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ORU-BOAS: Developing Reusable Building Blocks For Satellite Modularisation

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Abstract

In-Orbit Servicing (IOS) and In Space Manufacturing and Assembly (ISMA) present sustainable opportunities for the future of space exploration. In the past years, many efforts have been made to advance the building blocks required for these missions. In this paper, SENER Aeroespacial presents the concept of the project ORU-BOAS, a new approach in IOS and ISMA for the future of robotic missions.

The project aims to develop a standard module called ORU-BOAS (Orbital Replacement Unit-Based on Building Blocks for Advanced Assembly of Space Systems) for European Robotic scenarios. This module will allow the assembly, repair, or upgrade of space infrastructures directly in orbit for a wide range of missions, including life extension, refuelling, or de-orbiting. The ORU-BOAS will be able to hold a variety of payloads for such scenarios, providing a Standard Interface as the mechanical link, as well as electrical, data, and/or fluid transfer between modules. The Standard Interfaces will be based on previous developments made along the PERASPERA roadmap.

The purpose of the project is to define the most versatile ORU to bring a functional capacity to a bigger system. The ORU-BOAS is composed of an ORU platform, with all the common elements for integration of the payload; an ORU payload, depending on the mission of the module; and Standard Interfaces that allow interconnection of ORU-BOAS to other ORU-BOAS (to form larger space systems), satellites, space stations, or robotic arms among others.

ORU-BOAS provides the opportunity to address modularity and adaptability from the conception of the space system. It will allow customizable satellites while maintaining the standardization that allows robotic cooperation. SENER Aeroespacial leads the consortium including Thales Alenia Space, ISISPACE, EASN, and DLR. The roadmap of the project consists of developing a TRL 6 model by the end of 2024, which will then continue towards an In-Orbit Demonstration.

Keywords: ORU, In-Orbit Servicing, In Space Manufacturing and Assembly

Acronyms/Abbreviations

Data Handling System (DHS), End-Of-life (EOL), Electrical Power Subsystem (EPS), ElectroDynamic Tether (EDT), Force Torque Sensor (FTS), Hardware in the Loop (HIL), High-Power Energy Storage (HPES), In Orbit Demonstration (IOD), In-Orbit Servicing (IOS), In Space Manufacturing and Assembly (ISMA), International Space Station (ISS), Light-Weight-Robot (LWR), Launch and Early Operation (LEOP), sMart Integrated Avionics (MIA), Orbital Replacement Unit (ORU), Orbital Replacement Unit-Based on Building Blocks for Advanced Assembly of Space Systems (ORU-BOAS), Rendezvous and Docking (RVD), Standard Interface (SI), Standard Interface for Robotic Manipulation (SIROM), Thermal Control Subsystem (TCS).

1. Introduction

In this paper, the first results of the ORU-BOAS project are presented. This includes a market and economic study for the project, a description of the ORU designs for ORU-BOAS, their verification plan, and their in-orbit demonstration plan.

2. Context

In the frame of space exploration, versatility and adaptability are key aspects for new satellites. The development of sustainable, modular, flexible space infrastructures contributes to the protection of the future space ecosystem and increases the European space sector's competitiveness.

Space traffic management and space debris mitigation are topics that are gaining importance [1]. In this context, the maintainability and reusability of plug-and-play modules together with In-Orbit Servicing (IOS) and In Space Manufacturing and Assembly (ISMA) operations, overcome the problem of traditional disposable satellites that quickly become obsolete due to the market evolution.

The objective is, therefore, the creation of a space ecosystem in which modules are built and launched separately and system integration can be done in orbit. This configuration allows debris minimization through re-configuration, recycling, and reusability of existing structures, as well as their lifetime extension and repair. In addition, mission costs are reduced, increasing space accessibility.

In the ORU-BOAS project, a new approach in IOS and ISMA for the future of robotic missions is presented through the development of a standard module.

3. Project Overview

ORU-BOAS (Orbital Replacement Unit-Based on Building Blocks for Advanced Assembly of Space Systems) is a standard module for European Robotic Scenarios. This module is designed to assemble, repair, or upgrade space infrastructures directly in orbit for a wide range of missions, including life extension, refuelling, or de-orbiting. This ORU will include standard interfaces for interaction with other ORUs, satellite platforms, or robotics elements for mechanical, electrical, data, and/or fluid connection. It will also be prepared for plug-in of different types of payloads for each ORU to provide one specific service, or additional functionality to the target system.

The autonomy of the ORU is also a topic that is studied within the project. It is considered that in the future, transfer operations could even be done without the use of elements such as robotic arms.

