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).

Contents

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.
UPL: Uplink Page. All uplinks to the AGCs and LVDC can be found here.

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 (TI)

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/TPF maneuver sequence
VTI: Time tag of the state vectors used in the calclation (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 manuever.
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 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.
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 ${}^{\phi}{}_{pc}$
7. Circumlunar free-return flyby, specified H_{pc} and nominal ${}^{\phi}{}_{pc}$
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 return 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 ommited (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 Midcourse Tradeoff Display

COLUMN: Shows up to 4 midcourse correction solutions.
MODE: Shows the mode (1-9) that was calculated.
AZ MIN: Minimum approach azimuth at the landing site.
AZ MAX: Maximum approach azimuth at the landing site.
WEIGHT: Weight at ignition in lbs.
GETMCC: Estimated time of ignition of the midcourse correction (actual, not impulsive).
DV MCC: Total DV of the midcourse correction in feet per second.
YAW MCC: Yaw angle (out-of-plane) of the maneuver.
H PYCN: Height of pericynthion resulting from the maneuver.
GET LOI: Estimated time of ignition of LOI (actual, not impulsive).
DV LOI: Total DV of LOI maneuver.
AZ ACT: Actual approach azimuth at the landing site.
I FR: Free return inclination, Earth referenced.
I PR: Powered return (TEI) inclination, Earth referenced.
V EI: Velocity at entry interface in feet per second.
G EI: Flight path angle (gamma) at entry interface.
GETTEI: GET of the TEI maneuver.
DV TEI: Total DV of the TEI maneuver.
DV REM: DV remaining after TEI (not implemented).

GET LC: GET of splashdown.
LAT IP: Latitude of splashdown (impact point).
LNG IP: Longitude of splashdown (impact point).
DV PC: Total DV of lunar orbit plane change maneuver.

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 positive 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).

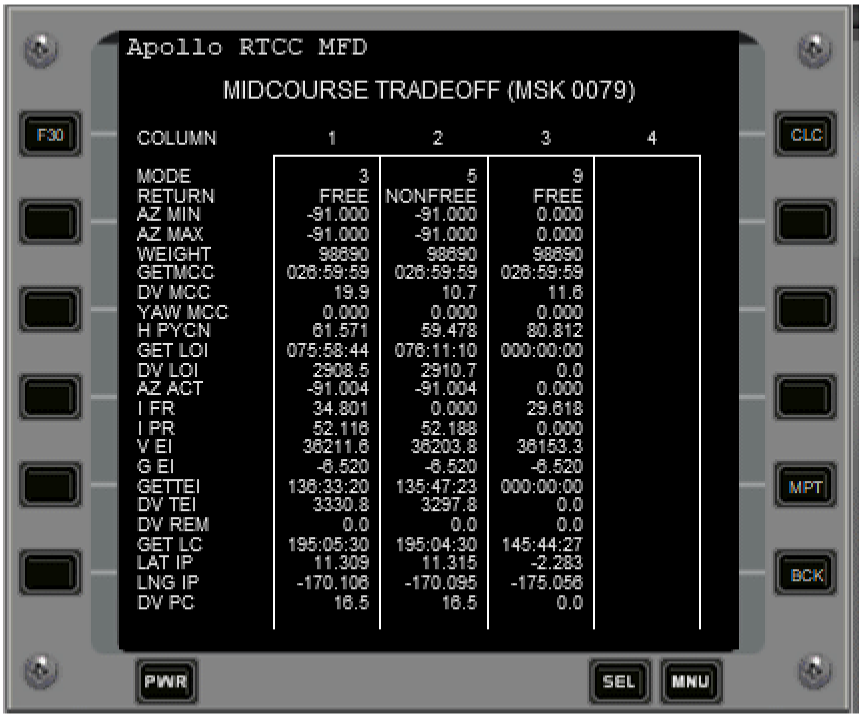

Figure 1: Midcourse Tradeoff Display

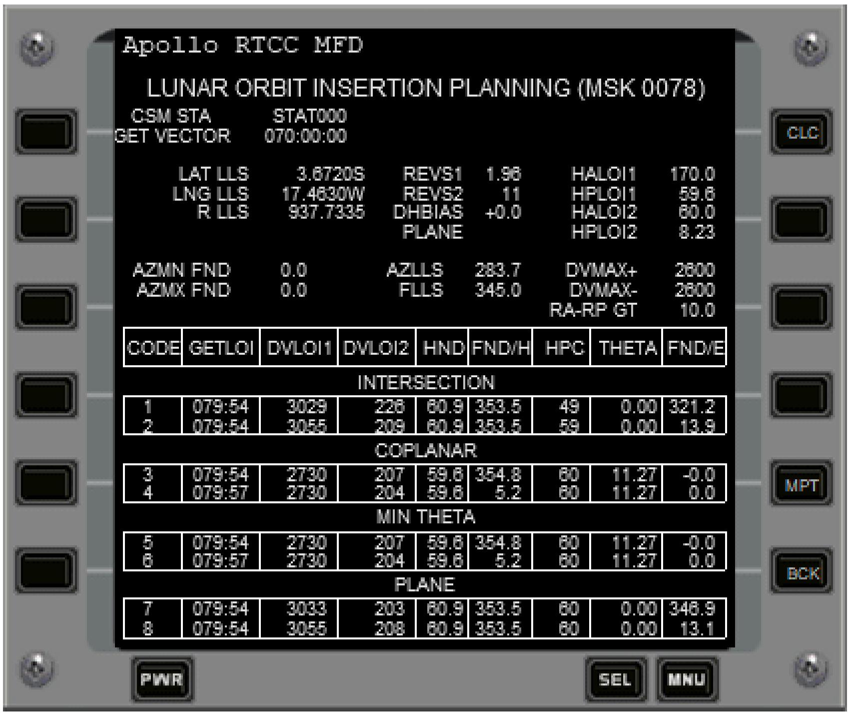

Figure 2: LOI Planning Display

3.6 Deorbit Targeting

3.7 Return-to-Earth Targeting

3.7.1 Introduction

The Return-to-Earth targeting calculates maneuvers for returning the spacecraft back to Earth from beyond Low Earth Orbit. For LEO maneuvers see the deorbit targeting. The objective is to calculate a single maneuver for changing the trajectory to one having safe entry-interface conditions and satisfying certain other constraints. Other constraints are dependent on the type of abort requiested. The safe entry interface condition is a velocity flight path angle target line at 400,000 feet. Either of two entries maybe be specified, a shallow or a steep target line. The steep target line was used for all lunar Apollo missions.

Dependent upon the request, the abort maneuver will be computed considering one of three types of impact areas:

1. An Unspecified Area
   This means that a safe reentry is guaranteed but no consideration is given to the location of the impact point (it maybe be quite undesirable).
2. A Primary Target Point (PTP)
   This would be defined by a pair of latitude-longitude values. Not currently implemented in NASSP.
3. An Alternate Target Point (ATP)
   This is actually not a point but is as many as five connected line segments (defined by latitude-longitude pairs) extending generally in a longitudinal direction.

Both the PTP and ATP targets can be defined by manual input. The Return-to-Earth Target Table Display contains up to five PTP and five ATP target names and definitions.

Three general types of abort maneuvers are available.

1. Time Critical Unspecified Area (TCUA)
   This is an inplane maneuver producing the trajectory with the earliest possible reentry. The abort is characterized by
   (a) Consuming all fuel provided for the maneuver, or
   (b) Having the maximum allowable reentry velocity, or
   (c) Having the minimum allowable time from maneuver to entry to Entry interface.
2. Fuel Critical Unspecified Area (FCUA)
   This is an inplane maneuver requiring the least fuel to obtain a safe entry interface. Not that if the pre-abort trajectory had a safe entry interface, a request for a FCUA abort having the same target line should result in a zero DV maneuver. In practice, because of convergence tolerances, a small maneuver will be computed.
3. ATP Abort
   This inplane maneuver produces a trajectory that impacts ATP trace. Multiple solutions are possible. If they exist, they are discrete and differ by twenty-four hour increments in time of landing.

