# MSL DSENDS EDL ANALYSIS AND OPERATIONS

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## ABSTRACT

The most recent planetary science mission to Mars is Mars Science Laboratory (MSL) with the Curiosity rover, launched November 26, 2011 and scheduled to land at Gale Crater on August 6, 2012. This rover is a large rover with a significantly larger and more advanced landing payload than any previous Mars lander mission. In addition, MSL will be the first use at Mars of a complete closed-loop Guidance Navigation and Control (GN&C) system, including guided entry with a lifting body (via center of gravity offset) to greatly reduce targeting errors during the Entry, Descent and Landing (EDL) phase. The hypersonic entry guidance enables the entry body to fly out the remnant delivery error from the final Trajectory Correction Maneuver (TCM) and other sources, resulting in less than a $25km \times 20km$ landing error relative to the selected Gale Crater landing target.

In order to achieve the above targeting criteria, high-fidelity simulation of approach and EDL is required, with the focus of this paper on the EDL phase. The tool used for approach TCM targeting and 6DOF EDL trajectory verification analysis is DSENDS. DSENDS is a high-fidelity simulation tool from JPL's Dynamics and Real-Time Simulation Laboratory for the development, test and operations of aero-flight vehicles. DSENDS inherently includes the capability to model a multi-body spacecraft with gravity, aerodynamics, sensors and thrusters. This capability is augmented for MSL with project-specific atmosphere, aerodynamics, sensors, thrusters and GN&C flight software to enable high-fidelity trajectory simulation.

This paper will present the operations experience of the JPL EDL trajectory simulation team, including both events to date and events from now until landing. To provide context an overview of the MSL project and the DSENDS tool is covered first. Details of the added MSL-specific models will be provided to define the simulation framework available for targeting, simulation and Monte Carlo analysis. Each of these three areas use the same DSENDS simulation tool but have significant configuration differences that will be explored. Targeting for cruise and approach maneuvers includes simulating the lifting nominal EDL trajectory in an in-plane open-loop EDL simulation mode and applying an offset between the cruise/approach and EDL reference trajectory planes to eliminate cruise stage recontact. Targeting also requires close integration with the maneuver design process, so the interface between the maneuver and EDL simulations is discussed. This open-loop EDL simulation is also used in a runout mode (vs targeting mode) for generation of Deep Space Network (DSN) station predictions for ground tracking of EDL. A weekly process of cruise navigation and maneuver design with EDL targeting is performed to update the expected maneuver and entry conditions for EDL based on the latest DSN-based navigation solutions. In

addition, high-fidelity EDL trajectory simulations are performed with these weekly solutions to supply trajectory and timing predictions of EDL events of interest. In order to determine dispersions about the expected trajectory, a selected set of EDL simulation input parameters are dispersed and multiple EDL full-fidelity simulations are executed. The results of these simulations are used to define statistics about the expected trajectory, timing and parameters of interest. These dispersed results provide a confirming simulation result for the prime MSL EDL simulation capabilities. Finally, other support functions such as onboard state initialization, landing hazard analysis and other post-processing are covered.