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Interplanetary Program To Optimize Simulated Trajectories (IPOST)

Volume I - User's Guide

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ABSTRACT

The Interplanetary Program to Optimize Simulated Trajectories (IPOST) is intended to support many analysis phases, from early interplanetary feasibility studies through spacecraft development and operations. The IPOST output provides information for sizing and understanding mission impacts related to propulsion, guidance, communications, sensor/actuators, payload, and other dynamic and geometric environments.

IPOST models three degree of freedom trajectory events, such as launch/ascent, orbital coast, propulsive maneuvering (impulsive and finite burn), gravity assist, and atmospheric entry. Trajectory propagation is performed using a choice of Cowell, Encke, Multiconic, Onestep, or Conic methods. The user identifies a desired sequence of trajectory events, and selects which parameters are independent (controls) and dependent (targets), as well as other constraints and the cost function.

Targeting and optimization is performed using the Stanford NPSOL (Nonlinear Programming Stanford Optimization Laboratory) algorithm. IPOST structure allows sub-problems within a master optimization problem to aid in the general constrained parameter optimization solution. An alternate optimization method uses implicit simulation and collocation techniques.

IPOST has been developed by Martin Marietta under contract NAS1-18147 to NASA/Langley. IPOST runs on a SUN and a Silicon Graphics computer.

FOREWORD

This report describing the formulation of the Interplanetary Program to Optimize Simulated Trajectories (IPOST) is provided in accordance with Statement of Work Part 4.9 of NASA Contract NAS1-18147. The report is presented as follows:

Volume I - Interplanetary Program to Optimize Simulated Trajectories User's Guide

Volume II - Interplanetary Program to Optimize Simulated Trajectories Analytic Manual

Volume III - Interplanetary Program to Optimize Simulated Trajectories Programmer's Manual

Volume IV - Interplanetary Program to Optimize Simulated Trajectories - Sample Cases

This work was conducted under the direction of Mr. Richard W. Powell of the Space Systems Division, National Aeronautics and Space Administration, Langley Research Center.

A number of people contributed to the development of IPOST and to this report. The first issue (Reference 1) was delivered in March, 1990, with the support of Garry Brauer, Sandy Fitzgerald, Phil Hong, Perry Kent, Mac Milleur, Dave Olson, Fred Petersen, and Beth Swickard. The current revision and expansion of IPOST and this report were developed by Garry Brauer, Phil Hong, Perry Kent, Dave Olson, Larry Rockwell, Brian Sutter and Candy Vallado with acknowledgement to Dick Powell, Scott Striepe and Prasun Desai at Langley Research Center for their inputs, suggestions and support.

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1.0 INTRODUCTION

The Interplanetary Program to Optimize Simulated Trajectories (IPOST) is intended to support many analysis phases, from early interplanetary feasibility studies through spacecraft development and operations. The IPOST output provides information for sizing and understanding mission impacts related to propulsion, guidance, communications, sensor/actuators, payload, and other dynamic and geometric environments.

Much of the overall architecture for IPOST has been derived from the Program to Optimize Simulated Trajectories (POST) (Reference 2). Indeed certain POST parameters and capabilities have been incorporated into IPOST to aid in POST-IPOST user compatibility. IPOST has extended trajectory capabilities to target planets and other celestial bodies with intermediate and velocity correction maneuvers. IPOST capabilities and limitations are summarized in Table 1-1.

FEATURE	CAPABILITY
Optimization method	Explicit (Master/subproblems), Implicit (collocation)
Optimization algorithm	NPSOL
Optimization parameter*	ΔV magnitude, mass, time, . . .
Maximum controls	25 (Master), 45 (subproblems), 1700 (collocation)
Control parameters*	Values of event criteria, ΔV, arrival conditions, thrust, . . .
Maximum targets	25 (Master), 45 (subproblems), 1700 (collocation)
Target parameters*	Time, position, velocity, orbital conditions, . . .
Targeting method	NPSOL, Newton-Raphson, special Onestep
Sensitivity matrix	Finite differencing, analytic for special interplanetary targeting
Maximum events	100
Event criteria*	Time, distance, speed, closest approach, . . .
Event activities	Info, impulsive ΔV, launch, orbit insertion, mass jettison
Maximum maneuvers/ subproblems	15
Trajectory propagation	Conic, Onestep, Multiconic, Encke, Cowell, implicit
Planetary bodies	Sun, nine planets, Earth's moon, any user-defined bodies
Ephemeris	Analytic, precision (JPL)
Trajectory perturbations	Central body, perturbing bodies, radiation pressure, J2, aerodynamics, thrust
Input/Output frames	Ecliptic or planet equator, Mean 1950 or Mean 2000
* User selectable	

Table 1 - 1. IPOST Features/Capabilities

IPOST, along with members of its family, such as POST and IPREP, can analyze and support almost every activity associated with space exploration.

IPOST is event driven. That is, the user defines a sequence of events which are executed in the simulation process. The events can be triggered by different criteria, such as absolute or relative time, distance from a body, or propellant consumption. At the event times, various activities can be initiated or terminated, such as employing a different thrust steering law, changing trajectory propagators or propagation step size, performing an impulsive delta velocity maneuver or jettisoning a probe or stage.

The time period between two contiguous events is called a phase. Trajectory propagation takes place in each phase. Five types of propagators are available (listed in order of increasing accuracy and decreasing computational speed): Conic, Onestep, Multiconic, Encke, Cowell. Propagator selection depends upon user needs, such as simple fast simulations for parametric feasibility analysis, or precision detailed trajectories to support subsystem design.

IPOST can run a single trajectory simulation or it can run multiple simulations. For multiple simulations, one can run a parametric scan and/or an optimization mode. The search mode will vary one parameter, such as planetary arrival time, over a specified interval and increment size, and perform a simulation (or optimization) for each search parameter value.

The optimization mode will optimize a user cost/objective function, such as maximum mass that can be placed in a desired orbit, subject to user-specified constraints. The constraint variables, such as periapsis altitude or orbital inclination, are called dependent variables or target parameters. The parameters which are free to vary, such as maneuver delta velocity (ΔV), are called independent variables or control parameters. As part of, or instead of, optimization, trajectory targeting can be performed. In this case, there is no cost function and the IPOST problem reduces to finding a set of control parameter values that meet specified target parameter conditions.

Generalized targeting and optimization uses the Stanford NPSOL algorithm. For certain types of problems, a trajectory decomposition method is available. There is a master optimization process which requires that the trajectory be divided into legs or sub-problems. Each subproblem is an optimization problem in itself, containing controls, constraints and an (optional) objective function. A special application of decomposition is the Interplanetary Targeting and Optimization Option (ITOO). This technique uses analytical partials generated during nominal trajectory propagation to determine minimum ΔV (or mass) trajectories, usually for gravity assist (swingby) missions.

In addition to the classic method of explicit optimization, there exists an option to perform implicit optimization using the collocation method. In this case, each phase is divided into independent segments which are allowed to vary subject to intersegment continuity and the equations of motion. Optimization using collocation is less sensitive to faulty initial guesses, but requires much greater CP time than explicit optimization to achieve the same level of accuracy.

IPOST input is via three namelists: $TOP, $TRAJ and $TAB. $TOP contains a description of the targeting and optimization problem. It must be input first. $TRAJ contains data that describes each mission event/phase. It must follow $TOP and there must be one $TRAJ for each event. $TAB is used to input tabular data such as thrust vs. time or drag coefficient vs. mach number and angle of attack. Input and output units are metric.

2.0 MISSION ANALYSIS TOOLS

The general area of mission analysis includes both atmospheric and exo-atmospheric flight. Although many software tools have been developed, only a few have proved to be useful for practical engineering studies. The POST family has evolved over the last 20 years to provide government and industry users with the capabilities to analyze all regimes of flight.

2.1 THE POST FAMILY

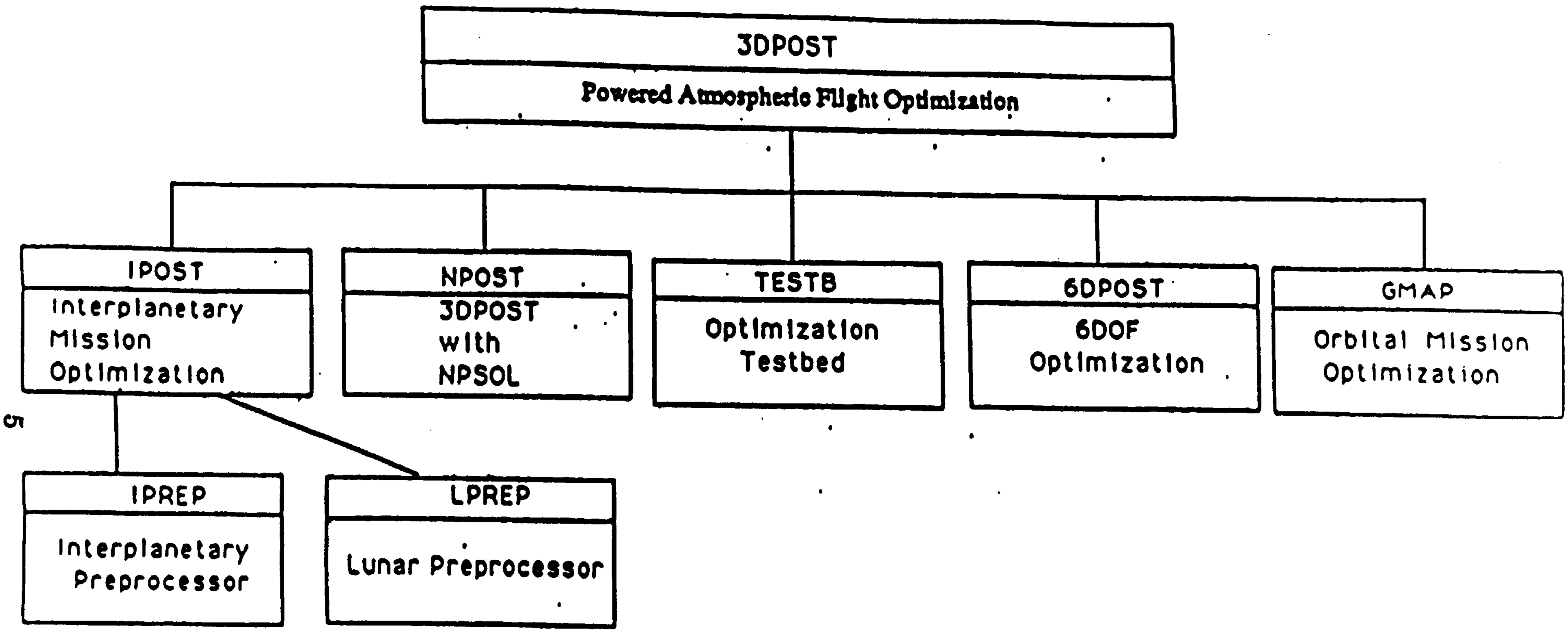
POST was developed in 1970 as a Space Shuttle Trajectory Optimization Program. Since that time, the program has been significantly improved with additional capabilities in the areas of vehicle modelling, trajectory simulation, and targeting and optimization. As the need has grown to analyze diverse missions, POST has spawned a number of related programs. In 1988, IPOST development was initiated in order to analyze future interplanetary missions. The complete POST family of tools consists of IPREP (Interplanetary PREProcessor), LPREP (Lunar PREProcessor), IPOST, TESTB (Testbed), GMAP (General Mission Analysis Program), NPOST and 6DPOST. (see Figure 2 - 1)

POST is capable of simulating and optimizing trajectories for aerodynamic vehicles operating in the vicinity of a single planetary body. POST can optimize a variety of trajectory problems, such as launch and ascent to orbit or escape, entry and landing of a probe, optimal aircraft cruise profiles, and vehicle guidance and control. Previous applications of POST have included launch vehicle and trajectory design for Voyager (Earth liftoff to hyperbolic escape), Mars ascent vehicle design (MRSR - Mars Rover and Sample Return), Manned Earth entry (return from Mars) simulation, and single stage to orbit (e.g. NASP - National AeroSpace Plane).

NPOST expanded on POST by using the NPSOL algorithm rather than PGA (Projected Gradient Algorithm) to provide an alternative technique which proved to be more robust. NPOST is currently used to optimize Titan II and Titan IV ascent trajectories.

6DPOST added rotational degrees of freedom and guidance feedback to POST, along with an improved input processor. An example of a 6DPOST application is Titan IV guidance coefficient and autopilot design for flight profiles requiring wind relief.

GMAP, developed in the mid-1970's, performs orbital mission optimization. Emphasis has been directed toward the evaluation of Earth synchronous missions, sun synchronous missions, drag influenced low altitude missions, and Shuttle applications. GMAP is applicable to a wide variety of mission analysis problems such as maneuvering and stationkeeping. Maneuver models include impulsive and finiteburn with various guidance and targeting schemes. GMAP contains a passive orbiting target vehicle to allow for simplified rendezvous analysis. There is no interplanetary capability beyond that of injecting a given payload to the desired outgoing asymptote. Examples of GMAP applications include multi-vehicle rendezvous simulation and multiple impulse LEO to GEO orbit transfer (minimum fuel).



POST Family Figure 2-1

TESTB is a software testbed containing simple 2 degree of freedom simulation models of launch vehicles and interplanetary missions. It allows for rapid prototyping and characterization of trajectory optimization concepts. Before implementation of new algorithms into highly complex programs such as IPOST and POST, TESTB can be used for proof of concept demonstration. TESTB has been used to compare NPSOL with PGA , as well as with stochastic optimization methods, and for collocation development with trajectory applications.

IPOST was developed from the POST architecture in direct response to interplanetary space exploration needs. Many of the trajectory simulation models were changed, while retaining the basic constrained parameter optimization capabilities of POST. As IPOST development progressed, it was clear that the non-linearities of interplanetary flight required feasible initial guesses for the optimization control parameters. Thus were born IPREP and LPREP.

IPREP and LPREP provide rapid grid-searches across launch and arrival windows. These scans of mission opportunities result in selection of a minimum energy solution. For speed of execution both programs use simple propagators (no integration) and minimal perturbing forces. IPREP/LPREP can be used as standalone mission opportunity characterization tools and/or to provide initial conditions for IPOST.

IPREP/LPREP model planetary phases of launch, arrival, flyby and orbit. Planetary constraints include event dates, flight time and trajectory/orbit conditions. Mission options include ballistic partial and multiple revolutions (Type I, II, III, etc.), low thrust (e.g. SEP and NEP), high thrust (impulsive), and gravity assist. Applications of IPREP/LPREP have included Voyager mission verification, solar probe mission design, and space station departure with lunar free return mission design.

The POST family has been developed to operate as a set of coherent mission analysis tools. For example, recent interest in manned space exploration has identified landing on Mars as a top national priority. One representative mission is illustrated in Figure 2 - 2.

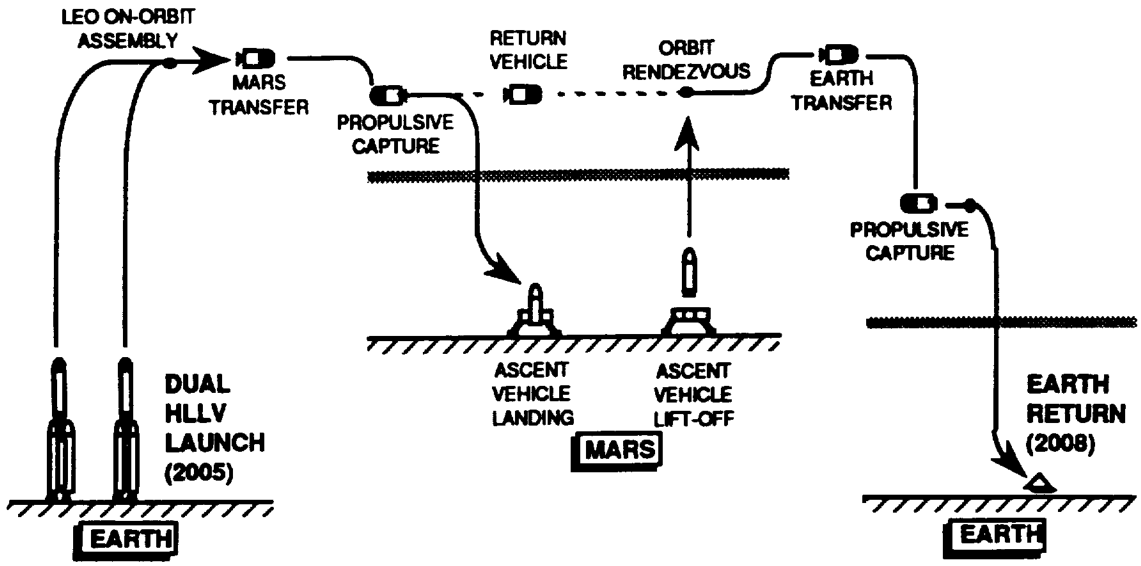


Figure 2 - 2. Mission to Mars

Application of IPREP, IPOST and POST to the representative Mars mission is shown in Figure 2 - 3. A number of alternative mission options can be examined including nuclear thermal propulsion, Venus gravity assist for outbound or return legs, abort trajectories and modes, and propulsive vs. aerobraking orbit capture. IPREP is initially used to define Earth launch windows and escape energy, Mars arrival time and orbit insertion energy, Mars stay time and escape energy from Mars, and Earth return windows and orbit capture energy. This information is used in IPOST to define precise trajectory and performance data for each major mission leg: Earth to Mars, Mars orbit, Mars to Earth. POST is used to simulate and design the atmospheric flight portion: Earth liftoff to escape, Mars entry and landing, Mars surface ascent to orbit, and Earth entry to touchdown. Together, all three programs provide a synergistic simulation and optimization capability which complements the overall system design and analysis. Input and output for each program has been designed to allow smooth connectivity across programs.

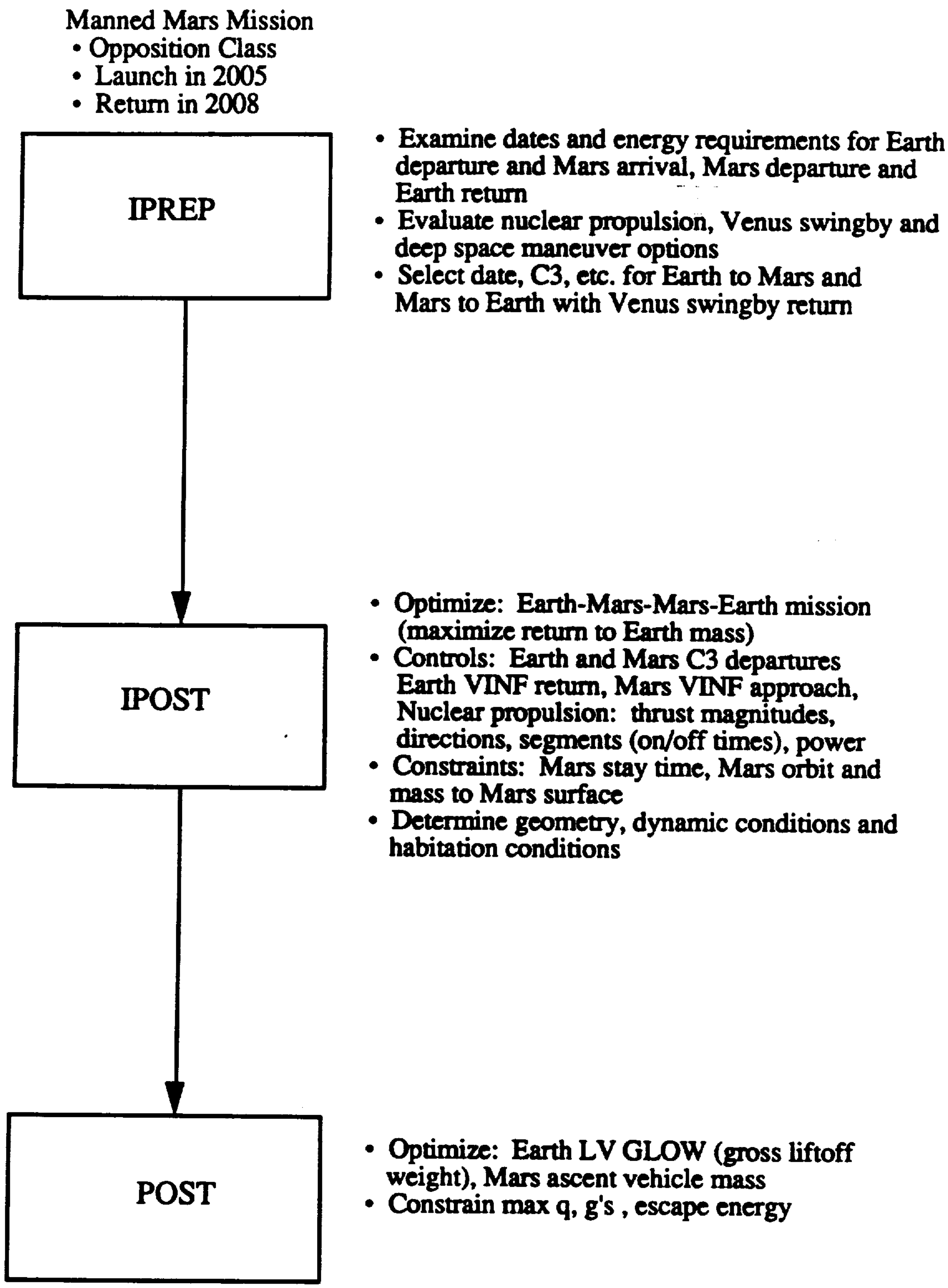


Figure 2 - 3. Interplanetary Mission Analysis Example Problem

2.2 COORDINATE SYSTEMS

There are many types of coordinate systems used in mission analysis applications. IPOST provides a number of systems to allow the user a maximum amount of analysis insight and flexibility.

2.2.1 INERTIAL ECLIPTIC SYSTEM

This system is used during heliocentric (sun-centered) interplanetary flight, although it is sometimes used as a fixed reference frame for the entire mission.

Center of system	-	the sun, planetary bodies, or planetary satellites
Primary plane	-	Earth ecliptic
X - axis	-	Earth vernal equinox direction

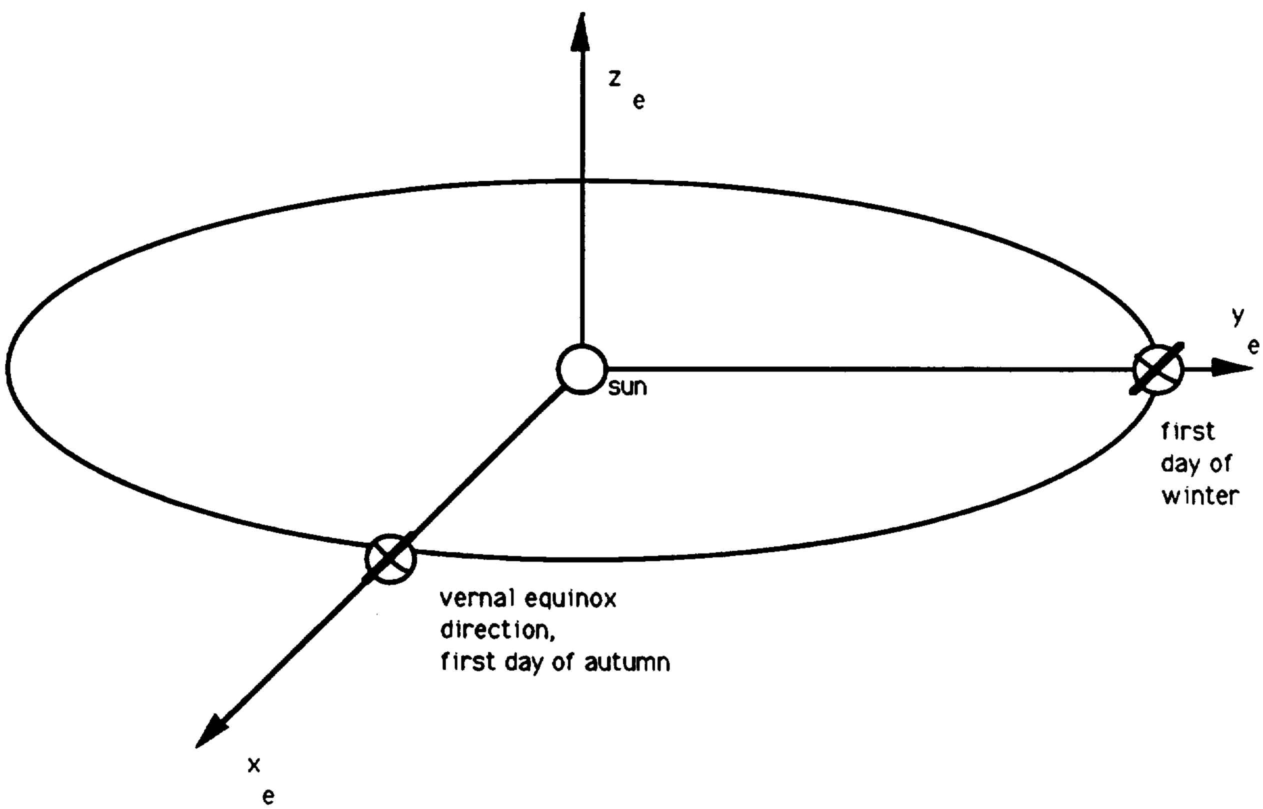


Figure 2 - 4. The inertial ecliptic coordinate system.
(The center can also be at any of the planetary bodies and satellites)

2.2.2 INERTIAL PLANETARY EQUATOR SYSTEM

This system is used during flight near a planetary body.

Center	-	planetary body
Primary Plane	-	planetary equator
X - axis	-	rotation of planetary vernal equinox direction through right ascension and declination angles of the planetary pole vector.

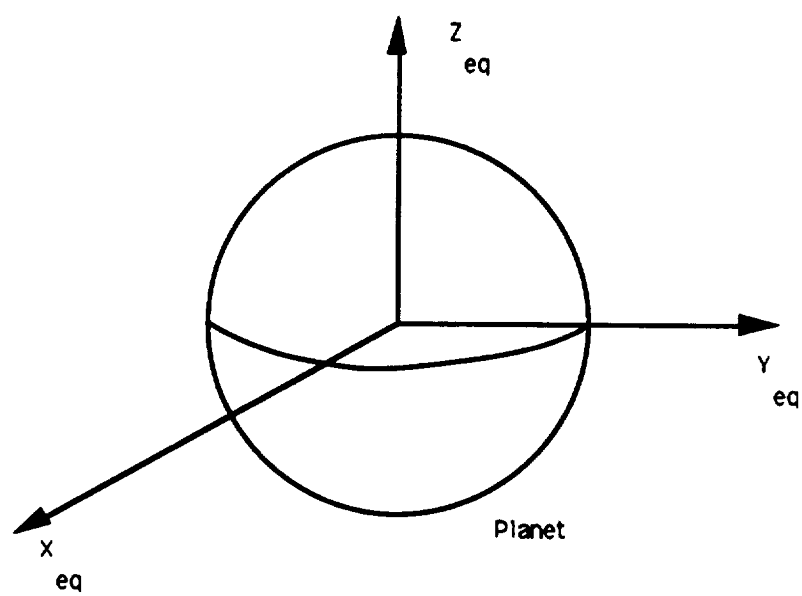
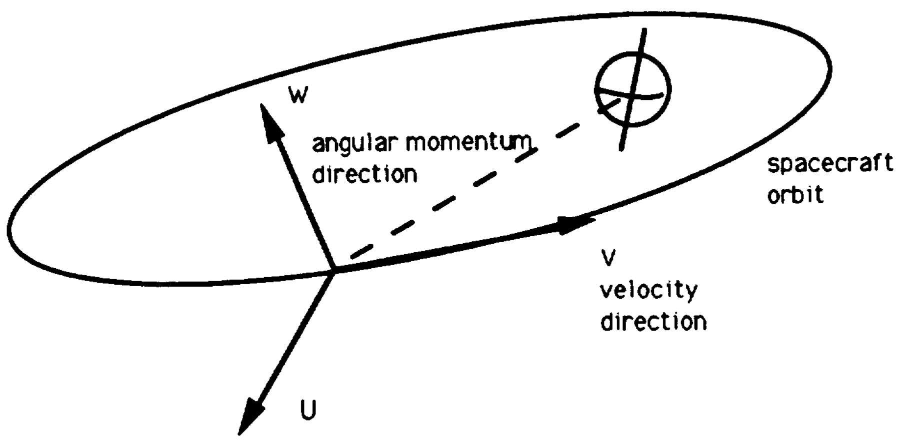


Figure 2 - 5. The planet equatorial coordinate system.

2.2.3 UVW SYSTEM

This system is used for vehicles whose longitudinal axis or whose thrust axis is along the velocity vector.

Center	-	S/C center of mass
Primary Plane	-	orbital plane of S/C
Primary axis (X)	-	cross product of S/C velocity U = V x W direction and S/C angular momentum direction



$$V = \frac{\vec{v}}{|\vec{v}|}$$

$$W = \frac{\vec{r} \times \vec{v}}{|\vec{r} \times \vec{v}|}$$

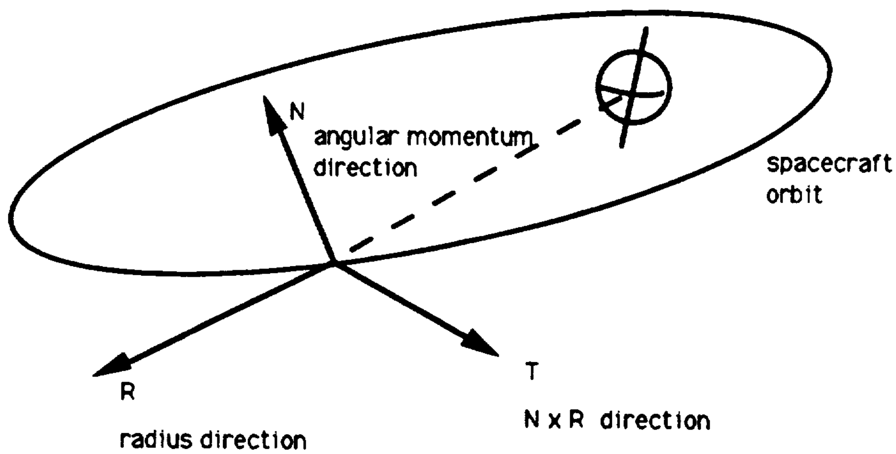
$$U = V \times W$$

Figure 2 - 6. The UVW Coordinate System.

2.2.4 RTN SYSTEM

This system is used for vehicles whose longitudinal axis is along the local vertical, such as gravity gradient stabilized s/c.

Center	-	S/C center of mass
Primary Plane	-	orbital plane of S/C
X - axis	-	radius vector direction



$$\vec{R} = \frac{\vec{r}}{|\vec{r}|}$$

$$\vec{N} = \frac{\vec{r} \times \vec{v}}{|\vec{r} \times \vec{v}|}$$

$$\vec{T} = \vec{N} \times \vec{R}$$

Figure 2 - 7. The RTN Coordinate System.

2.2.5 THE BODY FRAME COORDINATE SYSTEM

The body frame is used in conjunction with other reference frames to orient the vehicle in celestial space, and to identify locations and orientations of vehicle components, such as the primary thrust vector and antenna boresights.

Center	-	S/C center of mass
x_b axis	-	from center of mass through nose of S/C,
z_b axis	-	from center of mass through bottom of S/C, orthogonal to x
y_b axis	-	$\hat{x}_b \times \hat{z}_b$
P	-	pitch
R	-	roll
Y	-	yaw

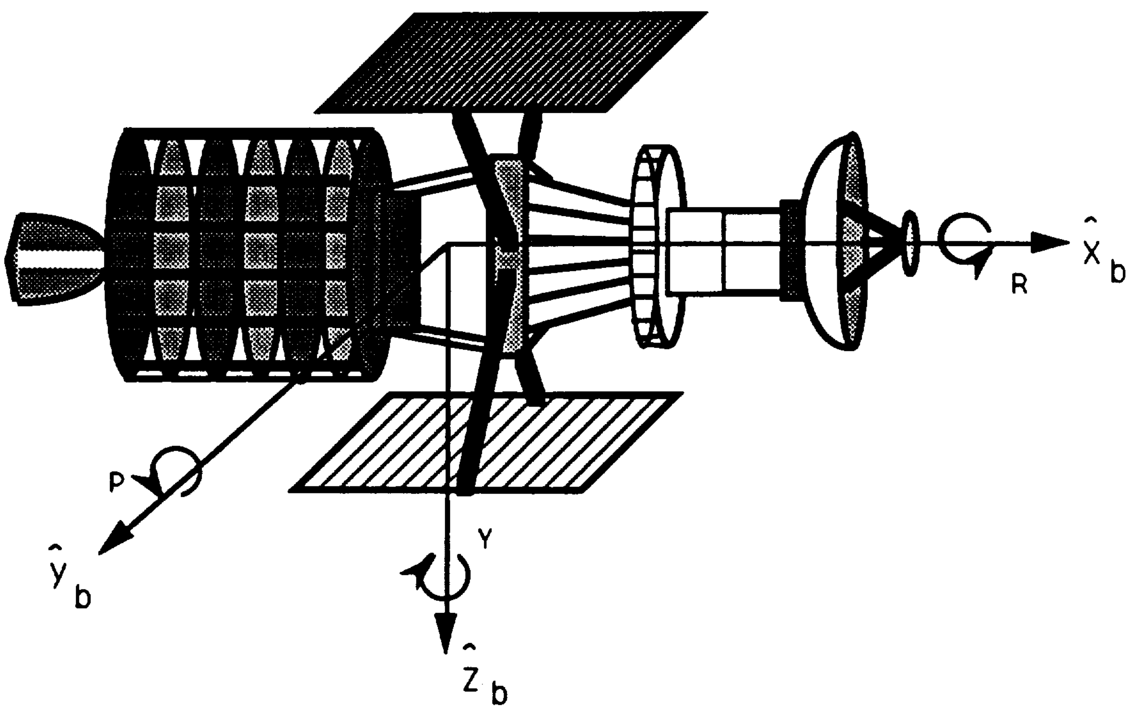
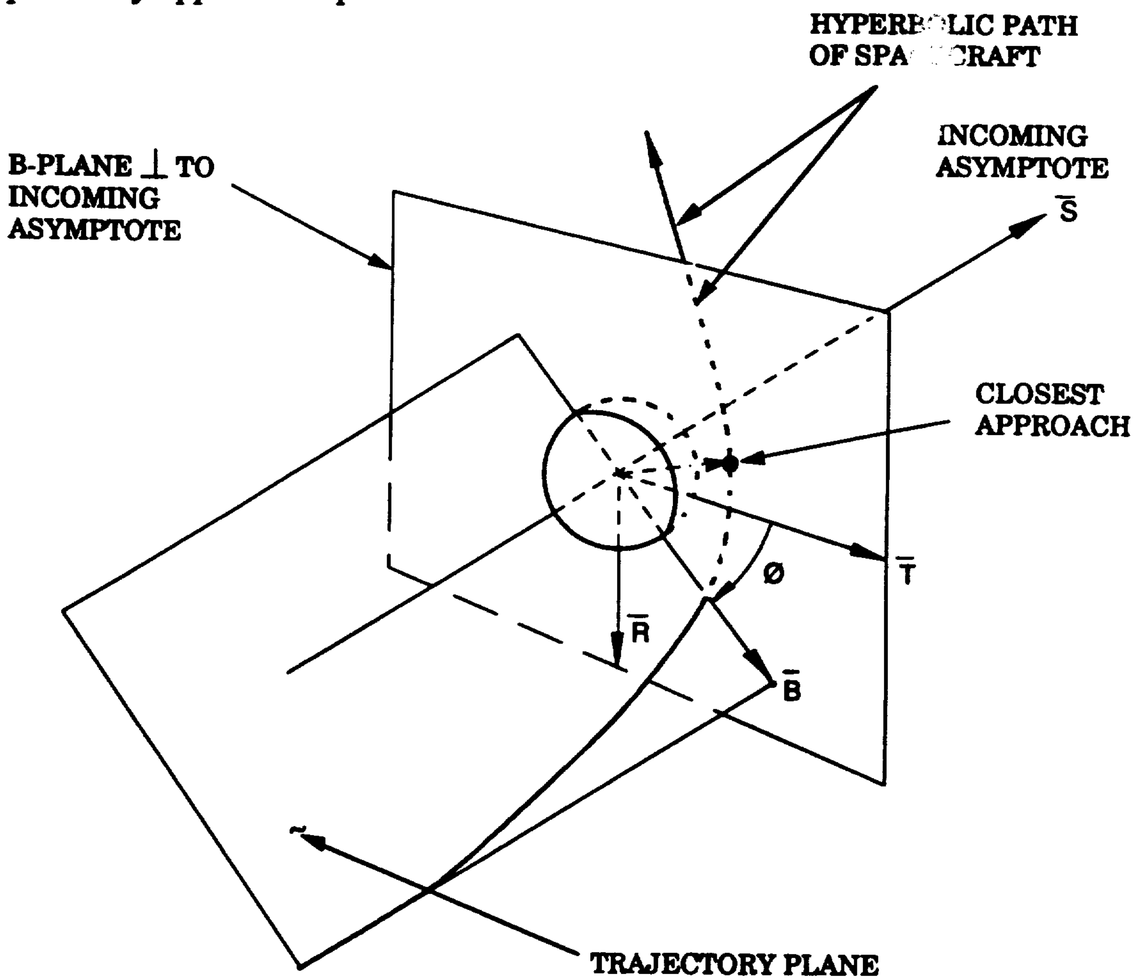


Figure 2 - 8. The body coordinate system.

2.2.6 THE B-PLANE

The B-plane coordinate frame is used for hyperbolic approach to, and departure from, a celestial body. It is often the most numerically stable system for describing planetary approach/departure conditions.



$\vec{B}$ = Impact Parameter (Vector from Planet Center to Aiming Point)

Ø = Orientation of $\vec{B}$ Relative to $\vec{T}$

$\vec{S}$ = Parallel to Incoming Asymptote

$\vec{T}$ = Parallel to Reference Plane (Ecliptic Unless Otherwise Specified)

$\vec{R} = \vec{S} \times \vec{T}$

Figure 2 - 9. B-Plane Coordinate System

2.2.7 CONE-CLOCK

The cone-clock system is used for determining the orientation of vehicle sensors and actuators. One application is to transform IPREP and QTOP thrust data into IPOST usable thrust acceleration profiles.

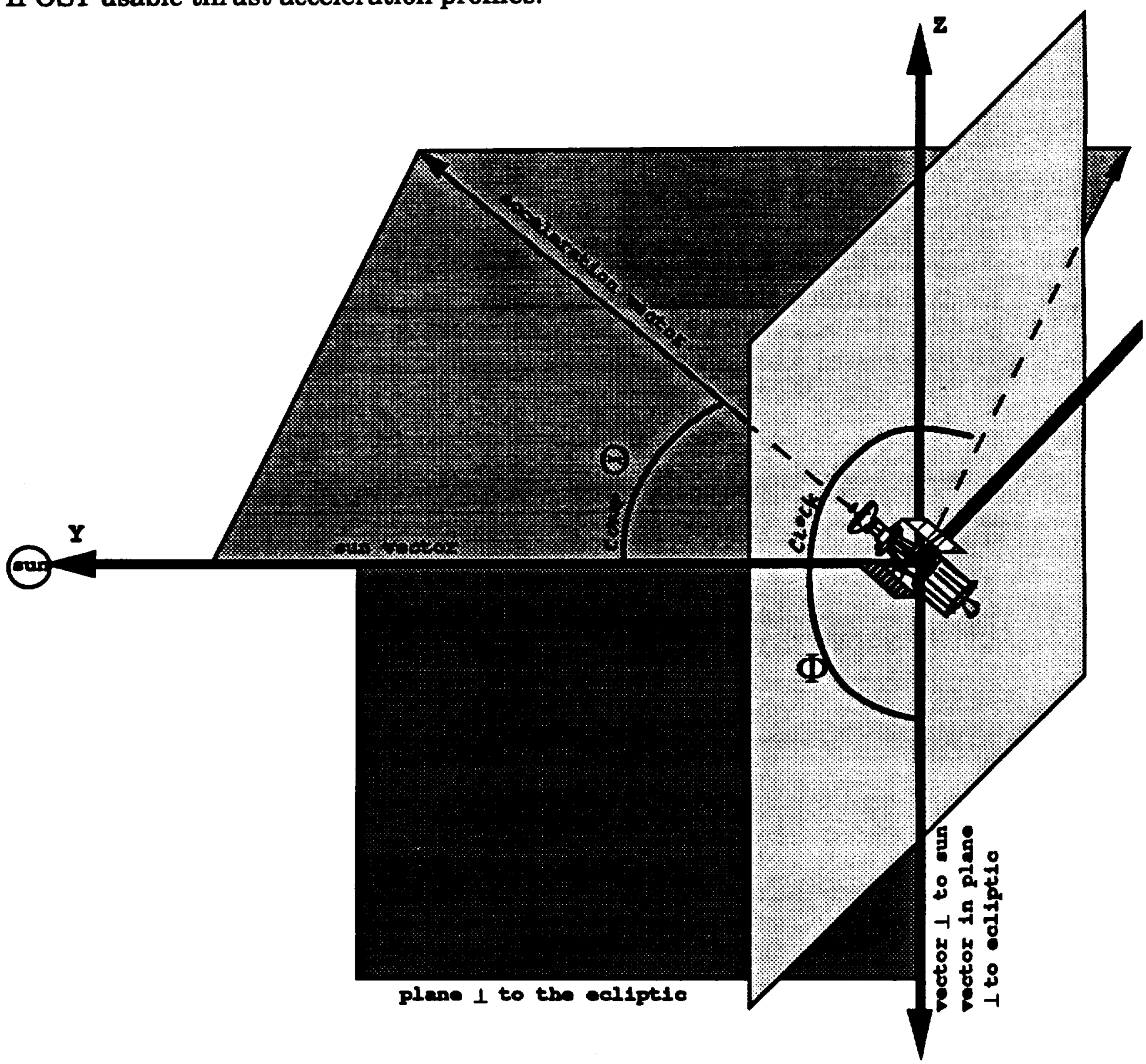


Figure 2 - 10. Cone/Clock Coordinate System

3.0 INTERPLANETARY MISSION ANALYSIS

Mission analysis is used to support all aspects of space exploration and applications missions (Figure 3-1). It covers both breadth and depth. In terms of breadth, mission analysis provides quantification, and optimization if needed, of desired performance measures for any major mission option. These options include planetary body encounters, means of propulsion, payload configurations, technology status, and mission goals. In terms of depth, mission analysis provides data used to support all levels of system/vehicle/ subsystem design and assessment.

Mission analysis provides information related to geometry, dynamics, event times/conditions, and mass/energy relationships. With this information, a great number of activities are supported. In addition to those activities listed in Table 3-1, mission analysis can have strong interactions with structural design and stress analysis, human factors and life support, including habitation and bio-engineering, payload design, including science and instrumentation analysis, and life cycle cost/risk assessment.

Mission Performance	Assessing measures of effectiveness; Performance optimization; Trading off of mass-energy-time
Propulsion	Optimization of propulsion performance; mode vs. phase, thrust vs. time, specific impulse, stage jettison, propellant and system mass
Communications	Analysis and optimization of coverage, link margins, positioning/pointing, blockage
Power	Assessing types of power sources and consumption patterns; Determining vehicle and solar array pointing
GN&C	Error analyses; Development of guidance and navigation requirements and capabilities; Design/analysis of sensor control systems
Thermal	Determining peak and cumulative thermal loads for active and passive systems
Operations	Developing mission profiles and event sequences; Determining command and telemetry data and rates; Sizing of software and data processing

Table 3 - 1. Representative Mission Analysis Applications

The breadth and depth of mission analysis depends upon the development phase. Pre-phase A studies involve early feasibility and concept definition. Usually the starting point is a desire to depart Earth within some large time window and to arrive at a desired target body, e.g., Saturn or a libration point. Only a few mission objectives are specified, such as robotic vs. human, or surface probe vs. orbiter. Mission constraints, for example launch vehicle type or interplanetary propulsion mode, are often ill defined. Intermediate mission objectives, such as flyby of another object of interest, are also open for investigation as mission enhancements or to improve mission viability. For mission concept studies simple software tools are used because large numbers of concept variations must be assessed and compared. This is the realm of tools like IPREP and LPREP. The output of pre-Phase A studies is a preliminary definition of mission opportunities and constraints, with identification of potential difficulties, or "tall poles".

Phase A studies examine mission feasibility, including preliminary definition of subsystem characteristics and performance. At this level, vehicle design is still very flexible, or "rubbery". System definition must address solutions to the tall poles identified in pre-Phase A studies. The need is for rapid, but reasonably accurate, vehicle trajectory information. Simulation models must be flexible and contain sufficient detail to provide reliable comparison of options. Robust performance optimization is needed because of widely varying initial conditions and environments. Phase A output is a set of feasible mission designs and performance comparisons, including preliminary subsystem design, usually with a recommended baseline. IPOST is the tool of choice, using simplified model options.

Phase B studies define the mission and system in detail. Each mission phase from liftoff through mission completion is simulated using models which accurately reflect all relevant mission activities and environments. In order to provide information on vehicle and subsystem performance, specific phases often are optimized, such as launch vehicle ascent, as well as multiple phases, such as Earth departure to Mars landing. Both IPOST and POST are the tools of choice depending upon what mission phases are to be examined. The output of Phase B studies is a complete mission and system design from which hardware and software can be developed and tested.

Phase C/D refers to conducting the operational and post-flight activities. Here the emphasis of mission analysis is on data base generation and validation, planning activities, such as maneuver design and implementation, anomaly resolution, and simulation support. IPOST (and POST) can be used to play "what if" games, such as contingency planning, troubleshooting, or mission redirection.

A general flow of mission analysis activity using IPOST is shown in Figure 3-2. This flow can be modified and used for all development phases. It demonstrates (a) early concept evaluation using IPREP/LPREP, with possible verification using IPOST, (b) end-to-end simulation/optimization needed for feasibility studies, and (c) the more detailed design/assessment used for system definition, production, integration and operations. IPOST output is used by the mission analyst to support all elements of the system (such as Figure 3 - 1) in a highly interactive and iterative fashion.

The following sections discuss the major elements of mission analysis. These include early concept comparison characterized by mission opportunity definition, vehicle and trajectory simulation, mission performance optimization, and how to set up IPOST to support the various mission analysis needs.

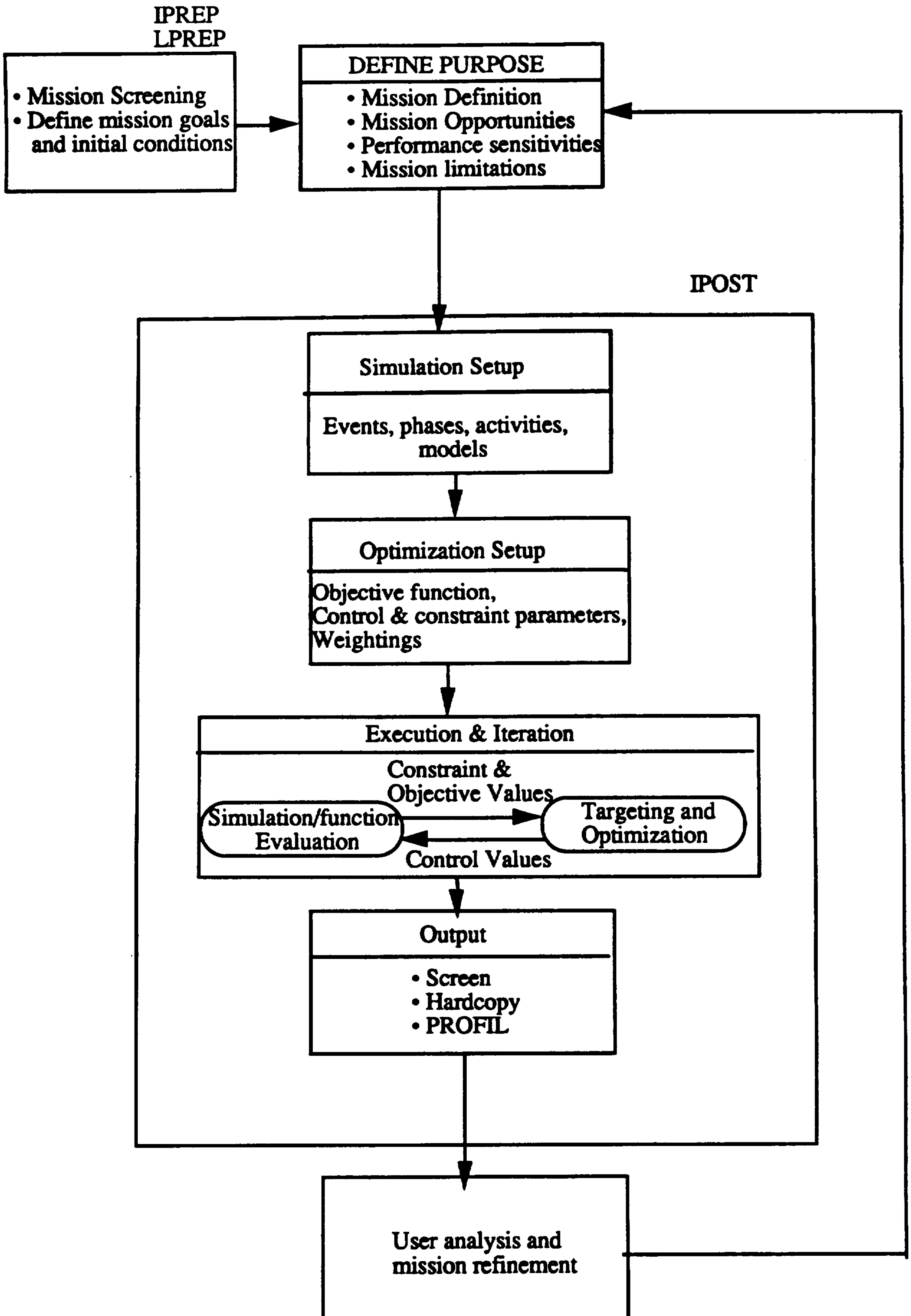


Figure 3 - 2 IPOST ACTIVITY FLOW

3.1 MISSION OPPORTUNITIES

A definition of mission opportunity would be the time to launch a S/C such that the mission meets requirements as well as optimizes certain mission characteristics, such as total ΔV, or initial mass. In other words, what are the mission conditions that get the most performance for the least cost. Occasionally, certain mission constraints prevent reaching an absolute optimum. Opportunities can still be found which meet mission constraints and represent a local optimum. There are also situations, due to the constraints imposed, where no feasible mission exists. Constraints include such things as boost capability vs. payload required, delta-v capability vs. delta-v required, launch times allowed due to planetary alignment, etc. There are a multitude of constraints which can be imposed as well as a multitude of variables to be optimized.

Simple trajectory models, such as conics and patched conics, are used to do quick mission opportunity studies. Grid-search type optimization can be used to look at large time spans, in which many missions are run and contour plots can be created over time to view changes in the cost function relative to departure and arrival dates.

To do pre-Phase A interplanetary mission opportunity studies, IPREP was created. Control of the mission design is left up to the user, such as, where the mission will fly, how to get there (high, low thrust, hybrid), what are the main concerns to optimize (minimize delta-v, maximize payload), and regions where the search for mission opportunities should occur. Once the basic mission is designed, the user may use IPREP to find a "best" mission, the top number of "best" missions, or a large set of data displaying encounter time and each mission cost so graphical mission studies may be performed. After the user has identified desirable mission performance regions, IPOST may be used to generate more accurate trajectory analyses and improve on this data.

IPREP uses a simple conic propagator and Lambert method (Reference 4) for ballistic segments, and Chebytop polynomial representations (Reference 5) for low thrust segments, of interplanetary trajectories. Gravity assist is modelled as an instantaneous velocity change. The grid search is performed on a user input time window for any body encountered during the mission. The best mission is calculated by the minimum cost, which is a user-selected weighting of initial mass and each maneuver ΔV, arrival velocity and departure velocity. IPREP can be used to generate the initial conditions for IPOST for interplanetary missions. By using IPREP, the user is able to generate more accurate initial conditions, thus saving IPOST computer and user analysis time.

To perform pre-Phase A lunar mission opportunity studies, LPREP has been created. As an offshoot of IPREP, it maintains the capability to search large regions of time quickly to perform mission opportunity analyses, and to generate initial conditions for IPOST.

Since the earth-moon problem is a three body problem rather than the more typical two body problem of interplanetary formulations, LPREP uses patched conics and actual targeting with a Newton-Raphson technique. Lunar mission conditions are generated to the same fidelity as interplanetary conditions. As in IPREP the grid search is performed on encounter time (launch and arrival) and optimization is done on total mission ΔV or with a generalized cost function.

A complete guide to usage of IPREP and LPREP may be found in Appendix B.

3.2 TRAJECTORY SIMULATION

A trajectory simulation is described by characteristics of the vehicle and by how the vehicle behaves over time (Table 3-2). It is important to define vehicle related characteristics because they represent necessary conditions that must be met, as well as the limits of trajectory fidelity, or accuracy.

VEHICLE MODEL	Propulsion Type	Nuclear Solar Chemical
	Aerodynamics	Lift Drag (constant coefficient or tabular)
	Mass	Variable (finite and impulsive thrust) Jettison
	Event Activities	Launch Orbit insertion Midcourse correction Jettison Planet/body or other changes
TRAJECTORY MODEL	Event Criteria	User selectable trigger parameter e.g., closest approach
	Event Categories	Primary Secondary Roving
	Propagation Methods	Explicit (Conic, Onestep, Multiconic, Encke, Cowell, and time step size) Implicit (Hermite polynomials over time segments)
	Environmental Forces	Central body asphericity Other body gravitational disturbances Atmosphere Solar Pressure

Table 3 -2 . Simulation Characteristics

Vehicle characteristics in a trajectory sense are associated with forces acting on the vehicle. Thus, it is necessary to describe propulsive modes (if any), aerodynamic properties (if any), and changes which affect mass properties, such as staging or reconfiguration.

Trajectories are organized by time ordered **events**. The events can represent instantaneous activities, such as initiation of a pitch rate or rocket ignition, and functional activities which are approximated as an instantaneous process, such as launch to escape or an orbit insertion maneuver. Events can also be user directed changes for simulation purposes, such as changing propagation methods or activating output displays. A **phase** is the time period between consecutive events.

At any point in time, the vehicle can be described by a seven element **state**, e.g., 3 cartesian position components, 3 cartesian velocity components, and mass. The vehicle state must always obey the equations of motion which operate between contiguous events, that is, during phases.

In general, there are two methods of computing a vehicle state between events, explicit and implicit. The **explicit** method requires an initial state, at completion of the starting event. The equations of motion are integrated, either analytically, numerically or both, such that the state at the beginning of the destination event is computed. States at intermediate times are computed by interrupting the trajectory propagation at the desired time(s). Historically, explicit methods are the most common process for predicting future states.

The **implicit** method requires vehicle states on each end of a time interval, either a phase or a phase segment. The start and end states of a phase or phase segment are used to generate coefficients of a vector function, such as a third order polynomial for each state component. Intermediate states are obtained by evaluating the vector function (interpolation). Implicit methods are often used during post-processing of results generated by explicit methods. Certain optimization methods, such as collocation, make use of implicit simulation representations.

3.2.1 EVENTS AND PHASES

Events and phases for a mission simulation must be organized with the specific application in mind. For feasibility assessments, many rapid simulation runs may be needed, either through a parametric scanning process or using targeting/optimization for a number of cases. The simulation should have as few events/phases as possible to speed up the run time. Typically, impulsive ΔV maneuvers and instantaneous activity approximations are used. Examples of the latter include launch to escape (LAUNCH) and orbit insertion from a hyperbolic approach (ORBINS).

For quick simulations, the criteria, (CRITR), for triggering events should be mission time, as opposed to a non-time criteria parameter, such as closest approach, because the simulation process must compute time-to-go in an iterative fashion for each propagation step.

As the accuracy of mission design increases, more detailed models and a finer structure of events/phases are needed. Formerly impulsive maneuvers may become finite burns with an event to initiate thrusting and an event to terminate thrusting. For even greater accuracy, the thrust period may be divided into thrusting and coasting segments. Thrusting segments may be divided further into segments which alter the thrust profile, such as changing the throttle levels or thrust vector orientation controls.

There is also the option to introduce different force models (see 3.2.2) in different propagation algorithms (see 3.2.3) and to alter step sizes depending upon mission phases. Usually there is also a need to change coordinate frames and/or planetary bodies for ease of user understanding or for propagation accuracy. All of these simulation alternatives are accomplished through changes in the event activity specification.

In addition to specifying event criteria and activities, IPOST allows the user to specify the event category. The **primary event category** is the most widely used. It is always triggered whenever the respective event criteria is encountered. Primary events must occur in consecutive order. A **roving event** can occur any time after its initiation when its criteria are met.

3.2.2 VEHICLE FORCES

The forces applied to the S/C during flight have a significant effect on the actual trajectory. Different mission phases and desired simulation accuracies dictate which forces are important. Studies can be done by turning forces on and off to aid the decision-making process of which forces are necessary to achieve the desired trajectory accuracy. Table 3 - 3 lists the vehicle forces implemented in IPOST including what trajectory propagators ~~can be used.~~

VEHICLE FORCES	IPOST RELATED VARIABLES	FORCE MAGNITUDE*
Central Body Gravity	IPBODY, GMU	$F = -\frac{\mu m}{r^2}$
Propulsion • Low Thrust • Nuclear or solar electric • High Thrust - Impulsive/event - General, tabular	IFORCE (5), PRPDT, SPI THRUST, WPROP, WJETT	 $F = \frac{2 \eta P(r, t)}{g I_{SP}}$ $F = \infty$ $F = F(m, t) - A_E P_A$
Gravitational Perturbations • Nonsphericity of central body • Noncentral bodies	 IFORCE (2), GJ2 IFORCE (1), RSOI, TSOI	 $F = F(J_2, \mu, \vec{r})$ $F = \sum_{i=1}^{n} \frac{\mu_i \vec{r_i}}{r_i^3}$
Radiation Pressure	IFORCE (3), SCSFA	$F = \frac{S_0 C_R A}{r^2}$
Aerodynamics • Drag and Lift • Atmospheric Density - Exponential Model - Pressure/Temp. vs. alt.	IFORCE (4), CD, CL IATMOS, ATMS, SCDRAG, ALT, PRES, TPT, ITABSZ	 $F = \frac{1}{2} \rho v^2 C_L A$ $F = \frac{1}{2} \rho v^2 C_D A$ $\rho = \rho_0 e^{-h/h_0}$ $\rho = \rho(p, T)$
* See Analytic Manual for detailed force model descriptions		

Table 3 - 3. Vehicle Forces

A force which is always active is the central body gravitational acceleration. During interplanetary flight the vehicle passes from one central body influence to another.

A major vehicle force is propulsion. During early concept feasibility, propulsive thrust is often modelled as an instantaneous velocity change, or impulsive ΔV ($F = \infty$). The simplicity of ΔV allows for rapid simulations which are needed in the parametric investigations of concept definition. As the vehicle and mission design progresses, higher fidelity propulsion models are needed, in particular finite thrust. Nuclear and solar electric propulsion provide very low thrust, on the order of .01g's or less. Low thrust propulsion must be activated for long mission times to accumulate sufficient orbit energy changes. High thrust propulsion typically operates over short durations. These include chemical systems, such as pressure regulated and blowdown. A moderate thrust propulsion technology is currently being advocated, namely nuclear thermal systems. All of these propulsion systems can be modelled in IPOST including user specified models, such as through tabular specification.

The most often utilized non-central body forces in interplanetary space flight are the gravitational forces of other planetary bodies. These are usually perturbations until the S/C approaches the sphere of influence (SOI). In this case the primary and secondary body forces are the same order of magnitude and the secondary forces can no longer be considered a mere perturbation, but also a major force. In interplanetary flight, the forces of other planets can have an effect on the shape of the trajectory. When in orbit about Earth, particularly for GEO S/C, the Sun and moon can have a significant effect on the orbit. This is the same for other planets and their satellites. While, from a mission opportunity standpoint, these effects may be small and less important, they need to be considered for highly accurate trajectories to be obtained.

When in orbit about planetary bodies, asphericity of the gravitational field can also have a significant effect on the S/C trajectory. IPOST models the predominant aspherical term, J_2.

Solar radiation exerts small forces on a vehicle with trajectory effects that accumulate over time. Radiation pressure effects are amplified for long mission durations (years), inner planet missions, and high area to mass ratio vehicles such as those having very large solar arrays.

For interplanetary missions, aerodynamic forces have limited, but important applications. Drag due to the atmosphere of the central body can be a significant force if the S/C altitude is low enough. This is the case for low altitude orbits, and for ascent and entry trajectories. Another aerodynamic consideration, involving both lift and drag, is for aerobraking techniques which can be used for orbit capture and orbit changes. An example of the latter is an aeroassist planetary encounter based upon the hypersonic wave-rider concept.

IPOST models the atmospheric interaction of lift and drag. Simple and tabular models for lift and drag coefficients are available. Exponential and pressure/temperature based atmospheric density models are also available.

Not all forces are active in each mission phase. In constructing the simulation event sequence, it is important to select or deselect the appropriate forces and force models. This is not only computationally efficient, but also minimizes errors caused by inadvertent force perturbations.

3.2.3 EXPLICIT PROPAGATION

The method of explicit propagation is specified as part of the event activities. Once selected, it will be used for the simulation until changed by a subsequent event. The type of study the user wants to perform will usually define the propagation method needed to achieve the level of accuracy required. There are 5 propagation methods in IPOST (Table 3 - 4) with different levels of capability as well as accuracy. The perturbing forces which are applicable for each propagator were described in Table 3 - 3.

Propagation Model	Assumptions/Method	Vehicle Forces
CONIC	Two-body motion: central body and vehicle	C
ONESTEP	Approximate three-body motion: primary body, secondary body (in orbit about primary), vehicle	C, SB
MULTICONIC	Approximate three-body motion with small perturbations, and step size control	C, SB, N, RP, LT
ENCKE	Perturbed two-body motion with step size, numerical integration or small perturbations	C, SB, N, RP, LT, D
COWELL	Numerical integration of equations of motion using any or all forces	C, SB, N, RP, LT, D, L, HT

where:
C = Central body gravity N = Nonsphericity of central body LT = Low thrust
SB = Secondary body RP = Radiation Pressure HT = High Thrust
L = Lift D = Drag

Table 3 - 4. Explicit Trajectory Propagation Models

The simplest propagation method is CONIC. CONIC propagation solves the two-body problem. Given an initial state, it will provide the final state at the new time. This propagator is fast, but does not allow for any forces other than central body gravity. When only two-body accuracy is desired (quick mission analysis with low accuracy), the conic propagator would be chosen.

On a higher fidelity level than the CONIC propagator, is the ONESTEP propagator. ONESTEP takes advantage of the quickness of the CONIC propagator, but is more accurate in that it allows for secondary body forces to be taken into account (Reference 6). No other perturbative forces are allowed; but it is a step up in accuracy from the CONIC propagator alone by providing an approximate solution to the three-body problem. ONESTEP is useful for propagation from low planetary orbit to outside the planet's SOI into interplanetary space or vice versa. It does no integration but computes the trajectory in a single step, hence the name ONESTEP.

