

# Propulsion Technologies for Small Satellites in Earth Orbit and for Space Exploration

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## Task 1.3.4: Enabling technologies for near-Earth satellites

### Task 1.4.4: Deep-Space Exploration with Miniaturized Platforms: Democratizing the Outer Space

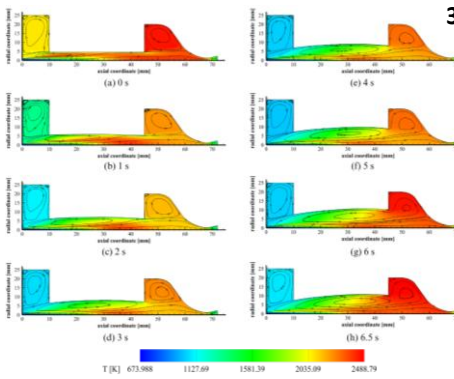
Space propulsion technologies are experiencing an extensive research and development effort to employ environmental-friendly and non-toxic propellants, and to enable technologies for distributed platforms and formation flying. In this framework, **UniNa** participates, to Spoke 1, by conducting numerical activities and carrying numerical and experimental activities on technologies for **green chemical space propulsion**, in particular for monopropellant or bipropellant hybrid systems, as well as devices for aerobraking and planetary atmospheric entry and **air-breathing electric propulsion** for low orbits.

#### Chemical Propulsion

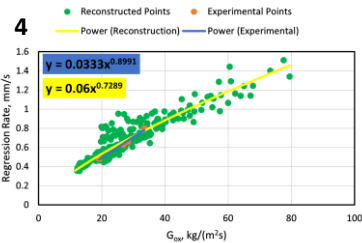
The first activity focuses on the **numerical and experimental assessment of H<sub>2</sub>O<sub>2</sub>-based 10N-class hybrid propellant thrusters**, as in Figure 1 and 2. The objective is to increase efficiency and safety and reduce costs and risks. **Hydrogen peroxide** represents a promising alternative to hydrazine-based thrusters, and Small-scale hybrid rocket engines have been selected among other types of chemical rocket engines because they combine the main advantages of solid and liquid propulsion, and suitable for **CubeSat platforms**.



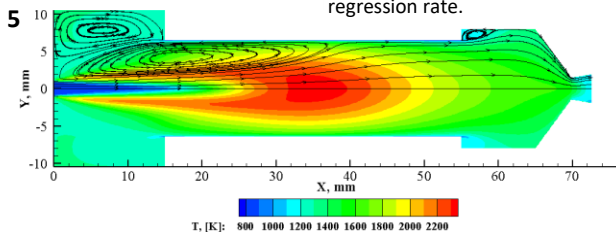
The study utilizes steady-state and transient **CFD simulations**. The numerical framework employs commercial solvers integrated with custom functions to simulate fuel grain regression. These results are validated against experimental data from small-scale green propellant thrusters, with a specific focus on evaluating decomposition strategies for hydrogen peroxide and assessing how geometry and heat fluxes influence internal ballistics, as in Figure 3.



**Experiments** are currently being conducted with the aim of characterizing the internal ballistics in the case of combustion between hydrogen peroxide and polymeric fuels like ABS and HDPE. The results with HDPE made it possible to derive a regression law as a function of the mass flux, as shown in Figure 4.



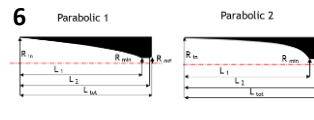
They were reproduced through numerical simulations, as in Figure 5, which allowed an assessment of the relatively high regression values obtained. It was observed that the large extent of the recirculation zone inside the combustion chamber leads to an increase in the convective flux over most of the fuel wall, resulting in a relatively high regression rate.



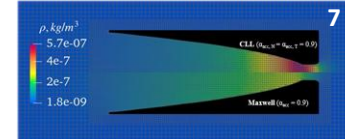
This study was carried out within the Space It Up project funded by the Italian Space Agency, ASI, and the Ministry of University and Research, MUR, under contract n. 2024-5-E.O - CUP n. I53D2400060005.

