50,000 Laps Around Mars: Navigating the Mars Reconnaissance Orbiter Through The Extended Missions (January 2009 – March 2017)

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The Mars Reconnaissance Orbiter (MRO) spacecraft was launched from Cape Canaveral Air Force Station on August 12, 2005, and following an interplanetary cruise of seven months, attained an orbit around Mars on March 10, 2006. After five months of aerobraking and three months of transition to the Primary Science Orbit (PSO), MRO began science operations in November 2006. Over ten years later, MRO continues to perform valuable science observations at Mars, provide telecommunication relay for surface assets, and characterize landing sites for future missions. Previous papers reported on the navigation of MRO from Mars orbit insertion through the end of the Primary Science Phase (PSP) in December 2008 [1, 2]. This paper will highlight the navigation of MRO through the extended missions from January 2009 through March 2017, specifically the Extended Science Phase and four extended missions. The MRO Navigation Team has been providing mission support through all these mission phases by performing the spacecraft orbit determination (OD) and maintaining the PSO through propulsive maintenance maneuvers. This manuscript will also describe the driving performance requirements levied on Navigation and how well those requirements have been met during the extended missions.

MRO operations for PSO is a 252 km $\times$ 317 km altitude, sun-synchronous orbit with the periapsis frozen over the south pole and the ascending node at 3:00 PM $\pm$ 15 minutes. Ideally the orbits are designed to exactly repeat after 4602 orbits in 349 sols (1 sol = 1.0275 Earth days) providing sub-5 km coverage at the equator. The near repeat cycle used for science planning is a 211-orbit cycle (16 sols) that walks about 0.5 deg (32.5 km) in longitude westward from the previous cycle. The orbit maintenance is done based on this near repeat cycle via propulsive maneuvers. In addition to these requirements for PSO, there are other drivers that define the weekly operational scenario for the science phase:

1. *Long-term prediction:* Off-nadir target angles must not change by more than 3° 28 days after OD data cutoff.
2. *Short-term prediction:* Predict Mars-relative position to within 1.5 km downtrack.
3. *Reconstruction:* Reconstruct Mars-relative position to within 100 m downtrack, 40 m crosstrack & 1.5 m radial.
4. *EDL relay & overflight phasing:* Perform maneuvers to phase the spacecraft in true anomaly as required to provide UHF communications to a lander during its entry, descent, and landing (EDL) phase or during overflights.

As an asset of the Mars Exploration Program Office, MRO continues to perform science observations and has provided telecommunication relay support to the Mars Exploration Rover (January 2004 – present), Mars Phoenix Lander (May 2008), and Mars Science Laboratory (August 2012 – present) [3]. It has also observed the close flyby of Comet Siding Spring at Mars in October 2014 [4] and imaged the ExoMars lander Schiaparelli in October 2016. MRO plans to provide telecommunication support for the EDL phases of the Red Dragon (SpaceX) and InSight (NASA) missions in November 2018. MRO is expected to reach its 50,000th orbit around Mars in March 2017. Since the beginning of the PSP in November 2006, MRO's navigation performance has continued to exceed expectations. This was no insignificant feat given the challenges of flying a low orbit and the variability of the Mars atmosphere, especially in achieving the tight accuracy requirements for MRO's high-resolution camera HiRISE.

References

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