The abort computations are separated into three distinct steps. They are (1) the trade-off, (2) the Abort Scan Table, and (3) return-to-Earth digitals. Associated with each step in the computations is a display which summarizes the results of that step. The construction of an abort solution may be viewed as combining models of the abort maneuver, the trajectory between maneuver and entry interface, and the reentry trajectory. The three are combined in a way that will satisfy the abort criteria and the solution constraints. The trade-off, Abort Scan Table, and return-to-Earth digital computations are characterized by the models used; the models progress from less precise to more precise solutions.

3.7.2 Tradeoff

Four major questions must be answered in abort planning:

1. How much fuel may be expended?
2. When may the maneuver be performed?
3. How soon must splashdown occur?
4. If the target is a PTP, how large a miss is acceptable?

There is a hidden difficulty in answering these questions — the best answer to any one of the above is not independent of the answers to the remaining three. Sometimes by relaxing tho acceptable miss by a few miles, the required velocity decreases by several thousand feet per second; sometimes shifting the time of the maneuver by a few minutes substantially reduces the time of landing or the chance of a miss.
The objective of this step of the computations is to provide the user with an overall picture of the abort situation for either ATP or PTP aborts. The abort situation is defined in terms of the above four parameters (three if the target is an ATP). To this end the user supplies parameter ranges within which his solutions of interest can be found. The RTE section imposes a mesh over the solution region and examines each mesh point for a solution. Those solutions existing are used to produce analog TV displays to assist the user in arriving at an optimum answer to the four questions given above.
As mentioned earlier, multiple solutions having different times of landing may be available for ATP and PTP aborts. As the time of abort is varied, these times of landing tend to vary smoothly where they exist. This leads to a natural grouping of solutions into families of solutions, each having similar times of landing. The Tradeoff Display is a multiple page (up to five) TV display; each page contains the analog information for a different family of solutions. Two display formats are used.

1. The Remote Earth ATP consisting of one analog graph, characteristic DV versus Time of Abort
2. Near-Earth ATP consisting of three analog graphs on each page:
    (a) Characteristic DV versus Time of Abort
    One curve representing the DV required for an inplane solution that impacts the ATP trace.
    (b) Time of Landing versus Time of Abort
    One time of landing curve corresponding to the curve in item a.

(c) Latitude of Impact versus Time of Abort
One curve representing the declination of impact. Although latitude is not considered a tradeoff parameter, it is helpful to know this information.

The abort solutions for the Tradeoff Display are constructed by combining an impulsive velocity change, a conic (analytic two-body) trajectory, and polynomial reentry functions. The reentry functions simulate either a high-speed G&N entry or a constant G-level entry and are valid only if entry interface occurred on one of the two target lines. They provide reentry range, cross range, and DT as a function of target line, entry profile and entry interface velocity, inclination, azimuth, and latitude. Solutions constructed for the Abort Scan Table or return-to-Earth digitals will be constrained to these conic entry interface conditions.

Currently the tradeoff display only works in Earth reference.

Inputs

MOD: Switch between near-Earth or remote Earth format.
REM: Choose the page (out of 5) for the remote Earth solution to be displayed
SIT: Choose the tradeoff site from the target table.
TV: Choose the vector time (MPT mode only).
MIN: Choose the minimum abort time.
MAX: Choose the maximum abort time.

PAG: Cycle between the tradeoff pages.
CLC: Calculate tradeoff solution.
ENT: Choose the entry profile.

3.7.3 Abort Scan Table (AST)

The Abort Scan Table Display is essentially a digital scratch pad that may be used to compare up to seven discrete abort solutions. One solution is inserted for each manual AST request. These computations are more precise than the tradeoff and less precise than return-to-Earth digital computations. They consist of an impulsive velocity change, an integrated coast trajectory, and polynomial reentry functions. The workflow to generate a Maneuver PAD or target load for a maneuver always involves first an AST calculation followed by using the Return-to-Earth Digitals.

Three types of AST solution can be generated. Unspecified area (time or fuel critical), specific area (ATP or PTP) and lunar search (specific site or fuel critical). The first two of these types work in both Earth and Moon sphere of influence, while the lunar search logic can only be used while in lunar orbit. The calculations that are different between Earth and Moon centered state vectors is chosen internally.

The two nominally used modes are lunar search for TEI and the fuel critical, unspecified area (FCUA) mode for transearth midcourse corrections.

Inputs

TYP: Cycle between the three AST types.
SIT: Choose the landing site or type of abort.
VTI: Choose the vector time for the abort (MPT mode only)
TIM: Choose the time of abort, or initial guess in the case of lunar search.
TDV: Choose the maximum DV for a time critical abort.
TZ: Choose the estimated landing time for PTP and ATP aborts.
AST: Go to the AST display page.
ENT: Choose the entry profile.
MD: Choose the maximum miss distance for a PTP abort.
INC: Choose the desired return inclination (lunar reference only). Using 0 as input will optimize the DV.
BCK: Back to entry targeting menu.

Display Buttons
DEL: Delete one or all AST rows.
CLC: Calculate AST solution.
RTE: Go to RTE Digitals inputs page.
BCK: Go back to AST inputs page.

Display Explanation

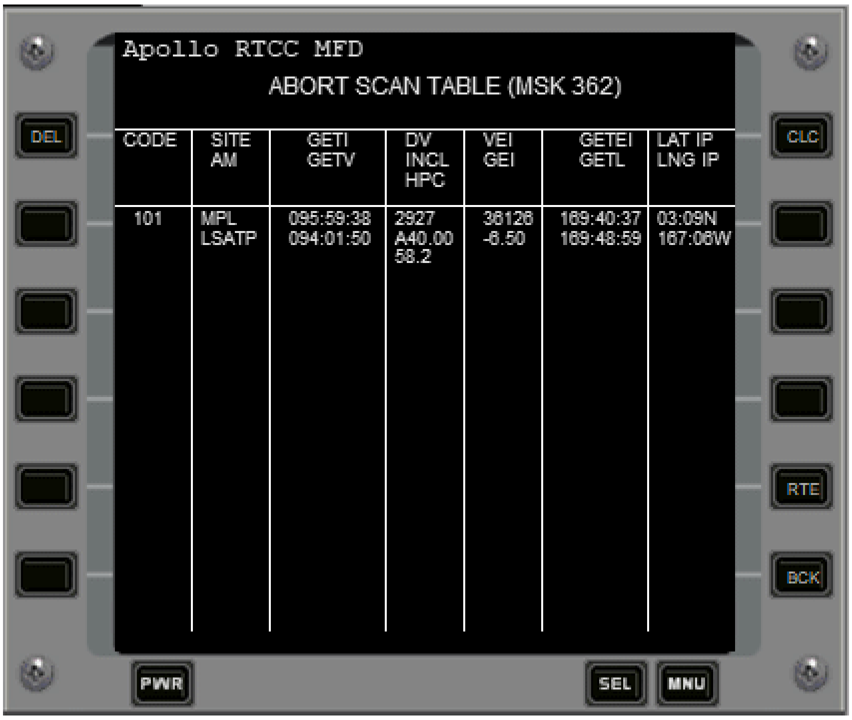

Figure 3: Example Abort Scan Table

CODE: Code associated with the AST solution. Starts at 101 and is incremented with

each new calculation.
SITE: When using PTP or ATP mode the specified landing site is shown, e.g. MPL for Mid Pacific Line.
AM: Abort Mode. First letter is E for Earth or L for Lunar centered. Second letter is S for lunar search or D for discrete time. Remaining letters show the abort type, ATP, PTP, TCUA or FCUA.
GETI: GET of the impulsive ignition.
GETV: GET of the state vector time used in the calculation.
DV: Total Delta V of the maneuver.
INCL: Earth relative inclination of the trajectory at entry interface. A for ascending and D for descending in terms of azimuth.
HPC: Height of pericynthion, only calulated in lunar reference.
VEI: Velocity at entry interface.
GEI: Flight path angle at entry interface.
GETEI: GET of entry interface.
GETL: GET of splashdown.
LAT IP: Latitude of impact.
LNG IP: Longitude of impact.

