An Educational 3U CubeSat Mission at Politecnico Di Torino: The ELECTRA Mission for TEC Research and Micro Thruster In-Orbit Testing

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An Educational 3U CubeSat mission at Politecnico di Torino: the ELECTRA Mission for TEC Research and Micro thruster In-Orbit Testing

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Abstract

ELECTRA - Electron Layer Exploration using CubeSat for TEC Research and Analysis – is a student-driven 3U CubeSat mission, under development at Politecnico di Torino, by the CubeSat student team in collaboration with the Systems and Technologies for Aerospace Research Laboratory (STAR lab) and the Navigation Signal Analysis and Simulation (NavSAS) research groups. The mission serves as an educational platform, providing students with hands-on experience in space mission design and development. Through collaboration with NavSAS, students gain expertise in Positioning, Navigation, and Timing (PNT), Global Navigation Satellite Systems (GNSS), and telecommunications. The project promotes multidisciplinary teamwork, problem-solving, and interaction with the research and industry sectors, bridging the gap between academia and the business world. The core scientific mission objective is the analysis of the ionospheric Total Electron Content (TEC) in Low Earth Orbit (LEO). By leveraging the CubeSat's natural orbital decay, the mission will monitor TEC variations at multiple altitudes, enhancing the understanding of ionospheric dynamics and space weather phenomena. The integration of GNSS-based Radio Occultation (RO) data will enable detailed vertical profiling of electron density, providing insights into equatorial plasma bubbles, Medium-Scale Traveling Ionospheric Disturbances (MSTIDs), and auroral irregularities. This data will contribute to improving space weather models and increasing the accuracy of satellite-based communication and navigation systems. Additionally, ELECTRA serves as an in-orbit demonstrator for the Solid-State Plasma (SSP) micro thruster, an advanced propulsion system designed for CubeSats. Its feasibility will be evaluated using Kinematic Precise Orbit Determination (POD) algorithms, which process GNSS measurements to track the CubeSat's trajectory with meter-level accuracy. This paper presents a detailed overview of the ELECTRA mission, covering its mission objectives, system architecture, and key subsystems, including payload design, propulsion, communication, and data processing. Furthermore, it discusses the lessons learned and best practices from the concurrent engineering approach adopted during the mission's conceptual and preliminary design phases. The paper highlights the educational impact of the CubeSat student project on both the student community and the educational approaches to target a more hands-on and comprehensive project-based education. These insights aim to provide valuable guidance for future educational CubeSat-based research and technology demonstration mission.

Abbreviations

ACPL	Acceptance Collision Probability Level
AIV/T	Assembly Integration Verification and Testing
AOCS	Attitude and Orbit Control System
C3	Cubesat Control Centre
CAMs	Collision Avoidance Manoeuvre
CE	Concurrent Engineering
COTS	Component Off The Shelf
DET	Department of Electronics and Telecommunications
D/M	Development Model
DSP	Digital Signal Processing
ECSS	European Cooperation for Space Standardization
EF/M	Electrical and Functional Model
ELECTRA	Electron Layer Exploration using CubeSat for TEC Research and Analysis
EPS	Electrical Power System
ESA	European Space Agency
GMSK	Gaussian Minimum Shift Keying
GNSS	Global Navigation Satellite System
INGV	Istituto Nazionale di Geofisica e Vulcanologia
LEO	Low Earth Orbit
LEOP	Launch and Early Operations Phase
NavSAS	Navigation Signal Analysis and Simulation
PF/M	Proto-Flight Model
PNT	Positioning, Navigation and Timing
POD	Precise Orbit Determination
PoliTO	Politecnico di Torino
Q/M	Qualification Model
RID	Review Item Discepancy
RO	Radio Occulation
ROT	Rate of TEC
ROTI	ROT Index
SSO	Sun-Syncronous Orbit
SSP	Solid State Propulsion
STARlab	Systems and Technologies for Aerospace Research Lab
TEC	Total Electron Content
TEGIX	TEC Gradient Index
UHF	Ultra High Frequency
V/M	Virtual Model
VHF	Very High Frequency
VTEC	Vertical TEC

1 Introduction

The CubeSat PoliTO team is a university student team based at Politecnico di Torino, composed of around 50 members from different countries and background. Over the years, the team gained experience in developing CubeSats missions: its first launch dates back to 2012, when the CubeSat e-st@r-I was delivered into orbit during Vega maiden flight; the second one, e-st@r-II, was launched in 2016, and it was operative until May 2024. To continue with this great tradition, the new CubeSat team mission takes a step into combining a scientific mission, with the aim of improving the knowledge of Earth's ionosphere, with the technology demonstration of a micro thruster, with the objective of filling the gap of propulsion onboard CubeSats.

