engineering proceedings

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Proceeding Paper

Prototyping and Testing System Interconnect Standard Interoperable for Orbital Services †

Raphaël Boissonnade [1,*], Come Berger [1], Montserrat Diaz-Carrasco [2], Ana Luisa Ruiz-Perez [2], Mathieu Deremetz [3], Pierre Letier [3], Thomas A. Schervan [4], Christopher Zeis [4], Mehmed Yüksel [5], Wiebke Brinkmann [5], Utku Akinci [5], Fabien Marty [6] and Matisse Briand [6]

[1] Thales Alenia Space France, 5 Allée des Gabians–BP 99, 06156 Cannes, France; come.berger@thalesaleniaspace.com
[2] SENER Aerospacial, Avenida de Zugazarte, 56, 48930 Las Arenas, Spain; montserrat.diaz@aeroespacial.sener (M.D.-C.); analuisa.ruiz@aeroespacial.sener (A.L.R.-P.)
[3] Space Applications Services, Leuvensesteenweg 325, 1932 Sint-Stevens-Woluwe, Belgium; mathieu.deremetz@spaceapplications.com (M.D.); pierre.letier@spaceapplications.com (P.L.)
[4] iBOSS GmbH, Dennewartstrasse 25-27, 52068 Aachen, Germany; thomas@iboss.space (T.A.S.); christopher.zeis@iboss.space (C.Z.)
[5] Robotics Innovation Center (RIC), German Reseach Center for Artificial Intelligence DFKI GmbH, Robert-Hooke-Str. 1, 28357 Bremen, Germany; mehmed.yueksel@dfki.de (M.Y.); wiebke.brinkmann@dfki.de (W.B.); utku.akinci@dfki.de (U.A.)
[6] In Extenso Innovation Croissance, 2000 Route des Lucioles, Les Algorithmes, Thalès B, 06410 Biot, France; fabien.marty@inextenso-innovation.fr (F.M.); matisse.briand@inextenso-innovation.fr (M.B.)
* Correspondence: raphael.boissonnade@thalesaleniaspace.com

[†] Presented at the 15th EASN International Conference, Madrid, Spain, 14–17 October 2025.

Abstract

The orbital space ecosystem is undergoing significant change, with numerous initiatives focused on in-orbit services, assembly, and manufacturing. These initiatives are being developed globally, with ongoing studies in America, Asia, and Europe. As these technologies evolve, questions arise about their compatibility and interoperability, especially for long-term in-orbit operations. The Space USB project addresses these challenges by aiming to connect European partners involved in the emerging interconnection systems market for in-orbit services. Its goal is to improve the compatibility and interoperability of these systems across Europe, with perspectives for broader international application. As part of this project, a prototype has been developed to connect with the interconnection systems of three European partners. A test campaign was conducted to assess the prototype's functionality, using a robotic system.

Keywords: SI; OOS; OSAM; ISAM; standard; interoperability

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Academic Editors: Spiros Pantelakis, Andreas Strohmayer and Gustavo Alonso

Published: 15 May 2026

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1. Introduction

In today's space ecosystem, Standard Interconnects (SIs) are essential for enabling operations in in-orbit servicing (IOS) and In-Space Assembly and Manufacturing (ISAM). These robotic operations rely on standardized interfaces that provide electrical, mechanical, and data connections, ensuring modularity and reparability. Several solutions have been proposed to address these needs, particularly within the realm of robotic servicing. In Europe, three key players are at the forefront of developing SI technology: Sener with SIROM, Space Applications Services with HOTDOCK, and iBOSS with iSSI®.

The Space USB project, led by Thales Alenia France, aims to establish a unified standard that meets the European requirements for IOS and ISAM robotic applications.

https://doi.org/10.3390/engproc2026133194

This initiative involves collaboration among the three aforementioned suppliers. An Advisory Board has also been engaged to provide valuable feedback from industry stakeholders, ensuring a balanced approach that aligns desired capabilities with the current state of the art.

Over the course of two years, the project focused on designing and testing a cohesive solution that would address the needs of large system integrators. This paper outlines the work conducted across the project focusing on the last part, the test campaign. The outcomes of this project are intended to be a significant step forward in the European space future on orbit servicing, contributing to the development of a future environment characterized by modularity, sustainability, and interoperability.

2. Space USB Project Approach

2.1. State of the Art

Figure 1 below introduce SIROM (1), HOTDOCK (2), iSSI® (3). They are modular interfaces that can function as both active and passive to electrically interconnect devices by supporting power and data transfer; all aspects are condensate into the CPI (4) interface resulting in the concatenation of the different features within the Space USB project initiative.