The ORU-BOAS is composed of an ORU platform, with all the common elements independent of the payload, such as structure, DHS (Data Handling System), power, and thermal subsystem. In addition, it also contains the previously mentioned payload depending on the specific mission, and Standard Interfaces (SIs) to allow interconnection.

A simplified ORU is going to be used in the EROSS IOD project, which will demonstrate in-orbit servicing with a platform.

Therefore, three different ORU designs will be addressed within the project:

- ORU-BOAS. Non-autonomous version of the ORU-BOAS concept. Will serve as a baseline for the future autonomous ORU concept. Its focus will be based on IOS and ISMA through Berthing operations.
- ORU-AUT. Version implementing extended autonomy of the ORU-BOAS platform, with the capacity to perform Rendezvous and Docking operations autonomously.
- ORU-IOD. Simplified ORU-BOAS concept. Designed to comply with EROSS IOD mission requirements.

For this project, SENER Aeroespacial leads the consortium including Thales Alenia Space, ISISpace, EASN, and DLR. The roadmap of the project includes developing a TRL 6 model by the end of 2024, which will then continue towards an In-Orbit Demonstration.

The ORU-BOAS project is one of the operational grants of the 2021 call for the European Union's Horizon Europe Framework Programme (HORIZON).

4. Market and economic study

Within the ORU-BOAS project, two main mission concept scenarios have been identified: IOS and ISMA.

4.1 IOS

Within In-Orbit Servicing, two mission concepts can be found:

- 1st generation services: The client spacecraft is not prepared, so it is mainly focused on tugging and inspection.
- 2nd generation services: The client spacecraft is prepared for servicing missions through the inclusion of standard interfaces for mechanical, data, electrical, or fluid connection. Two approaches can be considered, berthing using a robotic arm, or rendezvous and docking (RVD). Both approaches can follow a cooperative or un-cooperative client scenario. However, for RVD higher autonomy and additional capabilities of the platform are needed, and in case of an un-cooperative scenario, the mission becomes highly complex.

Traditionally IOS has been focused on Geostationary Orbit (GEO) applications due to the higher costs of these missions and consequent higher revenue per satellite [2]. However, the ORU-BOAS approach significantly reduces costs based on COTS, standardization, and modularity. This allows targeting Low Earth Orbits (LEO) that present a bigger market volume and growth rate. The target of the IOS missions within ORU-BOAS are, consequently, prepared client spacecrafts that being on LEO, are usually of reduced size (<2000kg launch mass).

Considering the current state-of-the-art COTS market, the main IOS-identified cases are:

- Maintenance Services: Restoration of the Client spacecraft's capabilities.
- Upgrade Services: Increment or additions to the spacecraft's existing capabilities.
- Tugging and Towing services: De-orbiting manoeuvres, orbit correction, and orbit relocation.

4.2 ISMA

In-Space Manufacturing and Assembly operations include:

- Expandable/Changeable Space System Architecture: It helps overcome the size, shape, and rigidity constraints of the spacecraft components derived from launch conditions.
- Cellular Satellite Architecture: It is based on the disaggregation of space vehicles into cardinal pieces. Two kinds of systems can be created, homogeneous (each unit constitutes a complete stand-alone system) or heterogeneous (one individual satellite at which units are aggregated to increase its performance) [3], [4].
- Structures Assembly: this case only requires ORUs during the mission's first phase to perform RVD manoeuvres and actuate its SI.

The Cellular Satellite Architecture operations would fit better in LEO due to the most favourable environment for the COTS components. Meanwhile, the large Structures Assembly can apply to any orbit because COTS would only be required to work during the Beginning of Life.

4.3 Conclusions

As it has been summarized in Table 1, the study concludes that the more interesting markets for ORU-BOAS are found mainly in LEO. Applications in LEO include mostly maintenance operations in terms of IOS and Cellular architecture and Expandable/Changeable Space System Architecture in terms of ISMA. The assembly of big structures is also considered a good option, being in this case a suitable application regardless of the orbit.

Table 1. ORU-BOAS market and economic study output summary

Mission type	Mission scenario	Targeted orbits
IOS	Specially maintenance	LEO
ISMA	Cellular architecture & Expandable/Changeable Space System architecture	LEO
ISMA	Structures assembly	LEO, MEO, HEO, GEO, Moon

5. Design Description

As has been previously commented, three ORU configurations will be developed within the project: ORU-BOAS, ORU-IOD, and conceptual ORU-AUT.

