6 months internship (master's level) at Ecole Centrale de Nantes : Machine learning for turbulent flow reconstruction

- **Location:** Ecole centrale de Nantes, GeM – Institut de Recherche en Génie Civil et Mécanique
- **Tutor:** Lucas Lestandi (Assoc. Prof.)
- **Contact:** lucas.lestandi@ec-nantes.fr
- **Compensation:** **~630€/months** depending on the latest "Journal Officiel" decree.
- **dates** : 6 months starting between January and March 2025

Context

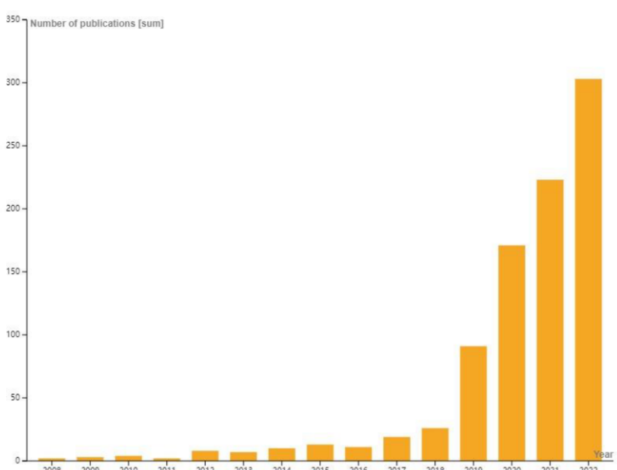

Figure 1: Yearly number of publication on ML for turbulent flows. Source : [1]

The accurate reconstruction of turbulent flows from simulation data is a key challenge in computational fluid dynamics (CFD). Traditional numerical methods, while robust, often face significant computational limitations when applied to high-resolution, extreme-scale simulations, such as those of Rayleigh-Taylor Instabilities (RTI) or free surface flows (waves). Turbulent flow is inherently chaotic and complex, involving multi-scale interactions that are difficult to capture with direct numerical simulations (DNS) alone. However, machine learning (ML) has emerged as a promising alternative or complement to traditional methods for modeling and reconstructing turbulent flows, offering potential improvements in both accuracy and computational efficiency.

This new opportunity to improve turbulent simulation has led to an exponential increase in the number of publications related to this subject as shown in figure 1. In the past few years, multiple review papers as [1,2] have tried to categorize the various works and explore their potential use and challenges. Among the most promising ML techniques, convolutional neural networks (CNNs) and autoencoders have been successfully applied in various areas of CFD. Recent studies have demonstrated the feasibility of using ML techniques to predict and reconstruct high-fidelity turbulent flows from low-resolution or incomplete data. In the meantime, companies are also looking to develop ML-based solutions [3]

This internship will explore the application of machine learning to two specific types of fluid dynamics simulations: Rayleigh-Taylor Instabilities (RTI) and free surface flows. RTI, a phenomenon occurring when fluids of different densities interact under gravitational forces, results in complex, highly unstable turbulent patterns. Similarly, free surface flows, such as waves interacting with structures or other fluid interfaces, are characterized by intricate turbulent behavior that is difficult to model accurately with traditional CFD approaches.

Presentation of the team and work environment

This internship is part of a broader international project funded by CEFIPRA (Indo-French Centre for the Promotion of Advanced Research) *Data reduction and surrogate modeling of transition to turbulence of Rayleigh-Taylor instability data obtained by DNS*.

The project is headed by Associate Professor Lucas Lestandi at Ecole Centrale de Nantes (ECN) and Assistant Professor Aditi Sengupta (IIT-ISM Dhanbad, Mechanical engineering dpt.) who has provided data and DNS solvers [4]. The internship will take place at Ecole Centrale de Nantes (France) in collaboration with Lucas Lestandi and Yassin Ajanif who is currently in his 2nd year PhD studies.

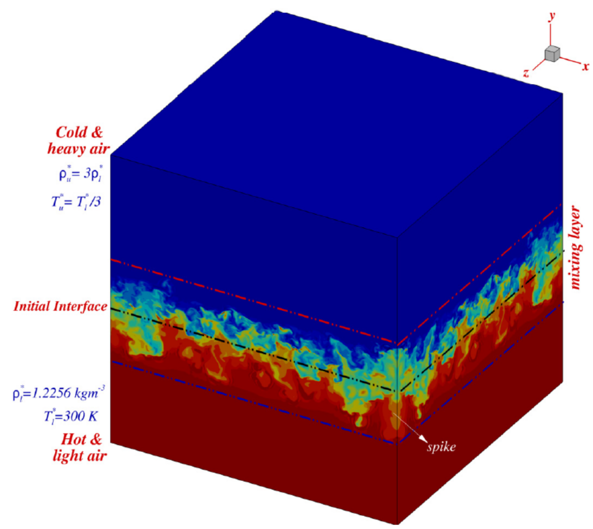

Figure 2: Visualization of the RTI simulation. Reproduced from [1]

Goals of the internship

For this project, the Indian team has provided high accuracy simulation tool (DNS) and produced 4Pb of data. Such large data is hard to handle and Yassin has developed data decomposition algorithms (SVD) tailored for out-of-core processing. However powerful this technique might be, it relies on linear algebra which cannot capture all of the flow turbulent properties (non-linear). Your role will be to explore the literature and apply the most promising techniques for turbulent flow data reconstruction. This will be done under direct supervision of Professor Lestandi who has co-authored 3 articles in the field of ML applied to simulation of mechanics and wishes to apply similar strategies for this project.

Main tasks are:

- explore literature and write a literature review
- apply technique to RTI data using ECN supercomputing facility
- run breaking wave simulation through conventional mean and apply ML techniques to the same problem

What you will learn

- Discover international research projects from the inside
- Develop strong data visualization and HPC skills, focusing on applied research.
- Contribute meaningfully to the project by delivering practical solutions for handling extreme-scale fluid dynamics datasets.
- Collaborate with experts in the field, gaining exposure to cutting-edge simulation tools and methodologies.

Intern profile

The ideal candidate is looking for a 5 or 6-month internship in a research lab to complete his masters or engineering degree in either of the following major: machine learning, scientific computing, applied math, mechanical engineering.

Required skills

- **Language:** Proficiency in written English is necessary. French or English for day-to-day communication
- At least one of the following **Computational Fluid Dynamics or Machine learning**
- Good knowledge of programming / scientific programming in **python** or **C++**.

References:

[1] Y. Zhang, D. Zhang, and H. Jiang, "Review of Challenges and Opportunities in Turbulence Modeling: A Comparative Analysis of Data-Driven Machine Learning Approaches," Journal of Marine Science and Engineering, vol. 11, no. 7, Art. no. 7, Jul. 2023, doi: 10.3390/jmse11071440.

[2] S. L. Brunton, B. R. Noack, and P. Koumoutsakos, "Machine Learning for Fluid Mechanics," Annu. Rev. Fluid Mech., vol. 52, no. 1, pp. 477–508, Jan. 2020, doi: 10.1146/annurev-fluid-010719-060214.

[3] https://www.monolithai.com/blog/machine-learning-for-turbulence-modeling

[4] A. Sengupta, P. Sundaram, V. K. Suman, and T. K. Sengupta, "Three-dimensional direct numerical simulation of Rayleigh-Taylor instability triggered by acoustic excitation," Physics of Fluids, vol. 34, no. 5, May 2022, doi: 10.1063/5.0091109.