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ESCAPE STRATEGIES AND PERFORMANCE ASSESSMENT OF SOLAR SAIL SPACECRAFT FROM CISLUNAR NRHO FOR DEEP SPACE EXPLORATION

Abstract

Near-Rectilinear Halo Orbits (NRHOs) have emerged as strategic hubs for cislunar operations, particularly for solar sail propulsion in deep space exploration. This study constructs a 4:1 synodically resonant solar sail NRHO within the Solar Radiation Pressure (SRP)-augmented Bicircular Restricted Four-Body Problem (BCR4BP) and conducts a systematic analysis of its stability and escape dynamics. Through large-scale parametric sweeps encompassing 168,042 trajectories, we compare three maneuver directions: tangential (velocity-aligned), 1.5-revolution, and 6.5-revolution most-stretching directions. The results demonstrate that the 6.5-revolution stretching direction achieves a direct escape rate of 50.09% at = 4 m/s and a peak total escape success rate of 79.83%, significantly outperforming other strategies. Notably, certain non-perilune regions enable escape with as low as 0.1 m/s, challenging the conventional perilune-optimized deployment. The continuous thrust from the solar sail alters long-term energy evolution, preventing energy plateauing observed in gravity-only models. Escape morphology is highly phase-dependent, with Quadrant II identified as the optimal "golden window" for direct escape. These findings provide a theoretical foundation and data-driven strategy for designing efficient solar sail deployment and escape trajectories in cislunar space.