64th International Astronautical Congress 2013

Paper ID: 19988
oral
student

ASTRODYNAMICS SYMPOSIUM (C1)
Mission Design, Operations & Optimisation (1) (6)

Author: Mr. Valentin Stolbunov
University of Toronto Institute for Aerospace Studies, Canada

Dr. Matteo Ceriotti
University of Glasgow, United Kingdom
Dr. Camilla Colombo
University of Southampton, Italy
Prof. Colin R. McInnes
University of Strathclyde, United Kingdom

OPTIMAL LAW FOR INCLINATION CHANGE IN AN ATMOSPHERE THROUGH SOLAR SAILING

Abstract

Solar sailing has for many years been an intriguing concept for spacecraft propulsion mainly due to its capability of providing a continuous (albeit relatively small) acceleration, without using propellant mass. Due to the sail's high area-to-mass ratio, most studies on solar sails focus on deep space missions or high-altitude Earth bounded orbits where the effect of the atmosphere is negligible. Recently, NASA's Nanosail-D2 demonstrated the de-orbiting capabilities of a large, low-mass, high-surface area sail, also showing the feasibility of deploying a sail in the upper layers of the atmosphere, at least as a de-orbiting device. However, relatively little work has been done on exploiting these effects by actively changing the attitude of the spacecraft, with the aim of changing the orbital elements. In particular, if a large area-to-mass ratio spacecraft is modelled as a reflective plate subject to solar radiation pressure and aerodynamic forces, then its attitude can be controlled to substantially vary the two forces. Solar sails may be used in the future as an alternative to traditional propellant-based propulsion, to control spacecraft in low Earth orbit. This is particularly applicable, in the near future, to small platforms like CubeSats, due to their limited mass and low orbit.

This work investigates optimal control laws for solar sails in an atmosphere. The aim of this paper is to devise a local optimal strategy for orbital inclination change for a solar sail spacecraft in low Earth orbit, combining the effects of the solar radiation pressure and atmospheric forces. The acceleration due to effects of atmospheric forces and solar radiation pressure is computed, depending on the orbital parameters and attitude of the sail. The attitude that maximizes the instantaneous orbital inclination change is then found through the Gauss' equations. When one of these effects dominates over the other, analytic expressions are found. When both effects are comparable, a numerical optimization is used. An additional constraint is introduced to avoid semi-major axis decrease, and thus prevent losses in orbital energy while increasing inclination. Different regions are identified, depending on which effect dominates or if the two are comparable. Arcs along the orbit are determined in which the optimal attitude can be found analytically, and the expression is derived. Simulations of the proposed control laws show consistent inclination changes of up to 10 degrees for orbit-raising missions of one year.