM,UVF,DUVI,DUVMM,DUVMP,G)
      GMAG=DSQRT(DOT(G,G,4))
      WRITE(6,108)F,G,GMAG
      DO 3 I=1,3
      REVMD(I)=REVM(I)
      VEVMPD(I)=VEVMP(I)
      DO 3 J=1,3
      SFM11D(I,J)=SFM11(I,J)
    3 SFM12D(I,J)=SFM12(I,J)
      IF(ICOMV.EQ.0)GO TO 40
C     OPTION TO COMPUTE TRIAL VARIANCE MATRIX (ICOMV=1)
      DO 4 I=1,4
      DO 4 J=1,4
      V(I,J)=V(I,J)*EPSV/GMAG
    4 CONTINUE
   40 WRITE(6,107)((V(I,J),J=1,4),I=1,4)
C     ACCELERATED GRADIENT ITERATION LOOP
    5 ITERD=ITERD+1
      WRITE(6,109)ITERD
      CALL MXV(V,G,S,4,4)
      DO 50 I=1,4
   50 S(I)=-S(I)
      SG=DOT(S,G,4)
      WRITE(6,110)S,SG
      IF(SG.LT.0.)GO TO 51
      DO 52 I=1,4
   52 S(I)=-S(I)
      SG=-SG
      WRITE(6,111)S,SG
   51 ALP=(FMIN-F)/SG
      ALPHA=DMIN1(1.0D+0,ALP)
    6 DO 61 I=1,4
      DX(I)=ALPHA*S(I)
   61 XS(I)=X(I)+DX(I)
      DO 62 I=1,3
   62 VEVOP(I)=XS(I)
      WRITE(6,112)DX,ALPHA,XS
      CALL COMF3(TSTART,XS(4),TEND,REVO,VEVO,VEVOP,REMO,VEMO,ERRMIN,
     1ILINC,KNRSAV,ITERD,ITLMAX,REVMD,VEVMPD,REVTAR,VEVTAR,SFM11D,
     2SFM12D,REVMS,VEVMMS,VEVMPS,FS,UVIS,UVMS,UVFS,SMI11S,SMI12S,
     3SMI21S,SMI22S,SFM11S,SFM12S,SFM21S,SFM22S)
      CALL COMG(SMI11S,SMI12S,SMI21S,SMI22S,SFM11S,SFM12S,VEVMPS,
     1VEVMMS,UVIS,UVMS,UVFS,DUVIS,DUVMMS,DUVMPS,GS)
      GSMAG=DSQRT(DOT(GS,GS,4))
      WRITE(6,113)FS,GS,GSMAG
      DO 701 I=1,4
  701 DG(I)=GS(I)-G(I)
      DO 7 I=1,3
      REVMD(I)=REVMS(I)
```

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      VEVMPD(I)=VEVMPS(I)
      DO 7 J=1,3
      SFM11D(I,J)=SFM11S(I,J)
    7 SFM12D(I,J)=SFM12S(I,J)
      CALL MXV(V,DG,R,4,4)
      DO 71 I=1,4
   71 R(I)=R(I)-DX(I)
      RMAG=DSQRT(DOT(R,R,4))
      P=DOT(DG,R,4)
      PMAG=DABS(P)
      SGS=DOT(S,GS,4)
      WRITE(6,114)DG,P,SGS,R,RMAG
    8 CALL VVT(R,TEMP1,4)
      DO 81 I=1,4
      DO 81 J=1,4
   81 V(I,J)=V(I,J)-TEMP1(I,J)/P
   82 IF(SGS.GT.0.)GO TO 83
      IF(FS.LT.F)GO TO 14
      ALPHA=ALPHA/10.0
      IF(ALPHA.LT.ALPMIN)GO TO 84
      GO TO 6
   84 DO 840 I=1,4
      DO 840 J=1,4
      V(I,J)=0.
      IF(I.EQ.J)V(I,J)=1.
  840 V(I,J)=V(I,J)*EPSV/GMAG
      WRITE(6,122)
      GO TO 40
   83 CONTINUE
C     CUBIC INTERPOLATION BETWEEN X AND XS
      Z=3.*(F-FS)/ALPHA+SG+SGS
      W2=Z*Z-SG*SGS
      IF(W2.LE.0.)GO TO 13
      W=DSQRT(W2)
      ALPHAC=ALPHA*(1.-(SGS+W-Z)/(SGS-SG+2.*W))
      DO 9 I=1,4
      DXC(I)=ALPHAC*S(I)
    9 XC(I)=X(I)+DXC(I)
      DO 901 I=1,3
  901 VEVOP(I)=XC(I)
      WRITE(6,115)DXC,ALPHAC,XC
      CALL COMF3(TSTART,XC(4),TEND,REVO,VEVO,VEVOP,REMO,VEMO,ERRMIN,
     1ILINC,KNRSAV,ITERD,ITLMAX,REVMD,VEVMPD,REVTAR,VEVTAR,SFM11D,
     2SFM12D,REVMC,VEVMMC,VEVMPC,FC,UVIC,UVMC,UVFC,SMI11C,SMI12C,
     3SMI21C,SMI22C,SFM11C,SFM12C,SFM21C,SFM22C)
      CALL COMG(SMI11C,SMI12C,SMI21C,SMI22C,SFM11C,SFM12C,VEVMPC,
     1VEVMMC,UVIC,UVMC,UVFC,DUVIC,DUVMMC,DUVMPC,GC)
      GCMAG=DSQRT(DOT(GC,GC,4))
      WRITE(6,116)FC,GC,GCMAG
      DO 902 I=1,4
  902 DGC(I)=GC(I)-G(I)
      DO 91 I=1,3
      REVMD(I)=REVMC(I)
      VEVMPD(I)=VEVMPC(I)
      DO 91 J=1,3
      SFM11D(I,J)=SFM11C(I,J)
   91 SFM12D(I,J)=SFM12C(I,J)
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      CALL MXV(V,GC,RC,4,4)
      DO 92 I=1,4
   92 RC(I)=RC(I)-DXC(I)
      RCMAG=DSQRT(DOT(RC,RC,4))
      PC=DOT(DGC,RC,4)
      CALL VVT(RC,TEMP1,4)
      DO 93 I=1,4
      DO 93 J=1,4
   93 V(I,J)=V(I,J)-TEMP1(I,J)/PC
      WRITE(6,117)DGC,PC,RC,RCMAG
      IF(FS.GT.F)GO TO 11
      IF(FC.GT.FS)GO TO 14
   10 DO 20 I=1,4
      X(I)=XC(I)
   20 G(I)=GC(I)
      DO 201 I=1,3
      UVI(I)=UVIC(I)
      UVM(I)=UVMC(I)
      DUVI(I)=DUVIC(I)
      DUVMM(I)=DUVMMC(I)
      DUVMP(I)=DUVMPC(I)
      REVMD(I)=REVMC(I)
      VEVMPD(I)=VEVMPC(I)
      DO 201 J=1,3
      SFM11D(I,J)=SFM11C(I,J)
  201 SFM12D(I,J)=SFM12C(I,J)
      F=FC
      GMAG=GCMAG
      GO TO 16
   11 IF(FC.LT.F)GO TO 10
C     FC GRTHN F. REPEAT INTERPOLATION IN REDUCED INTERVAL.
      FS=FC
      ALPHA=ALPHAC
      DO 250 I=1,3
      XS(I)=XC(I)
      GS(I)=GC(I)
      REVMS(I)=REVMC(I)
      VEVMPS(I)=VEVMPC(I)
      UVIS(I)=UVIC(I)
      UVMS(I)=UVMC(I)
      DUVIS(I)=DUVIC(I)
      DUVMMS(I)=DUVMMC(I)
      DUVMPS(I)=DUVMPC(I)
      DO 250 J=1,3
      SFM11S(I,J)=SFM11C(I,J)
  250 SFM12S(I,J)=SFM12C(I,J)
      SGS=DOT(S,GS,4)
      WRITE(6,121)SGS
      GO TO 82
   13 IF(FS.GT.F)GO TO 15
   14 F=FS
      GMAG=GSMAG
      DO 140 I=1,4
      X(I)=XS(I)
   40 G(I)=GS(I)
      DO 141 I=1,3
      UVI(I)=UVIS(I)
```

```
      UVM(I)=UVMS(I)
      DUVI(I)=DUVIS(I)
      DUVMM(I)=DUVMMS(I)
      DUVMP(I)=DUVMPS(I)
      REVMD(I)=REVMS(I)
      VEVMPD(I)=VEVMPS(I)
      DO 141 J=1,3
      SFM11D(I,J)=SFM11S(I,J)
  141 SFM12D(I,J)=SFM12S(I,J)
   15 CONTINUE
   16 DO 161 I=1,3
      REVM(I)=REVMD(I)
      VEVMP(I)=VEVMPD(I)
      DO 161 J=1,3
      SFM11(I,J)=SFM11D(I,J)
  161 SFM12(I,J)=SFM12D(I,J)
      WRITE(6,118)X,F,G,GMAG,REVMD,VEVMPD
      WRITE(6,107)((V(I,J),J=1,4),I=1,4)
      IF(GMAG.LT.EPS)GO TO 18
      IF(ITERD.LT.ITDMAX)GO TO 5
      WRITE(6,119)
   18 IPV=1
      IPTRAJ=1
      IFILE=IFILEX
      WRITE(6,120)
C     GENERATE OPTIMAL TRAJECTORY AND PRIMER VECTOR HISTORY
      DO 30 I=1,3
      PVO(I)=UVI(I)
      PVO(I+3)=DUVI(I)
      PVM(I)=UVM(I)
      PVM(I+3)=DUVMP(I)
   30 VEVOP(I)=X(I)
      CALL THRBDY(TSTART,X(4),REVO,VEVOP,REMO,VEMO,PVO,REVM,VEVMM,
     1REMM,VEMM,SMI11,SMI12,SMI21,SMI22)
      CALL THRBDY(X(4),TEND,REVM,VEVMP,REMM,VEMM,PVM,REVF,VEVF,REMF,
     1VEMF,SFM11,SFM12,SFM21,SFM22)
  100 FORMAT(4D20.11)
  101 FORMAT(6I5)
  102 FORMAT(1H0,40X,'3-BODY 3-IMPULSE BOUNDARY VALUE PROBLEM'/
     11H0,T8,'GAMMA',T28,'UDM',T48,'UTIME',T68,'UVELM',T88,'ERRMXM',
     2T108,'ERRMAX'/1H ,1P6D20.11/1H ,T8,'ME',T28,'MM'/1H ,1P2D20.11)
  103 FORMAT(1H ,T8,'TSTART',T28,'TM',T48,'TEND'/1H ,1P3D20.11/1H ,
     1T8,'REVO',T68,'VEVO'/1H ,1P6D20.11/1H ,T8,'REMO',T68,'VEMO'/
     21H ,1P6D20.11)
  104 FORMAT(1H0,T8,'VEVOP',T68,'VEVMP'/1H ,1P6D20.11/1H ,T8,'REVTAR',
     1T68,'VEVTAR'/1H ,1P6D20.11)
  105 FORMAT(1H0,T8,'KNR',T28,'ERRMIN',T48,'FMINM',T68,'EPS',T88,
     1'EPSV'/1H ,1P5D20.11)
  106 FORMAT(1H0,T8,'ICOMV',T28,'ITLMAX',T48,'ILINC',T68,'ITDMAX',T88,
     1'IFILEX'/1H ,I10,4I20)
  107 FORMAT(1H0,T8,'V'/1H ,1P6D20.11/1H ,1P6D20.11/1H ,1P4D20.11)
  108 FORMAT(1H ,T8,'F',T28,'G',T108,'GMAG'/1H ,1P6D20.11)
  109 FORMAT(1H1,T8,'ITERD'/1H ,I10)
  110 FORMAT(1H0,T8,'S',T88,'SG'/1H ,1P5D20.11)
  111 FORMAT(1H0,T8,'SIGNS OF S AND SG REVERSED'/1H ,T8,'S',T88,'SG'/
     11H ,1P5D20.11)
  112 FORMAT(1H0,T8,'DX',T88,'ALPHA'/1H ,1P5D20.11/1H ,T8,'XS'/1H ,
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   11H ,1P4D20.11)
113 FORMAT(1H ,T8,'FS',T28,'GS',T108,'GSMAG'/1H ,1P6D20.11)
114 FORMAT(1H ,T8,'DG',T88,'P',T108,'SGS'/1H ,1P6D20.11/1H ,T8,
   1'R',T88,'RMAG'/1H ,1P5D20.11)
115 FORMAT(1H0,T8,'CUBIC INTERPOLATION BETWEEN X AND XS'/1H0,T8,
   1'DXC',T88,'ALPHAC'/1H ,1P5D20.11/1H ,T8,'XC'/1H ,1P4D20.11)
116 FORMAT(1H ,T8,'FC',T28,'GC',T108,'GCMAG'/1H ,1P6D20.11)
117 FORMAT(1H ,T8,'DGC',T88,'PC'/1H ,1P5D20.11/1H ,T8,'RC',T88,
   1'RCMAG'/1H ,1P5D20.11)
118 FORMAT(1H0,T8,'OUTPUT OF THIS ITERATION'/1H0,T8,'X',T88,'F',
   1T108,'GMAG'/1H ,1P6D20.11/1H ,T8,'REVMD',T68,'VEVMPD'/1H ,
   21P6D20.11)
119 FORMAT(1H0,T8,'NO. OF DAVIDON ITERATIONS HAS REACHED MAXIMUM')
120 FORMAT(1H1)
121 FORMAT(1H0,T8,'SGS'/1H ,1P1D20.11)
122 FORMAT(1H0,T8,'RESTART WITH IDENTITY V MATRIX SCALED BY EPSV')
    RETURN
    END
```

```
      SUBROUTINE FOURBY(XTO,XTF,RSVO,VSVO,RSEO,VSEO,RSMO,
     1VSMO,PVO,RSVD,VSVD,RSED,VSED,RSMD,VSMD,S11,S12,S21,S22)
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION RSV(3),VSV(3),RSE(3),VSE(3),RSM(3),VSM(3),PVO(6),
     1S11(3,3),S12(3,3),S21(3,3),S22(3,3),REV(3),VEV(3),RMV(3),VMV(3),
     2REM(3),VEM(3),DR4RSV(3),DR4RSE(3),DR4RSM(3),BIGJ(6,6),STM(6,6),
     3STNTM(6,6),MTXSV(6,6),MTXEV(6,6),MTXMV(6,6),MTXSE(6,6),
     4MTXSM(6,6),MTXEM(6,6),DRSV(3),DVSV(3),DRSE(3),DVSE(3)
      DIMENSION RSVO(3),VSVO(3),RSEO(3),VSEO(3),RSMO(3),VSMO(3)
      DIMENSION RTM(3),DRSM(3),DVSM(3),DREV(3),DVEV(3),DRMV(3),
     1DVMV(3),DREM(3),DVEM(3),CRSV(3),CVSV(3),CRSE(3),CVSE(3),CRSM(3),
     2CVSM(3),CREV(3),CVEV(3),CRMV(3),CVMV(3),CREM(3),CVEM(3),PRSV(3)
     3,PVSV(3),PRSE(3),PVSE(3),PRSM(3),PVSM(3),RRSV(3),RVSV(3),
     4RRSE(3),RVSE(3),RRSM(3),RVSM(3),STMH(6,6),TEMP(6,6)
      DIMENSION VTM(3),PVTM(3),PVDTM(3),PV(6)
      DIMENSION RDV(3),VDV(3),RDS(3),VDS(3),RDE(3),VDE(3),RDM(3),
     1VDM(3),RDVD(3),VDVD(3),RDSD(3),VDSD(3),RDMD(3),
     2VDMD(3),RSVD(3),VSVD(3),RSED(3),VSED(3),RSMD(3),VSMD(3),RSL1(3),
     3VSL1(3),RDL1(3),VDL1(3),RDL1D(3),VDL1D(3)
      COMMON/TDATA/TO,T,H,RSV,VSV,REV,VEV,RMV,VMV,RSE,VSE,RSM,VSM,
     1REM,VEM,RSL1,VSL1,RDVD,VDVD,RDSD,VDSD,RDMD,VDMD,
     2RDL1D,VDL1D,PV,LM,LDM,ANGV,ANGE,ANGS
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CTM/TTM,RTM,VTM,LTM,LDTM,PVTM,PVDTM,STNTM
      DO 1 I=1,3
      RSV(I)=RSVO(I)
      VSV(I)=VSVO(I)
      RSE(I)=RSEO(I)
      VSE(I)=VSEO(I)
      RSM(I)=RSMO(I)
    1 VSM(I)=VSMO(I)
      TO=XTO
      MSME=MS+ME
      MSMM=MS+MM
      MEMM=ME+MM
      ESE=ME/MSME
      MSM=MM/MSMM
      MEM=MM/MEMM
      EEM=ME/MEMM
      SSE=MS/MSME
      SSM=MS/MSMM
      PSISV=0.
