2001 MARS ODYSSEY ORBIT DETERMINATION DURING INTERPLANETARY CRUISE

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Extended Abstract

Mars Odyssey was launched on April 7, 2001 into a Type I transfer orbit to Mars. Four Trajectory Correction Maneuvers (TCMs) were performed to achieve the required orbit insertion conditions at Mars. On October 24, 2001 UTC, after the six-month journey, Odyssey executed a nominal Mars Orbit Insertion burn (MOI) to be captured successfully at Mars. The excellent navigation performance during the interplanetary cruise resulted in orbit insertion conditions over the North pole of Mars well within 1–σ of the designed values. The achieved altitude above the North pole was less than 1 km away from the 300 km altitude navigational requirement. Aerobraking was then employed for nearly 3 months to reduce the spacecraft's orbital period from 19 hours down to 2 hours and prepare the orbit for science mapping. This paper will discuss the orbit determination (OD) processes and results of Mars Odyssey from launch to orbit insertion at Mars.

After two failed attempts to explore Mars with the Mars Climate Orbiter (MCO) and the Mars Polar Lander (MPL), NASA was under tremendous pressure to succeed with Mars Odyssey. The success of Mars Odyssey navigation was primarily contingent upon accurately determining the spacecraft's (S/C) orbit during the six month cruise to Mars. Several sources of error made the orbit determination process for Odyssey challenging. The largest of these errors was caused by the periodic autonomous Angular Momentum Desaturation (AMD) events. AMD events were performed every 16 – 20 hours to desaturate the momentum build-up on the reaction wheels caused by solar pressure torque. The placement of the thrusters in the spacecraft's reaction control system (RCS) allowed balanced and efficient spacecraft-frame y and z-axis wheel desats, but x-axis wheel desats were unbalanced and inefficient. Since the S/C's x-axis was continuously pointed towards Earth during cruise to maintain telecommunications over the high gain antenna, the x-axis wheel desats produced unobservable ΔV components orthogonal to the Earth–spacecraft direction. It was this source of error (along with the English–Metric conversion) that contributed to the problems with navigating MCO.

Another source of error affecting Odyssey navigation was caused by the noise and quality of the 2-way, X-Band Doppler and range tracking data from NASA's Deep Space Network (DSN) antennas. The low declination of the interplanetary trajectory constrained the tracking of Odyssey to DSN's Canberra, Australia complex for the first 2 months of cruise. During this time, several spacecraft activities were performed to check spacecraft health and calibrate science instruments and subsystems. These activities routinely corrupted the OD solutions and challenged the OD processes. Eventually, DSN's Goldstone, California and Madrid, Spain complexes could track Odyssey through the remainder of cruise but only at low elevations. Tracking data collected at such low elevations is more susceptible to uncalibrated ionospheric and tropospheric conditions which also may have been exaggerated by higher than usual solar activity at the time. Apart from the occasional noisy tracking pass, the Doppler residual data frequently exhibited unusual

structure that also had the potential of corrupting the OD solutions and producing inconsistent results. These signatures could not be attributed to any spacecraft activity.

Several navigational aides were brought forth to mitigate the aforementioned error sources and improve the accuracy of Odyssey's interplanetary cruise navigation. These include the incorporation of Very Long Baseline Interferometry (VLBI), Delta-Differenced One-way Range (ΔDOR) tracking data into the OD filtering process, active RCS thruster calibration, solar pressure calibration, and Differenced Range Versus Integrated Doppler (DRVID) measurements for media calibration. The ΔDOR data is formed by the near simultaneous observation of Odyssey from two DSN tracking stations separated by an intercontinental baseline. A similar observation is performed on a quasar that is angularly in close proximity to the S/C, and this data is differenced with the S/C observation to accurately measure the spacecraft-quasar angular separation. The ΔDOR data type complements the traditional 2-way X-Band Doppler and range radio-metric measurements by constraining the S/C's position in the Earth plane-of-sky frame. Thus, the out-of-the-ecliptic-plane component of Odyssey's position, which is unobservable with Doppler and range, can be determined from the ΔDOR data. The reduction of the S/C's position uncertainty in this direction was important in meeting the altitude requirement above the North pole of Mars for orbit insertion.

In addition, to reduce the effects of the AMD events on orbit determination during the final two months of interplanetary cruise, the Navigation Team requested the S/C's attitude and solar array position be adjusted in order to place the center of pressure of solar pressure as close to the S/C's center of mass as possible. This "low-torque" attitude nearly eliminated the build-up of momentum and thus minimized the number of AMD events during the most critical portion of cruise. In addition to a baseline filter case, OD solution consistencies were routinely evaluated through a battery of filter strategies and data combinations. Software tools were built to visualize and trend the results of these many cases and to help decipher the causes of solution discrepancies. Finally, OD strategies and results also were reviewed daily during the two months before MOI by the Navigation Advisory Group (NAG) at the Jet Propulsion Laboratory.

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Short Abstract

On October 24, 2001 UTC, after the six-month journey, Odyssey executed a nominal Mars Orbit Insertion burn to be captured successfully at Mars. The excellent navigation performance during the interplanetary cruise resulted in orbit insertion conditions over the North pole of Mars well within 1–σ of the designed values. The achieved altitude above the North pole was less than 1 km away from the 300 km altitude navigational requirement. Several sources of error made the orbit determination (OD) process for Odyssey challenging. The largest of these errors was caused by the periodic autonomous Angular Momentum Desaturation events. Several navigational aides were brought forth to mitigate the error sources and improve the accuracy of Odyssey's interplanetary cruise navigation. The most significant of these included the incorporation of Very Long Baseline Interferometry (VLBI), Delta-Differenced One-way Range (ΔDOR) tracking data into the OD filtering process and the placement of the spacecraft into a "low-torque" attitude during the final two months of interplanetary cruise. OD solution consistencies were routinely evaluated through a battery of filter strategies and data combinations. This paper will discuss the orbit determination processes and results of Mars Odyssey from launch to orbit insertion at Mars.