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# The Deployment Tests of the ESA-Dragliner in the Zero-G Lab

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## *ABSTRACT*

**The ESA-Dragliner project, led by the Finnish Meteorological Institute, in collaboration with Aurora Propulsion Technologies, GRADEL, and the University of Luxembourg, aims to develop, manufacture, assemble, and test a breadboard model of a tether-based deorbiting system for Low Earth Orbit (LEO) telecommunication satellites. The selected technology for the Dragliner project is the PB (Plasma Brake) microtether, an innovative propellant-free solution designed to efficiently deorbit satellites in LEO. Utilizing Coulomb drag, this system is lightweight, compact,**

**requires minimal power, and operates autonomously without drawing resources from the host satellite during deorbiting. The objective of this project is to design, manufacture, assemble, and test a Breadboard Model (BBM) of a Tether-based deorbiting system for Low-Earth Orbit Satcoms. Additionally, the project aims to analyze and optimize a deorbiting strategy utilizing this technology to achieve successful deorbiting of a LEO spacecraft of maximum 250 kg down to a maximum altitude of 400 km, within 2 years from 850 km original altitude, or 100 days from 550 km original altitude. This paper explains the plans of the deployment tests of the Dragliner project in the Zero-G Lab of SnT-University of Luxembourg.**

**Keywords:** Space Debris Removal; Space Tethers; Low Earth Orbit; Coulomb Drag

# 1 Introduction

The Dragliner, a European Space Agency (ESA) funded project, aims to design, manufacture, assemble, and test a breadboard model of a tether-based deorbiting system for telecommunication satellites in LEO. Led by the Finnish Meteorological Institute, the consortium includes Aurora Propulsion Technologies, GRADEL, and the University of Luxembourg. The chosen technology, the Plasma Brake microtether, offers a propellantless and efficient deorbiting solution by utilizing Coulomb drag [1]. This lightweight and compact system requires minimal power, operates autonomously, and does not rely on resources from the host satellite during deorbiting. The deployment of the tether presents several challenges, as historically, tethers in space have been very difficult to operate. Therefore, the system's reliability must be exceptionally high. In the event of a deorbiting failure, it is crucial to minimize the space debris hazard, ensuring that any debris parts are trackable [2–9].

The primary objective of the project is to elevate the Technology Readiness Level (TRL) of the satcom PB to level 4. This involves selecting a deployment strategy, configuring the deorbit system, choosing the tether material, finalizing the tether geometry, conducting simulations for deorbiting performance and tether dynamics, testing the tether material in zero-friction laboratory conditions, and designing the initial breadboard model of the most critical components of the deorbit system, including the main tether reels, the main tether itself, and the supporting tape tether and its housing.

When a high-voltage charged tether is introduced into streaming space plasma, its electric field disrupts the flow of plasma ions, extracting momentum from the plasma flow. This effect is known as electrostatic Coulomb drag. One application of this phenomenon is the electric solar wind sail, which utilizes the solar wind to generate interplanetary propulsion [10]. Another application is the PB, which employs the ionospheric ram flow to generate Coulomb drag, gradually deorbiting the satellite. Both positive and negative tether polarities can be used, as they result in a transfer of momentum, although the plasma physics involved differ. However, there are compelling reasons to select positive polarity in the case of the solar wind and negative polarity in the case of the ionospheric PB [11], [12].

The module deploys a tether approximately 5 km in length, composed of four conductive wires with diameters ranging from 25 to 50 micrometers. In addition to the aluminum wires used in previous Cubesat projects, we have evaluated the use of more advanced carbon fiber composite wires. To ensure redundancy and prevent the tether from breaking even if micrometeoroids damage some of its wires, a multi-wire tether structure is employed. The tether is deployed from a storage reel and is maintained at a voltage of -1 kV by an onboard high-voltage source. A metal-coated tape tether, approximately tens of meters long, serves as an electron-gathering surface to close the current loop [13]. Alternatively, conducting parts of the debris satellite could also be utilized for electron gathering. The power consumption of the system is approximately 2.2W.

