Apollo RTCC MFD

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1 Introduction

This document will explain the main functionality of the Apollo RTCC MFD for Project Apollo - NASSP 7.0 Beta and Orbiter 2010. Originally started to calculate the Apollo 7 rendezvous maneuvers, the MFD has expanded to include many more features which during the Apollo program were provided by Mission Control (MCC) and the Real-Time Computer Complex (RTCC).

Currently the features of the MFD are:

- Calculating rendezvous maneuvers by solving Lambert's Problem (Useable for the Apollo 7 phasing, NCC1 and TPI maneuvers).
- Coelliptic maneuvers (Usable for the Apollo 7 NSR burn).
- Generic orbit adjustment maneuvers (Usable for the Apollo 7 SPS burns).
- Return to Earth trajectories from anywhere in the Earth-Moon-System.
- All types of IMU transformation matrizes (REFSMMAT) used for the Apollo spacecraft.
- Lunar orbit insertion maneuvers, including Translunar Injection (TLI) and Mid-course Corrections (MCC).
- CSM and LM State Vector Update.
- Uplink to the AGC for Contiguous Block Updates.
- Displaying various Pre-Advisory Data (PAD).

2 Using the MFD

2.1 Main Menu

LAM: Lambert Targeting.
CDH: CDH/NSR maneuver.
ORB: Orbit Adjustment.
REF: REFSMMAT.
ENT: Reentry.
LOI: Lunar Insertion.
SV: State Vector.
MAN: Maneuver PAD.
ENP: Entry PAD.
CFG: Configuration menu.

2.2 Lambert Targeting

2.2.1 Explanation

The MFD uses advanced algorithms to efficiently solve Lambert's Problem. Lambert's Problem can be explained as finding the velocity vector V1 that leads to an orbit between position vectors R1 and R2 in the time DT.

The Lambert Targeting functionality of this MFD allows multi-revolution calculations and uses a predictor-corrector algorithm to find a solution even in a non-spherical gravity field. This functionality has its limits and will not work beyond a few revolutions. In this MFD instead of a time difference DT the user can set the GET for the maneuver (T1) and the time of arrival (T2). The position vector R2 is always the position of a target vessel or an offset to a target vessel. The displayed maneuver Delta V is the difference between the calculated V1 and the velocity at T1 before a maneuver.

2.2.2 Buttons

T1: Manuever Time. If the maneuver is supposed to be executed with a specified elevation angle relative to the target, type "E=27.45" to find the T1, when this elevation angle occurs. For this a target already needs to be set.
T2: Arrival time at the (offset) target. If this time is specified as relative to T1, type "T1+35min" to set T2 to a time 35 minutes after T1.
N: The number of revolutions from the maneuver (T1) to arrival (T2).
AXI: Multi-Axis maneuver as the default. An X-Axis maneuver only consists of a prograde or retrograde impulse. This can be used to achieve phasing relative to a target, without the need to also achieve a specific relative height or position offset left or right. Useful to minimize DV for simple phasing maneuvers.

SPH: Changes the calculation mode between spherical and non-spherical (perturbed) gravity. The Perturbed mode forces a multi-axis manuever.
TGT: The input for the target vessel. Switches between all vessels in the simulation.
CLC: Calculate the burn solution.
OFF: Set the offset from the target. Use e.g. "X=2.05" to set the individual parameters.
PHA: Choose a phase angle relative to the target vessel. This will calculate the necessary offset distance in front or behind the target.
UPL: Uplink the maneuver solution to the AGC.
BCK: Go back to the main menu.

2.3 Coelliptic Maneuver

2.3.1 Explanation

Coelliptic orbits are two orbits that are coplanar (identical inclination and longitude of the ascending node) and confocal (identical eccentricity and argument of periapsis). To achieve such an orbit relative to a target vessel this MFD can calulate a maneuver based on Program 33 of the AGC.

2.3.2 Buttons

TIM: Switches between fixed GET and finding the delta height of the maneuver or fixed delta height and finding the time of ignition.
CDH: The time of the CDH maneuver in GET. The time displayed below DH is the GET of the maneuver calculated in "Find GETI" mode.
DH: The delta height used in the constant delta height maneuver in nautical miles.
TGT: The input for the target vessel.
CLC: Calculate the burn solution.
UPL: Uplink the maneuver solution to the AGC.
BCK: Go back to the main menu.