      PSISE=0.
      PSISM=0.
      PSIEV=0.
      PSIMV=0.
      PSIEM=0.
      LM=0.
      LDM=0.
      CALL RVEMV(RSV,VSV,RSE,VSE,RSM,VSM,REV,VEV,RMV,VMV,REM,VEM)
      IF (IMTX.EQ.0) GO TO 2
      DO 2 I=1,6
      PV(I)=0.
      DO 2 J=1,6
      STM(I,J)=0.
      IF(I.EQ.J) STM(I,J)=1.0
```

```
 2 CONTINUE
   ISTEP=0
   T=XTO
   TGO=XTF-T
   CALL CSTEP(TGO,RSV,REV,RMV,RSE,RSM,REM,H,DR4RSV,DR4RSE,
  1DR4RSM,BIGJ)
   CALL DISP
   IF(IPV.EQ.0) GO TO 21
   LTM=1.
   TTM=XTO
   CALL PVEC(T,RSV,VSV,PVO,STM,PV,LM,LDM)
21 IF(IFILE.EQ.0) GO TO 22
   CALL FDATA
22 IF(IPTRAJ.EQ.0) GO TO 3
   WRITE(6,100)
   IF(IPV.EQ.0) GO TO 23
   WRITE(6,101)
23 CALL PTRAJ
 3 ISTEP=ISTEP+1
   CALL TWOBDY(RSV,VSV,H,MS,PSISV,IMTX,CRSV,CVSV,MTXSV)
   CALL TWOBDY(RSE,VSE,H,MSME,PSISE,0,CRSE,CVSE,MTXSE)
   CALL TWOBDY(RSM,VSM,H,MSMM,PSISM,0,CRSM,CVSM,MTXSM)
   CALL TWOBDY(REV,VEV,H,ME,PSIEV,IMTX,CREV,CVEV,MTXEV)
   CALL TWOBDY(RMV,VMV,H,MM,PSIMV,IMTX,CRMV,CVMV,MTXMV)
   CALL TWOBDY(REM,VEM,H,MEMM,PSIEM,0,CREM,CVEM,MTXEM)
   DO 4 I=1,3
   DRSV(I)=CRSV(I)-RSV(I)-H*VSV(I)
   DVSV(I)=CVSV(I)-VSV(I)
   DRSE(I)=CRSE(I)-RSE(I)-H*VSE(I)
   DVSE(I)=CVSE(I)-VSE(I)
   DRSM(I)=CRSM(I)-RSM(I)-H*VSM(I)
   DVSM(I)=CVSM(I)-VSM(I)
   DREV(I)=CREV(I)-REV(I)-H*VEV(I)
   DVEV(I)=CVEV(I)-VEV(I)
   DRMV(I)=CRMV(I)-RMV(I)-H*VMV(I)
   DVMV(I)=CVMV(I)-VMV(I)
   DREM(I)=CREM(I)-REM(I)-H*VEM(I)
   DVEM(I)=CVEM(I)-VEM(I)
   PRSV(I)=ESE*DRSE(I)+DREV(I)+MSM*DRSM(I)+DRMV(I)
   PVSV(I)=ESE*DVSE(I)+DVEV(I)+MSM*DVSM(I)+DVMV(I)
   PRSE(I)=MSM*DRSM(I)-MEM*DREM(I)
   PVSE(I)=MSM*DVSM(I)-MEM*DVEM(I)
   PRSM(I)=ESE*DRSE(I)+EEM*DREM(I)
   PVSM(I)=ESE*DVSE(I)+EEM*DVEM(I)
   RSV(I)=CRSV(I)+PRSV(I)
   VSV(I)=CVSV(I)+PVSV(I)
   RSE(I)=CRSE(I)+PRSE(I)
   VSE(I)=CVSE(I)+PVSE(I)
   RSM(I)=CRSM(I)+PRSM(I)
 4 VSM(I)=CVSM(I)+PVSM(I)
   CALL RVEMV(RSV,VSV,RSE,VSE,RSM,VSM,REV,VEV,RMV,VMV,REM,VEM)
   T=T+H
   CALL DELRV(H,RSV,REV,RMV,RSE,RSM,REM,CRSV,CREV,CRMV,CRSE,CRSM,
  1CREM,DR4RSV,DR4RSE,DR4RSM,RRSV,RVSV,RRSE,RVSE,RRSM,RVSM)
   DO 5 I=1,3
   RSV(I)=RSV(I)+RRSV(I)
   VSV(I)=VSV(I)+RVSV(I)
```

```
      RSE(I)=RSE(I)+RRSE(I)
      VSE(I)=VSE(I)+RVSE(I)
      RSM(I)=RSM(I)+RRSM(I)
    5 VSM(I)=VSM(I)+RVSM(I)
      CALL RVEMV(RSV,VSV,RSE,VSE,RSM,VSM,REV,VEV,RMV,VMV,REM,VEM)
      IF(IMTX.EQ.0) GO TO 70
      DO 6 I=1,6
      DO 6 J=1,6
    6 STMH(I,J)=MTXSV(I,J)+MTXEV(I,J)+MTXMV(I,J)-2.0*BIGJ(I,J)
      CALL MXM(STMH,STM,TEMP,6,6,6)
      DO 7 I=1,6
      DO 7 J=1,6
    7 STM(I,J)=TEMP(I,J)
   70 CALL DISP
      IF(IPV.EQ.0) GO TO 71
      CALL PVEC(T,RSV,VSV,PVO,STM,PV,LM,LDM)
   71 IF(IFILE.EQ.0) GO TO 72
      CALL FDATA
   72 IF(IPTRAJ.EQ.0) GO TO 8
      CALL PTRAJ
    8 IF (T.GE.XTF) GO TO 9
      TGO=XTF-T
      CALL CSTEP(TGO,RSV,REV,RMV,RSE,RSM,REM,H,DR4RSV,DR4RSE,
     1DR4RSM,BIGJ)
      GO TO 3
    9 DO 10 I=1,3
      RSVD(I)=RSV(I)
      VSVD(I)=VSV(I)
      RSED(I)=RSE(I)
      VSED(I)=VSE(I)
      RSMD(I)=RSM(I)
      VSMD(I)=VSM(I)
      DO 10 J=1,3
      S11(I,J)=STM(I,J)
      S12(I,J)=STM(I,J+3)
      S21(I,J)=STM(I+3,J)
   10 S22(I,J)=STM(I+3,J+3)
      IF(IPV.EQ.0) GO TO 11
      IF(IPVTM.EQ.0) GO TO 11
      WRITE(6,102)TTM,LTM,LDTM,RTM,VTM
   11 IF(IPTRAJ.EQ.0) GO TO 12
      WRITE(6,103)ISTEP
   12 CONTINUE
  100 FORMAT(1H1,40X,'FOUR-BODY TRAJECTORY'/1H0,T8,'T',T28,'TDAY',
     1T48,'H',T68,'RSVMAG',T88,'REVMAG',T108,'RMVMAG'/1H ,T8,'RSV',
     2T68,'VSV'/1H ,T8,'REV',T68,'VEV'/1H ,T8,'RMV',T68,'VMV'/1H0,T8,
     3'RSE',T68,'VSE'/1H ,T8,'RSM',T68,'VSM'/1H ,T8,'REM',T68,'VEM'/
     41H ,T8,'RSL1',T68,'VSL1'/1H0,T8,'RDVD',T68,'VDVD'/1H ,T8,'RDSD',
     5T68,'VDSD'/1H ,T8,'RDMD',T68,'VDMD'/
     61H ,T8,'RDL1D',T68,'VDL1D'/1H0,T8,'ANGV',T28,'ANGE',T48,'ANGS',
     61H0,T8,'RDL1D',T68,'VDL1D'/1H ,T8,'ANGV',T28,'ANGE',T48,'ANGS',
     7T68,'HDAY')
  101 FORMAT(1H ,T8,'PV',T68,'PVD'/1H ,T8,'PVMAG',T28,'PVDMAG')
  102 FORMAT(1H0,'TIME OF MAXIMUM PRIMER VECTOR MAGNITUDE'/1H0,T8,
     1'TTM',T28,'LTM',T48,'LDTM'/1H ,1P3D20.11/1H ,T8,'RTM',T68,'VTM'
     2/1H ,1P6D20.11)
  103 FORMAT(1H0,T8,'ISTEP FOR THIS LEG =    ',I5)
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RETURN
END
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      SUBROUTINE THRBDY(XTO,XTF,REVO,VEVO,REMO,VEMO,PVO,REVD,VEVD,
     1REMD,VEMD,S11,S12,S21,S22)
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION REVO(3),VEVO(3),REMO(3),VEMO(3),PVO(6),REVD(3),VEVD(3)
     1,REMD(3),VEMD(3),S11(3,3),S12(3,3),S21(3,3),S22(3,3),REV(3),
     2VEV(3),REM(3),VEM(3),RMV(3),VMV(3),PV(6),STM(6,6),DR4REV(3),
     3BIGJ(6,6),CREV(3),CVEV(3),MTXEV(6,6),CREM(3),CVEM(3),MTXEM(6,6),
     4CRMV(3),CVMV(3),MTXMV(6,6),DRMV(3),DVMV(3),
     5PREV(3),PVEV(3),RREV(3),RVEV(3),STMH(6,6),TEMP(6,6),REL(3),
     6VEL(3),RDVD(3),VDVD(3),RDED(3),VDED(3),RDLD(3),VDLD(3)
      DIMENSION RTM(3),VTM(3),PVTM(3),PVDTM(3),STNTM(6,6)
      COMMON/TDATA3/TO,T,H,REV,VEV,RMV,VMV,REM,VEM,REL,VEL,RDVD,
     1VDVD,RDED,VDED,RDLD,VDLD,PV,LM,LDM,ANGV,ANGE,ANGM
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CTM/TTM,RTM,VTM,LTM,LDTM,PVTM,PVDTM,STNTM
      DO 1 I=1,3
      REV(I)=REVO(I)
      VEV(I)=VEVO(I)
      REM(I)=REMO(I)
      VEM(I)=VEMO(I)
      RMV(I)=-REM(I)+REV(I)
    1 VMV(I)=-VEM(I)+VEV(I)
      TO=XTO
      MEMM=ME+MM
      MEM=MM/MEMM
      PSIEV=0.
      PSIEM=0.
      PSIMV=0.
      LM=0.
      LDM=0.
      IF(IMTX.EQ.0)GO TO 2
      DO 2 I=1,6
      PV(I)=0.
      DO 2 J=1,6
      STM(I,J)=0.
      IF(I.EQ.J)STM(I,J)=1.0
    2 CONTINUE
      ISTEP=0
      T=XTO
      TGO=XTF-T
      CALL CSTEP3(TGO,REV,RMV,REM,H,DR4REV,BIGJ)
      CALL DISP3
      IF(IPV.EQ.0) GO TO 21
      LTM=1.0
      TTM=XTO
      CALL PVEC(T,REV,VEV,PVO,STM,PV,LM,LDM)
   21 IF(IFILE.EQ.0) GO TO 22
      CALL FDATA3
   22 IF(IPTRAJ.EQ.0) GO TO 3
      WRITE(6,100)
      IF(IPV.EQ.0) GO TO 23
      WRITE(6,101)
   23 CALL PTRAJ3
    3 ISTEP=ISTEP+1
      CALL TWOBDY(REV,VEV,H,ME,PSIEV,IMTX,CREV,CVEV,MTXEV)
      CALL TWOBDY(REM,VEM,H,MEMM,PSIEM,0,CREM,CVEM,MTXEM)
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      CALL TWOBDY(RMV,VMV,H,MM,PSIMV,IMTX,CRMV,CVMV,MTXMV)
      DO 4 I=1,3
      DRMV(I)=CRMV(I)-RMV(I)-H*VMV(I)
      DVMV(I)=CVMV(I)-VMV(I)
      PREV(I)=DRMV(I)
      PVEV(I)=DVMV(I)
      REV(I)=CREV(I)+PREV(I)
      VEV(I)=CVEV(I)+PVEV(I)
      REM(I)=CREM(I)
      VEM(I)=CVEM(I)
      RMV(I)=-REM(I)+REV(I)
    4 VMV(I)=-VEM(I)+VEV(I)
      T=T+H
      CALL DELRV3(H,REV,RMV,CREV,CRMV,DR4REV,RREV,RVEV)
      DO 5 I=1,3
      REV(I)=REV(I)+RREV(I)
      VEV(I)=VEV(I)+RVEV(I)
      RMV(I)=-REM(I)+REV(I)
    5 VMV(I)=-VEM(I)+VEV(I)
      IF(IMTX.EQ.0) GO TO 70
      DO 6 I=1,6
      DO 6 J=1,6
    6 STMH(I,J)=MTXEV(I,J)+MTXMV(I,J)-2.0*BIGJ(I,J)
      CALL MXM(STMH,STM,TEMP,6,6,6)
      DO 7 I=1,6
      DO 7 J=1,6
    7 STM(I,J)=TEMP(I,J)
   70 CALL DISP3
      IF(IPV.EQ.0) GO TO 71
      CALL PVEC(T,REV,VEV,PVO,STM,PV,LM,LDM)
   71 IF(IFILE.EQ.0) GO TO 72
      CALL FDATA3
   72 IF(IPTRAJ.EQ.0) GO TO 8
      CALL PTRAJ3
    8 IF(T.GE.XTF) GO TO 9
      TGO=XTF-T
      CALL CSTEP3(TGO,REV,RMV,REM,H,DR4REV,BIGJ)
      GO TO 3
    9 DO 10 I=1,3
      REVD(I)=REV(I)
      VEVD(I)=VEV(I)
      REMD(I)=REM(I)
      VEMD(I)=VEM(I)
      DO 10 J=1,3
      S11(I,J)=STM(I,J)
      S12(I,J)=STM(I,J+3)
      S21(I,J)=STM(I+3,J)
   10 S22(I,J)=STM(I+3,J+3)
      IF(IPV.EQ.0) GO TO 11
      IF(IPVTM.EQ.0) GO TO 11
      WRITE(6,102)TTM,LTM,LDTM,RTM,VTM
   11 IF(IPTRAJ.EQ.0) GO TO 12
      WRITE(6,103)ISTEP
   12 CONTINUE
  100 FORMAT(1H1,40X,'THREE-BODY TRAJECTORY'/1H0,T8,'T',T28,'TDAY',
     1T48,'H',T68,'REVMAG',T88,'RMVMAG'/1H ,T8,'REV',T68,'VEV'/
     21H ,T8,'RMV',T68,'VMV'/1H ,T8,'REM',T68,'VEM'/1H ,T8,'REL1',
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   3T68,'VEL1'/1H0,T8,'RDVD',T68,'VDVD'/1H ,T8,'RDED',T68,'VDED'/
   41H ,T8,'RDLD',T68,'VDLD'/1H ,T8,'ANGV',T28,'ANGE',T48,'ANGM')
101 FORMAT(1H0,T8,'PV',T68,'PVD'/1H ,T8,'PVMAG',T28,'PVDMAG')
 12 FORMAT(1H0,T8,'TIME OF MAXIMUM PRIMER VECTOR MAGNITUDE'/1H0,
   1T8,'TTM',T28,'LTM',T48,'LDTM'/1H ,1P3D20.11/1H ,T8,'RTM',T68,
   2'VTM'/1H ,1P6D20.11)
103 FORMAT(1H0,T8,'ISTEP FOR THIS LEG V   ',I5)
    RETURN
    END
```

```
      SUBROUTINE TWOBDY(XRO,XVO,TAU,MU,PSI,IMTX,XRF,XVF,P)

C GENERAL SOLUTION OF TWO BODY PROBLEM WITH PARTIAL DERIVATIVES
C   RTRAN DOUBLE PRECISION SUBROUTINE
      DOUBLE PRECISION SO(6),TAU,MU,PSI,S(6),P(6,6),PI(6,6),ACC(3),
     1ACCO(3),R,RO,SIGO,ALPHA,PSIN,PSIP,A,AP,CO,C1,C2,
     2C3,C4,C5X3,S1,S2,S3,DTAU,DTAUN,DTAUP,U,FM1,G,FD,GDM1
      DOUBLE PRECISION XRO(3),XVO(3),XRF(3),XVF(3)
C          INPUTS
C SO(1),SO(2),SO(3)=XO,YO,ZO=POSITION COMPONENTS AT REFERENCE TIME TO
C SO(4),SO(5),SO(6)=XDO,YDO,ZDO=VELOCITY COMPONENTS AT REFERENCE TIME TO
C TAU=TIME INTERVAL (T-TO) FROM REFERENCE TIME TO TO SOLUTION TIME T
C MU=CONSTANT IN DIFF. EQS. (XDD,YDD,ZDD)=-MU*(X,Y,Z)/(R**3)
C PSI=APPROXIMATION FOR FINAL SOLUTION PSI OF KEPLER'S EQUATION
C
C          OUTPUTS
C PSI=GENERALIZED ECCENTRIC ANOMALY=SOLUTION OF KEPLER'S EQUATION
C S(1),S(2),S(3)=X,Y,Z=POSITION COMPONENTS AT SOLUTION TIME T=TO+TAU
C S(4),S(5),S(6)=XD,YD,ZD=VELOCITY COMPONENTS AT SOLUTION TIME T=TO+TAU
C P(I,J)=PARTIAL DERIVATIVE DS(I)/DSO(J) OF S(I) WITH RESPECT TO SO(J)
C PI(I,J)=PARTIAL DSO(I)/DS(J) WITH ROLES OF TO AND T REVERSED
C ACC(I)=-MU*S(I)/(R**3)=ACCELERATION COMPONENT AT SOLUTION TIME T
C ACCO(I)=-MU*SO(I)/(RO**3)=ACCELERATION COMPONENT AT REF TIME TO
C R=RADIUS AT TIME T=SQUARE ROOT OF (X**2+Y**2+Z**2)
C RO=RADIUS AT TIME TO
C
C START OF INITIAL COMPUTATIONS
      DO 9 I=1,3
      SO(I)=XRO(I)
    9 SO(I+3)=XVO(I)
C COMPUTE RADIUS RO
      S1=DMAX1(DABS(SO(1)),DABS(SO(2)),DABS(SO(3)))
      S2=(SO(1)/S1)**2+(SO(2)/S1)**2+(SO(3)/S1)**2
      RO=2.
