

HT100 In-Orbit Validation: μ HETSat Mission

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Abstract: with the advent of megaconstellation projects and very low Earth orbiting observation satellites, low power electric propulsion is expected to gain a central role in the small satellite market. In the 100-200W power range, among all possible types of electric propulsion devices, Hall Effect thrusters are the most appealing ones as they are robust, reliable, can be operated with moderately low voltages and can work at low power levels maintaining an adequate efficiency and a lifetime compatible with the more and more ambitious mission goals of modern satellites. Among existing Hall thrusters operating in the abovementioned power range, SITAEL HT100 is one of the most advanced devices, with unique design features that make it extremely compact and highly efficient. To fully validate this thruster in orbit, μ HETSat mission has been jointly supported by the Italian and European Space Agencies and the whole propulsion system is currently undergoing a complete qualification campaign that will make it ready to fly in space within 2018. In the present work the electric propulsion system is described in all its main subcomponents, showing its configuration as satellite payload and briefly giving an overview of its main tasks during the mission.

I. Introduction

A wide variety of missions can be accomplished by means of electric propulsion, many of them only attainable thanks to the high specific impulse that strongly limits the necessary mass of propellant to accomplish the target tasks. Up to now, electric propulsion has been widely used on large geostationary satellites, traditionally for station-keeping tasks and, more recently, also for orbit raising. Instead, as it proved somewhat difficult to scale down electric thrusters maintaining a good efficiency and because of the obvious limitations in terms of power availability, electric propulsion is still rarely adopted on small satellites. However, tide is rapidly changing in the last few years, in connection to the development of novel mission concepts (large satellite constellations) and international guidelines which prescribe that each S/C is properly decommissioned at the end of its operative life. And in the last few years SITAEL developed HT100, a compact Hall thruster working at power levels below 200W with peak efficiencies well above 30% [1]. After an extensive phase of development [2,3], HT100 thruster is now going to be launched by SITAEL on μ HETSat mission as a main propulsion system, with the task of maneuvering the satellite several times between a 600 km and a 500 km circular orbit, then lowering the satellite to 350 km for a drag-compensation phase and a successive semi-controlled re-entry (by means of electric propulsion a semi-controlled re-entry is possible, with huge propellant savings w.r.t. conventional chemical rockets). The mission, which is jointly supported by ASI (Italian Space Agency) and ESA (European Space Agency), will be carried out with SITAEL S-75 platform, a small satellite entirely designed in-house and based on previous heritage on ESEO program [4]. The paper starts with a brief presentation of

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the mission profile, then focuses on the propulsion system description and is closed by an overview of the ongoing activities.

II. μ HETSat Mission Profile

As recalled in the introduction, μ HETSat mission is solely aimed at validating HT100 in space, thus the propulsion system is also the mission payload. For a significant validation process, the thruster is expected to fire over 1000 hours, bringing the spacecraft from an initial altitude of 525 km to a target altitude of 425 km and back. This maneuver will be repeated nine times, so to accumulate a consistent number of firing hours. In this first phase of the mission the satellite will always stay below 525 km, so that in case of any major failure its reentry happens anyway well within the 25-year period prescribed as a guideline by most international standards. After cumulating about nearly 1000 hours of operation through nine up and down maneuvers, the satellite altitude will be lowered down to 350 km and there it is going to stay for several months by means of the HT100 (fired for 30 minutes every ‘n’ days, where ‘n’ is strictly dependent of the atmospheric density at that altitude, which is in turn dependent on the solar activity). After the mission completion, the satellite will be decommissioned performing a semi-controlled reentry.