MULTICONIC is more accurate than the previous two. The MULTICONIC propagator accounts for secondary body effects, and improves on ONESTEP's accuracy by allowing multiple steps and the addition of perturbative forces. It operates by performing a primary and secondary body conic trajectory each integration step, and adds in the perturbative accelerations halfway through the step.

In using the ONESTEP and MULTICONIC propagators, the secondary body must be in orbit about the primary body. If this is not true, the mission setup will be inconsistent with the algorithm assumptions and the trajectory calculated will be useless. For example, with either of these two propagators, whether the S/C is within the SOI of a planet or is escaping the planet toward another body (other than a moon), the planet should be the secondary body with the Sun being the primary body.

Numerical trajectory integration is performed with the COWELL propagator. The COWELL method directly integrates the equations of motion, including all perturbating forces. Even if the non-central body forces are on the same order of magnitude as the central-body forces, the COWELL propagator will deliver highly accurate trajectories. Although the COWELL propagator is the most accurate, it is also the slowest because it requires small integration steps.

Another trajectory integration technique is the ENCKE propagator. ENCKE performs explicit integration like COWELL, but integrates only the perturbations and adds them to two-body CONIC motion. The assumptions behind this method are that the perturbations are very small when compared to the central body force and therefore change much more slowly. Thus the integration step size can be much larger than that for COWELL, up to 10 times larger during interplanetary flight. Whenever the perturbations are small (low thrust, solar radiation pressure) ENCKE would be a good choice. Whenever the perturbation forces become large though (e.g., continuous high thrust or near the planetary SOI) the assumptions are no longer valid and a switch to COWELL should be performed.

It is not wise to mix propagator types within a simulation. The overall trajectory accuracy is only as good as its weakest link, or propagator in this case. One possible exception is to match similar type propagators, such as CONIC and ONESTEP or ENCKE and COWELL, for different phases. One must also be careful to be consistent in the step size adjustments.

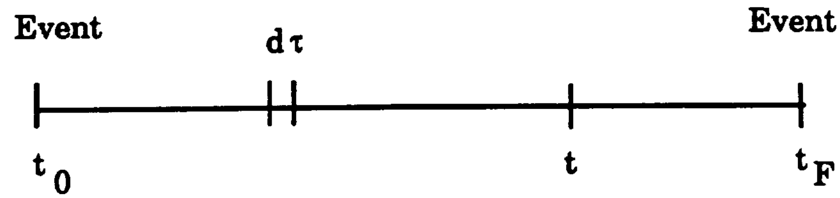
3.2.4 IMPLICIT SIMULATION

Implicit simulation computes the vehicle state between two junction points, or **nodes**. This trajectory **segment** can be a portion of a simulation phase or the entire phase. At nodes between events, the vehicle state must be the same for each side, that is, just prior to and just after the node. At nodes that correspond to events, the states on each side may be different. This discontinuity would occur if instantaneous event activities were specified, such as mass jettison or an impulsive ΔV maneuver.

The vehicle state is represented between nodes as Hermite, or cubic, polynomials. Each state component corresponds to a single Hermite polynomial. To compute the polynomial coefficients requires position, velocity, and acceleration (from evaluating the equations of motion) at each node. Figure 3 - 3 describes the methodology and compares it with explicit propagation. There is a crude correspondence between the integration step size of explicit propagation and the segment interval of implicit simulation. The latter is usually larger than the former for the same level of accuracy.

Define $\vec{X}(t_i) = \vec{X}_i$ = Vehicle state at t_i $= [x,y,z,\dot{x},\dot{y},\dot{z},m]^T$

EXPLICIT PROPAGATION

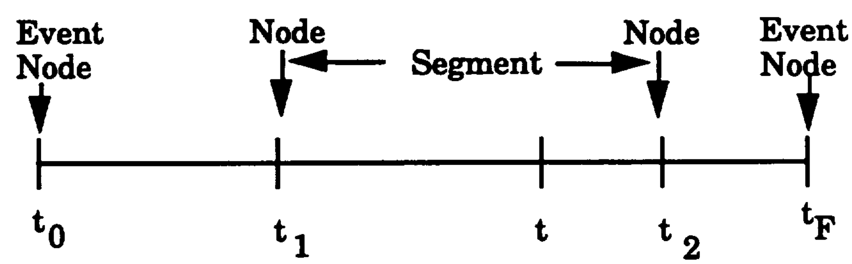


- Assume $\vec{X}_0 = \vec{X}(t_0)$ is known
- Integrate equations of motion

$$\vec{X}(t) = \vec{X}_0 + \int_{t_0}^{t} \dot{\vec{X}}(\tau)\, d\tau$$

where $\dot{\vec{X}}(\tau) = f(\vec{X}, \tau)$

IMPLICIT SIMULATION



- Assume $\vec{X}_1$ and $\vec{X}_2$ are known
- Determine cubic polynomial for each component of $\vec{X}(\tau)$, $t_1 \leq \tau \leq t_2$,
  For example, $x = a_0 + a_1 t + a_2 t^2 + a_3 t^3$
  where a_0, a_1, a_2, a_3 are computed from boundary conditions $\vec{X}_1, \dot{\vec{X}}_1, \vec{X}_2, \dot{\vec{X}}_2$
- Evaluate $x(t) = a_0 + a_1 t + a_2 t^2 + a_3 t^3$

$$y(t) = b_0 + b_1 t + b_2 t^2 + b_3 t^3$$

$$\vdots$$

$$\dot{z}(t) = f_0 + f_1 t + f_2 t^2 + f_3 t^3$$

$$m(t) = g_0 + g_1 t + g_2 t^2 + g_3 t^3$$

Figure 3 - 3. Explicit and Implicit Simulation Methods

To initialize implicit simulation (and optimization) requires some a-priori knowledge, however poor. Initial guesses usually come from an explicit simulation. The easiest method is to use a mission opportunity tool, such as IPREP, to compute states at major events. IPOST allows two methods of determining undefined nodal states: Linear interpolation between defined states and Hermite interpolation from a previously defined state. Another initialization method is to use states from a previous implicit simulation/optimization run, such as when increasing from N segments per phase to M segments per phase (M > N).

In general, it is better to start with as few segments per phase as possible, consistent with the initial guess accuracy, and then to build more accurate solutions as the simulation/optimization process progresses, as illustrated in Figure 3 - 4. Furthermore, the user needs to be aware of the dynamics involved in each phase. Some phases involve much more trajectory motion than others, which means there should be more Hermite polynomials, or segments, for the active phases then for the relatively quiescent or linear phases. These considerations will help control the region of stability and help prevent optimization divergence.

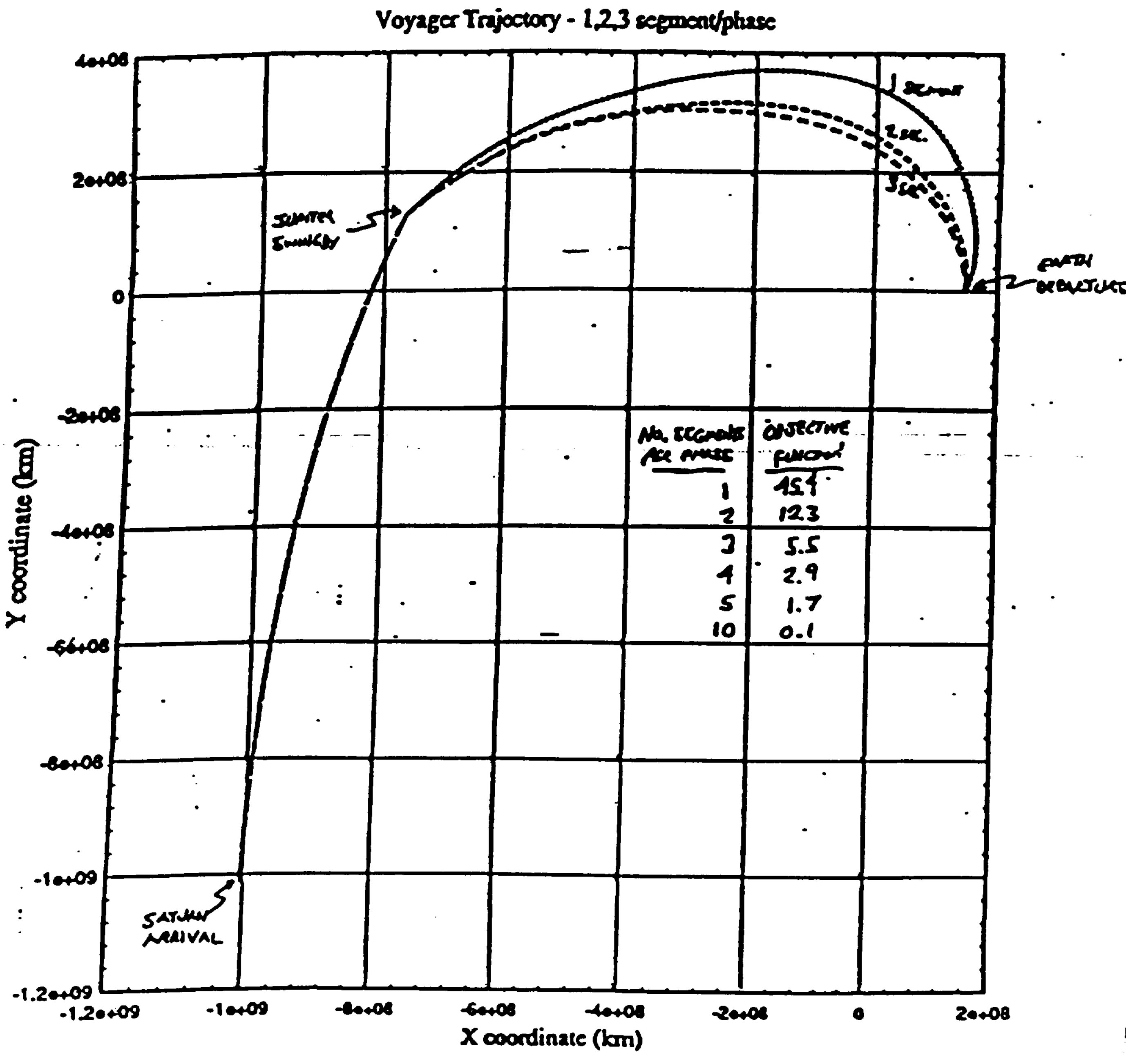


Figure 3 - 4. Implicit Simulation Accuracy

3.3 PERFORMANCE OPTIMIZATION

Mission optimization (Table 3-5) is a critical part of the system design process. Quite often the function to be optimized is either total system mass or mass delivered to the final destination. However, the objective function can also be flight time, electrical power, or any system parameter which is important to be optimized. Sometimes the **objective function** is called the system **cost**, in which case it is always minimized (a negative cost means the objective function is maximized).

Optimization Techniques	Maximize F (u,y) Subject to u (y) $\vec{y}_{min} \le \vec{y} \le \vec{y}_{max}$	Optimization Technique Master Problem and Subproblems Collocation None (Simulation or targeting only)
Optimization Variables	$F = F(\vec{u}, \vec{y})$	Typical Optimization Variables Final mass Sum of ΔV's Initial mass in Low Earth Orbit Flight Time
Control Variables (independent)	$\vec{u} = u_1, u_2, \ldots,$ upper and lower bounds, weighting	Typical Control (independent) Variables Initial mass Earth departure V_∞ magnitude Thrust start time ΔV direction Encounter conditions
Constraint Variables (dependent)	$\vec{y} = y_1, y_2, \ldots,$ upper and lower bounds, weighting	Typical Constraint (dependent) Variables Altitude Closest approach time BDT and BDR Inclination Velocity

Table 3 - 5. Optimization Characteristics

In order to optimize a function there must be some allowable degrees of freedom. Free parameters are called **control** or **independent** variables. Examples include initial mass and thrust management parameters (throttle setting and direction). Controls are usually given bounding values that reflect physical limitations, such as 0 to 1 for throttle setting.

Another important optimization consideration is the presence of constraints. **Constrained** or **dependent** variables are parameters that must be met within bounds in order to have a feasible mission. Examples are minimum altitude (closest approach to a planet surface), rendezvous velocity, and peak dynamic pressure or acceleration.

The optimization process must adjust the control parameters to jointly meet constraints and minimize cost. Optimization methods should be accurate, robust, and fast. Accuracy means finding a global optimum solution, as opposed to a local optimum. Robust means finding the optimal solution in the presence of widely varying conditions such as poor initial guesses of the control values (often the case) and non-linearities in cost function, constraints, trajectories, etc. Fast means rapidity in compute time and in user interaction/understanding. These goals are seldom achieved, particularly for complex missions.

Among the methods of optimization that a mission analyst must choose are problem formulations and mathematical solution techniques. In IPOST the optimization problem can be formulated in an explicit and an implicit form. The solution technique uses NPSOL or PGA algorithms.

Occasionally, no optimization is desired or needed. In this case, the analyst is interested in generating single pass trajectories or simulations, such as for sensitivity analyses. Alternately, the analyst may be looking for a mission that does the best job of meeting constraints (targeting only), and optimization is either premature or unnecessary.

3.3.1 OPTIMIZATION TECHNIQUES

There are two aspects to solving trajectory performance optimization problems: problem formulation and numerical solution. Problem formulation refers to the structure and organization of the optimization problem and its connection with the simulation process. This includes identification of control parameters, constraints and the objective function. The numerical solution refers to the algorithm which is applied in order to generate an optimal solution which meets all constraints.

Classical optimization formulations are straightforward. The control parameters correspond directly to mission relevant parameters, such as thrust magnitude, that a mission designer can select within limits. Constraints are mission relatable variables which are associated with mission goals. The objective or cost function is the most dominant parameter that characterizes mission success or viability. This classical formulation is difficult to solve, except for very simple simulations, due to non-linearities in the kinematics and dynamics associated with the time-ordered simulation. Because of these instabilities, IPOST uses decomposition techniques.

Decomposition breaks up the optimization problem into smaller, more tractable, sub-problems which are then unified or integrated by a master problem to achieve the overall solution. Decomposition (Reference 7) is applied to both explicit and implicit simulations.

Explicit optimization is similar to the classical approach in that all parameters are mission relatable quantities. Decomposition is applied by breaking up the simulation into major sections, or subproblems. Each **subproblem** represents a targeting problem, that is, meeting only constraints. The general subproblem is nonsquare, allowing the number of subproblem controls to be different than the number of subproblem constraints or targets. Each subproblem is solved in sequence with the beginning of one subproblem contingent upon the results of the previous subproblem. When the sequence of subproblems is completed, this represents a single simulation or mission pass.

The **master problem** has its own set of controls and constraints and is responsible for optimizing the objective function. The non-linearities of optimization are minimized by (a) reducing the dimensionality (number of controls and constraints) for the subproblems and the master problem, as opposed to one single master problem, as in the classical approach, and (b) reducing the simulation time span through subproblems. This decomposition method has been successfully used for very non-linear simulations, for example JPL's PLATO/MOSES were used to design the Voyager and Galileo missions (Reference 6). Section 3.3.2 discusses explicit optimization in more detail, and Section 3.4.2 discusses IPOST related parameters.

Implicit optimization also applies decomposition principles. In this case the simulation is divided into multiple segments per phase. The segment junctions are called **nodes**, with variable vehicle states on each side of the node. The controls are now the mission relatable free parameters plus all the vehicle states for all the nodes. The constraints are the classic mission constraints plus mathematically imposed restrictions to ensure continuity across nodes and to ensure that the equations of motion are met at the nodes and at the center of each segment. Clearly, the dimensionality of implicit optimization, or collocation, is quite large. In this case, the large dimensionality is offset by a reduction in non-linearity. Section 3.3.3 discusses implicit optimization in more detail, and Section 3.4.2 discusses IPOST related parameters.

The numerical solution of parameter optimization problems is as much art as science. IPOST uses primarily the NPSOL algorithm, although some versions allow the option to use PGA.

The projected gradient algorithm (PGA) is an iterative technique designed to solve a general class of nonlinear programming problems. PGA employs cost-function and constraint-gradient information to replace the multidimensional optimization problem by an equivalent sequence of one-dimensional searches. In this manner, it solves a difficult multidimensional problem by solving a sequence of simpler problems. In general, at the initiation of the iteration sequence, PGA is primarily a constraint-satisfaction algorithm. As the iteration process proceeds, the emphasis changes from constraint satisfaction to cost-function reduction. PGA is a combination of Rosen's projection method for nonlinear programming and Davidon's variable metric method for unconstrained optimization.

The NPSOL algorithm (Reference 8) uses major and minor iterations to solve the targeting and optimization problem. In the major iterations NPSOL seeks a significant decrease in the merit function along a direction of search $\vec{p}$. NPSOL defines the merit function as:

$$F(\vec{u}) = \sum_{i} [\, li * (ci\ (\vec{u}) - si)] + \frac{1}{2} \sum_{i} [ri * \ (ci\ (\vec{u}) - si)^{2}]$$

where $F(\vec{u})$ is the objective function
li is the vector of lagrange multipliers
ci is the i-th constraint function
si is the set of slack variables used to handle inactive constraints and
ri is the penalty vector for constraint violations.

Therefore, during NPSOL operation, the problem becomes better targeted and more optimized in a simultaneous fashion.

In the minor iteration NPSOL seeks the search direction $\vec{P}$ for the major iteration by minimizing the quadratic programming problem:

$$Q = \vec{g}^T \vec{p} + \frac{1}{2}\vec{p}^T H \vec{p},$$

subject to a set of constraints, where $\vec{g}$ is the gradient of $F(\vec{u})$, and H is the quasi-Newton approximation to the Hessian of the merit function.

Both PGA and NPSOL are gradient based algorithms. They require derivatives of the objective function and of the constraints with respect to the control variables. The former vector of derivatives is called the **objective gradient** and the latter matrix of derivatives is called the **Jacobian**, or sensitivity, matrix. In addition, NPSOL constructs a second derivative matrix or **Hessian**.

One of the keys to optimization success is a well conditioned Jacobian matrix. Usually, this is formed by finite differencing. In IPOST, the finite difference control perturbations can be input by the user or computed by NPSOL. If NPSOL computes the perturbation size for each control parameter, the appropriate perturbation is that control value which produces the most accurate partial derivative for the control-constraint (or objective) combination, which is just above the numerical noise threshold. It can use either forward or central differencing techniques. Quite often about a third of the run is spent computing an accurate Jacobian because many simulation passes, or **function evaluations**, are needed to produce the finite difference perturbation. NPSOL also has the option of "verifying" an input perturbation size by constructing and comparing a finite differenced Jacobian.

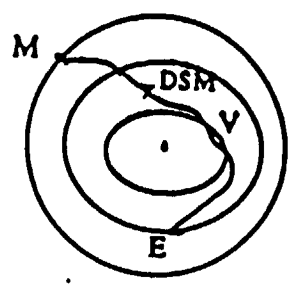
Another key to optimization guesses are "normalized" conditions. The ideal problem would have all values of the control parameters within one order of magnitude of each other. Similarly, all values of the constraints would be close to each other, and all non-zero elements of the Jacobian matrix would lie within a one order of magnitude range. The normalized conditions can be approached to some extent by adjusting the control parameter weights (WVU) and the constraint parameter weights (WVNLC). Section 3.4.2 discusses IPOST weighting techniques and options.

3.3.2 EXPLICIT OPTIMIZATION - MASTER/SUBPROBLEMS

To make the targeting/optimization for missions more stable, IPOST allows decomposition of the trajectory into a master problem and subproblems . If the trajectory has several legs (planetary encounters, impulsive corrections, etc.), each leg can become a subproblem and targeted individually.

For example, the user could choose a mission to launch from Earth park orbit, flyby Venus, do a deep space maneuver on the way to Mars and then enter park orbit at Mars, while maximizing the arrival payload (Figure 3 - 5). This problem could be set up as one entire master problem, the classical optimization approach, with approximately 10 control values, 6 constraints, and an optimization variable.

MAXIMIZE (mass) $_M$



MASTER PROBLEM ONLY		MASTER + SUBPROBLEMS
T_B, $\Delta\overline{V}_B$, T_V, T_{DSM}, $\Delta\overline{V}_{DSM}$, T_M $(BDT, BDR, VINF)_V$, $(R_p, R_a, i)_M$	MASTER PROBLEM • CONTROLS • CONSTRAINTS	T_B, T_V, T_{DSM}, T_M, $(BDT, BDR, VINF)_V$ NONE
N/A	SUBPROBLEM 1 • CONTROLS • CONSTRAINTS	$\Delta\overline{V}_B$ $(BDT, BDR, VINF)_V$
N/A	SUBPROBLEM 2 • CONTROLS • CONSTRAINTS	$\Delta\overline{V}_{DSM}$ $(R_p, R_a, i)_M$

Figure 3 - 5. Explicit Optimization Decomposition Example

Alternately, the problem can be decomposed with targeting performed on the subproblem level. The Earth to Venus trajectory would be solved with three controls and three targets, and the Venus to Mars trajectory would be solved by controlling the deep-space maneuver to target Mars. Above these two subproblems, on the master level, the user would control the encounter times as well as the flyby conditions at Venus to find the best conditions to maximize the arrival payload.

A special application of this master/subproblem description is the use of IT00 (Interplanetary Targeting and Optimization Option) for gravity assist missions, e.g., Voyager. IT00 uses analytic Jacobian partials and the ISTEP propagator. It is much faster than conventional methods.

Which is the better approach, to do three simple problems or one complex problem? The three simpler problems are much easier to follow, but of more importance is the improved stability of the overall optimization process. For very simple missions, all of the targeting and optimization can be done on the master level; but when the missions become more complex, decomposition is needed to make the problem tractable.

3.3.3 IMPLICIT OPTIMIZATION - COLLOCATION

The technique of collocation (References 9 and 10) requires setting up the trajectory as an implicit simulation (see 3.2.4). Each simulation phase is divided into one or more segments. Nodes occur at segment boundaries, including events. In collocation, the states on each side of each node, that is, the pre- and post-node states, are allowed to vary. These free states become additional control variables.

Additional constraints must also be introduced because the states are not totally free. For example, the state on each side of an **event node** is related by the event activity. Thus, an additional constraint is any state discontinuity arising from the activity, such as an impulsive ΔV.

Another set of constraints is introduced because the state on each side of a node which is internal to a simulation phase, or between events, must be the same. In some collocation formulations, the zero state differences for these **internal nodes** are introduced as constraints. However in IPOST, the state on each side of an internal node is explicitly set equal to the state on the other side. This has the effect of reducing the number of controls and constraints such that only a single state at each internal node become control variables.

One other IPOST refinement eliminates the state differences of the first event node by explicitly setting the post-event state equal to the pre-event state plus any state discontinuity associated with activities in the first event. In theory, all double states can be reduced to single states by this procedure, but this remains a future modification.

There are other constraints introduced by collocation. These constraints involve forcing the Hermite polynomials to meet the equations of motion at the mid-point (t_c) of each segment. The constraints, called **defects**, ($\vec{d}$) are formulated as:

$$\vec{d} = \dot{\vec{X}}(\vec{X}, tc) - \dot{\vec{X}}_{HP} = 0$$

$x \equiv [\dot{x}, \dot{y}, \dot{z}, \ddot{x}, \ddot{y}, \ddot{z}, \dot{m}]$, the seven element vehicle state derivatives

where $\dot{\vec{X}}(\vec{X}, tc)$ = equations of motion evaluated at t_c using the state values (x) interpolated from the Hermite polynomials.

$\dot{\vec{X}}_{HP}$ = analytic derivations of Hermite polynomials, e.g.,

if $y = b_0 + b_1 t + b_2 t^2 + b_3 t^3$

then $\dot{y}_{HP} = b_1 + 2 b_2 + 3 b_3 t^2$

The net result of collocation is that for any reasonable simulation/optimization problem there are hundreds more control and constraint parameters than in an explicit simulation/optimization(see Figure 3 - 6). In the IPOST formulation, an equal number of controls and constraints are added via collocation. For example, if a classical problem has 10 controls and 6 constraints, and the simulation has 5 phases with 4 segments per phase, then the total number of controls and constraints are :

Number of controls = 10 + nc * 7 = 192
Number of constraints = 6 + nc * 7 = 188
where nc = (number of segments per phase + 1) (number of phases) + 1

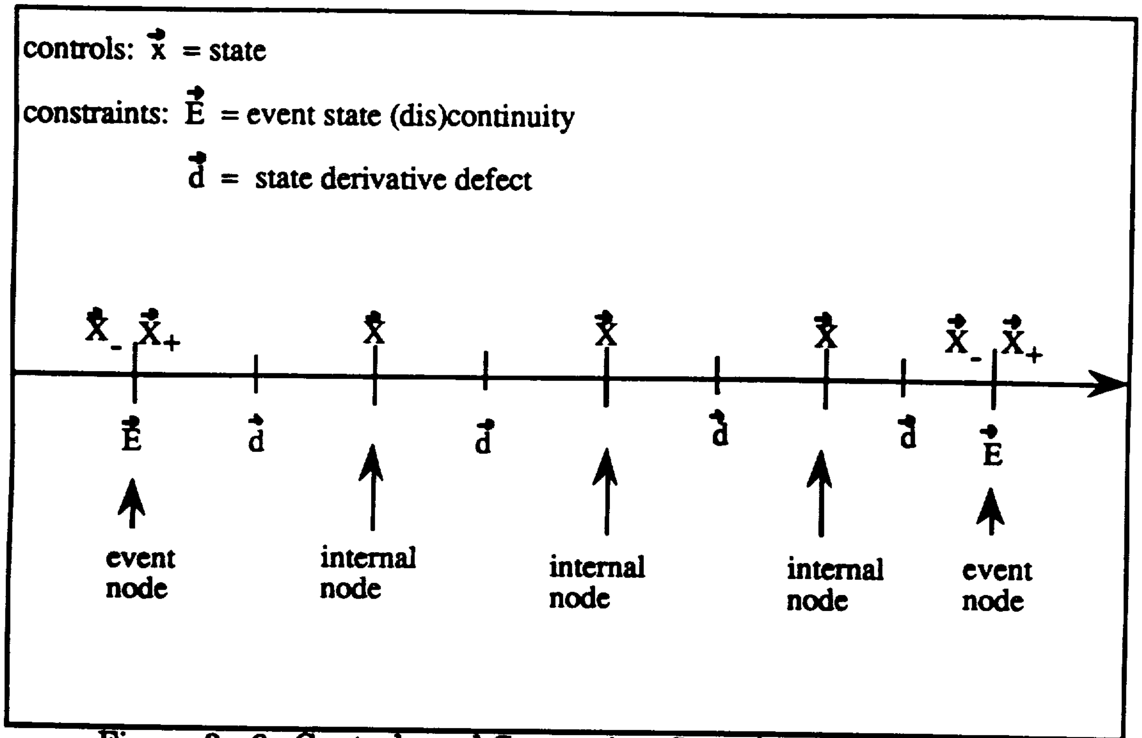


Figure 3 - 6. Controls and Constraints Introduced by Collocation

Although the dimensionality of the optimization problem has been greatly increased, there are several compensating features to collocation which ultimately expand its region of convergence. The first benefit is that each segment is relatively independent of the others because of the free states at each node. Thus, a change early in the mission is not amplified into extremely large, and unpredictable, changes later in the mission, as in explicit simulation/optimization.

Another collocation benefit is that most derivatives are analytic, and therefore rapidly, and accurately, computed. The few derivatives that must be done by finite differencing are of the "local" variety. That is, there is very little time mapping, at most over a single segment, which makes the finite differenced partials relatively stable and well-behaved.

Finally, the total Jacobian, although quite large, is a sparsely populated banded matrix. There are many techniques for efficient generation and manipulation of sparse matrices. In IPOST, the zero elements of the Jacobian are identified and pre-set, thus eliminating some of the finite differencing in NPSOL for Jacobian elements that should be zero.

3.4 IPOST PROGRAM SETUP AND OPERATIONS

In formulating a simulation/optimization problem for an interplanetary mission, it is usually best to construct the simulation flow first, and then optimization. This is because simulation is easier to visualize, and optimization relies on the simulation activities, sequences, and results. It is then a straightforward mapping into IPOST usage.

Each simulation event (activity, criteria and category) corresponds to a namelist ($TRAJ) input block. Whatever is established in the event description will be applied in the following time interval, or phase, until the next simulation event is encountered. After the simulation is defined in terms of $TRAJ blocks, the targeting/optimization namelist ($TOP) can be constructed.

$TOP will identify such options as master/subproblems vs. collocation, control vs. independent parameters (type, initial value, bounds, weights), constraint or dependent parameters (type, desired value, bounds, weights), and objective function identification.

If the mission is very complex, involving many events/activities and/or many control and constraint parameters, it is best to start as simple as possible, and build the problem solution in stages. This serves three purposes: (a) easier diagnosis of input and simulation errors, (b) developing a better feel for the complexity and sensitivities of simulation - optimization coupling, (c) building an orderly progression of parameter values, such as bounds and weights, to maintain solution stability.

For explicit simulation/optimization this means working the major mission phases first, with simple and few subproblems. For implicit simulation/optimization it also means starting with a portion of the mission, as well as using only a few segments per phase initially. Another option is to use a mission opportunity solution, such as from IPREP, as a starting point for a simple collocation problem. Then transition to the more complex explicit optimization formulation. Although tempting, it is usually disastrous to start immediately with the full blown complex problem unless one has successfully completed a very similar problem.

IPOST input is via three namelists: $TOP, $TRAJ and $TAB. $TOP must be input first. $TRAJ must follow $TOP , and there must be one $TRAJ for each event. $TAB is used to input tabular data for thrust, aerodynamic coefficients and spacecraft mass. There may be one or more $TAB, following each $TRAJ.

Input and output units are metric. Unless otherwise specified, the following units apply to both input and output parameters.

Time	days
Mass	kg
Position	km
Velocity	km/sec
Area	met^2
Volume	met^3
Density	kg/met^3
Force	Newtons (= $kg\text{-}met/sec^2$)
Pressure	$Newtons/met^2$
Power	watts (= $kg\text{-}met^2/sec^3$)

3.4.1 TRAJECTORY SIMULATION AND $TRAJ

IPOST trajectory simulation is based on event cycling. An event is a point in the trajectory where certain user input criteria (CRITR) are met. The event CRITR can be time-based or non-time-based. The user inputs an EVENT sequence number (e.g., EVENT = 5), a CRITR variable (e.g., CRITR = 'TDURP' or time of duration since the last event) and an event criteria VALUE (e.g., VALUE = 20.d0 or twenty days since the last event). This event will not begin until the variable in CRITR has achieved the state of VALUE.

Care must be taken in choosing variables and values of CRITR which are not time-based. If non-time-based CRITRs are chosen, such as when a specified radius is reached, the user must be sure that the trajectory will pass through the specified value. Otherwise the event will never be reached and an event cycling error will occur.

Once an event has been reached, any number of simulation changes can be made via $TRAJ inputs. Table 3 - 6 describes some commonly used inputs. These inputs include changing the primary and secondary bodies, switching out propagators or trajectory acceleration forces, requesting impulsive maneuvers, or changing the input, output frames. For a more complete list of trajectory simulation inputs, see Section 5.2.

Input state parameters are used only if the simulation state is to be initialized, e.g., launch, or reinitialized, e.g., return to Earth after a planetary stay.

The maneuver mode (MANTYP) identifies certain instantaneous activities. These activity approximations include LAUNCH (impulsive injection into a hyperbolic trajectory), IMPULS (impulsive midcourse maneuver ΔV) and ORBINS (impulsive orbit insertion from a hyperbolic trajectory).

For explicit simulation, the propagation mode (IPROP) and step size (DT) are important to specify. For implicit simulation, and collocation, the user specifies the number of segments per phase with the variable NSEGPH.

event data	EVENT	Event/phase number
	CRITR	Criteria for initiation
	VALUE	Criteria value
	IDBODY	Planetary body
	IDFRAM( )	Fame of reference
input state	INPUTX	Mode of state input/update
	X ( )	State vector
	IEPOCH	Type of epoch time
	DATE ( )	Calender date
propagation	IPROP	Propagation mode
	IPBODY( )	Primary and secondary bodies
	IFORCE	Perturbing forces
	DT	Propagation step size
maneuver/ guidance	MANTYP	Maneuver mode
	SPI	Specific impulse
	SCMASS	Vehicle mass
	THL	Throttle level capabilities
	WPROP	Propellant mass
	PRPDAT	Propulsion system characteristics
	PITCH & YAW	Vehicle pointing coefficients
input/ output	NAMLST	Flag for next namelist input
	PINC	Printout interval
	PRINC	PROFIL output interval

Table 3 - 6. COMMONLY USED $TRAJ INPUTS

The array of flags in IFORCE identify which forces are active for the current phase. A summary of force related parameters was shown in Table 3 -3. For example, finite burn segments are activated by IFORCE(5) which specifies the type of propulsive thrust (chemical/blowdown, electric propulsion, etc.) To deactivate thrust, set IFORCE(5) = 0 which is the a-priori default. WPROP specifies propellant mass, which is depleted as the vehicle thrusts and consumes propellant.

Depending upon the type of thrust, other parameters must be specified in PRPDAT. For example, low thrust solar or nuclear propulsion, require PRPDAT(9) through PRPDAT(15) which set values for thrust efficiency, housekeeping power, etc. Peak thrust is determined by the propulsion type through PRPDAT data. The thrust vector is assumed to be aligned along the vehicle x (roll) axis.

When thrusting, the user must specify throttle level (THL parameters), and direction, such as vehicle pitch (PITCH parameters) and yaw (YAW parameters). The throttle, pitch and yaw parameters can be represented by quadratic functions operating over the thrusting phase. For example, THL0 is thrust bias (initial thrust at beginning of phase), THL1 is the thrust rate of increase, and THL2 is the thrust acceleration coefficient. These coefficients can also be used as optimization control parameters along with thrust on and off times.

Spacecraft mass is a critical mission parameter and is often the objective function to be optimized. SCMASS in $TRAJ defines the mass. As propellant is consumed during thrusting phases, or mass is jettisoned, SCMASS diminishes accordingly. Two other mass related parameters are WPROP and WJETT.

The propellant mass, WPROP, can be specified at any event. Thereafter, WPROP will diminish (as does SCMASS) whenever thrusting occurs. A variable initial WPROP can be specified by using the parameter, FRACI, where WPROP = FRACI * SCMASS. Alternately, a mass fraction table (FMASIT) can be input which then will override FRACI.

Quite often a mission will jettison mass, such as a probe or spent fuel tanks or a complete stage. The form of jettison mass is dictated by the flag, JETT.
For JETT = 0, the value of WJETT input at any event is ejected.
For JETT = 1, and for negative values of JETT, a calculated value of mass is jettisoned at the current event.
For JETT = 2, the jettison mass (defined internally as WJETTM) is the input FRAC value, or WJETTM = FRAC. Alternately, FRAC can be replaced by values defined in the table FMASST. WJETTM is calculated and saved until another event specifies JETT = 1. JETT = -2 will result in the calculation and jettison of mass at the current event.
For JETT = 3, the calculated and saved jettison mass is

$$WJETTM = WPROP * (1/FRACI - 1)$$

Alternately, FRACI can be replaced by values defined by the table FMASIT. JETT = - 3 will result in the calculation and jettison of mass at the current event. Note that for JETT ≠ 3, the parameter FRACI (and its related table FMASIT) is used differently, in particular, to initialize WPROP as described earlier.

Atmospheric flight requires specification of the lift and drag coefficients, CL and CD, respectively, and the atmosphere model (IATMOS). The user must identify atmospheric characteristics. For example, the exponential density model (IATMOS = 1) requires base density (ATMS (1)), scale height (ATMS(6)), and minimum altitude (ATMS(7)). In all cases ALTATM(I) represents the maximum altitude of the sensible atmosphere for the Ith celestial body.

3.4.2 PERFORMANCE OPTIMIZATION AND $TOP

The $TOP namelist contains inputs which describe the targeting and optimization process. Table 3 - 7 illustrates commonly used inputs.

control or independent parameters	INDVR ( )	parameter name
	INDPH ( )	phase
	U ( )	initial value
	INDXI ( )	active parameter
	INDPLB ( )	min value
	INDPUB ( )	max value
	WVU ( )	weighting
target or constraint or dependent parameters	DEPVR ( )	parameter name
	DEPPH ( )	phase
	INDXD ( )	active parameter
	DEPTL ( )	tolerance/weighting
	DEPVLB ( )	min value
	DEPVUB ( )	max value
	WVNLC( )	weighting
Optimization Master problem	OPTVAR	Optimization variable
	OPTPH	Optimization phase
	FESN	Last event of simulation/optimization
	SRCHM	Method of optimization
	OPT	Targeting/optimization mode
	MXITOP	Maximum iterations

TABLE 3 - 7. COMMONLY USED $TOP INPUTS

Control parameters (independent variables) are defined in namelist $TOP by the array INDVR. Table 3 - 8 identifies allowable control parameters. In theory, any real variable in namelist $TRAJ can be used. An example of usage would be INDVR(3) = 6HPITCH1, which specifies that the third control parameter is the body pitch rate.

CHARACTER	DEFINITION
ALTIT	Park orbit altitude
C3	Escape energy
CRITR	Event criteria parameter
DEC	Escape asymptote declination
DEPSVLij	Subproblem dependent parameter ij
DVX	Delta velocity x-component
DVY	Delta velocity y component
DVZ	Delta velocity z component
INC	Orbit inclination
PITCH0	Initial pitch angle
PITCH1	Pitch angle rate
PITCH2	Pitch angle acceleration
RA	Escape asymptote right ascension
RAPOAP	Radius of apoapsis
ROLL0	Initial roll angle
ROLL1	Roll angle rate
ROLL2	Roll angle acceleration
SCMASS	Spacecraft mass
THL0	Initial thrust throttle level
THL1	Throttle level rate
THL2	Throttle level acceleration
VINFX0	Escape asymptote velocity X component
VINFY1	Escape asymptote velocity Y component
VINFZ2	Escape asymptote velocity Z component
VX	Velocity X component
VY	Velocity Y component
VZ	Velocity Z component
WJETT	Jettison mass
WPROP	Propellant mass
X	Position X component
Y	Position Y component
YAW0	Initial yaw angle
YAW1	Yaw angle rate
YAW2	Yaw angle acceleration
Z	Position Z component

TABLE 3 - 8. CHARACTER NAMES FOR CONTROL PARAMETERS

In Table 3 - 8, the parameter CRITR is used to represent another parameter. When INDVR = 5HCRITR, then the control parameter is the event criteria parameter that triggers the appropriate phase (INDPH). Event criteria parameters are defined in namelist $TRAJ and in Table 3 - 9.

CHARACTER	DEFINITION
ALTIT	Altitude
ANGAT1	Angle of attack (in-plane)
ANGAT2	Angle of attack (out-of-plane)
ANLONG	Longitude of ascending node
ARGP	Argument of periapsis
BDRO	B dot R (outgoing)
BDRI	B dot R (incoming)
BDT0	B dot T (outgoing)
BDTI	B dot T (incoming)
BTHETA	B-plane theta angle
C3	Launch energy
DEC	Declination of launch asymptote
DVMAG *	Delta velocity magnitude
DVSUM *	Summation of all DVMAGs over the course of the trajectory
ECCEN	Eccentricity
FPA	Relative flight path angle
HYPTA	Hyperbolic turn angle between asymptotes
INC	Inclination
LAT	Latitude
LONG	Longitude
LONGP	Longitude of periapsis
MEAAN	Mean anomaly
PERIOD	Orbital period
PITCH	Pitch angle for the S/C
RA	Right ascension of launch asymptote
RADIUS	Radius magnitude
RAPOAP	Radius of apoapsis
ROLL	Roll angle for the S/C
RPERI	Radius of periapsis
SCMASS	Vehicle mass
SMA	Semi-major axis of orbit
SMACH	Mach number
SPEED	Velocity magnitude
TDURP	Time since last event
TFP	Time from periapsis
THL	Throttle level

TABLE 3 - 9. CHARACTER NAMES FOR TARGETS/OPTIMIZATION/EVENT CRITERION/TABULAR VARIABLES

*Not available for CRITR.

TIME	Time in days
TIMRFi	Time of activity i (initiated by DTIMR(i))
TPERI *	Time of closest approach
TRUAN	True anomaly
VINFX	V-infinity X component
VINFY	V-infinity Y component
VINFZ	V-infinity Z component
VMAG	Velocity magnitude
VX	Inertial cartesian X velocity
VY	Inertial cartesian Y velocity
VZ	Inertial cartesian Z velocity
WPROP	Propellant mass
X	Inertial cartesian X position
Y	Inertial cartesian Y position
YAW	Yaw angle for the S/C
Z	Inertial cartesian Z position

TABLE 3 - 9. CHARACTER NAMES FOR TARGETS/OPTIMIZATION/EVENT CRITERION/TABULAR VARIABLES (Continued)
*Not available for CRITR.

The initial values of control or independent parameters are specified in the U array. It is always best to specify values that are closest to the optimal values. For missions with some degree of uncertainty, a mission opportunity tool, such as IPREP, should be used to generate initial guesses. For more defined missions, results of previous simulations and optimal solutions should be used.

Sometimes it is convenient to input all likely controls by specifying INDVR, INDPH, U,..., and then, for the problem at hand, selecting a subset for active controls. In this way, the user can select the most well-behaved controls for the problem or mission phase. The array INDXI allows this flexibility.

INDPLB and INDPUB are lower and upper bounds for each control parameter. If the bounds are too loose, there is the potential for the solution to wander and possibly converge within a mathematically feasible, but physically undersireable, region. If the bounds are too tight, there may not be enough freedom to find the true global optimization. It is often best to keep the bounds reasonably small, and then relax those bounds that are reached by the solution. This requires a certain amount of user interaction and awareness.

Another important control related parameter is the weighting (WVU). "Proper" weighting will improve the speed and robustness of the solution process. Improper weighting often leads to divergence.

Dependent, or target or constraints, parameters are described by a comparable set of variables to the control parameters. One key difference is that controls require an initial guess (U), whereas constraints are specified by their bounds (DEPVLB and DEPVUB). Another difference is that constraints permit usage of a normalized tolerance (DEPTL) which affects constraint error metrics. Is is recommended that the default value of DEPTL be used except where significant experience dictates otherwise.

The optimization process is characterized by OPTVAR (parameter to be optimized), OPTPH (phase of optimization parameter), FESN (final event number), SRCHM (optimization formulation type), OPT (maximize or minimize optimization parameter), and MXITOP (maximum number of iterations for performing selected optimization activities).

IPOST allows great flexibility in selecting variables.

Table 3 - 9 describes the allowable variables for target parameters (DEPVR), optimization parameter (OPTVAR), event criteria (CRITR), and table input independent parameter(s). Variables denoted by an asterisk are exceptions to CRITR availability.

The care and feeding of NPSOL is very important to the success of finding an optimal solution. One important aspect is the scaling or weighting of the control and constraint variables, WVU and WVNLC, respectively. Bad scaling of the problem can exacerbate the ill-conditioning and non-linearity of the problem. For independent variables experience shows that the best weighting is the magnitude of the variable. Since weighting is used in IPOST as a denominator, NPSOL will then operate on variables that are all roughly near unity. For dependent variables the weighting should be chosen so that the range of magnitudes in the sensitivity (Jacobian) matrix is minimized. For collocation, IPOST provides a set of default weightings for the supplementary controls (node states) and supplementary constraints (defects and event discontinuities). These defaults are described in more detail in Section 5.1 within the definition of WVNLC and WVU.

One important option is the ability to rescale independent and dependent variables. Initially, the user should input values of WVNLC and WVU. Good first values of WVNLC and WVU are the magnitudes of the dependent and independent variables, respectively. For the venturesome user, initial WVNLC and WVU values can be overridden by input flag (IRSCL). A robust option is to automatically renormalize the Jacobian after it is calculated by rescaling the dependent parameters (IRSCL = 2 and MXITOP(2) = 0). For example, MXITOP = 0,10, would mean that IPOST would first evaluate the trajectory and its jacobian, rescale the weightings for the problem, and run the problem for 10 iterations. In the NPSOL iteration output check COND T for improvement after rescaling. See variable IRSCL for rescaling options.

3.4.2.1 EXPLICIT OPTIMIZATION - MASTER/SUBPROBLEMS

For explicit optimization, the problem can be decomposed or partitioned into a number of subproblems which are tied together by a master problem. The subproblems are defined such that the beginning of one is the end of the previous subproblem. Each subproblem represents a targeting and/or optimization problem.

The parameters which define the master problem are the same as those in the previous section. For subproblem definition, there is an analogous set of parameters as illustrated in Table 3 - 10, with some important differences. The independent parameter active ID (INDSXI) specifies the subproblem for that control. For example, INDSXI(5) = 2 means that the fifth parameter corresponds to a control parameter for the second subproblem.

Variable	Master	Subproblem
Independent Parameters		
Name	INDVR ( )	INDSVR ( )
Phase	INDPH ( )	INDDSPH ( )
Initial value	U ( )	USUB ( )
Value lower boundary	INDPLB ( )	INDSLB ( )
Value upper boundary	INDPUB ( )	INDSUB ( )
Active ID	INDXI ( )	INDXSI ( )
Weighting	WVU ( )	WVUS ( )
Perturbation size	PERT ( )	PERTSB ( )
Dependent Parameters		
Name	DEPVR ( )	DEPSVR ( )
Phase	DEPPH ( )	DEPSPH ( )
Value upper bound	DEPVUB ( )	DEPSUB ( )
Value lower bound	DEPVLB ( )	DEPSLB ( )
Value target		DEPSVL ( )
Active ID	INDXD ( )	INDXSD ( )
Tolerance	DEPTL ( )	DEPSTL ( )
Weighting variables	WVNLC ( )	WVSNLC ( )
Weighting errors		WGTS ( )
Objective Parameters		
Name	OPTVAR ( )	OPTSVR ( )
Objective magnitude	OPT ( )	OPTS ( )
Phase	OPTPH ( )	OPTSPH ( )
Weighting	WOPT ( )	WOPTS ( )
Problem solution method	SRCHM	MODELT ( ) = SUBOPT
Number of iternations	MXITOP	MXITAR ( )

Table 3 - 10. Master and Subproblem Parameters

There is an option to use a subproblem target variable as a master problem control. For example, if INDVR = 8HDEPSVL02, then the master level control parameter is the L-th subproblem second dependent parameter. As with subproblem controls, the index INDSXSD specifies the subproblem for a given dependent parameter or target. For example, INDSRSD (3) = 1 means that the third dependent parameter is a target parameter for the first subproblem.

When using decomposition, it is important to note that each master level simulation pass requires that all the subproblems be targeted/optimized in sequence. This means that finite difference construction of the Jacobian matrix and objective gradient requires each perturbed pass to successfully perform subproblem targeting/optimization. This can be a very time consuming process for complex master-subproblem formulations.

Dependent parameter weighting for subproblems is different than master problem weighting. For subproblems, target weighting depends upon the solution method. For Newton-Raphson (MODELT = 'NRAPH'), which is the recommended and default method, the target weights are the target values (DEPSVR), unless the target value is zero (then the weight is unity). For specific targeting (MODELT = "TARG1S'), target weighting is specified by WVSNLC.

There are other properties associated with the Newton-Raphson method of solving subproblems. It is not necessary to have an equal number of controls as target parameters. IPOST solves the non-square targeting condition with a Singular Valued Decomposition algorithm. Whereas a master problem dependent parameter value is specified by an upper and lower bound, a subproblem dependent parameter is specified by a single value (DEPSVL). There is also a master-subproblem difference in usage of the dependent parameter tolerance. Whereas the master problem tolerance (DEPTL) is a normalized numerical tolerance that is not typically changed from its default value, the subproblem target tolerance (DEPSTL) for Newton-Raphson is an important user input, and serves as a bound on the desired target value. The value of DEPSTL affects both the speed and accuracy of subproblem convergence. An important guideline is to set the DEPSTL values for earlier subproblems <u>tighter</u> than for later subproblems to reduce numerical error, particularly at the master problem level. Inconsistent DEPSTL's will lead to erroneous solutions or divergence.

The use of analytic partials (ISTM = 'ANAL' in $TOP) will speed up run time and improve convergence stability in most cases. Analytic partials are available only for the Conic, Onestep, and Multiconic propagators, and available only for Interplanetary Targeting and Optimization Option (SRCHM = 'ITOO') or for Master problem only or for Sub-problems only.

For subproblem optimization each subproblem is constructed with parameters roughly equivalent to the method used in the master level. Subproblem optimization is selected by setting MODELT = 6HSUBOPT for the applicable problem.

Subproblem optimization usually requires much more time than Newton-Raphson targeting, and there is no guarantee that the optimum subproblem is consistent with the overall master problem optimum.

If the user intends to use the NPSOL41 algorithm to target the subproblem, but not optimize any variable simultaneously, the OPTSUP = 6HTARGET option should be used. This creates an objective which contains the magnitude of the errors of the constraint functions divided by the constraint target error weights, WGTS. In this way, the objective and constraints will produce a direction of search that is consistent for both sets and result in faster and more robust convergence.

All guidelines in selecting variable weights for the master problem should be used in the selection of subproblem variable weights. Similarly, all the variables normally contained within the NPINPUT file for master level optimization should be reproduced in a dedicated NPINPUT01, NPINPUT02, etc. file for each subproblem. The use of these variables is unchanged from the master level, and can be tailored for each subproblem.

The user may select a master problem control variable as the subproblem dependent variable in much the same manner as discussed earlier in subproblem targeting.

3.4.2.2 IMPLICIT OPTIMIZATION - COLLOCATION

The collocation method requires breaking up each phase into one or more segments. Extra degrees of freedom (controls) are introduced by adding the vehicle state vector at each segment boundary (node). The extra controls are mitigated by introducing extra constraints in the form of pre and post node state connectivity and by reducing the defects to zero (that is, forcing the state derivatives at segment centers to match the equations of motion).

For implicit optimization, or collocation, SRCHM must be set to 'COLLOC'. The independent (INDVR) and dependent (DEPVR) related variables must be augmented to include all nodal state and defect related parameters. The following checklist may be helpful in setting up a targeting and optimization problem using collocation.

First, set up the simulation with event data in $TRAJ. This defines how the implicit simulation is initialized, and how each phase is modelled. This discussion includes only those parameters directly related to collocation, and assumes all other mission data is already established and transformed into input. Some IPOST features are restricted by collocation, such as not allowing non-time CRITR's or LAUNCH or ORBINS (MANTYP) maneuvers.

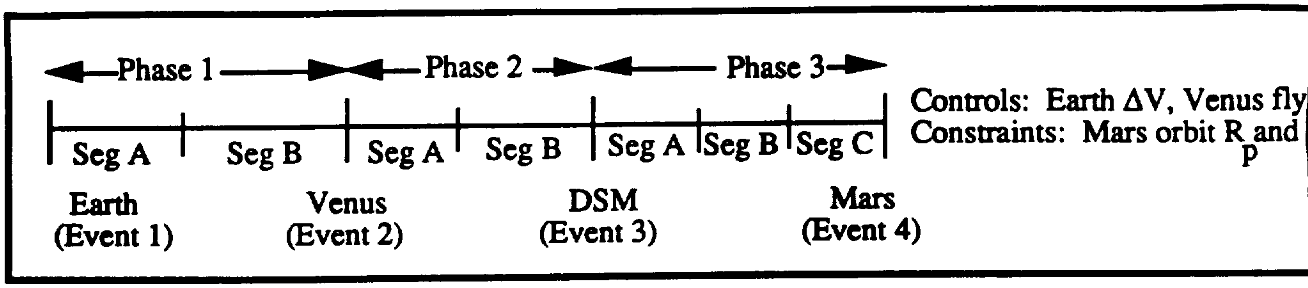
1. For each $TRAJ, which corresponds to the beginning of a phase, set NSEGPH equal to the number of segments per phase. It is usually best to start with as few segments as possible. It is also wise to make sure NSEGPH is consistent across the simulation by having those phases with high trajectory curvature use more segments than those phases with small curvature. One should avoid having zero length phases, such as not setting TDURP = 0.
2. For each $TRAJ, set NSGPH0, which is the number of input segment states for that phase. The default (NSGPH0 = 0) means all internal node states are interpolated based upon the initial and final phase states. Setting 2 < NSGPH0 ≤ NSEGPH means that the user must input the state values for those internal nodes specified by NSGPH0 (see item 6 for the order of the state input), and the post-event state.
3. There are two options which allow overriding the default control and constraint weightings. These are not recommended except for the experienced user. NSGPWD and NSGPWI are parameters in each $TRAJ which allow the user to override the constraint weightings (WVNLC) and control weightings (WVU) for this phase. The default values of NSGPWD and NSGPWI automatically set them both equal to NSGPH0. See item 8 for the order of weightings input.

Once the simulation has been set up, the optimization parameters in $TOP must be included. In addition to the standard parameters, such as OPTVAR and OPTPH, the following collocation specific parameters should be input.

4. SRCHM = 'COLLOC'

5. After the mission control parameters have been established, the collocation related control parameters (U and WVU) must be input. The order in which control parameters are input is also the order in which all independent parameters are displayed as output. In general, the order of input for U (initial control values) and WVU (control parameter weights) is: all mission controls, all pre-event states (7 components each in local body, IPBODY (1), cartesian form) starting with the second event and ending with the final event, all post-event states and internal node states in time order. Table 3 - 11 illustrates the input order for a mission that has four mission controls, 3 phases (4 events), and 2 - 2 - 3 segments per phase. Note that the number of input U's and WVU's may be affected by NSGPH0 and NSGPWI, respectively, that are in the $TRAJ inputs. When using NSGPWI to override default weights, a zero value of WVU will reinstitute the default value. The seven components of the state are the three components of position, in local body, IPBODY (1), ecliptic cartesian form, three components of velocity, in local body ecliptic cartesian form, and the spacecraft mass, SCMASS, in kilograms. The user can override the default and specify which body, with icbody, instead of local body, IPBODY(1), is the reference body for the collocation U's.
6. It is not necessary to input other collocation control related parameters. For example, the collocation control parameter upper bounds (INDPUB) and lower bounds (INDPLB) are automatically set to +10E10 and -10E10, respectively. For some problems, these bounding values may be too loose.
7. After the mission constraint parameters have been established, the collocation related constraint weights (WVNLC) must be input. In general, the order of input for WVNLC is: all mission constraints, all event state discontinuities, all segment defect states. This order of WVNLC parameter input is also the output order of all dependent parameters in IPOST display. Again, Table 3 - 11 shows an example of the input order. The number of input WVNLC's may be affected by NSGPWD which is in the $TRAJ input.
8. It is not necessary to input other collocation related parameters. For example, the collocation constraint parameter upper bounds (DEPVUB) and lower bounds (DEPVLB) are all set to zero because these constraints must be met exactly.
9. The user may select the method of state interpolation for those collocation states which are undefined (NSGPH0 < NSEGPH) by inputting COINTP. The default is linear interpolation.
10. As with explicit optimization, an important option is to rescale the constraints and/or weights using IRSCL. If rescaling is desired, it is recommended that IRSCL = 2 because this method of rescaling appears the most effective.

With collocation, the solution is very sensitive to control and constraint weightings, and with control parameter bounds. This applies to the mission parameters, as well as those parameters introduced by the collocation formulation. A rule of thumb is to begin as simple as possible, understand the sensitivities and quirks, and then build up to the desired solutions. As the problem/solution evolve, so must all tolerances, accuracy parameters, etc. in a coherent fashion. When to rescale weights, which control/constraint combinations to select, and event/segment adjustments will also evolve.



CONTROL PARAMETERS			CONSTRAINT PARAMETERS:		
U, WVU, INDPLB, INDPUB, INDPTL			WVNLC, DEPVLB, DEPVUB, DEPTL		
Parameter Name	Parameter(s)	Phase Number	Parameter Number	Parameter(s)	Phase Number
1	Earth DVX	1	1	Mars R_p	3
2	Earth DVY	1	2	Mars i	3
3	Earth DVZ	1	3 - 9	Event 1 state discont.	0/1
4	Venus TIMFR	1/2	10 - 16	Event 2 state discont.	1/2
5 - 11	pre Event 2 state	1/2	17 - 23	Event 3 state discont.	2/3
12 - 18	pre Event 3 state	2/3	24 - 30	Event 4 state discont.	3/4
19 - 25	pre Event 4 state	3/4	31 - 37	Defect Segment 1A	1
26 - 32	post Event 1 state	1	38 - 44	Defect Segment 1B	1
33 - 39	post Seg. 1A state	1	45 - 51	Defect Segment 2A	2
40 - 46	post Event 2 state	1/2	52 - 58	Defect Segment 2B	2
47 - 53	post Seg. 2A state	2	59 - 65	Defect Segment 3A	3
54 - 60	post Event 3 state	2/3	66 - 72	Defect Segment 3B	3
61 - 67	post Seg. 3A state	3	73 - 79	Defect Segment 3C	3
68 - 74	post Seg. 3B state	3			
75 - 81	post Event 4 state	3/4			

Table 3 - 11. Example Collocation Input/Output Parameter Order

3.4.2.3 MULTIPLE PROBLEM RUN CAPABILITY

IPOST has the capability to do several problem runs consecutively. After the first problem, the user may change some of the $TOP parameters and then run a second problem. The user requests a second problem by inputting NAMLST = 'TOP', at the end of the first problem. IPOST will run the second problem if NPSOL terminates with INFORM = 0, 1, 4 or 6 or if SRCHM = 'NONE'; otherwise, the first problem is considered a failure and the job is terminated. The user may change any $TOP variable, except the following:

Depph	Indph	Indxd
Depsph	Indsph	Indxi
Depsvr	Indsvr	
Depvr	Indvr	

The user can run a third or a fourth problem, after the second problem, subject to the same restrictions.

3.4.3 PROCESSING

As with all programs of this size and complexity, there will be blatant and subtle discrepancies. The more complex the problems become, the more difficult they are to solve, and there becomes more room for error in problem setup, simulation, targeting, optimization, etc.

There are generally two types of errors which occur, external and internal. External errors are user errors which cause program malfunctions. These are generally keystroke errors, model selection errors, improper data vs. initialization, etc. These are usually found quickly and easily. Input error diagnostics are in Section 6.4, Error Messages.

Internal errors are generally more difficult to find and to correct. Many times these can also be caused by input, and modelling, but in a more subtle way. An example of this type of problem would be that the subproblems will not successfully target. It could be that the parameters chosen as controls, or their allowable range of values, are inadequate to reach the specified targets. If the user has chosen forward differencing to calculate the sensitivities, possibly central differencing should be tried. Possibly, the size of the perturbations used in calculating the sensitivities was too large or too small. Perhaps control or constraint weightings were not chosen properly so that the Jacobian matrix elements vary by many orders of magnitude. As a general rule of thumb, weights should be chosen to normalize the control parameters, Jacobian matrix, and constraint parameters, in that order.

If the program has run successfully, and a solution has been given, but NPSOL has delivered that infamous message "EXIT NPSOL - Current point can not be improved upon," another question comes up. How can the user find a global solution rather than a possible local minimum? How can this solution be improved? Again, there are many possibilities and the user must use some common sense and knowledge in choosing the proper path to take. Checking the output and seeing what the program tried to do is a good starting point. Were there any controls constantly being pushed to one of their bounds? Perhaps they need to be loosened up some, or tightened up. Perhaps the weightings or perturbations are limiting the step sizes too much. Is the program taking giant leaps after each iteration? Again, perhaps the weightings or perturbations are allowing steps that are too large due to noise or non-linearities in the sensitivities. Check the objective gradient and Jacobian matrix. Do the elements seem to be near the same order of magnitude, or are there large differences? All of these things and more can be modified to improve solutions.

Past use of the NPSOL algorithm has shown that the problem is frequently badly scaled and that NPSOL terminates with an INFORM=6, 'Current point could not be improved upon' message. The NPSOL user's guide states that this can happen if:

1. Overly stringent accuracy has been requested, i.e., Optimality Tolerance is too small.
2. Routines OBJFUN or CONFUN may be incorrect or inaccurate.

3. The search direction has become inaccurate because of illconditioning in the Hessian. This tends to be reflected in large values of ItQP in the output. In this circumstance it may be worthwhile to rerun NPSOL from the final point.
4. The matrix of constraints in the working set is ill-conditioned, as indicated by an extremely large value of Cond T. This matrix is used in the QP minor iterations to find the search direction. In this circumstance it may be worthwhile to run NPSOL with a relaxed value of Feasibility Tolerance.

In addition to these recommended measures, a capability to rescale the targeting and optimization problem and resubmit to NPSOL has been incorporated into IPOST. This improves IPOST's ability to solve the problem.

More user flexibility is provided by a file called NPINPUT. The directives in this file (Table 3 - 12) allow direct access to some of the NPSOL options. These directives should only be altered by the experienced user. It is recommended that the NPSOL user's guide be a supplemental text.

Cold Start	The user does not provide NPSOL with the initial working set.
Derivative Level i	Specifies whether IPOST provides NPSOL with analytic derivatives. Always input i = 0 except when using ITOO.
Difference Interval r	The user can specify the perturbation interval used to estimate the gradients and sensitivities. If the user does not specify a value 'r', then NPSOL will estimate the finite difference interval. For a class of similar problems specifying Difference Interval will save execution time.
Feasibility Tolerance r	'r' defines the maximum acceptable absolute violations in linear and nonlinear constraints at a "feasible" point. Using this directive sets both the Linear Feasibility Tolerance and the Nonlinear Feasibility Tolerance.
Hessian No	'Hessian No' will help NPSOL run faster
Hessian Yes	'Hessian Yes' is recommended for later warm starts
Major Iteration Limit i	The maximum number of major iterations allowed before NPSOL termination.
Major Print Level i	Controls the amount of major iteration printout NPSOL produces. = 0 None = 1 Final solution only = 5 One line each major iteration. No final solution printout. > 9 Final solution and one line for each iteration > 19 The objective function, euclidean norm of the nonlinear constraint violations, values of the scaled nonlinear constraints and values of the scaled control variables each iteration.
Nonlinear Feasibility Tolerance r	'r' defines the maximum acceptable absolute violations in the nonlinear constraints at a "feasible" point.
Optimality Tolerance r	'r' is the number of correct figures desired in the objective function at the solution.
Warm Start	The user provides NPSOL with the initial working set.

Table 3 - 12. NPSOL Directives in NPINPUT File

4.0 SAMPLE CASES

The following sample cases illustrates a mission application of IPOST. This is by no means intended to cover all capabilities nor is it realistic in every detail, but it does provide a meaningful example for constructing and understanding a typical mission application. The sample case represents a Voyager 2 mission.

4.1 APPLICATIONS

Before the Voyager case is discusses, the context within which IPOST is applied should be explained.

Examples of mission applications are shown in Table 4 - 1. They illustrate some of the diverse IPOST model capabilities, including lunar, interplanetary, orbital, thrusting (impulsive, low, high), and gravity assist.

The typical IPOST application is usually in the form of run sequences which compare various mission options. These analysis threads build on each other, culminating in a reference mission which is used to support detailed system design and analysis. Table 4 - 2 illustrates representative mission threads which exercise key IPOST capabilities.

For example, in the Comet Rendezvous thread, each case is actually several runs of IPOST to generate parametric data such that mission decisions and refinements can be made. The sequence of multiple runs per case feeds each succeeding case with each case becoming more realistic in terms of model fidelity, and encompassing more system objectives and constraints.

