MESSENGER's Use of Solar Sailing for Cost and Risk Reduction

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The use of planetary gravity assists for deep-space missions is well documented. In most cases, the equivalent ΔV provided by the planetary flyby is mission enabling, because providing this ΔV via chemical propulsion either costs too much or requires a substantial reduction in the mass allocated to the mission payload. The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) mission used six planetary gravity assists in order to enable Mercury orbit insertion. The spacecraft was launched in August 2004 and successfully completed one Earth flyby, two Venus flybys, and three Mercury flybys before performing its orbit insertion maneuver in March 2011. A key element of MESSENGER's successful trajectory was achieving the proper gravity assist from each planetary flyby.

The criticality of the MESSENGER gravity assists levied tight accuracy requirements on the planetary-flyby targeting. Furthermore, MESSENGER's trajectory design required low-altitude Mercury flybys. Mission risk increases by targeting Mercury flyby altitudes near 200 km, as significant probability of impact remains up until months before the flyby. Less spectacular but equally damaging to the mission would be missing the closest-approach aim point by too great a distance. If the flyby were too distant from the planned aim point at closest approach, MESSENGER would need to use its propellant reserves to correct for the off-nominal gravity assist. For a large flyby targeting error, limited propellant reserves could prevent MESSENGER from returning to its nominal trajectory. Major errors could preclude Mercury orbit insertion or require modifications to the trajectory that increase mission complexity, cost, and risk by requiring additional Mercury flybys and extending mission duration. Accurate flybys preserve reserve propellant use for completion of the mission and for mission extension.

Throughout the mission, MESSENGER modified its strategy for achieving accurate planetary flybys. MESSENGER's Earth and Venus gravity assists used several propulsive maneuvers prior to each flyby to achieve the desired targeting in a manner that is typical for spacecraft using chemical propulsion. Although these maneuvers did not require much ΔV, they added cost and risk to the program because of the substantial effort required to plan and implement trajectory-correction maneuvers. Prior to the first Mercury flyby, MESSENGER successfully made use of solar radiation pressure on the spacecraft in lieu of a propulsive maneuver to improve the flyby targeting. The application of solar sailing was refined for the second and third Mercury flybys as well as for the approach to Mercury for the orbit insertion maneuver. This paradigm shift eliminated all planned flyby targeting and post-flyby clean-up maneuvers, reducing the flyby cost and decreasing the workload on spacecraft operators. Further, by using solar sailing to correct errors at the flybys, the flyby accuracy was improved, as solar sailing offers greater precision than the conventional targeting with trajectory-correction maneuvers.