The Deorbit System comprises two main units: the Base Unit and the Remote Unit. The Base Unit, attached to the carrying satellite, includes the Release Mechanism, as well as the Satellite Mechanical and

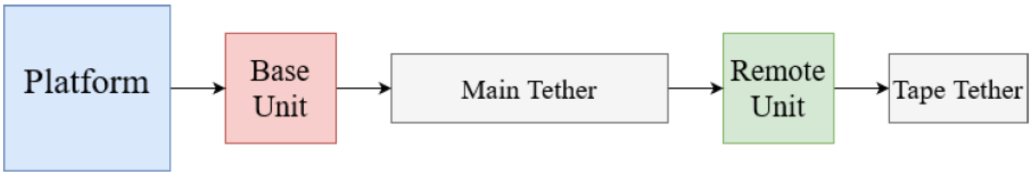

**Fig. 1 The high-level block diagram**

Electrical Interfaces. The Remote Unit contains the Tape Tether Assembly, the Main Tether Assembly, the Electrical Power System (High Voltage System, Battery, Solar Panels), Control Electronics (including Deployment Sensors).

The most critical functions to be demonstrated with the Breadboard Model will be determined during the project but will include at least the following:

- One critical function to be demonstrated with the Breadboard Model is measuring the force required to deploy the Main Tether from its reel and verifying that it is smaller than the gravity gradient force provided by the chosen End Mass and the selected length of the Tape Tether.
- Another crucial function to be demonstrated with the Breadboard Model is demonstrating the opening of the Main Tether and verifying its compatibility with the chosen ejection mechanism.

Although the fully deployed system is relatively large (current estimates suggest a length of around 5 km), it is very lightweight, occupies minimal volume at the carrying satellite's end, and requires little power. Additionally, the system operates autonomously and does not rely on any resources from the carrying satellite during deorbiting. Despite its significant size, the system poses no threat to other assets in space due to the extremely low mass of the tether itself. In the event of a potential impact with another satellite, any damage caused by the microtether would be similar to that caused by micrometeoroids in LEO conditions. It's important to differentiate the PB microtether from the more well-known electrodynamic tether. The PB microtether is much thinner and utilizes electrostatic drag instead of magnetic forces. The project will showcase the current deployment strategy, design trade-offs, material selections, critical components, and simulation results.

The high-level block diagram of the deployment scenario of the tethers can be seen from Fig. 1. Firstly, the Main Tether, which is approximately 5 km, will be deployed, and then the Tape Tether, which is approximately tens of meters, will be deployed. The physical architecture of the Deorbit System and the interfaces to the Platform are described in Fig. 2 (the drawing is not in scale). During the deployment tests in the Zero-G Lab, only the deployment test of the Main Tether will be realized. The Base Unit serves as the end mass will be located on top of the floating platforms [14], and the Base Unit will behave as if it is free-floating in space during the deployment. Due to the volume limitations of the Zero-G Lab, the Main Tether will not be fully released at their full length.

The paper is organized as follows; the Section-II conducts the detail of the Zero-G Lab, the facility where the tests will be conducted. Section-III explains main tether dynamical deployment test. Section-IV mentions about the future plans. Finally, Section-V gives the conclusion of the paper.

