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PROPOSITION DE SUJET DE THESE

Intitulé : Robust aerodynamic optimization of innovative wing and engine integration concepts

Référence : **MFE-DAAA-2022-16**
(à rappeler dans toute correspondance)

Début de la thèse : 01/10/2022	**Date limite de candidature :** 01/06/2022

Mots clés

Aerodynamics, CFD, uncertainty quantification, global sensitivity analysis

Profil et compétences recherchées

In the last year of a Research Master or Engineering School, you have notions in fluid mechanics and ideally in aerodynamics. You show an interest in aeronautics, research and innovation. You have a taste for digital and programming and have notions of Python, fortran and C++. You demonstrate a good sense of critical analysis and autonomy allowing you to adapt quickly to a technically demanding work environment.

Présentation du projet doctoral, contexte et objectif

Context :

During the last decades, computing power has largely improved, contributing to make 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 robust design techniques [5], [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 improving our knowledge therefore making our physical models more and more reliable. The second type is related to the variability in shape or flow conditions and can not be controlled but 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 design solution by numerical optimization, both type of uncertainty must be integrated in the design process. On the one hand, the state of the art of deterministic design optimisation provides, with the adjoint approach, the capability to efficiently tackle high-dimensional problems, expanding the potential achievable improvement as the design space becomes larger. 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 CFD, we are struggling with what is referenced as the “curse of dimensionality”. This curse represents the main bottleneck for the widespread application of UQ techniques in industrial context. The development of innovative methods able to overcome this issue represents an active research field, to which ONERA contributes in close collaboration with industrial aeronautical partners.

Among today’s research fields of interest in civil aircraft design, particular attention is devoted to the understanding and optimization of mutual aerodynamic interactions between the wing and new disruptive engine concepts. These interactions become stronger with the increasing size of next-generation ultra-efficient engines such as UHBR and open-rotor concepts, thus introducing additional sources of uncertainties in the design of both sub-systems. Taking into account these aspects using coupled aero-propulsive optimization strategies and suitable UQ modelling is of utmost importance to avoid an overall degradation of the aero-propulsive performance at the integration stage.

Objectives :

The main objective of this thesis is to extend the knowledge as well as the capability of dealing with wing engine aerodynamic robust design using advanced strategies. For this purpose, advanced approaches enabling to consider high-dimensional design space as well as different sources of uncertainties will exploited. Prior to any technical work, a deep bibliographic analysis will be initiated and continued throughout the whole thesis to be able to take benefit of the knowledge and experience already disseminated within the optimization (robust as well as deterministic) community.

The initial efforts will be devoted to increase the understanding of the engine integration problem by conducting a thorough analysis of the physics at stake regarding the leading phenomena driving the interactions between the engine and the wing. Coupled analyses will rely on the body-force approach [3], [4] in order to reduce the computational burden associated to RANS simulation of rotating engine components.

To be able to perform deterministic as well as robust design, uncertain parameters will have to be defined. The study will rely on non-intrusive UQ methods to avoid any developments in the CFD solver. To overcome the issue of dimensionality advanced strategies will be developed, validated and applied to complex industrial test cases. The main focus will be on uncertainties affecting the shape of the wing and engine components (representative of manufacturing deviations from the reference shape) as well as operating conditions.

Different approaches will be exploited and combined to efficiently compute the probability density function of the output quantities at reduced computational cost. On the one hand, surrogate modelling (i.e. kriging techniques) and dimension reduction techniques (i.e. active subspace techniques) can be employed to reduce the computational cost of UQ and robust design. On the other hand efficient, sparse quadratures methods can be exploited to minimize the number of evaluations required by generalized polynomial chaos techniques [1], [2]. Open-source toolboxes such as OpenTURNS (http://openturns.github.io/) and eQuadrature (https://equadratures.org/) will be used to compared the different approaches.

The final objective will be to define a suitable optimization strategy taking into account multiple deterministic objectives and constraints as well as uncertain outputs to find the best candidate in terms of aerodynamic robust design.

[1] Generalized polynomial chaos and stochastic collocation methods for uncertainty quantification in aerodynamics Jacques Peter, Eric Savin, Itham Salah el Din, NATO course, STO-AVT-326 Uncertainty Quantification in Computational Fluid Dynamics 2018

[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), 2017, 2018.

[5] Ghisu, T., and Shahpar, S., "Affordable Uncertainty Quantification for Industrial Problems: Application to Aero-Engine Fans." ASME. *J. Turbomach*. May 2018; 140(6): 061005. https://doi.org/10.1115/1.4038982

[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.

Collaborations envisagées

This PhD will be conducted in the frame of European project in close collaboration with industrial partners.

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