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The electric solar wind sail status report

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Abstract

The electric solar wind sail (E-sail) is a space propulsion concept which uses the natural solar wind dynamic pressure for producing spacecraft thrust. In its baseline form the E-sail consists of a number of long, thin, conducting and centrifugally stretched tethers which are kept in a high positive potential by an onboard electron gun. The method is efficient because the effective virtual sail area is millions of times larger than the physical area of the thin tethers wires which more than offsets the fact that the dynamic pressure of the solar wind is weak. An E-sail of 1 N thrust and 100 kg mass could be built in near future, providing a revolutionary level of propulsive performance (specific acceleration) for travel in the solar system. This is a review of the ongoing technical development work of the E-sail, covering tether construction, overall mechanical design alternatives, guidance and navigation strategies and dynamical and orbital simulations.

1. Introduction

The electric solar wind sail [1, 2, 3, 4] (electric sail or E-sail for short) is a novel propulsion method that uses the solar wind as a thrust source. The E-sail consists of a number (e.g., 50-100) of long, conducting tethers which are kept positively biased and centrifugally stretched by the spacecraft spin (Fig. 1). The tethers must be micrometeoroid-tolerant so they must have a redundant multiline construction. The solar wind ions are repelled by the positive E-sail tethers so that momentum is extracted from the solar wind flow. The E-sail has some similarities with other non-chemical propulsion systems: (1) it uses the solar wind momentum flux as a thrust source as does the magnetic sail, (2) it uses electric power to generate thrust as does the ion engine, (3) it makes use of long, conducting tethers as the electrodynamic tether propulsion. The E-sail can produce thrust anywhere in the solar wind and possibly also in the corotating plasmas of Jupiter and other giant planets.

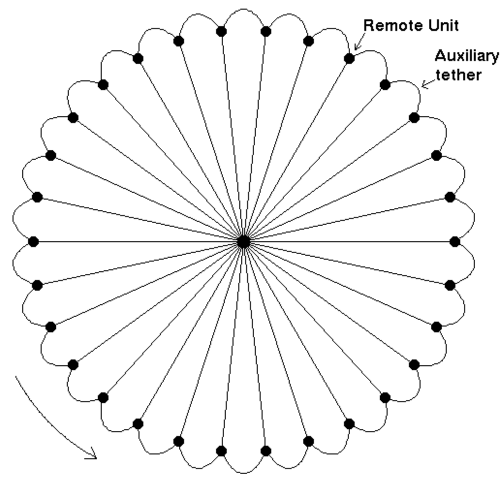

Figure 1: E-sail design which is mechanically stabilised by auxiliary tethers and Remote Units. The design has no moving parts during flight and its spin is generated by small thrusters on the Remote Units.

2. E-sail status

The plasma physical basis of the E-sail has been analysed using PIC simulations and later with a semianalytic approach which corrects some pitfalls in the simulations [2, 3]. The E-sail thrust per tether length is typically 500 nN/m at 1 AU and it scales as $1/r$ where r is the distance from the Sun. It has been shown that due to some lucky plasma physical feedbacks, the E-sail thrust varies much less than the solar wind itself [5] which in practice means that the E-sail is as navigable as any other propulsion system [5]. This is an interesting and nontrivial result because at first sight one might suspect the navigational accuracy to be poor due to the large and unpredictable natural variability of the solar wind.

Optimal E-sail trajectories for many solar system missions have been calculated. These include the inner planets [6], outer planets [7], potentially hazardous asteroids [8], an unconventional strongly non-Keplerian orbit for obtaining a permanent view to Sun's polar regions [9] and direct propulsive deflection of Earththreatening asteroids [10]. For outer planets, combining pure E-sail propulsion with a modest chemical thruster burn for orbit insertion at the target is advantageous [11].

The dynamics of E-sail tethers has been simulated with a custom-made programme which solves Newton's laws for 1-D elastic tethers together with electrodynamic and other governing equations. In cases which are relevant to the E-sail, mechanical stability of E-sail flight and tether deployment has been seen in these simulations.

About 4 m of nearly final-type E-sail tether has been manufactured using the ultrasonic wire-to-wire bonding technique which has been developed for this purpose. The ESTCube-1 nanosatellite (launch 2012) is Estonia's first satellite whose purpose is to deploy 10 m of E-sail tether and to measure the E-sail force acting on it in LEO. In LEO there is no solar wind, but the spacecraft-ionosphere relative motion is used as a substitute for it. In LEO, E-sail type thin tethers could be used as an efficient electrostatic plasma brake for deorbiting small or medium sized satellites [12].

After that we discuss the needed next step in E-sail experimental investigations which would be a solar wind test mission and ways how to do it potentially with low cost. Finally we give an overview of E-sail scientifi and commercial applications. The paper ends with conclusions.

3. Summary and Conclusions

We are not aware of any scientific, technical or other reason why the E-sail wouldn't eventually work at least roughly at the projected performance level. Because the projected performance level (deliverable impulse versus mass) is 2-3 orders of magnitude higher than for chemical rockets and ion engines, the margin for success is large. If better tether materials than aluminium could be employed (e.g., metallised carbon or silicon carbide fibre), the performance level could even increase significantly beyond this estimate. The test mission ESTCube-1 is under preparation and will be launched in 2012 to measure the E-sail effect for the first time. Also different solar wind test mission concepts are under study.

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