Paper ID: 51318
oral
student

IAF ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimization (1) (1)

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LOW-THRUST TRAJECTORY DESIGN FOR A CISLUNAR CUBESAT LEVERAGING STRUCTURES FROM THE BICIRCULAR RESTRICTED FOUR-BODY PROBLEM

Abstract

Advances in spacecraft technology miniaturization and an increase in launch opportunities have initiated concept development for CubeSat missions beyond the bounds of low Earth orbit. The upcoming Lunar IceCube (LIC) mission will deliver a 6U CubeSat to a low lunar orbit (LLO) via a ride-share opportunity during NASA's Exploration Mission 1. The destination orbit is a 100-km x 5000-km polar orbit, from which LIC will collect data on water transport throughout the lunar surface. This presents a challenging trajectory design scenario, as the vast change in energy required to transfer from the initial deployment state to the destination orbit is compounded by the limitations of the LIC's low-thrust engine with a maximum thrust magnitude of 1.24 mN.

This investigation addresses these challenges by developing a trajectory design framework that utilizes dynamical structures available in the Bicircular Restricted Four-Body Problem (BCR4BP) along with a robust direct collocation algorithm. Designing in the BCR4BP enables the gravitational force of the Sun to be leveraged to achieve part of the required energy change, while avoiding the additional perturbations of a full ephemeris model. The invariant manifolds of a staging orbit near the Moon are exploited to design a path for the LIC spacecraft from its deployment state to LLO. Periodic and quasi-periodic orbits generated in the BCR4BP provide staging orbit candidates. Maps are created that expedite the selection of invariant manifolds from these orbits that offer favorable connections between the LIC transfer phases. Subsequently, a direct collocation algorithm corrects the initial guess in the BCR4BP while including the variable low-thrust acceleration of the spacecraft engine. The robust convergence properties of direct collocation offer a key benefit, as they enable a wider variety of initial guesses despite large discontinuities in states or time. Finally, the trajectory developed in the BCR4BP is validated in a full ephemeris model.

Results indicate that this proposed framework offers an efficient and adaptable method for designing a baseline trajectory for the LIC mission. The BCR4BP's dynamical structures offer distinct paths and avoid the complexity of a large grid search. This characteristic along with the robustness of direct collocation yields an approach adaptable to changes in launch conditions, a necessary capability for secondary payloads. Thus, this low-energy trajectory design framework not only navigates the complexities of the LIC mission; it also may aid trajectory design for similar CubeSat missions beyond low Earth orbits.