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FINAL REPORT

USERS MANUAL FOR THE IMA PROGRAM

CONTRACT NAS8-37850

JANUARY 1991

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PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
GEORGE C. MARSHALL SPACE FLIGHT CENTER
MARSHALL SPACE FLIGHT CENTER, AL 35812

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ABSTRACT

This document summarizes a portion of the work done by Dynetics, Inc., under Contract NAS8-37850 to the National Aeronautics and Space Administration, George C. Marshall Space Flight Center, with technical coordination provided by Mr. A. Wayne Deaton of the Systems Analysis and Integration Laboratory. The work consisted of the development of a user-friendly, interactive computer program for the design of Earth-orbital mission profiles using impulsive delta-v approximations.

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1. INTRODUCTION

The Impulsive Mission Analysis (IMA) computer program provides a user-friendly means of designing a complete Earth-orbital mission profile using an 80386-based microcomputer. The IMA program produces a trajectory summary, an output file for use by the new SCOOT program (Reference 1), and several graphics, including ground tracks on a world map, altitude profiles, orbital profiles, relative motion plots, and sunlight/communication timelines. The user can design missions using any combination of three basic types of mission segments: 1) Double Co-elliptic Rendezvous, 2) Payload Delivery, and 3) Payload De-orbit/Spacecraft Recovery. Each mission segment is divided into one or more transfers, and each transfer is divided into one or more legs, each leg consisting of a coast arc followed by a burn arc.

The initial spacecraft orbit and the various destination (or target) orbits of the mission can be defined in any one of several coordinate systems. The various payloads can be given names and acceleration limits. Tracking stations can be named and located as the user desires, and the spacecraft (referred to as "maneuver vehicle") can be named and defined regarding its empty mass and the characteristics of up to six propulsion subsystems.

The user builds his mission by putting together the types of mission segments that are needed, and he specifies the target orbit (if required), geometrical constraints, propulsion configuration, and payload allocation for each transfer in the mission. He designs the mission with the help of a mission profile design screen where he can insert and delete transfers as required and can quickly review his mission setup.

The IMA program is structured so that a series of missions can be defined easily by successively modifying the previously defined mission in the sequence. Once program execution has begun, the IMA program will solve each mission in the sequence without requiring any user input between missions.

This version of the IMA computer program requires an 80386-based PC with an 80387 math coprocessor and VGA monitor for proper execution. An HP-compatible laser printer is also required for printing the graphics. The run command is contained in the IMA.BAT file, and the executable program is contained in the IMA.EXP file. In addition to the IMA.BAT and IMA.EXP files, the screen data and help files (i.e., SCREEN1.DAT, SCREEN1.HLP, ..., SCREEN21.DAT, SCREEN21.HLP), as well as the files MAPWORLD.DAT, FONT8.BIN, and FONT14.BIN, are also required (on the IMA directory) for execution of the IMA program. NOTE: These additional files are "hidden" files and will not appear in a directory listing. All input data files and subfiles (as well as IMA output files) should normally be kept in this IMA directory, as well. The user may wish to "hide" the input subfiles so that directory listings do not appear too cluttered, as all input files have four input subfiles associated with them.

2. USER INTERFACE

The IMA program provides the user with 20 different screens through which he interfaces with the IMA program. ***Figure 2-1*** illustrates the organization of the interface screens. The user can easily enter and delete data on these formatted screens and can move easily from one screen to the next. The user activities associated with the various screens are defined in the following subsections.

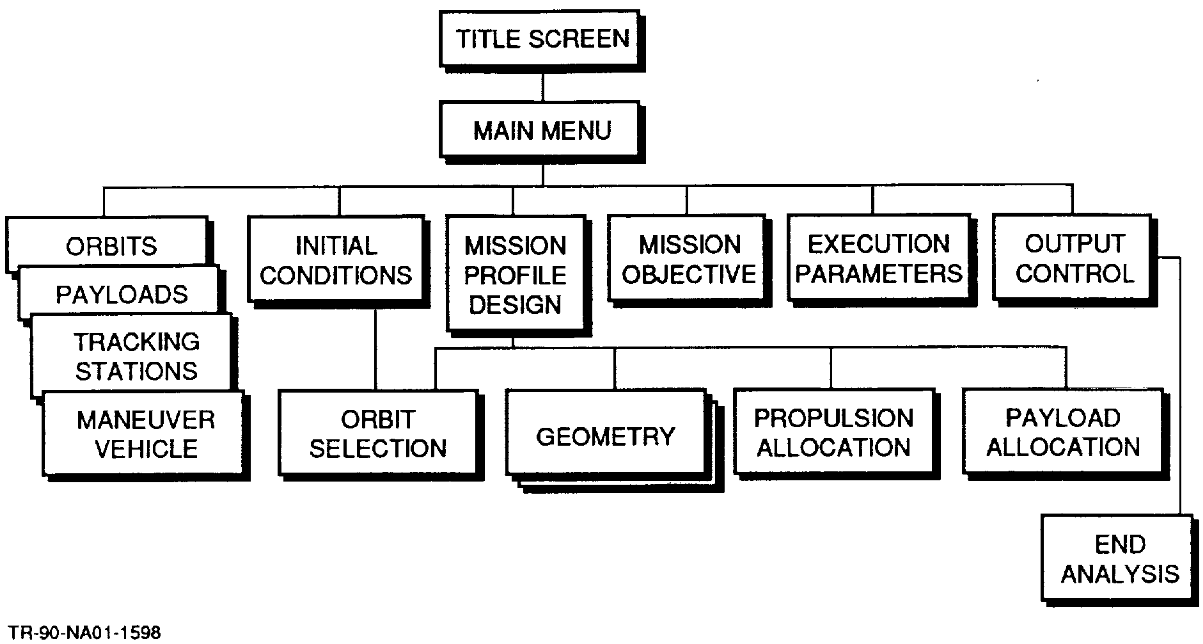

Figure 2-1. IMA User Interface Screen Organization

To run the IMA program, simply type "IMA." The program will initially supply the filename "DEFAULT.01" as the default input file. (If this file is to be used, "DEFAULT.01A" should be present on the IMA directory.) Unless the DEFAULT file has been "customized" (over-written), it initially contains a "blank" or "empty" set of data that will yield appropriate default values as necessary. Another way to start defining a new mission with no input data previously defined (i.e., create an input file from "scratch") is to enter a blank for the filename on the title screen. For more information on file naming conventions, etc., see the help documentation for the title screen and the "END ANALYSIS" screen.

Some input variables in the IMA program require an input and may not be left blank. In such cases, the user is not allowed to leave the edit field (nor perform other functions) while the field is still blank. Therefore, if the program is not responding to function keys, etc., the interface is probably waiting for a value (or character) to be entered. This may also occur if the if the user tries to delete an inserted line that is blank. Parameters that may be left free or unconstrained by the user may be left blank. Other parameters will default to a predetermined value if the user leaves the field blank. (These parameters are documented in the help documentations for the appropriate screens.) If it is desired to enter a value in exponential notation, use an uppercase "E" with no '+' signs (e.g., 2E3, etc.).

When editing a name or parameter, the left and right arrow keys will move the cursor <u>within</u> the field. ('Enter' is used to move <u>between</u> horizontal fields.) Hitting Alt-L will delete the characters from the current cursor position to the end of the edit field, while Alt-K will delete the entire entry. The Backspace and Delete keys function as normal within an edit field. The Home key moves the cursor to the beginning of the edit field, and the End key moves the cursor to the end of the edit field. Normally the IMA interface editor is in the "insert" mode. (Although the Insert key can be used to toggle between an "overstrike" mode, the editor is always reset to the "insert" mode when the user completes an entry, hits a function key, or moves to a new edit field.) Sometimes a function key (such as ESC, f2, etc.) must be hit more than once to perform the indicated function. (The cursor might first return to an initial or "home" edit field before the function may be performed.)

The user should set the desired units on the "EXECUTION PARAMETERS" screen before hitting "Execute" or "Add Another Mission" (f1 or f4), and the newly defined input file and IMA execution results that will be created will all be in terms of the units that are defined on that screen (although units can always be toggled on input data that is being defined/modified).

The user may interrupt mission execution by hitting the ESC key. After sufficient time passes for the IMA program to determine that ESC has been hit, execution will terminate and the user may return to the Main Menu to modify the input data for the mission that was undergoing execution. (The IMA program periodically checks to see if ESC has been hit so there could be a significant delay between the time an interrupt is requested and execution terminates.)

During mission execution, various types of messages may be sent to the screen. One type of message simply provides information to the user. Another type of message will query the user as to whether or not he wishes to continue execution. If the user answers 'N' <u>or</u> if he fails to respond within a given time interval (roughly 2 to 3 min), execution will continue. If the user answers 'Y', he will return to the Main Menu (where he may modify the mission). A "Halt" message will indicate an inability to solve the mission as defined and will return the user to the Main Menu. The messages that are sent to the screen during execution of a particular mission or sequence of missions are also written to a log file named "log.dat." This file is over-written (started over again) each time the IMA program is run or "restarted."

The temporary ("internal") data files that contain currently defined missions or newly generated execution results are normally deleted on exit, restart, or abort (although on restart the current input data may be retained in memory by leaving the filename blank on the initial screen). If for some reason the IMA program fails or is interrupted, all of the temporary files should still be stored on disk with the filenames of the form "internal." (or should be able to be recovered with a DOS "chkdsk/f" procedure). Since these files are normally deleted during a proper termination of the IMA program, these files should be renamed before running IMA again.

2.1 TITLE SCREEN

When the user executes the IMA program, the title screen shown in ***Figure 2-2*** will appear. From the title screen, the user specifies the input data file (to be read from disk) by entering either the entire file name or by entering "tag".## where ## is the mission number (up to 2 digits). If ## is unspecified, it will default to mission 01. (Unless an input file has been renamed, all input data files created from the IMA program are actually stored on disk in the form "tag".##a, where "a" is necessary to signify input data. The user does not need to enter the "a," however.)

NOTE: IF THE FILENAME IS LEFT BLANK, NO INPUT DATA FILE WILL BE READ. IN THIS CASE, A "BLANK" SET OF DATA WILL BE USED THAT WILL YIELD APPROPRIATE DEFAULT VALUES (AS NECESSARY) IF THE IMA PROGRAM HAS JUST BEEN ENTERED; OTHERWISE, THE INPUT DATA CURRENTLY IN MEMORY WILL BE KEPT (e.g., ON RESTART, ETC.).

When the user hits the Enter key, the main menu will be displayed. The f9 key will abort the program (all temporary files will be lost and no new data will be saved).

2.2 MISSION ANALYSIS MAIN MENU

When the user hits the ENTER key while the title screen is displayed, the mission analysis main menu shown in ***Figure 2-3*** will appear. The top four menu items contain the data base from which the mission can be planned. The f8 command will cause a return to the title (initial) screen where the user can respecify his input file. The unit choices are metric and english. When the user hits the Enter key, the menu item that has been selected by the cursor will be activated. Hitting the f9 key causes the program to abort (all temporary files will be lost and no new data will be saved).

In the normal course of mission definition, the user calls up each menu item, in order, and enters the data required by each corresponding screen. However, the user can address any menu item at any time. When defining a sequence of missions, the user will repeatedly return to the main menu to define each new mission in the sequence. In these cases, he may only need to change one or two values on a single screen to define the new mission. All other values will remain unchanged at the values set for the previous mission in the sequence.

The user can skip directly to the output control screen where he can call up pre-existing output files for display or printing.

```
       I M P U L S I V E   M I S S I O N   A N A L Y S I S
                    C O M P U T E R   P R O G R A M


             Enter the name of your input data file:



          H A P P Y    T R A I L S     T O     Y O U



                                                 Help (alt-f10)
```

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Figure 2-2. Title Screen

```
MISSION ANALYSIS MAIN MENU     Units: METRIC

                               Currently defining mission # 01

o  Orbits
o  Payloads
o  Tracking Stations and Satellites
o  Maneuver Vehicle

o  Initial Conditions
o  Mission Profile Design
o  Mission Objective
o  Execution Parameters

o  Output Control

Select screen (cursor)                       Toggle Units (f2)
Display selected screen (Enter)                 Help (alt-f10)
Respecify input file (initial screen) (f8)         Abort (f9)
```

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Figure 2-3. Main Menu Screen

2.3 ORBITS

Figure 2-4 shows the ORBITS screen. This screen is used to insert, delete, or modify orbits that will be needed in the mission profile design. To insert a new orbit, place the cursor on the row where the new orbit is to be inserted and hit alt-f1. A numbered space will be opened and the orbit (if any) previously occupying the row will be displaced downward and renumbered along with all other subsequent orbits in the list. The user can then type in the desired name for the orbit. To delete an orbit, place the cursor on the orbit and hit alt-f2. The subsequent orbits in the list will be displaced upward to fill the gap and will be renumbered accordingly.

```
Orbits                                       Units: METRIC

Orbit List                              Parameters for Selected Orbit
                                        Type: MEAN ORBITAL ELEMENTS
1.  SPACE STATION
2.  SPACE SHUTTLE                          GMT: 90-02-10-17-30-45.023
3.  OMV                               Apogee Altitude:   260.000 (km)
4.  HUBBLE TELESCOPE                 Perigee Altitude:   220.000 (km)
5.                                        Inclination:  28.50000 (deg)
6.                                    Right Ascension: 124.02550 (deg)
7.                                Argument of Perigee:  30.88630 (deg)
8.                                       True Anomaly:  45.50000 (deg)
9.
10.
11.
12.

Select (cursor)    Change Parameter Type (f3)     Toggle Units (f2)
Insert (alt-f1)    Edit Parameters (Enter/ESC)     Main Menu (ESC)
Delete (alt-f2)    Replace Input Data Subfile (f7)  Help (alt-f10)
```

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Figure 2-4. Orbits Screen

For any orbit selected with the cursor, the orbital parameters will be displayed on the right side of the screen along with the name of the orbital-parameter type. There are seven types of orbital parameters: mean orbital elements, osculating elements, Earth-centered inertial (ECI) Cartesian, Earth-centered inertial of date (ECID) Cartesian, Earth-centered fixed (ECF) Cartesian, ECF spherical, and Launch Inertial (LI) Cartesian. Further discussion of these types of orbital parameters is provided with the comments accompanying the orbit selection screen.