The first step in the Comet Rendezvous thread is to define mission requirements (necessary conditions) and goals (desired conditions), as well as any known constraints, such as technology status. In this thread, a mission requirement would be to successfully rendezvous with a specific comet in a specific time frame. A mission goal might be to collect data on planets or bodies that are encountered during the interplanetary trajectory from Earth to the comet. A mission constraint might be the availability of a Cesium ion thrust engine powered by solar arrays, which provide limits on power/thrust levels and on specific impulse.

The first case is an approximate impulsive ΔV solution using a Venus gravity assist. This examines coarse energy requirements, benefits of gravity assist, and optimum mission opportunities (launch-arrival dates with payload/launch mass sensitivities). The mission may be analyzed as separate phases, e.g., Earth to Venus, Venus to comet approach, rendezvous and stationkeeping.

The second case models a low thrust mission using a single thrust segment with variable steering and variable throttle. Implicit optimization (collocation) is used. This recognizes the coarseness of the initial guess, and provides rapid solution searches. A determination is made whether available technology is sufficient to provide the required payload mass at comet rendezvous.

As mission knowledge evolves, the third case introduces multiple coast/thrust segments. These added degrees of freedom provide more flexible, and more realistic, mission solutions. The optimization method can be implicit or explicit (with master-subproblems), depending upon how many, and what level, of mission decisions need to be made. This would include interplanetary and close encounter geometries, flight times, subsystem performance, etc.

The final case provides an end-to-end precision optimized reference trajectory for system analyses and subsystem design support. Science and mission objectives can be assessed with a high degree of confidence.

TEST CASE	MISSION DURATION	PLANETARY BODIES	ACTIVITIES	SIMULATION	OPTIMIZATION
VOYAGER I	5 years	Earth Jupiter Saturn	Launch, Midcourse ΔV, Gravity assist	E-J-S, 1 Step, 6 Phases	Minimize to total ΔV, 2 subproblems
GALILEO	4.2 years	Earth Venus Jupiter	Launch, Midcourse ΔV, Gravity assist, Probe	E-V-E-E-J, 1 Step, 9 Phases	Minimize total ΔV, 4 subproblems
LUNAR ORBITER	4 days	Earth Moon (Sun)	Launch, Midcourse ΔV, Orbit insertion	E-M, 1 Step, 3 Phases	Maximize final mass, Master problem only
VENUS ORBITER WITH SEP	5 months	Earth Venus	Launch, Solar Power, Low Thrust, Orbit Insertion	E-V, 6 Phases	Maximize final mass, Collocation, 5 seg/phase
MANNED MARS	3 years	Earth Mars	Launch (E,M), Midcourse ΔV, Orbit Insertion	E-M-M-E, 1 Step,Conic, 6 Phases	Minimize initial mass, 3 subproblems
SATURN ORBITER WITH NUCLEAR PROPULSION	4 years	Earth Saturn	Launch, Nuclear Power, Medium Thrust. Orbit Insertion	E-S, 1 Step, Encke, Cowell, 5 Phases	Maximize final mass, 2 subproblems
CRAF	2.3 years	Earth Venus Comet Asteroid	Launch, Midcourse ΔV, Gravity Assist, Flyby, Rendezvous	E-V-A-C, 7 Phases	Minimize total ΔV, Collocation, 3 seg/phases

Table 4 - 1 IPOST SAMPLE CASES

- Lunar Mission Thread
  - L1 Earth departure to lunar orbit with patched conic
  - L2 Space Station to moon with free return
  - L3 Space Station with finite burn escape to libration point
- Voyager II Thread
  - V1 EJS portion with ITOO (analytic partials)
  - V2 EJSUN with finite differences partials
- Comet Rendezvous with Solar Electric Propulsion Thread
  - C1 Approximate impulsive ΔV (DSM) with Venus gravity assist.
  - C2 Single thrust segment, simple collocation
  - C3 Multiple thrust segments, complex collocation
  - C4 Explicit optimization comparison
- Human Mission to Mars Thread
  - M1 EM launch/arrival date search, simple aerocapture
  - M2 MVE return leg optimization, Earth orbit capture
  - M3 Mars surface ascent to orbit (MAV design)
  - M4 EMMVE round-trip optimization

Case	Bodies	Propagator(s)	Forces	Optimization method
L1	E-Moon	Conic	-	M
L2	SS-Moon-E	1-step	SB, J2	M
L3	E - L1	Multiconic, Cowell	DB, HT	MS(2)
V1	E-J-S	1-step, Conic	SB	MS(3) + ITOO
V2	E-J-S-U-N	1-step	SB	MS(5)
C1	E-V-C	1-step, Conic	SB	MS(2)
C2	E-C	nseg = 1	DB, LT	collocation
C3	E-C	nseg = 6	DB, LT, SP	collocation
C4	E - C	Encke	DB, LT, SP	M
M1	E - M	1-step	SB	Search
M2	M-V-E	1-step	SB	MS(2)
M3	M	Cowell	HT, A	M
M4	E-M-M-V-E	1-step, Encke	SB, J2	MS(3)

A = Aerodynamics   LT = Low thrust   DB = Disturbing body
J2 = Zonal (J2)   SP = Solar pressure   M = Master only
HT = High thrust   SB = Secondary body   MS = Master + Sub(s)

Table 4 - 2. Example Mission Threads

4.2 VOYAGER 2

The Voyager 2 case illustrates a master subproblem formulation and multiple planetary encounters. Only the Earth-Jupiter-Saturn phase of Voyager is performed. The simulation has 8 events, starting in Earth park orbit and ending with a Saturn flyby. Total impulsive delta V is minimized in the master problem. The two subproblems target each of two legs, Earth to Jupiter and Jupiter to Saturn.

In setting up an IPOST problem, the trajectory simulation is defined first, as opposed to the optimization process, because it describes the primary mission.

The first $TRAJ namelist is event 5. This utilizes parameters such as S/C mass and propulsion characteristics. The initial date of July 31, 1977 precedes the actual Voyager launch date. The S/C is placed in a circular orbit about Earth, and trajectory propagation will use conic, or two-body, equations of motion.

The second event (#10) is triggered by a flight time of 20 days. The 1STEP propagator is activated in connection with activation of the LAUNCH mode. Hence, Voyager orbits the Earth for 20 days and then is impulsively injected onto an escape hyperbola. Using flight time as a control parameter would allow variation of initial launch date. For 1STEP, the primary body is the Sun and Earth is the secondary body.

The third event (#15) is initiated after a flight time of 20 days from the launch event. At this point, the S/C is well outside of the Earth's sphere of influence. The secondary body is now defined as Jupiter for 1STEP propagation. The reference body for trajectory calculations is also set to Jupiter.

At event 20, the triggering criteria is mission time. The intended value is Jupiter closest approach time which is not specified explicitly, but indirectly through the optimization process. A conic propagator is used with Jupiter as the primary body.

One day later, at event 23, an impulsive trajectory correction maneuver is executed. 1STEP is reactivated as the propagator as the vehicle flies away from Jupiter. The combination of gravity assist and midcourse correction will set up the trajectory for the flight towards Saturn.

The fifth event (#25) occurs 300 days after the midcourse maneuver. The secondary body for 1STEP is switched to Saturn, as is the reference body. A general rule of thumb is that planetary sphere's of influence for 1STEP (and Multiconic) are about 20 days for small inner planets (Mercury to Mars) and 200 days for large outer planets (Jupiter to Neptune).

The next event (#30) is Saturn's closest approach, on August 25, 1981. It occurs 1467 days after Earth park orbit escape.

A final event (#90) is used as a "dummy" event, and coincides with the previous event. This event is needed because final event computations are done only on the "minus" side of the event. The namelist specification of "NONE" means no more input follows; that is, this is the end of IPOST problem specification.

We now return to the optimization definition, or $TOP namelist. The NPSOL algorithm is used with finite difference perturbations being calculated internally by NPSOL. This is the normal mode, as opposed to the user specifying perturbations. A maximum of 10 iterations is allowed for master problem optimization and 600 iterations for each subproblem targeting process. A subproblem targeting iteration is typically much shorter than a master problem iteration because the latter must solve all subproblems successfully.

The master problem controls are Jupiter closest approach time (defined as the criterion of event 20), B dot T and B dot R of the Jupiter approach, or incoming, hyperbola (defined as the 2nd and 3rd dependent variables of subproblem 1). In addition to the initial guesses for control values, the upper and lower bounds, and weighting values are important inputs. These define the performance manifold and often mean the difference between problem convergence and divergence. The objective function is the sum of all delta V magnitudes, which in this case corresponds to the launch/escape maneuver at Earth and the Jupiter midcourse correction.

The two subproblems are defined next. The first subproblem ends at event 20 (Jupiter closest approach) and the second subproblem ends at event 30 (Saturn closest approach). IPOST automatically assumes that subproblems are non-overlapping. Both subproblems use a Newton-Raphson targeting technique, as opposed to subproblem optimization with NPSOL.

The control variables for subproblem 1 are the V-infinity vector of the Earth departure hyperbola. Controls for subproblem 2 are the ΔV components after Jupiter flyby. As in the master problem, important inputs are the control initial guesses (USUB), bounds (INDSLB and INDSUB), and weightings (WGTS).

The constraint or target variables for subproblem 1 are time from periapsis, B dot T and B dot R at Jupiter. For subproblem 2 the constraints are time from periapsis, B dot T and closest approach distance at Saturn. The use of B dot T as a control parameter (with loose bounds) at Saturn affects orbit inclination as well as which side of Saturn the S/C flies by. B dot T and B dot R are often used because of their stability in the targeting and optimization process. The choice of constraint parameters for subproblem 2 reflect termination of the mission at Saturn flyby. For the actual Voyager mission, which continues on to Uranus and Neptune, the constraint parameter types at Saturn would have been identical to those at Jupiter.

Because IPRINT was not input, the default value of IPRINT = 0 is used. This will result in only summary information of the master problem, plus the final trajectory, being output. Except for well tested production runs, it is recommended that more detailed levels of print be exercised.

The first page of output summarizes IPOST input, including initial conditions, event summary, targeting and optimization definition, master-subproblem structure, and NPSOL options.

The second page of output completes NPSOL parameter definition and then prints an iteration summary for each major (master level) iteration. This includes the objective function value (sum of delta V) and other conditions of the optimization process. Of some interest are the number of objective function evaluations (NFUN) and the condition number of the Jacobian (COND T). This problem does not have any nonlinear constraints, only control bounds, but if it did, the value of the nonlinear constraint norm is displayed, as well as the constraint values.

As the iterations progress, certain key parameters should be monitored. These are the objective function value (which should decrease), the condition numbers of the Hessian and Jacobian (which should remain small), and the value of the nonlinear constraint norm (which should decrease). Also of interest are the convergence indicators at the right side of the summary. When all these flags are "T", then successful optimization has been achieved (according to NPSOL). One cautionary note is that reliance on a few indicators, such as the convergence flags, can be misleading. It is important to examine all measures, including the final solution.

The iteration summary continues until page 4 of the output, where a maximum iteration limit has been reached (INFORM = 4). NPSOL is exited, and the final trajectory is displayed. Conditions at each event are output, including the minus and plus sides of each impulsive maneuver. At the end of each subproblem, a final iteration summary is displayed. In this case, Subproblem 1 convergence is summarized between trajectory blocks for event 15 and event 20 (Jupiter closest approach), and Subproblem 2 is summarized just before event 30 (Saturn closest approach).

The last solution has a total ΔV of 7.27 km/s, reduced from the initial solution of 7.67 km/s. Jupiter closest approach time is 711.9 days from launch, and B dot T, B dot R were selected as 1898454 km, 130291 km.

Finally, a master problem summary output is given which includes the number of iterations and CPU time. A valid solution may or may not meet all convergence criteria. Only the user, with adequate engineering experience, can make that judgment.

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```
i p o s t - interplanetary post simulation.  version  2.18  , dated 03-05-90.                    problem no.    1
p$top
c...  voyager ii earth-jupiter-saturn
  srchm     = 'npsol',
  iprint    = 0,
  ideb = 0,
  iephem    = 1,
  fesn      = 90,
  istm      = 'autopert',
  npad(1)   = 0,
  mxitop    = 30,
  mxitar    = 600,
  ftol      = 1.d-6,
c
c  master controls are jupiter tca, arrival bdt, arrival bdr,
c
  indxi     = 1,2,3,
  indvr     = 'critr','depsvl02','depsvl03',
  indph     = 3*20,
  u         = 708.,.180849d7,.129268d6,
  indplb    = 700., 0.d0,0.d0,
  indpub    = 720.,3.d7,2.d6,
  pert      = .01,1000.,1000.,
  wvu       = 10.,.180849d7,.129268d6,
c
c  minimize delta-v at swingby
c
  optvar    = 5hdvsum,
  opt       = -1,
  optph     = 90,
  wopt      = 1.,
  etanl     = .5,
c
c subproblem setup
c
  modelt    = 'nraph','nraph',
  spfesn    = 20,30,
  tolf      = 1.0d0,
  tolu      = 1.0d0,
  npi       = 10,
c
c controls
c
  indxsi    = 1,1,1, 2,2,2,
  indsvr    = 'vinfxo','vinfyo','vinfzo', 'dvx','dvy','dvz',
  indsph    = 3*10, 3*23,
  usub      = 2.26374, 9.45391, 3.16241, 0.d0,0.d0,0.d0,
  indslb    = -20., -20., -20.,-10.,-10.,-10.,
  indsub    =  20.,  20.,  20., 10., 10., 10.,
  wvus      =  20.,  20.,  20., 10., 10., 10.,
  pertsb    = .00001, .00001, .00001, 3*.00001,
  wgts     = .01,.180849d7,.129268d6,15.,.01,.206130d6,.2d6,
c
c targets
c
  indxsd    = 1,1,1, 2,2,2,
  depsvr    = 'tfp','bdti','bdri', 'tfp','bdti','rperi',
  depsph    = 3*20, 3*30,
```


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```
  depsvl    = -.0001,.180849d7,.129268d6, -.0001,.206130d6,200000.d0,
  depslb    = -.0001,.180849d7,.129268d6, -.0001,.206130d6,199999.d0,
  depsub    = -.0001,.180849d7,.129268d6, -.0001,.206130d6,200001.d0,
  depstl    =  .00005,       .1,        .1, .00005,      100.,      100.,
  wvsnlc    =  1.,    .180849d7,.129268d6,     1.,.206130d6,      .2d6,
c
c objective
c
  optsvr    = 'target','dvmag',
  opts      = -1,-1,
  optsph    = 20,23,
  wopts     = .10,.10,

 $
p$traj
  event     = 5,
  iepoch    = 'calend',
  date      = 1977,7,31,

  idfram    = 'ecliptic','mean2000',
  ipbody    = 3,
  idbody    = 3,
  iprop     = 'conic',

  scmass    = 1.d6,
  thrust    = 2.d5,
  spi       = 480.,

  inputx    = 'conic',
  x         = 6563.,0.,0.,0.,0.,0.,

 $
p$traj
c  earth escape
c
  event     = 10,
  critr     = 'timrfl',
  value     = 20.,

  iprop     = '1step',
  ipbody    = 0,3,

  mantyp    = 'launch',
  ilnch     = 2,

  rperi     = 6563.,
  rapoap    = 6563.,
  inc       = -1.,

 $
p$traj
c  change idbody
c
  event     = 15,
  critr     = 'tdurp',
  value     = 20.,
  ipbody    = 0,5,
  idbody    = 5,
```

```
 $
p$traj
c  jupiter tca
c  7/9/1979
c
  event      = 20,
  critr      = 'timrfl',
  iprop      = 'conic',
  ipbody     = 5,0,

 $
p$traj
c  powered swingby
c
  event      = 23,
  critr      = 'tdurp',
  value      = 1.,
  mantyp     = 'impuls',
  iprop      = '1step',
  ipbody     = 0,5,

 $
p$traj
c  change idbody
c
  event      = 25,
  critr      = 'tdurp',
  value      = 300.,
  ipbody     = 0,6,
  idbody     = 6,

 $
p$traj
c  saturn tca
c  8/25/1981
c
  event      = 30,
  critr      = 'timrfl',
  value      = 1487.,

 $
p$traj
c  this is the end
c
  event      = 90,
  critr      = 'tdurp',
  value      = 0.,
  namlst     = 'none',
 $
```

```
*** core requirements for problem   1 are ***

    parameter               octal   decimal
    event criteria data -    531b       345
    general data        -    224b       148
```

```
execution date and time Thu Oct 29

**** ipost input summary ****

*** trajectory inputs ***
initial epoch
    julian date ...2443355.5000
    calendar date ...1977 jul  31,   0 hr  0 min  0.0000 secs
initial body and frame of reference  3 , earth   ,  ecliptic, mean2000
initial state
    cartesian     6.56300000000D+03   0.00000000000D+00   0.00000000000D+00
                  0.00000000000D+00   7.79323386922D+00   0.00000000000D+00
    conic         6.56300000000D+03   0.00000000000D+00   0.00000000000D+00
                  0.00000000000D+00   0.00000000000D+00   0.00000000000D+00
initial state, heliocentric, ecliptic
                  9.34871650060D+07  -1.19661308795D+08  -5.77793013208D+03
                  2.29812686681D+01   2.60127502765D+01   1.48462231329D-03
input units - metric, output units - metric
event summary
number           trigger          value            type          propagator
    5.000          time       1.00000000000D+10    none            conic
   10.000          timrf1     2.00000000000D+01    launch          lstep
   15.000          tdurp      2.00000000000D+01    none            lstep
   20.000          timrf1     2.00000000000D+01    none            conic
   23.000          tdurp      1.00000000000D+00    impuls          lstep
   25.000          tdurp      3.00000000000D+02    none            lstep
   30.000          timrf1     1.48700000000D+03    none            lstep
   90.000          tdurp      0.00000000000D+00    none            lstep


***targeting/optimization inputs***
master problem optimization parameter   dvsum    at event       90
master problem optimization algorithm - npsol

master prob. control/indep parameters
evtnum           name
   20.000          critr
   20.000          depsvl02
   20.000          depsvl03

master problem  target/dep parameters
evtnum           name
total number of subproblems is   2
subproblem number   1
subproblem controls   vinfxo       vinfyo       vinfzo
          at event      10           10           10
subproblem targets    tfp          bdti         bdri
         at events      20           20           20
subproblem values    -0.10000E-03  0.18085E+07  0.12927E+06
     with tolerance   0.50000E-04  0.10000E+00  0.10000E+00
subproblem number   2
subproblem controls   dvx          dvy          dvz
          at event      23           23           23
subproblem targets    tfp          bdti         rperi
         at events      30           30           30
subproblem values    -0.10000E-03  0.20613E+06  0.20000E+06
     with tolerance   0.50000E-04  0.10000E+03  0.10000E+03
```

```
OPTIONS file
------------

    BEGIN  OPTIONS FOR NPSOL 4.0

       VERIFY LEVEL                       0
       DERIV LEVEL                        0
       DIFFERENCE INTERVAL                1.E-4
       MAJOR ITERATIONS LIMIT             30
       MAJOR PRINT LEVEL                  10
       NONLINEAR FEASIBILITY TOLERANCE    3.E-7
       OPTIMALITY TOLERANCE               1.E-6
       HESSIAN                            NO
       COLD START
    END

Calls to NPOPTN
---------------

    major iteration limit =  30


                      NPSOL  ---  Version 4.05   Nov  1989
                      ===================================


Parameters
----------

Linear constraints.....          0       Linear feasibility.....  5.96E-08      COLD start.............
Variables..............          3       Infinite bound size....  1.00E+20      Crash tolerance........  1.00E-02
Step limit.............   2.00E+00       Infinite step size.....  1.00E+20

Nonlinear constraints..          0       Optimality tolerance...  1.00E-06      Function precision.....  9.90E-14
Nonlinear Jacobian vars          3       Nonlinear feasibility..  3.00E-07
Nonlinear objectiv vars          3       Linesearch tolerance...  9.00E-01
EPS (machine precision)   3.55E-15       Derivative level.......         0      Verify level...........         0

Major iterations limit.         30       Major print level......        10
Minor iterations limit.         50       Minor print level......         0
RUN loaded from file...          0       RUN to be saved on file         0      Save frequency.........        31

Difference interval....   1.00E-04       Central diffce interval  5.11E-05

Workspace provided is     IW(    2500),  W(  770500).
To solve problem we need  IW(       9),  W(      60).


The user sets      0   out of     3   objective gradient elements.
Each iteration,      3   gradient elements will be estimated numerically.

 Itn ItQP     Step  Nfun     Objective Bnd Lin  Nz  Norm Gf  Norm Gz  Cond H Cond Hz  Cond T Conv
```

```
 0   1  0.0E+00     1  7.672923E+00   0   0   3  1.1E+01  1.1E+01  1.E+00  1.E+00  0.E+00 F FT
 1   1  3.7E-03     8  7.308022E+00   0   0   3  2.8E+00  2.8E+00  2.E+02  2.E+02  0.E+00 T FT
 2   1  2.3E-01    10  7.304856E+00   0   0   3  2.9E-01  2.9E-01  4.E+02  4.E+02  0.E+00 T FT
 3   1  3.7E-01    12  7.302548E+00   0   0   3  2.3E+00  2.3E+00  2.E+02  2.E+02  0.E+00 T FT
 4   1  2.1E-01    14  7.297528E+00   0   0   3  4.1E+00  4.1E+00  4.E+01  4.E+01  0.E+00 F FT
 5   1  5.2E-01    18  7.275443E+00   0   0   3  7.4E-01  7.4E-01  5.E+01  5.E+01  0.E+00 F FT
 6   1  3.8E-02    21  7.273502E+00   0   0   3  4.6E+00  4.6E+00  3.E+02  3.E+02  0.E+00 T FT
 7   1  1.5E-01    24  7.271064E+00   0   0   3  1.0E+01  1.0E+01  1.E+02  1.E+02  0.E+00 T FT
 8   1  7.4E-02    27  7.270613E+00   0   0   3  1.0E+01  1.0E+01  3.E+02  3.E+02  0.E+00 T FT
 9   1  3.1E-01    29  7.270559E+00   0   0   3  1.5E+00  1.5E+00  2.E+02  2.E+02  0.E+00 T FT
10   1  0.0E+00    31  7.270559E+00   0   0   3  1.1E+01  1.1E+01  2.E+02  2.E+02  0.E+00 T FT  C
11   1  4.0E-01    33  7.269980E+00   0   0   3  3.0E+00  3.0E+00  6.E+01  6.E+01  0.E+00 T FT  C
12   1  3.6E-01    36  7.269251E+00   0   0   3  9.4E+00  9.4E+00  1.E+02  1.E+02  0.E+00 T FT  C
13   1  2.2E-01    38  7.269194E+00   0   0   3  7.7E+00  7.7E+00  2.E+02  2.E+02  0.E+00 T FT  C

Exit  NP phase.  INFORM =  6 MAJITS =    14  NFUN =    53  NGRAD =    13

Variable        State      Value       Lower bound      Upper bound  Lagr multiplier     Residual

VARBL  1          FR     71.19363       70.00000        72.00000       0.0000000E+00      0.8064
VARBL  2          FR     1.049907      0.0000000E+00    16.58842       0.0000000E+00       1.050
VARBL  3          FR     1.009167      0.0000000E+00    15.47173       0.0000000E+00       1.009

Exit NPSOL - Current point cannot be improved upon.

Final nonlinear objective value =     7.269194

date   = 7 31 1977  0.00  julian =2443355.50000000  tdurp  =      0.00000000  critr  =   time          propid = conic
primid = earth            secid  = earth            idbody = earth            frame  = ecliptic        epoch  = mean2000
timrfl = 0.000000000E+00
state relative to idbody: earth
x      = 0.656300000E+04  y      = 0.000000000E+00  z      = 0.000000000E+00  radius = 0.656300000E+04  scmass = 0.100000000E+07
vx     = 0.000000000E+00  vy     = 0.779323387E+01  vz     = 0.000000000E+00  speed  = 0.779323387E+01  fpa    =-0.381666562E-12
sma    = 0.656300000E+04  eccen  = 0.889452357E-15  inc    = 0.000000000E+00  argp   = 0.000000000E+00  anlong = 0.000000000E+00
meaan  = 0.000000000E+00  truan  = 0.000000000E+00  tfp    = 0.000000000E+00  rperi  = 0.656300000E+04  vperi  = 0.779323387E+01
altp   = 0.184860000E+03  alta   = 0.184860000E+03  rapoap = 0.656300000E+04  altit  = 0.184860000E+03  period = 0.529132654E+04
lat    = 0.000000000E+00  long   = 0.000000000E+00  longp  = 0.000000000E+00

final conditions for phase   5

date   = 8 20 1977  0.00  julian =2443375.50000000  tdurp  =     20.00000000  critr  =   timrfl        propid = conic
primid = earth            secid  = earth            idbody = earth            frame  = ecliptic        epoch  = mean2000
timrfl = 0.200000000E+02
state relative to idbody: earth
x      =-0.589969126E+04  y      =-0.287517165E+04  z      = 0.000000000E+00  radius = 0.656300000E+04  scmass = 0.100000000E+07
vx     = 0.341412237E+01  vy     =-0.700558795E+01  vz     = 0.000000000E+00  speed  = 0.779323387E+01  fpa    =-0.368944343E-12
```

```
sma    = 0.656300000E+04  eccen  = 0.933848152E-15  inc    = 0.000000000E+00  argp   = 0.000000000E+00  anlong = 0.000000000E+00
meaan  =-0.154018047E+03  truan  =-0.154018047E+03  tfp    =-0.262011247E-01  rperi  = 0.656300000E+04  vperi  = 0.779323387E+01
altp   = 0.184860000E+03  alta   = 0.184860000E+03  rapoap = 0.656300000E+04  altit  = 0.184860000E+03  period = 0.529132654E+04
lat    = 0.000000000E+00  long   =-0.114591559E+03  longp  = 0.000000000E+00

initial conditions for phase   10 before launch   maneuver

date   = 8 20 1977   0.00  julian =2443375.50000000  tdurp  =    20.00000000  critr  =   timrfl          propid = lstep
primid = sun               secid  = earth              idbody = earth            frame  = ecliptic         epoch  = mean2000
state relative to idbody: earth
x      =-0.589969126E+04  y      =-0.287517165E+04  z      = 0.000000000E+00  radius = 0.656300000E+04  scmass = 0.100000000E+07
vx     = 0.341412237E+01  vy     =-0.700558795E+01  vz     = 0.000000000E+00  speed  = 0.779323387E+01  fpa    =-0.368944343E-12
sma    = 0.656300000E+04  eccen  = 0.977989025E-12  inc    = 0.000000000E+00  argp   = 0.000000000E+00  anlong = 0.000000000E+00
meaan  =-0.154018047E+03  truan  =-0.154018047E+03  tfp    =-0.262011247E-01  rperi  = 0.656300000E+04  vperi  = 0.779323387E+01

launch   maneuver print block
dvx    = 0.000000000E+00  dvy    = 0.000000000E+00  dvz    = 0.000000000E+00  dvmag  = 0.726903802E+01  tburn  = 0.363451901E+05
thrust = 0.200000000E+06  spi    = 0.480000000E+03  dmass  = 0.786526125E+06  wprop  = 0.213473875E+06

initial conditions for phase   10 after launch   maneuver

date   = 8 20 1977   0.00  julian =2443375.50000000  tdurp  =     0.00000000  critr  =   timrfl          propid = lstep
primid = sun               secid  = earth              idbody = earth            frame  = ecliptic         epoch  = mean2000
timrfl = 0.200000000E+02
state relative to idbody: earth
x      = 0.539908538E+04  y      =-0.363079018E+04  z      =-0.860353840E+03  radius = 0.656300000E+04  scmass = 0.213473875E+06
vx     = 0.846624114E+01  vy     = 0.113982302E+02  vz     = 0.502743918E+01  speed  = 0.150622719E+02  fpa    = 0.678730369E-10
sma    =-0.378167899E+04  eccen  = 0.273547253E+01  inc    = 0.210140784E+02  argp   = 0.338557485E+03  anlong = 0.346214360E+03
meaan  = 0.110262831E-09  truan  = 0.932129933E-10  tfp    = 0.820447591E-14  rperi  = 0.656300000E+04  vperi  = 0.150622719E+02
Incoming Asymptote
altp   = 0.184860000E+03  vinfm  = 0.102665986E+02  vinfx  = 0.845879397E+01  vinfy  = 0.515509334E+01  vinfz  = 0.269756621E+01
bmag   = 0.962867007E+04  btheta = 0.146505405E+02  bdt    = 0.931560777E+04  bdr    = 0.243531091E+04  hypta  = 0.685574849E+02
c3     = 0.105403046E+03  ra     = 0.313596327E+02  dec    = 0.152334011E+02  altit  = 0.184860000E+03
Outgoing Asymptote
altp   = 0.184860000E+03  vinfm  = 0.102665986E+02  vinfx  = 0.228372219E+01  vinfy  = 0.930772076E+01  vinfz  = 0.368157486E+01
bmag   = 0.962867007E+04  btheta = 0.335159352E-10  bdt    = 0.962867007E+04  bdr    = 0.563241978E-08  hypta  = 0.685574849E+02
c3     = 0.105403046E+03  ra     = 0.477356494E+02  dec    = 0.210140784E+02  altit  = 0.184860000E+03
state relative primary body: sun
x      = 0.127217712E+09  y      =-0.820339672E+08  z      =-0.436792502E+04
vx     = 0.241195310E+02  vy     = 0.363332875E+02  vz     = 0.502764333E+01
sma    =-0.764065373E+09  eccen  = 0.119808406E+01  inc    = 0.657694804E+01
argp   = 0.358595914E+03  anlong = 0.327199149E+03  meaan  = 0.826427088E-01

final conditions for phase  10

date   = 9  9 1977   0.00  julian =2443395.50000000  tdurp  =    20.00000000  critr  =   tdurp           propid = lstep
primid = sun               secid  = earth              idbody = earth            frame  = ecliptic         epoch  = mean2000
timrfl = 0.400000000E+02
state relative to idbody: earth
x      = 0.376000157E+07  y      = 0.158739624E+08  z      = 0.624537138E+07  radius = 0.174678263E+08  scmass = 0.213473875E+06
vx     = 0.203173312E+01  vy     = 0.882694248E+01  vz     = 0.346898945E+01  speed  = 0.969931652E+01  fpa    = 0.896603749E+02
sma    =-0.423902809E+04  eccen  = 0.244520940E+02  inc    = 0.209861894E+02  argp   = 0.354658935E+03  anlong = 0.350247545E+03
meaan  = 0.235819227E+06  truan  = 0.920041723E+02  tfp    = 0.208244417E+02  rperi  = 0.994140853E+05  vperi  = 0.101019848E+02
Incoming Asymptote
altp   = 0.930359453E+05  vinfm  = 0.969696358E+01  vinfx  = 0.279784107E+01  vinfy  = 0.862309935E+01  vinfz  = 0.344170678E+01
bmag   = 0.103566397E+06  btheta = 0.293642861E+01  bdt    = 0.103430413E+06  bdr    = 0.530549055E+04  hypta  = 0.876561614E+02
```

```
c3      = 0.940311026E+02  ra     = 0.720238854E+02  dec    = 0.207889236E+02  altit  = 0.174614482E+08
Outgoing Asymptote
altp    = 0.930359453E+05  vinfm  = 0.969696358E+01  vinfx  = 0.203123344E+01  vinfy  = 0.882480269E+01  vinfz  = 0.346814804E+01
bmag    = 0.103566397E+06  btheta = 0.114902014E+01  bdt    = 0.103545572E+06  bdr    = 0.207680044E+04  hypta  = 0.876561614E+02
c3      = 0.940311026E+02  ra     = 0.724091512E+02  dec    = 0.209561280E+02  altit  = 0.174614482E+08
```

```
state relative primary body: sun
x      = 0.150285280E+09  y      =-0.192526118E+08  z      = 0.624480435E+07
vx     = 0.850190251E+01  vy     = 0.376899896E+02  vz     = 0.347024635E+01
sma    = 0.540629909E+09  eccen  = 0.722689833E+00  inc    = 0.546372471E+01
argp   = 0.122731869E+02  anlong = 0.327174715E+03  meaan  = 0.149709769E+01

initial conditions for phase   15

date   = 9  9 1977  0.00  julian =2443395.50000000  tdurp  =      0.00000000  critr  =   tdurp         propid = 1step
primid = sun              secid  = jupiter          idbody = jupiter          frame  = ecliptic        epoch  = mean2000
timrfl = 0.400000000E+02
state relative to idbody: jupiter
x      = 0.489745562E+08  y      =-0.775239332E+09  z      = 0.116229646E+08  radius = 0.776871690E+09  scmass = 0.213473875E+06
vx     = 0.216184244E+02  vy     = 0.353434449E+02  vz     = 0.318606692E+01  speed  = 0.415531755E+02  fpa    =-0.545703154E+02
sma    =-0.733840318E+05  eccen  = 0.613754382E+04  inc    = 0.886012383E+01  argp   = 0.601522267E+02  anlong = 0.268106570E+03
meaan  =-0.494219226E+06  truan  =-0.545779220E+02  tfp    =-0.176328142E+03  rperi  = 0.450324327E+09  vperi  = 0.415560211E+02
Incoming Asymptote
altp   = 0.450252929E+09  vinfm  = 0.415492509E+02  vinfx  = 0.216174356E+02  vinfy  = 0.353394476E+02  vinfz  = 0.318593345E+01
bmag   = 0.450397705E+09  btheta =-0.769927828E+01  bdt    = 0.446337319E+09  bdr    =-0.603414482E+08  hypta  = 0.899906647E+02
c3     = 0.172634025E+04  ra     = 0.585455258E+02  dec    = 0.439766997E+01  altit  = 0.776800292E+09
Outgoing Asymptote
altp   = 0.450252929E+09  vinfm  = 0.415492509E+02  vinfx  = 0.216060613E+02  vinfy  = 0.353465658E+02  vinfz  = 0.318412471E+01
bmag   = 0.450397705E+09  btheta =-0.770070079E+01  bdt    = 0.446335820E+09  bdr    =-0.603525296E+08  hypta  = 0.899906647E+02
c3     = 0.172634025E+04  ra     = 0.585506623E+02  dec    = 0.439516837E+01  altit  = 0.776800292E+09
state relative primary body: sun
x      = 0.150285280E+09  y      =-0.192526118E+08  z      = 0.624480435E+07
vx     = 0.850190251E+01  vy     = 0.376899896E+02  vz     = 0.347024635E+01
sma    = 0.540629909E+09  eccen  = 0.722689833E+00  inc    = 0.546372471E+01
argp   = 0.122731869E+02  anlong = 0.327174715E+03  meaan  = 0.149709769E+01

final conditions for phase  15

date   = 7 12 1979 22.47  julian =2444067.43630849  tdurp  =    671.93630849  critr  =   timrfl        propid = 1step
primid = sun              secid  = jupiter          idbody = jupiter          frame  = ecliptic        epoch  = mean2000
timrfl = 0.711936308E+03
state relative to idbody: jupiter
x      = 0.433346698E+06  y      = 0.555192933E+06  z      =-0.910720487E+05  radius = 0.710156794E+06  scmass = 0.213473875E+06
vx     =-0.160812524E+02  vy     = 0.124780486E+02  vz     =-0.428381733E+00  speed  = 0.203590738E+02  fpa    =-0.800349572E-02
sma    =-0.219524281E+07  eccen  = 0.132349806E+01  inc    = 0.746726841E+01  argp   = 0.260688481E+03  anlong = 0.151430683E+03
meaan  =-0.169603607E-02  truan  =-0.140507246E-01  tfp    =-0.990053290E-04  rperi  = 0.710156782E+06  vperi  = 0.203590739E+02
Incoming Asymptote
altp   = 0.638758782E+06  vinfm  = 0.759666021E+01  vinfx  =-0.429597088E+00  vinfy  = 0.753775941E+01  vinfz  =-0.840759004E+00
bmag   = 0.190322247E+07  btheta = 0.393032065E+01  bdt    = 0.189874637E+07  bdr    = 0.130453055E+06  hypta  = 0.409244977E+02
c3     = 0.577092463E+02  ra     = 0.932619112E+02  dec    =-0.635421746E+01  altit  = 0.638758794E+06
Outgoing Asymptote
altp   = 0.638758782E+06  vinfm  = 0.759666021E+01  vinfx  =-0.743241371E+01  vinfy  =-0.143864811E+01  vinfz  = 0.631477984E+00
bmag   = 0.190322247E+07  btheta = 0.575328899E+01  bdt    = 0.189363550E+07  bdr    = 0.190788873E+06  hypta  = 0.409244977E+02
c3     = 0.577092463E+02  ra     =-0.106626238E+03  dec    = 0.476825608E+01  altit  = 0.638758794E+06
state relative primary body: sun
x      =-0.590802760E+09  y      = 0.535750241E+09  z      = 0.109528856E+08
vx     =-0.250125686E+02  vy     = 0.338743411E+01  vz     =-0.190899988E+00
sma    =-0.436025897E+09  eccen  = 0.180235266E+01  inc    = 0.206538027E+01
argp   = 0.749073322E+02  anlong = 0.340181580E+03  meaan  = 0.663792506E+02

initial conditions for phase   20
```

```
initial conditions for phase   20

date   = 7 12 1979 22.47  julian =2444067.43630849  tdurp  =       0.00000000  critr  =   timrfl      propid = conic
primid = jupiter          secid  = sun               idbody = jupiter           frame  = ecliptic     epoch  = mean2000
timrfl = 0.711936308E+03
```

```
state relative to idbody: jupiter
x      = 0.433346698E+06  y      = 0.555192933E+06  z      =-0.910720487E+05  radius = 0.710156794E+06  scmass = 0.213473875E+06
vx     =-0.160812524E+02  vy     = 0.124780486E+02  vz     =-0.428381733E+00  speed  = 0.203590738E+02  fpa    =-0.800349572E-02
sma    =-0.219524281E+07  eccen  = 0.132349806E+01  inc    = 0.746726841E+01  argp   = 0.260688481E+03  anlong = 0.151430683E+03
meaan  =-0.169603607E-02  truan  =-0.140507246E-01  tfp    =-0.990053290E-04  rperi  = 0.710156782E+06  vperi  = 0.203590739E+02
Incoming Asymptote
altp   = 0.638758782E+06  vinfm  = 0.759666021E+01  vinfx  =-0.429597088E+00  vinfy  = 0.753775941E+01  vinfz  =-0.840759004E+00
bmag   = 0.190322247E+07  btheta = 0.393032065E+01  bdt    = 0.189874637E+07  bdr    = 0.130453055E+06  hypta  = 0.409244977E+02
c3     = 0.577092463E+02  ra     = 0.932619112E+02  dec    =-0.635421746E+01  altit  = 0.638758794E+06
Outgoing Asymptote
altp   = 0.638758782E+06  vinfm  = 0.759666021E+01  vinfx  =-0.743241371E+01  vinfy  =-0.143864811E+01  vinfz  = 0.631477984E+00
bmag   = 0.190322247E+07  btheta = 0.575328899E+01  bdt    = 0.189363550E+07  bdr    = 0.190788873E+06  hypta  = 0.409244977E+02
c3     = 0.577092463E+02  ra     =-0.106626238E+03  dec    = 0.476825608E+01  altit  = 0.638758794E+06
state relative to secondary body: sun
x      =-0.590802760E+09  y      = 0.535750241E+09  z      = 0.109528856E+08
vx     =-0.250125686E+02  vy     = 0.338743411E+01  vz     =-0.190899988E+00
sma    =-0.436025897E+09  eccen  = 0.180235266E+01  inc    = 0.206538027E+01
argp   = 0.749073322E+02  anlong = 0.340181580E+03  meaan  = 0.663792506E+02

final conditions for phase  20

date   = 7 13 1979 22.47  julian =2444068.43630849  tdurp  =      1.00000000  critr  =  tdurp          propid = conic
primid = jupiter          secid  = sun              idbody = jupiter          frame  = ecliptic       epoch  = mean2000
timrf1 = 0.712936308E+03
state relative to idbody: jupiter
x      =-0.102687501E+07  y      = 0.100077151E+07  z      =-0.508351063E+05  radius = 0.143478225E+07  scmass = 0.213473875E+06
vx     =-0.152561988E+02  vy     = 0.908046614E+00  vz     = 0.851749155E+00  speed  = 0.153069144E+02  fpa    = 0.488279481E+02
sma    =-0.219524281E+07  eccen  = 0.132349806E+01  inc    = 0.746726841E+01  argp   = 0.260688481E+03  anlong = 0.151430683E+03
meaan  = 0.171290593E+02  truan  = 0.834908744E+02  tfp    = 0.999900995E+00  rperi  = 0.710156782E+06  vperi  = 0.203590739E+02
Incoming Asymptote
altp   = 0.638758782E+06  vinfm  = 0.759666021E+01  vinfx  =-0.429597088E+00  vinfy  = 0.753775941E+01  vinfz  =-0.840759004E+00
bmag   = 0.190322247E+07  btheta = 0.393032065E+01  bdt    = 0.189874637E+07  bdr    = 0.130453055E+06  hypta  = 0.409244977E+02
c3     = 0.577092463E+02  ra     = 0.932619112E+02  dec    =-0.635421746E+01  altit  = 0.136338425E+07
Outgoing Asymptote
altp   = 0.638758782E+06  vinfm  = 0.759666021E+01  vinfx  =-0.743241371E+01  vinfy  =-0.143864811E+01  vinfz  = 0.631477984E+00
bmag   = 0.190322247E+07  btheta = 0.575328899E+01  bdt    = 0.189363550E+07  bdr    = 0.190788873E+06  hypta  = 0.409244977E+02
c3     = 0.577092463E+02  ra     =-0.106626238E+03  dec    = 0.476825608E+01  altit  = 0.136338425E+07
state relative to secondary body: sun
x      =-0.593034070E+09  y      = 0.535409868E+09  z      = 0.110136302E+08
vx     =-0.241741362E+02  vy     =-0.819466808E+01  vz     = 0.108898104E+01
sma    =-0.414014692E+09  eccen  = 0.260368657E+01  inc    = 0.248596821E+01
argp   = 0.338523905E+03  anlong = 0.119411006E+03  meaan  = 0.485978921E+02

initial conditions for phase   23 before impuls   maneuver

date   = 7 13 1979 22.47  julian =2444068.43630849  tdurp  =      1.00000000  critr  =  tdurp          propid = 1step
primid = sun              secid  = jupiter          idbody = jupiter          frame  = ecliptic       epoch  = mean2000
state relative to idbody: jupiter
x      =-0.102687501E+07  y      = 0.100077151E+07  z      =-0.508351063E+05  radius = 0.143478225E+07  scmass = 0.213473875E+06
vx     =-0.152561988E+02  vy     = 0.908046614E+00  vz     = 0.851749155E+00  speed  = 0.153069144E+02  fpa    = 0.488279481E+02
sma    =-0.219524281E+07  eccen  = 0.132349806E+01  inc    = 0.746726841E+01  argp   = 0.260688481E+03  anlong = 0.151430683E+03
meaan  = 0.171290593E+02  truan  = 0.834908744E+02  tfp    = 0.999900995E+00  rperi  = 0.710156782E+06  vperi  = 0.203590739E+02

impuls   maneuver print block
dvx    = 0.455302180E-04  dvy    = 0.246251752E-04  dvz    =-0.146724351E-03  dvmag  = 0.155587387E-03  tburn  = 0.166069213E+00
thrust = 0.200000000E+06  spi    = 0.480000000E+03  dmass  = 0.705586125E+01  wprop  = 0.213466820E+06
```

```
initial conditions for phase   23 after impuls   maneuver

date   = 7 13 1979 22.47  julian =2444068.43630849  tdurp  =      0.00000000  critr  =   tdurp       propid = 1step
primid = sun              secid  = jupiter          idbody = jupiter          frame  = ecliptic    epoch  = mean2000
```

```
timrfl = 0.712936308E+03
state relative to idbody: jupiter
x      =-0.102687501E+07  y      = 0.100077151E+07  z      =-0.508351063E+05  radius = 0.143478225E+07  scmass = 0.213466820E+06
vx     =-0.152561533E+02  vy     = 0.908071239E+00  vz     = 0.851602431E+00  speed  = 0.153068623E+02  fpa    = 0.488281129E+02
sma    =-0.219530346E+07  eccen  = 0.132348641E+01  inc    = 0.746650342E+01  argp   = 0.260686214E+03  anlong = 0.151432351E+03
meaan  = 0.171284271E+02  truan  = 0.834914876E+02  tfp    = 0.999905525E+00  rperi  = 0.710150836E+06  vperi  = 0.203591082E+02
Incoming Asymptote
altp   = 0.638752836E+06  vinfm  = 0.759655526E+01  vinfx  =-0.429428880E+00  vinfy  = 0.753767121E+01  vinfz  =-0.840687472E+00
bmag   = 0.190323603E+07  btheta = 0.392959822E+01  bdt    = 0.189876154E+07  bdr    = 0.130430044E+06  hypta  = 0.409239162E+02
c3     = 0.577076519E+02  ra     = 0.932606748E+02  dec    =-0.635376275E+01  altit  = 0.136338425E+07
Outgoing Asymptote
altp   = 0.638752836E+06  vinfm  = 0.759655526E+01  vinfx  =-0.743231726E+01  vinfy  =-0.143863407E+01  vinfz  = 0.631382611E+00
bmag   = 0.190323603E+07  btheta = 0.575283674E+01  bdt    = 0.189365049E+07  bdr    = 0.190775284E+06  hypta  = 0.409239162E+02
c3     = 0.577076519E+02  ra     =-0.106620240E+03  dec    = 0.476760027E+01  altit  = 0.136338425E+07
state relative primary body: sun
x      =-0.593034070E+09  y      = 0.535409868E+09  z      = 0.110136302E+08
vx     =-0.241740906E+02  vy     =-0.819464346E+01  vz     = 0.108883431E+01
sma    =-0.414018469E+09  eccen  = 0.260367099E+01  inc    = 0.248561659E+01
argp   = 0.338526525E+03  anlong = 0.119408289E+03  meaan  = 0.485974250E+02

final conditions for phase  23

date   = 5  8 1980 22.47  julian =2444368.43630849  tdurp  =    300.00000000  critr  =  tdurp          propid = 1step
primid = sun              secid  = jupiter          idbody = jupiter          frame  = ecliptic       epoch  = mean2000
timrfl = 0.101293631E+04
state relative to idbody: jupiter
x      =-0.208098024E+09  y      =-0.301360930E+08  z      = 0.167864915E+08  radius = 0.210937806E+09  scmass = 0.213466820E+06
vx     =-0.824688791E+01  vy     =-0.767464927E+00  vz     = 0.624257848E+00  speed  = 0.830601351E+01  fpa    = 0.870742963E+02
sma    =-0.186883390E+07  eccen  = 0.589728383E+01  inc    = 0.173329246E+03  argp   = 0.399346646E+02  anlong = 0.325193209E+03
meaan  = 0.630628788E+04  truan  = 0.968242418E+02  tfp    = 0.289154191E+03  rperi  = 0.915221005E+07  vperi  = 0.977102314E+01
Incoming Asymptote
altp   = 0.908081205E+07  vinfm  = 0.823338891E+01  vinfx  =-0.743318183E+01  vinfy  =-0.344279315E+01  vinfz  = 0.826847133E+00
bmag   = 0.108614396E+08  btheta =-0.176635948E+03  bdt    =-0.108427236E+08  bdr    =-0.637349842E+06  hypta  = 0.802372049E+02
c3     = 0.677886930E+02  ra     =-0.155148057E+03  dec    = 0.576370769E+01  altit  = 0.210866408E+09
Outgoing Asymptote
altp   = 0.908081205E+07  vinfm  = 0.823338891E+01  vinfx  =-0.817496277E+01  vinfy  =-0.758924362E+00  vinfz  = 0.618636011E+00
bmag   = 0.108614396E+08  btheta =-0.174902994E+03  bdt    =-0.108184903E+08  bdr    =-0.964954632E+06  hypta  = 0.802372049E+02
c3     = 0.677886930E+02  ra     =-0.174170329E+03  dec    = 0.430912103E+01  altit  = 0.210866408E+09
state relative primary body: sun
x      =-0.974184351E+09  y      = 0.229413788E+09  z      = 0.328818838E+08
vx     =-0.126002267E+02  vy     =-0.125491850E+02  vz     = 0.770292069E+00
sma    =-0.256300375E+10  eccen  = 0.129348410E+01  inc    = 0.256989943E+01
argp   = 0.351055672E+03  anlong = 0.119694447E+03  meaan  = 0.719129706E+01

initial conditions for phase   25

date   = 5  8 1980 22.47  julian =2444368.43630849  tdurp  =      0.00000000  critr  =  tdurp          propid = 1step
primid = sun              secid  = saturn           idbody = saturn           frame  = ecliptic       epoch  = mean2000
timrfl = 0.101293631E+04
state relative to idbody: saturn
x      = 0.436006288E+09  y      = 0.126641919E+09  z      =-0.213492406E+08  radius = 0.454527721E+09  scmass = 0.213466820E+06
vx     =-0.113743257E+02  vy     =-0.288227647E+01  vz     = 0.552717232E+00  speed  = 0.117468421E+02  fpa    =-0.880253179E+02
sma    =-0.275171223E+06  eccen  = 0.569607410E+02  inc    = 0.269841380E+01  argp   = 0.292373562E+01  anlong = 0.102299021E+03
meaan  =-0.944095269E+05  truan  =-0.890306541E+02  tfp    =-0.447017053E+03  rperi  = 0.153987855E+08  vperi  = 0.119476806E+02
Incoming Asymptote
altp   = 0.153387855E+08  vinfm  = 0.117397370E+02  vinfx  =-0.113674760E+02  vinfy  =-0.288041445E+01  vinfz  = 0.552383113E+00
```

```
bmag    = 0.156715411E+08  btheta =-0.903710839E-01  bdt    = 0.156715216E+08  bdr    =-0.247182878E+05  hypta  = 0.889940664E+02
c3      = 0.137821425E+03  ra     =-0.165781050E+03  dec    = 0.269690121E+01  altit  = 0.454467721E+09
Outgoing Asymptote
altp    = 0.153387855E+08  vinfm  = 0.117397370E+02  vinfx  =-0.112592652E+02  vinfy  =-0.327816061E+01  vinfz  = 0.551393273E+00
bmag    = 0.156715411E+08  btheta =-0.185063650E+00  bdt    = 0.156714593E+08  bdr    =-0.506185198E+05  hypta  = 0.889940664E+02
c3      = 0.137821425E+03  ra     =-0.163913460E+03  dec    = 0.269206494E+01  altit  = 0.454467721E+09
```

```
state relative primary body: sun
x      =-0.974184351E+09  y      = 0.229413788E+09  z      = 0.328818838E+08
vx     =-0.126002267E+02  vy     =-0.125491850E+02  vz     = 0.770292069E+00
sma    =-0.256300375E+10  eccen  = 0.129348410E+01  inc    = 0.256989943E+01
argp   = 0.351055672E+03  anlong = 0.119694447E+03  meaan  = 0.719129706E+01

final conditions for phase  25

date   = 8 26 1981  0.00  julian =2444842.50000000  tdurp  =    474.06369151  critr  =   timrf1         propid = 1step
primid = sun              secid  = saturn           idbody = saturn           frame  = ecliptic         epoch  = mean2000
timrf1 = 0.148700000E+04
state relative to idbody: saturn
x      =-0.135228263E+06  y      = 0.404454447E+05  z      = 0.141744757E+06  radius = 0.200035230E+06  scmass = 0.213466820E+06
vx     =-0.151987656E+02  vy     =-0.117929374E+02  vz     =-0.111465811E+02  speed  = 0.222333560E+02  fpa    =-0.210938786E-01
sma    =-0.329365722E+06  eccen  = 0.160733463E+01  inc    = 0.602120192E+02  argp   = 0.125300170E+03  anlong = 0.184377547E+02
meaan  =-0.100297619E-01  truan  =-0.342173925E-01  tfp    =-0.621887707E-04  rperi  = 0.200035208E+06  vperi  = 0.222333569E+02
Incoming Asymptote
altp   = 0.140035208E+06  vinfm  = 0.107305177E+02  vinfx  =-0.102574128E+02  vinfy  =-0.310866351E+01  vinfz  = 0.515465435E+00
bmag   = 0.414467811E+06  btheta =-0.601741047E+02  bdt    = 0.206142240E+06  bdr    =-0.359567717E+06  hypta  = 0.515268380E+02
c3     = 0.115144010E+03  ra     =-0.163139777E+03  dec    = 0.275339599E+01  altit  = 0.140035230E+06
Outgoing Asymptote
altp   = 0.140035208E+06  vinfm  = 0.107305177E+02  vinfx  =-0.122575319E+01  vinfy  =-0.580408435E+01  vinfz  =-0.894170812E+01
bmag   = 0.414467811E+06  btheta =-0.260199533E+02  bdt    = 0.372457905E+06  bdr    =-0.181820449E+06  hypta  = 0.515268380E+02
c3     = 0.115144010E+03  ra     =-0.150496956E+03  dec    =-0.564389236E+02  altit  = 0.140035230E+06
state relative primary body: sun
x      =-0.140523513E+10  y      =-0.291999978E+09  z      = 0.610647598E+08
vx     =-0.137454390E+02  vy     =-0.212817024E+02  vz     =-0.110387217E+02
sma    =-0.229235104E+09  eccen  = 0.570065114E+01  inc    = 0.332341103E+02
argp   = 0.130483133E+03  anlong = 0.154617110E+02  meaan  = 0.216645061E+03

initial conditions for phase   30

initial conditions for phase   30

final conditions for phase  30

date   = 8 26 1981  0.00  julian =2444842.50000000  tdurp  =      0.00000000  critr  =   tdurp          propid = 1step
primid = sun              secid  = saturn           idbody = saturn           frame  = ecliptic         epoch  = mean2000
timrf1 = 0.148700000E+04
state relative to idbody: saturn
x      =-0.135228263E+06  y      = 0.404454447E+05  z      = 0.141744757E+06  radius = 0.200035230E+06  scmass = 0.213466820E+06
vx     =-0.151987656E+02  vy     =-0.117929374E+02  vz     =-0.111465811E+02  speed  = 0.222333560E+02  fpa    =-0.210938786E-01
sma    =-0.329365722E+06  eccen  = 0.160733463E+01  inc    = 0.602120192E+02  argp   = 0.125300170E+03  anlong = 0.184377547E+02
meaan  =-0.100297619E-01  truan  =-0.342173925E-01  tfp    =-0.621887707E-04  rperi  = 0.200035208E+06  vperi  = 0.222333569E+02
Incoming Asymptote
altp   = 0.140035208E+06  vinfm  = 0.107305177E+02  vinfx  =-0.102574128E+02  vinfy  =-0.310866351E+01  vinfz  = 0.515465435E+00
bmag   = 0.414467811E+06  btheta =-0.601741047E+02  bdt    = 0.206142240E+06  bdr    =-0.359567717E+06  hypta  = 0.515268380E+02
c3     = 0.115144010E+03  ra     =-0.163139777E+03  dec    = 0.275339599E+01  altit  = 0.140035230E+06
Outgoing Asymptote
altp   = 0.140035208E+06  vinfm  = 0.107305177E+02  vinfx  =-0.122575319E+01  vinfy  =-0.580408435E+01  vinfz  =-0.894170812E+01
bmag   = 0.414467811E+06  btheta =-0.260199533E+02  bdt    = 0.372457905E+06  bdr    =-0.181820449E+06  hypta  = 0.515268380E+02
c3     = 0.115144010E+03  ra     =-0.150496956E+03  dec    =-0.564389236E+02  altit  = 0.140035230E+06
state relative primary body: sun
x      =-0.140523513E+10  y      =-0.291999978E+09  z      = 0.610647598E+08
vx     =-0.137454390E+02  vy     =-0.212817024E+02  vz     =-0.110387217E+02
sma    =-0.229235104E+09  eccen  = 0.570065114E+01  inc    = 0.332341103E+02
```

```
argp   = 0.130483133E+03  anlong = 0.154617110E+02  meaan  = 0.216645061E+03
initial conditions for phase   90
```

```
esn =   90.000  fesn=   90.000
time=  2.44484250D+06
normal termination
cpu =   40.300 seconds
```

*** n p s o l s u m m a r y o u t p u t ***

	variables				constraints				objective function		
	name	phase	value	residual	name	phase	value	residual	name	phase	value
1	critr	20.0	0.71193631E+03	0.00000000E+00					dvsum	90.0	0.726919361E+01
2	depsvl	20.0	0.18987465E+07	0.00000000E+00							
3	depsvl	20.0	0.13045306E+06	0.00000000E+00							

total number of iterations = 14
total number of reloaded fn evals = 12
total number of function evaluations = 108
total cpu time = 5258.120 seconds

5.1 NAMELIST $TOP

The following is a description of input parameters for Namelist $TOP.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
ATARWT	REAL		Contingency targeting adjustments parameters. Applicable only for MODELT(i) = 'TARG1S'.
		2.D0	ATARWT(1) = fraction of target error that causes DR adjustment
		7.D0	ATARWT(2) = maximum number of target error increases (INCR) allowed
		3.D0	ATARWT(3) = DR scale factor for target error increase
		1.D0	ATARWT(4) = fraction of DVMAG that causes DR adjustment
		1.D1	ATARWT(5) = fraction of DR that causes DR adjustment
		8.D0	ATARWT(6) = maximum number of DR increases (INCPR) allowed
		5.D0	ATARWT(7) = DR scale factor for DR increase (big target error)
		0.7D0	ATARWT(8) = DR scale factor for DR increase (small target error)
		2*0.D0	T.B.D.
DEPPH(i)	INT.	25*900	The event at which dependent variable (target) i is to be satisfied. DEPPH is of type esn=INT.
DEPSLB	REAL	500*-10D10	The lower bound of variable DEPSVR.
DEPSPH(i)	REAL	45*999.D0	The event at which subproblem or dependent or variable (target) i is to be INT. satisfied. DEPSPH is of type esn=INT.
DEPSTL(i)	REAL	45*1.D0	The desired accuracy level within which DEPSVR(i) is considered to be satisfied.
DEPSUP	REAL	500*10D10	The upper bound of variable DEPSVR.
DEPSVL(i)	REAL	45*0.D0	The desired value of the subproblem dependent variable DEPSVR(i).
DEPSVR(i)	CHAR.	45*' '	The Character name of subproblem dependent variable (target) i. (See Table 3 - 9).

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
DEPTL(i)	REAL	25*1.D0	The desired accuracy level within which DEPVR(i) is considered to be satisfied.
DEPVLB(i)	REAL	25* -10.D10	The lower bound on the dependent variable DEPVR(i).
DEPVR(i)	CHAR.	25*' '	The Character name of dependent variable i.(See Table 3 - 9).
DEPVUB(i)	REAL	25* 10.D10	The upper bound on the dependent variable DEPVR(i).
FESN	INT.	999	The final event sequence number of the master problem. FESN is of type esn=INT.
IDEB	INT.	0	Trial step summary printout flag (i.e, print 'normal termination' at the end of each trajectory, call NOMOUT at the end of CNFUNC and print gradients) = 0, do not print trial summaries. = 1, print trial step summaries.
IEPHEM	INT.	0	Flag to specify type of planetary ephemeris to be used. = 0, analytic. = 1, precision.
IFDEG	INT.	25*0	A flag to allow angles with a range of 0 to 360 degrees to be used as target variables. = 0, no adjustment is made = 1, if ABS(E(i)) is greater than 180.0, set E(i) = E(i) plus or minus 360.0.
INDPH(i)	INT.	25*0	The phase at which INDVR(i) is to be initiated. INDPH is of type esn=INT.
INDPLB(i)	REAL	25*-10.D10	The lower bound on the independent variable INDVR(i).
INDPUB(i)	REAL	25*10.D10	The upper bound on the independent variable INDVR(i).