## 2 The Zero-G Lab

Different facilities worldwide employ a variety of technologies and methods to simulate in-orbit operations on the ground for various orbital scenarios, replicating microgravity across different degrees of freedom (DoF). While some facilities utilize robotic arms mounted on rails to achieve 6-DoF, they do not simulate orbital mechanics in microgravity. Others utilize pneumatic floating platforms with air

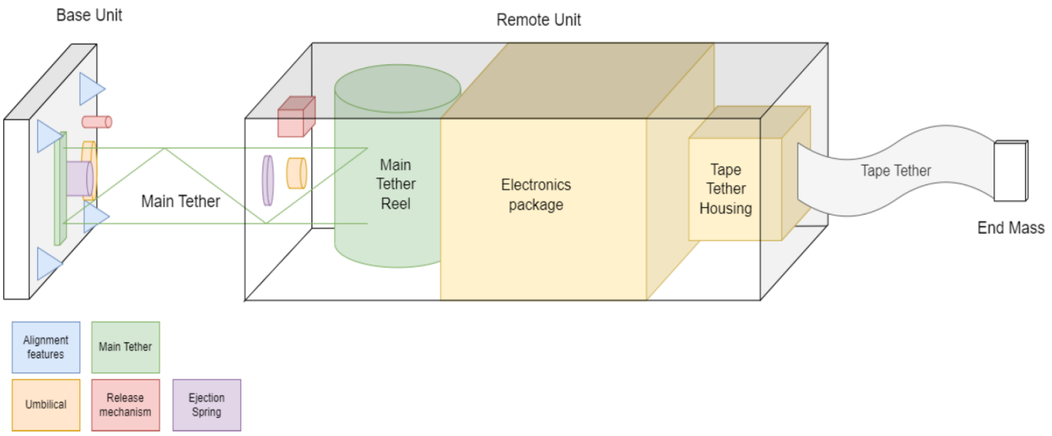

**Fig. 2 Physical architecture of Dragliner**

bearings and nozzles on a flat surface (such as a granite table or flat floor) to simulate microgravity across at least 3-DoF [15–21].

The Zero-G Lab at the University of Luxembourg, as shown in Fig. 3 and Fig. 4, features an advanced mechatronic system known as a floating platform. This platform is essential for conducting research on satellite operations in space. Specifically designed to replicate the microgravity conditions of space, the floating platform enables the testing and validation of different space technologies and systems [22, 23].

The floating platform consists of several components, such as a power source, computation board, solenoid valves, air-bearings, pressure tank, and sensors. Among these components, the air-bearings are particularly important for its functioning. These pneumatic elements release high-pressure air onto the epoxy floor, generating an almost frictionless environment. This setup simulates microgravity by eliminating mechanical contact between the air-bearing mounted beneath the platform and the floor. The floating platform is constructed using additive manufacturing and carbon-fiber materials. This construction not only extends experiment duration by enabling emulation of complex scenarios but also helps mitigate issues arising from mechanical disturbances caused by uneven flooring.

Incorporated into the Robot Operating System (ROS) network of the Zero-G Lab, the floating platform ensures that all data it produces is published to the topics/nodes accessible to the lab's UR10 robots. This integration facilitates synchronization between the floating platforms and UR10 robots, enabling them to execute a variety of orbital scenarios, including rendezvous, docking, capture, as well as passive and active space debris removal scenarios. A ROS-MATLAB bridge has been developed to program the floating platform, allowing programming using the widely-used MATLAB environment.

## 3 Main tether dynamical deployment test

The objective is to conduct a test to evaluate the deployment of the Main Tether and observe the dynamic behavior of the process. Additionally, the Reel Brake will be tested and the braking force generated by it measured.

The test will be conducted at the Zero-G lab using one floating platform and one robotic manipulator. Zero-G lab personnel will operate both the floating platform and the manipulator. In the event that the Reel Brake fails to activate or does not stop the platform, the Zero-G lab personnel will program the platform to stop before colliding with laboratory walls or any equipment.

