Proposals for Master Thesis/Internship at the von Karman Institute

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July 11, 2020

This document collects an updated list of project proposals for Master Thesis and internship at the von Karman Institute within our group. The file will be updated approximately every two-three months; if you have ideas that could fit within the framework of the proposed project, please do not hesitate to contact me at mendez@vki.ac.be. Projects are usually designed to have a healthy combination of Experimental (E), Theoretical (T) or Numerical (N) research, and are all linked to activities that result from our industrial collaborations and projects.

1. Analysis and tuning of a data-driven algebraic model for the turbulent heat flux using Artificial Neural Networks (T/N)

The ongoing Machine learning revolution is firmly rooted in Artificial Neural Networks (ANN) and their remarkable success in solving complex regression tasks such as image or speech recognition. ANN can also be used as advanced regression tools to develop new turbulence models or improving existing ones. The calibration of the model parameters is a notoriously unsolved problem in turbulence modeling. Simple models based on linear relations between the mean flow and second-order statistics have often failed to generalize outside the validation range selected for the model tuning, while more sophisticated methods have usually posed insurmountable challenges to the regression. This project contributes to the development of a turbulence modeling framework based on artificial neural networks. Specifically, the recalibration of existing turbulence models for the heat flux is of particular interest in view of applications to heavy liquid metals. These latter are characterized by a different dynamics of turbulence compared to common fluids (air or water), thus requiring a specific calibration of the thermal models based on high fidelity data (DNS and LES).

The student will work on optimizing an ANN for such purpose, carrying out an exhaustive hyperparameters study to identify general guidelines for similar modeling problems. The parametric study will concern the network architecture, the number of hidden layers, the choice of the optimization algorithm, activation, and cost functions, as well as testing of various regularization strategies. The student will learn to manage the most important Python packages for data-driven regression, and he/she will improve his/her knowledge in turbulence modeling.

What should you know. You have a good background on numerical linear algebra, and you have basic knowledge of turbulence modelling and numerical computing and programming.

Duration: 3-4 months. **Co-Supervisor**: Ir. M. Fiore.

2. Development of a 3D Solver for Integral Modeling of Coating flows (T/N)

Liquid films are encountered in many industrial applications and are the canonical flow in many heat and mass transfer equipment and coating processes. These flows are hydrodynamically unstable, meaning that their interface naturally tends to develop wavy interfaces and fascinating patterns (see, for example, the fantastic wave patterns produced on a liquid layer falling over the windshield of a car on rainy weather). Understanding these instabilities is fundamental in any application: they drastically enhance heat and mass transfer and severely compromise the quality of a coating process. This thesis aims at developing a numerical solver to study the 3D evolution of a liquid film on a moving substrate. The student will learn how to implement Finite Volume methods to solve complex fluid flow problems using Python and the fundamentals of parallel computing. Moreover, being involved in a large programming project, the student will develop significant computational proficiency.

What should you know. You have a good understanding of numerical methods and Computational Fluid Mechanics (CFD). You have a good background in numerical computing and programming.

Duration: 3-4 months. **Co-Supervisor**: Prof. Buchlin and Ir. Pino.

3. Modeling of Electromagnetic Actuators for Control of Metal Coatings (T/N)

Liquid metals are encountered in many coating industries (e.g., galvanization), where they are employed for their surface properties and chemical protection capabilities (e.g., versus corrosion) as well as in Nuclear applications (e.g., metal cooled reactors), where they are employed for their high thermal conductivity and low specific heat. While molten liquids play a critical role in many industrial applications, pumping or controlling their distribution on a surface is exceptionally challenging: these liquid are extremely heavy, and often flows at very high temperature. A critical technology in their usage is the use of electromagnetic actuators, which exploit the electrical conductivity of the metal to drive the liquid into motion using a carefully designed magnetic field.

This thesis aims at developing a simple numerical solver to study the possible application of electromagnetic actuators to control the liquid distribution of metal coats onto a surface. The student will learn the fundamentals of magneto-hydrodynamics and to implement basic 1D Finite Volume methods to study a simple, but an industrially relevant problem. Computational proficiency in Python will be naturally acquired.

What should you know. You have a good understanding of electromagnetism and viscous flows. You have a basic background in numerical computing and programming.

Duration: 3-4 months. **Co-Supervisor**: Prof. Buchlin and Ir. Pino.

4. Closed-Loop Control via Machine Learning Methods (T/N)

Closed-loop control refers to the process of interacting with a dynamical system via actuation that is informed by sensor measurements. The design of robust control strategies is fundamental in a wide range of applications for energy, transportation, and process industries and is one of the most challenging and active areas of research. Classical methodologies based on linear control theory and optimization are nowadays progressively being replaced by innovative model-free methods arising from the Big Data revolution: Genetic Programming and Genetic Algorithms, as well as Deep Neural Networks, are now offering a novel data-driven paradigm that might completely revolutionize applied science.

This thesis aims at studying different classical methodologies and compare them with the most advanced model-free methods based on Machine Learning techniques. The student will explore one of the most rapidly developing fields at the intersection between fluid mechanics and data science, will learn to control systems of growing complexity, and will acquire essential experience in one of the most sought-after areas of engineering: Machine Learning.

What should you know. You have a basic understanding of ordinary differential equations and dynamical systems in general. You have a basic background on control theory and basic knowledge of Matlab or Python programming.