2.4 Orbit Adjustment Maneuver

2.4.1 Explanation

The orbit adjustment functionality allows to calculate a maneuver with the desired apoapsis, periapsis and inclination values and the specificed time.

2.4.2 Buttons

GET: Choose the GET of the maneuver.
APO: Choose the apoapsis altitude for the maneuver in nautical miles.

PER: Choose the periapsis altitude for the maneuver in nautical miles.
INC: Choose the equatorial inclination of the desired orbit.
CLC: Calculate the oribt adjustment maneuver.
UPL: Uplink the maneuver solution to the AGC.
BCK: Go back to the main menu.

2.5 REFSMMAT

2.5.1 Explanation

The REFSMMAT (REFerence to Stable Member MATrix) is a rotation matrix relating the Apollo Basic Reference Coordinate System (BRCS) and the currently used IMU Stable Member Coordinate System. Depending on the mission phase the REFSMMAT is chosen, so that the IMU angles provide meaningful attitude values. Some types of REFSMMATs can be calculated by the AGC itself, but most were uplinked to the spacecraft from the ground. The REFSMMATs that can be calculated with this MFD are:

- Launch: Apollo 7 and 8 Launch REFSMMAT hardcoded in the MFD
- Landing Site: Not used for Apollo 7 or 8
- PTC: Passive Thermal Control, not used for Apollo 7 or 8.
- LOI-2: A special LVLH REFSMMAT for Apollo 8, calculated before the last translunar Midcourse Correction.
- P30: Alignment for a thrusting maneuver, equivalent to option 1 in Program 52.
- P30 retro: Alignment for a retrograde burn, useful for Earth orbit reentry maneuvers.
- LVLH: Local Vertical alignment, equivalent to option 2 in Program 52.
- Lunar Entry: Equivalent to option 2 in Program 52 with the GET of Entry Interface.

2.5.2 Buttons

TIM: The options "Landing Site"', "PTC", "'P30", "P30 retro " and "LVLH" require a time in GET to calculate the REFSMMAT. For a Landing Site REFSMMAT the time chosen is either the predicted landing or launch time. The time for P30 and P30 retro REFSMMATs is the maneuver time and is set on a maneuver calculation page (Lambert, CDH or Entry).
TYP: Choose betwen uplinking the REFSMMAT or the desired REFSMMAT. The desired REFSMMAT is the alignment, that Program 52 will align the platform to, based

on the knowledge of the attitude referenced to the old, currently used REFSMMAT. Only in rare cases the REFSMMAT itself would be uploaded, e.g. when activating the Lunar Module or if the difference to the previous REFSMMAT is very small. In doubt, uplink the desired REFSMMAT!
DWN: Downlink the current REFSMMAT from the AGC. If the type of REFSMMAT is known, select it by cycling through the REFSMMAT types by pressing OPT before doing the downlink. Useful for calculating PADs with a REFSMMAT not calculated by the RTCC MFD.
MCC: The calculated REFSMMAT usually depends heavily on the current orbit. If there is a maneuver between now and the set time or the reentry time, change the setting to MCC to take the maneuver into account. The LOI-2 REFSMMAT is special, because the calculation of two maneuver is required before the LOI-2 REFSMMAT can be calculated. This will be explained in more detail on the Lunar Insertion page.
OPT: Switch between the different options.
CLC: Calculate the REFSMMAT.
UPL: Uplink the REFSMMAT to the AGC.
LAT: Only for Landing Site: Choose the latitude of the landing site.
LNG: Only for Landing Site: Choose the longitude of the landing site.
BCK: Go back to the main menu.

2.6 Entry

2.6.1 Explanation

An extensive number of options are available for Return to Earth calculations. These are categorized as modes, types and options . The main "modes" of the Entry Targeting are "Entry", "Entry Update", "P37 Block Data" and "TEI".

On the "Entry" page reentry maneuvers in the Earth Sphere-Of-Influence can be calculated. The types of maneuver available in this mode are "Deorbit", for maneuvers during an Earth orbital mision in Low Earth Orbit (LEO). Additionally two options are aviailable for deorbit: A nominal deorbit maneuver is performed in such an attitude, that the 31.7° line in the left rendezvous window can be overlayed on the horizon to achieve deorbit with GN system failures. The option "Min DV" achieves a deorbit with the minimum amount of fuel.

