Shuttle FDO MFD 0.4.2

by indy91

September 18, 2024

1 Introduction

The Shuttle FDO MFD contains tools to calculate launch windows, rendezvous plans and individual maneuvers for Space Shuttle operations. It is based on the Launch Window Processor (LWP) and the Orbital Maneuver Processor (OMP), which were the programs used for these tasks by the actual Shuttle Flight Dynamics Officers (FDO). The Deorbit Opportunities Processor (DOPS), a lookahead display to find suitable deorbit opportunities, is also available. The MFD is mainly intended for use with the Space Shuttle Ultra and Space Shuttle Vessel addons for the Orbiter Space Flight Simulator 2016.

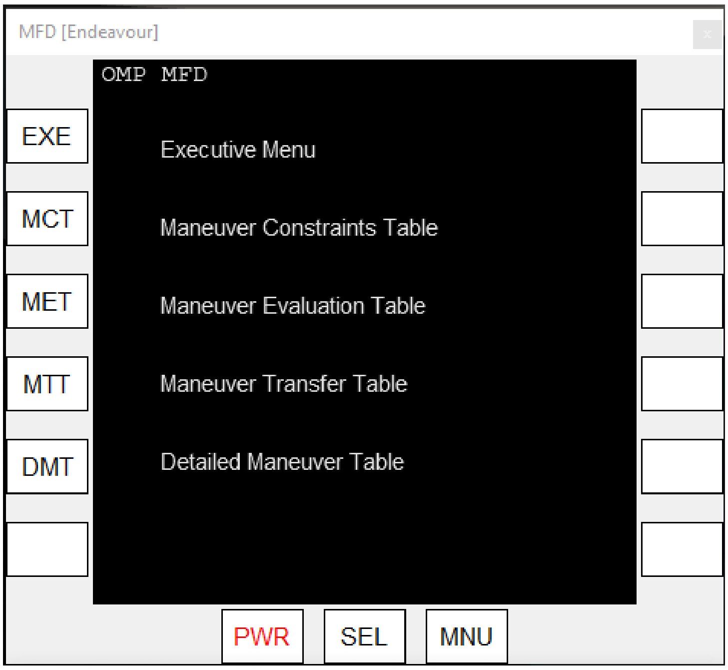


Figure 1: Main Menu

2 Configuration

The Configuration Menu is the place where several options can be selected before the function of the MFD are used. Additionally the settings and the OMP rendezvous plan can be saved or loaded in this menu.

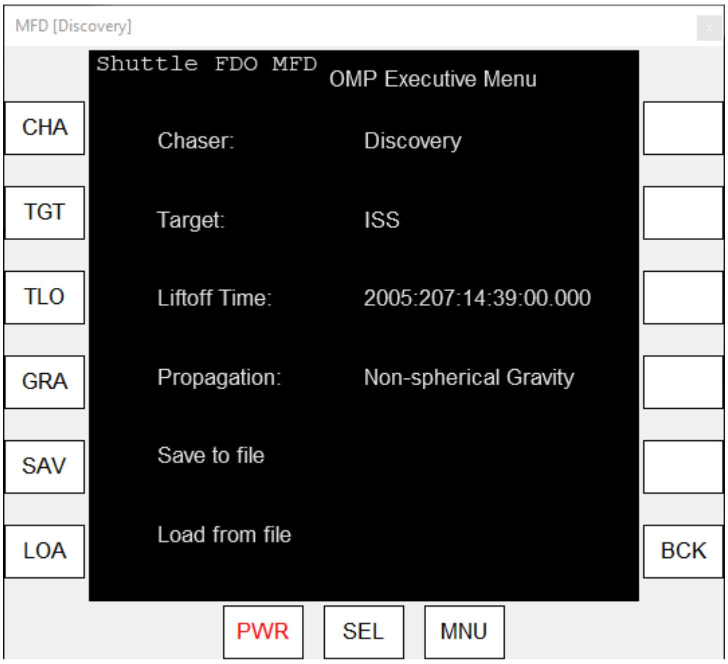


Figure 2: OMP Executive Menu

Buttons

CHA: Select the chaser vehicle.
TGT: Select the target vehicle.
DLO: Set the launch day. Format: "YYYY:DDD". Alternatively, leave the input blank and the current day will be loaded.
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.

TLO: Set the time of liftoff. Format: "HH:MM:SS".

3 LWP User's Guide

The Launch Window Processor is used to determine the times that launch can be done to get into the proper orbit to accomplish the rendezvous. It allows the use of inputs to easily determine the planar window open, inplane and close times as well as the phase window open and close times using phase angle constraints (if required). Before the processor can be used, the day of launch needs to be set on the Config Page.The processor is split in two parts. The first one, the LWP, calculates the optimum liftoff time as well as the opening and closing of the launch window. The LTP, the launch targeting processor, calculates many quantities for targeting the launch at a specific time.

There are three input pages and two output pages for the LWP.

3.1 LWP Input Page 1

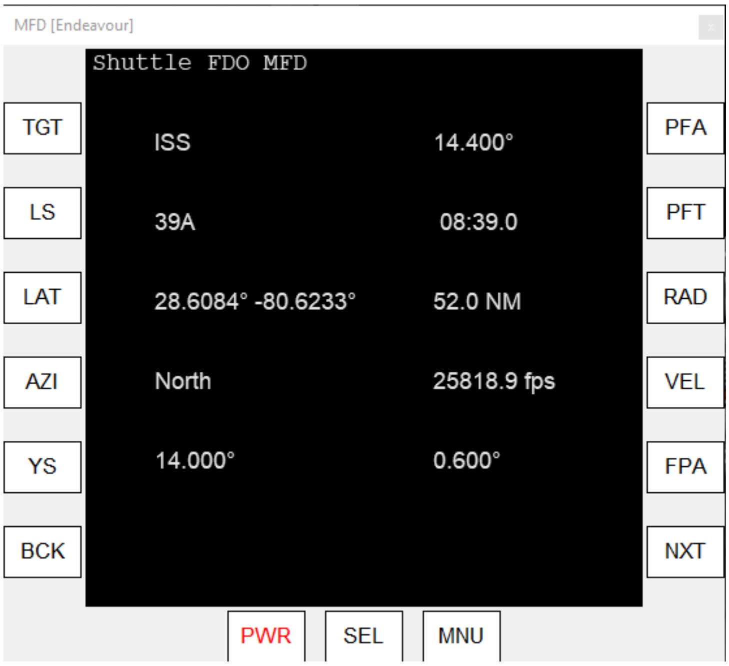


Figure 3: LWP Input Page 1

TGT: is the target vehicle, whose state vector is used as an input to the LWP.
LS: can be used to input a specific launch pad (39A or 39B currently), so that the coordinates are automatically loaded. Default is LC-39A.
LAT: can be used to overwrite the launchpad latitude (if you want to launch to the HST you might have to bias the latitude southwards in order to get the LWP to calculate a solution) and longitude.
AZI: to calculate either a northerly launch or a southerly launch.

YS: is the maximum yaw steering the Shuttle can do for the ascent to orbit. Not really relevant for SSU right now and it should probably always stay 14°.
PFA: is the powered flight arc from launch to insertion. The value only needs to be approximately right, so fine tuning it for a specific launch shouldn't be required. This applies to most numbers on the right side of this page
PFT: is the powered flight time from liftoff to insertion.
ALT: is the insertion altitude above the Earth equator in nautical miles.
VEL: is the insertion velocity. This and FPA below will need to be adjusted for the specific mission if the LWP output state vector is to be used in the OMP, because it's very different from e.g. a mission to the ISS as compared to a mission to the HST.
FPA: is the flight path angle at insertion.

3.2 LWP Input Page 2

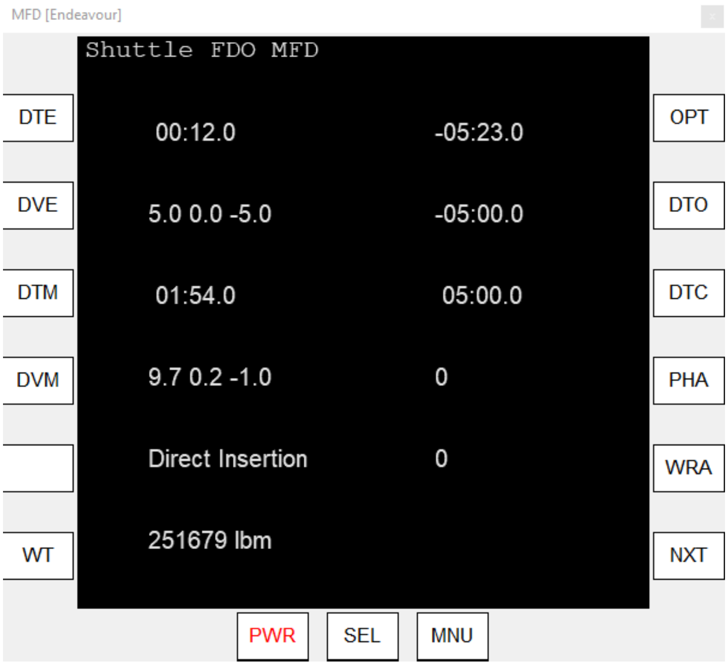


Figure 4: LWP Input Page 2

DTE: is the delta time from MECO to ET separation. Probably always 12 seconds.
DVE: is the DV vector of the ET separation maneuver. The DVX component should be either 0 ft/s (no +X translation maneuver or ET photo pitch maneuver) or 5 ft/s (to account for the +X translation maneuver). For DVZ the usual value is 5 ft/s. This is it the translation maneuver that is done automatically to get the Orbiter away from the ET. The value should be +5 ft/s if the attitude is heads down or -5 ft/s if the attitude is heads up.

DTM: is the delta time from MECO to the MPS dump; just like the ET sep maneuver this assumes an impulsive burn.
DVM: is the DV of the MPS dump. The FDO Console Handbook specifies numbers that are averages from flight data:
heads down: +9.2, -2.6, -4.2
heads up: +9.7 +0.2 -1.0
OPT: is the optimal, zero yaw steering delta time from the in-plane time. This is an empirical derived number depending on time it takes to ascent to orbit etc. The FDO Console Handbook has suggests a value of -5:40, for SSU the best value from testing is -5:23. This will only be accurate for 51.6° inclination and a specific Shuttle weight and insertion conditions but it should be quite close in all cases.
DTO: is the delta time for the opening of the launch window. Launch window to the ISS is usually 10 minutes long, so DTO and DTC are -5 minutes and + 5 minutes. SSU can't do any yaw steering yet so this is only used for information purposes, for the calculation of the phase angles.
DTC: is the delta time of the launch window closing.
PHA (for phase angle) and **WRA** (for wrap) are two flags used by the LWP and currently it will only be used in the phase angle calculation. For example, this will decide if a phase angle is 30° or 390°. Here are the numbers that should be input:

Expected OMS-2 Φ	-90 to 90°	90 to 270°	270 to 450°	450 to 630°	630 to 720°
Phase Control	2	0	2	0	2
Wrap	0	0	1	1	2

3.3 LWP Input Page 3

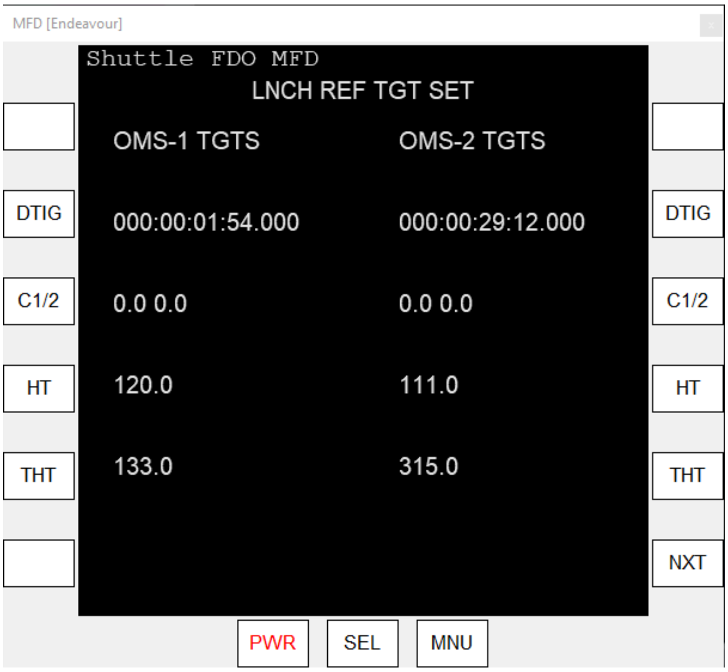


Figure 5: LWP Input Page 3

DTIG: Time of OMS-1 time of ignition from ET separation.
C1/2: C1 and C2 of the OMS-1 maneuver. Nominally zero.
HT: Height target of the OMS-1 maneuver.
THT: Angle measured from the launch site of the target position for the OMS-1 maneuver.