As shown in Fig. 5, the Base Unit is connected to the floating platform, while the Remote Unit is connected to a stationary UR10 robotic manipulator. During deployment, the Base Unit and the floating

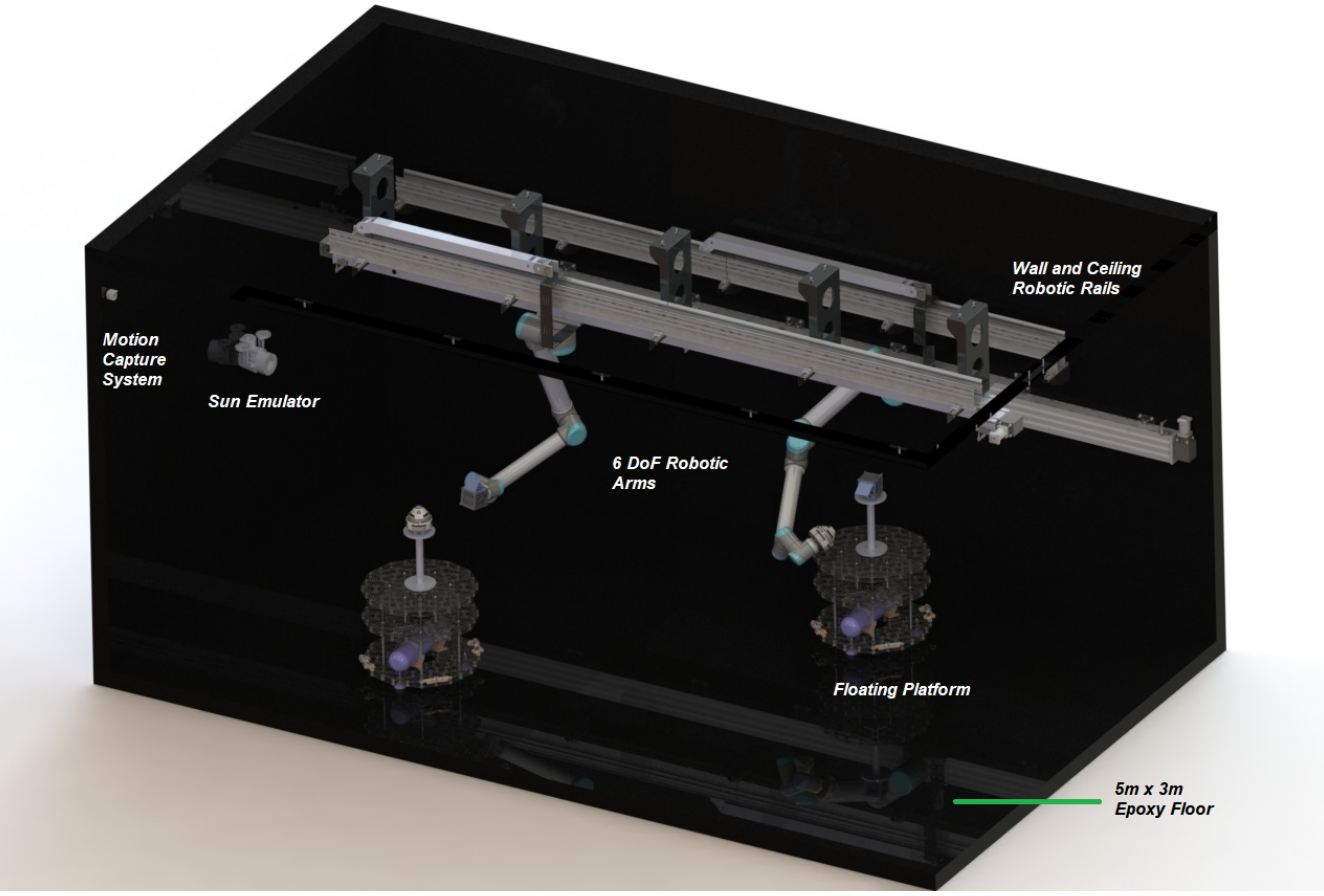

**Fig. 3 The perspective view of the Zero-G Lab**

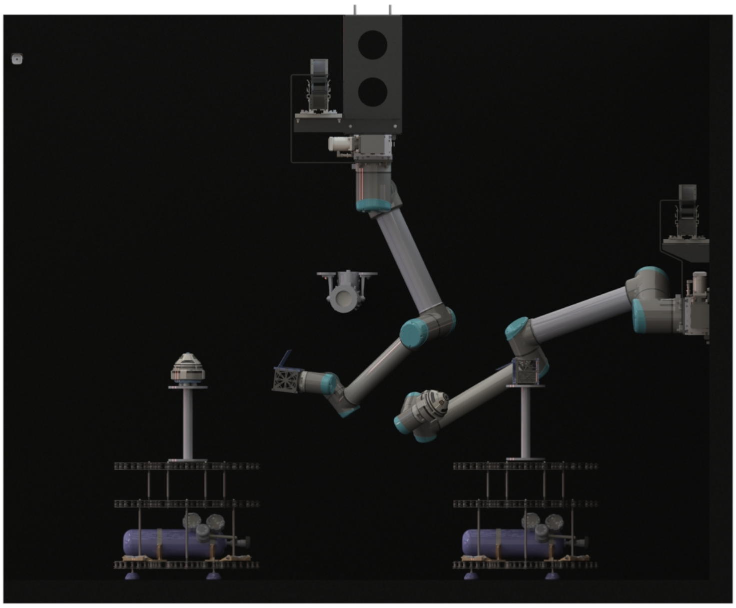

**Fig. 4 The side view of the Zero-G Lab**

platform will move away from the manipulator, simultaneously deploying the Main Tether connected to the Base Unit.

## 3.1 Test parameters

Test parameters of Main Tether dynamical deployment test are summarized below.

- Release speed: 0.1...0.2 m/s.
- Measurement of braking force: 10 mN accuracy.

## 3.2 Test scenarios

Test scenarios of Main Tether dynamical deployment test are summarized below.

- Initially, a deployment will be conducted using a Dyneema wire instead of the actual tether to verify the functionality of the test setup. This process will be repeated as necessary until the test setup operates as intended.
- The deployment will be conducted using a 50 $\mu$m aluminum wire instead of the actual tether to confirm that there are no effects that could cause the aluminum wire to break. This process will be repeated until the aluminum wire remains intact during the deployment, unreeling, and braking.
- At least two deployments will be conducted with the actual Main Tether installed in the reel.

## 3.3 Test procedures

Test procedures of Main Tether dynamical deployment test are given below.

