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Title

The Mission Assessment Post Processor (MAPP): A New Tool for Performance Evaluation of Human Lunar Missions.

Authors:

Jacob Williams
      ERC, Incorporated
      Engineering and Science Contract Group
      On-Orbit GN&C Section
      455 East Medical Center Blvd.
      Webster, TX 77598
      Phone: (281) 461-5921
      Jacob.Williams@escg.jacobs.com

Shaun M. Stewart
      ERC, Incorporated
      Engineering and Science Contract Group
      On-Orbit GN&C Section
      455 East Medical Center Blvd.
      Webster, TX 77598
      Phone: (281) 461-5340
      Shaun.Stewart@escg.jacobs.com

David E. Lee
      NASA Johnson Space Center
      Aeroscience & Flight Mechanics Division/EG5
      2101 Nasa Parkway, Houston, Texas, 77058
      Phone: (281) 483-8118
      david.e.lee@nasa.gov

Elizabeth C. Davis
      Jacobs Technology
      Engineering and Science Contract Group
      On-Orbit GN&C Section
      455 East Medical Center Blvd.
      Webster, TX 77598
      Phone: (281) 461-5042
      Elizabeth.Davis@escg.jacobs.com

Gerald L. Condon

NASA Johnson Space Center
Aeroscience & Flight Mechanics Division/EG5
2101 Nasa Parkway, Houston, Texas, 77058
Phone: (281) 483-8173
gerald.l.condon@nasa.gov

Timothy F. Dawn
NASA Johnson Space Center
Aeroscience & Flight Mechanics Division/EG5
2101 Nasa Parkway, Houston, Texas, 77058
Phone: (281) 483-8095
Timothy.F.Dawn@nasa.gov

Juan Senent
Odyssey Space Research
NASA Johnson Space Center
Aeroscience & Flight Mechanics Division/EG5
2101 Nasa Parkway, Houston, Texas, 77058
Phone: (281) 483-3709
juan.senent-1@nasa.gov

Extended Abstract:

The National Aeronautics and Space Administration's (NASA) Constellation Program paves the way for a series of lunar missions leading to a sustained human presence on the Moon. The proposed mission design includes an Earth Departure Stage (EDS), a Crew Exploration Vehicle (Orion) and a lunar lander (Altair) which support the transfer to and from the lunar surface. This report addresses the design, development and implementation of a new mission scan tool called the Mission Assessment Post Processor (MAPP) and its use to provide insight into the integrated (i.e., EDS, Orion, and Altair based) mission cost as a function of various mission parameters and constraints.

The Constellation architecture calls for semiannual launches to the Moon and will support a number of missions, beginning with 7-day sortie missions, culminating in a lunar outpost at a specified location. The operational lifetime of the Constellation Program can cover a period of decades over which the Earth-Moon geometry (particularly, the lunar inclination) will go through a complete cycle (i.e., the lunar nodal cycle lasting 18.6 years). This geometry variation, along with other parameters such as flight time, landing site location, and mission related constraints, affect the outbound (Earth to Moon) and inbound (Moon to Earth) translational performance cost. The mission designer must determine the ability of the vehicles to perform lunar missions as a function of this complex set of interdependent parameters. Trade-offs among these parameters provide essential insights for properly assessing the ability of a mission architecture to meet desired goals and objectives. These trades also aid in determining the overall usable propellant required for supporting nominal and off-nominal missions over the entire operational lifetime of the program, thus they support vehicle sizing.

The MAPP tool was developed to evaluate the performance of the Constellation lunar architecture and the integrated capability of the Altair, Orion, and EDS vehicles (i.e., mission availability based on various constraints). MAPP uses pre-computed Delta-V performance databases, orbit propagation, numerical interpolation, binary database storage techniques, and a set of user-defined mission parameters to quickly construct end-to-end mission performance data. Mission parameter inputs include (but are not limited to): departure epoch, landing site latitude and longitude, post lunar orbit insertion (LOI) extended loiter duration, pre trans-Earth injection (TEI) extended loiter duration, trans-lunar injection (TLI) window duration, outbound and inbound flight times, LOI and TEI three-burn sequence durations, geocentric transfer angles, lunar surface stay time, and Earth return target state information. Depending upon the size and number of mission parameter ranges, a full-scale analysis could require evaluation of billions of case permutations. Employing MAPP on a Linux computing cluster makes this analysis possible in a reasonable time frame.

The data generated by MAPP can be used to determine temporal availably of selected surface sites, abort options, propellant margins, and a wide range of other mission constraints of importance for mission design. The tool can also be used to generate vehicle requirements to meet specific mission design goals (e.g., anytime abort from the lunar surface). Thus, MAPP provides NASA with the ability to more effectively guide mission and vehicle design decisions. Without this capability, relying upon existing mission design tools and infrastructure would have required evaluation of hundreds of millions of mission permutations and perhaps taken years to complete. This paper describes the design, development and implementation of the MAPP tool, as well as its associated databases, and its utility in assessing human lunar mission architectures.

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THE MISSION ASSESSMENT POST PROCESSOR (MAPP): A NEW TOOL FOR PERFORMANCE EVALUATION OF HUMAN LUNAR MISSIONS (DRAFT).