The user may enter orbital parameters in any of the seven available types. To identify the orbital-parameter type for a selected orbit, hit f3 (repeatedly) until the name of the desired type is displayed. (Hitting f3 does not perform a real-time conversion of the parameters from one type to another.) To edit orbital parameters, hit Enter to move to the input data fields. The cursor keys can then be used to assist the editing of the orbital parameter values. Return to the orbit list (left side of screen) by hitting ESC or by hitting Enter on the last parameter.

When the user hits f7, a window (***Figure 2-5***) is displayed where he can name the Orbits data subfile that he wants to replace the data in the input data file. The escape key (ESC) is used to return to the Main Menu.

2.4 PAYLOADS

The PAYLOADS screen (***Figure 2-6***) is used to insert, delete, or modify payloads that will be needed in the mission profile design. To insert a new payload, place the cursor on the desired row and hit alt-f1. A numbered space will be opened and the payload (if any) previously occupying the row will be displaced downward and renumbered along with all other payloads below it. To delete a payload, select the payload with the cursor and hit alt-f2. The payloads below the deleted one will be displaced upward to fill the gap and will be renumbered accordingly.

The name, mass, or acceleration limit for any payload can be edited by the user. The default value for the acceleration limit is 1E8 m/s/s ("no limit").

When the user hits f7, a window will be displayed where he can name the payload data subfile that he wants to replace the data in the input data file. The escape key (ESC) is used to return to the Main Menu.

2.5 TRACKING STATIONS

The TRACKING STATIONS screen (***Figure 2-7)*** is used to insert, delete, or modify tracking stations (or geostationary satellites) that will be needed in the mission analysis. Note that all tracking satellites are assumed to be in geostationary orbits. The insertions, deletions, and modifications are accomplished in the same way as those for the orbits and payloads (see comments for those screens).

If the user hits f7, a window will be displayed where he can name the tracking data and satellites data subfile that he wants to replace the data from the input data file.

2.6 MANEUVER VEHICLE (SPACECRAFT)

The MANEUVER VEHICLE screen (***Figure 2-8***) is used to define the parameters of the maneuver vehicle that will be used in the analysis. All names and parameter values can be edited. Propulsion

```
Orbits                                 Units: METRIC
Orbit List                         Parameters for Selected Orbit
                                   Type: MEAN ORBITAL ELEMENTS
1.  SPACE STATION
2.  SPACE SHUTTLE                       GMT: 90-02-10-17-30-45.023
3.  OMV                          Apogee Altitude:   260.000 (km)
4.  HUBBLE TELESCOPE            Perigee Altitude:   220.000 (km)
5.    Orbits Subfile:  ELLIP.02                                g)
6.                                                             g)
7.                                                             g)
8.    (Enter subfile name as "tag".##, where ## is the         g)
9.    mission number.  If ## is unspecified, it will
10.   default to mission 01.  If the file name is left
11.   blank, no subfile will be read in and the current
12.   data will be retained.)

Select (cursor) Change Parameter Type (f3)      Toggle Units (f2)
Insert (alt-f1) Edit Parameters (Enter/ESC)       Main Menu (ESC)
Delete (alt-f2) Replace Input Data Subfile (f7)   Help (alt-f10)
```

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Figure 2-5. Orbits Subfile

```
Payloads                                   Units: METRIC
                                          Mass          Acc Limit
   Payload Name                           (kg)           (m/s/s)

1. Hubble Telescope                     40000.000         0.2500
2. Intelsat                              9850.000         9.8067
3. Docking Collar                         255.000      9999.0000
4.
5.
6.
7.
8.
9.
10.
11.
12.

Insert payload (alt-f1)   Edit name, mass, or     Toggle Units(f2)
Delete payload (alt-f2)   acceleration limit       Main Menu (ESC)
Replace Input Data Subfile (f7)                     Help (alt-f10)
```

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Figure 2-6. Payloads Screen

```
Tracking Stations and Satellites          Units:METRIC
Name                   Latitude(deg) Longitude(deg) Altitude(km)
1. TDRS No. 1          0.00000       -171.00000     35786.005
2. TDRS No. 2          0.00000       -41.00000      35786.005
3. TDRS No. 3          0.00000       73.40000       35786.005
4. Hawaii              22.13000      -159.67000     1.140
5. Guam                13.31000      144.74000      0.116
6.
7.
8.
9.
10.
11.
12.
13.
14.
15.
Insert Station  (alt-f1)    Edit name, latitude,  Toggle Units (f2)
Delete Station  (alt-f2)    longitude, and altitude Main Menu (ESC)
Replace Input Data Subfile (f7)                   Help (alt-f10)
```

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Figure 2-7. Tracking Stations Screen

```
Maneuver Vehicle                                Units: METRIC
Name: MARS SPACE TUG
Empty Mass:  15545  (kg)

Propulsion Subsystems       Usable                 Specific Impulse at
                            Propellant   Maximum   Two Thrust Conditions
   Name                     Capacity     Thrust    (maximum)      (zero)
                              (kg)        (N)        (sec)         (sec)

1. BI-PROPELLANT            2500.000      450.000   295.9600     250.0000
2. COLD GAS                  450.000      100.000   220.0000     215.0000
3. solid booster            1550.000     1200.000   245.0000     245.0000
4.
5.
6.

Insert Subsystem (alt-f1)          Edit names or      Toggle Units (f2)
Delete Subsystem (alt-f2)          parameter values    Main Menu (ESC)
Replace Input Data Subfile (f7)                         Help (alt-f10)
```

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Figure 2-8. Maneuver Vehicle Screen

subsystems are inserted, deleted, and modified in the same way as orbits, payloads, and tracking stations and satellites (see comments for those screens). Note that the maximum thrust values on this screen represent the maximum available for translational delta-v.

The "zero-thrust" condition for specific impulse does not imply that the propulsion subsystem can be throttled down continuously to zero thrust, but only serves to define the rate of change of specific impulse with respect to thrust.

If the user hits f7, a window will be displayed where he can name the data subfile to replace the data in the input data file.

2.7 INITIAL CONDITIONS

Figure 2-9 illustrates the INITIAL CONDITIONS screen. The user changes the initial orbit via f3, which transfers him to the "Orbit Selection" screen. (The default is orbit 1.) Upon returning to the "Initial Conditions" screen, the identification (I.D.) number and name of the selected initial orbit will be displayed. If the initial orbit has not been changed since restarting the program or beginning a new mission definition, the prompt "Change initial orbit" will be highlighted.

If the user selects an LI-type orbit with a free Greenwich Mean Time (GMT), a window will be displayed as shown in ***Figure 2-9*** for him to enter the earliest allowable GMT of launch.

The user must enter the desired values for the propellant fill and reserve fractions. He cannot change the propulsion subsystem names or propellant capacities on this screen (this is accomplished by accessing the "Maneuver Vehicle" screen from the main menu). The fill fraction is the fraction of the capacity. The reserve fraction is the minimum fraction of the propellant required by the mission that cannot be used. A fill fraction left blank will be optimized by the program in accord with the specified mission objective. The default value for the reserve fractions is zero.

2.8 MISSION PROFILE DESIGN

The MISSION PROFILE DESIGN screen (***Figure 2-10***) is used to design the mission profile by specifying the sequence of transfers, including target orbits, geometric constraints, propulsion configuration, and payload allocation.

Each transfer has two fields that can be edited directly on this screen: a type field and a name field. When the type field is selected with the cursor, the user hits the appropriate number key (1, 2, ..., 5) to specify the transfer type. When the name field is selected, the user can type in any name desired for the transfer. The f7 key will display a window indicating the acceptable segments (sequences of transfers which are currently supported). The window is illustrated in ***Figure 2-11***.

```
Initial Conditions                                      Units: METRIC

Initial Orbit: 02  SPACE SHUTTLE
    ******************************************************************
    You have selected an LI-type initial orbit with a free Launch GMT.
    Specify the earliest possible GMT.      GMT:  89-02-15-05-32-5.12
    ******************************************************************

                                    Usable
                                    Propellant        Fill        Reserve
Propulsion Subsystem                Capacity          Fraction    Fraction


1. BI-PROPELLANT                    2500.000 (kg)     1.0000      0.0500
2. COLD GAS                          450.000 (kg)     0.8500      0.0500
3. solid booster                    1550.000 (kg)     1.0000      0.0000


Change initial orbit (f3)       Edit fill or          Toggle Units (f2)
                                reserve fractions       Main Menu (ESC)
                                                          Help (alt-f10)
```

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Figure 2-9. Initial Conditions Screen

```
Mission Profile Design
                                                   Target
       Type    Name of Transfer                    Orbit     Payloads

1.    2BCDH    Ascend to Far Phs Orbit                         03
2.    2BCDH    Ascend to Near Phs Orbit                        03
3.    2BTOR    Rendezvous with Hubble              04 HUB      03
4.    2BCDH    Descend to Far Phs Orbit                        01 03
5.    2BCDH    Descend to Near Phs Orbit                       01 03
6.    2BTOR    Rendezvous with Shuttle             02 SPA      01 03



                                    specify transfer type (1,2,...,5)
Insert (alt-f1)    Change Orbit (f3) 1. 1BRC    1-burn to reentry conic
Delete (alt-f2)        Geometry (f4) 2. 2BCDH   2-burn to cdh phasing orbit
Help (alt-f10)       Propulsion (f5) 3. 2BSO    2-burn to saving orbit
Segment Info (f7)      Payloads (f6) 4. 2BTO    2-burn to target orbit
Main Menu (ESC)                      5. 2BTOR   2-burn to target-orbit rndzv
```

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Figure 2-10. Mission Profile Design Screen

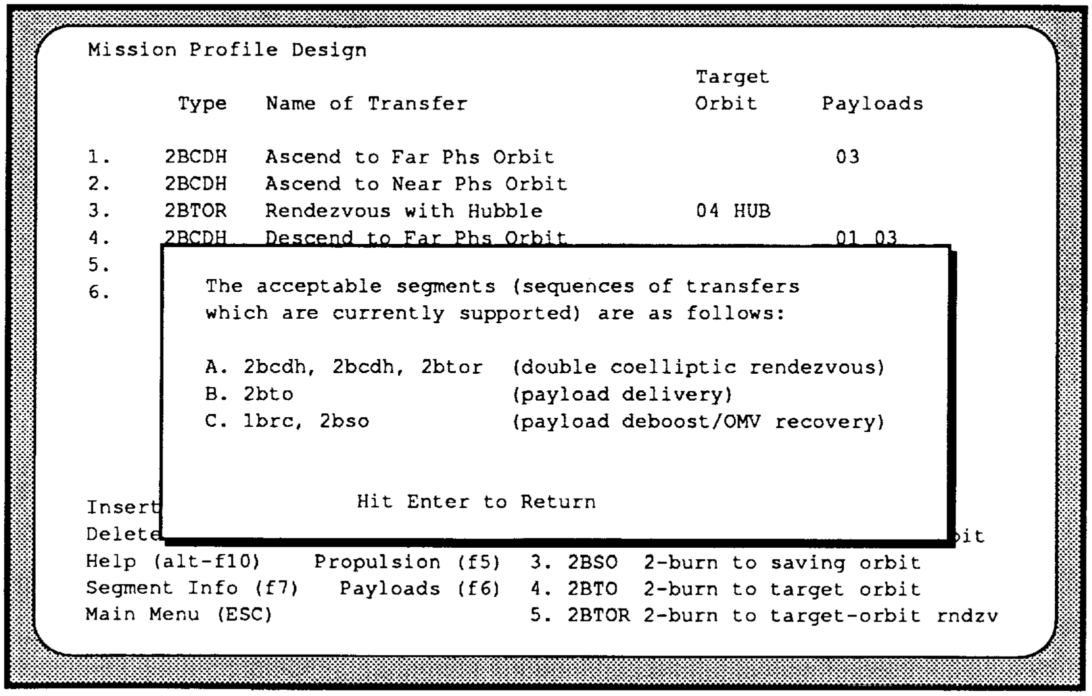

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Figure 2-11. Segment Definition Window

A new transfer is inserted by positioning the cursor to the desired row and hitting alt-f1. The transfer occupying that row (if any) and all subsequent transfers will be displaced downward and renumbered automatically. To save effort upon inserting a new transfer, values for parameters that are normally rippled through subsequent transfers will be taken from the previous transfer and copied to the inserted transfer (i.e., throttle fractions, reaction control system (RCS) flowrates, single burn-time limit information, and payloads). A transfer is deleted by positioning the cursor to the desired row and hitting alt-f2. The subsequent transfers are all displaced upward and are automatically renumbered.

The abbreviations for the transfer types are displayed on the lower right of the screen for the user's reference. "2b" denotes a two-burn transfer, etc.; "cdh" denotes a constant-delta-height phasing orbit; "to" denotes target orbit, "tor" denotes target orbit rendezvous; and "so" denotes saving orbit.

When the user selects a "2bso," a "2bto," or a "2btor" transfer (i.e., 3, 4, or 5), the f3 key can be used to call up the orbit selection screen. Upon specifying a new transfer of this type, the target orbit defaults to orbit 1 until changed otherwise. For each of these transfers, the selected target orbit number is displayed in the profile design screen along with the first three letters of the orbit name.

For every transfer, the user must define the geometric constraints and propulsion allocation by hitting f4 and f5 to call up the geometry and propulsion screens respectively. The f6 key will call up the payload allocation screen where the user will load or unload payloads to obtain the desired allocation. When he returns to the profile design screen, up to seven of the allocated payload I.D. numbers will be displayed. Each load and unload will affect all subsequent transfers as well as the selected transfer.