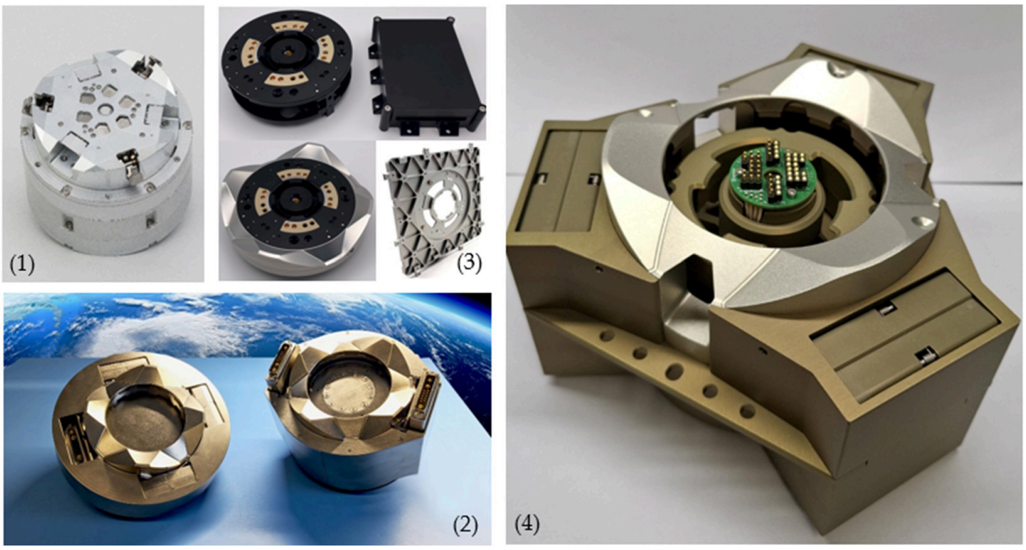

Figure 1. (**1**) SIROM E Active; (**2**) HOTDOCK passive and active; (**3**) iSSI baseline, with form-fit and integral design; (**4**) CPI from Space USB project.

A survey, conducted by DFKI [1], of 97 global interfaces led to the selection of 55 for further analysis, focusing on key characteristics such as redundancy, reliability, and performance. The results guided the development of the first specification for SIs.

2.2. Standard Specification

The Standard Specification was developed to outline technical requirements for SIs, targeting robotic operations involving mechanical connections, electrical power, and data transfer. The standard is intended to evolve as the technology matures, offering flexibility for future-use cases and customization for mission-specific needs.

2.3. Implementation

The second phase of the project focuses on creating a common passive interface (CPI), a unified interface model that provides passive connectivity to all three target SIs. This design eliminates the need for adaptors between the servicer and client by incorporating features compatible with all three interfaces.

2.4. Design

The CPI integrates mechanical features from each SI, addressing different symmetry axes in HOTDOCK (120°), iSSI (90°), and SIROM (120°). It combines these features into a single design with locking mechanisms that accommodate all three interfaces [2,3]. The mechanical system includes a mounting plate with alignment pins for various mounting configurations. The electrical design ensures compatibility between the interfaces, maintaining the existing subsystems for each SI and preventing conflicts.

3. Definition of Test Requirements and Objectives

This chapter describes the development and testing (based on similar exercises [4]) of the CPI under the Space USB project. The goal is to achieve these connections autonomously, without human assistance, using robotic or mechatronic systems controlled in a closed or open loop.

The project aims to "remove" human direct involvement from in-orbit operations, ensuring that the system can perform tasks like establishing electrical connections automatically. The key challenge addressed is how to validate an electrical connection process in space without human intervention. To test this, a robotic test bench (specifically the ROBY bench) was chosen to simulate operational constraints and validate the prototype. The focus of the tests is on ensuring electrical continuity through the connection, regardless of the specific signal type, as the primary task of the connector is simply to establish the connection. While the nature of the signals passing through the connection (e.g., power, CAN, Ethernet) will be important later, the current priority is to confirm that the system allows for uninterrupted electrical conduction. The goal of the testing campaign is to reach a technology readiness level (TRL) between TRL4 and TRL5, indicating significant progress toward operational use.

