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SROC: Space Rider Observer Cube Mission

Luca Deva[(1)], Giorgio Ammirante[(1)], Giorgio Taiano[(1)], Enrico Bassissi[(1)], Federico Parigi[(1)], Sabrina Corpino[(2)], Fabrizio Stesina[(2)], Luca Niero[(2)], Lucrezia Lovaglio[(2)], Valentina Rotti[(2)], Francesco Branz[(3)], Francesco Sansone[(4)], Francesco Topputo[(5)], Paolo Panicucci[(5)], Paolo Lunghi[(5)] Camille Pirat[(6)], Jeroen Van den Eynde[(6)], Giulia Vergallo[(6)]

[(1)] Tyvak International srl, Via Orvieto 19 10149 Torino Italy, +39 0111911607, luca.deva@tyvak.eu
[(2)] Politecnico di Torino, Corso Duca degli Abruzzi 24 10129 Torino Italy, sabrina.corpino@polito.it
[(3)] Università degli Studi di Padova, Via Gradenigo 6/A 35131 Padova Italy, francesco.branz@unipd.it
[(4)] Stellar Project, Viale dell'Industria 60 35129 Padova Italy, francesco.sansone@stellarproject.space
[(5)] Politecnico di Milano, Piazza Leonardo da Vinci 32 20133 Milano Italy, francesco.topputo@polimi.it
[(6)] ESTEC (European Space Research and Technology Centre), Keplerlaan 1 2201 AZ Noordwijk The Netherlands, camille.pirat@esa.int

PAPER

The SROC project aims at demonstrating the CubeSat capabilities and technologies required for successfully executing a rendezvous and docking with another operational spacecraft. This objective is captured by the SROC mission concept involving the development of 12U CubeSat, which acting as Chaser, will perform rendezvous, proximity operations, inspection and docking with Space Rider, to be finally retrieved in the reusable transportation system and complete the re-entry.
The preliminary design and the assessment of the risk associated to the Space Rider mission scenario led to purse the SROC objective through the achievement of an intermediate and complementary step involving: the in-orbit demonstration of rendezvous and docking operations between two collaborative 12U CubeSats and the on-ground qualification of the identified enabling technologies required to complete docking and retrieval operations in the Space Rider scenario.
The development of a mission scenario targeting the rendezvous and docking between 12U CubeSats and the on-ground qualification of a docking/retrieval compatible Dispenser and Solar Panels solution represent the subject of this paper, and the core objectives of the current SROC project, developed by a fully Italian consortium in the framework the ESA General Support Technology Programme (GSTP) supported by the Italian Space Agency (ASI).
The project aims to reach within Q1 2027 a detailed design at mission level, including the validation of the trajectory strategy, and at system level, including the design consolidation of the two CubeSats systems, the Dispenser and the Retractable solar panels solution. This achievement will pave the way for the in-orbit demonstration phase planned for 2028.

1 Introduction

CubeSats technologies can effectively aid in various proximity operations endeavours. These applications encompass tasks like assessing inactive satellites in preparation for active debris removal missions, monitoring and inspect spacecraft such as the International Space Station or the Lunar Gateway, support in orbit servicing activities 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 CubeSats and nanosatellites have the potential to cut the costs and development while integrating the dedicated sensing technology to observe and gather high quality 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].

In this context, SROC initial concept has been developed. It foresees the development of SROC spacecraft, a 12U CubeSat which initially stowed inside an ad-hoc designed Multi-Purpose CubeSat Dispenser (MPCD), is planned to be released in the LEO by Space Rider (SR), the European reusable space transportation system [6]. Once released, SROC spacecraft will perform rendezvous and proximity operations with Space Rider (SR) vehicle before completing the docking with the mothercraft thanks to the MPCD and the ad-hoc designed docking system. The successful execution of the docking sequence and the retraction of the SROC solar panels will allow the retrieval of the SROC spacecraft into MPCD and consequently complete the Space Rider re-entry phase.

