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Foresail - CubeSat platform and missions to higher orbits

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Abstract

Small affordable satellites have opened the opportunity for innovative small class science missions to Low Earth Orbit and beyond. Finnish Centre of Excellence in Research of Sustainable Space (FORESAIL) started a CubeSat program which aims to improve CubeSat technology radiation tolerance to explore the higher orbits and radiation belt. Currently, the Foresail satellite program consists of two development generations of CubeSat platforms, prepared for to different science missions. Two satellites, the Foresail-1 (FS1) and Foresail-1' (FS1') utilize the 3U CubeSat form factor and have been developed for Low Earth Orbit (LEO), whereas the Foresail-2 satellite aim towards a highly elliptical Geostationary Transfer Orbit (GTO) to study magnetic Ultra Low Frequency waves in the radiation belt region.

1 Introduction

The rapid development of small satellite technology and cost reductions in the space launch sector provide an opportunity for many smaller countries to conduct their own space missions. Along with booming commercial space activities, small innovative space science and Earth Observation satellites have been taking off. However, the currently available CubeSat platforms are usually not suitable for missions to higher orbit where high radiation levels does not allow usage of usual Commercial off-the-shelf (COTS) electronic components without protection. On the other hand those regions are particularly interesting for space science as many space weather processes take place in this energetic environment. Moreover, rapid dynamics and spatial distribution of phenomena in this region would benefit in simultaneous multi-point measurements in order to validate the predictions of the latest models. CubeSat platforms could provide a tool to achieve multi-point measurements with affordable price.

To extend the CubeSat usability in space science missions and improve CubeSat radiation tolerance, Finnish Centre of Excellence (CoE) in Research of Sustainable Space (FORESAIL) is developing a CubeSat missions to higher orbits with custom built satellite platform. The development is executed in to stages, where the first mission to Low Earth Orbit is testing and demonstration the key components and the second generation of satellites is aimed to Geostationary Transfer Orbit to demonstrate the technology, detect Ultra Low Frequency magnetosphere waves and carry out other scientific experiments.

The FORESAIL consortium consisting of Aalto University, University of Helsinki, University of Turku and the Finnish Meteorological Institute. The consortium brings together expertise on near Earth environment modeling and measurements, radiation detector development, innovative plasma instrument development and small satellite mission and platform development. The goal of the CoE is to promote sustainable use of space through innovative small satellite technologies which includes better radiation tolerance and deorbiting technologies.

In the following chapters we summarize the current state of Foresail missions and platform development.

2 Foresail-1 missions

The first mission developed by FORESAIL consortium is Foresail-1 (FS1) mission which is designed to LEO. The goal of the Foresail-1 mission Figure 1 is to measure charged particle precipitation and to demonstrate an electrostatic deorbiting device [6]. The Foresail-satellite platform is developed entirely at Aalto University and it includes elements of radiation protection, planned to be used later also in higher orbit missions. The satellite is designed for LEO and provides CubeSat platform, tailored for science measurements, attitude control, a radio communication link and onboard data storage. The satellite uses some heritage from Aalto University previous mission Aalto-1 [7, 4].

The FS1 satellite features two main payloads, the particle telescope (PATE), developed by University of Turku and plasma brake device (PB), developed by Finnish Meteorological Institute. Both devices have some heritage from earlier missions[2, 5, 4]. PATE aims to measure the flux of precipitating electrons and the solar energetic neutral atom

(ENA) flux at LEO. The instrument consists of two perpendicular particle telescopes, scintillator stack and readout electronics. The second payload is a deorbiting device called plasma brake (PB). It is an electrostatic tether for demonstrating orbital maneuvers by using electrostatic force in space plasma. The device will reel out a 60 m long tether which will use the plasma charged particles to slow down the satellite speed and lower the orbit till deorbiting to atmosphere. The device can be used also for measuring several plasma properties. The PB experiment consists of a motorised tether reel and a high-voltage source that, when turned on, biases the deployed tether to nominally -1 kV voltage relative to the spacecraft chassis [3].