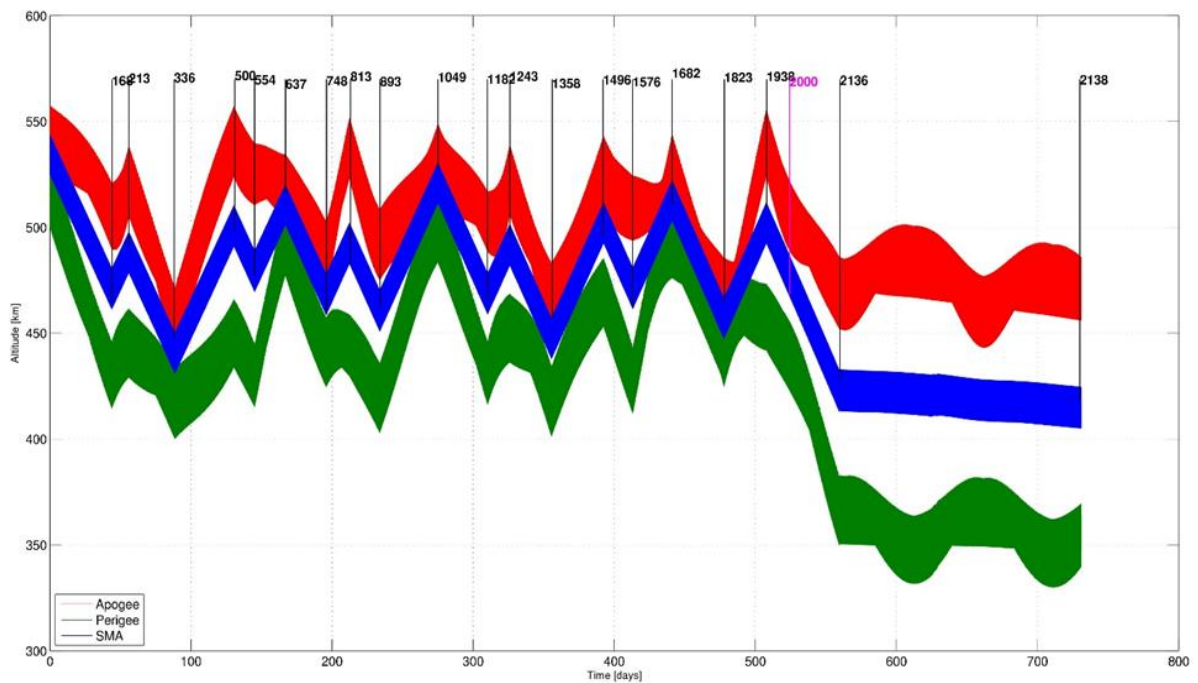


Table 1: μ HETSat ‘bounce’ maneuvers and drag compensation

The whole mission can be completed with about 3 kg of Xe, although 4.3 kg will be loaded in the tank to keep an adequate margin (1000 hours of firing time at 1 mg/s have been considered, 0.75 mg/s being the target total mass flow rate for the thruster unit, with an additional 20% margin on top of that).

A. Thrusting Strategy

Due to power constraints a precise thrusting strategy has been defined in order to be able to operate the thruster for a sufficient time (target is 1000 hours), maintaining the number of On/Off cycles within a reasonable limit.

Three main flight attitudes have been considered:

- Sun Pointing Mode (SPM) – for Nominal Sun phases
- Firing Mode (FM) – for Payload Mode and Nominal Eclipse phases
- Transition Mode (TM) – for the Nominal Maneuvers