The analysis and preliminary design of this mission concept led to identify a set of technical and programmatic risks which assessment converged in the elaboration of a complementary mission scenario and on the definition of on-ground qualification decoupled from the new in-orbit demonstration mission. The new mission scenario foresees the deployment of two 12U CubeSats in a Sun Synchronous Orbit, the separation of the two spacecrafts during the Commissioning phase, the Chaser rendezvous towards the Target leveraging on intersatellite link and visual based navigation will be used to guide the propulsion system operation up to the docking. Following the achievement of docking condition the two spacecraft will autonomously stabilize the attitude, to consequently execute the un-mating sequence, increase the relative distance and finally perform the safe disposal. In parallel to the design and implementation phases of this new scenario,

The MPCD dispenser and the retractable solar panels technologies required for the successful execution of the initial Space Rider mission concept will be consolidated and qualified through a dedicated environmental test campaign. This paper provides an overview of the mission and system concepts under development in the framework of the detailed design phase. This activity is executed as part of ESA contract no. 4000142560/23/NL/MG/cb by a fully Italian consortium composed by: Tyvak International as Prime Contractor and responsible for satellites design, AIT and operations, Politecnico di Torino as responsible for Mission Analysis, and the development of visual based Navigation and Guidance model, Politecnico di Milano supporting the GNC verification and validation, University of Padua and Stellar Project as responsible for the development, testing of the docking system.

2 Mission Objectives and Technology Demonstration

In the evolution of the initial mission concept, the SROC mission statement *"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"* has been declined in the following set of mission objectives:

- Primary mission objectives:
  - To demonstrate safe CubeSat Rendezvous and Docking
  - To demonstrate Target inspection
  - To demonstrate autonomous and robust GNC & FDIR for close-proximity operations
- Secondary mission objectives:
  - To qualify on ground MPCD
  - To qualify on ground the SROC retractable solar panels

To achievement of these mission objectives requires an advancement of CubeSat technology and capabilities related to:

- Formation flight and relative navigation:
  - Compact cold gas Propulsion system ensuring high granularity 6 DOF control and low time-to-fire compatible with proximity operations scenario
  - Navigation cameras and processing unit enabling visual based navigation at mission operative ranges
  - Navigation, Guidance and Control algorithms tailored on the selected sensor suite
  - Intersatellite communication supporting relative navigation between Chaser and Target at mission operative ranges
  - Communication architecture compatible with direct-to-Earth TMTC and intersatellite communication
- Docking and retrieval scenarios:
  - Fault tolerant and autonomous guidance, navigation and control algorithms supporting close approach and docking operations
  - Compact and reliable Docking system compatible with docking operation tolerances
  - Solar panels design compatible with RPOD mission power profile and the retrieval into dispenser volume post docking
  - Dispenser solution compatible with standard deployment and motorized retrieval mechanisms of the CubeSat once completed the docking
- Space targets observation and inspection:
  - Cameras characterized by a spatial resolution compatible with the target features

It is worth to highlight that in addition to the hardware related technology enhancement, the trajectory design and the robustness of the GNC algorithms play a heavy role in ensuring mission safety, in particular during the docking phase, subject of study for innovative solutions [7] [8].
Starting from the initial Space Rider mission scenario, the qualification and the in-orbit demonstration of these advanced technologies have the potential of opening a wide spectrum of novel applications for nanosatellites in the area of Inspection, in orbit servicing (IOS) and Debris removal missions.

3 CONCEPT OF OPERATIONS

The transition from the Space Rider mission concept to a new scenario involving the two 12U CubeSats operating respectively as Chaser and Target, led to define the Concept of Operations

resumed in Figure 1. The ConOps version presented in this paper is subject to refinement in the current stage of the project, taking in consideration inputs from system and subsystem level.

