POST2 END-TO-END DESCENT AND LANDING SIMULATION FOR THE AUTONOMOUS LANDING AND HAZARD AVOIDANCE TECHNOLOGY PROJECT

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The Program to Optimize Simulated Trajectories II (POST2) is used as a basis for an end-to-end descent and landing trajectory simulation that is essential in determining the design and performance capability of lunar descent and landing-system models and lunar environment models for the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project. This POST2-based ALHAT simulation provides descent and landing simulation capability by integrating lunar environment and lander system models (including terrain, sensor, guidance, navigation, and control models), along with the data necessary to design and operate a landing system for robotic, human, and cargo lunar-landing success. This paper presents the current and planned development and model-validation of the POST2-based end-to-end trajectory simulation used for the testing, performance and evaluation of ALHAT project system and models.

INTRODUCTION

The primary objective of the Autonomous Landing and Hazard Avoidance Technology (ALHAT) project is to develop an autonomous lunar precision-landing system, for a wide variety of lunar descent vehicles (robotic, human-piloted, and cargo), locations, and lighting conditions, that will safely and repeatedly land on the surface of the moon with the capability to detect and avoid surface hazards.[1] The Program to Optimize Simulated Trajectories II (POST2)[2,3,4] is used as a basis for an end-to-end descent and landing trajectory simulation that is essential in determining the design and performance capability of various lunar descent and landing-systems. Lunar vehicle models and lunar environment models are integrated into POST2 for the ALHAT project. These vehicle models include automated guidance, navigation and control (AGNC) as well as sensor models such as RADAR and light detection and ranging (LIDAR). This POST2-based ALHAT simulation provides descent and landing simulation capability to assess various sensor and AGNC combinations to design and operate an autonomous system for lunar-landing success.

TRAJECTORY DEVELOPMENT AND SIMULATION

The ALHAT end-to-end descent and landing trajectory development begins with a descent and landing trajectory simulation in the Program to Optimize Simulated Trajectories II (POST2). This initial simulation uses only three degrees-of-freedom (3DOF); that is, this trajectory simulation uses integration of only translational equations of motion along the trajectory. POST2 is a generalized point mass, discrete parameter targeting and optimization trajectory program used for engineering trade studies, reference trajectories, and mission planning and operation support. POST2 has the ability to simulate 3DOF, six-degree-of-freedom

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(6DOF), and multi-degree-of-freedom (multi-DOF) trajectories for multiple vehicles in various flight regimes (i.e. entry, launch, rendezvous, and intercept trajectories). POST2 also has the capability to incorporate different gravity, propulsion, guidance, control, sensor and navigation system models. Many of these models have been used in POST2 at NASA Langley Research Center to simulate the entry, descent, and landing trajectories for previous NASA missions, including Mars Exploration Rovers (MER)[5], Genesis, Stardust, Mars Path Finder (MPF). Additionally, POST2 is used to help design, develop and operate current and planned NASA robotic missions entry systems such as Mars Phoenix Lander[6] and Mars Science Laboratory[7], and human systems like the Crew Launch Vehicle (CLV) launch abort system.

The POST2 end-to-end descent and landing trajectory simulation supports ALHAT systems preliminary and detailed design, development, testing, and operations by establishing an end-to-end simulation that incorporates the latest engineering models of the ALHAT lunar descent and landing systems, as well as the lunar environment. The ALHAT project POST2 descent and landing simulations are initially constructed using models developed and validated for previous missions to provide an initial 3DOF-capability. The ALHAT project-defined Lunar Surface Access Module (LSAM) vehicle model, including parameters such as vehicle geometry, propulsion and mass properties, are implemented and validated in the simulation, along with a lunar 165x165 degree spherical harmonic gravity-field model and 0.25 degree grid-spacing lunar topography model based on the Clementine mission gravity and topography data archive.[8] In addition, sensors for AGNC, terrain-relative navigation (TRN), as well as hazard detection and avoidance (HDA) are modeled and are incorporated in the POST2 simulation. As these models and vehicle definitions mature, a 6DOF POST2-based ALHAT simulation will be developed.

The ALHAT project POST2 descent and landing nominal simulation begins with initialization of the vehicle position, velocity, as well as definition of the vehicle attitude. The following representative lunar landing trajectory is simulated using the ALHAT POST2. A de-orbit burn event with a nominal ΔV of 18 m/s from a 100 km orbit, is performed to reach a periapsis altitude of about 19 km. The braking phase begins with powered descent ignition, to reduce velocity from orbital speeds, at a nominal altitude of 19.3 km, in which the AGNC and sensor models are initialized and sensor-model altitude measurement updates begin. Sensor-model velocity measurement updates start at an altitude of 2.0 km. The approach phase of the trajectory begins with vehicle pitch-up and throttle-down, targeting a point in space directly above the landing site, which is triggered at a nominal altitude of 1.2 km. The vehicle remains in this phase until the start of vertical descent to the targeted landing site, with constant deceleration, at 97 m above the lunar surface. Figure 1 shows an example of the nominal descent and landing sequence of events and timeline, beginning at powered descent ignition. As the ALHAT program continues, this trajectory will change as the ALHAT system matures.

