The Space Rider Observer Cube (SROC) Cubesat Mission

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PAPER

The SROC project aims at demonstrating the critical capabilities and technologies required for successfully executing a rendezvous and docking mission in a safety-sensitive context. The European Space Agency (ESA) have funded the development of Space Rider Observer Cube (SROC) through the contribution of the Italian Space Agency (ASI) to ESA's General Support Technology Programme (GSTP). The project is led by Tyvak International as prime contractor of a fully Italian consortium, including Politecnico di Torino, Università di Padova and Stellar Project SRL.

1 INTRODUCTION

CubeSats technologies can effectively aid in various proximity operations endeavours through the capability of accurate examination of orbiting objects. These applications encompass tasks like assessing inactive satellites in preparation for active debris removal missions, monitoring and maintaining operational spacecraft such as the International Space Station or telecom satellites, and more. Looking ahead, CubeSats could also be utilized to inspect objects in deep space, including the cis-lunar human-tended station that will serve as the Gateway for future Artemis program exploration missions. Additionally, CubeSats can play a role in servicing missions by assisting in the assembly of large space infrastructures, reconfiguring and/or refurbishing/refuelling space assets, and even providing support to astronauts during extravehicular activities. The task of inspecting spacecraft in orbit has already proven to be quite challenging, but CubeSats and nanosatellites have the potential to fulfil this role by operating as free flyers near the target, equipped with appropriate sensing technology to observe and gather data. The close proximity inspection of spacecraft in orbit offers various benefits and can be applied to two main categories, namely the monitoring of operational space assets to enhance their capabilities and supporting their mission, as well as examining space debris to prepare for and potentially carry out active removal missions. Various organizations have contemplated incorporating compact platforms to facilitate the achievement of the aforementioned mission goals [4] [5]. In both the United States and Europe, missions have already been executed and are currently being developed, with the involvement of research institutions, universities, and private enterprises [1] [2]. Through these missions and studies, it has become evident that numerous obstacles related to proximity operations and formation flight must be tackled to ensure the forthcoming missions are executed with the necessary level of safety [3]. The focus of this article is a study that explores the rendezvous and docking capabilities of the Space Rider Observer Cube (SROC). The

SROC is a CubeSat that will be deployed as a payload on Space Rider (SR), which is the European Space Agency's new transportation vehicle with re-entry capability[6]. This paper provides an overview of the mission and system concepts for SROC, that has been developed during Phase B2 under ESA contract no. 4000142560/23/NL/MG/cb. The study also builds upon two former project phases conducted in 2022 and 2019 under ESA contracts respectively no. 4000136625/21/NL/MG and no. 4000126281/18/NL/KML/ig. In this article, it can be found comprehensive information about the structure of the mission and functioning of the SROC S/C. The article presents two mission scenarios: the Observe & Retrieve mission and the Observe mission. While many findings and considerations discussed in this study are applicable to missions targeting other objectives or involving debris inspection, it is important to note that there may be some variations that require further examination beyond the scope of this paper. Section 2 delves into the SROC mission description, providing essential details about the concept of operations and the architecture of the SROC mission. Section 3, 4 and 5 outline the key features of the SROC system, highlighting the most significant solutions implemented to meet the mission requirements. Finally, Section 6 concludes the paper by discussing the current results and their implications for future endeavours.

2 SROC MISSION

The Space Rider Observer Cube (SROC) mission is designed to demonstrate key capabilities and technologies required to successfully conduct rendezvous and docking missions in a safety-sensitive framework. The SROC space segment consists of a nanosatellite, a Docking System (DOCKS) and a Multi-Purpose CubeSat Dispenser (MPCD) for S/C deployment/retrieval. The system will perform proximity operations in the vicinity of Space Rider (SR) vehicle before docking with the mothership and re-entering Earth. The mission statement is outlined as follows: *"To operate a CubeSat in LEO to demonstrate capabilities in the close-proximity operations domain in a safety-critical context, including rendezvous and docking with another operational spacecraft."*
The SROC project aims at developing and testing in space novel key technologies in the area of proximity operations, such as: Propulsion systems (cold gas), Guidance Navigation and Control (hardware and software), Electro-optical systems (visual camera), Mechanisms (docking, deployment and retrieval), and at improving Autonomous Operations. All these technologies are of interest for a broad set of mission goals involving proximity operations. This in-orbit demonstration has the potential of opening a wide spectrum of novel applications for nanosatellites in the area of **inspection missions**. Furthermore, the development of the advanced technologies needed for the SROC mission will have a positive impact also for pursuing other mission objectives, especially in the domains of **in-orbit servicing**, space **exploration** and **debris mitigation**. From the SROC side, the mission will demonstrate enabling technologies in the proximity operations domain, which can also be transferred to other targets. From the Space Rider side, there is the opportunity to demonstrate the capability to deploy & retrieve payloads, thus expanding the range of possible applications of the vehicle.