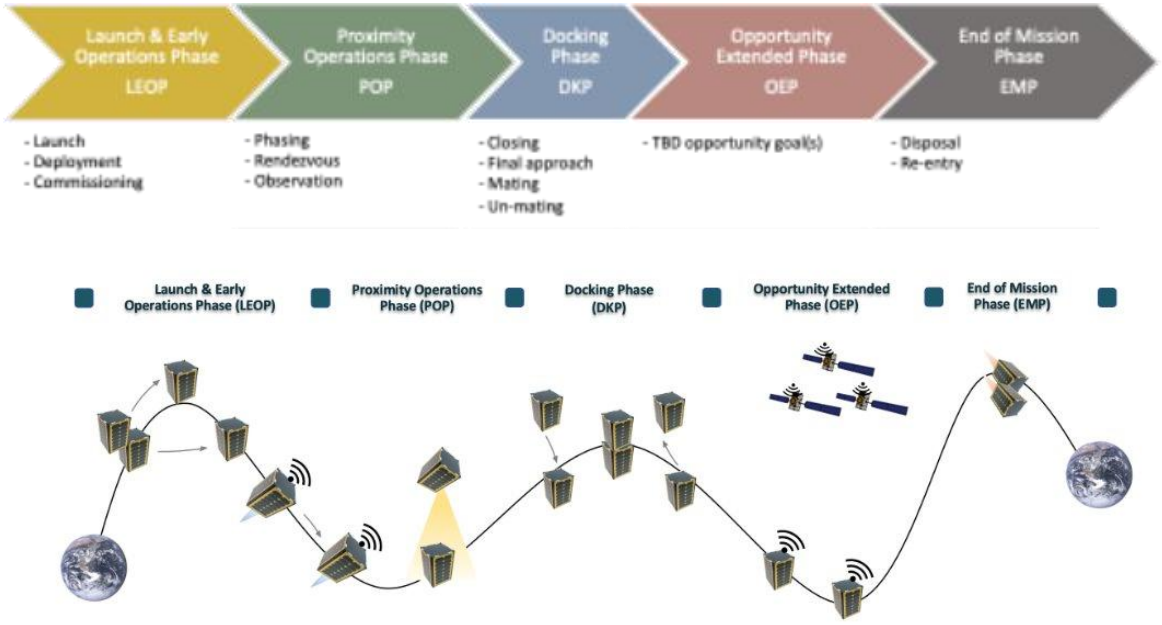


Figure 1. SROC Concept of Operations

The first phase of the SROC mission ConOps foresees the deployment via rideshare launch opportunity of the two 12U CubeSats in a Sun Synchronous Orbit at an altitude of 450-550km using two Tyvak 12U dispensers. Once released in orbit, the two satellites will autonomously perform the power activation sequence, the solar arrays deployment and the attitude stabilization in a fine pointing mode where the power generation is maximized orienting the solar arrays towards the Sun vector.
Post deployment the two spacecrafts will separate from each other while functional verification of the Chaser and Target subsystems is performed as part of the Commissioning phase.
Once confirmed the nominal behaviour of the systems, the Chaser will be commanded to execute the phasing manoeuvres required to reduce the orbital phase angle with the Target, up to n hold point characterized by an operative range enabling satellite relative navigation via intersatellite link.
The achievement of this operational condition kick-starts the rendezvous phase, where the Chaser will perform the set of manoeuvres to acquire a second hold point along Target in-track, characterized by an operative range enabling Visual Based Navigation (VBN) via NFOV camera part of the Chaser sensor suite. To satisfy target inspection objective, has been baselined an Observation phase where the Chaser will perform Target acquisitions maintaining a controlled and safe relative configuration with the Target. Once downlinked the acquired images, the Closing phase will be executed to reduce the intersatellite range to a final-approach gate. During closing manoeuvres, the overlap between the navigation cameras operative range and the relative GNSS data exchange via ISL will allow a safe handover between the NFOV and WFOV camera. The Closing phase can be considered completed once the Chaser, reached a hold point along Target in-track, will validate accuracy and persistency of the visual based navigation solutions.
During this gate point, the ground segment is involved to confirm the system functionalities and performances and to provide the go to kick-start the final approach phase where the Chaser will autonomously execute the docking sequence. In this final approach phase, the Chaser will switch to port-to-port guidance mode and leveraging on the close-range navigation cameras will execute straight-line manoeuvring sequence to target a mating between the two docking interfaces. Potential anomalies or contingency condition associated to the Chaser and Target vehicle are handled by FDIR logics based on navigation data and health status data exchanged via ISL which under predefined

conditions will trigger the execution of a Collison Avoidance Manoeuvre (CAM) and the abort of the docking sequence. The final approach phase is considered achieved when the intersatellite range reaches 5 mm and the first physical contact between the docking interfaces DOCKS-A (on Chaser side) and DOCKS-B (on Target side) is achieved. In this condition, the docking mechanism will first perform a soft docking based on electromagnet activation, and then a hard docking establishing a rigid mechanical connection between the two vehicles.

