Shuttle FDO MFD 0.1.6

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March 3, 2019

1 Introduction

The Shuttle FDO MFD contains tools to calculate rendezvous plans and individual maneuvers for Space Shuttle operations. It is based on the Orbital Maneuver Processor (OMP), which was the program used for this task by the actual Shuttle Flight Dynamics Officers (FDO). The MFD is mainly intended for use with the Space Shuttle Ultra addon for the Orbiter Space Flight Simulator 2016.

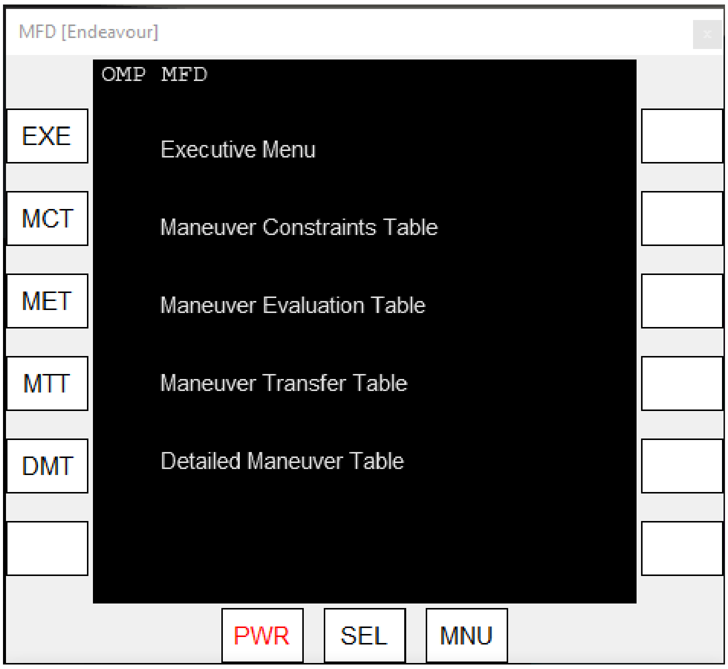

Figure 1: Main Menu

2 OMP User's Guide

2.1 Maneuvers and Constraints

The OMP is capable of computing many different types of maneuvers, for example it can target a desired orbit height for a Hohmann transfer, or downtrack distance from another spacecraft after a period of time. For all maneuver types, the user must specify a *primary constraint*, for example TIG of the burn in MET, or number of revs since a previous burn. Most maneuver types also require one or more *secondary constraints*; these are normally of a lighting or geometric nature. For the height adjust (HA) burn example mentioned above, a valid secondary constraint would be APO=1 in order to force TIG to occur at the next apoapsis. In other words, the OMP would begin searching for the next apoapsis, starting at the threshold time specified as the primary constraint. Another secondary constraint could be HD=160, which tells the OMP what height to target for the burn (160 nm in this example). Some secondary constraints define desired chaser-target relative position at a future time (downrange distance, or DR, for example).

The following passage is a complete list of all maneuvers supported by the OMP in the Shuttle FDO MFD.

2.1.1 Single Vehicle Maneuvers

The following list shows the maneuvers, which are supported in OMP for use with only a single vehicle. In other words, they are target independent.

APSO (Apsidal Shift)
This is a maneuver targeted to shift the chaser's line of apsides with a purely radial maneuver done halfway between the current and desired line of apsides. This maneuver is normally used with the A or P secondary constraints (not supported yet!).

CIRC (Circularization)
This maneuver is targeted to circularize the chaser's orbit at the maneuver time.

DVPY (Delta Velocity with Pitch and Yaw)
This maneuver is a PEG 7 maneuver, similar to the EXDV maneuver, defined by a delta velocity magnitude and a LVLH pitch and yaw thrust direction. These parameters are indicated by the DV, YAW and PIT secondary constraints.

DVYP (Delta Velocity with Yaw and Pitch)
Same as above.

EXDV (External Delta Velocity)

This is a PEG 7 targeted maneuver defined by LVLH velocity components as specified with DVLV secondary constraints in X, Y and Z order.

HA (Height Adjust)
This is a horizontally executed maneuver targeted to achieve a desired orbital altitude 180° from the maneuver point. Thus, this maneuver is targeted as a Hohmann transfer. The desired orbital altitude is indicated by the HD "'height desired"' secondary constraint.

HASH (Height Adjust and Apsidal Shift)
This is a maneuver targeted to achieve a desired orbital altitude 180° from the maneuver point and to simultaneously move the line of apsides to the maneuver point. THes desired altitude is indicated by the HD secondary constraint.

