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PROPOSITION DE SUJET DE THESE

Intitulé : Optimal Domain Decomposition in Multifidelity Modeling for Uncertain Geometries in Fluid-Structure Interaction: projection-based model reduction and data assimilation.

Référence : **SNA-DAAA-2024-16**
(à rappeler dans toute correspondance)

Début de la thèse : Octobre 2024	**Date limite de candidature :** 30/6/2024

Mots clés

Multifidelity, Reduced order models, Domain decomposition, Data assimilation, Optimization, Fluid-structure interaction

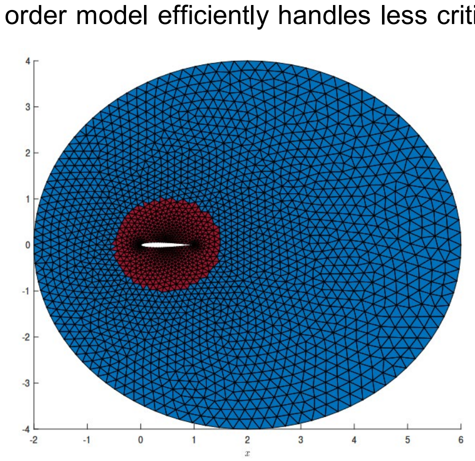
Profil et compétences recherchées

The applicant should have a Master's or engineering degree in applied mathematics, mechanical engineering, scientific computing, computer science, artificial intelligence or equivalent. Knowledge of and experience in Python programming is a plus. The ideal candidate has a good knowledge of either reduced order models or numerical methods for PDEs and CFD.

Présentation du projet doctoral, contexte et objectif

In the area of computational fluid dynamics and fluid-structure interaction in the turbulent regime, there may be geometric uncertainties that impact the numerical solution to be found. These geometric quantities affect the position of the structure, its shape or the geometric domain circumscription on which to apply a specific numerical model of turbulence (i.e., RANS). With respect to these uncertainties, however, it is usually possible to find some measurements of some direct physical quantities (such as velocity or pressure) or indirect quantities (e.g., aerodynamic coefficients). In this context, the measurements are recovered via high-fidelity numerical approaches.

High-fidelity models (HFMs), characterized by their detailed representation of physical phenomena, offer unparalleled accuracy but often come at the cost of high computational expenses. In contrast, reduced order models (ROMs) provide computationally efficient approximations, sacrificing some level of accuracy for speed. The fusion of these two modeling approaches presents a compelling paradigm, combining the strengths of both to address a wide range of practical applications. For instance, computational fluid dynamics simulations concerning turbulent phenomena in aerodynamics exemplify HFM. While these models provide a comprehensive understanding of system behavior, they demand substantial computational resources and time, making them impractical for real-time applications or large-scale parametric studies. The fusion of HFMs and ROMs leverages the strengths of each approach, creating a powerful and versatile toolset for modeling complex systems [1]. This integration typically involves coupling a high-fidelity model with a reduced order surrogate, where the high fidelity model provides detailed information in regions of interest, while the reduced order model efficiently handles less critical aspects of the system. This synergistic approach enables real-time or near-real-time simulations of systems that would be otherwise computationally prohibitive.



In this direction, one approach that has gained prominence in recent years is multifidelity in domain decomposition (DD) [2,3]. DD is a numerical technique used to solve partial differential equations (PDEs) by breaking down a complex domain into smaller, manageable subdomains (see figure on the left, it depicts a DD for a NACA airfoil geometry). Each subdomain is solved independently, and then the solutions are coupled at the interfaces between them. Multifidelity in DD is an extension of this method that combines simulations at different levels of fidelity to enhance the accuracy and efficiency of the overall solution. In multifidelity [4] approaches, simulations are conducted at multiple levels of fidelity. The objective for the thesis is to leverage the strengths of different fidelity models to achieve a more accurate and cost-effective solution.

Consequently, such an approach has measurable advantages over the computational efficiency, error reduction, optimization and uncertainty quantification up to the scalability of the original physical system.

In the realm of aerospace engineering and their applications, the fusion of numerical models with either real-world or high-fidelity data has become an essential paradigm. This process, known as data assimilation (DA), serves as a cornerstone for enhancing the accuracy and reliability of simulations [5]. DA not only allows to correct and refine model predictions but also enables the seamless integration of models with optimal control and ROM strategies. DA refers to the systematic integration of provided data with numerical models to estimate the state of a system, update model parameters, and improve predictive capabilities.

The methodological research of the thesis focuses on the following axis. The high-fidelity numerical data will be exploited for the creation of a proper database. It will then be used in such a way as to obtain a reduced basis and thus the possibility of finding a parametric numerical solution. In the context of physical phenomena whose uncertainty falls on the geometry, the interest of the research is to find the optimal domain decomposition between reduced part and high-fidelity part with a data-driven approach. This allows to circumscribe the geometric region of influence to the observable data and thus optimize the reduction process. As natural applications, this PhD investigates the interplay between DA and ROM through dynamic and mutually reinforcing relationship. In particular, DA provides the means to continuously update model parameters and states, ensuring that reduced-order models remain accurate representations of the true system. The possibility to dynamically define the subdomain of the reduced solution turns to be a milestone of the thesis. Among the test cases of interest, mostly stationary and turbulent fluid-structure interaction phenomena will be studied.

References

[1] Carlino, M. G. (2021). ADER scheme on Overset Grids with Compact Transmission and Hyper-reduction: Application to incompressible Navier-Stokes equations (PhD dissertation, Université de Bordeaux).

[2] Farhat, C., Lesoinne, M., & Pierson, K. (2000). A scalable dual-primal domain decomposition method. Numerical Linear Algebra with Applications, 7(7-8), 687-714.

[3] Brezzi, F., & Marini, L. D. (1994). A Three-field domain decomposition method. Contemporary Mathematics, 157, 27-27.

[4] Fadai-Ghotbi, A., Friess, C., Manceau, R., & Borée, J. (2010). A seamless hybrid RANS-LES model based on transport equations for the subgrid stresses and elliptic blending. Physics of Fluids, 22(5).

[5] Franceschini, L., Sipp, D., & Marquet, O. (2020). Mean-flow data assimilation based on minimal correction of turbulence models: Application to turbulent high Reynolds number backward-facing step. Physical Review Fluids, 5(9), 094603.

Collaborations envisagées

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