For the current cursor-selected transfer, the appropriate f3 through f6 "prompts" will be highlighted if the user has not yet called up the appropriate screen(s) since restarting the program or beginning a new mission definition (or since changing the transfer type).

2.9 ORBIT SELECTION

The ORBIT SELECTION screen (***Figure 2-12***) can be activated from either the "initial conditions" screen or, as in this case, from the "mission profile design" screen. In this case, the relevant transfer is identified. If activation occurred from the "initial conditions" screen, the word "INITIAL CONDITIONS" would be displayed at the top of the screen (***Figure 2-13***). The user cannot modify the orbit name or orbital parameters from this screen. Such modifications can only be accomplished by activating "Orbits" from the main menu.

The orbital parameter values displayed on this screen are for the user's information. There are seven types of orbital parameters: mean orbital elements, osculating elements, ECI Cartesian, ECID Cartesian, ECF Cartesian, ECF spherical, and LI Cartesian. The mean elements, osculating elements, and ECID Cartesian parameters are referenced to the ECID coordinate system existing at the indicated GMT. The ECF Cartesian and ECF spherical parameters are referenced to the Earth's equatorial plane and Greenwich meridian at the indicated GMT.

The ECI Cartesian parameters are referenced to the ECID coordinate system existing at Epoch 1950. These parameters are uniquely different from any of the preceding types of parameters in that the indicated GMT does not determine the reference coordinate system. However, the indicated GMT is the time at which the parameter values are valid and is used in transforming the ECI parameters to ECID parameters.

The LI coordinate system's orientation is determined by the launch GMT and by the longitude of the launch site. For this orbit type, a time after launch is also a required input. This time must be added to the launch GMT to obtain the time at which the orbital parameter values are valid. Note that for all orbit types except the LI Cartesian, the GMT is the time at which the orbital parameters are valid. The LI coordinate system can be thought of as rotating with the Earth until some launch reference time (Launch GMT) when the system becomes inertial. Note that the time after launch is specified (instead of GMT) to define the time when the LI parameter values are valid. If the ascent of the launch vehicle is invariant, then the only LI

```
Orbit Selection                                   Units: METRIC

TRANSFER NO. 3  2BTOR  Rendezvous with HUBBLE

Orbit List                                    Parameters for Selected Orbit
                                              Type: MEAN ORBITAL ELEMENTS
1. SPACE STATION
2. SPACE SHUTTLE                                 GMT:  90-02-05-12-30-25.650
3. OMV                                      Apogee Altitude:   500.000 (km)
4. HUBBLE TELESCOPE                        Perigee Altitude:   485.000 (km)
                                                Inclination:  28.53000 (deg)
                                            Right Ascension: 126.15500 (deg)
                                       Argument of Perigee:  58.99765 (deg)
                                               True Anomaly:  78.44582 (deg)


Select desired orbit (cursor)                             Toggle Units (f2)
Record selection and return to previous screen (ESC)         Help (alt-f10)
```

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Figure 2-12. Orbit Selection Screen (Target Orbit)

```
Orbit Selection                                   Units: METRIC

INITIAL CONDITIONS

Orbit List                               Parameters for Selected Orbit
                                         TYPE: LAUNCH INERTIAL (LI) CARTESIAN
1. SPACE STATION
2. SPACE SHUTTLE                          Launch GMT:  90-02-05-12-30-25.650
3. OMV                                                X:    405.800 (km)
4. HUBBLE TELESCOPE                                   Y:    398.103 (km)
                                                      Z:    233.113 (km)
                                                   XDOT:  1560.010 (m/s)
                                                   YDOT:  3406.550 (m/s)
                                                   ZDOT:  7208.104 (m/s)
                                      Time After Launch:  234.0552 (sec)
                                       Launch Longitude: -80.45000 (deg)


Select desired orbit (cursor)                          Toggle Units (f2)
Record selection and return to previous screen (ESC)      Help (alt-f10)
```

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Figure 2-13. Orbit Selection Screen (Initial Conditions)

parameter value that varies with launch time is the launch GMT. The use of LI parameters to specify the parking orbit ensures that the phasing is realistic for any value of launch GMT.

The reference time for the selected initial orbit (i.e., the time when the orbital parameter values are valid) will automatically become the initial time for the mission. For all orbital-parameter types except LI, the indicated GMT becomes the initial time. For the LI type, the initial time is the Launch GMT plus the indicated time after launch when the parameter values are valid. If the Launch GMT for an LI initial orbit is unspecified (blank), the program will automatically select a reasonable Launch GMT.

2.10 1BRC GEOMETRY

The 1BRC geometry screen (***Figure 2-14***) is used for the "one-burn to reentry conic" transfer, which, in conjunction with a following 2BSO transfer, constitutes the payload deboost/vehicle recovery mission segment.

```
1BRC Geometry                                       Units: METRIC

Transfer No. 8  Deboost Space Junk


Orbits (incl. fractions) prior to first impulse: Min  2.0        Max 100.0


Reentry Conditions
          Altitude:     47.500  (km)
       Path  Angle:    -15.55000 deg (must be negative value)
          Latitude:     15.45000 deg

Positive Latitude Rate? (Y,N): Y


                                                           Toggle Units (f2)
Return to Mission Profile Design (ESC)                        Help (alt-f10)
```

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Figure 2-14. IBRC Geometry Screen

If the orbits prior to first impulse are left blank, the program will assume that these parameters are unconstrained.

The user must input values for reentry altitude, flight path angle (which must be negative), and latitude (geometric). The user must also indicate whether the latitude rate at the "reentry" point is positive (if the user enters N, a negative rate is assumed).

2.11 2BCDH GEOMETRY

The 2BCDH geometry screen (***Figure 2-15***) is used for "two burn to constant delta height" transfers. The transfer number and name are displayed for the user's information. If the orbits prior to first impulse are left blank, the program will assume that these parameters are unconstrained. The user must input a non-zero value for the delta height of the phasing orbit, which is the terminus of the 2BCDH transfer. This delta height is the difference in altitudes of the phasing orbit and the subsequent rendezvous target orbit (target orbit of the first 2BTOR transfer following the 2BCDH transfer). A positive delta-height value indicates a phasing orbit that is higher than the rendezvous target orbit. If the target orbit is eccentric, both the apogee and perigee of the phasing orbit will be related to those of the target orbit by the delta-height value.

2.12 2BSO GEOMETRY

The 2BSO geometry screen (***Figure 2-16***) is used for the "two-burn to saving orbit" transfer, which, in conjunction with a preceding 1BRC transfer, constitutes the payload deboost/vehicle recovery mission segment (the terms "de-orbit" and "spacecraft" are sometimes substituted for "deboost" and "vehicle," respectively).

The user must specify the coast time (after the previous 1BRC impulse) before the saving impulse, which is the first impulse in the 2BSO transfer. The minimum buffer time between the saving impulse and minimum acceptable altitude (altitude for exoatmospheric assumption to hold) should not be less than 5 s. A value between 100 and 400 s is usually satisfactory. The default value for the minimum buffer time is 100 s. The IMA program uses the buffer time and coast time before the saving impulse in defining the parameters of the reentry conic (produced by the 1BRC transfer), which always precedes the 2BSO transfer.

2.13 2BTO GEOMETRY

The 2BTO geometry screen (***Figure 2-17***) is used for "Two Burn to Target Orbit" transfers. The transfer number and name are displayed for the user's information. The target orbit number and name are also displayed. Any blank that is entered will be interpreted by the program as a parameter that is not constrained.

2BCDH Geometry   Units: METRIC

Transfer No. 2 Ascend to Near Phs Orbit

Note: Destination orbit for this transfer is based on the target orbit
defined for the next rendezvous transfer in the mission profile.

Orbits (incl. fractions) prior to first impulse: Min 1.5000 Max 100.0000

Delta height of phasing orbit: -37.040
(neg value= phasing orbit lower than target)

Toggle Units (f2)
Return to Mission Profile Design (ESC)   Help (alt-f10)

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Figure 2-15. 2BCDH Geometry Screen

2BSO Geometry

Transfer No. 9 Save the Spacecraft
Target Orbit No. 7 Low Saving Orbit

Coast time before saving impulse: 1500.0000 sec

Minimum buffer time
between saving impulse
and minimum acceptable altitude: 120.0000 sec

Return to Mission Profile Design (ESC)   Help (alt-f10)

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Figure 2-16. 2BSO Geometry Screen

```
2BTO Geometry

Transfer No.  11  Deliver High-Res System
Target Orbit No. 12  Sun Synch Orbit

Orbits (incl. fractions) prior to first impulse: Min  3.5000 Max 100.0000

Return to Mission Profile Design (ESC)                    Help (alt-f10)
```

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Figure 2-17. 2BTO Geometry Screen

2.14 2BTOR GEOMETRY

The 2BTOR screen (***Figure 2-18***) is specialized for two-burn transfers to a target orbit rendezvous. In this case, the transfer and target orbit are displayed for the user's information.

With the exception of the "Total transfer angle" and "Terminal Point" information, a blank indicates that the variable is free to be optimized. For the terminal point, a blank is interpreted as zero. The total transfer angle for the two-burn rendezvous must be specified. The "optimization" of the location of impulse 1 does not produce an exact optimum, from the standpoint of minimum delta-v requirement, but does provide a reasonable value that can be adjusted by the user on subsequent mission designs. It is possible that some of the constraints will be mutually exclusive. In this case, the IMA program will not be able to find a solution.

2.15 PROPULSION SUBSYSTEM ALLOCATION

The format of the PROPULSION SUBSYSTEM ALLOCATION screen (***Figure 2-19***) allows flexibility in defining the utilization of the various propulsion subsystems. To save effort, the throttle fractions and RCS flowrates may be rippled forward through all of the subsequent transfers by hitting f3 (instead of

```
2BTOR Geometry                                 Units: METRIC
Transfer No.  3: Rendezvous with HUBBLE
Target Orbit No.  4: HUBBLE TELESCOPE

Orbits (incl. fractions) prior to first impulse: Min  5.0000  Max 100.0000


Impulse 1: -0.044600   deg ahead of/behind (+/-) target satellite
Impulse 2:
  occurs between   -20.000   min and   -15.000 min before/after(-/+) sunrise
  occurs at argument of latitude between             deg and          deg
Total transfer angle:   135.00000 deg


Terminal Point:        1.852 (km)   ahead of target (- for behind)

TDRSS communication window begins n.l.t      10.000  min before rendezvous
                              ends n.e.t      30.000  min after rendezvous

                                                          Toggle Units (f2)
Return to Mission Profile Design (ESC)                       Help (alt-f10)
```

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Figure 2-18. 2BTOR Geometry Screen

Propulsion Subsystem Allocation   Units: METRIC

Transfer No. 1: Ascent to Far Phs Orbit

Subsystem	Throttle Fraction	RCS Flowrate (kg/s) Coast	Burn	Pointing & Docking (kg) coast 1	coast 2
1. BI-PROPELLANT	1.0000	0.000000	0.000000	0.000	0.000
2. COLD GAS	0.0000	0.000085	0.000125	0.000	0.000
3. solid booster	0.0000	0.000000	0.000000	0.000	0.000

```
Single Burn-Time Limit:     1950.00  sec

  If the burn time exceeds the limit, do you
  want low-acceleration computations to be used
  (if appropriate) instead of supplemental
  coast-burn legs? (Y,N): N

Ripple appropriate value to subsequent transfers (f3)      Help (alt-f10)
Return to Mission Profile Design (ESC)                   Toggle Units (f2)
```

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Figure 2-19. Propulsion Subsystem Allocation Screen

Enter) with the cursor on the value to be rippled. Pointing and docking requirements will usually be unique for the particular transfer.

The throttle fraction is multiplied by the maximum thrust (Maneuver Vehicle Screen) to obtain the thrust level for each propulsion subsystem. If the acceleration limit (determined by the payload having the most restrictive limit) is reached during a thrust period, the throttle fraction of the subsystem having the highest thrust will be reduced to maintain the limit. If the thrusts of the other subsystems (which will not be reduced) are high enough to prevent satisfaction of the acceleration constraint, an error message will be displayed, and the user must reduce these throttle fractions. The default value for the throttle fractions is unity.

The default value for the RCS flowrates and for the pointing and docking requirements is zero. If coast 2 is undefined for a particular transfer, the program will ignore any pointing and docking values for that coast. There are currently no provisions for specifying pointing and docking requirements for any additional coasts beyond coast 2 that might result from additional transfer legs (due to the single burn-time limit).

The user may specify a single burn-time limit that will apply to all burns in the transfer. The single burn-time limit may be rippled forward through all of the subsequent transfers by hitting f3. The default value for the burn-time limit is 1E6 ("no limit"). NOTE: THE OPTION FOR LOW-ACCELERATION COMPUTATIONS IS NOT OPERATIONAL FOR THIS VERSION OF THE IMA PROGRAM. IF A BURN TIME EXCEEDS THE SPECIFIED LIMIT, THE IMA PROGRAM WILL INCREASE THE NUMBER OF BURNS IN THE TRANSFER UNTIL THE LIMIT IS SATISFIED. ALL TRANSFERS WILL HAVE AN EVEN NUMBER OF BURNS.

It is noted that all docking propellant requirements should be allocated to the first coast in a transfer sequence, because payloads cannot be added or subtracted during the transfer.

2.16 PAYLOAD ALLOCATION

The user can only allocate payloads with the PAYLOAD ALLOCATION screen ***(Figure 2-20)*** (to modify the names, masses, or acceleration limits of payloads, the user must access the "Payloads" screen from the main menu). When the Payload Allocation screen is accessed, payloads currently allocated will be highlighted. The user can load and unload cursor-selected payloads by hitting the f1 key. The result ripples down the list of transfers. For example, if the user unloads a payload from transfer no. 3, that payload is automatically unloaded from transfer nos. 4, 5, ..., etc.

