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ATTITUDE DYNAMICS OF AN ELECTRIC SAIL MODEL WITH A REALISTIC SHAPE

Abstract

The Electric Solar Wind Sail (E-sail) is an innovative propulsion system concept that gains propulsive acceleration from the interaction with the solar wind particles. The incoming ions interact with an artificial electric field produced by means of long charged tethers, which are deployed and maintained stretched by spin. Many studies exist to describe the behaviour of an E-sail in the interplanetary environment, and in most cases the E-sail is described in a simplified way assuming a flat shape resembling that of a disk. The real shape, however, is much more complex as it is the result of the coupling between the solar wind dynamic pressure and the centrifugal force due to the spacecraft rotation. This problem has been addressed in a recent paper, which deals with the analytical expressions of thrust and torque vectors of a spinning E-sail. The results discussed in that paper are based on the assumption of a Sun-facing and axially-symmetric sail, showing that the resultant thrust is aligned along the radial (Sun-spacecraft) direction, whereas the net torque is zero. Also, the equilibrium shape of each tether is shown to be well approximated by a natural logarithmic arc when the E-sail spin rate is sufficiently high, in accordance with recent simulations.

The aim of this work is to generalize the results discussed in that paper to the case when the spacecraft spin axis is not in the radial direction. Considering an axially-symmetric E-sail, the assumption is made that the E-sail maintains a "rigid" shape, independent of the pitch angle. Such an assumption is reasonable when the pitch angle is small, that is, when the tether arrangement is not far from the approximate equilibrium shape found in the Sun-facing configuration. In that case, it is possible to obtain analytical expressions of the thrust and torque vectors. In particular, the development of a net torque makes possible the analysis of the spacecraft attitude dynamics. In this context, numerical integration of the Euler's attitude equations is carried out, showing that the spacecraft performs a combined undamped precession with a nutation motion. The amplitude and the frequency of these two oscillatory motions are affected by the initial conditions, the spacecraft inertia tensor, and the E-sail design. It is shown that the external torque always makes the long-period thrust to be oriented in the radial direction.