3.7.4 Return-to-Earth Digitals

The final solution produced by the RTE section — the Return-to-Earth digital solution — consists of an integrated maneuver, an integrated trajectory from the end of the maneuver to entry interface, and an integrated reentry. Two solutions, each the result of a manual request, may be viewed with the Return-to-Earth digital display. Either of these solutions may be transferred into the Mission Plan Table, used to initiate execution of the spacecraft setting study aid, or used to generate a command load.
Computation of a solution is similar to the AST computations in that the same iteration algorithm is used to adjust independent and dependent variables to meet certain constraints on the dependent variables. The major differences can be listed:

1. The first guess is a converged solution being viewed in the AST Display.
2. The constraints at entry interface are taken from the entry interface state of the converged solution.
3. Independent variables are the target parameters for the finite maneuver integrator (PMMRKJ).
4. The reentry parameters are always obtained from an integrated reentry after the iteration converges to the entry interface conditions.

The same precision trajectory logic is used by the iteration algorithm except that now the finite maneuver integrator is used to perform the maneuver instead of making an impulsive velocity change. The user may specify to the Return-to-Earth digital computations any of four thrusters (SPS, SMRCS, DPS, or LMRCS). In addition to requesting a solution constructed as described above, the user may manually define a solution by defining, via the manual entry device (MED) a time for a vector fetch, a time of abort, and maneuver targets. This type of manual entry bypasses the iteration logic. The coast Encke integrator is used to propagate the fetched vector to the time of abort. The maneuver is integrated one time using the targets supplied. The coast Encke is used again to propagate the burnout vector to 400,000 feet at which point the reentry integrator is used to propagate to impact.

Inputs

COL: Solution will be shown in either primary or manual column.
AST: Choose AST code for the calculation.
REF: Choose REFSMMAT type for the calculation.
MAN: Choose maneuver code for the calculation. The code consists of four letters. The first letter is the spacecraft performing the maneuver, C for CSM and L for LM. The second letter is the thruster used for the maneuver. S for SPS, D for DPS or R for RCS. The third letter is the spacecraft configuration. D for docked, A for ascent stage docked and U for undocked. The last letter is always X for External DV guidance.
ULL: Choose the ullage thrusters and duration for the burn. The ullage thruster options are 2 or 4. If the burn is an RCS burn then the options are +2, +4, -2 or -4 and these will be the thrusters used for the maneuver.
TRM: Choose the trim angle option (calculated or system parameter)

DIS: Go to the RTE Digitals display
DOC: Choose the docking angle during the maneuver.
HEA: Choose heads up or down for the maneuver.
ITE: Choose iterate or not iterate for the maneuver. Iterate is the more accurate solution, but takes longer to calculate and has a small risk of not converging.
BCK: Go back to entry targeting page.

Display Buttons

CLC: Calculate RTE digitals solution.
SPL: Save the splashdown target from either primary or manual column.
TRA: In non-MPT mode the TIG and DV are save to be used for uplink and Maneuver PAD. In MPT mode the maneuver gets transferred to the MPT. The input is the MED format M74. To transfer the primary column enter "M74,CSM,,RTEP;" for the manual column "M74,CSM,,RTEM;"
BCK: Go back to RTE Digitals inputs page.

Display Explanation

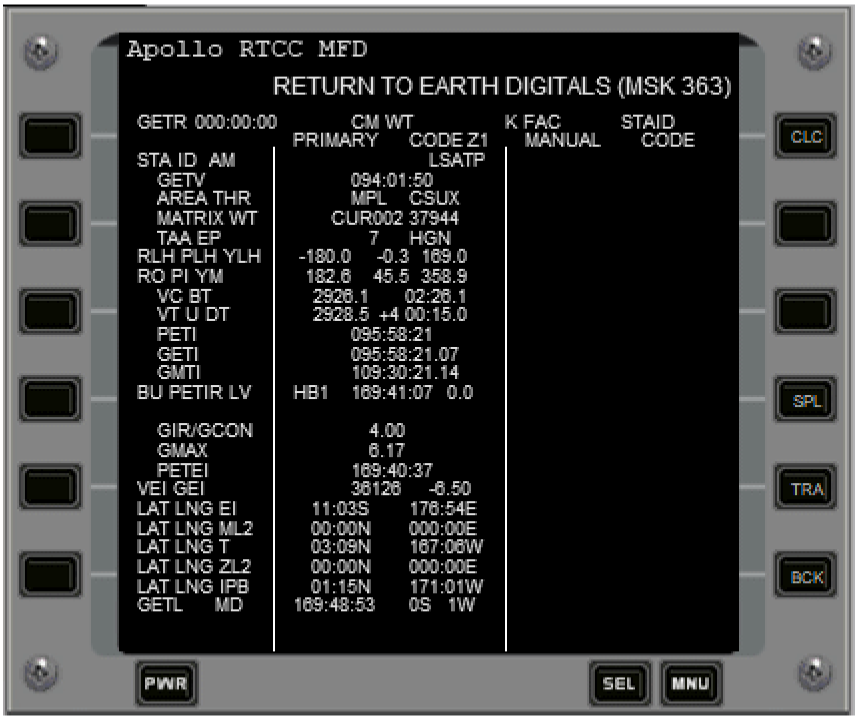

Figure 4: Example Return-to-Earth Digitals

GETR: Reference time in GET of an event.
STA ID: Station ID of the state vector used in the calculation (MPT mode only).
AM: Abort mode, see AST display explanation.
GETV: GET of vector, see AST.
AREA: Splashdown area, see AST.
THR: Maneuver code, see RTED inputs.
MATRIX: REFSMMAT used for the calculation.
WT: Total weight at main engine on.
TAA: True anomaly after abort.
EP: Primary entry profile used to generate entry simulation. HGN for G&N or HB1 for constant G reentry.
RLH: Roll angle at ignition in LVLH coordinates.
PLH: Pitch angle at ignition in LVLH coordinates.
YLH: Yaw angle at ignition in LVLH coordinates.
RO: Roll/outer gimbal angle at ignition in IMU coordinates.
PI: Pitch/inner gimbal angle at ignition in IMU coordinates.
YM: Yaw/middle gimbal angle at ignition in IMU coordinates.
VC: Delta V to be used in the EMS DV counter for the burn.
BT: Burn time of the maneuver, main engine on to cutoff.
VT: Total Delta V of the maneuver.
U: Number and direction of RCS thrusters used for ullage or as the main engines for the maneuver.
DT: Ullage duration.
PETI: Phase elapsed time of ignition, relative to GETR.

GETI: Ground elapsed time of ignition.
GMTI: GMT (since midnight launch day) of ignition.
BU: Backup entry profile.
PETIR: Phase elapsed time of initial roll (usually 0.05g)
LV: Lift vector orientation, initial roll angle.
GIR/GCON: G level of initial roll if constant G iteration was the backup entry profile. Otherwise constant G level to be used to generate backup impact coordinates.
GMAX: Maximum G level encountered during the reentry.
PETEI: Phase elapsed time of entry interface.
VEI: Velocity at entry interface.
GEI: Flight path angle at entry interface.
LAT LNG EI: Latitude and longitude at entry interface.
LAT LNG ML2: Latitude and longitude at splashdown if primary entry mode skipped out and maximum lift was used for second entry
LAT LNG T: Latitude and longitude of the splashdown target
LAT LNG ZL2 Latitude and longitude at splashdown if primary entry mode skipped out and zero lift (ballistic) was used for second entry
LAT LNG IPB: Latitude and longitude at splashdown with the backup entry mode.
GETL: GET at drogue chute deployment using the primary entry mode:
MD: Miss distance of the primary entry mode to the target splashdown coordinates. In nautical miles.

3.8 REFSMMAT

3.8.1 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.

3.8.2 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.

3.9 State Vector

3.9.1 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.

3.10 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.

3.11 Landmark Tracking

3.11.1 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°/s, in lunar orbit 0.3°/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.

3.11.2 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.