Jacob Williams _, Shaun M. Stewart y, David E. Lee z, Elizabeth C. Davis x, Gerald L. Condon {, and Timothy F. Dawn k

Performance evaluation of human lunar missions is a difficult problem, since it is a function of a complex set of interdependent parameters (such as departure epoch, Earth-Moon geometry, flight time, entry return constraints, etc.). A new tool, the Mission Assessment Post Processor (MAPP) has been developed in order to provide a global view of the mission space and statistical sensitivities for all onorbit mission phases. MAPP enables an assessment of the integrated performance over the operational lifetime of a lunar architecture. Mission design and vehicle sizing results will be shown for the Constellation lunar architecture.

INTRODUCTION

The National Aeronautics and Space Administration's (NASA) Constellation Program paves the way for a series of lunar missions leading to a sustained human presence on the Moon. The proposed mission design includes an Earth Departure Stage (EDS), a Crew Exploration Vehicle (Orion) and a lunar lander (Altair) which support the transfer to and from the lunar surface. This report addresses the design, development and implementation of a new mission scan tool called the Mission Assessment Post Processor (MAPP) and its use to provide insight into the integrated (i.e., EDS, Orion, and Altair based) mission cost as a function of various mission parameters and constraints.

The Constellation architecture calls for semiannual launches to the Moon and will support a number of missions, beginning with 7-day sortie missions, culminating in a lunar outpost at a specified location. The operational lifetime of the Constellation Program can cover a period of decades over which the Earth-Moon geometry (particularly, the lunar inclination) will go through a complete cycle (i.e., the lunar nodal cycle lasting 18.6 years). This geometry variation, along with other parameters such as flight time, landing site location, and mission related constraints, affect the outbound (Earth to Moon) and inbound (Moon to Earth) translational performance cost. The mission designer must determine the ability of the vehicles to perform lunar missions as a function of this complex set of interdependent parameters. Trade-offs among these parameters provide essential insights for properly assessing the ability of a mission architecture to meet desired goals and objectives. These trades also aid in determining the overall usable propellant required for supporting nominal and off-nominal missions over the entire operational lifetime of the program, thus they support vehicle sizing.

_ERC, Incorporated, Engineering and Science Contract Group, Houston, TX 77058
yERC, Incorporated, Engineering and Science Contract Group, Houston, TX 77058
zEG/Aeroscience and Flight Mechanics Division, NASA Johnson Space Center, Houston, TX 77058
xJacobs Technology, Engineering and Science Contract Group, Houston, TX 77058

jEG/Aeroscience and Flight Mechanics Division, NASA Johnson Space Center, Houston, TX 77058
kEG/Aeroscience and Flight Mechanics Division, NASA Johnson Space Center, Houston, TX 77058

The MAPP tool was developed to evaluate the performance of the Constellation lunar architecture and the integrated capability of the Altair, Orion, and EDS vehicles (i.e., mission availability based on various constraints). MAPP uses pre-computed Delta-V performance databases, orbit propagation, numerical interpolation, binary database storage techniques, and a set of user-defined mission parameters to quickly construct end-to-end mission performance data. Mission parameter inputs include (but are not limited to): departure epoch, landing site latitude and longitude, post lunar orbit insertion (LOI) extended loiter duration, pre trans-Earth injection (TEI) extended loiter duration, trans-lunar injection (TLI) window duration, outbound and inbound flight times, LOI and TEI three-burn sequence durations, geocentric transfer angles, lunar surface stay time, and Earth return target state information. Depending upon the size and number of mission parameter ranges, a full-scale analysis could require evaluation of billions of case permutations. Employing MAPP on a Linux computing cluster makes this analysis possible in a reasonable time frame. The data generated by MAPP can be used to determine temporal availably of selected surface sites, abort options, propellant margins, and a wide range of other mission constraints of importance for mission design. The tool can also be used to generate vehicle requirements to meet specific mission design goals (e.g., anytime abort from the lunar surface). Thus, MAPP provides NASA with the ability to more effectively guide mission and vehicle design decisions. Without this capability, relying upon existing mission design tools and infrastructure would have required evaluation of hundreds of millions of mission permutations and perhaps taken years to complete. This paper describes the design, development and implementation of the MAPP tool, as well as its associated databases, and its utility in assessing human lunar mission architectures.

1.0   MAPP ARCHITECTURE DESCRIPTION

1.1   MAPP Methodology Overview

The MAPP tool was developed to evaluate the performance of the Constellation lunar architecture and the integrated capability of the Altair, Orion, and EDS vehicles. MAPP uses pre-computed ΔV performance databases to quickly construct end-to-end missions, and by directly evaluating the full range of possible mission and vehicle parameter combinations results in literally billions of possible case combinations. For each of these cases, ΔV data is stored for all major maneuvers in addition to a cumulative total for each vehicle stage (i.e. EDS, Altair descent, Altair ascent, Orion SM). This allows for characterization of variations in the vehicle and mission performance with respect to selected mission design parameters (such as Earth departure epoch, Earth-Moon geometry, landing site location, TLI opportunity, and inbound and outbound flight time).

