Magnetospheric Multiscale Mission Navigation Performance Using the Goddard Enhanced Onboard Navigation System

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Abstract:

The Magnetospheric Multiscale Mission (MMS) is one of the most complex missions—from a flight dynamics perspective—that NASA Goddard Space Flight Center (GSFC) has ever flown. This mission consists of four identical spinning spacecraft with onboard orbit and time determination, provided by a weak-signal Global Positioning System (GPS) receiver and the Goddard Enhanced Onboard Navigation System (GEONS) software. The science objectives of the MMS mission require the four spacecraft to fly in a tetrahedral formation over highly eccentric Earth orbits. To address the primary science objective, which is the magnetic reconnection phenomena in Earth's magnetosphere, the mission is designed to provide the science data into two phases. Phase 1 collects data for the day side of the magnetic field when the spacecraft formation is resized from a 160-km down to 10-km scale size on a 1.2 Earth Radii (RE) × 12 RE orbit. Phase 2 collects the data for the night side of the magnetic field when the apogee of the orbit is raised to 25 RE and the spacecraft formation is resized from a 400-km down to a 30-km scale size. To achieve and maintain the desired formations during Phases 1 and 2, a series of resize and maintenance maneuvers are required and are executed in pairs.

Prior to MMS launch, the MMS navigation team has performed extensive analyses using realistically simulated GPS measurements to both characterize the expected GEONS performance and to determine the accuracy of spacecraft state and covariance solutions against MMS navigation requirements. This paper will present the results of GEONS performance analysis based on flight data collected during the commissioning phase of the MMS mission.

The key navigation requirements, which are derived from the MMS mission-level requirements, are summarized below. These requirements apply to GEONS solutions over the region of prime science interest, which is characterized as above 3 RE and outside of the maneuver recovery period (starting from the end of a maneuver until the first perigee after the maneuver).

- The science requirement for the definitive relative orbit knowledge is that the error in separation distance of a pair of spacecraft does not exceed the greater of 1% of separation or 100 m.
- Based on the mission level inter-spacecraft range (ISR) tolerance during close approach (CA), two onboard requirements are derived for the absolute and relative semi-major axis errors. Carpenter[1] has previously shown that the in-track errors result primarily from the semi-major axis errors, where the maximum and minimum errors occur at perigee and apogee, respectively. Therefore, a 6-km ISR at perigee over 4 orbital revolution sets a 50-

[1] Carpenter, J. Russell, "MMS Orbit Propagation Sensitivity to Navigation Errors," Volume 135 of the Advances in the Astronautical Sciences Series, AAS/AIAA Astrodynamics Conference, Aug. 9-13, 2009, Pittsburgh, PA. Pub. 2010. Paper Number AAS 09 – 323.

meter limitation on the semi-major axis errors of a single spacecraft during Phase 1 (eccentricity = 0.8181, 1.2 RE x 12 RE). The same CA requirement can be interpreted to set a 70-meter constraint on the relative semi-major axis errors between two spacecraft.

- The following navigation requirements are derived based on formation maneuver planning accuracy requirements during Phases 1 and 2 of the mission. For the first maneuver, the error in each component of the predicted velocity vector shall not exceed the greater of 1% of the associated component of the equivalent impulsive delta-V vector or 10 mm/s, where the prediction starts at one or two Space Network (SN) contacts prior to the maneuver. For the second maneuver, the error in each component of the predicted velocity vector shall not exceed the greater of 1% of the associated component of the equivalent impulsive delta-V vector or 2 mm/s, where the prediction starts at the SN contact post first maneuver and prior to the second maneuver.

To verify that GEONS can provide solutions that satisfy these requirements, Monte Carlo analyses of simulated data were conducted prior to launch. The requirements are met at all times except for the case where the error in the separation distance of a pair of spacecraft exceeds the requirement for few hours during the maneuver recovery period of the second maneuver. To ensure the definitive relative requirement is satisfied at all times, the GEONS solution downloaded at SN contact post perigee of the second maneuver is back propagated to the end of the maneuver and combined with the rest of the ephemeris and delivered as the final product to project scientists. A sample plot in Figure 1 indicates that the definitive relative results are significantly improved after back propagation.

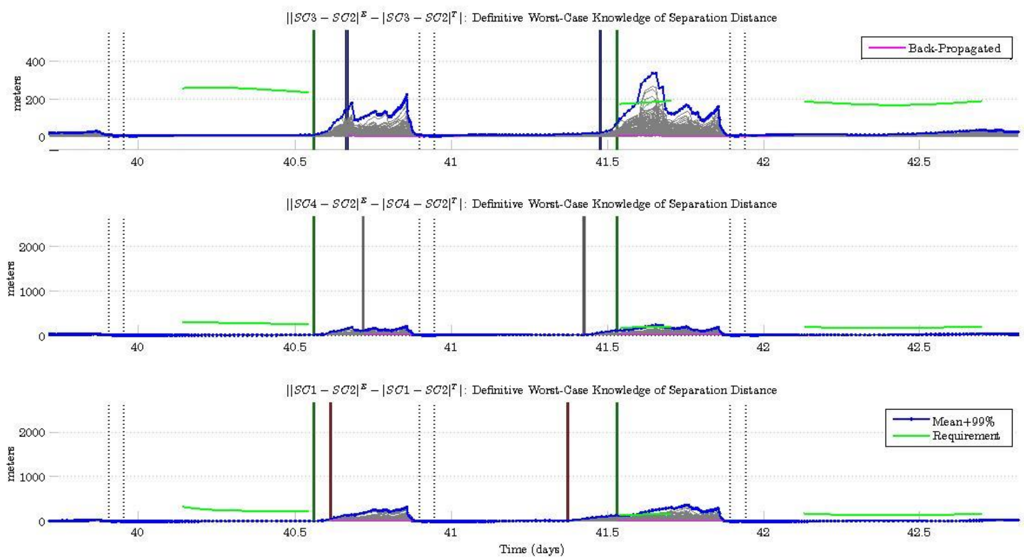

Figure 1. Definitive Relative plot for a pair of MMS spacecraft at the maneuver resize to 10 km formation.

An extensive evaluation of GEONS in-flight performance will be performed during the commissioning phase of the mission. A summary of the results will be presented in this paper.