



AERIS - Air-Breathing Electric Propulsion for Research in the Ionosphere and Thermosphere Satellite

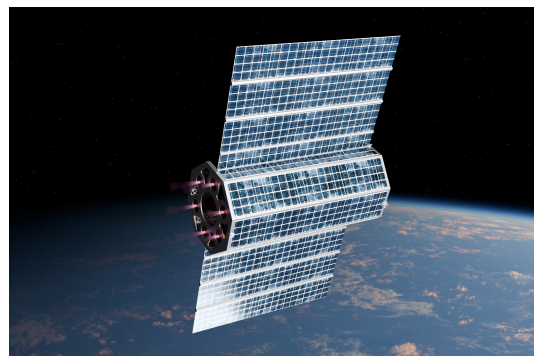
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The AERIS mission consists of a VLEO satellite designed to demonstrate the feasibility of ABEP systems for sustained operations in dense atmospheric regions. It will conduct scientific investigations through thermospheric measurements using a mass spectrometer and electrochemical sensors, satellite laser ranging, and gravity measurements by integrating conventional satellite subsystems with specialized payloads that will support the assessment of the performance of ABEP systems, advance the understanding of the atmospheric density and particle composition of VLEO, and contribute to gravimetry applications. It will be launched in 2034 and operate for at least 5 years.

The **mission analysis** for AERIS is targeting a sun-synchronous orbit with a semi-major axis of 6,620 km, which is defined by a Local Time of the Ascending Node (LTAN) of 18:00. These orbital characteristics were determined by performing simulations on *ASTOS* and by balancing propulsion requirements, EPS constraints, and payload needs. The satellite will launch with a Falcon 9 rocket at an initial altitude of 300 km. After natural decay, the satellite will reach the nominal orbit. There, its ABEP engines will be turned on to counteract drag forces. The satellite will then remain in an orbit with an altitude of 242 km for three years, followed by two years at an altitude of 230 km. Finally, it will undergo natural decay.

The **propulsion system** consists of six thruster units, each with a specular intake and an induced plasma thruster (IPT). Each intake is 1,860 mm long and 300 mm in diameter and can collect particles with approximately 70% efficiency. The thrusters use a radio-frequency (RF) birdcage antenna and a set of permanent ring magnets to ionize and accelerate the collected particles. For drag compensation in VLEO, the power requirement averages around 550 W, reaching specific impulses of 3,000 s at an altitude of 242 km. The total thrust generated at this is 8.6 mN. The propulsion system can adapt to different orbital altitudes during the mission by adjusting the power input. The performance of the ABEP system is characterized through an accelerometer.

The main objective of the **science payload** is to support the evaluation of key components of the ABEP system over the course of the mission. The payload consists of a combination of a quadrupole mass spectrometer and electrochemical sensors for measuring atomic oxygen (FIPEX), which will be used to evaluate the performance of the ABEP system and co-register thermospheric measurements. Additionally, the payload includes silver back-coated corner cube retroreflectors to enable Satellite Laser Ranging (SLR). The payload also features a high-quality accelerometer that, when combined with GNSS data, can be used for High-Low Satellite-to-Satellite Tracking (HL-SST) for gravity research.



Trade studies across subsystems guided efficient satellite integration performed by **System Engineering**, with the goal of achieving mission requirements and maximizing efficiency leading to the selection of a hexagonal geometry and six-thruster configuration. Increasing solar panel surface area and optimizing orientation addressed rising subsystem power demands, ensuring sufficient generation under worst-case conditions while balancing overall mass and power (20% of margin)

The potential overall total costs were determined by **project management** based on the CERs of the USCM-8. In addition to the respective masses of the individual subsystems (see Table 1), the following technology readiness levels (TRLs) were assumed as input values for the cost calculation: Structure/Thermal: 6; ACS: 7; EPS: 5; TT&C :8. The estimated total cost of the satellite is **\$853,159,400**.

