Lunar Reconnaissance Orbiter Orbit Determination Accuracy Analysis

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ABSTRACT

The Goddard Space Flight Center (GSFC) Flight Dynamics Facility (FDF) performs daily operational orbit determination (OD) and related product generation for LRO, using tracking data primarily from the White Sands WS1 station (designated WS1S by the FDF), and from Universal Space Network (USN) tracking stations located in Hawaii, Sweden, and Germany. LRO takes approximately twelve 20- to 60-minute tracking passes each day, with the tracking stations providing angles, range, and Doppler observations. The FDF performs OD daily, seven days per week, using the Goddard Trajectory Determination System (GTDS).

The Lunar Reconnaissance Orbiter (LRO) launched in June 2009 and began its mapping mission in September 2009. After arrival at the Moon in 2009, LRO was navigated into an elliptical 40 km by 200 km altitude commissioning orbit, where it remained from 27 June 2009 until 15 September 2009, when it entered its 50-km circular mission orbit. LRO completed a two-year mapping mission in December 2011, and on 11 December 2011 was returned to the early-mission commissioning orbit.

The LRO orbit requirements for FDF OD and prediction are:

- The FDF shall provide orbit determination support to LRO during all mission phases with an accuracy of 500 meters total position root mean squared (RMS) and 18 meters radial RMS.
- Predicted orbit accuracy shall be 800 meters root sum squared (RSS) over an 84-hour prediction span.

During the 2009 period in the commissioning orbit there were no definitive accuracy violations and five violations of the 84-hour predictive accuracy requirement. While in its mission orbit, over a two-year period, there was only one violation of the RMS radial requirement, there were no violations of the RMS total position requirement, and three violations of the 84-hour prediction requirement. Starting in mid-May 2012, after the return to the commissioning orbit in late 2011, the FDF began to observe a significant increase in the frequency of LRO orbit determination definitive and predictive accuracy violations.

Investigation of this issue began in June 2012 and quickly focused on the gravity model employed for LRO OD. Newer gravity models were obtained from the LRO and GRAIL science teams, and 120-day series of reprocessing runs covering March to July 2013 were performed to assess the gravity models. Additional improvements were also investigated, including adjusting the tracking data fit span, measurement bias estimation parameters, and data usage, as well as implementing refined solar radiation pressure modeling.

This analysis presents details of this investigation. In particular, it assesses the accuracy and utility of recent lunar gravity models for LRO mission operations orbit determination support compared with previous models. It also describes the current means and methods of FDF OD support for LRO, the OD accuracy obtainable using S-Band tracking and legacy orbit determination tools, and the limitations and challenges to be overcome toward further improving operational lunar orbit determination accuracy.

The results of the analysis show that the newer gravity models significantly improve LRO OD accuracy, but SRP effects still significantly degrade prediction accuracy during twice-yearly full-Sun exposure periods. Based on this analysis, the FDF implemented the LLGM-2 gravity model for LRO in 2012, later moving to a GRAIL-derived model in 2013.

The following conclusions are presented:

- The LP150Q model is inadequate for LRO OD accuracy requirements in the commissioning orbit, and shows some qualitative evidence of degradation in performance during the mission orbit due to the drift of LRO’s inclination.
- Given the dense tracking that LRO receives, a 36-hour tracking data arc for OD yields better definitive and predictive accuracy than a 60-hour arc when using batch least squares estimation.
- Gravity model errors and orbit geometry are the predominant definitive orbit error sources. Newer gravity models are significant improvements over the LP150Q model, but present challenges to operations due to their high fidelity.
- SRP effects significantly affect orbit prediction accuracy when LRO is in its full-Sun orbit periods, twice per year (in December-January and June-July). Estimating SRP is possible with a detailed box-and-wing spacecraft area model that incorporates specular and diffuse coefficients of reflectivity. This method improves prediction accuracy during full-Sun exposure, but is currently impractical for daily operations.