The MAPP tool uses multiple data processing steps (listed in Table 1) to evaluate the vehicle performance. The tool's primary mode of operation allows for the evaluation of the vehicle performance for a given mission type over the lunar nodal cycle. During this initial processing step, the vehicle ΔV data is generated for each trajectory and stored in the results database. Once the trajectory-specific ΔV databases (and/or corresponding vehicle-specific propellant loading

databases) are generated, the tool then uses several modes of post-processing the data to produce correlations between the mission design and vehicle performance. Figure 3 provides an overview of the MAPP tool program *main* function which is responsible for interpreting the user input case conditions, managing operation of each of the program's run modes, and storing and indexing performance data within the results database.

TABLE 1: MAPP ANALYSIS MODES

| MAPP Analysis Mode	Description
ΔV Database Generation	Primary MAPP Mode. Generates ΔV and propellant mass totals for each vehicle as a function of specified mission conditions.
Vehicle Capability Analysis	For a given set of vehicle capabilities, determine set of mission conditions which provide for integrated mission lunar access.
Extremal Searches	Identify minimum and maximum extremal conditions within a given set of feasible mission scenarios.
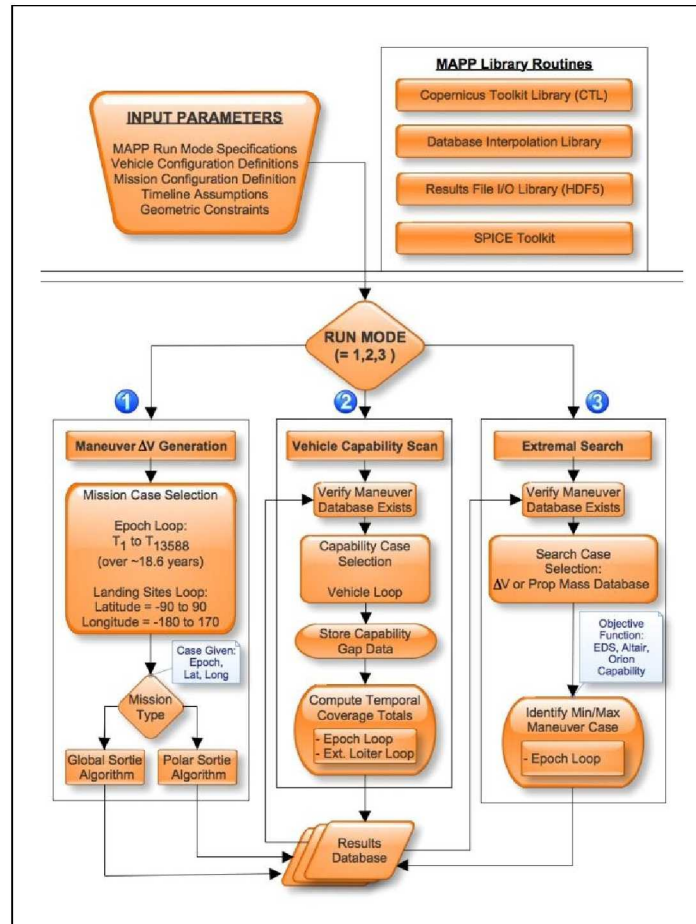
Figure 3: MAPP algorithm flowchart.

1.2 Construction of Maneuver ΔV Totals

For each mission case (with unique latitude/longitude/epoch combinations), the tool constructs a trajectory timeline and monitors the orbital geometry conditions required for calculating the maneuver estimates for each vehicle within the timeline. As part of the user specification, initial vehicle dry mass and propellant mass numbers are provided as inputs to the tool. As the tool steps through the trajectory timeline, maneuvers are computed as ΔVs and are converted to propellant mass using the rocket equation (given the current vehicle mass and active engine specific impulse [Isp]). An example maneuver list for the global sortie mission timeline is shown in Figure 4. After each maneuver, the propellant mass and ΔV totals for the thrusting vehicle are updated and stored in the database, resulting in cumulative totals for each vehicle for the entire mission. The computed propellant mass totals characterize the nominal 'undispersed' maneuvers and do not currently include ΔV or propellant mass impacts for guidance, navigation, and control (GN&C) dispersions, gravity losses, or thrust inefficiencies. These are book kept, separately.
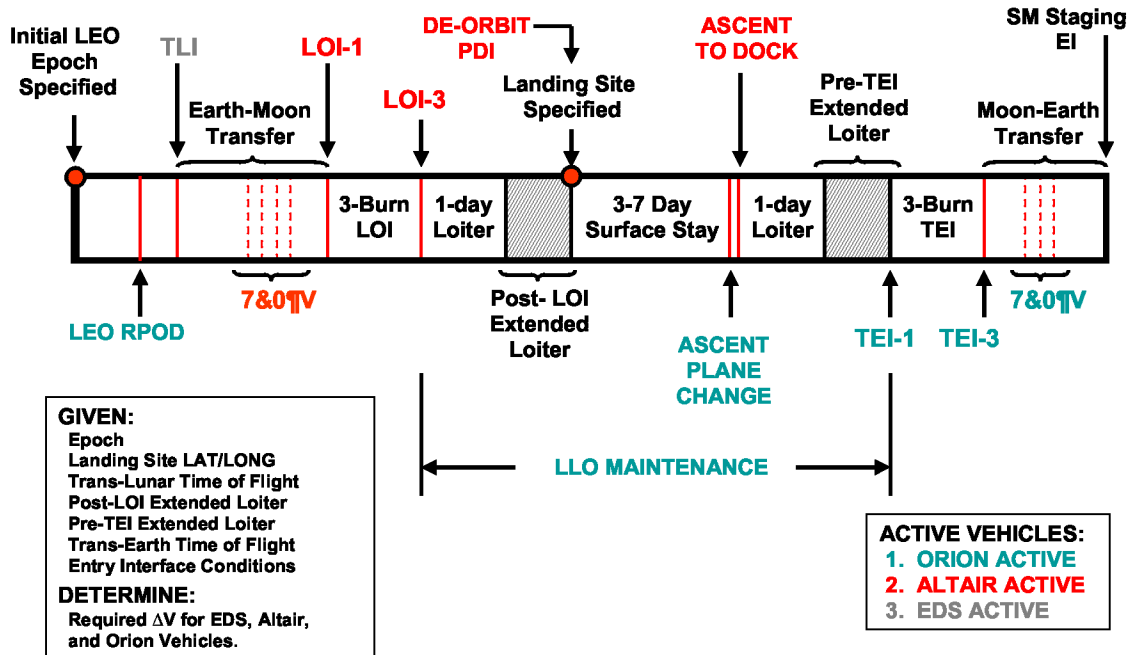
Figure 4: Global sortie mission timeline in MAPP.