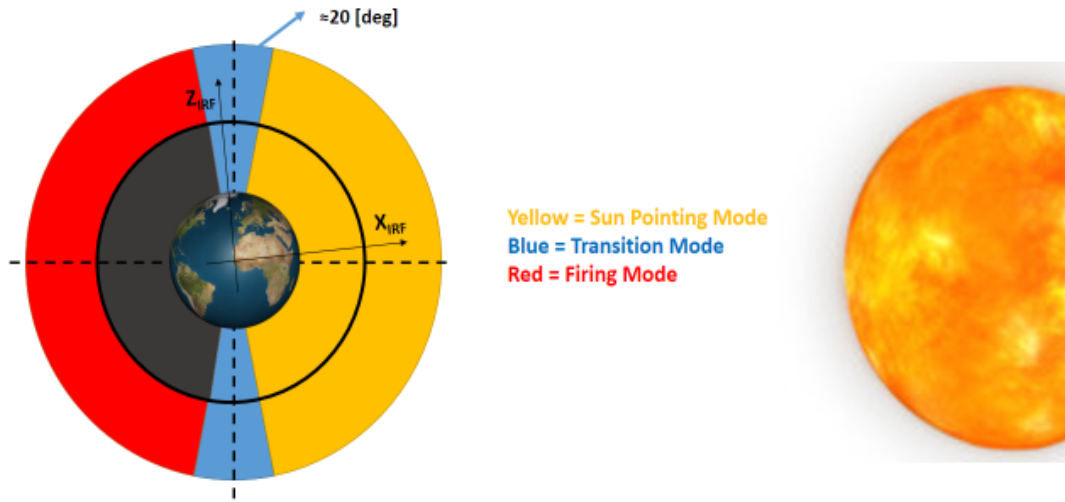


Figure 1: μ HETSat, main flight modes

Figure 1 shows the distribution of the three modes along the orbit. The S/C stores the required energy to complete the firing phase in SPM. With this attitude the S/C keeps the solar panels pointed towards the sun in order to charge the batteries, then, once close to the point where eclipse is about to start, the TM brings the S/C to the attitude desired for firing. The FM takes place during the eclipse, at the end of which another TM happens that brings back the S/C back to SPM. HT100 thruster is going to fire for a period close to thirty minutes once every four orbits.

III. Propulsion System Architecture

Among all the possible architectures for a low power electric propulsion system, the one presented here is based on a single thruster, privileging the system compactness and simplicity over its reliability. A fully redundant system with two thrusters and an internally redundant PPCU (2 Power Boards, 1 + 1 redundant, and two control boards, 1 + 1 redundant) is also under development for missions where higher reliability is required [5]. A single branch system like the one illustrated in Figure 2 also turns out to be much less expensive, which often is a crucial factor for small-satellite market.

The rationale behind this choice has been strengthened by SITAEL recent developments in Hall thruster technology, with the successful introduction of a magnetic field topology that remarkably reduces the thruster erosion, thus increasing its lifetime [6]. Such topology, known as magnetic shielding configuration and studied for a few years in the U.S. [7,8], prevents hot plasma to come in direct contact with the ceramic walls of the thruster acceleration channel. By using a long-life thruster a total impulse in excess of 200 kNs can be attained with a single device, fulfilling mission needs that would otherwise require the use of two ordinary HT100 fired one after the other (series configuration). The only redundancy that has been maintained is thus for the cathode (HC1), as this increases the whole system reliability with a minimum mass and volume penalty. The resulting overall subsystem mass (excluding tanks) is lower than 10 kg, well suitable for small satellite missions.