3.12 Map Update

3.12.1 Explanation

The Map Update is very different in Earth and Moon orbit. In Earth orbit the next ground station with the times of acqusition 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), acqusition of signal (AOS) and sunset (SS) are shown. These values are written down on the Apollo 8 Map Update forms.

3.12.2 Buttons

CLC: Calculate map update.
MOD: Cycle between Earth and Moon orbit.

3.13 Maneuver PAD

3.13.1 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.

3.13.2 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.

3.14 Entry PAD

3.14.1 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.

3.14.2 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.

3.15 VECPOINT

3.15.1 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.

3.15.2 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.

3.16 Configuration

MIS: Choose the mission number or manual options. Used to load mission specific parameters that are valid for any launch day of the mission.
TYP: Choose the type of vehicle configuration (CSM or LM, docked or undocked).
STA: Choose the type of LM configuration that is currently being used, ascent or descent configuration.
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.
DAT: Choose the launch date for the mission.
TIM: Choose the launch time for the mission. This will update the launch time of the CSM stored in the RTCC.
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.
UPD: Update the liftoff time automatically by downlinking that time from the CMC or LGC. This will actually update three values in the RTCC: CSM liftoff time, time of clock zeroing in the CMC, time of clock zeroing in the LGC. These times are normally all set to the actual liftoff time of the CSM to get a consistent basis to calculate Ground Elapsed Time in the RTCC.
BCK: Go back to the main menu.

4 Mission Planning

5 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.

5.1 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.

5.2 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.

5.3 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).

5.4 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.

6 Example: Midcourse Correction Planning

6.1 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.

To start off the calculation, go to the MCC page, under Maneuver Targeting, Midcourse. This takes you to the computation page of the processor. Here choose mode 3 (click twice on the MAN button). The Apollo 11 MCC-2 happened at about 26:45:00 GET, so press the TIG button and input that time. The other inputs can be left as they are. The solution will be shown in column 1, the maneuver is docked and the skeleton flight plan table no. 1 contains the preflight estimates. Press CON to check that all the constraints are as desired, especially the min and max azimuth constraints being identical. This should already be preloaded in the MFD, so no changes are necessary.
Back to the previous page (BCK button) and then to the midcourse tradeoff display (MID button) and everything should be ready for the calculation. Press CLC and the solution for the mode 3 calculation should be displayed in column 1. Using the Apollo 11 Before MCC-2 scenario that comes with NASSP this results in a maneuver of 19.7 ft/s (DV MCC).

You can now try different inputs and constraints, but if you are happy with the solution, you should now save the resulting data table from the MCC-2 calculation for use in the later MCC-3 and MCC-4 calculations. That is done by pressing the F30 button and typing: *F30,1;* The result can be checked under MCC Display, MSK button, "1597" input, F31 button. The F31 cycles between the preflight (table 1) and the nominal (table 2) targets. Only table 2 will be saved in scenarios.

Back to the Midcourse Tradeoff page, the maneuver still has to be converted from an impulsive, instant maneuver to a finite maneuver taking the thruster being used into account. For that click on the MPT button and then on the THR button until the thruster of your choice is selected. SPS is set by default and is the correct choice for the maneuver. Click the CLC button and the actual TIG and DV have now been generated. These can be used to display e.g. a Maneuver PAD for the midcourse.

6.2 Example 2: Apollo 11 MCC-4

MCC-4 will use the nodal targets (latitude, longitude, radius and time of the desired position at LOI, if it was an instant velocity change maneuver) that resulted from the MCC-2 calculation, and were stored in skeleton flight plan table number 2. MCC-4 is a mode 1 maneuver with a time of ignition of about 70:55:00 GET. Input this value with the TIG button, then press the SFP button so that it says 2, for SFP table 2. Go to the midcourse tradeoff display and press CLC. Converting it to a finite maneuver works the same way as for MCC-2. Possibly MCC-4 will be small enough to be done with the RCS.

6.3 Example 3: Apollo 12 MCC-2

Apollo 12 was the first mission to fly the so called hybrid mission profile. After TLI the trajectory is ideally free return, but with a pericynthion altitude higher than necessary for successful lunar orbit insertion. Therefore there has to be a midcourse correction that takes the trajectory to a close encounter with the Moon, but in the process making it non-free return. This maneuver was planned for MCC-2. After MCC-2 the same LOI-1 and LOI-2 maneuvers were flown as on the previous missions.

To accomplish the hybrid transfer maneuver, mode 5 of the midcourse processor has to be used. Use a TIG of about 30:53h GET, column 1, docked vehicle configuration and table 1 (preflight targets) of the skeleton flight plan. Use the MID button to go to the midcourse tradeoff display and then press CLC to calculate the solution. It should now have calculated fairly large maneuver, the nominal Delta V being 68.8 ft/s.

The trajectory after MCC-2 is not constrained to be free return, but was instead optimized for the smallest possible Delta V. This will also potentially have moved the time of ignition for LOI-1 away from the flight plan time. If it is not critical that the DV optimal solution for MCC-2 is being used, the LOI-1 TIG can be adjusted by constraining that time on the constraints page. This was done on the actual Apollo 12 mission and is not possible for free-return missions like Apollo 11.

The flight plan time for LOI-1 is 83:25:18.2 GET. Check which time ("GET LOI") the midcourse tradeoff page is showing after calculating the MCC-2 solution. If the times are different by more than a few seconds go to the midcourse constraints page and press the F23 button. The times that are input here are not directly the LOI GET, but instead the pericynthion time, which is a bit later than LOI-1. The convergence of the constrained solution works best if the minimum and maximum times input with the F23 button are 10 minutes apart. Usually the LOI TIG will now run into the lower or upper end of the constraint. As you can't predict on which end of the time window LOI will now be, this process is always one of trial and error. So start by inputting a min and max time that contains the GET of LOI. Then recalculate the solution on the midcourse tradeoff page and check what the new LOI GET is. By moving the time window to later or earlier times with the F23 button the LOI GET can be moved as well. This might take a few iterations until the LOI GET is close to the desired time. A few seconds off are acceptable

After this solution resulting in the desired LOI-1 time has been calculated the process is the same as for the Apollo 11 MCC-2. After committing to performing the maneuver as calculated use the F30 button to store the data table containing the numbers required to calculate MCC-3 and MCC-4. These are calculated with mode 1 just like for Apollo 11.

6.4 Example 4: Apollo 13 MCC-2

7 Manual Entry Device (MED) Formats

7.1 Acronyms

- **EBCDIC**: Extended Binary Coded Decimal Interchange Code (Characters)

- **FLP**: Floating Point

- **FXP**: Fixed Point (Integer)

- **MSK**: Manual Select Keyboard (display number)

7.2 MED List

MED Code: C10
Purpose: Initiate a CMC/LGC external delta-v update
Example: `C10,CMC,1,CSM;`

Desc. \ Item	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: G00
Purpose: CSM/LM REFSMMAT locker movement
Example: `G00,LEM,LLD,CSM,CUR;`

Item / Desc.	1	2	3	4	5	6
Item Name	CSM/LEM Vehicle	Matrix 1	CSM/LEM Vehicle	Matrix 2	GET	
Input Format	XXX	XXX	XXX	XXX	XXX:XX:XX	
Input Units	EBCDIC	EBCDIC	EBCDIC	EBCDIC	HH:MM:SS	
Checking Option	Exact	Exact	Exact	Exact	≤0Current Time	
Missing Item Option	Error	Error	Error	Error	=Current Time	

Notes: For matrix 1, valid codes are CUR, PCR, TLM, OST, MED, DMT, DOK, LCV, DOD, LLA, LLD, AGS for the LEM and CUR, PCR, TLM, OST, MED, DMT, DOD, LCV for the CSM. For matrix 2, valud codes are CUR, PCR, TLM, MED and LCV for the CSM and CUR, PCR, TLM, MED, LCV, LLA, and AGS for the LEM.

