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SCUOLA DI INGEGNERIA INDUSTRIALE
E DELL'INFORMAZIONE

HORUS

Executive Summary

Applied Space Mission Analysis and Design
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1. Mission Overview

The Very Low Earth Orbit (VLEO) environment is rapidly gaining attention due to its numerous advantages. Missions operating at this altitude unlock several benefits, including reduced downlink power, improved revisit times, cost-effective high-resolution imaging, and a cleaner orbital environment with reduced space debris.

Leading this new era of Earth observation is **HORUS** (High-resolution Orbiting Reconnaissance and Universal Surveillance). Designed to deliver ultra-high-resolution imagery with minimal latency and set to be a game changer in the Earth observation sector. With applications spanning environmental assessment, real-time disaster response, and dual-use operations, HORUS represents a strategic advance in surveillance and reconnaissance capabilities. In line with the strategic importance of the mission, HORUS is designed to rely completely on European technology: from components to ground segments and launchers. As one of the few satellites operating at such a low altitude, HORUS will serve as a crucial platform for validating satellite design, materials, and technologies in the VLEO environment.

1.1. Mission Objectives

Several key mission objectives have been set for the HORUS mission:

- To provide specific Earth coverage areas with high resolution, low latency from request to operations, minimum time resolution
- To ensure flexibility in terms of the target covered
- To provide fast data download
- To limit the time to launch and launch costs
- To demonstrate the TRL for VLEO

1.2. High Level Mission Requirements

The HORUS mission is designed to fulfill the following high level goals:

- The mission shall provide spatial resolution below 1 m
- The mission shall provide time resolution of less than 1 day
- The mission shall provide a time to fly not larger than $1-2$ $months$
- The mission shall have an operational life as far as the monitored event lasts
- The technology shall be European
- The launch shall take place after 2026
- The launcher shall be European
- The data shall be downloaded within 1 h after acquisition

1.3. Mission Architecture

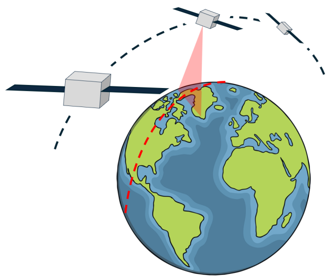

Figure 1: HORUS Architecture

The HORUS baseline architecture was designed as a compact single spacecraft optimized for VLEO operations. Depending on customer needs and the size of the target area, the system can be configured as a single drone or as multiple drones operating in formation flight or constellation. Due to its low altitude of flight and the wide range of potential mission applications, the spacecraft can be more accurately classified as a space-drone.

Main Bus [mm]	330x330x830
Solar panels [mm]	370x830
Dry Mass [kg]	96.67
Wet Mass [kg]	104.67

Table 1: HORUS Physical Properties

2. Environment

Despite the significant advantages of operating in VLEO, this environment also presents several challenges. The operational lifetime of satellites at such low altitudes is considerably reduced due to high atmospheric drag, which must be effectively counteracted to prevent rapid orbital decay. In addition, the increased atmospheric density in this region leads to aerodynamic heating, which strongly influences the structure design. Another major concern is the potential damage caused by the high concentration of atomic oxygen, which can be mitigated with a proper selection of materials. Furthermore, satellites in VLEO experience rapid thermal fluctuations due to frequent eclipse cycles, which must be carefully managed.

3. Launcher Selection

The selection of an appropriate launch vehicle is essential. As the high-level goals of this mission require the time to flight to be at most 2 months and the launcher to be European, a dual-launcher approach was chosen to minimize deployment delays due to the limited availability of European options. Specifically, the Ariane 6 and Vega-C, Europe's only active launch vehicles as of 2025, were selected. A preliminary analysis was performed on both vehicles to ensure that the satellite met all necessary requirements. Additionally, a detailed examination of the internal configuration was performed for the Vega-C, as it is the most constraining in terms of deployable mass and volume. It was concluded that the maximum number of satellites that could be integrated inside a single Vega-C is nine, eight on the Flexi-4 adapter in the main compartment and one in the Vespa+R inner compartment.