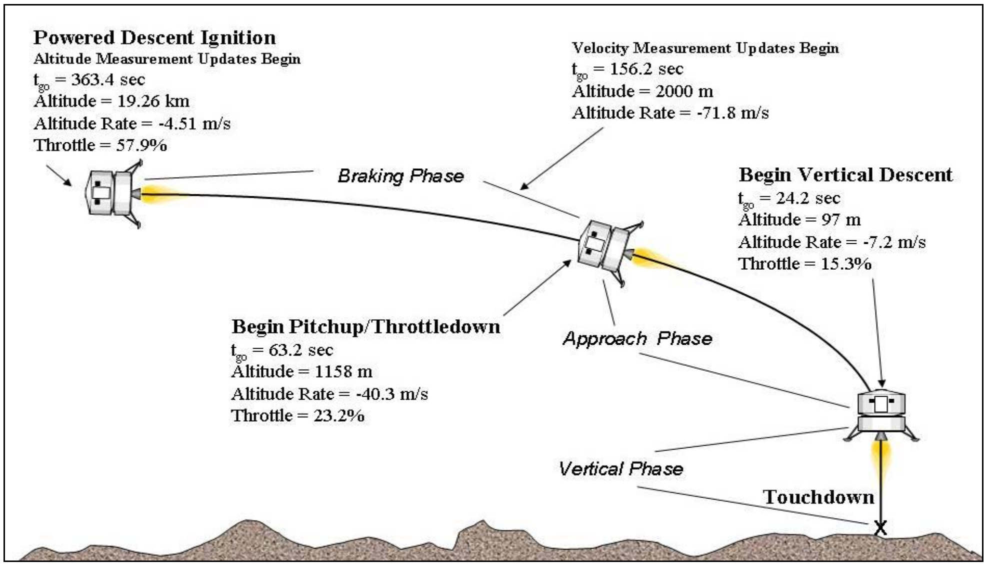

Figure 1. POST2 Nominal Powered Descent Trajectory Example

SIMULATION MODEL IMPLEMENTATION

The ALHAT POST2 end-to-end descent and landing trajectory simulation incorporates lunar- and ALHAT-specific models such as lunar gravity, topography, and terrain, ALHAT-defined vehicles, sensor, AGNC, TRN, and HDA models. These models are integrated into the simulation, tested and validated. A flight software interface is used in the POST2 simulation to interact with each ALHAT model provided by the model developer, vehicle and lunar environment models, and the main POST2 program which contains the dynamics and integration of the simulation as well as input/output, data handling, etc. The flight software interface (FSW) in POST2 allows for independent control of the data and update rates required from each individual model, and provides more control over the flow of information. The flight software interface also maintains control of spacecraft thrusters, inertial measurement unit (IMU) if required, coordinate systems and landing frame definitions. Figure 2 shows a simple flow diagram of the interaction of POST2, flight software interface, and lunar- and ALHAT-specific models. The lunar environment encompasses the lunar gravity, topography, and terrain models. As seen from the flow diagram, the only ALHAT model that communicates externally from the flight software, with the lunar environment, is the ALHAT sensor model.

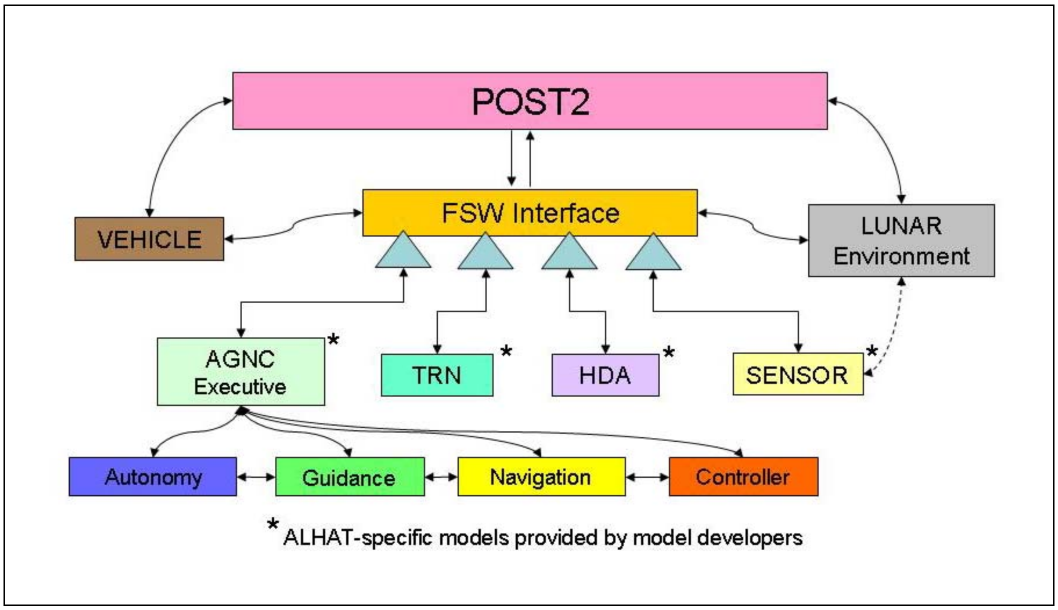

Figure 2. POST2 and ALHAT Software Interface

The models that are implemented in the ALHAT POST2 simulation must go through an independent verification and validation (IV&V) procedure. Verification ensures that the software provided satisfies the original design of the model itself. Validation of the model integration into POST2 is a check, usually output from test cases, that the model performance in POST2 fits the intended usage by the model developer. This IV&V procedure is defined by specific stages that must be successfully completed, meaning the model developers and integrators agree with the produced results, before continuing to the next stage. The responsibility of the model developer is to provide the software and documentation for the model, a set of test cases for stand-alone runs of the model, and model-specific input parameters with dispersions for use in Monte Carlo POST2 simulation and performance analysis. The model integrator is in charge of integrating the software from the model developer into the POST2 simulation, reproducing the set of test cases provided by the model developer, providing the results of the test cases to the model developer, and generating a trajectory simulation with results to be given to the model developer for validation. With this information, the model developer determines whether the results produced from the simulation with model-implementation are correct for the particular application of the model. The model integrator is to make certain that the output generated from the model implemented in the POST2 simulation matches the exact output of the set of test cases for stand-alone runs of the model. Once both the model developer and implementer are in agreement with the results produced from the POST2 simulation, then tuning and updates of the model, if necessary, can be conducted.

LUNAR GRAVITY AND TOPOGRAPHY MODEL

The lunar gravity model in the ALHAT POST2-based simulation uses spherical harmonic gravity coefficients complete to degree and order 165, or a 165 x 165 size gravity field, to determine the lunar gravitational acceleration on the spacecraft. The 165 x 165 gravity field (LP165P) was generated from Clementine spacecraft radio tracking data by NASA Goddard Space Flight Center.[8] Particularly, for use with nonsingular luna-potential models, the lunar gravity model utilizes the derivatives of the normalized Legendre polynomials with stable recursion formulas to handle instability in the Legendre function as the size of the gravity field increases.[9,10]

An ellipsoid lunar model is used in the POST2-based simulation which consists of physical and rotational characteristics, and gravitational parameter of the moon. Table 1 shows the spheroid lunar parameters used in the simulation.