6.1 ORU-BOAS

The ORU-BOAS module is composed of three main systems: platform, standard interfaces, and payloads. In Fig. 1 the ORU-BOAS prototype product tree is shown.

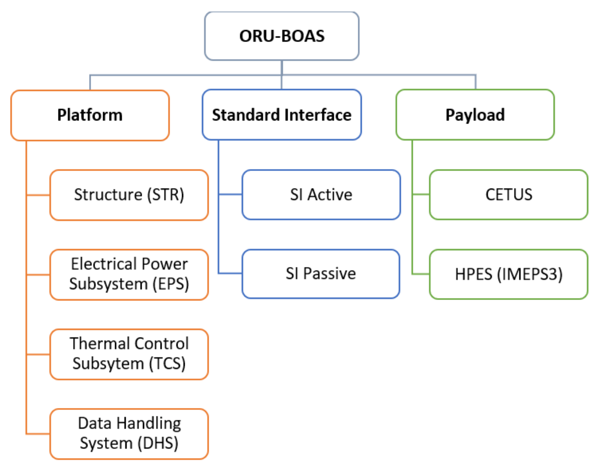

Fig. 1. ORU-BOAS Product tree

6.1.1 Platform Structure

For the ORU-BOAS platform, a 12U ISISPACE COTS structure is selected to fit the selected payloads (see Fig. 2). The choice of a 12U structures is based on a compromise between the following factors: available mass, volume fraction and involved costs, including launch. The modular structure is composed of detachable shear panels that allow access to all the spacecraft's avionics and electronics [5]. Customization of the module will be needed to allocate the standard interfaces.

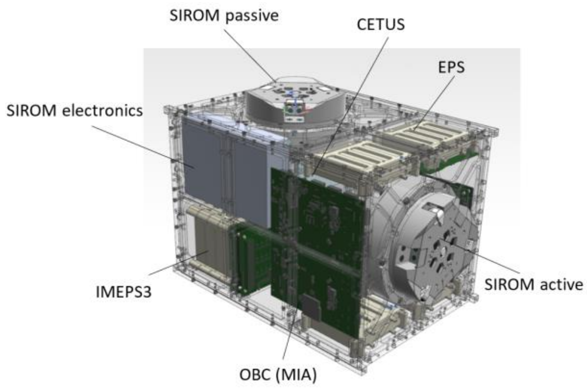

Fig. 2. ORU-BOAS Configuration (SENER)

6.1.2 Power Subsystem

The ORU-BOAS platform includes an ISISPACE Modular Electrical Power System (EPS) consisting of (see Fig. 3): Power Battery Unit (IPBU), Power Battery Pack (IPBP), Power Distribution Unit (IPDU), and a custom power distribution unit (to be studied if needed).

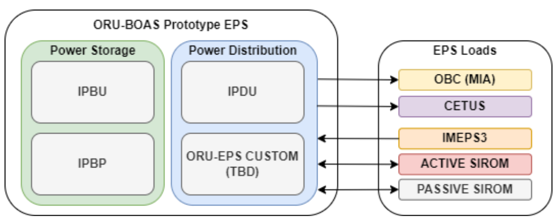

Fig. 3. ORU-BOAS Prototype EPS Configuration

6.1.3 Thermal Subsystem

The thermal control of ORU-BOAS will be mainly based on passive solutions for the platform and will provide the possibility of heaters implementation attached to the payload's structure on the sides. For simplicity, thermal tapes and coatings will be used for the thermal control.

For thermal monitoring, temperature sensors will be used.

6.1.4 MIA Data Handling System

The Data Handling System (DHS) is the main functionality provided by the on-board computer (OBC) embarked in the ORU-BOAS Platform. This OBC will be hosted in MIA, a custom execution platform developed by SENER which will be further developed and enhanced in the context of the ORU-BOAS project. The name MIA stands for sMart Integrated Avionics and is conceived as a multi-purpose, highly adaptable, and reusable execution platform for space and avionics applications. [6]

In this project, the MIA platform will provide a common framework and architecture for the different mission applications to coexist and be able to send data among each other. Each supported payload will communicate with the MIA platform (the OBC) through a particular interface either to provide data or to be commanded. In the same manner, the platform will have its particular services, including the ability to send/receive telemetry from external systems (i.e. the client or servicer units). The data bus incoming from the SIROM interface (when docked) will also be commandable and readable from the MIA platform.

In this context, the Data Handling System hosted in the MIA platform will have the ability to receive all the available sources of data at the ORU and forward them from one subsystem or interface to any other, translating protocols when needed. It will also implement some core OBC functionality internal to the unit, such as thermal and power control. To accomplish this, many apps will be needed (i.e. a separate app to manage every possible payload), which will be mission-dependent and updateable during any particular mission (see Fig. 4).

