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MINIMUM-THRUST LUNAR TRAJECTORIES

Abstract

Modern lunar exploration plans have stimulated a renewed interest in considering the possibility of using spacecraft (SC) equipped with electric propulsion systems (EPS) for cargo transfer within the lunar manned program. Since the mass of the EPS and of the onboard power supply system is almost proportional to the thrust, calculation of the minimum-thrust trajectories and analysis for the minimum thrust dependence on the transfer duration are the highly topical problems. The aim of the study is to analyze the minimum-thrust trajectories between the arbitrary elliptical Earth and Lunar orbits. To solve the minimum-thrust problem, an indirect method based on the use of the maximum principle and of the continuation method is used. The optimization problem for the considered type of trajectories gave rise to the necessity to overcome a number of computational problems. One of such problems is the necessity to choose the correct relation between the angular distance and the orbital transfer duration both in the geocentric and selenocentric segments to ensure the global minimum of the cost function. To solve the problem of calculating a trajectory with optimal ratio of the angular distance to transfer duration, the following techniques are proposed: 1) the use of the formulation of the trajectory optimization problem with the fixed angular distance and free transfer duration; 2) the use of an angular independent variable (auxiliary longitude, which coincides with the true longitude in unperturbed motion) as an independent variable in the differential equations of SC motion; 3) the calculation of the angular distances of the geocentric and selenocentric segments from the condition of equality of the minimum thrust in both segments to the given value; 4) the use of the Earth-Moon L1 libration point as a junction point of the geocentric and selenocentric segments of trajectory at the first phase of calculations; 5) the use of the optimal limited-power trajectory as an initial guess in the minimum-thrust problem. Numerical examples are given for the trajectories to the Moon with the minimum thrust, and the dependencies of the minimum thrust and of the required propellant consumption on the transfer duration are analyzed. The developed method and the obtained results can be used in the prospective lunar missions design, including the calculation of the boundary of domain of existence of the optimal lunar trajectories for a SC with EPS in the plane “specific impulse - thrust”.