2.1 Mission objectives

The achievement of SROC mission objectives will advance current CubeSat technology and capabilities in terms of:

- Functions related to **formation flight** missions:
    - Proximity Navigation
    - Guidance and Control capabilities
    - Communication architecture
    - Autonomous operations
- Technologies and functions associated with deployment, **docking and retrieval** of CubeSats:
    - Guidance, navigation and control algorithms for close approach up to docking
    - Deployment and retrieval mechanisms
    - Docking systems
- Space targets observation:
    - Imaging

2.2 Concepts of Operations

Due to the novelty and perceived complexity of the mission objectives, the SROC programme might require multiple sequential missions at incremental level of complexity. Two mission scenarios are considered at the moment:

- ***Observe*** mission. The spacecraft is deployed from Space Rider, but it is disposed into space after the inspection of the mothercraft, i.e. SROC is not retrieved in the SR cargo bay at the end of its mission. This scenario represents either an option for the first mission in a cost- and/or time-constrained framework, although with reduction of mission objectives, or it can be seen as the off-nominal scenario of the Observe & Retrieve case should any failure occur that prevents docking of SROC to SR.
- ***Observe & Retrieve*** mission. The spacecraft is deployed from Space Rider, observes the vehicle from close distance, and eventually approaches Space Rider, performs docking, and it is retrieved and stowed into its cargo bay for re-entry Earth. The "Observe and Retrieve" scenario is assumed as baseline for the study purpose and technology demonstration, but the "Observe" scenario will be most likely implemented in the first flight and it could therefore be assumed as baseline for operations. A further option would be performing multiple deployment/retrieval within the same mission in a sort of enhanced scenario called Observe & Reuse mission, which is however excluded for the first mission of the SROC system and from the context of this article.

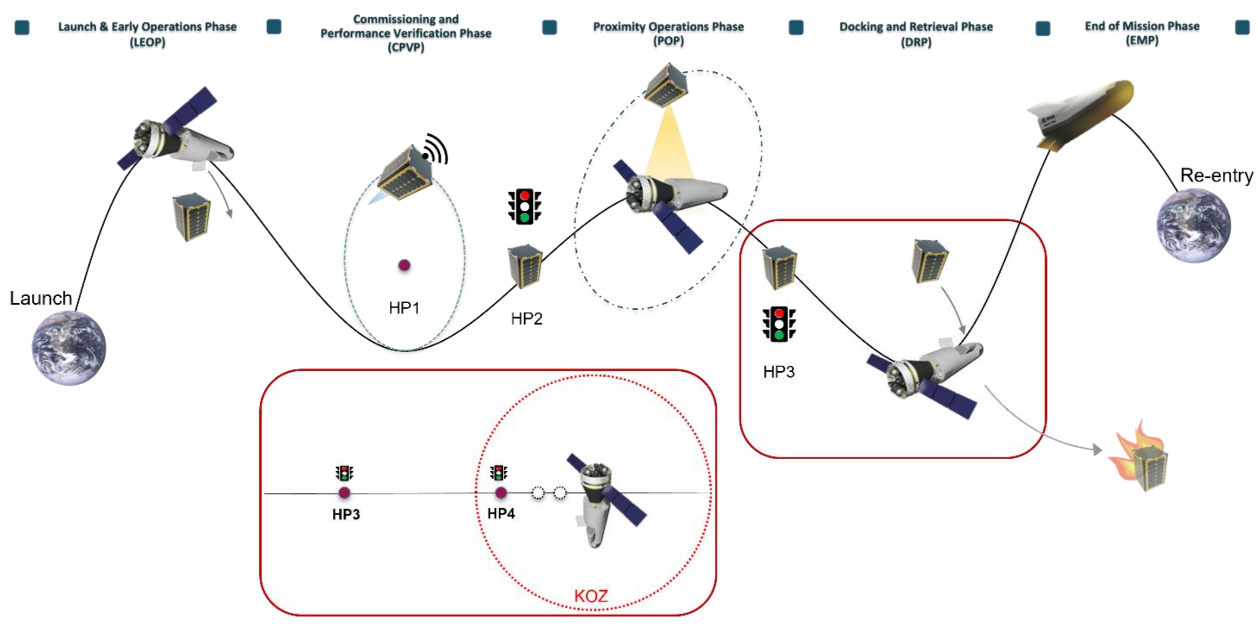


Figure 1: SROC Design Reference Mission

Figure 1 illustrates the design reference mission. In the current baseline the 12U SROC CubeSat will be launched with Vega C inside the Space Rider vehicle and deployed from the Multi-Purpose CubeSat Dispenser (MPCD) once in orbit. Target launch is the Space Rider Maiden Flight, currently planned Q3 2025. Once deployed and commissioned, SROC will fly in formation with Space Rider taking observation of the vehicle from close distance. At a certain point in time, SROC will rendezvous and dock with its Multi-Purpose CubeSat Dispenser hosted in the Space Rider Multi-Purpose Cargo Bay (MPCB). The docking and mating of SROC to the MPCD is made possible by the DOCKS interface that is developed ad-hoc for this mission., in which the Observe & Retrieve scenario is assumed as baseline, and the Observe scenario is considered as off-nominal mission in case the retrieval is not possible. The mission duration is approximatively 30 days from deployment to completion of retrieval in the cargo bay. In case of an independent disposal in orbit (i.e. no retrieval) is necessary, the SROC spacecraft will lower its orbit and disintegrate in Earth upper atmosphere in less than 1 year.