2.1.2 Dual Vehicle Maneuvers

The follow list shows the maneuvers which are supported in OMP using two vehicles, a chaser and a target.

NC (n^{th} Closing Maneuver)
This is a horizontally executed maneuver targeted to obtain the desired offset position from the target (phase angle) at a future time. This maneuver controls the X axis curvilinear distance. The offset position is indicated using the DR secondary constraint.

NCC (n^{th} Corrective Combination)
This is a Lambert targeted maneuver correcting the chaser's trajectory to achieve the desired offset position relative to the target. The desired curvilinear LVLH offset position is indicated by CXYZ secondary constraints in X, Y, Z order. Alternative, DR, WEDG and DH constraints can be used. The maneuver controls all curvilinear axes. It is a combination of three maneuvers: NC, NH and NPC. Typically, Y-offset is set to zero, creating a common node at the subsequent maneuver.

NH (n^{th} Height Adjust)
This is a horizontally executed maneuver targeted to a differential height from the target at some future time. It controls the Z curvilinear distance. The differential height is indicated using the DG secondary constraint.

NHRD (Height Adjust with Radial Component)
This maneuver is similar to the NH maneuver except it contains a radial component to null the radial velocity at the time of the maneuver. The differential height is indicated using the DG secondary constraint.

NPC (n^{th} Plane Change)

This is an out-of-plane maneuver placing the chaser in the target's phantom plane. The phantom plane is the target's actual plane offset by the amount of differential nodal regression calculated to occur between the NPC maneuver and the desired in-plane time (function of height difference). The in-plane time is indicated by the WEDG=0 secondary constraint, placed on a future maneuver. In addition, the maneuver should be placed at a common node between the chaser and phantom target planes which is indicated by the CN=1 secondary constraint. If this is not done, the chaser and target will remain in separate planes. The NPC maneuver controls the Y axis curvilinear distance.

If the WEDG secondary constraint is not used, the maneuver will place the chaser in the target's actual plane at the time of the maneuver.

NS (Node Shift)
This maneuver is targeted to place a common node approximately 90 degrees from the maneuver point.

NSR (n^{th} Slow Rate Maneuver)
This maneuver is targeted to put the chaser in an orbit coelliptic to the target. Coelliptic is defined as a condition where there are coincident lines of apsides. This maneuver is often executed alone, allowing the next maneuver to set up lighting for intercept.

SOI (Stable Orbit Initiation)
This is a Lambert targeted maneuver correcting the chaser's trajectory to achieve the desired offset position relative to the target at the subsequent SOR maneuver. The offset position is indicated with the CXYZ secondary constraints. The SOI maneuver must be followed by a SOR maneuver.

SOR (Stable Orbit Rendezvous)
This is the second maneuver of the Lambert pair SOI/SOR. This maneuver is Lambert targeted to re-intercept the SOR offset position after 270° of orbital travel, essentially stabilizing the chaser in the same orbit as the target, assuming offsets are small.

SOR can also be a stand-alone maneuver. The maneuver computed will be the same as an NCC maneuver in a NCC/NSR combination when the primary constraint for the NSR is WT=270 (M=0.75) and the secondary constraint offsets are the same as the SOR maneuver.

2.1.3 Threshold (Primary) Constraints

The following descriptions reference the threshold constraints (referred to as "'primary constraints"') supported by OMP. These constraints are used to define the Time of Ignition (TIG) of the maneuver if no secondary constraint is specified. If a geometric or lighting secondary constraint exists for the maneuver, the threshold constraint defines the threshold, or the time at which the OMP starts to search for the geometric or lighting constraint's value.

APS (Delta Apsides)
This specifies the number of chaser half orbits from the previous maneuver. For example, APS=2.0 would yield the same result as M=1.0.

CAN (Central Travel Angle)
This specifies that the maneuver will occur when the chaser has flown through the central travel angle specified in degrees.

DT (Delta Time)
This specifies the delta time from the previous maneuver's impulsive ignition time to the current maneuver's impulsive ignition time. The OMP expects this delta time in a DDD:HH:MM:SS.SSS format.

M (Delta Orbits)
This specifies the number of chaser orbits from the previous maneuver. The value may be a decimal fraction.

N (Delta Apsides)
This specifies the number of chaser half orbits from the previous maneuver.

REV (Delta Revolutions)
This specifies the number of chaser orbits from the previous maneuver in orbits. This value may be a decimal fraction.