DTIG: Time of OMS-2 time of ignition from ET separation.
C1/2: C1 and C2 of the OMS-2 maneuver. Nominally zero.
HT: Height target of the OMS-2 maneuver.
THT: Angle measured from the launch site of the target position for the OMS-2 maneuver.
NXT: Go to Launch Targeting Processor page.

3.4 LWP Output Page

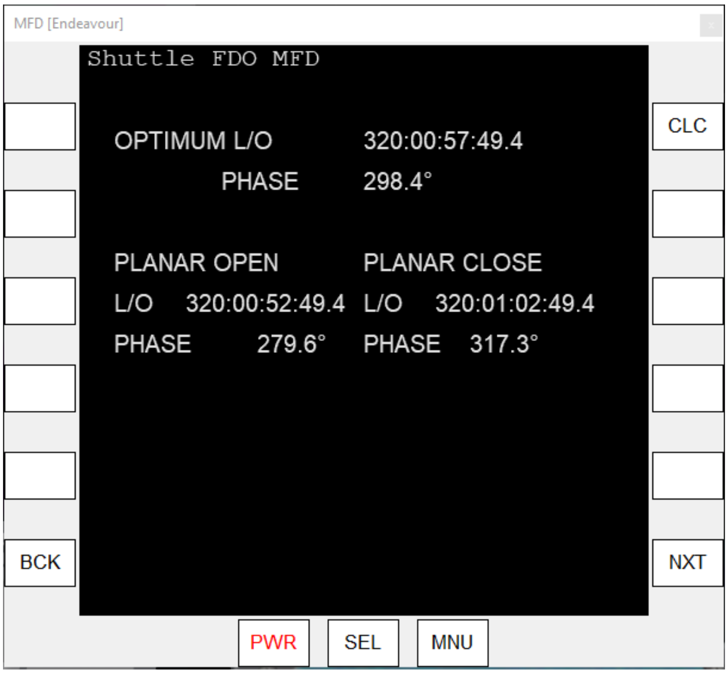


Figure 6: LWP Output Page

This page contains the CLC button to run the Launch Window Processor. It also displays the output parameters of the processor. At the top it has the optimum liftoff time and the phase angle at insertion associated with it. Below it has the same parameters, but for the planar opening and closing of the launch windows, as specified with the DTO and DTC parameters on the previous page.

3.5 LTP Output Page

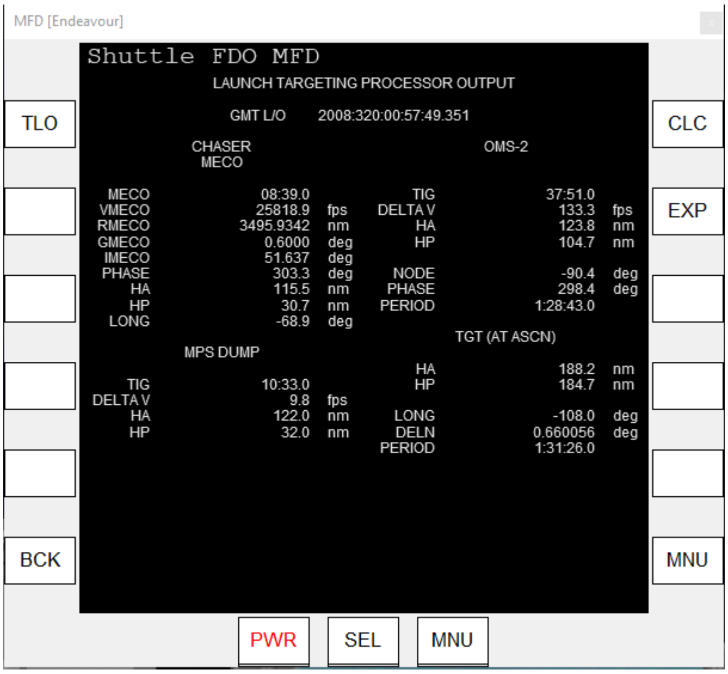


Figure 7: LTP Output Page

TLO Input actual launch time for launch targeting. The LWP automatically moves the optimum launch time here.
BCK Go back to LWP output page.

CLC Calculate launch targeting.
EXP Export launch targeting data for uplink. Not implemented yet.

4 OMP User's Guide

4.1 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.

4.1.1 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. The desired altitude is indicated by the HD secondary constraint.

NOSH (Node Shift)
This maneuver is targeted to shift the ascending or descending node location. The angle to be shifted is indicated using the DNOD secondary constraint. This maneuver has no unique rendezvous constraints.

PC (Plane Change)
This maneuver is targeted to change the orbital plane of the chaser. The amount of plane change is indicated by the DPC secondary constraint. When this maneuver is located at an ascending or descending node using the ASC or DSC secondary constraints, the plane change will be only in orbital inclination. This maneuver has no unique rendezvous constraints.

4.1.2 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$^{\text{th}}$ 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 DH secondary constraint.

NPC (n$^{\text{th}}$ 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$^{\text{th}}$ 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.

4.1.3 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.

4.1.4 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.

A (Angle from Apogee)
The maneuver is executed at a desired central travel angle from the chaser's apogee. The angle is input in degrees.

ALT (Altitude)
The maneuver is executed at a desired altitude above the surface of the Earth. The altitude is input in nautical miles.

APO (n^{th} 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.

ARG (Argument of Latitude)
The maneuver is executed when the specified argument of latitude is first encountered following the primary constraint's threshold epoch. Argument of latitude is the angle, measured in the plane of the chaser's orbit, from the ascending node to the chaser position. This angle is specified in degrees.

ASC (n^{th} Ascending Node)
The maneuver is executed at the n^{th} ascending node of the chaser's orbit after the threshold time where N is the constraint's value.

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.

DEC (Declination)
The maneuver is executed at the specified latitude of the chaser's orbit. The angle is input in degrees.

DSC ($\mathbf{n^{th}}$ Descending Node)
The maneuver is executed at the n^{th} descending node of the chaser's orbit after the threshold time, where n is the constraint's value.

LAT (Latitude)
The maneuver is executed at the specified latitude of the chaser's orbit. The angle is input in degrees.

LON (Longitude)
The maneuver is executed at the specified longitude of the chaser's orbit. The angle is input in degrees.

OPT (Optimum Node Shift)
The maneuver is executed at the optimum node shift point. This secondary constraint has no particular numeric value.

PER ($\mathbf{n^{th}}$ 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.

U (Argument of Latitude)
The maneuver is executed at the specified argument of latitude from the chaser's next ascending node. The angle is input in degrees.

4.1.5 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.

4.1.6 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.

DNOD (Delta Node)
This specifies the amount of node shift desired when the NOSH maneuver is executed. The angle is input in degrees.

DPC (Delta Plane Change)
This specifies the amount of plane change desired when the PC maneuver is executed. The angle is input in degrees.

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.

4.2 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.

4.2.1 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.

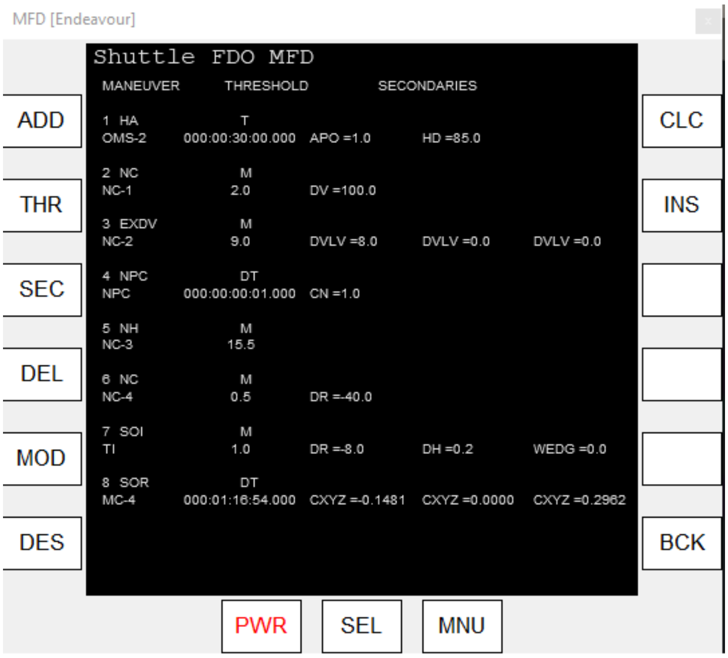


Figure 8: Maneuver Constraints Table

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.

4.2.2 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.

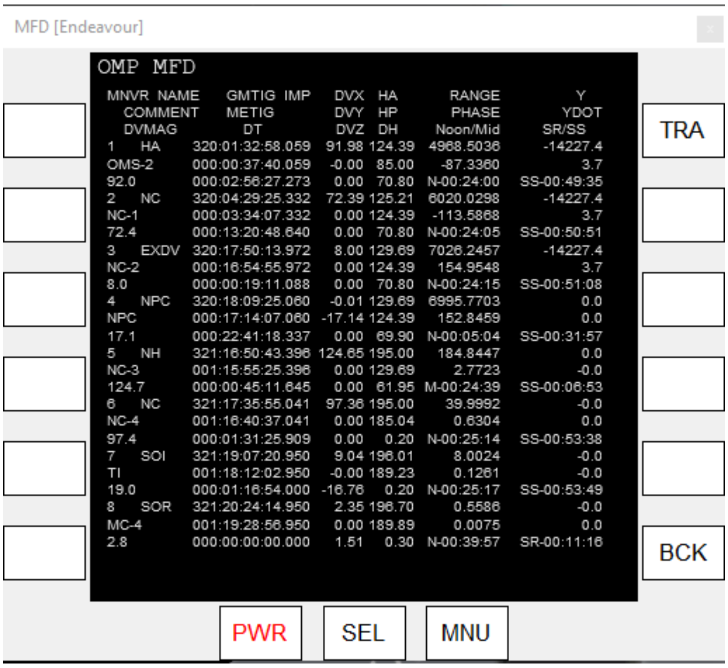


Figure 9: Maneuver Evaluation Table

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.

4.2.3 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.