4. Phases and Conceptual Operations

The lifespan of the HORUS mission shall be categorized into distinct phases according to the functionalities and tasks the system has to perform.

1. The *Launch and Early Operations* (LEOP) is the first phase of the mission. The satellite is launched, released from the deployer, detumbled, powered up, and eventually establishes its first connection to the ground station.
2. In *Commissioning* (COP) phase activation of all secondary hardware is performed to allow complete functionality of the spacecraft. Once the tests are completed, the spacecraft performs the orbital injection to reach the target orbit of the mission, in which the payload is then tested.
3. The *Observation Phase* (OBP) is the core of the mission. Once the satellite is in the correct target orbit, it begins to perform the nominal functionalities of the mission: orbital control and station-keeping, PL data acquisition, data processing and storage, communication with the GS and data transfer.
4. The *Disposal* phase is the last portion of the mission. Once the satellite has reached the end of its intended lifetime, all subsystems will be progressively switched off and the system will be passivated according to the ESA space debris mitigation requirements.

5. Risk and Cost

A risk analysis was performed for the HORUS mission, considering technical, procurement, and external criticalities. Once appropriate mitigation strategies were implemented, to ensure the robustness of the project and reduce the most critical risks to acceptable levels, the feasibility of the mission was demonstrated through a dedicated risk matrix. Finally, to assess mission costs, a parametric approach based on the use of *Cost Estimating Relationship* (CERs) was selected. The costs were divided into three main categories: *space segment*, *launch operations* and *operations costs*. The resulting cost for the production of the first HORUS drone is approximately 25.03 M€, with a margin of 20%. Adding the launch costs, the

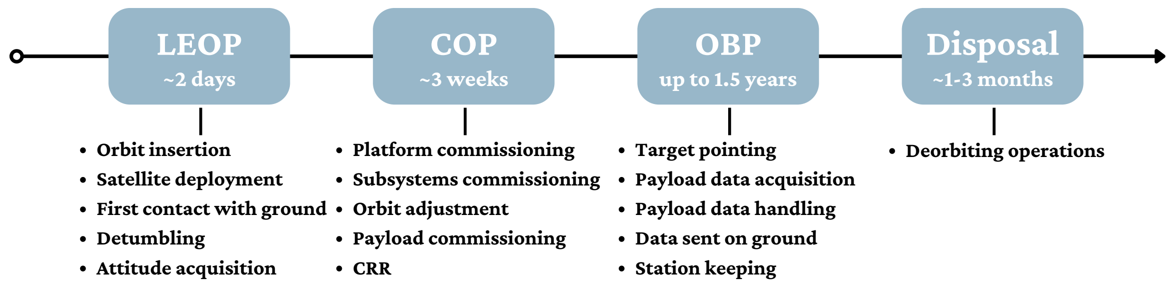

Figure 2: Mission Phases and ConOps

total reaches 26.47 M€. Since the final architecture could be made up of a constellation of drones, the scalability of the project was evaluated by analyzing a multiple-drone scenario. The cost analysis was conducted with a configuration of nine drones due to launcher constraints, resulting in a cost of 86.50 M€, which increases to 99.49 M€ when considering the launch costs.

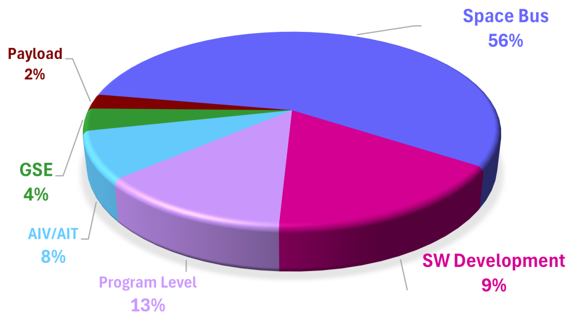

Figure 3: HORUS Space Segment cost distribution for the case of first drone without launch costs

6. Mission Timeline

The design, testing, and launch of the first drone will take approximately four years, with a target launch date in Q1 2029. During Phase C, a parallel production facility will be built over an estimated two-year period. This facility is expected to be operational by the end of 2029, with a production capacity of 20 drones per year.

