Mars Odyssey Mapping Orbit Determination

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Extended Abstract

The Odyssey spacecraft has successfully completed the first year of its primary mapping mission. Part of the credit of the success can be attributed to the ongoing determination of the Odyssey orbit, which has exceeded the science requirements. This paper will present the orbit determination (OD) strategy employed by the Odyssey navigation team, as well as the major challenges and accomplishments of the navigation process.

A proper discussion of the OD process must include three major elements: the collection of observations, the modeling of dynamic forces, and the filter. The observations are provided by the Deep Space Network (DSN), which measures the radio signal to produce range and Doppler measurements. In Odyssey's case, the primary data type is two-way, coherent Doppler. The dynamic model accounts for any forces acting on the spacecraft such as gravity, solar radiation pressure, and thruster events. A high resolution gravity model, MGS75C, which was developed using Mars Global Surveyor data, has enabled greatly improved Odyssey navigation accuracy. The OD filtering software, which was developed at the Jet Propulsion Laboratory, incorporates a modified batch, weighted least-squares, square-root information filter. The filter formulation also allows for stochastic parameter estimation, which is used to estimate the angular momentum desaturation perturbations.

Perhaps the greatest OD challenge is the modeling of angular momentum desaturation (AMD) events. Odyssey maintains three-axis stability using reaction wheels, which need to be regularly desaturated by firing reaction control system (RCS) thrusters. Since the RCS thrusters are not balanced or coupled, the AMD events cause a translational acceleration that perturbs the orbit. The equivalent change in velocity (ΔV) is typically between two and six mm/s, with an estimated uncertainty of up to one mm/s. The navigation team has typically been able to model these AMD events to within ten percent, however they remain the largest error source in the prediction solutions.

The navigation team delivers two distinct products: trajectory reconstructions and predictions. Reconstructions typically involve fitting twenty-four orbits of Doppler data (approximately two days). In addition to the spacecraft state, several dynamic parameters are estimated, such as atmospheric density, solar radiation pressure, periodic acceleration terms, and a subset of the spherical harmonic gravity coefficients. In addition, the AMD ΔVs must be estimated. An ideal ΔV can be computed using an empirical formula, however mis-modeling and thruster impingement cause errors in this ideal value. These errors are estimated using stochastic parameters. Based on overlap analysis, reconstructed position errors are generally less than twenty meters.

Prediction solutions are nominally delivered once a week and typically involve fitting three to twelve orbits of Doppler data. The trajectory is then propagated forward in time using the dynamic model. In order to ensure the most accurate prediction possible, the model incorporates the estimated state as well as the estimated dynamic parameters from the OD fit. The Odyssey flight team has developed a momentum management strategy that yields AMD events with predictable timing and imparted ΔV. The accuracy of the

predicted trajectory is determined using reconstruction solutions. The timing errors (measured at the descending equator crossing) are normally less than a few tenths of a second after seven days and less than a few seconds after twenty-one days. In order to meet requirements, the timing error of the predicted trajectory must be less than 2 seconds. At the beginning of mapping, prediction solutions were delivered twice per week in order to ensure that the requirement was met. However, due to the consistent accuracy of the solutions, it was evident that the requirement could still be met by reducing the solution frequency to once per week.

Because the AMD events are well understood, the Odyssey AMD strategy has also been used to control the orbit ground track walk. Towards the beginning of mapping, it was observed that the AMD events were causing the ground track walk to drift away from the desired repeat cycle. It was then determined that if the AMD events were forced to occur on the opposite side of the orbit (i.e., near periapsis, rather than near apoapsis), the drift in the ground track walk could be reversed. As shown in Figure 1, this phenomenon has been used to control the ground track walk without the use of orbit maintenance maneuvers.