2.3 Mission Architecture

Table 1 provides a concise overview of the SROC mission architecture, outlining the various mission elements and providing brief descriptions for each. To achieve the mission objectives, innovative technology is being developed and will undergo testing in orbit during different phases of the mission. The spacecraft itself is constructed using the reliable and proven Tyvak Renegade platform, with the integration of mission specific components necessary for the requirements of the mission. Similarly, the dispenser utilized in the mission is based on an existing item with a strong track record but has been enhanced with a newly designed retrieval mechanism. The DOCKS system represents a completely new development, drawing upon solutions previously explored at the Università di Padova and Stellar Project SRL. The breadboarding of mission-specific items have already commenced during phase B2. Ensuring the safety of the entire mission heavily relies on the design of the trajectory and the manoeuvring capabilities. This is particularly crucial during the docking phase, which has undergone thorough analysis and has introduced innovative solutions [7] [8]. The coordination between SROC and Space Rider, as well as its implications on safety, pose significant challenges for the mission's operations.

Table 1: SROC Mission Architecture

Mission element	Description of baseline	Options / Comments
Subject	Space Rider observations	Visual and Longwave Infrared Thermal Camera Module observations are considered for the baseline design
	Close Proximity Operations demonstration	Experiments: 1) execution of manoeuvre(s) for acquisition of hold points, for insertion into rendezvous trajectories with respect to Space Rider, for insertion into observation trajectories, 2) determination of relative distance from Space Rider with different sensors and techniques, 3) acquisition of Space Rider imagery
	Docking & Retrieval capability demonstration	Single deployment and retrieval of SROC (no reuse within the same mission)
Payload	Visual camera	The baseline solution for the payload is a visual camera based on Tyvak detector (the same used for the navigation cameras) with *ad-hoc* optics
Space Segment	1 CubeSat (SROC)	12U form factor, based on Tyvak Renegade platform, with deployable/retractable solar arrays and cold gas propulsion system
	1 Multi-Purpose CubeSat Dispenser (MPCD)	MPCD design is compliant with the Observe & Retrieve scenario
	1 Docking System (DOCKS)	DOCKS is the interface between SROC and the MPCD. It includes the sensors suite for supporting the navigation function for relative distance < 1m and the mechanisms needed to guarantee soft and hard docking of SROC to SR
Orbit & Constellation	LEO circular @400 km	Quasi-equatorial orbit (i=6.2 deg) assumed as baseline. Other orbits considered: i=37deg Midday-Midnight, i=37deg Dawn-Dusk, SSO Midday-Midnight, SSO Dawn-Dusk
	Formation flying with respect to SR	Rendezvous trajectory: passively safe in-plane + out-of-plane segments SR observation: Walking Safety Ellipse with relative inclination change and variable geometry Docking: along the in-track axis
	Disposal orbit	Manoeuvre(s) to avoid space debris impact, up to passivation of the satellite
	Re-entry (uncontrolled) orbit	Natual decay within 1 year
Communication Architecture	Store & Forward architecture	Direct link to Earth for downlink of mission data and back-orbit telemetry. Space-space-ground ISL selected both as a backup communication line and as primary communication during delicate mission phases where the spacecraft is not in ground station visibility.
Ground Segment	Ground station network	Network S-band ground stations.
	MCC	SROC MCC in Torino. The SROC MCC shall be in contact with the SR MCC for specific mission phases and/or needs
Operations	Mission Planning Spacecraft Control Flight dynamics	Drivers for Ops design: safety, reliability & autonomy Compliance with ESA standards Coordination with SR operations
Launch Segment	CSG spaceport + Vega C + Space Rider	Launch assumed Q3 2025 (baseline, target: SR maiden flight). Other late launch dates are considered

3 SYSTEM DESIGN

The space segment for the SROC mission is constituted by the following main items:

- SROC CubeSat:
  - CubeSat Bus (customized 12U Tyvak Renegade platform)
  - A set of optical cameras and sensors used for navigation and inspection (based on Tyvak heritage from other missions)
  - DOCKS a two-part docking mechanism co-hosted by SROC and MPCD, developed by Università di Padova and Stellar Project SRL;
  - A set of Payload GNC algorithms to support proximity operations with Space Rider (up to docking), developed by Politecnico di Torino
  - Payload Processing Unit Payload (Tyvak)
  - A cold-gas 6DoF thruster - Perseus Propulsion System - for proximity operations (T4i and Tyvak)
  - LEO space-space-ground Inter-satellite link (ISL)
- Multi-Purpose CubeSat Dispenser (MPCD), including:
  - Ad-hoc mechanical redesign of Tyvak 12U Dispenser
  - MPCD Avionics (Tyvak)
  - DOCKS-B Payload (Università di Padova and Stellar Project SRL)

The ground segment instead is composed by:

- SROC Mission Control Center (Tyvak)
- PGCC - Payloads Ground Control Center (Space Rider)
- Ground Station Network (Tyvak)
- Engineering Support Team (Politecnico di Torino, Università di Padova and Stellar Project SRL)

3.1 Spacecraft overview

SROC is a 12U CubeSat based on a standard Tyvak Renegade bus platform, customized for the specific mission needs. The processing platform is a system designed by Tyvak with a radiation hardened watchdog microcontroller, for hot-swap redundant functionality. The processing modules contain on-board storage for housekeeping telemetry collection. A combination of UHF, S, and X band radios options are available for telemetry and command of the satellite. The ADCS software can interface with multiple star trackers for guaranteed stellar coverage and a state-of the art Inertial Measurement Unit (IMU). As a backup, sets of redundant coarse sensors and magnetometers allow performing attitude determination functionality independent of the IMU and star trackers. For actuation, the system uses a family of reaction wheels depending on vehicle size and agility, along with torque rods for momentum management (in LEO missions). The Renegade platform power generation subsystem is highly modular to satisfy the power requirements of a vast range of missions. A standard deployable solar array configuration is generally proposed to maximize power generation. A high-efficiency MPPT transfers the energy sourced from solar arrays to the two parallelly-installed battery modules. The details of mechanical mounting of the payload are refined for each project and Tyvak works with payload project engineers to determine if a standard mounting configuration is appropriate for the mission payload. Tyvak conducts analyses to understand how thermal control should be implemented as required by the payloads, in addition to the standard thermal paths that are defined between the mounting points and the primary radiators. The baseline capabilities of the Renegade 12U Platform are listed in Table 2 below.