The CubeSat team proposes a CubeSat navigation-based mission, named Electron Layer Exploration using CubeSat for TEC Research and Analysis (ELECTRA). The mission will analyze and map the ionospheric Total Electron Content (TEC) in Low Earth Orbit (LEO) using dual-frequency Global Navigation Satellite System (GNSS) signals. This data will provide insights into space weather phenomena like solar storms, improving space weather forecasting and the resilience of satellite communications. Additionally, the ELECTRA mission acts as a demonstration for an innovative solid-state micro thruster, with precise orbit determination achieved through GNSS-based Kinematic Precise Orbit Determination (POD).

With a student-centered focus, the 3U CubeSat mission aims at enhancing students' interdisciplinary collaboration, problem-solving abilities, and interaction with real-world contexts, bridging the gap between academia and industry. Following these educational objectives, a concurrent engineering approach has been adopted during the conceptual and preliminary designing phase, allowing a faster and homogeneous development of the project. Additionally, the nano-satellite has an in-house AOCS, based on the knowledge and experience gained by the team through the projects in collaboration with Systems and Technologies for Aerospace Research Lab (STARlab) at Politecnico di Torino. Furthermore, the team is supported by the Navigation Signal Analysis and Simulation (NavSAS) research group of the Politecnico di Torino Department of Electronics and Telecommunications (DET), for the GNSS-related objectives, and by Istituto Nazionale di Geofisica e Vulcanologia (INGV) for the scientific data processing. Moreover, since January 2025 the ELECTRA mission is one of the five missions selected by European Space Agency (ESA) for Fly Your Satellite! Design Booster 2 programme, in which ESA Academy gives support during the design phase of student team missions. In conclusion, the ELECTRA project has started in Spring/Summer 2024, with the conceptual study of the mission and the objectives definition. This paper presents the design status related to the first ESA review, further iteration will occur to improve and to conclude the ELECTRA design. The timeline settled up by the team is targeting the launch in Q2 2027.

2 Mission Overview

2.1 Mission Description

The mission objectives fall into three categories: Education, Science, and Technology.

Education. As a student-driven project, education is a central pillar. The mission development, launch and operations provides hands-on training, helping students develop both technical and soft skills, including teamwork in multidisciplinary settings, project management under deadlines, and engagement with the research community. This environment fosters problem-solving, creativity, and collaboration while bridging the gap between academia and industry. Additionally, as the project is carried out in close collaboration with the NavSAS group at Politecnico di Torino and the INGV, the students are exposed to expertise in Positioning, Navigation and Timing (PNT), GNSS, and telecommunications applied to space systems, as well as data post-processing. Furthermore, the CubeSat Concurrent Design Facility [1] serves as an advanced development platform, enabling integrated system analysis and enhancing project quality.

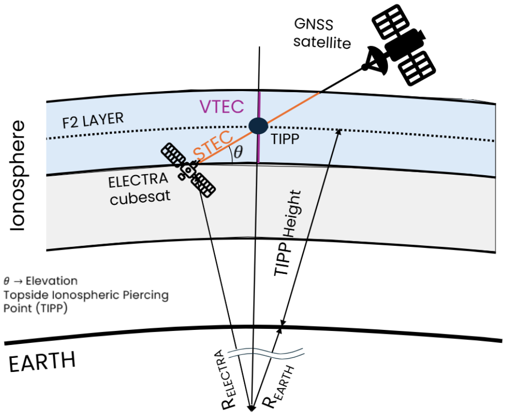

Fig. 1: ELECTRA Mission TEC, VTEC, STEC

Science. The ELECTRA mission aims to advance the understanding of ionospheric dynamics by analyzing the TEC in the topside ionosphere, namely the F2 layer. Exploiting natural orbital decay, the CubeSat will monitor TEC variations at multiple altitudes, generating high-resolution datasets across different ionospheric layers. Multi-frequency GNSS measurements will provide insights on plasma exchange between the ionosphere and plasmasphere, with a particular focus on geomagnetic storm conditions. In addition, GNSS Radio Occulation (RO) will be used to derive vertical electron density profiles, enabling the determination of key parameters such as the F-layer peak height (hmF2) and maximum electron density (NmF2) [2],[3],[4],[5],[6],[7]. These results will improve space weather models and mitigation strategies for satellite communications and navigation systems [8]. As an example, TEC estimates can contribute to enhancing positioning accuracy, as GNSS measurements can be corrected through the incorporation of TEC-based corrections. Ultimately, ELECTRA is a pilot for a future constellation of small satellites in LEO, designed to provide real-time, global ionospheric monitoring.

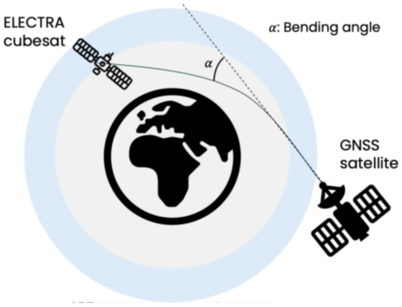

Fig. 2: ELECTRA Mission - Radio Occultation

Technology. The mission also serves as an in-orbit technology demonstrator for the novel Solid State Propulsion (SSP) micro-thruster [9]. This propulsion system offers advantages in mass, reliability, and miniaturization, critical features for CubeSats. Its performance will be evaluated through GNSS-based POD, which estimates position, velocity, and timing directly from GNSS data without force models or complex orbit dynamics [10],[11],[12],[13]. Kinematic POD provides precise orbit tracking with limited onboard resources [14], enabling real-time orbit solutions at meter-level accuracy when combining code and carrier-phase data [15],[16]. This approach represents a scalable and cost-effective solution for future CubeSat missions.