- Before proceeding to the deployment tests, a full functional test will be conducted. The holding mechanism will be replaced after this test. Subsequent tests will only include abbreviated functional tests between each deployment.
- Construct the test setup according to the provided drawings and connect the Electrical Ground Support Equipment (EGSE).
- Adjust the Power Supply Unit (PSU) to provide +10V and +6V.
- Ensure that the Zero-G lab personnel confirm that the floating platform is in a freely floating state and is ready to be deployed.
- Set up the video camera to record the deployment process and the movement of the platform.
- Manually flip the control switch to execute the release of the hold wire.
- Monitor the Power Supply Unit (PSU) and the Baseband Module. Ensure that the Base Unit and the floating platform separate from the Remote Unit. If necessary, change the ejector spring for subsequent tests to achieve the specified release speed.
- Monitor the separation distance and engage the Reel Brake after the tether have been deployed. This distance can be adjusted once the maximum deployment distance in the room is measured, considering the locations of the manipulator and the platform.
- Monitor the braking process and adjust the Pulse Width Modulation (PWM) setting if necessary for subsequent tests.

## 3.4 Expected outcome

The expected outcomes of Main Tether dynamical deployment test are given as follows.

- The Remote Unit has been successfully deployed from the Base Unit.
- Ensure that at least 2 meters of the Main Tether are successfully opened from the Reel without any issues.
- Ensure that the release speed of 0.15 m/s ±0.05 is achieved.

