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CISLUNAR TRANSFER DESIGN EXPLOITING PERIODIC AND QUASI-PERIODIC ORBITAL STRUCTURES IN THE FOUR-BODY PROBLEM

Abstract

In 2018, NASA's Strategic Plan detailed an objective to extend human exploration beyond Low Earth Orbit (LEO), specifically a framework for the development of a sustainable human presence within the lunar vicinity. One of the challenges in achieving this goal is an efficient strategy for path planning to support crewed spacecraft, as well as the delivery of architecture elements, beyond LEO and, ultimately, expanding further than the Moon. In the next decade, NASA plans to operate the lunar Gateway in a southern L2 Near Rectilinear Halo Orbit (NRHO) and leverage other orbits in cislunar space for Artemis program operations. However, the complex dynamics in these regimes present difficulties in preliminary, efficient path planning from Earth as well as operations in and around these destinations. Mission planning—crewed and uncrewed— benefits from design strategies that leverage the available structures in multi-body systems. This investigation is focused on low-energy transfer trajectories that leverage solar gravity to access the lunar region within the context of a four-body problem. Specifically, dynamical structures in the Bicircular Restricted Four Body Problem (BCR4BP), which serves as a useful model for preliminary trajectory design where the complex dynamics in both the Earth-Moon and Sun-Earth regimes are significant. The gravitation forces of the Sun, Earth, and Moon are incorporated within a single model, while reducing the complexity from an ephemeris model. The existence and stability of periodic and quasi-periodic orbits are explored in the BCR4BP. Poincaré maps offer information about manifold structures associated with periodic and quasi-periodic trajectories; purely ballistic low-energy transfers are then constructed to the lunar region. Subsequently, deterministic maneuvers are introduced to expand the available solution space. Lastly, additional mission constraints are imposed and solutions from the BCR4BP are validated in an ephemeris model to ensure that the geometries persist in a higher fidelity model. The results from this investigation demonstrate that leveraging dynamical structures in the BCR4BP aids in the construction of complex low-energy transfers in cislunar space. Including the gravitational force of all three bodies in a single model builds intuition during the design process. Exploiting the structured motion reduces the computation time required as compared to large grid searches. Furthermore, demonstrating the flexibility of this design strategy for constructing transfers to multiple types between various cislunar orbits informs future designs.