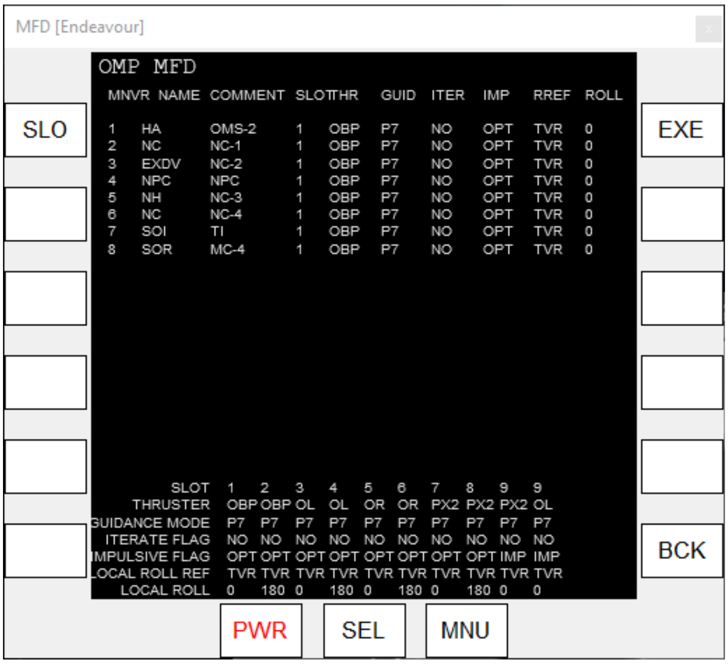


Figure 10: Maneuver Transfer Table

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.

4.3 Default Plans

A number of default rendezvous plans have been provided with the MFD. These cover various phase angles at insertion. They can be loaded like full save file on the config page, but they will not overwrite any other parameters like the vehicle name.

Plan Name	**Rendezvous on**	**Phase angle**
PlanA	Flight Day 2	39 to 93 DEG
PlanB	Flight Day 3	60 to 175 DEG
PlanC	Flight Day 3	175 to 327 DEG
PlanD	Flight Day 3	327 to 407 DEG

5 Detailed Maneuver Table

Any maneuver residing in the Maneuver Transfer Table may be placed in a DMT for display purposes. As such, DMTs function as the primary means of gaining insight into a maneuver's specifications. The central portion of the DMT is associated with Pre-Advisory Data (PAD) parameters. This segment is used to generate a PAD Flight note. The other parts of the DMT, which contain additional data about each maneuver, are currently not supported in the MFD.

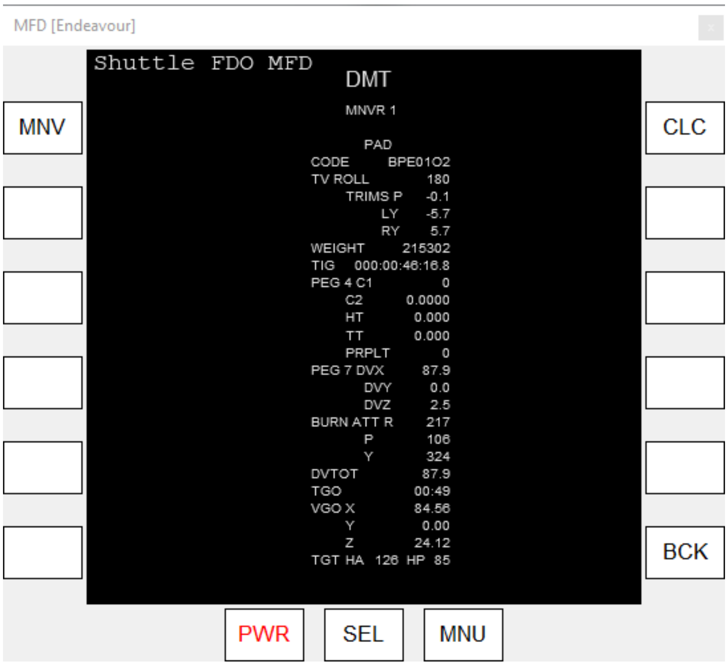


Figure 11: Detailed Maneuver Table

Buttons
MNV: Choose which of the maneuvers in the list transferred from the MTT should be displayed.
CLC: Calculate maneuver parameters for the chose burn.
BCK: Go back to previous menu.

6 DOPS User's Guide

The Deorbit Opportunities Processor computes landing opportunities to landing sites based on an orbital crossrange constraint. It is a lookahead study to select the right orbit and landing site at some point in the future. The actual deorbit burn would be targeted with the Deorbit Maneuver Processor. The time of ignition and landing time are derived as a simple curve fits from the time of closest approach to the site.

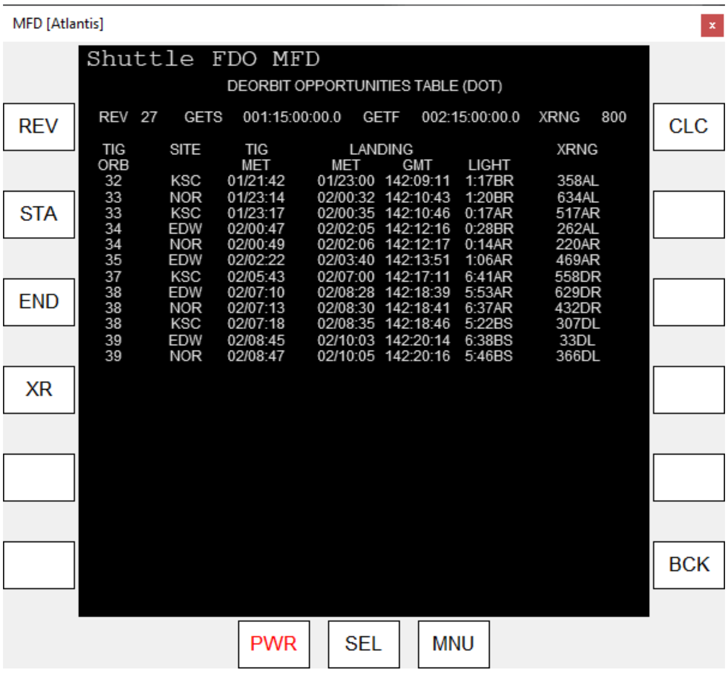


Figure 12: Deorbit Opportunities Table

Parameter	Description	Units
TIG ORB	Revolution number at landing	
SITE	Name of landing site	
TIG MET	MET of ignition	DD/HH:MM
LANDING MET	MET of landing	DD/HH:MM
LANDING GMT	GMT of landing	DD/HH:MM
LANDING LIGHT	Light condition at the time of landing	H:MM
XRNG	Crossrange at closest approach	Nautical miles

The light condition at landing is written in a coded format where a stands for after, b for before, r for sunrise, s for sunset. So e.g. 3:02ar would mean the landing time is 3 hours and 2 minutes after sunrise. For the crossrange, A stands for ascending node, D for descending node. L for landing site left of groundtrack, R for right of ground. So e.g. 102DR means at closest approach the landing site is 102 NM to the right of the groundtrack, during the descending pass.

The landing sites are defined in a config file which can be modified. It can be found under "\Config\MFD\ShuttleFDOMFD\DOPSLandingSites.txt". The required entries are name, latitude, longitude, radius and time zone relative to GMT. The table is prefilled with the three main landing sites used for the Shuttle, which are the Kennedy Space Center (KSC), Edwards Air Force Base (EDW) and Northrup Strip at White Sands (NOR), as well as many possible emergency landing sites.

Buttons

REV: Choose the revolution number associated with the starting time.
STA: Specify the MET to start searching for deorbit opportunities.
END: Specify the MET to end searching for deorbit opportunities.
XR: Specify the maximum crossrange in nautical miles.
SIT: Choose whether the deorbit opportunities are only calculated for the main landing sites in the continental US or for all landing sites in the DOPS table.
BCK: Go back to previous menu.

CLC: Calculate the DOPS solution.
PAG: Cycle between the pages of available solutions.

7 DMP User's Guide

The Deorbit Maneuver Processor (DMP) calculates guidance targets for a deorbit maneuver and verifies the maneuver to EI. The DMP processor then stores information associated with the deorbit maneuver, the burnout vector, the EI vector, the PEG 4/PEG 7 targets, the fuel usage/ΔV for the selected engine configuration, the Entry Target Generator (ETG) V/γ/range from entry interface (REI), and post maneuver weight, crossrange and perigee.

The DMP processor calls the ETG subroutine to calculate PEG 4D targets that satisfy the EI conditions for VEI, γEI, and REI. The DMP will generate a solution which conforms to the following guidelines:

1. The guidance targets calculated by the DMP processor are compatible with the onboard powered flight guidance.
2. The planned deorbit maneuver results in the achievement of a correlated V, γ, and range set at EI. This target set is calculated by ETG after being called by the DMP processor.
3. The deorbit maneuver is targeted to burn a specified amount of propellant, allowing achievement of landing weight or CG constraint.
4. The targeting is such that if the primary propulsion system fails to ignite, then a pre-designated backup propulsion system can perform the maneuver with no change in input guidance targets (including time of ignition (TIG)) and achieve nominal entry conditions.
5. In the TIG-free mode, the TIG is selected so that the same amount of Orbital Maneuvering System (OMS) propellant will be required for either prime or backup propulsion system with or without propellant wasting. A positive or zero propellant margin will result if the prime system fails during the burn.
6. The targeting ensures that minimal guidance and control transients will occur for a switchover from prime to backup thrusters anytime during the burn.
Consequently, body attitude changes for fuel wasting must be small when reverting to the backup propulsion system.
7. If it is not desired to find the guidance targets that are biased for both prime and backup propulsion systems, a solution can be found for any single designated propulsion system by setting the backup equal to the primary.
8. Entry crossrange will be computed, and in the event that excess fuel is burned out-of-plane (OOP), it will be burned in a direction that will decrease crossrange. 9. The deorbit solution for any future orbit may be computed by inputting the appropriate TIG threshold time.
10. A TIG-free or TIG-fixed mode can be designated.
11. A minimum Time of Free Fall (TFF) (time from burnout to EI) constraint will be enforced by relaxing the requirement for equal OOP thrust angles until the TFF exceeds or equals the minimum TFF.

7.1 Targeting Options

The following table shows the targeting options which are available in the DMP. These option allow a range of TIG modes, propellant usage, and thruster combinations to be made to accomodate operational situations.

Level I TIG Mode	Level II Propellant Usage	Level III Thruster Selection
1. TIG free	1. Propellant wasting	1. Solution biased for prime and backup thruster (not available in TIG-fixed)
2. TIG fixed	2. In plane	2. Solution for any designated thruster

The following comments are provided to help explain the various combinations of levels I and II.

a. 1,1 - A specified amount of OMS propellant will be expended. Solution will be such that the OOP thrust angle is the same for primary and backup systems.
b. 1,2 - Computes a solution such that the amount of OMS propellant expended is the same for both primary and backup systems.
c. 2,1 - Solution expends a specified amount of propellant to attain a specific CG or weight at EI.
d. 2,2 - Computes a solution to a nominal EI target that lies in the trajectory plane.

After selecting the proper combination of levels I and II, you must also specify a level III option. The allowable thruster combination for prime and backup are limited for TIG-free solutions since the difference in engine initial specific impulse (Isp) for OMS and RCS do not allow for equal propellant solutions. Any allowed thruster configuration may be designated for a TIG-fixed solution. The primary/backup combinations for each TIG mode are shown in the table below.