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
INDSLB(i)	REAL	500* -1.D38	The lower bound on the subproblem independent variable INDSVR(i)
INDSPH(i)	REAL or INT.	45*999.D0	The phase at which INDSVR(i) is to be applied. INDSPH is of type esn=INT.
INDSUB(i)	REAL	500*1.D38	The upper bound on the subproblem independent variable INDSVR(i).
INDSVR(i)	CHAR.	45* ' '	The Character name of the ith subproblem independent variable used for the targeting/optimization process.(See Table 3 - 8).
INDVR(i)	CHAR.	25* ' '	The Character name of the ith independent variable used for the targeting/optimization process. (See Table 3 - 8).
INDXD(j)	REAL or INT.	1,2,3,...25	An array containing the indices of the dependent variables to be used for targeting/optimization. The indices must be input in INDXD(j) in ascending order; e.g. INDXD = 1, 5,
INDXI(j)	INT.	1,2,3,...25	An array containing the indices of the independent variables to be used for targeting/optimization. The indices must be input in INDXI(j) ascending order; e.g. INDXI = 3, 5, 9, is acceptable.
INDXSD(i)	INT.	45*0	Mapping of subproblem dependent variables to individual subproblems.
INDXSI(i)	INT.	45*0	Mapping of subproblem independent variables to individual subproblems.
INIT	INT.	0	Flag to return to Master problem initialization if warning errors occur in the input data: = 0, do not return to master initialization. = 1, return to master initialization.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
INOUT	INT.	1	Flag for displaying processed inputs. = 0, do not display processed input. = 1, display processed input.
IPRINT	INT.	0	Global printout flag (each value will produce print from all smaller values): = 0, Print diagnostic and master problem summary output: (IDEB=0, IPRO=-1, LISTIN=-1, MSGLVL=1, PRNTPD=.FALSE.). = 1, Print nominal summary output: (IDEB=0, IPRO=0, LISTIN=-1, MSGLVL=10, PRNTPD=.FALSE.). = 2, Print more summary information: (IDEB=1, IPRO=1, LISTIN=-1, MSGLVL=15, PRNTPD=.FALSE.). = 3, Print subproblem nominal summary output: (IDEB=1, IPRO=2, LISTIN=-1, MSGLVL=15, PRNTPD=.FALSE.). = 4, Print massive debug output: (IDEB=1, IPRO=5, LISTIN=1, MSGLVL=99, PRNTPD=.TRUE.). = 5, Same as 4 with more debug output -NOTE- input of the individual flags, IDEB, IPRO, LISTIN, MSGLVL or PRNTPD will override that facet of the IPRINT flag.
IPRO	INT.	0	A flag to control the printing of trajectories during targeting/optimization. =-1, Print the final trajectory. = 0, Print the first and final trajectory. = 1, Print all nominal trajectories. = 2, Print all trajectories.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
IRSCL	INT.	2	Control weighting (WVU) and constraint weighting (WVNLC) rescaling option. Used with MXITOP (I), I > 1. Rescaling based upon elements of Jacobian matrix and Objective gradient. = 0, rescale WVNLC based upon largest constraint elements. = 1, rescale WVNLC and WVU based upon largest constraint and control elements. = 2, rescale WVNLC based upon renormalization of Jacobian elements.
ISMDEP	INT.	0	An index identifying the master level dependent variable DEPVR(i) to be used in the parameter search.
ISMIND ( )	INT.	25*0	Index of master level independent parameters that are reported/recorded after the search (ISMDEP ≠ 0).
ISTATE	INT.	60*0	NPSOL argument "ISTATE", indicates the status of every constraint with respect to the current prediction of the active set. = -2, This constraint violates its lower bound by more than FEATOL(j) in a QP subproblem. = -1, This constraint violates its upper bound by more than FEATOL(j) in a QP subproblem. = 0, The constraint is not in the predicted active set. = 1, This inequality constraint is included in the predicted active at its lower bound. = 2, This inequality constraint is included in the predicted active at its upper bound. = 3, The constraint is included in the predicted active as an equality.
ISTM	CHAR.	'ANAL'	Flag to define method of generating state transition matrices. = 'ANAL', analytic matrices. = 'CENTRAL', central finite differencing. = 'FORWARD', forward finite differencing.
ISUB(i)	INT.	15*0	Flag to control subproblem solution printout. = 0, do not print each subproblem solution ≠ 0, print each subproblem solution

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
ITARG(i)	INT.	15*9	Flag identifying the type of target parameters for subproblem i in ITOO targeting. See also SRCHM = 'TOO' and MODELT. Overrides DEPSVR. = 0, inactive. = 1, X, Y, Z = 2, VX, VY, VZ = 3, C3, RA, DEC = 4, VINFX, VINFY, VINFZ = 5, RPERI, BTHETA, TCA = 6, SMA, RPERI, INC = 7, DVX, DVY, DYZ = 8, RPERI, BTHETA, FPA = 9, RPERI, INC, MEAAN
ITOOWT	CHAR	'SVMASS'	Type of weighting for ITOO (SRCHM = "ITOO') = 'SUMDV2', sum of squares of ΔV. = 'SUMDV', sum of ΔV magnitudes. = 'SVMASS', sum of ΔV mass changes.
LISTIN	INT.	-1	INPUTX input display selector: =-1, no input display. = 0, display tables. = 1, display tables and namelist input. = 2, display namelist input.
LNCNLB	REAL	10*-10.D10	Linear Constraint lower bounds, BL.
LNCNUB	REAL	10*10.D10	Linear Constraint upper bounds, BU.
MODELT(i)	CHAR.	15*'NRAPH'	Subproblem targeting model selection flag, subproblem i. = 'NRAPH', Newton-Raphson method = 'TARG1S', Special Onestep method = 'SUBOP+', NPSOL41 Optimization
MODEW	INT.	1	Flag to control type of weighting to be used for independent variables. = 0, user input weighting. = 1, auto control weighting.
MSGLVL	INT.	10	This variable was superceded by 'Major Print Level' in npinput file.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
MXITAR(i)	INT.	10	Maximum number of subproblem targeting iterations. MXITAR is a singleton which applies to each subproblem.
MXITOP(i)	ARRAY	10, 5*-1	The maximum number of major iterations i =1,6 to be performed on NPSOL pass (i), before rescaling. MXITOP overrides the value of the "Major Iteration Limit" in the file NPINPUT. See also IRSCL for rescaling and section 3.4.2.
NAMLST	CHAR.	'TRAJ'	The next expected namelist. = 'NONE', no more namelist input. Solve problem. = 'TABLE', read namelist TAB next. = 'TOP', read namelist TOP next. = 'TRAJ', read namelist TRAJ next. NOTE: TRAJ and TABLE namelists can be read only in the first problem.
NLINES	INT.	60	The maximum number of lines per page of output.
NPAD(1)	REAL	9.D0	The desired average of minimum and maximum number of digits different between perturbed dependent or optimization variable values to be achieved by adjusting PERT(i). Increasing the value of NPAD(1) will cause PERT(i) to become larger. This option is disabled if NPAD(1)is input as zero.
NPAD(2)	REAL	4.D0	The number of significant figures different between nominal and perturbed dependent or optimization variable values below which the variable is ignored in selecting minimum and maximum required for PERT adjustment.
NPAD(3)	REAL	14.4494D0	The number of significant figures different between nominal and perturbed dependent or optimization variable values, above which the variable is ignored in selecting minimum and maximum required for PERT adjustment.
NPI	INT.	3	Number of previous iterations to compare error in Newton-Raphson subproblem targeting method before declaring solution divergent (MODELT = 'NRAPH').

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
NPINPT	CHAR*30	'NINPUT'	The name of the NPSOL NPFILE input.
NPVAR	INT.	0	Number of output parameters for PROFIL (PRNC > 0).
NSMINC	INT.	0	Number of search increments (ISMDEP $\neq$ 0).
NSMIND	INT.	0	Number of ismind listed controls.
OPT	INT.	0	A flag to select the type of optimization to be performed: = -1, Minimize the variable OPTVAR. = 0, No optimization. = 1, Maximize the variable OPTVAR.
OPTPH	REAL	999.D0	The phase at which the variable OPTVAR is to be optimized. OPTPH is of type esn=INT.
OPTS	INT.	25*0	A flag to select the type of subproblem optimization to be performed.
OPTSPH	REAL	25*900.D0	The phase at which the variable OPTSVR is to be optimized.
OPTSVR	CHAR	25*0	The character name of the subproblem variable to be optimized.
OPTVAR	CHAR	' '	The Character name of the variable to be optimized. (see Table 3 - 9).
OUTNAM	CHAR	100*' '	Output parameter names for PROFIL (PRNC > 0).
PDLMAX	REAL	2.D0	Trigger level for a second (central differences) perturbed trajectory. The magnitude of the difference between NPAD(1) and the average of the minimum and maximum number of digits different.
PERT(i)	REAL	25*.0001D0	The perturbation (increment) to be added to the independent variable, INDVR(i), whose value is currently U(i). Used to determine the sensitivity dE(j)/dU(i).

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
PERTSB(i)	REAL	45*.0001D0	The perturbation (increment) to be added to the subproblem independent variable, INDSVR(i), whose value is currently USUB(i). Used to determine the sensitivity dESUB(j)/dUSUB(i).
PRNTPD	LOG.	.FALSE.	A flag to activate printing of the number of significant digits difference due to the perturbations in the control parameters when generating the sensitivity matrix.
R(i,j)	REAL	0.	The Upper-Triangular Cholesky factor of the Hessian of the NPSOL problem. This must be input if a WARMSTART is used.
RFSOI(i)	REAL	15*0.5D0	The fraction of sphere of influence beyond which XYZ targeting occurs, subproblem i, TARG1S subproblem targeting model. (See MODELT).
SMINCR	REAL	0.	Size of each search increment (ISMDEP $\neq$ 0).
SPFESN(i)	REAL	15*999.D0	The final event sequence number for subproblem i. SPFESN is of type esn=INT.
SRCHM	CHAR	'NONE'	Master problem targeting optimization algorithm selector: = 'COLLOC', Use collocation algorithm = 'ITOO', special Interplanetary Option: analytical-partials, master and 3 x 3 subproblems = 'NONE', No master level targeting or optimization. = 'NPSOL', Use NPSOL at master level.
SMINCR	REAL	1.D0	Size of search increments.
TARGMT(i)	REAL	1.D0	Target error magnitude threshold for changing target weights, subproblem i, TARG1S subproblem targeting model.
TOLF	REAL	1.D0	Tolerance for convergence of the subproblems, tested against the sum of weighted target errors.
TOLU	REAL	1.D0	Tolerance for convergence of the subproblems, tested against the change in the subproblem controls.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
U(i)	REAL	25*0.D0	The initial values to be used for the variables specified by INDVR(i) at the beginning of phase INDPH(i). Collocation: The user inputs m initial values for the m user independent variables, U(1) to U(m). Next the user inputs initial values for the event nodes (and internal nodes if needed). IPOST can interpolate the remaining controls for the internal nodes(NSGPH0 in $TRAJ).
USUB(i)	REAL	45*0.D0	The initial values to be used for the subproblem variables specified by INDSVR(i) at the beginning of phase INDSPH(i).
WGTS	REAL	500*1.D0	The dependent variable scale factors used when optimizing to magnitude of dependent variable errors.
WOPT	REAL	1.D0	The weighting for the optimization variable. WOPT should be input as approximately one over the nominal value of OPTVAR.
WOPTS	REAL	25*1.D0	The weightings for the subproblem optimization variable.
WVLC	REAL	10*1.D0	The linear constraint weighting.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
WVNLC	REAL	25*1.D0	The dependent variable weighting for DEPVR(i). Collocation: IPOST will use a set of default values of WVNLC for the defects and event discrepancies if the user does not input values. The defaults are: WVNLC(nodei+0) = magnitude of U(nodei+3) velocity vector. WVNLC(nodei+1) = magnitude of U(nodei+3) velocity vector. WVNLC(nodei+2) = magnitude of U(nodei+3) velocity vector. WVNLC(nodei+3) = magnitude of U(nodei+3) velocity vector, squared, divided by the magnitude of the position vector of U(nodei). WVNLC(nodei+4) = magnitude of U(nodei+3) velocity vector, squared, divided by the magnitude of the position vector of U(nodei). WVNLC(nodei+5) = magnitude of U(nodei+3) velocity vector, squared, divided by the magnitude of the position vector of U(nodei). WVNLC(nodei+6) = absolute value of U(nodei+6), spacecraft mass. IPOST can interpolate a value for WVNLC if it lies between two input points.
WVSNLC(i)	REAL	25*1.D0	The weighting for the subproblem non-linear constraints.
WVUS	REAL	500*1.D0	The independent variable weighting for INDSVR.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
WVU	REAL	25*1.D0	The independent variable weighting for INDVR(i)/U(i). Recommended value is WVU(i) = abs(U(i)). Collocation: IPOST will use a set of default values of WVU for the defects and event discrepancies if the user does not input values. The defaults are: WVU(nodei+0) = magnitude of U(nodei) position vector. WVU(nodei+1) = magnitude of U(nodei) position vector. WVU(nodei+2) = magnitude of U(nodei) position vector. WVU(nodei+3) = magnitude of U(nodei+3) velocity vector. WVU(nodei+4) = magnitude of U(nodei+3) velocity vector. WVU(nodei+5) = magnitude of U(nodei+3) velocity vector. WVU(nodei+6) = absolute value of U(nodei+6), spacecraft mass. IPOST can interpolate a value for WVU if it lies between two input points.

5.2 NAMELIST $TRAJ

The following is a description of input parameters for Namelist $TRAJ. $TRAJ data sets correspond to as many events as the user desires. REAL refers to REAL*8, LOG refers to LOGICAL, INT refers to INTEGER*4, and CHAR refers to character variables.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
ALT(50)	REAL	VARIOUS	Tabular atmospheric altitude data (km) used to calculate density and speed of sound at a given altitude. Elements in the array correspond to atmospheric pressure (PRES), molecular weight (WGT), and temperature (TPT) for IATMOS = 1. Table size is specified by ITABSZ.
ALTATM(22)	REAL	22*0.D0	Altitude boundary of sensible atmosphere ALTATM (0) = Sun's altitude (1) = Mercury's altitude (2) = Venus' altitude (3) = Earth's altitude (4) = Mars' altitude (5) = Jupiter's altitude (6) = Saturn's altitude (7) = Uranus's altitude (8) = Neptune's altitude (9) = Pluto's altitude (10) = Earth's moon altitude ALTATM (11) through (22) reserved for other bodies' ALTATM.
ALTIT	REAL	0.	Circular altitude of park orbit (see MANTYP and ILNCH)

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
ATMS (10)	REAL		Atmospheric initial data. (Defaults are defined for Earth's atmospheric data.)
		1.225D0	ATMS(1) = Base density for exponential and tabular atmospheres. (Default is for tabular - kg/m .)
		1.01325D5	ATMS(2) = Base pressure for tabular atmosphere. (newton/m).
		28.964D0	ATMS(3) = Base molecular weight for tabular atmosphere. (kg/mole)
		3.139D-7	ATMS(4) = First order gravitational constant for tabular atmosphere. (1/m)
		287.D0	ATMS(5) = Specific gas constant for tabular atmosphere. (joules/kg/K)
		7.162D0	ATMS(6) = Scale height for exponential atmosphere. (km)
		0.D0	ATMS(7) = Base altitude for exponential atmosphere. (km)
		1.4.D0	ATMS(8) = Ratio of specific heat
		0.D0	ATMS(9) = T.B.D.
		0.D0	ATMS(10) = T.B.D.
BTHETA	REAL	0.	B-plane theta angle for escape (see MANTYP and ILNCH)
BTHRST	REAL	1.D0,2*0.D0	Thrust alignment unit vector in the body system.
C(i,j,k)	REAL	VARIOUS	The analytic elements of the planetary ephemeris. i - polynomial coefficient; third order in time; i = 1, 2, 3, 4 j - planet number; 0=sun, 3=earth,...; j = 0, 1, 2,..., 22 k - element type: 1 = semimajor axis 2 = eccentricity 3 = inclination 4 = longitude of ascending node 5 = argument of periapsis 6 = mean anomaly
CD	REAL	0.D0	Drag coefficient for the vehicle(can be overridden by $TAB input).
CL	REAL	0.D0	Lift coefficient for the vehicle (can be overridden by $TAB input).

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
COINTP	CHAR.	'linear'	How initial values of ordinary nodes are calculated from event nodes, by linear/hermite interpolation. 'linear' linear interpolation 'hemite' hemite interpolation
CONODE	CHAR.	'5'	Defines a property of collcoation internal nodes. = 'float', the internal nodes float so that any variable length is divided into nsegph segments of equal time duration. = 'fixed', the internal nodes are fixed in time. If any varaible length phase increases or desreases in duration , then the last segment absorbs the entire increase or decrease.
CRITR	CHAR.	'TIME '	The name of the event criterion variable. (see Table 3-9)
C3	REAL	0.D0	Escape energy. (see MANTYP and ILNCH)
DATE(i)	REAL	0.D0	Calendar Date. (Year,Month,Day,Hour,Minute,Seconds)
DEC	REAL	0.D0	Declination of launch asymptote. (see MANTYP and ILNCH)
DT	REAL	1.D0	Constant delta-time propagation step for the Multiconic, Cowell, and Encke propagators.
DTIMR(20)	REAL	20*0.D0	Reference time for activities. Initiated by setting DTIMR(i) = 1, Corresponding event criteria times are: TIMRF1,TIMRF2,...,TIMRF20. DTIMR(1) = Start of mission (first event) DTIMR(2) = Start of finite burn DTIMR(3) = Nuclear electric decay start DTIMR(4) = Blowdown propulsion initiation DTIMR(5) = Throttle level polynomial start DTIMR(6) = Body roll angle polynomial start DTIMR(7) = Body yaw angle polynomial start DTIMR(8) = Body pitch angle polynomial start DTIMR(9) = Not available DTIMR (10) = Not available DTIMR (11) through DTIMR(20) are vavailable for user specification.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
DVX(3)	REAL	3*0.D0	Delta velocity vector to be added to the state at the current maneuver. Use MANTYP = 'IMPULS'.
EVENT(1)	REAL	0.D0	Event Sequence Number for the current phase.
EVENT(2)	REAL	0.D0	Primary/Roving flag. = 0, Primary. = 1, Roving.
FRAC	REAL	0.0	The dry jettison mass function, evaluated according to input flag, JETT. For JETT: = 2, the dry jettison weight is equal to FRAC. = 3, the dry jettison weight is equal to WPROP (1/FRAC - 1). If Table FMASST is input, FRAC is overridden by the table lookup value.
FRACI	REAL	0.0	The initial fraction of total spacecraft mass, SCMASS, which is weight of propellant, WPROP. If Table FMASIT is input, FRACI is overridden by the table lookup value.
GJ2	REAL	VARIOUS	J_2 terms for the planets. GJ2(0) = Sun's GJ2. GJ2(1) = Mercury's GJ2. GJ2(2) = Venus's GJ2. GJ2(3) = Earth's GJ2. GJ2(4) = Mars' GJ2. GJ2(5) = Jupiter's GJ2. GJ2(6) = Saturn's GJ2. GJ2(7) = Uranus's GJ2. GJ2(8) = Neptune's GJ2. GJ2(9) = Pluto's GJ2. GJ2(10) = Earth's moon GJ2.
		12*0.D0	GJ2(11) - (22) Reserved for other bodies' GJ2.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
GMU	REAL	VARIOUS	Gravitational constants, (u), for planetary bodies. GMU(0) = Sun's GMU. GMU(1) = Mercury's GMU. GMU(2) = Venus's GMU. GMU(3) = Earth's GMU. GMU(4) = Mars' GMU. GMU(5) = Jupiter's GMU. GMU(6) = Saturn's GMU. GMU(7) = Uranus's GMU. GMU(8) = Neptune's GMU. GMU(9) = Pluto's GMU. GMU(10) = Earth's moon GMU.
		12*0.D0	GMU(11) - (22) Reserved for other bodies' GMU.
GO	REAL	9.80665D-3	Sea level gravitational constant. (km/sec)
IATMOS	INT.	1	Flag which specifies the type of atmospheric model to be used. = 1, user defined exponential atmospheric model. = 2, user defined tabular atmosphere data.
IBODY	INT.	VARIOUS	Four digit planetary code. First two digits correspond to the satellites of the planets; Last two digits correspond to the planet number. IBODY(0) = 0000 (Sun). IBODY(1) = 0001 (Mercury). IBODY(2) = 0002 (Venus). IBODY(3) = 0003 (Earth). IBODY(4) = 0004 (Mars). IBODY(5) = 0005 (Jupiter). IBODY(6) = 0006 (Saturn). IBODY(7) = 0007 (Uranus). IBODY(8) = 0008 (Neptune). IBODY(9) = 0009 (Pluto). IBODY(10) = 0103 (Earth's moon).
		12*0.D0	IBODY(11) - (22) Reserved for other bodies' identifiers.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
ICBODY	INT	-1	Reference Body for collocation node inputs (U's) = - 2, use IPBODY (1) of last phase = - 1, use IPBODY (1) for the phase = i > 0, use Body i, i = 0 sun, i = 3 Earth, etc.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
ICOORD	INT.	1	Flag which specifies the coordinate frame in which S/C body orientation is defined. = 1, inertial ecliptic system. = 2, inertial planet equatorial system. = 3, UVW system. = 4, RTN system = 5 B-plane system = 6 Cone and clock system
IDBODY	INT.	1	Index into IBODY array for the planetary body of the state vector.
IDFRAM(1)	CHAR.	'ECLIPTIC'	Frame of reference for input and output state vector. = 'ECLIPTIC', Ecliptic of 1950. = 'EARTHEQ', Earth equatorial. = 'BODYEQ', Body equatorial.
IDFRAM(2)	CHAR.	'MEAN1950'	Epoch of state vector. = 'MEAN1950', Mean 1950 = 'MEAN2000', Mean 2000 = 'MEANDATE', Mean of date.
IDT	INT.	1	Flag defining the step size for Multiconic and Encke propagators. = 1, constant step size (DT). ≠ 1, calculate step size depending on maximum step size (DT) and scaling(STEP).
IEPOCH	CHAR.	'JULIAN'	Date input type flag. = 'CALEND' is calendar date. = 'JULIAN' is Julian date.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
IFORCE (5)	INT.	5*0	Array of perturbing force flags. = 0, off. ≠ 0, on. IFORCE(1) = number of perturbing bodies. IFORCE(2) = J_2 force for central body (flag). IFORCE(3) = solar radiation pressure (flag). IFORCE(4) = atmospheric lift and drag (flag). IFORCE(5)= thrust acceleration = 1, generalized thrust profile (Table input) = 2, blowdown system = 3, electric (nuclear or solar) propulsion If IFORCE (1) is non-zero, input NPERT.
ILNCH	INT.	0	Flag for initializing state, assumes launch from park orbit. (requires ALTIT = park orbit altitude INC = hyperbola inclination BTHETA = B-plane angle used if INC < O) = 0, no launch inputs = 1, input C3, RA, DEC = 2, input VINFX, VINFY, VINFZ
INC	REAL	0.D0	Orbital inclination. (see MANTYP)

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
INPUTX	CHAR.	'NONE'	Mode of state input/update. = 'NONE', no state input/update. (reset after each $TRAJ) = 'CARTES', input X as cartesian state. = 'CONIC', input X as conic state.
IPBODY(i)	INT.	0,3	Index into IBODY array for primary and secondary bodies for propagator. (See IPROP) IPBODY(1) = Primary body index. IPBODY(2) = Secondary body index. = 0, Sun = 1, Mercury = 2, Venus = 3, Earth = 4, Mars = 5, Jupiter = 6, Saturn = 7, Uranus = 8, Neptune = 9, Pluto = 10, Earth's moon = 11 - 22, other user defined bodies.
IPROP	CHAR.	'1STEP'	Propagator mode. = '1STEP', Onestep. (requires IPBODY(1) and IPBODY(2)) = 'CONIC', 2-Body Conic. (requires IPBODY(1)). = 'MULTIC', Stumpf Multiconic (requires IPBODY(1),IPBODY(2) and NPERT)). = 'COWELL', Cowell propagator. (requires
IPBODY(1)			= 'ENCKE', Encke propagator. (requires
IPBODY(1)).			
ITABSZ	INT.	22	Size of input atmospheric table parameters (ALT, PRES, TPT, WGT.)

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
JETT	INT	0	Mass fraction jettison calculation flag. = 0, do nothing at this event. = 1, jettison previously calculated and saved value of jettison_dry_weight. = 2, set WJETTM = FRAC, or table lookup of FMASST, and save it to be jettisoned later (JETT = 1). = - 2, set WJETTM = FRAC, or table lookup of FMASST, and jettison at this phase. = 3, set WJETTM = WPROP * (1/x - 1) and save it to be jettisoned later, where x = FRAC or table lookup of FMASST. = - 3, set WJETTM = WPROP * (1/x - 1) and jettison at this phase., where x = FRAC or table lookup of FMASST. JETT is reset to 0 after each phase initialization.
JULDAT	REAL	0.0	The Julian date in days.
MANTYP	CHAR.	'NONE'	Type of impulsive maneuver and subsequent state initialization. = 'NONE', no impulsive maneuver = 'LAUNCH', launch event (requires ILNCH). = 'IMPULS', generalized impulsive ΔV (requires DVX, DVY, DVZ) = 'ORBINS', orbit insertion (requires RAPOAP, RPERI, INC of desired final orbit)
MASSFI	CHAR	'NONE'	Initialize mass flag. = 'NONE', do not initialize weight this phase. = 'WPROP=', set WPROP = SCMASS * FRACI. = 'SCMASS = ', set SCMASS = WPROP/FRACI. MASSFI is reset to 'NONE' after each phase initialization.
MDL	INT.	1	The event cycling/phasing model. = 1, hit VALUE exactly. = 2, hit VALUE, positive derivative. = 3, hit VALUE, negative derivative. = 5, mdl=1 with 360 discontinuity. = 6, mdl=2 with 360 discontinuity. = 7, mdl=3 with 360 discontinuity. = 8, hit if greater than VALUE. = 9, hit it less than VALUE.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
NAMLST	CHAR.	'TRAJ'	Namelist flag for next input. = 'NONE', no more namelist, solve problem. = 'TABLE', read namelist TAB next. = 'TOP', solve problem, then read namelist TOP to start the next problem. = 'TRAJ', read namelist TRAJ next. NOTE: TRAJ and TABLE namelists can be read only in the first problem.
NPERT	INT.	21*0	Index into IBODY array for the perturbing bodies. (IFORCE(1) > 0). (IPROP='MULTIC', 'COWELL', or 'ENCKE'). = 0, Sun = 1, Mercury = 2, Venus = 3, Earth = 4, Mars = 5, Jupiter = 6, Saturn = 7, Uranus = 8, Neptune = 9, Pluto = 10, Earth's moon = 11 - 22 other user defined bodies.
NSEGPH	INT.	0	Number of collocation segments for this phase.
NSGPH0	INT.	0	Number of collocation input values of controls (U) for this phase. NSGPH0 = 0 means to interpolate between events to obtain internal node states.
NSGPWD	INT.	-1	Number of collocation input values of WVNLC for this phase. NSGPWD has a role similar to NSGPH0. The default for NSGPWD = NSGPH0. NSGPWD may be set = 0 for any phase.
NSGPWI	INT.	-1	Number of collocation input values of WVU for this phase. NSGPWI has a role similar to NSGPH0. The default for NSGPWI is NSGPWI = NSGPH0. NSGPWI may be set = 0 for any phase.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
NTIMES	INT.	0	Number of repetitions of a repeating roving event. < 0, Repeat the event NTIMES using option 2 of ROVET. = 0, Do not repeat the event. > 0, Repeat the event NTIMES using option 1 of ROVET.
PDUMP	REAL	0.D0	Fraction of remaining WPROP to be added to jettison mass (WJETT).
PINC	REAL	1.0D6	Print interval for the trajectory print block.
PITCH0, PITCH1, PITCH2, PITCH3	REAL	3*0.D0	Coefficients for cubic time dependent motion of pitch angle.
PLANET	CHAR	VARIOUS	Planet names associated with IBODY.
POLEV(i,j,k)	REAL	VARIOUS	Coordinates of polar axis, Earth Equatorial Mean 1950. i - polynomial coefficient, third order in time; i = 1,2,3,4 j - planet number; 0 = sun,...3 = Earth,... k - angle type; 1 = right ascension, 2 = declination
PRES (50)	REAL	EARTH	Tabular pressures for atmosphere corresponding to ALT. (newtons/m^2)
PRNC	REAL	-1.	Output interval for PROFIL data file. < 0., no PROFIL output. = 0., all events and propagation steps. > 0., output interval (days).

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
PRPDAT	REAL	15*0.D0	Data for pressure regulated and blowdown propulsion systems. PRPDAT(1) = Not input. Internally set equal to Table input ($TAB) Vacuum thrust for generalized thrust propulsion. PRPDAT(2) = Exhaust area for generalized thrust propulsion. PRPDAT(3) = Maximum mass flow rate for blowdown propulsion. PRPDAT(4) = Propellant density for blowdown propulsion. PRPDAT(5) = Initial tank volume for blowdown propulsion. PRPDAT(6) = Ullage ratio for blowdown propulsion. PRPDAT(7) = Ratio of specific heats for blowdown propulsion. PRPDAT(8) = Initial thrust for blowdown system. PRPDAT(9) = Thrust efficiency for electric propulsion. PRPDAT(10) = Housekeeping power for electric propulsion. PRPDAT (11) = Maximum power for electric propulsion. PRPDAT (12) = decay constant for nuclear electric. PRPDAT (13) to (15) = Solar array constants for solar electric propulsion.
PSCALE	REAL	1.	Propellant consumption effectiveness. (rate scale factor).
RA	REAL	0.D0	Right ascension of launch asymptote (see MANTYP and ILNCH).
RAPOAP	REAL	0.D0	Desired apoapsis radius. (MANTYP = 'ORBINS')

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
RE	REAL	VARIOUS	Planetary radii. RE(0) = Sun's radius. (695950.) RE(1) = Mercury's radius. (2433.) RE(2) = Venus's radius. (6053.) RE(3) = Earth's radius. (6378.) RE(4) = Mars' radius. (3386.) RE(5) = Jupiter's radius. (71370.) RE(6) = Saturn's radius. (60369.) RE(7) = Uranus's radius. (24045.) RE(8) = Neptune's radius. (22716.) RE(9) = Pluto's radius. (5700.) RE(10) = Earth's moon radius (1738.)
		12*0.D0	RE(11) - (22) Reserved for other bodies' radii.
RECT	REAL	0.01	Encke propagation rectification threshold, $\lvert \Delta R/Ro \rvert$.
ROLL0, ROLL1, ROLL2, ROLL3	REAL	3*0.D0	Coefficients for quadratic time dependent motion of roll angle.
ROVET	REAL	2*0.D0	Values for repeating roving events. Option 1: ROVET(1)=x, ROVET(2)=dx, where x = value of CRITR on first occurrence of the event, and x + n*dx is the value of CRITR on the n- the repetition of the event. Option 2: ROVET(1)=x1, ROVET(2)=x2, ROVET(NTIMES+1)=xn, where xi = value of CRITR for the i-th occurrence of the event. Note: This option is limited to nine repetitions. (See NTIMES: if NTIMES > 0, Option 1 is selected if NTIMES < 0, Option 2 is selected).

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
RSOI	REAL	VARIOUS	Radius of sphere of influence for each planetary body. RSOI(0) = Sun's RSOI. RSOI(1) = Mercury's RSOI. RSOI(2) = Venus's RSOI. RSOI(3) = Earth's RSOI. RSOI(4) = Mars' RSOI. RSOI(5) = Jupiter's RSOI. RSOI(6) = Saturn's RSOI. RSOI(7) = Uranus's RSOI. RSOI(8) = Neptune's RSOI. RSOI(9) = Pluto's RSOI. RSOI(10) = Earth's moon RSOI.
		12*0.D0	RSOI(11) - (22) Reserved for SOI of other bodies.
SCDRAG	REAL	3*0.D0	S/C areas normal to the three body axes used in calculating atmospheric effects.
SCMASS	REAL	1.D6	Vehicle mass instantaneous update.
SCSFA	REAL	3*0.D0	S/C areas normal to the three body axes, includes reflectivity coefficients for use in calculating solar radiation pressure.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
SFC	REAL	1.024D17	Solar flux constant, kg-m/s^2.
SPI	REAL	1.D6	Engine specific impulse.
STEP	REAL	1.D0	Step size scaling factor for Multiconic and Encke propagators.
THEDOT	REAL	VARIOUS	Planetary rotation rate. (rad/sec) THEDOT(0) = Sun's rotation rate. THEDOT(1) = Mercury's rotation rate. THEDOT(2) = Venus's rotation rate. THEDOT(3) = Earth's rotation rate. THEDOT(4) = Mars' rotation rate. THEDOT(5) = Jupiter's rotation rate. THEDOT(6) = Saturn's rotation rate. THEDOT(7) = Uranus's rotation rate. THEDOT(8) = Neptune's rotation rate. THEDOT(9) = Pluto's rotation rate. THEDOT(10) = Earth's moon rotation rate.
		12*0.D0	THEDOT(11) = (22) Reserved for other bodies' rotation rates.
THL0, THL1, THL2, THL3	REAL	3*0.D0	Coefficients for quadratic time dependent setting throttle level.
THRUST	REAL	1000.	Average thrust level for impulsive maneuver.
TOL	REAL	1.0D-12	Hybrid tolerance for event cycling, TOL = (vd-va)/(1+abs(vd)), where va = actual value of the CRITR var. vd = VALUE.
TPT(50)	REAL	VARIOUS	Tabular data for atmospheric molecular temperatures corresponding to ALT. (K)

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
TSOI	REAL	VARIOUS	Time of sphere of influence in days for each planetary body. (requires IPROP = '1STEP') TSOI(0) = Sun's TSOI. TSOI(1) = Mercury's TSOI. TSOI(2) = Venus's TSOI. TSOI(3) = Earth's TSOI. TSOI(4) = Mars' TSOI. TSOI(5) = Jupiter's TSOI. TSOI(6) = Saturn's TSOI. TSOI(7) = Uranus's TSOI. TSOI(8) = Neptune's TSOI. TSOI(9) = Pluto's TSOI. TSOI(10) = Earth's moon TSOI.
		12*0.D0	TSOI(11) - (22) Reserved for other bodies.
VALUE	REAL	1.0D10	The desired value of the criterion variable (CRITR) at which the event is to occur.
VINFX, VINFY, VINFZ	REAL	3*0.D0	Hyperbolic excess velocity (launch V-infinity) (see MANTYP and ILNCH)
WGT(50)	REAL	EARTH	Tabular values for atmospheric molecular weights corresponding to ALT. (kg/mole)
WJETT	REAL	0.D0	Jettison mass for this event. (kg)
WPROP	REAL	1.D6	Propellant mass. (kg)
X(i)	REAL	6*0.D0	State vector to be input/updated for NPUTX='CARTES', X=X,Y,Z,VX,VY,VZ; for INPUTX='CONIC', X=(semi-major-axis, ecc., inc., long.-of-asc.-node, arg.-of-periapsis, mean-anomaly).
YAW0, YAW1, YAW2, YAW3	REAL	3*0.D0	Coefficients for quadratic time dependent motion of yaw angle.

5.3 NAMELIST $TAB

The following is a description of input parameters for namelist $TAB. The $TAB data must follow the $TRAJ event data which is applicable. Currently, only four parameters can be input as tables: thrust vs. time, drag coefficient vs. angle of attack and mach number, lift coefficient vs. angle of attack and mach number and S/C mass vs. C3.

VARIABLE NAME	TYPE	STORED VALUE	DESCRIPTION
IXTRP i = 1,2	INT.	2*1	A flag to activate the no-extrapolation feature for argument values that exceed the table boundaries in x and y, respectively. = 0, do not extrapolate. Use the last table value instead. = 1, Extrapolate to obtain the table value.
NAMLST	CHAR	'TRAJ'	Namelist flag for next input. = 'NONE', no more namelists, end of input stream. = 'TOP', $TOP will follow. = 'TRAJ', $TRAJ will follow = 'TABLE', $TAB will follow
TABLE ( )	REAL	0.D0	Table input array (see below).

The table inputs for IPOST are generalized to include:

1) Allowable size for each table of 2500 entries. The total size of all tables is limited by the amount of storage allocated to IBKT. Both of these values can be changed by a simple program modification to satisfy user requirements.

2) Generalized argument specification. The argument to be used for each table is specified by input and can be any computed output variable.

3) Constant-valued, monovariant or bivariant table types.

4) Linear interpolation capability.

5) A no-extrapolation feature for argument values that exceed the table boundaries. This feature is obtained by inputting the flag IXTRP (i) to request no-extrapolation in x and y respectively, as follows:
=0, Do not extrapolate. Use the last table value instead.
=1, Extrapolate to obtain the table value.

Each table is input in namelist $TAB as the array TABLE. As a result, each table being input requires a separate input of namelist $TAB.

These tables are available in IPOST.

CDT is the drag coefficient (will override CD in $TRAJ)
CLT is the lift coefficient (will override CL in $TRAJ)
FMASIT is the initial mass fraction defining WPROP as a fraction of SCMASS, or vice versa. FMASIT overrides FRACI.
FMASST is the jettison mass fraction table. JETT is the jettison . FMASST overrides FRAC.
SMASST is the vehicle mass (will override SCMASS in $TRAJ)
THRSTT is the vacuum thrust in the generalized thrust model IFORCE(5) = 1 in $TRAJ

The choices for independent parameter(s) are defined in Table 1-5.

The elements of the array TABLE are different depending on the type of table being input.

Table pointers are used by the table look-up routines for all tables (except constant-valued tables) to provide efficient operation of the table look-up routines. These pointers should always be input as 1. The number of pointers for a given table depends on the table type, i.e., monovariant or bivariant. For example, a monovariant table has one pointer which is input as TABLE (7), and a bivariant table has five pointers input as TABLE (10) through TABLE (14).

Constant-Valued Tables

The table elements for constant-valued tables are:

TABLE(1) The Hollerith name of the table.

TABLE(2) The table type.
=0, Constant-valued table.

TABLE(3) The table value. A typical constant-valued table would be input as follows:

TABLE = 6HTHRSTT,0,2000000.,

Monovariant Tables

Monovariant tables are formed by a series of ordered pairs of x and f(x) which represent a curve that is a series of line segments.

The size of a monovariant table is obtained by:

$$n = 7 + 2 * n_x$$

The table elements for monovariant tables are:

TABLE(1)	The Hollerith name of the table.
TABLE(2)	The table type. =1, Monovariant table.
TABLE(3)	The Hollerith name of the x argument.
TABLE(4)	The number of x values in the curve, n_x
TABLE(5)	The interpolation type. =0, Step table, i.e., no interpolation. =1, Linear interpolation.
TABLE(6)	The type of x values. =-1, Decreasing values. = 1, Increasing values.
TABLE(7)	The initial value of the x pointer.
TABLE(8)	The first table value (x1). A typical monovariant table would be input as follows

TABLE = 3HCDT,1,6HSMACH ,n_x,1,1,1,

$x_1, f(x_1), x_2, f(x_2), \ldots, x_{n_x}, f(x_{n_x}),$

Bivariant Tables

Bivariant tables are formed by a family of monovariant curves, where a monovariant curve is input for each value of y. As a result, the arguments are x and y and the function is f(x,y). The x arguments in each curve do not need to be the same value; however, there must be the same number of x values in each curve.

The size of a bivariant table is obtained by:

$$n = 14 + n_y * (2 * n_x + 1)$$

The table elements for bivariant tables are:

TABLE(1)	The Hollerith name of the table.
TABLE(2)	The table type. =2, Bivariant table.
TABLE(3)	The Hollerith name of the x argument.
TABLE(4)	The Hollerith name of the y argument.
TABLE(5)	The number of x values in each curve, n_x
TABLE(6)	The number of y values (curves) in the family , n_y
TABLE(7)	The interpolation type =1, Linear interpolation.
TABLE(8)	The type of x values =-1, Decreasing x values. = 1, Increasing x values.
TABLE(9)	The type of y values =-1, Decreasing y values. = 1, Increasing y values.
TABLE(10)	The initial value of the y_l curve pointer (input = 1).
TABLE(11)	The initial value of the x pointer on the y_l curve (input = 1).
TABLE(12)	The initial value of the x pointer on the y_l+1 curve (input = 1).
TABLE(13)	The initial value of the x pointer on the y_l+2 curve (input = 1).
TABLE(14)	The initial value of the x pointer on the y_l+3 curve (input = 1).

TABLE(15) The first table value (y_1). A typical bivariant table would be input as follows:

TABLE = 6HCDT ,2,6HSMACH ,6HANGAT1, n_x,n_y

1,1,1,1,1,1,1,1,

y_1, x_1, $f(x_1,y_1)$, x_2, $f(x_2,y_1)$, ...,x_{n_x}, $f(x_{n_x},y_1)$,

y_2, x_1, $f(x_1,y_2)$, x_2, $f(x_2,y_2)$, ...,x_{n_x},$f(x_{n_x},y_2)$,

.

.

.

y_{n_y} , x_1, $f(x_1, y_{n_y})$, x_2, $f(x_2, y_{n_y})$, ..., x_{n_x} , $f(x_{n_x}, y_{n_y})$,

6.0 OUTPUT DESCRIPTION

6.1 STANDARD OUTPUT

During IPOST execution, a variety of output is made available to the user. A number of print flags, such as IPRINT, control the degree and type of output. These flags are discussed in Section 6.3. This section will describe the standard default output.

The first output which appears during execution is an echo of the namelist inputs, $TOP, and all the $TRAJ's. After the namelist echo, there will be an input summary of what events have been chosen along with the criteria, the initial trajectory inputs and the subproblem setup, if any. An NPSOL summary, the master problem controls, constraints and optimization will also be displayed.

For explicit optimization using decomposition, IPOST starts to solve the master problem by first solving each subproblem in consecutive order. The first subproblem is iterated until the desired target conditions are reached. A summary of results is displayed. After all subproblems have been solved, with their results displayed, the master problem can proceed to optimize the cost (objective) function. Each master problem control parameter is perturbed (assuming gradients are computed by finite differencing, and not analytically), and the sequence of subproblems is repeated, in order to evaluate cost and constraint parameter values. The subproblem solutions are not normally displayed for perturbed master problem trajectories. The objective gradient and constraint gradients are displayed for the specified master problem control parameters.

The master problem now determines the appropriate master problem control parameter step size and direction in order to optimize cost and maintain constraints. For the new set of control parameters, the subproblem sequence is solved once again and the master problem iteration is completed when a summary is displayed.

When the cost function cannot be optimized further and all constraints are satisfied, the master problem concludes with a convergence summary. If a PROFIL file has been generated, then a parameter list is displayed.

The final optimized trajectory is now displayed. The trajectory time history display consists of a print block at each event (start of a phase), at user specified print intervals during a phase, and at the end of a phase (next event).

Certain activities will trigger additional print data. For example, when propulsion has been activated, a print block associated with propulsion data and a print block associated with vehicle orientation are displayed. Trajectory displays can also occur at other stages of the IPOST solution process. These occurrences are controlled by IPRO ($TOP) and IPRINT ($TOP).

IPRINT is the general control flag. As the value IPRINT increases, the volume of output increases. For example, IPRINT = 0 will print only cursory data for the run, whereas IPRINT = 5 will print massive amounts of debug printout.

6.2 PROFIL OUTPUT

A binary output file (PROFIL) can be written. It is activated by setting a non-negative value of PRNC in $TRAJ. Additional inputs required are, NPVAR and OUTNAM. NPVAR specifies how many variables are to be in each PROFIL block, and OUTNAM lists the specific variable names. For example, PRNC = 100, NPVAR = 2 and OUTNAM = 'TIMRF', 'DVMAG ' will produce mission time (days) and ΔV magnitude in each PROFIL block starting with the current event, and then every 100 days thereafter. Any variable in the data dictionary, corresponding to Tables 3 - 8 and 3 - 9, can be used in OUTNAM. Up to 100 parameters can be included in a PROFIL block.

6.3 DEBUG PRINT

There are several debug print flags in IPOST. The first is the generalized debug flag IPRINT. IPRINT can have a value from 0 - 4, with the amount of debug print increasing as the value of IPRINT increases. With IPRINT = 0, there is no debug print. With IPRINT = 4, a horrendous amount of printout will occur from trajectory data, to subproblem sensitivity matrices, to entry and exit messages from different subroutines. More will be added in later revisions of this document as to what each level of IPRINT will supply the user. IPRINT can be set at each event, so debug can be performed only in problem areas.

The debug print flag, IPRO, determines the amount of trajectory data the user sees. If IPRO = -1, the default, the user will only see the final targeted and optimized trajectory. If IPRO = 1, the original nominal trajectory will be printed, along with the final targeted and optimized trajectory. If IPRO = 1, all the nominal trajectories will be printed along with the final. Finally, if IPRO = 2, every trajectory performed will be printed.

IDEB is a trial step summary debug print flag. When NPSOL is performing trial steps calculating the sensitivity matrices required, IDEB is defaulted to 0 and the user will not see these calculations. If the user would like to see these steps, IDEB may be set equal to one.

6.4 ERROR MESSAGES

The error messages are presented in alphabetical order as follows:

Message: BAD IEPOCH VALUE
Source/Type: DYNXMI/fatal
Condition/Corrective Action: Invalid value for IEPOCH. Possible values are 'CALEND', 'JULIAN', or 'NOINPUT'. Check input data.

Message: BAD IDFRAM VALUE
Source/Type: DYNXMI/fatal
Condition/Corrective Action: Invalid value for IDFRAM. Possible values are 'ECLIPTIC' or 'EQUATOR'. Check input data.

Message: BAD INPUTX VALUE
Source/Type: DYNXMI/fatal
Condition/Corrective Action: Invalid value for INPUTX. Possible values are 'CONIC', 'CARTES', 'DELTAV', or 'NONE'. Check input data.

Message: CNFUNC, UNUSABLE NOMINAL
Source/Type: CNFUNC,warning
Condition/Corrective Action: The trajectory went beyond realistic conditions, such as mass less than zero, and was prematurely terminated. Reconsider formulation of the problem.

Message: CYCXM PROBLEM
Source/Type: CYCXM/fatal
Condition/Corrective Action: The conditions for one of the pending events could not be met in 20 iterations. Check the event criteria and the integration step size inputs.

Message: DINPT - ESN NOT FOUND
Source/Type: DINPT/fatal
Condition/Corrective Action: The data for the event printed above this message as -ESN = XXX.XXX does not exist.

Message: ERROR - NO PENDING EVENTS. DUMP OF IBKT
Source/Type: TGOEMI/warning
Condition/Corrective Action: No event criteria have been input. Check the value of each CRITR variable.

Message: EXCEEDED MAXIMUM NUMBER OF PENDING EVENTS. DUMP OF IBKT
Source/Type: TGOEMI/warning
Condition/Corrective Action: The number of events that have been specified as roving events exceeds the allowable maximum of 10. Reduce the number of roving events and rerun the job.

Message: *GRAD* FATAL TERMINATION
Source/Type: GRAD2/fatal
Condition/Corrective Action: The indicated error condition caused the targeting/optimization algorithm to terminate the program execution. Check the problem setup and the inputs in namelist TOP.

Message: *PAD* NOISE, INCREASE PERT
Source/Type: PAD/warning
Condition/Corrective Action: An independent variable perturbation value, PERT or PERTSB, is too small, or the independent variable has no effect on the dependent variables when using the targeting/optimization algorithm. PAD will automatically adjust the pert and try the perturbed function evaluation again. If the results are unsatisfactory, rerun the problem with a larger input value of PERT/PERTSB.

Message: *PAD*PATHOLOGICAL NOISE/PERTURBATION
Source/Type: PAD/fatal
Condition/Corrective Action: An independent variable perturbation causes noise and polarization in separate dependent variables. PAD cannot adjust the size of the perturbation. The problem may be pathological. Reformulate the problem.

Message: *PAD* POLARIZATION, DECREASE PERT
Source/Type: PAD/warning
Condition/Corrective Action: An independent variable perturbation value, PERT or PERTSB, is too large, or the independent variable has no effect on the dependent variables when using the targeting/optimization algorithm. PAD will automatically adjust the pert and try the perturbed function evaluation again. If the results are unsatisfactory, rerun the problem with a smaller input value of PERT/PERTSB.

Message: READAT - CASE WON'T FIT
Source/Type: READAT/fatal
Condition/Corrective Action: The constant-valued general input data exceeds maximum number of cells. Reduce the amount of general data

Message: READAT - FATAL INPUT ERRORS
Source/Type: READAT/fatal
Condition/Corrective Action: The Hollerith input names shown are incorrect. Check all variables containing Hollerith inputs to see that the names are valid and spelled correctly.

Message: RTOP - NAMELIST ERROR
Source/Type: RTOP/fatal
Condition/Corrective Action: A namelist error has occurred. Check input data.

Message: RTRAJ - NAMELIST ERROR
Source/Type: RTRAJ/warning
Condition/Corrective Action: A namelist error has occurred. Check input data.

Message: RTRAJX, DATA BUFFER - EXCEEDED SIZE OF BUFFERS (GBKT OR IBKT)
Source/Type: RTRAJX/fatal
Condition/Corrective Action: The constant-valued input data exceeds the maximum number of cells. Reduce the amount of input data.

Message: RTRAJX, NO. EVENT NO. WAS INPUT
Source/Type: RTRAJX/fatal
Condition/Corrective Action: A phase was input with no event number (EVENT), or it is zero. Input the event number as EVENT(1).

Message: SERCH "name"
Source/Type: SERCH/fatal/warning
Condition/Corrective Action: The character input variable "name" is not valid or is misspelled. This is a warning error only if the misspelled variable is a print variable. Check the character name in question. Message: Q-DYNXM - NO PROPAGATOR HAS BEEN CHOSEN Source/Type: DYNXM/warning Condition/Corrective Action: No propagator has been input. Check input data.

Message: SETIC, IND. PHASE XXX.XXX NOT FOUND
Source/Type: SETIC/fatal
Condition/Corrective Action: Phase number XXX.XXX was requested as a control parameter phase but does not exist. Check the phase numbers input in INDPH and INDSPH.

Message: SRADRX - BAD ORDERING, INDXI/D/LC
Source/Type: SRADRX/fatal
Condition/Corrective Action: The specified indices of the independent and dependent variables are not in ascending order when using the targeting/optimization algorithm. Check the values of INDXI and INDXD.

Message: SRADRX - READAT - INDXI/D/LC ARE ZERO
Source/Type: SRADRX/fatal
Condition/Corrective Action: The specified indices of the independent and dependent variables are zero when using the targeting/optimization algorithm. Check the values INDXI and INDXD.

Message: TGOEMI PROBLEM
Source/Type: TGOEMI/fatal
Condition/Corrective Action: No event criteria have been input or too many pending events have been requested. Check the value of each CRITR variable.

Message: THE TIME OF PERIAPSIS WAS NOT FOUND WITHIN MAX ITERATIONS IN SUBROUTINE ONESTP
Source/Type: ONESTP/fatal
Condition/Corrective Action: The time of periapsis was not found within the maximum number of iterations = 50.

Message: TSPXM - BAD IV-TO-END
Source/Type: TSPXM/warning
Condition/Corrective Action: The data and the dictionary do not match.
Message: *TTS CONTROL DIVERG IN NEWTON RAPHSN*
Source/Type: TTS/fatal
Condition/Corrective Action: Select alternate initial conditions and restart.

Message: *TTS CONVERGENCE NOT REACHED IN TARG1S
Source/Type: TTS/fatal
Condition/Corrective Action: Select alternate initial conditions and restart.

Message: *TTS DIFF NO. DEP. INDEP VARIABLES *
Source/Type: TTS/fatal
Condition/Corrective Action: Number of subproblem independent controls has to equal number of subproblem dependent target variables. Check input data.

Message: *TTS FUNCTION DIVERG IN NEWTON RAPHSN*
Source/Type: TTS/fatal
Condition/Corrective Action: Select alternate initial conditions and restart.

Message: *TTS ITER EXCEEDED IN NEWTON RAPHSON *
Source/Type: TTS/fatal
Condition/Corrective Action: Select alternate initial conditions and restart.

Message: *TTS PROPAGATION MODEL NOT PROVIDED *
Source/Type: TTS/fatal
Condition/Corrective Action: Correct input data. Allowed values are 'NRAPH', 'TARG1S', 'NULL', or 'NONE'.

Message: *TTS TARG1S TARGETS NOT AT SAME PHASE*
Source/Type: TTS/fatal
Condition/Corrective Action: Redefine inputs. All targets for one subproblem occur at the same phase.

Message: *TTS WRONG NUMBER (NOT 3) INDEP VARIA*
Source/Type: TTS/fatal
Condition/Corrective Action: Three subproblem independent control variables required. Check input data.

6.5 IPOST POST-PROCESSING

Machine processing of IPOST generated data is in the form of IPPOST. IPPOST is a tool which processes an IPOST (and certain versions of POST) generated PROFIL data file. It allows the user to display PROFIL data in various forms. IPPOST is an interactive tool which makes use of the NCAR Graphics package. There are approximately 55 commands which provide capability ranging from a simple data echo to generating an x-y plot of any 3 variables versus any fourth, independent, variable. Access to the command list, and command descriptions, can be obtained by entering "man" after IPPOST is brought on-line. In addition, a "help" menu is available.

7.0 REFERENCES

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APPENDIX A: ACRONYMS

BDT	B dot T
BDR	B dot R
CP	Computer Processor
CRAF	Comet Rendezvous Asteroid Flyby
DEC	Declination
DOF	Degrees of freedom
DSM	Deep Space Maneuver
DT	Delta time
GEO	Geostationary orbit
GLOW	Gross Liftoff Weight
GMAP	General Mission Analysis Program
HEO	High Earth Orbit
IMLEO	Inserted/injected Mass in Low Earth Orbit
IMU	Inertial Measurement Unit
IPOST	Interplanetary Program to Optimize Simulated Trajectories
IPREP	Interplanetary PREProcessor
ISP	Specific Impulse
ITOO	Interplanetary Targeting and Optimization Option
IUS	Inertial Upper Stage
LEO	Low Earth Orbit
LPREP	Lunar PREProcessor
NPOST	NPSOL POST
NPSOT6D	NPSOL POST6D
NPSOL	Non-linear Programming Stanford Optimization Laboratory
PGA	Projected Gradient Algorithm
POST	Program to Optimize Simulated Trajectories
RA	Right Ascension
RCA	Radius of closest approach
RPERI	Radius of periapsis
RTN	Radius Tangent Normal - Coordinate system defined by the radius vector and the orbit nominal vector
S/C	Spacecraft
SEP	Solar electric propulsion
SOI	Sphere of influence
SPDY	Seconds/day
SQP	Sequential Quadratic Programming
SVD-LUD	Singular value decomposition, LU decomposition
TCM	Trajectory correction maneuver
TFP	Time from periapsis
TOF	Time of flight
TPBV	Two-point boundary value
UVW	Coordinate system defined by the S/C velocity and the orbit nominal vector
VINF	Velocity at infinity (hyperbolic excess velocity)

APPENDIX B: IPREP/LPREP USER'S GUIDE

B-1 INTRODUCTION

IPREP (Interplanetary PREProcessor) provides rapid grid-search optimization on launch and arrival windows, minimum mission delta-v, or mass optimization. IPREP uses simple propagators (no integration) and minimal perturbing forces so that the trajectory calculations will be as quick as possible.

IPREP has two modes in which it executes, depending on the current value of the variable 'namlst.' If namlst = inter (Namelist top sets the initial namlst value, after that, it is set at the end of each following namelist), then IPREP will run an interplanetary mission. In this case, IPREP utilizes a simple conic propagator and Lambert method solutions to provide the velocity requirements at each planet in an interplanetary trajectory. Gravity assist is also modeled as a local conic perturbation. A Chebychev polynomial represents low thrust segments. The grid search is performed on a user input time window for any body encountered during the mission. The best mission is calculated by the minimum cost, which is a user selected weighting of each encounter delta-v, arrival velocity, departure velocity, and initial mass.

If namlst = 'lunar' then IPREP will run a lunar mission. In this case IPREP employs patched conics and actual targeting (utilizing a Newton-Raphson technique), since the earth-moon problem is more complicated than interplanetary conic formulations. Lunar mission conditions are generated to the same fidelity as interplanetary conditions. The grid search is also performed on encounter time (launch or arrival) and optimization is done on total mission delta-v.

Interplanetary and lunar namelists can be chained together to run as many missions the user desires from one input desk. At the end of each namelist, simply set the namlst variable to the type of namlst desired to be read in next. When all the namelists are input, simply set the last value of namlst to 'none.'

The following sections describe input and output for the three namelists in IPREP, analytic models and algorithms, and program architecture. Most of the detailed models can be found in the IPOST documentation (Reference B - 1), and the mission analysis context of IPREP, LPREP, and IPOST can be found in the IPOST Mission Analysis Guide (Reference B - 2).

B-2.0 INPUT

B-2.1 INTER NAMELIST INPUTS

Variable	Type	Default	Description
abf (50)	real	-1.d0	Aerobrake mass fraction for each encounter (orbit insertion)
acc(50)	real	0.d0	Acceleration due to low thrust engines for each leg used in launch and orbit insertion spirals.
advmax(50)	real	50.d0	Maximum delta-v allowed for s deep space leg arrival.
alphaw	real	30.d0	Powerplant specific mass for low thrust engines (kg/kw)
altatm (22)	real	various	altitude of the atmosphere for the planets. Used for calculating entry velocity during aerobraking. (km)
bb	real	0.d0	Used with dd in the low thrust efficiency equation = $bb/(1+(dd/c)^2)$
c(4,22,6)	real	various	Coefficients for analytic ephemeris time dependent elements. The first array element defines the time based coefficient, the second the planetary number, and the third, the orbital element, a, e, - M.
cmax	real	1.d38	Maximum value of the cost function allowed. Filtering is performed on all trajectories whose cost function is greater than this max value.

cntrl	character	'auto'	='auto', grid is refined about the minimum trajectory until the maximum number of iterations (number of times the grid is to be refined) has been met. Only the minimum cost trajectory is printed out. = 'manual', grid is not refined. Data for each trajectory is saved and printed out. This will be useful for plotting and determining minimum trajectories 'manually'. = 'sort', and initial pass through the grid is made in the manual mode, the data is sorted by the minimum cost function, a user input number (nsave) is saved and the grid is refined about each of these sets of points. This is to aid in avoiding local minimums.
cs	real	0.d0	Exhaust velocity for the lowthrust engines.
csat(7,20)	real	0.d0	Orbital elements of planetary satellites for calculation of satellite closest approaches. csat(1,i) = semi-major axis (km) csat(2,i) = eccentricity csat(3,i) = inclination (radians) csat(4,i) =longitude of the node (rad) csat(5,i) = argument of periapsis (rad) csat(6,i) = mean anomaly (rad) csat(7,i) = epoch time (Julian date) i is the index of the satellite given by isat(j,k). The number of satellites for each encounter is given by nsat.
date(6)	real	0.d0	Epoch time can be input as a calendar date as follows: (1) = year, (2) = month, (3) = day, (4) = hours, (5) = minutes, (6) = seconds.
dd	real	0.d0	Used with bb in the low thrust efficiency equation

dvmax	real	10.d0	Maximum delta-v allowed for any maneuver. Filtering is performed on any trajectory which has a maneuver delta-v greater than this value.
ep	real	0.d0	Epoch time from which launch and flyby times are measured (julian date).
frac(50)	real	0.d0	Mass fraction included in the mass calculation for each maneuver. The tankage mass is calculated to be this percentage of the propellant plus payload mass
frame	character	ecliptic	Input/output frame. Default of ecliptic, or can be 'equator', and the frame will be each planet's equator.
gmu(0:22)	real	various	Gravitational parameter for planetary bodies.
gmusat(20)	real	0.d0	Gravitational parameter for each satellite input in csat.
go	real	9.806d-3	Gravitational acceleration (km/s^2)
har (50)	real	-1.d0	User input arrival vinf magnitude for low thrust encounters, if desired. Otherwise, it will be calculated.
hdep (50)	real	-1.d0	User input departure vinf magnitude for low thrust encounters. Otherwise, vinf will be calculated.
hinc(50)	real	-1.d0	Inclination (deg) of the orbit for each encounter. For launch and orbit insertion maneuvers, the inclination is input, and for swingby maneuvers the inclination is calculated. = -1., the inclination for the launch and orbit insertion maneuvers will be set equal to the declination of the launch or arrival asymptote, respectively.

ibod(50)	integer	0.d0	Encounter body for each leg. = 0, Sun = 1, Mercury = 2, Venus = 3, Earth = 4, Mars = 5, Jupiter = 6, Saturn = 7, Uranus = 8, Neptune = 9, Pluto
idvmax(50)	real	50.d0	Maximum delta-v for a deep-space leg departure. Number of satellite bodies input for each encounter. See isat and csat.
iephem	integer	0	= 0, use analytic ephemeris = 1, use JPL precision ephemeris.
iepoch	character	julian	Flag setting epoch time input as either 'ep' or 'date' = 'julian' , input ep as julian date = 'calend', input date as calendar date, program will convert.
ilnch(50)	integer	1	Flag designating type of launch maneuver. = 1, high thrust launch = 2, low thrust launch
iorbit(50)	integer	1	Flag designating type of orbit insertion maneuver. = 1, high thrust orbit insertion = 2, low thrust orbit insertion
ipbod(50)	integer	0	Central body (primary body) for each leg of the mission. Can have the same values as ibod above.
iprep	integer	2	Print flag which determines the type of printout. = 1, short form of printout including only the cost function value and the encounter times. See also 'outfile'. = 2, long form of printout including detailed trajectory calculations.

isat(10,50)	integer	0	Satellite encounter bodies for each leg. E.G.: isat (2,3) = 4. User must input csat(1:7,4). This satellite is the second moon of the third encounter body. The 4 designates which body in the satellite ephemeris to look at.
itrmax	integer	5	Maximum number of grid refinements desired.
manvr(50)	character	'none'	Type of maneuver to be performed at each encounter. = 'launch', perform launch from park orbit = 'swngby', perform delta-v flyby = 'orbins', perform insertion into park orbit.
namlst	character*8	'none'	Designates next namelist to be read.
ncone (50)	integer	4	Number of cone angles for each low thrust leg
nconop (50)	integer	2	= 0, all cone angles allowed = 2, program chooses the best ncone cone angles
ncop (50)	integer	1	= 0, input cs for each low thrust leg = 1, optimizes cs for each low thrust leg
nleg	integer	0	Total number of segments to be performed in the trajectory sequence.
nmuop (50)	integer	1	=0, input wmu for each low thrust leg =1, optimize wmu for each low thrust leg
npow (50)	integer	0	The type of power supply for each low thrust leg. = 0, constant = 1, variable
nrev(50)	integer	0	The number of revolutions the S/C makes during a particular trajectory segment.

nsat(50)	real	0	Number of satellite bodies input for each encounter. See isat and csat.
nsave	integer	10	The number of minimum missions from the initial grid sweep which will be optimized. Required when cntrl = 'sort'.
nsig(50)	integer	7	The number of significant digits required in calculating the optimal deepspace maneuver. The solution is very sensitive to this number and can be greatly affected by its value. Since interplanetary problems can be vastly different, changing this variables value is strongly encouraged.
outfile	character	'none'	Name of the output file in which the trajectory information is stored after the run (only required when iprep = 1).
planet(22)	character	various	Names of the planetary bodies
plosp	real	1.d0	Degradation level of power at failure in low thrust. New power equals old power times plosp.
ploss	real	0.d0	Time variation in power of low thrust engines. $p = p_0 e^{-(ploss)t}$ where p0 is limited power at .
plost	real	1.d0	Specifies a fraction of the trip where discontinuous power loss occurs.
prop	character	conic	Propagator selected = 'conic', calculate simple Lambert method conic solutions between encounter points = 'lowthr', use Chebytop method to calculate controlled low thrust trajectories between encounter points = 'bplane', calculate a deepspace maneuver along with conic trajectories between encounter points

pyload	real	0.d0	Required payload at the end of the mission. The initial S/C mass will be 'backed out' from this required mass. If not input then will be calculated from the initial value for scmass. (kg)
rapoap(50)	real	0.d0	Radius of apoapsis for park orbit before launch or after orbit insertion (km).
re(22)	real	various	Equatorial radius of the planetary bodies.
rperi(50)	real	0.d0	Radius of periapsis for park orbit before launch or after orbit insertion (km).
rpmax(50)	real	0.d0	Maximum radius allowed for swingby closest approach (km).
rpmin(50)	real	0.d0	Minimum radius allowed for swingby closest approach (km).
scmass	real	-1.d0	If input is greater than 0, this will be initial S/C mass
spi(50)	real	1.d6	Specific impulse for the spacecraft engines for each maneuver (seconds).
tanks	real	0.d0	Tankage mass fraction for low thrust engines.
thrust(50)	real	1.d6	Thrust for the spacecraft engines for each maneuver (newtons).
tilt	real	90.d0	Angle the plane of the solar panels make with the S/C sun vector.

tm(3,50)	real	0.d0	tm(1,i) = minimum time of flight for the ith leg tm(2,i) = maximum time of flight for the ith leg tm(3,i) = time increment for the ith leg, which defines the grid size If tm(1,i) = -1, then the user has chosen to fix this encounter time by inputing the julian date of the encounter into tm(2,i) and zero into tm(3,i).
tmax	real	1.d6	Maximum total trip time in days. Filtering is done on missions whose total trip time exceeds this maximum value.
tol(5,50)	real	1.d38	Weighting used in calculation of the cost function for each segment. The cost function is defined more extensively in the analytic section for IPREP. tol(1,i) = weighting on departure v-inf magnitude. tol(2,i) = weighting on arrival v-inf magnitude. tol(3,i) = weighting on departure mass. tol(4,i) = weighting on arrival mass. tol(5,i) = weighting on encounter delta-v (launch, swingby, or orbins) tol(6,i) = weighting on deepspace maneuver delta-v. tol(7,i) = weighting on time of flight for current leg.
wjett(2,50)	real	0.d0	Jettison mass for deep-space burns. wjett(1,i) = jettison mass. wjett(2,i) = +1.d0, jettison after burn. = -1d.0, jettison before burn.
wmu(50)	real	0.d0	Powerplant mass fraction for each of the lowthrust legs.
wpmax	real	1.d38	Maximum amount of propellant allowed.

