PROPOSITION DE POST-DOCTORAT

Intitulé : Robust optimisation of aerodynamic shapes for innovative engine and aircraft design

Référence : **PDOC-DAAA-2024-01**
(à rappeler dans toute correspondance)

Début du contrat : Octobre-Novembre 2023	**Date limite de candidature : 31/07/2023**

Durée : 18 mois

Mots clés : Uncertainty Quantification, CFD, Robust Optimisation, Aerodynamics

Profil et compétences recherchées

- A Ph.D. degree in a relevant field such as Aeronautics, Mechanics, Applied Mathematics or Applied Physics with focus on mathematical modelling and/or numerical simulations.
- Sound background in statistics and good skills in scientific programming.
- Experience in CFD is desirable.
- Knowledge of Uncertainty Quantification is a plus.
- Good publication record as a first authors in peer-reviewed journals.
- Ability and high self-motivation to work both independently and as part of international research project.
- Excellent oral and written English.

Présentation du projet post-doctoral, contexte et objectif

Context:

During the last decades, computing power has largely increased, contributing to make Computational Fluid Dynamics (CFD) a quite mature tool for industrial design, widely exploited for various applications. However, the awareness of discrepancies between the ideal conditions of numerical simulations and the real ones has motivated the increasing attention towards sensitivities of classical optimal shapes to uncertain parameters [5], and robust design techniques [6].

These uncertainties are usually of two kinds: epistemic and aleatory. The first one originates in our lack of knowledge in the modelling of the physical phenomena. In this context, Uncertainty Quantification (UQ) can help making our physical models more reliable. The second type is related to the variability in shape or flow conditions and although it cannot be controlled, it still needs to be taken into account in the design process. For example, deviations of real aerodynamic shapes from their reference design are often encountered, not only due to manufacturing tolerances but also to temporary and permanent degradation of aerodynamic surfaces along their lifespan.

Consequently, to be able to provide a robust aerodynamic shape by numerical optimisation, uncertainties must be integrated in the design process. The state of the art of shape optimisation provides, with the adjoint approach, the capability to tackle high dimensional design space [12]. However, on the other hand, the number of uncertain inputs can also become significantly large and, today, for such complex cases treated with High-Fidelity (HiFi) CFD, designers are struggling with what is known as the "curse of dimensionality". This curse represents the main bottleneck for the widespread application of UQ techniques in the industrial framework. The development of innovative approaches able to overcome this issue represents an active research field, to which ONERA contributes by internal projects as well as in close collaboration with industrial aeronautical partners, such as in the framework of the ongoing project UE NEXTAIR (*multi-disciplinary digital - enablers for*

NEXT-generation AIRcraft design and operations, https://cordis.europa.eu/project/id/101056732). Indeed one of the main objectives of the NEXTAIR project is to improve the efficiency of uncertainty quantification and robust optimisation techniques enabling their industrial up-scaling with application to innovative and greener concepts.

Research Activity and Objectives:

The postdoctoral research fellow will strongly contribute to the development and demonstration of robust CFD-based aerodynamic shape optimisation in the framework of NEXTAIR. In a first step he will assess the most advanced non-intrusive UQ methodologies enabling the high-dimensionality on the academic and industrial test cases considered in the project. The main focus will be on efficient polynomial chaos techniques [1], [2] which can afford a reduced number of expensive CFD computations: compressed sensing (Least Angle Regression [9], Basis Pursuite Denoise [10]) and adjoint-gradient enhanced variants [11] of the standard least-square approximation. One particularity of this research work is the availability of analytical derivatives (adjoint) of the aerodynamics performance with respect to the design and uncertainty variables. This information will be used to improve the uncertainty propagation and large-scale robust optimization process It will first be considered as accurate then as possibly slightly biased [11]. The implementation of the gPC methods will mainly rely on the functionalities already available in the open-source toolboxes OpenTURNS [7] (http://openturns.github.io/) and eQuadrature [8] (https://equadratures.org/) although further and specific developments may be needed. Once the most reliable UQ methodology has been identified, the research activity will address the proper formulation of the robust optimisation problem and its effective implementation, strongly contributing to the expected demonstrations on different configurations. Two challenging test cases will be considered: 1) the robust aeroelastic optimisation of high aspect-ratio wing with respect to uncertainties affecting the twist law and the stiffness of the wing structure; 2) the robust aero-propulsive optimisation of an Unducted Single Fan (USF) engine concept and a wing in interaction. For this second test case uncertainties on boundary conditions will be introduced for the propeller blade design while uncertainties on the engine parameters will be considered for the wing shape optimisation, through a body-force modelling [3], [4] of the propeller and the stator.

References:

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[2] Savin, E., Resmini, A., & Peter, J. E. (2016). Sparse polynomial surrogates for aerodynamic computations with random inputs. In 18th AIAA Non-Deterministic Approaches Conference (p. 0433).

[3] W. Thollet, “Body force modeling of fan-airframe interactions”, Ph.D. dissertation, Institut Supérieur de l’Aéronautique et de l’Espace (ISAE-SUPAERO), 2017.

[4] B. Godard, “Étude et méthodologies de simulation de doublet entrée d’air - soufflante pour la conception de turbofan de nouvelle génération”, Ph.D. dissertation, Institut Supérieur de (ISAE-SUPAERO), 2018.

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[6] C. Sabater, P. Bekemeyer and S. Görtz. "Robust Design of Transonic Natural Laminar Flow Wings under Environmental and Operational Uncertainties," AIAA 2021-0071. *AIAA Scitech 2021 Forum*. January 2021.

[7] Baudin, Michaël, Dutfoy, Anne, Iooss, Bertrand, Popelin, Anne-Laure. OpenTURNS: An Industrial Software for Uncertainty Quantification in Simulation, Handbook of Uncertainty Quantification, Springer International Publishing, 1–38, 2016.

[8] P Seshadri, G Parks. Effective-Quadratures (EQ): Polynomials for Computational En-gineering Studies. The Journal of Open Source Software 2 (11), 2017.

[9] B. Efron, T. Hastie, I. Johnstone, and R. Tibshirani, 2004, “Least angle regression”, Annals of Statistics 32, 407–499.

[10] Chen, S., & Donoho, D. (1994, October). Basis pursuit. In Proceedings of 1994 28th Asilomar Conference on Signals, Systems and Computers (Vol. 1, pp. 41-44). IEEE.

[11] Ghisu, T., Lopez, D. I., Seshadri, P., & Shahpar, S. (2021). Gradient-enhanced least-square polynomial chaos expansions for uncertainty quantification and robust optimization. In AIAA AVIATION 2021 FORUM (p. 3073).

[12] J. Peter, F. Renac, A. Dumont, M. Méheut. Discrete adjoint method for shape optimization and mesh adaptation in the elsA code. Status and challenges. Congrès 3AF Toulouse, 2015.

Collaborations extérieures

Laboratoire d'accueil à l'ONERA

Département : DAAA

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