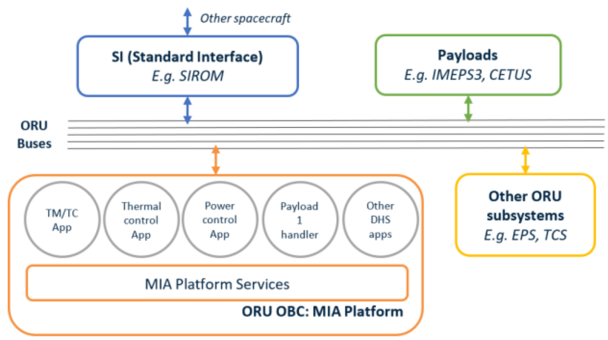

Fig. 4. MIA DHS applications and platform services within the global ORU-BOAS architecture

The main characteristic of the MIA platform is a layered and modular architecture, where different software layers are deployed on top of each other using standardized interfaces. This allows for great portability and reusability of components, as well as flexibility to adapt to the needs of different projects and systems. These layers include:

- Hardware layer
- Time and Space Partition layer (Hypervisor) (not included in ORU-BOAS)
- Operating System layer
- Abstraction layer
- Service layer
- Application layer

6.1.5 Standard Interface: SIROM E

SIROM (Standard Interface for Robotic Manipulation) is a robotic interface integrating mechanical, data, power, and thermal coupling in a single and compact electro-mechanism. As a standard interface, SIROM allows the coupling of payloads-to-manipulators, payloads-to-payloads, as well as payloads-to-spacecraft.

Since the start of the project SIROM with the PERASPERA call (H2020 OG5), the product has converged to the following families:

- Family E: Electrical power and data transfer. Offers an integrated version (X01) and a version with external electronics (X02).
- Family F: only for refuelling, without electrical connection between SIROMs. The electronics for this version are always external to the SIROM mechanism.
- Family G: includes the refuelling connector as well as electrical connection for data transfer. Power transference is not available. The electronics for this version are always external to the SIROM mechanism.

For ORU-BOAS, the family used is SIROM family E with external electronics (E01-X02) for easier distribution inside the ORU. In future applications, family F or G could also be used to provide refuelling functionality to the system (see Fig. 5).

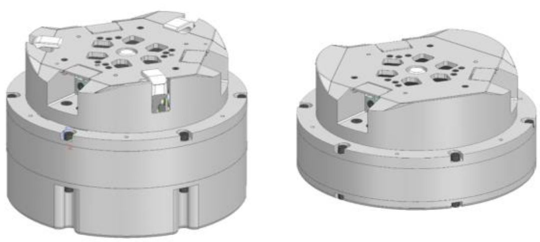

Fig. 5. SIROM E in Active X02 (left) and Passive (right) versions (SENER)

The main features of the SIROM mechanism include [7]:

- Androgynous design: Active versions capable of capturing either a Passive or an identical configuration.
- Cost-optimized: Passive version designed to reduce costs when multiple matting ports are needed to be installed.
- The latches of the Active SIROM are responsible for capturing (before contact) the Passive SIROM and establishing the required preload to clamp the assembly.
- High-capture range latches based on the docking system for ISS. The mechanism includes three capture hooks (or latches) evenly distributed 120º apart.
- Self-aligning capability after contact using guiding petals.
- Compact design including data, electrical, and/or fluid transfer capabilities. Mass <1,8kg.
- High-pressure fluid connector with minimal leakage (SIROM G or F).
- Deployable covers to protect the electronic components from electrostatic discharge (ESD).
- Motor-based actuation to perform 3 operations: mechanical capture, covers deployment, and connectors mating.

6.1.6 HPES - IMEPS3

The ORU-BOAS platform will incorporate the newest ISISPACE Modular EPS, the ISISPACE Modular EPS version 3 (IMEPS3). This new EPS is a continuation of the successful modular EPS line introduced in 2015. The IMEPS3 builds on the heritage of the IMEPS2 but supports voltages up to 50V and higher currents than its predecessor, resulting in much higher power transfers. It is intended for micro-satellite platforms, even though its small size allows it to be practical in nano-satellite platforms as well. The system would typically be employed for 32V or 48V EPS configurations. The IMEPS3 system has been designed to minimize failure propagation across boards. In addition, each board has maximized robustness through the selective use of redundancy, component oversizing and application of protection devices.