Payload Allocation Units: METRIC

Transfer No. 4: Descend to Far Phs Orbit

Payload Name	Mass (kg)	Accel. Limit (m/s/s)
1. Hubble Telescope	40000.000	0.2500
2. Intelsat	9850.000	9.8067
3. Docking Collar	255.000	9999.0000

Select Payload (cursor) Toggle Units (f2)
Load/Unload Selected Payload (f1) Return to Mission Profile Design (ESC)
(Loaded payloads are highlighted) Help (alt-f10)

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Figure 2-20. Payload Allocation Screen

2.17 MISSION OBJECTIVE

The user can select either the "Conserve Propellant" or "Conserve Time" mission objective on the MISSION OBJECTIVE screen (***Figure 2-21***). If he selects Conserve Propellant, a window will be displayed (as shown) for specification of a maximum mission time and weighting factors for the various propellant subsystems. If no maximum mission time is entered, the IMA program will assume that the time is unconstrained. The default value for the weighting factors is unity, meaning that equal weight will be given to conserving the propellants of the different propulsion subsystems in proportion to the usable capacities (refer to ***Figure 2-8***). A weighting factor of zero will cause the IMA program to ignore the conservation of propellant for the corresponding subsystem.

```
Mission Objective

                                        **********************************
o Conserve Propellant  >>>>>>>>>> Maximum Mission Time:    120.000 hr

o Conserve Time                   Propulsion              Weighting
                                  Subsystem               Factor

                                  BI-PROPELLANT             1.0000
                                  COLD GAS                  0.7500
                                  solid booster             0.0000
                                  **********************************


Select Objective (cursor)            If "Conserve Propellant" is selected,
Help (alt-f10)                       enter max. mission time and weighting
Main Menu (ESC)                      factors for propellant subsystems.
```

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Figure 2-21. Mission Objective Screen

2.18 EXECUTION PARAMETERS

On the EXECUTION PARAMETERS screen (***Figure 2-22***), the user may specify a minimum allowable altitude to be used by the IMA program. The default value is 185.2 km (100 nmi).

The user can specify an event and time delay to be used as a reference for mission elapsed time (MET). If he only enters a zero in one or more of the time-delay data fields (days, hours, minutes, or seconds), the MET will be measured from the initial-orbit reference time. If he does not specify a time delay (leaves all data fields blank), the IMA program will choose a time delay so that the MET spent in the initial orbit is as little as is allowed by the minimum stay-time constraint (specified on the initial transfer's geometry screen). VEHICLE CONSUMABLES WILL BE BASED ON MISSION ELAPSED TIME.

The user should set the desired units before hitting f1 or f4, as the current input file and IMA execution results that will be created will all be in terms of the units that are defined on this screen (although units can always be toggled on input data that is being defined or modified).

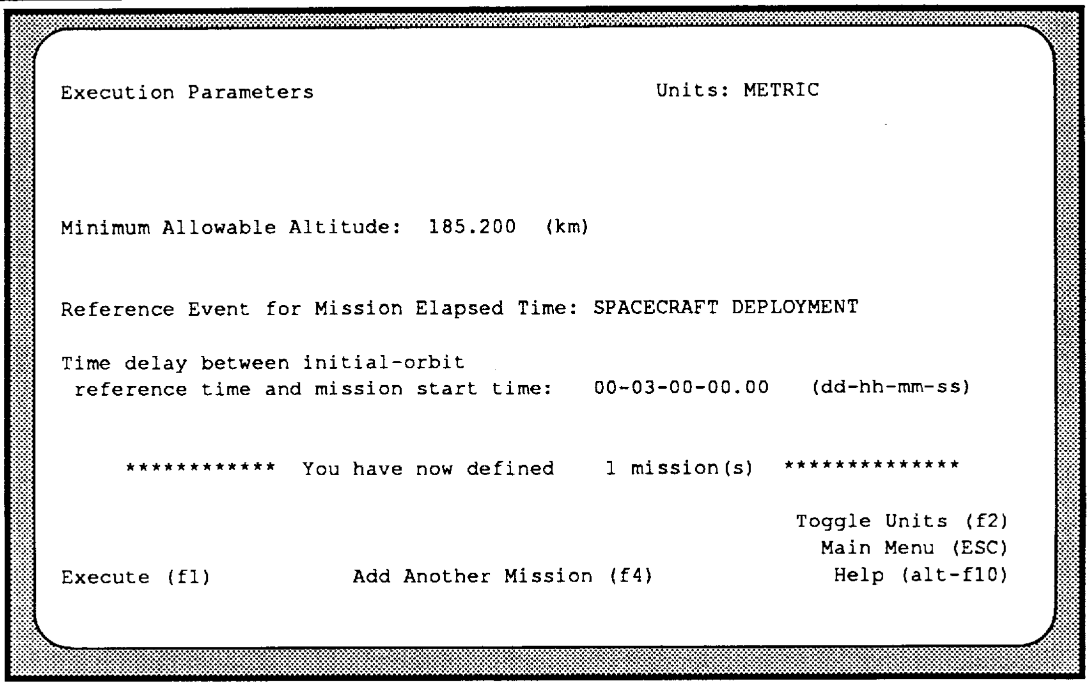

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Figure 2-22. Execution Parameters Screen

The "Execute" option (f1) on this screen initiates program computations. If the user wants to add another mission to the execution sequence, he hits f4 instead of f1. The main menu will be displayed, and the user can define another mission. He can continue in this way to define up to 99 missions. When he hits f1, the program will execute the sequence of missions that he has defined.

If the user is modifying a mission that had caused a halt (return to Main Menu) during execution, he may resume execution by hitting f1. In this case, the program will begin executing the previously defined sequence beginning with the newly modified mission. All results from previous missions are retained, as well as any subsequent missions in the previously defined sequence (the user may not add additional missions at this point).

If the user decides that the mission he has just defined is not needed or needs to be modified, he can hit ESC and return to the Main Menu.

2.19 OUTPUT CONTROL

The OUTPUT CONTROL screen (***Figure 2-23***) can be accessed from the main menu. Also, the OUTPUT CONTROL screen will appear automatically when the IMA program completes its computations. Usually, the user will want to output the most recent IMA results (which reside in temporary data files).

However, he can also use this screen to output from a file that was created sometime in the past. If a pre-existing file is to be output, the user may enter the file name as "tag".##, where ## is the mission number. If ## is unspecified, it will default to 01. The program will read in the correct file depending on the type of output (item) selected. (It is sometimes possible to view an arbitrary text file (such as "log.dat") from this screen by entering the entire file name (with the 3-letter extension) and hitting f3 or f6 after moving the cursor to TRAJECTORY SUMMARY or SAMBO INPUT FILE. If the file is currently open, however (such as the "log.dat" file after a halt/return to main menu), the file cannot be viewed.)

```
Output Control
********  You have executed   1  sequential mission(s)   **********
File to be output:
(if the results of the just-completed execution or the current input data are
to be output, leave a blank unless sequential missions were defined/executed
and you want a mission other than the most recent.  In this case enter 1 or 2
or ...  to identify which mission in the sequence you want.  If you want to
output a pre-existing file, you may type in the appropriate file name as
"tag".##  where ## is the mission number.  If unspecified, ## defaults to 01.)
o  Input Data
o  Trajectory Summary
o  Sunlight/Communication Timelines
o  Ground Track
o  Altitude Profile
o  Relative Motion Plot
o  Orbital Flight Profile
o  SAMBO Input File

Select item (cursor)                           End Analysis/ Save Files (f1)
Output to screen (f3)                                       Help (alt-f10)
Output to laser printer (f6)                               Main Menu (ESC)
```

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Figure 2-23. Output Control Screen

The first time the user hits f6 to print data/results for the particular mission sequence that has just been defined and/or executed, he will be prompted to enter a file "tag" (if desired) that will be used on printouts (since the temporary files containing current input data and execution results have not yet been named by the user). If a "tag" is entered, it will be supplied as the default "saved files tag" in the End Analysis screen where files may be saved. (See the End Analysis help documentation for additional information on file names, etc.) If a "tag" is not entered, the user will be prompted again the next time he hits f6.

When the user has completed his output, he must go to the End Analysis screen if all missions have been executed. There the user may save selected input and/or output files. If all defined missions have not been executed, the user may return to the main menu.

2.20 END ANALYSIS

The END ANALYSIS screen is shown in ***Figure 2-24.*** The user specifies individual output files that will (or will not) be saved by selecting them with the cursor and hitting f5 (in a toggle mode). An entire row may be selected by hitting f6, and an entire column may be selected by hitting f7 (also in toggle modes). Initially, the most recent files are already highlighted (selected to be saved), but can be "un-highlighted" (rejected) if desired. The output files will all have the tag that is defined on this screen. If a "tag" was specified in the Output Control screen, this "tag" (which was used on printouts) will initially be supplied as the default "saved files tag." Upon exiting or restarting IMA (f1 or f8), the selected (highlighted) files will be saved on disk in the form "tag".##?, where ## is the mission number and ? is a letter identifying the type of file ("a" for input data, etc.). The user normally has no need to remember the identifying letters, as the program deduces the appropriate letter when necessary. NOTE: ALL TEMPORARY FILES WILL BE DESTROYED WHEN THE USER RESTARTS OR EXITS THE PROGRAM. However, the current input data will still be in internal memory upon restart (f8). INPUT data files (and subfiles) are stored in unformatted files and cannot be edited from DOS.

```
End Analysis
*********  You have executed   2  sequential mission(s)   ***********
Saved Files Tag:   SAMPLE        * Specify the "tag" only (no extension).
The files selected below will be saved with the tag that you have specified
along with an appropriate extension (based on the program's naming conventions).
THE HIGHLIGHTED (SELECTED) FILES ARE ONLY SAVED ON EXIT (f1) OR RESTART (f8).

 Files to be Saved                        Mission No.
                                          1   2

 a) Input Data/ Subfiles(m,o,p,s)         _   _
 b) Trajectory Summary                    _   _
 c) Sunlight/Communication Timelines      _   _
 d) Ground Track                          _   _
 e) Altitude Profile                      _   _
 f) Relative Motion Plot                  _   _
 g) Orbital Flight Profile                _   _
 h) SAMBO Input File                      _   _
Move to file entry (cursor)                  Previous (Output) Screen (ESC)
Select/reject selected file (f5)             Exit IMA Program (& save) (f1)
Select/reject entire row (f6)                         Restart (& save) (f8)
Select/reject entire column (f7)                             Help (alt-f10)
```

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Figure 2-24. End Analysis Screen

3. OUTPUT DEFINITION

The IMA program output is divided into eight parts: 1) Input Data, 2) Trajectory Summary, 3) Sunlight/Communication Timelines (pictorial), 4) Ground Track (pictorial), 5) Altitude Profile (pictorial), 6) Relative Motion Plot (pictorial), 7) Orbital Flight Profile (pictorial), and 8) SAMBO Input File. The user may selectively display or print each part as described in Subsection 2.19. Each output part is contained in an internal file with a name that is composed of a user-supplied tag (such as "lomas2") followed by a period, two digits indicating the mission number, and a letter (a, b, ..., h) indicating the particular output part. For example, the file with user-supplied tag "lomas2" containing the trajectory summary for mission No. 1 would have the name "lomas2.01b". The file containing the SAMBO Input File for mission No. 3 would have the name "lomas2.03h". When the user uses the IMA output screen to display or print the output files, he only needs to know the user-supplied tag and mission number. He need not be concerned with the file-naming convention.

3.1 INPUT DATA

One of the IMA outputs is a complete compilation of the user input. The input for a sample file (lomas2.01) is shown in Appendix A. The input quantities are defined in the various subsections of Section 2.

3.2 TRAJECTORY SUMMARY

A sample trajectory summary is shown in Appendix B. The summary consists of four parts: 1) Burn Arcs, 2) Mean Orbit Elements, 3) Propellant Usage, and 4) Earth-Centered Spherical Coordinates.

The Burn Arcs summary defines the start time, duration, delta-v, and plane change of each burn in the mission profile. It also indicates the extent to which each burn has tracking coverage. No tracking coverage for a particular station is indicated by the term NONE. Coverage only during the initial part of the burn is indicated by the term BEG. Coverage only during the final part of the burn is indicated by the term END. Coverage during the entire burn is indicated by the term FULL. The start time for each burn is measured from the mean-elapsed-time (MET) reference Julian Day, shown at the beginning of the Burn Arcs summary.

The Mean Orbit Elements are shown at the initial time and immediately before (-) and after (+) each impulse in the mission profile. These "mean elements" are in truth merely secular elements and do not include the long-period oscillations. The apogee and perigee values are altitudes above the Earth's equatorial radius. The MET of each impulse (midpoint of burn) is expressed in days after the MET reference Julian Day (shown on Burn Arcs summary).

The Propellant Usage summary shows the initial propellant loading, the propellant used during each burn, and the propellant remaining after each burn for each propulsion subsystem. The end time of each burn is expressed in days after the MET reference Julian day (shown on Burn Arcs summary).

The Earth-Centered Spherical Coordinates are shown at the initial time and before and after each impulse in the same way as the mean orbit elements are shown. The velocity (magnitude), flight-path angle, and heading angle relate to the inertial velocity vector. The altitude is measured above the earth's equatorial radius, the latitude is geocentric, and the longitude is measured positive eastward from the Greenwich meridian. The MET of each impulse is expressed in days after the MET reference Julian Day (shown on Burn Arcs summary).