4. Test Campaign

4.1. Robotic Test Bench

The goal is to functionally validate a prototype via robotic interconnection, avoiding dependency on specific robotic solutions. Robotics enhances safety, efficiency, and repeatability in complex environments (e.g., space), reducing human errors and biases while improving traceability, precision, and test completeness. The ROBY bench digitizes scenarios, enabling real-time data analysis (trajectories, forces) and early fault detection. However, robots lack human adaptability—intuition, spontaneity, and contextual problem-solving—potentially limiting responses to unforeseen anomalies. While automation strengthens reproducibility and standardization, it risks overlooking nuanced real-world scenarios. Robotic benches like ROBY bridge theory and practice, validating modular interfaces for missions (e.g., Space USB), but human expertise remains critical for ambiguous or innovative challenges.

4.2. Test Configuration Trade-Off

For Space USB, a single test bench (one ROBY arm) was chosen over multiple benches to ensure standardization, consistency, and reduced calibration efforts. While parallel testing could speed validation, cost, precision, and low failure risk favored this approach—prioritizing reproducibility over throughput, aligned with space-project rigor.

4.3. Test Plan

The section provides an overview of the test procedures, explaining the conventions and classifications used in the test campaign for Space USB. It introduces two main configurations—electrical and mechanical—which are crucial for validating the interconnection systems.

Three configurations—(2), (3), and (4)—are defined (refer to Figure 2 below) for mechanical capture, primarily based on previous work by the DFKI partner in the PERIOD project [5]. These configurations test mechanical interfaces for alignment, locking, and electrical connectivity under various conditions, such as misalignment or gaps. These tests are considered at lower priority because they extend beyond the scope of the Space USB project, which focuses on validating the core functionality of the prototype. An additional full test of this ORU configuration is optional (5).