#### Electric Propulsion

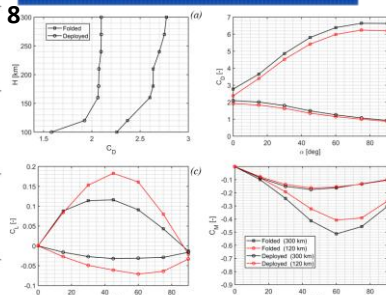
The second activity involves the **numerical analysis of air intakes for VLEO (Very Low Earth Orbit) Air-Breathing Electric Propulsion**. This work aims to develop propellantless propulsion systems to enable long-duration Earth Observation missions. Using open-source DSMC codes such as SPARTA and DS2V/DS3V, the study performs 2D and 3D simulations validated against literature and through code-to-code comparisons. The analysis investigates the impact of altitude, geometry, and angle of attack on performance, while specifically examining how Gas-Surface Interactions (GSI) affect intake efficiency and drag force across various scenarios.



The results, as in Figure 6 and 7, shows that a parabolic shape improves the intake performances, and by a comparison on GSI models, the Maxwellian GSI is less efficient.



Another objective of the activities is the assessment of the aerodynamic behaviour of **aerobraking and planetary entry devices**, and the design of possible innovative solutions for their aerodynamic control. DSMC enables a comprehensive aerodynamic assessment under rarefied and continuum flow conditions, as in Figure 8, axisymmetric 2D simulations were conducted to determine the drag coefficient (CD) profile of the capsule, having a mass as a function of altitude.



#### Publications

- A. Sannino, et al., Design and Performances of Intake for Atmosphere-Breathing Electric Propulsion Systems with Direct Simulation Monte Carlo Method, *Physics of Fluids* 37, 027189 (2025)
- A. Sannino, et al., Re-Entry Comparison of a Spacecraft in Low Earth Orbit: Propulsive Assisted vs. Non-Propulsive Configurations, *Aerospace* 2025 12(2), 79
- S. Cassese, et al., Properties and Behavior of 3D-Printed ABS Fuel in a 10 NHybrid Rocket: Experimental and Numerical Insights, *Aerospace* 2025 12, 291
- S. Cassese, et al., Relevant Fluid Dynamics Aspects of the Internal Ballistics in a Small-Scale Hybrid Thruster, *Fluid Dynamics & Materials Processing* 2025
- S. Cassese, et al., Firing Tests and Simulations of a CubeSat-Scale H2O2-Based Hybrid Rocket, *Journal of Propulsion and Power*, 2025
- V. Pessina, et al., Numerical investigation of critical aspects for the intake of atmosphere-breathing electric propulsions for VLEO applications, *CEAS Space Journal*, September 2025
- S. Cassese, et al., Fuel Characterization, Performance Assessment and Thermal Analysis of a Hydrogen Peroxide-based Hybrid Thruster for CubeSats, 75<sup>th</sup> International Astronautical Congress, 14-18 October 2024, Milan
- S. Cassese, et al., Durable Oxide Catalysts free of Noble metals for Hydrogen Peroxide Thrusters, 75<sup>th</sup> International Astronautical Congress, 14-18 October 2024, Milan
- A. Sannino, et al., Performance Analysis of different air intakes for ABEP in VLEO and evaluation of scale effects, 75<sup>th</sup> International Astronautical Congress, 14-18 October 2024, Milan
- S. Cassese, et al., Design and testing of a Hybrid Rocket for Small Spacecraft, *AIAA Scitech* 2025, 6-10 January 2025, Orlando
- V. Pessina, et al., Investigation of critical aspects for atmosphere-breathing electric propulsion with Direct Simulation Monte Carlo method for VLEO and ULEO applications, 2<sup>nd</sup> International Symposium on Very Low Earth Orbit Missions and Technologies, 13-14 January 2025, Stuttgart
- S. Cassese, et al., Exploring the Potential of Palladium Catalysts in Hydrogen Peroxide Monopropellant Engines: New Approaches and Performance Analysis, *EUCASS*, 29 June - 4 July 2025, Rome
- R. Guida, et al., Novel Insights on Fluid Dynamics and Performance of 10N-class HTP-based Hybrid Thrusters, 76<sup>th</sup> International Astronautical Congress, 29 September-3 October 2025, Sydney