T (Time)
The maneuver's impulsive ignition time will occur at the specified time. The OMP expects MET in DDD:HH:MM:SS.SSS format.

WT (Central Travel Angle)
This specifies that the maneuver will occur when the chaser has flown through the central travel angle specified in degrees.

2.1.4 Geometric (Secondary) Constraints

The following documentation reference geometric (secondary) constraints supported by OMP. These constraints are used to alter the maneuver's TIG to meet the geometric constraint in relation to the Earth, inertial space, the chaser or target orbit, or the target.

APO (nth Apogee)

The maneuver is executed at the n^{th} apogee of the chaser's orbit after the threshold constraint, where N is the constraint's value.

APS (n^{th} Apsidal Crossing)
The maneuver is executed at the n^{th} chaser apsidal crossing after the threshold constraint. To insure convergence, minimum delta-height between the chaser's apogee and perigee must be >10 nm.

CN (Common Node)
The maneuver is executed at a common nodal crossing of the target and chaser orbit planes. When used in conjunction with the WEDG secondary constraint, the chaser maneuver will be executed at a phantom common nodal crossing such that the two vehicles will be coplanar at the WEDG specified time.

PER (n^{th} Perigee)
The maneuver is executed at the n^{th} perigee of the chaser's orbit after the threshold constraint, where n is the constraint's value.

2.1.5 Lighting (Secondary) Constraints

The following descriptions reference lighting (secondary) constraints supported by OMP. These constraints allow maneuver times to be based on lighting events. All constraint values are input in minutes from the event, where positive values are after the event.

LITI (Time from Sunrise)
The maneuver is executed at a time relative to orbital sunrise. This is similar to the NITO lighting constraint.

LITM (Time from Noon)
The maneuver is executed at a time relative to orbital noon.

LITO (Time from Sunset)
The maneuver is executed at a time relative to orbital sunset. This is similar to the NITI lighting constraint.

NITI (Time from Sunset)
The maneuver is executed at a time relative to orbital sunset. This is similar to the LITO lighting constraint.

NITM (Time from Midnight)
The maneuver is executed at a time relative to orbital midnight.

NITO (Time from Sunrise)

The maneuver is executed at a time relative to orbital sunrise. This is similar to the LITI lighting constraint.

2.1.6 Other Secondary Constraints

The following descriptions reference remaining secondary constraints supported by OMP. These constraints are used to modify maneuver solutions or to provide the OMP with desired relative state information.

CXYZ (Curvilinear Offsets)
This specifies the chaser relative X, Y and Z position in the target centered local vertical curvilinear coordinate system. The distances are input in nm. Positive distances are when the chaser is leading, below and to the right of the target. OMP expects these to be input in an X, Y, Z ordered triplet (e.g. CXYZ= -8.0, CXYZ=0.0, CXYZ=0.2 for Ti position when targeting an NCC maneuver).

DH (Delta Altitude)
This specifies a desired differential height at the chaser maneuver time with the target propagated along its actual orbit to a condition of phase match. The distance is input in nautical miles. Positive distances are when the chaser is below the target.

DR (Down Range Offset)
This specifies the downrange position that is desired at the maneuver's TIG in nautical miles. Positive distances are when the chaser is leading the target.

DV (First Guess Delta Velocity)
This supplies an initial guess of a minimum DV magnitude for the chaser maneuver's NC and NH, in fps. This secondary constraint gives orbital wrap around capability for phasing. DV is used for NC maneuvers to insure convergence since OMP uses 0 fps for the default initial guess.

When used in conjunction with either the DVPY or DVYP maneuvers, this secondary constraint defines the total DV magnitude of the maneuver.

DVLV (Local Vertical Delta Velocity)
This specifies the external delta velocity component in the LVLH X, Y and Z direction for the EXDV maneuver, in fps. OMP expects these to be input in an X, Y, Z ordered triplet (e.g. DVLV=3.0, DVLV=0.0, DVLV=0.0 for a posigrade 3 fps maneuver).

HD (Height Desired)
This specifies the desired chaser altitude to be achieved after 180 degrees of orbital travel from a HA or HASH maneuver, in nautical miles. Positive altitudes are when the chaser

is above the surface of the Earth.

NULL (Null Y-dot)
This specifies that the out-of-plane relative velocity between the chaser and target be nulled at the time of the chaser's maneuver. This secondary constraint has no particular numeric value.

PIT (Pitch)
This specifies the pitch value for the DVPY or DVYP maneuvers in degrees.