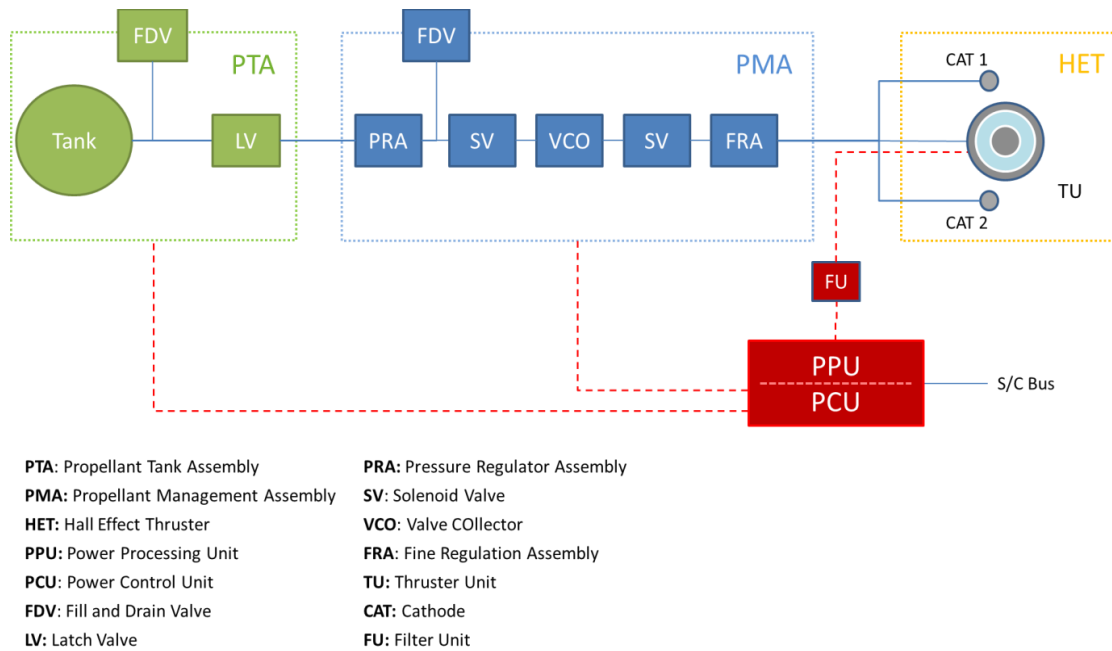


Figure 2: Propulsion subsystem, main constituting elements

A. Thruster Unit

The thruster unit consists of one thruster (SITAEL HT100) and two hollow cathodes. HT100 is the lowest power EP thruster ever developed in Europe, with a nominal operating power of 175 W. It can be operated in a power range between 120 and 300 W, with a peak efficiency exceeding 35% and a maximum specific impulse of about 1,300 s. Dedicated tests have demonstrated the capability of maintain a steady operation down to anode power levels of about 80W. With a design based on permanent magnets and a total mass lower than 450 g, HT100 is also the most lightweight Hall thruster of this class.

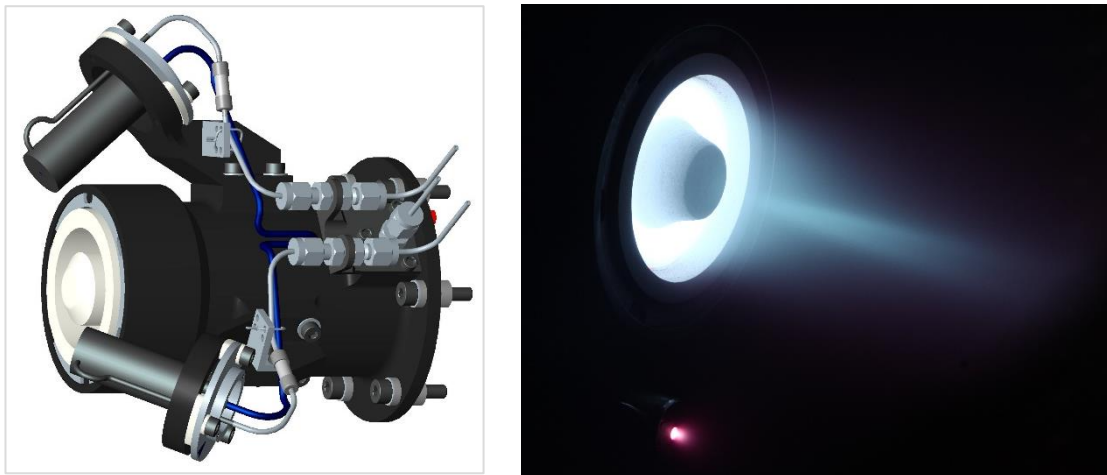


Figure 3: thruster unit layout (left), HT100 firing at SITAEL premises in Pisa (right) in a special configuration with the cathode parallel to the thruster axis

HT100 has been thoroughly tested in the last two years, demonstrating a lifetime in excess of 2200 hours and cumulating in the course of the endurance test a total impulse close to 80 kNs.

B. Power Processing and Power Control Units

The power processing unit and the power control units are two boards located in the same tray on top of the payload bay. As the thruster is working at a fixed operating point throughout the mission, both units have been kept as simple as possible in order to save mass, size and complexity. The PPU/PCU tray has a volume of $280 \times 280 \times 50 \text{ mm}^3$ and their combined mass is slightly lower than 1.5 Kg.

The Power Processing Unit (PPU) performs the power conversion functions of the Electrical Propulsion System and provides power conditioning and control for the HT100 Hall effect thruster. Besides being in charge of generating all the supply voltages and currents required for proper operation of the thruster, the PPU also provides all the related protections and telemetries.

