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Supervisor Expression of Interest

MSCA - Marie Sklodowska Curie Action - (PF) Postdoctoral Fellowship 2025

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Link "Pagina docente": link
Department Name: Aerospace Science and Technology
Research topic: Uncertainty Quantification in Highly Compressible Fluid Flows

MSCA-PF Research Area Panels:

- ☐ ECO_Economic Sciences
- ☒ ENG_Information Science and Engineering
- ☐ ENV_Environmental and Geosciences
- ☐ LIF_Life Sciences
- ☐ MAT_Mathematics
- ☐ PHY_Physics
- ☐ SOC_Social Sciences and Humanities
- ☐ CHE_Chemistry

Brief description of the Department and Research Group (including URL if applicable):

The Department of Aerospace Science and Technology (DAER) at Politecnico di Milano ranks at the top in "Mechanical, Aeronautical & Manufacturing Engineering". The Department has a long tradition of cutting-edge research and strong expertise in highly compressible flows. The Department has access to top-notch experimental facilities and computational resources.
The Physical Fluid Dynamic Laboratory (link) at DAER gathers a large number of Researchers including, 1 Full Professor, 3 Assistant Professors, 2 post-docs, 20+ PhDs. The Team is involved in numerous research activities, from fundamentals to applications, including theoretical, computational, and experimental aspects. Team members' experience stands upon solid foundations built thanks to the coordination and involvement in many projects. Namely, 1 ERC (NSHOCK), 1 ERC PoC (PROVA), 2 HE-MSCA-PF (UN-BIASED, NI2PhORC), 3 MSCA-DN (UTOPIAE, TRACES, NITROS), several national/European projects (H2020-ICE-GENESIS, H2020-MONNALISA, PRIN2022-HERMES, PRIN2022-NICTURB), and others. The PRIN2022-HERMES, coordinated by this Supervisor, deals with the topics touched on by the research project described in the following section.

The PFD lab closely collaborates with international partners on the specific topics related to the project proposed in this call. Namely, Prof. Anabel del Val (Assistant Professor, Aerospace Engineering & Mechanics, University of Minnesota), Prof. Marco Panesi (Director of the CHESS-Center Hypersonics & Entry Studies at the University of Illinois Urbana-Champaign), Prof. Marco Fossati (Strathclyde University, member of the Aerospace Centre of Excellence-ACE and director of the Future Air-Space Transportation Technologies-FASTT), Prof. Thierry Magin (Professor, Aeronautics and Aerospace Department, von Kármán Institute for Fluid Dynamics).

TITLE of the project: Uncertainty Quantification in Highly Compressible Fluid Flows

Brief project description:

The Space Economy market is estimated to reach $1.8 trillion in 2035. Potential players interested in the aerodynamic analysis of reusable launchers are private companies e.g., SpaceX, Blue Origin, Virgin Galactic. In the Italian economic system, the interest is confirmed by private companies offering end-to-end solutions for accessing space e.g., D-Orbit, Leaf Space, Fast Aerospace, and by politics e.g., planning of large-scale infrastructure (Criptalie Spaceport in Grottaglie in Taranto). These are distributed all over the Italian territory, contributing to the economic growth of the country. Supersonic commercial airliners are also subject to renewed interest e.g., Boom Technology or the Lockheed Martin X-59 Quesst, facing regulatory barriers due to boom noise. The industrial race to conquer the aerospace market is fast-paced and requires a streamlined aerodynamic analysis process to rapidly accommodate a continuously evolving environment. New knowledge and technologies become available, contributing to extending the depth of fundamental investigations in fluid mechanics.

The accuracy of numerical tools must be rigorously analyzed and improved. The prospective Postdoctoral Fellow will propose a research project focused on enhancing uncertainty analysis in highly compressible flows, with applications to space exploration, including access to space (launch systems) and atmospheric entry. The core objective is to develop uncertainty quantification (UQ) frameworks for computational fluid dynamics (CFD) models of varying fidelity and computational cost to improve simulations through enhanced models and closures. The primary challenge is to extend the capabilities, accuracy, and reliability of numerical analysis by conducting extensive UQ studies. The project should aim to refine turbulence and transition closures, model thermochemical nonequilibrium effects, or improve gas-surface interaction boundary conditions, with a particular focus on—but not limited to—the Reynolds-Averaged Navier-Stokes (RANS) model. These closure models are inherently uncertain due to both epistemic and aleatoric factors, stemming from limited physical understanding and incomplete knowledge of vehicle operating conditions, such as the partially unknown atmospheric composition. Additionally, the scarcity of reliable high-fidelity data further increases the complexity of the task. It is envisioned that the type of problems that will be analyzed in this project will present challenges both on the modeling side and the UQ side. The modeling challenges are related to how we could efficiently surrogate the CFD model to make many-query problems, such as UQ, tractable. This is especially challenging for highly compressible flows because they exhibit large gradients around shock waves and boundary layers, as well as highly nonlinear behavior due to nonequilibrium thermochemical effects. On the UQ side, the large number of dimensions to be considered in problems of interest can challenge current state-of-the-art practices for both forward uncertainty analyses and Bayesian inference problems. Therefore, the high-speed flow community calls for efficient approaches to be established by the candidate Fellow.

The project will be aligned with the key pillars defined in the Horizon Europe programme, in particular Pillar II: Global Challenges & European Industrial Competitiveness, meeting the expectation of Cluster 4 (Digital, Industry & Space) in the Horizon Europe Strategic Plan 2021-2024. Namely, to "*open strategic autonomy in developing, deploying and using global space-based infrastructures, services, applications and data, including by reinforcing the EU's independent capacity to access space, securing the autonomy of supply for critical technologies and equipment and fostering the EU's space sector competitiveness*". This project promotes the participation of Italy in future EU initiatives supporting 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 competitività nel sistema produttivo* urged in the Italian PNRR (Piano Nazionale di Ripresa e Resilienza). By improving the aerodynamic analysis, this project supports *the research, development, and prototyping, of green technologies for the next generation of launchers*.