3.3 SUNLIGHT/COMMUNICATION TIMELINES

A sunlight/communication timeline is provided for a seventy-three-minute interval near the end of each rendezvous (2BTOR) transfer. The timeline begins twenty-five minutes before the final rendezvous impulse (midpoint of rendezvous burn) and ends forty-eight minutes after the final rendezvous impulse. Example timelines are shown in ***Figure 3-1*** for the two rendezvous transfers in the lomas2.01 mission.

```
          FILE: lomas2.01
SUNLIGHT/COMMUNICATION COVERAGE
(MARKS ON THE TIMELINES ARE SPACED ONE-MINUTE APART)


LEG  6
SUN  .........................V....################################...........
TRK1 ########################.................................................
TRK2 ................###########################################..............
TRK3 ................................................#########################

LEG 12
SUN  ......###################V###############................................
TRK1 ###########################################..............................
TRK2 .............................############################################
TRK3 #########...................................................#############
```

Figure 3-1. Sunlight/Communication Timelines

The instant of the final rendezvous impulse (midpoint of the rendezvous burn) is indicated in ***Figure 3-1*** by the character "V". Each minute where there is sunlight or tracking coverage is indicated by a dot ".". Each minute where there is shadow or no tracking coverage is indicated by the character "#". Time can be resolved only to the nearest minute in the sunlight/communication timelines.

3.4 GROUND TRACK

A ground track, superimposed on a Mercator projection of the earth's surface, is provided for the entire mission. Each displayed screen or printed page contains 24 hours of ground track in two 12-hour segments as shown in ***Figure 3-2*** (on following page). The elapsed hours since the MET reference Julian Day are indicated in the figure with numerals enclosed in rectangles. The impulses (midpoints of burns) are indicated in the figure with numerals enclosed in circles.

3.5 ALTITUDE PROFILE

A "mean" altitude profile, being the difference between the semimajor axis of the spacecraft's conic and the earth equatorial radius, is provided for the entire mission as shown in ***Figure 3-3***.

In ***Figure 3-3***, the starting and ending points of each burn are connected with straight lines. For a short burn, the change in the semimajor axis (and hence mean altitude) of the spacecraft conic appears almost instantaneous.

3.6 RELATIVE MOTION PLOT

For each rendezvous segment in the mission, a relative motion plot is provided like that shown in ***Figure 3-4*** for the first rendezvous in the lomas2.01 mission. In interpreting the relative motion plots, the motion of the spacecraft should be visualized as counter-clockwise (toward the left).

In addition to the final rendezvous (2BTOR) transfer, several hours in the near phasing orbit are shown on the relative motion plot. The hours prior to the final rendezvous impulse (midpoint of the final burn) are indicated by numerals enclosed in rectangles. Trajectory variations during the two finite burns of the 2BTOR transfer are not shown on the plot; the burns are approximated as impulses. The target reference point, defined by the target-orbit elements, is at the origin of the relative coordinate system. In the example of ***Figure 3-4***, the actual target point coincides with the target reference point because no offset for the terminal point was indicated on the 2BTOR geometry screen when the user defined his mission constraints. The vertical coordinate value on the relative motion plot is the difference in the radius magnitudes of the spacecraft and target reference point. The horizontal coordinate value is the product of the target radius magnitude and the argument-of-latitude difference between the spacecraft and target reference point. Negative values indicate that the spacecraft is below and behind the target reference point.

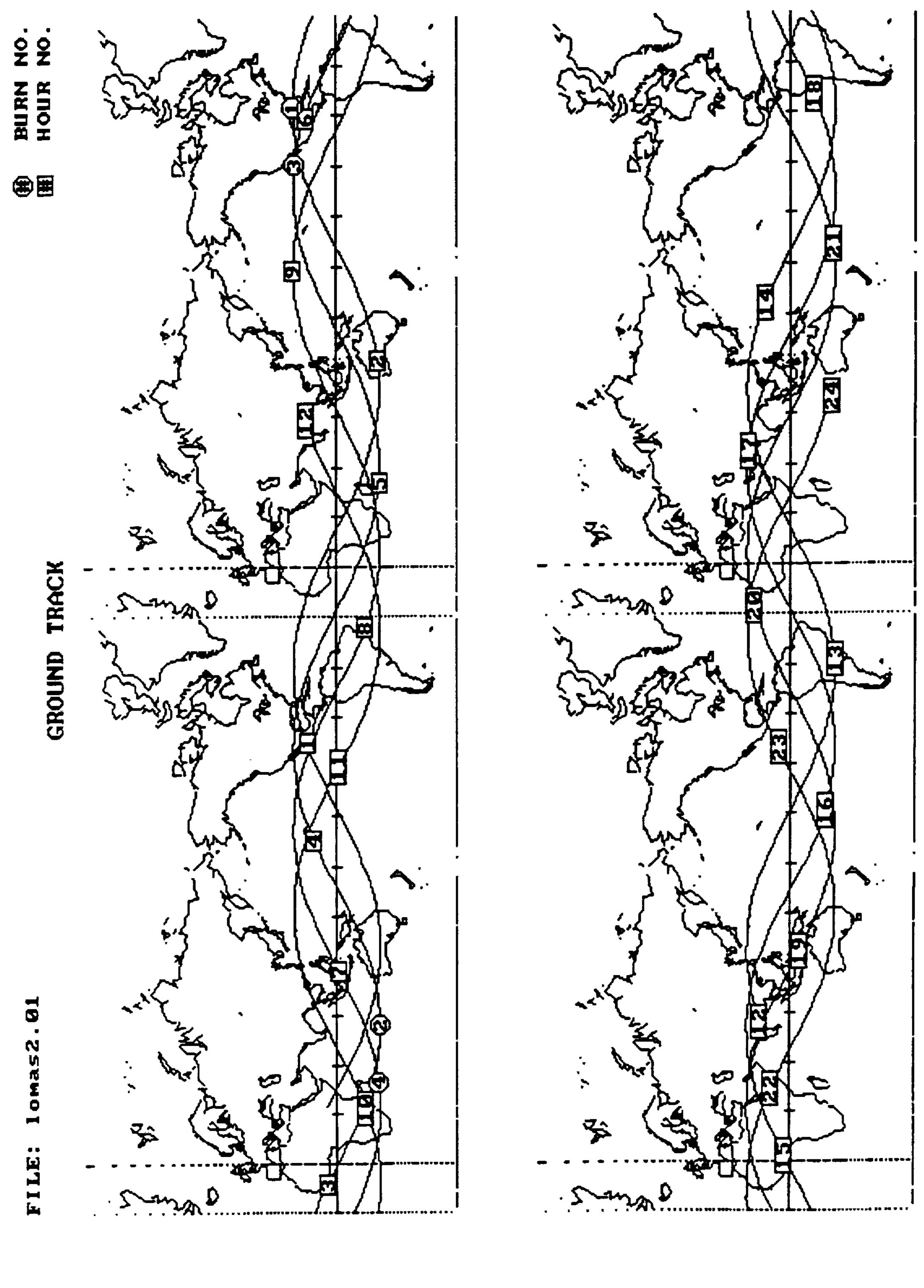

Figure 3-2. Ground Track

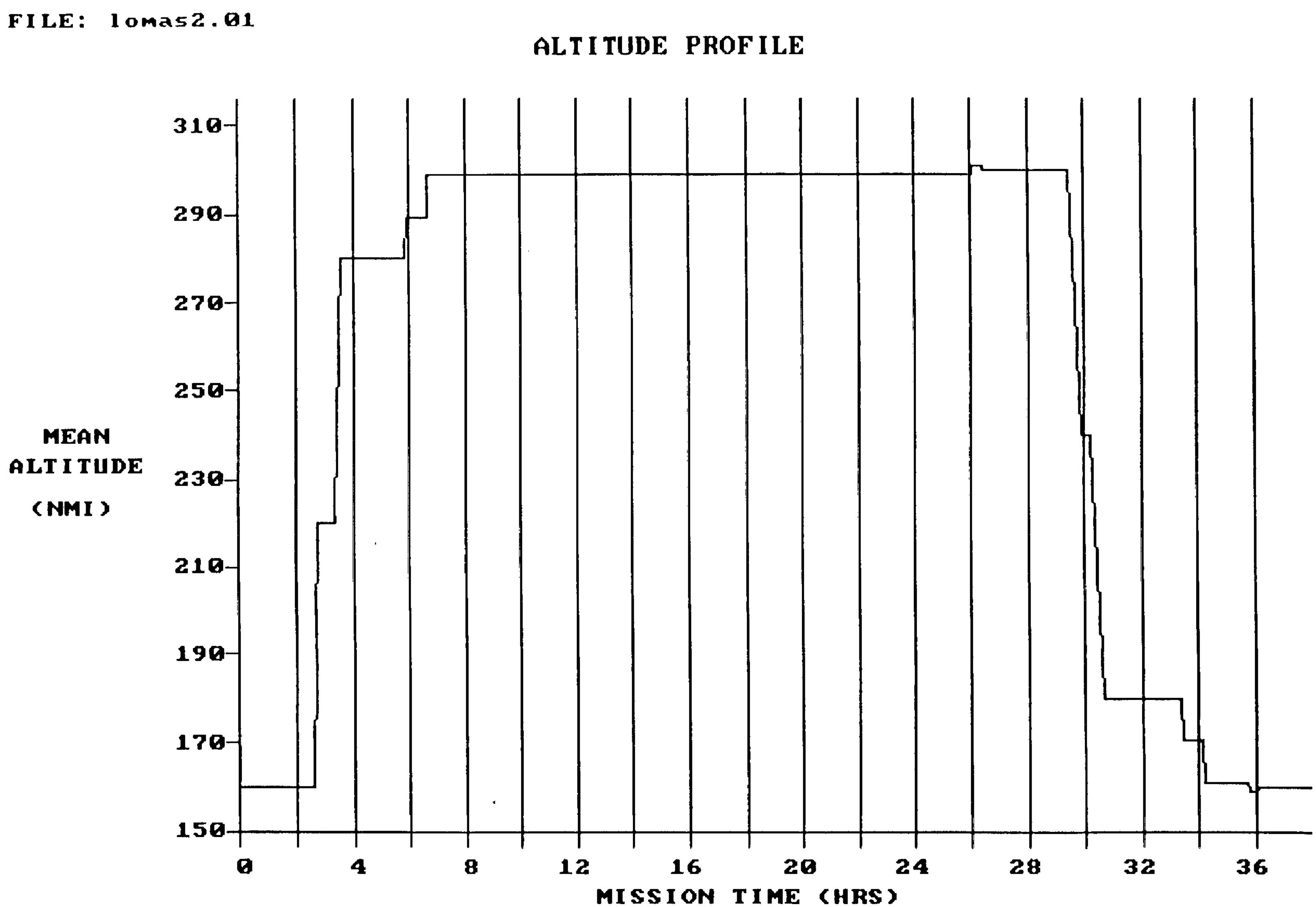

Figure 3-3. Mean Altitude Profile

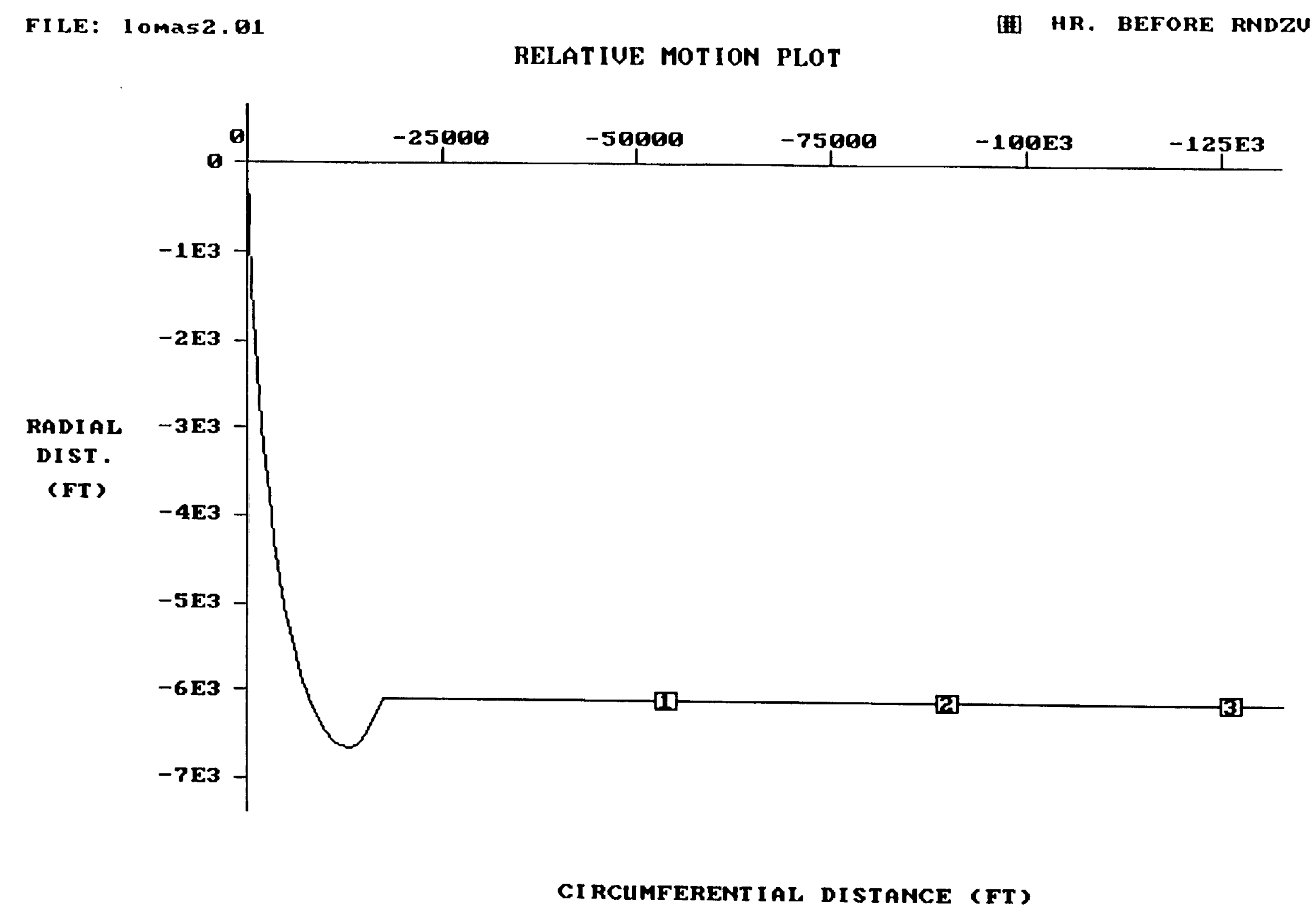

Figure 3-4. Relative Motion Plot

3.7 ORBITAL FLIGHT PROFILE

An orbital flight profile is provided for the entire mission, with each displayed screen or printed page showing the profile for one mission segment, as illustrated in ***Figure 3-5***.