1.2.1 Copernicus Trajectory Optimization Tool

A NASA trajectory optimization tool called Copernicus [4], currently being developed at the Johnson Space Center (JSC), is used in constructing the primary maneuver databases (specifically for modeling the optimized finite burn maneuver costs for LOI and TEI). The Copernicus Toolkit Library (CTL) also forms a core component of the MAPP tool. The CTL is a static library, originally created as part of Copernicus, which can be incorporated into other Fortran tools. The CTL provides an interface to the Jet Propulsion Laboratory (JPL) SPICE system and routines which are used for modeling the motion of the Sun, Earth, and Moon over the lunar nodal cycle in addition to many aerospace and math utilities, coordinate and state transformation routines. The CTL also provides routines for handling file input and output in multiple data storage formats. A comma-separated value (CSV) option is used for generating human-readable ASCII text files, and a binary hierarchical data format (HDF5) option is used for compact storage of data and increased file I/O speed.

1.2.2 Maneuver Performance Databases

The primary design aspect of the MAPP tool that allows it to quickly evaluate the cost associated with a particular lunar mission is its reliance on pre-processed maneuver databases which relate geometric conditions to the resulting maneuver ΔVs. The maneuver ΔV databases are designed to be independent of epoch (with the exception of the TLI database) which allows the databases themselves to be generated in a relatively short time-frame. Accessing these performance databases instead of integrating individual trajectories allows MAPP to process millions of mission variations in a relatively short time. Table 2 shows a list of maneuver databases with related information. Some maneuvers (e.g., LEO rendezvous ΔV, TCMs, Altair descent and ascent ΔV) are currently modeled as constants instead of databases.

TABLE 2: ΔV MANEUVER DATABASES IN MAPP

ΔV Database	Vehicle	Engine	Independent Variables
TLI	EDS	Main	departure epoch, Earth-Moon transfer time
LOI[1]	Altair	Descent	V_∞^- magnitude, arrival relative declination, LOI duration
Lunar Orbit Maintenance (LOM)	Orion	Auxiliary[2]	LDO inclination at descent, LAN at descent, duration in LDO
APC	Orion	Main	landing site latitude and longitude, lunar surface stay time
TEI	Orion	Main	departure relative declination, V_∞^+ magnitude, TEI duration

1.2.2.1   Trans-Lunar Injection Database

A lunar trajectory utility tool, called Earth Orbit to Lunar Orbit (EOLO), provides two pieces of information for the maneuver databases: the TLI ΔV and the V_∞^- arrival vector at the Moon[3]. It is assumed that these values are only a function of the nominal TLI epoch, and the Earth-Moon flight time (which varies as a function of the TLI opportunity number). EOLO computes a transfer (every 12 hours over a lunar nodal cycle) to a LOI target. It is assumed that the TLI magnitude and arrival V_∞^- vector for this transfer is valid for all landing sites. The V_∞^- vector produced by EOLO is given as magnitude, right ascension, and declination in Moon-centered J2000 frame. An additional preprocessing step is used to convert these vectors to a body-fixed Moon frame using the Copernicus Toolkit routines [5]. This process is also applied to the Lunar Orbit to Earth Entry (LOEE) database discussed in the TEI section.

The database currently contains data for a 2.0-4.5 day range of outbound transfer times. In addition, separate files are given for North to South lunar arrival and South to North arrival. The data presented in this report reflect a North to South lunar polar arrival case. Ongoing MAPP development plans include the addition of the South to North lunar polar arrival case. At that point, MAPP could choose the more demanding of these two lunar arrival cases, for the purposes of finding a worst or conservative case to be used in vehicle sizing. Related planned capabilities would allow MAPP to account for cases when navigation or other operations related constraints drive a mission design to solutions that are not performance optimal.