Table 1
POST2 ELLIPSOID LUNAR MODEL

Lunar Parameter	Value
Polar Radius	1738.00 km
Equatorial Radius	1738.54 km
Rotational rate	2.661699 E-6 rad/s
Gravitational Parameter	4.902801056 E+12 m^3/s^2

The lunar topography model implemented in the ALHAT POST2-based simulation is based on 0.25 degree resolution topographic data captured and cataloged from the Clementine spacecraft via LIDAR by the Massachusetts Institute of Technology. This topographic database consists of topographic height data per latitude (from 89.875 to -89.875 degrees) and longitude (from 0.125 to 359.875 degrees) point for every 0.25 degree with respect to an ellipsoid with a radius of 1738 km and flattening of 1/3234.93, and is used by the lunar topography model to calculate height above the surface. Height above the surface in POST2 is determined first by interpolation (if necessary) of the topographic height for the spacecraft, with respect to the ellipsoid, from querying the database. Once the topographic height is determined, the geodetic altitude of the spacecraft, also with respect to the ellipsoid, is calculated in POST2. The resulting height above the topographic surface is the difference between the calculated geodetic altitude and topographic height. Figure 3 shows the geodetic altitude and height above the surface for the ALHAT POST2 nominal trajectory. Figure 4 shows a lunar topographic contour plot, lunar topographic height is in meters, with a circle of radius 10 km and centered at the POST2 nominal trajectory target landing location.