2.2 Mission data products

The mission will generate both scientific and technical data products, aimed at advancing space technology and ionospheric science. These outputs will support improvements in satellite navigation, communications, and CubeSat propulsion.

2.2.1 Technical Data Products

Dual-frequency GNSS observables from the onboard receivers will demonstrate the use of GNSS-based POD for small satellites in LEO. This approach offers a cost-effective alternative to traditional ground-based tracking and paves the way for autonomous navigation of future CubeSats. Telemetry from the SSP micro-thruster will be combined with GNSS data to validate its in-orbit performance, confirming its viability as a compact propulsion solution for CubeSat platforms.

2.2.2 *Scientific Data Products*

The post-processed ionospheric dataset will improve understanding of space weather effects on the ionosphere, particularly the impact of TEC variations on satellite systems. Data from ELECTRA will be merged with ground-based measurements below the F2 region and extended with measurements above it.

The analysis will cover multiple latitudes:

- **Low latitudes:** investigation of Pre-Reversal Enhancement (PRE) and equatorial plasma bubbles, using TEC and scintillation indices.
- **Mid latitudes:** characterization of Medium-Scale Traveling Ionospheric Disturbances (MSTIDs), using TEC gradients and irregularity indices.
- **High latitudes:** study of auroral and polar cap irregularities caused by particle precipitation, using GNSS-derived TEC and in-situ electron density.

Thanks to its sun-synchronous orbit, ELECTRA will provide UTC-synchronized measurements over different regions at nearly the same local time each day. This ensures temporal consistency and comparability across datasets.

2.2.3 *Data Access and Distribution*

All raw and processed data will be downlinked to the Ground Station at Politecnico di Torino. Stakeholders will access numerical products including pseudorange, pseudorange rate, timestamp, TEC estimates, carrier-to-noise ratio (C/N_0), and navigation data. Each GNSS receiver will provide data at a minimum rate of 1 Hz in the scientific region of interest.

The expected data volume is 904 bit per satellite in view per sampling frequency. This dataset will support on-ground POD estimation, filtering weak GNSS signals to optimize downlink efficiency and enabling accurate TEC mapping to achieve mission objectives.

2.2.4 *Data processing and Analysis*

The ionosphere will be studied by monitoring several characteristics and parameters. Due to the intrinsic complexity of its nature, it is necessary to follow a precise processing pipeline as depicted in Figure 3. Depending on the processing step and on the measurement source, RO or POD antenna, it is possible to retrieve different indexes useful to study the dynamic of the ionosphere (Rate of TEC (ROT) and ROT Index (ROTI), TEC Gradient Index (TEGIX)), studying its irregularities or to obtain vertical projection of the TEC (Vertical TEC (VTEC)).

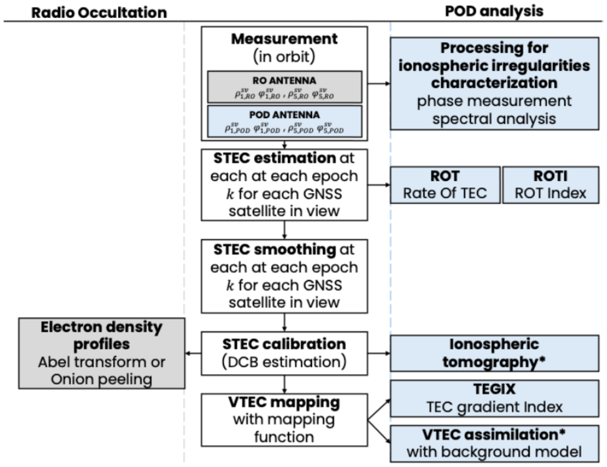

Fig. 3: Data processing pipeline

2.3 *Concept of Operation*

The ELECTRA mission is structured around a series of defined phases, from its earliest stages of test and integration to its final de-orbit and atmospheric re-entry, illustrated in Figure 4.

With ground operations complete, the mission enters the Launch and Early Operations Phase (LEOP). The phase begins with the launch itself, which typically lasts up to a couple of hours, from ignition through orbital insertion. Once separation from the launcher occurs, the deployment and detumbling sequence begins, lasting for about three days, until a stable attitude is achieved.

The final step of LEOP is the in-orbit checkout phase, which typically extends over the first month of operations. During this time, subsystems and payload components are sequentially activated, to test and confirm functionality and overall health. One exception is the micro-thruster, which remains inactive during this phase. Since the thruster is a technology demonstration and its early activation could jeopardise the mission in the event of a malfunction, its use is deliberately postponed.