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[1] The LOI database and associated independent variables reflect a global sortie mission design approach. The LOI DV for the polar sortie mission originates from V-infinity data sets as described in section 3.2.2.2.

[2] Generally, lunar orbit maintenance (LOM) burns are performed with auxiliary engines. However the engine used can be based upon the size of the maneuver. For example, larger LOM maneuvers can be done with the main engines.

[3] Note that V_∞^- represents the V-infinity at planetary arrival and V_∞^+ represents the V-infinity at departure (of the Moon in this case) as depicted in Figure 5.

1.2.2.2 Lunar Orbit Insertion Database

For the polar sortie mission, the LOI is modeled as a single maneuver which delivers the Altair/Orion stack into a 90° inclined polar orbit. This maneuver varies only as a function of the arrival V_∞^- magnitude and is computed using data from the EOLO database. For the global sortie mission however, the LOI can require execution of a large plane change maneuver in order to insert into the lunar parking orbit which is aligned with the landing site at the time of descent. For this reason, the LOI for a global sortie mission can be significantly more expensive than that of the polar sortie mission and is modeled as a three-burn maneuver sequence. The three-burn maneuver database used for modeling the LOI for the global sortie mission was generated by Copernicus. It consists of an arrival LOI-1 burn that captures the Orion/Altair stack from an approach hyperbola to a lunar elliptical orbit. LOI-2 performs a plane change and LOI-3 circularizes the elliptical orbit into the desired LDO (see left side of Figure 5). It is assumed that the LOI ΔV is a function solely dependant on V_∞^- vector magnitude, the relative declination, and the LOI duration (i.e. the time between LOI-1 and LOI-3). The relative declination of the arrival V_∞^- vector is defined as the angle between V_∞^- and the lunar parking orbit (or the complement of the angle between V_∞^- and the orbit angular momentum vector). The V_∞^- vector is obtained from the previous EOLO database lookup (as a function of the departure epoch and the Earth-Moon transfer time). The target lunar parking orbit is obtained from the ascent plane change (APC) database lookup (as a function of the target landing site and the lunar surface stay time). To eliminate the epoch dependency, the Earth perturbations were ignored for the optimized three-burn sequences generated by Copernicus. The LOI database contains data for: 750-1200 m/s V_∞^+ magnitude, 0°-90° relative declination, and 0.5-2 day LOI duration. For this report, only the 1 day LOI duration was used.
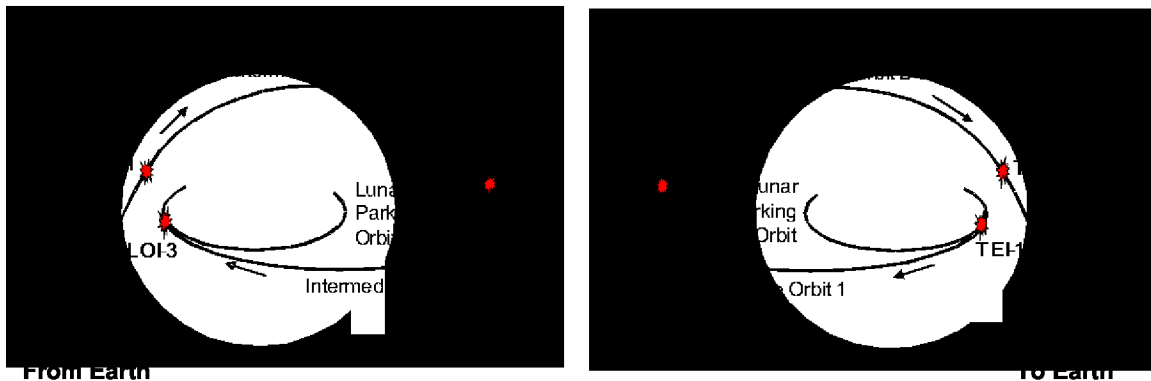

Figure 5: Lunar arrival and departure geometries.

1.2.2.3 Lunar Orbit Maintenance Database

The lunar orbit maintenance (LOM) ΔV database was generated in Satellite Toolkit (STK) using a control law that maintains periapse altitude above a specified minimum constraint. Also included in the LOM ΔV budget is an orbit circularization maneuver which is conducted prior to the ascent plane change [2, 6]. The LOM ΔV is assumed to be only a function of the final inclination and LAN at the time of Altair descent, and the time spent in orbit (which is the total

time of the surface stay and nominal and extended loiters for the post-LOI and pre-TEI phases of flight). The database contains data for 7-21 day orbit stay durations and was designed to accommodate a 7 day lunar surface stay mission with variations in lunar orbit time due to LOI and TEI durations and extended post-LOI and pre-TEI loiter time.

1.2.2.4 Ascent Plane Change Database

The APC database was generated using a method that provides a minimum overall plane change given that an ascent could occur anytime during the lunar surface stay [3, 7]. This ensures that the Orion APC ΔV allocation will be sufficient for covering plane change requirements for both nominal and early return abort situations. For preliminary implementation within the global sortie mission, data from the ESAS [1] and the orbit maintenance database were merged to create the APC database which is a function of landing site and surface stay time. For the polar sortie mission, a slightly different approach is taken in which the wedge angle between the final perturbed LDO and the landing site ascent plane is computed to model the APC ΔV. The targeting within both APC databases assumes the orbit is perturbed by only the J2 term of the Moon's gravity field. In the future, the full lunar gravity field data model from STK will be used.