4 SPACECRAFT SYSTEM DESIGN

The space segment for the SROC mission scenario foresees:

- Chaser CubeSat, including:
  - Spacecraft Bus based on Tyvak Renegade 12U avionics
  - Tyvak standard trifold deployable solar arrays
  - Three optical cameras used for navigation and inspection (design based on Tyvak heritage from previous missions)
  - Payload Processing Unit
  - DOCKS-A, active docking system developed by Università di Padova and Stellar Project SRL
  - A cold-gas 6DoF propulsion system Perseus, developed by T4i and Tyvak International to support proximity operations
  - Space-space ISL module and antenna to support R-GNSS navigation and safe docking sequence
  - Space-space-ground ISL, to extend the communication with the satellite beyond the Ground station visibility windows thanks to communication relay provided by Iridium constellation
- Target CubeSat
  - Spacecraft Bus based on Tyvak Renegade 12U avionics
  - Tyvak standard trifold deployable solar arrays
  - One optical camera
  - Payload Processing Unit
  - DOCKS-B, passive docking system developed by Università di Padova and Stellar Project SRL
  - A cold gas 6DoF propulsion system Perseus, developed by T4i and Tyvak International to support proximity operations
  - Space-space ISL module and antenna to support R-GNSS navigation and safe docking sequence
  - Space-space-ground ISL module and antennas, based on Iridium constellation relay

4.1 Platform Overview

SROC spacecrafts are based on Tyvak 12U Renegade Platform, customized for the specific mission needs. The Platform OBDH subsystem includes a Tyvak designed Flight Computer Module acting as main processing unit and covering on-board storage, telemetry collection and monitoring and running ADCS algorithm and applications. The AOCS subsystem sensor suite includes a pair of orthogonally oriented Star Tracker modules, two Coarse Sensor Modules equipped with magnetometers and sun sensors, a COTS Inertial Measurement Unit (IMU) and a GNSS receiver with dedicated antenna. Attitude control is provided by three Reaction wheels and three torque rods for momentum management. Regarding the EPS, two trifold deployable solar arrays hosting a total of 120 cells will generate the power which is following regulated by high-efficiency MPPT module and consequently transferred to the two parallelly-installed Battery modules. The 12V unregulated power buses provided by the batteries are distributed and regulated at the required voltage levels by a Load

Controller Module. In addition to the standard S-Band equipment for TMTC purpose, the SROC spacecraft Communication system includes two mission specific equipment to support RPOD scenario: a space-to-space ISL equipment enabling Chaser and Target direct communication, and a space-space-ground ISL leveraging on Iridium constellation relay.
The space-to-space ISL will operate in two different modes during the mission, a the first mode where relative navigation between Chaser and Target is enabled via GNSS data exchange, and a second mode where a subset of critical telemetry is exchanged between the two spacecrafts to allow the FDIR monitoring and the potential CAM triggering during the docking phase.
The space-space-ground ISL instead will exploit the communication relay provided by Iridium constellation, to extend the communication with the satellite beyond the Ground station visibility windows.

4.2 Visual based navigation sensor suite

The baseline selected foresees the utilization of three of optical cameras: a NFOV (Narrow Field of View), a WFOV (Wide Field of View) and a UWFOV (Ultra Wide Field of View) camera.
The three cameras are based on a fixed aperture/focus lens and the flight proven Tyvak Visible Imager, a dedicated PCBA hosting a CMOS sensor, an integrated processing unit via COTS System on Module (SOM), memory storage and the circuitry required for camera control and monitoring.
The images generated by the three cameras are transferred and processed by a dedicated COTS Payload Processing Unit represented by NVIDIA Jetson GPU.
The visual based navigation capabilities are based on the detection of spacecraft features and LED patterns in the target intersatellite range.
The operative range of each camera is under definition in the current phase, taking in consideration the camera Field of View (FoV), the spatial resolution, navigation algorithm performances, radiometric constrains (including SNR, exposure and scene radiance) and depth of field.
The navigation strategy foresees to exploit VBN solution up to the first mechanical contact between the docking interfaces, verifying a continuity of the VBN operational range without coverage gaps or critical transitions between the different cameras/targets.

4.3 Docking system (DOCKS)

DOCKS is conceived as a smart integrated docking system that merges 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: a navigation sensors package, a docking mechanism and a dedicated computer. This concept allows to develop a highly specialized system that is specifically tailored for the docking procedure. The docking system design to be independent from the satellite, except for power supply and for propulsion and attitude control functions. To implement docking capabilities, DOCKS requires two different parts (or interfaces): one mounted on the Chaser (DOCKS-A) and the other mounted on the Target (DOCKS-B). Figure 2 presents an overview of the two interfaces.
The DOCKS system is a combination actuators and sensors, making it unique among other docking systems described in the literature.
The system intelligence resides in DOCKS-A, where the processing unit is hosted. This units 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 in the last centimetres before the docking.
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

ensuring operative overlap. The selected configuration has been designed to allow self-alignment through the geometry of the parts that get in contact within a target tolerance, specifically the centring cone on DOCKS–A and the concave drogue on DOCKS-B. In addition, 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. 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 electromagnet will be deactivated once the claws are completely closed and the hard docking is confirmed.