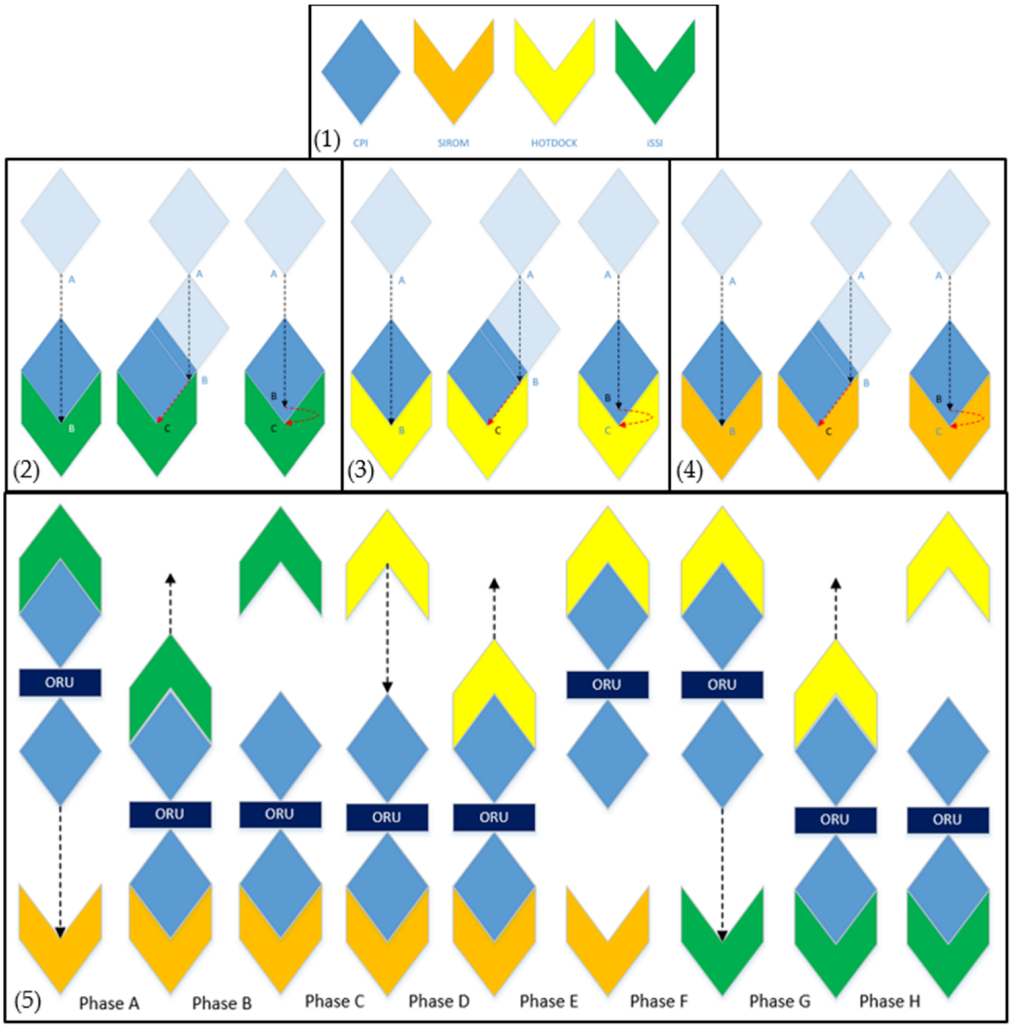

Figure 2. Test configurations: (**1**) conventions; (**2**) iSSI standard tests; (**3**) HOTDOCK standard tests; (**4**) SIROM standard tests; (**5**) ORU test sequence (optional).

4.4. GSE Architecture and Set-Up

The arm will move towards a programmed trajectory until contact is made (refer to Table 1). The robotic arm will carry a common passive interface (CPI), while the fixed support will hold three active interconnection systems. The idea is to use a modular support system that can easily switch between active interconnection systems and the CPI, providing flexibility and reducing the risk during testing.

Table 1. Test matrix.

Robot Refrence Position (*)	SIROM	HOTDOCK	iSSI
P0	X = 900, Y = −160, Z = 1500 Q1 = 0, Q2 = 0, Q3 = 1, Q4 = 0		
P1	X = 1045, Y = −450, Z = 1500 Q1 = 0, Q2 = 0.113, Q3 = 0.994, Q4 = 0	X = 1108, Y = −158 Z = 1500 Q1 = 0, Q2 = −0.91 Q3 = 0.415, Q4 = 0	X = 1045, Y = 142 Z = 1500 Q1 = 0, Q2 = 0.423 Q3 = 0.906, Q4 = 0
P2	X = 1045, Y = −450, Z = 1085 Q1 = 0, Q2 = 0.113 Q3 = 0.994, Q4 = 0	X = 1108, Y = −158, Z = 1100 Q1 = 0, Q2 = −0.91 Q3 = 0.415, Q4 = 0	X = 1045, Y = 142 Z = 1115 Q1 = 0, Q2 = 0.423 Q3 = 0.906, Q4 = 0

* X, Y, Z, in mm; Q1, Q2, Q3, Q4, in the robot reference frame.

The test bench is used as a flexible interface system, allowing for reusing, adapting, or creating new means based on prior experience with similar interconnection systems. The main challenge is the mechanical set-up for attaching either the passive interface or the active interconnection systems to the robotic arm, considering the need for electrical connections, especially with active systems that require access to multiple connectors.

The support for these interconnection systems (refer to Figure 3 below) will need to accommodate varying sizes and masses, with adjustability to ensure all components can be positioned correctly. This includes ensuring that the contact reference planes for all interfaces are at the same elevation, simplifying the movement and approach programming.

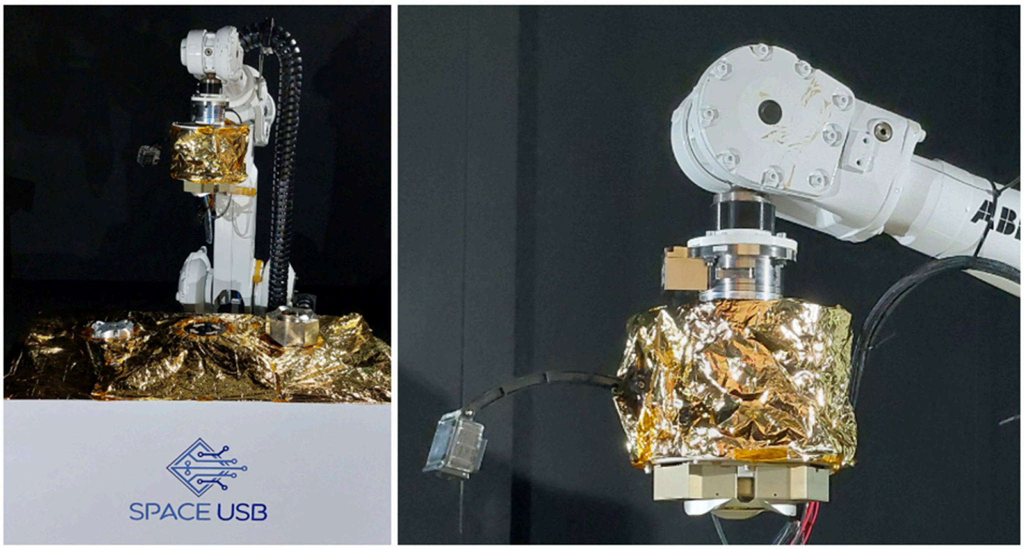

Figure 3. Test bench configuration for Space USB prototype test.