1.2.2.5 Trans-Earth Injection Database

An internal NASA lunar trajectory utility tool, known as LOEE provides a database of V_∞^+ vectors for departure from the Moon targeted to Earth return. LOEE computes this vector assuming a coplanar departure from a polar orbit (with the LAN optimized to minimize the ΔV). A simplifying assumption in MAPP applies this vector for departures from all orbits (i.e. all landing sites). Thus, the V_∞^+ vector is considered to be a function only of the Moon-Earth transfer time and the Earth EI conditions. Currently, in MAPP, only the 0° azimuth EI condition (South to North Earth arrival) is used. The 0º azimuth results in the most demanding performance requirement for a given flight time and encompasses the entry conditions for the more difficult coastal water landing targets (versus minimum performance returns with the Moon-Earth transfer plane in or near the Moon's orbit plane about the Earth). Overall, it results in the greatest geocentric Earth return wedge angles and provides some conservativeness to the results. Future updates to the MAPP tool will include other entry conditions in addition to velocity and flight path angle constraints.

Copernicus was used to produce a finite burn TEI database using a methodology similar to that used with the LOI database. For the purpose of simplifying the MAPP database generation process, it is assumed that the TEI ΔV is a function only of the V_∞^+ departure vector magnitude, the relative declination, and the TEI duration (i.e. the time between TEI-1 and TEI-3). The relative declination of the departure V_∞^+ vector is defined as the angle between V_∞^+ and the lunar parking orbit. This vector is obtained from a LOEE database lookup (as a function of the Moon-Earth transfer time and the EI conditions). The initial lunar parking orbit is obtained by propagating the Altair rendezvous orbit (assuming a LAN precession due to the Moon's gravity J2 term). The TEI database contains data for: 700-1500 m/s V_∞^+ magnitude, 0°-90° relative declination, and 1-2 day TEI duration. Figure 6 shows the variation in TEI ΔV as a function of

V_∞^+ vector magnitude and relative declination for the 1.5, 1.75, and 2.0 day TEI duration cases (currently, only the 2 day data is being used).
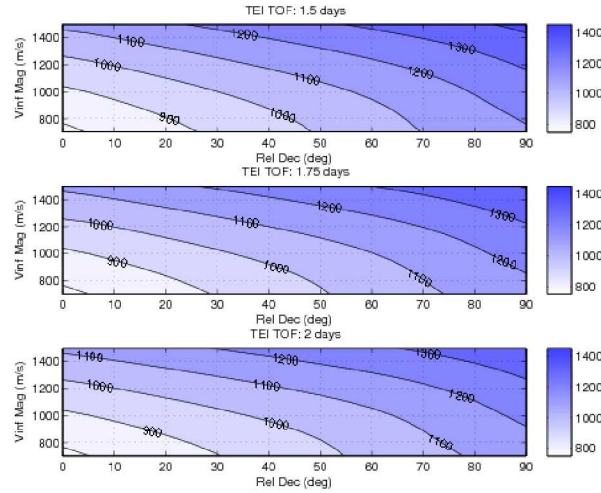

Figure 6: TEI database, showing the ΔV (m/s) contours for TEI as a function of the V_∞^+ departure vector magnitude, the relative declination, and the TEI duration.

1.2.3 Linear and Spline Interpolation Techniques

A core capability of the MAPP algorithm lies in the use of various interpolation routines for sampling the sparse input databases. In MAPP, up to 3-dimensional (3D) interpolation is used (e.g. TEI ΔV is a function of three variables: relative declination, TEI three-burn duration, and V_∞^+ magnitude). Routines were written for the tool to perform multi-dimensional linear interpolation and extrapolation of data grids. In addition, the 2-dimentional (2D) and 3D piecewise polynomial spline routines from the NIST Core Math Library are sometimes used to improve upon the linear fit approximation when specifically trying to isolate locations of minima and maxima extremal points within the data.

1.2.4 Orbit Propagation

The final MAPP component necessary for quickly constructing ΔV estimates for a mission is the use of orbit propagation to model perturbations of the lunar parking orbit and to provide the geometry inputs required for each database lookup. By precession of the orbit LAN, accounting for the influence of J2 (see equation 2.3.30 in [8]), this approximates a significant component of the perturbing effects of the Moon's non-spherical mass distribution on the lunar parking orbit. For a circular orbit, the equation modeling the J2-induced nodal precession rate is given by:

$$\dot{\Omega} \cong -\frac{3}{2} J_2 \sqrt{\frac{\mu_{Moon}}{a^7}} R_{Moon}^2 \cos\left(i\right)$$

where
      i is the orbit inclination
      a is the orbit semi-major axis

The inclination and other orbital elements are assumed to be constant in the inertial frame. Precession takes place during the period in low lunar orbit (i.e., from LOI-3 to TEI-1). It is necessary to perform this process backward and forward in time. For example, for a global sortie mission, the target orbit at Altair descent is determined from the APC database, and this orbit must be propagated backward in time to determine the orbit at LOI-3 (which is needed to compute the relative declination). The use of propagation for modeling the perturbed orbital elements (rather than full numerical integration of the trajectory from arrival to departure) provides sufficient accuracy over the duration of a lunar mission for evaluating geometric orbit conditions, and significantly decreases the processor time required to model the variation of the lunar orbit. This allows MAPP to build ΔV estimates for all maneuvers near the Moon which are accurate enough for early vehicle capability sizing.

