Electric solar-wind sail for asteroid touring missions and planetary protection

P. Janhunen[1]

[1]Finnish Meteorological Institute

The electric solar-wind sail (electric sail, E-sail [1,2]) is a relatively new concept for moving around in the solar system without consuming propellant and by using the thrust provided by the natural solar wind to produce propulsion. The E-sail is based on deploying, using the centrifugal force, a set of long, thin metallic tethers and charging them to high positive voltage by actively removing negative charge from the system by an electron gun. To make the tethers resistant towards inevitable wire cuts by micrometeoroids, they must be made by bonding from multiple (typically 4) thin (25–50 µm) aluminium wires. Production of the tethers was a technical challenge which was recently overcome.

According to present numerical estimates, the E-sail could produce up to 1 N of propellantless thrust out of less than 200 kg package which is enough to give characteristic acceleration of 1 mm/s^2 to a spacecraft weighing 1 tonne, thus producing 30 km/s of delta-v per year. The thrust scales as $\sim 1/r$ where r is the solar distance. There are ways to control and vector the thrust enough to enable inward and outward spiralling missions in the solar system.

The E-sail working principle has been indirectly measured in a laboratory, and ESTCube-1 CubeSat experiment is underway in orbit (in late March 2014 it was waiting to be started) to measure the E-sail thrust acting on a short 10-m long tether. A full-scale mission requires $\sim$ 1000 km of tether altogether (weighing $\sim$10 kg). The production of a 1-km piece of tether has been demonstrated in laboratory [3].

If the E-sail holds up its present promise, it would be ideally suited for asteroid missions because it enables production of similar level of thrust than ion engines, but needs only a small fraction of the electric power and never runs out of propellant because it does not use any (the "propellant" being the natural solar-wind plasma flow). Here we consider especially a mission which would tour the asteroid belt for a long time, moving from asteroid to asteroid in a bit similar way as, e.g., Mars rovers move from rock to rock on the planet's surface. After starting from the Earth, the mission would slowly spiral outward, making rendezvous with interesting asteroids along the way, as well as flybys or even a larger number of asteroids as opportunities arise. The spacecraft would do remote sensing of the bodies and perhaps also deploy small CubeSat-sized expendable landers on them (the mother spacecraft cannot land on an asteroid or else it would lose the E-sail tethers). The mission would first explore near-Earth objects, then pass through the main belt and end up with the Trojans, exploring asteroids in rendezvous and flyby modes all the time. Asteroids in roughly circular orbits and at low inclination would be the easiest and most likely targets for rendezvous mode encounters, while there would be less restrictions for flyby mode observations.

Besides for pure asteroid science, the E-sail could also be used for planetary protection, either through direct propulsive deflection of a dangerous asteroid [4] or by accelerating a relatively lightweight impactor spacecraft to a retrograde orbit and in that way maximizing the available deflecting impact energy for given impactor mass. E-sails could take a number of such impactors to retrograde storage orbits from which they could be commanded to impact a dangerous asteroid with relatively short warning time. Such impactor fleet would not be dangerous to the Earth because the vehicles can be designed to burn completely in the atmosphere, in the unlikely event that due to some mishap one of them would collide with the Earth.

The E-sail has potentially large applicability to asteroids as it promises "free" transportation in the solar system. As a next step, a solar-wind test mission is needed to demonstrate the technology in the authentic environment.

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