The IMEPS3 retains its heritage split of EPS functionalities into power conditioning, power storage and power distribution. The elements making up the IMEPS3 are the Power Conditioning Unit – High Power (PCU-HP), Power Battery Pack (PBP) and Power Distribution Unit – High Power (PDU-HP). The PCU-HP provides regulated voltage taken from solar panels using maximum power point tracking (MPPT). The PBP provides power storage in either 8-series (PBP-8S1P) or 12-series (PBP-12S1P) Li-Ion battery cell configurations (for 32V and 48V EPS respectively). The PDU-HP (see Fig. 6) provides power distribution to the platform in twelve separate protected power channels that can be selectively connected to the input rail voltage or to one of 3 buck regulated voltages. It also provides a portion of the CSKB header such that it can power currently existing CSKB subsystems as well, in addition to convenient connectors for interfacing with the system.

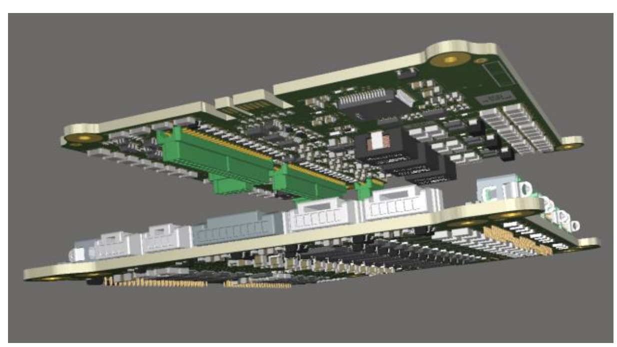

Fig. 6. IMEPS3 (ISISPACE)

What sets the IMEPS series apart from the competition is the high level of modularity and redundancy that is attained in a small package. Many of the board types can be combined without needing hardware modifications, allowing for late project alterations of the EPS configuration if necessary. Also, changes in a new generation of a platform family can easily extend or reduce the system to adapt to the novel power needs. Apart from extending, the same mechanism is used to provide redundancy, where the only difference is in the paralleling of the output power channels of many of the boards, a feat made possible by current backflow protection on all output channels. This allows a fully redundant electrical power supply to the loads to be realised with no hardware re-configuration.

Next to the IMEPS3, a solar array rotator mechanism is also being designed for the ORU-BOAS project. The rotator would allow to make the most of the available sunlight and feed this power into the high-power EPS. The solar tracking arrays together with the IMEPS3 will form the High-Power Energy Storage (HPES) payload of the ORU-BOAS platform.

6.1.7 Micro-CETUS

The Micro-CETUS is a reduced-volume deorbit device based on an ElectroDynamic Tether (EDT) to be used as payload of the ORU-BOAS platform.

The space sector, under the latent threat of the Kessler syndrome [8] is immersed in a transformation driven by the appearance of mega-constellations and “new space”, that can pose an important risk in LEO [9]. The new needs of the market create opportunities for both new and previously dismissed technologies. EDTs are one of them and, due to their passive and propellant-less character, they arise as a promising low-cost and simple solution for deorbiting space debris [10]. Despite it having been successfully demonstrated in space, the implementation of EDT into a reliable deorbiting system with reduced mass, power consumption, and volume still needs to be proved.

SENER, in collaboration with European partners through the E.T.PACK [11,12] and E.T.PACK-F projects, aims to develop and qualify a prototype of a 12U deorbit device based on a 500-meter EDT by 2025 (see Fig. 7). The E.T.PACK deorbit device prototype, which has undergone extensive testing (including functional, vibration, and communication tests), serves as the foundation for the Micro-CETUS deorbit device. Although both systems operate on the same principle, they differ significantly in terms of size (12U vs. approximately 2U), autonomy (E.T.PACK deorbit device designed for self-deorbiting, while Micro-CETUS is intended for deorbiting existing cooperative payloads), and the technology employed for electron emission.

The principle of operation of an EDT deorbit device is based on the Lorentz force. When a conductive tether moves at a relative velocity with respect to the Earth’s magnetic field, an electric field appears at the faraway plasma for an observer attached to the tether [13]. If there is good electrical contact between the tether and the plasma, this electric field produces a steady electrical current through the tether. This electrical current, in the presence of the external magnetic field, generates the Lorentz force that can be used as drag or thrust. In the case of deorbit devices, the system must be deployed in such a way that it produces a drag force, as depicted in Fig. 7. The electrons are collected passively by a bare tether and ejected back to the plasma by an electron emitter.