   10 R=RO
      RO=(R+S2/R)*.5
      IF(RO.LT.R) GO TO 10
      RO=RO*S1
C COMPUTE OTHER PARAMETERS
      SIGO=SO(1)*SO(4)+SO(2)*SO(5)+SO(3)*SO(6)
      ALPHA=SO(4)**2+SO(5)**2+SO(6)**2-2.*MU/RO
C INITIALIZE SERIES MOD COUNT M TO ZERO
      M=0
C INITIALIZE BOUNDS PSIN AND PSIP FOR PSI OR SET PSI=0 IF TAU=0
      IF(TAU) 20,30,40
   20 PSIN=-1.D+38
      PSIP=0.
      DTAUN=PSIN
      DTAUP=-TAU
      GO TO 50
   30 PSI=0.
      GO TO 100
   40 PSIN=0.
      PSIP=+1.D+38
      DTAUN=-TAU
      DTAUP=PSIP
C USE APPROXIMATION FOR PSI IF IT IS BETWEEN BOUNDS PSIN AND PSIP
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 50   IF(PSI.GT.PSIN.AND.PSI.LT.PSIP) GO TO 100
C TRY NEWTON'S METHOD FOR INITIAL PSI SET EQUAL TO ZERO
      PSI=TAU/RO
C(  ET PSI=TAU IF NEWTON'S METHOD FAILS
      IF(PSI.LE.PSIN.OR.PSI.GE.PSIP) PSI=TAU
C END OF INITIAL COMPUTATIONS
C
C BEGINNING OF LOOP FOR SOLVING KEPLER'S EQUATION
C BEGINNING OF SERIES SUMMATION
C COMPUTE ARGUMENT A IN REDUCED SERIES OBTAINED BY FACTORING OUT PSI'S
 100 A=ALPHA*PSI*PSI
      IF(DABS(A).LE.1.) GO TO 120
C SAVE A IN AP AND MOD A IF IT EXCEEDS UNITY IN MAGNITUDE
      AP=A
 110 M=M+1
      A=A*.25
      IF(DABS(A).GT.1.) GO TO 110
C SUM SERIES C5X3=3*S5/PSI**5 AND C4=S4/PSI**4
 120 C5X3=(1.+(1.+(1.+(1.+(1.+(1.+(1.+A/342.)*A/272.)*A/210.)*A/156.)
     1      *A/110.)*A/72.)*A/42.)/40.
      C4=(1.+(1.+(1.+(1.+(1.+(1.+(1.+A/306.)*A/240.)*A/182.)*A/132.)
     1      *A/90.)*A/56.)*A/30.)/24.
C COMPUTE SERIES C3=S3/PSI**3,C2=S2/PSI**2,C1=S1/PSI,C0=S0
      C3=(.5+A*C5X3)/3.
      C2=.5+A*C4
      C1=1.+A*C3
      C0=1.+A*C2
      IF(M.LE.0) GO TO 140
 EMOD SERIES C0 AND C1 IF NECESSARY WITH DOUBLE ANGLE FORMULAS
 30 C1=C1*C0
      C0=2.*C0*C0-1.
      M=M-1
      IF(M.GT.0) GO TO 130
C DETERMINE C2,C3,C4,C5X3 FROM C0,C1,AP IF DEMOD REQUIRED
      C2=(C0-1.)/AP
      C3=(C1-1.)/AP
      C4=(C2-.5)/AP
      C5X3=(3.*C3-.5)/AP
C COMPUTE SERIES S1,S2,S3 FROM C1,C2,C3
 140 S1=C1*PSI
      S2=C2*PSI*PSI
      S3=C3*PSI*PSI*PSI
C END OF SERIES SUMMATION
C COMPUTE RESIDUAL DTAU AND SLOPE R FOR KEPLER'S EQUATION
      G=RO*S1+SIG0*S2
      DTAU=(G+MU*S3)-TAU
      R=DABS(RO*C0+(SIG0*S1+MU*S2))
      IF(DTAU) 200,300,210
C RESET BOUND
 200 PSIN=PSI
      DTAUN=DTAU
      GO TO 220
 210 PSIP=PSI
      DTAUP=DTAU
 TRY NEWTON'S METHOD AND INITIALIZE SELECTOR N
 220 PSI=PSI-DTAU/R
      N=0
```

```
C ACCEPT PSI IF IT IS BETWEEN BOUNDS PSIN AND PSIP
  230 IF(PSI.GT.PSIN.AND.PSI.LT.PSIP) GO TO 100
C SELECT ALTERNATE METHOD OF COMPUTING PSI OR STOP ITERATIONS
      N=N+1
      GO TO (1,2,3,4,300),N
C TRY INCREMENTING BOUND WITH DTAU NEAREST ZERO BY THE RATIO 4*DTAU/TAU
    1 IF(DABS(DTAUN).LT.DABS(DTAUP)) PSI=PSIN*(1.-(4.*DTAUN)/TAU)
      IF(DABS(DTAUP).LT.DABS(DTAUN)) PSI=PSIP*(1.-(4.*DTAUP)/TAU)
      GO TO 230
C TRY DOUBLING BOUND CLOSEST TO ZERO
    2 IF(TAU.GT.0.) PSI=PSIN+PSIN
      IF(TAU.LT.0.) PSI=PSIP+PSIP
      GO TO 230
C TRY INTERPOLATION BETWEEN BOUNDS
    3 PSI=PSIN+(PSIP-PSIN)*(-DTAUN/(DTAUP-DTAUN))
      GO TO 230
C TRY HALVING BETWEEN BOUNDS
    4 PSI=PSIN+(PSIP-PSIN)*.5
      GO TO 230
C END OF LOOP FOR SOLVING KEPLER'S EQUATION
C
C COMPUTE REMAINING THREE OF FOUR FUNCTIONS FM1,G,FD,GDM1
  300 FM1=-MU*S2/RO
      FD=-MU*S1/RO/R
      GDM1=-MU*S2/R
C COMPUTE COORDINATES AT SOLUTION TIME T=TO+TAU
      DO 310 I=1,3
      S(I)=SO(I)+(FM1*SO(I)+G*SO(I+3))
      S(I+3)=(FD*SO(I)+GDM1*SO(I+3))+SO(I+3)
      XRF(I)=S(I)
   10 XVF(I)=S(I+3)
      IF (IMTX.EQ. 0) GO TO 500
C COMPUTE ACCELERATIONS
      DO 320 I=1,3
      ACC(I)=-MU*S(I)/R/R/R
  320 ACCO(I)=-MU*SO(I)/RO/RO/RO
C END OF COMPUTATION FOR COORDINATES AND ACCELERATIONS
C
C COMPUTATION OF PARTIAL DERIVATIVES
C COMPUTE COEFFICIENTS FOR STATE PARTIALS
      U=S2*TAU+MU*(C4-C5X3)*PSI*PSI*PSI*PSI*PSI
      P(1,1)=-(FD*S1+FM1/RO)/RO
      P(1,2)=-FD*S2
      P(2,1)=FM1*S1/RO
      P(2,2)=FM1*S2
      P(1,3)=P(1,2)
      P(1,4)=-GDM1*S2
      P(2,3)=P(2,2)
      P(2,4)=G*S2
      P(3,1)=-FD*(CO/RO/R+1./R/R+1./RO/RO)
      P(3,2)=-(FD*S1+GDM1/R)/R
      P(4,1)=-P(1,1)
      P(4,2)=-P(1,2)
      P(3,3)=P(3,2)
      P(3,4)=-GDM1*S1/R
      P(4,3)=-P(1,2)
      P(4,4)=-P(1,4)
```

```
C COMPUTE COEFFICIENTS FOR MU PARTIALS
      P(1,5)=-S1/RO/R
      P(2,5)=S2/RO
      P(3,5)=U/RO-S3
      P(1,6)=-P(1,5)
      P(2,6)=S2/R
      P(3,6)=-U/R+S3
      DO 400 I=1,3
C MATRIX ACCUMULATIONS FOR STATE PARTIALS
      DO 400 J=1,4
      PI(J,I)=P(J,1)*SO(I)+P(J,2)*SO(I+3)
  400 PI(J,I+3)=P(J,3)*SO(I)+P(J,4)*SO(I+3)
      DO 410 I=1,3
      DO 420 J=1,3
      P(I,J)=S(I)*PI(1,J)+S(I+3)*PI(2,J)+U*S(I+3)*ACCO(J)
      P(I,J+3)=S(I)*PI(1,J+3)+S(I+3)*PI(2,J+3)-U*S(I+3)*SO(J+3)
      P(I+3,J)=S(I)*PI(3,J)+S(I+3)*PI(4,J)+U*ACC(I)*ACCO(J)
  420 P(I+3,J+3)=S(I)*PI(3,J+3)+S(I+3)*PI(4,J+3)-U*ACC(I)*SO(J+3)
      P(I,I)=P(I,I)+FM1+1.
      P(I,I+3)=P(I,I+3)+G
      P(I+3,I)=P(I+3,I)+FD
  410 P(I+3,I+3)=P(I+3,I+3)+GDM1+1.
C END OF COMPUTATION FOR PARTIAL DERIVATIVES
C
C END OF PROGRAM - ALL OUTPUTS HAVE BEEN COMPUTED
  500 CONTINUE
      RETURN
      END
```

```
 SUBROUTINE CSTEP(TGO,RSV,REV,RMV,RSE,RSM,REM,H,
1DR4RSV,DR4RSE,DR4RSM,BIGJ)
 IMPLICIT REAL*8(A-H,M,O-Z)
 DIMENSION RSV(3),VSV(3),REV(3),VEV(3),RMV(3),VMV(3),RSE(3),
1VSE(3),RSM(3),VSM(3),REM(3),VEM(3),DR4RSV(3),DR4RSE(3),
2DR4RSM(3),URSV(3),UREV(3),URMV(3),URSE(3),URSM(3),UREM(3),
3UMTX(3,3),SVSV(3,3),EVEV(3,3),VMVM(3,3),SESE(3,3),SMSM(3,3),
4EMEM(3,3),BIGJ(6,6),TEMP1(3),TEMP2(3),TEMP3(3),TEMP4(3),
5TEMP5(3),TEMP6(3),TEMP7(3),TEMP8(3),TEMP9(3)
 DIMENSION RSVRSV(3),REVREV(3),RMVRMV(3),RSERSE(3),RSMRSM(3),
1REMREM(3),DEVSE(3),DSVSE(3),DMVSM(3),DSVSM(3),DMVEM(3),
2DEMSM(3),DEVEM(3),DEMSE(3),DSMSE(3)
 COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
 RSV3=VMAG(RSV)**3
 REV3=VMAG(REV)**3
 RMV3=VMAG(RMV)**3
 RSE3=VMAG(RSE)**3
 RSM3=VMAG(RSM)**3
 REM3=VMAG(REM)**3
 CALL UNITV(RSV,URSV)
 CALL UNITV(REV,UREV)
 CALL UNITV(RMV,URMV)
 CALL UNITV(RSE,URSE)
 CALL UNITV(RSM,URSM)
 CALL UNITV(REM,UREM)
 DO 1 I=1,3
 RSVRSV(I)=RSV(I)/RSV3
 REVREV(I)=REV(I)/REV3
 RMVRMV(I)=RMV(I)/RMV3
 RSERSE(I)=RSE(I)/RSE3
 RSMRSM(I)=RSM(I)/RSM3
 REMREM(I)=REM(I)/REM3
 DEVSE(I)=REVREV(I)+RSERSE(I)
 DSVSE(I)=RSVRSV(I)-RSERSE(I)
 DMVSM(I)=RMVRMV(I)+RSMRSM(I)
 DSVSM(I)=RSVRSV(I)-RSMRSM(I)
 DMVEM(I)=RMVRMV(I)+REMREM(I)
 DEMSM(I)=REMREM(I)-RSMRSM(I)
 DEVEM(I)=REVREV(I)-REMREM(I)
 DEMSE(I)=REMREM(I)+RSERSE(I)
 DSMSE(I)=RSMRSM(I)-RSERSE(I)
 DO 1 J=1,3
 UMTX(I,J)=0.0
 IF(I.EQ.J) UMTX(I,J)=1.0
1 CONTINUE
 CALL VVT(URSV,SVSV,3)
 CALL VVT(UREV,EVEV,3)
 CALL VVT(URMV,VMVM,3)
 CALL VVT(URSE,SESE,3)
 CALL VVT(URSM,SMSM,3)
 CALL VVT(UREM,EMEM,3)
 DO 2 I=1,3
 DO 2 J=1,3
 SVSV(I,J)=(UMTX(I,J)-3.0*SVSV(I,J))/RSV3
 EVEV(I,J)=(UMTX(I,J)-3.0*EVEV(I,J))/REV3
 VMVM(I,J)=(UMTX(I,J)-3.0*VMVM(I,J))/RMV3
 SESE(I,J)=(UMTX(I,J)-3.0*SESE(I,J))/RSE3
```

```
      SMSM(I,J)=(UMTX(I,J)-3.0*SMSM(I,J))/RSM3
      EMEM(I,J)=(UMTX(I,J)-3.0*EMEM(I,J))/REM3
    2 CONTINUE
      CALL MXV(SVSV,DEVSE,TEMP1,3,3)
      CALL MXV(EVEV,DSVSE,TEMP2,3,3)
      CALL MXV(SVSV,DMVSM,TEMP3,3,3)
      CALL MXV(VMVM,DSVSM,TEMP4,3,3)
      CALL MXV(EVEV,DMVEM,TEMP5,3,3)
      CALL MXV(SESE,DEMSM,TEMP6,3,3)
      CALL MXV(VMVM,DEVEM,TEMP7,3,3)
      CALL MXV(SMSM,DEMSE,TEMP8,3,3)
      CALL MXV(EMEM,DSMSE,TEMP9,3,3)
      DO 3 I=1,3
      DR4RSV(I)=MS*ME*(TEMP1(I)+TEMP2(I))+MS*MM*(TEMP3(I)+TEMP4(I))
     1+ME*MM*(TEMP5(I)-TEMP6(I)+TEMP7(I)+TEMP8(I))
      DR4RSE(I)=-(MS+ME)*MM*TEMP6(I)-MM*MS*TEMP9(I)+MM*ME*TEMP8(I)
      DR4RSM(I)=(MS+MM)*ME*TEMP8(I)+ME*MS*TEMP9(I)-ME*MM*TEMP6(I)
    3 CONTINUE
      CPERR=VMAG(DR4RSV)/24.0
      H=DSQRT(DSQRT(ERRMAX/CPERR))
      IF(TGO.LT.H) H=TGO
      DO 4 I=1,6
      DO 4 J=1,6
      BIGJ(I,J)=0.0
      IF(I.EQ.J) BIGJ(I,J)=1.0
      IF((J-I).EQ.3) BIGJ(I,J)=H
    4 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE CSTEP3(TGO,REV,RMV,REM,H,DR4REV,BIGJ)
      IMPLICIT REAL*8(A-H,M,O-Z)
      DIMENSION REV(3),RMV(3),REM(3),DR4REV(3),BIGJ(6,6),UREV(3),
     1URMV(3),RMVRMV(3),REMREM(3),REVREV(3),DMVEM(3),DEVEM(3),
     2UMTX(3,3),EVEV(3,3),MVMV(3,3),TEMP1(3),TEMP2(3)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      REV3=VMAG(REV)**3
      RMV3=VMAG(RMV)**3
      REM3=VMAG(REM)**3
      CALL UNITV(REV,UREV)
      CALL UNITV(RMV,URMV)
      DO 1 I=1,3
      RMVRMV(I)=RMV(I)/RMV3
      REMREM(I)=REM(I)/REM3
      REVREV(I)=REV(I)/REV3
      DMVEM(I)=RMVRMV(I)+REMREM(I)
      DEVEM(I)=REVREV(I)-REMREM(I)
      DO 1 J=1,3
      UMTX(I,J)=0.