1.3 Global Sortie and Polar Sortie ΔV Algorithm Flowcharts

Figure 7 shows a summary of the ΔV generation algorithms for the global sortie and polar sortie mission types. The primary distinction between the two algorithms stems from a difference in the design of the LDO arrival conditions which are targeted during LOI. For the polar sortie mission case, a one-burn LOI is used to target a polar orbit with an unconstrained LAN, independent of the landing site location. After separation from Orion, the Altair vehicle performs an on-orbit plane change to set up an in-plane descent and landing[4]. In contrast, the plane change requirement for the global sortie mission generally requires a three-burn LOI sequence to accommodate possible large plane changes. After LOI, the spacecraft has achieved the desired LDO to support an in-plane descent and landing. This approach increases the LOI ΔV requirement on the Altair vehicle, but eliminates the need for conducting a plane change prior to descent.

For both the global and polar mission types, the descent and landing are assumed to be in-plane maneuvers starting from a 100 km LLO. After completion of the 7-day surface stay, the Orion is responsible for conducting a plane change in order to align into the lunar rendezvous orbit (LRO) for the in-plane Altair ascent. This allows the lunar descent and ascent maneuvers to be modeled as constants for all mission configurations. After the rendezvous and docking is completed, a three-burn TEI maneuver is modeled using a common algorithm for both mission types. In both cases, the TEI is modeled as a function of the LRO inclination and LAN, the three-burn time of flight, the departure epoch, and EI targeting conditions. The LOEE database is used to convert these conditions into the required input parameters for the TEI ΔV database. During the flight returning to the Earth, the Orion vehicle is responsible for conducting three TCMs and disposing of the SM stage prior to EI. These maneuvers, in addition to the LEO rendezvous proximity operations and docking (RPOD) maneuvers, are modeled as constants for all cases.

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[4] Given that the polar sortie landing site always lies within a 4° latitude band of the pole, then this plane change requirement, using J2-only propagation, will not exceed 4°. Propagation of lunar orbits with higher fidelity lunar gravity models can result in orbit "wobble", causing plane changes greater than 4°.
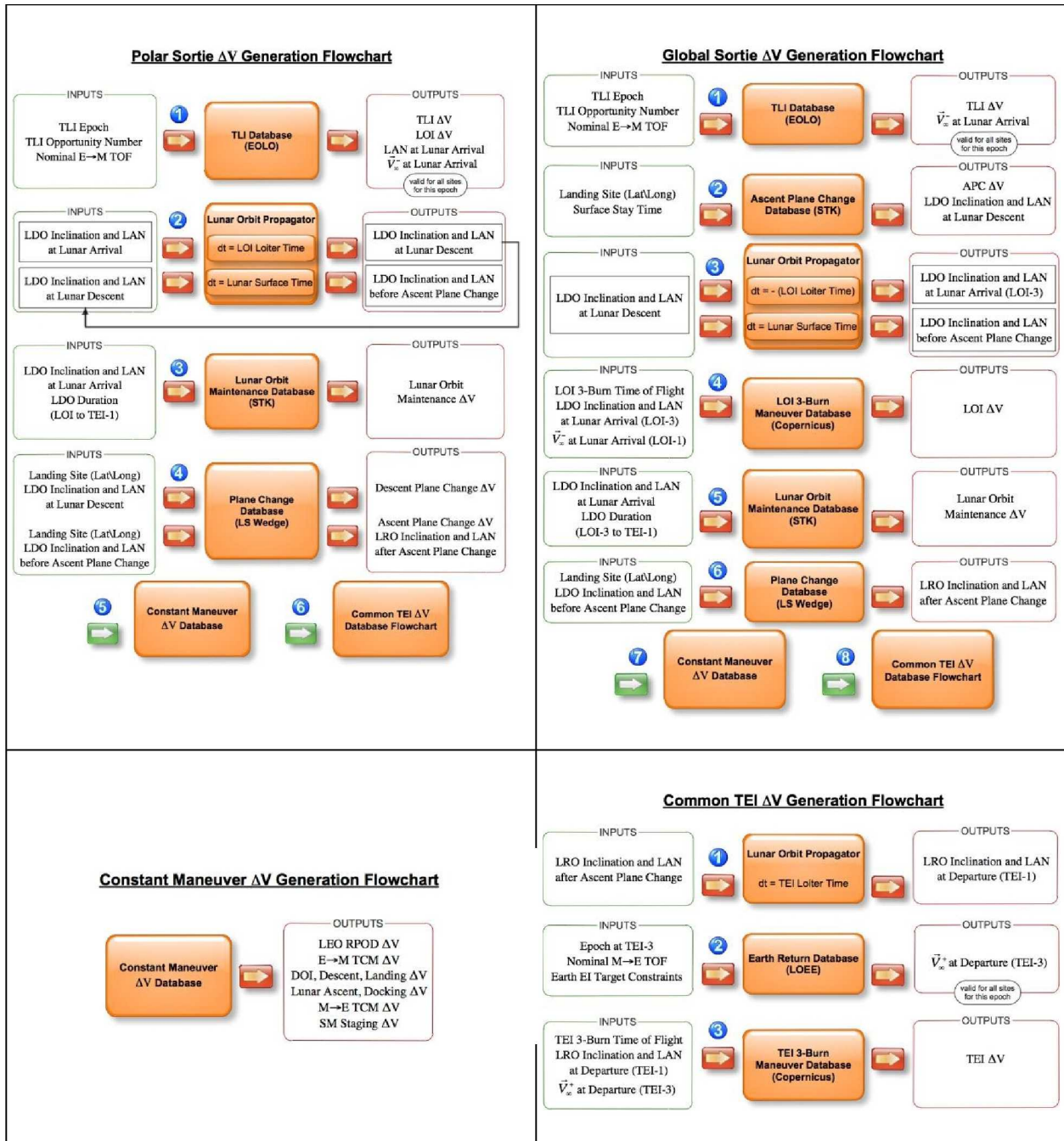
Figure 7: MAPP ΔV generation algorithm flowcharts.

