IAF ASTRODYNAMICS SYMPOSIUM (C1)
Guidance, Navigation and Control (2) (4)

Author: Mr. Livio Carzana
Delft University of Technology (TU Delft), The Netherlands

Dr. Pieter Visser
Delft University of Technology (TUD), The Netherlands
Dr. Jeannette Heiligers
Delft University of Technology (TU Delft), The Netherlands

HIGH-FIDELITY OPTIMAL CONTROL LAWS TO CHARACTERIZE THE MANEUVERING CAPABILITIES OF EARTH-BOUND SOLAR SAILS

Abstract

Solar sailing is a propulsion method that uses solar radiation pressure (SRP) as main source of thrust and is particularly suited for heliocentric flight regimes. Therefore, several studies have been conducted on the solar-sail dynamics and control for interplanetary missions. However, the vast majority of sailcraft launched to date have flown around Earth, as will those scheduled for launch in the near future. Around Earth, the dynamics of a solar sail are affected by the presence of eclipses and additional sources of acceleration apart from SRP, particularly atmospheric drag and the Earth's planetary radiation pressure (PRP). Since these accelerations can reach magnitudes in the order of (or even larger than) the SRP acceleration, it is crucial to include them in the Earth-bound sailcraft dynamics. Despite their importance, the majority of research conducted on Earth-bound solar sailing either neglects these accelerations or treats them as uncontrollable sources of perturbation. However, to fully determine the potential of solar sailing for mission applications close to Earth, it is also necessary to account for SRP, PRP, and atmospheric drag in the trajectory optimization. In this way, these accelerations can be exploited to enhance the solar-sail maneuvering capabilities.

In light of the above, this paper presents a novel trajectory optimization method that considers eclipses, SRP, PRP, atmospheric drag, and gravitational accelerations in the optimization process. After introducing the models describing these accelerations, the optimal control problem is defined and the associated trajectory optimization algorithm used to solve it is discussed. The optimization method is designed to compute steering laws that change any orbital element in a locally optimal manner under the effect of the aforementioned high-fidelity dynamics. For validation purposes, orbit-raising and inclination-changing steering laws for a set of orbital scenarios are computed through the newly devised optimization method and compared to a computationally intensive, yet accurate, grid search-based method. Finally, the high-fidelity trajectory optimization algorithm is exploited to fully characterize the maneuvering and transfer capabilities of real-life solar sails in the near-Earth environment. To this aim, NASA's upcoming ACS3 solar-sail mission is taken as reference and a parametric analysis is conducted to determine ACS3's orbit-raising and inclination-changing capabilities for a large set of near-Earth orbits. The results of this study will aid the mission design process of future Earth-bound solar-sail missions and enable a higher sail performance for a wide range of mission applications, including active-debris removal and in-orbit servicing.