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OPTIMAL LONG-DURATION LOW-THRUST TRANSFERS BETWEEN LIBRATION POINT ORBITS

Abstract

In this paper, we investigate the numerical computation of minimum-energy low-thrust transfers between Libration point orbits via optimal control theory and indirect shooting methods. We will focus our attention on transfers between Lyapunov orbits around L1 and L2 in the Earth-Moon restricted three-body problem. These departure and arrival planar periodic orbits will be computed using Lindstedt-Poincaré techniques. We know from related studies that low-energy transfers may exist for particular values of the transfer duration when the two orbits share the same Jacobi constant. Trying to determine the associated optimal control laws in a direct way by using shooting methods appears to be very difficult or even impossible from a medium value of the transfer duration. This is due to numerical difficulties regarding the computation of the shooting function and its Jacobian, but also to the existence of local optima with higher energy values than that of the low-energy solution.

In this paper, we develop a three-step methodology for computing low-thrust minimum-energy transfers without using information from invariant manifolds. With this aim, we first determine a feasible control with quadratic-zero-quadratic time structure connecting the departure and arrival orbits. Then we build an optimal control problem whose solution is equal to this feasible control. In the second step, this problem is embedded in a family of problems depending on a parameter ϵ. For each problem, the departure location from the first orbit and the arrival location at the target orbit are fixed to the non-optimal values associated with the initial feasible control. These problems are solved by continuation on ϵ, until we obtain a locally energy-optimal control law connecting the two Lyapunov orbits. Each problem is solved thanks to an indirect single shooting method. The Jacobian of the shooting function is computed using variational equations. Finally, in the last step of the method, the minimum-energy solution is obtained by determining the optimal values of the departure location from the initial orbit and of the arrival location at the target orbit.

Numerical results are provided demonstrating the efficiency of the developed approach for different values of the transfer duration leading to trajectories with one or two revolutions around the Moon.

In conclusion, this paper proposes a new methodology that allows the computation of low-thrust minimum-energy transfers between Libration point orbits. This methodology based on indirect optimal control, variational equations and continuation techniques makes no use of invariant manifolds contrarily to existing approaches.