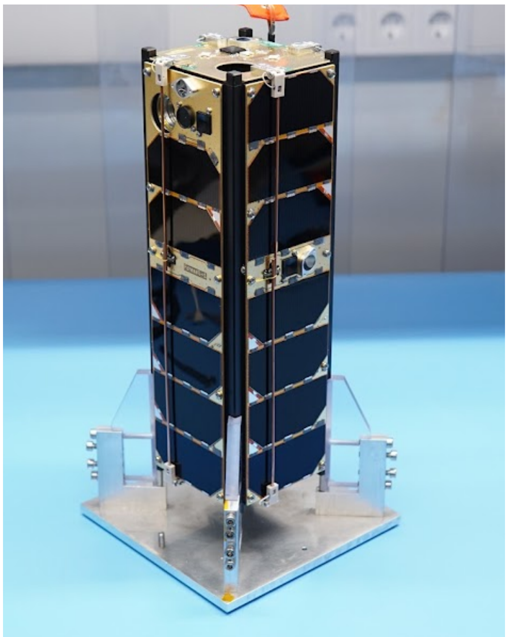

Figure 1. Foresail-1 satellite flight model in laboratory.

For fast development and deployment, the FS1 satellite uses a common CubeSat 3U form factor to utilize commercial launch. The science case needs a polar off-mid-day orbit measuring for ENAs and energetic electron precipitation. Both satellites feature two payloads – PATE and PB – as well RPi camera for imaging the PB's tip mass and MATTI magnetometer. In case FS1p will be launched in SSO, PB will be used to achieve a drifting RAAN (with respect to the Sun) for ENA measurements.

Additionally the satellite features secondary payloads. The RPi Camera is a small COTS camera payload which is mostly designed to capture images for project's PR purposes. The camera is also used for PB deployment monitoring, but has no formal requirement from PB experiment. Another payload MATTI (MAgnetometer Technology Test Instrument) is an AMR based magnetometer designed to be used in a CubeSat. MATTI is an experimental payload, designed for getting more experience on CubeSat magnetometer designs and measurements. The primary objective is to demonstrate what performance can be achieved with COTS components.

The payload suite is supported by custom built modular avionics, which is integrated to radiation protected stack. The OBC (Onboard Computer) is the satellite's main computer which is responsible for most of the satellite platform's computational and data storage needs. OBC consists of two cold redundant TI Hercules series MCUs Both MCUs have a full set of sensors used in ADCS (Attitude Detection and Control System) calculations. Coincidentally OBC will also run all the ADCS algorithms. ADCS can provide 3-axis stabilized attitude control using based on air coil magnetorquers and spin rates up to $130\,^\circ\,\mathrm{s}^{-1}$ for initial plasma brake deployment. Cold redundancy is acquired with a dedicated arbiter (ARB) mcu that tracks heartbeat signal from whichever MCU is currently activated. ARB also controls avionics bus interface switches that isolate the MCUs from each other. Avionics stack and payloads talk with separate RS-485 busses for bus link budget reasons.

The UHF-band radio subsystem operates as the main Telemetry, Tracking and Commanding (TT&C) radio on board. The radio operates on the 70 cm amateur radio band at 437.125 MHz. Foresail-1 provides a message repeater service for amateur radio operators. The service utilizes the Skylink protocol, also developed at Aalto University, by assigning a virtual channel for this service. The message repeater will randomly transmit uplinked messages from a message buffer. The main ground station is located at Aalto University Campus in Otaniemi, Finland.

The Foresail-1 satellite was launched in May 2022. The satellite deployed nominally and operated successfully for two weeks. Unfortunately, after two weeks the satellite was lost due to misconfiguration of communication system during the commissioning phase. Despite of rescue and reset campaign lasting several months, it was not possible to resume contact with the satellite. A replacement satellite integration was started in the end of 2022 under the name of Foresail-1' (FS1') and the launch is expected in the end of 2023 or beginning of 2024.

3 Foresail-2 missions and platforms

The first-generation platform functions as a test bed for next, more advanced missions, namely Foresail-2 to higher orbits. These missions will utilize a next generation 6U satellite platform, developed by utilising the lessons learned from Foresail-1 missions. The Foresail-2 mission is aimed to high elliptical orbits which exposes the satellite to harsh radiation environment. The first mission that will use the new 6U platform will be Foresail-2 [1] (shown in Figure 2).

The satellite will probe the magnetosphere with a highly sensitive magnetometer, developed by the Austrian Space Research Institute (IWF), which is typically not found in small satellites of this scale. The instrument requires high grade magnetic cleanliness from the satellite platform, which adds additional challenge to the satellite platform design. Additionally, the Relativistic Electron and Proton Ex-

