POLITECNICO DI MILANO

PhD in INGEGNERIA AEROSPAZIALE / AEROSPACE ENGINEERING - 40th cycle

THEMATIC Research Field: HYPERSONIC VEHICLE ENHANCEMENT VIA ROBUST MULTI-FIDELITY OPTIMIZATION - PRIN 2022 - HERMES - GORI - CUP - D53D23004340001

Monthly net income of PhDscholarship (max 36 months)
€ 1500.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	Ordinary space missions typically entail a space-to-ground transition phase during which the spacecraft sustains a hypersonic flight regime. For instance, in both commercial and research missions, we acknowledge the atmospheric descent of re-usable modules or crewed spacecraft or the return of scientific samples. Improving the design of re-entry vehicles is of the utmost importance for the future of the Space Economy. In particular, hypersonic applications are affected by many uncertainty sources related to the operating condition and to the environment e.g., atmospheric descent in an extra-terrestrial atmosphere. Therefore, the performances of the vehicle must be thoroughly investigated considering a wide spectrum of unknown variables. Unfortunately, accurate computational models are burdensome to evaluate and the analysis of all possible combinations of uncertain parameters is next to impossible. The goal of this PhD is to deliver a novel design approach establishing a fully controlled synergy among computational models of variable fidelity for hypersonic applications, to serve the robust design of the next generation of hypersonic vehicles. The project seeks an enhancement of the design process under uncertain conditions by exploiting a multi-fidelity approach to reduce the overall computational cost of the design procedure. The ultimate goal is to reduce the costs associated with

	reaching Space, a scope dictated by the key pillars in the Horizon Europe programme (Pillar II: Global Challenges &European Industrial Competitiveness), and meets the expectation of Cluster 4 (Digital, Industry &Space) as reported in the Horizon Europe Strategic Plan 2021-2024. Not only, this project supports also the key objectives listed in “Investimento 4: Tecnologia satellitare ed economia spaziale, Space Factory, Subproject II (Access to space)” of the Mission 1 (C2) “Digitalizzazione, innovazione e competitivita` nel sistema produttivo” urged in the Italian PNRR (Piano Nazionale di Ripresa e Resilienza). Indeed, by improving the vehicle design, this project supports "the research, development and prototyping of green technologies for the next generation of launchers”.
Methods and techniques that will be developed and used to carry out the research	Robust optimization typically chases the minimization of some statistics of a target performance, or Quantity of Interest (QoI). Generally, the estimation of the QoI is costly and challenging. Consequently, robust design applications require the development of cheap and efficient uncertainty estimation methods. This project focuses on the exploitation of variable fidelity methods. The core idea is to combine predictions from multiple computational models to build a surrogate approximating the response of the random QoI to the uncertain inputs, for a fixed design. After, the uncertainty space can be sampled using traditional Monte-Carlo techniques, querying the surrogate to evaluate the statistics of the QoI. In doing so, this project is expected to mainly rely on co-kriging surrogates, according to the autoregressive formulation developed by Kennedy &O’Hagan (2001) and later improved by Le Gratiet (2013). The goal is to seek an efficient alternative to Multi-Level Monte Carlo methods. The Researcher will need to develop new techniques for building the surrogate serving the UQ analysis and integrate it within the vehicle optimization process. In particular, devise innovative acquisition criteria for the adaptive sampling of the uncertainty space needed to enrich the surrogate training set. Note that the autoregressive formulation from Le Gratiet opens the path

	for devising efficient in-filling strategies capable of selecting the accuracy level at which the QoI should be evaluated, saving computational resources. The optimization problem will be solved using the Bayesian Efficient Global Optimization (EGO) strategy which efficiently samples the design space to find the optimum. The student will employ the open-source SU2-NEMO CFD suite for simulating the problem. Models of different fidelity will consist of different choices concerning the physics e.g., frozen/unfrozen chemistry, or the resolution of the grid. The student is expected to spend a 6 months period abroad. A possible partner is the Future Air-Space Transportation Technology Center at Strathclyde University, Glasgow, the leading SU2-NEMO developer. The timeline of the work is: • Year 1: development of multi-fidelity modelling methods • Year 2: mastering CFD analysis for hypersonic flows and period abroad • Year 3: Numerical robust optimization of a hypersonic application
Educational objectives	The PhD candidate will receive an inter-disciplinary and an inter-national training. Inter-disciplinary training: the student is expected to become an expert in Bayesian techniques for robust design, an expert in multi-fidelity surrogate modelling techniques, and an expert CFD engineer in hypersonic applications. Expertise in the different fields will need to be unified and integrated within the optimization framework, offering a scientific inter-disciplinary challenge to the student. Training will be delivered continuously throughout the action time frame (1) via formal lectures in courses offered by the PhD school, (2) by one-to-one meetings, (3) through hands-on activities. International training: the student is expected to spend a 6 month period at a partner institution to engage in international research endeavours. The participation to international conferences e.g., AIAA conferences, is also expected to foster the development of the interpersonal relations skills of the student. Moreover, the Researcher will become part of a quite

	large research group including PhD students, post-docs, and junior and senior faculties. Belonging to this group will offer him/her the opportunity to discuss aerospace challenges on a daily basis, trespassing the boundaries of mere hypersonics. This is an opportunity to broaden her/his network and start cross-disciplinary collaborations with other researchers at the department.
Job opportunities	Morgan Stanley estimates that the global space industry could generate revenue of $1 trillion or more in 2040 (https://www.morganstanley.com/ideas/investing-in-space). This is further confirmed by the recent blossoming of private space companies e.g., SpaceX, Virgin Galactic, and Blue Origin, and the renewed interest in Human Space Exploration and private space flight i.e., space tourism, which are fostering cutting-edge innovations in the field. The same is confirmed for the Italian economic ecosystem. Indeed, we have recently witnessed the birth of many Italian start-ups and private companies offering end-to-end solutions for accessing space services e.g., D-Orbit, Leaf Space, and the planning of large-scale space infrastructure e.g., the Criptaliae Spaceport in Grottaglie, Taranto. These are distributed all over the Italian territory, proving the long-term investment supported by the country and representing an opportunity for the economic growth and development of the country as a whole. Therefore, industrial employment opportunities for the PhD candidate expert in hypersonic flows and robust optimization are available both at a national scale or international scale. The importance of hypersonic applications is relevant not only to commercial exploitation but also to the Academic sector since it presents unprecedented challenges. If interested, the PhD Researcher may pursue a successful academic career by continuing fundamental research in hypersonics. Currently, our research group is actively collaborating with the Aerospace Centre of Excellence at Strathclyde University (UK), with the Center for Hypersonics &Entry Systems Studies (CHESS) at the

	University of Illinois Urbana-Champaign (USA), the Aerospace Design Lab at Stanford University (USA), the Von Karman Institute for Fluid Dynamics (BE), and the Politecnico di Bari. These collaborations will offer a launching pad to a deserving student.
Composition of the research group	1 Full Professors 0 Associated Professors 3 Assistant Professors 11 PhD Students
Name of the research directors	Prof. Giulio Gori

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents (more than 80Km out of Milano)	--

Scholarship Increase for a period abroad	
Amount monthly	750.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information
The PhD candidate will receive a desk, possibly through a hot-desking procedure, and a personal computer, if needed. Apart from the compulsory ones, the PhD candidate will have the opportunity to follow additional courses and receive economic support to attend summer schools and participate in conferences. There will be the possibility of paid teaching assistantship.