B-2.2 LUNAR NAMELIST INPUTS

Variable	Type	Default	Description
ep	real	0.d0	Epoch time upon which all encounter times are based (julian date).
hinc(1)	real	0.d0	Inclination of park orbit about initial body, whether primary body (istyle = 1,2,3,or 4) or secondary body (istyle = 5).
hinc(2)	real	0.d0	Inclination of orbit about second encounter body, whether secondary body (istyle = 1,2,3, or 4) or primary body (istyle = 5).
hinc(3)	real	0.d0	Inclination of orbit about third encounter body which will be the primary body when istyle = 3 or 4.
iephem	integer	1	= 0, use analytic ephemeris = 1, use JPL precision ephemeris
ipbod	integer	3	Primary body id from ibod array.
iprint	integer	0	= 0, summary print = 1, full print

istyle	integer	1	Controls the program operation. = 1, launch from primary park orbit and target to conditions at the secondary (one burn) = 2, launch from primary park orbit, target to secondary, enter park orbit about secondary (two burns). = 3, launch from primary park orbit, target to secondary, enter park orbit about secondary, launch from secondary park orbit, target to primary, enter park orbit about primary (four burns). = 4, launch from primary park orbit, target to secondary is such a way as to return to primary with a zero delta-v swingby. Provides a free return trajectory. = 5, launch from secondary, target to primary, enter orbit about primary. = 6, start with precessing park orbit about primary, and calculate all of the coplanar launch opportunities during the user input time frame. Targeting of lunar closest approach radius and inclination. = 7, start with precessing park orbit about the primary, and calculate all of the coplanar launch opportunities to the user input libration point during the requested time frame. = 8, start with park orbit about the moon, precessing S/S orbit about Earth and calculate coplanar return missions from the moon. = 9, calculate missions from moon to libration points. = 10, roundtrip with coplanar launch from Earth, orbit insertion at moon, launch from moon with coplanar arrival at Earth.
itbod	integer	10	Secondary body id .
lib	integer	0	The libration requested to be targeted to.

mxitar	integer	100	Maximum number of iterations to be allowed in the Newton-Raphson targeting scheme.
npi	integer	5	Number of previous iterations in Newton-Raphson to check against for divergence, either in increasing target error, or increasing control changes.
orb(1:6)	real	0.d0	Orbital elements at epoch when ilnch = 6,7.
ra(1:3)	real	0.d0	Same as hinc above, except applies to the radius of apoapsis for park orbits.
rp(1:3)	real	0.d0	Same as hinc above, except applies to the radius of periapsis.

If 'istyle' = 1 or 2 then

tm(1,1)	real	0.d0	Days from epoch for initial launch from the primary.
tm(2,1)	real	0.d0	Days from epoch for final launch from the primary.
tm(3,1)	real	0.d0	Time increment to step through the above region.
tm(1,2)	real	0.d0	Minimum time of flight to the planet (total trip time).
tm(2,2)	real	0.d0	Maximum time of flight to the secondary SOI.
tm(3,2)	real	0.d0	Time increment to step through the above region.
tol(1)	real	1.d0	Weighting on launch delta-v from primary for calculating the cost function.
tol(2)	real	1.d0	Weighting on orbit insertion Δv at secondary for calculating the cost function.

If 'istyle' = 3 then add

tm(1,3)	real	0.d0	Minimum stay time at secondary
tm(2,3)	real	0.d0	Maximum stay time at secondary
tm(3,3)	real	0.d0	Time increment to step through the above region.
tm(1,4)	real	0.d0	Minimum time of flight on departure from secondary SOI to primary arrival.
tm(2,4)	real	0.d0	Maximum time of flight on departure from secondary SOI to primary arrival.
tm(3,4)	real	0.d0	Time increment to step through the above region.
tol(3)	real	1.d0	Weighting on launch delta-v from secondary for calculating the cost function.
tol(4)	real	1.d0	Weighting on orbit insertion Δv at primary for calculating the cost function.

Or if 'istyle' = 4 then add

tm(1,3)	real	0.d0	Minimum time of flight on departure from the secondary SOI to primary arrival.
tm(2,3)	real	0.d0	Maximum time of flight on deparure from the secondary SOI to primary arrival.
tm(3,3)	real	0.d0	Time increment to step through the above region.

If 'istyle' = 5, then the time and weighting variables are defined as

tm(1,1)	real	0.d0	Days from epoch for the initial departure from the secondary SOI.
tm(2,1)	real	0.d0	Days from epoch for the final departure from the secondary SOI.
tm(3,1)	real	0.d0	Time increment to step through the above region.
tm(1,2)	real	0.d0	Minimum time of flight on departure from the secondary SOI to primary arrival.
tm(2,2)	real	0.d0	Maximum time of flight on departure from the secondary SOI to primary arrival.
tm(3,2)	real	0.d0	Time increment to step through the above region.
tol(1)	real	1.d0	Weighting on the launch delta-v from secondary for calculating the cost function.
tol(2)	real	1.d0	Weighting on the orbit insertion delta-v at the primary for calculating the cost function.

If 'istyle' = 6 or 7, then the time variables are defined as

tm(1,1)	real	0.d0	Days from epoch for initial launch from the primary.
tm(2,1)	real	0.d0	Days from epoch for final launch from the primary.
tof	real	0.d0	Time of flight from LEO to arrival at LLO or one of the libration points when istyle = 6,7.

If 'istyle' = 8 or 9, then the time variables are defined as

tm(1,1)	real	0.d0	Days from epoch for initial launch from secondary.
tm (2,1)			Days from epoch for final launch from secondary.
tm (3,1)			Time increment to step through the above region.
tof			Time of flight from LLO to LEO as one of the libration points.

If 'istyle' = 10, then add to the information under istyle = 6

tm(1,2)	real	0.d0	Days from arrival at secondary for initial launch to primary.
tm(2,2)	real	0.d0	Days from arrival at secondary for final launch to primary.
tof(2)	real	0.d0	Time of flight from LLO to LEO.

B-2.3 SPIRAL NAMELIST INPUTS

a1	real	0.d0	Semi-major axis of initial orbit (km).
a2	real	0.d0	Semi-major axis of final orbit (km).
argp	real	0.d0	Argument of periapsis for initial orbit.
e1	real	0.d0	Eccentricity of initial orbit.
e2	real	0.d0	Eccentricity of final orbit.
hinc1	real	0.d0	Inclination of initial orbit.
hinc2	real	0.d0	Inclination of final orbit.
ipri	integer	0	Central body id.
longn	real	0.d0	Longitude of node for initial orbit.
namlst	character*8	'none'	Designates next namelist to be read.
nrev	integer	1	The number of revolutions required for the spiral.
nt	integer	0	= 0, no tracking from previous solutions from one rev to the next = 1, track from previous solutions.
time	real	0.d0	Julian date for commencement of the spiral maneuver.

B-3.0 SAMPLE CASES

The following sections give some sample cases for IPREP. These cases, along with the above description of the namelist inputs should give the user a good idea of how to set up their own input decks and run this program.

There are two interplanetary sample cases: The first is a Mars rountrip mission and the second is a low thrust mission to Jupiter. The roundtrip trajectory to Mars has a Venus flyby on the outbound leg. The weighting on the cost function values is set so the total mission delta-v will be minimized, with a strong emphasis on the delta-v at the Venus swingby. The purpose is to find the minimum mission which also has a zero delta-v at the flyby. As can be seen from the output on the next page (section B-3.1), the Venus swingby delta-v was negligible, and the total mission delta-v was 12.0782 km/s.

The first LUNAR sample case is a lunar free return mission. The minimum cost in this case will be the minimum total mission delta-v, which happens, in this case, to be only the launch delta-v. As can be seen in the output in section B-3.2, the S/C flew by the moon at an altitude of 200.0 km (the radius of the moon is 1738 km), and returned to the Earth with an altitude of 200 km. These values can be changed in the input by the user.

The second LUNAR sample case is a departure from a space station orbit to LLO. All of the coplanar launch opportunities for the input period of time are printed out.

The first SPIRAL sample case is an Earth-centered trajectory going from LEO to GEO, maintaining close to zero eccentricity. The rev counter was set to 20.

The second SPIRAL sample case is an Earth-centered trajectory going from LEO to a highly eccentric orbit (e2 = .8) using the tracking capability of Chebytop (nt = 1). The rev counter for this case was also set to 20.

B-3.1 IPREP SAMPLE CASES

B-3.1.1 MARS ROUNDTRIP

```
p$top
  namlst   = 'inter',
 $end


*****Interplanetary Trajectory Case*****


p$inter
c...namelist to test preprocessor
  cntrl      = 'auto',
  outfile    = 'nothing.dat'
  itrmax     = 2,
  iprep      = 2,
  iephem     = 1,
  nleg       = 5,
  cmax       = 500.,
  ep         = 2455500.,
  pyload     = 1.d5,
  spi(1)     = 480.,480.,480.,480.,480.,
  ipbod(1)   = 0,
  wjett(1)   = 0.,
  ibod(1)    = 3,
  manvr(1)   = 'launch',
  rperi(1)   = 6878.,
  rapoap(1)  = 6878.,
  tm(1,1)    = 0.,50.,10.,
  tol(5,1)   = 1.,
  ipbod(2)   = 0,
  wjett(2)   = 0.,
  ibod(2)    = 2,
  manvr(2)   = 'swngby',
  rpmin(2)   = 6657.2,
  rpmax(2)   = -1.,
  tm(1,2)    = 100.,200.,10.,
  tol(5,2)   = .1,
  ipbod(3)   = 0,
  wjett(3)   = 0.,
  ibod(3)    = 4,
  manvr(3)   = 'orbins',
  rperi(3)   = 3880.,
  rapoap(3)  = 36327.,
  tm(1,3)    = 100.,200.,10.,
  tol(5,3)   = 1.,
  ibod(4)    = 4,
  manvr(4)   = 'launch',
  rperi(4)   = 3880.,
  rapoap(4)  = 36327.,
  tm(1,4)    = 60.,60.,0.,
  tol(5,4)   = 100.,
  ibod(5)    = 3,
  manvr(5)   = 'orbins',
  rperi(5)   = 6878.,
  rapoap(5)  = 78036.,
  tm(1,5)    = 200.,300.,10.,
  tol(5,5)   = 1.,
  namlst     = 'none',
 $end
```

```
date    = 11 22 2010  0.00 jd = 2455522.5000 pri bod= sun           body   = earth
manvr  =    launch      jettis = 0.000000E+00 dv     =  4.4544485   dv p/c =  0.0000000   rperi   = 0.687800E+04
   ecliptic             x      = 0.751814E+08 y      = 0.116718E+09 z      = 0.505992E+08 inc     = 0.677147E+01
  departure             vinfx  = 0.488694E+01 vinfy  =-0.232691E+01 vinfz  = 0.642685E+00 vinfm   = 0.545067E+01
turn    = 0.827661E+02 bdt     = 0.152271E+05 bdr    = 0.000000E+00 dec    = 0.677147E+01 ra      =-0.254614E+02

date    =  5  8 2011 12.00 jd = 2455690.0000 pri bod= sun           body   = venus
manvr  =    swngby      jettis = 0.000000E+00 dv     =  0.0046129   dv p/c =  0.0000000   rperi   = 0.745829E+04
   ecliptic             x      = 0.103562E+09 y      =-0.275754E+08 z      =-0.189602E+08 inc     = 0.191969E+02
    arrival             vinfx  = 0.100911E+02 vinfy  =-0.374588E+01 vinfz  =-0.165344E+01 vinfm   = 0.108902E+02
turn    = 0.311637E+02 bdt     = 0.938530E+04 bdr    = 0.289854E+04 dec    =-0.873289E+01 ra      =-0.203652E+02
  departure             vinfx  = 0.107391E+02 vinfy  = 0.175617E+01 vinfz  = 0.229543E+00 vinfm   = 0.108841E+02
turn    = 0.311898E+02 bdt     = 0.928075E+04 bdr    = 0.322469E+04 dec    = 0.120844E+01 ra      = 0.928745E+01
    equator             x      = 0.100733E+09 y      =-0.373640E+08 z      =-0.173734E+08 inc     = 0.197479E+02
    arrival             vinfx  = 0.970870E+01 vinfy  =-0.469639E+01 vinfz  =-0.151052E+01 vinfm   = 0.108902E+02
turn    = 0.311637E+02 bdt     = 0.933524E+04 bdr    = 0.305592E+04 dec    =-0.797287E+01 ra      =-0.258144E+02
  departure             vinfx  = 0.108526E+02 vinfy  = 0.698799E+00 vinfz  = 0.444363E+00 vinfm   = 0.108841E+02
turn    = 0.311898E+02 bdt     = 0.925491E+04 bdr    = 0.329813E+04 dec    = 0.233985E+01 ra      = 0.368420E+01

date    = 10 10 2011 12.00 jd = 2455845.0000 pri bod= sun           body   = mars
manvr  =    orbins      jettis = 0.000000E+00 dv     =  2.6082180   dv p/c =  0.0000000   rperi   = 0.388000E+04
   ecliptic             x      =-0.338165E+08 y      = 0.213560E+09 z      = 0.988674E+08 inc     = 0.168967E+02
    arrival             vinfx  = 0.455777E+01 vinfy  = 0.219854E+01 vinfz  = 0.153712E+01 vinfm   = 0.528862E+01
turn    = 0.328757E+02 bdt     = 0.519008E+04 bdr    = 0.000000E+00 dec    = 0.168967E+02 ra      = 0.257513E+02

date    = 12  9 2011 12.00 jd = 2455905.0000 pri bod= sun           body   = mars
manvr  =    launch      jettis = 0.000000E+00 dv     =  3.5903649   dv p/c =  0.0000000   rperi   = 0.388000E+04
   ecliptic             x      =-0.144204E+09 y      = 0.179436E+09 z      = 0.861969E+08 inc     = 0.867088E+01
  departure             vinfx  = 0.501604E+01 vinfy  =-0.408608E+01 vinfz  =-0.986635E+00 vinfm   = 0.654448E+01
turn    = 0.236486E+02 bdt     = 0.477641E+04 bdr    = 0.000000E+00 dec    =-0.867088E+01 ra      =-0.391664E+02

date    =  6 26 2012 12.00 jd = 2456105.0000 pri bod= sun           body   = earth
manvr  =    orbins      jettis = 0.000000E+00 dv     =  1.4679334   dv p/c =  0.0000000   rperi   = 0.687800E+04
   ecliptic             x      = 0.135397E+08 y      =-0.138974E+09 z      =-0.602471E+08 inc     = 0.292709E+02
    arrival             vinfx  = 0.418019E+01 vinfy  =-0.280043E+00 vinfz  =-0.234828E+01 vinfm   = 0.480279E+01
turn    = 0.913346E+02 bdt     = 0.168824E+05 bdr    = 0.000000E+00 dec    =-0.292709E+02 ra      =-0.383268E+01

cmin    = 0.861263E+01 dvmag   = 0.121256E+02 in wt  = 0.131440E+07
fin wt  = 0.100000E+06 tank wt= 0.000000E+00 prop wt= 0.121440E+07

*****Run Completed*****
```

B-3.1.2 LOW THRUST TO JUPITER

```
1$prep
c
c   test of voyager 1
c
  iepoch=6hcalend,
  date=1977,8,1,
  cntrl      = 'auto',
  iephem     = 0,
  itrmax     = 2,
  iprep      = 2,
  nleg       = 3,
  cmax       = 10000.,
  pyload     = 100000.,
  spi(1)     = 3*4.d3,
  thrust(1)  = 20000.,20000.,20000.,
  acc(1)     = 3*1.d-4,
  ipbod(1)   = 0,
  hinc(1)    = -1.,
  wjett(1)   = 0.,
  ibod(1)    = 3,
  manvr(1)   = 'launch',
  rperi(1)   = 6678.,
  rapoap(1)  = 6678.,
  prop(1)    = 'lowthr',
  nrev(1)    = 0,
  tm(1,1)    =  0.,20.,10.,
  tol(3,1)   = 100000.,
  tol(5,1)   = 1.,
  ipbod(2)   = 0,
  wjett(2)   = 0.,
  ibod(2)    = 5,
  prop(2)    = 'lowthr',
  manvr(2)   = 'swngby',
  rpmax(2)   = 200000.,
  rpmin(2)   = 80000.,
  tm(1,2)    = 500.,600.,50.,
  tol(5,2)   = 1.,
  ipbod(3)   = 0,
  wjett(3)   = 0.,
  ibod(3)    = 6,
  manvr(3)   = 'none',
  rperi(3)   = 100000.,
  rapoap(3)  = 1000000.,
  tm(1,3)    = 500.,700.,50.,
  tol(5,3)   = 1.,
  $end

date    =   8  1 1977  0.00 jd = 2443356.5000 pri bod= sun          body   = earth
manvr  =   launch     jettis = 0.000000E+00 mf/mi  = 0.858158E+00 time   = 0.321822E+00 rperi  = 0.667800E+04
  ecliptic            x      = 0.933622E+08 y      =-0.119740E+09 z      = 0.691977E+04 inc    = 0.100811E+00
 departure            vinfx  = 0.000000E+00 vinfy  = 0.447419E+00 vinfz  =-0.787227E-03 vinfm  = 0.447419E+00
turn   = 0.170628E+03 bdt    = 0.163213E+06 bdr    = 0.000000E+00 dec    =-0.100811E+00 ra     = 0.900000E+02

 vtmode input                nc rn  np1 np2 nb1 nb2 nv1 nv2   d1     d2      h1    h2  npo nt
                             3 0.0  3   5   2   2   2   0   3356.5 3919.0  12.3   0.0  0   0

common block input           tilt   ploss   angl   ayou
                             90.0    0.00    0.0    1.0
```

```
common block input        e1      e2        e3        e4        e5        e6        e7
                          0.00000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0
                          0.00000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000 0.0

internal parameters       nl nit
                           3   7

output                    d1      h1    al1    be1    d2      h2    al2   be2   jv
                          3356.5  0.0   25.6   0.0    3919.0  13.6  96.4  -0.1  11.079
```

predicted constant isp trajectory

```
common block input               bb   1.00          dd   0.00              tanks   0.00

efficiency (eta)      1.000                      powerplant specific mass (alphaw)    30.000  kg/kw

optimized powerplant fraction (muw)     0.285    optimized exhaust velocity (c)    19.603  km/sec

optimized cone angles   180.00    67.50   114.43   139.85

constant isp j (jc)    16.766  m2/sec3           thrust duration   110.006  days

final mass fraction (mul)     0.530              payload mass fraction (mul)    0.245
```

time	x	y	z	r	mag.a	cone	clock	ra.he	dec.he	ra.uvw	dec.uvw	ra.rtn	d
0.00	0.62408	-0.80040	0.00005	1.01495	6.4367	114.4342	270.1026	-7.0976	-0.5941	-40.5369	-0.0888	-40.6639	-
9.37	0.74298	-0.69085	0.00004	1.01454	6.7053	114.4342	269.9977	-11.5407	0.0201	-39.3025	0.0066	-39.2193	
18.75	0.84822	-0.56103	0.00003	1.01697	6.9973	114.4342	269.8774	-14.8684	0.7858	-37.6092	0.1145	-36.9909	
28.12	0.93669	-0.41388	0.00003	1.02405	7.3159	114.4342	269.7387	-17.1846	1.7455	-35.3291	0.2379	-33.7119	
37.50	1.00602	-0.25300	0.00005	1.03735	7.6648	114.4342	269.5770	-18.6177	2.9574	-32.3339	0.3806	-29.0891	
46.88	1.05482	-0.08241	0.00009	1.05804	8.0487	114.4342	269.3862	-19.2818	4.5040	-28.5085	0.5482	-22.8672	
56.25	1.08277	0.09381	0.00015	1.08683	8.4731	114.4342	269.1574	-19.2643	6.5005	-23.7733	0.7488	-14.9660	
65.63	1.09056	0.27186	0.00025	1.12393	8.9448	114.4342	268.8789	-18.6274	9.0987	-18.1207	0.9928	-5.6726	

```
acmag =  0.6436E+01 +  0.2779E-01 t +  0.9651E-04 t^2 +  0.9512E-06 t^3   Chi^2 =  0.2453E-05

yaw   = -0.7103E+01 + -0.5350E+00 t +  0.6861E-02 t^2 + -0.2114E-04 t^3   Chi^2 =  0.7083E-03

pitch = -0.6074E+00 +  0.6732E-01 t +  0.6116E-04 t^2 +  0.1773E-04 t^3   Chi^2 =  0.2443E-02
```

time	x	y	z	r	mag.a	cone	clock	ra.he	dec.he	ra.uvw	dec.uvw	ra.rtn
75.00	1.07968	0.44847	0.00038	1.16912	9.4721	139.8508	268.5357	7.0826	9.0020	13.1527	0.9099	26.3523
84.38	1.05218	0.62111	0.00055	1.22183	10.0654	139.8508	268.1045	9.0186	12.3045	19.5365	1.1818	32.5614
93.75	1.01035	0.78798	0.00075	1.28130	10.7380	139.8508	267.5547	11.3871	16.7109	25.1827	1.5318	37.2780
103.12	0.95648	0.94795	0.00100	1.34665	11.5069	139.8508	266.8358	14.0640	22.5902	29.9834	1.9932	40.6759

```
acmag =  0.5536E+01 +  0.6468E-01 t + -0.4211E-03 t^2 +  0.3446E-05 t^3   Chi^2 =  0.2435E-21

yaw   =  0.2206E+02 + -0.7195E+00 t +  0.8814E-02 t^2 + -0.2510E-04 t^3   Chi^2 =  0.7245E-19

pitch = -0.2192E+02 +  0.9376E+00 t + -0.1260E-01 t^2 +  0.7458E-04 t^3   Chi^2 =  0.1268E-26

  112.50   0.89273   1.10042   0.00128   1.41701    0.0000
```

121.87	0.82104	1.24523	0.00161	1.49154	0.0000
131.25	0.74305	1.38247	0.00198	1.56951	0.0000
140.62	0.66016	1.51244	0.00239	1.65024	0.0000
150.00	0.57354	1.63554	0.00284	1.73319	0.0000
159.37	0.48413	1.75222	0.00333	1.81787	0.0000
168.75	0.39268	1.86295	0.00386	1.90389	0.0000
178.13	0.29983	1.96819	0.00443	1.99090	0.0000
187.50	0.20607	2.06839	0.00505	2.07864	0.0000
196.88	0.11179	2.16397	0.00570	2.16686	0.0000
206.25	0.01732	2.25532	0.00639	2.25539	0.0000
215.63	-0.07709	2.34278	0.00712	2.34406	0.0000
225.00	-0.17125	2.42669	0.00789	2.43274	0.0000
234.38	-0.26498	2.50734	0.00870	2.52132	0.0000
243.75	-0.35816	2.58499	0.00954	2.60971	0.0000
253.12	-0.45069	2.65989	0.01042	2.69782	0.0000
262.50	-0.54250	2.73224	0.01133	2.78560	0.0000
271.87	-0.63353	2.80225	0.01228	2.87300	0.0000
281.25	-0.72373	2.87009	0.01325	2.95996	0.0000
290.62	-0.81307	2.93591	0.01426	3.04645	0.0000
300.00	-0.90153	2.99987	0.01530	3.13244	0.0000
309.37	-0.98909	3.06208	0.01636	3.21790	0.0000
318.75	-1.07574	3.12266	0.01746	3.30280	0.0000
328.12	-1.16148	3.18172	0.01858	3.38714	0.0000
337.50	-1.24631	3.23934	0.01973	3.47088	0.0000
346.87	-1.33024	3.29562	0.02090	3.55402	0.0000
356.25	-1.41326	3.35063	0.02209	3.63655	0.0000
365.62	-1.49541	3.40443	0.02330	3.71846	0.0000
375.00	-1.57667	3.45709	0.02454	3.79973	0.0000
384.37	-1.65707	3.50866	0.02579	3.88036	0.0000
393.75	-1.73662	3.55918	0.02706	3.96035	0.0000
403.12	-1.81534	3.60871	0.02835	4.03968	0.0000
412.50	-1.89323	3.65728	0.02965	4.11836	0.0000
421.88	-1.97033	3.70492	0.03096	4.19638	0.0000
431.25	-2.04663	3.75166	0.03229	4.27373	0.0000
440.63	-2.12217	3.79754	0.03363	4.35041	0.0000
450.00	-2.19696	3.84256	0.03498	4.42642	0.0000
459.38	-2.27101	3.88676	0.03633	4.50175	0.0000
468.75	-2.34435	3.93015	0.03769	4.57641	0.0000
478.13	-2.41698	3.97275	0.03906	4.65038	0.0000
487.50	-2.48894	4.01456	0.04043	4.72367	0.0000
496.88	-2.56022	4.05559	0.04181	4.79628	0.0000
506.25	-2.63086	4.09586	0.04318	4.86820	0.0000
515.63	-2.70087	4.13536	0.04455	4.93942	0.0000
525.00	-2.77026	4.17411	0.04592	5.00996	0.0000
534.38	-2.83905	4.21210	0.04729	5.07979	0.0000
543.75	-2.90726	4.24934	0.04866	5.14893	0.0000
553.12	-2.97490	4.28583	0.05001	5.21736	0.0000
562.50	-3.04200	4.32155	0.05136	5.28509	0.0000

```
date   =   2 14 1979 12.00 jd = 2443919.0000 pri bod= sun            body   = jupiter
manvr  =    swngby      jettis = 0.000000E+00 dv      =  0.0000000   dv p/c =  0.0000000   rperi  = 0.199167E+06
   ecliptic             x      =-0.455082E+09 y       = 0.646502E+09 z      = 0.768393E+07 inc    = 0.369855E+01
    arrival             vinfx  =-0.150558E+01 vinfy   = 0.134755E+02 vinfz  =-0.219493E-01 vinfm  = 0.135593E+02
turn   = 0.101749E+03 bdt      = 0.559316E+06 bdr     = 0.361438E+05 dec    =-0.927481E-01 ra     = 0.963751E+02
  departure             vinfx  =-0.128592E+02 vinfy   =-0.421361E+01 vinfz  = 0.860547E+00 vinfm  = 0.135593E+02
turn   = 0.101749E+03 bdt      = 0.560445E+06 bdr     =-0.648478E+04 dec    = 0.363874E+01 ra     =-0.161857E+03
    equator             x      =-0.632076E+09 y       =-0.474896E+09 z      =-0.879158E+07 inc    = 0.517721E+01
    arrival             vinfx  =-0.134132E+02 vinfy   =-0.192568E+01 vinfz  =-0.482165E+00 vinfm  = 0.135593E+02
```

```
turn   = 0.101749E+03 bdt   = 0.558550E+06 bdr   = 0.465127E+05 dec   =-0.203785E+01 ra    =-0.171830E+03
  departure          vinfx = 0.457259E+01 vinfy =-0.127086E+02 vinfz = 0.119916E+01 vinfm = 0.135593E+02
turn   = 0.101749E+03 bdt   = 0.560392E+06 bdr   = 0.100871E+05 dec   = 0.507374E+01 ra    =-0.702111E+02

 vtmode input               nc rn  np1 np2 nb1 nb2 nv1 nv2   d1      d2     h1    h2  npo nt
                            3  0.0  5   6   2   2   1   0  3919.0 4456.5  13.6   0.0  0   0

common block input          tilt  ploss  angl  ayou
                            90.0   0.00   0.0   1.0

common block input            e1       e2        e3        e4        e5        e6       e7
                            0.00000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000  0.0
                            0.00000 0.0000000 0.0000000 0.0000000 0.0000000 0.0000000  0.0

internal parameters         nl nit
                             2   8

output                        d1     h1    al1    be1      d2    h2    al2    be2   jv
                            3919.0  13.6 -161.9   3.6   4456.5  18.1 -166.7   2.4  0.000
```

predicted constant isp trajectory

```
common block input          bb   1.00            dd   0.00              tanks   0.00

efficiency (eta)     1.000                   powerplant specific mass (alphaw)    30.000  kg/kw

optimized powerplant fraction (muw)    0.003  optimized exhaust velocity (c)    45.134  km/sec

optimized cone angles    43.43    62.43    -1.02    157.50

constant isp j (jc)    0.001  m2/sec3        thrust duration   354.410  days

final mass fraction (mul)    0.997           payload mass fraction (mul)    0.994
```

time	x	y	z	r	mag.a	cone	clock	ra.he	dec.he	ra.uvw	dec.uvw	ra.rtn	d
0.00	-3.04200	4.32155	0.05136	5.28509	0.0278	62.4262	86.3552	-40.1495	-0.0968	-7.3027	-5.8920	2.6321	-
13.44	-3.22508	4.23452	0.06011	5.32315	0.0278	62.4262	86.3612	-40.5422	-0.0978	-5.5226	-5.9368	6.0397	-
26.87	-3.40697	4.14601	0.06884	5.36671	0.0278	62.4262	86.3686	-40.8915	-0.0987	-3.8228	-5.9775	9.2680	-
40.31	-3.58764	4.05608	0.07753	5.41562	0.0278	62.4262	86.3772	-41.2019	-0.0996	-2.2082	-6.0147	12.2952	-
53.75	-3.76705	3.96480	0.08620	5.46971	0.0278	62.4262	86.3866	-41.4775	-0.1005	-0.6817	-6.0486	15.1093	-
67.19	-3.94520	3.87224	0.09484	5.52882	0.0278	62.4262	86.3967	-41.7222	-0.1013	0.7559	-6.0796	17.7073	-
80.62	-4.12206	3.77847	0.10344	5.59276	0.0278	62.4262	86.4071	-41.9393	-0.1020	2.1051	-6.1081	20.0922	-
94.06	-4.29762	3.68356	0.11201	5.66134	0.0278	62.4262	86.4178	-42.1321	-0.1027	3.3678	-6.1343	22.2723	-
107.50	-4.47188	3.58758	0.12055	5.73437	0.0278	62.4262	86.4283	-42.3032	-0.1034	4.5467	-6.1586	24.2587	-
120.94	-4.64483	3.49059	0.12904	5.81166	0.0278	62.4262	86.4385	-42.4553	-0.1040	5.6452	-6.1813	26.0646	-
134.38	-4.81649	3.39267	0.13750	5.89302	0.0278	62.4262	86.4481	-42.5904	-0.1046	6.6673	-6.2027	27.7039	-
147.81	-4.98685	3.29388	0.14593	5.97826	0.0278	62.4262	86.4570	-42.7106	-0.1052	7.6171	-6.2230	29.1906	-
161.25	-5.15593	3.19427	0.15431	6.06719	0.0278	62.4262	86.4650	-42.8175	-0.1057	8.4988	-6.2426	30.5384	-

```
acmag =  0.2776E-01 +  0.2221E-06 t +  0.1778E-11 t^2 +  0.1426E-16 t^3   Chi^2 =  0.3561E-29

yaw   = -0.4015E+02 + -0.3051E-01 t +  0.1197E-03 t^2 + -0.2051E-06 t^3   Chi^2 =  0.3479E-04

pitch = -0.9676E-01 + -0.7867E-04 t +  0.1974E-06 t^2 + -0.3399E-09 t^3   Chi^2 =  0.2298E-10
```

174.69	-5.32374	3.09391	0.16265	6.15963	0.0278	43.4305	86.4720	-44.9709	-0.0979	25.5381	-5.8228	40.0958	-
188.13	-5.49031	2.99286	0.17096	6.25539	0.0278	43.4305	86.4776	-44.9798	-0.0988	26.1007	-5.8504	40.7058	-
201.56	-5.65565	2.89116	0.17922	6.35431	0.0278	43.4305	86.4819	-44.9866	-0.0998	26.6173	-5.8774	41.2471	-
215.00	-5.81978	2.78887	0.18745	6.45622	0.0278	43.4305	86.4845	-44.9915	-0.1007	27.0917	-5.9041	41.7273	-
228.44	-5.98273	2.68604	0.19564	6.56095	0.0278	43.4305	86.4855	-44.9950	-0.1016	27.5279	-5.9304	42.1531	-
241.87	-6.14452	2.58271	0.20378	6.66836	0.0278	43.4305	86.4849	-44.9974	-0.1025	27.9291	-5.9565	42.5305	-
255.31	-6.30517	2.47893	0.21189	6.77829	0.0278	43.4305	86.4823	-44.9989	-0.1033	28.2985	-5.9826	42.8647	-
268.75	-6.46473	2.37473	0.21996	6.89060	0.0278	43.4305	86.4778	-44.9997	-0.1042	28.6388	-6.0088	43.1604	-
282.19	-6.62320	2.27015	0.22800	7.00516	0.0278	43.4305	86.4713	-45.0000	-0.1051	28.9526	-6.0352	43.4218	-
295.62	-6.78062	2.16522	0.23600	7.12185	0.0278	43.4305	86.4627	-44.9999	-0.1059	29.2421	-6.0619	43.6524	-
309.06	-6.93702	2.05998	0.24396	7.24053	0.0278	43.4305	86.4520	-44.9995	-0.1068	29.5095	-6.0889	43.8556	-
322.50	-7.09242	1.95446	0.25188	7.36110	0.0278	43.4305	86.4390	-44.9989	-0.1076	29.7565	-6.1164	44.0342	-
335.94	-7.24686	1.84869	0.25977	7.48345	0.0278	43.4305	86.4238	-44.9982	-0.1085	29.9849	-6.1444	44.1908	-
349.37	-7.40035	1.74268	0.26763	7.60748	0.0278	43.4305	86.4063	-44.9974	-0.1094	30.1963	-6.1732	44.3277	-

```
acmag =  0.2776E-01 +  0.2221E-06 t +  0.1777E-11 t^2 +  0.1496E-16 t^3   Chi^2 =  0.7873E-25

yaw   = -0.4463E+02 + -0.3646E-02 t +  0.1171E-04 t^2 + -0.1236E-07 t^3   Chi^2 =  0.9338E-06

pitch = -0.8124E-01 + -0.1252E-03 t +  0.2151E-06 t^2 + -0.2505E-09 t^3   Chi^2 =  0.2085E-10
```

362.81	-7.55293	1.63647	0.27545	7.73309	0.0000
376.25	-7.70462	1.53008	0.28324	7.86019	0.0000
389.69	-7.85545	1.42353	0.29100	7.98869	0.0000
403.13	-8.00545	1.31682	0.29872	8.11852	0.0000
416.56	-8.15463	1.21000	0.30642	8.24960	0.0000
430.00	-8.30303	1.10306	0.31408	8.38186	0.0000
443.44	-8.45066	0.99602	0.32172	8.51524	0.0000
456.88	-8.59756	0.88891	0.32933	8.64966	0.0000
470.31	-8.74374	0.78172	0.33691	8.78507	0.0000
483.75	-8.88922	0.67447	0.34446	8.92142	0.0000
497.19	-9.03403	0.56717	0.35199	9.05866	0.0000
510.63	-9.17819	0.45983	0.35949	9.19673	0.0000
524.06	-9.32171	0.35247	0.36696	9.33559	0.0000
537.50	-9.46462	0.24508	0.37442	9.47520	0.0000

```
date   =  8  5 1980  0.00 jd = 2444456.5000 pri bod= sun           body   = saturn
manvr  =   none        jettis = 0.000000E+00 dv     =  0.0000000   dv p/c =  0.0000000   rperi   = 0.100000E+06
   ecliptic            x      =-0.141590E+10 y      = 0.366632E+08 z      = 0.560125E+08 inc     = 0.241346E+01
    arrival            vinfx  =-0.176423E+02 vinfy  =-0.417343E+01 vinfz  = 0.764107E+00 vinfm   = 0.181453E+02
turn   = 0.647259E+02 bdt     = 0.181760E+06 bdr    = 0.000000E+00 dec    = 0.241346E+01 ra      =-0.166691E+03

cmin   = 0.478496E+01 dvmag  = 0.355271E-14 in wt  = 0.478496E+06 fin wt = 0.100000E+06 tank wt= 0.000000E+00 prop wt= 0.37850E+06
```

B-3.1.3 LUNAR FREE RETURN

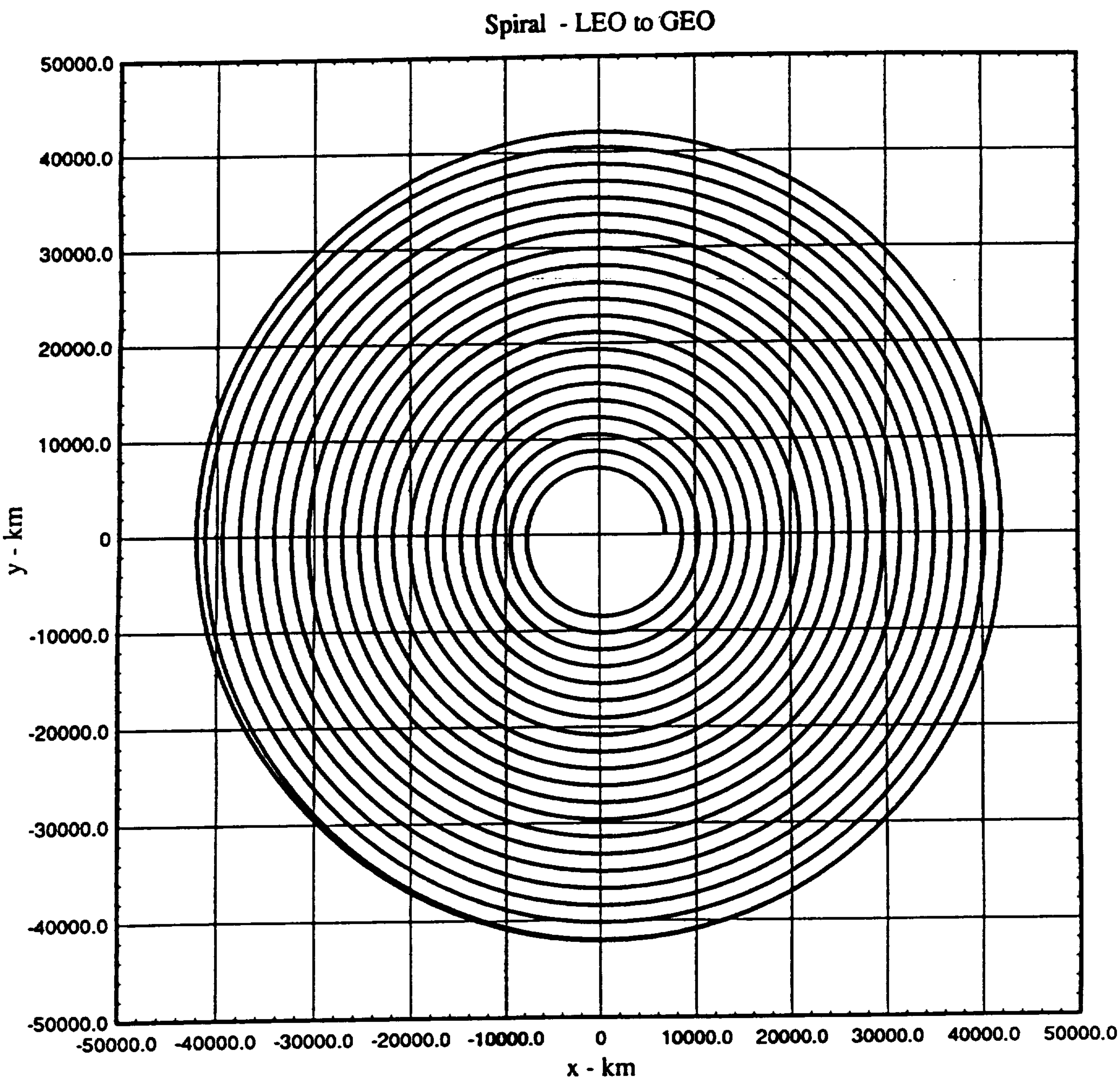
```
 p$top
   namlst = 'lunar',
  $end

*****Translunar Trajectory Case*****

 warning-    1 records skipped before group name lunar    found.  ** line no. =      6

  p$lunar
  c
    iephem   = 1,
    istyle   = 4,
    ep       = 2449900.2,
    tm(1,1)  = 0.,
    tm(2,1)  = 60.,
    tm(3,1)  = 1.,
    tm(1,2)  = 1.5,
    tm(2,2)  = 3.0,
    tm(3,2)  = .1,
    hinc(1)  = 28.5,
    rp(1)    = 6878.,
    ra(1)    = 6878.,
    rp(2)    = 1938.,
    hinc(2)  = 160.,
    rp(3)    = 6578.,
    namlst   = 'none',
   $end
 icntl =         19icnt2 =         41

 ipost phasei/lunar output:  best mission

 primary= earth        second = moon

    t1    2449900.2000     t2    2449903.1351     t3    2449906.0283

 s/c state relative to primary at epoch:    j2000  eartheq

 x      = 0.685207072174E+04 y      = 0.551578391903E+03 z      = -.227534836700E+03 r      = 0.687800000000E+04
 vx     = -.656659329432E+00 vy     = 0.666261409776E+01 vz     = -.362371849256E+01 v      = 0.761268440196E+01
 sma    = 0.687800000000E+04 ecc    = 0.746425129664E-15 inc    = 0.285000000000E+02 long-n = 0.181107243756E+03
 arg-p  = 0.000000000000E+00 m-anom = -.307220673217E+01 t-anom = -.176024479545E+03

 s/c state relative to primary before launch:    j2000   pri eq

 x      = 0.685207072174E+04 y      = 0.551578391902E+03 z      = -.227534836700E+03 r      = 0.687800000000E+04
 vx     = -.656659329432E+00 vy     = 0.666261409776E+01 vz     = -.362371849256E+01 v      = 0.761268440196E+01
 sma    = 0.687800000000E+04 ecc    = 0.373368850232E-15 inc    = 0.285000000000E+02 long-n = 0.181107243756E+03
 arg-p  = 0.000000000000E+00 m-anom = -.307220673217E+01 t-anom = -.176024479545E+03

 launch maneuver:
 dvx    = -.266053380945E+00 dvy    = 0.269943778636E+01 dvz    = -.146819288682E+01 dv-mag = 0.308437013292E+01

 s/c state relative to primary after launch:    j2000   pri eq

 x      = 0.685207072174E+04 y      = 0.551578391903E+03 z      = -.227534836701E+03 r      = 0.687800000000E+04
 vx     = -.922712710377E+00 vy     = 0.936205188412E+01 vz     = -.509191137937E+01 v      = 0.106970545349E+02
```

```
sma    = 0.269515519038E+06 ecc    = 0.974480133743E+00 inc    = 0.285000000000E+02 long-n = 0.181107243756E+03
arg-p  = 0.183975520455E+03 m-anom = 0.381895896462E-15 t-anom = 0.754182442054E-11

s/c state relative to secondary on arrival:     j2000    pri eq

x      = -.191538081325E+04 y      = -.921799758225E+02 z      = 0.280532461431E+03 r      = 0.193800909947E+04
vx     = -.936423541140E-03 vy     = 0.239621969222E+01 vz     = 0.780978659272E+00 v      = 0.252027723802E+01
sma    = -.379420429452E+04 ecc    = 0.151078143111E+01 inc    = 0.159999995664E+03 long-n = 0.206454724064E+03
arg-p  = 0.250386234955E+02 m-anom = 0.105272024020E-11 t-anom = 0.865930577644E-09
r-peri = 0.193800909947E+04 v-peri = 0.252027723802E+01 tfp    = 0.709799838244E-15 fpa    = 0.276072146351E-11
turn-a = 0.485543642151E+02 b-theta= -.161543940979E+03 bdt    = -.407577874409E+04 bdr    = -.136026166413E+04
vinf-x = 0.743317160190E+00 vinf-y = 0.845928293897E+00 vinf-z = 0.155126919154E+00
c3     = 0.129217944009E+01 ra     = 0.486942283597E+02 dec    = 0.784342359413E+01

s/c state relative to primary on arrival:     j2000    pri eq

x      = 0.651413699684E+04 y      = -.469816705163E+03 z      = -.784459572180E+03 r      = 0.657800010417E+04
vx     = 0.128060850495E+01 vy     = -.379731246131E+00 vz     = 0.108615709790E+02 v      = 0.109433942675E+02
sma    = 0.277940994331E+06 ecc    = 0.976333105809E+00 inc    = 0.914901314346E+02 long-n = 0.355695796697E+03
arg-p  = 0.353148561906E+03 m-anom = 0.397790636840E-14 t-anom = 0.880025705591E-10
total cost =     3.084370132921875

have a happy day!

*****Run Completed*****
```

B-3.1.4 PRECESSING SPACE STATION ORBIT TO LLO

```
 p$top
   namlst = 'lunar',
  $end


*****Translunar Trajectory Case*****


 p$lunar
 c
 c --- test of lunar phase1
 c --- interplanetary program to optimize space trajectories
 c
   istyle  = 6,
   ep      = 2450000.,
   iephem  = 1,
   iprint  = 1,

   tm(1,1) = 0.,
   tm(2,1) = 10.,
   tof     = 3.,

   orb(1)  = 6878.,0.,28.5,0.,0.,0.,

   rp(2)   = 1838.,
   ra(2)   = 1838.,
   hinc(2) = 16.,
   namlst  = 'none',
  $end
                  x          y          z         xd         yd         zd       dvmag        dvx        dvy        dvz

Encounters     Launch= 2450004.3    SOI Arr=   2.39376   SOI->Inj=   0.61444
Prim  Park    3709.62   -5603.24   -1466.03   6.099613   3.186706   3.254626
Injection     3709.62   -5603.24   -1466.03   8.574837   4.479872   4.575354   3.089229   2.475224   1.293166   1.320728
SOI Arr    -137480.83  307470.64   99932.89  -0.545856   0.750426   0.181881
SOI Sec DV  -19747.07  -59930.74  -19348.39   0.373767   1.020517   0.313418   0.030984   0.029158  -0.007079  -0.007728
Sec Arr       1525.94     909.23    -472.28  -1.237009   2.207857   0.253736
Injection     1525.94     909.23    -472.28  -0.794322   1.417733   0.162932   0.910227   0.442687  -0.790124  -0.090804


*****Run Completed*****
```

B - 3.1.5 SPIRAL LEO TO GEO


Spiral - LEO to GEO
50000.0
40000.0
30000.0
20000.0
10000.0
0
-10000.0
-20000.0
-30000.0
-40000.0
-50000.0
y - km
-50000.0
-40000.0
-30000.0
-20000.0
-10000.0
0
10000.0
20000.0
30000.0
40000.0
50000.0
x - km

```
1$top
  namlst = 'spiral',
 $end
```

*****Spiral Orbit Transfer Case*****

```
1$spiral
c raise periapsis, raise apoapsis
  a1 = 6878.d0,
  a2 = 42122.d0,
  time = 2444140.d0,
  ipri = 3,
  nrev = 20,
  namlst = 'spiral',
 $end
```

rev 1

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.000000E+00	0.687800E+04	-0.395987E-11	0.000000E+00	0.687800E+04	0.906807E+02	0.270000E+03	0.148750E-03
0.227581E+03	0.666068E+04	0.171805E+04	0.000000E+00	0.687869E+04	0.908496E+02	0.270000E+03	0.148423E-03
0.455161E+03	0.602138E+04	0.333513E+04	0.000000E+00	0.688332E+04	0.911550E+02	0.270000E+03	0.147876E-03
0.682742E+03	0.499946E+04	0.474902E+04	0.000000E+00	0.689549E+04	0.915778E+02	0.270000E+03	0.147026E-03
0.913146E+03	0.364109E+04	0.588303E+04	0.000000E+00	0.691864E+04	0.921005E+02	0.270000E+03	0.145798E-03
0.114395E+04	0.204191E+04	0.664872E+04	0.000000E+00	0.695520E+04	0.926888E+02	0.270000E+03	0.144167E-03
0.137476E+04	0.307127E+03	0.699989E+04	0.000000E+00	0.700662E+04	0.933069E+02	0.270000E+03	0.142133E-03
0.161314E+04	-0.151140E+04	0.691244E+04	0.000000E+00	0.707575E+04	0.939395E+02	0.270000E+03	0.139646E-03
0.185404E+04	-0.325970E+04	0.637653E+04	0.000000E+00	0.716141E+04	0.945359E+02	0.270000E+03	0.136796E-03
0.209493E+04	-0.481178E+04	0.543795E+04	0.000000E+00	0.726116E+04	0.950567E+02	0.270000E+03	0.133695E-03
0.234700E+04	-0.613233E+04	0.410190E+04	0.000000E+00	0.737774E+04	0.954932E+02	0.270000E+03	0.130287E-03
0.260577E+04	-0.709340E+04	0.245626E+04	0.000000E+00	0.750663E+04	0.958048E+02	0.270000E+03	0.126731E-03
0.286453E+04	-0.761314E+04	0.647854E+03	0.000000E+00	0.764065E+04	0.959679E+02	0.270000E+03	0.123226E-03
0.313456E+04	-0.767405E+04	-0.128829E+04	0.000000E+00	0.778144E+04	0.959799E+02	0.270000E+03	0.119726E-03
0.341585E+04	-0.723642E+04	-0.322974E+04	0.000000E+00	0.792446E+04	0.958306E+02	0.270000E+03	0.116337E-03
0.369714E+04	-0.633911E+04	-0.497716E+04	0.000000E+00	0.805956E+04	0.955376E+02	0.270000E+03	0.113273E-03
0.398626E+04	-0.501592E+04	-0.646995E+04	0.000000E+00	0.818656E+04	0.951171E+02	0.270000E+03	0.110500E-03
0.428842E+04	-0.330275E+04	-0.761842E+04	0.000000E+00	0.830352E+04	0.945869E+02	0.270000E+03	0.108023E-03
0.459058E+04	-0.137123E+04	-0.828981E+04	0.000000E+00	0.840245E+04	0.940079E+02	0.270000E+03	0.105965E-03
0.489604E+04	0.676139E+03	-0.845628E+04	0.000000E+00	0.848327E+04	0.934181E+02	0.270000E+03	0.104277E-03
0.521138E+04	0.275604E+04	-0.809016E+04	0.000000E+00	0.854672E+04	0.928499E+02	0.270000E+03	0.102894E-03
0.552672E+04	0.467191E+04	-0.720991E+04	0.000000E+00	0.859125E+04	0.923640E+02	0.270000E+03	0.101806E-03
0.584262E+04	0.630853E+04	-0.587318E+04	0.000000E+00	0.861927E+04	0.919938E+02	0.270000E+03	0.100931E-03
0.616237E+04	0.757491E+04	-0.414351E+04	0.000000E+00	0.863411E+04	0.917642E+02	0.270000E+03	0.100175E-03
0.648212E+04	0.836926E+04	-0.214399E+04	0.000000E+00	0.863951E+04	0.916975E+02	0.270000E+03	0.994547E-04
0.680186E+04	0.864020E+04	0.570221E-11	0.000000E+00	0.864020E+04	0.917995E+02	0.270000E+03	0.986785E-04

rev 2

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.680186E+04	0.864020E+04	-0.551214E-11	0.000000E+00	0.864020E+04	0.906118E+02	0.270000E+03	0.771657E-04
0.712210E+04	0.836758E+04	0.215611E+04	0.000000E+00	0.864091E+04	0.907386E+02	0.270000E+03	0.770039E-04
0.744234E+04	0.756581E+04	0.418396E+04	0.000000E+00	0.864564E+04	0.909780E+02	0.270000E+03	0.767556E-04
0.776258E+04	0.628441E+04	0.595555E+04	0.000000E+00	0.865808E+04	0.913147E+02	0.270000E+03	0.763845E-04
0.808604E+04	0.458547E+04	0.737194E+04	0.000000E+00	0.868171E+04	0.917334E+02	0.270000E+03	0.758580E-04
0.840997E+04	0.258619E+04	0.832664E+04	0.000000E+00	0.871902E+04	0.922071E+02	0.270000E+03	0.751625E-04
0.873390E+04	0.416955E+03	0.876160E+04	0.000000E+00	0.877152E+04	0.927068E+02	0.270000E+03	0.742954E-04
0.906643E+04	-0.184388E+04	0.864732E+04	0.000000E+00	0.884172E+04	0.932165E+02	0.270000E+03	0.732376E-04
0.940183E+04	-0.401405E+04	0.797542E+04	0.000000E+00	0.892861E+04	0.936974E+02	0.270000E+03	0.720218E-04

0.973724E+04	-0.594081E+04	0.680044E+04	0.000000E+00	0.902991E+04	0.941179E+02	0.270000E+03	0.706897E-04
0.100852E+05	-0.756556E+04	0.514182E+04	0.000000E+00	0.914746E+04	0.944677E+02	0.270000E+03	0.692267E-04
0.104407E+05	-0.874097E+04	0.310768E+04	0.000000E+00	0.927698E+04	0.947162E+02	0.270000E+03	0.676938E-04
0.107962E+05	-0.937159E+04	0.869779E+03	0.000000E+00	0.941186E+04	0.948454E+02	0.270000E+03	0.661687E-04
0.111642E+05	-0.943259E+04	-0.150975E+04	0.000000E+00	0.955265E+04	0.948525E+02	0.270000E+03	0.646422E-04
0.115447E+05	-0.888424E+04	-0.388077E+04	0.000000E+00	0.969485E+04	0.947308E+02	0.270000E+03	0.631587E-04
0.119252E+05	-0.777271E+04	-0.601681E+04	0.000000E+00	0.982940E+04	0.944935E+02	0.270000E+03	0.618019E-04
0.123143E+05	-0.614534E+04	-0.783228E+04	0.000000E+00	0.995539E+04	0.941541E+02	0.270000E+03	0.605664E-04
0.127176E+05	-0.405739E+04	-0.921715E+04	0.000000E+00	0.100707E+05	0.937279E+02	0.270000E+03	0.594579E-04
0.131208E+05	-0.170387E+04	-0.100245E+05	0.000000E+00	0.101683E+05	0.932598E+02	0.270000E+03	0.585253E-04
0.135277E+05	0.785930E+03	-0.102178E+05	0.000000E+00	0.102480E+05	0.927796E+02	0.270000E+03	0.577531E-04
0.139453E+05	0.330035E+04	-0.976779E+04	0.000000E+00	0.103103E+05	0.923140E+02	0.270000E+03	0.571183E-04
0.143628E+05	0.561634E+04	-0.869848E+04	0.000000E+00	0.103541E+05	0.919087E+02	0.270000E+03	0.566169E-04
0.147810E+05	0.759353E+04	-0.707938E+04	0.000000E+00	0.103817E+05	0.915906E+02	0.270000E+03	0.562163E-04
0.152033E+05	0.911937E+04	-0.499204E+04	0.000000E+00	0.103963E+05	0.913807E+02	0.270000E+03	0.558783E-04
0.156256E+05	0.100762E+05	-0.258187E+04	0.000000E+00	0.104017E+05	0.912973E+02	0.270000E+03	0.555678E-04
0.160479E+05	0.104024E+05	0.728616E-11	0.000000E+00	0.104024E+05	0.913462E+02	0.270000E+03	0.552452E-04

rev 3

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.160479E+05	0.104024E+05	-0.655754E-11	0.000000E+00	0.104024E+05	0.905514E+02	0.270000E+03	0.450596E-04
0.164708E+05	0.100745E+05	0.259422E+04	0.000000E+00	0.104031E+05	0.906514E+02	0.270000E+03	0.449714E-04
0.168937E+05	0.911018E+04	0.503282E+04	0.000000E+00	0.104079E+05	0.908474E+02	0.270000E+03	0.448431E-04
0.173166E+05	0.756925E+04	0.716199E+04	0.000000E+00	0.104205E+05	0.911264E+02	0.270000E+03	0.446562E-04
0.177431E+05	0.552980E+04	0.886052E+04	0.000000E+00	0.104445E+05	0.914751E+02	0.270000E+03	0.443945E-04
0.181701E+05	0.313054E+04	0.100039E+05	0.000000E+00	0.104823E+05	0.918713E+02	0.270000E+03	0.440500E-04
0.185971E+05	0.526998E+03	0.105224E+05	0.000000E+00	0.105356E+05	0.922906E+02	0.270000E+03	0.436205E-04
0.190336E+05	-0.217570E+04	0.103810E+05	0.000000E+00	0.106065E+05	0.927175E+02	0.270000E+03	0.430973E-04
0.194733E+05	-0.476720E+04	0.957289E+04	0.000000E+00	0.106942E+05	0.931205E+02	0.270000E+03	0.424946E-04
0.199130E+05	-0.706811E+04	0.816139E+04	0.000000E+00	0.107966E+05	0.934735E+02	0.270000E+03	0.418309E-04
0.203666E+05	-0.899646E+04	0.618035E+04	0.000000E+00	0.109148E+05	0.937657E+02	0.270000E+03	0.411022E-04
0.208284E+05	-0.103857E+05	0.375814E+04	0.000000E+00	0.110447E+05	0.939727E+02	0.270000E+03	0.403364E-04
0.212903E+05	-0.111268E+05	0.109125E+04	0.000000E+00	0.111802E+05	0.940800E+02	0.270000E+03	0.395692E-04
0.217657E+05	-0.111879E+05	-0.173111E+04	0.000000E+00	0.113210E+05	0.940848E+02	0.270000E+03	0.388002E-04
0.222548E+05	-0.105291E+05	-0.453109E+04	0.000000E+00	0.114626E+05	0.939821E+02	0.270000E+03	0.380510E-04
0.227438E+05	-0.920379E+04	-0.705522E+04	0.000000E+00	0.115968E+05	0.937825E+02	0.270000E+03	0.373603E-04
0.232421E+05	-0.727284E+04	-0.919314E+04	0.000000E+00	0.117221E+05	0.934977E+02	0.270000E+03	0.367287E-04
0.237557E+05	-0.481066E+04	-0.108145E+05	0.000000E+00	0.118362E+05	0.931409E+02	0.270000E+03	0.361606E-04
0.242693E+05	-0.203574E+04	-0.117581E+05	0.000000E+00	0.119330E+05	0.927473E+02	0.270000E+03	0.356786E-04
0.247868E+05	0.896003E+03	-0.119785E+05	0.000000E+00	0.120120E+05	0.923419E+02	0.270000E+03	0.352773E-04
0.253157E+05	0.384474E+04	-0.114449E+05	0.000000E+00	0.120734E+05	0.919474E+02	0.270000E+03	0.349468E-04
0.258446E+05	0.656073E+04	-0.101869E+05	0.000000E+00	0.121167E+05	0.916001E+02	0.270000E+03	0.346850E-04
0.263742E+05	0.887841E+04	-0.828563E+04	0.000000E+00	0.121440E+05	0.913227E+02	0.270000E+03	0.344769E-04
0.269081E+05	0.106638E+05	-0.584073E+04	0.000000E+00	0.121585E+05	0.911333E+02	0.270000E+03	0.343041E-04
0.274421E+05	0.117831E+05	-0.301988E+04	0.000000E+00	0.121639E+05	0.910475E+02	0.270000E+03	0.341491E-04
0.279761E+05	0.121646E+05	0.937697E-11	0.000000E+00	0.121646E+05	0.910707E+02	0.270000E+03	0.339923E-04

rev 4

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.279761E+05	0.121646E+05	-0.852164E-11	0.000000E+00	0.121646E+05	0.905001E+02	0.270000E+03	0.285623E-04
0.285108E+05	0.117813E+05	0.303236E+04	0.000000E+00	0.121653E+05	0.905819E+02	0.270000E+03	0.285104E-04
0.290455E+05	0.106545E+05	0.588168E+04	0.000000E+00	0.121702E+05	0.907472E+02	0.270000E+03	0.284376E-04
0.295801E+05	0.885404E+04	0.836838E+04	0.000000E+00	0.121829E+05	0.909851E+02	0.270000E+03	0.283336E-04
0.301187E+05	0.647414E+04	0.103489E+05	0.000000E+00	0.122071E+05	0.912836E+02	0.270000E+03	0.281892E-04
0.306578E+05	0.367498E+04	0.116808E+05	0.000000E+00	0.122453E+05	0.916240E+02	0.270000E+03	0.279997E-04
0.311970E+05	0.637258E+03	0.122826E+05	0.000000E+00	0.122991E+05	0.919851E+02	0.270000E+03	0.277633E-04
0.317465E+05	-0.250705E+04	0.121139E+05	0.000000E+00	0.123706E+05	0.923524E+02	0.270000E+03	0.274758E-04
0.322995E+05	-0.551958E+04	0.111695E+05	0.000000E+00	0.124589E+05	0.926994E+02	0.270000E+03	0.271439E-04