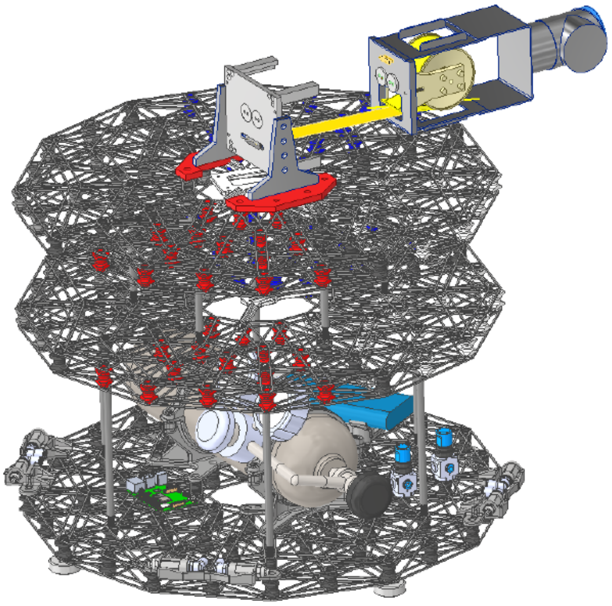

**Fig. 5** **The floating platform as integrated with the tether mechanism**

- Confirm that the Reel brake has been successfully activated, and verify that the tether is still intact after the test, remaining attached at both ends.

## 4 Future Plans

The future plans include the interpretation of the data collected during the experiments using statistical methods. The insights obtained during the tests will guide the project team to develop, manufacture and assemble the ESA-Dragliner as the end-product.

## 5 Conclusion

The goal of the Dragliner project is to design a preliminary tether-based passive deorbit system for LEO satellites and advance it to TRL 4 by demonstrating its most critical functions with a Breadboard Model. This system aims to deorbit satellites after their decommissioning significantly faster than the 25 years required by current regulations, while using considerably fewer spacecraft resources compared to traditional deorbiting methods such as chemical or electric propulsion. The proposed system will utilize a Coulomb Drag microtether, also known as a Plasma Brake, which harnesses momentum from ionospheric plasma ram flow through electrostatic interaction. The paper has summarized the test plans of the Dragliner in the Zero-G Lab. The output of the tests will be published after the end of the project.

## Appendix

More info about ESA-Dragliner project can be found in this link. A general overview of the Zero-G Lab is available in the following video, named The Zero-G Lab: Testing in Micro-Gravity Environment.

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# References

[1] I. Iakubivskyi et al. Coulomb drag propulsion experiment of estcube-2 and foresail-1. *Acta Astronautica*, 177:771–783, 2020. DOI: https://doi.org/10.1016/j.actaastro.2019.11.030.

[2] J. Drmola and T. Hubik. Kessler syndrome: System dynamics model. *In:Space Policy*, pages 29–39, 2018. DOI: 10.1016/j.spacepol.2018.03.003.

[3] Discos, consulted in september 2022. https://sdup.esoc.esa.int/discosweb/statistics/.

[4] J. C. Liou. Active debris removal and the challenges for environment remediation. *Report - NASA Orbital Debris Program Office, NASA Johnson Space Center, Houston, Texas, USA*, 2012.

[5] C. Bonnal. Active debris removal recent progress and current trends. *Acta Astronautica*, pages 51–60, 2013. DOI: https://doi.org/10.1016/j.actaastro.2012.11.009.

[6] G. Borelli, G. Gaias, and C. Colombo. Rendezvous and proximity operations design of an active debris removal service to a large constellation fleet. *Acta Astronautica*, 205:33–46, 2023. ISSN: 0094-5765. DOI: https://doi.org/10.1016/j.actaastro.2023.01.021.

[7] R.M. Færgestad et al. Coupled finite element-discrete element method (fem/dem) for modelling hypervelocity impacts. *Acta Astronautica*, 203:296–307, 2023. ISSN: 0094-5765. DOI: https://doi.org/10.1016/j.actaastro.2022.11.026.