Then comes the operative phase of ELECTRA, which represents the core of the mission and spans approximately two years. It is divided into two major sub-phases: science operations and technology demonstration.

In parallel with routine platform support, the spacecraft conducts its scientific mission. The core scientific objective of ELECTRA is the study of the ionosphere using dual-frequency signals from GNSS. The scientific data collected in orbit is transmitted to the primary ground station. Once on the ground, data is further processed and analysed, contributing to the broader scientific community's understanding of ionospheric dynamics.

Then, approximately one year into the operative phase, the SSP micro-thruster is activated for the first time. By waiting until a substantial amount of science data has already been collected, the mission ensures that its primary goals are not compromised. When the thruster is eventually activated, its performance is carefully evaluated using POD data to assess its impact on the CubeSat's trajectory and orbital control. These results will not only demonstrate the capabilities of the SSP micro-thruster but also inform the design of future propulsion systems for small satellites.

As the operational life of ELECTRA concludes, the mission transitions into its end-of-life phase. The first step is the passivation of the Electrical Power System (EPS) and the propulsion subsystem. Following passivation, the satellite gradually re-enters the Earth's atmosphere.

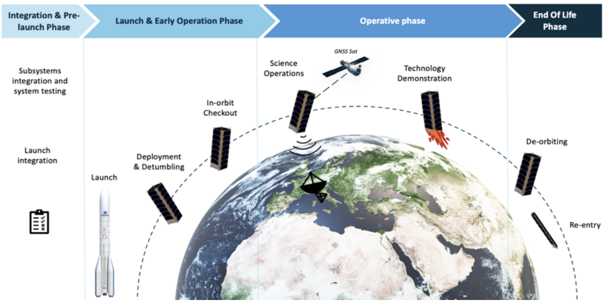

Fig. 4: ELECTRA Mission Design Reference

The operative modes of the ELECTRA mission are depicted in the State Diagram with their transition (Figure 5).

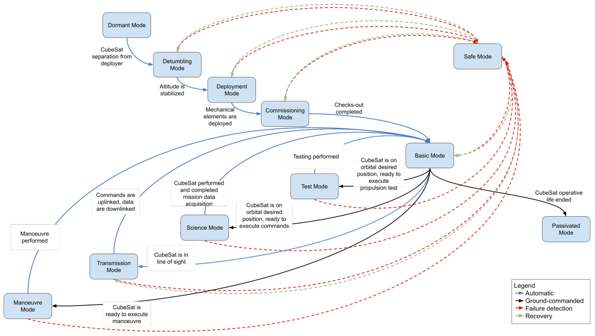

Fig. 5: State Diagram

Depending on the current mission phase, certain operational modes may be activated, and, as a result, specific subsystems will be turned on or off, following Table 1.

	Dormant	Detumbling	Deployment	Commissioning	Manoeuvre	Science	Transmission	Basic	Safe	Passivated	Testing
GNSS	Off	Off	Off	On	On	On	Off	Off	Off	Off	Off
AOCS	Off	On	On	On	On	On	On	On	On	Off	On
TT&C	Off	Off	Off	On	On	On	On	On	On	Off	On
EPS	Off	On	On	On	On	On	On	On	On	Off	On
Prop.	Off	Off	Off	Off	On	Off	Off	Off	Off	Off	Off
Mech.	Off	Off	On	Off	On	Off	Off	Off	Off	Off	Off
OBDH	Off	On	On	On	On	On	On	On	On	Off	On

Table 1: Subsystem states across operational modes

2.4 *Mission Analysis*

2.4.1 *Orbit Selection*

The chosen orbit has the following characteristics:

Table 2: Orbital parameters

Orbit Parameter	Value
Inclination	97.40°
Eccentricity	0.001
Altitude	500 km

The selected orbit altitude is 500 km, ensuring the CubeSat operates within the F2 ionospheric layer limit. Additionally, this altitude was selected to comply with the ESA Space Debris Regulation, specifically concerning the satellite lifetime limit in LEO.

The orbital inclination was determined through a trade-off to optimize data reception with the primary ground station, Cubesat Control Centre (C3) (Politecnico di Torino, 45°03'28.28" N, 7°39'23.91" E). Initially, a 55° inclination was preferred for optimal communication with C3. However, a Sun-Syncronous Orbit (SSO) was ultimately chosen due to the greater availability of launches to Sun-synchronous orbits and the improved latitude coverage they provide for scientific purposes. Data transmission will prioritize Ground Station C3, with the Kiruna station serving as a backup.

