PhD THESIS PROPOSITON

Title : Multidisciplinary system level trade-offs with respect to environmental impact for reusable first stage of launch vehicle

Reference : **TIS-DTIS-2026-07**

Thesis beginning : ADU	**Application deadline :** ADU

Keyword : Multidisciplinary Design Optimization, Reusable launch vehicle design, environmental impact, uncertainty quantification

Skills

Aerospace engineering, applied mathematics, probability/statistics, numerical methods

PhD subject :

This PhD thesis is part of a European Doctoral Network called SLICE (Space Launch Impact on Climate and Environment)dealing with different aspects of the environmental impact for launch vehicles.

In the context of the New Space, the access to space has been significantly developing, under the leadership of public and private actors. Particularly, the number of launch systems and the number of flights are rapidly increasing, motivated by different needs such as mega constellations, space exploration, *etc*. Despite the current limited number of spaceflights compared to the aeronautic industry, the rapid increase of launches per year and the specificities of rocket flight, the environmental impact of space industries is becoming a key-driver for the next decade. One of the particularities of launch vehicle systems is to eject gases in the upper layers of the atmosphere that implies large lifetime duration and a potentially significant contribution to the climate change. In addition, the launch vehicle design might involve a variety of different propellants. The propulsion modes can vary during the flight and the accurate estimation of emissions along the trajectory is still a challenge. Apart from the atmospheric emission, the impact of launch vehicles covers a wide spectrum of effects (degradation of air and water quality, biodiversity near the launch pads, ozone depletion, pollutant emission near the manufacturing sites, energy consumption, propellant synthesis) and the environmental impact has to be assessed in a global Life Cycle Analysis.

The assessment of environmental impact of reusable launch vehicles depends on both architectural and technological choices (*e.g.*, type of return strategy, type of propellant, trajectory shape). The design of new reusable launch vehicle requires a multidisciplinary analysis and optimization process coupling different physical models such as propulsion, aerodynamics, structure and trajectory. Moreover, such a process needs to assess a system-level trades-off between performance and environmental impacts through the addition of a discipline associated to the environmental impact estimation, (for example with radiative forcing calculation [1]). In this PhD thesis, it is proposed to focus on the trade-off associated to different architectures and technological choices corresponding to the reusable first stage [2] (*e.g.*, toss-back/glider strategies, liquid propellant choices). The performance and environmental assessments require the simulation of both ascent and return trajectories. An important challenge in the introduction of environmental impact in a multidisciplinary process in early design phases is to be able to deal with the computational cost of rocket engine emissions and climate model and their associated uncertainty levels. A possibility is to rely on models with different fidelities translating different computational costs and different prediction accuracies (*e.g.*, high fidelity model is associated with a high computational cost and a high accuracy whereas low fidelity model is associated with a smaller computational cost but higher model uncertainties) [4].

The objectives of the PhD thesis is to develop a multidisciplinary optimization approach dealing with multi-fidelity models for the rocket engine emissions and the climate impacts in system-level trade-offs assessment. The multi-fidelity models will allow to aggregate information generated by different models while taking into account the different uncertainty levels relating to the environmental impact assessment [3]. Moreover, during the PhD thesis, the rocket emissions and climate impact models will be updated according to the other data generated in the European Doctoral Network project. Therefore, a methodology for adaptive refinement of the multi-fidelity model to reduce the uncertainties associated to the rocket emissions and climate impact will be developed.

The proposed methodology will be applied to the design of reusable first stage for different types of architectures in order to balance between overall performance and climate impact through dedicated optimization strategy.

The PhD thesis will deal with the following phases:

- State-of-the-art on multidisciplinary design optimization of reusable launch vehicle, rocket emission models and climate impact models
- Development of a multi-fidelity design process to account for model uncertainties and system level trade-off
- Application to reusable launch vehicle design

Références:

[1] John D. DeSain and Brian B. Brady. Potential atmospheric impact generated by space launches worldwide update for emission estimates from 1985 to 2013. Aerospace Report TOR-2014-02140, Space and Missile Systems Center Air Force Space Command, 483 N. Aviation Blvd. El Segundo, CA 90245-2808, Jan 2014.

[2] M. Balesdent, L. Brevault, B. Paluch,et al. (2023). Multidisciplinary design and optimization of winged architectures for reusable launch vehicles. *Acta Astronautica*.

[3] N. Murray, S. Bekki, R. Toumi, and T. Soares. On the uncertainties in assessing the atmospheric effects of launchers. Progress in Propulsion Physics, 4:671–688, 2013.

[4] L. Brevault, M. Balesdent, M., & A. Hebbal, (2020). Overview of Gaussian process based multi-fidelity techniques with variable relationship between fidelities, application to aerospace systems. *Aerospace Science and Technology*, *107*, 106339.

[5] A. De Oliveira, M. Balesdent, L. Brevault, & A. Urbano (2025). Integrating Life Cycle Assessment into an Early-Stage Multidisciplinary Design Analysis Tool for Sustainable Launcher Development, EUCASS 2025

Collaborations

European Doctoral Network, potential collaborations with DLR, ISAE, Univ. Dresden, DEIMOS, CERFACS, IPSL, PSI, VKI, Politecnico di Torino, Univ Stuttgart, Univ Leeds, Univ Strathclyde, Univ Bruxelles, EPFL

Host laboratory at ONERA

Department : Traitement de l'information et systèmes

Location (ONERA) : Palaiseau

Contact : Mathieu Balesdent et Loïc Brevault

Tél. : +33 1 80 38 66 08 / +33 1 80 38 66 88

Email : mathieu.balesdent@onera.fr / loic.brevault@onera.fr

Thesis director

Nom : Mathieu Balesdent

Laboratory : ONERA

Tél. : +33 1 80 38 66 08

Email : mathieu.balesdent@onera.fr

Pour plus d'informations : https://www.onera.fr/rejoindre-onera/la-formation-par-la-recherche