7. Subsystems Overview

7.1. Payload

To fulfil the high level goals and mission requirements, a high-resolution optical payload was selected after a trade-off analysis among optical cameras present on the market. The selected camera allows to achieve the desired resolution while ensuring good coverage performances in terms of swath width. Beyond the main optical features, it is a dual-channel payload, which allows to enter into imaging mode both in illumination and dark conditions.

7.2. Mission Analysis

The mission is designed to be flexible and to guarantee scalability depending on customer needs. The circular and polar orbits at $\approx$ 260 km traveled by HORUS drones guarantee precise targeting while minimizing the effects of orbital perturbations derived from such a challenging environment. HORUS ensures a valid option for a wide range of applications, offering variable-size fleets depending on the target area.

City	Small Country	Medium Country
150 km^2	15000 km^2	35000 km^2
1 drone	10 drones	20 drones

Table 2: Coverage Examples

Moreover, by exploiting several orbital planes, the user can select any schedule to observe any location on the globe at the desired time.

7.3. Propulsion

The two main propulsive needs of the HORUS mission are the initial orbit insertion and the successive station keeping and drag compensation. As the total ΔV budget of this mission is in the hundreds of m/s and the direction of thrusting is only along one axis, it was chosen

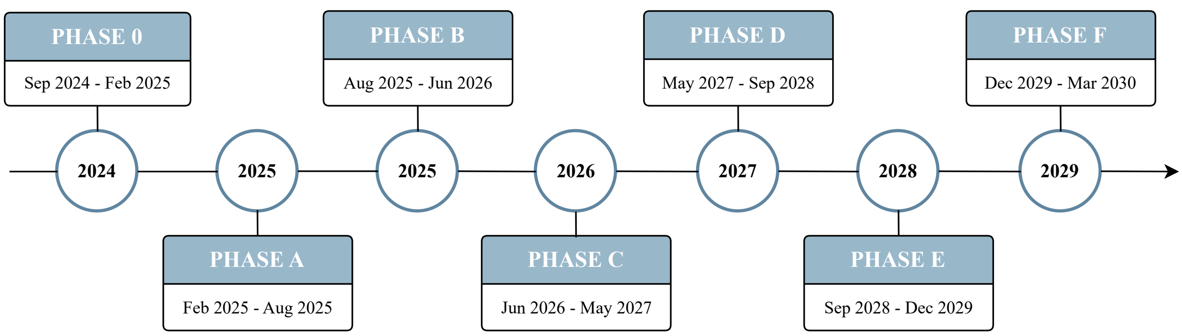

Figure 4: Mission Timeline

to use a single primary propulsion system. To limit the mass of propellant required, and at the same time limit the manoeuvrers duration, this choice fell on a Xenon-powered Hall Effect Electric Thruster. In particular, the HEET propulsion system is also chosen because of its low system mass, relatively low power consumption, high specific impulse, and wide thrust range. Most of the subsystem is commercially bought, except for the propellant tanks which are developed in-house. This is done to minimize the volume of the tanks while maximizing, at the same time, the pressure inside the tank, thus maximizing the propellant mass as well.

7.4. Tracking, Telemetry and Telecommand

The Tracking, Telemetry and Telecommand Subsystem provides fast and robust communication between the spacecraft and the ground segment. The ground segment is an all-European network of public and private companies' S-band antennas. HORUS can transmit the payload data at a rate up to 25 Mbps with a wide field of view, thanks to 4 patch antennas properly placed on the main body. Patch antennas ensure isotropic communication that relaxes the requirements imposed on the ADCS. Advanced encoding and modulation techniques are in place to give the communication a high level of reliability. The extensive ground network and the transmitter-amplifier duo allow the spacecraft to downlink up to 40 B&W pictures after less than 1 hour from acquisition, providing almost real-time global coverage.