Table 3: GS visibility

	Accesses	Max Dur. [min]	Min Dur. [min]	Mean Dur. [min]
C3	5	7.42	6.08	7.10
Kiruna	13	11.55	2.21	8.94

2.4.2 *Decay analysis*

In order to comply with the ESA's new Zero Debris policy, analyses were conducted to evaluate the satellite's orbital decay period and ensure compliance with the requirements set by the Space Debris Mitigation Regulation. The orbital decay was calculated using the OSCAR tool provided by the ESA-DRAMA software. An analysis of the decay was conducted using two solar activity prediction models (Latest Predictions and Monte-Carlo) over an entire solar cycle, starting from a provisional launch date, April 1, 2027. Simulations were performed twice a year, every six months, for the entire 11-year solar cycle, for both prediction models.

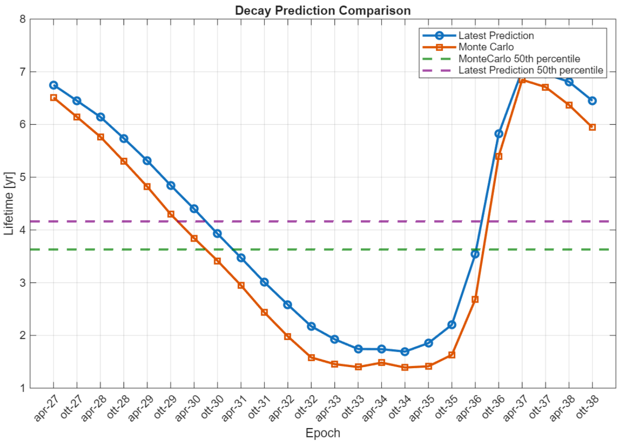

Fig. 6: Decay Prediction Comparison

2.4.3 *Collision Avoidance Manoeuvre*

Since the ELECTRA satellite is equipped with a propulsion system, analyses were carried out to assess the collision probability and the feasibility of implementing potential Collision Avoidance Manoeuvre (CAMs). These analyses followed the procedures outlined in the ESA Space debris mitigation requirements, using the ARES tool to evaluate the Acceptance Collision Probability Level (ACPL), the required Delta-V, and the number of CAMs. To identify an ACPL that ensures a 90% risk reduction, two simulations were performed, considering both the beginning and the end of the satellite's operational lifetime. The selected ACPL value is $1 \cdot 10^{-5}$. In Figure 7, the graph showing the Delta-V budget required to perform a Collision Avoidance Manoeuvre as a function of the time interval between the event and the manoeuvre is represented.

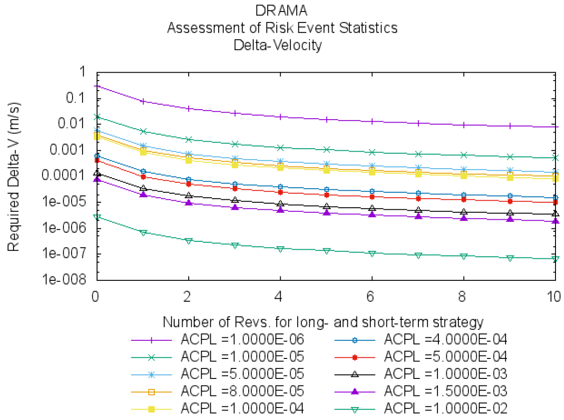

Fig. 7: Delta-V budget for a collision avoidance manoeuvre

3 System Overview

3.1 *Design Process*

The system design process started with mission objectives and a functional analysis, aimed at identifying the key functions required to achieve mission objectives. The functional analysis served as the basis for the requirements definition, payload selection, and system architecture design, in an iterative process to obtain the best trade-off between mission objectives and constraints. The requirements definition was carried out in close collaboration with the scientific advisors and mission specialists, making use of Concurrent Engineering sessions.
As a result, a preliminary set of requirements has been established strictly following ECSS standards and managed using Valispace platform, which serves as the team's main repository for requirement traceability, version control, and cross-disciplinary collaboration.

3.2 *Payloads*

The payload of the ELECTRA mission is made up of two main instruments: two dual-frequency GNSS receivers and a solid-state micro thruster.
The **scientific payload** includes two AsteRx-m3 Pro by Septentrio, dual-frequency multi-constellation GNSS receivers capable of tracking GPS, GLONASS, Galileo and other constellations; each receiver is connected to two TAOGLAS GVLB258. A GNSS multiband patch antennas. The two antennas are placed at a 90 ° angle, one pointing the zenith to receive direct GNSS signals and the other one pointing the satellite local horizontal to receive limb GNSS signals for radio occultation measurements.
Both receivers are connected to both antennas through power dividers for redundancy reasons. The GNSS receivers will be used to retrieve dual-frequency measurements to calculate TEC and to perform POD.
The **propulsion payload** consists of a low-power vacuum arc ion thruster supplied by SSP. The vacuum arc thruster creates a pulsed electric arc between two electrodes on the thruster. The arcs are concentrated in the cathode spots, where the cathode material is turned into high-velocity plasma, generating thrust. As the system relies on a solid state propellant, it has a very simple architecture with no moving parts and no tanks, thus it is extremely reliable.