WEDG (Wedge Angle) This specifies wedge angle for the NPC maneuver to target at some future maneuver. This secondary constraint should be placed on the maneuver for which the desired wedge angle is to be achieved. For example, in order to target an NPC maneuver to put the chaser in the target's plane at Ti, a secondary constraint of WEDG=0.0 should be placed on the SOI maneuver in the plan.

YAW (Yaw)
This specifies the yaw value for the DVPY or DVYP maneuvers, in degrees.

2.2 OMP Displays

There are several displays that OMP uses for data input, execution, and viewing. There is a section for each of the displays. A copy of the display along with a parameter definition will be given in each of these sections. The format for the parameter definitions will give the parameter on the left side of the page and the description on the right. After each description, the units of the parameter will be given in parenthesis, if applicable.

2.2.1 Maneuver Constraints Table (MCT)

The MCT is used to input maneuver constraints for the OMP to process when generating a rendezvous plan. Three columns are provided to allow the user to specify maneuver type, primary constraint, and secondary constraints for each maneuver.

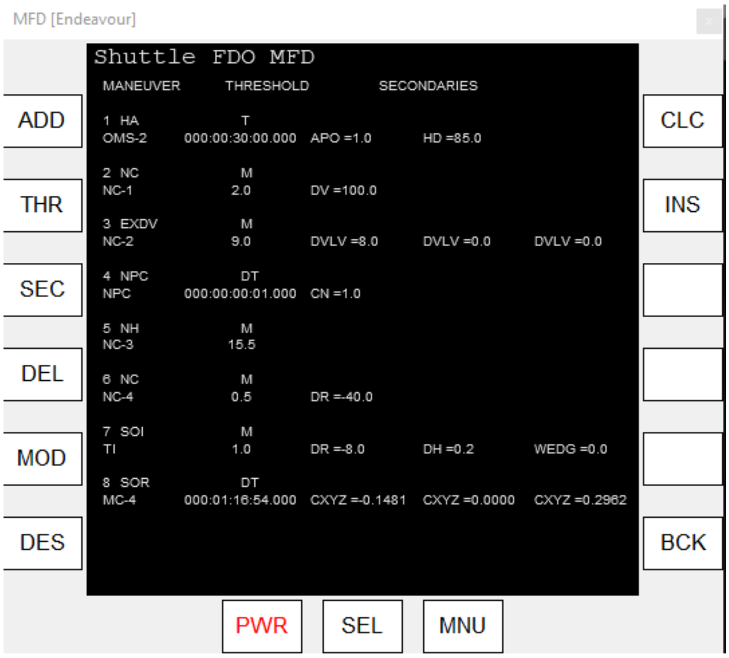

Figure 2: Maneuver Constraints Table

Parameter	Description	Units
MANEUVER	Maneuver ID	4 characters max.
THRESHOLD	Threshold constraint and associated value	4 characters max.
SECONDARIES	Secondary constraint and associated values	4 characters max.

Buttons:

ADD: Add a maneuver to the MCT. The input format is: "Maneuver-Type Maneuver-Name".
THR: Add/modify threshold (primary) constraints. Input format: "Maneuver-ID Threshold-Type Threshold-Value".
SEC: Add secondary constraint. Input format: "Maneuver-ID Constraint-Type Constraint-Value".
DEL: Delete maneuver from table. Input format: "Maneuver-ID".
MOD: Modify maneuver in the table. Input format: "Maneuver-ID Maneuver-Type Maneuver-Name".
DES: Delete secondary constraint from table. Input format: "Maneuver-ID Secondary-ID".
INS: Insert maneuver into table. Input format: "Maneuver-ID Maneuver-Type Maneuver-Name".
MOS: Modify secondary constraint in the table. Format: "Maneuver-ID Secondary-ID Constraint-Type Constraint-Value.

CLC: Calculate rendezvous plan.
BCK: Go back to previous menu.

2.2.2 OMP Executive Menu

The Executive Menu is the place where several options can be selected before a rendezvous plan is created or run. Additionally the rendezvous plans can be saved or loaded in this menu.