Standardizing the approach phase (contact and locking) will streamline the validation and testing process, ensuring a single approach trajectory regardless of the interface type. Tests will also consider constraints related to "On-Orbit Service" (OOS), with plans to reuse equipment from previous projects, adapting it as necessary for the current test requirements. The key challenge here is managing the increased distance between the robotic arm and the fixed table in the OOS configuration, which could impact the lifting capacities of the robotic arm. However, the study suggests that the last 10 cm of approach between the contact surfaces is critical for test success, and the robotic arm's capacity can handle this without any dimensional constraints.

The campaign focuses on creating a flexible, adaptable testing environment where the robotic arm can interact with different devices under test, using standardized approaches to simplify testing and reduce risks.

4.5. Evaluation Method

General definition acceptance criteria define what constitutes a pass or failure for the prototype in each test case [6]. This might include quantitative metrics (e.g., performance benchmarks, load capacity) and qualitative feedback (e.g., usability satisfaction).

Defining acceptance criteria for the Space USB prototype test is challenging because prototypes typically focus on essential functionalities, rather than fully quantitative benchmarks. Instead of strict performance-based criteria, a more qualitative, needs-oriented approach is suggested, considering the product's intended uses.

At this stage, just after the prototype design phase, it is too early to make definitive judgments on potential limitations based solely on theoretical concepts. The test plan should remain flexible to either expand on results with further measurements or adjust if unexpected results challenge key design choices. Prototyping inherently requires adaptable acceptance criteria that prioritize validating design and concept decisions over performance benchmarking.

This flexible, iterative approach aligns with the test sequencing and prioritization methodology, which is visualized in a test matrix. Further details on this methodology will be discussed in a dedicated section. The acceptance criteria are all specified as much as possible in the description of each of the tests which can be found in the chapters below.

4.6. Example of Test Results

The results (due to the confidential nature of the benchmark and its evaluation, only selected results are shown in this paper for illustration purposes only) (refer to Table 2 below) of the tests cover different aspects. Reports are issued with all the collected data (test sequences performed, and data recorded by the test benches in digital, graphical, or raw form, depending on the sources, referenced frame). These data are transmitted to the partners for detailed analysis, which will feed into the final deliverable of the Space USB study (Test Results and Development Plan).

Table 2. Tests results.

Test	SIROM	HOTDOCK	iSSI
Direct Coupling	Passed	Passed	Passed
Axial Bias *	Passed	Passed	Passed
Angular Bias *	Passed	Passed	Passed

* Sensitivity test ran.

The data includes [7] the robotic bench measurements (reference UTC time, robotic tool motion within the test bench, relative motion wrt another robotic or room's frame); [8] the sensor readings of force/torque during the motion, contact and latching; [9] additional details of each specific trajectory (intermediate points, movement speed, timing, etc.) or of the robotic arm states (joint angles, motor statuses, internal timing, . . .). In addition, electrical measurements are also presented to verify proper connection (impedance measurements or results from data transmission tests).

5. Conclusions and Way Forward

In future trials, we could imagine delving deeper into the aspects of robotic autonomy development and validation. Robotic environments can replicate a wide variety of connection scenarios, allowing for the training and testing of autonomy algorithms (control, learning, error correction) under realistic conditions, and strengthening them against the challenges of space. By simulating numerous scenarios, robotic test benches accelerate machine learning and the development of robust action policies for critical operations such as docking, assembly, or orbital maintenance. An entirely automated system may give an illusion of safety or completeness: the validity of the results then depends on the ability to design comprehensive scenarios and maintain human oversight to monitor and reinterpret if necessary. This will be something to watch for in the case of future trials.

The future of satellite product and interface standardization is closely linked to both technological advancements and the global movement toward sustainable space operations. Going forward, the focus will be on promoting openness, interoperability, and sustainability. Key next steps involve adopting new technologies, developing collaborative policies, and fostering a circular space economy. These efforts aim to expand participation in sustainable space initiatives and reduce the environmental impact of space activities.

