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Cubesat experiments for Coulomb drag propulsion for interplanetary missions and space debris mitigation

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Two 3-unit cubesats, FORESAIL-1 and ESTCube-2 soon to be launched (2022), both accommodate an electrostatic tether that can be charged to a high voltage with respect to the ambient ionospheric plasma in low-Earth orbit. The high voltage sheath around the tether serves as an electrostatic obstacle that perturbates the plasma ram flow causing Coulomb drag and a net braking force to reduce the orbital speed of the tether-spacecraft system.

According to the theory and particle-in-cell computer simulations, the Coulomb drag is a promising candidate for propellantless and continuous low-thrust propulsion in the solar wind with the plasma flow speeds typically being 440 km/s. In this presentation, we review its applications both to interplanetary missions as in ESA call for ideas, 2016, a 50-cubesat fleet to the main belt asteroids, and to space debris mitigation as in ESA cleansat building block 15, electrostatic tether plasma brake, 2017.

The key components of our payloads are a reeling system for the tether deployment and a high voltage power system: FORESAIL-1 (-1 kV); and ESTCube-2 (-1 kV, +0.5 kV, and +1.0 kV). In this presentation, we describe these payloads in further detail: The reeling system is such that the tether reel is supported by a ceramic bearing and rotated by a stepper motor and associated driver electronics. The 60-metre long tether is manufactured by knitting out of four thin aluminium wires with individual wire thickness of 50 micrometre. The multi-wire structure is required for redundancy against micrometeoroids. The tether is deployed by the centrifugal force provided by an end mass at the tip of the tether. During the launch, the reel and the end mass are secured by launch locks. The high voltage contact to the tether reel is realised by a slider connector. The payload electronics also contain the control electronics and electric power system. All this is miniaturised in order the payload spatial sizes to be less than that of one cubesat unit.

Concerning the high voltage polarity, the positive (negative) tether naturally collects electron (ion) current from the ambient plasma as electrons (ions) tend to neutralise the positive (negative) tether bias. Thus the high voltage system has to maintain the selected tether bias. In the solar wind, it is preferable to use the positive bias as it can be maintained by using electron emitters that are much simpler than the ion emitters. In the ionosphere, the plasma number density is large enough, and no ion emitter is required as an electron collecting surface as a conducting part of the spacecraft can be incorporated instead. For this reason, the payload on board ESTCube-2 has two electron emitters to enable the testing of the positive polarity high voltage system and the electron emitters for future development of the Coulomb drag propulsion in the solar wind. As a third topic of our presentation, the basics of the Coulomb drag propulsion are shortly covered.

Our tether payloads have been designed and built to measure the braking force caused by the Coulomb drag to the electrostatic tether in a low-Earth orbit plasma environment. It is a cornerstone measurement in the roadmap of evaluating Coulomb drag as space propulsion. On our roadmap, we are already developing a 6-unit cubesat (FORESAIL-2) for experiments in geostationary transfer orbit and further envisioning FORESAIL-3 and ESTCube-3, for example in lunar transfer orbit to measure the Coulomb drag in the solar wind.