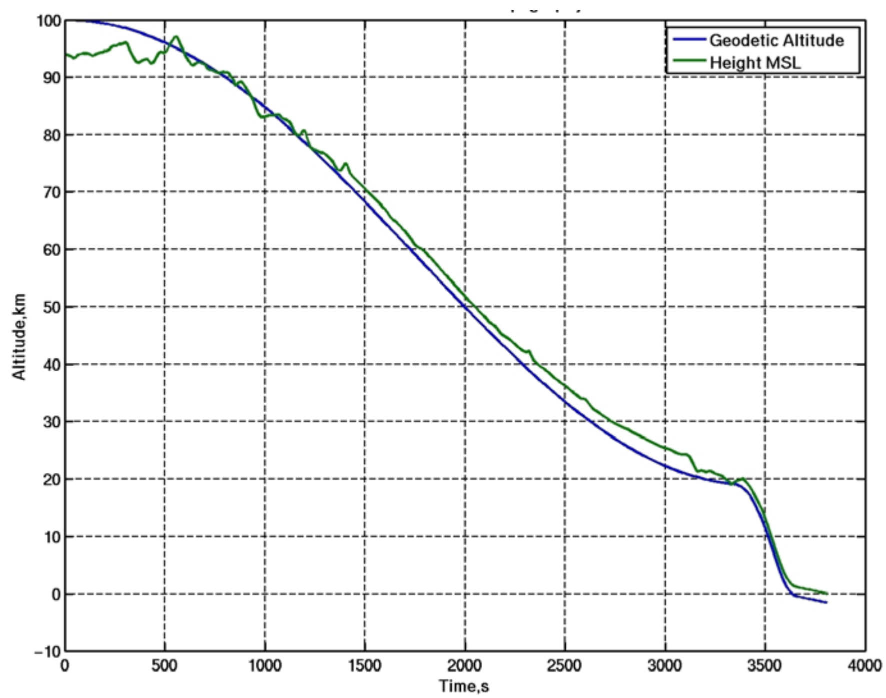

Figure 3. ALHAT POST2 Nominal Trajectory Height above Surface

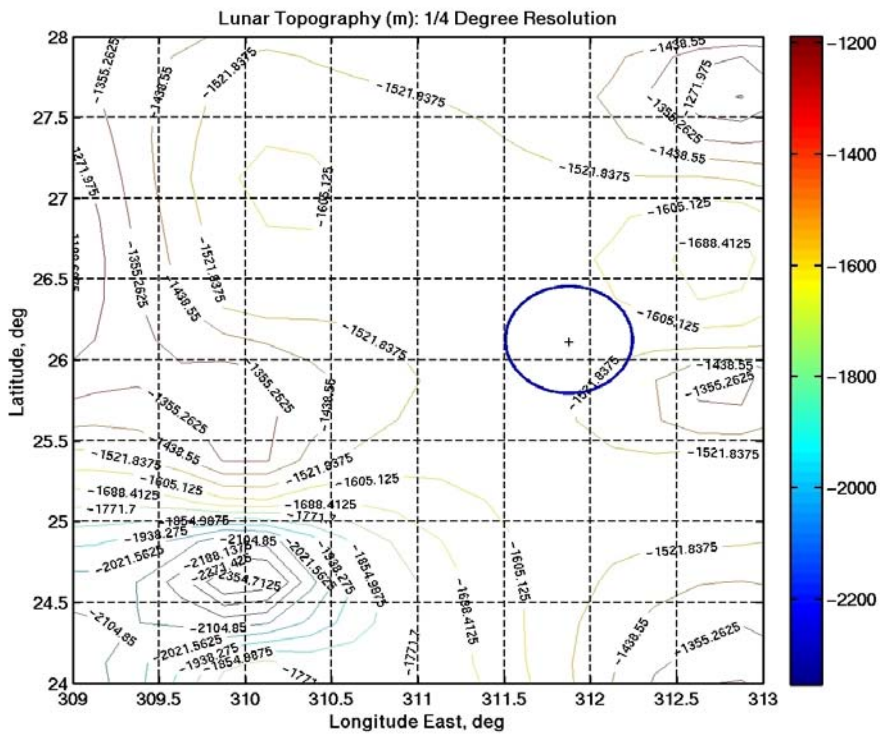

Figure 4. Contour Plot of Lunar Topography in POST2

ALHAT-DEFINED VEHICLES MODELED

LSAM

The ALHAT project-defined Lunar Surface Access Module vehicle model is a working vehicle model, in the sense that modifications and reassessment of the design are in progress, and is intended for preliminary ALHAT analysis only. The current LSAM model is the vehicle model used in the ALHAT POST2-based simulation. This model is an Apollo-like, four-legged landing gear configured lunar-lander containing four pump-fed, oxygen-hydrogen propulsion, two-axis gimbaled descent engines. Each engine is clustered orthogonally from one another near the vehicle centerline, and has a thrust capability of 66,700 N, specific impulse of 440 seconds, and is throttleable from 100% to 10%. The height of the vehicle is 10.5 m with a base maximum leg span of 12.0 m. The total mass input into the POST2-based simulation at low lunar orbit (before the de-orbit burn is performed) is 42,284 kg, with a landed mass of approximately 27,155 kg.[11] Figure 5 shows a representation of the geometry of the LSAM vehicle and the center of gravity (CG) with respect to the POST2-defined body reference frame, LSAM-defined body structural frame, and the POST2-defined body-centered frame (same as LSAM-defined body-centered frame). The POST2 body reference axes (x_{BR}, y_{BR}, and z_{BR}) are aligned as shown with its origin at the LSAM docking interface, x-axis pointing toward the base of the lander, z-axis pointing toward the lunar access or spacecraft-defined panel, and the y-axis completing the right hand system. Also, the POST2 body-centered axes (x_B, y_B, and z_B) are aligned as shown with its origin at the LSAM CG, x-axis pointing toward the nose of the vehicle along the centerline, z-axis pointing toward the lunar access or spacecraft-defined panel, and the y-axis completing the right hand system. The LSAM body structural axes (x_L, y_L, and z_L) are aligned as shown with its origin at the LSAM docking interface, x-axis pointing away from the base of the lander, z-axis pointing toward the lunar access or spacecraft-defined panel, and the y-axis completing the right hand system; note that, the LSAM body structural and POST2 body axis are parallel. Input CG and engine locations from the ALHAT-specific models with respect to the LSAM body structural frame are transformed to the POST2 body reference frame for input into the POST2 simulation.

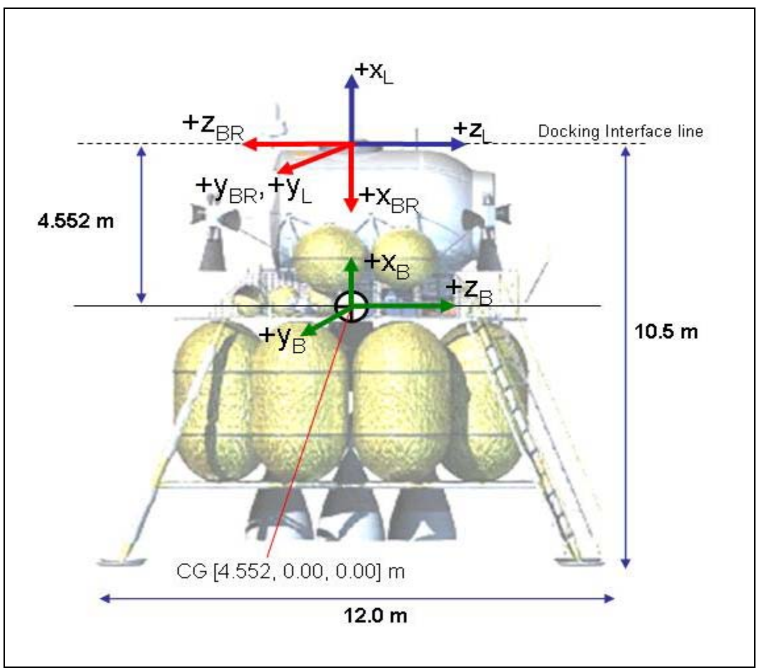

Figure 5. LSAM Vehicle Model in POST2 Simulation

Table 2 is a table of the ALHAT LSAM vehicle model mass properties at low lunar orbit and lunar landing.[11] The mass properties are with respect to the POST2 body reference and POST2 body-centered coordinate frame.

Table 2
ALHAT LSAM Vehicle Model Mass Properties

LSAM	AT LOW-LUNAR ORBIT	AT LUNAR LANDING
MASS (KG)	42,284	27,155
CG (M)	[4.552, 0.000, 0.000]	[3.950, 0.000, 0.000]
INERTIA ABOUT CG (KG-M^2)	157,205 0 0 0 237,013 0 0 0 237,013	115,274 0 0 0 182,146 0 0 0 182,146
DESCENT STAGE PROPELLANT MASS (KG)	17,399	2,269

The LSAM vehicle also has a 16-reaction control system (RCS) jet (in clusters of 4) attitude control configuration for control in yaw, pitch and roll directions. Each thruster has a 445 N thrust with a specific impulse of about 317 seconds.

Robotic Lander Model

The ALHAT project also uses a representative robotic lander vehicle (based on the Lunar Precursor Robotic Project (LPRP)-defined reference design) for the preliminary vehicle model used in ALHAT analysis. The current robotic vehicle used in the POST2 simulation is a descent and landing vehicle that contains a rover for lunar excursions and scientific purposes. The vehicle has a symmetric, four-legged landing gear and a four main-engine, non-gimbaled, liquid propellant configuration for descent. Each engine is clustered orthogonally from one another near the vehicle periphery, and has a thrust of 5,338 N and specific impulse of 309 seconds. The robotic vehicle also has a 16-reaction control system (RCS) jet (in clusters of 4) attitude control configuration, located 2.2 m from the centerline to each cluster, for control in yaw, pitch and roll directions. Each thruster has a 50 N thrust with a specific impulse of about 170 seconds. The height of the vehicle is 3.0 m from the ground line to the rover platform (not including rover), with a base width of 4.0 m across the platform. The total mass at low lunar orbit (before the de-orbit burn is performed) is 5,810 kg. Figure 6 shows a representation of the robotic vehicle model geometry and center of gravity (CG) with respect to the POST2-defined body reference frame and the POST2-defined body-centered frame (previously defined for the LSAM vehicle model).