      IF(I.EQ.J) UMTX(I,J)=1.0
    1 CONTINUE
      CALL VVT(UREV,EVEV,3)
      CALL VVT(URMV,MVMV,3)
      DO 2 I=1,3
      DO 2 J=1,3
      EVEV(I,J)=(UMTX(I,J)-3.0*EVEV(I,J))/REV3
    2 MVMV(I,J)=(UMTX(I,J)-3.0*MVMV(I,J))/RMV3
      CALL MXV(EVEV,DMVEM,TEMP1,3,3)
      CALL MXV(MVMV,DEVEM,TEMP2,3,3)
      DO 3 I=1,3
    3 DR4REV(I)=ME*MM*(TEMP1(I)+TEMP2(I))
      CPERR=VMAG(DR4REV)/24.0
      H=DSQRT(DSQRT(ERRMAX/CPERR))
      IF(TGO.LT.H) H=TGO
      DO 4 I=1,6
      DO 4 J=1,6
      BIGJ(I,J)=0.
      IF(I.EQ.J) BIGJ(I,J)=1.0
      IF((J-I).EQ.3) BIGJ(I,J)=H
    4 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DELRV(H,RSV,REV,RMV,RSE,RSM,REM,CRSV,CREV,CRMV,
     1CRSE,CRSM,CREM,DR4RSV,DR4RSE,DR4RSM,RRSV,RVSV,RRSE,RVSE,
     2RRSM,RVSM)
      IMPLICIT REAL*8(A-H,M,O-Z)
      DIMENSION RSV(3),REV(3),RMV(3),RSE(3),RSM(3),REM(3),CRSV(3),
     1CREV(3),CRMV(3),CRSE(3),CRSM(3),CREM(3),DR4RSV(3),DR4RSE(3),
     2DR4RSM(3),RRSV(3),RVSV(3),RRSE(3),RVSE(3),RRSM(3),RVSM(3)
      DIMENSION SSV(3),SEV(3),SMV(3),SSE(3),SSM(3),SEM(3),DDRSV(3),
     1DDRSE(3),DDRSM(3)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      H2=H*H
      H26=H2/6.0
      H23=H2/3.0
      RSV3=VMAG(RSV)**3
      REV3=VMAG(REV)**3
      RMV3=VMAG(RMV)**3
      RSE3=VMAG(RSE)**3
      RSM3=VMAG(RSM)**3
      REM3=VMAG(REM)**3
      CRSV3=VMAG(CRSV)**3
      CREV3=VMAG(CREV)**3
      CRMV3=VMAG(CRMV)**3
      CRSE3=VMAG(CRSE)**3
      CRSM3=VMAG(CRSM)**3
      CREM3=VMAG(CREM)**3
      DO 1 I=1,3
      SSV(I)=CRSV(I)/CRSV3-RSV(I)/RSV3
      SEV(I)=CREV(I)/CREV3-REV(I)/REV3
      SMV(I)=CRMV(I)/CRMV3-RMV(I)/RMV3
      SSE(I)=CRSE(I)/CRSE3-RSE(I)/RSE3
      SSM(I)=CRSM(I)/CRSM3-RSM(I)/RSM3
      SEM(I)=CREM(I)/CREM3-REM(I)/REM3
      DDRSV(I)=MS*SSV(I)+ME*(SSE(I)+SEV(I))+MM*(SSM(I)+SMV(I))
      DDRSE(I)=(MS+ME)*SSE(I)+MM*(SSM(I)-SEM(I))
      DDRSM(I)=(MS+MM)*SSM(I)+ME*(SSE(I)+SEM(I))
      RRSV(I)=H2*(DR4RSV(I)*H23+DDRSV(I))/20.0
      RVSV(I)=H*(DR4RSV(I)*H26+DDRSV(I))/4.0
      RRSE(I)=H2*(DR4RSE(I)*H23+DDRSE(I))/20.0
      RVSE(I)=H*(DR4RSE(I)*H26+DDRSE(I))/4.0
      RRSM(I)=H2*(DR4RSM(I)*H23+DDRSM(I))/20.0
      RVSM(I)=H*(DR4RSM(I)*H26+DDRSM(I))/4.0
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DELRV3(H,REV,RMV,CREV,CRMV,DR4REV,RREV,RVEV)
      IMPLICIT REAL*8(A-H,M,O-Z)
      DIMENSION REV(3),RMV(3),CREV(3),CRMV(3),DR4REV(3),RREV(3),
     1RVEV(3),SEV(3),SMV(3),DDREV(3)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      H2=H*H
      H26=H2/6.0
      H23=H2/3.0
      REV3=VMAG(REV)**3
      CREV3=VMAG(CREV)**3
      RMV3=VMAG(RMV)**3
      CRMV3=VMAG(CRMV)**3
      DO 1 I=1,3
      SEV(I)=CREV(I)/CREV3-REV(I)/REV3
      SMV(I)=CRMV(I)/CRMV3-RMV(I)/RMV3
      DDREV(I)=ME*SEV(I)+MM*SMV(I)
      RREV(I)=H2*(DR4REV(I)*H23+DDREV(I))/20.0
    1 RVEV(I)=H*(DR4REV(I)*H26+DDREV(I))/4.0
      RETURN
      END
```

```
      SUBROUTINE COMIC(REVMAG,VEVMAG,LON,THE,OINC,OBL,RSEO,VSEO,
     1REVO,VEVO,RSVO,VSVO,VSVI)
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION RSEO(3),VSEO(3),REVO(3),VEVO(3),RSVO(3),VSVO(3),
     1VSVI(3),TEMP(3),VEVOP(3)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/TRIG/CLON,SLON,CTHE,STHE,CINC,SINC,COBL,SOBL
      IF(ITER.GT.0) GO TO 1
      VCIR=DSQRT(ME/REVMAG)
      CINC=DCOS(OINC)
      SINC=DSIN(OINC)
      COBL=DCOS(OBL)
      SOBL=DSIN(OBL)
    1 CLON=DCOS(LON)
      SLON=DSIN(LON)
      CTHE=DCOS(THE)
      STHE=DSIN(THE)
      REVO(1)=REVMAG*(CLON*CTHE-SLON*CINC*STHE)
      REVO(2)=REVMAG*(COBL*(SLON*CTHE+CLON*CINC*STHE)
     1          +SOBL*SINC*STHE)
      REVO(3)=REVMAG*(-SOBL*(SLON*CTHE+CLON*CINC*STHE)
     1          +COBL*SINC*STHE)
      VEVOP(1)=VEVMAG*(-CLON*STHE-SLON*CINC*CTHE)
      VEVOP(2)=VEVMAG*(COBL*(-SLON*STHE+CLON*CINC*CTHE)
     1          +SOBL*SINC*CTHE)
      VEVOP(3)=VEVMAG*(-SOBL*(-SLON*STHE+CLON*CINC*CTHE)
     1          +COBL*SINC*CTHE)
      CALL UNITV(VEVOP,TEMP)
      DO 2 I=1,3
      VEVO(I)=VCIR*TEMP(I)
      VSVO(I)=VSEO(I)+VEVO(I)
      RSVO(I)=RSEO(I)+REVO(I)
    2 VSVI(I)=VSEO(I)+VEVOP(I)
      RETURN
      END
```

```
      SUBROUTINE COMIC3(REVMAG,VEVMAG,LON,THE,OINC,REVO,VEVO,VEVOP)
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION REVO(3),VEVO(3),VEVOP(3),TEMP(3)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      COMMON/TRIG3/CLON,SLON,CTHE,STHE,CINC,SINC
      IF(ITER.GT.0) GO TO 1
      VCIR=DSQRT(ME/REVMAG)
      CINC=DCOS(OINC)
      SINC=DSIN(OINC)
    1 CLON=DCOS(LON)
      SLON=DSIN(LON)
      CTHE=DCOS(THE)
      STHE=DSIN(THE)
      REVO(1)=REVMAG*(CLON*CTHE-SLON*CINC*STHE)
      REVO(2)=REVMAG*(SLON*CTHE+CLON*CINC*STHE)
      REVO(3)=REVMAG*SINC*STHE
      VEVOP(1)=VEVMAG*(-CLON*STHE-SLON*CINC*CTHE)
      VEVOP(2)=VEVMAG*(-SLON*STHE+CLON*CINC*CTHE)
      VEVOP(3)=VEVMAG*SINC*CTHE
      CALL UNITV(VEVOP,TEMP)
      DO 2 I=1,3
    2 VEVO(I)=VCIR*TEMP(I)
      WRITE(6,100)REVO,VEVO
      WRITE(6,101)VEVOP
  100 FORMAT(1H0,T8,'REVO',T68,'VEVO'/1H ,1P6D20.11)
  101 FORMAT(1H ,T8,'VEVOP'/1H ,1P3D20.11)
      RETURN
      END
```

```
      SUBROUTINE COMFG(TSTART,TEND,REVMAG,XD,OINC,OBL,
     1RSEO,VSEO,RSMO,VSMO,FD,TESTRD,GD,TSID,LTD,S11,S12,S21,S22,
     2UVI,UVF)
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION RSEO(3),VSEO(3),RSMO(3),VSMO(3),REVO(3),VEVO(3),
     1RSVO(3),VSVO(3),VSVI(3),RSVTAR(3),VSVTAR(3),REMF(3),VEMF(3),
     2PVO(6),RSVF(3),VSVF(3),RSEF(3),VSEF(3),RSMF(3),VSMF(3),
     3S11(3,3),S12(3,3),S21(3,3),S22(3,3),TSID(3),DVI(3),UVI(3),
     4DVF(3),UVF(3),DRODX(3,3),DVODX(3,3),TEMP1(3,3),TEMP2(3,3),
     5GD(3),LTD(3,3),XD(3),REVF(3),VEVF(3),RMVF(3),VMVF(3)
      DIMENSION DUVI(3),DUM(3),S12I(3,3)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/TRIG/CLON,SLON,CTHE,STHE,CINC,SINC,COBL,SOBL
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/TARG/AY,AZ,ATAR,RSVTAR,VSVTAR
      VEVMAG=XD(1)
      LON=XD(2)
      THE=XD(3)
      VEVMPS=VEVMAG/UVELM
      LOND=LON/DTR
      THED=THE/DTR
      WRITE(6,108)
      WRITE(6,101)XD,VEVMPS,LOND,THED
      CALL COMIC(REVMAG,VEVMAG,LON,THE,OINC,OBL,RSEO,VSEO,
     1REVO,VEVO,RSVO,VSVO,VSVI)
      CALL FOURBY(TSTART,TEND,RSVO,VSVI,RSEO,VSEO,RSMO,VSMO,
     1PVO,RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,S11,S12,S21,S22)
      CALL RVEMV(RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,REVF,VEVF,RMVF,VMVF,
     1REMF,VEMF)
      WRITE(6,102)RSVF,VSVF
      IF(ITER.GT.0) GO TO 11
      IF(ITAR.GT.0) GO TO 11
      CALL CTAR(RSEF,VSEF,RSMF,VSMF,REMF,VEMF,AY,AZ,ATAR,RSVTAR,
     1VSVTAR)
   11 DO 2 I=1,3
      TSID(I)=RSVF(I)-RSVTAR(I)
      DVI(I)=VSVI(I)-VSVO(I)
    2 DVF(I)=VSVTAR(I)-VSVF(I)
      TESTRD=VMAG(TSID)
      DVIMAG=VMAG(DVI)
      DVFMAG=VMAG(DVF)
      DVIMPS=DVIMAG/UVELM
      DVFMPS=DVFMAG/UVELM
      CALL UNITV(DVI,UVI)
      CALL UNITV(DVF,UVF)
      FD=DVFMAG
      CALL MXV(S11,UVI,DUM,3,3)
      DO 21 I=1,3
   21 DUM(I)=UVF(I)-DUM(I)
      CALL INVERT(S12,S12I)
      CALL MXV(S12I,DUM,DUVI,3,3)
      WRITE(6,103)DVI,UVI
      WRITE(6,104)DVF,UVF
      WRITE(6,105)DUVI,TSID
      WRITE(6,106)DVIMAG,DVFMAG,DVIMPS,DVFMPS,FD,TESTRD
      DRODX(1,1)=0.
      DRODX(1,2)=REVMAG*(-SLON*CTHE-CLON*CINC*STHE)
```

```
      DRODX(1,3)=REVMAG*(-CLON*STHE-SLON*CINC*CTHE)
      DRODX(2,1)=0.
      DRODX(2,2)=REVMAG*COBL*(CLON*CTHE-SLON*CINC*STHE)
      DRODX(2,3)=REVMAG*(COBL*(-SLON*STHE+CLON*CINC*CTHE)
     1           +SOBL*SINC*CTHE)
      DRODX(3,1)=0.