Table 2: Renegade platform specifications (NB: LEO application)

Specification	Capabilities

Spacecraft Platform	12U
Payload Mass	~10kg
Payload Volume	~9U
Data Buses	RS-422, USB2.0, CAN-bus, Ethernet
Power Rails	9-12.6V Unregulated, 3.3V & 5V
Stability	10 arcsec over 1 s
System Position Knowledge	+/- 5m
Peak deployable array Power	Up to ~120W
Energy Storage	Up to ~150Wh

Given the particular mission profile, the Renegade platform for SROC wouldn't mount some subsystems typical for a LEO mission:

- Standard Renegade Trifold Solar Arrays (power generation performed instead by customized retractable solar panel configuration)
- Standard radios (removal of UHF antenna module, and instead mounting a COTS S-band antenna and a LEO space-space-ground Inter-satellite link).

In addition to the standard Renegade OBDH, EPS/TCS, ADCS subsystems and standard structure, the spacecraft would host the following mission specific subsystems/components:

- Navigation Cameras (with heritage camera and dedicated processor to perform optical navigation)
- Longwave Infrared Thermal Camera Module (for Space Rider observation)
- LIDAR (COTS component)
- Communications subsystem (the aforementioned items)
- Propulsion subsystem (providing both translational and attitude control)
- DOCKS-A Payload
- Customized payload interface boards and structure, for thermo/mechanical mating, interconnection, and power/data distribution.

3.2 Mechanical Configuration

The following pictures illustrate the general mechanical configuration and subsystem accommodation, with the aid of the conceptual CAD up to the PDR details level reached.

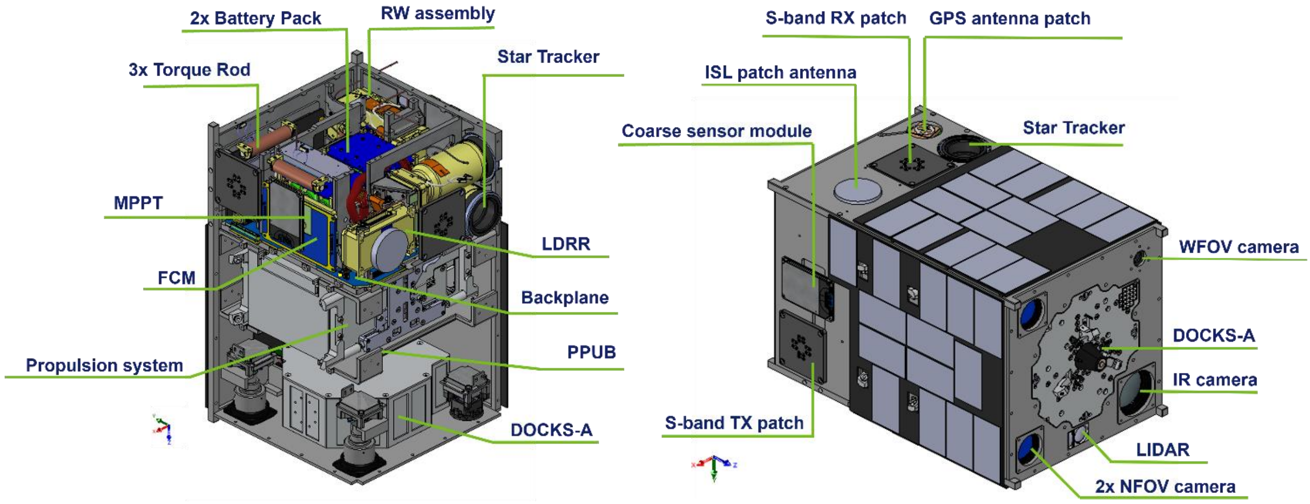


Figure 2: SROC internal/external configuration

Following the reference system showed in the bottom part of the figures, the SROC spacecraft is organized into three bays hosting different subsystems, as three 4U sections stacked on top of each other along the Z direction:

- A bottom section for the payload, the navigation and observation cameras, the LIDAR and the docking system.
- A centre section for the thruster module.
- A top section for the main bus avionics.