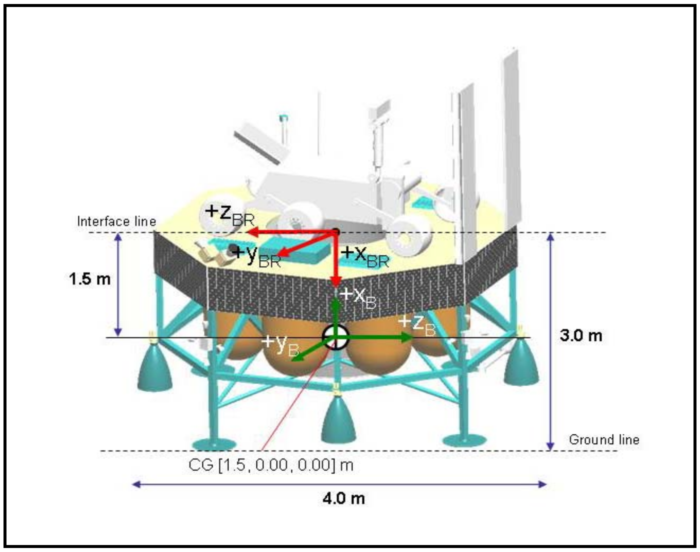

Figure 6. Robotic Vehicle Model in POST2 Simulation

Table 3 is a table of the robotic vehicle model mass properties, at low lunar orbit. It should be noted that the mass properties for the robotic vehicle are a current best estimate, and are expected to be updated as the LPRP robotic vehicle matures. These mass properties are with respect to the POST2 body reference (for CG), and POST2 body-centered coordinate frame (for inertias).

Table 3
Robotic Vehicle Model Mass Properties

ROBOTIC	AT LOW-LUNAR ORBIT
MASS (KG)	5,810
CG (M)	[1.5, 0.0, 0.0]
INERTIA ABOUT CG ($KG\text{-}M^2$)	11,620 0 0 0 10,167 0 0 0 9,151
PROPELLANT MASS (KG)	4,186

LOW-FIDELITY SENSOR MODEL

A low-fidelity sensor model for altimetry, velocimetry, HDA and TRN are planned to be implemented, tested and validated in POST2. An altimeter and velocimeter system are currently modeled in POST2 to include the capabilities and requirements of a representative ALHAT-specific system. A high-fidelity sensor model will be implemented and validated in the POST2 simulation as the sensor definition and design progresses. Table 4 and Table 5 show the current altimeter and velocimeter system capabilities and requirements for the ALHAT project.

Table 4
ALTIMETER SYSTEM CAPABILITIES FOR ALHAT

CAPABILITY	DESCRIPTION
SYSTEM CAPABILITY	a) Bias of < 0.5 m, (1 sigma) b) Scale Factor of < 0.1%, (1 sigma) c) Noise of < 0.025% + 0.05 m, (1 sigma)
SURFACE REFLECTION	lunar Surface, > 7 % Albedo
ALTITUDE RANGE	Measure range to surface in the nadir direction to better than 5m of accuracy for the following altitude ranges: a) 1 m < h < 20 km b) 20 km < h
RELATIVE VELOCITY	0 m/s < v < 1750 m/s
DESCENT ROCKET MOTOR	Continuous Operation
SYSTEM OUTPUT RATE	5 Hz

Table 5
VELOCIMETER SYSTEM CAPABILITIES FOR ALHAT

CAPABILITY	DESCRIPTION
SYSTEM CAPABILITY	a) Bias error of < 0.1 m/s (τ > 100 sec), (1 sigma) b) Scale Factor of < 0.1% (τ > 100 sec) , (1 sigma) c) Noise of < 0.03 m/s, (1 sigma)
SURFACE REFLECTION	lunar Surface, > 7 % Albedo
ALTITUDE RANGE	h < 2 km
RELATIVE VELOCITY	0 m/s < v < 200 m/s
DESCENT ROCKET MOTOR	Continuous Operation
SYSTEM OUTPUT RATE	5 Hz

The three-sigma sensor altitude (h_{sensor}) determined by the altimeter is modeled as

$$h_{sensor} = h_{truth} (1 + SF_h) + (p_{noise} h_{truth} + h_{noise}) + h_{bias} \quad (1)$$

where h_{truth} is the truth (or navigated) altitude and p_{noise}, h_{noise}, h_{bias}, and SF_h are the noise percentage, noise addition, bias, and scale factor specifications, respectively. The sensor altitude measurement updates begin at a truth altitude of 20 km above the lunar surface at a data rate of 5 Hz. The sensor velocity is broken down into horizontal and vertical velocity components. The three-sigma sensor velocity, for horizontal and vertical, (v_{sensor}) determined by the velocimeter is modeled as

$$v_{sensor} = v_{truth} (1 + SF_v) + v_{noise} + v_{bias} \quad (2)$$

where v_{truth} is the truth horizontal velocity and v_{noise}, v_{bias}, and SF_v are the noise, bias, and scale factor specifications, respectively. The velocimeter measurement updates begin at a truth altitude of 2 km above the surface at a data rate of 5 Hz.

The checks that were conducted to validate the low-fidelity sensor model implementation included a comparison of the truth altitude versus sensor-determined altitude of an ALHAT POST2 nominal trajectory to ensure that the scale factor, noise and bias specifications of the altimeter were correctly modeled. Figure 7 shows the comparison of the truth and sensor altitude for settings of 0.5 m and 0.1%, for h_{bias} and SF_h, respectively.

