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ELECTRIC SAIL DISPLACED ORBIT CONTROL WITH SOLAR WIND UNCERTAINTIES

Abstract

The Electric Solar Wind Sail (or E-sail) is a recently proposed propellantless system for spacecraft propulsion. It essentially consists of a spinning grid of tethers, which are kept at a high positive potential and maintained stretched by the centrifugal force. When immersed in the solar wind plasma, the tethers interact with the incoming charged particles, exchanging momentum and generating thrust. The peculiarity of the E-sail makes exotic mission scenarios to be feasible, such as non-Keplerian orbits and artificial Lagrangian point maintenance, which could be very difficult, or even impossible, to achieve with a conventional thruster.

The analysis of E-sail trajectories is usually conducted with a deterministic approach. In this context, the characteristics of the solar wind, such as plasma number density and particle velocity, are taken as constant, which corresponds to assuming a fixed value of the solar wind dynamic pressure. Under these hypotheses, the E-sail propulsive acceleration varies as a function of the Sun-spacecraft distance, the sail attitude, and the grid voltage, making the spacecraft trajectory easily predictable by numerically integrating the differential equations of motion.

However, the main problem with this approach is the extreme unpredictability of the solar wind properties. As observed by in-situ measurements, indeed, the plasma dynamical pressure undergoes many fluctuations, with the same order of magnitude of the mean value. The time history of these fluctuations shows a very irregular behavior with appreciable variations even in few hours. Hence, the dynamical pressure involved in the E-sail thrust generation cannot be taken as constant during a typical operating phase.

The aim of this work is to analyze the propulsive acceleration generated by an E-sail with a statistical approach, accounting for the variations of plasma properties along the flight. The solar wind dynamical pressure is modeled as a random variable with a gamma distribution, where the shape and scale parameters are selected to fit the available data in terms of mean value and standard deviation.

The manuscript is organized as follows. First, the effects of the solar wind fluctuations on the spacecraft motion are estimated, showing the importance of a control system to track the nominal trajectory. Then, the possibility of actively controlling the grid voltage in response to the dynamical pressure fluctuations is proposed. Different control strategies are discussed and tested in a possible mission scenario, consisting in the maintenance of an artificial Lagrangian point L1.