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FUEL-OPTIMAL TRAJECTORIES NEAR LAGRANGE POINTS

Abstract

The problem of time-fixed fuel-optimal trajectories with high-thrust propulsion in the vicinity of a Lagrange point is tackled via the linear version of the primer vector theory. More precisely, the proximity to a Lagrange point i.e. any equilibrium point - stable or not - in the circular restricted three-body problem allows for a linearization of the dynamics. Furthermore, the assumption of high-thrust propulsion leads to a cost function written as the integral of the p-norm of the control vector, where the value of p depends on the thruster configuration (1 for ungimbaled and 2 for steerable). In this context, the primer vector theory gives necessary and sufficient optimality conditions for admissible solutions to two-value boundary problems. Similarly to the case of rendezvous in the restricted two-body problem, the in-plane and out-of-plane trajectories being uncoupled, they can be treated independently. As a matter of fact, the out-of-plane dynamics is simple enough for the optimal control problem to be solved analytically via this indirect approach. As for the in-plane dynamics, the primer vector solution of the so-called primal problem is derived by solving a hierarchy of linear ($p = 1$) or semi-definite ($p = 2$) programs, as proposed recently for the aforementioned rendezvous. The optimal thrusting strategy is then numerically obtained from the necessary and sufficient conditions. Finally, in-plane and out-of-plane control laws are combined to form the complete 3-D fuel-optimal solution. Results are compared to the direct approach that consists in working on a discrete set of times in order to perform optimization in finite dimension. Examples are provided near various Lagrange points in the Sun-Earth and Earth-Moon systems, hinting at the extensive span of possible applications of this technique in station-keeping as well as mission analysis, for instance when connecting manifolds to achieve escape or capture.