7.5. Attitude and Orbital Control

The ADCS is essential to ensure precise system accuracy, as HORUS is a high-resolution imaging mission requiring strict pointing. According to the mission requirements, the most suitable architecture is a three-axis stabilized. Sensors suite includes: Sun sensors, magnetometer, gyroscopes, and star sensors; while the control is devoted to four powerful reaction wheels in pyramidal configuration. Eventually, magnetic torquers are employed for desaturation and detumbling purposes. The attitude is mainly retrieved with a Multiplicative Extended Kalman Filter, providing satellite quaternion and angular velocity. Regarding the control, a linearized reduced quaternion model is employed for LQR and LQI design of imaging, orbit control, Sun pointing, and telecommunication modes.
Due to the low altitude, atmospheric drag presents a significant challenge. To counteract its effects, the selected station keeping strategy is based on the continuous assessment of deviations from the ideal trajectory, and the execution of corrective manoeuvrers to maintain the target orbit. Therefore, a Directional Adaptive Guidance (DAG) strategy has been implemented, optimizing corrections of the orbital elements while minimizing power consumption. This approach was further refined to meet the stringent requirements for phasing and altitude, ensuring the precision and reliability of imaging operations throughout the mission.

7.6. Electric Power System

The Electrical Power System (EPS) of the HORUS mission is designed to ensure reliable power generation, storage, and distribution in a VLEO environment. The system is sized according to mission requirements, operational mode power requests, and orbital constraints. The power budget is margined at both component and system levels, following ECSS standards. The baseline power architecture consists of solar panels as the primary energy source, complemented by a secondary battery system to provide energy during eclipses and peak demand periods. A set of six panels, two of which are body mounted, is the output of the sizing process. Triple-junction solar cells with high BoL efficiency are selected. To optimize energy extraction, Maximum Power Point Tracking (MPPT) is implemented. A "Planar" Sun pointing algorithm is also derived, with slew manoeuvrers only about the roll axis, minimizing the cross-section. Instead, the battery employs Li-ion cells, a well-established technology in the space field. Extrasolar cell strings and battery redundancy ensure continued operation in the event of partial failures.

7.7. Thermal Control

The Thermal Control Subsystem is designed to ensure all spacecraft components remain within their operational temperature ranges using a quasi-passive thermal management system. Given the varying heat fluxes encountered across different mission orbits, a highly flexible thermal design is essential. Radiators are integrated into the bottom surfaces of both the solar arrays and the main body. To minimize exposure to external sources, only the solar assemblies and radiators interact with the environment, while the core body remains thermally isolated through insulating spacers. Heat switches, operating on a temperature-activated logic, regulate cooling based on internal dissipation and external conditions. Phase Change Materials are strategically positioned near the payload to ensure stable operating conditions. Thermal regulation is further optimized through the overall attitude control strategy, ensuring alignment with power production requirements. Additionally, thermal straps connect solar panels to radiative surfaces, optimizing power generation efficiency. Coatings and surface treatments are applied considering degradation effects in the VLEO environment.

7.8. Data Handling

The On-Board Data Handling subsystem is responsible for managing, processing, and storing all data from both the platform and the payload. The selected architecture is a federated bus configuration, consisting of a main OBC that runs the flight software and manages the overall platform control, and a secondary OBC dedicated specifically to the AOCS subsystem, running the GNC algorithms. The CAN bus has been chosen as the primary bus due to its high reliability and the interfaces available on the OBCs, while a SpaceWire has been selected as a high-speed bus to minimize latency between payload data acquisition and downlink. Redundancy is ensured both on the hardware and the software. To withstand the VLEO radiation environment, a 1 mm aluminium shielding will be produced, according to Total Ionization Dose analysis, to mitigate the risk of OBC failures.

