MONTE CARLO ANALYSIS OF THE SOIL MOISTURE ACTIVE-PASSIVE (SMAP) MISSION

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Keywords: Monte Carlo, deltaV

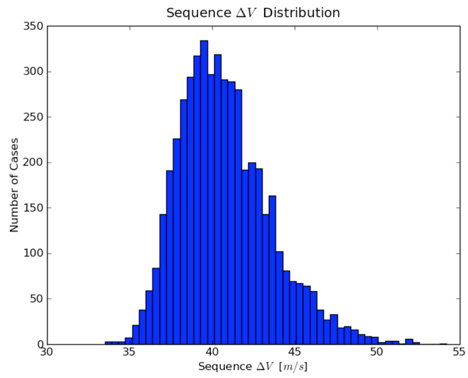
ABSTRACT

The Jet Propulsion Laboratory Soil Moisture Active-Passive (SMAP) mission, developed in response to the 2007 National Research Councils Decadal Survey, will observe soil moisture content and the freeze/thaw state of the Earth surface [1]. It is currently planned for launch in November 2014 and has a nominal mission lifetime of 3 years. The operational orbit of the SMAP mission is designed to be frozen and sun-synchronous, providing repeat coverage every 8 days. At launch, the SMAP spacecraft will inject to an approximately 568 × 664 kilometer orbit that permits the launch vehicle upper stage to deorbit naturally within a NASA-required 25 year time interval [2].

The SMAP spacecraft is 3-axis stabilized and utilizes a large (6 meter diameter) antenna for science observations. The SMAP spacecraft uses a blowdown propulsion system with eight 4.5N thrusters, of which four thrusters are used for orbit adjustment and the remaining thrusters are used for attitude control during orbit adjustment and spacecraft safeing events. With a blowdown propulsion system, the thrust output is reduced as onboard propellant is depleted. The SMAP spacecraft is propellant-limited; the design currently accommodates a propellant tank that holds 80 kilograms of hydrazine, which must be used to perform orbit acquisition, operational orbit maintenance, attitude control, and orbit disposal at the end of mission. As a pre-PDR phase project, the mission ΔV (delta-velocity) budget accommodates best estimates of expected propellant consumption as well as margin and operational contingency values. A significant proportion of this propellant is expected to be consumed during the orbit acquisition process; it is vital to estimate the propellant required (maneuver magnitude ΔV) for orbit acquisition to have confidence that all mission activities can be accomplished with this limited propellant tank.

A Monte Carlo analysis performed using an analytical technique has been developed for this process. An injection sequence containing eight propulsive maneuvers (including two calibration maneuvers) has been planned to transfer the spacecraft from the injection orbit to the science orbit; the injection sequence will correct launch vehicle injection errors as well as raise the apses heights of the injection orbit to those of the science orbit. An analytical simulation procedure has been developed to simulate this transfer sequence; key simulation components are injection orbit sampling, state propagation, and impulsive maneuver design and execution. The analytical simulation can be run quickly for multiple injection orbits, maneuver design strategies, and maneuver timelines, among other injection sequence parameters. The simulation autonomously designs and implements orbit correction maneuvers; the science orbit is achieved at the end of simulation. A Monte Carlo analysis is performed on the injection sequence using the analytical simulation framework by correcting 5000 randomly sampled injection states and compiling

statistics on the sequence performance. An injection covariance matrix has been provided by Orbital Science for a sample injection target. The covariance matrix is sampled assuming a Gaussian, zero mean distribution of correlated Keplerian orbital elements. The spacecraft state is propagated forward in time between maneuver epochs using analytical rate equations. The rates account for perturbations due to a non-spherical Earth and atmospheric drag. At each maneuver epoch, an impulsive maneuver (either in-plane, out-of-plane, or a combination of the two in the spacecraft RTN frame) is designed based on a predetermined framework of simulation logic statements [3]. These logic statements choose an appropriate maneuver attitude, magnitude, and true anomaly for implementation in the simulation; the designed maneuvers satisfy currently known operational constraints. In the simulation, these impulsive maneuvers account for 3-σ execution error to model spacecraft attitude and maneuver magnitude uncertainty. Following each simulation, an additional 5% ΔV magnitude is added to the sequence to account for finite burn losses (among other unmodeled effects). Sample analytical results are verified by simulating the injection sequence using a fully integrated trajectory model containing finite burns. Results (histogram of sequence ΔV and maneuver 99%ile values) are shown in Figure 1 for transferring from the ~ 568 × 664 km injection orbit target to the operational science orbit. Histogram plots of both single maneuver and sequence ΔV are used for sequence assessment.



Maneuver	99%ile ΔV (m/s)
INC-1	37.6
INP-2	22.3
INP-2	23.6
INC-2	0.50
INP-3	0.64
INP-4	0.33
Sequence	50.6 m/s

Figure 1: Sequence Statistics for ~ 568 × 664 km Injection Orbit.

In this paper, the SMAP injection sequence Monte Carlo analysis is discussed in detail. Statistical results for the current nominal launch vehicle target are presented in context of the mission ΔV budget. Results of the Monte Carlo analysis using the current injection orbit reports that the Injection Sequence ΔV 99% confidence level is 50.6 m/s; this value, along with the ΔV needed for all other mission activities, can currently be met by the 80 kg tank.

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Agency.

References

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