Currently, different satellite operators and manufacturers have developed their own interfaces for tasks such as deorbiting, rendezvous, and servicing, resulting in a fragmented landscape. Integrating various subsystems—like navigation aids, mechanical capture mechanisms, and communication protocols—into a single, unified standard presents significant technical challenges and requires extensive systems engineering expertise. The lack of standardized criteria and the variation in licensing requirements across jurisdictions further complicate the implementation of universal standards for satellite services. Space USB is the first step ever taken towards interoperability in space, so indirect interoperability can still be considered a success.

The main barriers include deeply ingrained proprietary practices, technical and functional diversity, regulatory uncertainty, economic risks, and the need for rigorous verification processes. Addressing these challenges will require strong collaboration across the industry, active engagement from governments and regulators, and continued investment in open, standardized frameworks. In-orbit servicing and debris removal missions, such as those planned by the European Commission, ESA, and commercial providers, will provide valuable practical experience and demonstrate the benefits of standardization.

Author Contributions: R.B., writing—original draft preparation. C.B., M.D.-C., A.L.R.-P., M.D., P.L., T.A.S., C.Z., M.Y., W.B., U.A., F.M., M.B., Validation. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been carried out within the project Space USB, which is funded by the European Union within the frame of the Horizon Europe Work program under HORIZON-CL4-2023-SPACE-01-12: Future Space Ecosystem and Enabling Technologies with grant agreement No. 101135215.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results. The authors declare no conflicts of interest.

References

1. Yüksel, M.; Brinkmann, W.; Utku, A.; Boissonnade, R.; Diaz-Carrasco, M.; Perez, A.R.; Schervan, T.A.; Zeis, C.; Letier, P.; Deremetz, M.; et al. Towards Sustainable Space Ecosystem: A State of the Art Survey on Standardizing Spacecraft Service Interfaces for Modular Orbital Systems. In Proceedings of the IAC 2025 Proceedings, (IAC-2025), Sydney, NSW, Australia, 29 September–3 October 2025.
2. Deremetz, M. Design of an interoperable interface for in-space operations and services of modular spacecraft. In Proceedings of the IAC 2025 Proceedings, IAC-25-D1.1.4x98083, Sydney, Australia, 29 September–3 October 2025.
3. Díaz-Carrasco, M. Space USB: Defining an enhanced standardization level for Space Standard Interconnects. In Proceedings of the 18th Symposium on Advanced Space Technologies in Robotics and Automation (ASTRA), Leiden, The Netherlands, 7–9 October 2025.
4. Brinkmann, W. A Standard Interconnect Benchmark for a European In-orbit Services, Manufacturing and Assembly (ISMA) Demonstrator. In Proceedings of the IAC 2022 Proceedings, (IAC-2022), Paris, France, 18–22 September 2022.
5. Yüksel, M. A Methodology for Electromechanical Evaluation of Multifunctional Interconnect for On-Orbit Servicing Demonstration. Available online: https://period-h2020.eu/sites/default/files/2022-09/PERIOD_Electricat_evaluation-SI_Benchmark-MYueksel.pdf (accessed on 2 June 2022).
6. NASA. Technology Readiness Assessment: Best Practices Guide. Available online: https://science.nasa.gov/wp-content/uploads/2023/11/tra-tech-showcase-2023-beauchamp-copy.pdf (accessed on 11 January 2023).
7. Andiappane, S.; Dubanchet, V. Validation of the I3DS Suite of sensors for orbital and planetary missions. In Proceedings of the 69th International Astronautical Congress (IAC), I3DS_IAC_2018, Bremen, Germany, 1–5 October 2018.
8. Dubanchet, V.; Andiappane, S.; Mora Portela, D.; Rodríguez Reina, A.; Suatoni, M. Experimental assessment of I3DS performances: A suite of sensors for on-orbit rendezvous. In Proceedings of the 70th International Astronautical Congress (IAC), I3DS_IAC_2019, Washington, DC, USA, 21–25 October 2019.
9. Dubanchet, V.; Bejar Romero, J.; Paraskevas, I.; Lopez Negro, P.; Cuffolo, A.; Maye, F.; Reinab, A.R.; Manriqueb, P.R.; Alonsob, M.; Dezainde, S.T.; et al. EROSS project–Ground validation of an autonomous GNC architecture towards future European servicing missions. In Proceedings of the 72th International Astronautical Congress (IAC), EROSS_IAC_2021, Dubai, United Arab Emirates, 25–29 October 2021.

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https://doi.org/10.3390/engproc2026133194