Asteroid touring by electric sail technology

Executive Summary of ESA TRP project

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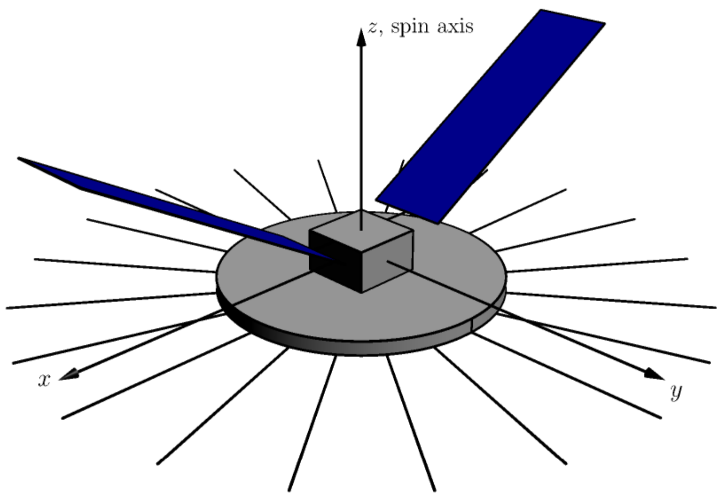
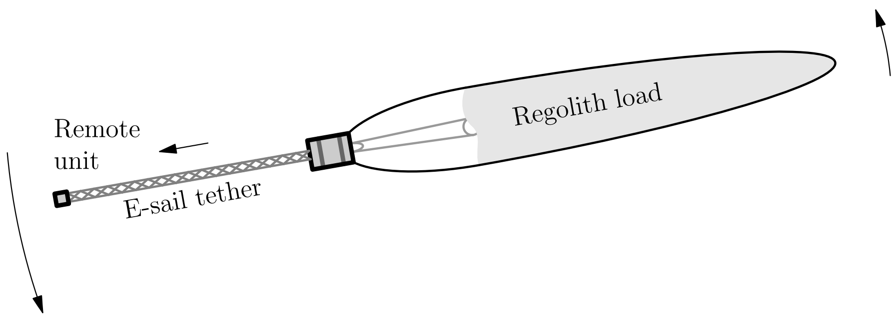
Abstract

The electric solar wind sail (E-sail) uses the solar wind to generate propellantless propulsion. We analyse asteroid-related E-sail mission architectures. We find that the E-sail enables a portfolio of advanced mission scenarios. A large number of asteroids can be surveyed at low cost per asteroid in flyby mode. Sample return is possible with moderate mass. Asteroid mining can become economical because the propellantless nature and low mass of the E-sail enable a high mass ratio. A systematic study of the options and a detailed analysis of the most promising ones are included in this report.





Executive summary

The electric solar wind sail (E-sail, Chapter 1) uses the solar wind to generate propellantless propulsion. The system consists of one or more long and thin metallic tethers that are kept at high positive potential. To maintain the bias voltage, an electron gun is used which pumps out negative charge from the system. This is needed to compensate for the thermal electron current gathered by the tethers from the solar wind plasma. The electric power requirement is low compared to typical electric propulsion, only of order 0.7 W/mN.

A multi-tether E-sail with the so-called TI configuration can control its spinrate and spinplane orientation using the E-sail effect itself (section 1.4). A single-tether E-sail can also do this for the spinplane orientation, but for the spinrate magnitude, the orbital Coriolis acceleration cannot be cancelled by the E-sail effect in this case. Therefore a single-tether E-sail needs a traditional thruster placed in the remote unit at the tip of the tether (section 1.5.1). The single-tether E-sail has the benefit of enabling platform pointing without moving parts.

Candidate mission ideas were critically surveyed for suitability with E-sail propulsion (Chapter 2). For asteroids, gravity assist manoeuvres are typically not available and so low-thrust propulsion methods such as electric propulsion and E-sail often have an advantage over chemical propulsion. The E-sail is the most efficient low-thrust method known, so it suits well for asteroid missions. The main limitation of the E-sail is that it is not possible to land or even go close to an asteroid with the opened tether rig, and the tethers cannot be reliably retracted and re-opened. For flyby missions this is not a limitation. For rendezvous, orbiting, landing and sample return missions, however, other solutions must be sought. A secondary limitation is that the E-sail dictates the platform's orientation, so pointing of antennas and instruments cannot be done by turning the platform.