[8] Vladimir Aslanov and Alexander Ledkov. 2 - space debris problem. https://www.sciencedirect.com/science/article/pii/B9780323992992000045, 2023. ISBN: 978-0-323-99299-2. DOI: https://doi.org/10.1016/B978-0-323-99299-2.00004-5.

[9] P. Bernhard, M. Deschamps, and G. Zaccour. Large satellite constellations and space debris: Exploratory analysis of strategic management of the space commons. *European Journal of Operational Research*, 304(3):1140–1157, 2023. ISSN: 0377-2217. DOI: https://doi.org/10.1016/j.ejor.2022.04.030.

[10] P. Janhunen. Electric sail for spacecraft propulsion. *Journal of Propulsion and Power*, 20:763–764, 2004. DOI: https://arc.aiaa.org/doi/10.2514/1.8580.

[11] P. Janhunen and A. Sandroos. Simulation study of solar wind push on a charged wire: basis of solar wind electric sail propulsion. *Annales Geophysicae*, 25:755–767, 2007. DOI: https://doi.org/10.5194/angeo-25-755-2007.

[12] P. Janhunen. Electrostatic plasma brake for deorbiting a satellite. *Journal of Propulsion and Power*, 26:370–372, 2010. DOI: https://arc.aiaa.org/doi/10.2514/1.47537.

[13] P. Janhunen. Simulation study of the plasma brake effect. *Annales Geophysicae*, 32:1207–1216, 2014. DOI: https://doi.org/10.5194/angeo-32-1207-2014.

[14] B. C. Yalçın et al. Lightweight floating platform for ground-based emulation of on-orbit scenarios. *IEEE Access*, pages 94575 – 94588, 2023. DOI: https://doi.org/10.1109/ACCESS.2023.3311202.

[15] J. Artigas et al. The oos-sim: An on-ground simulation facility for on-orbit servicing robotic operations. In *2015 IEEE International Conference on Robotics and Automation (ICRA)*, pages 2854–2860. IEEE, 2015. DOI: https://doi.org/10.1109/ICRA.2015.7139588.

[16] H. Benninghoff et al. European proximity operations simulator 2.0 (epos)-a robotic-based rendezvous and docking simulator. *Journal of large-scale research facilities (JLSRF)*, 2017. DOI: 10.17815/jlsrf-3-155.

[17] L. Cassinis et al. On-ground validation of a cnn-based monocular pose estimation system for uncooperative spacecraft. In *8th European Conference on Space Debris, Darmstadt, Germany*, 2021. DOI: https://doi.org/10.1016/j.actaastro.2022.04.002.

[18] H. Kolvenbach and K. Wormnes. Recent developments on orbit, a 3-dof free floating contact dynamics testbed. In *13th International Symposium on Artificial Intelligence, Robotics and Automation in Space (i-SAIRAS 2016)*, volume 6, 2016.

[19] P. Tsiotras. Astros: A 5dof experimental facility for research in space proximity operations. In *AAS Guidance and Control Conference*, volume 114, 2014.

[20] M. Wilde et al. Orion: A simulation environment for spacecraft formation flight, capture, and orbital robotics. In *2016 IEEE Aerospace Conference*, pages 1–14. IEEE, 2016. DOI: 10.1109/AERO.2016.7500575.

[21] H. Krüger and S. Theil. TRON-hardware-in-the-loop test facility for lunar descent and landing optical navigation. *IFAC Proceedings Volumes*, 43(15):265–270, 2010.

[22] M. Olivares-Mendez et al. Establishing a multi-functional space operations emulation facility: Insights from the zero-g lab. *SSRN*, 2023. DOI: https://dx.doi.org/10.2139/ssrn.4602588.

[23] M. Olivares-Mendez et al. Zero-g lab: A multi-purpose facility for emulating space operations. *Journal of Space Safety Engineering*, pages 509 – 521, 2023. DOI: https://doi.org/10.1016/j.jsse.2023.09.003.