THE DEVELOPMENT OF THE MSL GUIDANCE, NAVIGATION, AND CONTROL SYSTEM FOR ENTRY, DESCENT, AND LANDING

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ABSTRACT

On August 5, 2012, the Mars Science Laboratory (MSL) mission successfully delivered the Curiosity rover to its intended target. It was the most complex and ambitious landing in the history of the red planet. A key component of the landing system, the requirements for which were driven by the mission ambitious science goals, was the Guidance, Navigation, and Control (GN&C) system. This paper will describe the technical challenges of the MSL GN&C system, the resulting architecture and design needed to meet those challenges, and the development process used for its implementation and testing.

EXTENDED ABSTRACT

On August 5, 2012, the Mars Science Laboratory (MSL) mission successfully delivered the one-ton Curiosity rover to its intended target, the bottom of Gale Crater. It was the most complex and ambitious Entry, Descent, and Landing (EDL) operation in the history of exploration of the red planet.

The complexity of MSL EDL was driven by a quantum leap in the EDL performance required to meet the mission ambitious science goals. Amongst these improvements in performance was the reduction of the landing ellipse by almost an order of magnitude, and the increase in rover mass by more than a factor of four, both in comparison to previous rover missions.

The Guidance, Navigation, and Control (GN&C) system was a key component in the MSL EDL design, and played major role in achieving the required improvement in EDL performance.

To meet the challenge of reducing the landing ellipse size, MSL GN&C incorporated Entry Guidance for the first time in a Mars mission. In this technique, the center of mass of the entry capsule is displaced from its axis of symmetry in order for the capsule to trim aerodynamically with a non-zero angle-of-attack, thus generating a Lift vector. Then an Entry Guidance algorithm adjusts the direction of this Lift vector by commanding changes to the capsule attitude through RCS thruster firings, based on navigation data from an Inertial Measurement Unit (IMU).
To meet the challenge of landing a one ton rover, the design of EDL used the SkyCrane, a new landing technique that lowers the rover gently to the ground suspended with bridles from a propulsive stage. This new landing architecture imposed unprecedented functional and performance requirements on the design and implementation of the GN&C system. Such system not only had to be stable during the operation of the SkyCrane but also had to achieve very low touchdown velocities in order not to damage the rover wheels upon impact nor damage the rover with the thruster plumes.

Designing and implementing a GN&C design that met all these new unprecedented capabilities and stringent requirements, required a major effort including the development of new landing radar, the Terminal Descent Sensor (TDS), the development of throtable terminal descent engines based on a Viking design, and the development of the GN&C algorithms and Flight Software that controlled the vehicle during the landing phase. In addition, the effort also required development and validation of detailed and complex models for simulations and analysis for end-to-end system performance evaluation.

This paper will describe the requirements and technical challenges of the MSL GN&C system, the resulting architecture and design needed to meet those challenges, and the development process used for its implementation and testing. It will also describe the testing campaign required to test and validate the relevant models such as the landing radar, the landing engines, the flexible structure, and the IMU. Finally, this paper will describe the methodology employed to develop and test the Flight Software, including the different testing environments, from MATLAB algorithm development, through Montecarlo simulations, and ending with hardware-in-the-loop testing in the flight vehicle.