A fleet of 50 single-tether E-sails performing flybys of more than 300 main-belt asteroids was proposed with name “Multi-Asteroid Touring” (MAT) in response to the 'Call for new ideas' in 2016 (Appendix D). To keep the telemetry costs down, automatic optical navigation based on planets and known asteroids was envisioned, similar to that demonstrated by Deep Space 1 in 1998–2001. Optical images and near-infrared spectra of the flown-by asteroids would be stored in memory throughout the nominally 3.2 year mission for each member of the fleet, and downlinked at a final Earth flyby to a 16 m ground antenna in a 3-hour telemetry session transferring 10 gigabytes of data from flash memory, for each 50 spacecraft. An engineering design of the spacecraft was carried out where the mass came out to be 6 kg without launchpod structure (Slavinskis et al., 2018).

In spring 2018, the MAT proposal was looked at in a CDF study “Small Planetary Platform”. The main criticisms raised were the need for autonavigation software (which, although demonstrated 20 years ago by Deep Space 1, would need to be developed again in Europe) and the mass-constrained nature of the design (in order to accomplish its main-belt tour in a single orbit, it needs 1.0 mm/s^2 characteristic acceleration and scaling the thrust up is nontrivial because the single tether cannot be made arbitrarily long due to material tensile strength constraints). To address these criticism, a NEO version of MAT was developed (Chapter 5). Surveying NEOs instead of main-belt asteroids relaxes the characteristic acceleration requirement and so removes the mass-constrained nature of the design. It also enables ordinary navigation methods based on telemetry sessions to be used. As a bonus, it also removes the need to perform spinrate management by a thruster at the tether tip because the mission can be accomplished by fully radial propulsion in which case the orbital Coriolis effect is known to vanish.

In the multi-tether mission category, asteroid sample return was analysed in detail (Chapter 4). A two-spacecraft mission architecture is used where E-sail mothership is parked at the edge of the asteroid's Hill's sphere to avoid risk of tethers colliding with potential unseen minimoons of the asteroid. A separate science spacecraft lands, takes the sample and re-docks with the mothership. The entry capsule is part of the mothership and the sample canister is transferred from the science spacecraft at the re-docking. The telecommunication subsystem is part of the science spacecraft. The science spacecraft can be turned freely because it has no tethers, so pointing of the antennas and the science instruments is possible to do without moving parts. The mothership has 18 tethers, each of length 15 km and the total wet mass of the two spacecraft is 142 kg including 20 % margin. A simple scheme for docking and attachment was sketched and analysed.

The missions thus far analysed are scientific, although they also have some features that can benefit asteroid mining and resource prospecting. For economically profitable asteroid mining, however, the mass ratio (the ratio of the mass returned in the target orbit, versus the initial launch mass) should be high. To check how high mass ratio can be feasible, we analysed a single-tether mission architecture for returning regolith from NEO to LEO (Chapter 6). Reaching LEO is requires aerobraking, but it was selected as the target orbit because it is more likely to have near-term customers e.g. for regolith-extracted LOX than higher orbits. The spacecraft is a 6-U cubesat weighing 8 kg. After launch to marginal or other escape orbit, it deploys a single-tether E-sail to go the asteroid. At the asteroid the tether is abandoned and the spacecraft maps the asteroid for regolith pools and lands. It crawls on the surface, filling a lightweight plastic snail-shaped container with regolith as it goes. When up to 300 kg has been collected, it lifts off using gas propulsion and deploys a second E-sail tether for flying back to Earth. Near Earth, the tether is jettison so that it burns in the atmosphere, while the spacecraft itself deploys an aerobrake to lower the apogee gradually to LEO altitude. The maximum mass of 300 kg originates from the requirement that the achieved nominal acceleration is 1 km/s/year, which allows a triptime from a typical NEO of less than four years. The corresponding mass ratio is 37.5 which should be high enough for economical retrieval of NEO regolith to LEO for the purposes of LOX extraction.

The E-sail enables a portfolio of advanced mission scenarios. A large number of asteroids can be surveyed at low cost per asteroid in flyby mode. Application to NEOs is easier, but with some investment in autonavigation software and some risk-taking in miniaturisation, also main-belt asteroids can be surveyed. Sample return is possible with 140 kg total mass. Asteroid mining can become economical because the propellantless nature and low mass of the E-sail enable high mass ratio when returning from material from NEO to LEO, for example.