

Apollo RTCC MFD

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1 Introduction

The Apollo RTCC MFD provides the necessary calculation tools to fly complete Apollo missions with Project Apollo - NASSP 8.0. As much as possible it tries to replicate the same calculations, inputs and display as were used by the actual flight controllers during Apollo. 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).

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2 Main Menu

The main menu is dividing the MFD in the following categories:

TAR: Targeting menu. Contains the various maneuver computation pages.

PAD: Pre-Advisory Data. Shows the PADs that the Apollo crews received during a mission.

UTI: Utility. All additional calculation pages that are not for specific maneuvers.

MCC: MCC Displays. Shows the "TV Guide", a list of displays that were available in the MOCR.

PLN: Mission Plan Table. A central feature of the maneuver planning during a mission. Currently optional.

CFG: Configuration. Various settings for the MFD.

3 Targeting

The targeting menu consists of the many maneuver calculation pages:

REN: Rendezvous menu. Contains the calculations for rendezvous maneuvers.

ORB: Orbit Adjustment. Contains the inputs and display for the General Purpose Maneuver processor.

TLI: TLI Planning. Currently under construction.

MCC: Midcourse Correction. Contains the inputs and displays for the Translunar Midcourse Correction Processor.

LOI: Lunar Orbit. Contains the inputs and displays for the Lunar Orbit Insertion processor.

ENT: Entry. Contains the inputs and displays for the Return-to-Earth processor (RTEP).

DES: DOI Targeting. Contains the inputs and display for the Lunar Descent Planning Processor (LDPP).

LIF: Lunar Liftoff. Contains the inputs and display for the Lunar Launch Window Processor (LLWP).

ASC: Lunar Ascent. Contains the inputs and display for the Lunar Ascent Integrator (LAI).

ABO: Descent abort. Contains the inputs and display for the Powered Descent Abort Program (PDAP).

3.1 Rendezvous

This MFD page contains the three main calculation tools for rendezvous maneuvers, as well as a separate section for the Skylab rendezvous profile:

LAM: Lambert targeting. Contains the inputs and display for the Two-Impulse (TI) processor.

CDH: CDH/NSR maneuver. Contains the inputs and display for the Coelliptic Rendezvous processor (SPQ).

DKI: Docking initiate. Contains the inputs and display for the Docking Initiation Processor (DKI)

SKY: Skylab rendezvous. Replicates the rendezvous programs of the onboard software in the AGC of the Skylab missions.

3.1.1 Lambert Targeting (T1)

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.

OPT: Calculation option. General calculation mode, NCC/NSR maneuver sequence, TPI/PTF maneuver sequence

VTI: Time tag of the state vectors used in the calculation (MPT mode only)

T1: Maneuver Time. If the maneuver is supposed to be executed with a specified elevation angle relative to the target, input any negative time.

T2: Arrival time at the (offset) target. If this time is specified as an orbital travel angle, input any negative time.

N: The number of revolutions from the maneuver (T1) to arrival (T2).

SPH: Changes the calculation mode between spherical and non-spherical (perturbed) gravity. The Perturbed mode forces a multi-axis maneuver.

TGT: The input for the target vessel. Switches between all vessels in the simulation (non-MPT mode)

CLC: Calculate the burn solution.

OFF: Set the offset from the target. In the general calculation mode use e.g. "X=2.05" to set the individual parameters. In the NCC/NSR and TPI/PTF modes the inputs are phase angle and delta height.

PHA: Choose a phase angle relative to the target vessel. This will calculate the necessary offset distance in front or behind the target.

AXI: Multi-Axis maneuver as the default. An X-Axis maneuver only consists of a pro-grade 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.

BCK: Go back to the main menu.

3.1.2 Coelliptic Maneuver Processor (SPQ)

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 calculate a maneuver based on Program 33 of the AGC and the maneuver to initiate the coelliptic sequence, based on Program 32 of the AGC.

Buttons **INI:** Go to SPQ initialization page.

VEH: Choose which of the two vehicles is the chaser and which is the target (MPT mode only).

CHA: Threshold time for the state vector of the chaser vehicle (MPT mode only).

TGT: Threshold time for the state vector of the target vehicle (MPT mode only).