MED Code: G03
Purpose: Compute and save local vertical CSM/LM platform alignment
Example: `G03,CSM,100:00:00;`

Item / Desc.	1	2	3	4	5	6
Item Name	CSM or LEM Vehicle	GET				
Input Format	XXX	XXX:XX:XX				
Input Units	EBCDIC	HH:MM:SS				
Checking Option	Exact					
Missing Item Option	Error	Error				

Notes:

MED Code: P08
Purpose: Update pitch angle from horizon
Example: `P08,31.6;`

Item / Desc.	1	2	3	4	5	6
Item Name	Pitch Angle					
Input Format	FLP					
Input Units	degrees					
Checking Option	None					
Missing Item Option	Error					

Notes:

MED Code: P10
Purpose: Update liftoff time for specified vehicle
Example: `P10,CSM,13:32:00;`

Item / Desc.	1	2	3	4	5	6
Item Name	Vehicle	GMTALO	Traj/No traj Ind.			
Input Format	EBCDIC	H:M:S(.TH)	EBCDIC			
Input Units	VEH	hours	EBCDIC			
Checking Option	Note 1	T≥0.	Exact (note 4)			
Missing Item Option	Error	Error	Insert ”NO TRAJ”			

Notes:(1) Veh. must be in MHGVNM (CSM, LEM)
(2): First veh. (MGLGMT, MCGMTL), second veh. (MGGGMT, MCGMTS)
(3): Must be ”TRAJ” or ”NO TRAJ” (”TRAJ” allowed in NPHASE, PRELAUNCH, PRELAUNCH 2 (L.S.))

MED Code: P12
Purpose: Enter GMTGRR and launch azimuth for selected vehicle
Example: `P12,CSM,13:32:00,72.0;`

Desc. \ Item	1	2	3	4	5	6
Item Name	Vehicle	GMTGRR	Launch Azimuth			
Input Format	EBCDIC	H:M:S(.TH)	FLP			
Input Units	EBCDIC	hours	deg.			
Checking Option	Exact 1	≥ 0	$70. \leq A \leq 110.$			
Missing Item Option	Error	Error	Error			

Notes: (1) CSM, IU1, IU2. IU1 and IU2 valid at all times. CSM valid only prior to GOST initialization.
(2) See GMSMED documentation (flowchart).

MED Code: P15
Purpose: Update GMTZS for specified vehicle
Example: `P15,AGC,13:32:00;`

Item / Desc.	**1**	**2**	**3**	**4**	**5**	**6**
Item Name	Vehicle	GMTZS	DT from GMTZS (LGC) to AGS on			
Input Format	EBCDIC	hours	hours			
Input Units	EBCDIC	hours	hours			
Checking Option	Exact 1	≥ 0	≥ 0			
Missing Item Option	Error	Ignore	Ignore			

Notes: (1) AGC, LGC, AGS
(2) See Flowchart of GMSMED for storing details.

MED Code: P16
Purpose: Generate an ephemeris for one vehicle using a vector from the other vehicle
Example: `P16,CSM,LEM;`

Item / Desc.	1	2	3	4	5	6
Item Name	Old vehicle	New vehicle	GMT	Maneuver number		
Input Format	EBCDIC	EBCDIC	h:m:s(.th)	FXP		
Input Units	EBCDIC	EBCDIC	hours	FXP		
Checking Option	Exact	Exact	≥0	≥0		
Missing Item Option	Error	Error	Insert zero	Insert zero		

Notes: (1) Vehicle must be CSM, LEM
(2) GMT and maneuver are mutually exclusive (i.e., must be one but not both).

MED Code: P51
Purpose: Offsets and elevation angle for two-impulse solution
Example: `P51,15,-4,26.6,130;`

Item / Desc.	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		

Notes:

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			

Notes:

MED Code: P80
Purpose: Initialize number of vehicles, first launch vehicle, mission date
Example: `P80,1,CSM,7,16,1969;`

Item / **Desc.**	**1**	**2**	**3**	**4**	**5**	**6**
Item Name	Number of vehicles	First Launch Vehicle	Month	Day	Year	Delta Day
Input Format	FXP	EBCDIC	EBCDIC	FXP	FXP	FXP
Input Units	NA	EBCDIC	EBCDIC	NA	NA	NA
Checking Option	N = 1	Exact 1	Exact 2	$1 \leq D \leq 31$	$50 \leq Y \leq 1980$	≥ 0
Missing Item Option	Note 4	Note 5	Note 4	Note 4	Note 4	Note 4

Notes: (1) Vehicle must be in MHGVNM.
(2) Date is checked by internal caldenar on final logic. Then reference day is calculated (Jan 1 = day 0) along with days in month, etc. These values are stored in GZGENCSN.
(3) On entry, link to EMLAMPNP to rotate P and N matrices and sun/moon tables.
(4) If in Nophase, items 1-5 required, 6 may be input (zero inserted if missing). If in any phase, items 1-5 must be missing, and item 6 must be input.

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)	

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:

(1)

IND	IND CODE	PARAMETER
GMT	1	TIME
GET	2	TIME
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;`

Desc. \ Item	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

8 MOCR Displays

8.1 FDO Launch Analog No. 1 (MSK 0040)

The purpose of the FDO Launch Analog No. 1 is to serve as the primary display for trajectory evaluation during launch. The inertial flight-path angle (γ) in degrees versus the inertial velocity (V) in feet per second is plotted on a half-second cylce.

8.2 FDO Launch Analog No. 2 (MSK 0041)

The purpose of the FDO Launch Analog No. 2 is to display conditions of $(\gamma, \mathrm{V})_{\mathrm{EI}}$. The flight-path angle versus inertial velocity at entry interface $(\gamma \text{ vs } \mathrm{V})_{\mathrm{EI}}$ is plotted. The plot is initialized when apogee altitude is equal to or above entry interface. It is then updated and terminated at reaching orbit.

8.3 FDO Launch Digital No. 1 (MSK 0043)

TBD.

8.4 FDO Orbit Digitals (MSK 0045 and 0046)

8.4.1 Function

The function of the Flight Dynamics Officer (FDO) Orbit Digitals Display is to compute present position information and predicted data concerning apogee/poergee and longitude crossings as manually requested.

8.4.2 Display Parameters

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
Vehicle	Vehicle name		
Rev	Current revolution number associated with subject vehicle and central body		(1)
Vector ID	Last vector used for updating the ephemeris		(2)
GMT ID	GMT Time of anchor vector	Hr:min:sec	(2)
GET ID	GET Time of anchor vector	Hr:min:sec	(2)
GET	Current ground elapsed time	Hr:min:sec	(1)
Weight	Total current weight of subject vehicle	lbs.	(1)
K-Factor	Atmospheric density multiplier considered in generating the ephemeris		(1), (2)
λ_{PP}	Present position, longitude (Seleno- graphic for moon)	deg.	(1), (2)
ϕ_{PP}	Present position, latitude (geodetic for earth, Selenographic for moon)	deg.	(1), (2)
$\mathrm{GET}_{\mathrm{CC}}$*	GET of arrival at next cape crossing	Hr:min:sec	(1), (2)

(1) Output cycle (12 sec.)
(2) Trajectory Update, MSK Request
∗ For lunar orbit this will be the time of the vehicle crossing of the 180deg selenographic longitude.

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
N_{PP}	True anomaly	deg.	(1), (2)
λ_{AN}	Longitude of the ascending node (earth fixed or moon fixed)	deg.	Node crossing, (2)
h	Current oblate height (Spherical for moon)	N.M.	(1), (2)
V_i	Current inertial velocity	f.p.s.	(1), (2)
γ	Current inertial flightpath angle	deg.	(1), (2)
a	Semimajor axis of orbital ellipse	N.M.	(1), (2)
e	Eccentricity of orbital ellispe		(1), (2)
i	Orbital inclination to central body equator	deg.	(1), (2)
GET_{EI}	GET of arrival at unsafe altitude	Hr:min:sec	(2)
ϕ_{EI}	Geodetic latitude of entry interface	deg.	(2)
λ_{EI}	Longitude of entry interface	deg.	(2)
PET	Phase elapsed time (GET of an event minus GETR)	Hr:min:sec	(4)

(1) Output cycle (12 sec.)
(2) Trajectory Update, MSK Request
(4) These times will be updated when a new GETR and a new event is specified.

