2020 Doctoral research projects for PhD recruitment
Institut Pprime

TURBULENT FLOW CONTROL BY MACHINE LEARNING

Department: Fluids, Thermal and Combustion Sciences
Research team: Incompressible Turbulence and Control
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3-year contract: 1768 € raw monthly salary. **Funding guaranteed for 3 years.**

Key-words: flow control, closed-loop, Machine Learning, Genetic Programming Control, Reinforcement Learning, Recurrent Neural Network, Deep Reinforcement Learning

Framework and objectives.

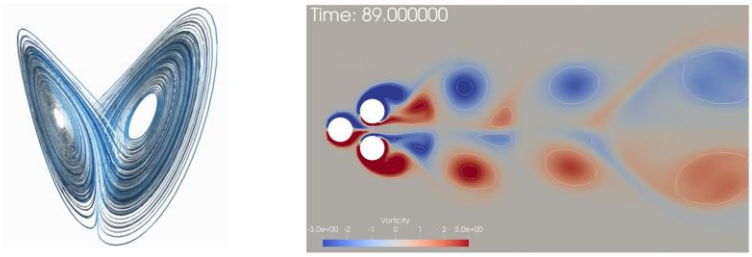
In recent years, continuous progress has been made on the performance of both civilian and military aircraft and helicopters, particularly in terms of flight envelope, radiated noise, maneuverability, vibration, etc. However, further improvements can be achieved by using **closed-loop fluid flow control** 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. Unfortunately, closed-loop control is currently only usable in a fairly limited range of flow configuration. Indeed, a turbulent flow exhibits both a broad spectrum of spatial scales and a very rich temporal dynamics. High-frequency phenomena (of the order of kHz) therefore require sufficiently fast control, able to adapt to changes in the state of the system. The time required to estimate the state of the system and calculate the command is thus less than the millisecond. This observation explains the difficulties of closed-loop control. As both flow manipulation and open-loop control are commonplace, there is very little example of closed-loop control over sufficiently realistic configurations, especially three-dimensional and turbulent configurations.

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 and means.

We propose to use a **pure data-driven approach**, rather than physical models, and to exploit newly developed **Machine Learning** methods. Genetic Programming Control (GPC), Reinforcement Learning (RL), Recurrent Neural Network (RNN), and Deep Reinforcement Learning (DRL) seem particularly well suited. We will focus our efforts on the intrinsic difficulties related to turbulent flow control: large-scale system, unknown and time-varying delays between actions and effects on the objective function, statistical non-stationarity, low observability, real-time constraint, etc. Our strategies will be developed and tested on model dynamical systems (Lorenz, Ginzburg-Landau) to facilitate developments and, subsequently, on a turbulent flow configuration, the wake of three staggered cylinders (Fluidic Pinball) individually controlled by unsteady rotation (see Figure). To do this, we will rely on our expertise in control theory, large-scale approximation methods, statistical learning, etc. and our first successes with Machine Learning strategies (Guéniat et al., 2016, Pivot et al., 2017, Mathelin et al., 2017, Bucci et al., 2019).

The funding is guaranteed for 3 years. This subject is part of the ASTRID project FLOWCON (2018-2020) coordinated by Lionel Mathelin (LIMSI). This topic is also at the heart of the CNRS Research Group "Flow Control Separations", whose Director is Laurent Cordier (Pprime). For the submission step, the FLOWCON project was supported by Dassault Aviation via a letter of support.



(a) (b)

Illustrations of some of the configurations used to develop our closed-loop control strategies. (a) Model dynamical system (Lorenz). (b) Wake of three staggered cylinders controlled by unsteady rotation (Fluidic Pinball).

Applicant profile, prerequisites.

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