0.328525E+05	-0.819434E+04	0.952147E+04	0.000000E+00	0.125621E+05	0.930037E+02	0.270000E+03	0.267771E-04
0.334205E+05	-0.104259E+05	0.721812E+04	0.000000E+00	0.126808E+05	0.932548E+02	0.270000E+03	0.263743E-04
0.339974E+05	-0.120287E+05	0.440813E+04	0.000000E+00	0.128110E+05	0.934324E+02	0.270000E+03	0.259501E-04
0.345744E+05	-0.128802E+05	0.131259E+04	0.000000E+00	0.129469E+05	0.935243E+02	0.270000E+03	0.255230E-04
0.351660E+05	-0.129412E+05	-0.195231E+04	0.000000E+00	0.130877E+05	0.935277E+02	0.270000E+03	0.250943E-04
0.357722E+05	-0.121721E+05	-0.518100E+04	0.000000E+00	0.132289E+05	0.934389E+02	0.270000E+03	0.246759E-04
0.363784E+05	-0.106333E+05	-0.809298E+04	0.000000E+00	0.133628E+05	0.932666E+02	0.270000E+03	0.242880E-04
0.369945E+05	-0.839911E+04	-0.105532E+05	0.000000E+00	0.134876E+05	0.930210E+02	0.270000E+03	0.239322E-04
0.376270E+05	-0.556309E+04	-0.124112E+05	0.000000E+00	0.136009E+05	0.927140E+02	0.270000E+03	0.236116E-04
0.382595E+05	-0.236716E+04	-0.134910E+05	0.000000E+00	0.136971E+05	0.923742E+02	0.270000E+03	0.233381E-04
0.388960E+05	0.100619E+04	-0.137386E+05	0.000000E+00	0.137754E+05	0.920232E+02	0.270000E+03	0.231094E-04
0.395447E+05	0.438914E+04	-0.131217E+05	0.000000E+00	0.138364E+05	0.916808E+02	0.270000E+03	0.229209E-04
0.401934E+05	0.750505E+04	-0.116751E+05	0.000000E+00	0.138793E+05	0.913771E+02	0.270000E+03	0.227713E-04
0.408428E+05	0.101632E+05	-0.949192E+04	0.000000E+00	0.139064E+05	0.911318E+02	0.270000E+03	0.226528E-04
0.414969E+05	0.122081E+05	-0.668950E+04	0.000000E+00	0.139207E+05	0.909607E+02	0.270000E+03	0.225555E-04
0.421510E+05	0.134899E+05	-0.345796E+04	0.000000E+00	0.139261E+05	0.908774E+02	0.270000E+03	0.224698E-04
0.428052E+05	0.139268E+05	0.795142E-11	0.000000E+00	0.139268E+05	0.908868E+02	0.270000E+03	0.223848E-04

rev 5

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.428052E+05	0.139268E+05	-0.776134E-11	0.000000E+00	0.139268E+05	0.904567E+02	0.270000E+03	0.192302E-04
0.434600E+05	0.134882E+05	0.347052E+04	0.000000E+00	0.139275E+05	0.905253E+02	0.270000E+03	0.191978E-04
0.441148E+05	0.121988E+05	0.673058E+04	0.000000E+00	0.139324E+05	0.906681E+02	0.270000E+03	0.191534E-04
0.447696E+05	0.101388E+05	0.957477E+04	0.000000E+00	0.139453E+05	0.908752E+02	0.270000E+03	0.190910E-04
0.454287E+05	0.741842E+04	0.118371E+05	0.000000E+00	0.139696E+05	0.911361E+02	0.270000E+03	0.190050E-04
0.460884E+05	0.421941E+04	0.133575E+05	0.000000E+00	0.140081E+05	0.914343E+02	0.270000E+03	0.188923E-04
0.467481E+05	0.747572E+03	0.140424E+05	0.000000E+00	0.140623E+05	0.917514E+02	0.270000E+03	0.187517E-04
0.474189E+05	-0.283817E+04	0.138463E+05	0.000000E+00	0.141342E+05	0.920737E+02	0.270000E+03	0.185809E-04
0.480935E+05	-0.627150E+04	0.127657E+05	0.000000E+00	0.142230E+05	0.923785E+02	0.270000E+03	0.183834E-04
0.487681E+05	-0.931988E+04	0.108810E+05	0.000000E+00	0.143268E+05	0.926459E+02	0.270000E+03	0.181645E-04
0.494587E+05	-0.118545E+05	0.825541E+04	0.000000E+00	0.144458E+05	0.928662E+02	0.270000E+03	0.179241E-04
0.501589E+05	-0.136706E+05	0.505784E+04	0.000000E+00	0.145763E+05	0.930218E+02	0.270000E+03	0.176704E-04
0.508592E+05	-0.146323E+05	0.153390E+04	0.000000E+00	0.147125E+05	0.931021E+02	0.270000E+03	0.174141E-04
0.515750E+05	-0.146934E+05	-0.217334E+04	0.000000E+00	0.148533E+05	0.931048E+02	0.270000E+03	0.171565E-04
0.523065E+05	-0.138141E+05	-0.583056E+04	0.000000E+00	0.149942E+05	0.930265E+02	0.270000E+03	0.169048E-04
0.530379E+05	-0.120620E+05	-0.913025E+04	0.000000E+00	0.151279E+05	0.928749E+02	0.270000E+03	0.166704E-04
0.537798E+05	-0.952466E+04	-0.119128E+05	0.000000E+00	0.152523E+05	0.926590E+02	0.270000E+03	0.164549E-04
0.545391E+05	-0.631498E+04	-0.140073E+05	0.000000E+00	0.153650E+05	0.923894E+02	0.270000E+03	0.162604E-04
0.552983E+05	-0.269822E+04	-0.152234E+05	0.000000E+00	0.154607E+05	0.920904E+02	0.270000E+03	0.160939E-04
0.560619E+05	0.111657E+04	-0.154985E+05	0.000000E+00	0.155386E+05	0.917808E+02	0.270000E+03	0.159542E-04
0.568383E+05	0.493364E+04	-0.147984E+05	0.000000E+00	0.155991E+05	0.914784E+02	0.270000E+03	0.158390E-04
0.576147E+05	0.844938E+04	-0.131633E+05	0.000000E+00	0.156417E+05	0.912086E+02	0.270000E+03	0.157475E-04
0.583918E+05	0.114479E+05	-0.106982E+05	0.000000E+00	0.156687E+05	0.909889E+02	0.270000E+03	0.156752E-04
0.591739E+05	0.137524E+05	-0.753831E+04	0.000000E+00	0.156830E+05	0.908335E+02	0.270000E+03	0.156163E-04
0.599560E+05	0.151968E+05	-0.389608E+04	0.000000E+00	0.156883E+05	0.907543E+02	0.270000E+03	0.155651E-04
0.607381E+05	0.156890E+05	0.106125E-10	0.000000E+00	0.156890E+05	0.907557E+02	0.270000E+03	0.155152E-04

rev 6

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.607381E+05	0.156890E+05	-0.956705E-11	0.000000E+00	0.156890E+05	0.904198E+02	0.270000E+03	0.135590E-04
0.615210E+05	0.151950E+05	0.390870E+04	0.000000E+00	0.156897E+05	0.904786E+02	0.270000E+03	0.135378E-04
0.623038E+05	0.137431E+05	0.757948E+04	0.000000E+00	0.156946E+05	0.906040E+02	0.270000E+03	0.135093E-04
0.630867E+05	0.114235E+05	0.107811E+05	0.000000E+00	0.157076E+05	0.907873E+02	0.270000E+03	0.134696E-04
0.638741E+05	0.836272E+04	0.133253E+05	0.000000E+00	0.157321E+05	0.910189E+02	0.270000E+03	0.134152E-04
0.646621E+05	0.476393E+04	0.150341E+05	0.000000E+00	0.157708E+05	0.912843E+02	0.270000E+03	0.133441E-04
0.654502E+05	0.858050E+03	0.158021E+05	0.000000E+00	0.158253E+05	0.915669E+02	0.270000E+03	0.132553E-04
0.662501E+05	-0.316898E+04	0.155785E+05	0.000000E+00	0.158975E+05	0.918541E+02	0.270000E+03	0.131475E-04
0.670540E+05	-0.702295E+04	0.143615E+05	0.000000E+00	0.159867E+05	0.921257E+02	0.270000E+03	0.130228E-04

0.678580E+05	-0.104448E+05	0.122402E+05	0.000000E+00	0.160909E+05	0.923644E+02	0.270000E+03	0.128842E-04
0.686790E+05	-0.132824E+05	0.929244E+04	0.000000E+00	0.162102E+05	0.925606E+02	0.270000E+03	0.127319E-04
0.695102E+05	-0.153118E+05	0.570729E+04	0.000000E+00	0.163409E+05	0.926991E+02	0.270000E+03	0.125711E-04
0.703414E+05	-0.163836E+05	0.175493E+04	0.000000E+00	0.164774E+05	0.927705E+02	0.270000E+03	0.124080E-04
0.711891E+05	-0.164447E+05	-0.239453E+04	0.000000E+00	0.166182E+05	0.927727E+02	0.270000E+03	0.122440E-04
0.720533E+05	-0.154553E+05	-0.648003E+04	0.000000E+00	0.167588E+05	0.927027E+02	0.270000E+03	0.120836E-04
0.729175E+05	-0.134900E+05	-0.101672E+05	0.000000E+00	0.168923E+05	0.925673E+02	0.270000E+03	0.119337E-04
0.737927E+05	-0.106498E+05	-0.132719E+05	0.000000E+00	0.170165E+05	0.923746E+02	0.270000E+03	0.117957E-04
0.746862E+05	-0.706661E+04	-0.156030E+05	0.000000E+00	0.171287E+05	0.921343E+02	0.270000E+03	0.116710E-04
0.755798E+05	-0.302919E+04	-0.169555E+05	0.000000E+00	0.172240E+05	0.918672E+02	0.270000E+03	0.115638E-04
0.764778E+05	0.122693E+04	-0.172580E+05	0.000000E+00	0.173016E+05	0.915902E+02	0.270000E+03	0.114738E-04
0.773893E+05	0.547810E+04	-0.164748E+05	0.000000E+00	0.173617E+05	0.913194E+02	0.270000E+03	0.113995E-04
0.783008E+05	0.939367E+04	-0.146514E+05	0.000000E+00	0.174041E+05	0.910768E+02	0.270000E+03	0.113404E-04
0.792131E+05	0.127327E+05	-0.119045E+05	0.000000E+00	0.174310E+05	0.908781E+02	0.270000E+03	0.112939E-04
0.801306E+05	0.152967E+05	-0.838716E+04	0.000000E+00	0.174452E+05	0.907359E+02	0.270000E+03	0.112562E-04
0.810481E+05	0.169036E+05	-0.433422E+04	0.000000E+00	0.174505E+05	0.906612E+02	0.270000E+03	0.112238E-04
0.819656E+05	0.174512E+05	0.122281E-10	0.000000E+00	0.174512E+05	0.906579E+02	0.270000E+03	0.111926E-04

rev 7

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.819656E+05	0.174512E+05	-0.128300E-10	0.000000E+00	0.174512E+05	0.903881E+02	0.270000E+03	0.991588E-05
0.828839E+05	0.169019E+05	0.434689E+04	0.000000E+00	0.174519E+05	0.904394E+02	0.270000E+03	0.990138E-05
0.838022E+05	0.152874E+05	0.842838E+04	0.000000E+00	0.174569E+05	0.905511E+02	0.270000E+03	0.988224E-05
0.847205E+05	0.127081E+05	0.119875E+05	0.000000E+00	0.174699E+05	0.907154E+02	0.270000E+03	0.985579E-05
0.856437E+05	0.930698E+04	0.148134E+05	0.000000E+00	0.174945E+05	0.909236E+02	0.270000E+03	0.981974E-05
0.865675E+05	0.530838E+04	0.167105E+05	0.000000E+00	0.175334E+05	0.911626E+02	0.270000E+03	0.977268E-05
0.874912E+05	0.968435E+03	0.175615E+05	0.000000E+00	0.175882E+05	0.914176E+02	0.270000E+03	0.971394E-05
0.884277E+05	-0.349982E+04	0.173104E+05	0.000000E+00	0.176606E+05	0.916765E+02	0.270000E+03	0.964261E-05
0.893683E+05	-0.777432E+04	0.159570E+05	0.000000E+00	0.177501E+05	0.919216E+02	0.270000E+03	0.955997E-05
0.903089E+05	-0.115696E+05	0.135991E+05	0.000000E+00	0.178547E+05	0.921371E+02	0.270000E+03	0.946798E-05
0.912675E+05	-0.147099E+05	0.103292E+05	0.000000E+00	0.179743E+05	0.923140E+02	0.270000E+03	0.936693E-05
0.922369E+05	-0.169524E+05	0.635663E+04	0.000000E+00	0.181050E+05	0.924387E+02	0.270000E+03	0.926005E-05
0.932063E+05	-0.181344E+05	0.197610E+04	0.000000E+00	0.182417E+05	0.925031E+02	0.270000E+03	0.915143E-05
0.941931E+05	-0.181955E+05	-0.261547E+04	0.000000E+00	0.183825E+05	0.925049E+02	0.270000E+03	0.904213E-05
0.951972E+05	-0.170960E+05	-0.712928E+04	0.000000E+00	0.185230E+05	0.924416E+02	0.270000E+03	0.893510E-05
0.962013E+05	-0.149175E+05	-0.112039E+05	0.000000E+00	0.186563E+05	0.923193E+02	0.270000E+03	0.883483E-05
0.972170E+05	-0.117745E+05	-0.146308E+05	0.000000E+00	0.187803E+05	0.921453E+02	0.270000E+03	0.874234E-05
0.982518E+05	-0.781790E+04	-0.171986E+05	0.000000E+00	0.188921E+05	0.919284E+02	0.270000E+03	0.865876E-05
0.992867E+05	-0.335993E+04	-0.186874E+05	0.000000E+00	0.189871E+05	0.916871E+02	0.270000E+03	0.858674E-05
0.100326E+06	0.133741E+04	-0.190175E+05	0.000000E+00	0.190644E+05	0.914365E+02	0.270000E+03	0.852612E-05
0.101380E+06	0.602262E+04	-0.181512E+05	0.000000E+00	0.191243E+05	0.911912E+02	0.270000E+03	0.847608E-05
0.102434E+06	0.103380E+05	-0.161395E+05	0.000000E+00	0.191665E+05	0.909709E+02	0.270000E+03	0.843628E-05
0.103488E+06	0.140174E+05	-0.131108E+05	0.000000E+00	0.191932E+05	0.907895E+02	0.270000E+03	0.840492E-05
0.104548E+06	0.168410E+05	-0.923603E+04	0.000000E+00	0.192074E+05	0.906588E+02	0.270000E+03	0.837971E-05
0.105608E+06	0.186105E+05	-0.477239E+04	0.000000E+00	0.192127E+05	0.905885E+02	0.270000E+03	0.835822E-05
0.106668E+06	0.192134E+05	0.131784E-10	0.000000E+00	0.192134E+05	0.905821E+02	0.270000E+03	0.833770E-05

rev 8

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.106668E+06	0.192134E+05	-0.119113E-10	0.000000E+00	0.192134E+05	0.903607E+02	0.270000E+03	0.746941E-05
0.107729E+06	0.186088E+05	0.478509E+04	0.000000E+00	0.192141E+05	0.904060E+02	0.270000E+03	0.745918E-05
0.108789E+06	0.168317E+05	0.927729E+04	0.000000E+00	0.192191E+05	0.905067E+02	0.270000E+03	0.744585E-05
0.109850E+06	0.139928E+05	0.131938E+05	0.000000E+00	0.192321E+05	0.906555E+02	0.270000E+03	0.742757E-05
0.110916E+06	0.102513E+05	0.163015E+05	0.000000E+00	0.192569E+05	0.908445E+02	0.270000E+03	0.740274E-05
0.111983E+06	0.585288E+04	0.183868E+05	0.000000E+00	0.192959E+05	0.910620E+02	0.270000E+03	0.737037E-05
0.113049E+06	0.107891E+04	0.193208E+05	0.000000E+00	0.193509E+05	0.912942E+02	0.270000E+03	0.732995E-05
0.114129E+06	-0.383049E+04	0.190421E+05	0.000000E+00	0.194236E+05	0.915299E+02	0.270000E+03	0.728090E-05
0.115213E+06	-0.852546E+04	0.175523E+05	0.000000E+00	0.195133E+05	0.917532E+02	0.270000E+03	0.722401E-05

0.116298E+06	-0.126940E+05	0.149578E+05	0.000000E+00	0.196182E+05	0.919496E+02	0.270000E+03	0.716058E-05
0.117401E+06	-0.161371E+05	0.113657E+05	0.000000E+00	0.197379E+05	0.921108E+02	0.270000E+03	0.709091E-05
0.118515E+06	-0.185927E+05	0.700580E+04	0.000000E+00	0.198688E+05	0.922243E+02	0.270000E+03	0.701714E-05
0.119630E+06	-0.198847E+05	0.219706E+04	0.000000E+00	0.200057E+05	0.922828E+02	0.270000E+03	0.694201E-05
0.120762E+06	-0.199458E+05	-0.283657E+04	0.000000E+00	0.201465E+05	0.922843E+02	0.270000E+03	0.686637E-05
0.121913E+06	-0.187363E+05	-0.777853E+04	0.000000E+00	0.202868E+05	0.922266E+02	0.270000E+03	0.679225E-05
0.123064E+06	-0.163447E+05	-0.122405E+05	0.000000E+00	0.204200E+05	0.921150E+02	0.270000E+03	0.672265E-05
0.124227E+06	-0.128989E+05	-0.159895E+05	0.000000E+00	0.205438E+05	0.919564E+02	0.270000E+03	0.665838E-05
0.125410E+06	-0.856902E+04	-0.187939E+05	0.000000E+00	0.206552E+05	0.917588E+02	0.270000E+03	0.660027E-05
0.126593E+06	-0.369058E+04	-0.204192E+05	0.000000E+00	0.207500E+05	0.915387E+02	0.270000E+03	0.655009E-05
0.127781E+06	0.144792E+04	-0.207768E+05	0.000000E+00	0.208271E+05	0.913099E+02	0.270000E+03	0.650780E-05
0.128983E+06	0.656714E+04	-0.198275E+05	0.000000E+00	0.208868E+05	0.910857E+02	0.270000E+03	0.647288E-05
0.130186E+06	0.112822E+05	-0.176275E+05	0.000000E+00	0.209289E+05	0.908839E+02	0.270000E+03	0.644509E-05
0.131389E+06	0.153020E+05	-0.143171E+05	0.000000E+00	0.209555E+05	0.907172E+02	0.270000E+03	0.642323E-05
0.132598E+06	0.183853E+05	-0.100849E+05	0.000000E+00	0.209696E+05	0.905962E+02	0.270000E+03	0.640572E-05
0.133807E+06	0.203174E+05	-0.521057E+04	0.000000E+00	0.209749E+05	0.905300E+02	0.270000E+03	0.639091E-05
0.135016E+06	0.209756E+05	0.139387E-10	0.000000E+00	0.209756E+05	0.905218E+02	0.270000E+03	0.637689E-05

rev 9

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.135016E+06	0.209756E+05	-0.141922E-10	0.000000E+00	0.209756E+05	0.903368E+02	0.270000E+03	0.576594E-05
0.136226E+06	0.203156E+05	0.522329E+04	0.000000E+00	0.209763E+05	0.903773E+02	0.270000E+03	0.575853E-05
0.137436E+06	0.183759E+05	0.101262E+05	0.000000E+00	0.209813E+05	0.904689E+02	0.270000E+03	0.574896E-05
0.138646E+06	0.152775E+05	0.144001E+05	0.000000E+00	0.209944E+05	0.906049E+02	0.270000E+03	0.573592E-05
0.139861E+06	0.111955E+05	0.177895E+05	0.000000E+00	0.210192E+05	0.907780E+02	0.270000E+03	0.571827E-05
0.141077E+06	0.639740E+04	0.200631E+05	0.000000E+00	0.210584E+05	0.909774E+02	0.270000E+03	0.569528E-05
0.142293E+06	0.118944E+04	0.210800E+05	0.000000E+00	0.211136E+05	0.911905E+02	0.270000E+03	0.566657E-05
0.143523E+06	-0.416105E+04	0.207738E+05	0.000000E+00	0.211864E+05	0.914070E+02	0.270000E+03	0.563173E-05
0.144758E+06	-0.927640E+04	0.191476E+05	0.000000E+00	0.212763E+05	0.916120E+02	0.270000E+03	0.559130E-05
0.145992E+06	-0.138182E+05	0.163164E+05	0.000000E+00	0.213815E+05	0.917925E+02	0.270000E+03	0.554616E-05
0.147247E+06	-0.175640E+05	0.124022E+05	0.000000E+00	0.215014E+05	0.919404E+02	0.270000E+03	0.549657E-05
0.148513E+06	-0.202327E+05	0.765496E+04	0.000000E+00	0.216324E+05	0.920445E+02	0.270000E+03	0.544403E-05
0.149779E+06	-0.216347E+05	0.241806E+04	0.000000E+00	0.217694E+05	0.920982E+02	0.270000E+03	0.539042E-05
0.151064E+06	-0.216958E+05	-0.305756E+04	0.000000E+00	0.219102E+05	0.920995E+02	0.270000E+03	0.533642E-05
0.152368E+06	-0.203763E+05	-0.842762E+04	0.000000E+00	0.220503E+05	0.920465E+02	0.270000E+03	0.528347E-05
0.153672E+06	-0.177716E+05	-0.132769E+05	0.000000E+00	0.221835E+05	0.919439E+02	0.270000E+03	0.523366E-05
0.154989E+06	-0.140232E+05	-0.173480E+05	0.000000E+00	0.223071E+05	0.917981E+02	0.270000E+03	0.518762E-05
0.156326E+06	-0.932007E+04	-0.203891E+05	0.000000E+00	0.224183E+05	0.916166E+02	0.270000E+03	0.514598E-05
0.157664E+06	-0.402119E+04	-0.221508E+05	0.000000E+00	0.225128E+05	0.914143E+02	0.270000E+03	0.510995E-05
0.159006E+06	0.155842E+04	-0.225360E+05	0.000000E+00	0.225898E+05	0.912037E+02	0.270000E+03	0.507955E-05
0.160364E+06	0.711164E+04	-0.215038E+05	0.000000E+00	0.226492E+05	0.909974E+02	0.270000E+03	0.505445E-05
0.161722E+06	0.122265E+05	-0.191155E+05	0.000000E+00	0.226912E+05	0.908113E+02	0.270000E+03	0.503447E-05
0.163080E+06	0.165867E+05	-0.155234E+05	0.000000E+00	0.227177E+05	0.906569E+02	0.270000E+03	0.501876E-05
0.164445E+06	0.199295E+05	-0.109338E+05	0.000000E+00	0.227318E+05	0.905445E+02	0.270000E+03	0.500623E-05
0.165809E+06	0.220242E+05	-0.564877E+04	0.000000E+00	0.227371E+05	0.904821E+02	0.270000E+03	0.499569E-05
0.167174E+06	0.227378E+05	0.125449E-10	0.000000E+00	0.227378E+05	0.904727E+02	0.270000E+03	0.498579E-05

rev 10

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.167174E+06	0.227378E+05	-0.162196E-10	0.000000E+00	0.227378E+05	0.903158E+02	0.270000E+03	0.454351E-05
0.168540E+06	0.220224E+05	0.566150E+04	0.000000E+00	0.227385E+05	0.903523E+02	0.270000E+03	0.453801E-05
0.169905E+06	0.199202E+05	0.109751E+05	0.000000E+00	0.227435E+05	0.904363E+02	0.270000E+03	0.453097E-05
0.171271E+06	0.165621E+05	0.156065E+05	0.000000E+00	0.227567E+05	0.905616E+02	0.270000E+03	0.452142E-05
0.172642E+06	0.121398E+05	0.192775E+05	0.000000E+00	0.227815E+05	0.907211E+02	0.270000E+03	0.450853E-05
0.174013E+06	0.694194E+04	0.217393E+05	0.000000E+00	0.228208E+05	0.909053E+02	0.270000E+03	0.449175E-05
0.175385E+06	0.130000E+04	0.228392E+05	0.000000E+00	0.228761E+05	0.911023E+02	0.270000E+03	0.447080E-05
0.176772E+06	-0.449156E+04	0.225053E+05	0.000000E+00	0.229491E+05	0.913023E+02	0.270000E+03	0.444538E-05
0.178163E+06	-0.100273E+05	0.207427E+05	0.000000E+00	0.230392E+05	0.914918E+02	0.270000E+03	0.441586E-05

0.179554E+06	-0.149423E+05	0.176748E+05	0.000000E+00	0.231446E+05	0.916587E+02	0.270000E+03	0.438287E-05
0.180966E+06	-0.189907E+05	0.134386E+05	0.000000E+00	0.232647E+05	0.917955E+02	0.270000E+03	0.434662E-05
0.182390E+06	-0.218724E+05	0.830405E+04	0.000000E+00	0.233957E+05	0.918917E+02	0.270000E+03	0.430819E-05
0.183814E+06	-0.233844E+05	0.263911E+04	0.000000E+00	0.235328E+05	0.919413E+02	0.270000E+03	0.426891E-05
0.185258E+06	-0.234455E+05	-0.327847E+04	0.000000E+00	0.236736E+05	0.919424E+02	0.270000E+03	0.422934E-05
0.186721E+06	-0.220160E+05	-0.907663E+04	0.000000E+00	0.238137E+05	0.918933E+02	0.270000E+03	0.419051E-05
0.188185E+06	-0.191984E+05	-0.143133E+05	0.000000E+00	0.239468E+05	0.917984E+02	0.270000E+03	0.415393E-05
0.189661E+06	-0.151474E+05	-0.187065E+05	0.000000E+00	0.240702E+05	0.916635E+02	0.270000E+03	0.412009E-05
0.191159E+06	-0.100710E+05	-0.219842E+05	0.000000E+00	0.241812E+05	0.914957E+02	0.270000E+03	0.408947E-05
0.192658E+06	-0.435175E+04	-0.238823E+05	0.000000E+00	0.242755E+05	0.913085E+02	0.270000E+03	0.406294E-05
0.194161E+06	0.166893E+04	-0.242951E+05	0.000000E+00	0.243524E+05	0.911135E+02	0.270000E+03	0.404053E-05
0.195680E+06	0.765615E+04	-0.231800E+05	0.000000E+00	0.244116E+05	0.909223E+02	0.270000E+03	0.402203E-05
0.197200E+06	0.131708E+05	-0.206035E+05	0.000000E+00	0.244535E+05	0.907496E+02	0.270000E+03	0.400730E-05
0.198720E+06	0.178713E+05	-0.167298E+05	0.000000E+00	0.244800E+05	0.906060E+02	0.270000E+03	0.399573E-05
0.200246E+06	0.214738E+05	-0.117827E+05	0.000000E+00	0.244940E+05	0.905010E+02	0.270000E+03	0.398652E-05
0.201772E+06	0.237310E+05	-0.608697E+04	0.000000E+00	0.244993E+05	0.904421E+02	0.270000E+03	0.397882E-05
0.203298E+06	0.245000E+05	0.153326E-10	0.000000E+00	0.245000E+05	0.904320E+02	0.270000E+03	0.397163E-05

rev 11

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.203298E+06	0.245000E+05	-0.152059E-10	0.000000E+00	0.245000E+05	0.902973E+02	0.270000E+03	0.364362E-05
0.204826E+06	0.237293E+05	0.609971E+04	0.000000E+00	0.245007E+05	0.903305E+02	0.270000E+03	0.363945E-05
0.206353E+06	0.214644E+05	0.118240E+05	0.000000E+00	0.245057E+05	0.904080E+02	0.270000E+03	0.363415E-05
0.207880E+06	0.178468E+05	0.168128E+05	0.000000E+00	0.245189E+05	0.905240E+02	0.270000E+03	0.362700E-05
0.209413E+06	0.130841E+05	0.207655E+05	0.000000E+00	0.245438E+05	0.906720E+02	0.270000E+03	0.361737E-05
0.210947E+06	0.748647E+04	0.234155E+05	0.000000E+00	0.245832E+05	0.908431E+02	0.270000E+03	0.360484E-05
0.212481E+06	0.141058E+04	0.245983E+05	0.000000E+00	0.246387E+05	0.910262E+02	0.270000E+03	0.358920E-05
0.214030E+06	-0.482204E+04	0.242368E+05	0.000000E+00	0.247118E+05	0.912121E+02	0.270000E+03	0.357022E-05
0.215584E+06	-0.107781E+05	0.223377E+05	0.000000E+00	0.248020E+05	0.913883E+02	0.270000E+03	0.354817E-05
0.217137E+06	-0.160664E+05	0.190331E+05	0.000000E+00	0.249076E+05	0.915436E+02	0.270000E+03	0.352350E-05
0.218713E+06	-0.204174E+05	0.144748E+05	0.000000E+00	0.250278E+05	0.916707E+02	0.270000E+03	0.349639E-05
0.220301E+06	-0.235120E+05	0.895306E+04	0.000000E+00	0.251589E+05	0.917602E+02	0.270000E+03	0.346763E-05
0.221889E+06	-0.251339E+05	0.286010E+04	0.000000E+00	0.252961E+05	0.918062E+02	0.270000E+03	0.343820E-05
0.223498E+06	-0.251951E+05	-0.349940E+04	0.000000E+00	0.254369E+05	0.918072E+02	0.270000E+03	0.340854E-05
0.225127E+06	-0.236556E+05	-0.972565E+04	0.000000E+00	0.255769E+05	0.917615E+02	0.270000E+03	0.337943E-05
0.226756E+06	-0.206250E+05	-0.153496E+05	0.000000E+00	0.257099E+05	0.916731E+02	0.270000E+03	0.335196E-05
0.228398E+06	-0.162713E+05	-0.200649E+05	0.000000E+00	0.258332E+05	0.915477E+02	0.270000E+03	0.332653E-05
0.230063E+06	-0.108218E+05	-0.235792E+05	0.000000E+00	0.259440E+05	0.913916E+02	0.270000E+03	0.330351E-05
0.231728E+06	-0.468226E+04	-0.256137E+05	0.000000E+00	0.260382E+05	0.912174E+02	0.270000E+03	0.328355E-05
0.233398E+06	0.177945E+04	-0.260542E+05	0.000000E+00	0.261149E+05	0.910358E+02	0.270000E+03	0.326667E-05
0.235084E+06	0.820064E+04	-0.248562E+05	0.000000E+00	0.261740E+05	0.908578E+02	0.270000E+03	0.325274E-05
0.236771E+06	0.141150E+05	-0.220915E+05	0.000000E+00	0.262158E+05	0.906967E+02	0.270000E+03	0.324163E-05
0.238459E+06	0.191560E+05	-0.179361E+05	0.000000E+00	0.262422E+05	0.905625E+02	0.270000E+03	0.323292E-05
0.240152E+06	0.230181E+05	-0.126316E+05	0.000000E+00	0.262562E+05	0.904639E+02	0.270000E+03	0.322601E-05
0.241846E+06	0.254379E+05	-0.652517E+04	0.000000E+00	0.262615E+05	0.904082E+02	0.270000E+03	0.322025E-05
0.243540E+06	0.262622E+05	0.195776E-10	0.000000E+00	0.262622E+05	0.903976E+02	0.270000E+03	0.321491E-05

rev 12

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.243540E+06	0.262622E+05	-0.151425E-10	0.000000E+00	0.262622E+05	0.902807E+02	0.270000E+03	0.296653E-05
0.245235E+06	0.254361E+05	0.653793E+04	0.000000E+00	0.262629E+05	0.903111E+02	0.270000E+03	0.296331E-05
0.246930E+06	0.230087E+05	0.126730E+05	0.000000E+00	0.262679E+05	0.903831E+02	0.270000E+03	0.295925E-05
0.248625E+06	0.191314E+05	0.180191E+05	0.000000E+00	0.262811E+05	0.904911E+02	0.270000E+03	0.295379E-05
0.250326E+06	0.140283E+05	0.222535E+05	0.000000E+00	0.263061E+05	0.906292E+02	0.270000E+03	0.294644E-05
0.252027E+06	0.803098E+04	0.250916E+05	0.000000E+00	0.263455E+05	0.907888E+02	0.270000E+03	0.293690E-05
0.253729E+06	0.152111E+04	0.263573E+05	0.000000E+00	0.264011E+05	0.909599E+02	0.270000E+03	0.292499E-05
0.255446E+06	-0.515252E+04	0.259682E+05	0.000000E+00	0.264744E+05	0.911336E+02	0.270000E+03	0.291053E-05
0.257169E+06	-0.115289E+05	0.239326E+05	0.000000E+00	0.265648E+05	0.912983E+02	0.270000E+03	0.289373E-05

0.258892E+06	-0.171903E+05	0.203914E+05	0.000000E+00	0.266705E+05	0.914434E+02	0.270000E+03	0.287492E-05
0.260636E+06	-0.218438E+05	0.155110E+05	0.000000E+00	0.267908E+05	0.915622E+02	0.270000E+03	0.285424E-05
0.262394E+06	-0.251514E+05	0.960199E+04	0.000000E+00	0.269220E+05	0.916457E+02	0.270000E+03	0.283229E-05
0.264152E+06	-0.268833E+05	0.308099E+04	0.000000E+00	0.270593E+05	0.916888E+02	0.270000E+03	0.280981E-05
0.265931E+06	-0.269444E+05	-0.372042E+04	0.000000E+00	0.272001E+05	0.916897E+02	0.270000E+03	0.278714E-05
0.267731E+06	-0.252950E+05	-0.103747E+05	0.000000E+00	0.273399E+05	0.916469E+02	0.270000E+03	0.276488E-05
0.269532E+06	-0.220514E+05	-0.163858E+05	0.000000E+00	0.274729E+05	0.915642E+02	0.270000E+03	0.274386E-05
0.271346E+06	-0.173952E+05	-0.214231E+05	0.000000E+00	0.275961E+05	0.914470E+02	0.270000E+03	0.272438E-05
0.273183E+06	-0.115725E+05	-0.251742E+05	0.000000E+00	0.277067E+05	0.913011E+02	0.270000E+03	0.270675E-05
0.275020E+06	-0.501268E+04	-0.273451E+05	0.000000E+00	0.278008E+05	0.911382E+02	0.270000E+03	0.269144E-05
0.276863E+06	0.189004E+04	-0.278132E+05	0.000000E+00	0.278773E+05	0.909683E+02	0.270000E+03	0.267849E-05
0.278723E+06	0.874519E+04	-0.265323E+05	0.000000E+00	0.279364E+05	0.908017E+02	0.270000E+03	0.266779E-05
0.280583E+06	0.150593E+05	-0.235795E+05	0.000000E+00	0.279781E+05	0.906507E+02	0.270000E+03	0.265927E-05
0.282443E+06	0.204406E+05	-0.191424E+05	0.000000E+00	0.280044E+05	0.905247E+02	0.270000E+03	0.265259E-05
0.284310E+06	0.245623E+05	-0.134806E+05	0.000000E+00	0.280184E+05	0.904320E+02	0.270000E+03	0.264730E-05
0.286178E+06	0.271447E+05	-0.696339E+04	0.000000E+00	0.280237E+05	0.903791E+02	0.270000E+03	0.264291E-05
0.288045E+06	0.280244E+05	0.197043E-10	0.000000E+00	0.280244E+05	0.903683E+02	0.270000E+03	0.263885E-05

rev 13

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.288045E+06	0.280244E+05	-0.171700E-10	0.000000E+00	0.280244E+05	0.902659E+02	0.270000E+03	0.244733E-05
0.289913E+06	0.271430E+05	0.697612E+04	0.000000E+00	0.280251E+05	0.902939E+02	0.270000E+03	0.244481E-05
0.291781E+06	0.245530E+05	0.135218E+05	0.000000E+00	0.280301E+05	0.903611E+02	0.270000E+03	0.244164E-05
0.293649E+06	0.204161E+05	0.192254E+05	0.000000E+00	0.280434E+05	0.904621E+02	0.270000E+03	0.243740E-05
0.295524E+06	0.149728E+05	0.237413E+05	0.000000E+00	0.280684E+05	0.905914E+02	0.270000E+03	0.243171E-05
0.297399E+06	0.857591E+04	0.267676E+05	0.000000E+00	0.281079E+05	0.907412E+02	0.270000E+03	0.242432E-05
0.299274E+06	0.163229E+04	0.281163E+05	0.000000E+00	0.281636E+05	0.909017E+02	0.270000E+03	0.241508E-05
0.301166E+06	-0.548207E+04	0.276997E+05	0.000000E+00	0.282369E+05	0.910646E+02	0.270000E+03	0.240388E-05
0.303063E+06	-0.122785E+05	0.255280E+05	0.000000E+00	0.283274E+05	0.912192E+02	0.270000E+03	0.239086E-05
0.304959E+06	-0.183129E+05	0.217506E+05	0.000000E+00	0.284333E+05	0.913554E+02	0.270000E+03	0.237626E-05
0.306879E+06	-0.232692E+05	0.165485E+05	0.000000E+00	0.285536E+05	0.914669E+02	0.270000E+03	0.236022E-05
0.308813E+06	-0.267901E+05	0.102526E+05	0.000000E+00	0.286849E+05	0.915453E+02	0.270000E+03	0.234318E-05
0.310746E+06	-0.286323E+05	0.330387E+04	0.000000E+00	0.288223E+05	0.915856E+02	0.270000E+03	0.232571E-05
0.312701E+06	-0.286939E+05	-0.393940E+04	0.000000E+00	0.289631E+05	0.915865E+02	0.270000E+03	0.230809E-05
0.314678E+06	-0.269350E+05	-0.110219E+05	0.000000E+00	0.291028E+05	0.915463E+02	0.270000E+03	0.229078E-05
0.316655E+06	-0.234788E+05	-0.174205E+05	0.000000E+00	0.292358E+05	0.914687E+02	0.270000E+03	0.227442E-05
0.318647E+06	-0.185202E+05	-0.227804E+05	0.000000E+00	0.293589E+05	0.913586E+02	0.270000E+03	0.225925E-05
0.320662E+06	-0.123244E+05	-0.267685E+05	0.000000E+00	0.294693E+05	0.912217E+02	0.270000E+03	0.224551E-05
0.322677E+06	-0.534404E+04	-0.290763E+05	0.000000E+00	0.295633E+05	0.910687E+02	0.270000E+03	0.223357E-05
0.324699E+06	0.199992E+04	-0.295722E+05	0.000000E+00	0.296398E+05	0.909090E+02	0.270000E+03	0.222347E-05
0.326737E+06	0.928925E+04	-0.282086E+05	0.000000E+00	0.296987E+05	0.907525E+02	0.270000E+03	0.221512E-05
0.328775E+06	0.160033E+05	-0.250676E+05	0.000000E+00	0.297403E+05	0.906104E+02	0.270000E+03	0.220847E-05
0.330815E+06	0.217251E+05	-0.203488E+05	0.000000E+00	0.297667E+05	0.904917E+02	0.270000E+03	0.220326E-05
0.332861E+06	0.261065E+05	-0.143295E+05	0.000000E+00	0.297806E+05	0.904041E+02	0.270000E+03	0.219914E-05
0.334907E+06	0.288516E+05	-0.740164E+04	0.000000E+00	0.297859E+05	0.903538E+02	0.270000E+03	0.219573E-05
0.336953E+06	0.297866E+05	0.185005E-10	0.000000E+00	0.297866E+05	0.903429E+02	0.270000E+03	0.219260E-05

rev 14

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.336953E+06	0.297866E+05	-0.193242E-10	0.000000E+00	0.297866E+05	0.902526E+02	0.270000E+03	0.204257E-05
0.339000E+06	0.288498E+05	0.741435E+04	0.000000E+00	0.297873E+05	0.902785E+02	0.270000E+03	0.204056E-05
0.341047E+06	0.260972E+05	0.143708E+05	0.000000E+00	0.297923E+05	0.903414E+02	0.270000E+03	0.203806E-05
0.343094E+06	0.217007E+05	0.204317E+05	0.000000E+00	0.298056E+05	0.904364E+02	0.270000E+03	0.203471E-05
0.345148E+06	0.159170E+05	0.252293E+05	0.000000E+00	0.298307E+05	0.905580E+02	0.270000E+03	0.203023E-05
0.347202E+06	0.912039E+04	0.284438E+05	0.000000E+00	0.298702E+05	0.906989E+02	0.270000E+03	0.202441E-05
0.349257E+06	0.174280E+04	0.298752E+05	0.000000E+00	0.299260E+05	0.908501E+02	0.270000E+03	0.201714E-05
0.351328E+06	-0.581256E+04	0.294310E+05	0.000000E+00	0.299995E+05	0.910036E+02	0.270000E+03	0.200833E-05
0.353404E+06	-0.130293E+05	0.271228E+05	0.000000E+00	0.300900E+05	0.911492E+02	0.270000E+03	0.199808E-05

0.355481E+06	-0.194368E+05	0.231087E+05	0.000000E+00	0.301960E+05	0.912776E+02	0.270000E+03	0.198658E-05
0.357581E+06	-0.246956E+05	0.175845E+05	0.000000E+00	0.303165E+05	0.913826E+02	0.270000E+03	0.197394E-05
0.359696E+06	-0.284293E+05	0.109014E+05	0.000000E+00	0.304478E+05	0.914564E+02	0.270000E+03	0.196051E-05
0.361810E+06	-0.303815E+05	0.352459E+04	0.000000E+00	0.305852E+05	0.914944E+02	0.270000E+03	0.194673E-05
0.363947E+06	-0.304430E+05	-0.416053E+04	0.000000E+00	0.307260E+05	0.914951E+02	0.270000E+03	0.193283E-05
0.366106E+06	-0.285741E+05	-0.116710E+05	0.000000E+00	0.308657E+05	0.914573E+02	0.270000E+03	0.191917E-05
0.368266E+06	-0.249050E+05	-0.184568E+05	0.000000E+00	0.309986E+05	0.913841E+02	0.270000E+03	0.190624E-05
0.370440E+06	-0.196439E+05	-0.241386E+05	0.000000E+00	0.311216E+05	0.912803E+02	0.270000E+03	0.189425E-05
0.372639E+06	-0.130749E+05	-0.283634E+05	0.000000E+00	0.312320E+05	0.911513E+02	0.270000E+03	0.188340E-05
0.374837E+06	-0.567433E+04	-0.308076E+05	0.000000E+00	0.313258E+05	0.910071E+02	0.270000E+03	0.187395E-05
0.377042E+06	0.211060E+04	-0.313312E+05	0.000000E+00	0.314022E+05	0.908566E+02	0.270000E+03	0.186595E-05
0.379264E+06	0.983385E+04	-0.298847E+05	0.000000E+00	0.314610E+05	0.907089E+02	0.270000E+03	0.185935E-05
0.381487E+06	0.169476E+05	-0.265555E+05	0.000000E+00	0.315026E+05	0.905749E+02	0.270000E+03	0.185408E-05
0.383710E+06	0.230098E+05	-0.215551E+05	0.000000E+00	0.315289E+05	0.904626E+02	0.270000E+03	0.184996E-05
0.385940E+06	0.276508E+05	-0.151785E+05	0.000000E+00	0.315428E+05	0.903796E+02	0.270000E+03	0.184670E-05
0.388171E+06	0.305584E+05	-0.783985E+04	0.000000E+00	0.315481E+05	0.903317E+02	0.270000E+03	0.184402E-05
0.390401E+06	0.315488E+05	0.173601E-10	0.000000E+00	0.315488E+05	0.903208E+02	0.270000E+03	0.184156E-05

rev 15

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.390401E+06	0.315488E+05	-0.235691E-10	0.000000E+00	0.315488E+05	0.902405E+02	0.270000E+03	0.172236E-05
0.392633E+06	0.305567E+05	0.785257E+04	0.000000E+00	0.315495E+05	0.902646E+02	0.270000E+03	0.172075E-05
0.394864E+06	0.276415E+05	0.152197E+05	0.000000E+00	0.315546E+05	0.903238E+02	0.270000E+03	0.171874E-05
0.397095E+06	0.229853E+05	0.216380E+05	0.000000E+00	0.315678E+05	0.904133E+02	0.270000E+03	0.171607E-05
0.399333E+06	0.168612E+05	0.267173E+05	0.000000E+00	0.315929E+05	0.905281E+02	0.270000E+03	0.171249E-05
0.401572E+06	0.966488E+04	0.301199E+05	0.000000E+00	0.316325E+05	0.906613E+02	0.270000E+03	0.170785E-05
0.403811E+06	0.185332E+04	0.316342E+05	0.000000E+00	0.316884E+05	0.908041E+02	0.270000E+03	0.170205E-05
0.406067E+06	-0.614300E+04	0.311622E+05	0.000000E+00	0.317619E+05	0.909492E+02	0.270000E+03	0.169502E-05
0.408329E+06	-0.137800E+05	0.287176E+05	0.000000E+00	0.318526E+05	0.910868E+02	0.270000E+03	0.168684E-05
0.410591E+06	-0.205606E+05	0.244668E+05	0.000000E+00	0.319587E+05	0.912082E+02	0.270000E+03	0.167766E-05
0.412877E+06	-0.261219E+05	0.186205E+05	0.000000E+00	0.320792E+05	0.913074E+02	0.270000E+03	0.166757E-05
0.415178E+06	-0.300685E+05	0.115501E+05	0.000000E+00	0.322106E+05	0.913772E+02	0.270000E+03	0.165684E-05
0.417478E+06	-0.321305E+05	0.374537E+04	0.000000E+00	0.323481E+05	0.914131E+02	0.270000E+03	0.164583E-05
0.419802E+06	-0.321921E+05	-0.438161E+04	0.000000E+00	0.324889E+05	0.914138E+02	0.270000E+03	0.163471E-05
0.422149E+06	-0.302132E+05	-0.123200E+05	0.000000E+00	0.326285E+05	0.913780E+02	0.270000E+03	0.162379E-05
0.424496E+06	-0.263311E+05	-0.194930E+05	0.000000E+00	0.327613E+05	0.913088E+02	0.270000E+03	0.161344E-05
0.426858E+06	-0.207675E+05	-0.254968E+05	0.000000E+00	0.328843E+05	0.912106E+02	0.270000E+03	0.160384E-05
0.429245E+06	-0.138254E+05	-0.299582E+05	0.000000E+00	0.329945E+05	0.910887E+02	0.270000E+03	0.159515E-05
0.431633E+06	-0.600462E+04	-0.325389E+05	0.000000E+00	0.330883E+05	0.909523E+02	0.270000E+03	0.158758E-05
0.434026E+06	0.222126E+04	-0.330901E+05	0.000000E+00	0.331646E+05	0.908099E+02	0.270000E+03	0.158116E-05
0.436438E+06	0.103784E+05	-0.315607E+05	0.000000E+00	0.332234E+05	0.906701E+02	0.270000E+03	0.157587E-05
0.438850E+06	0.178918E+05	-0.280434E+05	0.000000E+00	0.332649E+05	0.905432E+02	0.270000E+03	0.157164E-05
0.441262E+06	0.242944E+05	-0.227614E+05	0.000000E+00	0.332911E+05	0.904368E+02	0.270000E+03	0.156834E-05
0.443682E+06	0.291950E+05	-0.160274E+05	0.000000E+00	0.333050E+05	0.903580E+02	0.270000E+03	0.156573E-05
0.446102E+06	0.322653E+05	-0.827806E+04	0.000000E+00	0.333103E+05	0.903122E+02	0.270000E+03	0.156359E-05
0.448522E+06	0.333110E+05	0.200845E-10	0.000000E+00	0.333110E+05	0.903014E+02	0.270000E+03	0.156164E-05

rev 16

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.448522E+06	0.333110E+05	-0.201478E-10	0.000000E+00	0.333110E+05	0.902295E+02	0.270000E+03	0.146574E-05
0.450943E+06	0.322635E+05	0.829080E+04	0.000000E+00	0.333117E+05	0.902520E+02	0.270000E+03	0.146442E-05
0.453363E+06	0.291857E+05	0.160687E+05	0.000000E+00	0.333168E+05	0.903079E+02	0.270000E+03	0.146280E-05
0.455784E+06	0.242699E+05	0.228443E+05	0.000000E+00	0.333301E+05	0.903926E+02	0.270000E+03	0.146064E-05
0.458212E+06	0.178054E+05	0.282052E+05	0.000000E+00	0.333552E+05	0.905013E+02	0.270000E+03	0.145775E-05
0.460641E+06	0.102094E+05	0.317960E+05	0.000000E+00	0.333948E+05	0.906274E+02	0.270000E+03	0.145400E-05
0.463069E+06	0.196387E+04	0.333931E+05	0.000000E+00	0.334508E+05	0.907629E+02	0.270000E+03	0.144932E-05
0.465516E+06	-0.647342E+04	0.328934E+05	0.000000E+00	0.335244E+05	0.909003E+02	0.270000E+03	0.144365E-05
0.467968E+06	-0.145306E+05	0.303123E+05	0.000000E+00	0.336151E+05	0.910308E+02	0.270000E+03	0.143704E-05

0.470420E+06	-0.216843E+05	0.258248E+05	0.000000E+00	0.337213E+05	0.911459E+02	0.270000E+03	0.142962E-05
0.472897E+06	-0.275481E+05	0.196565E+05	0.000000E+00	0.338419E+05	0.912400E+02	0.270000E+03	0.142147E-05
0.475389E+06	-0.317076E+05	0.121989E+05	0.000000E+00	0.339733E+05	0.913061E+02	0.270000E+03	0.141279E-05
0.477881E+06	-0.338795E+05	0.396617E+04	0.000000E+00	0.341109E+05	0.913402E+02	0.270000E+03	0.140388E-05
0.480397E+06	-0.339410E+05	-0.460264E+04	0.000000E+00	0.342517E+05	0.913408E+02	0.270000E+03	0.139489E-05
0.482937E+06	-0.318522E+05	-0.129689E+05	0.000000E+00	0.343913E+05	0.913068E+02	0.270000E+03	0.138605E-05
0.485477E+06	-0.277572E+05	-0.205291E+05	0.000000E+00	0.345240E+05	0.912412E+02	0.270000E+03	0.137767E-05
0.488032E+06	-0.218911E+05	-0.268550E+05	0.000000E+00	0.346469E+05	0.911481E+02	0.270000E+03	0.136989E-05
0.490613E+06	-0.145759E+05	-0.315530E+05	0.000000E+00	0.347570E+05	0.910325E+02	0.270000E+03	0.136285E-05
0.493194E+06	-0.633491E+04	-0.342702E+05	0.000000E+00	0.348508E+05	0.909031E+02	0.270000E+03	0.135671E-05
0.495781E+06	0.233192E+04	-0.348490E+05	0.000000E+00	0.349270E+05	0.907680E+02	0.270000E+03	0.135151E-05
0.498387E+06	0.109230E+05	-0.332368E+05	0.000000E+00	0.349857E+05	0.906354E+02	0.270000E+03	0.134721E-05
0.500993E+06	0.188361E+05	-0.295313E+05	0.000000E+00	0.350271E+05	0.905148E+02	0.270000E+03	0.134378E-05
0.503600E+06	0.255790E+05	-0.239677E+05	0.000000E+00	0.350533E+05	0.904137E+02	0.270000E+03	0.134110E-05
0.506215E+06	0.307393E+05	-0.168763E+05	0.000000E+00	0.350672E+05	0.903386E+02	0.270000E+03	0.133899E-05
0.508829E+06	0.339721E+05	-0.871628E+04	0.000000E+00	0.350725E+05	0.902949E+02	0.270000E+03	0.133726E-05
0.511443E+06	0.350732E+05	0.238859E-10	0.000000E+00	0.350732E+05	0.902842E+02	0.270000E+03	0.133569E-05

rev 17

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.511443E+06	0.350732E+05	-0.263569E-10	0.000000E+00	0.350732E+05	0.902195E+02	0.270000E+03	0.125767E-05
0.514059E+06	0.339704E+05	0.872903E+04	0.000000E+00	0.350739E+05	0.902406E+02	0.270000E+03	0.125659E-05
0.516674E+06	0.307299E+05	0.169176E+05	0.000000E+00	0.350790E+05	0.902935E+02	0.270000E+03	0.125526E-05
0.519290E+06	0.255545E+05	0.240507E+05	0.000000E+00	0.350923E+05	0.903739E+02	0.270000E+03	0.125349E-05
0.521912E+06	0.187497E+05	0.296931E+05	0.000000E+00	0.351174E+05	0.904770E+02	0.270000E+03	0.125113E-05
0.524536E+06	0.107539E+05	0.334720E+05	0.000000E+00	0.351571E+05	0.905969E+02	0.270000E+03	0.124807E-05
0.527159E+06	0.207443E+04	0.351520E+05	0.000000E+00	0.352131E+05	0.907256E+02	0.270000E+03	0.124425E-05
0.529801E+06	-0.680383E+04	0.346246E+05	0.000000E+00	0.352868E+05	0.908563E+02	0.270000E+03	0.123962E-05
0.532448E+06	-0.152813E+05	0.319070E+05	0.000000E+00	0.353776E+05	0.909803E+02	0.270000E+03	0.123423E-05
0.535096E+06	-0.228080E+05	0.271828E+05	0.000000E+00	0.354839E+05	0.910898E+02	0.270000E+03	0.122817E-05
0.537769E+06	-0.289743E+05	0.206924E+05	0.000000E+00	0.356046E+05	0.911793E+02	0.270000E+03	0.122151E-05
0.540458E+06	-0.333466E+05	0.128477E+05	0.000000E+00	0.357360E+05	0.912421E+02	0.270000E+03	0.121442E-05
0.543146E+06	-0.356284E+05	0.418699E+04	0.000000E+00	0.358736E+05	0.912744E+02	0.270000E+03	0.120714E-05
0.545859E+06	-0.356899E+05	-0.482364E+04	0.000000E+00	0.360144E+05	0.912750E+02	0.270000E+03	0.119978E-05
0.548597E+06	-0.334912E+05	-0.136179E+05	0.000000E+00	0.361539E+05	0.912427E+02	0.270000E+03	0.119255E-05
0.551334E+06	-0.291833E+05	-0.215653E+05	0.000000E+00	0.362867E+05	0.911802E+02	0.270000E+03	0.118569E-05
0.554087E+06	-0.230146E+05	-0.282132E+05	0.000000E+00	0.364095E+05	0.910918E+02	0.270000E+03	0.117932E-05
0.556867E+06	-0.153264E+05	-0.331478E+05	0.000000E+00	0.365195E+05	0.909818E+02	0.270000E+03	0.117355E-05
0.559647E+06	-0.666518E+04	-0.360014E+05	0.000000E+00	0.366132E+05	0.908588E+02	0.270000E+03	0.116852E-05
0.562433E+06	0.244256E+04	-0.366079E+05	0.000000E+00	0.366893E+05	0.907302E+02	0.270000E+03	0.116426E-05
0.565238E+06	0.114676E+05	-0.349128E+05	0.000000E+00	0.367479E+05	0.906041E+02	0.270000E+03	0.116074E-05
0.568043E+06	0.197804E+05	-0.310192E+05	0.000000E+00	0.367894E+05	0.904893E+02	0.270000E+03	0.115793E-05
0.570850E+06	0.268636E+05	-0.251740E+05	0.000000E+00	0.368156E+05	0.903929E+02	0.270000E+03	0.115573E-05
0.573664E+06	0.322835E+05	-0.177252E+05	0.000000E+00	0.368295E+05	0.903212E+02	0.270000E+03	0.115401E-05
0.576477E+06	0.356789E+05	-0.915450E+04	0.000000E+00	0.368347E+05	0.902794E+02	0.270000E+03	0.115259E-05
0.579291E+06	0.368354E+05	0.304752E-10	0.000000E+00	0.368354E+05	0.902688E+02	0.270000E+03	0.115131E-05

rev 18

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.579291E+06	0.368354E+05	-0.264836E-10	0.000000E+00	0.368354E+05	0.902103E+02	0.270000E+03	0.108719E-05
0.582106E+06	0.356772E+05	0.916726E+04	0.000000E+00	0.368361E+05	0.902302E+02	0.270000E+03	0.108629E-05
0.584921E+06	0.322742E+05	0.177665E+05	0.000000E+00	0.368412E+05	0.902804E+02	0.270000E+03	0.108519E-05
0.587736E+06	0.268391E+05	0.252570E+05	0.000000E+00	0.368545E+05	0.903568E+02	0.270000E+03	0.108373E-05
0.590558E+06	0.196939E+05	0.311811E+05	0.000000E+00	0.368797E+05	0.904550E+02	0.270000E+03	0.108179E-05
0.593382E+06	0.112984E+05	0.351481E+05	0.000000E+00	0.369194E+05	0.905692E+02	0.270000E+03	0.107927E-05
0.596205E+06	0.218501E+04	0.369109E+05	0.000000E+00	0.369755E+05	0.906919E+02	0.270000E+03	0.107612E-05
0.599047E+06	-0.713421E+04	0.363558E+05	0.000000E+00	0.370492E+05	0.908164E+02	0.270000E+03	0.107230E-05
0.601894E+06	-0.160319E+05	0.335017E+05	0.000000E+00	0.371401E+05	0.909346E+02	0.270000E+03	0.106786E-05

0.604742E+06	-0.239317E+05	0.285408E+05	0.000000E+00	0.372465E+05	0.910389E+02	0.270000E+03	0.106286E-05
0.607617E+06	-0.304004E+05	0.217284E+05	0.000000E+00	0.373672E+05	0.911242E+02	0.270000E+03	0.105736E-05
0.610507E+06	-0.349856E+05	0.134964E+05	0.000000E+00	0.374986E+05	0.911840E+02	0.270000E+03	0.105152E-05
0.613397E+06	-0.373773E+05	0.440779E+04	0.000000E+00	0.376363E+05	0.912148E+02	0.270000E+03	0.104550E-05
0.616312E+06	-0.374387E+05	-0.504465E+04	0.000000E+00	0.377771E+05	0.912154E+02	0.270000E+03	0.103943E-05
0.619252E+06	-0.351301E+05	-0.142669E+05	0.000000E+00	0.379166E+05	0.911845E+02	0.270000E+03	0.103346E-05
0.622191E+06	-0.306093E+05	-0.226014E+05	0.000000E+00	0.380493E+05	0.911250E+02	0.270000E+03	0.102779E-05
0.625148E+06	-0.241381E+05	-0.295713E+05	0.000000E+00	0.381721E+05	0.910407E+02	0.270000E+03	0.102253E-05
0.628131E+06	-0.160768E+05	-0.347426E+05	0.000000E+00	0.382820E+05	0.909359E+02	0.270000E+03	0.101776E-05
0.631114E+06	-0.699545E+04	-0.377326E+05	0.000000E+00	0.383756E+05	0.908186E+02	0.270000E+03	0.101360E-05
0.634104E+06	0.255321E+04	-0.383668E+05	0.000000E+00	0.384517E+05	0.906960E+02	0.270000E+03	0.101007E-05
0.637113E+06	0.120121E+05	-0.365889E+05	0.000000E+00	0.385102E+05	0.905757E+02	0.270000E+03	0.100716E-05
0.640123E+06	0.207246E+05	-0.325071E+05	0.000000E+00	0.385516E+05	0.904662E+02	0.270000E+03	0.100483E-05
0.643134E+06	0.281483E+05	-0.263803E+05	0.000000E+00	0.385778E+05	0.903741E+02	0.270000E+03	0.100301E-05
0.646152E+06	0.338278E+05	-0.185741E+05	0.000000E+00	0.385917E+05	0.903056E+02	0.270000E+03	0.100159E-05
0.649170E+06	0.373858E+05	-0.959273E+04	0.000000E+00	0.385969E+05	0.902654E+02	0.270000E+03	0.100042E-05
0.652188E+06	0.385976E+05	0.278775E-10	0.000000E+00	0.385976E+05	0.902550E+02	0.270000E+03	0.999368E-06

rev 19

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.652188E+06	0.385976E+05	-0.210982E-10	0.000000E+00	0.385976E+05	0.902018E+02	0.270000E+03	0.946181E-06
0.655207E+06	0.373840E+05	0.960549E+04	0.000000E+00	0.385983E+05	0.902206E+02	0.270000E+03	0.945432E-06
0.658227E+06	0.338184E+05	0.186155E+05	0.000000E+00	0.386034E+05	0.902684E+02	0.270000E+03	0.944513E-06
0.661246E+06	0.281237E+05	0.264633E+05	0.000000E+00	0.386167E+05	0.903413E+02	0.270000E+03	0.943299E-06
0.664273E+06	0.206381E+05	0.326690E+05	0.000000E+00	0.386419E+05	0.904350E+02	0.270000E+03	0.941681E-06
0.667301E+06	0.118429E+05	0.368241E+05	0.000000E+00	0.386817E+05	0.905440E+02	0.270000E+03	0.939586E-06
0.670328E+06	0.229559E+04	0.386697E+05	0.000000E+00	0.387378E+05	0.906611E+02	0.270000E+03	0.936967E-06
0.673375E+06	-0.746457E+04	0.380870E+05	0.000000E+00	0.388116E+05	0.907800E+02	0.270000E+03	0.933792E-06
0.676428E+06	-0.167824E+05	0.350964E+05	0.000000E+00	0.389025E+05	0.908929E+02	0.270000E+03	0.930093E-06
0.679481E+06	-0.250553E+05	0.298987E+05	0.000000E+00	0.390090E+05	0.909925E+02	0.270000E+03	0.925935E-06
0.682561E+06	-0.318265E+05	0.227643E+05	0.000000E+00	0.391297E+05	0.910740E+02	0.270000E+03	0.921362E-06
0.685658E+06	-0.366246E+05	0.141451E+05	0.000000E+00	0.392612E+05	0.911311E+02	0.270000E+03	0.916496E-06
0.688754E+06	-0.391261E+05	0.462855E+04	0.000000E+00	0.393989E+05	0.911605E+02	0.270000E+03	0.911487E-06
0.691875E+06	-0.391875E+05	-0.526570E+04	0.000000E+00	0.395397E+05	0.911611E+02	0.270000E+03	0.906428E-06
0.695023E+06	-0.367689E+05	-0.149158E+05	0.000000E+00	0.396792E+05	0.911316E+02	0.270000E+03	0.901454E-06
0.698170E+06	-0.320352E+05	-0.236375E+05	0.000000E+00	0.398119E+05	0.910747E+02	0.270000E+03	0.896730E-06
0.701334E+06	-0.252616E+05	-0.309294E+05	0.000000E+00	0.399346E+05	0.909941E+02	0.270000E+03	0.892341E-06
0.704525E+06	-0.168273E+05	-0.363373E+05	0.000000E+00	0.400445E+05	0.908940E+02	0.270000E+03	0.888364E-06
0.707717E+06	-0.732571E+04	-0.394638E+05	0.000000E+00	0.401380E+05	0.907820E+02	0.270000E+03	0.884893E-06
0.710915E+06	0.266385E+04	-0.401257E+05	0.000000E+00	0.402140E+05	0.906648E+02	0.270000E+03	0.881949E-06
0.714133E+06	0.125567E+05	-0.382649E+05	0.000000E+00	0.402725E+05	0.905498E+02	0.270000E+03	0.879517E-06
0.717352E+06	0.216689E+05	-0.339951E+05	0.000000E+00	0.403138E+05	0.904451E+02	0.270000E+03	0.877577E-06
0.720571E+06	0.294329E+05	-0.275866E+05	0.000000E+00	0.403400E+05	0.903570E+02	0.270000E+03	0.876061E-06
0.723798E+06	0.353720E+05	-0.194231E+05	0.000000E+00	0.403539E+05	0.902913E+02	0.270000E+03	0.874873E-06
0.727026E+06	0.390926E+05	-0.100310E+05	0.000000E+00	0.403591E+05	0.902527E+02	0.270000E+03	0.873903E-06
0.730253E+06	0.403598E+05	0.286378E-10	0.000000E+00	0.403598E+05	0.902425E+02	0.270000E+03	0.873027E-06

rev 20

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.730253E+06	0.403598E+05	-0.342133E-10	0.000000E+00	0.403598E+05	0.901940E+02	0.270000E+03	0.828542E-06
0.733481E+06	0.390909E+05	0.100437E+05	0.000000E+00	0.403605E+05	0.902118E+02	0.270000E+03	0.827910E-06
0.736710E+06	0.353626E+05	0.194644E+05	0.000000E+00	0.403656E+05	0.902574E+02	0.270000E+03	0.827138E-06
0.739938E+06	0.294083E+05	0.276696E+05	0.000000E+00	0.403789E+05	0.903270E+02	0.270000E+03	0.826118E-06
0.743174E+06	0.215824E+05	0.341569E+05	0.000000E+00	0.404041E+05	0.904166E+02	0.270000E+03	0.824762E-06
0.746411E+06	0.123875E+05	0.385002E+05	0.000000E+00	0.404439E+05	0.905209E+02	0.270000E+03	0.823006E-06
0.749648E+06	0.240619E+04	0.404286E+05	0.000000E+00	0.405001E+05	0.906330E+02	0.270000E+03	0.820809E-06
0.752905E+06	-0.779492E+04	0.398182E+05	0.000000E+00	0.405740E+05	0.907467E+02	0.270000E+03	0.818148E-06
0.756168E+06	-0.175330E+05	0.366910E+05	0.000000E+00	0.406649E+05	0.908547E+02	0.270000E+03	0.815046E-06