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
GETR	GET of reference (elapsed time of an event)	Hr:min:sec	(4)
GET_λ	Time S/C will pass over λ below	Hr:min:sec	Computed or manually entered
REV_λ	Revolution associated with GET_λ		Manually entered or computed
λ	The longitude associated with above GET	deg.	Manually entered or computed
h_a**	Spherical height of next apogee at GET_a	N.M.	Crossing of Apogee, (2), maneuver executed
ϕ_a**	Latitude of next apogee at GET_a. Geocentric in earth reference, seleno- graphic around moon	deg.	Crossing of Apogee, (2), maneuver executed
λ_a**	Longitude of next apogee at GET_a	deg.	Crossing of Apogee, (2), maneuver executed
GET_a**	Time of arrival at next apogee	Hr:min:sec	Crossing of Apogee, (2), maneuver executed
h_p**	Spherical height of next perigee at GET_p	N.M.	Crossing of Perigee, (2), maneuver executed
ϕ_p**	Latitude at next perigee at GET_p. Geocentric relative to the earth , selenographic around moon	deg.	Crossing of Perigee, (2), maneuver executed
λ_p**	Longitude of next perigee at GET_p	deg.	Crossing of Perigee, (2), maneuver executed
GET_p**	Time of arrival at next perigee	Hr:min:sec	Crossing of Ppogee, (2), maneuver executed
GET_{BV}	Time tag of vector from which apogee/perigee values were computed	Hr:min:sec	Computed or manually entered
REV_{BV}	Revolution of GET_{BV}		Computed or manually entered

(2) Trajectory Update, MSK Request
(4) These times will be updated when a new GETR and a new event is specified.
** Also displayed manually for future time periods as requested.

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
T_0	Orbital Period	Hr:min:sec	(1)
REF1, REF2, REF3	Indicator of which central body is being referenced for present position data and for manual Apogee/Perigee and longitude		
NV_1	Number of vectors used for interpolation for present position values		
NV_2	Number of vectors used in interpolation for base vector for predicted apogee/perigee data		
Trajectory Update Number	Update number associated with subject vehicle ephemeris		(2)

8.5 Mission Plan Table (MSK 0047)

8.5.1 Function

8.6 Space Digitals (MSK 0082)

8.6.1 Function

The function of the Space Digitals Display is to compute and display parameters necessary to evaluate and monitor trajectories involving Earth-moon relationships. At the top of the display present position data are shown. In column 1 orbital elements at an input time are displayed. Column 2 has the time of lunar sphere of influence entry, numbers for the closest approach to the Moon and at the node, the intersection with the lunar orbit plane (TBD). The third column shows the time of lunar sphere of influence exit, the closest approach to Earth after that exit and, if applicable, the state at Earth entry interface.

8.6.2 Display

The update associated with this display are:

(1) Time cycle (12 sec)
(2) Trajectory update
(3) Manual entries (3)
(4) MSK request
(5) Reinitialization

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
Vector-ID	Identification of the last vector used to update the ephemeris	None	(1), (2), (4), (5)
Weight	Total vehicle weight	lbs	(1), (2), (4), (5)
GMTV	Greenwich time-tag of the vector	HHH:MM:SS.SS	(1), (2), (4), (5)
GETV	Ground elapsed time-tag of the vector	HHH:MM:SS.SS	(1), (2), (4), (5)
GET Axis	Ground elapsed time used to define the earth-moon line in the initialization of the earth-moon transit display	HHH:MM:SS.SS	(1), (2), (4), (5)
GETR	Ground elapsed time reference (elapsed time of an event)	HHH:MM:SS.SS	(1), (2), (4), (5)
GET	Current ground elapsed time for which V, GAM, PHI, LAM, H, PSI and ADA were computed	HHH:MM:SS.SS	(1)
REF	Inertial reference body used to compute V, GAM, PHI, LAM, H, PSI and ADA	HHH:MM:SS.SS	(1)
V	Current velocity (earth centered inertial or lunar centered inertial)	ft/sec	(1), (2), (4), (5)

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
GAM	Current inertial flightpath angle (earth or lunar reference)	deg	(1), (2), (4), (5)
H	Current altitude above an oblate earth or spherical above the moon assuming landing site radius	nm	(1), (2), (4), (5)
PHI	Current geodetic latitude or current selenographic latitude respect to a spherical moon whose radius is the landing site	deg	(1), (2), (4), (5)
LAM	Current earth longitude or current selenographic longitude	deg	(1), (2), (4), (5)
PSI	Current heading angle with respect to the earth or moon, measured clockwise from north	deg	(1), (2), (4), (5)
ADA	Current true anomaly	deg	(1), (2), (4), (5)
VEH ID	Vehicle for which the space digitals are computed	XXX	(2), (3), (4), (5)
GET Vector 1	Ground elapsed time of the vector used to compute the quantities below	HHH:MM:SS.SS	(3)
REF	The inertial reference body used to compute the quantities (i.e., if GET Vector 1 is inside the lunar sphere of influence, REF is MOON)	None	(3)
WT	Total weight at time of GET Vector 1	lbs	(3)
GETA	Ground elapsed time of next apogee (reference from GET Vector 1)	HHH:MM:SS.SS	(3)
HA	Height of apogee above a spherical earth or height of apolune above a spherical moon whose radius is the landing site (referenced from GET Vector 1)	nm	(3)
HP	Height of perigee above a spherical earth or height of perilune above a spherical moon whose radius is the landing site (referenced from GET Vector 1)	nm	(3)

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
IEMP	Inclination of the trajectory with respect to the earth-moon plane (referenced from GET Vector 1)	deg	(3)
HS	Altitude above a spherical earth or moon (referenced from GET Vector 1)	nm	(3)
PHI	Geocentric latitude or selenographic latitude with respect to a spherical moon of landing site radius (referenced from GET Vector 1)	deg	(3)
OMG	Right ascension of the ascending node (inertial)	deg	(3)
PRA	Inertial right ascension of perigee	deg:min	(3)
K	Density multiplier used in the computation of the above quantities	None	(3)
GET Vector 2	Ground elapsed time of the vector supplied by the ephemeris and from which the quantities below will be computed	HHH:MM:SS.SS	(3)
GETSI Sphere Entrance	The first ground elapsed time after GET Vector 2 that the vehicle will pass through the lunar sphere of influence with a negative lunar altitude rate (rate with respect to the moon is decreasing)	HHH:MM:SS.SS	(3)
GETCA	Ground elapsed time of closest approach to the moon	HHH:MM:SS.SS	(3)
VCA	Velocity with respect to a moon-centered inertial coordinate system at the point of closest approach to the moon	ft/sec	(3)
HCA	Altitude at the point of closest approach to a spherical moon of landing site radius	nm	(3)
PSICA	Heading angle at the point of closest approach to the moon measured clockwise from north	deg	(3)
PHICA	Selenographic latitude with respect to a spherical moon at the point of closest approach to the moon	deg	(3)

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
LCA	Selenographic longitude with respect to the moon	deg	(3)
GETMN	Ground elapsed time of arrival at the node defined by the planes of the approach hyperbola and the desired lunar parking orbit	HHH:MM:SS.SS	(3)
PMN	Selenographic latitude relative to a spherical moon at GETMN	deg	(3)
LMN	Selenographic longitude relative to a spherical moon at GETMN	deg	(3)
HMN	Selenographic height relative to a spherical moon of landing site radius	nm	(3)
DMN	Wedge angle between the planes of the approach hyperbola and the desired lunar parking orbit (Note: A positive sign indicates that the inclination of the desired lunar parking orbit is less than the inclination of the approach hyperbola)	deg	(3)
GET Vector 3	Ground elapsed time of the vector supplied by the ephemeris and from which the quantities below will be computed	HHH:MM:SS.SS	(3), (2)
GETSE Sphere Exit	The first ground elapsed time after GET Vector 3 that the vehicle will pass through the lunar sphere of influence with a positive lunar altitude rate (Note: Altitude with respect to the moon is increasing)	HHH:MM:SS.SS	(3), (2)
GETEI	Ground elapsed time of entry interface	HHH:MM:SS.SS	(3), (2)
VEI	Earth centered velocity at entry interface	ft/sec	(3), (2)
GEI	Inertial flightpath angle at entry interface	deg	(3), (2)
PEI	Geodetic latitude at entry interface	deg	(3), (2)
LEI	Earth longitude at entry interface	deg	(3), (2)