MOD: Calculation mode, CSI or CDH maneuver.

TIM: Switches between fixed GET and finding the delta height of the maneuver or fixed delta height and finding the time of ignition.

TIG: The time of the maneuver in GET. If the option is used to find the CDH time based on delta height this is an initial guess.

CLC: Calculate the burn solution.

BCK: Go back to the main menu.

Init page buttons **DH:** Delta height at the CDH maneuver.

E: Desired elevation angle at TPI.

TPI: Desired TPI time.

BCK: Go back to SPQ calculation page.

3.1.3 Docking Initiation Processor (DKI)

Explanation The basic function of the DKI is to compute impulsive maneuvers; the result of these maneuver is the rendezvous of the CSM and LM spacecraft. The DKI attains a coelliptic orbit by doing three maneuvers: (1) phase, (2) height, (3) a coelliptic maneuver that puts the chaser in a coelliptic orbit with the target. From this orbit a terminal phase maneuver (TPI) and a terminal velocity match maneuver (TPF) maybe be performed to achieve the actual rendezvous.

Several plans are available:

- CSI/CDH Sequence: DKI maneuver is phasing, followed by CSI, CDH and TPI.
- HAM-CSI/CDH Sequence: DKI maneuver is phasing, followed by a boost (10 ft/s), height, CSI, CDH and TPI maneuvers.
- Rescue-2 Sequence: DKI maneuver is height, followed by CSI, CDH and TPI.
- TPI Time Only: Calculates only the TPI time based on lighting.
- High Dwell Sequence: DKI maneuver is phasing, followed by height, CSI, CDH and TPI.

Buttons **INI:** Go to DKI initialization page.

PRO: Choose the rendezvous profile.

CHA: Choose which vehicle is chaser, and which is the target.

VTI: Choose time at which the state vectors should be taken from the ephemerides (MPT mode only)

TIG: Choose the time of ignition for the DKI maneuver.

TPI: Estimate for the time of the TPI maneuver.

TGT: Choose the other vehicle involved in the rendezvous sequence (non-MPT mode only)

OPT: Go to DKI options page.

MPT: Create finite maneuver from impulsive burn.

BCK: Go back to the main menu.

Init page buttons **DH:** Delta height at the CDH maneuver.

E: Desired elevation angle at TPI.

BCK: Go back to DKI calculation page.

Options page buttons **MAN:** Maneuvers separated by half orbits (or multiples of them) or time differences.

RAD: Adds a 50 ft/s radial component for the burn, as done on some missions.

TPI: Cycle through TPI options.
SUN: Input time for TPI options.
NHC: Choose the number of half-revs between CSI and CDH.
NPB: Choose the number of half-revs between Phasing and Boost.
DT1: Choose the time between abort and Boost/CSI.
DT2: Choose the time between boost and HAM.
DT3: Choose the time between HAM and CSI.
BCK: Go back to the DKI page.

3.2 General Purpose Maneuver (GPM)

3.2.1 Explanation

The following explanation was taken from IBM RTCC Apollo Programming Systems, Missions Systems, General, Volume II (NTRS ID 19730062603):

The function of the General Purpose Maneuver Processor is to provide the flight controller with two main capabilities:

1. To determine the effect that a specified incremental velocity applied at a given maneuver point (along a given pitch and yaw) will have on the orbit.
2. To determine the maneuver required to obtain a specified orbit or orbital change.

The first capability is more commonly known as a flight controller special-maneuver request and has six options for the maneuver point:

1. An equatorial (nodal) crossing
2. A specified longitude
3. A specified time
4. A specified height
5. An apogee crossing
6. A perigee crossing

The second capability is divided into eight types with various maneuver points:

1. A plane change at a certain equatorial crossing, longitude, time, or height.
2. A circularization maneuver at a longitude or height.
3. A maneuver at perigee to adjust apogee or vice-versa.
4. A maneuver to adjust the height 180° around from the maneuver point at a longitude or time.

5. A maneuver to shift the ascending node at an optimum time, longitude, time or height.
6. A maneuver to obtain a specified apogee and perigee at an optimum time, longitude, or height.
7. A maneuver to shift the ascending node and adjust the height 180° around from the maneuver point at a longitude or time.
8. A maneuver to shift the line of apsides to the maneuver point and obtain a specified height 180° around from the maneuver point at a time, longitude, or height.

