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IN-FLIGHT PROPULSION SYSTEM CHARACTERIZATION FOR BOTH MARS EXPLORATION ROVER SPACECRAFT

ABSTRACT FOR PAPER SUBMITTAL/APPROVAL (November, 2003)

The Mars Exploration Rover (MER) propulsion systems have performed excellently during the first few months of mission operations. Cruise stage propulsion systems were constructed at the Jet Propulsion Laboratory (JPL) for both the MER-A ("Spirit") and MER-B ("Opportunity") cruise stages, under NASA contract. MER is the scientifically ambitious follow-up to the highly successful Mars Pathfinder mission of 1997, largely an engineering demonstration for reduced-cost access to the Martian surface. MER-A was launched on June 10, 2003, with arrival set for January 3, 2004. MER-B followed a few weeks later, with launch on July 7, 2003 and landing slated for January 24, 2004.

The MER cruise stage propulsion system is a relatively simple, monopropellant, blowdown hydrazine design, utilizing two titanium propellant tanks, two pressure transducers, service valves, two latch valves, propellant line heaters, a propellant filter, and a myriad of propellant feed lines. The MER retinue of rocket engines includes eight 5-N monopropellant hydrazine thrusters, four in each oppositely mounted cluster. The MER thruster geometry is essentially the same as Mars Pathfinder, allowing full redundancy for attitude, spin, pointing, and trajectory correction with a minimum number of rocket engines. This geometry, however, is not optimal with respect to propellant utilization, given the large cosine losses. However, this is of no concern for the MER mission, given the large propellant reserves. MER-A and MER-B were launched with 52 kg of hydrazine each; the remaining hydrazine mass (with little expected to be used through end of mission) is estimated at 32 kg for MER-A and 39 kg for MER-B.

An assessment has been made of MER propulsion telemetry (mostly pressures and temperatures) during the first few months of mission operations. Generally, the trends seen in propulsion data are as expected and are well understood. For example, difference plots of multiple pressure transducer channels vs. time have demonstrated no discernible pressure transducer drift, the same result as Cassini (cf. AIAA-2002-4152, "Initial Cassini Propulsion System In-Flight Characterization"). This is in stark contrast to the linear pressure sensor drifts noted on other interplanetary missions (e.g., TOPEX, Voyager, and Galileo, cf. AIAA-97-2946,

"Final Galileo Propulsion System In-Flight Characterization"). The MER mission is short enough that only relatively large pressure transducer drifts would be discernible at this point; however, drifts of the same size as noted for Galileo, TOPEX, and Voyager should just be perceptible by the end of the MER cruise mission.

Propulsion consumables on MER have generally not been tracked since launch, except for propellant. Consumable usage has generally been close to predicted values, but much less than the capability of the propulsion system. There is no concern for exceeding any propulsion consumable limit during the MER mission.

Each MER cruise stage has executed two TCMs (Trajectory Correction Maneuvers) en route to Mars (to date). Maneuver performance has generally been excellent, within a few percent of expectations. This is important for MER, since maneuvers are done "open loop" and thus TCM burn time prediction errors translate into trajectory errors.

The first MER-A TCM, TCM-A1, had about 2.7% less delivered thrust than expected for the axial (negative z-axis) portion of the maneuver. This is in contrast to the lateral portion of the burn, which suggested around 1.5% more delivered thrust than expected. Propulsive models were updated based on TCM-A1 data, generally incorporating inferred shifts but also biasing slightly against overburns, which are more costly. TCM-A2 apparently showed further thrust degradation for the axial thrusters of a few percent; the TCM-A2 lateral component was not observable due to a poor Earth-look angle (near ninety degrees).

The initial MER-B TCM, TCM-B1, was a purely axial maneuver in the negative z-direction. The inferred thrust was around 4.4% lower than the expected thrust for the TCM-B1 actual tank pressure; perhaps plume impingement losses are greater than expected. TCM-B2 was very similar to TCM-A2, in that the maneuver was comprised of a negative z-axis axial portion followed by an unobservable (in Doppler) lateral portion. The thrust level "rebounded" slightly during TCM-B2, leading to an axial overburn of +1.4%. Neither spacecraft has performed a positive z-axis maneuver, but that capability exists. Tweaking the thruster models should lead to improved maneuver accuracy during Mars approach.

Attitude control thruster performance will be investigated during turns, pointing corrections, and spin rate corrections. Actual impulse bits as delivered by the thrusters will be compared to thruster ground models for impulse bit vs. on-time. These data may help refine the impulse bit models, which will lead to better models for pulse-mode hydrazine consumption for the 5-N thruster. An early result from analyzing spindown thruster performance on both spacecraft suggests that the delivered thrust is 2.3-2.8% lower than expected, based on flight acceptance test data.

A comparison of three different hydrazine consumption models will

be made at the end of the mission. Hydrazine mass remaining may be calculated from (1) pressure and temperature telemetry, (2) reconstructed hydrazine usage during propulsive maneuvers, and (3) an on-board estimate of remaining hydrazine mass, essentially a simplified version of (2). Insight is expected from the discrepancies and trends in these data sets.

The in-flight characterization of both MER-A and MER-B cruise stage propulsion systems are in progress. All critical propulsion functions that will be required for the remainder of the mission, including EDL (entry, descent, and landing), have been demonstrated. In summary, both MER propulsion systems have performed very well during the first few months of cruise to Mars. The prospects for a successful EDL and surface mission remain excellent for both spacecraft.