Primary thruster	Backup thruster	Allowed for TIG-free	Allowed for TIG-fixed
2 OMS	1 OMS	Yes	Yes
2 OMS	2 OMS	Yes	Yes
1 OMS	1 OMS	Yes	Yes
RCS	RCS	Yes	Yes
2 OMS	RCS	No (no optimum solution exists for these combinations)	Yes
1 OMS	RCS	No (no optimum solution exists for these combinations)	Yes

7.2 Input page

Buttons
ITI: Maneuver with fixed or free TIG.
TIG: Enter time of ignition (fixed) or threshold time (free).
WAS: Propellant to be wasted or zero for in-plane solution.
TPR: Select primary thruster.
TBU: Select backup thruster.
SIT: Select the landing site with runway. The valid sites and their coordinates are listed in the LandingSites.txt file under Config/MFD/ShuttleFDOMFD.

DTS: Go to output display.
BCK: Go back to previous menu.

7.3 Output page

The following values are displayed on the output page of the DMP:

Parameter	Description	Units
SITE	The selected landing site with runway	
TIGMET	Time of ignition in mission elapsed time	DD:HH:MM:SS
C1	C1 for PEG-4D targeting	fps
C2	C2 for PEG-4D targeting	
HT	Height for PEG-4D targeting	nautical miles.
THETA	Angle from TIG position to entry interface	degrees
PL	Propellent to be wasted for PEG-4D targeting	pounds
DVPR	Delta V of the maneuver with the primary thruster	fps
VEI	Velocity at entry interface	fps
cEI	Flight path angle at entry interface	degrees
REI	Range from EI to landing site	nautical miles
XR	Crossrange to landing site	nautical miles
OOP	Out of plane angle for the burn	degrees
TFF	Time of free fall, from cutoff to entry interface	MM:SS
HP	Height of perigee	nautical miles
DW	Propellant expended during the burn	pounds
DVX	Delta V in X-direction for PEG-7 targeting	fps
DVY	Delta V in Y-direction for PEG-7 targeting	fps
DVZ	Delta V in Z-direction for PEG-7 targeting	fps

7.4 Error conditions

Errors are displayed at the bottom of the DMP display. Some are real errors, that instantly stop the calculation, and some are just warnings, where the processing is finished with some constraint potentially being violated. The possible messages are:

1. LANDING SITE NOT IN TABLE

   Enter a landing site (including runway) that is in the landing site table under Config/MFD/ShuttleFDOMFD/LandingSites.txt.

2. MAX ITERATIONS EXCEEDED - MITER = N

   In one of the DMP iteration loops the maximum iterations were used. The value of MITER printed out identifies the logic area in which the maximum was exceeded. Processing terminated.

3. FREE FALL TIME FORCED TO TFFMIN CONSTRAINT

   An acceptable solution was found but the freefall time minimum was encountered. Thus, equal yaw angles were not achieved. Normal termination.

4. FREE FALL TIME CONSTRAINT VIOLATED

   A solution was found but freefall time less than the input minimum was required. Normal termination.

5. FREE FALL TIME FORCED TO TFFMIN CONSTRAINT - SOLUTION UNACCEPTABLE IN DV

   An unacceptable DV resulted even after reaching the minimum freefall time. Processing terminated.

6. PEG: NO PHYSICAL SOLUTION FOUND

   No solution was possible from the LTVCON process. Processing terminated.

7. PEG: VGO EQUAL ZERO

   A zero Delta V solution found. Processing terminated.

8. PEG: NO CONVERGENCE - MAX ITERATIONS EXCEEDED

   No PEG solution was found within the maximum allowed PEG iterations. Processing terminated.

8 OMP Walkthrough

The following text is a walkthrough of a full rendezvous with the FDO MFD. It is intended to be used with the "STS-126 - FDO MFD Test" scenario which can be found in the SSU/Testing Scenarios folder. The scenario is starting at L-10 minutes, but any planning with the MFD can not be done before orbital insertion, best after OMS-1 and/or the MPS dump, so that no trajectory changes are done during the planning phase. The mission should be flown with non-spherical gravity disabled.

8.1 Pre OMS-2 Planning

The first step is to load the STS-126 config file for the MFD. Open the OMP Executive Page by pressing EXE in the main menu of the MFD. Then load the file by pressing LOA and typing "STS-126". This should load several parameters to the page.

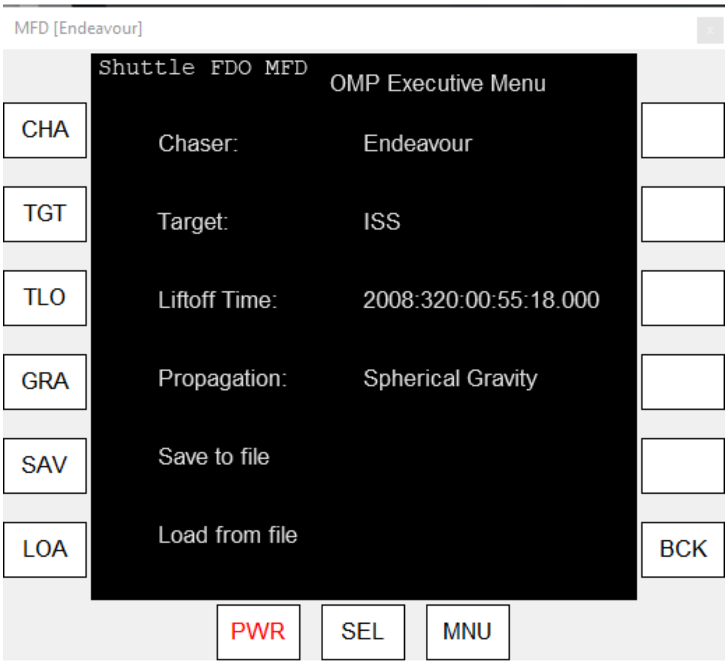
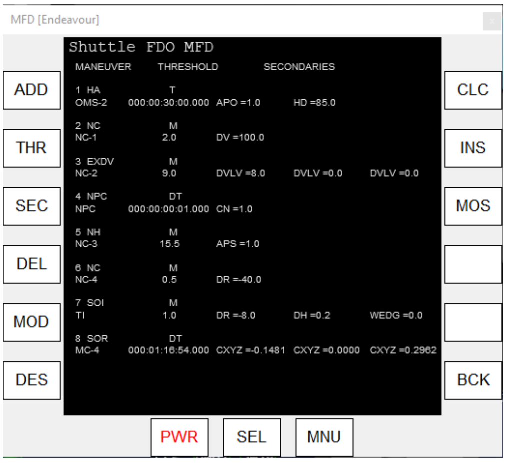


Figure 13: STS-126 Executive Page

Next go back (press BCK) to the main menu and open the Maneuver Constraints Table (press MCT). You should now see the initial, TIG-less plan for the rendezvous. TIG-less means that it is kept as generic as possible, so that it will work for any insertion conditions, and no time of ignition of a maneuver has been fixed in time yet. Run this initial plan by pressing CLC. It is useful to have two instances of the MFD open at all times, the External MFD is quite useful for this. At this stage it is best to have the maneuver constraints table and the maneuver evaluation table (in the main menu press

MET) open. When the initial plan was run the MET should be populated with numbers for each maneuver:



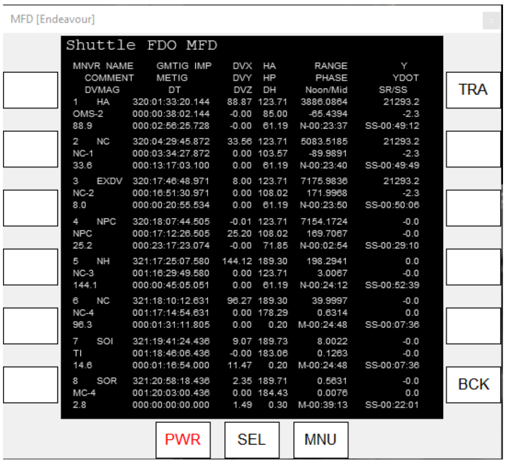


Figure 14: First iteration

8.1.1 Iteration to Correct Ti Lighting and Radial DV

After the TIG-free plan has been run and verified to be a good "ballpark" estimate of the actual rendezvous, the next step is to "freeze" TIGs and perform fine-tuning of the profile. This includes: fixing Ti lighting and eliminating radial DV. The first step is to re-save the TIG-free plan to another name in order to begin working with a new plan name. This can be done on the OMP Executive page by pressing SAV and giving the modified plan a new name. This might be something like "STS-126A". Next, use the TIG-free MET to determine Ti lighting under the "SR/SS" column. The desired TIG is generally near orbit noon and conforms to a mission-specific offset from sunset. For an ISS rendezvous the desired Ti TIG will generally be SS -36 min.

Now using the Maneuver Evaluation Table and desired time of Ti, you can compute how many minutes the lighting is off, and then move the TIG of the final NC burn as necessary to nail Ti lighting. The best way to change Ti TIG is to switch the TIG of the first burn on Day-of-Rendezvous (DOR) to a primary constraint of T (time). That time will be equal to its TIG-free MET output plus Ti error computed above. In this example case the relevant numbers for the Ti burn from the evaluation table were:

-METIG: 001:18:46:06.436
-SR/SS: SS-00:07:36

So the TIG is in error by 28:24 minutes for the desired lighting conditions. As described above it is best to change the first burn on DOR by those 28 minutes. This is an easier technique than fixing Ti first and then working backwards to determine fixed TIGs for

NC-3 and NC-4. In this case the first burn on the DOR is NC-3, a NH type burn and the 5th burn in the table with a TIG of currently 001:16:29:49.580. Now change its TIG to 28:24 minutes earlier by pressing THR and typing: 5 T 1:16:1:26. This will give the NC-3 maneuver a fixed TIG of the specified time. There also was a secondary constraint on the maneuver to place it at an apsis. That will now have to be removed to use the fixed TIG that was input. To delete the constraint press DES and type: "5 1" to delete the 1st secondary constraint of the 5th maneuver. Calculate the plan again by pressing CLC and check the Ti lighting condition. In my case it is now "SS-00:36:06", which should be close enough to the desired lighting.

When the plan is re-generated, it likely that Ti will have a non-zero radial component. In fact, in the example case, SOI DVZ is -73 fps! This is because Ti is not located on the line of apsides. This is the "maneuver line" connecting apogee and perigee. (For the case of rendezvous with a target in a non-circular orbit we are actually referring to *relative* apses, where the chaser-target height differences are minimum and maximum. In this case, the chaser-target "line of *relative* apsides" maybe not necessarily coincide with the geocentric line of apsides.) In order for TIG to be purely horizontal/prop efficient, it must be performed very close to the line of apsides, and it must be located at the correct relative height, which is assured by a NH maneuver (NC-3 in this case). If either of these are not met, a radial component will be added to SOI in order to simultaneously satisfy downtrack, height, and time-of-flight constraints for SOR.

The preferred technique to place Ti on the line of apsides (and thus eliminate DVZ) is to move the TIG of one of the prior large phasing burns. This rotates the line of apsides so that Ti falls on the line. To do this, locate a prior NC or NH maneuver in the profile that starts from as nearly a circular orbit as possible. It must be a large burn (DV >about 20 fps) in order to have enough "muscle" to move the line of apsides. There may be one or two candidate burns that can be used. In this case we would normally use the NC-1 burn for this purpose, but with 30 fps we can figure out (by trial and error) that it doesn't have enough muscle to get the Ti DVZ to 0. So instead we will fix the TIGs of NC-3 and NC-4. The NC-4 TIG will now assure the Ti lighting and by modifying the NC-3 TIG, the orientation of the line of apsides is moved without significant DV penalty to the plan. In the OMP, this is done by changing the primary constraints to T and fixing the time based on previous MET output. Add a small bias to the NC-3 TIG in order to see if it improves Ti DVZ. Continue tweaking until Ti DVZ is less than 1 fps. This is very much a trial and error process. In the example case the NC-4 TIG to get the Ti lighting right was 1:16:46:29, the NC-3 TIG to get the Ti DVZ component to close to zero is 1:16:05:47. This concludes the pre OMS-2 planning, so it is best to save the current plan under a new name. This is also the best time to give NC-1 a fixed TIG. The first maneuver in the constraints table always needs a "T" as the primary threshold and soon OMS-2 will be deleted from the table. So press THR and type: "2 T XXX:XX:XX:XX.XXX" and use the exact time of NC-1 from the previous run, on the evaluation page.

