2020 Doctoral research projects for PhD recruitment
Institut Pprime

TURBULENT FLOW CONTROL BY MACHINE LEARNING: IMPOSITION OF SYMMETRY AND INVARIANCE CONDITIONS

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3-year contract: 1715 € raw monthly salary. **Funding guaranteed for 3 years.**

Key-words: flow control, closed-loop, Machine Learning, imposition of symmetry and invariance conditions, Deep Neural Networks, Recurrent Neural Networks, Reinforcement Learning

Framework.

In recent years, continuous progress has been made on the performance of both civilian and military aircraft and helicopters, particularly in terms of flight envelope, radiated noise, maneuverability, vibration, etc. However, further improvements can be achieved by using **closed-loop fluid flow control** around the machine. This strategy consists of using measurements from sensors placed on the system, to adapt, if possible in real time, the control command to impose. From a control point of view, the main interest of closed loop is to improve the robustness of the control law. In practice, the development of closed-loop control strategies is largely complicated by the **highly non-linear and multi-scale nature of the turbulent flows** encountered in the targeted configurations.

In order to develop efficient control strategies, various issues must be addressed. In the classical approach followed in flow control, it is indeed necessary:

1. to model the flow dynamics;
2. to estimate the state of the system from scattered and/or indirect measurements;
3. to place optimally actuators (used to introduce control) and sensors (used to reconstruct the state);
4. to determine optimally a control law.

Objectives.

This thesis will contribute to the development of **realistic closed-loop control strategies for unsteady turbulent flows**. Applications include the drag reduction around profiles (by attaching the boundary layer or delaying its separation), the reduction of radiated noise, the flow vectorization to improve the maneuverability or to remove some of the moving air spoilers, the decrease of vibrations induced by dynamic stall, etc.

Work program, methodologies and means.

We propose to develop a widely **bio-inspired approach**. In the living world, insects and birds develop very efficient flight control strategies by having at their disposal a minimum of sensors/actuators and without knowing a priori dynamical models. On the other hand, by interacting with their environment, they acquire information that is used as they evolve to optimize their performance. We will therefore develop an approach based solely on measurements (**Data Driven**), and not on a priori knowledge of physical models, and will exploit recently developed **Machine Learning** methods.

We will first focus our efforts on the dynamical modeling of turbulent flows based on data. For this purpose, we will make extensive use of neural networks, either deep (Deep Neural Network, DNN) or recurrent (Recurrent Neural Network, RNN). We are particularly interested in the **properties of symmetry and invariance** verified by the flow. A first approach will consist in imposing in the architecture of the neural models the properties of symmetry and invariance which are supposed to be verified by the system. A second approach will consist in studying the capacity of these neural models to autonomously derive these symmetry and invariance properties.

In a second step, we will revisit the **data assimilation methods** classically used in the literature (variational or stochastic approaches) under the prism of machine learning methods.

Finally, we will couple previously developed neural models to a **Deep Reinforcement Learning** (DRL) algorithm in order to determine a control strategy. Our strategies will be developed and tested on simple dynamical systems (Lorenz, Ginzburg-Landau, ...) to facilitate the development and, subsequently, on a case of turbulent flow.

The funding is guaranteed for 3 years in the framework of the 80|Prime interdisciplinary project opened by the CNRS. This topic is at the heart of the CNRS Research Group "Flow Control Separations", whose Director is Laurent Cordier (Pprime).

Applicant profile, prerequisites.

Master in Fluid Mechanics / Applied Mathematics / Machine Learning. Appetite for interdisciplinary approaches and machine learning. Desire to go beyond the borders.