Orbit Transfers for Dawn's Vesta Operations: Navigation and Mission Design Experience

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ABSTRACT

Dawn, as a mission belonging to NASA's Discovery Program, was launched on September 27, 2007 to explore main belt asteroids in order to yield insights into important questions about the formation and evolution of the solar system. Its objective is to acquire data from orbit around two complementary bodies, Vesta and Ceres, the two most massive asteroids in the main belt. From July of 2011 to August of 2012, the Dawn spacecraft returned much valuable science data, collected during the four planned mapping orbits at its first target asteroid, Vesta. Each orbit was designed to enable a different set of scientific observations. Such a mission would have been impossible without the low thrust ion propulsion system (IPS).

Maneuvering a spacecraft only using the IPS for the transfers between the mapping orbits posed many technical challenges to Dawn's flight team at NASA's Jet Propulsion Laboratory. Each transfer needs a robust plan that accounts for uncertainties in maneuver execution, orbit determination, and physical characteristics of Vesta. This plan must meet the requirements of the target orbit and spacecraft safety, and it also needs to include margin to accommodate unforeseen anomalies. The plan also must be compatible with the capabilities of the operations team, which was limited in size by funding.

The use of an IPS dictates some fundamental differences from missions that rely on conventional chemical propulsion. Dawn's transfer phase typically take several weeks of time encompassing many orbits around Vesta and cannot be flown in one design. Each transfer is broken into several design cycles to ensure controllability. The individual design cycle durations vary from one month long in the early approach phase to a short two days in transfer to and from the low altitude mapping orbit (LAMO). For each cycle, the time-dependent optimal thrust direction and magnitude of the next cycle are updated using renewed spacecraft states and characteristics of Vesta.

Dawn's transfer orbits are mostly filled with powered flight but strategically designed coasting periods are also inserted. These coasting periods are for obtaining tracking data for orbit determination, downloading spacecraft engineering data, and uploading the sequence of commands to the spacecraft using the ground antennae at NASA's Deep Space Network (DSN). The coasting periods dictate the ground operational process cycle of building sequences of commands to be executed by the on-board computer. While the maneuver designs are performed during the sequence building cycles, coasting period placement has to be decided well in advance to meet the DSN's planning schedule and to build the flight team's work schedule. The

transfer timeline needs to be completed, typically, two months in advance and must be robust to mission design uncertainties and last minute changes in DSN station availability. Human factors were also considered in this process by minimizing non-prime-shift work to lessen the flight team's fatigue and stress during the yearlong operation at Vesta.

This paper discusses mission design and navigational experience during Dawn's Vesta operations. Topics include requirements and constraints from Dawn's science and spacecraft teams, orbit determination and maneuver design and building process for transfers, developing timelines for thrust sequence build cycles, and the process of scheduling very demanding coverage with ground antennae at DSN.