The type "Midcourse" is for Trans Earth Coast (TEC) midcourse maneuver during a lunar mission. The "Abort" option can be used for a direct return maneuver during Trans Lunar Coast (TLC). The fourth option, "Corridor Control", is identical to the "Midcourse" type, but does not try to achieve a specific splashdown longitude. This is equivalent to the Minimum DV option of Program 37 in the AGC.

The second mode, "Entry Update", is used to generate the splashdown coordinates for the AGC. Without any inputs, the splashdown latitude and longitude are calucu-lated based on a nominal reentry profile. If a longer or short reentry is desired, or if the splashdown longitude is supposed to be changed, then the entry range can be adjusted to achieve th enew entry profile. The splashdown coordinates are then available in the MFD for e.g. the Entry PAD.

The mode "P37 Block Data" is identical to the "Abort" type on the Entry page, but it will display the standard format of a Block Data update instead. These numbers can be used with the AGCs program 37 to calculate an onboard solution for the maneuver.

Outside of the Earths SOI, so for Apollo mission this means in the Lunar SOI, the TEI mode can be used. One nominal and two abort maneuver types are available here. The nominal TEI, "Trans Earth Injection", is used in a low lunar orbit for a Return to Earth. A "Flyby" is a maneuver at a specified time on a circumlunar trajectory. The Flyby maneuver usually is performed at the same time as the last MCC before reaching the Moon, in the case of an abort.

The type "PC+2" is an abort maneuver similar to the flyby, but instead performed two hours after reaching the closest point to the Moon, called pericynthion.

All three TEI types have the option to be calculated with variable return time. The "Normal Return" option uses a standard return time +/- 12 hours, depending on the desired splashdown longitude. This option should be used for nominal TEI maneuvers and flyby and PC+2 maneuvers that act as course correction on a free-return trajectory. The slow and fast return options are for fuel and time critical aborts respectively.

2.6.2 Buttons

TIG: Set the estimated time for the reentry maneuver. This will be the fixed TIG for a MCC or an abort maneuver and the initial guess to find the time of a deorbit maneuver in Earth orbit and other modes.
LMO: An option switch for either a manually selected splashdown longitude or a specified landing zone. The landing zones can have variable splashdown longitude as a function of latitude.
LNG: The desired splashdown longitude. For an Earth orbit deorbit maneuver the longitude is the parameter that will determine the TIG.
ANG: The reentry angle at Entry Interface (EI). If left to zero, the MFD will internally calculate the correct angle to ensure a safe reentry. Note that the polynomial used to calculate the reentry angle is optimized for a Lunar entry, so to achieve a realistic reentry from Earth orbit a historically used figure will give better results. For compatibility with the onboard Program 37, abort maneuvers use the long entry range used by the AGC, while nominal maneuvers use the short range entry (approx. 1285NM) actually used for the manned missions. The short range entry always ensures that no skip is performed.

OPT: Options for the reentry maneuver. The options are depending on the targeting mode.
TYP: The type of reentry maneuver. The types are depending on the targeting mode.
CLC: Calculate the reentry maneuver.
MOD: Cycles through the modes "Entry", "Entry Update", "P37 Block Data" and "TEI".
RAN: Adjust the entry range in Entry Update mode.
UPL: Uplinks the calculated data to the AGC.
BCK: Go back to the main menu.

2.7 Lunar Insertion

On this page the various maneuvers can be calculated to achieve insertion into the nominal lunar parking orbit of 60NM. Four maneuver types are available:

- TLI: Translunar Injection performed with the S-IVB.
- MCC: Midcourse correction maneuvers performed throughout the Translunar Coast.
- LOI-1 (w/ MCC): A special mode for the LOI-1 calculation, necessary for LOI-2 REFSMMAT.
- LOI-1 (w/o MCC): The normal case for the Lunar Insertion Maneuver 1. The goal for LOI-1 is an elliptical orbit in the plane of the desired parking orbit and intersecting the altitude of the final lunar orbit achieved with LOI-2.
- LOI-2: Achieves the 60NM lunar parking orbit.

The Translunar Injection is executed by the S-IVB and achieves specific coordinates at a specified time relative to the Moon. The TLI calculated with the RTCC MFD does not ensure a free-return trajectory yet, but the historical pericynthion state, as taken from the mission reports, can be achieved.

The special case for the LOI-2 is necessary, because two maneuvers (MCC and LOI-1) occur between the time of calculation and uplink of the REFSMMAT and the desired state in lunar orbit when this REFSMMAT is being calculated. The procedure to calculate the REFSMMAT therfore requires first the calculation of the last Translunar MCC, then the LOI-1 maneuver with the MCC option and then finally on the actual REFSMMAT page the DVs and GETs for the MCC and LOI-1 maneuver can be checked and the REFSMMAT can be calculated.