In the top section of the S/C, most of the Tyvak standard Renegade avionic modules are depicted. As regards the internal accommodation of the avionics, in the standard Tyvak platform the avionics block is rotated 90° compared to the current position, mounted on the internal YM panel. Having also accommodated Perseus, the propulsion system, it was decided to keep it central and to opt for the solution of rotating the avionics block, while still respecting the requirements mentioned previously and not causing interference problems. The backplane is a PCBA spanning across the whole avionics box volume, providing interconnections between the various modules. These include flex cables, cable-to-board connectors, and board-to-board connectors. The Payload Interface Board (PIB) can be considered as the extension of the Backplane towards mission-specific and COTS modules (such as MDRR and GNSS receiver, Propulsion subsystem). All free power and data interfaces available to payloads are routed to the PIB, which conditions them and distributes them to the various supported modules through dedicated power and data connectors. The main innovation is the inclusion of a specific board, called Payload Processing Unit Board. The introduction of this Mission specific board is justified by several factors, first and foremost the high number of SROC payloads and the consequent number of connections required, which is difficult to manage only with the PIB without a complete redesign of the board. Furthermore, the need to have a processor dedicated to image processing for navigation purposes. In doing so, the NRE required for the PIB is practically minimized, while the design focus is on the PPUB. To conclude the internal configuration of the satellite, in the lower part of the figure it can be seen a detail of the Payload Bay. In particular, the accommodation of four cameras and LIDAR is baselined considering the available volume. Furthermore, at the center of the figure lies the DOCKS-A module, which is connected to the PPUB at the top of the shielding. Both the PPUB and the ISL radio are interfaced to the PIB, which serves as the central node for power and data management between the main avionics and the rest of the system. Lastly, from the bottom figure, one can observe the satellite configuration with deployed solar panels (after separation from launch vehicle and adequate inhibit timer) compared to the previous figures depicting the stowed configuration (throughout launch/separation phases and before docking).

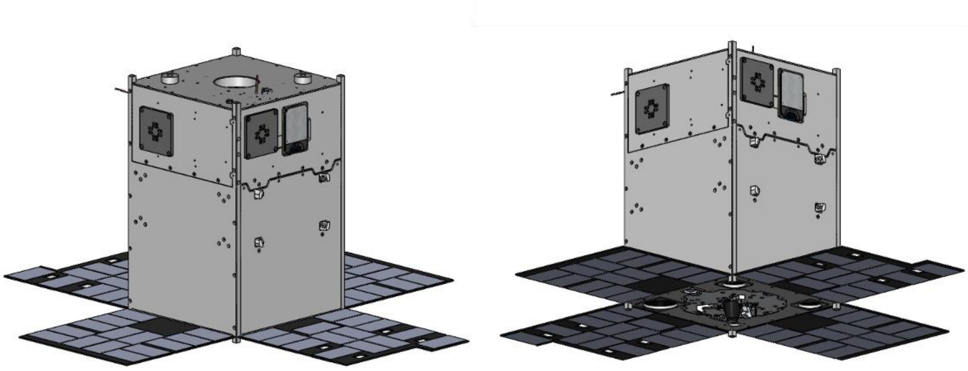


Figure 3: SA deployed configuration

3.3 Payloads overview

Camera Suite

The baseline selected foresees the utilization of three types of optical cameras: the WFOV (Wide Field of View) the NFOV (Narrow Field of View) camera and the FLIR TAU 2+ model. The WFOV/NFOV cameras both utilize the enhanced version of the Tyvak VIS IMG (Visible Imager) PCBA, minor changes also include the lenses and mechanical support structure.
In Table 3 and Table 4 are summarized the main characteristics of the WFOV/NFOV and Infrared cameras respectively.

Table 3: Visible cameras main characteristics

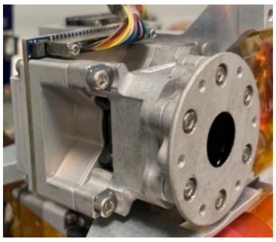
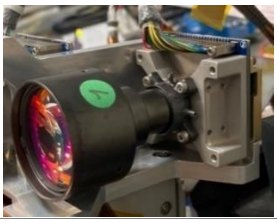
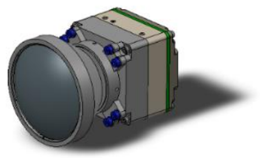
Common characteristics	COTS CMOS sensor assembled on the Tyvak Visible Imager PCBA; 3.1 Mpixels, RGB Bayer Color Filter Array; Fixed aperture and fixed focus lenses (no moving parts in orbit)
WFOV Visible Camera 	Optics focal length 3 mm F/N 2.8 ± 37° H x ± 29.4° V sensor field of view Target spatial resolution @ 40 m ~2.9 cm/px
NFOV Visible Camera 	Optics focal length 70 mm F/N 2.8 ± 1.9° H x ± 1.4° V sensor field of view Target spatial resolution @ 200 m ~0.7 cm/px

Table 4: Infrared camera characteristics

FLIR TAU 2+	Based on VOx Microbolometer sensor
	Thermal Spectral Range LWIR 7.5 – 13.5 µm
	Array Format 640 x 512 pixels
	Optics focal length 49.98 mm
	F/N 1.2
	± 6.21° H x ± 4.98° V sensor field of view
	GSD @ 600 km ~204 m/px

Payload Processing Unit (PPU)

The selection of the Payload Processing Unit COTS that will be integrated on top of the PPUB was a joint effort between Tyvak International and Politecnico di Torino, in order to ensure the most suitable and valid component for both the payload processing point of view and for the physical integration and interface with the satellite, while guaranteeing a flight heritage. Among the possibilities, a commercial HW accelerator was selected. This HW accelerator is a Graphic Processing Units (GPUs), originally developed for use in generating computer graphics, virtual reality training environments and video that rely on advanced computations and floating-point capabilities for drawing geometric objects, lighting, and color depth. AI algorithms need a lot of data to analyze and learn from: this requires substantial computing power for executions and shift large amounts of data. GPUs can perform these operations because they are specifically designed to quickly process large amounts of data used in rendering video and graphics. Their strong computational abilities have helped to make them popular in machine learning and artificial intelligence applications. The COTS HW was selected having in mind Flight heritage & TRL, Space-grade certification, Algorithms compatibility, Voltage/power characteristics, interfaces and processing power limitations.

