James Webb Space Telescope Navigation Optimization Challenges

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Full Abstract

The James Webb Space Telescope (JWST) is a NASA flagship mission launched on December 25, 2021. The early orbit phase was highlighted by three midcourse correction burns that were performed to maneuver the vehicle into a libration orbit at the second Sun-Earth-Moon (SEM) libration point (L2). During the coast to L2, the vehicle's primary observatory and sunshield were deployed. Once the tennis-court-sized sunshield was unfurled and tensioned into place, the large area exposed to solar radiation pressure (SRP) dictated that the SRP force model would need to account for the vehicle's geometry, reflective properties, and orientation relative to the Sun. Following the insertion of JWST into its L2 libration orbit on January 24, 2022, the commissioning phase for the vehicle's observatory commenced along with the first cycle of routine station-keeping maneuvers.

The NASA Goddard Space Flight Center's Flight Dynamics Facility (FDF) provides navigation services for the JWST mission. The FDF serves as the prime or backup navigation operations center for more than 30 active missions spanning a wide array of flight regimes performing orbit determination, maneuver planning, trajectory optimization, and tracking data evaluation.

Definitive orbit determination for JWST is performed by the FDF using an Extended Kalman Filter (EKF) to estimate the vehicle's trajectory and reflective properties using Deep Space Network (DSN) TRK-2-34 tracking data and spacecraft attitude telemetry. For the purposes of orbit prediction and station-keeping maneuver targeting, the sensitivity of the SRP force to the vehicle's orientation requires that predictive attitude information must be incorporated to generate accurate orbit predictions and maneuver plans.

Predictive attitude plans are provided to the FDF by the JWST Spacecraft Operations Center (SOC). Short-term (28 day) orbit predictions are propagated using a Short Range Attitude Plan (SRAP) to model the vehicle's future attitude states for up to a week. SRAP attitude data is highly reliable, as it reflects finalized planned attitude states that the vehicle will be commanded to attain during the ensuing week. A Long Range Attitude Plan (LRAP) can be implemented to model predicted attitude states beyond one week, but these predictions are tentative and subject to revision due to changes in science operations plans. Instead, a conservative approach of applying a Sun-Pointing Neutral (SPN) attitude configuration is utilized for long-term (2 year) orbit predictions where reliable planned attitude data is not available. SPN attitude mode aligns the net SRP force along the JWST-to-Sun vector where it becomes independent of the vehicle's angle of rotation about this vector, defined as the Sun yaw.

Given the dynamic instability of the libration orbit, station-keeping thrust must be applied in either the sunward or anti-sunward direction to balance the resulting orbit. The attitude constraints of the vehicle also impose limits on the available pointing directions for station-keeping thrusters. The thrusters cannot be aligned with the optimal pointing direction for sunward maneuvers, rendering sunward maneuvers to be significantly less fuel efficient than anti-sunward maneuvers. Consequently, station-keeping

maneuvers must be targeted to balance the orbit while ensuring that the next maneuver will also be performed in the anti-sunward direction to optimize propellant usage.

When targeting a station-keeping maneuver, the attitude and SRP modeling configuration which is applied to the predicted post-maneuver trajectory will dictate the direction of the subsequent station-keeping maneuver, assuming nominal propulsion system performance. If the predicted post-maneuver attitude states result in an SRP model which under-predicts the cumulative SRP impact on the post-maneuver orbit, a targeted anti-sunward maneuver will be larger than necessary and the next maneuver will need to be executed sunward in order to compensate. In contrast, an anti-sunward maneuver which is targeted using an SRP model which over-predicts the cumulative SRP impact will achieve station-keeping while ensuring that the next maneuver will likewise be performed anti-sunward. For this reason, station-keeping maneuvers are targeted while applying the SPN attitude mode, as this mode entails the largest possible SRP area cross-section and therefore a larger modeled cumulative SRP impact.

This paper documents the NASA Goddard Space Flight Center's FDF support for JWST on-orbit operations and the analysis projects undertaken utilizing the experiences and data accumulated throughout the first full year of routine science operations. The results of these analysis efforts have been used to implement improvements to orbit prediction accuracy and maneuver efficiency which have the potential to prolong the lifespan of JWST to continue to conduct ground-breaking infrared astronomy for decades to come.