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DESIGN OF MINIMUM-TIME LOW-THRUST TRANSFER BETWEEN QUASI-PERIODIC ORBITS

Abstract

Many recent missions by government space agencies and private companies aim to explore cislunar space. Among the structures essential for transfer around the Moon are heteroclinic connections between the libration points L_1 and L_2. These connections represent the trajectories that belong to the unstable manifold of one orbit and the stable manifold of another. Although the connections between periodic orbits are rare, every pair of quasi-periodic orbits at the same Jacobi energy should generically have a heteroclinic transfer, providing many more transfer options around the Moon due to the higher dimension of their manifolds. Thus, heteroclinic connections between quasi-periodic orbits disclose useful transfer trajectories without consuming fuel. In contrast, the drawback of these transfer trajectories lies in their long time of flight.

To address such issues, this study aims to optimize the transfer time of the heteroclinic connections between quasi-periodic orbits under a low-thrust constraint. The departure and arrival phases on each quasi-periodic orbit are included in the optimization parameters to fully utilize the higher dimension of these connections. The minimum-time optimization problem is constructed based on time regularization in the Earth-Moon restricted three-body problem. The low-thrust constraint ensures that the time-optimal trajectory remains around the heteroclinic connections; the proposed method can find near-fuel-optimal rapid transfer trajectories. By appropriately setting the maximum thrust acceleration, this study explores feasible transfer options for different missions.

In the computation, we first calculate all the connections between a quasi-periodic orbit around L_1 and one around L_2 via the fully numerical method. The optimization problem is formulated by transforming real time to fictitious time, a new independent variable increasing monotonically. The transfer time in the real time variable is minimized by adjusting the departure and arrival phases, state, and control inputs. This optimization is performed from one of the found connections, and finds the time-optimal transfer trajectory within the given thrust level. We demonstrate the effectiveness of the proposed method by comparing the obtained results with the phase-fixed solutions generated from all the found connections.