A major feature of μHETSat PPU is the possibility of offering two modes of operations selectable by means of a latch relay:

- Floating CRP Mode (default relay contact position, i.e. OPEN): corresponding to the conventional approach, in this mode of operation the thruster Common Return Potential (CRP) is defined by the Beam Stray Current (IBSC) flowing through a “bleeder” resistor connected between CRP and the spacecraft Ground.
- Grounded CRP Mode (relay contact CLOSE): at some point during the ESEO-HET mission it will then be possible to decide whether the conditions are right for verifying the implications of forcing the CRP potential to the spacecraft Ground potential. This will be achieved by latching ON a relay contact connected in parallel to the above mentioned “bleeder” resistor. While in this mode of operation, the current flowing between the CRP and the spacecraft Ground, coincident with IBSC, will be monitored in order to study its dependence from relevant environmental variables, such as altitude, sunlight or eclipse, solar activity, season, orbital positions, etc. Such set of experimental data could later be used for validating models developed for the prediction of such effects. It shall be remarked how the verification of the implications of operating a Hall Effect Thruster while its CRP is forced to spacecraft Ground would be of crucial importance for the assessment of future applications based on the so called Direct Drive approach.

The PPU input voltage is between 22 and 25V, while the Anode Voltage that the PPU can supply is between 200 and 400V (discrete steps of 25V) with a maximum processable power of 220W. At a power level of 150W and an applied anode voltage of 250V, the PPU efficiency is 90%.

The PCU has the same architecture of the one already developed for ESEO, properly adapted to be interfaced with μHETSat PPU and On-board Computer in order to accomplish the following main tasks:

- Telecommand/Telemetry and Housekeeping exchange with the OBDH via CAN bus.
- Sequence generation in order to control the thruster operations on: start-up, stop, regulated thrust, power setting, and failure recovery.
- Electro-valves switching.
- Monitoring of diagnostic parameters, while implementing the corresponding recovery, and-or reporting, actions.

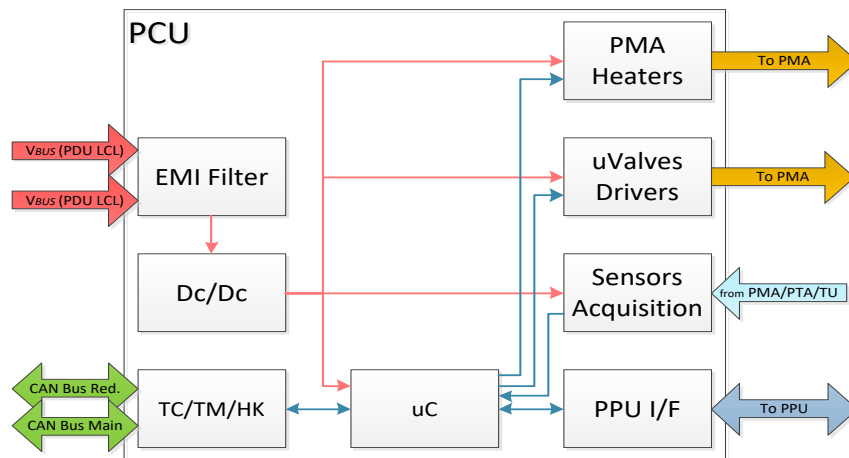


Figure 4: PCU block diagram

C. Propellant Feeding System and Tank

The Propellant Management Assembly (PMA) is simplified thanks to the choice of operating the thruster unit at a fixed point. In this way, the mass flow rate to the anode and the cathodes can be regulated by means of calibrated orifices with no need of more complex valves. PMA system has three barriers (as typically required) and a total mass lower than 3 kg.

As for its architecture, PMA is divided into three main sections, respectively “high”, “low” and “not” pressurized sections. The high-pressure section is composed by the high-pressure stage of the Pressure Regulator Assembly (PRA). The low-pressure section is the main section and is composed by two subparts: one to collect and monitor the propellant at low pressure and one to distribute it to the different anode and cathode lines. A low-pressure fill and drain valve (LPFDV) ensures access to this section both during the tests and pre-lunch drain phases. PMA is fully equipped with pressure transducers, temperature sensors and heaters on the Valve Collector (VCO) in order to ensure correct conditions for the propellant through the whole system. Downstream the low-pressure section, there is a non-pressurized section of the PMA, composed by the pressure transducers used to monitor the outlets and by all the fittings and tubes acting as mechanical interfaces with the Thruster Unit.

