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 a rendezvous maneuver by solving Lambert's Problem (Useable for the Apollo 7 phasing, NCC1 and TPI maneuvers).
- Calculating coelliptic maneuvers (Usable for the Apollo 7 NSR burn).
- Calculating generic orbit adjustment maneuvers (Usable for the Apollo 7 SPS burns).
- Calculating deorbit and trans-earth Midcourse Correction burns (based on the P37 precision trajectory computations).
- Calculating the IMU transformation matrix (REFSMMAT) for the Alignment for Thrusting Maneuvers, Landing Site, Passive Thermal Control (PTC), Reentry Maneuvers and Alignment to Local Vertical at a specified time.
- Uplinking to the AGC the solutions for: CMC Desired REFSMMAT Update, CMC External Delta V Update, CMC Retrofire External Delta V Update, CMC Entry Update
- Displaying the Maneuver PAD and Entry PAD for a burn or reentry calculated with the MFD

2 Usage

2.1 Main Menu

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

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

TIM: Choose the time mode for the inputs T1 and T2. GET is the Ground Elapsed Time from the start of the mission. In MJD mode the Modified Julian Time has to be used for T1 and T2. In SimT mode the Simulation Time is being used.
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.
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).
UNI: The displayed unit of the burn solution. The options are meters per second or feet per second.

SPH: Changes the calculation mode between spherical and non-spherical (perturbed) gravity
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.
OFF: Switch to the offset page.

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.
DH: The delta height used in the constant delta height maneuver in nautical miles.
UNI: The displayed unit of the burn solution. The options are meters per second or feet per second.
ORI: The reference system used in the burn solution.
TGT: The input for the target vessel.
CLC: Calculate the burn solution.

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.

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.

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.
- 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.
MCC: The calculated REFSMMAT 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.
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

On this page different types of reentry maneuvers can be calculated, which are based on Program 37 of the AGC. For an Earth orbit reentry only the "Deorbit" mode is used. For a Trans Earth Coast (TEC) midcourse maneuver during a lunar mission choose the "Midcourse" mode. The "Abort" option can be used for a direct return maneuver during Trans Lunar Coast (TLC).

The AGC has two different uplink modes for reentry: Retrofire External Delta V Update and Entry Update. The first update not only uploads the burn parameters, but also the splashdown latitude and longitude that is going to be targeted. The Entry Update only updates those coordinates based on the current trajectory. On the Entry page the user can cycle through these two modes to calculate a reentry maneuver, or only the coordinates. The third mode in the MFD is the P37 Block Data PAD, which gives the numbers for an abort maneuver calculated with P37.

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.
LAT: The desired splashdown latitude. Only longitude is a parameter used in the calculations, so this currently has no function.
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 right 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.

TYP: The type of reentry maneuver. The options are "Midcourse", "Deorbit" and "Abort".
CLC: Calculate the reentry maneuver.
MOD: Cycles through the option "Entry", "Entry Update" and "P37 Block Data".
UPL: Uplinks the calculated data to the AGC.
BCK: Go back to the main menu.

2.7 State Vector

2.7.1 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.

2.8 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.

2.9 Maneuver PAD

2.9.1 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.

2.9.2 Buttons

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 and the Apollo 7 TPI PAD.
BCK: Go back to the main menu.

2.10 Entry PAD

2.10.1 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.

2.10.2 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.
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.

2.11 Configuration

MIS: Choose the MJD of the mission launch for the Ground Elapsed Time calculations.
TYP: Choose the type of vessel (CSM or LM).
DV: Choose the mode the DV values are displayed in. The options are decimal number or AGC DSKY format.
REF: Choose the reference body of the vessel.
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.
BCK: Go back to the main menu.

3 Example: Apollo 7 Rendezvous

This MFD can be used to replace 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.
- UNI should be set to "ft/s", so that the displayed burn solution corresponds to the numbers shown in the External DV program of the AGC.
- 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.

A first calculation results in a burn vector of (-2.4, 0, -38.1). The burn is a retrograde burn, so every other term than XOFF should be zero. The ZOFF is a free paramater that can be adjusted to reach this goal. After some testing a good burn solution can be found with a z-offset (ZOFF) of +1.1 NM. The resulting DV vector is (-1.7,0,0). These values can now be used for P30 in the AGC.

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.
- UNI and TGT are 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 below are so +14816 meters or 8 NM for ZOFF.

The resulting burn solution is 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. 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 this elevation angle 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 maneuverare:

- 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.

4 Example: Apollo 8

4.1 LOI-2 REFSMMAT

The REFSMMAT for the Lunar Orbit Circulation (LOI-2) REFSMMAT "is such that if a horizontal, in-plane, heads-up, posigrade burn were being made at LOI-2, the gimbal angle (FDAI) readout would be approximately 0,0,0. (R-P-Y)."

To achieve these conditions calculate a preliminary LOI-1 burn with IMFD or LTMFD and receive the numbers for the burn with Project Apollo MFD. If you have the time of ignition and the Delta V components, open the Apollo RTCC MFD and set these numbers on the Maneuver PAD page via the manual TIG and DV inputs. Now go back to the main menu and select the REFSMMAT page and choose LVLH as the REFSMMAT option. The required time will be set to the TIG of the LOI-2 maneuver, which is 73:30:54 GET. Press CLC and uplink the solution.