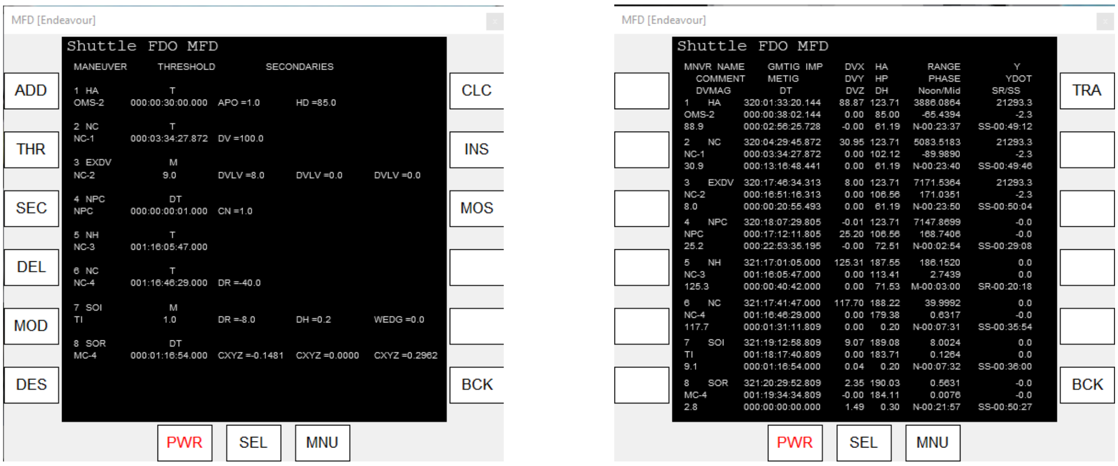


Figure 15: Final state before OMS-2

8.1.2 Executing OMS-2

OMS-2 targeting is not directly covered by the Orbital Maneuver Processor, but it needs to achieve the same perigee altitude that was used in planning the rendezvous profile. For STS-126 this was 85 NM. The FDO MFD currently doesn't export PEG-4 targets, so OMS-2 targeting can be done by trial and error for the PEG-4 targets, or by using a FDO MFD provided PEG-7 burn. As an example for executing a burn we will use PEG-7.

When you are happy with the general rendezvous plan, press the TRA button the evaluation page. This transfers the maneuvers in the plan to the next page. Now go to the Maneuver Transfer Table. This table will now be populated by the maneuvers from the plan. We only care about the OMS-2 burn here, because we don't need to plan the later burns in all detail yet. On this page we need to select a burn profile for OMS-2. The maneuver will be with both OMS engines (OBP option), using PEG-7 guidance (P7), it should have an optimized time of ignition (OPT option) with a roll angle of 180 degrees. All this is covered by slot 2 of the default burn profiles. To use this profile for OMS-2 press SLO and type: 1 2. This will have changed the roll angle of the burn to 180 degress. Nothing else needs to be changed here, so press EXE to export the maneuver data to the next page.

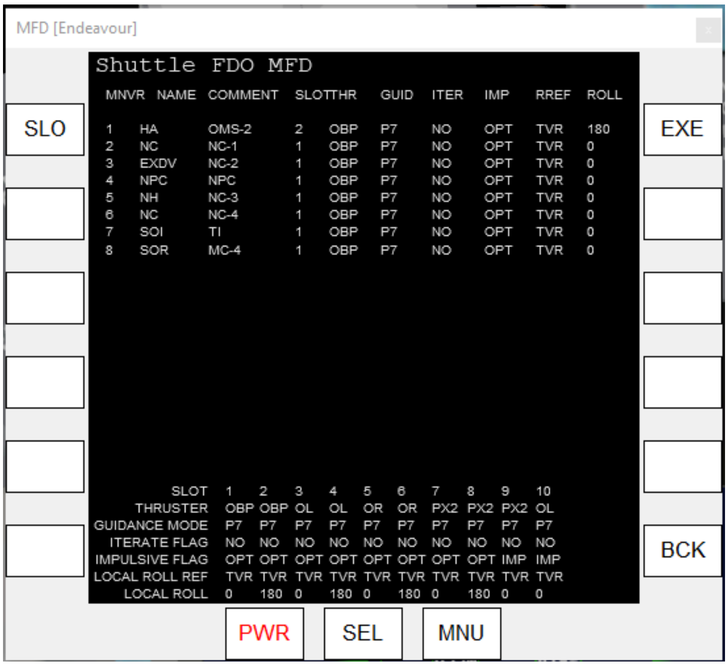


Figure 16: MTT for OMS-2

On the Detailed Maneuver Table you can find all the numbers that would be found on a Maneuver PAD. To get the PAD for OMS-2 press MNV and type 1 to choose the first maneuver in the table. Then press CLC to calculate the PAD. The TIG and PEG 7 DV from this page need to be input to the MNVR EXEC display of the Shuttle computer. Note that the TIG and DV are not identical to the ones on the maneuver evaluation table for the maneuver. On the MTT we calculated a finite burn from the impulsive burn in the OMP, so the TIG was moved to an earlier time to achieve the same trajectory as if the maneuver was impulsive. The DV was kept inertial and thus has now a small, positive DVZ component.The numbers that are used in the actual execution of a burn should always be taken from the DMT, and not the MET, because in case of longer burns they will give much more accurate results.

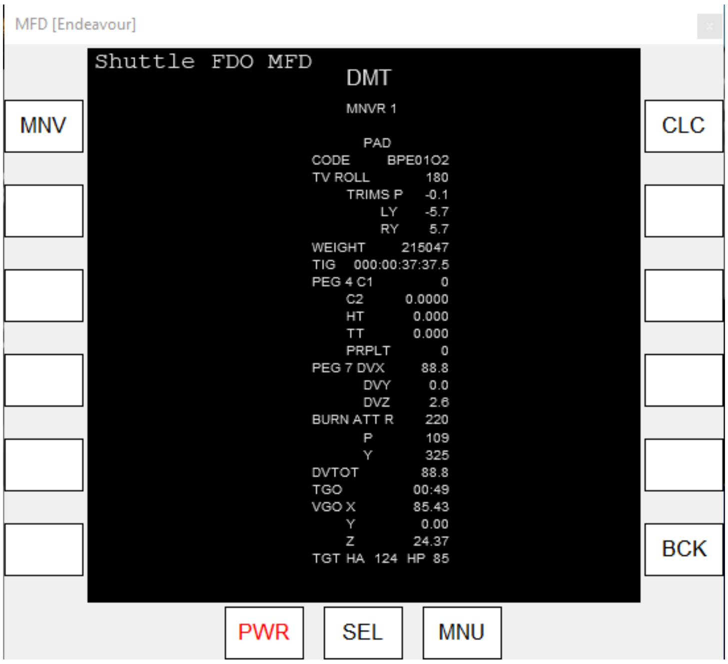


Figure 17: DMT for OMS-2

8.2 Pre NC-1 Planning

After OMS-2 has been executed the maneuver should be deleted from the constraints table. Press DEL and type 1 to delete the 1st maneuver in the list. Then re-save the plan under a new name. You can re-calculate the maneuver plan right now, or wait until shortly before NC-1. The Shuttle flight plans usually have an update to the crew scheduled at 30 minutes before the planned TIG.

All the major planning was done before OMS-2, so there is not much to do before NC-1. One thing that can be done at this stage is to move the NC-1 TIG a little bit, to re-optimize the Ti DVZ. As before, it is desirable to get that value below 1 fps. If OMS-2 went very well this shouldn't be necessary and the NC-1 TIG can stay as it is. At this point the NC-2 TIG should be fixed at its current value, again by using the current TIG from the evaluation table as a primary threshold (THR button) on the constraints page.

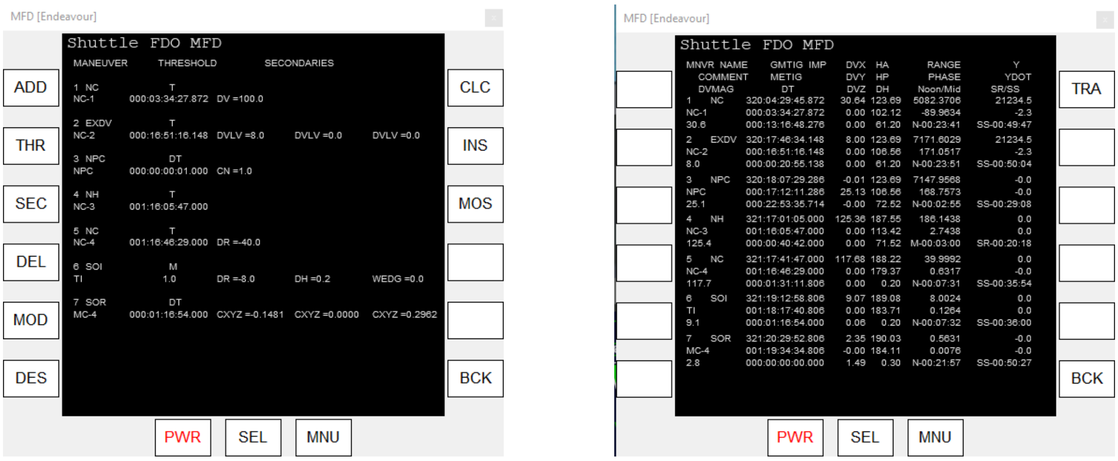


Figure 18: Final state before NC-1

8.2.1 Executing NC-1

Executing NC-1 is very similar to OMS-2 and most other burns, so it will not be talked about in that much detail again. When you are happy with the constraints and evaluation tables press TRA to transfer the maneuvers in the list to the MTT. On the MTT choose again slot 2 for maneuver 1 (NC-1 this time). The general technique for the Shuttle seems to have been to use 180 degrees roll for most burns prior to day-of-rendezvous. In this attitude usually the horizon can be monitored during the burn. The maneuvers on the day-of-rendezvous (NH and NC) will use 0 degrees roll angle because of attitude timeline constraints. Press EXE to export the data to the DMT, then on the DMT press MNV and type 1. Then press CLC to calculate the numbers on the DMT, just like for OMS-2.