3.4 Docking System - DOCKS

DOCKS is conceived as a **smart integrated docking system** that merges in itself the multiple functionalities required to achieve a successful and safe docking manoeuvre. The final goal is to implement a docking system that is loosely dependent on the host satellite. The different functionalities are provided by different hardware components and devices. Specifically, DOCKS integrates (1) a navigation sensors package, (2) a docking mechanism and (3) a dedicated computer. This concept allows to develop a highly specialized system that is specifically tailored for the docking procedure. The docking system is largely autonomous that does not depend on the host satellite, except for power supply and for propulsion and attitude control functions. In order to implement docking capabilities, DOCKS is composed by two parts (or interfaces): one mounted on SROC (DOCKS-A) and the other mounted on MPCD (DOCKS-B). Figure 4 presents a conceptual scheme of DOCKS as an integrated system, with schematic interfaces with SROC and MPCD. The DOCKS system is a combination actuators and sensors, making it unique among other docking systems described in the literature. The advantages of having an integrated navigation-docking system are modularity, compatibility, and optimized performance. DOCKS is a standalone subsystem that could equip a large variety of orbital platforms as an add-on module that would provide docking functionalities to a conventional satellite.

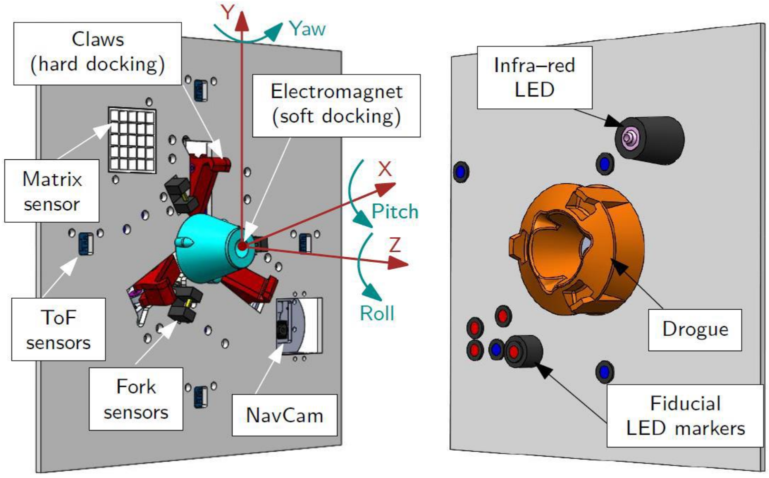


Figure 4: DOCKS–A (on the left) and DOCKS–B (on the right) with their main components

The all-in-one design improves compatibility with the systems of the host satellite, which are only required to provide standard features and resources like power supply and orbital/attitude control. Finally, the joint design of sensors and mechanisms allows to optimize the performance of both to better suite the operational scenario. The system intelligence resides in DOCKS-A, where the local computer is located. The computer allows DOCKS to operate as a standalone subsystem collecting data through the navigation sensors, estimating the relative pose between DOCKS-A and DOCKS-B, providing SROC with close-proximity pose estimates, controlling the docking actuation. The three components of DOCKS (sensors, mechanism and computer) cooperate constantly and make DOCKS an autonomous subsystem. DOCKS includes a navigation sensor package that measures the relative position and orientation of DOCKS-B with respect of DOCK-A from approximately one metre of distance up until contact. The six pose parameters considered are three distances and three orientations. Multiple sensors are used in conjunction in order to retrieve measurements of all the parameters throughout the whole range of operation of DOCKS (in terms of relative distance). The different sensors are based on diverse technologies, adding to fault tolerance and redundancy. The sensor suite includes a camera-based vision system, a set of Time-of-Flight (ToF) distance sensors and a custom matrix sensor with IR beacon reference. Each sensor works at a different range with some overlapping. The selected configuration has been designed to tolerate a certain amount of misalignment and to allow self-alignment through the geometry of the parts that get in contact, specifically the centring cone on DOCKS–A and the concave drogue on DOCKS-B. The centring cone hosts an electromagnet to enable the soft-docking functionality. The goal is to obtain stable preliminary contact between DOCKS-A and DOCKS-B, thus allowing the safe activation of the claws to achieve hard-docking. The electromagnet is activated at a relative distance (DOCKS-A to DOCKS-B) of approximately 1.0 m and is deactivated once the claws are completely closed. When the two parts are aligned, the claws activation signal is provided to the computer board by a set of acknowledgement fork sensors that are triggered by specifically designed features on the DOCKS drogue. The servomotors are activated, and the claws grasp the outer rim of the drogue. The concept of DOCKS is based on the synergy between the hardware and software tehcnologies. Among the innovative aspects of the proposed design is the capability to locally execute software that, beside managing the operations of DOCKS, provides major GNC functionalities to the host satellite. Specifically, accurate state estimation is run on the DOCKS computer based on the measurements provided by the sensors. This allows to compute the control error w.r.t. the reference trajectory during final approach.

4 Multi-Purpose Cubesat Dispenser (MPCD)

The MPCD (Multi-Purpose CubeSat Dispenser) is a modified Tyvak 12U CubeSat Deployer designed to meet the needs of the Observe and Retrieve mission of the SROC project, i.e. to have a dispenser capable not only of releasing the satellite but also of retrieving it for re-entry to Earth, trying to exploit the flight heritage of the current deployer as much as possible. MPCD represents an interface between the launch vehicle, Space Rider, and the CubeSat, SROC, and would be located in the cargo bay of Space Rider (MPCB).

