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HYBRID SOLAR SAIL AND SEP PROPULSION FOR NOVEL EARTH OBSERVATION MISSIONS

Abstract

Solar electric propulsion (SEP) is a flight proven technology. Despite the high specific impulse typical of modern SEP, the life of the spacecraft is limited by the mass of propellant available on-board. Mission duration could be extended by adding a propellant-less form of propulsion, such as a solar sail. Solar sails have been investigated in the past, but have never been successfully demonstrated, mainly due to technological difficulties in deployment. Moreover, an intrinsic restriction of solar sails is that the acceleration cannot point towards the sun, therefore their applicability is limited. The intriguing concept of a hybrid propulsion spacecraft appears attractive: by combining the two forms of propulsion, the drawbacks of the two systems cancel each other. A small sail can provide part of the acceleration needed, saving propellant mass and enabling longer missions. In addition, the thruster enables a smaller, more reliable sail, and provides an acceleration component towards the sun. The SEP system also guarantees higher system reliability with respect to the pure sail. This almost completely unexplored concept will be applied to the continuous monitoring of the Earth polar regions through a pole-sitter, i.e. a spacecraft that is stationary above one pole of the Earth. The continuous, hemispherical, real-time view of the pole will enable a wide range of new applications: line-of-sight telecommunications with polar regions will be a key issue in future as changes to the arctic ice pack opens navigation channels for shipping. Also, the pole-sitter spacecraft could provide a platform for real-time observation of the poles for climate science at modest resolution (similar to the DSCOVR mission), as opposed to periodic images that can be obtained by low polar orbits. In this paper, families of 1-year-periodic, minimum-propellant orbits are found, for different values of the sail lightness number and distance from the pole. The first guess is generated with a semi-analytical procedure; the subsequent optimal control problem is then solved using a pseudo-spectral method. The process gives a nominal control to maintain these orbits. However, for stability issues, a feedback control is investigated to guarantee the station-keeping in presence of perturbations. Results show that a considerable mass can be saved by using a medium-sized solar sail, thus allowing extended life-time and improved reliability. The hybrid solar sail therefore appears to be a novel means of combining the benefits of SEP and solar sails to enable novel orbits which seem to have compelling new applications.