Table 1: Subsystem Budget Estimation

| Subs. | Power (W) | Mass (kg) | Cost (\$) |
|--------------|----------------|---------------|------------------|
| PROP | 802.81 | 81.60 | 745,800 |
| ACS | 174.52 | 52.54 | 751,200 |
| Payload | 17.52 | 15.48 | 5,014,800 |
| COMMS | 49.20 | 5.68 | 597,600 |
| EPS | 15.00 | 50.00 | 1,200,000 |
| TCS | 15.00 | 20.00 | 100,000 |
| TOTAL | 1074.05 | 275.30 | 8,409,400 |

The AERIS **attitude determination and control design** addresses challenges in the extreme VLEO environment, such as increased disturbance forces and torques caused by aerodynamics and magnetic dipoles. The ACS actuators consist of four reaction wheels, five magnetorquers, and two aerodynamic panels that use the residual atmosphere to stabilize the attitude. Sun sensors, magnetometers, gyroscopes, star trackers, and GNSS receivers are also employed for navigation and determining the satellite's pose. The permanent magnets of the ABEP system have a strong internal dipole moment of $1,200 \text{ Am}^2$ and are compensated by three magnetorquers aligned along the same axis. This minimizes the disturbance torques induced by the Earth's magnetic field. Altitude is maintained using the ABEP system for drag compensation.

The **electrical power system** uses deployable *GaAs* arrays feeding an *Airbus MEGA PCDU* on a regulated bus, with energy stored in *STELLAR-BATT* packs. With con-

servative pointing and degradation assumptions, the EPS meets a continuous 1 kW load at end-of-life (EOL). Optional perovskite (PSC) add-ons, mounted as bifacial thin film and connected to isolated maximum power point tracking (MPPT) inputs, provide extra daily energy margin without affecting the baseline sizing.

The **communication system** of AERIS consists of a low data rate telemetry and command system with an uplink of 50 kbit s^{-1} and a telemetry downlink of 73 kbit s^{-1} and a high datarate downlink with 42 Mbit s^{-1} . The telemetry and command system uses the S-Band with a redundant transceiver architecture and two high beam angle patch antennas, one facing nadir and one facing zenith.

Table 2: Communication Link Budget

| Parameter | TT&C | TT&C | DDS |
|---------------------|----------|--------|----------|
| | Downlink | Uplink | Downlink |
| Band | S-Band | | X-Band |
| TX Power [W] | 2.0 | 2000.0 | 2.0 |
| Path length [km] | 367.2 | 367.2 | 277.8 |
| RX G/T [dB] | 9.1 | -24.5 | 27.0 |
| TX Gain [dB] | 3.0 | 31.0 | 3.0 |
| Bit rate [Mbps] | 0.073 | 0.050 | 41.57 |
| Bandwidth [MHz] | 0.025 | 0.017 | 14.0 |
| E_b/N_0 [dB] | 9.1 | 55.0 | 16.0 |
| E_b/N_0 req. [dB] | 10.5 | 10.5 | 10.5 |
| Link margin [dB] | 21.7 | 42.5 | 3.5 |

For low drag, the satellite can not be pointed at the ground station. Therefore, also for the high data rate downlink in the X-Band a low directivity patch antenna facing nadir is used. The resulting link budget analysis, which considers the worst case for both systems can be seen in table 2. The achieved E_b/N_0 for BPSK modulation with a bit error rate of 10^{-6} is higher than the required value. Therefore, reliable communication is possible even when the transmit power is decreased or the data rate is increased.

The **thermal control system** consists on a hybrid design that maintains all satellite components within their required temperature ranges. It uses passive elements, Multilayer Insulation (MLI) for isolation, heat pipes to transfer waste heat from thrusters, and radiators to reject that heat to space, as the primary method for efficiency and reliability. Active heaters were added for survival in extreme cold, specifically to prevent the batteries and propulsion lines from freezing during extended eclipses.