The tank is a titanium alloy vessel of 2.8 liters with a MEOP of 150 bar. Considering the mission needs and taking an adequate margin of the propellant mass, 4.3 kg of Xe are going to be stored in it at a nominal operating pressure of 76 bar (beginning of life).

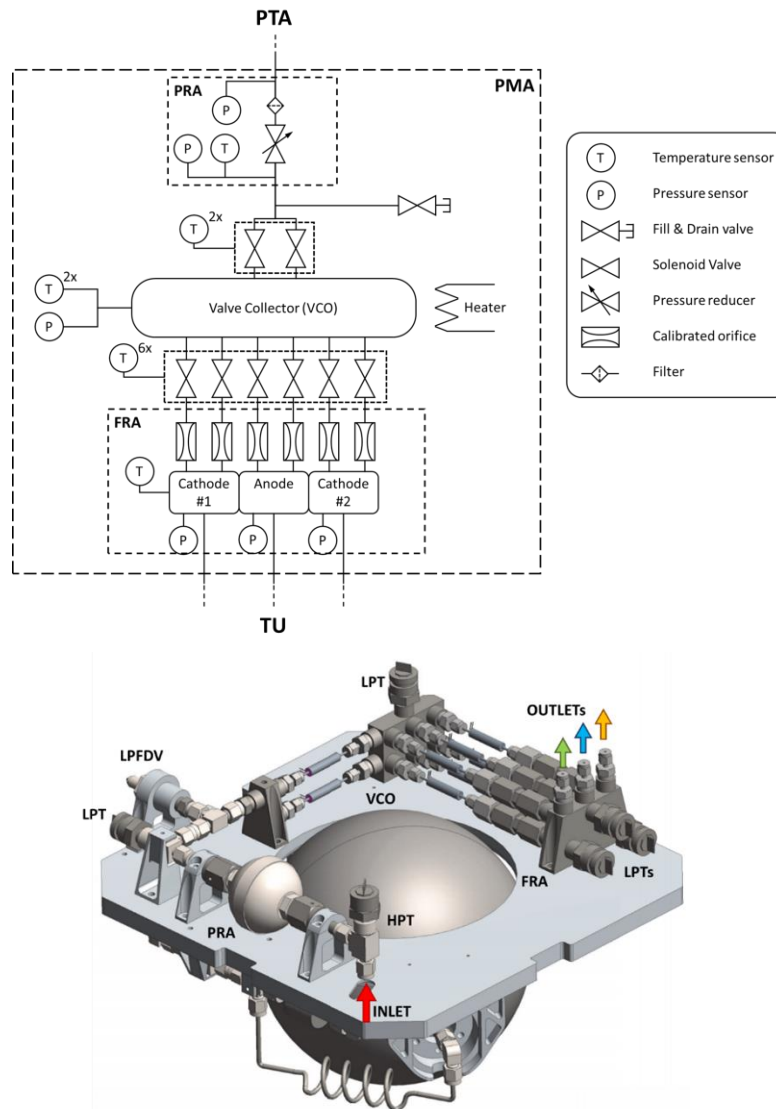


Figure 5: μHETSat Propellant Management Assembly

IV.S-75, SITAEL Small Platform

The propulsion system will be accommodated in SITAEL S-75 platform. S-75 is the smallest platform developed by SITAEL for commercial purposes, capable of hosting 20 kg of payload in its lower bay and directly stemming from S-50 platform previously designed for ESEO programme. Payload size has to be within 320x320x400 mm³, which almost perfectly fits with the target size of our electric propulsion system. A large portion of the payload bay is occupied by the Xe tank. The tank has been aligned with the S/C longitudinal axis in order to minimize the effects linked to the variation of the position of the center of gravity due to propellant consumption. Attitude control system has been improved w.r.t. ESEO by using four reaction wheels as primary actuators on the three axis (instead of momentum wheel /magneto-torquers combination) to allow more rapid S/C attitude changes during flight mode transitions.