7.9. Structure

The structure of the HORUS spacecraft is designed to withstand the challenging operational environment of VLEO. The main body is a cuboid shaped structure made of Aluminium Al-7075-T6, with a 1.6 mm wall thickness, optimized for both mass efficiency and mechanical robustness. The spacecraft features deployable solar arrays, with two panels per side, designed to maximize power generation from the Sun while efficiently dissipating excess heat into deep space. A comprehensive set of structural analyses, including modal analysis, quasi-static analysis, sine and random vibration analyses and linear buckling analysis, is conducted on the main structure, ensuring a reliable platform for the high resolution payload. Analyses on the panel structure were also performed, as these constitute the main components of the secondary structure and are particularly sensitive.

7.10. Configuration

The configuration is tailored for optimal performance in VLEO, ensuring that each subsystem operates as required. The main body is connected to the solar arrays at the two lateral edges, with the Sun-pointing faces of both the main body and the panels fully covered by solar cells for efficient power generation. The opposite side of the spacecraft is primarily covered by radiators, both on the main body and the solar panels. Sensors and antennas are carefully positioned to meet the requirements of subsystems such as TTMTC and ADCS, including star sensors and patch antennas. Regarding the internal configuration, the main drivers were minimizing the Centre of Mass shift and achieving optimal heat fluxes between components, in order to meet the demands of both ADCS and TCS. The payload has been strategically positioned close to the CoM to minimize disturbances and ensure optimal performance.

8. Conclusion

The conducted mission design has demonstrated the feasibility of developing a highly flexible observation mission in Very Low Earth Orbit. The strength of HORUS lies in its ability to attract both private and public sector interest due to its adaptability to a wide range of scenarios and applications. One of the key challenges identified in its development was an external factor: the availability of suitable launchers. Frequent and reliable launch opportunities are essential to achieve HORUS mission objectives.

In today's space economy, HORUS has few direct competitors, making it highly appealing to investors and funding opportunities.