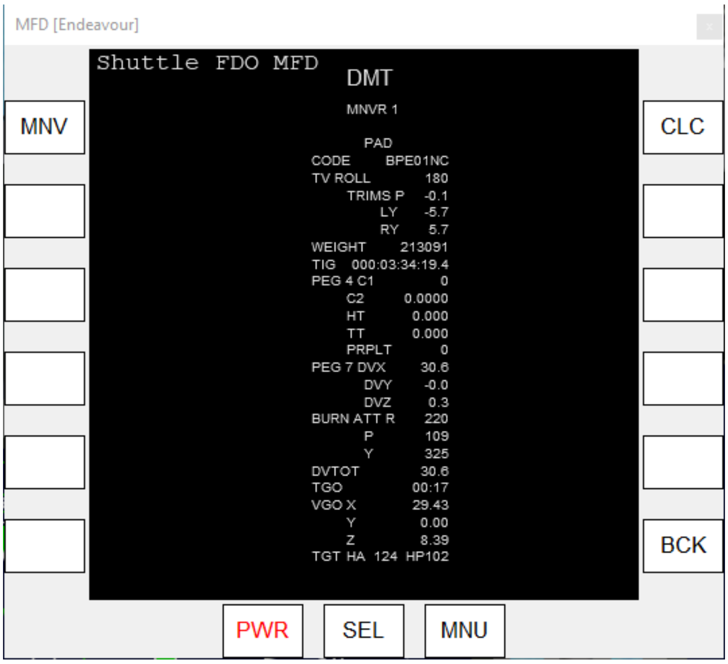


Figure 19: DMT for NC-1

8.3 Pre NC-2 Planning

Planning NC-2 involves a little bit more work than for NC-1. NC-1 was the phasing maneuver (NC type) that tried to achieve a specific phasing (-40NM) at the time the Shuttle reaches the NC-4 maneuver point. Only one maneuver can ever target a specific phasing constraint, so before NC-1 was executed NC-2 was in the plan as fixed DV maneuver of the type EXDV, with a positive bias of 8 fps. The bias is used to avoid any maneuver that will have to lower the orbit. NC-2 will now be switched to the type NC and even if NC-1 went a bit bad so that NC-2 needs to correct the phasing, in all likelihood the NC-2 DVX will not be so different from before that it becomes a retrograde (DVX becoming negative) burn. If NC-1 hasn't been deleted from the plan yet press DEL and type "1". To change NC-2 go to the constraints page and press MOD, to modify a maneuver. Then type "1 NC NC-2". This changes the first maneuver in the list to the type NC, with the new and old name NC-2. Then, delete the now useless secondary constraints on NC-2 of the type DVLV. These only apply to a EXDV type maneuver. For this press the DES button and type "1 1" to delete the first secondary constraint of the first maneuver. Do this three times and the secondary constraints will be gone.

Now re-save the plan under a new name and press CLC on the constraints page. As before NC-1 you should check if the Ti DVZ component now has a DVZ of larger than 1 fps. If yes vary the NC-2 TIG a little bit to get it below 1 fps again. When this is done, fix the maneuver following NC-2 in time, this is the NPC maneuver which will be done shortly after NC-2. There is a "CN = 1.0" constraint on the NPC maneuver which would modify the TIG, so this should now be deleted by pressing DES and typing "2 1". Now save the plan again.

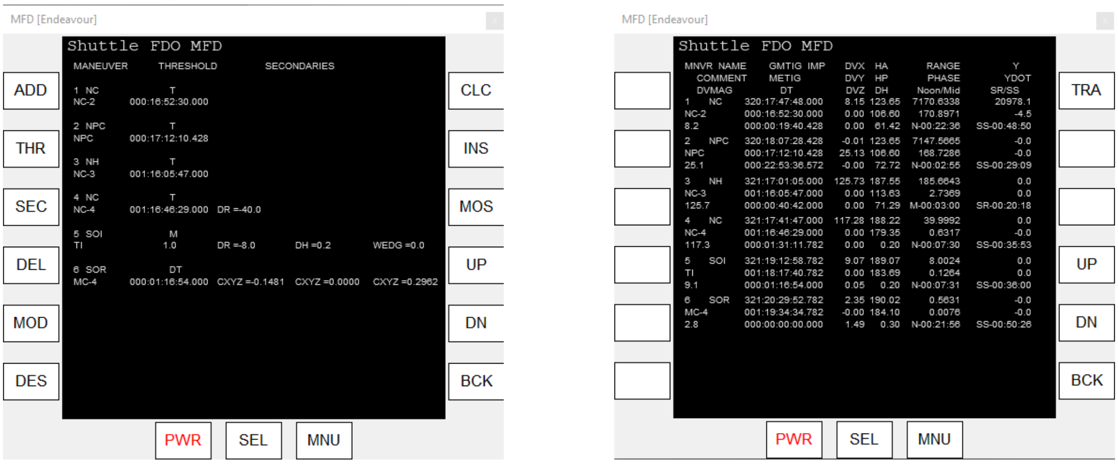


Figure 20: Final state before NC-2

8.3.1 Executing NC-2

NC-2 is a smaller burn than the ones before, so it's not necessary to use both OMS engines for it. For practice we are going to use the left OMS engine for this burn. Press TRA on the evaluation page as usual and go to the maneuver transfer table. Here we need to find the right predefined burn profile for a maneuver with the left OMS engine (code OL), 180 degrees roll and optimized TIG (code OPT). Slot 4 is the one which has these parameters, so press SLO and type "1 4". Then export the maneuvers to the DMT by pressing EXE. On the DMT select the first maneuver as usual and calculate the Maneuver PAD values for NC-2. Make sure to use all the right options from the PAD on the ORBIT MNVR EXEC (engine selection, TV ROLL, TRIM LOAD etc.)

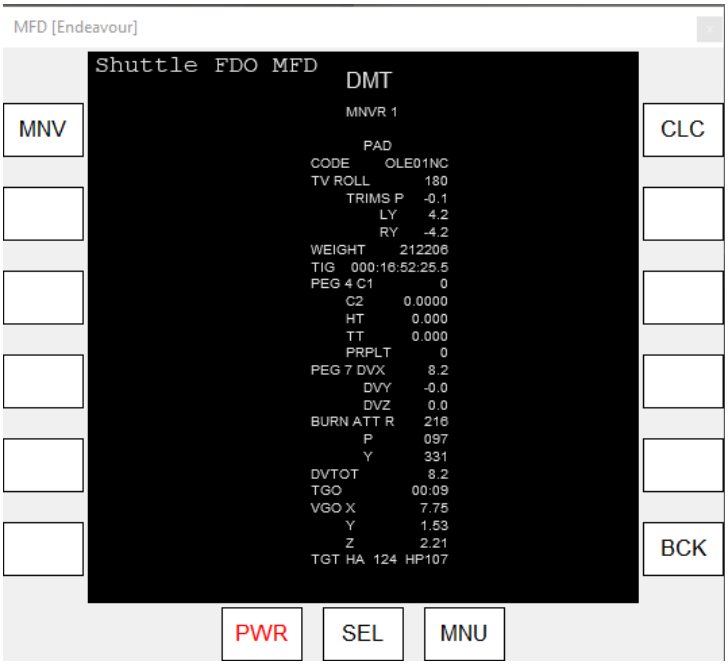


Figure 21: DMT for NC-2

8.4 Pre NPC Planning

We have already done most of the planning required for the NPC maneuver, which will align the planes of the Shuttle and the ISS. And that is a good thing, because the NPC burn will happen shortly after the NC-2 burn. In case it is too close to NC-2 to be feasible, try to let the MFD find a later common node by using a later primary threshold (T) and re-add the "CN = 1.0" secondary constraint to the maneuver. Alternatively, delete the NPC maneuver completely and just null the out of plane error as much as possible with the NC-2 maneuver by adding a "NULL = 0" secondary constraint to it.

Delete the NC-2 maneuver from the plan by pressing DEL and typing "1". There is now no maneuver left to target the -40 NM downrange constraint on the NC-4 maneuver. Usually there is a third NC maneuver on the evening of FD2, but it was omitted in this plan (and it was cancelled on the actual STS-126 mission). So that constraint will now also be deleted by press DES and typing "3 1". Save the current plan under a new name and run it by pressing CLC on the constraints page.

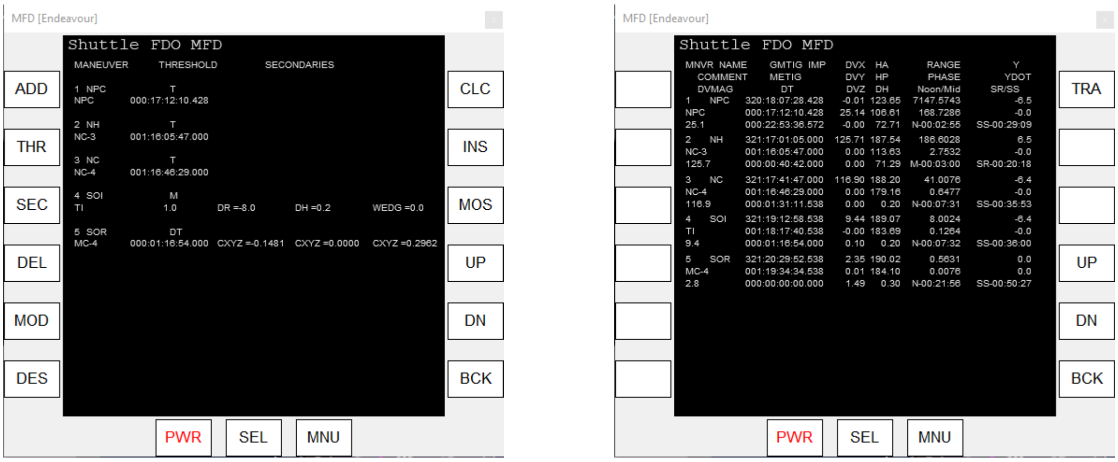


Figure 22: Final state before NPC

8.4.1 Executing NPC

For some variety we will perform this maneuver with the right OMS engine. Transfer the maneuver plan as usual to the MTT and there choose the 6th maneuver profile instead of the 4th we used the last time. For that press SLO and then type "1 6". Then press EXE and go to the DMT, where you press MNV and type "1" and then press CLC to get the Maneuver PAD numbers.

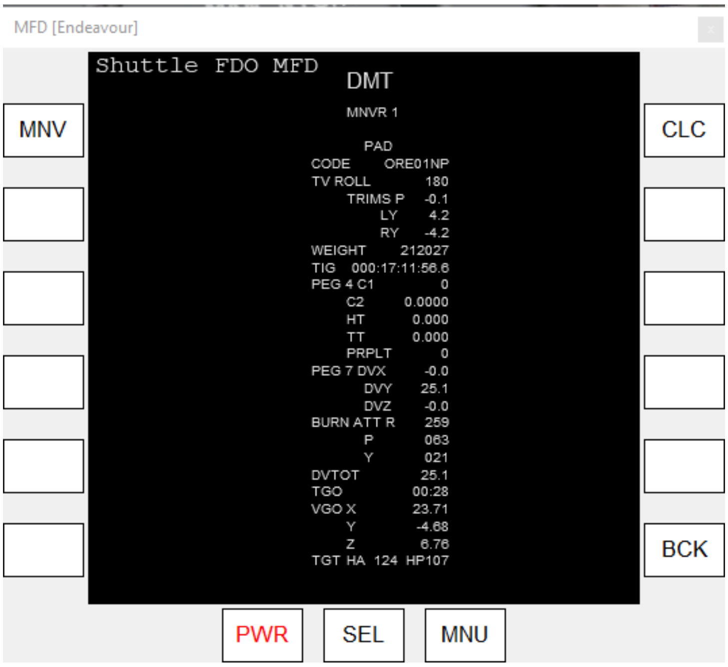


Figure 23: DMT for NPC

8.5 Pre NH (NC-3) Planning

Some time before crew wakeup on the day of rendezvous the preliminary plan for the final few rendezvous maneuvers should be defined. As the first step we need to check the phasing at NC-4. The last maneuver that was targeting the nominal -40 NM distance at NC-4 was the NC-2 maneuver. There is no phasing maneuver left to correct any errors, but the same can be achieved by moving the TIG of the NH burn to an earlier or later time. This is a trial and error process. Once it is close enough to 40 NM again (+/- 1NM should be sufficient) the NC-4 TIG needs to be adjusted by the same amount, because a Ti DVZ component will have been re-introduced. Moving the NH and NC-4 TIGs more than a few seconds is of course undesirable, because it will change the Ti lighting that was so carefully adjusted before. Next, the Ti TIG should be fixed in time by giving it a T primary constraint, rounded to a full second. It is used as a baseline time for the whole terminal rendezvous and it will simply procedures to have it at a full second. Re-calculate and save the plan.