The output from the GPM Processor is a display containing such maneuver information as DV, pitch, yaw, maneuver time, maneuver height, etc., and such post maneuver information as apogee and perigee heights, longitude of the ascending nodes, eccentricity, etc. A table containing the elements before and after the maneuver at the impulsive time is also output so the maneuver may be transferred to the Mission Plan Table, if desired.

3.2.2 Buttons

SET: Make an input for the GPM processor.

⌇: Move the marker down.

⌈⌈: Move the marker up.

CLC: Calculate the maneuver.

MPT: Create finite maneuver from impulsive burn.

BCK: Go back to the main menu.

3.3 TLI Planning

To be determined.

3.4 Midcourse Correction Processor

3.4.1 Introduction

During the translunar coast phase of an Apollo mission, it is necessary to have the capability to either correct dispersions in the nominal trajectory or determine an alternate flight plan which is within the capability of the spacecraft. This capability is provided by the midcourse correction processor. The processor has the ability to correct a dispersed state vector to some nominal end conditions, reoptimize the lunar landing mission, and generate a circumlunar flyby alternate mission. The computation types to obtain these requirements are:

1. The x, y, z, and t target update (XYZ midcourse mode).
2. The best adaptive path (BAP) reoptimization.
3. The free-return lunar flyby mode.

One or more mission options are available under each mode. The mission options, listed below, are defined by their mode, type of return, lunar parking orbit (LPO) orientation, and whether the mission is tied to a landing site.

1. X, Y, Z and T target update.
2. Free-return, fixed LPO orientation, landing site.
3. Free-return, free LPO orientation, landing site.
4. Nonfree-return, fixed LPO orientation, landing site
5. Nonfree-return, free LPO orientation, landing site
6. Circumlunar free-return flyby to nominal H_{pc} and ϕ_{pc}
7. Circumlunar free-return flyby, specified H_{pc} and nominal ϕ_{pc}
8. SPS lunar flyby to specified H_{pc} and $INCL_{fr}$
9. Optimized RCS flyby to desired or optimal inclination of free return

The MCC processor implemented in the RTCC MFD presents the last state of the processor, as used for Apollo 14 through the end of the program. Certain procedural differences for using the processor with the earlier missions arise from this, but all lunar Apollo missions are fully supported.

3.4.2 Input/Output

Inputs for all midcourse modes fall into two categories: those from the data table (also called skeleton flight plan), and those which are manually entered during the mission by the user. The data table contains variables which are needed to execute the different options. These variables may be target parameters used in the XYZ and T mode or first guesses for certain variables. The table also contains parameters which change according to the nominal mission design and launch day (e.g., the lunar landing site). Output parameters from a BAP midcourse can be used to update the data table for later midcourse calculations or the XYZ and T midcourse mode. The data table and the manual inputs are defined in table I and II.

Output from the MCC program are of three types: those displayed, those that are needed for executing the midcourse maneuver, and those which update the data table. Displayed parameters are shown in table III. Output for the data table is shown in table I. BAP's are the only options that update the data table.

In the RTCC MFD the MCC processor consists of three display pages: computational inputs, constraints on the solutions and the MCC tradeoff display (modelled after the real display used in Mission Control Houston). On the constraints page some of the inputs are made in the MED format (Manual Entry Device), which is the same format as was used in the real RTCC. The MEDs for the midcourse processor all have codes starting with an F, e.g. F22. The MED inputs are checked for errors and certain omissions are replaced by default values.

3.4.3 Computation page:

MAN: Maneuver option (1 to 9), see description above.

VTI: Vector time. Time tag of the state vector from the ephemeris (mission planning mode only).

IG: Impulsive time of ignition of the midcourse maneuver.

COL: Column for the solution. The Midcourse Tradeoff display can hold up to 4 different solutions from the MCC processor.

CFG: Configuration for the midcourse maneuver, options are docked or undocked. Used to calculate certain display parameters only.

SFP: Skeleton flight plan (data table) used for initial guesses and target parameters. Table 1 usually contains the preflight data, table 2 the results of a previous BAP midcourse calculation that were transferred from the midcourse tradeoff. Tables 3 to 5 will be supported in the future.