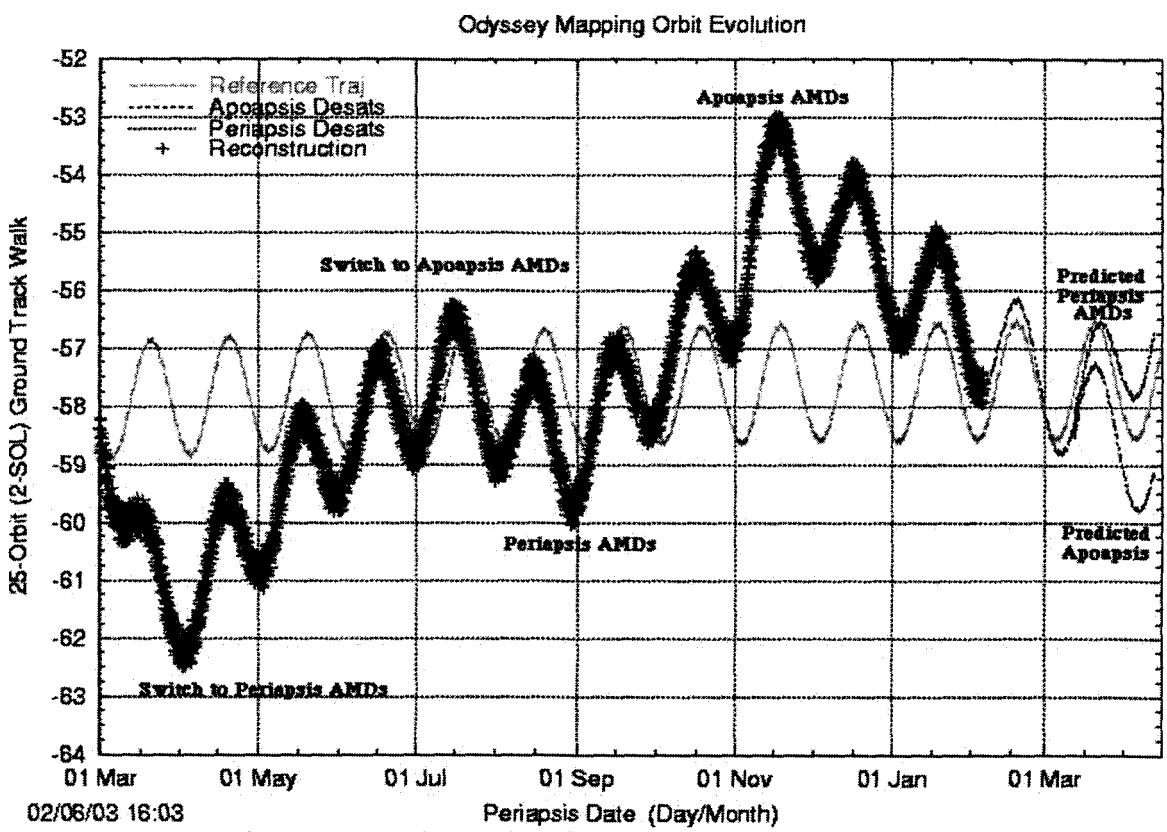

Figure 1: As shown in the above plot, the ground track walk can be controlled by choosing which side of the orbit the AMDs are triggered.

Condensed Abstract

The Odyssey spacecraft has successfully completed the first year of its primary mapping mission. Part of the credit of the success can be attributed to the ongoing determination of the Odyssey orbit, which has exceeded the science requirements. This paper will present the orbit determination (OD) strategy employed by the Odyssey navigation team, as well as the major navigation challenges and accomplishments. The most significant challenge in the OD process has been the trending and modeling of angular momentum desaturation (AMD) events, which significantly perturb the orbit. The predictable nature of the Odyssey momentum management strategy has allowed the navigation team to accurately model the trajectory perturbations due to the AMD thruster firings. In addition, the AMD perturbations have been used to control the desired orbit characteristics, mitigating the need for orbit maintenance maneuvers.