Proposals for Master Thesis/Internship at the von Karman Institute

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This document collects an updated list of project proposals for Master Thesis and internship at the von Karman Institute (VKI) within my group. These project will be carried out in the framework of the VKI's Short Training Program (STP). For more information on the STP program, please visit and apply at:

https://www.vki.ac.be/index.php/short-training-program

The file will be updated approximately every six 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.

All theses 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. Projects involving experimental activities have a minimum duration of 5 months. Note that the order in which these are listed does not reflect the relevance of the project.

1. Development of Machine Learning Methods for Flow Control (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.

Duration: 3-4 months. **Co-Supervisor**: Ir. F.Pino.

2. Experimental Analysis of Flow Control Schemes for Sloshing Control (T/E)

The closed-loop control of fuel sloshing in spacecraft tanks is one of the critical enablers to optimize vehicle maneuverability and to minimize the risks of engine re-ignition due to improper propellant location at the tank outlet. While sloshing control has been traditionally addressed using passive methods (e.g., adding baffles in the tank or filtering out sloshing resonant modes from the Guidance Navigation and Control (GNC) system), closed-loop control offers significant advantages in terms of stabilization performances, reduced fuel consumption and self-tuning capabilities to cope with unpredictable forcing.

This thesis will contribute to the development of future launchers by testing and developing novel data-driven methods for propellant sloshing control. The thesis will combine theoretical and experimental work. In particular, it is of interest to test different open loop strategies in the Shakespeare laboratory (see https://www.vki.ac.be/index.php/news/710-von-karman-institute-test-laboratory-shakespeare-accredited-by-belac).

The student will first analyze various control methods on simplified (linear models of the sloshing problem) and will then implement the best control strategy in a simplified laboratory test bench. After an initial training on control methods and the fundamentals of sloshing, the student will be involved in all the steps of the experiments, from the design of the experimental set up, to its instrumentation and the post-processing of the data.

What should you know. You have a basic understanding of ordinary differential equations and control theory in general. You have a good working knowledge of Python programming. Experience in experimental work is a valuable plus.

Duration: 5-6 months. **Co-Supervisor**: Dr. Simonini.

3. 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 re-calibration 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.

4. Heat Transfer Phenomena in 3D-Printed Cooling Channels for Space Engines (N/T) Additive manufacturing is revolutionizing the design, optimization, and production of many components in the aerospace industry. While enabling unprecedented freedom in shapes design and optimization and reducing manufacturing costs, additive manufactured products are characterized by significantly higher wall roughness. In the cooling channels of rocket thrust chambers, the higher wall roughness modifies pressure drop and heat transfer in a currently unpredictable way. This project aims to studying and isolating the effect of the increased wall roughness on the flow thermohydraulic performing experiments in 3D printed cooling mini-channels. The experimental data will produce benchmark test cases to validate high-fidelity numerical models and cost-efficient engineering tools. Two-phase flow phenomena like nucleate and film boiling will be studied.

The student will perform Conjugated Heat Transfer numerical simulations to support the design of the experimental test section. Furthermore, the activity foresees the development of an inverse method for the heat conduction equation. The model will be developed with the temperature field obtained with the numerical simulations

What should you know. You have a good background in CFD and in heat transfer phenomena.

Duration: 5-6 months. **Co-Supervisor**: Dr. Scelzo and Ir. Peveroni.

5. 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: 5-6 months. **Co-Supervisor**: Dr. Simonini and Ir. Fiorini.

6. 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**: Ir. Pino.

7. CFD study of flapping aerodynamics with the overset method (N/T)

Flapping wing micro air vehicles (FWMAVs) mimic birds and insects to reproduce their outstanding flight capabilities. Their wings manipulate complex flow structures in highly unsteady, low Reynolds flows. Currently, flapping aerodynamics is still not fully understood and high fidelity Computational Fluid Dynamic simulations could shed the light on the different bird maneuvers.

This project aims to develop a CFD environment to accurately simulate and analyze flapping wings in realistic flight regimes. Starting with simple wing shapes in flapping motion, the student will perform CFD simulations in OpenFOAM using the overset meshing technique. The student will study the numerical limits of the environment: different grids, turbulence models, schemes, etc will be compared. Then, CFD computations will highlight the benefits of bio-inspired wings and will evaluate the aerodynamic performance of different wing kinematics corresponding to flight scenarios such as hovering and forward flight. The project will be concluded by the dynamic CFD simulation of a simple flapping drone performing a typical bird maneuver. The high fidelity CFD environment will then pave the way towards a complete understanding of flapping flight.

What should you know. You have a basic background in CFD. Experience with OpenFOAM is a plus.

Duration: 3-4 months. **Co-Supervisor**: Dr. Koloszar and Ir. Poletti