MID: Go to midcourse tradeoff display MFD page.

HPC: Pericynthion altitude for lunar flyby modes.

INC: Free return inclination for lunar flyby modes 8 and 9. Mode 9 is further divided into mode 9A (RCS optimized flyby) and 9B (SPS optimized flyby to specified free re-

turn inclination). If the input inclination is 0, then mode 9A, the fully optimized flyby, will be used. Otherwise the specified inclination is attained. By using a plus or minus sign for the inclination an ascending or descending return can be specified (travelling from south to north and north to south at reentry respectively).

CON: Go to midcourse constraints MFD page.

BCK: Go back to previous menu.

3.4.4 Constraints page:

F22: Azimuth constraints. Input method: "F22, Minimum Azimuth, Maximum Azimuth;" Limited to -110° to -70° . Used by modes 3 and 5. Constrains the approach azimuth to the landing site at the time of landing. Special logic is used if the min and max azimuths are set the identical. In that case the lunar orbit has a fixed orientation, although without imposing the LOI/DOI geometry. This should be done for missions which used the LOI-1/LOI-2 maneuver sequence (Apollo 8,10-12). Example: F22,-90,-90;

F23: Time constraints. Input method: "F23, TLMIN, TLMAX;" Used by modes 4-5. This sets a minimum or maximum time limit for the arrival at pericynthion. Useful for missions with stricter timing requirements for arriving in lunar orbit (Apollo 14 to 17). If omitted (input: "F23;") The constraints are zeroed and the pericynthion time is not constraint.

F24: Reentry constraints. Input method: "F24, Flight Path Angle, Reentry Range;" Used in the free return and lunar flyby modes. Inputs are the flight path angle at entry interface and the range from entry interface to landing.

F29: Pericynthion height limits. Input method: "F29, HPMIN, HPMAX;" Used in mode 9 only. Can be used to force the solution indirectly to a different splashdown longitude.

LAT: Latitude bias for modes 8 and 9. TBD

INC: Maximum inclination for the powered return (TEI). Not enforce yet.

LOI: Apolune and perilune height of the LOI (LOI-1) ellipse.

DOI: Apolune and perilune height of the DOI (LOI-2) ellipse.

REV: Input: REVS1 REVS2. Number of orbits spent in the first (LOI to DOI/LOI-2) and second (DOI/LOI-2 to landing site) lunar orbit. REVS2 is always an integer, REVS1 can contain partial orbits.

ROT: Input: SITEROT ETA. The first parameter is the true anomaly at the landing site at the time of landing. Usually PDI should happen at perilune, which will be 15° ahead of the landing site. In that case 15 should be the input. ETA is the true anomaly of LOI on the post LOI orbit. This will usually be consistent with the REVS1 parameter, which will put DOI at perilune.

PC: Revolutions before and after the lunar orbit plane change maneuver. Used to estimate the trajectory in lunar orbit. The first parameter M is the number of orbits between the lunar landing and the plane change maneuver. The parameter N is the number of orbits between the plane change and lunar ascent. **BCK:** Back to midcourse calculation page.

3.4.5 Example 1: Apollo 11 MCC-2

As mentioned in the introduction of this section, the version of the midcourse correction processor implemented in the RTCC MFD was used for Apollo 14 to 17. Apollo 11 would have used mode 2 of the processor for their MCC-2. Modes 2 and 4 were changed to only apply to the LOI/DOI maneuver sequence of those later missions. The same capability was retained in modes 3 and 5 though, by inputting the same desired azimuth as min and max azimuth on the constraints page.

3.4.6 Example 2: Apollo 11 MCC-4

3.4.7 Example 3: Apollo 13 MCC-2

3.5 Lunar Orbit Insertion (LOI) Processor

3.5.1 Introduction

The LOI processor calculates the LOI-1 maneuver for an Apollo lunar mission. The maneuver is targeted based on the following assumed trajectory profile to the landing site. All plane change is accomplished with the first burn. A second burn (LOI-2 or DOI) adjusts the inplane orbital elements so that a specified orbit occurs at the landing site. It is not not always possible to meet all desired end conditions; thus various solutions are computed.