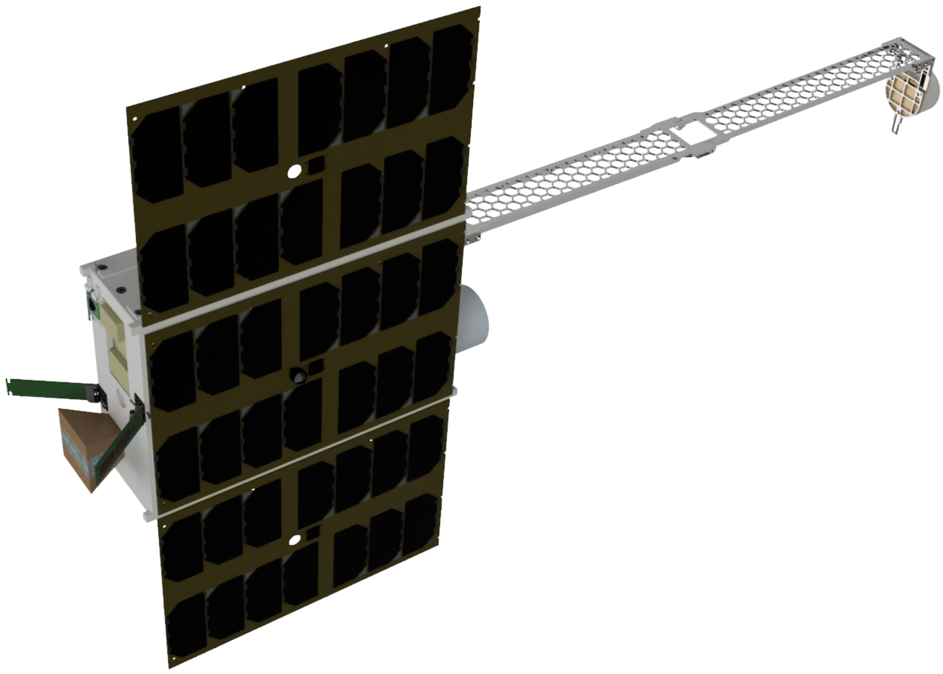

Figure 2. Foresail-2 satellite shown in its science configuration with tether and boom extended

periment (REPE) by the University of Turku will measure electrons and protons with a particle telescope stack. Together with the Coulomb Drag Experiment (CDE) by the Finish Meteorologic Institute (FMI) it enables further research of the plasma environment around the Earth. The Coulomb Drag Experiment is similar electrostatic tether as in FS1 [3], but the tether length is longer and the device is designed for high radiation environment .

The Magnetometer Aboard the ForeSail2 cubesaT (MAST) is developed by the Austrian Space Research Institute (ASRI) and will be mounted on a boom. The boom will separate the measurement head from the spacecraft to reduce the magnetic noise in measurements. The boom itself has to be made out of non-magnetic material and additionally has to fit the requirements of a CubeSat. Aalto University develops this boom in close collaboration with the ASRI.

The CDE tether charging system includes both negative and positive polarity high voltage (HV) capability, which is an upgrade in relation to FS1. The negative mode is used at the perigee as a plasma brake (PB) to demonstrate new deorbiting technology. Whereas the positive mode around the apogee as an E-Sail. The high GTO would provide to test the CDE in soilar wind for the first time. The mechanics and electronics of the experiment is based on the heritage of the payloads onboard Foresail-1 (PB) and ESTCUBE-2 (PB and E-sail).

The communication distance is one of the challenges going to high elliptical orbits and a special communication radio is under development for the mission. The platform will use commercial S-band frequency in full duplex mode. According to the feasibility study, it is possible to establish a up- and downlink, but it requires a ground station network and dynamic date rates at different orbital segments.

As CDE and REPE need a spinning spacecraft in addition to the weak magnetic field, the attitude determination and control system will require unusual solutions. Unfortunately commercially available reaction wheels cannot be used to aid the thruster system as their spinning frequency interferes with the frequencies measured by MAST. Therefore a thruster based system is favoured over magnetorquers because of their higher control authority.

Radiation protection in these orbits has been simulated extensively to be able to use COTS components. A shielding solution of an 6 mm aluminium satellite body yielded good results for the six-month mission goal.

This 6U CubeSat will be launched, according to current plans, not earlier than 2025 into a highly elliptical Earth orbit to study ULF-waves and related effects.

4 Conclusion

CubeSat platform usage for demanding science missions is complicated task, as the scientifically more interesting regions have harsh radiation environment, not suitable for COTS components usually used in LEO CubeSats. Space science sets also other requirements to platform, such as magnetic cleanliness, which are difficult to achieve with small and affordable platform. Despite the difficulties, CubeSat satellites will find their way to more extensive science use due affordable launch market. This work presented the efforts of Finnish FORESAIL consortium in the path of making CubeSat usage possible in high orbits science missions and providing science measurements of ULF waves in magnetosphere.

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