      DRODX(3,2)=-REVMAG*SOBL*(CLON*CTHE-SLON*CINC*STHE)
      DRODX(3,3)=REVMAG*(-SOBL*(-SLON*STHE+CLON*CINC*CTHE)
     1           +COBL*SINC*CTHE)
      DVODX(1,1)=-CLON*STHE-SLON*CINC*CTHE
      DVODX(1,2)=VEVMAG*(SLON*STHE-CLON*CINC*CTHE)
      DVODX(1,3)=VEVMAG*(-CLON*CTHE+SLON*CINC*STHE)
      DVODX(2,1)=COBL*(-SLON*STHE+CLON*CINC*CTHE)
     1           +SOBL*SINC*CTHE
      DVODX(2,2)=VEVMAG*COBL*(-CLON*STHE-SLON*CINC*CTHE)
      DVODX(2,3)=VEVMAG*(COBL*(-SLON*CTHE-CLON*CINC*STHE)
     1           -SOBL*SINC*STHE)
      DVODX(3,1)=-SOBL*(-SLON*STHE+CLON*CINC*CTHE)
     1           +COBL*SINC*CTHE
      DVODX(3,2)=-VEVMAG*SOBL*(-CLON*STHE-SLON*CINC*CTHE)
      DVODX(3,3)=VEVMAG*(-SOBL*(-SLON*CTHE-CLON*CINC*STHE)
     1           -COBL*SINC*STHE)
      CALL MXM(S21,DRODX,TEMP1,3,3,3)
      CALL MXM(S22,DVODX,TEMP2,3,3,3)
      DO 3 I=1,3
      DO 3 J=1,3
    3 TEMP1(I,J)=TEMP1(I,J)+TEMP2(I,J)
      CALL MTRANS(TEMP1,TEMP2,3,3)
      CALL MXV(TEMP2,UVF,GD,3,3)
      DO 4 I=1,3
    4 GD(I)=-GD(I)
      WRITE(6,107)GD
      CALL MXM(S11,DRODX,TEMP1,3,3,3)
      CALL MXM(S12,DVODX,TEMP2,3,3,3)
      DO 5 I=1,3
      DO 5 J=1,3
      LTD(I,J)=TEMP1(I,J)+TEMP2(I,J)
    5 CONTINUE
  101 FORMAT(1H0,T8,'XD',T68,'VEVMPS',T88,'LOND',T108,'THED'/1H ,
     11P6D20.11)
  102 FORMAT(1H ,T8,'RSVF',T68,'VSVF'/1H ,1P6D20.11)
  103 FORMAT(1H ,T8,'DVI',T68,'UVI'/1H ,1P6D20.11)
  104 FORMAT(1H ,T8,'DVF',T68,'UVF'/1H ,1P6D20.11)
  105 FORMAT(1H ,T8,'DUVI',T68,'TSID'/1H ,1P6D20.11)
  106 FORMAT(1H ,T8,'DVIMAG',T28,'DVFMAG',T48,'DVIMPS',T68,'DVFMPS',
     1T88,'FD',T108,'TESTRD'/1H ,1P6D20.11)
  107 FORMAT(1H ,T8,'GD'/1H ,1P3D20.11)
  108 FORMAT(1H0,T8,'--------------------')
      RETURN
      END
```

```
      SUBROUTINE COMFG3(TSTART,TEND,REVMAG,XD,OINC,REMO,
     1VEMO,FD,TESTRD,GD,TSID,LTD,S11,S12,S21,S22,UVI,UVF)
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION REMO(3),VEMO(3),REVO(3),VEVO(3),VEVOP(3),REVTAR(3),
     1VEVTAR(3),PVO(6),REVF(3),VEVF(3),REMF(3),VEMF(3),S11(3,3),XD(3),
     2S12(3,3),S21(3,3),S22(3,3),TSID(3),DVI(2),UVI(3),DVF(3),UVF(3),
     3DRODX(3,3),DVODX(3,3),TEMP1(3,3),TEMP2(3,3),GD(3),LTD(3,3)
      DIMENSION DUVI(3),DUM(3),S12I(3,3)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      COMMON/TRIG3/CLON,SLON,CTHE,STHE,CINC,SINC
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/TARG/AY,AZ,ATAR,REVTAR,VEVTAR
      VEVMAG=XD(1)
      LON=XD(2)
      THE=XD(3)
      VEVMPS=VEVMAG/UVELM
      LOND=LON/DTR
      THED=THE/DTR
      WRITE(6,108)
      WRITE(6,101)XD,VEVMPS,LOND,THED
      CALL COMIC3(REVMAG,VEVMAG,LON,THE,OINC,REVO,VEVO,VEVOP)
      CALL THRBDY(TSTART,TEND,REVO,VEVOP,REMO,VEMO,PVO,REVF,VEVF,
     1REMF,VEMF,S11,S12,S21,S22)
      WRITE(6,102)REVF,VEVF
      IF(ITER.GT.0) GO TO 11
      IF(ITAR.GT.0) GO TO 11
      CALL CTAR3(REMF,VEMF,AY,AZ,ATAR,REVTAR,VEVTAR)
   11 DO 2 I=1,3
      TSID(I)=REVF(I)-REVTAR(I)
      DVI(I)=VEVOP(I)-VEVO(I)
    2 DVF(I)=VEVTAR(I)-VEVF(I)
      TESTRD=VMAG(TSID)
      DVIMAG=VMAG(DVI)
      DVFMAG=VMAG(DVF)
      DVIMPS=DVIMAG/UVELM
      DVFMPS=DVFMAG/UVELM
      CALL UNITV(DVI,UVI)
      CALL UNITV(DVF,UVF)
      FD=DVFMAG
      CALL MXV(S11,UVI,DUM,3,3)
      DO 21 I=1,3
   21 DUM(I)=UVF(I)-DUM(I)
      CALL INVERT(S12,S12I)
      CALL MXV(S12I,DUM,DUVI,3,3)
      WRITE(6,103)DVI,UVI
      WRITE(6,104)DVF,UVF
      WRITE(6,105)DUVI,TSID
      WRITE(6,106)DVIMAG,DVFMAG,DVIMPS,DVFMPS,FD,TESTRD
      DRODX(1,1)=0.
      DRODX(1,2)=REVMAG*(-SLON*CTHE-CLON*CINC*STHE)
      DRODX(1,3)=REVMAG*(-CLON*STHE-SLON*CINC*CTHE)
      DRODX(2,1)=0.
      DRODX(2,2)=REVMAG*(CLON*CTHE-SLON*CINC*STHE)
      DRODX(2,3)=REVMAG*(-SLON*STHE+CLON*CINC*CTHE)
      DRODX(3,1)=0.
      DRODX(3,2)=0.
      DRODX(3,3)=REVMAG*SINC*CTHE
```

```
      DVODX(1,1)=-CLON*STHE-SLON*CINC*CTHE
      DVODX(1,2)=VEVMAG*(SLON*STHE-CLON*CINC*CTHE)
      DVODX(1,3)=VEVMAG*(-CLON*CTHE+SLON*CINC*STHE)
      DVODX(2,1)=-SLON*STHE+CLON*CINC*CTHE
      DVODX(2,2)=VEVMAG*(-CLON*STHE-SLON*CINC*CTHE)
      DVODX(2,3)=VEVMAG*(-SLON*CTHE-CLON*CINC*STHE)
      DVODX(3,1)=SINC*CTHE
      DVODX(3,2)=0.
      DVODX(3,3)=-VEVMAG*SINC*STHE
      CALL MXM(S21,DRODX,TEMP1,3,3,3)
      CALL MXM(S22,DVODX,TEMP2,3,3,3)
      DO 3 I=1,3
      DO 3 J=1,3
    3 TEMP1(I,J)=TEMP1(I,J)+TEMP2(I,J)
      CALL MTRANS(TEMP1,TEMP2,3,3)
      CALL MXV(TEMP2,UVF,GD,3,3)
      DO 4 I=1,3
    4 GD(I)=-GD(I)
      WRITE(6,107)GD
      CALL MXM(S11,DRODX,TEMP1,3,3,3)
      CALL MXM(S12,DVODX,TEMP2,3,3,3)
      DO 5 I=1,3
      DO 5 J=1,3
      LTD(I,J)=TEMP1(I,J)+TEMP2(I,J)
    5 CONTINUE
  100 FORMAT(1H0,T8,'COMPUTED TARGET'/1H0,T8,'REVTAR',T68,'VEVTAR'/
     11H ,1P6D20.11)
  101 FORMAT(1H0,T8,'XD',T68,'VEVMPS',T88,'LOND',T108,'THED'/1H ,
     11P6D20.11)
  102 FORMAT(1H ,T8,'REVF',T68,'VEVF'/1H ,1P6D20.11)
  103 FORMAT(1H ,T8,'DVI',T68,'UVI'/1H ,1P6D20.11)
  104 FORMAT(1H ,T8,'DVF',T68,'UVF'/1H ,1P6D20.11)
  105 FORMAT(1H ,T8,'DUVI',T68,'TSID'/1H ,1P6D20.11)
  106 FORMAT(1H ,T8,'DVIMAG',T28,'DVFMAG',T48,'DVIMPS',T68,'DVFMPS',
     1T88,'FD',T108,'TESTRD'/1H ,1P6D20.11)
  107 FORMAT(1H ,T8,'GD'/1H ,1P3D20.11)
  108 FORMAT(1H0,T8,'-------------------')
      RETURN
      END
```

```
      SUBROUTINE COMF(TSTART,TM,TEND,RSVO,VSVO,VSVI,RSEO,VSEO,RSMO,
     1VSMO,ERRMIN,ILINC,KNRSAV,ITERD,ITLMAX,RSVMD,VSVMPD,RSVTAR,
     2VSVTAR,S11D,S12D,RSVM,VSVMM,VSVMP,DV,UVI,UVM,UVF,SMI11,SMI12,
     3SMI21,SMI22,SFM11,SFM12,SFM21,SFM22)
      IMPLICIT REAL*8(A-H,K-M,O-Z)
C     EXTRAPOLATE STATES TO TM AND SOLVE LAMBERT PROBLEM FROM TM TO
C     TEND
      DIMENSION RSVO(3),VSVO(3),VSVI(3),RSEO(3),VSEO(3),RSMO(3),
     1VSMO(3),PVO(6),RSVM(3),VSVMM(3),RSEM(3),VSEM(3),RSMM(3),
     2VSMM(3),SMI11(3,3),SMI12(3,3),SMI21(3,3),SMI22(3,3),SFM11(3,3),
     3SFM12(3,3),SFM21(3,3),SFM22(3,3),S11D(3,3),S12D(3,3),
     4RSVMX(3),VSVMPX(3),DRM(3),TEMP1(3,3),DUM(3),
     5RSVF(3),VSVF(3),RSEF(3),VSEF(3),RSMF(3),VSMF(3),VSVMP(3),
     6DVI(3),DVM(3),DVF(3),UVI(3),UVM(3),UVF(3),DVMPX(3)
      DIMENSION RSVTAR(3),VSVTAR(3),RSVMD(3),VSVMPD(3)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      KNR=KNRSAV
      WRITE(6,100)
      WRITE(6,101)VSVI,TM
C     ADVANCE STATES FROM TSTART TO TM
      CALL FOURBY(TSTART,TM,RSVO,VSVI,RSEO,VSEO,RSMO,VSMO,
     1PVO,RSVM,VSVMM,RSEM,VSEM,RSMM,VSMM,SMI11,SMI12,SMI21,SMI22)
      IF(ITERD.GT.0) GO TO 3
      DO 2 I=1,3
      VSVMPX(I)=VSVMP(I)
    2 RSVMX(I)=RSVM(I)
      KNR=KNRSAV
      CALL LAMB(TM,TEND,RSVMX,VSVMPX,RSEM,VSEM,RSMM,VSMM,KNR,ITLMAX,
     1ERRMIN,RSVTAR,RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,SFM11,SFM12,SFM21,
     2SFM22)
      GO TO 71
C     INCREMENTAL SOLUTION OF SECOND LEG LAMBERT PROBLEM
    3 DO 4 I=1,3
      VSVMPX(I)=VSVMPD(I)
      RSVMX(I)=RSVMD(I)
      DRM(I)=(RSVM(I)-RSVMD(I))/ILINC
      DO 4 J=1,3
      SFM11(I,J)=S11D(I,J)
    4 SFM12(I,J)=S12D(I,J)
      WRITE(6,102)RSVMD,RSVM,DRM,ILINC
      WRITE(6,106)VSVMPD
      DO 7 ITERL=1,ILINC
      CALL INVERT(SFM12,TEMP1)
      CALL MXV(SFM11,DRM,DUM,3,3)
      CALL MXV(TEMP1,DUM,DVMPX,3,3)
      DO 5 I=1,3
      DVMPX(I)=-DVMPX(I)
      RSVMX(I)=RSVMX(I)+DRM(I)
    5 VSVMPX(I)=VSVMPX(I)+DVMPX(I)
      WRITE(6,103)ITERL,DVMPX,RSVMX,VSVMPX
      KNR=KNRSAV
    6 CALL LAMB(TM,TEND,RSVMX,VSVMPX,RSEM,VSEM,RSMM,VSMM,
     1KNR,ITLMAX,ERRMIN,RSVTAR,RSVF,VSVF,RSEF,VSEF,RSMF,VSMF,SFM11,
     2SFM12,SFM21,SFM22)
    7 CONTINUE
      SAVE VSVMP AND COMPUTE DV
   71 DO 8 I=1,3
```

```
      VSVMP(I)=VSVMPX(I)
      DVI(I)=VSVI(I)-VSVO(I)
      DVM(I)=VSVMP(I)-VSVMM(I)
    8 DVF(I)=VSVTAR(I)-VSVF(I)
      DVIMAG=VMAG(DVI)
      DVMMAG=VMAG(DVM)
      DVFMAG=VMAG(DVF)
      DV=DVIMAG+DVMMAG+DVFMAG
      DVIMPS=DVIMAG/UVELM
      DVMMPS=DVMMAG/UVELM
      DVFMPS=DVFMAG/UVELM
      DVMPS=DV/UVELM
      CALL UNITV(DVI,UVI)
      CALL UNITV(DVM,UVM)
      CALL UNITV(DVF,UVF)
      WRITE(6,104)DVI,UVI,DVM,UVM,DVF,UVF,DVIMAG,DVMMAG,DVFMAG,
     1DV,DVIMPS,DVMMPS,DVFMPS,DVMPS
  100 FORMAT(1H0,40X,'FIRST LEG TRAJECTORY')
  101 FORMAT(1H0,T8,'VSVI',T68,'TM'/1H ,1P4D20.11)
  102 FORMAT(1H0,T8,'SOLVE SECOND LEG LAMBERT PROBLEM IN INCREMENTS'
     1/1H0,T8,'RSVMD',T68,'RSVM'/1H ,1P6D20.11/1H ,T8,'DRM',T68,
     2'ILINC'/1H ,1P3D20.11,I10)
  103 FORMAT(1H1,T8,'ITERL',T28,'DVMPX'/1H ,I10,10X,1P3D20.11/1H ,T8,
     1'RSVMX',T68,'VSVMPX'/1H ,1P6D20.11)
  104 FORMAT(1H0,T8,'DVI',T68,'UVI'/1H ,1P6D20.11/1H ,T8,'DVM',T68,
     1'UVM'/1H ,1P6D20.11/1H ,T8,'DVF',T68,'UVF'/1H ,1P6D20.11/1H ,
     2T8,'DVIMAG',T28,'DVMMAG',T48,'DVFMAG',T68,'DV'/1H ,1P4D20.11/
     31H ,T8,'DVIMPS',T28,'DVMMPS',T48,'DVFMPS',T68,'DVMPS'/1H ,
     41P4D20.11)
  106 FORMAT(1H ,T8,'VSVMPD'/1H ,1P3D20.11)
      RETURN
      END
```

```
      SUBROUTINE COMF3(TSTART,TM,TEND,REVO,VEVO,VEVOP,REMO,VEMO,
     1ERRMIN,ILINC,KNRSAV,ITERD,ITLMAX,REVMD,VEVMPD,REVTAR,VEVTAR,
     2S11D,S12D,REVM,VEVMM,VEVMP,DV,UVI,UVM,UVF,SMI11,SMI12,SMI21,
     3SMI22,SFM11,SFM12,SFM21,SFM22)
      IMPLICIT REAL*8(A-H,K-M,O-Z)