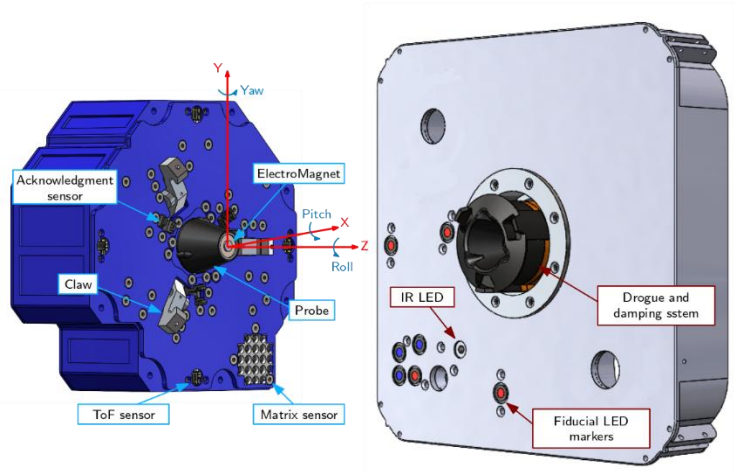


Figure 2. DOCKS overview

5 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 Space Rider mission scenario. The key design driver foresees the development of a dispenser capable not only of releasing the satellite but also of retrieving it for re-entry to Earth, trying to exploit and maximize the flight heritage of the Tyvak deployer.
MPCD will represent the interface between the Space Rider and the SROC CubeSat and is planned to be integrated during the mission in the cargo bay of Space Rider (MPCB).
The main modifications needed to transform the standard Tyvak flight-proven deployer into MPCD involve a motorized ball-screw mechanism for the bidirectional actuation of the Pusher Plate post satellite deployment: pusher-plate extension to expose the docking interface to the Chaser, and pusher-plate retraction for retrieval SROC satellite once completed the docking. Compared to the standard design, the Pusher Plate will host the DOCKS-B passive docking system. In addition, an ad-hoc designed latching mechanism will secure SROC in a stowed configuration within the MPCD after retrieval and during the Space Rider re-entry.
The MPCD operation will be managed by dedicated electronics and avionics module, which will ensure the monitoring, control and power conditioning of the motorized system and the associated sensor suite and will enable power and data interface with Space Rider. The control electronics will be hosted in a “Avionics Box”, which also includes an engineering camera, to document the MPCD and SROC operations during the docking phase. In Figure 3 are presented the main MPCD configurations during the different phases.

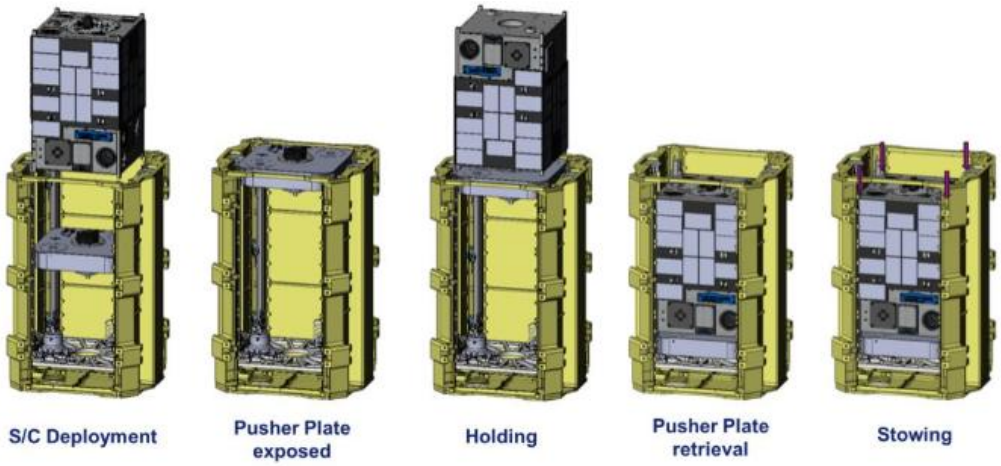


Figure 3. MPCD configurations

The MPCD concept of operations can be resumed in the following phases:

- Release: SROC is deployed by the MPCD via an ejection spring mechanism. The actuation is commanded via SR payload interfaces and controlled by the MPCD avionics box. Upon receiving the command from the SR payload interfaces, the MPCD avionics box initiates the actuation sequence via redundant actuation chain and ensuring that the spacecraft deployment with the nominal release velocity.
- Pusher Plate Exposed: A motorized linear actuator extends the springs and moves the pusher plate outside the MPCD collar in an exposed configuration. When activated, the linear actuator precisely controls the extension, ensuring that the pusher plate reaches the optimal position enabling docking operations.
- Holding: The pusher plate is maintained in the exposed position in preparation for the docking operations, during the spacecraft rendezvous and final approach, and until confirmation that the SROC DOCKS-A system has successfully mated with the DOCKS-B system integrated in the MPCD pusher plate.
- Pusher Plate Retrieval: Upon receiving the command, the MPCD initiates the retrieval sequence, and the motorized linear actuator retracts the pusher plate and the SROC spacecraft back into the MPCD dispenser in a stowed configuration. The pusher plate automatically stops when it reaches the down position.
- Stowing: An ad-hoc designed latching system and a dedicated brake will be activated to hold the pusher plate and spacecraft in the stowed position during the SR 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 MPCD motorized mechanism would only be involved during the Docking/Retrieval phase.

6 RETRACTABLE SOLAR PANELS (RSP)

To support autonomous and safe RPOD operations a wide set of sensor, actuators and processing unit needs to be integrated in Chaser architecture and operated up to the achievement of the “docked condition”.
Consequently, the associated power demand shall be satisfied by the spacecraft power generation capabilities to ensure autonomy and responsiveness during safety critical phases.

Despite this need is easily satisfied in a standard CubeSat mission through the adoption of a deployable solar panels configuration, to enable the Chaser retrieval post docking in the MPCD volume, a retraction of the deployed solar panels in a stowed configuration is required.
This context, compatible with Space Rider mission scenario, led to kick-start within SROC program a development process targeting the on-ground qualification of a Retractable solar panels solution finalized to validate the technology for future docking and retrieval applications.
The currently baselined design foresees a decoupling between the deployment and the retraction functionality. The deployment sequence is indeed planned to be executed via flight-proven Hold Down Release Mechanism (HDRM) to avoid unintended deployment once stowed into the deployer during launch window and a set of hinge spring to ensure the solar panel rotation up to the final position. The retraction of each solar panels starting from its fully deployed configuration is planned to be performed by an ad-hoc designed Retract Hold Down Mechanism (RHDM) including a space-rated COTS stepper motor coupled with a COTS planetary gearhead providing the torque and control required to win the hinge spring contribution restore the initial solar panel configuration. The solar panel position feedback of the deployed and stowed/retracted condition is provided by dedicated microswitches. The confirmation via telemetry of the achievement of the solar panel retrieved condition, will allow to trigger a locking system ensuring the solar panel mechanical lock in a fixed stowed configuration.
The RHDM will include a Solar Panel Control Board (SPCB) to drive the stepper motor and manage power and data interfaces with the Platform.
The technical risks associated to the Retractable solar panel system maturity are mitigated through the adoption of a model philosophy involving the development of an initial Breadboard design within phase C, and the realization of a RSP Engineering Qualification Model (EQM) which during phase D is planned to undergo to the following verification steps: acceptance at subunits level, functional tests in standalone configuration, retraction test in ambient and thermal cycling condition while integrated in a satellite Structural and Qualification Model (SQM), vibration and thermo-vacuum testing at qualification levels defined by the baselined launcher while the RSP and the SQM are integrated in MPCD EQM model.

7 CONCLUSIONS

The analysis of an initial mission concept involving RPOD between a 12U CubeSat, acting as chaser, and Space Rider, led to develop a independent mission scenario targeting the demonstration of rendezvous, observation and docking involving two collaborative CubeSats, and the definition of on-ground qualification process for two enabling technologies, a docking/retrieval compatible Dispenser and retractable Solar Panels design.
The current project stage foresees the mission and system design consolidation finalized to the achievement of the Critical Design Review within Q1 2027, with the target to kick start the operative phase within 2028.

8 ACKNOWLEDGEMENTS

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