Fig. 7. Artistic representation of the E.T.PACK Deorbit Device during its lifetime (SENER)

6.2 ORU-IOD

The ORU-IOD module is a simplified version of ORU-BOAS that is composed of the same three main systems: platform, standard interfaces, and payloads (see Fig. 8).

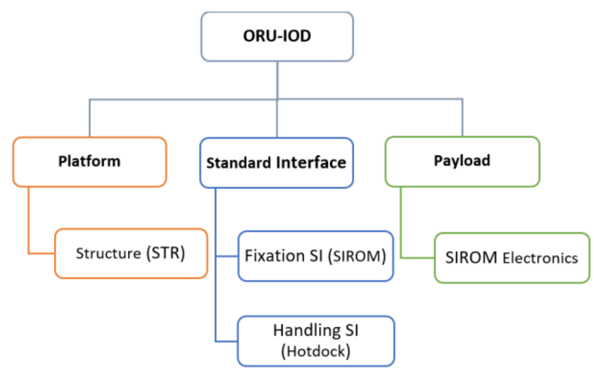

Fig. 8. ORU-IOD Product Tree

The ORU-IOD includes two SIs attached to an 8U structure, one passive, which will be Space Application’s Hotdock, and one active, which will be the SIROM E-X02 including its electronics. The passive SI will serve as the handling interface for interaction with the robotic arm. The active SI will be the fixation interface for attachment to the client and servicer sides (see Fig. 9).

Additionally, by including an active SIROM, the ORU-IOD can also be coupled to other ORU units with

SIROMs, allowing stacking of ORUs. In any case, this scenario would need to be operated from the robotic arm, since the ORU-IOD does not have autonomy to control or power the SIs.

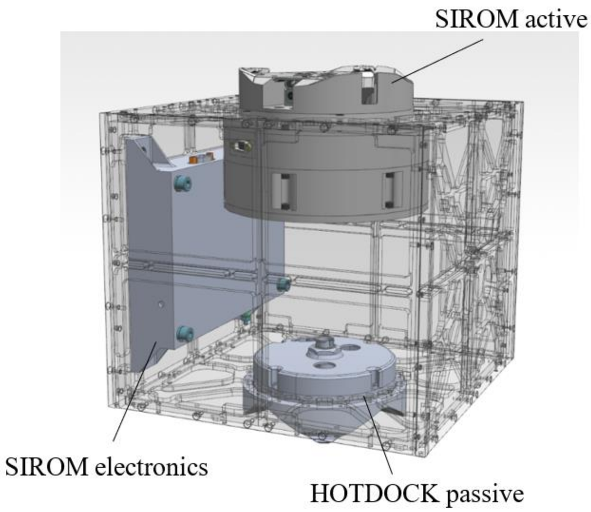

Fig. 9. ORU-IOD Configuration (SENER)

6.3 ORU-AUT

The ORU-AUT is a conceptual design of a scaled-up version of ORU-BOAS capable of performing RVD manoeuvres autonomously. For that, three additional subsystems are required:

- GNC Subsystem: For the attitude determination and control, absolute and relative navigation, and trajectory computation.
- TM&TC Subsystem: For Inter-satellite communication and Ground Communications.
- Propulsion Subsystem: To provide trajectory Control.

Due to the additional elements needed within the module, a 16U structure is selected.

6.3.1 GNC and Propulsion Subsystems

In terms of the navigation and control performance of the system, a GNSS solution is selected together with additional sensors to cover the whole range of accuracies up till the final approach.

For the final approach, the restrictions of the capture range of the SIROM are considered. As navigation sensors, therefore, a star-tracker technology is selected, which is a well-established solution within CubeSats. Two additional sensors are also selected, fine sun sensors and an IMU to provide high update rate measurements. Visual navigation is also included for the additional accuracy needed at close range.

In terms of attitude control, due to the tight pointing requirements established, reaction wheels are selected, which are simple and well-proven CubeSat used technology. This solution will need the use of a momentum-damping mechanism.

As for the thrusters, the technological solution to be implemented shall be based on Cold gas considering the required thrusts. This propulsion type has already been miniaturized and presents high levels of TRL on CubeSat platforms. A total of 12 thrusters are considered necessary to minimize torque errors. For their allocation, the maximum reduction of the residual torque and the minimum impingement distance to prevent the target's contamination by the thruster's plume are taken into account.

The control will be based on robust control strategies due to the increased noise found on miniaturized components used on CubeSats. Hence, the computed trajectories obtained by the optimal guidance will serve as reference trajectory, and the control will take charge of following them.

7 Verification and test plan

7.1 ORU-BOAS Validation Plan

The model philosophy for ORU-BOAS is to develop a TRL 4 Engineering Model (EM) prototype along the scope of the project while developing the conceptual design for a complete model.