0.759431E+06	-0.261789E+05	0.312567E+05	0.000000E+00	0.407715E+05	0.909502E+02	0.270000E+03	0.811558E-06
0.762721E+06	-0.332525E+05	0.238002E+05	0.000000E+00	0.408923E+05	0.910281E+02	0.270000E+03	0.807722E-06
0.766028E+06	-0.382635E+05	0.147938E+05	0.000000E+00	0.410238E+05	0.910828E+02	0.270000E+03	0.803638E-06
0.769335E+06	-0.408749E+05	0.484933E+04	0.000000E+00	0.411615E+05	0.911109E+02	0.270000E+03	0.799433E-06
0.772668E+06	-0.409363E+05	-0.548671E+04	0.000000E+00	0.413023E+05	0.911114E+02	0.270000E+03	0.795186E-06
0.776028E+06	-0.384078E+05	-0.155647E+05	0.000000E+00	0.414417E+05	0.910832E+02	0.270000E+03	0.791008E-06
0.779387E+06	-0.334612E+05	-0.246735E+05	0.000000E+00	0.415744E+05	0.910287E+02	0.270000E+03	0.787039E-06
0.782763E+06	-0.263851E+05	-0.322874E+05	0.000000E+00	0.416971E+05	0.909516E+02	0.270000E+03	0.783351E-06
0.786167E+06	-0.175777E+05	-0.379320E+05	0.000000E+00	0.418069E+05	0.908558E+02	0.270000E+03	0.780008E-06
0.789572E+06	-0.765598E+04	-0.411949E+05	0.000000E+00	0.419003E+05	0.907485E+02	0.270000E+03	0.777090E-06
0.792983E+06	0.277448E+04	-0.418845E+05	0.000000E+00	0.419763E+05	0.906363E+02	0.270000E+03	0.774613E-06
0.796415E+06	0.131013E+05	-0.399409E+05	0.000000E+00	0.420348E+05	0.905262E+02	0.270000E+03	0.772568E-06
0.799847E+06	0.226131E+05	-0.354830E+05	0.000000E+00	0.420761E+05	0.904259E+02	0.270000E+03	0.770936E-06
0.803280E+06	0.307175E+05	-0.287929E+05	0.000000E+00	0.421022E+05	0.903414E+02	0.270000E+03	0.769661E-06
0.806721E+06	0.369162E+05	-0.202720E+05	0.000000E+00	0.421161E+05	0.902784E+02	0.270000E+03	0.768663E-06
0.810161E+06	0.407995E+05	-0.104692E+05	0.000000E+00	0.421213E+05	0.902412E+02	0.270000E+03	0.767850E-06
0.813602E+06	0.421220E+05	0.239493E-10	0.000000E+00	0.421220E+05	0.902312E+02	0.270000E+03	0.767117E-06

rev 21

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.813602E+06	0.421220E+05	-0.287645E-10	0.000000E+00	0.421220E+05	0.158968E+03	0.270000E+03	0.615712E-13
0.817044E+06	0.407987E+05	0.104753E+05	0.000000E+00	0.421220E+05	0.848596E+01	0.900000E+02	0.176555E-13
0.820485E+06	0.369118E+05	0.202924E+05	0.000000E+00	0.421220E+05	0.606193E+01	0.270000E+03	0.130175E-13
0.823926E+06	0.307056E+05	0.288345E+05	0.000000E+00	0.421220E+05	0.189817E+02	0.270000E+03	0.231829E-13
0.827368E+06	0.225701E+05	0.355648E+05	0.000000E+00	0.421220E+05	0.874205E+01	0.900000E+02	0.132903E-13
0.830809E+06	0.130164E+05	0.400604E+05	0.000000E+00	0.421220E+05	0.108232E+02	0.270000E+03	0.255927E-14
0.834251E+06	0.264486E+04	0.420389E+05	0.000000E+00	0.421220E+05	0.185667E+02	0.270000E+03	0.138643E-13
0.837692E+06	-0.789288E+04	0.413759E+05	0.000000E+00	0.421220E+05	0.670340E+01	0.270000E+03	0.109897E-14
0.841133E+06	-0.179347E+05	0.381131E+05	0.000000E+00	0.421220E+05	0.179547E+03	0.900000E+02	0.876318E-14
0.844575E+06	-0.268496E+05	0.324556E+05	0.000000E+00	0.421220E+05	0.165221E+03	0.900000E+02	0.996974E-14
0.848016E+06	-0.340774E+05	0.247587E+05	0.000000E+00	0.421220E+05	0.166139E+03	0.270000E+03	0.131350E-13
0.851458E+06	-0.391640E+05	0.155061E+05	0.000000E+00	0.421220E+05	0.179635E+03	0.900000E+02	0.159351E-13
0.854899E+06	-0.417899E+05	0.527928E+04	0.000000E+00	0.421220E+05	0.165551E+03	0.900000E+02	0.196561E-13
0.858340E+06	-0.417899E+05	-0.527928E+04	0.000000E+00	0.421220E+05	0.165515E+03	0.270000E+03	0.196396E-13
0.861782E+06	-0.391640E+05	-0.155061E+05	0.000000E+00	0.421220E+05	0.179619E+03	0.270000E+03	0.159091E-13
0.865223E+06	-0.340774E+05	-0.247587E+05	0.000000E+00	0.421220E+05	0.166104E+03	0.900000E+02	0.131394E-13
0.868665E+06	-0.268496E+05	-0.324556E+05	0.000000E+00	0.421220E+05	0.165321E+03	0.270000E+03	0.100023E-13
0.872106E+06	-0.179347E+05	-0.381131E+05	0.000000E+00	0.421220E+05	0.179592E+03	0.270000E+03	0.876759E-14
0.875547E+06	-0.789287E+04	-0.413759E+05	0.000000E+00	0.421220E+05	0.716755E+01	0.900000E+02	0.107918E-14
0.878989E+06	0.264486E+04	-0.420389E+05	0.000000E+00	0.421220E+05	0.186406E+02	0.900000E+02	0.138599E-13
0.882430E+06	0.130164E+05	-0.400604E+05	0.000000E+00	0.421220E+05	0.108866E+02	0.900000E+02	0.255598E-14
0.885872E+06	0.225701E+05	-0.355648E+05	0.000000E+00	0.421220E+05	0.879117E+01	0.270000E+03	0.132961E-13
0.889313E+06	0.307056E+05	-0.288345E+05	0.000000E+00	0.421220E+05	0.188418E+02	0.900000E+02	0.231424E-13
0.892754E+06	0.369118E+05	-0.202924E+05	0.000000E+00	0.421220E+05	0.601361E+01	0.900000E+02	0.130152E-13
0.896196E+06	0.407987E+05	-0.104753E+05	0.000000E+00	0.421220E+05	0.852726E+01	0.270000E+03	0.176505E-13
0.899637E+06	0.421220E+05	0.225554E-10	0.000000E+00	0.421220E+05	0.159057E+03	0.900000E+02	0.614514E-13

Total Time for Spiral Maneuver = 0.104125E+02 days

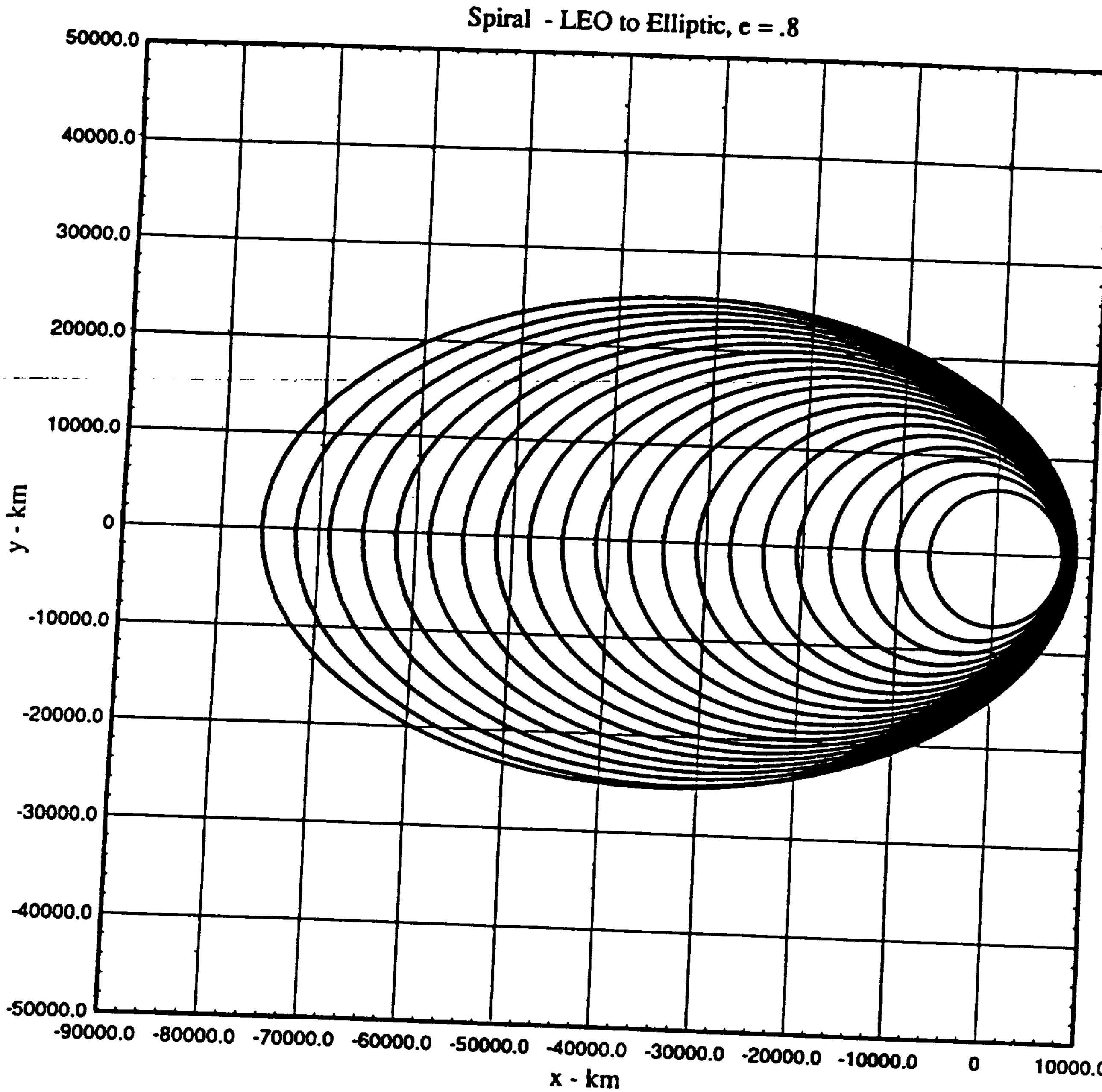
*****Spiral Orbit Transfer Case*****

*** warning- e o f encountered before namelist group name "spiral " was found.

Spiral failed:
Possibly try different value for nrev.

```
*****Spiral Orbit Transfer Case*****

 ^

*** fatal namelist error ***; err. num.=  1
end of file encountered on input.                                  ** line no. =     14
```

B - 3.1.6 SPRIAL LEO TO ELLIPTIC


Spiral - LEO to Elliptic, e = .8
50000.0
40000.0
30000.0
20000.0
10000.0
0
-10000.0
-20000.0
-30000.0
-40000.0
-50000.0
y - km
-90000.0
-80000.0
-70000.0
-60000.0
-50000.0
-40000.0
-30000.0
-20000.0
-10000.0
0
10000.0
x - km

```
1$top
  namlst = 'spiral',
 $end
```

```
*****Spiral Orbit Transfer Case*****
```

```
1$spiral
c raise periapsis, raise apoapsis
  a1 = 6878.d0,
  a2 = 42122.d0,
  e2 = .8d0,
  time = 2444140.d0,
  ipri = 3,
  nrev = 20,
  nt   = 1,
  namlst = 'none',
 $end
```

rev 1

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.000000E+00	0.687800E+04	-0.563885E-11	0.000000E+00	0.687800E+04	0.433425E+02	0.900000E+02	0.354842E-03
0.224295E+03	0.666120E+04	0.168434E+04	0.000000E+00	0.687085E+04	0.303331E+02	0.900000E+02	0.268217E-03
0.448589E+03	0.602481E+04	0.325550E+04	0.000000E+00	0.684811E+04	0.120856E+02	0.900000E+02	0.202164E-03
0.672884E+03	0.500630E+04	0.461752E+04	0.000000E+00	0.681062E+04	0.117516E+02	0.270000E+03	0.162174E-03
0.891851E+03	0.369980E+04	0.566209E+04	0.000000E+00	0.676372E+04	0.365574E+02	0.270000E+03	0.146831E-03
0.111006E+04	0.216531E+04	0.635425E+04	0.000000E+00	0.671305E+04	0.578135E+02	0.270000E+03	0.143835E-03
0.132827E+04	0.489449E+03	0.664814E+04	0.000000E+00	0.666613E+04	0.747602E+02	0.270000E+03	0.140903E-03
0.154273E+04	-0.119472E+04	0.652306E+04	0.000000E+00	0.663157E+04	0.889798E+02	0.270000E+03	0.131507E-03
0.175596E+04	-0.280090E+04	0.599342E+04	0.000000E+00	0.661560E+04	0.102930E+03	0.270000E+03	0.114289E-03
0.196918E+04	-0.423785E+04	0.508988E+04	0.000000E+00	0.662316E+04	0.119424E+03	0.270000E+03	0.912320E-04
0.218532E+04	-0.543024E+04	0.385149E+04	0.000000E+00	0.665744E+04	0.143488E+03	0.270000E+03	0.671980E-04
0.240321E+04	-0.629082E+04	0.235849E+04	0.000000E+00	0.671840E+04	0.178427E+03	0.900000E+02	0.522348E-04
0.262109E+04	-0.676370E+04	0.719592E+03	0.000000E+00	0.680187E+04	0.135648E+03	0.900000E+02	0.556646E-04
0.284635E+04	-0.682927E+04	-0.101735E+04	0.000000E+00	0.690463E+04	0.104133E+03	0.900000E+02	0.705513E-04
0.307897E+04	-0.646059E+04	-0.274213E+04	0.000000E+00	0.701844E+04	0.803922E+02	0.900000E+02	0.859951E-04
0.331159E+04	-0.569155E+04	-0.429299E+04	0.000000E+00	0.712906E+04	0.582553E+02	0.900000E+02	0.987124E-04
0.354944E+04	-0.455696E+04	-0.561025E+04	0.000000E+00	0.722778E+04	0.340405E+02	0.900000E+02	0.113665E-03
0.379602E+04	-0.309457E+04	-0.661651E+04	0.000000E+00	0.730442E+04	0.861108E+01	0.900000E+02	0.141359E-03
0.404260E+04	-0.143763E+04	-0.720487E+04	0.000000E+00	0.734690E+04	0.130548E+02	0.270000E+03	0.189908E-03
0.428898E+04	0.310268E+03	-0.734409E+04	0.000000E+00	0.735064E+04	0.292843E+02	0.270000E+03	0.261064E-03
0.453473E+04	0.204204E+04	-0.702479E+04	0.000000E+00	0.731557E+04	0.411241E+02	0.270000E+03	0.352281E-03
0.478048E+04	0.365716E+04	-0.625603E+04	0.000000E+00	0.724656E+04	0.501180E+02	0.270000E+03	0.460142E-03
0.502468E+04	0.504268E+04	-0.507616E+04	0.000000E+00	0.715515E+04	0.573471E+02	0.270000E+03	0.579550E-03
0.525804E+04	0.606998E+04	-0.361066E+04	0.000000E+00	0.706268E+04	0.633425E+02	0.270000E+03	0.700119E-03
0.549139E+04	0.672752E+04	-0.188677E+04	0.000000E+00	0.698709E+04	0.688739E+02	0.270000E+03	0.820960E-03
0.572474E+04	0.695532E+04	0.517951E-11	0.000000E+00	0.695532E+04	0.742056E+02	0.270000E+03	0.934853E-03

rev 2

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.572474E+04	0.695532E+04	-0.635163E-11	0.000000E+00	0.695532E+04	0.496226E+02	0.900000E+02	0.180423E-03
0.604000E+04	0.654693E+04	0.255232E+04	0.000000E+00	0.702685E+04	0.310441E+02	0.900000E+02	0.127419E-03
0.635526E+04	0.539237E+04	0.480988E+04	0.000000E+00	0.722583E+04	0.401343E+01	0.900000E+02	0.916538E-04
0.667052E+04	0.366863E+04	0.656489E+04	0.000000E+00	0.752042E+04	0.279596E+02	0.270000E+03	0.771780E-04
0.697829E+04	0.164719E+04	0.769199E+04	0.000000E+00	0.786638E+04	0.541490E+02	0.270000E+03	0.757403E-04
0.728499E+04	-0.504071E+03	0.822326E+04	0.000000E+00	0.823870E+04	0.727599E+02	0.270000E+03	0.758756E-04
0.759169E+04	-0.263155E+04	0.820301E+04	0.000000E+00	0.861478E+04	0.867448E+02	0.270000E+03	0.726224E-04

0.789314E+04	-0.458182E+04	0.771239E+04	0.000000E+00	0.897074E+04	0.986111E+02	0.270000E+03	0.654500E-04
0.819284E+04	-0.630062E+04	0.683879E+04	0.000000E+00	0.929876E+04	0.110555E+03	0.270000E+03	0.553325E-04
0.849254E+04	-0.774511E+04	0.565856E+04	0.000000E+00	0.959198E+04	0.124839E+03	0.270000E+03	0.437168E-04
0.879634E+04	-0.889358E+04	0.422654E+04	0.000000E+00	0.984680E+04	0.145370E+03	0.270000E+03	0.324285E-04
0.910259E+04	-0.970840E+04	0.261737E+04	0.000000E+00	0.100550E+05	0.177664E+03	0.270000E+03	0.247453E-04
0.940884E+04	-0.101692E+05	0.912038E+03	0.000000E+00	0.102100E+05	0.142322E+03	0.900000E+02	0.244829E-04
0.972545E+04	-0.102725E+05	-0.882616E+03	0.000000E+00	0.103103E+05	0.110191E+03	0.900000E+02	0.306788E-04
0.100524E+05	-0.998811E+04	-0.269883E+04	0.000000E+00	0.103463E+05	0.875494E+02	0.900000E+02	0.391138E-04
0.103794E+05	-0.932094E+04	-0.440730E+04	0.000000E+00	0.103104E+05	0.690726E+02	0.900000E+02	0.473164E-04
0.107137E+05	-0.826528E+04	-0.597134E+04	0.000000E+00	0.101967E+05	0.505830E+02	0.900000E+02	0.555565E-04
0.110603E+05	-0.680518E+04	-0.732023E+04	0.000000E+00	0.999482E+04	0.302907E+02	0.900000E+02	0.660239E-04
0.114069E+05	-0.501835E+04	-0.831011E+04	0.000000E+00	0.970781E+04	0.957005E+01	0.900000E+02	0.821879E-04
0.117532E+05	-0.296904E+04	-0.885542E+04	0.000000E+00	0.933989E+04	0.947900E+01	0.270000E+03	0.108104E-03
0.120986E+05	-0.748137E+03	-0.887060E+04	0.000000E+00	0.890210E+04	0.254768E+02	0.270000E+03	0.146623E-03
0.124440E+05	0.152786E+04	-0.827396E+04	0.000000E+00	0.841384E+04	0.385818E+02	0.270000E+03	0.199314E-03
0.127872E+05	0.367505E+04	-0.700986E+04	0.000000E+00	0.791480E+04	0.495641E+02	0.270000E+03	0.265726E-03
0.131152E+05	0.541220E+04	-0.516160E+04	0.000000E+00	0.747890E+04	0.589430E+02	0.270000E+03	0.340044E-03
0.134432E+05	0.660350E+04	-0.275950E+04	0.000000E+00	0.715688E+04	0.677933E+02	0.270000E+03	0.419014E-03
0.137712E+05	0.703264E+04	0.652587E-11	0.000000E+00	0.703264E+04	0.763147E+02	0.270000E+03	0.492422E-03

rev 3

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.137712E+05	0.703264E+04	-0.896515E-11	0.000000E+00	0.703264E+04	0.535359E+02	0.900000E+02	0.104418E-03
0.141872E+05	0.635238E+04	0.348235E+04	0.000000E+00	0.724427E+04	0.288556E+02	0.900000E+02	0.684874E-04
0.146032E+05	0.453405E+04	0.635338E+04	0.000000E+00	0.780532E+04	0.708609E+01	0.270000E+03	0.484247E-04
0.150192E+05	0.204591E+04	0.832180E+04	0.000000E+00	0.856960E+04	0.426558E+02	0.270000E+03	0.441263E-04
0.154253E+05	-0.620723E+03	0.936822E+04	0.000000E+00	0.938876E+04	0.661032E+02	0.270000E+03	0.450895E-04
0.158300E+05	-0.324496E+04	0.966849E+04	0.000000E+00	0.101985E+05	0.815145E+02	0.270000E+03	0.446355E-04
0.162347E+05	-0.568160E+04	0.936912E+04	0.000000E+00	0.109572E+05	0.931059E+02	0.270000E+03	0.417220E-04
0.166325E+05	-0.781105E+04	0.861630E+04	0.000000E+00	0.116298E+05	0.103165E+03	0.270000E+03	0.368896E-04
0.170280E+05	-0.962446E+04	0.752091E+04	0.000000E+00	0.122145E+05	0.113484E+03	0.270000E+03	0.308463E-04
0.174234E+05	-0.111138E+05	0.616479E+04	0.000000E+00	0.127091E+05	0.125939E+03	0.270000E+03	0.242828E-04
0.178243E+05	-0.122831E+05	0.459684E+04	0.000000E+00	0.131151E+05	0.143904E+03	0.270000E+03	0.179424E-04
0.182284E+05	-0.131119E+05	0.288279E+04	0.000000E+00	0.134251E+05	0.173076E+03	0.270000E+03	0.132482E-04
0.186325E+05	-0.135904E+05	0.109093E+04	0.000000E+00	0.136341E+05	0.146886E+03	0.900000E+02	0.123386E-04
0.190503E+05	-0.137199E+05	-0.789389E+03	0.000000E+00	0.137426E+05	0.112692E+03	0.900000E+02	0.154718E-04
0.194817E+05	-0.134690E+05	-0.270599E+04	0.000000E+00	0.137381E+05	0.899034E+02	0.900000E+02	0.204605E-04
0.199132E+05	-0.128335E+05	-0.454133E+04	0.000000E+00	0.136133E+05	0.729392E+02	0.900000E+02	0.256900E-04
0.203543E+05	-0.117939E+05	-0.627411E+04	0.000000E+00	0.133589E+05	0.572095E+02	0.900000E+02	0.309738E-04
0.208117E+05	-0.103110E+05	-0.784694E+04	0.000000E+00	0.129573E+05	0.404685E+02	0.900000E+02	0.368925E-04
0.212690E+05	-0.843218E+04	-0.911026E+04	0.000000E+00	0.124136E+05	0.226541E+02	0.900000E+02	0.445934E-04
0.217259E+05	-0.618629E+04	-0.996544E+04	0.000000E+00	0.117295E+05	0.448280E+01	0.900000E+02	0.561735E-04
0.221817E+05	-0.362591E+04	-0.102938E+05	0.000000E+00	0.109137E+05	0.126634E+02	0.270000E+03	0.741125E-04
0.226375E+05	-0.832493E+03	-0.995074E+04	0.000000E+00	0.998551E+04	0.280019E+02	0.270000E+03	0.100993E-03
0.230905E+05	0.201229E+04	-0.877256E+04	0.000000E+00	0.900040E+04	0.416422E+02	0.270000E+03	0.138697E-03
0.235232E+05	0.452211E+04	-0.671384E+04	0.000000E+00	0.809477E+04	0.537754E+02	0.270000E+03	0.186256E-03
0.239560E+05	0.639542E+04	-0.370261E+04	0.000000E+00	0.738990E+04	0.658328E+02	0.270000E+03	0.241621E-03
0.243888E+05	0.710996E+04	0.107075E-10	0.000000E+00	0.710996E+04	0.777989E+02	0.270000E+03	0.294485E-03

rev 4

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.243888E+05	0.710996E+04	-0.123865E-10	0.000000E+00	0.710996E+04	0.570218E+02	0.900000E+02	0.674086E-04
0.249145E+05	0.607404E+04	0.445257E+04	0.000000E+00	0.753123E+04	0.246576E+02	0.900000E+02	0.396058E-04
0.254401E+05	0.349159E+04	0.783273E+04	0.000000E+00	0.857571E+04	0.191107E+02	0.270000E+03	0.284991E-04
0.259658E+05	0.259122E+03	0.987575E+04	0.000000E+00	0.987915E+04	0.548239E+02	0.270000E+03	0.280358E-04
0.264789E+05	-0.295898E+04	0.107778E+05	0.000000E+00	0.111766E+05	0.738074E+02	0.270000E+03	0.289711E-04
0.269903E+05	-0.596280E+04	0.108616E+05	0.000000E+00	0.123907E+05	0.867405E+02	0.270000E+03	0.282179E-04
0.275017E+05	-0.865135E+04	0.103419E+05	0.000000E+00	0.134833E+05	0.966208E+02	0.270000E+03	0.259646E-04

0.280043E+05	-0.109432E+05	0.939496E+04	0.000000E+00	0.144229E+05	0.105352E+03	0.270000E+03	0.227243E-04
0.285040E+05	-0.128634E+05	0.813548E+04	0.000000E+00	0.152202E+05	0.114423E+03	0.270000E+03	0.188984E-04
0.290037E+05	-0.144248E+05	0.664232E+04	0.000000E+00	0.158807E+05	0.125435E+03	0.270000E+03	0.148329E-04
0.295102E+05	-0.156451E+05	0.495769E+04	0.000000E+00	0.164118E+05	0.141434E+03	0.270000E+03	0.108725E-04
0.300208E+05	-0.165116E+05	0.314177E+04	0.000000E+00	0.168078E+05	0.168450E+03	0.270000E+03	0.774119E-05
0.305314E+05	-0.170186E+05	0.125663E+04	0.000000E+00	0.170649E+05	0.150405E+03	0.900000E+02	0.679416E-05
0.310593E+05	-0.171700E+05	-0.718611E+03	0.000000E+00	0.171851E+05	0.113359E+03	0.900000E+02	0.860061E-05
0.316045E+05	-0.169330E+05	-0.273924E+04	0.000000E+00	0.171531E+05	0.901182E+02	0.900000E+02	0.118116E-04
0.321496E+05	-0.162990E+05	-0.469194E+04	0.000000E+00	0.169609E+05	0.740733E+02	0.900000E+02	0.152979E-04
0.327070E+05	-0.152414E+05	-0.656523E+04	0.000000E+00	0.165953E+05	0.600164E+02	0.900000E+02	0.188621E-04
0.332849E+05	-0.137083E+05	-0.831149E+04	0.000000E+00	0.160312E+05	0.455371E+02	0.900000E+02	0.227012E-04
0.338628E+05	-0.117309E+05	-0.978025E+04	0.000000E+00	0.152731E+05	0.300881E+02	0.900000E+02	0.272335E-04
0.344401E+05	-0.931509E+04	-0.108718E+05	0.000000E+00	0.143166E+05	0.136066E+02	0.900000E+02	0.334775E-04
0.350161E+05	-0.648229E+04	-0.114563E+05	0.000000E+00	0.131631E+05	0.312562E+01	0.270000E+03	0.429529E-04
0.355920E+05	-0.327158E+04	-0.113586E+05	0.000000E+00	0.118204E+05	0.192438E+02	0.270000E+03	0.576862E-04
0.361643E+05	0.176099E+03	-0.103386E+05	0.000000E+00	0.103401E+05	0.343307E+02	0.270000E+03	0.792075E-04
0.367112E+05	0.344275E+04	-0.820655E+04	0.000000E+00	0.889944E+04	0.485438E+02	0.270000E+03	0.110397E-03
0.372580E+05	0.609989E+04	-0.468981E+04	0.000000E+00	0.769435E+04	0.633070E+02	0.270000E+03	0.150392E-03
0.378049E+05	0.718728E+04	0.112460E-10	0.000000E+00	0.718728E+04	0.792507E+02	0.270000E+03	0.193624E-03

rev 5

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.378049E+05	0.718728E+04	-0.590813E-11	0.000000E+00	0.718728E+04	0.586178E+02	0.900000E+02	0.434894E-04
0.380758E+05	0.690791E+04	0.242441E+04	0.000000E+00	0.732099E+04	0.447313E+02	0.900000E+02	0.346492E-04
0.383466E+05	0.611857E+04	0.467124E+04	0.000000E+00	0.769788E+04	0.274090E+02	0.900000E+02	0.272145E-04
0.386421E+05	0.481525E+04	0.678349E+04	0.000000E+00	0.831880E+04	0.500386E+01	0.900000E+02	0.217937E-04
0.390235E+05	0.271770E+04	0.891087E+04	0.000000E+00	0.931609E+04	0.244392E+02	0.270000E+03	0.189306E-04
0.394049E+05	0.413502E+03	0.104018E+05	0.000000E+00	0.104100E+05	0.475484E+02	0.270000E+03	0.187803E-04
0.398998E+05	-0.260511E+04	0.115519E+05	0.000000E+00	0.118420E+05	0.670771E+02	0.270000E+03	0.194455E-04
0.405365E+05	-0.626897E+04	0.120473E+05	0.000000E+00	0.135808E+05	0.823590E+02	0.270000E+03	0.195217E-04
0.411732E+05	-0.954356E+04	0.117512E+05	0.000000E+00	0.151383E+05	0.927023E+02	0.270000E+03	0.184451E-04
0.420513E+05	-0.133436E+05	0.104618E+05	0.000000E+00	0.169559E+05	0.104119E+03	0.270000E+03	0.156403E-04
0.430501E+05	-0.166593E+05	0.818552E+04	0.000000E+00	0.185616E+05	0.117498E+03	0.270000E+03	0.114802E-04
0.440489E+05	-0.189480E+05	0.538415E+04	0.000000E+00	0.196981E+05	0.137912E+03	0.270000E+03	0.714867E-05
0.452403E+05	-0.203987E+05	0.168160E+04	0.000000E+00	0.204679E+05	0.159787E+03	0.900000E+02	0.397751E-05
0.464558E+05	-0.204940E+05	-0.220913E+04	0.000000E+00	0.206128E+05	0.944508E+02	0.900000E+02	0.668810E-05
0.476531E+05	-0.192397E+05	-0.588663E+04	0.000000E+00	0.201201E+05	0.672032E+02	0.900000E+02	0.110381E-04
0.487040E+05	-0.170242E+05	-0.876695E+04	0.000000E+00	0.191490E+05	0.479982E+02	0.900000E+02	0.149568E-04
0.497549E+05	-0.137364E+05	-0.110730E+05	0.000000E+00	0.176437E+05	0.272070E+02	0.900000E+02	0.196600E-04
0.506825E+05	-0.991507E+04	-0.123553E+05	0.000000E+00	0.158418E+05	0.679424E+01	0.900000E+02	0.260885E-04
0.513636E+05	-0.655946E+04	-0.126227E+05	0.000000E+00	0.142253E+05	0.872872E+01	0.270000E+03	0.337526E-04
0.520448E+05	-0.278177E+04	-0.120555E+05	0.000000E+00	0.123723E+05	0.241206E+02	0.270000E+03	0.457542E-04
0.525700E+05	0.325397E+03	-0.108180E+05	0.000000E+00	0.108229E+05	0.359892E+02	0.270000E+03	0.594794E-04
0.529704E+05	0.268637E+04	-0.924743E+04	0.000000E+00	0.962973E+04	0.453567E+02	0.270000E+03	0.734865E-04
0.533709E+05	0.484947E+04	-0.700860E+04	0.000000E+00	0.852278E+04	0.554171E+02	0.270000E+03	0.909175E-04
0.536754E+05	0.617654E+04	-0.482133E+04	0.000000E+00	0.783549E+04	0.637552E+02	0.270000E+03	0.105900E-03
0.539524E+05	0.697911E+04	-0.250620E+04	0.000000E+00	0.741545E+04	0.718168E+02	0.270000E+03	0.119498E-03
0.542295E+05	0.726460E+04	0.630411E-11	0.000000E+00	0.726460E+04	0.799946E+02	0.270000E+03	0.131139E-03

rev 6

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.542295E+05	0.726460E+04	-0.731784E-11	0.000000E+00	0.726460E+04	0.602054E+02	0.900000E+02	0.303472E-04
0.545532E+05	0.687719E+04	0.291922E+04	0.000000E+00	0.747111E+04	0.438721E+02	0.900000E+02	0.234327E-04
0.548769E+05	0.580996E+04	0.555603E+04	0.000000E+00	0.803897E+04	0.232217E+02	0.900000E+02	0.179023E-04
0.552300E+05	0.411838E+04	0.793206E+04	0.000000E+00	0.893748E+04	0.268500E+01	0.270000E+03	0.143762E-04
0.556858E+05	0.152607E+04	0.101988E+05	0.000000E+00	0.103123E+05	0.334907E+02	0.270000E+03	0.130492E-04
0.561416E+05	-0.119880E+04	0.116945E+05	0.000000E+00	0.117558E+05	0.549802E+02	0.270000E+03	0.133128E-04
0.567331E+05	-0.464435E+04	0.127612E+05	0.000000E+00	0.135800E+05	0.720975E+02	0.270000E+03	0.138185E-04

0.574941E+05	-0.870629E+04	0.131022E+05	0.000000E+00	0.157311E+05	0.854123E+02	0.270000E+03	0.137268E-04
0.582550E+05	-0.122649E+05	0.126487E+05	0.000000E+00	0.176187E+05	0.945361E+02	0.270000E+03	0.128509E-04
0.593045E+05	-0.163394E+05	0.111632E+05	0.000000E+00	0.197887E+05	0.104743E+03	0.270000E+03	0.108180E-04
0.604981E+05	-0.198631E+05	0.869522E+04	0.000000E+00	0.216829E+05	0.116775E+03	0.270000E+03	0.791089E-05
0.616918E+05	-0.222868E+05	0.572626E+04	0.000000E+00	0.230107E+05	0.135150E+03	0.270000E+03	0.487861E-05
0.631157E+05	-0.238282E+05	0.183984E+04	0.000000E+00	0.238991E+05	0.163184E+03	0.900000E+02	0.245703E-05
0.645684E+05	-0.239478E+05	-0.223688E+04	0.000000E+00	0.240521E+05	0.927281E+02	0.900000E+02	0.434961E-05
0.659992E+05	-0.226478E+05	-0.611104E+04	0.000000E+00	0.234577E+05	0.667937E+02	0.900000E+02	0.750350E-05
0.672552E+05	-0.203236E+05	-0.918583E+04	0.000000E+00	0.223031E+05	0.493162E+02	0.900000E+02	0.103375E-04
0.685112E+05	-0.168407E+05	-0.117155E+05	0.000000E+00	0.205150E+05	0.305306E+02	0.900000E+02	0.135962E-04
0.696198E+05	-0.127422E+05	-0.132231E+05	0.000000E+00	0.183633E+05	0.116327E+02	0.900000E+02	0.177733E-04
0.704338E+05	-0.908803E+04	-0.136684E+05	0.000000E+00	0.164139E+05	0.334016E+01	0.270000E+03	0.226336E-04
0.712479E+05	-0.488853E+04	-0.132712E+05	0.000000E+00	0.141429E+05	0.187819E+02	0.270000E+03	0.303418E-04
0.718756E+05	-0.133312E+04	-0.121233E+05	0.000000E+00	0.121964E+05	0.310469E+02	0.270000E+03	0.394644E-04
0.723542E+05	0.146332E+04	-0.105487E+05	0.000000E+00	0.106497E+05	0.409519E+02	0.270000E+03	0.492250E-04
0.728328E+05	0.413833E+04	-0.816745E+04	0.000000E+00	0.915603E+04	0.519052E+02	0.270000E+03	0.621164E-04
0.731967E+05	0.586091E+04	-0.571382E+04	0.000000E+00	0.818524E+04	0.613610E+02	0.270000E+03	0.738778E-04
0.735278E+05	0.694597E+04	-0.300631E+04	0.000000E+00	0.756865E+04	0.708758E+02	0.270000E+03	0.849846E-04
0.738589E+05	0.734192E+04	0.725448E-11	0.000000E+00	0.734192E+04	0.807349E+02	0.270000E+03	0.943973E-04

rev 7

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.738589E+05	0.734192E+04	-0.795142E-11	0.000000E+00	0.734192E+04	0.612810E+02	0.900000E+02	0.220850E-04
0.742385E+05	0.682519E+04	0.343253E+04	0.000000E+00	0.763973E+04	0.426329E+02	0.900000E+02	0.163935E-04
0.746181E+05	0.544251E+04	0.644480E+04	0.000000E+00	0.843542E+04	0.186364E+02	0.900000E+02	0.122206E-04
0.750322E+05	0.334251E+04	0.904438E+04	0.000000E+00	0.964226E+04	0.101697E+02	0.270000E+03	0.996734E-05
0.755667E+05	0.266348E+03	0.114048E+05	0.000000E+00	0.114079E+05	0.410458E+02	0.270000E+03	0.945007E-05
0.761013E+05	-0.285178E+04	0.128843E+05	0.000000E+00	0.131961E+05	0.606585E+02	0.270000E+03	0.980139E-05
0.767948E+05	-0.669135E+04	0.138670E+05	0.000000E+00	0.153970E+05	0.757674E+02	0.270000E+03	0.101413E-04
0.776872E+05	-0.111261E+05	0.140724E+05	0.000000E+00	0.179394E+05	0.875684E+02	0.270000E+03	0.998389E-05
0.785796E+05	-0.149597E+05	0.134841E+05	0.000000E+00	0.201398E+05	0.957491E+02	0.270000E+03	0.928523E-05
0.798103E+05	-0.193106E+05	0.118278E+05	0.000000E+00	0.226450E+05	0.104984E+03	0.270000E+03	0.777830E-05
0.812101E+05	-0.230524E+05	0.918587E+04	0.000000E+00	0.248152E+05	0.115877E+03	0.270000E+03	0.567295E-05
0.826099E+05	-0.256208E+05	0.605764E+04	0.000000E+00	0.263272E+05	0.132438E+03	0.270000E+03	0.346871E-05
0.842797E+05	-0.272585E+05	0.199041E+04	0.000000E+00	0.273311E+05	0.166650E+03	0.900000E+02	0.157404E-05
0.859832E+05	-0.273998E+05	-0.227062E+04	0.000000E+00	0.274937E+05	0.905240E+02	0.900000E+02	0.295942E-05
0.876612E+05	-0.260441E+05	-0.633539E+04	0.000000E+00	0.268036E+05	0.659389E+02	0.900000E+02	0.531761E-05
0.891340E+05	-0.235996E+05	-0.959172E+04	0.000000E+00	0.254743E+05	0.498822E+02	0.900000E+02	0.743088E-05
0.906069E+05	-0.199121E+05	-0.123221E+05	0.000000E+00	0.234164E+05	0.326930E+02	0.900000E+02	0.979884E-05
0.919070E+05	-0.155370E+05	-0.140260E+05	0.000000E+00	0.209315E+05	0.151314E+02	0.900000E+02	0.126897E-04
0.928616E+05	-0.115966E+05	-0.146253E+05	0.000000E+00	0.186650E+05	0.813101E+00	0.900000E+02	0.159613E-04
0.938162E+05	-0.700378E+04	-0.143801E+05	0.000000E+00	0.159950E+05	0.144147E+02	0.270000E+03	0.211532E-04
0.945523E+05	-0.303454E+04	-0.133238E+05	0.000000E+00	0.136650E+05	0.268001E+02	0.270000E+03	0.274250E-04
0.951135E+05	0.169876E+03	-0.117677E+05	0.000000E+00	0.117690E+05	0.370075E+02	0.270000E+03	0.343705E-04
0.956748E+05	0.334645E+04	-0.929087E+04	0.000000E+00	0.987517E+04	0.485719E+02	0.270000E+03	0.440090E-04
0.961015E+05	0.548536E+04	-0.661124E+04	0.000000E+00	0.859056E+04	0.589275E+02	0.270000E+03	0.533088E-04
0.964898E+05	0.689106E+04	-0.352568E+04	0.000000E+00	0.774062E+04	0.697828E+02	0.270000E+03	0.625386E-04
0.968781E+05	0.741924E+04	0.868003E-11	0.000000E+00	0.741924E+04	0.812585E+02	0.270000E+03	0.705022E-04

rev 8

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.968781E+05	0.741924E+04	-0.842660E-11	0.000000E+00	0.741924E+04	0.620875E+02	0.900000E+02	0.168690E-04
0.973165E+05	0.675155E+04	0.396072E+04	0.000000E+00	0.782756E+04	0.410466E+02	0.900000E+02	0.117500E-04
0.977549E+05	0.502146E+04	0.732908E+04	0.000000E+00	0.888428E+04	0.136790E+02	0.900000E+02	0.857655E-05
0.982331E+05	0.250356E+04	0.101153E+05	0.000000E+00	0.104205E+05	0.171914E+02	0.270000E+03	0.720411E-05
0.988504E+05	-0.103986E+04	0.125372E+05	0.000000E+00	0.125802E+05	0.472200E+02	0.270000E+03	0.709863E-05
0.994678E+05	-0.452790E+04	0.139902E+05	0.000000E+00	0.147047E+05	0.650247E+02	0.270000E+03	0.742621E-05
0.100269E+06	-0.873829E+04	0.148939E+05	0.000000E+00	0.172681E+05	0.785303E+02	0.270000E+03	0.764203E-05

0.101299E+06	-0.135306E+05	0.149800E+05	0.000000E+00	0.201861E+05	0.891415E+02	0.270000E+03	0.746860E-05
0.102330E+06	-0.176347E+05	0.142735E+05	0.000000E+00	0.226873E+05	0.965691E+02	0.270000E+03	0.691235E-05
0.103751E+06	-0.222650E+05	0.124641E+05	0.000000E+00	0.255163E+05	0.105000E+03	0.270000E+03	0.577078E-05
0.105368E+06	-0.262320E+05	0.966055E+04	0.000000E+00	0.279543E+05	0.114907E+03	0.270000E+03	0.420083E-05
0.106984E+06	-0.289515E+05	0.637929E+04	0.000000E+00	0.296460E+05	0.129823E+03	0.270000E+03	0.255023E-05
0.108913E+06	-0.306892E+05	0.213448E+04	0.000000E+00	0.307634E+05	0.170348E+03	0.900000E+02	0.103799E-05
0.110880E+06	-0.308503E+05	-0.230844E+04	0.000000E+00	0.309366E+05	0.879880E+02	0.900000E+02	0.209011E-05
0.112818E+06	-0.294325E+05	-0.655874E+04	0.000000E+00	0.301544E+05	0.648316E+02	0.900000E+02	0.389836E-05
0.114519E+06	-0.268595E+05	-0.998732E+04	0.000000E+00	0.286562E+05	0.499946E+02	0.900000E+02	0.551400E-05
0.116220E+06	-0.229602E+05	-0.129024E+05	0.000000E+00	0.263371E+05	0.341121E+02	0.900000E+02	0.729491E-05
0.117721E+06	-0.183072E+05	-0.147821E+05	0.000000E+00	0.235301E+05	0.177019E+02	0.900000E+02	0.939111E-05
0.118824E+06	-0.140869E+05	-0.155174E+05	0.000000E+00	0.209578E+05	0.404256E+01	0.900000E+02	0.117009E-04
0.119926E+06	-0.911849E+04	-0.154073E+05	0.000000E+00	0.179034E+05	0.108381E+02	0.270000E+03	0.153449E-04
0.120776E+06	-0.476021E+04	-0.144385E+05	0.000000E+00	0.152030E+05	0.231706E+02	0.270000E+03	0.198006E-04
0.121425E+06	-0.117165E+04	-0.129121E+05	0.000000E+00	0.129651E+05	0.335197E+02	0.270000E+03	0.248520E-04
0.122073E+06	0.248998E+04	-0.103731E+05	0.000000E+00	0.106677E+05	0.454786E+02	0.270000E+03	0.321393E-04
0.122566E+06	0.505521E+04	-0.750471E+04	0.000000E+00	0.904852E+04	0.565339E+02	0.270000E+03	0.394987E-04
0.123014E+06	0.681402E+04	-0.406048E+04	0.000000E+00	0.793211E+04	0.685855E+02	0.270000E+03	0.472568E-04
0.123462E+06	0.749656E+04	0.906018E-11	0.000000E+00	0.749656E+04	0.815944E+02	0.270000E+03	0.544954E-04

rev 9

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.123462E+06	0.749656E+04	-0.652587E-11	0.000000E+00	0.749656E+04	0.635591E+02	0.900000E+02	0.124442E-04
0.123775E+06	0.715691E+04	0.287895E+04	0.000000E+00	0.771426E+04	0.492386E+02	0.900000E+02	0.100512E-04
0.124088E+06	0.621745E+04	0.552259E+04	0.000000E+00	0.831599E+04	0.319574E+02	0.900000E+02	0.798664E-05
0.124447E+06	0.463097E+04	0.810116E+04	0.000000E+00	0.933138E+04	0.984486E+01	0.900000E+02	0.638870E-05
0.124966E+06	0.185209E+04	0.109531E+05	0.000000E+00	0.111086E+05	0.215513E+02	0.270000E+03	0.542317E-05
0.125485E+06	-0.109476E+04	0.129456E+05	0.000000E+00	0.129918E+05	0.448705E+02	0.270000E+03	0.538419E-05
0.126260E+06	-0.538836E+04	0.147827E+05	0.000000E+00	0.157341E+05	0.653519E+02	0.270000E+03	0.568835E-05
0.127355E+06	-0.109045E+05	0.158705E+05	0.000000E+00	0.192557E+05	0.808439E+02	0.270000E+03	0.588961E-05
0.128451E+06	-0.157041E+05	0.158605E+05	0.000000E+00	0.223198E+05	0.899255E+02	0.270000E+03	0.573597E-05
0.130211E+06	-0.220394E+05	0.144764E+05	0.000000E+00	0.263686E+05	0.997809E+02	0.270000E+03	0.501418E-05
0.132303E+06	-0.276617E+05	0.115451E+05	0.000000E+00	0.299743E+05	0.109591E+03	0.270000E+03	0.375818E-05
0.134395E+06	-0.314928E+05	0.783143E+04	0.000000E+00	0.324519E+05	0.122024E+03	0.270000E+03	0.233612E-05
0.137057E+06	-0.340577E+05	0.253929E+04	0.000000E+00	0.341523E+05	0.178223E+03	0.270000E+03	0.734993E-06
0.139790E+06	-0.341712E+05	-0.308445E+04	0.000000E+00	0.343102E+05	0.803708E+02	0.900000E+02	0.174930E-05
0.142460E+06	-0.318363E+05	-0.834424E+04	0.000000E+00	0.329117E+05	0.577333E+02	0.900000E+02	0.346953E-05
0.144622E+06	-0.280796E+05	-0.121141E+05	0.000000E+00	0.305813E+05	0.421641E+02	0.900000E+02	0.491145E-05
0.146785E+06	-0.224725E+05	-0.150516E+05	0.000000E+00	0.270474E+05	0.239066E+02	0.900000E+02	0.668186E-05
0.148608E+06	-0.160939E+05	-0.164032E+05	0.000000E+00	0.229800E+05	0.527019E+01	0.900000E+02	0.904831E-05
0.149752E+06	-0.112022E+05	-0.163684E+05	0.000000E+00	0.198346E+05	0.796417E+01	0.270000E+03	0.115190E-04
0.150896E+06	-0.555981E+04	-0.151971E+05	0.000000E+00	0.161821E+05	0.225711E+02	0.270000E+03	0.155626E-04
0.151703E+06	-0.117161E+04	-0.132724E+05	0.000000E+00	0.133240E+05	0.342918E+02	0.270000E+03	0.201124E-04
0.152239E+06	0.182758E+04	-0.112134E+05	0.000000E+00	0.113614E+05	0.434171E+02	0.270000E+03	0.244843E-04
0.152774E+06	0.466485E+04	-0.827218E+04	0.000000E+00	0.949683E+04	0.544822E+02	0.270000E+03	0.303144E-04
0.153142E+06	0.627563E+04	-0.563465E+04	0.000000E+00	0.843403E+04	0.637020E+02	0.270000E+03	0.350044E-04
0.153460E+06	0.722849E+04	-0.293925E+04	0.000000E+00	0.780322E+04	0.728417E+02	0.270000E+03	0.390805E-04
0.153779E+06	0.757388E+04	0.772967E-11	0.000000E+00	0.757388E+04	0.824108E+02	0.270000E+03	0.423336E-04

rev 10

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.153779E+06	0.757388E+04	-0.807813E-11	0.000000E+00	0.757388E+04	0.639493E+02	0.900000E+02	0.975111E-05
0.154132E+06	0.715267E+04	0.324473E+04	0.000000E+00	0.785423E+04	0.484783E+02	0.900000E+02	0.765869E-05
0.154485E+06	0.600931E+04	0.617268E+04	0.000000E+00	0.861475E+04	0.292433E+02	0.900000E+02	0.597159E-05
0.154890E+06	0.413348E+04	0.895364E+04	0.000000E+00	0.986171E+04	0.512213E+01	0.900000E+02	0.477406E-05
0.155475E+06	0.954843E+03	0.119352E+05	0.000000E+00	0.119733E+05	0.274202E+02	0.270000E+03	0.417772E-05
0.156061E+06	-0.232689E+04	0.139596E+05	0.000000E+00	0.141522E+05	0.496797E+02	0.270000E+03	0.423727E-05
0.156936E+06	-0.701640E+04	0.157739E+05	0.000000E+00	0.172640E+05	0.683476E+02	0.270000E+03	0.448494E-05

0.158172E+06	-0.129524E+05	0.167851E+05	0.000000E+00	0.212015E+05	0.824975E+02	0.270000E+03	0.462231E-05
0.159408E+06	-0.180713E+05	0.166866E+05	0.000000E+00	0.245971E+05	0.908528E+02	0.270000E+03	0.448328E-05
0.161394E+06	-0.247907E+05	0.151587E+05	0.000000E+00	0.290580E+05	0.999661E+02	0.270000E+03	0.390541E-05
0.163755E+06	-0.307327E+05	0.120603E+05	0.000000E+00	0.330144E+05	0.109002E+03	0.270000E+03	0.292279E-05
0.166116E+06	-0.347757E+05	0.818271E+04	0.000000E+00	0.357254E+05	0.120229E+03	0.270000E+03	0.181297E-05
0.169119E+06	-0.374848E+05	0.268317E+04	0.000000E+00	0.375808E+05	0.173084E+03	0.270000E+03	0.515464E-06
0.172203E+06	-0.376145E+05	-0.315578E+04	0.000000E+00	0.377466E+05	0.777752E+02	0.900000E+02	0.132187E-05
0.175215E+06	-0.351657E+05	-0.863105E+04	0.000000E+00	0.362094E+05	0.568407E+02	0.900000E+02	0.269079E-05
0.177656E+06	-0.312119E+05	-0.125812E+05	0.000000E+00	0.336521E+05	0.423120E+02	0.900000E+02	0.383417E-05
0.180096E+06	-0.252917E+05	-0.157051E+05	0.000000E+00	0.297711E+05	0.251305E+02	0.900000E+02	0.521397E-05
0.182154E+06	-0.185257E+05	-0.172178E+05	0.000000E+00	0.252914E+05	0.732622E+01	0.900000E+02	0.700785E-05
0.183444E+06	-0.133050E+05	-0.172822E+05	0.000000E+00	0.218105E+05	0.554143E+01	0.270000E+03	0.885813E-05
0.184735E+06	-0.722773E+04	-0.161958E+05	0.000000E+00	0.177354E+05	0.199528E+02	0.270000E+03	0.118948E-04
0.185645E+06	-0.243054E+04	-0.142968E+05	0.000000E+00	0.145019E+05	0.315929E+02	0.270000E+03	0.153573E-04
0.186250E+06	0.911706E+03	-0.122062E+05	0.000000E+00	0.122402E+05	0.408177E+02	0.270000E+03	0.187749E-04
0.186854E+06	0.415823E+04	-0.913340E+04	0.000000E+00	0.100354E+05	0.522617E+02	0.270000E+03	0.235115E-04
0.187269E+06	0.606305E+04	-0.629136E+04	0.000000E+00	0.873738E+04	0.620637E+02	0.270000E+03	0.274780E-04
0.187628E+06	0.722280E+04	-0.330915E+04	0.000000E+00	0.794476E+04	0.720968E+02	0.270000E+03	0.310444E-04
0.187988E+06	0.765120E+04	0.753959E-11	0.000000E+00	0.765120E+04	0.826758E+02	0.270000E+03	0.339278E-04

rev 11

time (secs)	x (km)	y (km)	z (km)	r (km)	cone (deg)	clock (deg)	acc (km/s^2)
0.187988E+06	0.765120E+04	-0.804646E-11	0.000000E+00	0.765120E+04	0.639886E+02	0.900000E+02	0.788323E-05
0.188383E+06	0.713837E+04	0.361893E+04	0.000000E+00	0.800331E+04	0.476134E+02	0.900000E+02	0.591799E-05
0.188778E+06	0.577425E+04	0.682433E+04	0.000000E+00	0.893944E+04	0.264195E+02	0.900000E+02	0.452919E-05
0.189230E+06	0.360019E+04	0.978958E+04	0.000000E+00	0.104306E+05	0.486616E+00	0.900000E+02	0.364470E-05
0.189885E+06	0.269352E+02	0.128800E+05	0.000000E+00	0.128801E+05	0.326152E+02	0.270000E+03	0.330131E-05
0.190540E+06	-0.357851E+04	0.149274E+05	0.000000E+00	0.153503E+05	0.536727E+02	0.270000E+03	0.340352E-05
0.191518E+06	-0.865012E+04	0.167184E+05	0.000000E+00	0.188237E+05	0.708105E+02	0.270000E+03	0.359401E-05
0.192900E+06	-0.149955E+05	0.176602E+05	0.000000E+00	0.231678E+05	0.838370E+02	0.270000E+03	0.368829E-05
0.194282E+06	-0.204301E+05	0.174814E+05	0.000000E+00	0.268884E+05	0.915803E+02	0.270000E+03	0.356563E-05
0.196503E+06	-0.275337E+05	0.158202E+05	0.000000E+00	0.317550E+05	0.100055E+03	0.270000E+03	0.309776E-05
0.199143E+06	-0.337984E+05	0.125628E+05	0.000000E+00	0.360577E+05	0.108403E+03	0.270000E+03	0.231603E-05
0.201784E+06	-0.380566E+05	0.852603E+04	0.000000E+00	0.390000E+05	0.118529E+03	0.270000E+03	0.143459E-05
0.205142E+06	-0.409119E+05	0.282274E+04	0.000000E+00	0.410091E+05	0.167339E+03	0.270000E+03	0.369837E-06
0.208591E+06	-0.410567E+05	-0.322815E+04	0.000000E+00	0.411834E+05	0.751318E+02	0.900000E+02	0.102203E-05
0.211960E+06	-0.384905E+05	-0.891415E+04	0.000000E+00	0.395093E+05	0.558884E+02	0.900000E+02	0.212776E-05
0.214689E+06	-0.343359E+05	-0.130381E+05	0.000000E+00	0.367280E+05	0.422827E+02	0.900000E+02	0.304914E-05
0.217418E+06	-0.280996E+05	-0.163385E+05	0.000000E+00	0.325043E+05	0.260342E+02	0.900000E+02	0.414694E-05
0.219718E+06	-0.209470E+05	-0.180004E+05	0.000000E+00	0.276187E+05	0.898179E+01	0.900000E+02	0.554127E-05
0.221162E+06	-0.154020E+05	-0.181552E+05	0.000000E+00	0.238083E+05	0.352172E+01	0.270000E+03	0.696175E-05
0.222606E+06	-0.890137E+04	-0.171464E+05	0.000000E+00	0.193193E+05	0.176978E+02	0.270000E+03	0.929293E-05
0.223623E+06	-0.370962E+04	-0.152743E+05	0.000000E+00	0.157183E+05	0.291803E+02	0.270000E+03	0.119790E-04
0.224299E+06	-0.356143E+02	-0.131613E+05	0.000000E+00	0.131614E+05	0.384433E+02	0.270000E+03	0.146823E-04
0.224975E+06	0.361513E+04	-0.997810E+04	0.000000E+00	0.106128E+05	0.501721E+02	0.270000E+03	0.185484E-04
0.225438E+06	0.582308E+04	-0.694983E+04	0.000000E+00	0.906688E+04	0.604612E+02	0.270000E+03	0.219066E-04
0.225841E+06	0.720686E+04	-0.368771E+04	0.000000E+00	0.809555E+04	0.713163E+02	0.270000E+03	0.250490E-04
0.226243E+06	0.772852E+04	0.915522E-11	0.000000E+00	0.772852E+04	0.827671E+02	0.270000E+03	0.277427E-04

rev 12

time (secs)	x (km)	y (km)	z (km)	r (km)	cone (deg)	clock (deg)	acc (km/s^2)
0.226243E+06	0.772852E+04	-0.734952E-11	0.000000E+00	0.772852E+04	0.651343E+02	0.900000E+02	0.620151E-05
0.226585E+06	0.734820E+04	0.315428E+04	0.000000E+00	0.799659E+04	0.511318E+02	0.900000E+02	0.499715E-05
0.226927E+06	0.630807E+04	0.603422E+04	0.000000E+00	0.872946E+04	0.338175E+02	0.900000E+02	0.398578E-05
0.227330E+06	0.452718E+04	0.889832E+04	0.000000E+00	0.998376E+04	0.119492E+02	0.900000E+02	0.318999E-05
0.227947E+06	0.127891E+04	0.122037E+05	0.000000E+00	0.122705E+05	0.210938E+02	0.270000E+03	0.268102E-05
0.228564E+06	-0.210541E+04	0.145000E+05	0.000000E+00	0.146520E+05	0.444486E+02	0.270000E+03	0.266988E-05
0.229555E+06	-0.732079E+04	0.167942E+05	0.000000E+00	0.183205E+05	0.647116E+02	0.270000E+03	0.283121E-05

0.231014E+06	-0.141746E+05	0.182898E+05	0.000000E+00	0.231395E+05	0.803089E+02	0.270000E+03	0.298132E-05
0.232472E+06	-0.200677E+05	0.184826E+05	0.000000E+00	0.272823E+05	0.889108E+02	0.270000E+03	0.294841E-05
0.235004E+06	-0.283755E+05	0.170898E+05	0.000000E+00	0.331245E+05	0.981143E+02	0.270000E+03	0.262265E-05
0.238072E+06	-0.357952E+05	0.137673E+05	0.000000E+00	0.383515E+05	0.106356E+03	0.270000E+03	0.199268E-05
0.241140E+06	-0.408252E+05	0.948183E+04	0.000000E+00	0.419119E+05	0.115354E+03	0.270000E+03	0.125838E-05
0.245173E+06	-0.442933E+05	0.312888E+04	0.000000E+00	0.444037E+05	0.156855E+03	0.270000E+03	0.290409E-06
0.249327E+06	-0.444175E+05	-0.366230E+04	0.000000E+00	0.445683E+05	0.710487E+02	0.900000E+02	0.859806E-06
0.253369E+06	-0.411994E+05	-0.998141E+04	0.000000E+00	0.423912E+05	0.528212E+02	0.900000E+02	0.184035E-05
0.256520E+06	-0.362444E+05	-0.143155E+05	0.000000E+00	0.389690E+05	0.391303E+02	0.900000E+02	0.263646E-05
0.259670E+06	-0.288331E+05	-0.176375E+05	0.000000E+00	0.337999E+05	0.221358E+02	0.900000E+02	0.363354E-05
0.262274E+06	-0.204709E+05	-0.189915E+05	0.000000E+00	0.279237E+05	0.428028E+01	0.900000E+02	0.497232E-05
0.263784E+06	-0.144820E+05	-0.187523E+05	0.000000E+00	0.236934E+05	0.793039E+01	0.270000E+03	0.629240E-05
0.265294E+06	-0.749856E+04	-0.171747E+05	0.000000E+00	0.187403E+05	0.220363E+02	0.270000E+03	0.849921E-05
0.266317E+06	-0.218574E+04	-0.147974E+05	0.000000E+00	0.149580E+05	0.334715E+02	0.270000E+03	0.109524E-04
0.266950E+06	0.125161E+04	-0.124413E+05	0.000000E+00	0.125041E+05	0.424149E+02	0.270000E+03	0.132670E-04
0.267584E+06	0.455816E+04	-0.905527E+04	0.000000E+00	0.101378E+05	0.540037E+02	0.270000E+03	0.164936E-04
0.267996E+06	0.636496E+04	-0.613714E+04	0.000000E+00	0.884179E+04	0.636059E+02	0.270000E+03	0.189855E-04
0.268344E+06	0.741951E+04	-0.320950E+04	0.000000E+00	0.808394E+04	0.732451E+02	0.270000E+03	0.211140E-04
0.268692E+06	0.780584E+04	0.731784E-11	0.000000E+00	0.780584E+04	0.833590E+02	0.270000E+03	0.227695E-04

rev 13

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.268692E+06	0.780584E+04	-0.845828E-11	0.000000E+00	0.780584E+04	0.648916E+02	0.900000E+02	0.514040E-05
0.269069E+06	0.735516E+04	0.346545E+04	0.000000E+00	0.813067E+04	0.505197E+02	0.900000E+02	0.399351E-05
0.269446E+06	0.614182E+04	0.658527E+04	0.000000E+00	0.900488E+04	0.317402E+02	0.900000E+02	0.313542E-05
0.269890E+06	0.411263E+04	0.962453E+04	0.000000E+00	0.104664E+05	0.844101E+01	0.900000E+02	0.250728E-05
0.270570E+06	0.507687E+03	0.130519E+05	0.000000E+00	0.130618E+05	0.257475E+02	0.270000E+03	0.217294E-05
0.271250E+06	-0.317353E+04	0.153873E+05	0.000000E+00	0.157112E+05	0.482136E+02	0.270000E+03	0.220361E-05
0.272342E+06	-0.876833E+04	0.176815E+05	0.000000E+00	0.197362E+05	0.669794E+02	0.270000E+03	0.232808E-05
0.273950E+06	-0.160464E+05	0.191321E+05	0.000000E+00	0.249704E+05	0.815164E+02	0.270000E+03	0.244616E-05
0.275558E+06	-0.222688E+05	0.192637E+05	0.000000E+00	0.294446E+05	0.895756E+02	0.270000E+03	0.241423E-05
0.278348E+06	-0.310107E+05	0.177521E+05	0.000000E+00	0.357323E+05	0.982124E+02	0.270000E+03	0.214325E-05
0.281729E+06	-0.388012E+05	0.142768E+05	0.000000E+00	0.413444E+05	0.105890E+03	0.270000E+03	0.162735E-05
0.285111E+06	-0.440781E+05	0.983306E+04	0.000000E+00	0.451616E+05	0.114015E+03	0.270000E+03	0.102770E-05
0.289556E+06	-0.477177E+05	0.326691E+04	0.000000E+00	0.478294E+05	0.150025E+03	0.270000E+03	0.221591E-06
0.294134E+06	-0.478547E+05	-0.374784E+04	0.000000E+00	0.480013E+05	0.685835E+02	0.900000E+02	0.691657E-06
0.298590E+06	-0.444894E+05	-0.102863E+05	0.000000E+00	0.456630E+05	0.519745E+02	0.900000E+02	0.150317E-05
0.302062E+06	-0.392985E+05	-0.147908E+05	0.000000E+00	0.419897E+05	0.390465E+02	0.900000E+02	0.216122E-05
0.305534E+06	-0.315209E+05	-0.182803E+05	0.000000E+00	0.364381E+05	0.228143E+02	0.900000E+02	0.297712E-05
0.308404E+06	-0.227214E+05	-0.197659E+05	0.000000E+00	0.301157E+05	0.555357E+01	0.900000E+02	0.405294E-05
0.310068E+06	-0.163959E+05	-0.195954E+05	0.000000E+00	0.255501E+05	0.638918E+01	0.270000E+03	0.510499E-05
0.311732E+06	-0.897675E+04	-0.180687E+05	0.000000E+00	0.201757E+05	0.202873E+02	0.270000E+03	0.686505E-05
0.312860E+06	-0.327463E+04	-0.156936E+05	0.000000E+00	0.160316E+05	0.314832E+02	0.270000E+03	0.883809E-05
0.313558E+06	0.465685E+03	-0.132986E+05	0.000000E+00	0.133067E+05	0.404421E+02	0.270000E+03	0.107341E-04
0.314257E+06	0.413609E+04	-0.978909E+04	0.000000E+00	0.106270E+05	0.523155E+02	0.270000E+03	0.134541E-04
0.314710E+06	0.619501E+04	-0.669404E+04	0.000000E+00	0.912076E+04	0.623106E+02	0.270000E+03	0.156237E-04
0.315094E+06	0.742528E+04	-0.352427E+04	0.000000E+00	0.821921E+04	0.726242E+02	0.270000E+03	0.175360E-04
0.315478E+06	0.788316E+04	0.972544E-11	0.000000E+00	0.788316E+04	0.833734E+02	0.270000E+03	0.190950E-04

rev 14

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.315478E+06	0.788316E+04	-0.829989E-11	0.000000E+00	0.788316E+04	0.644144E+02	0.900000E+02	0.439813E-05
0.315891E+06	0.735550E+04	0.378200E+04	0.000000E+00	0.827085E+04	0.498529E+02	0.900000E+02	0.321335E-05
0.316303E+06	0.595819E+04	0.713707E+04	0.000000E+00	0.929719E+04	0.295859E+02	0.900000E+02	0.248191E-05
0.316790E+06	0.367522E+04	0.103398E+05	0.000000E+00	0.109735E+05	0.494232E+01	0.900000E+02	0.199553E-05
0.317535E+06	-0.282838E+03	0.138760E+05	0.000000E+00	0.138789E+05	0.298996E+02	0.270000E+03	0.179332E-05
0.318280E+06	-0.425410E+04	0.162452E+05	0.000000E+00	0.167929E+05	0.513727E+02	0.270000E+03	0.184533E-05
0.319477E+06	-0.102198E+05	0.185388E+05	0.000000E+00	0.211691E+05	0.689429E+02	0.270000E+03	0.193596E-05