QUANTITY	DEFINITION	DIMENSIONS	UPDATES
PSIEI	Heading angle with respect to earth at entry interface	deg	(3), (2)
GETVP	Ground elapsed time of arrival at vacuum perigee	HHH:MM:SS.SS	(3)
VVP	Earth centered velocity at vacuum perigee	ft/sec	(3)
HVP	Altitude above an oblate earth at vacuum perigee	nm	(3)
PVP	Geodetic latitude at vacuum perigee	deg	(3)
LVP	Earth longitude at vacuum perigee	deg	(3)
PSIVP	Heading angle with respect to earth at vacuum perigee	deg	(3)
IE	Inclination angle with respect to the earth at vacuum perigee	deg	(3)
LN	Geographic longitude of the earth return ascending node	deg	(3)

8.7 Vector Comparison Display (MSK 1591)

8.7.1 Function

The Vector Comparison Display shows the local spherical elements, the classical elements and UVW coordinates for a base (first) vector. The differences between the elements of this vector and the second, third, and fourth vectors (if input) will then be computed. From one to four vectors can be specified for comparison. Any available state vector in the evaluation or usable vector tables can be used (see Vector Panel Summary).

The UVW coordinate system, essentially a local vertical, local horizontal coordinate system, is defined as follows:

- X Axis (U): Vector pointing in the direction of the spacecraft's position vector

- Y Axis (V): Vector perpendicular to the x- and z-axes, pointing in the direction of travel for a circular orbit

- Z Axis (W): Vector pointing in the direction normal to the orbit (along the angular momentum vector)

8.7.2 Buttons

TIM: Time of comparison. GMT is assumed if input is positive, GET if negative. Time of V1 vector will be used for comparison if zero is used as the input time.
VEH: Vehicle for the comparison. Only relevant if mission planning mode is active in the MFD and an ephemeris vector was chosen.
V1: Choose ID of first (base) vector from vector panel summary.
V2: Choose ID of second state vector.
V3: Choose ID of third state vector.
V4: Choose ID of fourth state vector.

CLC: Calculate display parameters.
REF: Reference body (Earth or Moon) for the comparison values.
BCK: Back to last menu

8.7.3 Display Parameters

Name	Definition	Unit	Comment
H_a	Keplerian height of apogee (1st column); difference in height of apogee from reference vector (2nd through 4th columns)	n.mi.	Cannot be computed for hyperbolic or parabolic orbits.
H_p	Keplerian height of perigee (1st column); difference in height of perigee from reference vector (2nd through 4th columns)	n.mi.	Cannot be computed for parabolic orbits.
V	Inertial velocity magnitude (1st column); difference in velocity from reference vector (2nd through 4th columns).	ft/sec	
γ	Flightpath angle (1st column); difference in angle from reference vector (2nd through 4th columns).	deg	
ψ	Azimuth (1st column); difference in azimuth from reference vector (2nd through 4th columns).	deg	
ϕ	Latitude (1st column); difference in latitude from reference vector (2nd through 4th columns)	deg	
λ	Longitude (1st column);difference in longitude from reference vector (2nd through 4th columns).	deg	
h	Height above launch pad (Earth) or lunar landing site (1st column);difference in height from reference vector (2nd through 4th columns).	n.mi.	

Name	Definition	Unit	Comment
a	Semimajor axis (1st column); difference in semimajor axis from reference vector (2nd through 4th columns).	n.mi.	Cannot be computed for parabolic orbit.
e	Eccentricity (1st column); difference in eccentricity from reference vector (2nd through 4th columns)	none	
i	Inclination (1st column); difference in inclination from reference vector (2nd through 4th columns)	deg	
ω_{p}	Argument of perigee (1st column);difference in ω_{p} from reference vector (2nd through 4th columns)	deg	
Ω	Right ascension of the ascending node (1st column);difference in Ω from reference vector (2nd through 4th columns)	deg	
ν	True anomaly (1st column);difference in true anomaly from reference vector (2nd through 4th columns)	deg	
UVW	UVW position coordinates of vehicle (1st column);difference in UVW coordinates from reference vector in feet (2nd through 4th columns).	n.mi., ft	Differences are computed in feet
$\dot{U}\dot{V}\dot{W}$	velocity components (1st column);difference in UVW velocity from reference vector (2nd through 4th columns).	ft/sec	

8.8 Vector Panel Summary (MSK 1591)

8.8.1 Function

The Vector Panel Summary will display the ephemeris anchor vector identifications, anchor vector times and current GMT. It will also display the vector identification and time for each vector in a Usable Vector Slot and each vector in an Evaluation Vector Slot. GMT of ullage tailoff are displayed for the last executed maneuver for both vehicles. The time tags of all available telemetry vectors will also be displayed. The display is updated every six seconds, so inputs on the page might not cause an instant change to the display.

8.8.2 Display Parameters and Buttons

The left and right half of the display are showing information about state vectors for CSM and LM respectively. The two sides are identical, so the following description applies to both. Each side is divided into several panels: CMC, LGC, AGS, IU, High Speed Radar, Differential Correction (DC) and Last Executed Maneuver. The first four panels show information about state vectors from telemetry and vectors that have been moved to RTCC tables:

UV = Usable Vector Table
EV = Evaluation Vector Table
TH = Telemetry (High Speed)
TL = Telemetry (Low Speed)

The TL vector slot has not been implemented yet. Pressing the TLM button will get data from all computers in the vessel where the RTCC MFD is open (AGS not yet implemented) and save them in the high speed telemetry tables. In reality the telemetry vectors get continually updated if telemetry is received, so for a more permanent saving solution the vectors can be moved to the evaluation vector table with the EV buttons. The vector is then moved to that table, assigned a vector ID and is then available for comparison using the vector compare display (MSK 1590). The telemetry vectors are not guaranteed to be valid, so the evaluation vectors were checked before being "moved up" to the usable vector table, which can be done with the UV buttons. Once in the usable vector table the vectors are available for ephemeris updates.

The High Speed Radar panel is not currently implemented. It was a vector that is generated automatically at the end of a powered maneuver using radar data and could, if no telemetry vector was available, be a first estimate of the actual cutoff state.

Differential Correction (DC) is the state vector derived from long period ground tracking of the spacecraft during coasting flight. In the RTCC MFD it is simply generated with the DC button and entering the name of the vessel in the simulation. The DC panel will then be updated with a vector ID (APIC/APIL for Orbiter API and C/L for the CSM or LM) and a vector time. The HSR and DC vectors are moved directly to the usable vector table.

The last panel shows the last executed maneuver in the mission plan table of the vehicle. The displayed times are ullage on and end of the thrust tailoff period after cutoff.

To cause an ephemeris update the TUP button on each side can be pressed and then a vector from the usable vector table is chosen to do the update.

9 Config Files

The RTCC loads various configuration files to load constants, mission and launch day specific parameters. The files are located at Config\ProjectApollo\RTCC.

9.1 Star Table

The RTCC star table is stored in the Star Table.txt file. It contains unit vector of all RTCC navigation stars, starting with the star that get used by the Apollo Guidance Computer. The file is equivalent to the RTCC mission table named EZJGSTAR.

9.2 Mission Constants

For each Apollo mission a file with mission constants (e.g. "Apollo 8 Constants.txt") is loaded. These numbers are constant for all possible launch days of a mission. They usually are related to hardware or software which doesn't get changed for a different launch day. Some of these parameters are saved and loaded in scenarios.