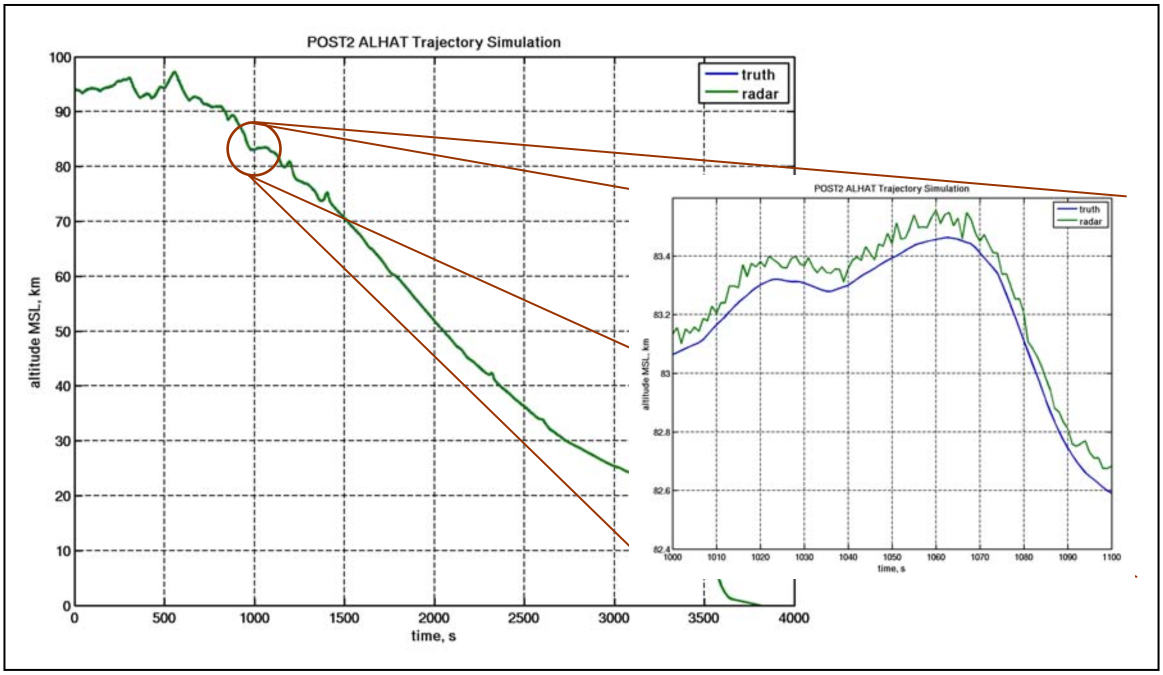

Figure 7. ALHAT POST2 Nominal Truth vs. Sensor Altitude

Additionally, a comparison of the truth horizontal and vertical velocity an ALHAT POST2 nominal trajectory versus sensor horizontal and vertical velocity was checked to validate the implementation of the scale factor, noise and bias specifications of the velocimeter. Figure 8 and Figure 9 show the comparison of the truth and sensor horizontal and vertical velocity for settings of 0.1 m/s and 0.1%, and cc for v_{bias}, and SF_v, respectively.