The orbital flight profile shown in ***Figure 3-5*** is for a Double Co-elliptic Rendezvous mission segment. This example consists of six impulses, which is the minimum number for this type of segment. Each impulse location is identified with an encircled numeral. The impulses are numbered consecutively, beginning with the first impulse in the mission. The mission segment illustrated in ***Figure 3-5*** is the first segment in the mission, so the first impulse in the segment is numbered "1". The initial orbit and each target orbit in the mission are indicated by solid circles even though the orbits may actually be elliptical. The transfer conics are indicated by dashed lines. The scales of the orbits and transfer conics are distorted to allow a useful qualitative visual interpretation of the orbital flight profile; plots to scale would be very difficult to analyze visually. However, the angular locations of the impulses are accurately plotted. The perigee locations of the initial and target orbits are indicated with short radial lines (these lines are meaningless and are arbitrarily located for circular orbits). The horizontal line extending from the center of the plot to the right extremity is the argument-of-latitude reference for the initial and target orbits. Each orbit is marked with an identification symbol so that its apogee and perigee altitudes (above the equatorial radius) can be determined from the legend at the lower right of the plot.

3.8 SAMBO INPUT FILE

The IMA program computes a SAMBO input file that can be used by the enhanced SAMBO program (now known as the SCOOT program, Reference 1). The SAMBO input file, named "tag.nnh" (where "tag" is a user-supplied tag and nn is a two-digit number identifying the mission), must be renamed "IMA_SCOOT.DAT" for use by the SCOOT program. A description of the IMA_SCOOT.DAT file is provided in Subsection 3.1 and Appendix B of Reference 1.

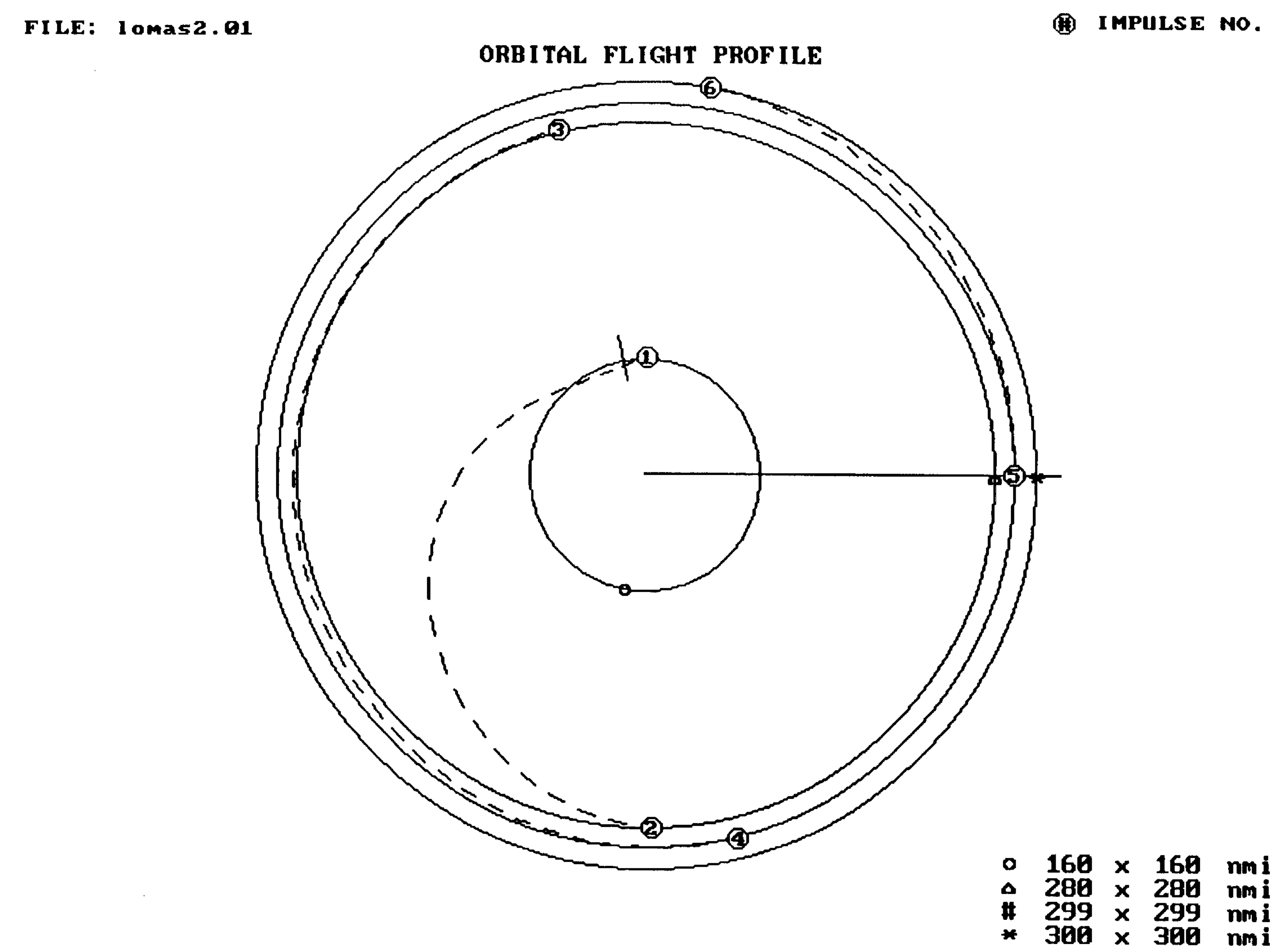

Figure 3-5. Orbital Flight Profile

4. PROGRAM OPERATION

The basic structure of the IMA program is illustrated in ***Figure 4-1***.

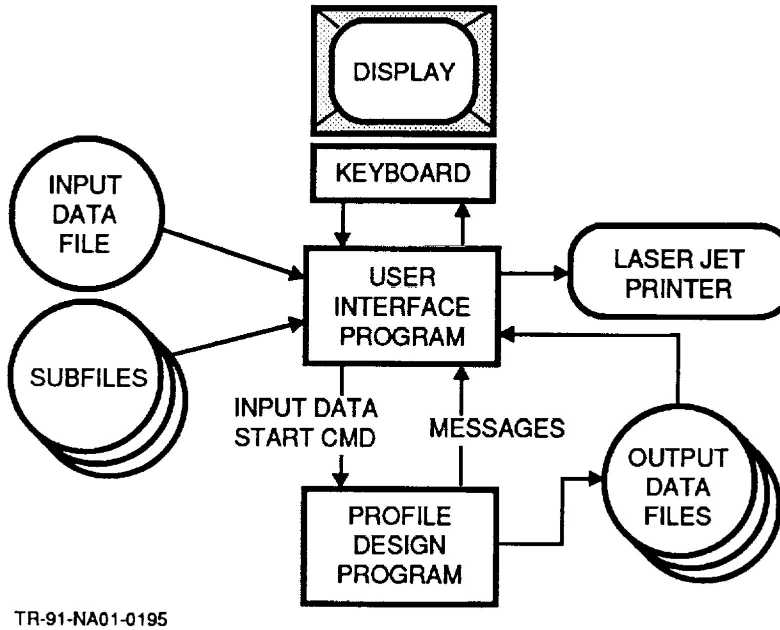

Figure 4-1. IMA Program Structure

The user interface program is a comprehensive program that includes numerous graphics routines, and a description of its operation is outside the scope of this user's manual. However, a complete listing of the user interface program is provided in Reference 2. After the user has entered all required data on the various display screens and has executed the IMA program as described in Section 2, the user interface program calls the profile design program, which is treated as a subroutine. The various input data are supplied to the profile design program through common blocks. The profile design program interacts with the user interface program during execution by the transmission of messages and flags. The messages are displayed on the screen, and, in some cases, the user is provided with the option to continue execution or return to the main menu. Some messages are warnings that indicate the possibility of a problem. The user should be able to determine if there is a significant problem by reading the messages and checking the program output for erroneous results. When the profile design program has finished execution, it notifies the user interface program by means of a flag, and the user is presented with the output-control screen from which he can display or print any of the data in the output data files.

4.1 PROFILE DESIGN PROGRAM

The profile design program is structured as shown in ***Figure 4-2***.

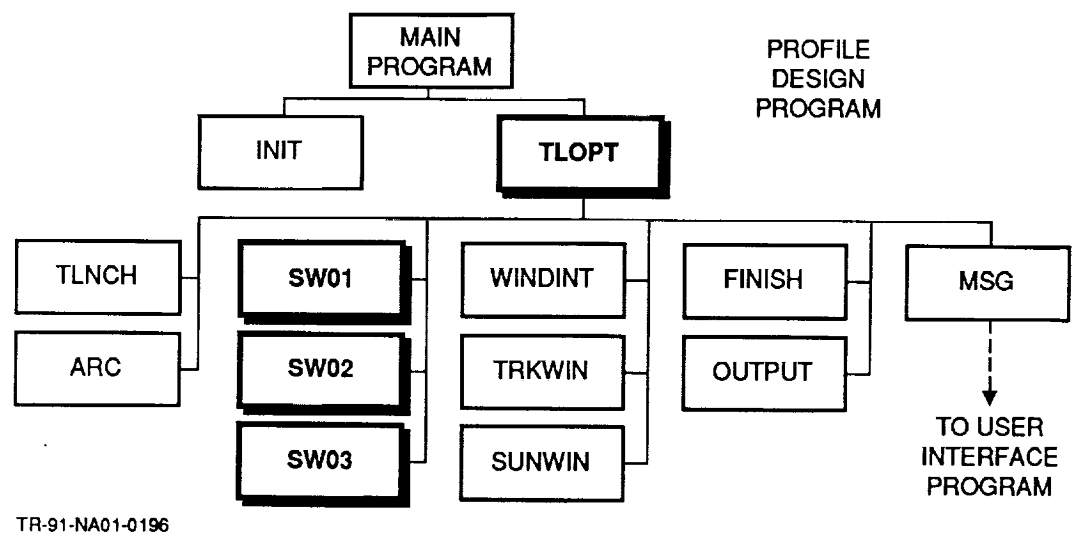

Figure 4-2. Profile Design Program

The MAIN program sets the values for various data constants, calls the INIT subroutine for the computation of mission-dependent values, and calls the Top-Level Optimizer (TLOPT) subroutine for the computation of the quasi-optimum mission profile. Most of the subroutines shown in ***Figure 4-2*** call other subroutines that are not shown. There are approximately fifty-five subroutines in the profile design program. Most of these subroutines are self-explanatory or include ample explanatory comments. A complete program listing is provided in Appendix C. Additional descriptions of the TLOPT, SW01, SW02, and SW03 subroutines are provided in the following paragraphs.

4.1.1 <u>TLOPT Subroutine</u>

The TLOPT subroutine determines the quasi-optimum mission profile by determining the best starting and ending times (joint times) for each mission segment and the best orbit-plane orientations for those orbits with unspecified values for the right ascension of the ascending node. TLOPT varies the joint times and right ascensions according to an empirical method that is a compromise between optimality and computer-time requirement. TLOPT calls Subroutine FINISH for an approximation of the portion of the mission profile that is downstream of the joint time being varied. This approximation allows TLOPT to estimate the cost function. TLOPT calls Subroutines SW01, SW02, and SW03 (segment workers) for the solutions of the rendezvous, payload delivery, and payload deorbit mission segments, respectively. All segments terminate at a target orbit. The target orbit for a rendezvous segment must have all of its elements defined by the user. The target orbit for a payload delivery segment can have a free right ascension and must have a free true anomaly; any user-specified value for true anomaly will be ignored by the segment worker. The target orbit (saving orbit) for a deorbit segment must have a free true anomaly, right ascension, and inclination; any user-specified values for these elements will be ignored by the segment worker.

In the first phase of operation, TLOPT indicates to the segment workers that mean-orbit approximations can be used, and the rendezvous and payload delivery segment workers treat the initial orbit and target orbits as circular orbits with radii equal to the semimajor axes; the mean-orbit approximations allow for more efficient computations by the segment workers without significantly altering the timing of the various orbit transfers in the mission profile. TLOPT calls Subroutines WINDINT, SUNWIN, TRKWIN, and ARC to define sunlight, tracking, and argument-of-latitude windows that constrain the selection of ending times for the rendezvous segments.

In the second (final) phase of operation, TLOPT indicates to the segment workers that the eccentricities and arguments of perigee of the initial orbit and target orbits are to be included in the computations. The joint times and right ascensions remain fixed (except for minor adjustments in some joint times) at the quasi-optimum values that were determined in the first phase. In this final phase, TLOPT simply calls the segment workers in the appropriate sequence without iteration or adjustment. However, in this final phase, the computation time required by each segment worker is greater than was required in the first phase of operation. For the SW01 and SW02 segment workers, the time required is much greater because their final-phase computations involve iterations that can determine the minimum delta-velocity transfers between inclined elliptical orbits. These iterative computations are used in the final phase of operation even if the orbits are circular.

After all mission segments have been computed in the final phase of operation, TLOPT calls Subroutine OUTPUT for the computation and writing of all output files.

