A Multidisciplinary Design Optimization Framework for a Reusable Vehicle for Multipurpose Missions

Iara Alexa Alves Figueiras*[1], Girolamo Musso[1], Alain De Souza[1], Frederico Afonso[1], and Fernando Lau[1]

[1]IDMEC, Instituto Superior Técnico – Av. Rovisco Pais 1049-001 Lisboa Portugal, Portugal

Abstract

The New Space Portugal initiative represents a strategic national effort to strengthen Portugal's position within the evolving space sector. By fostering collaboration between academia and industry, the initiative aims to accelerate the development of innovative, sustainable, and commercially viable space technologies. As part of this initiative, universities play a central role by advancing research efforts and establishing new educational programs that support the development of specialized expertise in space systems.
A key academic contribution within this initiative is the ongoing development of a multidisciplinary design and optimization framework for next-generation space vehicles, supported by two PhD theses. This framework integrates five building blocks - propulsion, mass and sizing, aerodynamics, trajectory, and life cycle assessment (LCA) - supported by both genetic and gradient-based optimization techniques. Initially tailored for conventional sounding rockets, the framework is now being extended to accommodate more complex vehicle architectures, particularly reusable lifting-body geometries designed for multipurpose missions, potentially including orbital maneuvering, in-orbit servicing, satellite deployment, logistics, debris removal, and atmospheric re-entry. This vehicle is intended to operate as part of a small-lift launch system, with mission definition requirements incorporating feedback from companies of the consortium, ensuring alignment with real-world operational needs and market trends.

As part of the ongoing Ph.D. contributing to the development of the multidisciplinary framework, at the moment, a significant upgrade in the framework is the implementation of the Class/Shape Transformation (CST) method for geometric parameterization and mesh generation to be able to use low-fidelity methods for the aerodynamic coefficients prediction. In addition to the aerodynamic modeling, several modules have been developed or enhanced within the framework: the LCA building block estimates vehicle emissions using data from ESA, SSSD, and ecoinvent databases, with impact analysis performed through SimaPro® and combustion data generated via CEA software; a basic control module has also been implemented, featuring a PID controller and a simplified wind model to assess environmental effects on performance. Future developments of the framework include the incorporation of aerothermal and preliminary structural modeling, enabling the transition toward a fully coupled aerothermodynamic-structural optimization tool for re-entry-capable systems.
Beyond research, the framework also supports educational innovation. Its development supports the creation of new curricular units at Instituto Superior Técnico, including "Space Vehicle Design" and "Space Sustainability". These additions aim to establish a secondary specialization in the Space curricula, providing future engineers with the skills and systems-thinking mindset required by the New Space sector.

*Speaker

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