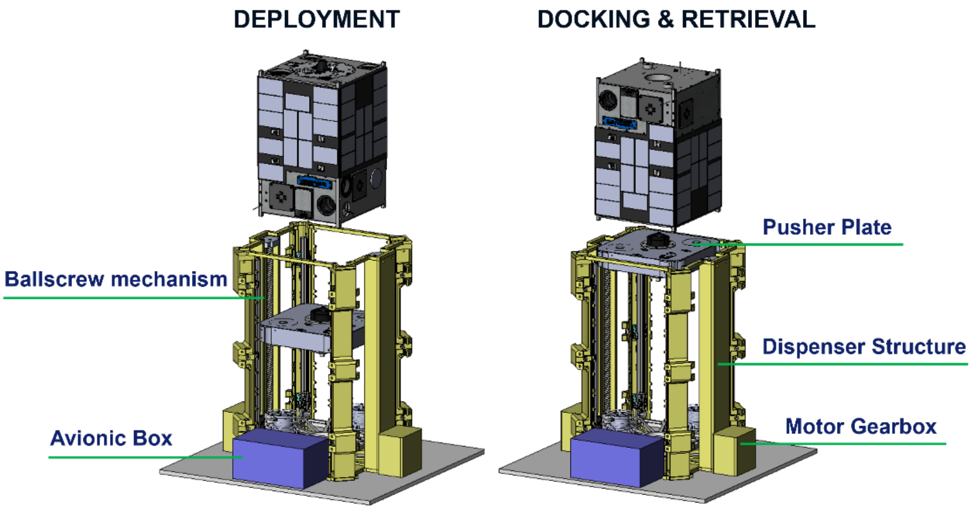


Figure 5: MPCD with SROC at Deployment and Docking/Retrieval

The main modifications needed to transform the standard Deployer into the MPCD involve a double ball-screw mechanism for the bidirectional actuation of the Pusher Plate (overextension for docking, retraction for retrieval), modifications in the Pusher Plate itself to host the DOCKS-B docking systems components, and a latching system to secure SROC within the MPCD after retrieval. Additionally, dedicated electronics and avionics need to be attached to the MPCD, in order to provide monitoring and control functionality for its operation as well as power conditioning, and to expose the interfaces with the electrical and data lines provided by Space Rider. The dedicated set of avionics would be hosted in an ad-hoc "Avionics Box", (blue box in Figure 5), which also includes an engineering camera, in order to document the MPCD operations. The MPCD would be employed for the release and recovery of SROC within the Space Rider MPCB. These activities are articulated into several distinct phases (Figure 6) that are detailed in Table 5.

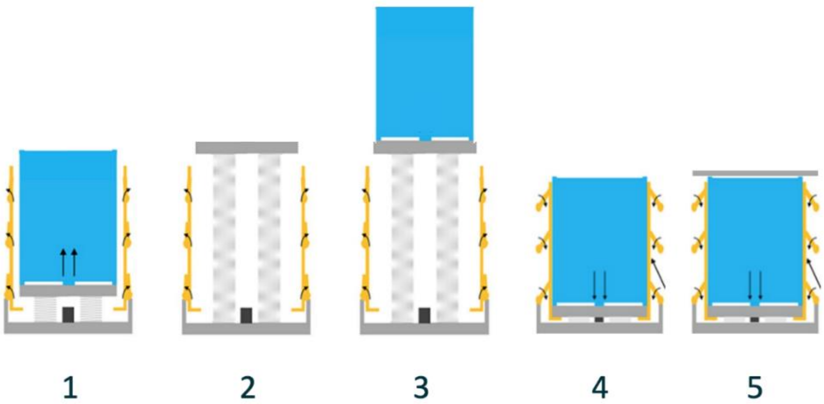


Figure 6: MPCD Phases representation

Table 5: MPCD Phases description

Phase/Activity	Description
Release	SROC is deployed by the MPCD via a standard ejection mechanism. The actuation is commanded via SR payload interfaces and controlled by the MPCD avionics box, as opposed to a Deployment Sequencer as in a standard launch.
Pusher Plate Ascent	A linear actuator brings the pusher plate outside the MPCD for the docking phase.
Docking	SROC docks with the DOCKS-B system on the MPCD Pusher Plate.
Pusher Plate Retrieval	The linear actuator retracts the pusher plate (and SROC) back into MPCD for stowing.
Latching	A mechanical latch secures SROC within the MPCD to fix the assembly for the re-entry phase.

In order to ensure maximum reliability in the deployment sequence, the Release is planned to be actuated exactly like it would be in the standard Deployer (i.e. through the release of the Hold Down and Release Mechanism (HDRM) and dynamic rails and spring-loaded pusher plate impulse). The extra mechanization in MPCD would only come into play during the Docking/Retrieval phase.
The current baseline for the Reduced Scenario (during the first mission) is to fly a complete MPCD system and exercise the Pusher Plate Ascent and Retrieval activities, to demonstrate its operability in the target environment, even though the docking itself would not take place. This would act as a Demonstration verification and de-risking activities for subsequent Observe & Retrieve missions.

