The Final Two Years: MESSENGER's Trajectory from the Third Year in Orbit through Mercury Impact

Dawn P. Moessner[1] **and James V. McAdams**[2]

[1] *MESSENGER Mission Design Analyst, The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel MD, 20723, 443-778-9137, Dawn.Moessner@jhuapl.edu*

[2] *MESSENGER Mission Design Lead Engineer, The Johns Hopkins University Applied Physics Laboratory, 11100 Johns Hopkins Road, Laurel MD, 20723, 443-778-8685, Jim.McAdams@jhuapl.edu*

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ABSTRACT

The MErcury Surface, Space ENvironment, GEochemistry, and Ranging (MESSENGER) spacecraft, designed and operated by The Johns Hopkins University Applied Physics Laboratory (JHU/APL) in Laurel, Maryland, began its Second Extended Mission (XM2) on 18 March 2013 after successful completion of its Primary Mission and First Extended Mission (XM1). This XM2 orbital phase will continue until the spacecraft impacts Mercury in late March 2015. During XM1, the MESSENGER team evaluated several XM2 options that efficiently utilized all remaining available propellant to extend mission duration and achieve the proposed scientific objectives. Among the many factors that were considered when designing the XM2 trajectory and associated maneuvers were propellant management, altitude selection for periods during which periapsis altitude changes little over several successive orbits, spacecraft thermal management, timing of communication-disrupting solar conjunctions, expected levels of solar activity, visibility of Earth near periapsis, and surface lighting during periods of lower altitude and over selected regions. Moreover, in November 2013, MESSENGER observed short-period comet Encke near its perihelion and hyperbolic-orbit comet 2012 S1 ISON shortly before its perihelion from distances as close as 0.0249 AU and 0.2420 AU, respectively.

The spacecraft's orbit is continually evolving through XM2 due to a variety of perturbations, including those due to solar gravity, spatial variations in Mercury's gravity field, and solar radiation pressure, as well as planned maneuvers. The spacecraft is in an orbit with an 8-h period for the first 15 months of XM2, a time when periapsis altitude decreases from around 450 km to 115 km just prior to the ninth orbit correction maneuver (OCM-9) on 17 June 2014. Throughout XM2, the periapsis latitude continually decreases from a mission peak of 84° N to a mission low of 58° N. As a result of four OCMs, the orbit period will increase from $8^h\ 0^m$ prior to OCM-9 to $8^h\ 17^m$ after OCM-12 on 21 January 2015. The progression of periapsis altitude and latitude throughout XM2 can be seen in Figure 1. The purpose of OCMs 9-11 during the latter part of XM2 is to target times before the next OCM when periapsis altitude settles with little variation over many orbits to about 25 km above the terrain features beneath the spacecraft. The final planned OCM, OCM-12, targets an extended period when periapsis altitude settles with little variation over many orbits to about 15 km. The combined periapsis-raising effect of OCMs 9-12 will delay Mercury surface impact from August 2014 until March 2015. This low-periapsis-altitude campaign results in approximately 200 orbits with periapsis altitudes at or below 30 km.

Several factors, including spacecraft heating and planetary lighting, were carefully considered when designing the low-periapsis-altitude campaign. Marked on Figure 1 are "hot seasons," periods when the spacecraft crosses Mercury's equatorial plane closest to local solar times of noon and midnight and the orbit periapsis occurs over the Sun-facing side of the planet. This orbit orientation causes solar radiation reflected off of Mercury's surface to increase the environmental thermal input on the spacecraft's anti-Sun surfaces when the spacecraft is at low altitudes over Mercury's sunlit surface, thus elevating spacecraft operating temperatures. Although periods of low-altitude operation during a hot season increase spacecraft temperature nearly to allowable limits, Mercury surface visibility was also considered. The surface is not visible at periapsis when the solar incidence angle at periapsis is greater than 84°. Although the surface may not be visible during the lowest altitude of the orbit (i.e., periapsis) during such times, the surface is still visible from higher altitudes when the spacecraft is in other portions of the orbit. As seen in Figure 1, periods of surface visibility at periapsis occur around a hot season. In the current trajectory design, the first and last intervals with nearly steady low periapsis altitude occur soon after a hot season with periapsis altitudes near 50 km. The second and third intervals with nearly steady low periapsis altitude, in contrast, do not occur shortly after a hot season.

Trajectory perturbations, in combination with planned OCMs, cause changes in the spacecraft's orbit, including variations in periapsis altitude that lead to Mercury impact on or near 28 March 2015. Although the impact of the spacecraft onto the surface of Mercury in late March 2015 will not be visible from Earth, impact should occur before communications are disrupted by a solar conjunction in early April 2015. Both the impact time and periapsis altitude targets are calculated using the spacecraft altitude above terrain rather than the altitude above a reference spherical surface. This calculation has been accomplished with a digital elevation model released in January 2013 by Robert Gaskell of the MESSENGER Science Team.

In this paper we summarize MESSENGER's orbit evolution from the beginning of the third year in Mercury orbit on 18 March 2013 through Mercury impact on 28 March 2015. Included are details of OCMs 9-12, including operational implementation and effects on the spacecraft's orbit as well as information on the low-periapsis-altitude campaign enabled by these maneuvers.

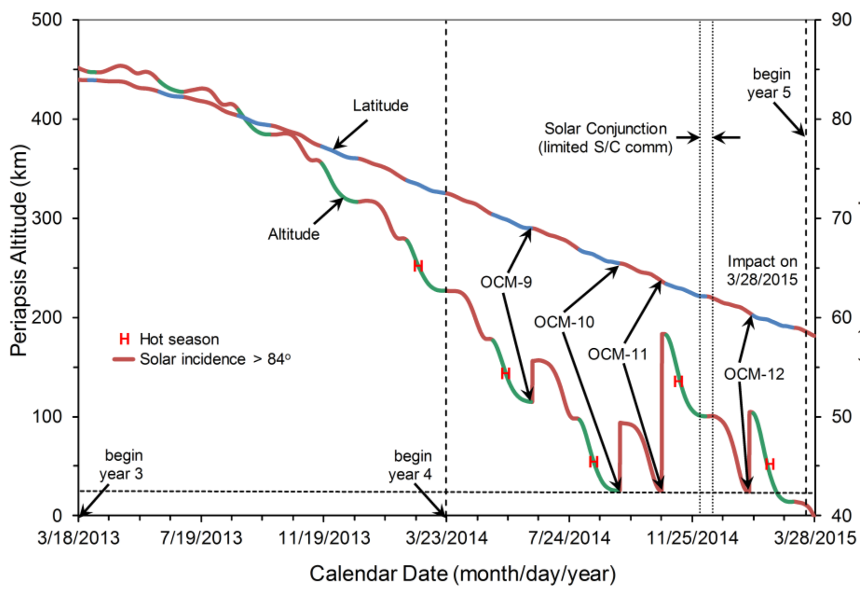

Figure 1: Mercury periapsis progression during MESSENGER's Second Extended Mission