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DISPLACED GEOSTATIONARY ORBITS USING HYBRID LOW-THRUST PROPULSION

Abstract

Hybrid low-thrust propulsion is a relatively unexplored, but very promising concept in which a solar electric propulsion system (SEP) is augmented with a solar sail. Although SEP is proven to be highly efficient, the available propellant mass poses severe limits on its applications. Therefore, complementing the SEP-system with a propellantless propulsion system like a solar sail will greatly enhance its applicability. Similarly, SEP can complement the pure solar sail by enabling a thrust component in the direction of the Sun, which the solar sail is unable to generate.

Preliminary studies have already demonstrated the advantages of hybrid low-thrust propulsion over sole SEP and solar sail propulsion for a limited number of applications. This paper will extend these studies by considering the dynamics of the hybrid low-thrust trajectory in a two-body problem including acceleration terms for the solar sail and the SEP-system. Furthermore, five control variables are considered, including the in- and out-of-plane angles of the SEP thrust force, the SEP thrust magnitude and the in- and out-of-plane angles of the solar sail thrust force. By allowing these controls to vary, the solar sail can lower the demand on the SEP-system, while the SEP-system can provide the required acceleration when the solar sail is unable to do so.

A direct, pseudo-spectral method for solving the optimal control problem is subsequently taken at hand to apply the described dynamics to a test case: a hybrid low-thrust Earth-Mars transfer. Two conflicting performance indices, induced by the two types of propulsion, are optimized in a weighted sum approach: the required propellant mass and the transfer time. Similar optimizations are carried out for pure SEP and solar sail trajectories to allow for a comparison between the different propulsion techniques.

The advantage of hybrid low-thrust propulsion over sole SEP and solar sail propulsion becomes even more apparent when trajectories towards displaced non-Keplerian orbits are considered. By requiring a nearly continuous acceleration, these orbits are inaccessible using traditional propulsion techniques. Examples include artificial equilibria high above the Earth poles and displaced geostationary orbits that overcome the limits imposed by east-west spacing requirements in the geostationary orbit. Building upon the findings for the Earth-Mars test case, this paper will investigate transfers to such displaced non-Keplerian orbits. Again, the optimal hybrid low-thrust transfer is compared with optimized trajectories employing only SEP or a solar sail. For all cases the comparison highlights the substantially better performance of hybrid low-thrust propulsion.