The ORU-BOAS test campaign will be focused on demonstrating the capabilities of all subsystems individually and assembled.

A docking test is also foreseen for the ORU-BOAS EM. These tests will be performed by DLR at their facilities, which include robotic arms to simulate the rendezvous and docking of a target satellite.

7.2 Functional Tests at DLR

The facility at DLR is composed of a fixed-base Light-Weight-Robot (LWR) equipped with a force torque sensor at the end-effector as shown in Fig. 10. The force torque sensor at the end-effector can measure the external forces and torques acting in the basis frame (x-y-z). This represents the input to a model-based 0-g body dynamics. A passive double integrator provides a command to the robot, which mimics the 0-g condition on ground [14] and simulates the ORU-BOAS elements. As such, rendezvous manoeuvre in 0-g condition can be performed on-ground and the latching of the SIROM on the ORU-BOAS can also be evaluated.

The validation will be performed in two phases. Firstly, in a co-simulation framework developed within the ORU-BOAS project and later, on the on-ground test bench. For the co-simulation, an external dynamics engine simulates the plant, which is composed of the orbital elements of the ORU-BOAS. A middleware communicates with the dynamics engine and the control software prototyped in Matlab/Simulink.

Within the ORU-BOAS project, the functional tests will cover the following scenarios:

- Orbital mission scenario
- Simulation of on-ground test-bench
- On-ground test bench for Hardware in the loop (HIL) experiments

Fig. 10. Light-Weight -Robot with a force-torque sensor at the end effector (DLR)

7.2.1 Orbital Mission Scenario

For the validation, it will be firstly utilized a developed Co-simulation framework. The overall model will be the AOCS controller used for the rendezvous of the two ORU-BOAS. This will include the passivity-based AOCS feedback control algorithm, the online trajectory generator, and the required state machine handling. Also, the actuators model can be included in this block.

The model (developed in Simulink/Matlab) communicates with a middleware to an external dynamics engine (CoppeliaSim). The dynamics engine provides feedback on the state of the plant. For the control action appropriate sensors and actuator models can be integrated. The developed Co-simulation framework enables the functional validation of the AOCS controller, which will be later integrated into the on-ground tests bench for HIL experiments.

7.2.2 Simulation of on-ground test-bench

The previous validation considers the motion of the satellite in an absolute dynamics formulation. However, in the ORU-BOAS project, the relevant mission phase is related to the relative motion between two satellites. Thus, a novel formulation is exploited to use only one robotic arm, which simulates the relative dynamics between the two controlled ORUs. As such a second step of validation is required and the previous co-simulation software is augmented with new elements, i.e. the Relative dynamics computation block and the simulated LWR. Note that the relative dynamics are simulated with the motion of the LWR [15].

In addition, the absolute states will be reconstructed in software and the facility will replicate the forces (e.g., centrifugal forces), as they would be in the mission scenario. This is meant to ensure the dynamics consistency of the on-ground test bench with the orbital scenario.

7.2.3 *On-ground test-bench for HIL experiments*

After the AOCS control and the relative dynamics have been evaluated in Co-simulation, these elements will be exported and code will be generated for the real-time PC of the LWR. The Force Torque sensor (FTS) will now be included in the loop with the relative dynamics formulation block. In contrast with the previous validation stage, all the contact dynamics is taken into account as can be seen by the feedback available from the FTS sensor.

Further, the absolute states will be reconstructed for control input and also to visualize the motion, as will be in the mission scenario. Note that the LWR will be equipped with the ORU-BOAS elements provided by SENER with the corresponding control for latching/unlatching the SIROM interface.

7.3 ORU-IOD Validation Plan

The ORU-IOD model philosophy is driven by the in-orbit demonstration foreseen in the scope of EROSS-IOD. Within the current phase of the project (in parallel with ORU-BOAS), SENER will develop a TRL 6 EM. The test campaign will include environmental tests as well as fully functional tests.

For the next phases, QM (Qualification Model) and FM (Flight Model) units are foreseen.

8 In Orbit Demonstration

The ORU-IOD model is foreseen to be part of the In-Orbit Demonstration of the EROSS IOD project. The development of the In-Orbit Servicing systems will pave the way to a more sustainable exploitation of the space environment and the new emerging space market. The EROSS IOD mission, which has the scope to validate the technologies required to fulfil these challenging objectives, will include the transfer from the servicer to the client spacecraft of the ORU.