There are four solution types, each with a positive-negative solution, for a total of eight solutions. A positive solution is one whose perilune is rotated ahead (i.e., in the direction of motion); a negative solution is one whose perilune is rotated behind (i.e., opposite to the direction of motion). The four types are as follows.

- Plane solutions: obtain the desired azimuth at the landing site, giving up the lunar orbit perilune if necessary, which is if the node between the incoming trajectory (approach hyperbola) and the orbit after LOI occurs at an altitude below the desired perilune, or above the desired apolune. This is the type of LOI maneuver generally used for Apollo 12 and earlier.
- Coplanar solutions: obtain the desired lunar orbit shape (apolune and perilune) in the plane of the approach hyperbola with a pre-hyperbolic perilune impulsive point for the positive solution and a post-hyperbolic perilune impulsive point for the negative solution. This solution type therefore has no plane change.
- Minimum Theta solutions: obtain the desired lunar orbit shape (apolune and perilune) and minimize the wedge angle between the actual and desired lunar orbit plane within an input maximum allowable DV.
- Intersection solutions: adjusts the first lunar orbit perilune altitude to obtain a specified altitude difference (or intersection with no altitude difference) between it and the altitude on the post-DOI lunar orbit. This is the type of LOI maneuver generally used for Apollo 13 and later and has no use if the second lunar orbit maneuver (LOI-2) is a circularization maneuver.

The LOI processor implemented in the RTCC MFD is based on the one used for Apollo 14 and later. Most capabilities of earlier programs are retained, so that all lunar missions are still supported.

3.5.2 Inputs

The inputs for the LOI processor are divided in initialization parameters and computation parameters.

Computation Parameters

INI: Got to LOI initialization page.

VTI: Time for taking the state vector from the CSM ephemeris (MPT mode only).

APO: Apolune height after LOI.

PER: Perilune height after LOI.

DVP: Maximum DV for positive Min Theta solution.

DVN: Maximum DV for negative Min Theta solution.

DIS: Got to LOI display.

AMN: Choose the minimum approach azimuth to the landing site.

ADS: Choose the desired approach azimuth to the landing site.

AMX: Choose the maximum approach azimuth to the landing site.

BCK: Back to main menu.

Initialization Parameters

HA: Apolune height after DOI/LOI-2.

HP: Perilune height after DOI/LOI-2.

DW: Angle of perilune from the landing site (negative if the landing site is post-perilune).

R1: Number of revolutions in the first lunar orbit (may have a fractional part).

R2: Number of revolutions in the second lunar orbit.

ETA: True anomaly of LPO-1 for transferring from the hyperbola to LPO-1.

DHB: Altitude constraint of the intersection solutions. The bias is negative if LPO-2 is to be below the LPO-1 perilune.

PLA: A flag to specify if plane or minimum Theta nodes should be used to compute intersection solutions.

BCK: Back to LOI computation page

3.5.3 LOI Display

This display is based on the actual display used by the flight controllers for Apollo 14.

Display Parameters

CSM STA: Station ID of the state vector used to target the maneuvers (not implemented).

GET VECTOR: GET of state vector used to target LOI.

LAT LLS: Latitude of the landing site in degrees.

LNG LSS: Longitude of the landing site in degrees.

R LLS: Radius of the landing site in nautical miles.

REVS 1: Revolutions in LPO-1.
REVS 2: Revolutions in LPO-2.
DH BIAS: Height bias for the intersection solutions.
AZ LLS: Desired azimuth at the landing site.
FLLS: Angle of perilune from the landing site.
HALOI1: Apolune height on first lunar orbit.
HPLOI1: Perilune height on first lunar orbit.
HALOI2: Apolune height on second lunar orbit.
HPLOI2: Perilune height on second lunar orbit.
DVMAX+: Maximum allowable DV for the positive Min Theta solution.
DVMAX-: Maximum allowable DV for the negative Min Theta solution.
RA-RP GT: Tolerance for the calculation of DVLOI2 in nautical miles.

