Assessment and Verification of SLS Block 1-B Exploration Upper Stage State and Stage Disposal Performance

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One of the SLS Navigation System's key performance requirements is a constraint on the payload system's delta-v allocation to correct for insertion errors due to vehicle state uncertainty at payload separation. The SLS navigation team has developed a Delta-Delta-V analysis approach to assess the effect on trajectory correction maneuver (TCM) design needed to correct for navigation errors. This approach differs from traditional covariance analysis based methods and makes no assumptions with regard to the propagation of the state dynamics. This allows for consideration of non-linearity in the propagation of state uncertainties.

The Delta-Delta-V analysis approach re-optimizes perturbed SLS mission trajectories by varying key mission states in accordance with an assumed state error. The state error is developed from detailed vehicle 6-DOF Monte Carlo analysis or generated using covariance analysis. These perturbed trajectories are compared to a nominal trajectory to determine necessary TCM design. To implement this analysis approach, a tool set was developed which combines the functionality of a 3-DOF trajectory optimization tool, Copernicus, and a detailed 6-DOF vehicle simulation tool, Marshall Aerospace Vehicle Representation in C (MAVERIC).

In addition to delta-v allocation constraints on SLS navigation performance, SLS mission requirement dictate successful upper stage disposal. Due to engine and propellant constraints, the SLS Exploration Upper Stage (EUS) must dispose into heliocentric space by means of a lunar fly-by maneuver. As with payload delta-v allocation, upper stage disposal maneuvers must place the EUS on a trajectory that maximizes the probability of achieving a heliocentric orbit post Lunar fly-by considering all sources of vehicle state uncertainty prior to the maneuver. To ensure disposal, the SLS navigation team has developed an analysis approach to derive optimal disposal guidance targets. This approach maximizes the state error covariance prior to the maneuver to develop and re-optimize a nominal disposal maneuver (DM) target that, if achieved, would maximize the potential for successful upper stage disposal.

For EUS disposal analysis, a set of two tools was developed. The first considers only the nominal pre-disposal maneuver state, vehicle constraints, and an a priori estimate of the state error covariance. In the analysis, the optimal nominal disposal target is determined. This is performed by re-formulating the trajectory optimization to consider constraints on the eigenvectors of the error ellipse applied to the nominal trajectory. A bisection search methodology is implemented in the tool to refine these dispersions resulting in the maximum dispersion feasible for successful disposal via lunar fly-by. Success is defined based on the probability that the vehicle will not impact the lunar surface and will achieve a characteristic energy (C3) relative to the Earth such that it is no longer in the Earth-Moon system. The second tool propagates post-disposal maneuver states to determine the success of disposal for provided trajectory achieved states. This is performed using the optimized nominal target within the 6-DOF vehicle simulation.

This paper will discuss the application of the Delta-Delta-V analysis approach for performance evaluation as well as trajectory re-optimization so as to demonstrate the system’s capability in meeting performance constraints. Additionally, further discussion of the implementation of assessing disposal analysis will be provided.