5. Development of Parallel Particle Image Velocimetry Tool-Box (E/N)

Initially developed at the von Karman Institute in the early '80s by Meynart, Particle Image Velocimetry (PIV) is nowadays one of the fundamental methods for velocity measurements in fluid flows. This techniques is non-intrusive and is based on the measurement of the velocity of a fluid element by measuring the displacement of tracer particles injected within the flow. The recent technological evolution on the illumination sources (typically dual cavity laser systems) and recording technology (usually high-speed CMOS camera) has given to this technique the possibility to reach unprecedented time and spatial resolutions, and evolve into a 3D method.

At the core of the method is the evaluation of the images of tracer particles to extract their displacement and hence the velocity field. This is typically done using cross-correlation of various portions of the images, progressively reduced, deformed and shifted in multiple steps, until the final velocity field is obtained. At the von Karman Institute, we use open-source tools in Python (OpenPIV) and Matlab (PIVlab) as well as expensive commercial solutions and in-house codes. This work aims at further developing the existing tools at the von Karman Institute, by implementing a complete Python toolbox working with state of the art evaluation schemes and parallel computing. The student will learn the fundamentals of PIV, mastering the image evaluation process along with the required image and data processing tools and parallel computing.

What should you know. You have a good working knowledge of Python and/or Matlab programming.

Duration: 4-5 months. **Co-Supervisor**: Dr. Simonini.

7. Measurement of Dynamic Contact Angles via Image Processing (T/E)

The ability of a liquid to spread over a surface, known as wetting, is of great interest both from fundamental and applied points of view. Lubrication, coating, and printing are some examples of technological applications that entirely rely on good wetting. Almost any wettability study involves the measurement of the contact angles, that is the angle that the liquid interface forms with the solid surface at the three-phase contact line. In dynamic conditions, as the liquid moves along and spreads over the solid surface, the motion of the contact line is governed by several complex mechanisms that are still poorly understood and the subject of active research.

This project aims at developing an inverse method for dynamic contact line measurement combining high-speed flow visualization, image processing techniques, and system identification via Machine Learning methods. The project fits in the framework of an ongoing Ph.D. thesis. The student will take part in the measurement campaign and contribute to the development of the identification algorithm in Python. The procedure consists of acquiring a set of high-speed videos of a moving interface, use image processing methods to retrieve the interface motion, and finally use a regression-based algorithm to fit the interface dynamics on a model of the dynamic contact line. Because of its multidisciplinary structure, the project offers the student the possibility to develop skills at the intersection between experimental fluid mechanics and data processing.

What should you know. You have a good understanding of experimental fluid mechanics and optics. You have a basic background on computing and programming, required for image processing.

Duration: 4-5 months. **Co-Supervisor**: Dr. Simonini and Ir. Fiorini.

8. Development of a Python Package for Data-Driven Decomposition (T/N/E)

The data-driven modal decomposition of experimental and numerical data is becoming an increasingly important step in the post-processing of large numerical and experimental datasets. These decomposition aims at representing a large dataset (produced by LES calculations or large PIV campaigns) as combinations of simple structures, referred to as modes, that capture the essential dynamics in the data. As the size of numerical and experimental datasets continue to grow with the progress of our experimental and numerical capabilities, these decompositions play an essential role in distilling the relevant information, enabling filtering, data compression, feature recognition and to developing reduced models of complex phenomena. Examples of such decomposition are the Proper Orthogonal Decomposition (POD) or the Dynamic Mode Decomposition (DMD), and the recently proposed Multiscale POD.

This thesis aims at developing a Python Package to perform data-driven modal analysis of experimental and numerical data. Both experimental data from PIV and numerical simulations using LES will be used as the initial database, and the decomposition implemented will include both the classical POD and DMD as well as more advanced decomposition. The student will learn the fundamentals of data-driven sciences, process many large scale datasets produced at the von Karman Institute, and learn how to develop Python packages.

What should you know. You have a good background on numerical linear algebra, and you have basic knowledge of numerical computing and programming.

Duration: 3-4 months. **Co-Supervisor**: Prof. Chazot and Ir. Torres.

9. Modeling of Water Curtains to Mitigate Hazardous Heavy Clouds (T/N)

In petrochemical and gas industries, it is of paramount importance to be able to handle the accidental release of dangerous toxic or flammable clouds. A widely recognized solution consists of using water curtains: arrays of various sprays of water released perpendicularly to the flow direction of the gas cloud. These provide three barriers against the diffusion of the cloud, linked to the capability of the water curtain to exchange momentum, mass, and energy. The first barrier, due to the momentum exchange, is represented by the ability of water spray to entrain external flows and hence eventually force part of the cloud towards the ground. The second barrier, due to mass exchange, is represented by the ability of water to absorb various dangerous compounds chemically. The third barrier, due to energy exchange, is linked to the large heat capacity of the water, its large latent heat, and radiation absorption spectra. These properties make water capable of significantly reducing the cloud temperature and provide significant thermal shielding.

This thesis aims at developing a theoretical model and a numerical simulation to study the performance of a water spray in the mitigation of various hazardous gas release. The student will first work in the formulation of a Eulerian/Lagrangian software in Python and then analyze multiple test cases. He/she will learn about the modeling of two-phase flows, numerical computing, and Python programming.

What should you know. You have a good background in Computational Fluid Dynamics (CFD) and basic knowledge of Python programming.

Duration: 5-6 months. **Co-Supervisor**: Prof. Laboureur.