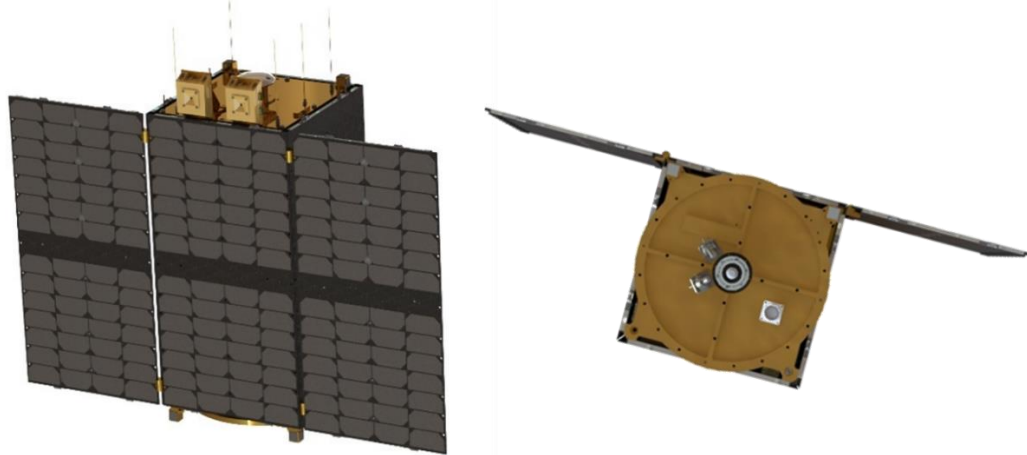


Figure 6: SITAEL S-75 platform with deployed solar panels; on the right a frontal view of the bottom plate shows the thruster collocation

The spacecraft is equipped with both sun and Earth sensor to constantly measure its attitude, as well as with four momentum wheels to control it. Power is generated through a deployable solar array that can provide up to 160 W when in full sunlight (around the Earth). Battery capacity has been doubled w.r.t. the one available on ESEO S/C and is 680 Whr on μ HETSat in order to supply the thruster during its operation. The thruster unit is installed in the center of the bottom plate and is the only part of the propulsion system that is protruding outside the S/C and directly sees the outer space. PTA is behind the thruster, in the middle of the payload bay surrounded by the PMA plate (where all the valves, sensors and pressure regulating systems are placed). PPU and PCU stay in the first tray on top of the payload bay. No thrust orientation mechanisms have been included, as this would make the system much more complicated. To orient the thrust vector the attitude of the whole satellite is properly changed (up to 180° around the nadir axis when going from S/C pushing phase to S/C braking phase).

Here follows a table indicating the masses of the main subsystems and showing the payload fraction.

Subsystem / Payload	Mass [kg]
Structure	30,4
Power System	7,4
AOCS	8,9
TMTC	1,2
OBDAH	0,4
Harness	2,2
Payload (dry-mass, including tank)	7,9
Propellant	4,3
Total Mass	62,7

Table 2: μ HETSat mass budget (including margins; an additional 5% margin has been considered on top of the indicated total mass value)

V.Ongoing Activities and Conclusions

An intensive assembly and test campaign is presently ongoing in order to fully validate the electric propulsion system at EQM level. All subsystems will be validated separately and then assembled together in an EQM model of the whole payload bay for final tests and a global check of its functions. In parallel PFM manufacturing and assembly line has been already carefully planned to comply with the tight schedule. Two thruster unit EQMs have been manufactured in order to have the possibility of performing the HET endurance test and the HET performance / environmental test at the same time. Procurement phase is also in an advanced state and focused on getting all the necessary parts according to ECSS quality standards. Assembly will take place in SITAEL clean room in Pisa for the thruster unit and in the larger clean rooms in Mola di Bari for the whole satellite. Mola di Bari premises are also hosting part of the environmental tests, while thruster unit acceptance tests and thermal-vacuum tests are carried out in Pisa premises.

μ HETSat is going to be the first mission entirely designed and handled by SITAEL that entails electric propulsion and is a cornerstone as it is paving the way for many other future applications of HT100 and low power electric thrusters in general.

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