PROPOSITION DE SUJET DE THÈSE

Intitulé : Optimization strategies for the control of complex flows

Début de la thèse : Octobre 2023

Mots clés

Fluid mechanics, data-driven optimisation, computational fluid mechanics

Profil et compétences recherchées : Fluid mechanics, applied mathematics

Présentation du projet doctoral, contexte et objectif

The characterization of fluid instabilities and their mitigation through control techniques are of crucial importance to improve the efficiency of a wide range of fluid systems, in particular in terms of energy consumption. Applications may range from the enhancement of fuel injection systems in turbomachines to preventing transition to turbulence of boundary-layer flows in order to reduce drag. Accordingly, engineering applications may greatly benefit from the development of efficient and easily implementable methodologies for flow control.

Optimal control theory forms a powerful mathematical and well-established approach to identify flow control strategies. It can first be employed to identify external disturbances that are most amplified in the flow [1]. Identified based on the so-called 'worst-case scenario' or otherwise, control strategies may then be derived to reach the desired objective [2], e.g. preventing the development of flow perturbations or reducing drag. All these cases may be formulated as optimization problems where the aim is to minimize (or maximize) a given cost function under the constraint of the equations governing the flow. The latter are taken into account through a Lagrangian formalism and the introduction of adjoint variables and models, enabling the design of efficient gradient-based optimization procedures. However, the **derivation/implementation of the adjoint equations associated with the considered computational fluid dynamics (CFD) code is usually a delicate and computationally demanding task**. This is all the more true in the case where complex phenomena such as shocks and chemical reactions, which require elaborate numerical methods to handle, are involved (an example of which is shown in figure 1); thus hindering the application of the adjoint approach to aeronautical/engineering applications of interest.

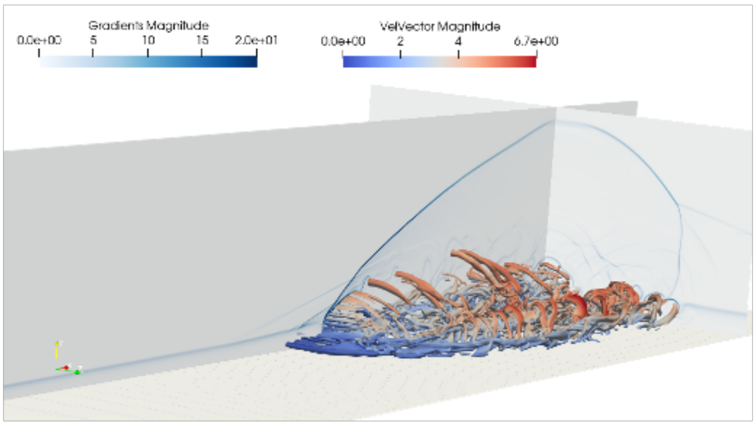

Figure 1: Direct numerical simulation of a normal jet injection into a high-speed crossflow, density gradient and velocity magnitude are illustrated.

In this context, **the main goal of this PhD project is to develop adjoint-free optimization techniques to enable the identification of control strategies for flows exhibiting complex physics as encountered in engineering applications**. We will in particular consider boundary-layer flows of increasing complexity as illustrated in Figure 1, gradually adding the consideration of crossflows, compressibility effects, shocks and chemical reactions. The aim of control will be to mitigate flow disturbances and prevent transition to turbulence through heating/cooling at the wall, among various possibilities to investigate.

As an alternative to the adjoint approach, we will consider **ensemble-based variational techniques (Ens-Var)** [3], which are significantly easier to implement, and where the optimal control strategy is searched in a subspace that is spanned by an ensemble of realizations, i.e. a number of simulations corresponding to different controls (e.g. different wall heat-flux fields). Building on a first application in the context of high-speed flows [4], the PhD student will explore the possibilities that are offered by ensemble-based variational techniques in the identification of control strategies and investigate several paths of methodological innovations. **In particular, we will target several strategies to ensure the physical soundness and practical feasibility of the identified control strategy, such as assisting the generation of ensembles based on resolvent/stability analysis [5-7] or the consideration of elaborate penalizations in the optimization problem.**

The project is envisioned as a cofinancement, with half of the funding for the thesis being provided by ONERA (this portion has already been approved by ONERA). The student will be attached to SMAER, but hosted by both Sorbonne Université and ONERA. The project will benefit from collaborations with the Florida Institute of Technology and Coventry University.

T. Sayadi will provide the expertise required to perform the linear instability analysis and the underlying large-scale simulations (HPC), and **V. Mons** will aid the adaptation and implementation of the Ens-Var techniques which will be used to perform the optimisation.

We have targeted ISCD as our funding body due to the following two reasons: (i) This project is positioned between multiple disciplines, including computer science, applied mathematics, and fluid mechanics, making ISCD and ideal host. In addition, (ii) this project is dependent on large-scale simulations reinforcing the High-performance Computing (HPC) initiative of the institute (the simulation of Figure 1 for example was performed on 1000 cores, using DARI allocation). We aim to implement an asynchronous scheduling code for making the embarrassingly parallel function calls needed in the Ens-Var technique even more efficient, thereby strengthening the HPC aspect of the project.

References

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Collaborations envisagées

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