5 Optical and GNC Algorithms Design and Development

The study also focused on some fundamental aspects of guidance navigation and control such as the identification of sensors sets and their operative ranges, the preliminary analysis of visual navigation strategies and definition of a preliminary, robust state Observer, the selection and verification via analysis of the of guidance and control strategies for nominal and off-nominal final approach, and the derivation of the GNC requirements. The above considerations led to consider specific algorithms such as Visual Odometry to identify the relative position and velocity of SROC vs Space Rider.
The initial step involved the identification of feature points within images using a feature detector algorithm. Following a meticulous assessment, optimal performances were achieved by the KAZE algorithm which identified numerous features (Figure 7). Subsequently, a matching process was executed to establish correspondences between two consecutive frames.

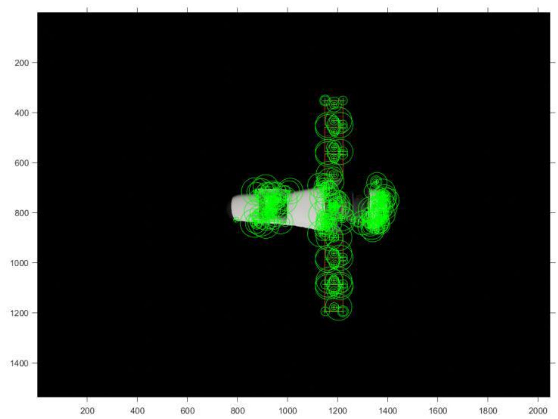


Figure 7: Space Rider feature detection

The results appear promising; however, upon computing the camera pose for more than two views, a correction become necessary to reduce the reprojection error and estimate the real pose. This process, known as bundle adjustment, involves minimizing the reprojection error through an estimation process. By solving a nonlinear least squares problem, the algorithm aims to determine the 3D points that minimize the re-projection error, thereby enhancing the triangulation accuracy for subsequent views.

A set of Guidance and Control algorithms were explored in order to identify the factors driving system behaviour, as well as the constraints and performance criteria, particularly for the close-range, final approach and mating phases. A detailed Matlab/Simulink model was developed to maintain a Model & Simulation Bases Approach that carried out quick delivery of results for further analyses. Nominal approaches trajectories and attitudes for the several identified scenarios have been defined using a Tracking Model Predictive Control. The results indicate that successful docking is achievable along the +InTrack approach axis, with a maximum velocity of 0.2 meters per second, implemented for safety considerations (Figure 8).

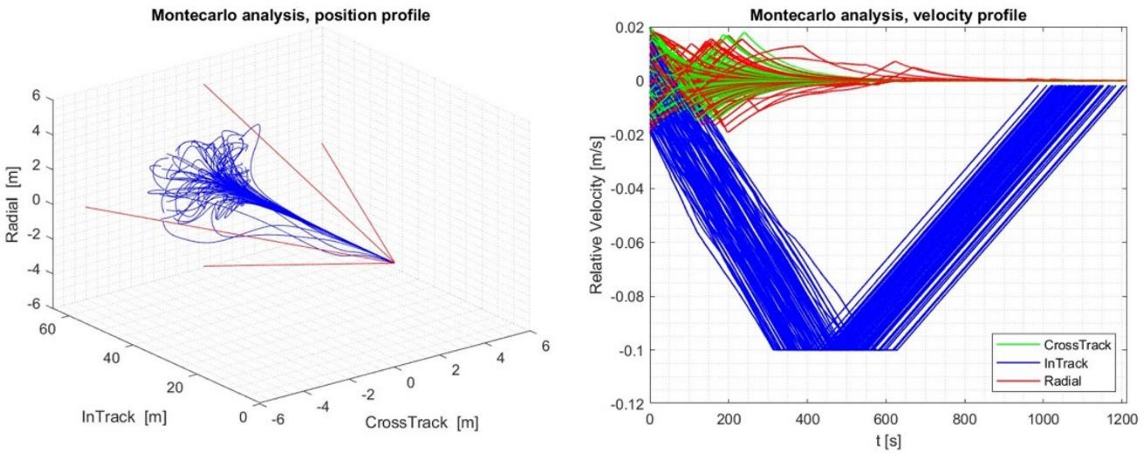


Figure 8: Approach trajectory: position profile (left), velocity profile (right)

Furthermore, an initial analysis of off-nominal conditions was conducted, contingent upon specific assumptions regarding the type of Collision Avoidance Manoeuvre (CAM), the dimensions of the avoidance box (i.e., Space Rider dimensions), and the initial conditions of the state vector (position and velocity, attitude, and angular velocity).

6 CONCLUSIONS

The outcomes of the development plan, particularly regarding mission-specific items, are noteworthy. A comprehensive evaluation of safety has been conducted, taking into account all significant safety-related incidents and offering remedies to minimize any potential hazards. The development of critical technologies and exploration of design solutions are of utmost importance in order to advance the field of proximity operations and potentially serve other missions and applications. It is crucial to note that the inspection of a functioning spacecraft in orbit presents unique challenges that have not yet been addressed by any previous missions. One key focus area is the GNC of spacecraft, which must achieve a level of accuracy and safety that is currently only attained by highly complex systems, such as visiting vehicles to the International Space Station (ISS). Another distinctive aspect of the project pertains to the operations involving deployment, docking, and retrieval. It is important to acknowledge that the mission-critical aspects pose both technical and programmatic challenges. However, it is equally important to recognize that the development and demonstration of new technologies related to these critical areas have the potential to significantly contribute to the success of more intricate CubeSat missions, such as interplanetary exploration [9] or other scientific mission.

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