C     EXTRAPOLATE STATES TO TM AND SOLVE LAMBERT PROBLEM FROM TM TO
C     TEND
      DIMENSION REVO(3),VEVO(3),VEVOP(3),REMO(3),VEMO(3),PVO(6),
     1REVM(3),VEVMM(3),VEVMP(3),REMM(3),VEMM(3),SMI11(3,3),SMI12(3,3),
     2SMI21(3,3),SMI22(3,3),SFM11(3,3),SFM12(3,3),SFM21(3,3),
     3SFM22(3,3),S11D(3,3),S12D(3,3),REVMX(3),VEVMPX(3),DRM(3),
     4REVF(3),VEVF(3),REMF(3),VEMF(3),DVI(3),DVM(3),DVF(3),
     5UVI(3),UVM(3),UVF(3),DVMPX(3),REVTAR(3),VEVTAR(3),REVMD(3),
     6VEVMPD(3),TEMP1(3,3),DUM(3)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      WRITE(6,100)
      WRITE(6,101)VEVOP,TM
C     ADVANCE STATES FROM TSTART TO TM
      CALL THRBDY(TSTART,TM,REVO,VEVOP,REMO,VEMO,PVO,REVM,VEVMM,
     1REMM,VEMM,SMI11,SMI12,SMI21,SMI22)
      IF(ITERD.GT.0)GO TO 3
      DO 2 I=1,3
      VEVMPX(I)=VEVMP(I)
    2 REVMX(I)=REVM(I)
      KNR=KNRSAV
      CALL LAMB3(TM,TEND,REVMX,VEVMPX,REMM,VEMM,KNR,ITLMAX,ERRMIN,
     1REVTAR,REVF,VEVF,REMF,VEMF,SFM11,SFM12,SFM21,SFM22)
      GO TO 71
C     INCREMENTAL SOLUTION OF SECOND LEG LAMBERT PROBLEM
    3 DO 4 I=1,3
      VEVMPX(I)=VEVMPD(I)
      REVMX(I)=REVMD(I)
      DRM(I)=(REVM(I)-REVMD(I))/ILINC
      DO 4 J=1,3
      SFM11(I,J)=S11D(I,J)
    4 SFM12(I,J)=S12D(I,J)
      WRITE(6,102)REVMD,REVM,DRM,ILINC
      WRITE(6,106)VEVMPD
      DO 7 ITERL=1,ILINC
      CALL INVERT(SFM12,TEMP1)
      CALL MXV(SFM11,DRM,DUM,3,3)
      CALL MXV(TEMP1,DUM,DVMPX,3,3)
      DO 5 I=1,3
      DVMPX(I)=-DVMPX(I)
      REVMX(I)=REVMX(I)+DRM(I)
    5 VEVMPX(I)=VEVMPX(I)+DVMPX(I)
      WRITE(6,103)ITERL,DVMPX,REVMX,VEVMPX
      KNR=KNRSAV
    6 CALL LAMB3(TM,TEND,REVMX,VEVMPX,REMM,VEMM,KNR,ITLMAX,ERRMIN,
     1REVTAR,REVF,VEVF,REMF,VEMF,SFM11,SFM12,SFM21,SFM22)
    7 CONTINUE
C     SAVE VEVMP AND COMPUTE DV
   71 DO 8 I=1,3
      VEVMP(I)=VEVMPX(I)
      DVI(I)=VEVOP(I)-VEVO(I)
      DVM(I)=VEVMP(I)-VEVMM(I)
    8 DVF(I)=VEVTAR(I)-VEVF(I)
```

```
      DVIMAG=VMAG(DVI)
      DVMMAG=VMAG(DVM)
      DVFMAG=VMAG(DVF)
      DV=DVIMAG+DVMMAG+DVFMAG
      DVIMPS=DVIMAG/UVELM
      DVMMPS=DVMMAG/UVELM
      DVFMPS=DVFMAG/UVELM
      DVMPS=DVMAG/UVELM
      CALL UNITV(DVI,UVI)
      CALL UNITV(DVM,UVM)
      CALL UNITV(DVF,UVF)
      WRITE(6,104)DVI,UVI,DVM,UVM,DVF,UVF,DVIMAG,DVMMAG,DVFMAG,
     1DV,DVIMPS,DVMMPS,DVFMPS,DVMPS
100 FORMAT(1H0,40X,'FIRST LEG TRAJECTORY')
101 FORMAT(1H0,T8,'VEVOP',T68,'TM'/1H ,1P4D20.11)
102 FORMAT(1H0,T8,'SOLVE SECOND LEG LAMBERT PROBLEM IN INCREMENTS'
     1/1H0,T8,'REVMD',T68,'REVM'/1H ,1P6D20.11/1H ,T8,'DRM',T68,
     2'ILINC'/1H ,1P3D20.11,I10)
103 FORMAT(1H1,T8,'ITERL',T28,'DVMPX'/1H ,I10,10X,1P3D20.11/1H ,T8,
     1'REVMX',T68,'VEVMPX'/1H ,1P6D20.11)
104 FORMAT(1H0,T8,'DVI',T68,'UVI'/1H ,1P6D20.11/1H ,T8,'DVM',T68,
     1'UVM'/1H ,1P6D20.11/1H ,T8,'DVF',T68,'UVF'/1H ,1P6D20.11/1H ,
     2T8,'DVIMAG',T28,'DVMMAG',T48,'DVFMAG',T68,'DV'/1H ,1P4D20.11/
     31H ,T8,'DVIMPS',T28,'DVMMPS',T48,'DVFMPS',T68,'DVMPS'/1H ,
     41P4D20.11)
106 FORMAT(1H ,T8,'VEVMPD'/1H ,1P3D20.11)
      RETURN
      END
```

```
      SUBROUTINE COMG(SMI11,SMI12,SMI21,SMI22,SFM11,SFM12,VTMP,
     1VTMM,UVI,UVM,UVF,DUVI,DUVMM,DUVMP,G)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION SMI11(3,3),SMI12(3,3),SMI21(3,3),SMI22(3,3),
     1SFM11(3,3),SFM12(3,3),VTMP(3),VTMM(3),UVI(3),UVM(3),UVF(3),
     2G(4),SMI12I(3,3),TEMP1(3,3),DUM1(3),DUM2(3),DUM3(3),
     3SFM12I(3,3),DUVI(3),DUVMM(3),DUVMP(3),SMI12T(3,3),GVI(3),DVM(3)
      CALL INVERT(SMI12,SMI12I)
      CALL MXV(SMI11,UVI,DUM3,3,3)
      DO 1 I=1,3
    1 DUM3(I)=UVM(I)-DUM3(I)
      CALL MXV(SMI12I,DUM3,DUVI,3,3)
      CALL MXV(SMI22,DUVI,DUM2,3,3)
      CALL MXV(SMI21,UVI,DUM1,3,3)
      DO 2 I=1,3
    2 DUVMM(I)=DUM1(I)+DUM2(I)
      CALL INVERT(SFM12,SFM12I)
      CALL MXV(SFM11,UVM,DUM1,3,3)
      DO 3 I=1,3
    3 DUM1(I)=UVF(I)-DUM1(I)
      CALL MXV(SFM12I,DUM1,DUVMP,3,3)
      PVMMAG=DOT(DUVMM,UVM,3)
      PVPMAG=DOT(DUVMP,UVM,3)
      CALL MTRANS(SMI12,SMI12T,3,3)
      DO 4 I=1,3
    4 DUM3(I)=DUVMP(I)-DUVMM(I)
      CALL MXV(SMI12T,DUM3,GVI,3,3)
      DO 5 I=1,3
      G(I)=GVI(I)
    5 DVM(I)=VTMP(I)-VTMM(I)
      G(4)=-DOT(DUVMP,DVM,3)
      WRITE(6,100)DUVI,PVMMAG,PVPMAG
      WRITE(6,101)DUVMM,DUVMP
      WRITE(6,102)G
  100 FORMAT(1H ,T8,'DUVI',T68,'PVMMAG',T88,'PVPMAG'/1H ,1P5D20.11)
  101 FORMAT(1H ,T8,'DUVMM',T68,'DUVMP'/1H ,1P6D20.11)
  102 FORMAT(1H ,T8,'G'/1H ,1P4D20.11)
      RETURN
      END
```

```
      SUBROUTINE CTAR(RSEF,VSEF,RSMF,VSMF,REMF,VEMF,AY,AZ,ATAR,RSVTAR,
     1VSVTAR)
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION RSEF(3),VSEF(3),REMF(3),VEMF(3),RSVTAR(3),VSVTAR(3),
     1RSL1(3),VSL1(3),UXLS(3),TEMP(3),UZLS(3),UYLS(3),CLS(3,3),
     2CSL(3,3),RLTARL(3),VLTARL(3),RLTAR(3),TEMP1(3),OMGSL(3)
      DIMENSION RSMF(3),VSMF(3)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      MEM=MM/(ME+MM)
      WRITE(6,100)
      DO 1 I=1,3
      RSL1(I)=(1.-GL1)*(RSEF(I)+MEM*REMF(I))
    1 VSL1(I)=(1.-GL1)*(VSEF(I)+MEM*VEMF(I))
      IF(AY.NE.0.) GO TO 11
      IF(AZ.NE.0.) GO TO 11
      DO 12 I=1,3
      RSVTAR(I)=RSL1(I)
   12 VSVTAR(I)=VSL1(I)
      GO TO 5
   11 CALL UNITV(RSL1,UXLS)
      CALL VXV(RSEF,VSEF,TEMP)
      CALL VXV(RSMF,VSMF,TEMP1)
      DO 13 I=1,3
   13 TEMP(I)=ME*TEMP(I)+MM*TEMP1(I)
      CALL UNITV(TEMP,UZLS)
      CALL VXV(UZLS,UXLS,UYLS)
      DO 2 J=1,3
      CLS(1,J)=UXLS(J)
      CLS(2,J)=UYLS(J)
    2 CLS(3,J)=UZLS(J)
      CALL MTRANS(CLS,CSL,3,3)
      MU=(ME+MM)/(MS+ME+MM)
      BL=(1.-MU)/(1.-GL1)**3+MU/GL1**3
      OMEGAN=DSQRT(1.-BL/2.+DSQRT((3.*BL/2.)**2-2.*BL))
      KTAR=2.*OMEGAN/(OMEGAN**2+2.*BL+1.)
      CATAR=DCOS(ATAR)
      SATAR=DSIN(ATAR)
      RLTARL(1)=KTAR*AY*SATAR
      RLTARL(2)=AY*CATAR
      RLTARL(3)=AZ*SATAR
      VLTARL(1)=KTAR*OMEGAN*AY*CATAR
      VLTARL(2)=-OMEGAN*AY*SATAR
      VLTARL(3)=OMEGAN*AZ*CATAR
      WRITE(6,101)RLTARL,VLTARL
      CALL MXV(CSL,RLTARL,RLTAR,3,3)
      RMAG=VMAG(RSL1)
      VY=DOT(UYLS,VSL1,3)
      DO 3 I=1,3
    3 OMGSL(I)=VY*UZLS(I)/RMAG
      CALL VXV(OMGSL,RLTAR,TEMP)
      CALL MXV(CSL,VLTARL,TEMP1,3,3)
      DO 4 I=1,3
      RSVTAR(I)=RSL1(I)+RLTAR(I)
    4 VSVTAR(I)=VSL1(I)+TEMP1(I)+TEMP(I)
    5 CONTINUE
      WRITE(6,102)RSVTAR,VSVTAR
```

```
      WRITE(6,103)
100 FORMAT(1H0,T8,'COMPUTED TARGET')
101 FORMAT(1H0,T8,'RLTARL',T68,'VLTARL'/1H ,1P6D20.11)
102 FORMAT(1H ,T8,'RSVTAR',T68,'VSVTAR'/1H ,1P6D20.11)
103 FORMAT(1H0)
      RETURN
      END
```

```
      SUBROUTINE CTAR3(REMF,VEMF,AY,AZ,ATAR,REVTAR,VEVTAR)
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION REMF(3),VEMF(3),REVTAR(3),VEVTAR(3),REL(3),VEL(3),
     1UXLE(3),TEMP(3),UZLE(3),UYLE(3),CLE(3,3),CEL(3,3),RLTARL(3),
     2VLTARL(3),RLTAR(3),TEMP1(3),OMGEL(3)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      WRITE(6,100)
      DO 1 I=1,3
      REL(I)=(1.-GAMMA)*REMF(I)
    1 VEL(I)=(1.-GAMMA)*VEMF(I)
      IF(AY.NE.O.) GO TO 11
      IF(AZ.NE.O.) GO TO 11
      DO 12 I=1,3
      REVTAR(I)=REL(I)
   12 VEVTAR(I)=VEL(I)
      GO TO 5
   11 CALL UNITV(REGM,UXLE)
      CALL VXV(REMF,VEMF,TEMP)
      CALL UNITV(TEMP,UZLE)
      CALL VXV(UZLE,UXLE,LYLE)
      DO 2 J=1,3
      CLE(1,J)=UXLE(J)
      CLE(2,J)=UYLE(J)
    2 CLE(3,J)=UZLE(J)
      CALL MTRANS(CLE,CEL,3,3)
      MU=MM/(ME+MM)
      BL=(1.-MU)/(1.-GAMMA)**3+MU/GAMMA**3
      OMEGAN=DSQRT(1.-BL/2.+DSQRT((3.*BL/2.)**2-2.*BL))
      KTAR=2.*OMEGAN/(OMEGAN**2+2.*BL+1.)
      CATAR=DCOS(ATAR)
      SATAR=DSIN(ATAR)
      RLTARL(1)=KTAR*AY*SATAR
      RLTARL(2)=AY*CATAR
      RLTARL(3)=AZ*SATAR
      VLTARL(1)=KTAR*OMEGAN*AY*CATAR
      VLTARL(2)=-OMEGAN*AY*SATAR
      VLTARL(3)=OMEGAN*AZ*CATAR
      WRITE(6,101)RLTARL,VLTARL
      CALL MXV(CSL,RLTARL,RLTAR,3,3)
      RMAG=VMAG(REL)
      VY=DOT(UYLE,VEL,3)
      DO 3 I=1,3
    3 OMGEL(I)=VY*UZLE(I)/RMAG
      CALL VXV(OMGEL,RLTAR,TEMP)
      CALL MXV(CEL,VLTARL,TEMP1,3,3)
      DO 4 I=1,3
      REVTAR(I)=REL(I)+RLTAR(I)
    4 VEVTAR(I)=VEL(I)+TEMP1(I)+TEMP(I)
    5 CONTINUE
      WRITE(6,102)REVTAR,VEVTAR
      WRITE(6,103)
  100 FORMAT(1HO,T8,'COMPUTED TARGET')
  101 FORMAT(1H ,T8,'RLTARL',T68,'VLTARL'/1H ,1P6D20.11)
  102 FORMAT(1H ,T8,'REVTAR',T68,'VEVTAR'/1H ,1P6D20.11)
  103 FORMAT(1HO)
      RETURN
```

END

```
      SUBROUTINE LAMB(TO,TF,RSV,VSV,RSE,VSE,RSM,VSM,KNR,ITLMAX,
     1ERRMIN,RSVTAR,RSVX,VSVX,RSEX,VSEX,RSMX,VSMX,S11,S12,S21,S22)
C     SOLVE LAMBERT PROBLEM BY NEWTON-RAPHSON METHOD ITERATING ON
      INITIAL VELOCITY
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION RSV(3),VSV(3),RSE(3),VSE(3),RSM(3),VSM(3),RSVTAR(3),
     1S11(3,3),S12(3,3),S21(3,3),S22(3,3),RSVX(3),VSVX(3),RSEX(3),
     2VSEX(3),RSMX(3),VSMX(3),REVX(3),VEVX(3),RMVX(3),VMVX(3),
     3REMX(3),VEMX(3),ERR(3),G2(2,2),G(3,3),GI(3,3),G2I(2,2),VIT(3),
     4DELV(3),UDELV(3),KDELV(3),PVO(6)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      ITER=1
      TESTRP=100.0
      WRITE(6,108)
      WRITE(6,100)TO,TF,RSV,VSV
      DO 1 I=1,3
      PVO(I)=0.
      PVO(I+3)=0.
