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HYBRID LOW-THRUST TRANSFERS TO EIGHT-SHAPED ORBITS FOR POLAR OBSERVATION

Abstract

The existence of doubly-symmetric, so-called eight-shaped orbits at the collinear libration points in the circular restricted three-body problem has long been established. However, only recently has their potential for observation of the polar and high-latitude regions of the Earth been investigated. Through the use of multiple spacecraft and by exploiting the dwell time over the poles, continuous coverage can be achieved, which will enhance future Earth observation and telecommunication missions. In this paper, the concept of eight-shaped orbits for polar observation will be extended by assessing their accessibility through the design of optimal transfers from Earth.

For that, the transfer is modelled by distinguishing between a low-thrust, near-Earth phase and a ballistic, interplanetary phase. The first is modelled as a multi-revolution, two-body spiral trajectory, starting from a low-Earth orbit (LEO). Subsequently, an orbital averaging technique is used that includes locally optimal control laws to increase semi-major axis, eccentricity and inclination until insertion into the second phase. This second, interplanetary phase is modelled in the full three-body problem and exploits the stable manifolds that wind onto the eight-shaped orbits.

To perform the spiral trajectory, the novel concept of hybrid low-thrust propulsion is proposed, where a solar electric propulsion (SEP) thruster is augmented with a solar sail. The idea is that the solar sail can provide part of the acceleration required to perform the transfer, thereby lowering the demand on the SEP system and reducing the propellant consumption with respect to a pure SEP case.

To find optimum transfers, the objective is to maximise the mass inserted into the eight-shaped orbit (or equivalently into the manifold) for a given mass in LEO. The optimisation is carried out using a direct pseudospectral method that solves the optimal control problem in the spiral trajectory and links the two phases in an end-point constraint. Additional parameters are taken into account to optimise the length of the manifold and the point along the eight-shaped orbit where the manifold winds onto it.

Results are provided for a variety of eight-shaped orbits that are particularly useful for polar observation. These include solar-sail displaced eight-shaped orbits which can provide some advantage in terms of visibility over natural eight-shaped orbits and provide an additional purpose to the solar sail used in the transfer. Finally, to assess the performance of hybrid low-thrust, the results are compared with pure SEP transfers and the expected, better performance of hybrid low-thrust propulsion is highlighted.