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ANALYTICAL THREE-PHASE TRANSFER TO A SOLAR POLAR ORBIT USING SOLAR SAIL PROPULSION

Abstract

A general solution for the transfer trajectory from the Earth to a solar polar orbit using solar sail propulsion is presented, deriving for the first time the optimal trajectory architecture without the need for engineering assumptions and numerical analysis. As previously believed [1], the 3-phase transfer involves spiralling in close to the sun, performing a rapid inclination increase, and spiralling back out to the final target orbit. However, the general solution allows the split of inclination change per phase to be optimised for the minimum transfer duration, negating the need for assumptions used in previous numerical optimisations.

This method offers significant advantages over the numerically optimised solutions currently available [1] as it allows for a complete understanding of the optimal structure of the trajectory to be gained. The insights provided by the analytical solution can be used to rapidly generate a holistic understanding of the architectural options available and hence how the mission and system design could be traded; for example increased thermal system mass (due to a reduction in the minimum solar approach distance) against reduced transfer time or sail size. An analytical solution exists for the 2-phase transfer and has been used to define feasible transfer trajectories [2]; by extending this work to include the previously identified optimal 3-phase transfer option, trajectory architectures with significantly reduced transfer times can be identified.

Scientific missions to observe the solar poles have been proposed since the 1970s [3]. Solar Orbiter, due to launch in 2017, will allow space based observations only within 36 deg. of the solar equator due to the high velocity change required to increase inclination. The use of solar sail propulsion uniquely overcomes this [4]. Thus, an analytical description of time-optimal transfer trajectories for such a mission offers significant advantages for system design trade studies and future mission design.

[1] Macdonald et al. (2006) Solar polar orbiter: a solar sail technology reference study. Journal of Spacecraft and Rockets, 43 (5). pp. 960-972. ISSN 0022-4650

[2] Macdonald (2013) Analytical, circle-to-circle low-thrust transfer trajectories with plane change. AIAA Guidance, Navigation and Control Conference, Boston, Massachusetts.

[3] Bohlin (1979) Advanced Solar Space Missions. 17th Aerospace Sciences Meeting, New Orleans, Louisiana.

[4] Goldstein et al. (1998) A Solar Polar Sail Mission: Report of a Study to Put a Scientific Spacecraft in a Circular Polar Orbit about the Sun. SPIE International Symposium on Optical Science, Engineering and Instrumentation, San Diego, California.