In the frame of the EROSS IOD mission, it will be possible to demonstrate these kinds of technologies exploiting the Servicer’s GNC/robotics capabilities that enable the In-orbit replacement of ORU payload (specific functional module that provides a service to the target satellite or space modular system) through Standard Interfaces. The SI allows the mechanical attachment, as well as functional (power, data, thermal, fluid) transfer between ORUs and the servicer/client satellite, the robotic arm, and the rest of the ORUs already integrating the modular system.

8.1 Conceptual Operation (ConOps)

The IOS scenario for IOD consists of 6 phases as can be seen in Fig. 11.

8.1.1 Phase 1: LEOP

During Launch and Early Operations, the IOD system actively reaches the nominal LEO for the mission through launcher propulsion. In this phase, the ORU is supported by the HRM and Standard Interface.

8.1.2 Phase 2: Commissioning

During this phase, deployments required on the servicer are performed. The IOD system is validated with an initial functional check, including robotics and propulsion systems. The SC correct insertion is verified after the orbit injection, the HRMs attached to the ORU are released and commissioning activities are completed. The main objectives are to establish an autonomous communication link with ground to send telemetry and to validate the status of the system.

8.1.3 Phase 3: Rendezvous and Berthing

This phase includes the rendezvous and berthing operation of the client spacecraft. During this phase of the IOD mission, the ORU remains attached to the servicer and switched off. The duration of this phase is 3 months.

8.1.4 Phase 4: Transfer Operation

The transfer operation starts after the RVD/servicing demonstration mission. The ORU is robotically transferred and connected to the dummy client, and the robotic arm is un-docked from the ORU. Phase 4 finishes with the docking confirmation from the client spacecraft.

8.1.5 Phase 5: ORU IOD Demonstration

Once the ORU is attached to the Client spacecraft, it can be operated during the mission extension duration (9 months). The dummy client will remain attached to the servicer, which provides attitude control.

During this mission extension, the ORU internal electronics can be switched on to perform a basic test of the SI. The dummy client shall provide power to the ORU using the active SIROM placed in the platform. The electronics of the androgynous SIROM inside the ORU will be active.

At this point, the client will be able to request basic telemetry to the SI on the ORU, which will report the status (Stand-by, since the SI is behaving as passive). This will validate the low-power transfer and CAN bus connection between the SIs. For a more complete test, the androgynous SIROM can be commanded to a closed position, always redundant with the active SIROM, which will remain closed during the whole demonstration. After validating the status of the SI through telemetry, it will be opened again to go back to the original position.

8.1.2 Phase 6: ORU-IOD End-Of-life (EOL)

At the end of the mission, the servicer/dummy client composite performs a controlled re-entry.

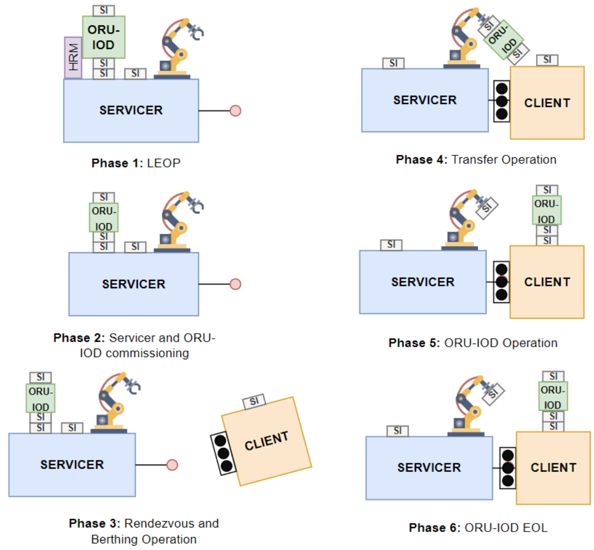

Fig. 11. Conceptual Operations of ORU-IOD IOS

9 Conclusions

The use of plug-and-play modules together with IOS and ISMA operations, is considered key to achieving a sustainable future space ecosystem. In this context, the ORU-BOAS project aims to develop a standard module including an ORU platform, payloads, and SIs. This module is designed to assemble, repair, or upgrade space infrastructures directly in orbit for a wide range of missions, including life extension, refuelling, and de-orbiting.

Three ORU designs are addressed in the project. Two of them are the ORU-BOAS and the ORU-AUT, being the ORU-AUT an ORU-BOAS version with the capacity to perform Rendezvous and Docking operations autonomously. Additionally, a simplified version of ORU-BOAS is presented, ORU-IOD, which is foreseen to be integrated into an in-orbit demonstration mission within the EROSS IOD project.

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