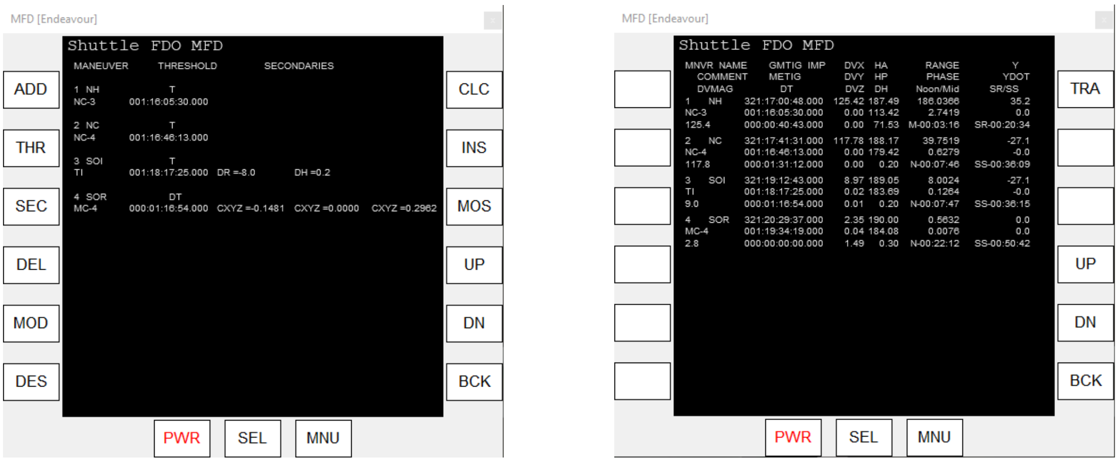


Figure 24: Final state before NH

At this point a whole FD3 Rendezvous Package could be created, which is given to the crew at the beginning of FD3 as part of an Execute Package. This contains a full list of maneuvers on the day of rendezvous, relative motion plots (can't be generated by the FDO MFD) and preliminary Maneuver PADs for the NH, NC-4 and Ti maneuvers. The relative timing of the rendezvous maneuvers can be found in the Reference Data section of the rendezvous checklist, for a target altitude of 210 NM. As explained in the description of the impulsive flag on the MTT page the onboard targeted maneuvers will not be modified in their TIG to account for the finite burntime, so they can now be generated:

NCC: 001:17:19:43.000
Ti: 001:18:17:25.000
MC1: 001:18:37:25.000
MC2: 001:19:07:19.000
MC3: 001:19:24:19.000
MC4: 001:19:34:19.000

On the MTT page we can now generate burn profiles for NH, NC-4 and Ti. So this time we not only choose a burn profile for the first maneuver in the list, but the other ones as well. NH and NC-4 will use both OMS engines (OBP), the optimal ignition time (OPT) and a roll angle of 0 degrees. Ti usually uses the left OMS engine (OL) and the impulsive (IMP) ignition time. We could also generate a PAD for MC4, which will use the RCS for the burn. The desired burn profiles are therefore: profile 1 for NH and NH-4, profile 10 for Ti and profile 9 for MC4.

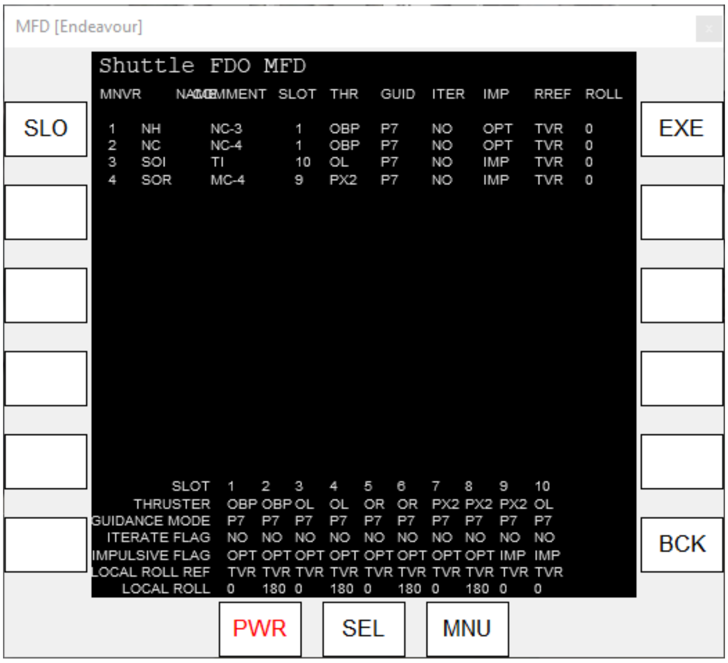


Figure 25: MTT for DOR maneuvers

Optionally you can now generate Maneuver PADs for all four maneuvers.

8.5.1 Executing NH

When we get closer to the NH TIG we can run the plan again and generate the final Maneuver PAD for the NC-3 (NH) maneuver.

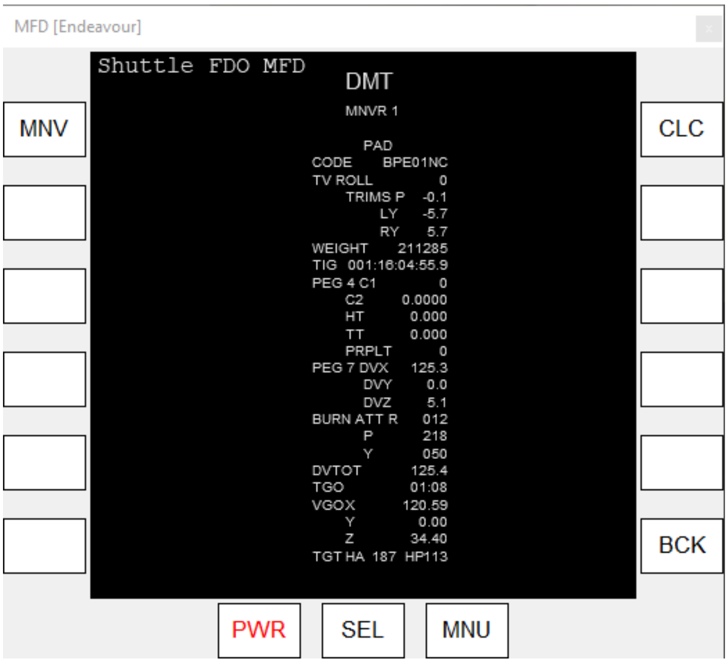


Figure 26: DMT for NH

8.6 Pre NC (NC-4) Planning

As before, delete the maneuver that was last executed (the NH maneuver in this case) and remove any constraints associated with that burn. That is the DH constraint on NC-4 in this case. The NC-4 TIG should be slightly varied to minimize the Ti DVZ component, anything below 1 fps is good enough. Save the plan under a new name.

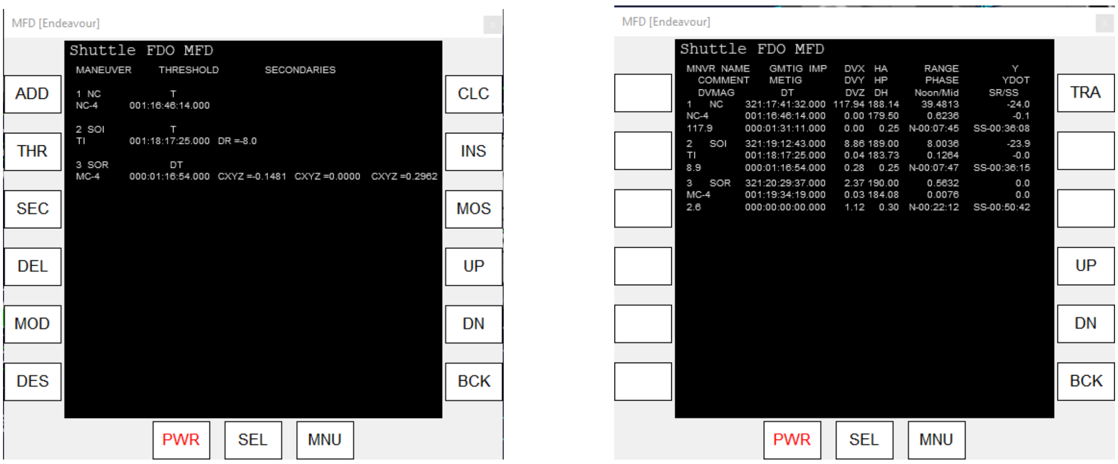


Figure 27: Final state before NC-4

8.6.1 Executing NC-4

Nothing special about this burn.

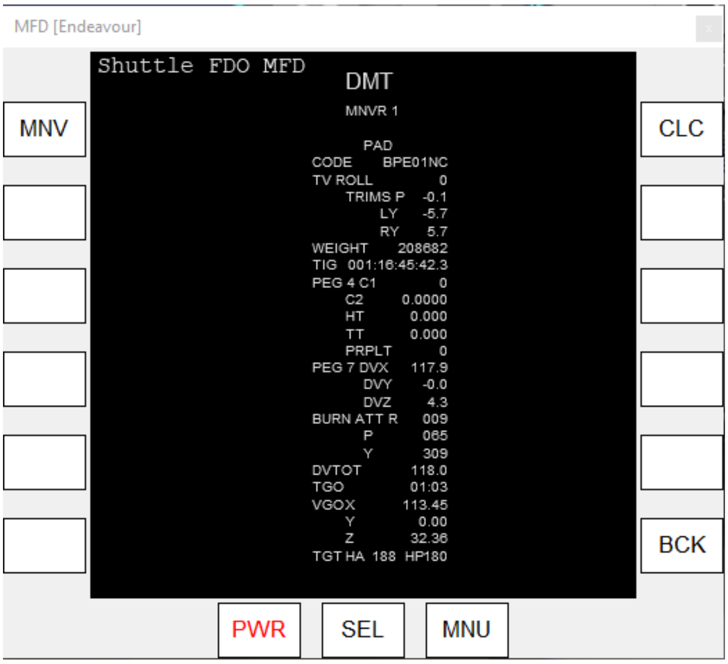


Figure 28: DMT for NC-4

8.7 Pre NCC Planning

The remaining part of the rendezvous could be flow with just the onboard tools, especially SPEC 34. But the "ground solutions" can also be calculated with the FDO MFD. For the NCC maneuver we first delete NC-4, then we insert the NCC maneuver at the previously calculated time. For that press INS on the constraints page and type "1 NCC NCC" to add a NCC type maneuver with the name NCC in the first position of the table. Then add a threshold of type T to the NCC maneuver with the time of, in my case, 001:17:19:43. The NCC type maneuver targets all three axes (downtrack, delta height, out-of-plane), so we can re-introduce the DH and WEDG secondary constraints that we already before on the Ti maneuver.

