



## Electric Solar Wind Sail in tailwind

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### Abstract

The Electric Solar Wind Sail (E-sail) is a novel propulsion concept that enables faster space travel to many solar system targets. E-sail uses charged solar wind particles as the source of its propulsion. This is achieved by deploying long, conducting and charged tethers, which get pushed by the solar wind by Coulomb drag [1].

E-sail technology is being developed to technical readiness level (TRL) 4-5 by the European Union's Seventh Framework Programme for Research and Technological Development, EU FP7, in a project named ESAIL (<http://www.electric-sailing.fi/fp7>). Prototypes of the key parts are to be produced. The design will be scalable so that a real solar wind demonstration mission could be scaled up from them. We review here the latest results of the constantly evolving E-sail project.

### 1. Electric Solar Wind Sail

The Electric Solar Wind Sail (E-sail) uses charged tethers to extract momentum from the solar wind ions (mainly protons) to obtain propulsive thrust. It is a new propulsion method for interplanetary travel, which was invented in 2006 and is currently under development [1].

The produced thrust of an E-sail is inversely proportional to the distance from the Sun as  $F \sim 1/r$

[1]. The E-sail requires no propellant and discharging of the wires by solar wind thermal electrons can be counteracted by an electron gun powered by modest-sized solar panels. To enable manoeuvring and trajectory control, the E-sail thrust can be steered in a cone of  $\sim 30^\circ$  around the solar wind velocity vector.

At 1 AU distance from the Sun, approximately 2000 km of E-sail tether is required to produce 1 N of thrust if using 20 kV voltage. This could be achieved for example by having hundred 20 km long tethers spun out centrifugally from the spacecraft hub. This E-sail propulsion system would weigh  $\sim 100$  kg and be able to transport a 1000 kg payload relatively swiftly in the solar system. Alternatively, it could be used to boost a 200 kg payload at over 50 km/s out of the solar system or to deflect an Earth-threatening three million tonne asteroid in ten years.

### 2. Structure

An E-sail spacecraft consists of a central unit, out of which several (up to 100) highly charged tethers are deployed centrifugally. Our baseline maximum tether length is 20 km, but with current materials (aluminium alloys) lengths up to 100 km could be developed. At the end of each tether is a Remote Unit (RU). These RUs weigh a few hundred grams and are connected with each other by elastic auxiliary tethers. The auxiliary tethers take care of mechanical stability and are made of non-conducting material such as

polyimide (Kapton). A schematic drawing of an E-sail is displayed in Figure 1.

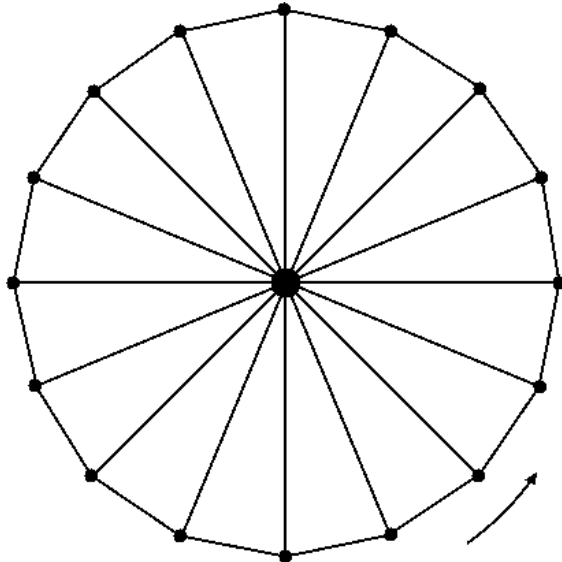


Figure 1. Sketch of a 16-tether E-sail spacecraft. Shown are the central spacecraft and Remote Units, connected with each other by main tethers and auxiliary tethers. The whole E-sail rotates around its central craft in order to keep the tethers centrifugally stretched. The structure can be made resistant to breakages of the main tethers, but the auxiliary tethers made of perforated polyimide tape are mission critical so they must be designed against micrometeoroid damage by a sufficient margin.

The E-sail thrust is produced by thousands of kilometres of charged tethers interacting with the solar wind particles. The E-sail tethers need to be lightweight, conducting, micrometeoroid impact resistant and be able to withstand the pull created by the centrifugal acceleration keeping them stretched. Their outer surface area should be minimised in order to minimise the collected thermal electron current and thus the power consumption of the electron gun. Designing and manufacturing the conducting main tethers and reliably deploying them in space is likely the main engineering challenge of the project.

The design requirements of the tethers can be met by knitting four 25-50  $\mu\text{m}$  thin aluminium wires into a 2-3 cm wide mesh-like tether. The wires are connected to each other by a novel ultrasonic wire-to-wire bonding method. There are already over 20 meters of tether produced by an automated ‘tether-factory’ made for this purpose. We have also successfully demonstrated repeated reeling and unreeling of the tether. The production rate is being

increased as more automation is added. Non-invasive quality control methods are also being developed.

Initially, the auxiliary tethers are on reels in the RUs while the main tether reels are in the main spacecraft. When deploying, the rotation of the whole system is kept up by small thrusters at RUs. Deployment of the main and auxiliary tethers are scheduled and actively controlled.

### 3. Test missions

An E-sail payload is currently scheduled to fly on two low Earth orbit (LEO) CubeSat test missions: ESTCube-1 (Estonia) and Aalto-1 (Finland), going to be launched in late 2012 and during 2013, respectively. Both CubeSats will deploy short E-sail tethers of at least 10 m and measure the E-sail force exerted on them by the  $\sim 7$  km/s relative speed between the orbiting satellite and nearly stationary ionosphere. The tether voltage is varied in sync with the rotation of the satellite. In this way E-sail effect can be accumulated over many spins and measured by measuring the change in the spin period.

### 4. Summary and discussions

The design and production of Electric Solar Wind Sail prototypes is in good progress. Tethers, auxiliary tethers and Remote Units produced by the current ESAIL EU FP7 project are to reach TRL 4-5 by 2013 and designed so as to be applicable or scalable to a groundbreaking 1 N E-sail mission. E-sail technology could be available for solar system research within ten years and if successful, it might revolutionise the way we think about space travel and plan our future exploration missions.

### References

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