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MESSENGER's Mercury Orbit Insertion Maneuver: Design Chronology, Contingency Preparedness, and Final Results

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Early on March 18, 2011, MESSENGER will become the first spacecraft to orbit the planet Mercury. This paper highlights major milestones in the design history, contingency preparedness, and final reconstruction of the 862 m/s Mercury orbit insertion (MOI) maneuver. The design history for this maneuver includes such improvements as a cost-saving, risk-reducing simplification from two maneuvers to one. Contingency preparedness analyses for MOI, one of the most thorough ever completed for an orbiter mission, revealed new insights into maneuver design and trajectory optimization that preserved the potential for full recovery from about 82% of all MOI under-burn scenarios. In addition, final results of MOI will be compared to the final design targets.

The design of MOI for the March 2011 Mercury arrival, first identified in 1998, underwent a number of improvements, refinements, and tests up until one year before orbit insertion. These improvements included a cost-saving simplification from a two-part MOI to a single MOI maneuver, refinements to maneuver ΔV minimization, and accuracy enhancements to the maneuver model determined from in-flight performance. Two in-flight maneuver tests boosted the MESSENGER flight team's confidence in the ability to complete the variable-thrust-direction requirement for MOI. To further prepare for the critical orbit insertion maneuver, several contingency strategies were developed.

Recovery options from an anomalous or missed MOI were identified, designed, documented, and practiced. For MOI ΔV completion less than 70%, the spacecraft would enter a new orbit around the Sun. For MOI ΔV completion greater than 70%, the spacecraft would enter orbit around Mercury. Contingency recovery plans were developed to use no more than two maneuvers to insert the spacecraft into the desired primary science orbit around Mercury. In the event that less than 52% of MOI ΔV was completed, the recovery strategy delayed the timing of the first of two recovery maneuvers until nearly three months after the missed or anomalous MOI. Additional strategies were designed for recovery for a number of problems that would place the spacecraft in a Mercury-centered orbit that fail to meet primary science orbit requirements.

In order to meet science requirements and engineering safety constraints, the MESSENGER spacecraft's initial primary science orbit must have a 200-km (± 25 km) periapsis altitude, 12-hour (± 10 minute) orbit period, and 119.1º argument of periapsis (60º N periapsis latitude, with 56º N to 62º N acceptable). The 82.5º (± 1º) initial inclination was chosen to ensure that end-of-mission inclination does not exceed 85.0º relative to Mercury's equator. The Mercury orbit-insertion strategy uses a single maneuver, minimizing the time and propellant required to deliver the spacecraft into the primary science orbit. This strategy uses one "turn while burning" variable-thrust-direction maneuver with the LVA (large velocity adjust) thruster operating during steady state at 683.5-N thrust, 316.1-s specific impulse, and a fuel-oxidizer mixture ratio of 0.84. The maneuver's timing and time-varying orientation were optimized to minimize propellant usage. The MOI maneuver slows the spacecraft's Mercury-relative velocity by orienting the thrust vector nearly opposite the instantaneous spacecraft velocity vector. Initial thrust time for MOI provides the best possible simultaneous link margin during MOI using antennas at Deep Space Network locations in Goldstone, California, and Canberra, Australia.