www.onera.fr

ONERA

THE FRENCH AEROSPACE LAB

## PROPOSITION DE SUJET DE THESE

**Intitulé : Model Predictive Control based on domain decomposed reduced order models with adaptive hyper-reduction**

Référence : **MFE-DAAA-2025-029**
*(à rappeler dans toute correspondanc02e)*

| | |
|---|---|
| **Début de la thèse :** Octobre 2025 | **Date limite de candidature :** 15th May 2025 |

**Mots clés**

Flow control, Model reduction, CFD

**Profil et compétences recherchées**

Master 2 in Fluid Mechanics or Applied Mathematics, Engineering schools, … Good knowledge in numerical analysis.

**Présentation du projet doctoral, contexte et objectif**

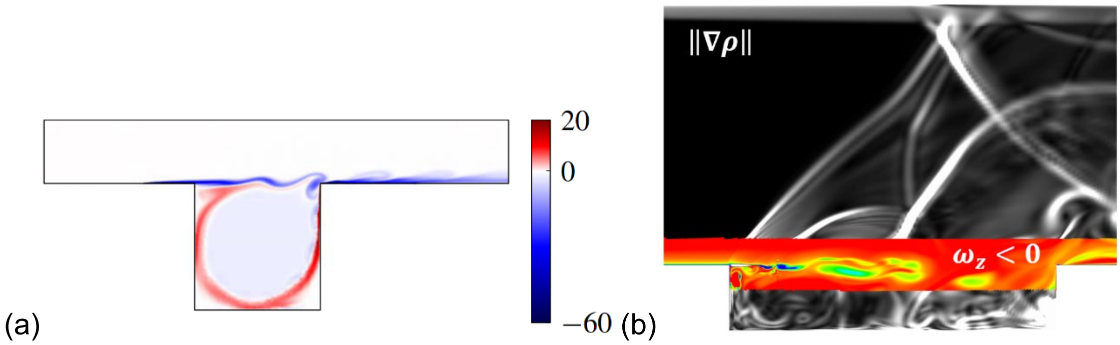


Figure1: (a) Incompressible open-cavity flow at Re=7500, (b) supersonic (M=1,6) open-cavity flow.

The objective of this thesis is to apply model predictive control (MPC) to reduced-models that are learned on the fly by projecting the Navier-Stokes equations on a POD basis that evolves adaptively due to new states that are encountered as control is applied. We consider as a first step the case of full-state-measurement, in which the current state is assumed to be known at all times (data-assimilation techniques could be leveraged in future work to adapt the methodology to the case of partial-state-measurements). The current sub-space (or manifold) can therefore be obtained and adapted through incremental SVD techniques [Singler] while the reduced-order model can be derived by hyper-reduction techniques [Farhat] and efficiently modified on the fly [Duraisamy]. To enhance the efficiency of the reduced-order-model, a physics-informed clustering of the spatial domain [Costanzo] can be additionally employed to obtain low-order approximations of the flow state in a number of dynamically distinct sub-domains. An approximation of the flow in the full domain can then be handled by a domain decomposition technique to fit the ensemble of local representations [Iollo].

With respect to reinforcement learning techniques, the present approach has the advantage of incorporating models obtained by physical governing equations and should therefore be more accurate and robust to extrapolation. This feature allows the overall algorithm to be quicker in finding the descent path toward the control objective. Several parameters are at hand to tune the accuracy of the models: number of sub-domains, size of adaptive reduced basis in each sub-domain, number of points used in the hyper-reduction technique to enforce the residuals of the

Navier-Stokes equations to be zero, correction or closure-term that can in principle be added to match past and current observations in the case where the model only captures part of the frequency context.

We will apply the methodology to cases of increasing complexity:

1. stabilization of 2D incompressible open cavity-flow at Re=7500 (see figure 1a).
2. stabilization of supersonic open-cavity flow with data obtained from 2.5D LES simulation (see figure 1b) and model obtained by projecting a 2D URANS model.

References:


- [Singler]Fareed, H., Singler, J. R., Zhang, Y., & Shen, J. (2018). Incremental proper orthogonal decomposition for PDE simulation data. Computers & Mathematics with Applications, 75(6), 1942-1960.
- [Farhat] Farhat, C., Chapman, T., & Avery, P. (2015). Structure-preserving, stability, and accuracy properties of the energy-conserving sampling and weighting method for the hyper reduction of nonlinear finite element dynamic models. International journal for numerical methods in engineering, 102(5), 1077-1110.
- [Duraisamy] Huang, C., & Duraisamy, K. (2023). Predictive reduced order modeling of chaotic multi-scale problems using adaptively sampled projections. arXiv preprint arXiv:2301.09006.
- [Iollo] Riffaud, S., Bergmann, M., Farhat, C., Grimberg, S., & Iollo, A. (2021). The DGDD method for reduced-order modeling of conservation laws. Journal of Computational Physics, 437, 110336.
- [Costanzo] Costanzo, S. (2022). Numerical methods for control and optimisation of fluid flows (Doctoral dissertation, Sorbonne Université).


**Collaborations envisagées**

The thesis will be led within the project DINAMIC funded by ANR. You will work in close connection with M2N at CNAM (Taraneh Sayadi) and ETH Zürich (George Haller). 3 PhD students will be hired at the same time, that will closely collaborate.


| **Laboratoire d’accueil à l’ONERA** | **Directeur de thèse** |
| --- | --- |
| Département : DAAA | Nom : Taraneh Sayadi |
| Lieu (centre ONERA) : Meudon | Laboratoire : M2N/CNAM |
| **Contact** : Denis Sipp & Colin Leclercq | Email : taraneh.sayadi@lecnam.net |
| Email : denis.sipp@onera.fr | |


Pour plus d’informations : https://www.onera.fr/rejoindre-onera/la-formation-par-la-recherche