2.7.1 Buttons

MAN: The maneuver types "TLI", "MCC", "LOI-1 (w/ MCC)", "LOI-1 (w/o MCC)" and "LOI-2" can be selected.
TIM: Depending on the maneuver type, this GET is used as the maneuver time or the estimated maneuver time.
GET: For TLI and MCCs here the pericynthion GET is the input.
APA: Apoapsis altitude in nautical miles.
PEA: Periapsis altitude in nautical miles. For the LOI-2 maneuver ths is the altitude of the desired circular orbit.
INC: Selenographic inclination of the desired orbit after LOI-1.
CLC: Calculate the lunar insertion maneuver.
LAT: Selenographic latitude of the pericynthion state.
LNG: Selenographic latitude of the pericynthion state.
ALT: Selenographic latitude of the pericynthion state.
UPL: Uplinks the calculated data to the AGC.
BCK: Go back to the main menu.

2.8 State Vector

2.8.1 Explanation

The state vector of the vessel can be calculated and uplinked here. Additionally to the functionality in the Project Apollo MFD, this MFD can calculate a state vector in the future, which sometimes was used during the Apollo program to prevent an internal state vector integration of the AGC.
The AGC has two slots for state vectors: CSM and LM. For the CSM the MFD will prevent uplinking a state vector that is not the vessel itself. The vessel for the LM can be freely chosen.

2.9 Buttons

MOD: Choose between calculating the state vector "now" and at a specified GET.
TIM: Set the desired GET for the state vector in GET mode.
TGT: Set the target vessel.
SLT: Switch between the slots.
CLC: Calculate a state vector.
UPL: Uplinks the calculated data to the AGC.
BCK: Go back to the main menu.

2.10 Maneuver PAD

2.10.1 Explanation

The Maneuver Pre-Advisory Data (PAD) contains all necessary numbers to safely conduct a burn with the SPS or RCS. A complete explanation of each item on the PAD can be found in all Apollo flight plans, e.g. here. Additionally to the Maneuver PAD the very similar Apollo 7 TPI PAD was added as a second mode.

2.10.2 Buttons

VEH: The vehicle configuration is only displayed here and chosen on the configuration page.
ENG: Choose between the Service Propulsion System (SPS) and the Reaction Control System (RCS) for the maneuver.
HEA: Choose between conducting the maneuver in a heads-up or a heads-down orientation.
TIG: If you want to display a Maneuver PAD for a maneuver not calculated with the Apollo RTCC MFD you can manually enter the desired Time of Ignition and Delta V.
DV: See above.
CLC: Calculate the missing numbers on the Maneuver PAD.
OPT: Switch between the Maneuver PAD, the Apollo 7 TPI PAD and the TLI PAD.
REQ: Request a maneuver solution calculated with LTMFD or IMFD.
BCK: Go back to the main menu.

2.11 Entry PAD

2.11.1 Explanation

The Entry PAD contains all numbers to conduct a safe reentry. There are two types of Entry PADs: Earth Orbit Reentry and Lunar Entry. A complete explanation of each item on the PAD can be found in most Apollo flight plans, e.g. here.

2.11.2 Buttons

MAN: For a lunar entry you can choose between calculating a direct Entry PAD without any additional maneuvers or a Entry PAD for a previously calculated Midcourse Correction. For an Earth orbit entry a deorbit maneuver has to be performed in any case.
DWN: Downlink the splashdown coordinates from the AGC.
CLC: Calculate the missing numbers on the Entry PAD.
OPT: Switch between the Earth Entry PAD and the Lunar Entry PAD.

BCK: Go back to the main menu.

2.12 Configuration

MIS: Choose the mission number or manual options. Used to set the MJD of the mission launch for the Ground Elapsed Time calculations.
TYP: Choose the type of vehicle configuration (CSM or LM, docked or undocked).
REF: Choose the reference body of the vessel. Should be automatically set correctly at scenario start. The use of this parameter is slowly phased out, so that no incorrect setting here leads to failed calculations.
SXT: Change the time of the sextant star check, which is part of the procedure for a normal maneuver. During Earth orbit missions the Earth often blocks the sextant from viewing many stars, so adjusting the time of the check before the maneuver allows the MFD to find a suitable star.
UPL: Inhibit or enable uplinks during times of no available ground stations. Currently all ground stations being used for Apollo 7 are implemented.
MJD: If the manual mission options is used, a launch MJD can be chosen.
BCK: Go back to the main menu.