4.1.2 SW01 Subroutine

SW01 is the "segment worker" that determines the quasi-optimum solution for a Double Co-elliptic Rendezvous mission segment. The argument list for this subroutine is identical to that for the SW02 and SW03 subroutines. It includes:

INPUTS

1) Mode flag that indicates the first or second (final) phase of operation and, for the first phase, indicates the type of solution desired for the segment:

   A. Minimum time;

   B. Minimum delta-velocity with optimum final time determined by the segment worker; and

   C. Minimum delta-velocity, given the final time specified by the calling program, TLOPT;

2) ID number of the first transfer in the segment;

3) ID number of the first leg in the segment;

4) Burn time of the leg just prior to the start of the segment;

NOTE: The segment starts at the mid-point of this burn time, although the propellants remaining at the start of the leg are those left after this burn is completed.

5) Julian date at the start of the segment;

6) Propellants remaining at the start of the segment; and

7) Julian date at end of segment (not specified for some modes).

NOTE: The ending and starting times for all segments occur at the impulse points. The burn times are centered on the impulse points.

OUTPUTS

1) Julian date at end of segment (for modes where it is not specified);

2) Propellants remaining at the end of the segment;

3) ID number of the last leg in the segment;

4) Burn time of the final leg of the segment; and

5) Error flag indicating the type of error, if any, in the segment-worker computations.

The rendezvous segment worker, SW01, computes the rendezvous segment according to predetermined rules. The first rule is that the segment will consist of three transfers: 1) a transfer to a far phasing orbit, 2) a transfer to a near phasing orbit, and 3) a two-impulse rendezvous transfer to the target orbit, at a point in advance of or behind the target satellite as indicated by user input. The two transfers to the phasing orbits are both referred to as "two-burn to constant delta-height" (2BCDH) transfers, and the final rendezvous transfer to the target orbit is referred to as a "two-burn to target orbit rendezvous" (2BTOR) transfer (refer to Subsections 2.11 and 2.14 for definitions of the geometry inputs associated with these transfers). It is important to remember that the target orbit for the rendezvous segment must be completely specified.

The second rule for the rendezvous mission segment is that all out-of-plane delta-velocity will be accomplished by the first transfer in the segment (to the far phasing orbit). The second 2BCDH transfer and the 2BTOR transfer will be accomplished without any out-of-plane delta-velocity component.

The third rule is that the apogee and perigee of each of the two phasing orbits will be related to those of the target orbit by the delta-height values input by the user (refer to Subsection 2.11). Each delta-height value can be any value desired by the user. A positive value indicates that the phasing orbit will be higher than the target orbit and a negative value indicates that the phasing orbit will be lower than the target orbit. When the target orbit is elliptical, the difference in apogee altitudes of the target and phasing orbits will be the same as the difference in perigee altitudes.

The fourth rule is that the 2BTOR transfer will consist of only two impulses and the central angle between the two impulses must be specified by the user. The timing of the first impulse in the 2BTOR transfer can either be "optimized" by the segment worker or can be specified by the user in terms of a phase relationship of the maneuver vehicle with respect to the target satellite at the time of the first impulse (refer to Subsection 2.14).

The transfers to the far and near phasing orbits are both 2BCDH transfers. However, the segment worker will add burns (impulses) to these 2BCDH transfers as required to keep the longest burn time within the "Single Burn Time Limit" specified by the user on the Propulsion Subsystem Allocation screen (refer to Subsection 2.15). Burns are added in pairs by the segment worker so that the transfer is accomplished by an even number of burns (impulses), with a maximum allowable number of twelve burns. The segment worker SW01 notifies the TLOPT program, through values in a common block, when it has to increase the number of burns in one or both of the 2BCDH transfers.

4.1.3 SW02 Subroutine

SW02 is the segment worker that determines the quasi-optimum solution for a Payload Delivery mission segment. The Payload Delivery segment consists of a single "two-burn to target orbit" (2BTO) transfer. The argument list for SW02 is identical to that for the SW01 and SW03 subroutines (refer to Subsection 4.1.2, preceding). SW02 will add pairs of burns to the original two burns in the 2BTO transfer as required to prevent any burn time from exceeding the "Single Burn Time Limit" specified by the user on the Propulsion Subsystem Allocation screen. It is important to note that no payload has to be delivered to the target orbit, which can be thought of as a holding orbit, phasing orbit, or any other kind of orbit desired by the user.

In the initial phase of operation, SW02 is responsible for calculating the true anomaly of the target orbit and will ignore any user-input value. For those modes where TLOPT specifies the ending time for the Payload Delivery segment, SW02 will adjust this ending time by the minimum amount necessary to correspond to an efficient transfer. The resulting target-orbit true anomaly will be output by the SW02 subroutine through a common block.

Since it is allowable for the user to leave undefined the right ascension of the 2BTO target orbit's ascending node, TLOPT may notify SW02, in some of the modes in the initial phase of operation, to determine the target orbit's right ascension so as to minimize the delta-velocity required for the 2BTO transfer. In this case, SW02 determines the target-orbit right ascension requiring minimum plane change for the 2BTO transfer and notifies TLOPT of the resulting value through a common block.

In the final phase of operation, SW02 must comply with the final time specified by TLOPT and with the target orbit's right ascension and true anomaly as determined in the initial phase of operation. SW02 computes the 2BTO transfer in the same way that SW01 computes the 2BCDH transfer from the initial orbit to the far phasing orbit.

4.1.4 SW03 Subroutine

SW03 is the segment worker that determines the quasi-optimum solution for a Payload Deorbit mission segment. The Payload Deorbit segment consists of a "one burn to reentry conic" (1BRC) transfer and a "two burn to saving orbit" (2BSO) transfer. Refer to Subsections 2.10 and 2.12 for the definitions of the geometry inputs associated with the 1BRC and 2BSO transfers. Unlike the other segment workers, SW03 will not add burns to either transfer to satisfy a "Single Burn-Time Limit." The argument list for SW03 is identical to those for SW01 and SW02. The two transfers in this segment are accomplished without any out-of-plane delta-velocity component. Therefore, the target orbit will have the same inclination as the starting orbit for the segment. The target orbit's right ascension will be a little different from that of the starting orbit because of the differential regression of the lines of nodes during the segment time. SW03 is responsible for computing the inclination, right ascension, and true anomaly for the target (saving) orbit, and any user-specified values for these elements will be ignored.

SW03 first minimizes the delta-velocity required for the 1BRC transfer to a reentry conic that terminates at the user-specified reentry conditions. The first impulse of the 2BSO transfer is constrained to occur at the end of a coast period on the reentry conic equal to "coast time before saving impulse" (CTBSI). The transfer angle and transfer time of the 2BSO transfer are then optimized by SW03 to minimize the 2BSO delta-velocity. This piece-wise treatment of the two transfers, and the treatment of CTBSI as a constraint equation instead of an inequality, will not produce an overall minimum delta-velocity for the segment. However, a more optimum overall treatment would require significant additional computer time and therefore was not incorporated. In most cases, the solution of the deorbit segment by SW03 is not only fairly close to a minimum delta-velocity solution but is also fairly close to a minimum-propellant solution. Experience has shown that, in most cases, the overall optimization of the deorbit mission segment will reduce the SW03-computed propellant consumption by only a small percentage.

When TLOPT specifies an end time for the deorbit segment, SW03 uses the specified end time to determine how many revolutions there should be in the starting orbit before the 1BRC impulse is executed and, in this way, is able to achieve an end time that is very close to the value specified by TLOPT. The specified end time does not influence SW03's piece-wise optimization of the 1BRC and 2BSO transfers.

APPENDIX A. INPUT FILE FOR THE IMA PROGRAM

The input file for the IMA program is the result of the user's definition of the mission through the various interface screens. This file contains all of the information that has been supplied by the user, as well as the default data. This appendix contains a sample input data file with the name "lomas2.01," with the "01" indicating that the input file is the first (or only) mission in a sequence of missions that were obtained from a single execution of the IMA program.

FILE: lomas2.01

INPUT DATA FILE UNITS: ENGLISH

ORBITS SUBFILE UNITS: ENGLISH

Number of Orbits 2

Orbit No. 1 space station orbit
Type No. 1 MEAN ORBITAL ELEMENTS

Orbital Parameters

GMT	93-07-21-00-00- 0.00	
Apogee Altitude:	160.000	(nmi)
Perigee Altitude:	160.000	(nmi)
Inclination:	28.50000	(deg)
Right Ascension:	165.86400	(deg)
Arg of Perigee:	100.00000	(deg)
True Anomaly:	66.60000	(deg)

Orbit No. 2 large payload orbit
Type No. 1 MEAN ORBITAL ELEMENTS

Orbital Parameters

GMT	93-07-21-00-00- 0.00	
Apogee Altitude:	300.000	(nmi)
Perigee Altitude:	300.000	(nmi)
Inclination:	28.50000	(deg)
Right Ascension:	164.67999	(deg)
Arg of Perigee:	100.00000	(deg)
True Anomaly:	116.16000	(deg)

PAYLOADS SUBFILE UNITS: ENGLISH

Number of Payloads 1

Payload No. 1 large payload

Mass: 40000.000 (lbm)
Acceleration Limit: 0.328E+09 (f/s/s)

TRACKING STATIONS SUBFILE UNITS: ENGLISH

Number of Tracking Stations 3

Tracking Station No. 1 tdrss no.1

Latitude :	0.00000	(deg)
Longitude:	0.00000	(deg)
Altitude :	19363.000	(nmi)

Tracking Station No. 2 tdrss no.2

Latitude :	0.00000	(deg)
Longitude:	120.00001	(deg)
Altitude :	19363.000	(nmi)

Tracking Station No. 3 tdrss no.3

Latitude :	0.00000	(deg)
Longitude:	240.00002	(deg)
Altitude :	19363.000	(nmi)

MANEUVER VEHICLE SUBFILE UNITS: ENGLISH

Name: orbital maneuvering vehicle

Empty Mass: 10514.100 (lbm)

Number of Propellant Subsystems 3

Propulsion Subsystem No. 1 bi-propellant

Useable Propellant Capacity:	9000.000	(lbm)
Maximum Thrust :	220.000	(lb)
ISP at Maximum Thrust :	272.1750	(sec)
ISP at Zero Thrust :	272.1750	(sec)

Propulsion Subsystem No. 2 mono-propellant

Useable Propellant Capacity:	1180.000	(lbm)
Maximum Thrust :	91.200	(lb)
ISP at Maximum Thrust :	209.0000	(sec)
ISP at Zero Thrust :	209.0000	(sec)

Propulsion Subsystem No. 3 gn2

Useable Propellant Capacity:	165.000	(lbm)
Maximum Thrust :	1.000	(lb)
ISP at Maximum Thrust :	100.0000	(sec)
ISP at Zero Thrust :	100.0000	(sec)

INITIAL CONDITIONS

Initial orbit: 01 space station orbit

Propulsion Subsystem	Fill Fraction	Reserve Fraction
1. bi-propellant	1.0000	0.0000
2. mono-propellant	1.0000	0.0000
3. gn2	1.0000	0.0000

MISSION PROFILE DESIGN

Number of Transfers 6

Transfer No. 1 trnsfr to 280 far-phasing orbit
Type 2 (2BCDH)

Number of Payloads on Transfer: 0

Propulsion Subsystem Allocation

	Throttle	RCS Flowrate (lbm/s)		Pointing & Docking (lbm)	
Subsystem	Fraction	Coast	Burn	coast 1	coast 2
1.bi-propellant	1.0000	0.000000	0.000000	0.000	0.000
2.mono-propellant	0.0000	0.000185	0.000185	0.000	0.000
3.gn2	0.0000	0.000000	0.000000	0.000	0.000

Single Burn Time Limit: 0.100E+07 (sec)

If the burn time exceeds the limit,
will low-acceleration computations be used? (y,n): N

Orbits (incl. fractions) prior to first impulse: Min 0.0000
Max 15.0000

Delta Height of phasing orbit: -20.000 (nmi)
(neg value=phasing orbit lower than target)

Transfer No. 2 trnsfr to 299 near-phasing orbit
Type 2 (2BCDH)

Number of Payloads on Transfer: 0

Propulsion Subsystem Allocation

	Throttle	RCS Flowrate (lbm/s)		Pointing & Docking (lbm)	
Subsystem	Fraction	Coast	Burn	coast 1	coast 2
1.bi-propellant	1.0000	0.000000	0.000000	0.000	0.000
2.mono-propellant	0.0000	0.000185	0.000185	0.000	0.000
3.gn2	0.0000	0.000000	0.000000	0.000	0.000

Single Burn Time Limit: 0.100E+07 (sec)

If the burn time exceeds the limit,
will low-acceleration computations be used? (y,n): N

Orbits (incl. fractions) prior to first impulse: Min 1.0000
Max 15.0000

Delta Height of phasing orbit: -1.000 (nmi)
(neg value=phasing orbit lower than target)

Transfer No. 3 trnsfr to 300 lrg. pld rendez
Type 5 (2BTOR)

Target Orbit: 2 large payload orbit

Number of Payloads on Transfer: 0

Propulsion Subsystem Allocation

Subsystem	Throttle Fraction	RCS Flowrate (lbm/s) Coast	RCS Flowrate (lbm/s) Burn	Pointing & Docking (lbm) coast 1	Pointing & Docking (lbm) coast 2
1.bi-propellant	0.8290	0.000000	0.000000	0.000	0.000
2.mono-propellant	0.0000	0.000185	0.000185	0.000	0.000
3.gn2	0.0000	0.000000	0.000000	0.000	0.000

Single Burn Time Limit: 0.100E+07 (sec)

If the burn time exceeds the limit,
will low-acceleration computations be used? (y,n): N

Orbits (incl. fractions) prior to first impulse: Min 1.0000
Max 15.0000

Impulse 1: -0.04360 deg ahead of/behind (+/-) target satellite
Impulse 2:
occurs between min and min before/after (-/+) sunrise
occurs at argument of latitude between deg and deg
Total transfer angle: 80.00000 deg

Terminal Point: 0.000 (nmi) ahead of target (- for behind)

TDRSS communication window begins n.l.t. min before rendezvous
ends n.e.t. min after rendezvous

Transfer No. 4 trnsfr to 180 far-phasing orbit
Type 2 (2BCDH)