Table 4: Micro-thruster specifications

Parameter	Value
Nominal Power Range	1–10 W
Thrust-to-Power Ratio	8–14 μN/W
Maximum Thrust	0.7 mN
Specific Impulse	600–1100 s
Total Impulse	200 Ns

The thruster will be activated by a Pulsed Width Pulsed Modulation signal (PWPM) sent by the AOCS board, and its thrust will depend both on the supplied power and the pulse frequency.

3.3 *Spacecraft architecture*

The spacecraft is a 3U CubeSat that relies on a distributed system architecture. All subsystems are designed using *off-the-shelf* components to ensure reliability, except the AOCS board and the Interface Board which are designed and developed in-house.

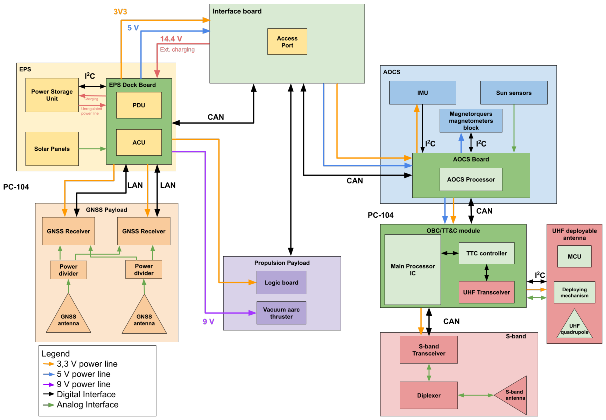

Fig. 8: ELECTRA System Architecture

Figure 8 shows the system architecture of the spacecraft, highlighting the main power and data interfaces between the subsystems.

The boards are arranged in two PC/104 stacks placed at the top and bottom of the satellite, connected through a custom interface board. The **Interface Board** is mounted parallel to one of the spacecraft's longitudinal side panels, aligned with the external access port at the opposite side of the thruster, as shown in Figure 9. The custom Interface Board ensures a faster and more robust connection between the boards and hosts additional components such as power converters, umbilical connectors, and sensors, thereby increasing flexibility during the design phase.

This particular configuration allows to keep a central volume behind the thruster clear from circuit boards to mitigate thermal loading and electromagnetic interference.

The system relies mainly on a CAN bus for subsystem communication and a dedicated LAN interface for payload data transfer.

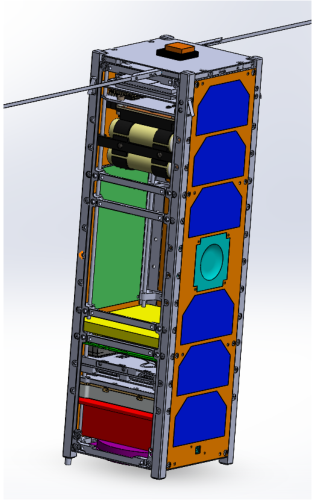

Fig. 9: ELECTRA spacecraft

4 Subsystems Overview

All ELECTRA subsystems have been modeled and analyzed in terms of performance and budgets (e.g., momentum budget for AOCS, power and energy budget for EPS) to ensure compliance with mission requirements.

They can be divided into two categories:

- **In-house developed subsystem:** the Attitude and Orbit Control System (AOCS), which required extensive design, modeling, and testing activities, and is therefore presented in detail.
- **Component Off The Shelf (COTS)-based subsystems:** all the others, for which trade-off analyses were carried out to identify the most suitable solutions available on the market. Their main characteristics are summarized in Table 5.

4.1 *AOCS*

The AOCS is developed in-house, except for the actuators. It consists of two boards: one dedicated to sensors and software allocation, and one COTS board from ISISpace hosting the actuators.

Sensors: four fine sun sensors, one 3-axis magnetometer, and an IMU including a 3-axis gyroscope, accelerometer, and magnetometer.

Actuators: three magnetorquers, two torque rods, and one air core torquer, integrated in an ISISpace board with flight heritage since 2013.

At first, it can be surprisingly that ELECTRA is equipped only with magnetorquers; however the decision was taken based on the pointing accuracy assessment. The assessment's results highlighted that the S-band antenna has the most stringent pointing accuracy, of 30°. Simulations proved that the sole utilization of magnetorquers is enough to meet the requirement, thus leading to the exclusion of reaction wheels, especially seen their large volumes and demanding energyconsumpion.

In-house development in an educational environment can be challenging yet a learning experience. In this development the team is not alone but it is mentored and supported by the STARlab research group, which has a strong knowledge and heritage in this subsystem development. A first in-house version of the AOCS board has been developed, featuring an *STM32F4* MCU and a *MTi-3* IMU. This version will be used to test attitude control methods on a frictionless platform, representing a first step towards a robust and efficient flight model with attitude and orbit determination and control algorithms, entirely developed by students.