    1 VIT(I)=VSV(I)
    2 WRITE(6,101)ITER,VIT
      CALL FOURBY(TO,TF,RSV,VIT,RSE,VSE,RSM,VSM,PVO,RSVX,
     1VSVX,RSEX,VSEX,RSMX,VSMX,S11,S12,S21,S22)
      CALL RVEMV(RSVX,VSVX,RSEX,VSEX,RSMX,VSMX,REVX,VEVX,RMVX,VMVX,
     1REMX,VEMX)
      DO 3 I=1,3
    3 ERR(I)=RSVTAR(I)-RSVX(I)
      TESTR=VMAG(ERR)
      DO 4 I=1,3
      DO 4 J=1,3
    4 G(I,J)=-S12(I,J)
      WRITE(6,102)RSVX,VSVX
      WRITE(6,107)ERR,TESTR
      IF(ERR(3).NE.0.0) GO TO 5
      DO 6 I=1,3
      DO 6 J=1,3
    6 G2(I,J)=G(I,J)
      D2=G2(1,1)*G2(2,2)-G2(1,2)*G2(2,1)
      G2I(1,1)=G2(2,2)/D2
      G2I(1,2)=-G2(1,2)/D2
      G2I(2,1)=-G2(2,1)/D2
      G2I(2,2)=G2(1,1)/D2
      DO 7 I=1,2
      DO 7 J=1,2
      GI(I,J)=G2I(I,J)
      GI(I,3)=0.0
    7 GI(3,J)=0.0
      GI(3,3)=0.0
      GO TO 8
    5 CALL INVERT(G,GI)
    8 IF (TESTR.GE.TESTRP) GO TO 9
      DO 10 I=1,3
   10 VSV(I)=VIT(I)
      IF (TESTR.LT.ERRMIN) GO TO 14
      CALL MXV(GI,ERR,DELV,3,3)
      DO 11 I=1,3
   11 DELV(I)=-DELV(I)
      TESTRP=TESTR
```

```
      DV=VMAG(DELV)
      CALL UNITV(DELV,UDELV)
      KNR=2.0*KNR
      IF(KNR.GT.DV) KNR=DV
      GO TO 12
    9 KNR=KNR/10.0
   12 DO 13 I=1,3
      KDELV(I)=KNR*UDELV(I)
   13 VIT(I)=VSV(I)+KDELV(I)
      ITER=ITER+1
      KLV=VMAG(KDELV)
      KLVMIN=10.D-24
      IF(KLV.LT.KLVMIN) GO TO 14
      IF(ITER.LT.ITLMAX) GO TO 2
      WRITE(6,112)
      STOP
   14 CONTINUE
      WRITE(6,109)
      WRITE(6,110)VSV
      WRITE(6,111)RSVX,VSVX
      WRITE(6,103)REVX,VEVX
      WRITE(6,104)RMVX,VMVX
      WRITE(6,105)RSEX,VSEX
      WRITE(6,106)RSMX,VSMX
  100 FORMAT(1H0,T8,'TO',T28,'TF'/1H ,1P2D20.11/1H ,T8,'RSV',T68,
     1'VSV'/1H ,1P6D20.11)
  101 FORMAT(1H0,T8,'ITER',T28,'VIT'/1H ,I10,10X,1P3D20.11)
  102 FORMAT(1H ,T8,'RSVX',T68,'VSVX'/1H ,1P6D20.11)
  103 FORMAT(1H ,T8,'REVX',T68,'VEVX'/1H ,1P6D20.11)
  104 FORMAT(1H ,T8,'RMVX',T68,'VMVX'/1H ,1P6D20.11)
  105 FORMAT(1H ,T8,'RSEX',T68,'VSEX'/1H ,1P6D20.11)
  106 FORMAT(1H ,T8,'RSMX',T68,'VSMX'/1H ,1P6D20.11)
  107 FORMAT(1H ,T8,'ERR',T68,'TESTR'/1H ,1P4D20.11)
  108 FORMAT(1H1)
  109 FORMAT(1H0,T8,'LAMBERT PROBLEM HAS CONVERGED')
  110 FORMAT(1H0,T8,'CONVERGED VSV'/1H ,1P3D20.11)
  111 FORMAT(1H0,T8,'RSVX',T68,'VSVX'/1H ,1P6D20.11)
  112 FORMAT(1H0,T8,'NO. OF LAMBERT ITERATIONS HAS REACHED MAXIMUM')
      RETURN
      END
```

```
      SUBROUTINE LAMB3(TO,TF,REV,VEV,REM,VEM,KNR,ITLMAX,ERRMIN,REVTAR,
     1REVF,VEVF,REMF,VEMF,S11,S12,S21,S22)
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      THIS ROUTINE
C     SOLVES 3-BODY LAMBERT PROBLEM BY NEWTON-RAPHSON METHOD ITERATING
C     ON INITIAL VELOCITY.
      DIMENSION REV(3),VEV(3),REM(3),VEM(3),REVTAR(3),REVF(3),VEVF(3),
     1REMF(3),VEMF(3),S11(3,3),S12(3,3),S21(3,3),S22(3,3),VIT(3),
     2PVO(6),RMVF(3),VMVF(3),ERR(3),G(3,3),G2(2,2),G2I(2,2),GI(3,3),
     3DELV(3),UDELV(3),KDELV(3)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      ITER=1
      TESTRP=100.0
      WRITE(6,100)TO,TF,REV,VEV
      DO 1 I=1,3
      PVO(I)=0.
      PVO(I+3)=0.
    1 VIT(I)=VEV(I)
    2 WRITE(6,101)ITER,VIT
      CALL THRBDY(TO,TF,REV,VEV,REM,VEM,PVO,REVF,VEVF,REMF,VEMF,S11,
     1S12,S21,S22)
      DO 21 I=1,3
      RMVF(I)=-REMF(I)+REVF(I)
   21 VMVF(I)=-VEMF(I)+VEVF(I)
      DO 3 I=1,3
    3 ERR(I)=REVTAR(I)-REVF(I)
      TESTR=VMAG(ERR)
      DO 4 I=1,3
      DO 4 J=1,3
    4 G(I,J)=-S12(I,J)
      WRITE(6,102)REVF,VEVF
      WRITE(6,105)ERR,TESTR
      IF(ERR(3).NE.0.0) GO TO 5
      DO 6 I=1,2
      DO 6 J=1,2
    6 G2(I,J)=G(I,J)
      D2=G2(1,1)*G2(2,2)-G2(1,2)*G2(2,1)
      G2I(1,1)=G2(2,2)/D2
      G2I(1,2)=-G2(1,2)/D2
      G2I(2,1)=-G2(2,1)/D2
      G2I(2,2)=G2(1,1)/D2
      DO 7 I=1,2
      DO 7 J=1,2
      GI(I,4)=G2I(I,J)
      GI(I,3)=0.
    7 GI(3,J)=0.
      GI(3,3)=0.
      GO TO 8
    5 CALL INVERT(G,GI)
    8 IF(TESTR.GE.TESTRP) GO TO 9
      DO 10 I=1,3
   10 VEV(I)=VIT(I)
      IF(TESTR.LT.ERRMIN) GO TO 14
      CALL MXV(GI,ERR,DELV,3,3)
      DO 11 I=1,3
   11 DELV(I)=-DELV(I)
      TESTRP=TESTR
```

```
      DV=VMAG(DELV)
      CALL UNITV(DELV,UDELV)
      KNR=2.0*KNR
      IF(KNR.GT.DV) KNR=DV
      GO TO 12
    9 KNR=KNR/10.0
   12 DO 13 I=1,3
      KDELV(I)=KNR*UDELV(I)
   13 VIT(I)=VEV(I)+KDELV(I)
      ITER=ITER+1
      KLV=VMAG(KDELV)
      KLVMIN=10.D-24
      IF(KLV.LT.JLVMIN) GO TO 14
      IF(ITER.LT.ITLMAX) GO TO 2
      WRITE(6,110)
      STOP
   14 CONTINUE
      WRITE(6,107)
      WRITE(6,108)VEV
      WRITE(6,109)REVF,VEVF
      WRITE(6,103)RMVF,VMVF
      WRITE(6,104)REMF,VEMF
  100 FORMAT(1H0,T8,'TO',T28,'TF'/1H ,1P2D20.11/1H ,T8,'REV',T68,
     1'VEV'/1H ,1P6D20.11)
  101 FORMAT(1H0,T8,'ITER',T28,'VIT'/1H ,I10,10X,1P3D20.11)
  102 FORMAT(1H ,T8,'REVF',T68,'VEVF'/1H ,1P6D20.11)
  103 FORMAT(1H ,T8,'RMVF',T68,'VMVF'/1H ,1P6D20.11)
  104 FORMAT(1H ,T8,'REMF',T68,'VEMF'/1H ,1P6D20.11)
  105 FORMAT(1H ,T8,'ERR',T68,'TESTR'/1H ,1P4D20.11)
  107 FORMAT(1H0,T8,'LAMBERT PROBLEM HAS CONVERGED')
  108 FORMAT(1H0,T8,'CONVERGED VEV'/1H ,1P3D20.11)
  109 FORMAT(1H0,T8,'REVF',T68,'VEVF'/1H ,1P6D20.11)
  110 FORMAT(1H0,T8,'NO. OF LAMBERT ITERATIONS HAS REACHED MAXIMUM')
      RETURN
      END
```

```
      SUBROUTINE DISP
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION RSV(3),VSV(3),RSE(3),VSE(3),RSM(3),VSM(3),UXDS(3),
     1Q(3),TEMP1(3),TEMP2(3),UZDS(3),UYDS(3),OMGSD(3),RDVD(3),VDVD(3),
     2RDMD(3),VDMD(3),CDS(3,3),RDV(3),VDV(3),RDS(3),
     3VDS(3),RDM(3),VDM(3),RDSD(3),VDSD(3)
      DIMENSION RSB(3),VSB(3),RSD(3),VSD(3),REV(3),VEV(3),RMV(3),
     1VMV(3),PV(6),RSL1(3),VSL1(3),RDL1(3),VDL1(3),RDL1D(3),VDL1D(3),
     2URSV(3),URSE(3),UREV(3),REM(3),VEM(3)
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/TDATA/TO,T,H,RSV,VSV,REV,VEV,RMV,VMV,RSE,VSE,RSM,VSM,
     1REM,VEM,RSL1,VSL1,RDVD,VDVD,RDSD,VDSD,RDMD,VDMD,
     2RDL1D,VDL1D,PV,LM,LDM,ANGV,ANGE,ANGS
      ESE=ME/(MS+ME)
      MEM=MM/(ME+MM)
      DO 1 I=1,3
      RSB(I)=RSE(I)+MEM*REM(I)
      VSB(I)=VSE(I)+MEM*VEM(I)
      RSD(I)=RSE(I)
      VSD(I)=VSE(I)
      RSL1(I)=(1.-GL1)*RSB(I)
    1 VSL1(I)=(1.-GL1)*VSB(I)
      CALL UNITV(RSE,UXDS)
      CALL VXV(RSE,VSE,Q)
      CALL UNITV(Q,UZDS)
      CALL VXV(UZDS,UXDS,UYDS)
      DO 3 J=1,3
      CDS(1,J)=UXDS(J)
      CDS(2,J)=UYDS(J)
    3 CDS(3,J)=UZDS(J)
      RSEMAG=VMAG(RSE)
      VY=DOT(UYDS,VSE,3)
      DO 4 I=1,3
    4 OMGSD(I)=UZDS(I)*VY/RSEMAG
      DO 5 I=1,3
      RDV(I)=RSV(I)-RSD(I)
      VDV(I)=VSV(I)-VSD(I)
      RDS(I)=-RSD(I)
      VDS(I)=-VSD(I)
      RDM(I)=RSM(I)-RSD(I)
      VDM(I)=VSM(I)-VSD(I)
      RDL1(I)=RSL1(I)-RSD(I)
    5 VDL1(I)=VSL1(I)-VSD(I)
C     COMPUTE STATE VECTOR IN ROTATING FRAME
      CALL MXV(CDS,RDV,RDVD,3,3)
      CALL VXV(OMGSD,RDV,TEMP1)
      DO 6 I=1,3
    6 TEMP2(I)=VDV(I)-TEMP1(I)
      CALL MXV(CDS,TEMP2,VDVD,3,3)
      CALL MXV(CDS,RDS,RDSD,3,3)
      CALL VXV(OMGSD,RDS,TEMP1)
      DO 7 I=1,3
    7 TEMP2(I)=VDS(I)-TEMP1(I)
      CALL MXV(CDS,TEMP2,VDSD,3,3)
      CALL MXV(CDS,RDM,RDMD,3,3)
      CALL VXV(OMGSD,RDM,TEMP1)
      DO 9 I=1,3
```

```
    9 TEMP2(I)=VDM(I)-TEMP1(I)
      CALL MXV(CDS,TEMP2,VDMD,3,3)
      CALL MXV(CDS,RDL1,RDL1D,3,3)
      CALL VXV(OMGSD,RDL1,TEMP1)
      DO 10 I=1,3
   10 TEMP2(I)=VDL1(I)-TEMP1(I)
      CALL MXV(CDS,TEMP2,VDL1D,3,3)
C     COMPUTE ANGLES AT SUN,EARTH AND VEHICLE
      CALL UNITV(RSE,URSE)
      CALL UNITV(REV,UREV)
      CALL UNITV(RSV,URSV)
      ANGV=DARCOS(DOT(UREV,URSV,3))/DTR
      ANGE=DARCOS(-DOT(URSE,UREV,3))/DTR
      ANGS=180.0-(ANGV+ANGE)
      RETURN
      END
```

```
      SUBROUTINE DISP3
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION REV(3),VEV(3),RMV(3),VMV(3),REM(3),VEM(3),REL(3),
     1VEL(3),RDVD(3),VDVD(3),RDED(3),VDED(3),
     2RDLD(3),VDLD(3),PV(6),UXDE(3),UYDE(3),UZDE(3),Q(3),CDE(3,3),
     3OMGED(3),RDV(3),VDV(3),RDE(3),VDE(3),RDL(3),
     4VDL(3),TEMP1(3),TEMP2(3),UREM(3),URMV(3),UREV(3),RED(3),VED(3)
      COMMON/CONST3/ME,MM,GAMMA,UDM,UTIME,UVELM,ERRMAX,DTR
      COMMON/TDATA3/TO,T,H,REV,VEV,RMV,VMV,REM,VEM,REL,VEL,RDVD,
     1VDVD,RDED,VDED,RDLD,VDLD,PV,LM,LDM,ANGV,ANGE,ANGM
      EEM=ME/(ME+MM)
      DO 1 I=1,3
      RED(I)=REM(I)
      VED(I)=VEM(I)
      REL(I)=(1.-GAMMA)*REM(I)
    1 VEL(I)=(1.-GAMMA)*VEM(I)
      CALL UNITV(REM,UXDE)
      CALL VXV(REM,VEM,Q)
      CALL UNITV(Q,UZDE)
      CALL VXV(UZDE,UXDE,UYDE)
      DO 2 J=1,3
      CDE(1,J)=UXDE(J)
      CDE(2,J)=UYDE(J)
    2 CDE(3,J)=UZDE(J)
      REMMAG=VMAG(REM)
      VY=DOT(UYDE,VEM,3)
      DO 3 I=1,3
    3 OMGED(I)=UZDE(I)*VY/REMMAG
      DO 4 I=1,3
      RDV(I)=REV(I)-RED(I)
      VDV(I)=VEV(I)-VED(I)
      RDE(I)=-RED(I)
      VDE(I)=-VED(I)
      RDL(I)=REL(I)-RED(I)
    4 VDL(I)=VEL(I)-VED(I)
C     COMPUTE STATES IN ROTATING FRAME
      CALL MXV(CDE,RDV,RDVD,3,3)
      CALL VXV(OMGED,RDV,TEMP1)
      DO 5 I=1,3
    5 TEMP2(I)=VDV(I)-TEMP1(I)
      CALL MXV(CDE,TEMP2,VDVD,3,3)
      CALL MXV(CDE,RDE,RDED,3,3)
      CALL VXV(OMGED,RDE,TEMP1)
      DO 6 I=1,3
    6 TEMP2(I)=VDE(I)-TEMP1(I)
      CALL MXV(CDE,TEMP2,VDED,3,3)
      CALL MXV(CDE,RDL,RDLD,3,3)
      CALL VXV(OMGED,RDL,TEMP1)
      DO 8 I=1,3
    8 TEMP2(I)=VDL(I)-TEMP1(I)
      CALL MXV(CDE,TEMP2,VDLD,3,3)
C     COMPUTE ANGLES AT VEHICLE, EARTH AND MOON
      CALL UNITV(REM,UREM)
      CALL UNITV(RMV,URMV)
      CALL UNITV(REV,UREV)
      ANGV=DARCOS(DOT(URMV,UREV,3))/DTR
      ANGM=DARCOS(-DOT(UREM,URMV,3))/DTR
```

```
ANGE=180.0-(ANGV+ANGM)
RETURN
END
```

```
      SUBROUTINE PTRAJ
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION RSV(3),VSV(3),REV(3),VEV(3),RMV(3),VMV(3),RSE(3),
     1VSE(3),RSM(3),VSM(3),RDVD(3),VDVD(3),RDSD(3),VDSD(3),
     2RDMD(3),VDMD(3),PV(6),RSL1(3),VSL1(3),RDL1D(3),VDL1D(3)
      DIMENSION REM(3),VEM(3)
      COMMON/TDATA/TO,T,H,RSV,VSV,REV,VEV,RMV,VMV,RSE,VSE,RSM,VSM,
     1REM,VEM,RSL1,VSL1,RDVD,VDVD,RDSD,VDSD,RDMD,VDMD,
     2RDL1D,VDL1D,PV,LM,LDM,ANGV,ANGE,ANGS
      COMMON/CONST/MS,ME,MM,GL1,AUM,UTIME,UVELM,ERRMAX,DTR
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      TDAY=(T-TO)*UTIME
      HDAY=H*UTIME
      RSVMAG=VMAG(RSV)
      REVMAG=VMAG(REV)
      RMVMAG=VMAG(RMV)
      WRITE(6,101)
      WRITE(6,100)T,TDAY,H,RSVMAG,REVMAG,RMVMAG
C     PRINT STATES IN INERTIAL S-FRAME
      WRITE(6,100)RSV,VSV
      WRITE(6,100)REV,VEV
      WRITE(6,100)RMV,VMV
      WRITE(6,101)
      WRITE(6,100)RSE,VSE
      WRITE(6,100)RSM,VSM
      WRITE(6,100)REM,VEM
      WRITE(6,100)RSL1,VSL1
      WRITE(6,101)
C     PRINT STATES IN ROTATING D-FRAME
      WRITE(6,100)RDVD,VDVD
      WRITE(6,100)RDSD,VDSD
      WRITE(6,100)RDMD,VDMD
      WRITE(6,100)RDL1D,VDL1D
      WRITE(6,101)
      WRITE(6,102)ANGV,ANGE,ANGS,HDAY
      IF(IPV.EQ.0) GO TO 1
C     PRINT PRIMER VECTOR
      WRITE(6,100)PV
      WRITE(6,103)LM,LDM
    1 CONTINUE
      WRITE(6,104)
  100 FORMAT(1H ,1P6D20.11)
  101 FORMAT(1H )
  102 FORMAT(1H ,1P4D20.11)
  103 FORMAT(1H ,1P2D20.11)
  104 FORMAT(1H0,'------------------------------')
      RETURN
      END
```

```
      SUBROUTINE PTRAJ3
      IMPLICIT REAL*8(A-H,L-M,O-Z)
      DIMENSION REV(3),VEV(3),RMV(3),VMV(3),REM(3),VEM(3),REL(3),
     1VEL(3),RDVD(3),VDVD(3),RDED(3),VDED(3),RDLD(3),VDLD(3),PV(6)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/TDATA3/TO,T,H,REV,VEV,RMV,VMV,REM,VEM,REL,VEL,RDVD,
     1VDVD,RDED,VDED,RDLD,VDLD,PV,LM,LDM,ANGV,ANGE,ANGM
      TDAY=(T-TO)*UTIME
      HDAY=H*UTIME
      REVMAG=VMAG(REV)
      RMVMAG=VMAG(RMV)
      WRITE(6,101)
      WRITE(6,100)T,TDAY,H,HDAY,REVMAG,RMVMAG
C     PRINT STATES IN INERTIAL E-FRAME
      WRITE(6,100)REV,VEV
      WRITE(6,100)RMV,VMV
      WRITE(6,100)REM,VEM
      WRITE(6,100)REL,VEL
      WRITE(6,101)
C     PRINT STATES IN ROTATING D-FRAME
      WRITE(6,100)RDVD,VDVD
      WRITE(6,100)RDED,VDED
      WRITE(6,100)RDLD,VDLD
      WRITE(6,102)ANGV,ANGE,ANGM
      IF(IPV.EQ.0) GO TO 1
      WRITE(6,101)
      WRITE(6,100)PV
      WRITE(6,103)LM,LDM
  100 FORMAT(1H ,1P6D20.11)
  101 FORMAT(1H )
  102 FORMAT(1H ,1P3D20.11)
  103 FORMAT(1H ,1P2D20.11)
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE FDATA
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION RSV(3),VSV(3),REV(3),VEV(3),RMV(3),VMV(3),RSE(3),
     1VSE(3),RSM(3),VSM(3),RSL1(3),VSL1(3),RDVD(3),VDVD(3),RDSD(3),
     2VDSD(3),RDMD(3),VDMD(3),RDL1D(3),VDL1D(3),PV(6),
     3DUM(9),REM(3),VEM(3)
      COMMON/TDATA/TO,T,H,RSV,VSV,REV,VEV,RMV,VMV,RSE,VSE,RSM,VSM,
     1REM,VEM,RSL1,VSL1,RDVD,VDVD,RDSD,VDSD,RDMD,VDMD,
     2RDL1D,VDL1D,PV,LM,LDM,ANGV,ANGE,ANGS
C     EACH RECORD CONSISTS OF 100 DOUBLE PRECISION UNFORMATED NUMBERS
C     FILED SEQUENTIALLY. THE LAST 15 NUMBERS ARE BLANKS FILLED WITH
C     ZEROS AND MAY BE USED FOR FUTURE EXPANSION.