3 Example: Apollo 7 Rendezvous

This MFD can be used to replicate the ground solutions for the rendezvous and other SPS burns during the Apollo 7 mission. As an example the inputs for the following maneuvers will be presented:

1. Separation burn at 3:20:00 GET.
2. NCC1 burn at 26:25:00 GET.
3. NSR burn at 28:00:00 GET.
4. TPI burn at ca. 29:25:00 GET.

3.1 Separation burn

These calculations should be done shortly before the time of the maneuver. The following steps have to be done for the separation burn:

- Maneuver time (T1) is at 003:20:00h GET.
- The time for the next maneuver (T2) will be at 026:25:00h.
- The time between T1 and T2 is 23:05h, which can be calculated as about 15.4 revolutions with the current orbital period. The correct value for the input N is therefore 15.

- AXI: The phasing maneuver was an x-axis only maneuver, so this option should be chosen here.
- SPH: 15 orbits is too long a time to calculate the maneuver with non-spherical gravity. Therefore choose the option "Spherical".
- The target vessel of the rendezvous is the Apollo 7 SIVB, which has the name "AS-205-S4BSTG".
- At the arrival time the CSM has to be 70NM in front of the SIVB. Set this value pressing OFF and type "X=70" to set a 70NM offset in front (positive x-axis) of the S-IVB stage.
- A value for YOFF would be "Left" or "Right" from the vessel at arrival time. This is not desired, so this can be left as zero. A ZOFF value is not specified, so this should remain 0 for now.

The resulting DV vector should be close to (-1.7,0,0). These values can now be used for P30 in the AGC or directly uplinked.

3.2 NCC1 burn

At 26:25:00 GET a SPS burn was executed that will put the CSM on a trajectory resulting in a phase angle of 1.32° behind and 8NM below the SIVB at 28:00:00GET. The required inputs are here:

- T1 is set to 26:25:00 GET (NCC1 time).
- T2 is set to 28:00:00 GET (NSR time).
- The time between T1 and T2 is with 1:35h slightly longer than an orbital period. No good results were found with N set to 0, so it should be set to 1.
- AXI: Because a precise position relative to the S-IVB is desired for the rendezvous sequence, the option multi-axis should be chose.
- TGT is the same as before.
- For this short, 90 minute transfer between T1 and T2 the "Perturbed" calculation option can be used.
- The phase angle function can be used to create the x-offset. The value -1.32° results in approx. –82.58 NM for XOF.
- The ZOF value in the CSM coordinate system is positive for an offset below the target. 8NM is used for ZOFF during the coelliptic rendezvous phase.

The resulting burn solution should be close to the vector (66.5, -1.8, 180.5). This can be used in a P30/P40 automatic SPS burn with the CSM.

3.3 NSR burn

The NSR burn nominally happens at 28:00:00 GET and places the CSM in a coelliptic orbit with a constant delta height to the target. On the CDH page of the MFD the inputs for the burn are the GET (028:00:00) and the Delta Height (DH) of the orbit, which is 8 NM for Apollo 7. Because the GET is variable, the option "Find GETI" should be used. A positive value here means below the target. When calculating the burn, the new time for the maneuver is also displayed below the number for DH. The new time is chosen, so that the delta height of the burn is exactly the specified 8NM. The results should be close to:

- 028:00:30 GET
- DX: -92.7 fps
- DY: +1.6 fps
- DZ: -106.2 fps

These numbers can be used for the external DV program (P30).

3.4 TPI burn

The TPI maneuver nominally was calculated by the AGC itself, but a backup solution was calculated on the ground. This backup solution can be replicated with the MFD. On the Lambert page first set the S-IVB as the target. Then press T1 and type "E=27.45". The MFD will now try to find the T1, when an elevation angle of 27.45° occurs. To find the T2, which is 35 minutes after T1, press T2 and type "T1+35min". T2 will now be set to that time. Leave N as zero, calculation mode to "Perturbed" and the three offset coordinates to zero. Usual values for the maneuver:

- 29:21:38 GET
- DX: +13.7 fps
- DY: +0.9 fps
- DZ: -7.9 fps

On the Maneuver PAD page press OPT and CLC to display the TPI PAD.