Name	**Description**	**Default Value**	**Unit**
AGCEpoch	The epoch of the coordinate system used by the Apollo Guidance Computer (and in the future the RTCC). Used to convert state vectors to the uplink coordinate system.	40221.525 (Apollo 7-10)	Days (MJD)
MCCLEX	Octal LGC address for external DV uplink	3433	None
MCCLRF	Octal LGC address for REFSMMAT uplink (and downlink)	1733	None
MCCCXS	Octal CMC address for desired REFSMMAT uplink	306	None
MCCLXS	Octal LGC address for desired REFSMMAT uplink	3606	None
MCCCRF	Octal CMC address for REFSMMAT uplink (and downlink)	1735	None
MCCLRF	Octal LGC address for REFSMMAT uplink (and downlink)	1733	None
MCLRLS	LGC address for landing site vector uplink (and downlink)	2022	None
PZREAP_RRBIAS	Relative range override for the Return-to-Earth processor	1285.0	Nautical Miles
PZREAP_IRMAX	Maximum return inclination for the Return-to-Earth processor	40.0	Degrees
MCLADA	Geodetic latitude of the launch pad used for launch REFSMMAT calculation	28.608202 (LC-39A)	Degrees
MDVSTP_PHIL	Geodetic latitude of the launch pad used for TLI simulation and LVDC state vector uplink calculation	28.608202 (LC-39A)	Degrees
MCLGRA	Longitude of the launch pad	-80.604133 (LC-39A)	Degrees

Name	Description	Default Value	Unit
PDI_v_IGG	PDI ignition algorithm velocity	5545.46	Feet per second
PDI_r_IGXG	PDI ignition algorithm x-axis position	-130519.86	Feet
PDI_r_IGZG	PDI ignition algorithm z-axis position	-1432597.3	Feet
PDI_K_X	PDI ignition algorithm coefficient	0.617631	None
PDI_K_Y	PDI ignition algorithm coefficient	0.755e-6	Feet per Feet^2
PDI_K_V	PDI ignition algorithm coefficient	410.0	Seconds
PDI_RBRFG	PDI braking phase position target	171.835, 0.0, -10678.596	Feet
PDI_VBRFG	PDI braking phase velocity target	-105.876, 0.0, -1.04	Feet per second
PDI_ABRFG	PDI braking phase acceleration target	0.6241, 0.0, -9.1044	Feet per second^2
PDI_JBRFGZ	PDI braking phase jerk	-0.01882677	Feet per second^3
PDI_RARFG	PDI approach phase position target	111.085, 0.0, -26.794	Feet
PDI_VARFG	PDI approach phase velocity target	-4.993, 0.0, 0.248	Feet per second
PDI_AARFG	PDI approach phase acceleration target	-0.2624, 0.0, -0.512	Feet per second^2
PDI_JARFGZ	PDI approach phase jerk	0.00180772	Feet per second^3

9.3 Launch Day Init Parameters

For each launch day of a given mission (e.g. "1968-12-21 Init.txt" for Apollo 8) a few parameters are being loaded as initial values. These parameters are almost all saved and loaded and may be overwritten during a mission, so they are only loaded from file once when the RTCC is first being started.

Name	**Description**	**Default Value**	**Unit**
LSLat	Latitude of the lunar landing site	0.0	Degrees
LSLng	Longitude of the lunar landing site	0.0	Degrees
LSRad	Radius of the lunar landing site	Mean lunar radius	Nautical miles
LDPPDwellOrbits	Number of dwell orbits desired between DOI and PDI used by the Lunar Descent Planning Processor	0	None
LDPPDescentFlightArc	Powered flight arc of descent for the Lunar Descent Planning Processor	15.0	Degrees
LDPPHeightofPDI	Height of PDI used by the Lunar Descent Planning Processor	50000.0	Feet
PZLOIPLN_HP_LLS	Height of perilune at PDI for the LOI Targeting	8.23	Nautical Miles
TLCC_AZ_min	Minimum approach azimuth to the landing site used by the Translunar Midcourse Processor	-110.0	Degrees
TLCC_AZ_max	Maximum approach azimuth to the landing site used by the Translunar Midcourse Processor	-70.0	Degrees
REVS1	Number of orbits between LOI-1 and LOI-2 (or DOI for the later missions) used by the TLMCC and LOI targeting	2.0	None (double)
REVS2	Number of orbits between LOI-2 (or DOI for the later missions) and PDI used by the TLMCC and LOI targeting	11	None (Integer)
LOPC_M	Number of revolutions from first pass over lunar landing site to lunar orbit plane change maneuver. Used by LOPC routine of the TLMCC processor	3	None
LOPC_N	Number of revolutions from lunar orbit plane change maneuver to second pass over lunar landing site. Used by LOPC routine of the TLMCC processor	8	None

Name	Description	Default Value	Unit
LOI_psi_DS	Desired approach azimuth to the lunar landing site. Used by the LOI targeting	270.0	Degrees
eta_1	True anomaly on LPO-1 (orbit after LOI-1) for transferring from the hyperbola to LPO-1. Used by TLMCC and LOI targeting	0.0	Degrees
H_P_LPO1	Perilune height on LPO-1 (orbit after LOI-1). Used by TLMCC and LOI targeting	60.0	Nautical miles
PZLTRT_DT_Ins_TPI	Time between insertion and TPI for the short rendezvous profile in lunar orbit	40.0	Minutes
SITEROT	Angle of perilune from the lunar landing site (negative if the site is post-perilune). Used by the TLMCC and LOI targeting	-15.0	Degrees

9.4 Skeleton Flight Plan Table

The skeleton flight plan table is a table of initial guesses for the translunar midcourse correction processor. The files are launch day specific and have the format e.g. "1968-12-21 SFP.txt".

Name	Description	Unit
SFP_DPSI_LOI	Delta Azimuth of LOI	Degrees
SFP_DPSI_TEI	Delta Azimuth of TEI	Degrees
SFP_DT_LLS	Time from LOI to the first pass (time of landing) over the landing site	Hours
SFP_DV_TEI	Delta velocity of the TEI maneuver	Feet per second
SFP_GAMMA_LOI	Flight path angle before LOI maneuver	Degrees
SFP_GET_TLI	Ground elapsed time of TLI ignition	Hours
SFP_GMT_ND	GMT at the node	Hours
SFP_GMT_PC1	GMT of TLI pericynthion	Hours
SFP_GMT_PC2	GMT of LOI pericynthion	Hours
SFP_H_ND	Height of the node	Nautical miles
SFP_H_PC1	Height of TLI pericynthion	Nautical miles
SFP_H_PC2	Height of LOI pericynthion	Nautical miles
SFP_INCL_FR	Inclination of free return	Degrees
SFP_LAT_LLS	Latitude of the lunar landing site	Degrees
SFP_LAT_ND	Latitude of the node	Degrees
SFP_LAT_PC1	Latitude of TLI pericynthion	Degrees
SFP_LAT_PC2	Latitude of LOI pericynthion	Degrees
SFP_LNG_LLS	Longitude of the lunar landing site	Degrees
SFP_LNG_ND	Longitude of the node	Degrees
SFP_LNG_PC1	Longitude of TLI pericynthion	Degrees
SFP_LNG_PC2	Longitude of LOI pericynthion	Degrees
SFP_PSI_LLS	Approach azimuth to the landing site	Degrees
SFP_RAD_LLS	Radius of the lunar landing site	Nautical miles
SFP_T_LO	Time in lunar orbit (LOI to TEI)	Hours
SFP_T_TE	Time of transearth coast (TEI to entry interface)	Hours

9.5 TLI Targeting Parameters

The files containing the TLI targeting parameters follow the launch day specific format "‘1968-12-21 TLI.txt”. They contain the numbers needed to calculate the time of restart preparations and the TLI maneuver in the RTCC. The format of the file follows the MSC card format from the MSC internal note RTCC REQUIREMENTS FOR APOLLO 11 (MISSION G) PREFLIGHT INFORMATION (69-FM-171), which can be found here. The PDF pages 32 to 40 show the format. One line in the config file is equal to one punch card. Note that only the first day of a monthly launch window is stored per file, instead of the up to ten.