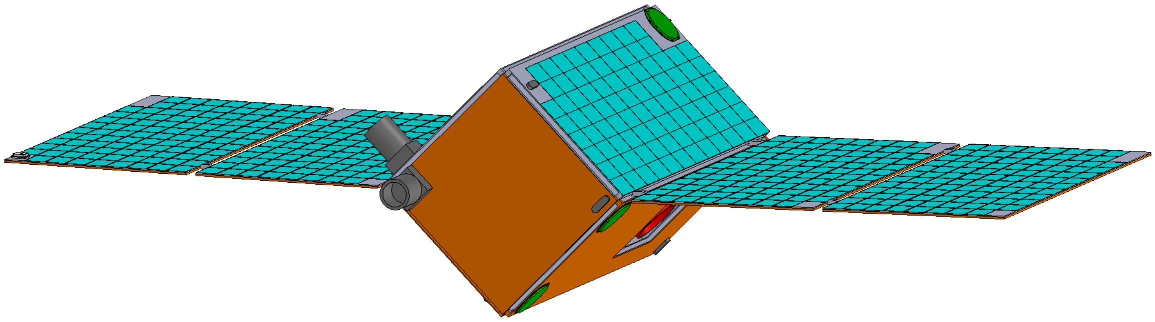

Figure 5: HORUS external configuration

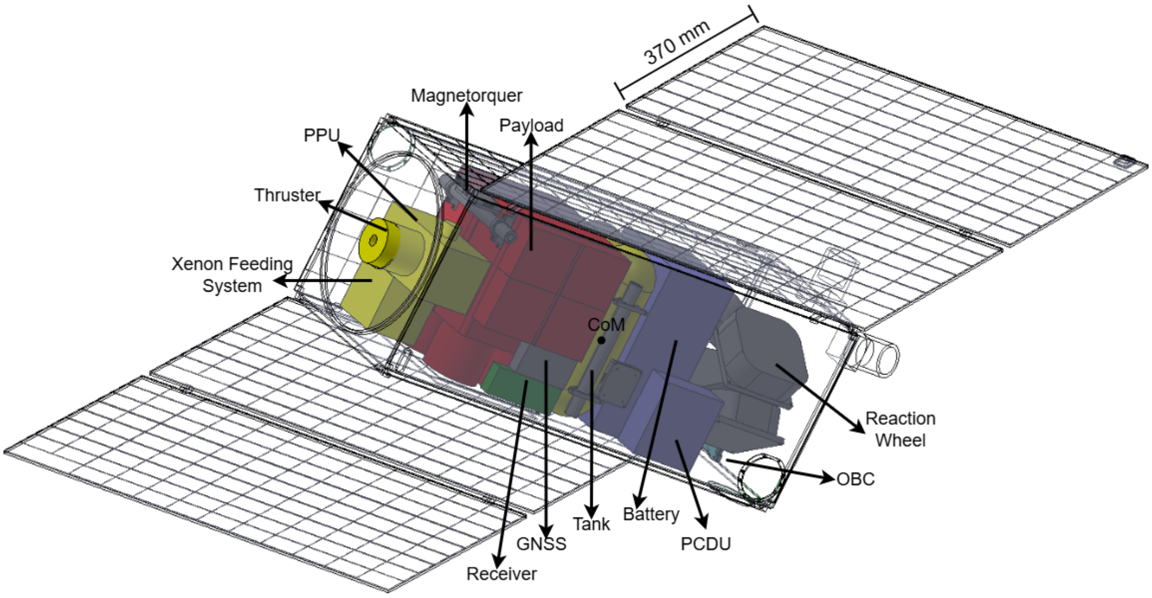

Figure 6: HORUS lower internal configuration

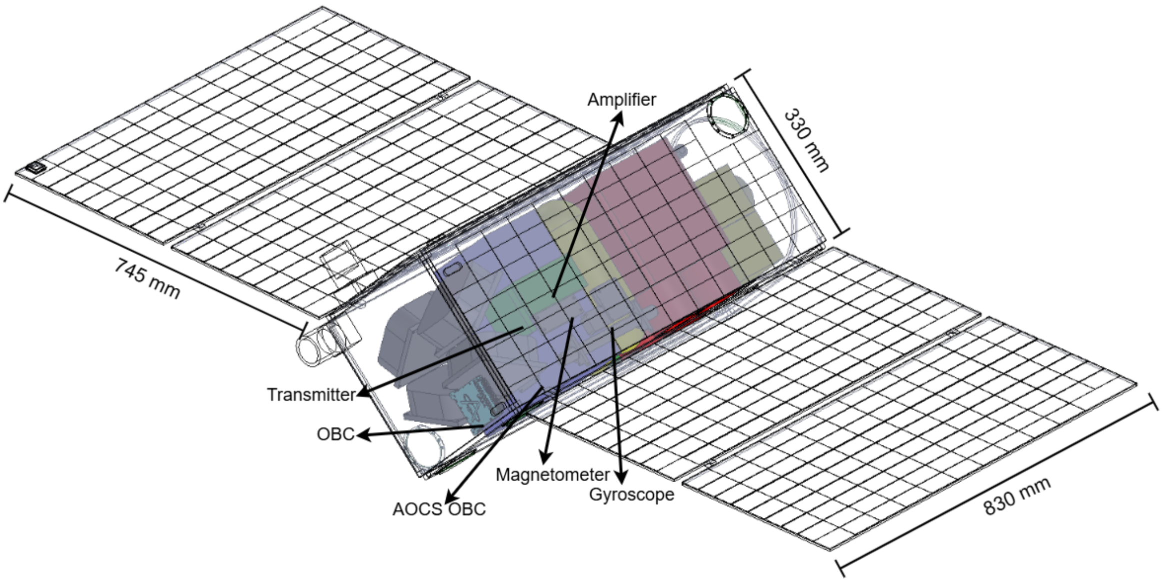

Figure 7: HORUS upper internal configuration