4.2 COTS Subsystems

The remaining subsystems are mainly COTS and their main specifications are summarized in Table 5 supertabular booktabs array

Table 5: Main specifications of ELECTRA subsystems (excluding AOCS)

Subsystem	**Key Features / Components**
EPS	86Wh Li-Ion battery (8× 18650 cells, 4S-2P); 24 AzurSpace 3G30A GaAs solar cells (30% efficiency @BOL); GOMspace *NanoPower P60 System + BPX battery*; Energy budget assumptions: noon–midnight orbit, 9.25 W max power @BOL, 30% max DoD.
OBDH	Data management via CAN bus; Alén Space *TRISKEL* (OBC + TT&C, PC104); Dual Cortex-M7 MCUs; FreeRTOS-based flight software; FDIR by students; Persistent 1 Gb NAND + up to 128 GB SD cards.
TT&C	Dual link: UHF + S-band. UHF for telecommand uplink, beacon, and backup telemetry; S-band for primary downlink (payload + housekeeping) and telecommands. Hardware: *Satlab SRS 3* transceiver, WiRan diplexer, ANYWAVES patch antenna, ISISpace UHF antenna (axial turnstile).
Structure & Mechanisms	3U chassis (Spacemind, aluminum alloy, PC104-compatible, ECSS qualified); UHF antenna deployment via burn wire (ISISpace, redundant heating, armed/disarmed safeguard, deployment detection switch).
Thermal Control	Passive TCS; heaters in battery pack (4 resistive, 6 W total, software-controlled); temperature sensors at critical locations; external coatings (e.g., Teflon). Active heater usage under evaluation.

5 AIV/T Overview

As last step in the design process, the Assembly Integration Verification and Testing (AIV/T) process has been defined: the ELECTRA mission will follow a proto-flight model philosophy, a model philosophy chosen after a trade-off (against the prototype and the hybrid philosophy), mainly due to the educational nature of the project. In particular, the proto-flight philosophy allows a lighter and cost-effective testing plan, the optimal choice for such educational mission.

The selected model philosophy includes the following models that are intended to be adopted throughout the different verification stages:

- *Development stage*:
  - Virtual Model (V/M),
  - Development Model (D/M),
  - FlatSat Model;
- *Proto-flight stage*:
  - Electrical and Functional Model (EF/M),
  - Qualification Model (Q/M),
  - Proto-Flight Model (PF/M).

The FlatSat model is crucial element in the AIV/T process, as it will allow to emulate the spacecraft operations thanks to software and hardware in the loop testings. The team has planned a complete FlatSat development to verify the design of in-house developments, while pinpoint any issues at subsystem and system level.

Indeed, the key point of the testing plan is the differentiation between COTS and in-house subsystems.The former will undergo a simplified test campaign and, based on the test carried out by the provider, they will be integrated directly into the FlatSat model after incoming inspections performed by the team. The latter, undergoes a more thorough test campaign, consisting in both hardware and software in-the-loop testings as well as including environmental testings with qualification models, to reach high Technology Readiness Levels (TRLs) before first space flight.

Finally, after the qualification process of the in-house produced subsystems the team will continue to progress in the verification process at system level. This final phase includes the proto-flight integration of COTS subsystems with the in-house produced subsystems. The integration will be conducted in the STARlab and will allow students to perform the last series of tests that will close-out system requirements such as Full Functional Test, Mission Test, Environmental Test and Electro Magnetic Compatibility Test. In addition, a End-To-End Test is planned to be performed with the C3 segment.

The AIV/T plan, shown in Figure 10, covers a critical role within a space mission, enhancing its success. Accordingly, the team will write detailed test procedures, and it is implementing rules and training for the proper use of laboratory facility and its instrumentation, following a Product and Quality assurance approach.

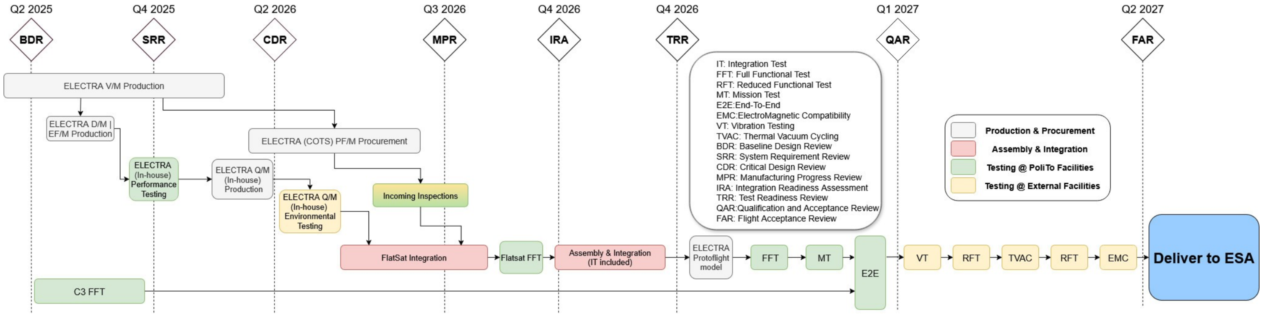

Fig. 10: ELECTRA Development and Verification plan at system level decomposition

6 Ground Segment Overview

The ground segment chosen to assist the space operations and operate ELECTRA is the team's ground station ”Cubesat Control Centre”, located at the Polytechnic University of Turin [17]. C3 for short, is being developed by the Cubesat PoliTO Team members and is currently in the final stage of testing and development, awaiting assembly. It is capable of communicating in radioamateur VHF, radioamateur UHF and S-Band frequencies reserved for space operations.

