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USING CAPSTONE'S MISSION EXTENSION TO NAVIGATE THE FUTURE OF CISLUNAR TECHNOLOGY

Abstract

Launched in late June 2022, the Cislunar Autonomous Position System Technology, Operations, and Navigation Experiment (CAPSTONE) has been operating in the Earth-Moon, Southern L2 Near Rectilinear Halo Orbit (NRHO) for more than two years. After successfully completing its primary mission objectives, CAPSTONE was awarded a 15 month mission extension in September of 2024. The goal of this extension was to continue to use CAPSTONE to provide valuable and informative data to the NASA Gateway program and leverage the platform to raise the TRL of several cislunar technologies. This paper presents a detailed analysis of the operational data obtained throughout the mission, including navigation performance, maneuver strategies, and results of the Cislunar Autonomous Positioning System (CAPS), and overviews the ongoing onboard technology demonstrations.

Prior to the CAPSTONE spacecraft's launch, Advanced Space conducted a series of analyses to quantify expected navigation and maneuver performance and to qualify the different methodologies, which have been used to operate CAPSTONE in the NRHO. This paper presents a retrospective analysis that quantifies the as-flown operations performance in comparison to pre-flight expectations and highlights how these operational strategies have been adapted and used to support the NASA Gateway team. Additionally, a detailed characterization of the CAPS performance will be described. These ongoing experiments involve the spacecraft communicating using a two-way, coherent signal to obtain range and Doppler navigation measurements that can be processed onboard for absolute state estimation. This study characterizes the results of crosslink experiments to date. Analyses showing potential performance of future iterations of crosslink navigation using CAPS are also highlighted to preview a path forward for autonomous deep-space navigation.

Finally, the mission extension technology demonstrations focused on spacecraft autonomy and navigation will be briefed. A focus will be placed on the concept of navigating a spacecraft in the cislunar regime using optical measurements derived from the Moon's horizon and demonstrate the effectiveness of these techniques using real imagery from the CAPSTONE spacecraft. Generated optical-only orbit determination solutions for CAPSTONE are presented and demonstrate the possibility of autonomously navigating the spacecraft, as well as potential future space vehicles, such as NASA's planned Gateway space station, in the NRHO.

By continuing operations, CAPSTONE provides a low-cost, high-impact opportunity to refine critical technologies for upcoming lunar missions, contributing to the broader goals of NASA, commercial lunar initiatives, and commercial partners in cislunar space.