      DO 1 I=1,15
    1 DUM(I)=0.
      RSVMAG=VMAG(RSV)
      VSVMAG=VMAG(VSV)
      REVMAG=VMAG(REV)
      VEVMAG=VMAG(VEV)
      RMVMAG=VMAG(RMV)
      VMVMAG=VMAG(VMV)
      WRITE(8)T,H,RSV,VSV,REV,VEV,RMV,VMV,RSE,VSE,RSM,VSM,REM,VEM,
     1RSL1,VSL1,RDVD,VDVD,RDSD,VDSD,RDMD,VDMD,RDL1D,VDL1D,
     2PV,LM,LDM,ANGV,ANGE,ANGS,RSVMAG,VSVMAG,REVMAG,VEVMAG,RMVMAG,
     3VMVMAG,DUM
      RETURN
      END
```

```
      SUBROUTINE FDATA3
      IMPLICIT REAL*8(A-H,K-M,O-Z)
      DIMENSION REV(3),VEV(3),RMV(3),VMV(3),REM(3),VEM(3),REL(3),
     1VEL(3),RDVD(3),VDVD(3),RDED(3),VDED(3),RDLD(3),VDLD(3),PV(6),
     2DUM(14)
      COMMON/TDATA3/TO,T,H,REV,VEV,RMV,VMV,REM,VEM,REL,VEL,RDVD,
     1VDVD,RDED,VDED,RDLD,VDLD,PV,LM,LDM,ANGV,ANGE,ANGM
      DO 1 I=1,14
    1 DUM(I)=0.
      REVMAG=VMAG(REV)
      VEVMAG=VMAG(VEV)
      RMVMAG=VMAG(RMV)
      REMMAG=VMAG(REM)
      VEMMAG=VMAG(VEM)
      WRITE(8)T,H,REV,VEV,RMV,VMV,REM,VEM,REL,VEL,RDVD,VDVD,RDED,
     1VDED,RDLD,VDLD,PV,LM,LDM,ANGV,ANGE,ANGM,DUM
      RETURN
      END
```

```
      SUBROUTINE COMAUG(F,G,TSI,LT,V,L,FG,GG)
      IMPLICIT REAL*8(A-H,L-N,O-Z)
      DIMENSION TSI(3),G(3),LTLI(3,3),LT(3,3),L(3,3),NU(3),GG(3),
     1TEMP1(3,3),TEMP2(3,3),DUM(3),V(3,3)
      CALL MTRANS(LT,L,3,3)
      CALL MXM(LT,V,TEMP1,3,3,3)
      CALL MXM(TEMP1,L,TEMP2,3,3,3)
      CALL INVERT(TEMP2,LTLI)
      CALL MXM(LTLI,LT,TEMP1,3,3,3)
      CALL MXM(TEMP1,V,TEMP2,3,3,3)
      CALL MXV(TEMP2,G,NU,3,3)
      DO 1 I=1,3
    1 NU(I)=-NU(I)
      FG=F+DOT(NU,TSI,3)
      CALL MXV(L,NU,DUM,3,3)
      DO 2 I=1,3
    2 GG(I)=G(I)+DUM(I)
      WRITE(6,100)FG,GG
      WRITE(6,101)
  100 FORMAT(1H ,T8,'FG',T28,'GG'/1H ,1P4D20.11)
  101 FORMAT(1H0,T8,'---------------------')
      RETURN
      END
```

```
      SUBROUTINE COMDX(LTS,LS,TSIS,DX)
      IMPLICIT REAL*8(A-H,L,O-Z)
      DIMENSION LTS(3,3),LS(3,3),TSIS(3),DX(3),TEMP1(3,3),TEMP2(3,3)
      CALL MXM(LTS,LS,TEMP1,3,3,3)
      CALL INVERT(TEMP1,TEMP2)
      CALL MXM(LS,TEMP2,TEMP1,3,3,3)
      CALL MXV(TEMP1,TSIS,DX,3,3)
      DO 1 I=1,3
    1 DX(I)=-DX(I)
      RETURN
      END
```

```
      SUBROUTINE UPX(XD,FD,TESTRD,GD,TSID,LTD,LD,FGD,GGD,S11D,S12D,
     1S21D,S22D,UVID,UVFD,X,F,TESTR,G,TSI,LT,L,FG,GG,S11,S12,S21,S22,
     2UVI,UVF)
      IMPLICIT REAL*8(A-H,L,N,O-Z)
      DIMENSION XD(3),GD(3),TSID(3),LTD(3,3),LD(3,3),X(3),G(3),
     1TSI(3),LT(3,3),L(3,3),S11D(3,3),S12D(3,3),S21D(3,3),S22D(3,3),
     2S11(3,3),S12(3,3),S21(3,3),S22(3,3),GG(3),UVID(3),UVFD(3),
     3UVI(3),UVF(3),GGD(3)
      F=FD
      TESTR=TESTRD
      FG=FGD
      DO 1 I=1,3
      X(I)=XD(I)
      G(I)=GD(I)
      TSI(I)=TSID(I)
      GG(I)=GGD(I)
      UVI(I)=UVID(I)
      UVF(I)=UVFD(I)
      DO 1 J=1,3
      LT(I,J)=LTD(I,J)
      L(I,J)=LD(I,J)
      S11(I,J)=S11D(I,J)
      S12(I,J)=S12D(I,J)
      S21(I,J)=S21D(I,J)
      S22(I,J)=S22D(I,J)
    1 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PVEC(T,R,V,PVO,STM,PV,LM,LDM)
      IMPLICIT REAL*8(A-H,L,O-Z)
      DIMENSION R(3),V(3),PVO(6),PV(6),STM(6,6),DL(3),DLD(3),
     1RTM(3),VTM(3),PVTM(3),PVDTM(3),STNTM(6,6)
      COMMON/FLAG/IMTX,IPV,IPTRAJ,IPVTM,IFILE,ITER,ITAR
      COMMON/CTM/TTM,RTM,VTM,LTM,LDTM,PVTM,PVDTM,STNTM
      CALL MXV(STM,PVO,PV,6,6)
      DO 3 I=1,3
      DL(I)=PV(I)
    3 DLD(I)=PV(I+3)
      LM=VMAG(DL)
      LDM=DOT(DL,DLD,3)/LM
      IF(IPVTM.LE.0) GO TO 2
      IF(LM.LE.LTM) GO TO 2
      LTM=LM
      LDTM=LDM
      TTM=T
      DO 1 I=1,3
      RTM(I)=R(I)
      VTM(I)=V(I)
      PVTM(I)=DL(I)
      PVDTM(I)=DLD(I)
      DO 1 J=1,3
      STNTM(I,J)=STM(I,J)
      STNTM(I,J+3)=STM(I,J+3)
      STNTM(I+3,J)=STM(I+3,J)
    1 STNTM(I+3,J+3)=STM(I+3,J+3)
    2 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE RVEMV(RSV,VSV,RSE,VSE,RSM,VSM,REV,VEV,RMV,VMV,
     1REM,VEM)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION RSV(3),VSV(3),RSE(3),VSE(3),RSM(3),VSM(3),REV(3),
     1VEV(3),RMV(3),VMV(3),REM(3),VEM(3)
      DO 1 I=1,3
      REV(I)=-RSE(I)+RSV(I)
      VEV(I)=-VSE(I)+VSV(I)
      RMV(I)=-RSM(I)+RSV(I)
      VMV(I)=-VSM(I)+VSV(I)
      REM(I)=-RSE(I)+RSM(I)
    1 VEM(I)=-VSE(I)+VSM(I)
      RETURN
      END
```

```
      SUBROUTINE MXV(A,V,VN,M,N)
      IMPLICIT REAL*8(A-H,O-Z)
C     MATRIX VECTOR MULTIPLICATION A(M,N) V(N)=VN(M)
      DIMENSION A(M,N),V(N),VN(M)
      DO 4 I=1,M
      S=0.
      DO 3 J=1,N
    3 S=S+A(I,J)*V(J)
    4 VN(I)=S
      RETURN
      END
```

```
      SUBROUTINE VVT(V,VV,IDIM)
      IMPLICIT REAL*8(A-H,O-Z)
C     OUTER PRODUCT OF 2 VECTORS OF DIMENSION IDIM
      DIMENSION V(IDIM),VV(IDIM,IDIM)
      DO 1 I=1,IDIM
      DO 1 J=1,IDIM
    1 VV(I,J)=V(I)*V(J)
      RETURN
      END
```

```
      DOUBLE PRECISION FUNCTION DOT(V1,V2,IDIM)
      IMPLICIT REAL*8(A-H,O-Z)
C     DOT PRODUCT OF 2 VECTORS
      DIMENSION V1(IDIM),V2(IDIM)
      S=0.
      DO 1 I=1,IDIM
      S=S+V1(I)*V2(I)
      DOT=S
      RETURN
      END
```

```
      DOUBLE PRECISION FUNCTION VMAG(V)
      IMPLICIT REAL*8(A-H,O-Z)
C     MAGNITUDE OF VECTORS OF DIMENSION IDIM
      DIMENSION V(3)
      S=0.
      DO 1 I=1,3
      S=S+V(I)**2
      VMAG=DSQRT(S)
      RETURN
      END
```

```
      SUBROUTINE INVERT(B,BI)
      IMPLICIT REAL*8(A-H,O-Z)
C     INVERSION OF A 3X3 MATRIX
      DIMENSION B(3,3),BI(3,3)
      D=B(1,1)*(B(2,2)*B(3,3)-B(2,3)*B(3,2))+B(2,1)*(B(1,3)*B(3,2)-
     1B(1,2)*B(3,3))+B(3,1)*(B(1,2)*B(2,3)-B(1,3)*B(2,2))
      BI(1,1)=(B(2,2)*B(3,3)-B(2,3)*B(3,2))/D
      BI(2,1)=(B(2,3)*B(3,1)-B(2,1)*B(3,3))/D
      BI(3,1)=(B(2,1)*B(3,2)-B(2,2)*B(3,1))/D
      BI(1,2)=(B(1,3)*B(3,2)-B(1,2)*B(3,3))/D
      BI(2,2)=(B(1,1)*B(3,3)-B(1,3)*B(3,1))/D
      BI(3,2)=(B(1,2)*B(3,1)-B(1,1)*B(3,2))/D
      BI(1,3)=(B(1,2)*B(2,3)-B(1,3)*B(2,2))/D
      BI(2,3)=(B(1,3)*B(2,1)-B(1,1)*B(2,3))/D
      BI(3,3)=(B(1,1)*B(2,2)-B(1,2)*B(2,1))/D
      RETURN
      END
```

```
      SUBROUTINE UNITV(A,UA)
      IMPLICIT REAL*8(A-H,O-Z)
      DIMENSION A(3),UA(3)
      S=0.
      DO 1 I=1,3
    1 S=S+A(I)**2
      AMAG=DSQRT(S)
      DO 2 I=1,3
    2 UA(I)=A(I)/AMAG
      RETURN
      END
```

```
      SUBROUTINE VXV(V1,V2,V3)
      IMPLICIT REAL*8(A-H,O-Z)
C     CROSS PRODUCT OF 2 3-DIMENSIONAL VECTORS
      DIMENSION V1(3),V2(3),V3(3)
      V3(1)=V1(2)*V2(3)-V1(3)*V2(2)
      V3(2)=V1(3)*V2(1)-V1(1)*V2(3)
      V3(3)=V1(1)*V2(2)-V1(2)*V2(1)
      RETURN
      END
```

```
      SUBROUTINE MTRANS(A,B,IROW,ICOL)
      IMPLICIT REAL*8(A-H,O-Z)
C     TRANSPOSE A MATRIX OF IROW X ICOL
      DIMENSION A(IROW,ICOL),B(ICOL,IROW)
      DO 1 I=1,IROW
      DO 1 J=1,ICOL
    1 B(J,I)=A(I,J)
      RETURN
      END
```

```
      SUBROUTINE MXM(A,B,C,K,L,M)
      IMPLICIT REAL*8(A-H,O-Z)
C      MATRIX MULTIPLICATION A(K,L) B(L,M)=C(K,M)
      DIMENSION A(K,L),B(L,M),C(K,M)
      DO 4 I=1,K
      DO 4 J=1,M
      S=0.
      DO 3 N=1,L
    3 S=S+A(I,N)*B(N,J)
    4 C(I,J)=S
      RETURN
      END
```

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