The ”Keep it simple, stupid!” philosophy employed in the development of the ground station ensured modularity, especially in software development and digital signal processing (DSP), enabling the implementation of multiple modulation schemes using GNU Radio - namely GMSK with the AX.25 protocol. This enabled also the possibility to deploy the ground station partially according to the necessity of the team. Due to the characteristics of the SSO orbit, the frequency and timing of satellite passes require continuous attention, including during nighttime hours of the team members. To address this, significant automation measures have been implemented, enabling automated uplink and downlink procedures, pass scheduling and simplified data management.

While the ELECTRA mission is under development, the ground station is being adapted to enable communication even in the laboratory - employing a reduced version of the ground station - during the assembly, integration, and testing phase of the satellite.

7 Discussion

The ELECTRA mission is conducted within the ESA Academy Fly Your Satellite! Design Booster framework [18], which ensures that the student team experiences a project lifecycle similar to professional space missions. The program mirrors the European Cooperation for Space Standardization (ECSS) project structure, with formal design review, including Review Item Discepancy (RID) handling and co-location campaigns, as well as testing opportunities within ESA facilities. This approach exposes students to the discipline and rigor of industry-standard space projects, while still keeping education and learning as a primary objectives.

In parallel, the CubeSat team follows an internal concurrent engineering workflow: dedicated Concurrent Engineering (CE) sessions are usually organized to accelerate the decision-making, reduce inconsistencies and provide students with direct experience of collaborative design environments, similar to the ESA's Concurrent Design Facility. A visual documentation of one of these sessions, in Figure 11, illustrates how students engaged in multidisciplinary discussions, simulating the conditions of a professional space engineering. This dual environment, a structured ESA-driven lifecycle and an internal concurrent design workflow, has been key to bridging education with real-world practice. Students learn not only how to size and design the mission and its systems, but also how to manage documentation, handle requirements, present at reviews, and resolve discrepancies raised by external reviewers. These are skills often underestimated in purely academic projects, yet essential in professional contexts.

Fig. 11: CubeSat PoliTO Team members during a Concurrent Engineering session

At the same time, challenges specific to a student-driven environment persist. The high turnover rate and uneven experience levels required the team to continuously refine its documentation practices and knowledge transfer mechanisms. Furthermore, the pressure of preparing deliverables for ESA reviews had to be balanced against the educational mission, ensuring that deadlines fostered learning rather than creating excessive stress.

By combining ESA's structured review process with student-led concurrent engineering sessions, the ELECTRA mission created a hybrid project culture: rigorous enough to produce a credible CubeSat design, but flexible enough to serve as an effective educational tool.

8 Conclusions

The ELECTRA mission is above all an educational initiative, where students from diverse backgrounds, supported by ESA, Politecnico di Torino and some partners from the industry, are given the opportunity to experience the entire life cycle of a space mission. From early mission definition to subsystem design, integration, launch and operations, the teams is (and will be) directly responsible for technical and managerial decisions, problem-solving and hands-on implementation. This approach ensures that the mission is not just an academic exercise, but a complete system engineering experience.

This environment replicates the multidisciplinary and multicultural nature of real space projects, where communication, negotiation, and trade-offs are as critical as technical knowledge.

Bridging the gap with the ”real world” required adopting professional practices: structured design reviews, requirements tracking, system and subsystems modeling and simulation, and interface control. These processes were not only technical necessities but also training tools, helping students to understand how aerospace projects are managed in industry.

In this context, the CE approach provides an effective framework to manage complexity and accelerates the design process. By parallelizing tasks and fostering continuous collaboration between disciplines, CE reduces communication gaps and improves consistency across the project. For students, it also offers a clear view of how decisions in one domain immediately impact others, reinforcing a system engineering thinking.

Nevertheless, several challenges emerged naturally in a student-lead mission such as the inexperience, high turnover, and balancing educational objectives with technical robustness. However, these challenges are not limitations but rather integral parts of the educational mission. They indeed provide opportunities for personal growth, teamwork, and resilience, mirroring the iterative nature of professional projects.

Ultimately, ELECTRA mission shows how a university CubeSat can act as a bridge between academia and the space sector, equipping students with both technical competencies and the soft skills needed in their future careers. The combination of real institutional support, structured engineering methodologies, and a student-led environment ensures not only the delivery of a CubeSat mission but also the creation of a new generation of engineers prepared for the demands of the space industry.

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