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PROPOSITION DE SUJET DE THESE

Efficient Monolithic Solution Algorithms for High-Fidelity Aerostructural Analysis and Optimization.

Référence : **SNA-DAAA-2019-16** (à rappeler dans toute correspondance)

Laboratoire d'accueil à l'ONERA :
Domaine : Simulation Numérique Avancée (SNA)
Lieu (centre ONERA) : Châtillon (92)
Département : Aérodynamique - Aéroélasticité - Acoustique (DAAA)
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Aerostructural optimization is a keystone process to concurrently improve aerodynamic performance and reduce the structural mass of an aircraft. The increasing raise of composite materials in modern aircraft structures noticeably increased structural flexibility. In this context, fluid-structure interactions are to be considered when designing such highly-flexible structures. Optimization based on tightly integrated high-fidelity aerostructural analysis is particularly attractive because many of the objectives and constraints relevant to aircraft design include both aerodynamic and structural responses. To improve the design by considering a large number of parameters, gradient-based multi-disciplinary design optimization (MDO) techniques are required and now effective and widely used [1], [2]. However, gradient-based MDO is efficient if the computation of gradients is fast and accurate. This means that efficient solution strategies are required for the coupled problem driving the nonlinear multi-disciplinary analysis (MDA) and for the coupled linear sensitivity analysis for gradient computation purpose.

Two major approaches have been addressed in the literature: the partitioned approach and more recently the monolithic approach. The partitioned approach (also referred to as staggered method) has been used extensively in past research [3], [4], [5] (including at ONERA [6], [7], [8]). It is easier to implement, as it allows reusing existing routines from monodisciplinary solvers. However, this approach may lack of robustness when considering strong fluid-structure interactions and requires advanced relaxation techniques which then often lead to large computational costs. On the other hand, the monolithic approach offers a promising alternative which aims at solving the coupled system directly using iterative techniques. However, other difficulties linked to the numerical complexity of the fully coupled system arise and advanced scaling and preconditioning strategies associated to efficient iterative solvers are required (see [10] for an illustration of an advanced iterative Krylov solver applied to CFD problems). In addition, the nonlinear solution process for the coupled MDA problem often requires a non trivial initialization step [2], [9]. Also recent demonstrations have only been performed on inviscid flows governed by the Euler equations, which makes the current conclusions by the authors difficult to extend to RANS simulations.

The envisaged work plan of this PhD will be as follows:

o Literature review of iterative solvers and preconditioners best suited for structured-mesh CFD problems. Specifically, preconditioners, domain decomposition methods and advanced Krylov iterative solvers will be reviewed (see [11] for a comprehensive review). Some demonstrative numerical experiments will be performed with the core solver of the elsA CFD software. New promising solution techniques will be implemented and tested in a modular Python environment wrapping the elsA solver.

o Review of steady aeroelastic solution process and existing coupled-gradient computational approaches for aerostructural design [8].

o Explore alternative monolithic solution strategies for the coupled nonlinear MDA problem and the coupled tangent/adjoint linear sensitivity analysis problems. This exploratory work will be performed in a modular Python environment that will allow rapid and flexible prototyping of promising preconditioners and solvers.

o Demonstrate the new fully-coupled monolithic solver efficiency on a simple three dimensional flexible shape optimization of a standalone ONERA M6 wing and compare with the existing staggered solver.

o Application to a full aerostructural optimization of a civil transport aircraft composite wing box (typically the NASA Common Research Model configuration).

[1] Z. Zhang, S. Khosravi, and D. W. Zingg, "High-Fidelity Aerostructural Optimization with Integrated Geometry Parameterization and Mesh Movement," Structural and Multidisciplinary Optimization, vol. 55, pp. 1217-1235, 2017.

[2] G. K. W. Kenway, G. J. Kennedy, and J. R. R. A. Martins, "Scalable Parallel Approach for High-Fidelity Steady-State Aeroelastic Analysis and Adjoint Derivative Computations," AIAA Journal, vol. 52, pp. 935-951, 2014.

[3] J. J. Reuther, J. J. Alonso, J. R. R. A. Martins, and S. C. Smith, "A Coupled Aero-Structural Optimization Method for Complete Aircraft Configurations," in AIAA Paper 99-0187, 1999.

[4] K. Maute, M. Nikbay, and C. Farhat, "Coupled Analytical Sensitivity Analysis and Optimization of Three-Dimensional Nonlinear Aeroelastic Systems," AIAA Journal, vol. 39, pp. 2051-2061, 2001. [5] J. R. R. A. Martins, "A Coupled-adjoint Method for High-fidelity Aero-structural Optimization," Stanford University, Ph.D. dissertation, 2002.

[6] M. Marcelet, J. Peter, and G. Carrier, "Sensitivity Analysis of a Strongly Coupled System Using the Discrete Direct and Adjoint Approach," Revue Européenne de mécanique numérique, vol. 17, pp. 1077-1106, 2008.

[7] C. Blondeau, T. Achard, P. Girodroux-Lavigne, and R. Ohayon, "Recent Achievements towards Aero-Structure Gradient Computation using High-Fidelity CFD-CSM in the Onera elsA Software," in International Forum on Aeroelasticity and Structural Dynamics, IFASD 2015, Saint Petersburg, Russia, 2015.

[8] T. Achard, C. Blondeau, and R. Ohayon, "High-Fidelity Aerostructural Gradient Computation Techniques with Application to a Realistic Wing Sizing," AIAA Journal, Vol. 56, No. 11 (2018), pp. 4487-4499, doi:10.2514/1.J056736.

[9] Zimi, J. Zhang and David, W. Zingg, "Efficient Monolithic Solution Algorithm for High-Fidelity Aerostructural Analysis and Optimization," AIAA Journal, vol. 56, no. 3, pp. 1251-1265, 2018.

[10] X. Pinel and M. Montagnac, "Block Krylov Methods to Solve Adjoint Problems in Aerodynamic Design Optimization," AIAA Journal, vol. 51, pp. 2183-2191, 2013.

[11] Y. Saad, “Iterative methods for sparse linear systems”, Second Edition, SIAM, 2003.

PROFIL DU CANDIDAT

Formation : Master recherche ou Ecoles d'ingénieurs + Master recherche

Spécificités souhaitées : Mécanique des fluides, Mécanique des structures, Méthodes numériques. Goût pour la programmation et bon niveau d’Anglais seront également appréciés.