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LOW-ENERGY LUNAR TRANSFER DESIGN USING HIGH- AND LOW-THRUST ON BALLISTIC CAPTURE TRAJECTORIES

Abstract

This study considers the problem of calculating low-energy transfers to the Moon into a temporary capture orbit in four-body ephemeris model, which includes: the Earth, the Moon, the Sun, and the spacecraft. The transfer is carried out using a transit orbit in the vicinity of one of the collinear libration points L1 or L2 of the Earth-Moon system. The use of a transit orbit makes it possible to reduce the fuel consumption. Another way to increase the efficiency of lunar missions is to use electric propulsion systems (EPS) with a high specific impulse for their implementation, which can significantly reduce fuel consumptions for the transfer. Low-thrust trajectories are characterized by a slow change in the specific orbital energy, so a typical trajectory between Earth and lunar orbits enters the lunar Hill sphere through an opening in the vicinity of the L1 point. To effectively use the effects of the three-body problem, it is advisable to include motion along invariant manifolds of libration points (or halo orbits) in the lunar trajectory, which allow one to obtain lunar capture orbit. At the same time, the use of EPS leads to a significant increase in the transfer duration to the Moon from low Earth orbits. To reduce the flight time, we can use an upper stage to obtain an intermediate orbit around the Earth. Therefore, we consider the three segments of trajectory: the high-thrust segment, the low-thrust segment and coasting motion along the temporary capture orbit. In order to properly distribute the values of characteristic velocity between the first segments, end-to-end trajectory optimization with a single cost function (fuel consumptions) is necessary. This will reduce the total transfer duration when using low-energy trajectories. After entering the temporary capture orbit, depending on the mission goals, the necessary lunar orbit can be formed, or a maneuver can be performed to enter the required departure trajectory. We propose a method of solving the problem, which consists in determining a suitable transit orbit and in calculating the optimal trajectory from the initial Earth orbit to the transit trajectory to the Moon. The Pontryagin's maximum principle is used in combination with the continuation method to solve the problem of optimal control and determine the optimal junction point with the transit orbit. Numerical examples are given of calculating low-energy trajectories for transfer to the lunar capture orbit with optimization of the junction point with the transit trajectory.