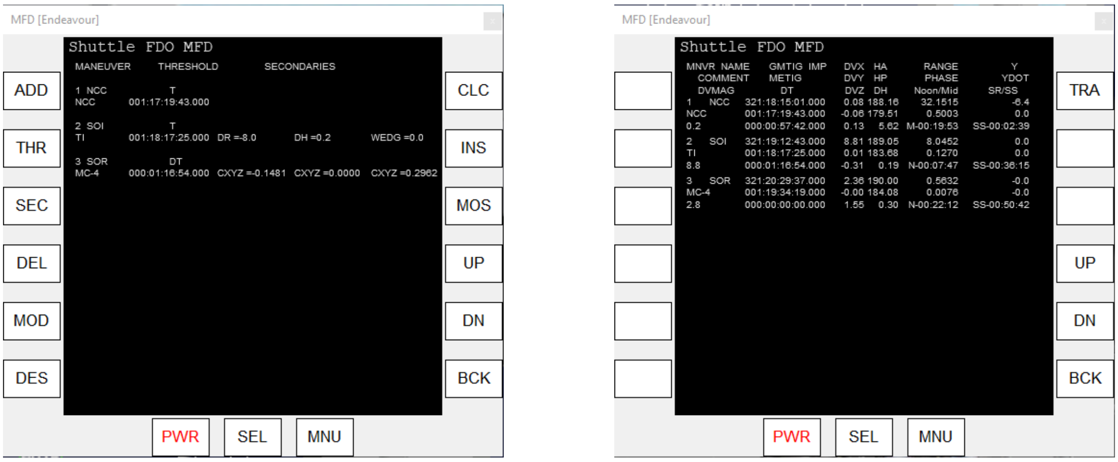


Figure 29: MCT and MET before NCC

8.7.1 Executing NCC

In all likelihood NCC will be a very small burn, so a multi-axis RCS burn is more than sufficient to execute it. None of the remaining burns should be slipped in time for crew procedure reasons, so the IMP option should be used on the MTT. That means burn profile 9 is the right choice on that page.

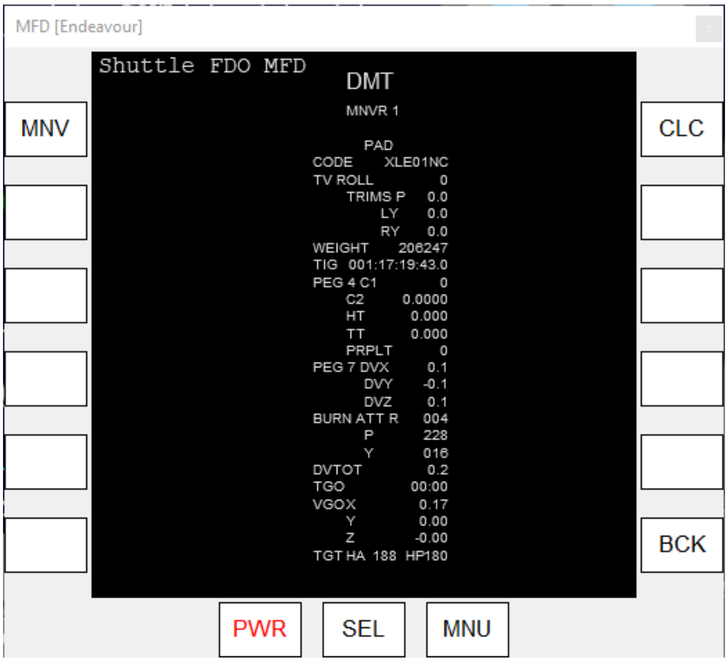


Figure 30: DMT for NCC

8.8 Pre Ti Planning

For Ti only the previous maneuver and the associated secondary constraints need the be removed, the rest of the rendezvous plan should stay as it is.

Figure 31: MCT and MET before Ti

8.8.1 Executing Ti

The desired burn profile for Ti is using the left OMS engine, so that the Ku-Band antenna can stay locked onto the target vehicle even in the burn attitude. So profile 10 should be chosen on the MTT.

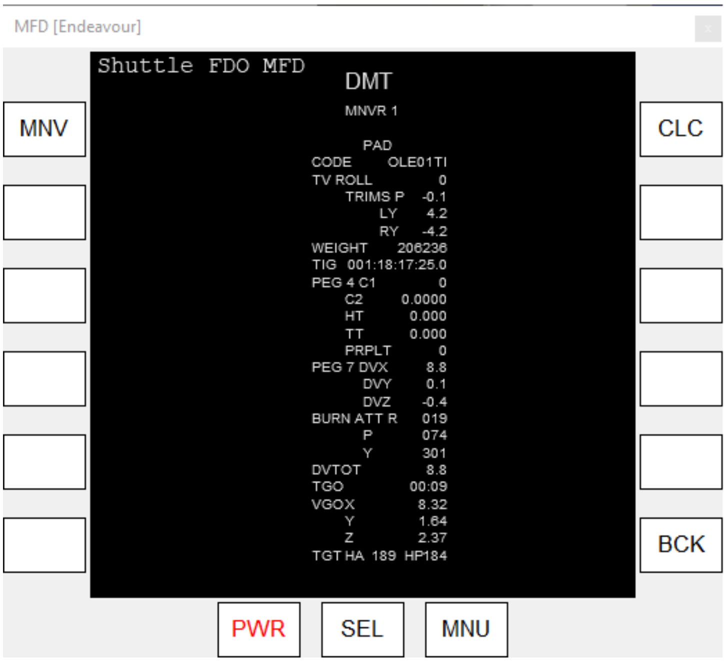


Figure 32: DMT for Ti

8.9 MC Maneuvers

The MC maneuvers can be targeted with the FDO MFD by adding them as the SOI maneuver in the plan. Just modify the previous plan by changing the name of the SOI maneuver from Ti to MC1 (or 2 etc.) and then changing the primary threshold to the previously calculated MC TIG.

This concludes the walkthrough of a full rendezvous with the ISS. While the general principle of this rendezvous profile will apply to most other Shuttle rendezvous scenarios, the details will always be different. Flight Day 4 rendezvous have more phasing correction maneuvers, some missions even included a coelliptic profile. Some of these variations and additional procedures will be added to this manual as special focus chapters.

9 Landing Sites

The landing sites in the table below are the ones available for the deorbit opportunities and deorbit maneuver processor displays. They are defined in two separate config files, LandingSites.txt and DOPSLandingSites.txt, in the Config/MFD/ShuttleFDOMFD/ folder. The runways IDs are the names to be input to the deorbit maneuver processor. The SPEC 50 codes are typically values, but don't apply to all missions.

Code	Name	Runways	SPEC 50 Code
KSC	Kennedy Space Center	KSC15, KSC33	1
BEN	Ben Guerir	BEN18, BEN36	2
MRN	Moron AB	MRN02, MRN20	3
ZZA	Zaragoza	ZZA12R, ZZA30L	4
MYR	Myrtle Beach	MYR18, MYR36	5
ILM	Wilmington	ILM06, ILM24	6
NKT	Cherry Point	NKT32L, NKT23R	7
NTU	Oceana NAS	NTU32R, NTU23L	8
WAL	Wallops	WAL04, WAL28	9
DOV	Dover AFB	DOV19, DOV32	10
ACY	Atlantic City	ACY13, ACY31	11
FOK	Gabreski	FOK06, FOK24	15
FMH	Cape Cod CGAS	FMH23, FMH32	16
PSM	Pease International	PSM16, PSM34	17
YHZ	Halifax International	YHZ23, YHZ32	18
YJT	Stephenville	YJT09, YJT27	19
YYT	St Johns International	YYT11, YYT29	20
YQX	Gander International	YQX21, YQX31	21
YYR	Goose Bay	YYR26, YYR34	22
LAJ	Lajes AB	LAJ15, LAJ33	23
BEJ	Beja AB	BEJ01L, BEJ19R	24
IKF	Keflavik International	IKF20, IKF29	25
INN	Shannon	INN06, INN24	26
FFA	Fairford	FFA09, FFA27	27
KBO	Köln-Bonn	KBO14L, KBO32R	28
FMI	Istres AB	FMI15, FMI33	29
ESN	Esenboga	ESN03R, ESN21L	30
KKI	King Khaled	KKI15R, KKI33L	31
JDG	Diego Garcia	JDG13, JDG31	32
AMB	Amberley RAAF	AMB15, AMB33	33
PTN	Tindal RAAF	PTN14, PTN32	33
JTY	Yokota AB	JTY18, JTY36	34

Code	Name	Runways	SPEC 50 Code
GUA	Andersen AFB	GUA06L, GUA24R	35
WAK	Wake Island	WAK10, WAK28	36
HNL	Honolulu	HNL08R, HNL26L	37
EDF	Elmendorf	EDF06, EDF24	38
HAO	Hao Atoll	HAO12, HAO30	39
EDT	Edwards Temp	EDT04L, EDT22R	40
HAW	Ascension	HAW13, HAW31	41
NOR	Northrup	NOR17, NOR23	42
NOR	Northrup	NOR05, NOR35	43
EDW	Edwards AFB	EDW15, EDW18L	44
EDW	Edwards AFB	EDW04, EDW22	45
AAT	Tamanrasset	AAT02, AAT20	-
AHS	Hoedspruit AFB	AHS18, AHS36	-
AML	Sal International	AML01, AML19	-
ARL	Stockholm Arlanda	ARL01, ARL19	-
AWG	Rio Gallegos	AWG07, AWG25	-
BDA	Bermuda	BDA12, BDA30	-
BYD	Banjul International	BYD14, BYD32	-
CBA	Casablanca	CBA17, CBA35	-
CEF	Westover	CEF05, CEF23	-
DDN	Darwin International	DDN11, DDN29	-
DNA	Kadena AB	DNA05L, DNA23R	-
DOV	Dover AFB	DOV01, DOV14	-
DYS	Dyess AFB	DYS16, DYS34	-
EIP	Easter Island	EIP10, EIP28	-
EST	Nuevo Pudahuel Airport	EST17, EST35	-
FFO	Wright-Patterson AFB	FFO05L, FFO23R	-
GDV	Gran Canaria	GDV03L, GDV21R	-
GSA	Chania International	GSA11, GSA29	-
GUS	Grissom AFB	GUS05, GUS23	-
JDG	NSF Diego Garcia	JDG13, JDG31	-
KIN	Kinshasa	KIN06, KIN24	-
LIN	Lincoln	LNK18, LNK36	-
LRB	Roberts International	LRB04, LRB22	-
MCF	MacDill AFB	MCF04, MCF22	-
MCO	Orlando International	MCO18R, MCO36L	-
MUO	Mountain Home AFB	MUO12, MUO30	-
MHW	Grant County	MHW14L, MHW32R	-
NID	China Lake	NID03, NID21	-
NKX	MCAS Miramar	NKX06L, NKX24R	-
NZC	Cecil Airport	NZC18L, NZC36R	-

Code	**Name**	**Runways**	**SPEC 50 Code**
OOY	Dakar	OOY18, OOY36	-
PBG	Plattsburgh International	PBG17, PBG35	-
PEA	RAAF Base Pearce	PEA18L, PEA36R	-
PMR	Cape Canaveral AFS	PMR13, PMR31	-
RCA	Ellsworth AFB	RCA13, RCA31	-
ROZ	Naval Station Rota	ROZ10, ROZ28	-
VBG	Vandenberg AFB	VBG12, VBG30	-
YNN	Nassau International	YNN14, YNN32	-

10 Changelog

Version 0.4.2:

- Deorbit Opportunities for all possible landing sites.
- Minor DOPS bug fix.

Version 0.4.1:

- Updated landing site table for deorbit maneuver targeting.
- Minor DMP bug fix.

Version 0.4.0:

- Add Deorbit Maneuver Processor.