ARTEMIS Orbit Determination Accuracy in the Earth-Moon Lissajous Region

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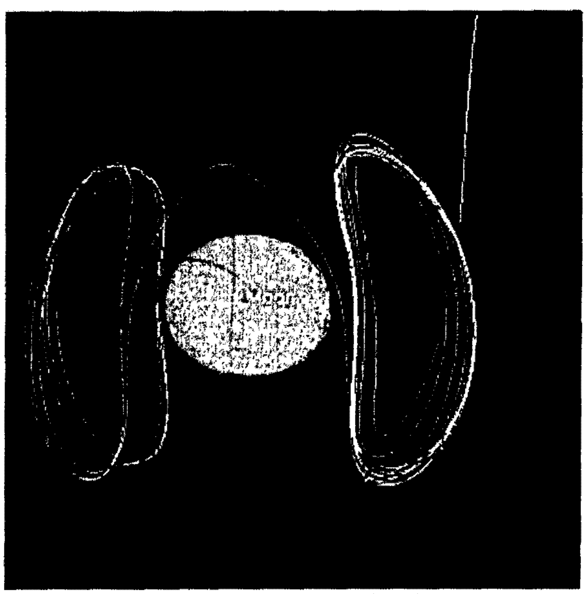
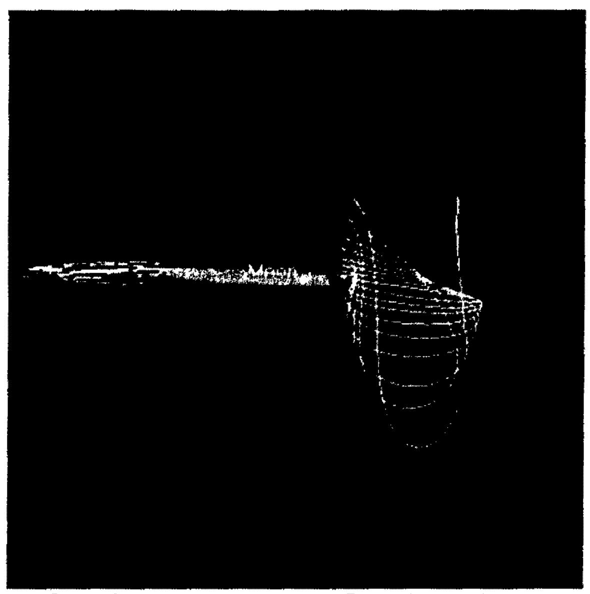
ABSTRACT

The ARTEMIS mission, part of the THEMIS extended mission, is the first to fly spacecraft in the Earth-Moon Lissajous regions. In 2009, two of the five THEMIS spacecraft were redeployed from Earth-centered orbits to arrive in Earth-Moon Lissajous orbits in late 2010. Starting in August 2010, the ARTEMIS P1 spacecraft executed numerous stationkeeping maneuvers, initially maintaining a lunar L2 Lissajous orbit before transitioning into a lunar L1 orbit. The ARTEMIS P2 spacecraft entered a L1 Lissajous orbit in October 2010. In April 2011, both ARTEMIS spacecraft will suspend Lissajous stationkeeping and will be maneuvered into lunar orbits. The success of the ARTEMIS mission has allowed the science team to gather unprecedented magnetospheric measurements in the lunar Lissajous regions.



P1 Orbit in Earth-Moon X-Y Lissajous Plane



P1 Orbit in Earth-Moon X-Z Lissajous Plane

In order to effectively perform lunar Lissajous stationkeeping maneuvers, the ARTEMIS operations team has provided orbit determination solutions with typical accuracies on the order of 0.1 km in position and 0.1 cm/s in velocity. The ARTEMIS team utilizes the Goddard Trajectory Determination System (GTDS), using a batch least squares method, to process range and Doppler tracking measurements from the NASA Deep Space Network (DSN), Berkeley Ground Station (BGS), Merritt Island (MILA) station, and United Space Network (USN). The team has also investigated processing of the same tracking data measurements using the Orbit Determination Tool Kit (ODTK) software, which uses an extended Kalman filter and recursive smoother to estimate the orbit. The orbit determination results from each of these methods will be presented and we will discuss the advantages and disadvantages associated with using each method in the lunar Lissajous regions.

Orbit determination accuracy is dependent on both the quality and quantity of tracking measurements, fidelity of the orbit force models, and the estimation techniques used. Prior to Lissajous operations, the team determined the appropriate quantity of tracking measurements that would be needed to meet the required orbit determination accuracies. Analysts used the Orbit Determination Error Analysis System (ODEAS) to perform covariance analyses using various tracking data schedules. From this analysis, it was determined that 3.5 hours of DSN TRK-2-34 range and Doppler tracking data every other day would suffice to meet the predictive orbit knowledge accuracies in the Lissajous region. The results of this analysis are presented.

Both GTDS and ODTK have high-fidelity environmental orbit force models that allow for very accurate orbit estimation in the lunar Lissajous regime. These models include solar radiation pressure, Earth and Moon gravity models, third body gravitational effects from the Sun, and to a lesser extent third body gravitational effects from Jupiter, Venus, Saturn, and Mars. Increased position and velocity uncertainties following each maneuver, due to small execution performance errors, requires that several days of post-maneuver tracking data be processed to converge on an accurate post-maneuver orbit solution. The effects of maneuvers on orbit determination accuracy will be presented, including a comparison of the batch least squares technique to the extended Kalman filter/smoother technique. We will present the maneuver calibration results derived from processing post-maneuver tracking data.

A dominant error in the orbit estimation process is the uncertainty in solar radiation pressure and the resultant force on the spacecraft. An estimation of this value can include many related factors, such as the uncertainty in spacecraft reflectivity and surface area which is a function of spacecraft orientation (spin-axis attitude), uncertainty in spacecraft wet mass, and potential seasonal variability due to the changing direction of the Sun line relative to the Earth-Moon Lissajous reference frame. In addition, each spacecraft occasionally enters into Earth or Moon penumbra or umbra and these shadow crossings reduce the solar radiation force for several hours. The effects of these events on orbit determination accuracy will be presented.

In order to plan for upcoming stationkeeping maneuvers, the maneuver planning team must take the current orbit estimate, propagate it forward to the planned maneuver time, and determine the optimal maneuver to maintain the Lissajous orbit for one or more revolutions. The propagation is performed using a Runge-Kutta 7/8 integrator and typically the position and velocity uncertainty increases with propagation time, increasing the overall uncertainty of the orbit state at the maneuver execution time. The effect of orbit knowledge uncertainty on stationkeeping operations will be presented.