Number of Payloads on Transfer: 1
01 - large payload

Propulsion Subsystem Allocation

Subsystem	Throttle Fraction	RCS Flowrate (lbm/s) Coast	Burn	Pointing & Docking (lbm) coast 1	coast 2
1.bi-propellant	1.0000	0.000000	0.000000	0.000	0.000
2.mono-propellant	0.0000	0.000300	0.000300	0.000	0.000
3.gn2	0.0000	0.000000	0.000000	25.000	0.000

Single Burn Time Limit: 0.100E+07 (sec)

If the burn time exceeds the limit,
will low-acceleration computations be used? (y,n): N

Orbits (incl. fractions) prior to first impulse: Min 2.0000
Max 30.0000

Delta Height of phasing orbit: 20.000 (nmi)
(neg value=phasing orbit lower than target)

Transfer No. 5 trnsfr to 161 near-phasing orbit
Type 2 (2BCDH)

Number of Payloads on Transfer: 1
01 - large payload

Propulsion Subsystem Allocation

Subsystem	Throttle Fraction	RCS Flowrate (lbm/s) Coast	Burn	Pointing & Docking (lbm) coast 1	coast 2
1.bi-propellant	1.0000	0.000000	0.000000	0.000	0.000
2.mono-propellant	0.0000	0.000300	0.000300	0.000	0.000
3.gn2	0.0000	0.000000	0.000000	0.000	0.000

Single Burn Time Limit: 0.100E+07 (sec)

If the burn time exceeds the limit,
will low-acceleration computations be used? (y,n): N

Orbits (incl. fractions) prior to first impulse: Min 1.0000
Max 20.0000

Delta Height of phasing orbit: 1.000 (nmi)
(neg value=phasing orbit lower than target)

Transfer No. 6 trnsfr to 160 init. orbit rendez
Type 5 (2BTOR)

Target Orbit: 1 space station orbit

Number of Payloads on Transfer: 1
01 - large payload

Propulsion Subsystem Allocation

Subsystem	Throttle Fraction	RCS Flowrate (lbm/s) Coast	Burn	Pointing & Docking (lbm) coast 1	coast 2
1.bi-propellant	0.0000	0.000000	0.000000	0.000	0.000
2.mono-propellant	1.0000	0.000300	0.000300	0.000	0.000
3.gn2	0.0000	0.000000	0.000000	0.000	0.000

Single Burn Time Limit: 0.100E+07 (sec)

If the burn time exceeds the limit,
will low-acceleration computations be used? (y,n): N

Orbits (incl. fractions) prior to first impulse: Min 1.0000
Max 20.0000

Impulse 1: 0.04130 deg ahead of/behind (+/-) target satellite
Impulse 2:
occurs between min and min before/after (-/+) sunrise
occurs at argument of latitude between deg and deg
Total transfer angle: 80.00000 deg

Terminal Point: 0.000 (nmi) ahead of target (- for behind)

TDRSS communication window begins n.l.t. min before rendezvous
ends n.e.t. min after rendezvous

MISSION OBJECTIVE: Conserve Propellant

Maximum Mission Time: 72.000 hrs

Propulsion Subsystem	Weighting Factor
bi-propellant	1.0000
mono-propellant	1.0000
gn2	1.0000

EXECUTION PARAMETERS

Minimum Allowable Altitude: 100.000 (nmi)

Reference Event for Mission Elapsed Time: initial orbit

Time delay between initial-orbit
reference time and mission start time: 00-00-00- 0.00

APPENDIX B. TRAJECTORY SUMMARY

This appendix contains the trajectory summary part of the IMA program output that is the result of the input data defined in Appendix A. The trajectory summary provides the user with a "quick look" at the IMA program's quasi-optimum solution of the mission.

FILE: lomas2.01

TRAJECTORY SUMMARY: B U R N   A R C S

M.E.T. REF: space station orbit   JULIAN DAY=2449189.5000000

TRACKING STATIONS

1 tdrss no.1

2 tdrss no.2

3 tdrss no.3

BURN NO.	START TIME (HR MIN SEC)			DURATION (SEC)	DELTA-V (FPS)	PLANE CHNG (DEG)	TRACKING COVERAGE STA1	STA2	STA3	STA4
				TRANSFER NO. 1: trnsfr to 280 far-phasing orbit						
1	2	35	12.2	681.803	234.49	0.24891	END	NONE	FULL	
2	3	21	55.9	655.911	231.68	0.24859	BEG	FULL	NONE	
				TRANSFER NO. 2: trnsfr to 299 near-phasing orbit						
3	5	52	9.0	88.434	31.71	0.00000	NONE	NONE	FULL	
4	6	39	47.5	88.001	31.67	0.00000	FULL	FULL	NONE	
				TRANSFER NO. 3: trnsfr to 300 lrg. pld rendez						
5	26	5	48.7	25.514	7.63	0.00000	NONE	FULL	FULL	
6	26	26	53.3	41.426	12.41	0.00000	FULL	NONE	FULL	
				TRANSFER NO. 4: trnsfr to 180 far-phasing orbit						
7	29	26	43.0	1691.574	203.43	0.00548	END	BEG	FULL	
8	30	13	40.9	1665.904	205.07	0.00230	FULL	END	BEG	
				TRANSFER NO. 5: trnsfr to 161 near-phasing orbit						
9	33	23	15.9	266.429	33.25	0.00000	FULL	NONE	FULL	
10	34	8	38.8	265.764	33.29	0.00000	NONE	FULL	END	
				TRANSFER NO. 6: trnsfr to 160 init. orbit rendez						
11	35	43	1.0	132.071	6.88	0.00000	NONE	FULL	NONE	
12	36	2	16.5	226.591	11.81	0.00000	NONE	FULL	FULL	

TRAJECTORY SUMMARY: MEAN ORBIT ELEMENTS

IMPULSE NO.	M.E.T. (DAYS)	APOGEE (N. MI.)	PERIGEE (N. MI.)	TR.ANOM (DEG)	ARG. P (DEG)	INCLIN (DEG)	R. ASCEN (DEG)
	INITIAL CONDITIONS						
	0.000000	160.0000	160.0000	66.6000	100.0000	28.5000	165.8640
	TRANSFER NO. 1: trnsfr to 280 far-phasing orbit						
1-	0.111725	160.0000	160.0000	347.6001	101.3651	28.5000	165.0255
1+		280.0016	159.9985	359.5863	89.8373	28.4965	164.5039
2-	0.144026	280.0016	159.9985	180.3677	90.2100	28.4965	164.2750
2+		280.0016	279.9998	271.0356	0.0000	28.5000	163.7540
	TRANSFER NO. 2: trnsfr to 299 near-phasing orbit						
3-	0.245060	280.0000	280.0000	0.0000	103.9679	28.5000	163.0781
3+		299.0000	280.0000	0.0000	103.9679	28.5000	163.0781
4-	0.278142	299.0000	280.0000	180.0000	104.3251	28.5000	162.8587
4+		299.0000	299.0000	284.3251	0.0000	28.5000	162.8587
	TRANSFER NO. 3: trnsfr to 300 lrg. pld rendez						
5-	1.087517	299.0000	299.0000	248.4019	111.6245	28.5000	157.5398
5+		302.9864	298.9062	342.5491	17.4773	28.5000	157.5398
6-	1.102245	302.9864	298.9062	62.3918	17.6346	28.5000	157.4432
6+		300.0000	300.0000	80.0264	0.0000	28.5000	157.4432
	TRANSFER NO. 4: trnsfr to 180 far-phasing orbit						
7-	1.236676	300.0000	300.0000	336.6035	113.2190	28.5000	156.5606
7+		300.0010	179.9999	179.6782	270.1544	28.5000	156.5491
8-	1.269142	300.0010	179.9999	359.8867	270.5218	28.5000	156.3234
8+		180.0000	180.0000	270.4128	0.0000	28.5000	156.3186
	TRANSFER NO. 5: trnsfr to 161 near-phasing orbit						
9-	1.392698	180.0000	180.0000	180.0000	74.9023	28.5000	155.4091
9+		180.0000	161.0000	180.0000	74.9023	28.5000	155.4091
10-	1.424209	180.0000	161.0000	0.0000	75.2834	28.5000	155.1750
10+		161.0000	161.0000	75.2834	0.0000	28.5000	155.1750
	TRANSFER NO. 6: trnsfr to 160 init. orbit rendez						
11-	1.488970	161.0000	161.0000	329.2768	118.1931	28.5000	154.6895
11+		161.0553	157.4599	165.7538	281.7161	28.5000	154.6895
12-	1.502891	161.0553	157.4599	245.5836	281.8863	28.5000	154.5849
12+		160.0000	160.0000	167.4699	0.0000	28.5000	154.5849

TRAJECTORY SUMMARY: PROPELLANT USAGE UNITS: LB.

SYSTEM		INITIAL LOADING
1	bi-propellant	9000.00
2	mono-propellant	1180.00
3	gn2	165.00

BURN NO.	END TIME (DAYS)	PROPELLANTS USED DURING BURN SYSTEM 1	SYSTEM 2	SYSTEM 3	PROPELLANTS REMAINING SYSTEM 1	SYSTEM 2	SYSTEM 3
	TRANSFER NO. 1: trnsfr to 280 far-phasing orbit						
1	0.115671	551.10	0.13	0.00	8448.90	1178.15	165.00
2	0.147822	530.17	0.12	0.00	7918.72	1177.64	165.00
	TRANSFER NO. 2: trnsfr to 299 near-phasing orbit						
3	0.245572	71.48	0.02	0.00	7847.24	1176.07	165.00
4	0.278651	71.13	0.02	0.00	7776.11	1175.55	165.00
	TRANSFER NO. 3: trnsfr to 300 lrg. pld rendez						
5	1.087665	17.10	00.00	0.00	7759.01	1162.61	165.00
6	1.102485	27.76	0.01	0.00	7731.25	1162.38	165.00
	TRANSFER NO. 4: trnsfr to 180 far-phasing orbit						
7	1.246465	1367.30	0.51	0.00	6363.95	1158.65	140.00
8	1.278782	1346.56	0.50	0.00	5017.39	1157.81	140.00
	TRANSFER NO. 5: trnsfr to 161 near-phasing orbit						
9	1.394240	215.36	0.08	0.00	4802.04	1154.82	140.00
10	1.425747	214.82	0.08	0.00	4587.22	1154.00	140.00
	TRANSFER NO. 6: trnsfr to 160 init. orbit rendez						
11	1.489734	0.00	57.67	0.00	4587.22	1094.71	140.00
12	1.504203	0.00	98.94	0.00	4587.22	995.46	140.00

TRAJECTORY SUMMARY: EC SPHERICAL COORDINATES

IMPULSE NO.	M.E.T. (DAYS)	VELOCITY (FPS)	F.P.ANGLE (DEG)	HEADING (DEG)	ALTITUDE (N. MI.)	LATITUDE (DEG)	LONGITUDE (DEG)
	INITIAL CONDITIONS						
	0.000000	25354.013	0.0000	117.8419	160.0000	6.3488	35.2709
	TRANSFER NO. 1: trnsfr to 280 far-phasing orbit						
1-	0.111725	25354.013	0.0000	89.4382	160.0000	28.4949	-85.2514
1+		25560.767	-0.0067	89.6871	160.0000	28.4949	-85.2514
2-	0.144026	24737.094	-0.0061	89.6864	280.0004	-28.4949	84.1727
2+		24942.164	-00.0000	89.4378	280.0004	-28.4949	84.1727
	TRANSFER NO. 2: trnsfr to 299 near-phasing orbit						
3-	0.245060	24942.164	0.0000	97.4665	280.0000	27.5841	-118.3500
3+		24973.877	0.0000	97.4665	280.0000	27.5841	-118.3500
4-	0.278142	24847.104	0.0000	82.3487	299.0000	-27.5371	49.8878
4+		24878.777	0.0000	82.3487	299.0000	-27.5371	49.8878
	TRANSFER NO. 3: trnsfr to 300 lrg. pld rendez						
5-	1.087517	24878.777	0.0000	61.5000	299.0000	0.0126	-173.7833
5+		24885.241	-0.0094	61.5000	299.0000	0.0126	-173.7833
6-	1.102245	24878.597	0.0277	84.6279	300.0000	28.0309	-100.5353
6+		24875.455	0.0000	84.6279	300.0000	28.0309	-100.5353
	TRANSFER NO. 4: trnsfr to 180 far-phasing orbit						
7-	1.236676	24875.455	0.0000	89.9036	300.0000	28.4998	-138.8320
7+		24672.052	0.0053	89.9091	300.0000	28.4998	-138.8320
8-	1.269142	25489.023	-0.0018	89.7782	180.0000	-28.4992	29.8782
8+		25283.953	0.0000	89.7759	180.0000	-28.4992	29.8782
	TRANSFER NO. 5: trnsfr to 161 near-phasing orbit						
9-	1.392698	25283.953	0.0000	98.0495	180.0000	-27.4316	-33.1684
9+		25250.704	0.0000	98.0495	180.0000	-27.4316	-33.1684
10-	1.424209	25383.789	0.0000	82.1467	161.0000	27.4843	135.6478
10+		25350.496	0.0000	82.1467	161.0000	27.4843	135.6478
	TRANSFER NO. 6: trnsfr to 160 init. orbit rendez						
11-	1.488970	25350.496	0.0000	88.6270	161.0000	28.4697	125.5461
11+		25344.366	0.0070	88.6270	161.0000	28.4697	125.5461
12-	1.502891	25351.401	-0.0260	117.9246	160.0000	5.9419	-157.7570
12+		25354.013	0.0000	117.9246	160.0000	5.9419	-157.7570

REFERENCES

1. Williams, D. F., "User's Manual for SCOOT," Dynetics, Inc., TR-90-NASA-37850-085, October 1990.
2. Williams, D. F. and Bret Gunn, "Program Listing of the IMA User Interface Program," Dynetics, Inc., October 1990.