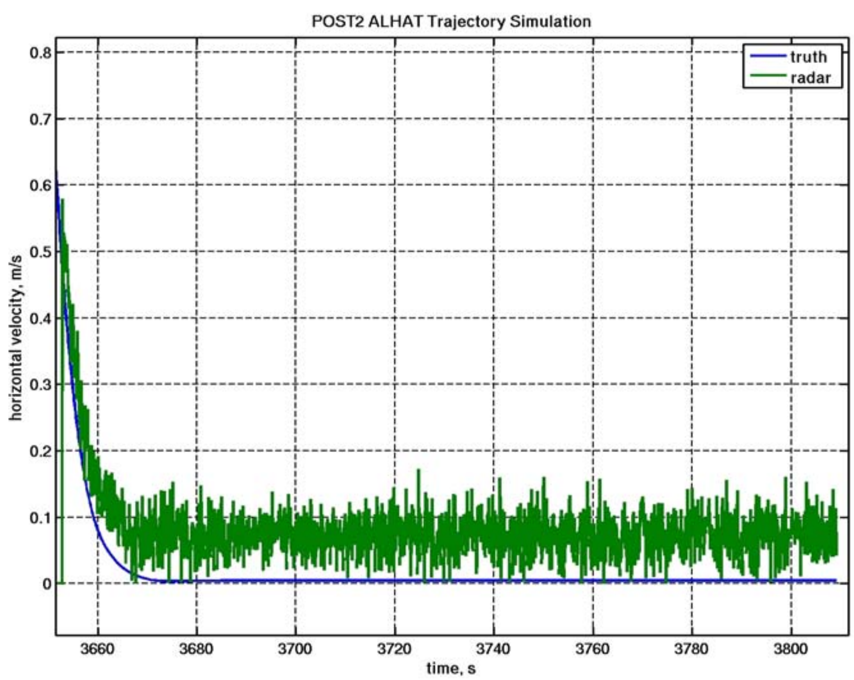

Figure 8. ALHAT POST2 Nominal Truth vs. Sensor Horizontal Velocity

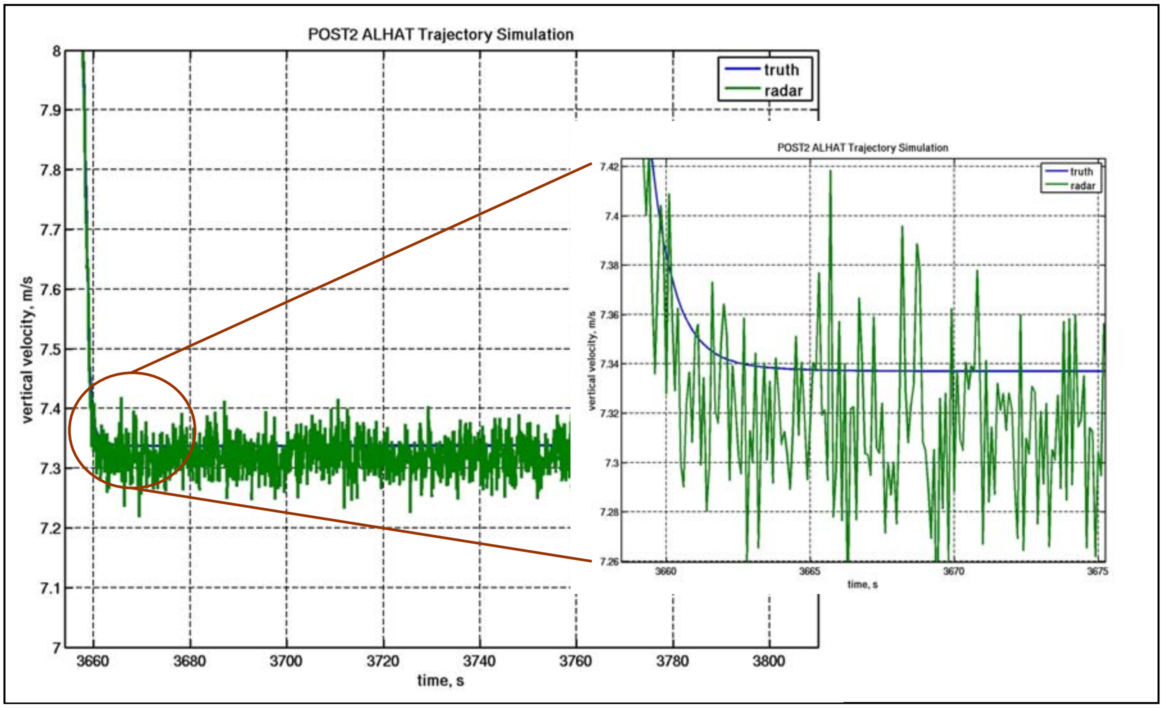

Figure 9. ALHAT POST2 Nominal Truth vs. Sensor Vertical Velocity

GNC MODEL

The ALHAT-specific guidance, navigation, and control (GNC) model[11,12] consists of separate models for each guidance, navigation and control algorithm, and an interface (GNC scheduling routine) for all of the models. The role of the navigation in the simulation is to determine the vehicle's state vector (position, velocity, and attitude) at the current time. The role of the guidance is to determine the appropriate thrust acceleration commands to meet lunar landing requirements. Finally, the role of the controller in the simulation is to maneuver the vehicle and set engine attitude and throttles as necessary to satisfy the commands of the guidance system. Figure 10 is a diagram of the interface between the GNC algorithms, flow of input and output variable type, and the interface to the flight software (FSW) in the ALHAT POST2 simulation. The vehicle position and velocity updates, and IMU accumulated delta-V, from the GNC module to the POST2 interface, and vice versa, is always in the lunar-centered inertial (LCI) coordinate frame. However, the target landing-site position vector is always in the lunar-centered, lunar-fixed (LCLF) coordinate frame, and the vehicle position, velocity, and attitude quaternion data for the sensor, TRN, and HDA models is in the local vertical, local horizontal (LVLH) coordinate frame. Also, it should be noted that data coming from the sensor models includes IMU (attitude quaternion and delta-V), star tracker, as well as altimeter and velocimeter data.

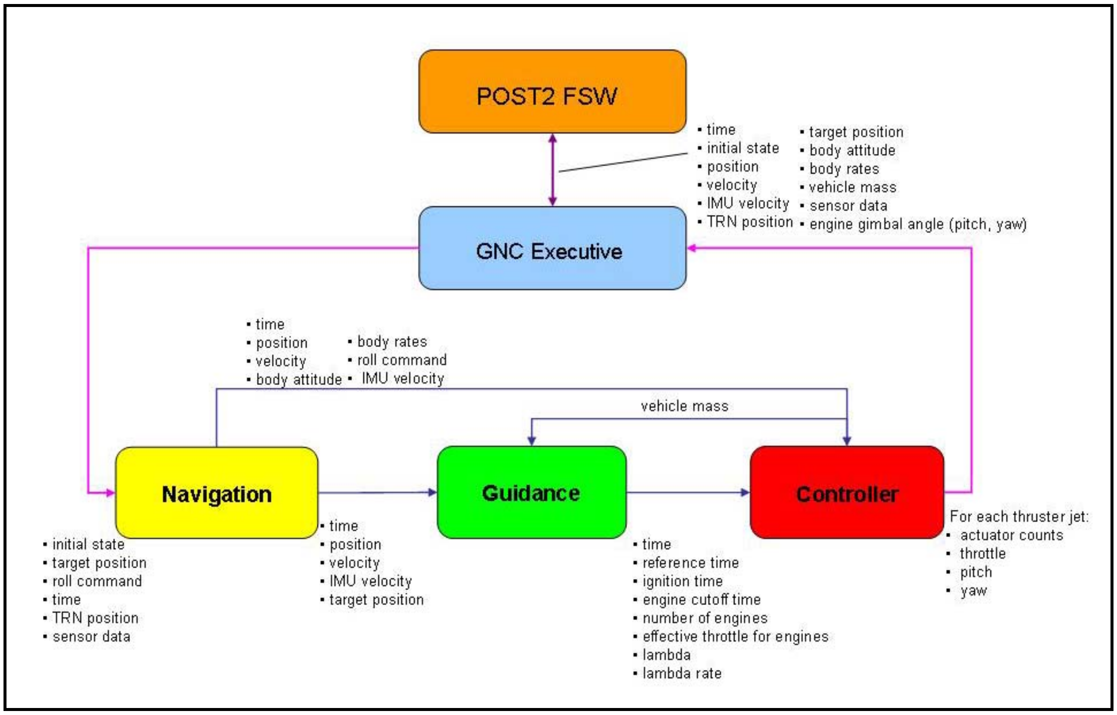

Figure 10. ALHAT GNC Model Interaction with POST2

The GNC model implementation into POST2 is an example of the IV&V process previously defined. The GNC model-developers deliver the model computer code with a set of test cases. The model code is compiled by the integrator and the set of test cases are run in a stand-alone mode of the GNC model. These test cases consist of input and original output for a 3DOF and 6DOF run with and without the navigation filter. The inputs given for the case with the navigation filter turned off includes time, vehicle position and velocity, target landing point, body rotational rate, vehicle mass and engine gimbal angle. The inputs given for the case with the navigation filter turned on include time, vehicle mass and engine gimbal angle, body accelerations from the IMU, body rotational rate, and data from the sensor and TRN models. The output of the test cases consist of throttle command, engine gimbal command-vector, and jet firing commands for the controller, thrust-pointing direction, engine reference time, ignition time, and cutoff time from guidance for the controller, and the state of the spacecraft for navigation. Once the test cases are run and verified in a stand-alone mode, and the GNC model is integrated into the POST2 simulation, a test trajectory is generated using the ALHAT POST2 simulation. The test trajectory output, specific to the GNC model, is then ready for validation from the GNC model developers.