CODE: Code for the eight possible solutions.
GETLOI: Impulsive GET of LOI ignition.
DVLOI1: Total DV of LOI-1 in feet per second.
DVLOI2: Total DV of DOI/LOI-2 in feet per second.
HND: Height of the node (impulsive LOI ignition point).
FND/H: True anomaly at LOI on the approach hyperbola (pre LOI).
HPC: Height of perilune on the first lunar orbit.
THETA: Angle between the desired lunar orbit plane and the actual achieved plane.
FND/E: True anomaly at LOI on the first ellipse (post LOI).

3.6 Entry

3.6.1 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 mission in Low Earth Orbit (LEO). Additionally two options are available 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 calculated 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 the new 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 AGC's program 37 to calculate an onboard solution for the maneuver.

Outside of the Earth's 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 pericyynthion.

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.

3.6.2 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.

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.

3.7 REFSMMAT

3.7.1 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: Calculates the Launch REFSMMAT, which is also calculated internally in the AGC at liftoff.
- 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.

3.7.2 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 between 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.

3.8 State Vector

3.8.1 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.

3.9 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.

3.10 Landmark Tracking

3.10.1 Explanation

On the Landmark Tracking page coordinates on the spherical bodies (Earth and Moon) in Orbiter 2010 can be converted to AGC coordinates. Also the contents of a Landmark Tracking PAD can be calculated. These are used for the correct timing of a pitchdown maneuver for better tracking with Program 22.

T1 is the time at which the CSM comes over the horizon and becomes visible from the landmark. At this time the astronaut can begin looking at the landmark to find the specific point he wants to track.

T2 is the time at which the CSM is at an elevation angle of 35° from the landmark. If any marks on the landmark are to be done, then at this time the pitchdown maneuver should be started. In Earth orbit this is usually $0.5^\circ/\text{s}$, in lunar orbit $0.3^\circ/\text{s}$.

The other displayed values are the distance of the landmark from the ground track of the CSM orbit and the AGC inputs. The AGC uses geodetic latitude, longitude divided by 2 and altitude in nautical miles as the inputs.

3.10.2 Buttons

TIM: Estimated time over the landmark.

LAT: Geocentric latitude of the landmark. If the landmark is listed in a marker file, then that latitude should be used as an input here.

LNG: Longitude of the landmark.

CLC: Calculate AGC coordinates and Landmark Tracking PAD.

3.11 Map Update

3.11.1 Explanation

The Map Update is very different in Earth and Moon orbit. In Earth orbit the next ground station with the times of acquisition and loss of signal (AOS and LOS) are displayed. In lunar orbit a few more times are displayed: loss of signal (LOS), sunrise (SR), crossing of the prime meridian (PM), acquisition of signal (AOS) and sunset (SS) are shown. These values are written down on the Apollo 8 Map Update forms.

3.11.2 Buttons

CLC: Calculate map update.

MOD: Cycle between Earth and Moon orbit.

3.12 Maneuver PAD

3.12.1 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.

3.12.2 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.

3.13 Entry PAD

3.13.1 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](#).

3.13.2 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.

3.14 VECPOINT

3.14.1 Explanation

The VECPOINT page, named after a routine in the AGC, is calculating the IMU angles to point a specific part of the CSM or LM in the direction of a celestial object/astronomical body. Any body present in Orbiter 2010 can be chosen. The X-axis of the spacecraft is along its longitudinal axis, so +X is pointing the CSM directly at the body and the SPS engine directly away from it.

3.14.2 Buttons

BOD: Type the name of the body e.g. Sun, Moon etc.

DIR: Choose the direction of the spacecraft to be pointed at the celestial object.

CLC: Calculate the IMU angles.

3.15 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.

EPO: Choose the AGC epoch. Usually this is a MJD at around January 1st of the yearly coordinate system defining period. This value should be automatically chose correctly for the AGC version in use.

BCK: Go back to the main menu.

4 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.

4.1 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.

4.2 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.

4.3 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).

4.4 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.