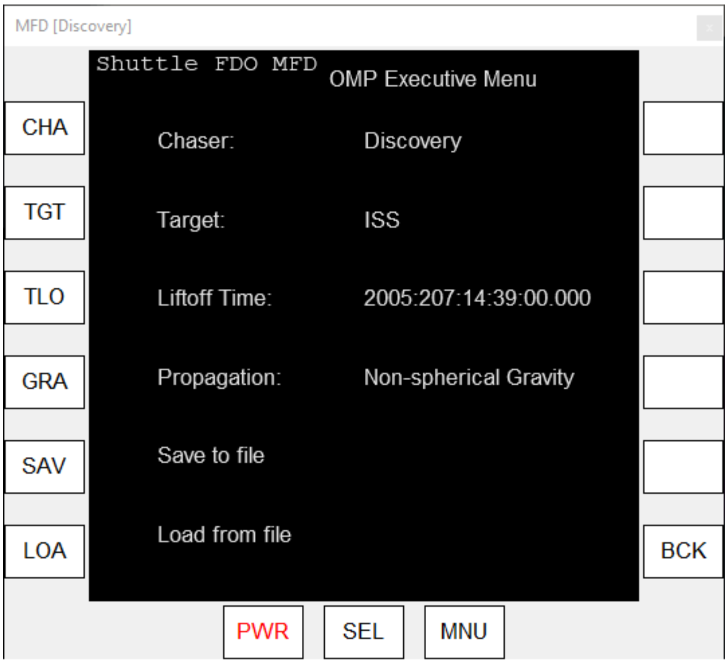

Figure 3: OMP Executive Menu

Buttons

CHA: Select the chaser vehicle.
TGT: Select the target vehicle.
TLO: Set the time of liftoff. Format: "YYYY:DDD:HH:MM:SS".
GRA: Cycle between the two gravity options of the MFD (Taking non-spherical gravity into account or not).
SAV: Save a constraints table to file.
LOA: Load a constraints table from file.
BCK: Go back to previous menu.

2.2.3 Maneuver Evaluation Table (MET)

After a plan is run, the output may be viewed on the Maneuver Evaluation Table (MET). The table contains numbers associated with each maneuver of the mission plan.

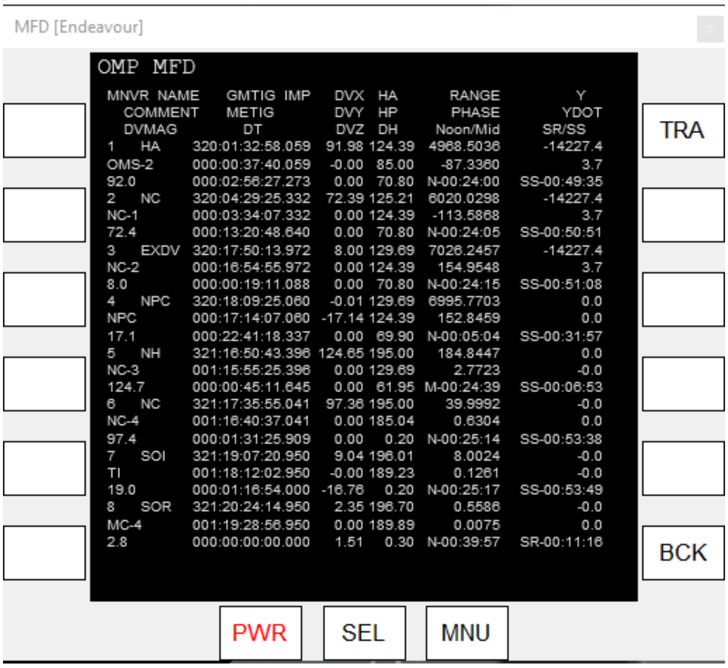

Figure 4: Maneuver Evaluation Table

Parameter	Description	Units
MNVR NAME	Maneuver type	
COMMENT	Maneuver comment/name	
DVMAG	Total DV of maneuver	fps
GMTIG	Impulsive GMT of ignition	DDD:HH:MM:SS.SSS
METIG	Impulsive MET of ignition	DDD:HH:MM:SS.SSS
DT	Time until next maneuver	DDD:HH:MM:SS.SSS
DVX,Y,Z	Cartesian components of DV in Orbiter-centered LVLH coordinates	fps
HA, HP	Chaser apsis altitude above a spherical Earth at the maneuver's burnout	NM
DH	Chaser altitude minus target altitude at phase match with the chaser at the maneuver's TIG	NM
RANGE	Distance between the chaser and target at the maneuver's TIG	NM
PHASE	Phase angle between the chaser and target at the maneuver's TIG. + if chaser is trailing the target	deg
NOON/MID	Time from TIG until next orbital noon or midnight	HH:MM:SS
Y	Distance of the chaser from the target's orbital plane at the maneuver's TIG	feet
YDOT	Chaser's out-of-plane velocity at the maneuver's burnout	fps
SR/SS	Time from TIG until next orbital sunrise or sunset	HH:MM:SS

Buttons
TRA: Transfer maneuver plan to Maneuver Transfer Table.
BCK: Go back to previous menu.