TRN AND HDA MODEL

Terrain relative navigation (TRN) and hazard detection avoidance (HDA) are terrain-mapping capabilities used to for accomplishing safe, precision-landing on the surface of the moon. These terrain-mapping capabilities are facilitated by terrain sensor data-processing with terrain-mapping algorithms.[13] For these initial simulation runs, the terrain-mapping functions change responsibility throughout the ALHAT lunar descent and landing trajectory, in that from de-orbit burn to terminal descent, the TRN functions are active and from terminal descent to lunar surface touchdown, the HDA functions are active. The TRN model functions consist of global position estimation, and as altitude decreases, local positioning and velocity estimation. The HDA model functions consist of crater and rock hazard detection, and safe site selection. The ALHAT-specific TRN and HDA models are currently low-fidelity models implemented into the POST2-based simulation. These low-fidelity models will be updated with increasing fidelity as the ALHAT system matures. Specifically for the ALHAT POST2-based simulation, the low-fidelity TRN model pre-selects an offset in landing site location (a priori dispersed landing site locations), with a random noise applied for dispersion analysis. Figure 11 illustrates the low-fidelity TRN model function. The light blue circular area in the figure represents the Monte Carlo 3-sigma vehicle state space, the blue star-like symbols represent known surface features for TRN, the red star-like symbol is the target landing site, and the red dashed line represents a correctly adjusted trajectory by the TRN system. The low-fidelity HDA model in the POST2 simulation randomly selects a divert target point at a pre-determined altitude. The dispersed descent trajectories for each of the randomly selected divert target points create the three-sigma up- and down-range performance space. Figure 12 illustrates the low-fidelity HDA divert model function. The light blue circular area in the figure represents the Monte Carlo 3-sigma vehicle state space, the star-like symbols represent possible randomly selected divert landing locations on the lunar surface within the 3-sigma up- and down-range space, and the red dashed lines represent trajectories resulting from the divert maneuver.

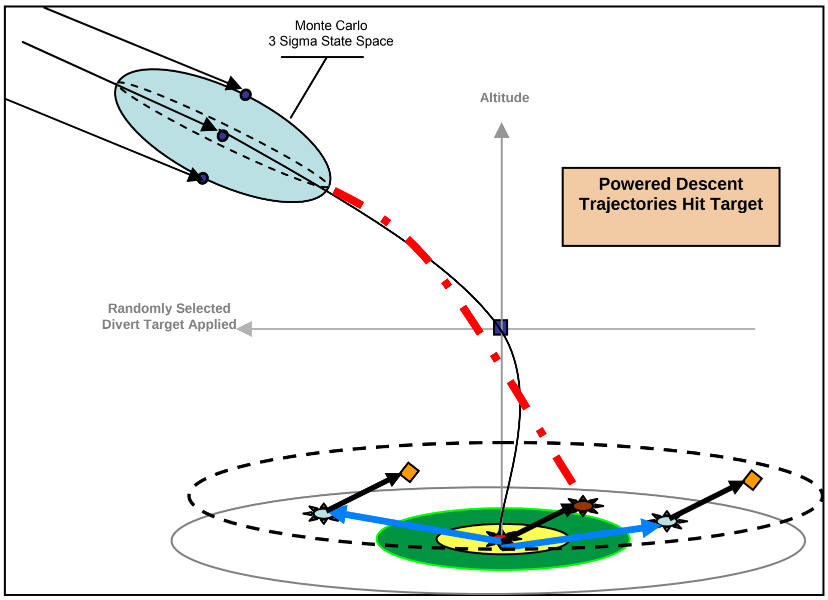

Figure 11. ALHAT TRN Model Function in POST2

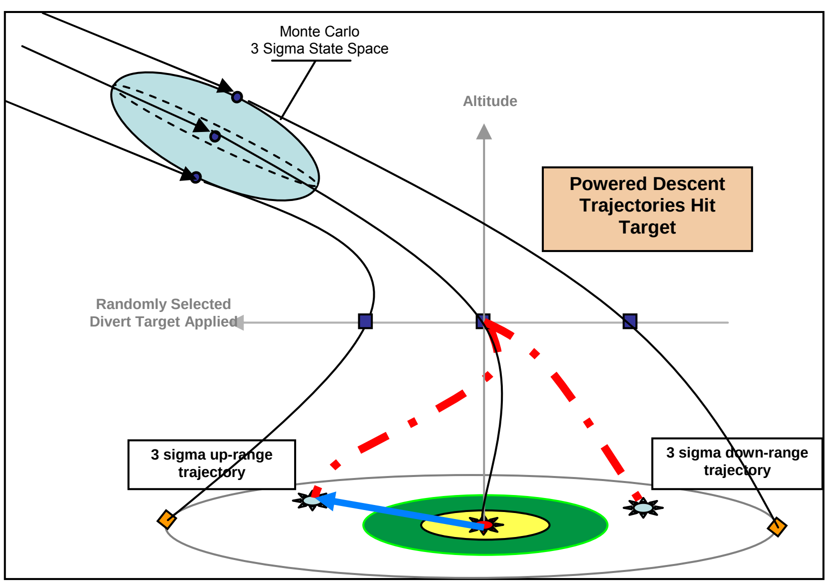

Figure 12. ALHAT HDA Divert Model Function in POST2

SUMMARY

The ALHAT POST2-based end-to-end simulation provides descent and landing simulation capability to assess various sensor and GNC combinations to optimally design and operate an autonomous system for lunar-landing success. An IV&V process of the ALHAT models implemented into the POST2 software has been discussed, along with the description of each lunar- and ALHAT-specific model incorporated into the POST2 end-to-end simulation at this time. The IV&V procedure provides the framework for the incorporation of future higher-fidelity ALHAT-specific lunar descent and landing system models.

FUTURE WORK

Further advancements in system-model development allow the incorporation of detailed sensor models used by the GNC, TRN and HDA algorithms. As the ALHAT system matures and progresses, a fully-defined ALHAT lunar descent and landing system will be included in the POST2 end-to-end descent and landing simulation with a 6DOF-capability (integration of translational and rotational equations of motion along a trajectory) for the terminal descent phase, including hazard detection avoidance and precision-targeting models during support of the ALHAT project. Specifically, for the GNC model, an autonomous flight manager capability for the GNC system (creating an AGNC module) will be implemented in the ALHAT POST2-based simulation as updates become available. Also, higher-fidelity altimetry and velocimetry sensors, TRN and HDA models will also be implemented and validated in the ALHAT POST2 simulation when it becomes available. The increase in fidelity of the models discussed, and their validation in the POST2 simulation, will expand the capability of the ALHAT POST2-based end-to-end descent and landing trajectory simulation for total system performance analysis of proposed robotic, cargo and human lunar lander systems.

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