5 Manual Entry Device (MED) Formats

5.1 Acronyms

- **EBCDIC**: Extended Binary Coded Decimal Interchange Code (Characters)
- **FLP**: Floating Point
- **FXP**: Fixed Point (Integer)
- **MSK**: Manual Select Keyboard (display number)

5.2 MED List

MED Code: C10

Purpose: Initiate a CMC/LGC external delta-v update

Example: C10,CMC,1,CSM;

Item Desc.	1	2	3	4	5	6
Item Name	Vehicle Type	Maneuver Number	MPT Indicator			
Input Format	EBCDIC	FXP	EBCDIC			
Input Units						
Checking Option	Exact	Min/Max(2)	Exact(3)			
Missing Item Option	Error(1)	Error	Error			

Notes:(1) CMC, LGC

(2) 1-15

(3) CSM/LEM

MED Code: P51

Purpose: Offsets and elevation angle for two-impulse solution

Example: P51,15,-4,26.6,130;

<div>Item Desc.</div>	1	2	3	4	5	6
Item Name	Delta Height	Phase Angle	Elevation Angle of Target	Travel Angle for Terminal Phase		
Input Format	FLP	FLP	FLP	FLP		
Input Units	NM	deg.	deg.	deg.		
Checking Option	None	None	None	None		
Missing Item Option	Ignore	Ignore	Ignore	Ignore		

MED Code: P52

Purpose: Two-impulse corrective combination nominals

Example: P52,28:00:00,8,-1.32;

Item Desc.	1	2	3	4	5	6
Item Name	Nom. Time of NSR maneuver	Nom. Height Difference at NSR	Nom. Phase Angle at NSR			
Input Format	H:M:S(.TH)	FLP	FLP			
Input Units	hours	NM	deg.			
Checking Option	≥ 0	None	None			
Missing Item Option	Error	Error	Error			

MED Code: U00

Purpose: Space digitals initialization

Example: U00,CSM;

Item Desc.	1	2	3	4	5	6
Item Name	VEH ID	CENTRAL BODY				
Input Format	VEH	A				
Input Units	EBCDIC	EBCDIC				
Checking Option	Exact (1)	Exact(2)				
Missing Item Option	Error	Assume "E"				

Notes: (1) CSM or LEM

(2) E for Earth (=1)

M for moon (=3)

(3) EBCDIC name and numeric code

MED Code: U01

Purpose: Space digitals

Example: U01,1,GET,100:00;00;

Item Desc.	1	2	3	4	5	6
Item Name	MANUAL COLUMN	OPTION IND	PARAM- ETER	INCLINA- TION	ASCENDING NODE	
Input Format	N	AAA	HHH:MM:SS OR NN	NNN.NNN	NNN.NNN	
Input Units	FXP	EBCDIC	hours or FXP	deg	deg	
Checking Option	MINMAX(1)	Exact(2)	None	MINMAX(4)	None	
Missing Item Option	Error	Error	Error	None(3)	None(3)	

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Notes: (1) $1 \leq N \leq 3$
(2) GET or MNV
(3) Mandatory when manual column = 2, otherwise illegal
(4) 0° to 180°

MED Code: U02

Purpose: Initiate checkout monitor

Example: U02,CSM,GET,100:00:00,90:00:00,ECT,FT;

Item Desc.	1	2	3	4	5	6
Item Name	Veh Id	Option Ind	Parameter	Threshold Time	Reference	Feet
Input Format	Veh	AAA	HHH:MM:SS OR NN	HHH:MM:SS	AAA	AA
Input Units	EBCDIC	EBCDIC	Hours, FXP or FLP	Hours	EBCDIC	EBCDIC
Checking Option	Exact(2)	Exact(1)	Special(3)	None	Exact(5)	Exact(7)
Missing Item Option	Error	Error	Error	Special(4)	Insert(6)	Insert zero

Notes:

	<u>IND</u>	<u>IND CODE</u>	<u>PARAMETER</u>
	GMT	1	TIME
	GET	2	TIME
(1)	MVI	3	FXP MNV. NO.
	MVE	4	FXP MNV. NO.
	RAD	5	FLP RADIAL CUTOFF
	ALT	6	FLP ALTITUDE CUTOFF
	FPA	7	FLP FLIGHTPATH ANGLE CUTOFF

(2) CSM or LEM

(3) Parameter must be consistent with option ind.