1.4 Integrated Capability Assessment

The MAPP tool offers a variety of mission assessment capabilities. This report examines selected aspects of mission capability from both the perspective of an individual spacecraft (i.e., Altair only) and an integrated mission (i.e., for both Altair and Orion) including: temporal availability for selected landing sites over a lunar nodal cycle and gap analysis. Temporal availability refers to the percent of time in a lunar nodal cycle that spacecraft performance capability allows execution of a mission to a given landing site (latitude and longitude).

Evaluating this capability for all landing sites, for a global sortie mission, results in a contour plot of the percent mission availability over the global sortie region. The lunar nodal cycle covers a complete variation of the Moon's inclination from its minimum of 18.3° to a maximum of 28.7° and addresses essentially all of the Earth-Moon geometric variations anticipated to occur over the operational lifetime of the Constellation Program. The gap analysis provides a specific investigation of the periods of time that missions to a selected lunar landing site cannot be executed as a result of performance limitations. While, ideally, a zero gap would provide maximum mission flexibility by eliminating performance based restrictions[5], practically, gaps may exist in mission capability for certain landing sites.

1.5 Lunar Surface and Temporal Coverage

Two basic metrics for assessing vehicle capabilities are employed: lunar surface coverage and temporal coverage. Lunar surface coverage refers to the percentage of the lunar surface area that could be achieved for a given vehicle configuration and mission design assumption set. This surface coverage reflects the amount of the lunar surface on which a landing can be executed, with subsequent return. The other metric of vehicle capability, temporal coverage, reflects the percentage of the lunar nodal cycle (over the epoch range January 1, 2018 through August 7, 2036), over which a mission could be conducted to a given landing site.

The MAPP tool constructs a series of epoch-dependent lunar surface access tables (see Figure 8). The data for each epoch slice contain binary values (e.g., 0 or 1) to indicate if a mission can be performed to the landing site latitudes and longitudes in the grid at that epoch. MAPP accumulates the binary data in these tables to create a single temporal coverage map for all landing sites over the entire lunar nodal cycle and for a given set of vehicle capabilities.
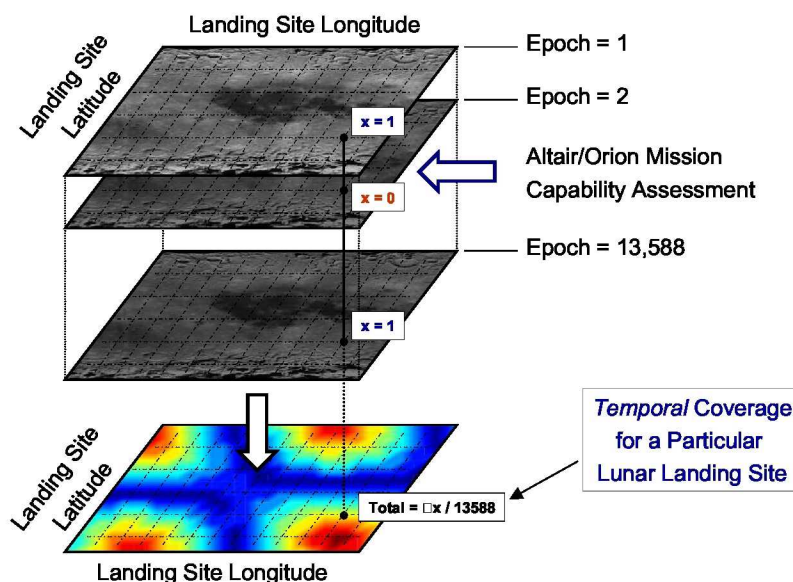

Figure 8: Generation of temporal coverage contours.

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[5] Performance constraints are one of a number of mission parameters that could preclude a viable mission. Other possible limitations are lighting constraints and entry, descent, and landing constraints.

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