0.321238E+06	-0.179159E+05	0.199486E+05	0.000000E+00	0.268128E+05	0.825534E+02	0.270000E+03	0.202977E-05
0.323000E+06	-0.244653E+05	0.200236E+05	0.000000E+00	0.316148E+05	0.901335E+02	0.270000E+03	0.199994E-05
0.326057E+06	-0.336412E+05	0.183998E+05	0.000000E+00	0.383443E+05	0.982653E+02	0.270000E+03	0.177268E-05
0.329762E+06	-0.418043E+05	0.147767E+05	0.000000E+00	0.443390E+05	0.105432E+03	0.270000E+03	0.134545E-05
0.333467E+06	-0.473298E+05	0.101781E+05	0.000000E+00	0.484118E+05	0.112751E+03	0.270000E+03	0.850027E-06
0.338338E+06	-0.511419E+05	0.340189E+04	0.000000E+00	0.512549E+05	0.142816E+03	0.270000E+03	0.173606E-06
0.343354E+06	-0.512912E+05	-0.383346E+04	0.000000E+00	0.514343E+05	0.661658E+02	0.900000E+02	0.564912E-06
0.348235E+06	-0.477768E+05	-0.105876E+05	0.000000E+00	0.489359E+05	0.511237E+02	0.900000E+02	0.124336E-05
0.352040E+06	-0.423479E+05	-0.152583E+05	0.000000E+00	0.450129E+05	0.388882E+02	0.900000E+02	0.179329E-05
0.355844E+06	-0.342023E+05	-0.189090E+05	0.000000E+00	0.390813E+05	0.233374E+02	0.900000E+02	0.246979E-05
0.358988E+06	-0.249663E+05	-0.205190E+05	0.000000E+00	0.323163E+05	0.662252E+01	0.900000E+02	0.334771E-05
0.360812E+06	-0.183069E+05	-0.204120E+05	0.000000E+00	0.274188E+05	0.506134E+01	0.270000E+03	0.419912E-05
0.362635E+06	-0.104589E+05	-0.189319E+05	0.000000E+00	0.216288E+05	0.187439E+02	0.270000E+03	0.562299E-05
0.363870E+06	-0.437629E+04	-0.165598E+05	0.000000E+00	0.171283E+05	0.296651E+02	0.270000E+03	0.723394E-05
0.364636E+06	-0.339966E+03	-0.141313E+05	0.000000E+00	0.141354E+05	0.386132E+02	0.270000E+03	0.879994E-05
0.365401E+06	0.369074E+04	-0.105119E+05	0.000000E+00	0.111410E+05	0.507242E+02	0.270000E+03	0.110961E-04
0.365898E+06	0.600738E+04	-0.725177E+04	0.000000E+00	0.941683E+04	0.610607E+02	0.270000E+03	0.129826E-04
0.366318E+06	0.742432E+04	-0.384454E+04	0.000000E+00	0.836068E+04	0.719960E+02	0.270000E+03	0.147078E-04
0.366739E+06	0.796048E+04	0.871171E-11	0.000000E+00	0.796048E+04	0.832311E+02	0.270000E+03	0.162684E-04

rev 15

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.366739E+06	0.796048E+04	-0.804646E-11	0.000000E+00	0.796048E+04	0.654107E+02	0.900000E+02	0.353236E-05
0.367111E+06	0.753727E+04	0.341954E+04	0.000000E+00	0.827669E+04	0.524354E+02	0.900000E+02	0.278688E-05
0.367483E+06	0.639149E+04	0.652327E+04	0.000000E+00	0.913259E+04	0.349582E+02	0.900000E+02	0.222262E-05
0.367930E+06	0.441627E+04	0.964471E+04	0.000000E+00	0.106077E+05	0.134813E+02	0.900000E+02	0.177961E-05
0.368641E+06	0.731438E+03	0.133388E+05	0.000000E+00	0.133588E+05	0.217216E+02	0.270000E+03	0.150239E-05
0.369351E+06	-0.305316E+04	0.158930E+05	0.000000E+00	0.161836E+05	0.449049E+02	0.270000E+03	0.150634E-05
0.370562E+06	-0.916079E+04	0.186083E+05	0.000000E+00	0.207410E+05	0.640989E+02	0.270000E+03	0.157378E-05
0.372399E+06	-0.173172E+05	0.204866E+05	0.000000E+00	0.268251E+05	0.798922E+02	0.270000E+03	0.168588E-05
0.374235E+06	-0.242717E+05	0.208718E+05	0.000000E+00	0.320116E+05	0.882726E+02	0.270000E+03	0.169255E-05
0.377620E+06	-0.345948E+05	0.194979E+05	0.000000E+00	0.397111E+05	0.970310E+02	0.270000E+03	0.153046E-05
0.381778E+06	-0.438524E+05	0.158320E+05	0.000000E+00	0.466228E+05	0.104145E+03	0.270000E+03	0.117662E-05
0.385936E+06	-0.501071E+05	0.110298E+05	0.000000E+00	0.513067E+05	0.110761E+03	0.270000E+03	0.756541E-06
0.391543E+06	-0.545215E+05	0.368557E+04	0.000000E+00	0.546459E+05	0.133579E+03	0.270000E+03	0.151211E-06
0.397331E+06	-0.546552E+05	-0.420204E+04	0.000000E+00	0.548165E+05	0.631769E+02	0.900000E+02	0.490114E-06
0.402948E+06	-0.505082E+05	-0.115124E+05	0.000000E+00	0.518036E+05	0.490531E+02	0.900000E+02	0.109640E-05
0.407200E+06	-0.443292E+05	-0.163595E+05	0.000000E+00	0.472516E+05	0.367482E+02	0.900000E+02	0.157847E-05
0.411451E+06	-0.350749E+05	-0.200227E+05	0.000000E+00	0.403876E+05	0.207048E+02	0.900000E+02	0.219436E-05
0.414916E+06	-0.246869E+05	-0.213557E+05	0.000000E+00	0.326421E+05	0.336093E+01	0.900000E+02	0.302917E-05
0.416808E+06	-0.176287E+05	-0.209242E+05	0.000000E+00	0.273604E+05	0.817364E+01	0.270000E+03	0.382211E-05
0.418699E+06	-0.933289E+04	-0.189631E+05	0.000000E+00	0.211354E+05	0.218780E+02	0.270000E+03	0.516737E-05
0.419944E+06	-0.312364E+04	-0.161652E+05	0.000000E+00	0.164643E+05	0.327609E+02	0.270000E+03	0.663396E-05
0.420670E+06	0.711072E+03	-0.135556E+05	0.000000E+00	0.135742E+05	0.415282E+02	0.270000E+03	0.800672E-05
0.421397E+06	0.445009E+04	-0.978765E+04	0.000000E+00	0.107518E+05	0.535970E+02	0.270000E+03	0.999533E-05
0.421853E+06	0.644974E+04	-0.661670E+04	0.000000E+00	0.924012E+04	0.634300E+02	0.270000E+03	0.114828E-04
0.422231E+06	0.760902E+04	-0.346947E+04	0.000000E+00	0.836268E+04	0.734693E+02	0.270000E+03	0.127488E-04
0.422609E+06	0.803780E+04	0.871171E-11	0.000000E+00	0.803780E+04	0.838074E+02	0.270000E+03	0.137515E-04

rev 16

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.422609E+06	0.803780E+04	-0.902850E-11	0.000000E+00	0.803780E+04	0.652891E+02	0.900000E+02	0.299647E-05
0.422990E+06	0.760362E+04	0.349173E+04	0.000000E+00	0.836703E+04	0.528674E+02	0.900000E+02	0.234029E-05
0.423371E+06	0.643093E+04	0.665718E+04	0.000000E+00	0.925607E+04	0.354062E+02	0.900000E+02	0.186707E-05
0.423832E+06	0.439938E+04	0.985888E+04	0.000000E+00	0.107959E+05	0.142162E+02	0.900000E+02	0.149400E-05
0.424574E+06	0.569200E+03	0.136865E+05	0.000000E+00	0.136983E+05	0.220510E+02	0.270000E+03	0.126663E-05
0.425317E+06	-0.335024E+04	0.163275E+05	0.000000E+00	0.166676E+05	0.452089E+02	0.270000E+03	0.127376E-05
0.426603E+06	-0.975592E+04	0.191807E+05	0.000000E+00	0.215192E+05	0.638564E+02	0.270000E+03	0.131607E-05

0.428569E+06	-0.183431E+05	0.211828E+05	0.000000E+00	0.280210E+05	0.797569E+02	0.270000E+03	0.141906E-05
0.430536E+06	-0.256476E+05	0.216296E+05	0.000000E+00	0.335506E+05	0.881141E+02	0.270000E+03	0.143269E-05
0.434220E+06	-0.366490E+05	0.202658E+05	0.000000E+00	0.418790E+05	0.967517E+02	0.270000E+03	0.130273E-05
0.438764E+06	-0.465247E+05	0.164933E+05	0.000000E+00	0.493617E+05	0.103552E+03	0.270000E+03	0.100515E-05
0.443309E+06	-0.531914E+05	0.115284E+05	0.000000E+00	0.544263E+05	0.109523E+03	0.270000E+03	0.650220E-06
0.449482E+06	-0.579294E+05	0.386555E+04	0.000000E+00	0.580582E+05	0.126417E+03	0.270000E+03	0.128544E-06
0.455859E+06	-0.580661E+05	-0.437546E+04	0.000000E+00	0.582307E+05	0.608592E+02	0.900000E+02	0.416137E-06
0.462043E+06	-0.536013E+05	-0.120048E+05	0.000000E+00	0.549292E+05	0.479838E+02	0.900000E+02	0.940278E-06
0.466685E+06	-0.470098E+05	-0.170146E+05	0.000000E+00	0.499942E+05	0.360603E+02	0.900000E+02	0.135471E-05
0.471327E+06	-0.371342E+05	-0.207844E+05	0.000000E+00	0.425551E+05	0.202853E+02	0.900000E+02	0.188765E-05
0.475095E+06	-0.260648E+05	-0.221068E+05	0.000000E+00	0.341772E+05	0.306845E+01	0.900000E+02	0.261239E-05
0.477116E+06	-0.186604E+05	-0.216143E+05	0.000000E+00	0.285550E+05	0.829445E+01	0.270000E+03	0.329386E-05
0.479136E+06	-0.993949E+04	-0.195333E+05	0.000000E+00	0.219168E+05	0.218746E+02	0.270000E+03	0.445392E-05
0.480456E+06	-0.343321E+04	-0.166018E+05	0.000000E+00	0.169531E+05	0.324955E+02	0.270000E+03	0.570967E-05
0.481216E+06	0.540331E+03	-0.139063E+05	0.000000E+00	0.139167E+05	0.412422E+02	0.270000E+03	0.688856E-05
0.481976E+06	0.442914E+04	-0.100044E+05	0.000000E+00	0.109410E+05	0.535495E+02	0.270000E+03	0.861901E-05
0.482446E+06	0.648741E+04	-0.675254E+04	0.000000E+00	0.936393E+04	0.634265E+02	0.270000E+03	0.989438E-05
0.482833E+06	0.767488E+04	-0.354280E+04	0.000000E+00	0.845311E+04	0.735570E+02	0.270000E+03	0.109774E-04
0.483220E+06	0.811512E+04	0.823653E-11	0.000000E+00	0.811512E+04	0.838748E+02	0.270000E+03	0.118487E-04

rev 17

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.483220E+06	0.811512E+04	-0.902850E-11	0.000000E+00	0.811512E+04	0.650662E+02	0.900000E+02	0.256807E-05
0.483609E+06	0.767048E+04	0.356086E+04	0.000000E+00	0.845671E+04	0.532862E+02	0.900000E+02	0.198092E-05
0.483998E+06	0.647215E+04	0.678547E+04	0.000000E+00	0.937718E+04	0.358459E+02	0.900000E+02	0.158065E-05
0.484473E+06	0.438614E+04	0.100650E+05	0.000000E+00	0.109792E+05	0.150122E+02	0.900000E+02	0.126337E-05
0.485247E+06	0.414046E+03	0.140229E+05	0.000000E+00	0.140290E+05	0.224568E+02	0.270000E+03	0.107849E-05
0.486021E+06	-0.363697E+04	0.167484E+05	0.000000E+00	0.171387E+05	0.455665E+02	0.270000E+03	0.108824E-05
0.487383E+06	-0.103382E+05	0.197381E+05	0.000000E+00	0.222816E+05	0.635723E+02	0.270000E+03	0.110754E-05
0.489480E+06	-0.193533E+05	0.218632E+05	0.000000E+00	0.291984E+05	0.796099E+02	0.270000E+03	0.120292E-05
0.491577E+06	-0.270055E+05	0.223717E+05	0.000000E+00	0.350683E+05	0.879694E+02	0.270000E+03	0.122199E-05
0.495571E+06	-0.386909E+05	0.210202E+05	0.000000E+00	0.440322E+05	0.964998E+02	0.270000E+03	0.111757E-05
0.500513E+06	-0.491901E+05	0.171438E+05	0.000000E+00	0.520920E+05	0.103013E+03	0.270000E+03	0.865246E-06
0.505455E+06	-0.562720E+05	0.120189E+05	0.000000E+00	0.575412E+05	0.108395E+03	0.270000E+03	0.563059E-06
0.512215E+06	-0.613368E+05	0.404236E+04	0.000000E+00	0.614698E+05	0.119851E+03	0.270000E+03	0.111608E-06
0.519202E+06	-0.614762E+05	-0.454691E+04	0.000000E+00	0.616441E+05	0.586807E+02	0.900000E+02	0.356775E-06
0.525972E+06	-0.566896E+05	-0.124901E+05	0.000000E+00	0.580492E+05	0.469896E+02	0.900000E+02	0.812800E-06
0.531015E+06	-0.496844E+05	-0.176585E+05	0.000000E+00	0.527291E+05	0.354164E+02	0.900000E+02	0.117148E-05
0.536058E+06	-0.391861E+05	-0.215319E+05	0.000000E+00	0.447121E+05	0.198929E+02	0.900000E+02	0.163569E-05
0.540137E+06	-0.274312E+05	-0.228426E+05	0.000000E+00	0.356967E+05	0.277731E+01	0.900000E+02	0.226926E-05
0.542291E+06	-0.196730E+05	-0.222889E+05	0.000000E+00	0.297292E+05	0.846043E+01	0.270000E+03	0.286077E-05
0.544445E+06	-0.105160E+05	-0.200833E+05	0.000000E+00	0.226699E+05	0.219509E+02	0.270000E+03	0.387135E-05
0.545842E+06	-0.371010E+04	-0.170127E+05	0.000000E+00	0.174125E+05	0.322745E+02	0.270000E+03	0.495591E-05
0.546633E+06	0.393964E+03	-0.142322E+05	0.000000E+00	0.142377E+05	0.410052E+02	0.270000E+03	0.597669E-05
0.547424E+06	0.442266E+04	-0.101997E+05	0.000000E+00	0.111172E+05	0.535690E+02	0.270000E+03	0.749366E-05
0.547907E+06	0.653236E+04	-0.687185E+04	0.000000E+00	0.948125E+04	0.634645E+02	0.270000E+03	0.859408E-05
0.548302E+06	0.774284E+04	-0.360679E+04	0.000000E+00	0.854169E+04	0.736618E+02	0.270000E+03	0.952598E-05
0.548697E+06	0.819244E+04	0.966208E-11	0.000000E+00	0.819244E+04	0.839139E+02	0.270000E+03	0.102896E-04

rev 18

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.548697E+06	0.819244E+04	-0.874339E-11	0.000000E+00	0.819244E+04	0.646571E+02	0.900000E+02	0.223023E-05
0.549097E+06	0.773212E+04	0.364976E+04	0.000000E+00	0.855023E+04	0.536056E+02	0.900000E+02	0.168484E-05
0.549497E+06	0.649548E+04	0.694791E+04	0.000000E+00	0.951130E+04	0.360661E+02	0.900000E+02	0.134224E-05
0.549987E+06	0.434249E+04	0.103068E+05	0.000000E+00	0.111842E+05	0.154871E+02	0.900000E+02	0.107163E-05
0.550792E+06	0.231235E+03	0.143763E+05	0.000000E+00	0.143782E+05	0.230836E+02	0.270000E+03	0.926727E-06
0.551597E+06	-0.394511E+04	0.171748E+05	0.000000E+00	0.176220E+05	0.460130E+02	0.270000E+03	0.938900E-06
0.553035E+06	-0.109337E+05	0.202907E+05	0.000000E+00	0.230490E+05	0.633328E+02	0.270000E+03	0.937617E-06

0.555263E+06	-0.203672E+05	0.225319E+05	0.000000E+00	0.303729E+05	0.794882E+02	0.270000E+03	0.102632E-05
0.557491E+06	-0.283595E+05	0.230993E+05	0.000000E+00	0.365765E+05	0.878520E+02	0.270000E+03	0.104951E-05
0.561800E+06	-0.407280E+05	0.217608E+05	0.000000E+00	0.461769E+05	0.962751E+02	0.270000E+03	0.965472E-06
0.567150E+06	-0.518510E+05	0.177835E+05	0.000000E+00	0.548158E+05	0.102521E+03	0.270000E+03	0.749954E-06
0.572500E+06	-0.593484E+05	0.125029E+05	0.000000E+00	0.606511E+05	0.107360E+03	0.270000E+03	0.490938E-06
0.579865E+06	-0.647434E+05	0.421730E+04	0.000000E+00	0.648807E+05	0.113941E+03	0.270000E+03	0.986114E-07
0.587483E+06	-0.648858E+05	-0.471543E+04	0.000000E+00	0.650569E+05	0.566347E+02	0.900000E+02	0.308483E-06
0.594860E+06	-0.597742E+05	-0.129682E+05	0.000000E+00	0.611648E+05	0.460651E+02	0.900000E+02	0.707611E-06
0.600315E+06	-0.523523E+05	-0.182929E+05	0.000000E+00	0.554562E+05	0.348107E+02	0.900000E+02	0.102003E-05
0.605769E+06	-0.412260E+05	-0.222676E+05	0.000000E+00	0.468554E+05	0.195176E+02	0.900000E+02	0.142696E-05
0.610168E+06	-0.287830E+05	-0.235646E+05	0.000000E+00	0.371988E+05	0.248888E+01	0.900000E+02	0.198416E-05
0.612453E+06	-0.206857E+05	-0.229519E+05	0.000000E+00	0.308980E+05	0.862965E+01	0.270000E+03	0.250021E-05
0.614738E+06	-0.111120E+05	-0.206312E+05	0.000000E+00	0.234334E+05	0.220130E+02	0.270000E+03	0.338391E-05
0.616211E+06	-0.401872E+04	-0.174355E+05	0.000000E+00	0.178927E+05	0.319760E+02	0.270000E+03	0.432496E-05
0.617033E+06	0.212564E+03	-0.145816E+05	0.000000E+00	0.145832E+05	0.406742E+02	0.270000E+03	0.521197E-05
0.617856E+06	0.438194E+04	-0.104359E+05	0.000000E+00	0.113185E+05	0.534677E+02	0.270000E+03	0.654363E-05
0.618354E+06	0.655760E+04	-0.702930E+04	0.000000E+00	0.961318E+04	0.633875E+02	0.270000E+03	0.750252E-05
0.618760E+06	0.780505E+04	-0.369285E+04	0.000000E+00	0.863458E+04	0.736949E+02	0.270000E+03	0.831667E-05
0.619165E+06	0.826976E+04	0.753959E-11	0.000000E+00	0.826976E+04	0.838790E+02	0.270000E+03	0.900742E-05

rev 19

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.619165E+06	0.826976E+04	-0.921858E-11	0.000000E+00	0.826976E+04	0.641569E+02	0.900000E+02	0.195684E-05
0.619576E+06	0.779445E+04	0.373494E+04	0.000000E+00	0.864310E+04	0.539321E+02	0.900000E+02	0.144196E-05
0.619986E+06	0.652126E+04	0.710357E+04	0.000000E+00	0.964301E+04	0.363078E+02	0.900000E+02	0.114676E-05
0.620491E+06	0.430509E+04	0.105378E+05	0.000000E+00	0.113833E+05	0.160363E+02	0.900000E+02	0.914514E-06
0.621325E+06	0.644370E+02	0.147125E+05	0.000000E+00	0.147126E+05	0.236556E+02	0.270000E+03	0.803189E-06
0.622160E+06	-0.422847E+04	0.175811E+05	0.000000E+00	0.180824E+05	0.463847E+02	0.270000E+03	0.816836E-06
0.623673E+06	-0.115033E+05	0.208261E+05	0.000000E+00	0.237918E+05	0.629902E+02	0.270000E+03	0.796826E-06
0.626035E+06	-0.213603E+05	0.231867E+05	0.000000E+00	0.315260E+05	0.793345E+02	0.270000E+03	0.880192E-06
0.628397E+06	-0.296961E+05	0.238140E+05	0.000000E+00	0.380653E+05	0.877408E+02	0.270000E+03	0.906910E-06
0.633030E+06	-0.427538E+05	0.224904E+05	0.000000E+00	0.483085E+05	0.960695E+02	0.270000E+03	0.839503E-06
0.638799E+06	-0.545050E+05	0.184148E+05	0.000000E+00	0.575317E+05	0.102067E+03	0.270000E+03	0.654180E-06
0.644567E+06	-0.624208E+05	0.129809E+05	0.000000E+00	0.637562E+05	0.106406E+03	0.270000E+03	0.430755E-06
0.652557E+06	-0.681495E+05	0.439014E+04	0.000000E+00	0.682908E+05	0.108697E+03	0.270000E+03	0.883085E-07
0.660825E+06	-0.682946E+05	-0.488203E+04	0.000000E+00	0.684689E+05	0.547114E+02	0.900000E+02	0.268788E-06
0.668827E+06	-0.628548E+05	-0.134403E+05	0.000000E+00	0.642757E+05	0.452012E+02	0.900000E+02	0.620044E-06
0.674703E+06	-0.550160E+05	-0.189176E+05	0.000000E+00	0.581776E+05	0.342421E+02	0.900000E+02	0.893671E-06
0.680580E+06	-0.432624E+05	-0.229910E+05	0.000000E+00	0.489920E+05	0.191684E+02	0.900000E+02	0.125230E-05
0.685304E+06	-0.301305E+05	-0.242741E+05	0.000000E+00	0.386921E+05	0.220808E+01	0.900000E+02	0.174495E-05
0.687724E+06	-0.216902E+05	-0.236033E+05	0.000000E+00	0.320559E+05	0.882866E+01	0.270000E+03	0.219852E-05
0.690144E+06	-0.116939E+05	-0.211664E+05	0.000000E+00	0.241819E+05	0.221291E+02	0.270000E+03	0.297705E-05
0.691694E+06	-0.431274E+04	-0.178444E+05	0.000000E+00	0.183582E+05	0.316903E+02	0.270000E+03	0.379948E-05
0.692546E+06	0.389962E+02	-0.149206E+05	0.000000E+00	0.149206E+05	0.403555E+02	0.270000E+03	0.457478E-05
0.693399E+06	0.434205E+04	-0.106684E+05	0.000000E+00	0.115182E+05	0.533817E+02	0.270000E+03	0.574864E-05
0.693912E+06	0.658248E+04	-0.718579E+04	0.000000E+00	0.974498E+04	0.633132E+02	0.270000E+03	0.658908E-05
0.694328E+06	0.786712E+04	-0.377853E+04	0.000000E+00	0.872748E+04	0.737247E+02	0.270000E+03	0.730525E-05
0.694745E+06	0.834708E+04	0.636747E-11	0.000000E+00	0.834708E+04	0.837996E+02	0.270000E+03	0.794026E-05

rev 20

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.694745E+06	0.834708E+04	-0.782470E-11	0.000000E+00	0.834708E+04	0.635845E+02	0.900000E+02	0.173363E-05
0.695165E+06	0.785757E+04	0.381614E+04	0.000000E+00	0.873523E+04	0.542698E+02	0.900000E+02	0.124104E-05
0.695586E+06	0.654985E+04	0.725205E+04	0.000000E+00	0.977204E+04	0.365764E+02	0.900000E+02	0.985172E-06
0.696105E+06	0.427320E+04	0.107593E+05	0.000000E+00	0.115768E+05	0.166777E+02	0.900000E+02	0.784456E-06
0.696968E+06	-0.936442E+02	0.150378E+05	0.000000E+00	0.150381E+05	0.242383E+02	0.270000E+03	0.701856E-06
0.697832E+06	-0.450055E+04	0.179757E+05	0.000000E+00	0.185305E+05	0.467523E+02	0.270000E+03	0.716535E-06
0.699422E+06	-0.120628E+05	0.213504E+05	0.000000E+00	0.245225E+05	0.625843E+02	0.270000E+03	0.679251E-06

0.701921E+06	-0.223465E+05	0.238305E+05	0.000000E+00	0.326690E+05	0.791685E+02	0.270000E+03	0.758275E-06
0.704419E+06	-0.310276E+05	0.245167E+05	0.000000E+00	0.395447E+05	0.876449E+02	0.270000E+03	0.788033E-06
0.709383E+06	-0.447762E+05	0.232085E+05	0.000000E+00	0.504335E+05	0.958841E+02	0.270000E+03	0.734259E-06
0.715580E+06	-0.571560E+05	0.190365E+05	0.000000E+00	0.602428E+05	0.101649E+03	0.270000E+03	0.573913E-06
0.721777E+06	-0.654904E+05	0.134524E+05	0.000000E+00	0.668578E+05	0.105521E+03	0.270000E+03	0.380087E-06
0.730410E+06	-0.715552E+05	0.456044E+04	0.000000E+00	0.717004E+05	0.104078E+03	0.270000E+03	0.798802E-07
0.739347E+06	-0.717028E+05	-0.504707E+04	0.000000E+00	0.718802E+05	0.529023E+02	0.900000E+02	0.235832E-06
0.747993E+06	-0.659314E+05	-0.139070E+05	0.000000E+00	0.673822E+05	0.443930E+02	0.900000E+02	0.546554E-06
0.754302E+06	-0.576727E+05	-0.195350E+05	0.000000E+00	0.608914E+05	0.337036E+02	0.900000E+02	0.787496E-06
0.760611E+06	-0.452867E+05	-0.237049E+05	0.000000E+00	0.511156E+05	0.188321E+02	0.900000E+02	0.110528E-05
0.765670E+06	-0.314591E+05	-0.249721E+05	0.000000E+00	0.401657E+05	0.191291E+01	0.900000E+02	0.154332E-05
0.768227E+06	-0.226731E+05	-0.242421E+05	0.000000E+00	0.331926E+05	0.907838E+01	0.270000E+03	0.194493E-05
0.770784E+06	-0.122501E+05	-0.216856E+05	0.000000E+00	0.249065E+05	0.223184E+02	0.270000E+03	0.263578E-05
0.772410E+06	-0.458246E+04	-0.182345E+05	0.000000E+00	0.188015E+05	0.314338E+02	0.270000E+03	0.335938E-05
0.773291E+06	-0.118574E+03	-0.152431E+05	0.000000E+00	0.152436E+05	0.400669E+02	0.270000E+03	0.404090E-05
0.774173E+06	0.430875E+04	-0.108903E+05	0.000000E+00	0.117117E+05	0.533295E+02	0.270000E+03	0.507983E-05
0.774700E+06	0.661006E+04	-0.733538E+04	0.000000E+00	0.987424E+04	0.632590E+02	0.270000E+03	0.581991E-05
0.775127E+06	0.792996E+04	-0.386039E+04	0.000000E+00	0.881968E+04	0.737621E+02	0.270000E+03	0.645313E-05
0.775553E+06	0.842440E+04	0.906018E-11	0.000000E+00	0.842440E+04	0.836845E+02	0.270000E+03	0.704404E-05

rev 21

time(secs)	x(km)	y(km)	z(km)	r(km)	cone(deg)	clock(deg)	acc(km/s^2)
0.775553E+06	0.842440E+04	-0.997887E-11	0.000000E+00	0.842440E+04	0.254355E+02	0.900000E+02	0.261577E-06
0.775985E+06	0.791970E+04	0.390062E+04	0.000000E+00	0.882816E+04	0.162779E+03	0.270000E+03	0.460160E-07
0.776416E+06	0.657519E+04	0.740618E+04	0.000000E+00	0.990377E+04	0.175891E+03	0.270000E+03	0.450090E-07
0.776951E+06	0.422852E+04	0.109961E+05	0.000000E+00	0.117811E+05	0.131966E+03	0.900000E+02	0.644070E-07
0.777851E+06	-0.299981E+03	0.154010E+05	0.000000E+00	0.154039E+05	0.772942E+02	0.270000E+03	0.557935E-07
0.778750E+06	-0.485250E+04	0.184174E+05	0.000000E+00	0.190459E+05	0.845563E+02	0.270000E+03	0.629366E-07
0.780429E+06	-0.127398E+05	0.219229E+05	0.000000E+00	0.253558E+05	0.833028E+02	0.900000E+02	0.719809E-07
0.783081E+06	-0.234852E+05	0.245192E+05	0.000000E+00	0.339521E+05	0.722196E+02	0.900000E+02	0.442159E-07
0.785734E+06	-0.325341E+05	0.252636E+05	0.000000E+00	0.411912E+05	0.717500E+02	0.900000E+02	0.157960E-07
0.791075E+06	-0.470158E+05	0.239767E+05	0.000000E+00	0.527766E+05	0.637456E+02	0.270000E+03	0.156616E-08
0.797760E+06	-0.600316E+05	0.197251E+05	0.000000E+00	0.631892E+05	0.716224E+02	0.270000E+03	0.201105E-08
0.804446E+06	-0.687480E+05	0.140165E+05	0.000000E+00	0.701623E+05	0.745267E+02	0.270000E+03	0.527603E-08
0.813753E+06	-0.750129E+05	0.492238E+04	0.000000E+00	0.751743E+05	0.422960E+01	0.270000E+03	0.520702E-10
0.823388E+06	-0.750129E+05	-0.492238E+04	0.000000E+00	0.751743E+05	0.422961E+01	0.900000E+02	0.520702E-10
0.832696E+06	-0.687480E+05	-0.140165E+05	0.000000E+00	0.701623E+05	0.745267E+02	0.900000E+02	0.527603E-08
0.839381E+06	-0.600316E+05	-0.197251E+05	0.000000E+00	0.631892E+05	0.716224E+02	0.900000E+02	0.201105E-08
0.846067E+06	-0.470158E+05	-0.239767E+05	0.000000E+00	0.527766E+05	0.637456E+02	0.900000E+02	0.156616E-08
0.851408E+06	-0.325341E+05	-0.252636E+05	0.000000E+00	0.411912E+05	0.717500E+02	0.270000E+03	0.157960E-07
0.854060E+06	-0.234852E+05	-0.245192E+05	0.000000E+00	0.339521E+05	0.722196E+02	0.270000E+03	0.442159E-07
0.856713E+06	-0.127398E+05	-0.219229E+05	0.000000E+00	0.253558E+05	0.833028E+02	0.270000E+03	0.719810E-07
0.858391E+06	-0.485250E+04	-0.184174E+05	0.000000E+00	0.190459E+05	0.845562E+02	0.900000E+02	0.629368E-07
0.859291E+06	-0.299975E+03	-0.154010E+05	0.000000E+00	0.154039E+05	0.772943E+02	0.900000E+02	0.557930E-07
0.860191E+06	0.422852E+04	-0.109961E+05	0.000000E+00	0.117811E+05	0.131966E+03	0.270000E+03	0.644070E-07
0.860726E+06	0.657519E+04	-0.740619E+04	0.000000E+00	0.990377E+04	0.175891E+03	0.900000E+02	0.450088E-07
0.861157E+06	0.791970E+04	-0.390062E+04	0.000000E+00	0.882816E+04	0.162779E+03	0.900000E+02	0.460163E-07
0.861588E+06	0.842440E+04	0.113411E-10	0.000000E+00	0.842440E+04	0.254355E+02	0.270000E+03	0.261577E-06

Total Time for Spiral Maneuver = 0.997209E+01 days

*****Run Completed*****

B-4.0 ANALYTIC MODELS

B-4.1 INTER TRAJECTORY SIMULATION

Given the times of encounter of each of the planets in the trajectory sequence, a sun-centered conic approximation can be calculated from the ephemeris positions of any two subsequent planets and the time of flight between the encounters. With the positions and the time of flight known, a simple Lambert-type solution will be calculated to provide the sun-centered velocity at each of the encounter points. The Lambert algorithm can be found in reference B-3. Once the sun-centered velocities are calculated, then the escape velocity (v_∞) can be obtained by subtracting away the planetary velocity from the heliocentric s/c velocity.

$$v_\infty = v_{s/c} - v_{planet}$$

The v_∞'s of arrival and departure at each planet can then be utilized to calculate launches, orbital insertions, and gravity-assist swingbys. A generalized gravity-assist mission is shown in figure 1.

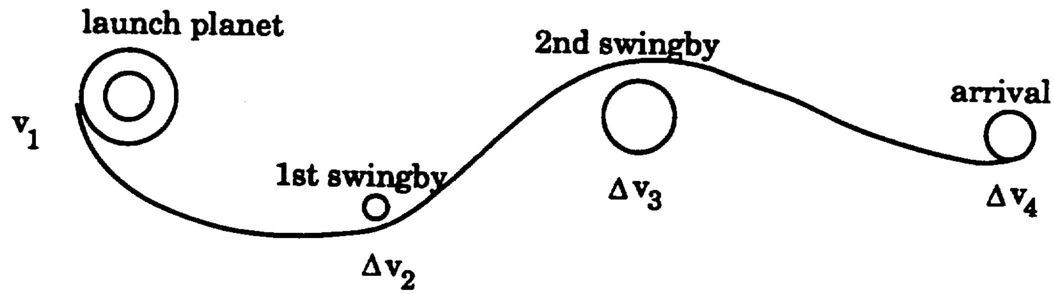


figure 1. Generalized Interplanetary Mission

In this mission, a launch maneuver is performed from planet 1. Two gravity-assist swingbys are performed at planets 2 and 3, which may, or may not require ΔV's, depending on the planetary geometry. Finally, an orbital insertion maneuver is performed at planet 4. The heliocentric portions of the trajectory are difined by the ephemeris positions of the planets, and the v_∞'s calculated by the above equation. The launch, swingby, and orbital insertion maneuvers will be discussed in the following sections.

IPREP also has the capability of calculating low thrust trajectories between two encounter points. Applying the core programs used in QT2 (reference B-6), IPREP approximates the powered heliocentric trajectory using Chebychev polynomials. Output gives S/C acceleration vector magnitude and direction due to the low thrust engines. The thrust acceleration direction output from the low thrust routines is given in the cone/clock angles system shown in Figure 2 -9. The cone angle for the acceleration vector may be constrained from 1 to 4 constant values or allowed to vary continuously along with the clock angle and magnitude.

Since IPOST does not accept cone and clock angles for S/C orientation, IPREP converts the acceleration vector to magnitude, yaw, and pitch in the heliocentric, ecliptic system. During the periods where the cone angle is fixed, cubic polynomial coefficients are calculated for magnitude, yaw and pitch. These polynomials are time-dependent and fit into IPOST inputs. A sample low thrust case is shown.

B-4.2 LAUNCH MANEUVER

Since we know the radius of periapsis (r_p), the radius of apoapsis (r_a), and the inclination (i) of our park orbit (these are all user inputs), along with the v_∞ which we calculated from the Lambert solution, we can obtain the Δ required at the launch planet to reach the target planet.

$$C_3 = v_\infty^2$$

v-infinity unit vector,

$$vu = \text{unit}\,(v_\infty)$$

semi-major axis,

$$a = \left(\frac{-\mu}{C_3}\right)$$

declination of escape asymptote,

$$\delta = \text{atan}\left(\frac{vu_z}{\sqrt{vu_x^2 + vu_y^2}}\right)$$

$$b = r_p \sqrt{1 - \frac{2a}{r_p}}$$

$$\phi = \text{atan}\frac{b}{a}$$

park orbit periapsis velocity,

$$v_{park} = \sqrt{2\mu\left(\frac{1}{r_p} - \frac{1}{(r_p + r_a)}\right)}$$

escape periapsis velocity,

$$v_p = \frac{bv_\infty}{r_p}$$

If the inclination of the park orbit is greater than the declination of the departure asymptote then no plane change is required and the Δv is simply calculated

$$\Delta v = \text{abs}\,(v_p - v_{park}).$$

If the inclination of the park orbit is less than the declination of the departure asymptote, then a plane change is required and the Δv is calculated

$$\Delta v_{pc} = 2v_p \sin\left(\frac{\text{abs}\,(\delta) - i}{2}\right)$$

and

$$\Delta v = \text{abs}\,(v_p - v_{park}) + \Delta v_{pc}.$$

B-4.3 SWINGBY MANEUVER

Since we know the incoming and outgoing v-infinity vectors to the swingby planet, we can calculate the required delta-v at the flyby, if one is needed. The two asymptotes define the required turn, which in turn defines the radius of closest approach. If the radius of closest approach is not within the mission limits the user has defined (beneath the surface of the planet for instance) then a delta-v will be required to achieve the proper turn angle with the user defined radius. Also, if the magnitudes of the asymptotes are different, a delta-v will be required to give the proper escape velocity.

$$v_\infty(in) = | v_\infty(in) |$$

$$v_\infty(out) = | v_\infty(out) |$$

required turn angle,

$$\phi = \cos^{-1}\left(\frac{v_\infty(in)\ v_\infty(out)}{v_\infty(in) v_\infty(out)}\right)$$

flyby radius,

$$rca = \mu\left(\frac{\left(\frac{1}{\sin\left(\frac{\phi}{2}\right)} - 1\right)}{v_\infty^{2}(out)}\right)$$

if $r_{ca} > r_{max}$ then $r_{ca} = r_{max}$, or
if $r_{ca} < r_{min}$ then $r_{ca} = r_{min}$,

where r_{max} and r_{min} are the user input bounds for the closest approach. If one or the other of these cases is true, then the needed turn angle cannot be achieved within the user specified bounds for closest approach. A delta-v is required to get the proper turn angle,

$$\phi_m = 2 \sin\left(\frac{1}{1 + \frac{r_{ca} v_\infty^{2}(out)}{\mu}}\right)$$

where f_m is the turn angle the planets gravity is capable of within the bounds of r_{max} and r_{min}. The delta-v required to make up the turn angle difference is then

$$\Delta v = \sqrt{v_\infty^{2}(in) + v_\infty^{2}(out) - 2 v_{\infty(in)} v_{\infty(out)} \cos(\phi - \phi_m)}\ .$$

If a delta-v is not required to change the turn angle, then the delta-v calculation is made only for the change in magnitude,

$$\Delta v = | v_\infty(in) - v_\infty(out) | .$$

Also included in IPREP is a periapsis burn optimization method for minimizing the delta-v of the swingby. The specifics of this method can be found in reference B-4.

B-4.4 ORBITAL INSERTION MANEUVER

The orbit insertion maneuver is calculated using the v_∞ vector, the inclination of the desired park orbit, the radii of periapsis and apoapsis of the desired park orbit.

$$v_\infty = |v_\infty|$$

$$r_{hyp} = r_p$$

where r_{hyp} is the hyperbolic periapsis, and r_p is the desired periapsis for the park orbit.

$$\phi = 2 \sin\left(\frac{1}{1 + \frac{r_{hyp} v_\infty}{\mu}}\right)$$

$$e = \sqrt{\tan^2\phi + 1}$$

$$a = \frac{r_{hyp}}{1 - e^2}$$

$$v_{hyp} = \sqrt{\frac{2\mu}{r_{hyp}} - v_\infty^2}$$

$$v_\infty^2(out) = \frac{r_p + r_a}{2}$$

$$v_p = \sqrt{\frac{2\mu}{r_{hyp}} - \frac{\mu}{a_1}}$$

$$\Delta v_1 = v_{ph} - v_p$$

If the declination of the incoming asymptote (Δ) is greater than the inclination of the park orbit (i), then there is also a plane change required,

$$\Delta v_2 = 2\, v_\infty \sin\left(\frac{\delta - i}{2}\right)$$

Now, the total delta-v required is

$$\Delta v = \Delta v_1 + \Delta v_2 \,.$$

B-4.5 OPTIMUM MIDCOURSE - DESCRIPTION OF THE PROBLEM

In the coplanar case, the evaluation of the optimal transfer is easily accomplished using the solution of Lambert's problem. However, if the plane of the arrival planet is sufficiently inclined, the point at arrival is close to the peak of this inclined surface, and the initial and final trajectory points are at a maximum angular displacement with respect to the central attracting body, one can be assured that the single impulse solution will be non-optimal. In these and other slightly perturbed casesd, a two impulse solution with one of the impulses being a midcourse maneuver is always a superior solution. Numerous studies and implementations of analytic solutions have been developed to identify the placement and timing of this midcourse maneuver. However, it is questionable whether these analytic solutions are sufficiently robust to find optimal solutions when the objective function diverges significantly away from the one originally used in the derivation of the analytic solution. To eliminate this uncertainity, the authors developed a method of "stacked optimizers" which is not as mathematically elegant as many of the closed-form solutions derived in recent years but does remove the dependence upon the derivation of the solution.

To employ the staked optimizer method, the problem pf the optimal midcourse maneuver needed to be divided up into a set of independent subproblems. Each subproblem would need to converge upon a local optimum before its result would be fet to the upper level optimization. The stacked optimizer approach essentially uses three levels of optimizers. The initial level is a one-dimensional minimizer that requires a bracketed range to enclose the domain of acceptable control variables. At this level the control variable is the time of the midcourse maneuver and is bounded by the launch and arrive dates. This level of optimization simply tests values of a function by perturbing values of midcourse maneuver timing until a minimum value for the objective function, usually delta velocity is found. The function that is tested by the first level optimizer is itself a two dimensional optimizer. This second level optimizer uses the heliocentric declination and right ascension as control variables. Again, these variables are perturbed until a set of values are found that result in a converged objective function value. These perturbed values are used as constants in a final thrid level optimizer. In this final level of optimization the position magnitude is optimized in the direction defined by the higher level angular direction components until a minimum objective value is identified. In all three levles, the objective function value is the same as that evaluated by the third level magnitude optimzer, it is simply carried to the top as each optimzer converges.

It is important to note that the method used to calculate the objective function does not affect the optimization method used to determine where the original midcourse exists, but that differences to the objective function will change where the optimal midcourse is placed. Essentially, this method converges on the mimimum regardless of how thwe objective is calculated. In this manner, each level of optimization is itself given a converged solution for optimal delta velocity. As each subproblem is satisfied with a converged solution, the next higher level recomputes with perturbed control variables until a global minimum is found.

This numerical method lends itself easily to modifications of the obective function evaluation since the stacked optimizers will converge on the solution regardless of the methos used to generate the objective function. Therefore, if the mission analyst wished to optimize on delta velocity injection, modcourse, arrival, or any combination of these in a scaled or unscaled manner, he/she could expect the method to converge upon the true minimum for his/her problem. Additionally, the implementation used by the authors allows the user to constrain many of the delta velocities. Again, this method has no difficulty re-evaluating midcourse maneuvers to satisfy the constraints.

B-4.6 MASS MODELING

For each delta-v which occurs in the interplanetary trajectory, there is also a delta-mass which is calculated by the rocket equation.

$$m_f = m_i e^{-\Delta v/(gIsp)}$$

where m_i is the initial mass before the burn, m_f is the final mass after the burn, Δv is the delta-v of the burn, Isp is the specific impulse of the rocket engines, and g is the acceleration due to gravity (9.806×10^{-3} km/s^2). Since the change in mass is entirely propellant, the mass of the tankage to hold this propellant also needs to be calculated. Therefore

$$m_{tank} = f \times m_{prop}$$

$$m_{prop} = m_i - m_f$$

and

$$f = \text{tankage mass fraction.}$$

Therefore the final mass for any trajectory leg burn will be

$$m_f = m_i - m_{prop} - m_{tank} - m_{jettison}$$

where $m_{jettison}$ is the mass of any structure, probe, or payload jettison for the current leg of the mission.

This process is repeated for each burn until a final mass is calculated for the entire mission, which will be the payload for the vehicle, $m_{payload}$. This value can be maximized at arrival. Also within IPREP is the capability to input $m_{payload}$ and back out what the initial mass would be by reversing the above calculations. Then the initial mass can be minimized when a specific payload is required for the mission.

B-4.7 COST MODELING

The cost equation in IPREP for each interplanetary trajectory is as follows.

$$\text{cost} = \sum_{i=1}^{n}\left(\frac{v_{\infty}(\text{out})}{tol_{1i}} + \frac{v_{\infty}(\text{in})}{tol_{2i}} + \frac{mass_{(\text{out})}}{tol_{3i}} + \frac{mass_{(\text{in})}}{tol_{4i}} + \frac{\Delta v_i}{tol_{5i}}\right)$$

where the tol_{ji}'s are the weightings on each of these cost variables for each trajectory leg. The defaults for each of these weights is $+\infty$ so the cost function will only be dependent on the variables for which the user inputs tolerances.

B-4.8 LPREP TRAJECTORY SIMULATION

Since the Earth-Moon problem is much more complicated than a similar interplanetary problem, simple conic trajectories have insufficient precision to fulfill the accuracy requirements. By allowing only the Earth to affect the trajectory until the s/c encounters the lunar sphere of influence (SOI), and then switching to a Moon-centered system, assuming it is now only moving under lunar gravitation, we can still use 2-body orbital mechanics. This is still an estimate, called the patched-conic approximation, but it is sufficient for our needs.

The setup is much the same as in IPREP. A general Earth-Moon roundtrip trajectory is shown in figure B-4.2 below.

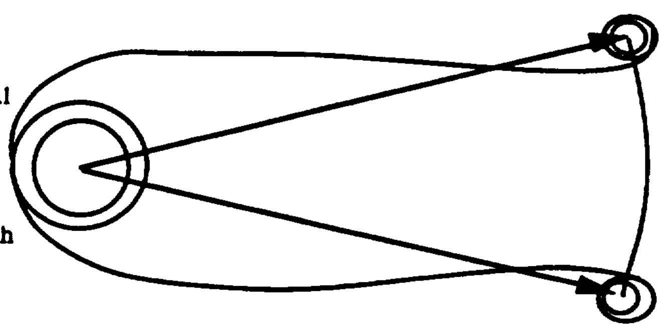


Figure 4.2 Earth-Moon roundtrip trajectory

In figure B-4.2 a departure is made from low-Earth orbit , the s/c is flown to lunar periapsis, an orbit insertion maneuver is performed to place the s/c into low-lunar orbit, some time later a launch maneuver is performed to return to perigee and another maneuver is performed to place the s/c back into low-Earth orbit.

Another difference between LPREP and IPREP is that LPREP uses a Newton-Raphson method to target to actual conditions at the Moon and Earth. The development of the Newton-Raphson method can be found in reference B-1. The user inputs the park orbit periapsis, apoapsis and inclination at both the Earth and Moon, and the time of flight from perigee to the lunar SOI (or vice-versa if a return mission is being calculated). A point is chosen on the lunar SOI and a 2-body conic trajectory is calculated from perigee to this point utilizing methods in reference B-5. The trajectory state is then converted to the Moon system and the trajectory is again propagated by 2-body conics to perilune. The target conditions are then calculated, along with the errors and sensitivity matrix. The point of penetration of the SOI is then changed accordingly, until the proper target conditions are achieved.

The return trajectory is solved the same way as the departure, i.e the Earth-Moon trajectory is calculated and then the velocity vectors are reversed. This gives you a Moon-Earth trajectory.

The free return trajectory is done much the same way as the Earth-Moon problem except that the time to the Moon becomes a free variable (along with the penetration point on the SOI) and the return perigee becomes a new target.

The algorithm must find the correct point of penetration and time of flight to not only get the proper flyby conditions at the Moon but also the correct return radius. No delta-v is performed at the moon, thus constituting a 'free' return.

In figures B-4.3 and B-4.4, there are two launches from a space station orbit shown. In figure B-4.3, the space station orbit and the trans-lunar trajectory are coplanar, so there is no need for a plane change maneuver at Earth launch. In other words, δ, the declination of the moon relative to the space station orbit at arrival is zero, or near zero. Figure B-4.4 shows a translunar trajectory where δ is not zero. Past studies have shown that the cheapest lunar missions occur when this value of δ is at zero. A plane change at launch is very expensive, so if the mission is limited to a coplanar launch, then mission opportunities will occur only when δ is at, or near, zero. Figure B-4.5 is a graph of how δ, the declination of the moon relative to the space station orbit, changes over time. The space station orbit is precessing with time, due to J_2 effects, about 7° per day. It can be seen from figure B-4.5 that opportunities with coplanar launches occur approximately every 6 to 11 days. Trans-lunar trajectory will be flown coplanar, targeting to lunar periapsis, and the insertion into lunar orbit (including any necessary plane changes) will be performed. Lunar orbital plane changes are relatively cheap.

Return from the moon to Earth is calculated similarly, except that the necessary plane change is performed at launch from the moon with a coplanar arrival into space station orbit at the Earth.

The same missions can be performed to Earth-moon libration points. The libration point setup is shown in figure B-4.6.

The cost of the mission is currently based on the total delta-v. The best mission will be the one with the minimum delta-v. There will be improved cost analysis in future updates.

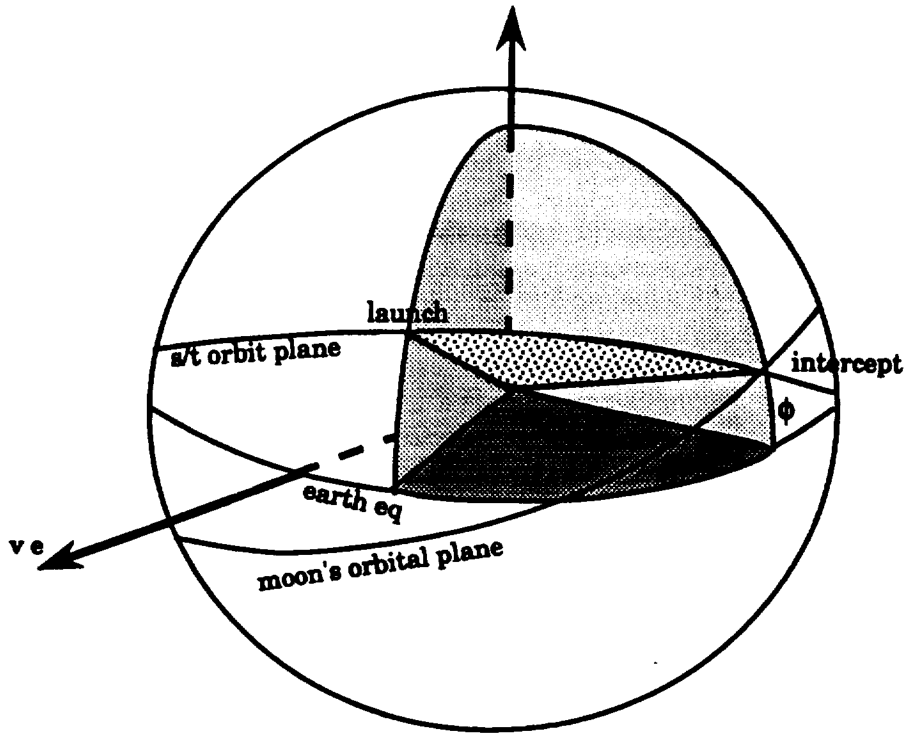


Figure B - 4.3 Zero Declination Lunar Transfer

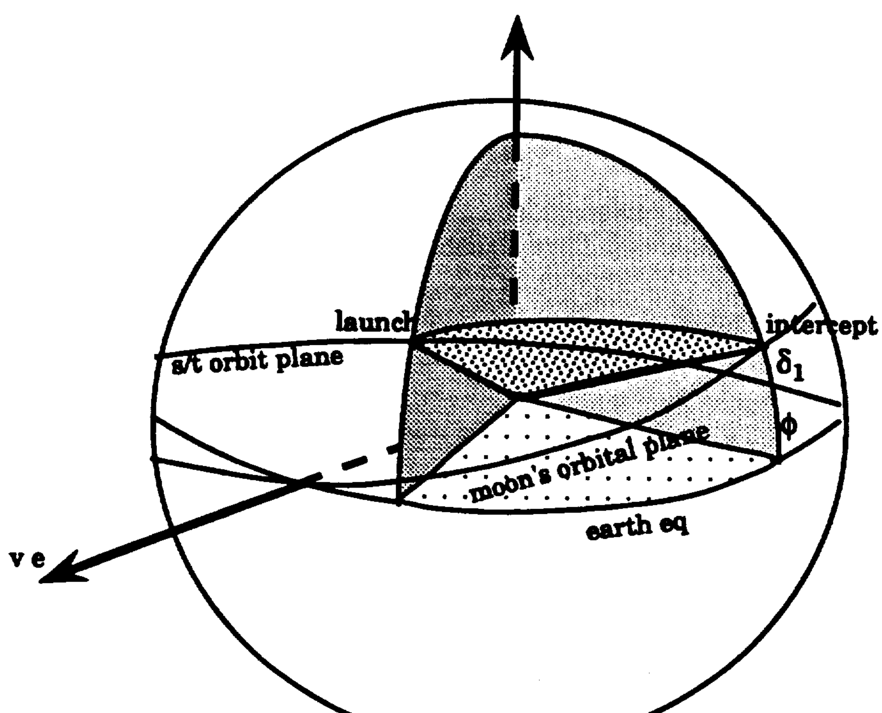


Figure B - 4 Non-Zero Declination Lunar Transfer

Declination of Moon Relative to S/T Orbit

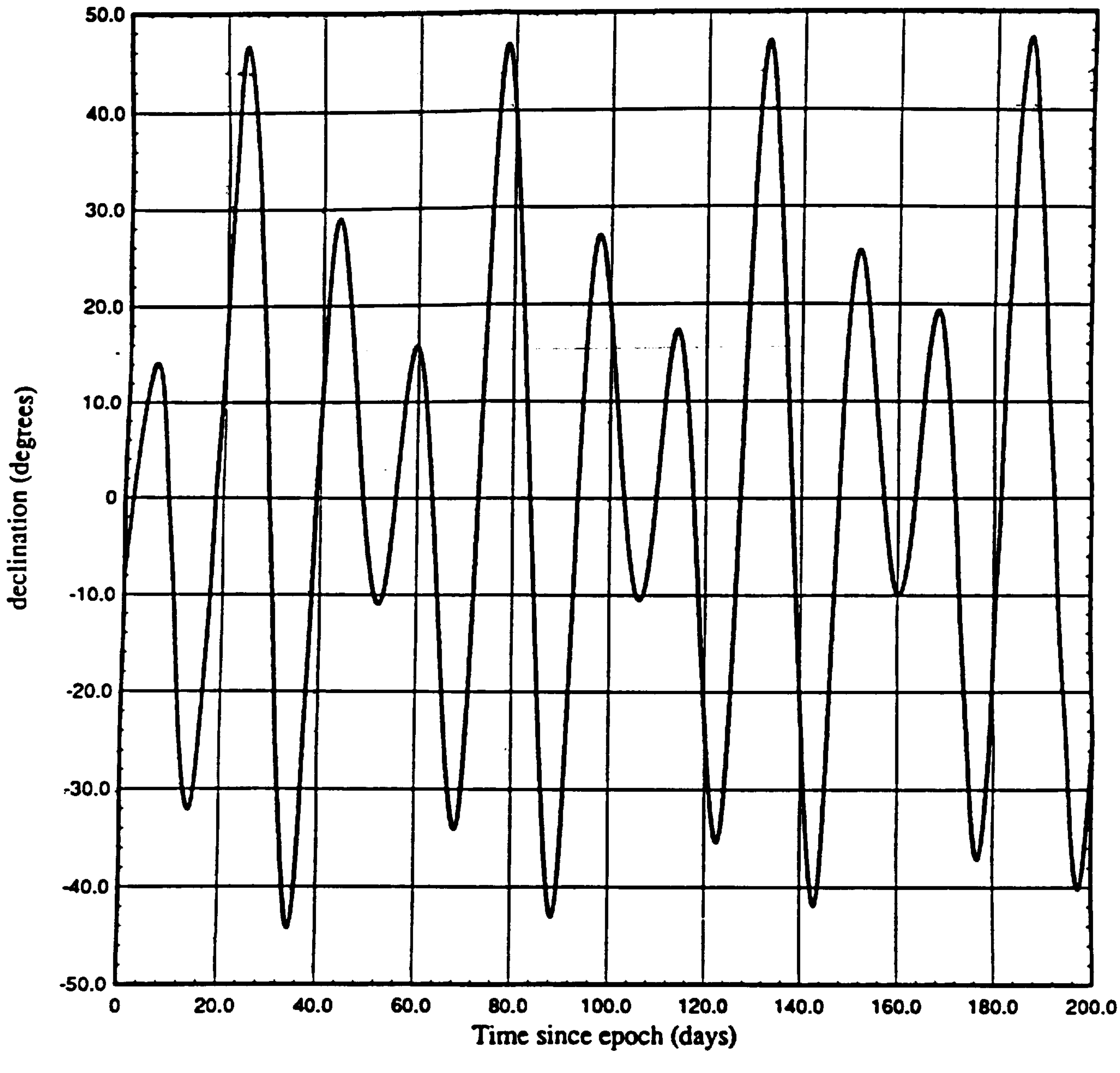


Figure B - 4.5 Lunar Declination Relative to Space Station

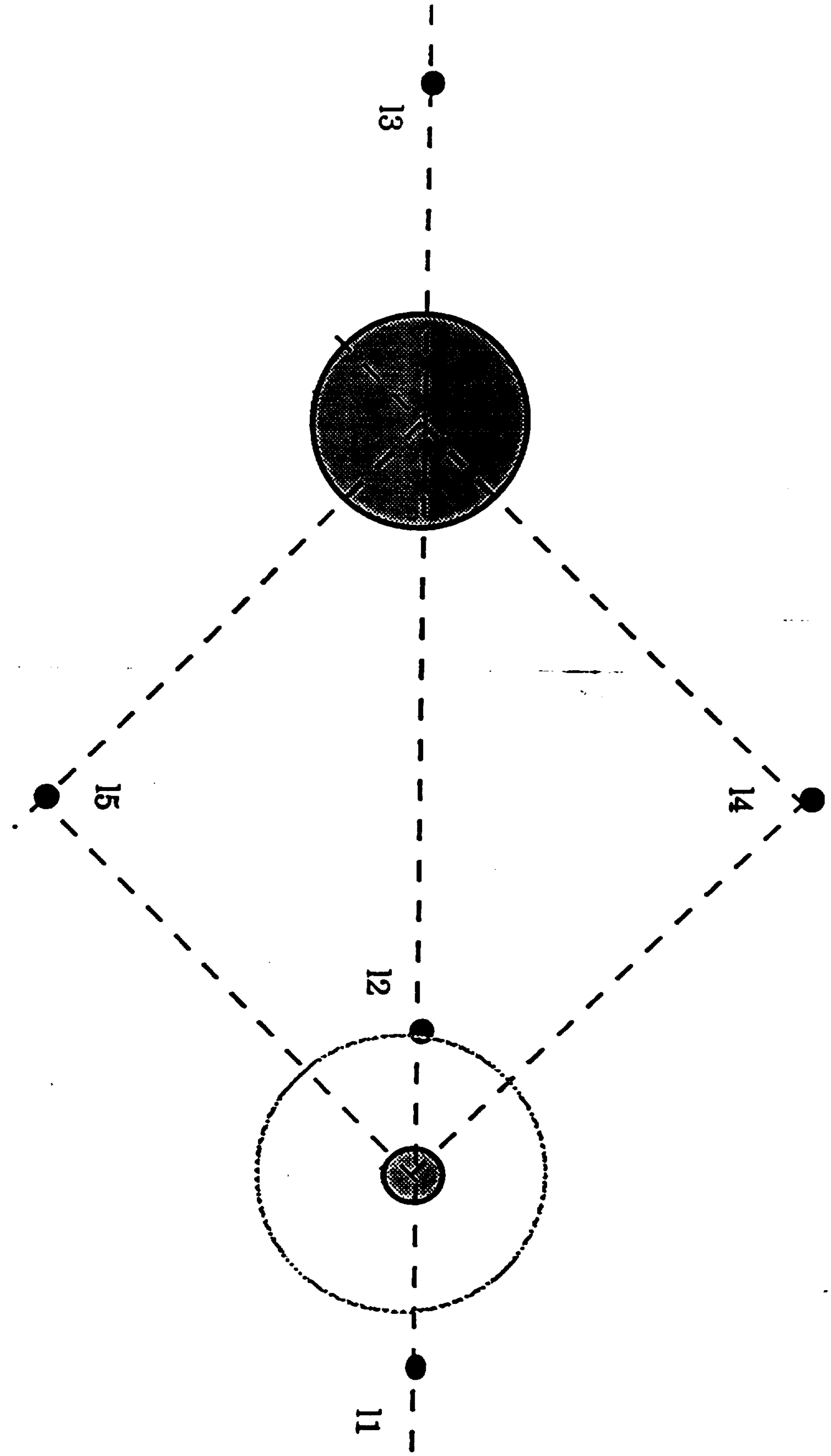


Figure B - 4.6 Libration Points

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13. ABSTRACT *(Maximum 200 words)*

IPOST is intended to support many analysis phases, from early interplanetary feasibility studies through spacecraft development and operations. The IPOST output provides information for sizing and understanding mission impacts related to propulsion, guidance, communications, sensor/actuators, payload, and other dynamic and geometric environments. IPOST models three degree of freedom trajectory events, such as launch/ascent, orbital coast, propulsive maneuvering (impulsive and finite burn), gravity assist, and atmospheric entry. Trajectory propagation is performed using a choice of Cowell, Encke, Multiconic, Onestep, or Conic methods. The user identifies a desired sequence of trajectory events, and selects which parameters are independent (controls) and dependent (targets), as well as other constraints and the coat function. Targeting and optimization is performed using the Stanford NPSOL algorithm. IPOST structure allows sub-problems within a master optimization problem to aid in the general constrained parameter optimization solution. An alternate optimization method uses implicit simulation and collocation techniques.

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