(4) Optional for GET, GMT, illegal for MVI, MVE, mandatory for RAD, ALT, FPA

(5) ECI=0, ECT=1, MCI=2, MCT=3

(6) Assume ECI(=0)

(7) FT

(8) Reference indicator set negative if FT input

MED Code: U07

Purpose: Moonrise/Moonset Display

Example: U07,GET,100:00:00;

Item Desc.	1	2	3	4	5	6
Item Name	IND	PARAM				
Input Format	AAA	HHH:MM:SS or NN				
Input Units	Note 2	hours or FXP				
Checking Option	Exact(1)	none or MIN- MAX(4)				
Missing Item Option	Error	Error(3)				

Notes: (1) GET if time to be input, REV if REV to be input

(2) GET or REV

(3) Insert zero

(4) Current REV \leq REV \leq Last REV in Cape Table

MED Code: U08

Purpose: Sunrise/Sunset Display

Example: U08,GET,100:00:00;

Item Desc.	1	2	3	4	5	6
Item Name	IND	PARAM				
Input Format	AAA	HHH:MM:SS or NN				
Input Units	Note 2	hours or FXP				
Checking Option	Exact(1)	none or MIN- MAX(4)				
Missing Item Option	Error	Error(3)				

Notes: (1) GET if time to be input, REV if REV to be input

(2) GET or REV

(3) Insert zero

(4) Current REV \leq REV \leq Last REV in Cape Table

MED Code: U12

Purpose: Predict apogee/perigee (FDO Orbit Digitals)

Example: U12,CSM,GET,100:00:00;

Item Desc.	1	2	3a	3b	3c	4
Item Name	VEH ID	IND	REV NO	TIME	MNV NO	CENTRAL BODY
Input Format	VEH	AAA	N	HHH:MM:SS	NN	A
Input Units	EBCDIC	EBCDIC	FXP	GMT	FXP	EBCDIC
Checking Option	Exact(3)	Exact(1)	MINMAX(2)	None	None	Exact(4)
Missing Item Option	Error	Error	Error	Error	Error	Assume "E"(5)

Notes: (1) IND = REV, parameter 3a entered
= GET, parameter 3b entered
= MNV, parameter 3c entered
(2) Current REV \leq REV \leq Last REV in Cape Table
(3) CSM or LEM
(4) E for Earth (=0)
(5) This parameter is valid only when IND=REV

MED Code: U13

Purpose: Longitude crossing times (FDO Orbit Digitals)

Example: U13,CSM,1,90;

Item Desc.	1	2	3	4	5	6
Item Name	VEH ID	REV NO	Longitude	CENTRAL BODY		
Input Format	VEH	NN	+DDD.XXXX	A		
Input Units	EBCDIC	FXP	LONG	EBCDIC		
Checking Option	Exact(2)	MINMAX(1)	None	Exact(3)		
Missing Item Option	Error	Error	Error	Assume "E"		

Notes: (1) Current REV \leq REV \leq Last REV in Cape Table

(2) CSM or LEM

(3) E for Earth (=0)

MED Code: U14

Purpose: Compute longitude at given time (FDO Orbit Digitals)

Example: U14,CSM,100:00:00;

Item Desc.	1	2	3	4	5	6
Item Name	VEH ID	TIME				
Input Format	VEH	HHH:MM:SS				
Input Units	EBCDIC	GET				
Checking Option	Exact(1)	None				
Missing Item Option	Error	Error				

Notes: (1) CSM or LEM

MED Code: U20

Purpose: Generate detailed maneuver table display

Example: U20,CSM,1;

Item Desc.	1	2	3	4	5	6
Item Name	MPT ID	Maneuver Number	MSK Number	REFSMMAT	Heads up/ Heads down	
Input Format	AAA	NN	NN	AAA	A	
Input Units	EBCDIC	FXP	FXP	EBCDIC	D,U	
Checking Option	Exact(1)	MINMAX(2)	Exact(3)	Exact(4)	Note (5)	
Missing Item Option	Error	Error	assume 54	assume CUR	Note (6)	

Notes: (1) CSM or LEM

(2) $1 \leq NN \leq 15$

(3) 54 or 69

(4) CUR = 1, PCR = 2, TLM = 3, OST = 4, MED = 5, DMT = 6, DOD = 7, LCV = 8, DES = 9, LLA = 10, LLD = 11

(5) If item 4 \neq DES, item 5 must not be input

(6) Assume U if item 4 = DES and item 5 is missing