POLITECNICO DI MILANO

PhD in INGEGNERIA AEROSPAZIALE / AEROSPACE ENGINEERING - 40th cycle

PNRR 630 Research Field: HIGH-FIDELITY STUDY OF THE PARTICLE-LADEN TURBULENT FLOW IN THE HUMAN LUNGS

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	The dynamics of multi-phase flows are of fundamental importance, and crucial to many industrial and technological processes. In the present case, the interest is focused on internal air flows laden with micro- and nano-sized particles. The motivation of the research is grounded upon the need of pharmaceutical companies for a detailed understanding of the process of deposition of solid microparticles or liquid microdroplets within the tracheobronchial tract of the human respiratory system. High-fidelity data are essential to fine-tune lower-fidelity models that are routinely used to tailor the design process (of drugs, inhalers, sprays, etc) to a specific use case. During normal respiration, inhaled air often contains foreign particles such as dust, fumes, other pollutants and pathogens. Drug delivery via nose and mouth involves drug particles suspended in the airflow. Invasive experimental setups that deal with human subjects are difficult to undertake and do not provide imaging data in realistic physiological conditions. Computational Fluid and Particle Dynamics (CFPD) therefore is a suitable and convenient alternative. At DAER, we have recently developed a unique computer code for the high-fidelity simulation (namely, direct numerical simulation of the Navier-Stokes equations, DNS) of the airflow down to the bronchial generations where the continuum hypothesis loses significance. This flow is characterized by wildly separated lengthscales and develops within an extremely complex geometry: DNS of such computational size were

	previously not available. So far, however, the discretized equations only describe minimalistic physics: an incompressible, single-phase flow that develops within a network of rigid ducts. The goal of the work is to extend the capabilities of the code, by enriching the considered physics and at the same time by improving its relevant understanding, as the combination of multiphase particle-laden flows in such a complex environment raises several fundamental questions with practical interest.
Methods and techniques that will be developed and used to carry out the research	The existing code builds on very solid ground and works thanks to a next-generation immersed-boundary method that combines robustness and accuracy with simplicity and computational efficiency. Thanks to its remarkable efficiency, we are already routinely affording extreme-scale DNS simulations of the flow within the human lungs, with up to 50 billion points in space and hundreds of thousands of time steps. The goal of the project is to progress towards Computational Fluid and Particle Dynamics (CFPD) simulations, by extending the complexity of the described physics while maintaining adequate computational efficiency. In terms of physics, particles will be considered with a Discrete Element Approach (DEM) of increasing complexity. Although the single-way coupling of the particle motion with the fluid phase will mostly suffice to describe the deposition pattern in the dilute regime, two- or even four-way coupling might be required to assess the flow and turbulence modulation consequences of the high particle density that is typical of inhalers and sprays. From the viewpoint of the HPC design, the current CPU implementation is already exceptionally efficient but deserves improvement to achieve a levelled load balancing in case of particularly intricated anatomies. The CPU solver will be extended to support at compile-time an alternate version that is GPU-based. An architecture-independent solver should guarantee maximum flexibility in deployment on any modern HPC platform.
Educational objectives	The PhD candidate will gain first-hand experience in a

	broad array of disciplines, ranging from High-Performance Computing techniques to advanced programming skills, from CFD and CFPD to advanced knowledge of the physics of turbulent multiphase flows. In addition, these will be applied in a context where the unique industrial environment of a high-tech pharmaceutical company will provide the development with a clear goal, guidance, and the necessary expertise to design the DEM approach. It should be noted that only part of these techniques belong to the conventional skill set of a person with a background in aerospace engineering. Hence, the present work constitutes a unique opportunity to build an exceptionally strong curriculum and to enable knowledge transfer in several related fields.
Job opportunities	The job opportunities created by this research project are naturally all those in the general field of fluid mechanics, with computational fluid dynamics obviously prevailing. The bleeding-edge techniques and tools used and developed throughout the research work will make for a significant number of job opportunities. Besides the classic employment fields related to aeronautical engineering, the project will expose the PhD candidate to modern programming techniques (GPU programming, collaborative programming, etc) and to diverse application fields. As a result, in addition to the conventional CFD-related jobs, potential placement will be possible in a vast array of research-oriented companies, ranging from top-tier HPC centres to pharmaceutical companies.
Composition of the research group	1 Full Professors 0 Associated Professors 2 Assistant Professors 4 PhD Students
Name of the research directors	Prof. Maurizio Quadrio

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

National Operational Program for Research and Innovation	
Company where the candidate will attend the stage (name and brief description)	Chiesi Farmaceutici SpA
By number of months at the company	6
Institution or company where the candidate will spend the period abroad (name and brief description)	ETH Zurigo
By number of months abroad	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.