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Corresponding author: MAZOUFFRE Stéphane
e-mail of corresponding author: stephane.mazouffre@cnrs-orleans.fr
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Title

Experimental validation of the electric sail concept

Authors

Stéphane Mazouffre [1], Ulysse Weller [2]*

** Corresponding author*
[1] CNRS, ICARE laboratory, Orléans, France, stephane.mazouffre@cnrs-orleans.fr
[2] CNES, Propulsion, Pyrotechnie et Aerothermodynamie Dpt, Toulouse, France, ulysse.weller@cnes.fr

Abstract

The electric sail (E-sail) is a type of propellantless propulsion device for spacecraft that relies on the solar wind, a stream of charged particles released from the upper atmosphere of the Sun, to generate thrust in contrast to the light sail that uses photons. The E-sail concept was proposed and developed by P. Janhunen in the 2000s as an efficient propulsion means for interplanetary and even interstellar journeys [1,2]. In short, an electric sail is a net of gigantic wires, termed tethers, polarized to high voltages to disturb the trajectory of charged particles in such a way momentum from the solar wind is transferred to the structure, which generates thrust. An E-sail can operate with a positive polarization (ion are deflected, electrons are captured) or with a negative polarization (electrons are attracted, ions are repelled). The virtual area of the sail, i.e. the are seen by the charged particles, can be extremely large although the geometrical surface is extremely small. This originates from the fact that charged particles interact with the plasma sheath, a thick boundary layer that surrounds the wires. The latter increases with the voltage and varies as $n_e^{-0.5}$, where n_e is the plasma density. In deep space, as the plasma density is very low, the plasma sheath can extend over 100s of meters with wires 100s of micrometers in diameter. The working principle of an electric sail is thus relatively straightforward and its architecture is simple and lightweight, making it attractive for exploration missions. The E-sail is nevertheless not without weak point, the main one being the very low linear thrust level, which leads to very long trip duration [2].

Although many theoretical and numerical works on electric sails have been performed over the past two decades, only a very limited amount of studies were dedicated to the experimental verification of the E-sail concept either in the lab or in space, without success so far for these latter cases. In this contribution, we present recent findings on ion deflection by a polarized wire obtained in a vacuum chamber at very low pressure. A small low-power Hall thruster fed with krypton as propellant was used as a solar wind simulator. The (Kr+) ion kinetic energy was around 150 eV and the plasma density reached 10^{14} m^{-3}. A 64 mm long 0.1 mm in diameter tungsten wire used as an E-sail. The wire was vertically mounted 28 cm downstream of the plasma source exit plane on the axis. A set of diagnostic was placed 5 cm behind the wire in the horizontal plane that contains the source axis. A Langmuir probe measured the plasma parameters (n_e, T_e). A Faraday cup measured the ion current density. An energy analyzer recorded the ion kinetic energy. Measurements clearly reveal the impact of the polarization in both positive and negative modes upon the plasma disturbance and the ion trajectories. Ions are deflected whatever the applied voltage, the impact being more marked for large values. Experiments indirectly demonstrate momentum from the beam is imparted to the wire, the core principle of an E-sail.

References

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