2.2.4 Maneuver Transfer Table (MTT)

A rendezvous plan may be transferred to the Detailed Maneuver Table after it has been generated. The OMP computes an impulsive TIG and LVLH DV components, but the DMT needs more information about the burn. It requires the chaser vehicle's thruster selection and thrust vector roll angle (TVR) in order to compute burn attitude, plus guidance mode. The Maneuver Transfer Table (MTT) is used to define this information before a plan is transferred to the DMT - it essentially allows the burn to be converted from impulsive to finite.

At the bottom of the MTT are ten slots where different configurations may be defined. A standard configuration is provided when the display is first called, one for each potential maneuver in the plan. The user may choose from any of the ten slots to define the configuration for a burn. Manual editing of the options is not supported in the MFD at this time.

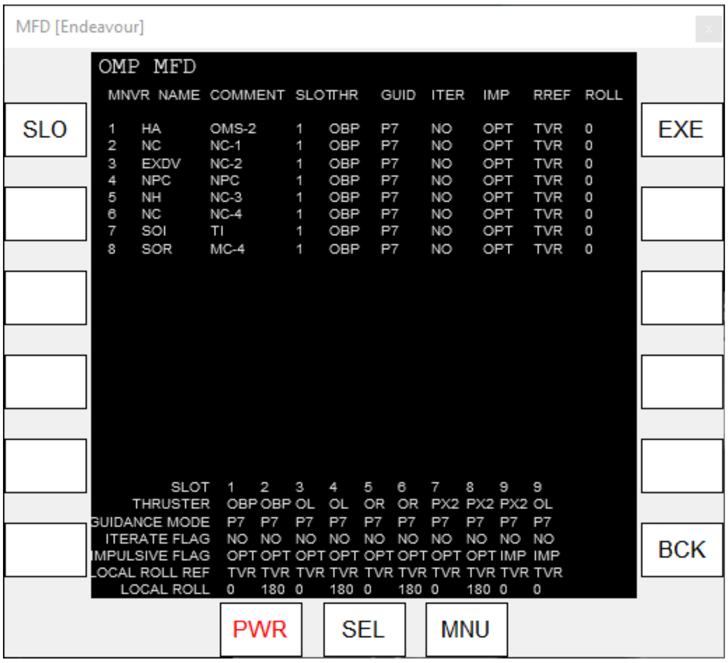

Figure 5: Maneuver Transfer Table

Parameter	Description	Units
MNVR	Maneuver number	1-9
NAME	Maneuver type	4 characters
COMMENT	Comment associated with maneuver	10 characters max.
SLOT	Slot number to reference characteristics from table below	
THRUSTERS	Thruster selection for the maneuver	PX2, OL, OR, OBP
GUID	Guidance mode for the maneuver	PEG7
ITER	Iteration flag	YES, NO
IMP	Impulsive/Optimize flag	IMP, OPT
RREF	Local roll reference for the maneuver	TVR
ROLL	Local roll angle for the maneuver	deg

Buttons

SLO: Choose which of the slots with maneuver options is applied to the maneuver. Input format: "Maneuver-ID Slot-ID"

EXE: Calculate maneuver parameters based on the thruster and attitude selection and transfer them to the Detailed Maneuver Table.
BCK: Go back to previous menu.

The currently available thruster options are two +X thrusters (PX2), both OMS engines (OBP), left OMS engine (OL) and right OMS engine (OR).

The impulsive flag may be set to either IMPulsive (IMP) or OPTimize (OPT) to control TIG selection during the transfer to the DMT. If OPT is chosen, the maneuver's burn arc is taken into account by "splitting the TIG". That is, the transferred TIG is set equal to the OMP TIG minus one-half of the length of the burn. The OMP's impulsive delta velocities, converted to the inertial frame, are then applied to the burn. When IMP is chosen, the transferred TIG is the same as the OMP-computed TIG. In normal practice, the impulsive flag is set to OPT for any non-Lambert burns in order to center the burn arc about the impulsive TIG. This is extremely important for big burns (>50 fps) that have a significant burn arc. On day of rendezvous, NCC, Ti, and all mid-course burns are transferred as IMP so that the same TIG is used consistently between ground and onboard, to assure that the timeline in the Rendezvous Checklist is adhered to.

3 Detailed Maneuver Table

4 Example