Multi-fidelity aeroelastic analysis and sensitivity analysis for gradient-based structural optimization

Kristofer Jovanov, * Roeland De Breuker, † and Mostafa M. Abdalla ‡

Delft University of Technology, 2629 HS Delft, The Netherlands

Christophe Blondeau, §

ONERA BP72 - 29 avenue de la Division Leclerc, FR-92322 Chatillon Cedex, France

In this paper a linear aerodynamics-based preconditioner is presented with the capability of reducing the solution time of high-fidelity aeroelastic analysis and sensitivity analysis. The idea is to improve the spectral properties of the linear systems in the aforementioned analyses by the application of a low-fidelity aerodynamic model as a preconditioner. Subsequently, the linear systems can be solved by fewer number of iterations, efficiently reducing the overall computation time. The solution method is demonstrated on the Onera M6 wing. The structural model of a classical wing box layout is solved by Nastran whereas the aerodynamic pressure distribution is obtained by solving the Euler equations using elsA. The low-fidelity sensitivities used to construct the preconditioner are obtained by an inhouse vortex-lattice code. The multi-fidelity approach shows improved convergence properties especially for flexible wings.

I. Introduction

The trend of employing high-fidelity models in the early design stages has become more pronounced with increasing computational resources, the advent of code parallelism and improving solution algorithms.[1–4] Nevertheless, high-fidelity models based on the Euler or the RANS equations are still considered computationally expensive. This has resulted in efforts to accelerate the convergence of high-fidelity analysis and sensitivity analysis through multi-fidelity modelling.

The idea is to make use of a mathematical model of presumably lower fidelity in order to speed up the convergence of the computationally heavier, but more accurate, models. In this work the high-fidelity aerodynamic model is based on the Euler equations. This enables an estimation of recompression shocks in the transonic flight regime. The low-fidelity aerodynamic model, based on vortex-lattice theory, does not have the predictive capability to capture these nonlinear effects due to the inherent approximations in the governing equations. The structural models in fluid-structure problems are in comparison to the aerodynamic models not considered computationally expensive. A modest number of degrees of freedom is typically sufficient to provide accurate structural deformations and stresses. Consequently, we only apply the multi-fidelity methodology to the aerodynamic models.

II. Methodology

In this work the linear systems in the aeroelastic analysis and sensitivity analysis are solved by the Krylov subspace method, GMRES.[5] Krylov methods, in general, experience faster convergence compared to stationary iterative schemes, such as the Jacobi, the Gauss-Seidel or the SOR method. However, to maintain a robust and efficient convergence rate of GMRES it is necessary to construct a quality preconditioner. The task of the preconditioner is to improve the spectral properties of the system matrix, such that when applied to an iterative solver, the number of iterations decrease. We construct this

*Ph.D. Student, Faculty of Aerospace Engineering, Aerospace Structures and Computational Mechanics, Kluyverweg 1; K.Jovanov@tudelft.nl

†Assistant Professor, Faculty of Aerospace Engineering, Aerospace Structures and Computational Mechanics, Kluyverweg 1; R.deBreuker@tudelft.nl

‡Associate Professor, Faculty of Aerospace Engineering, Aerospace Structures and Computational Mechanics, Kluyverweg 1; M.M.Abdalla@tudelft.nl

§Research Scientist,Aeroelasticity and Structural Dynamics Department, ONERA; Christophe.Blondeau@onera.fr

preconditioner based on the low-fidelity aerodynamic model. Thus we have a physics-based preconditioner that can accelerate the convergence of both the aeroelastic analysis as well as the sensitivity analysis.

III. Results

The results in Figure 1 indicate that the addition of a low-fidelity model significantly reduces the computation time. The test case was the Onera M6 wing at a transonic flight condition of Mach 0.84. The blue line is the covergence rate of the preconditioned system without the low-fidelity model whereas the red line is the conergence rate of the preconditioned system with the low-fidelity model. The increase in efficiency is a factor of 2 for this particular test case.

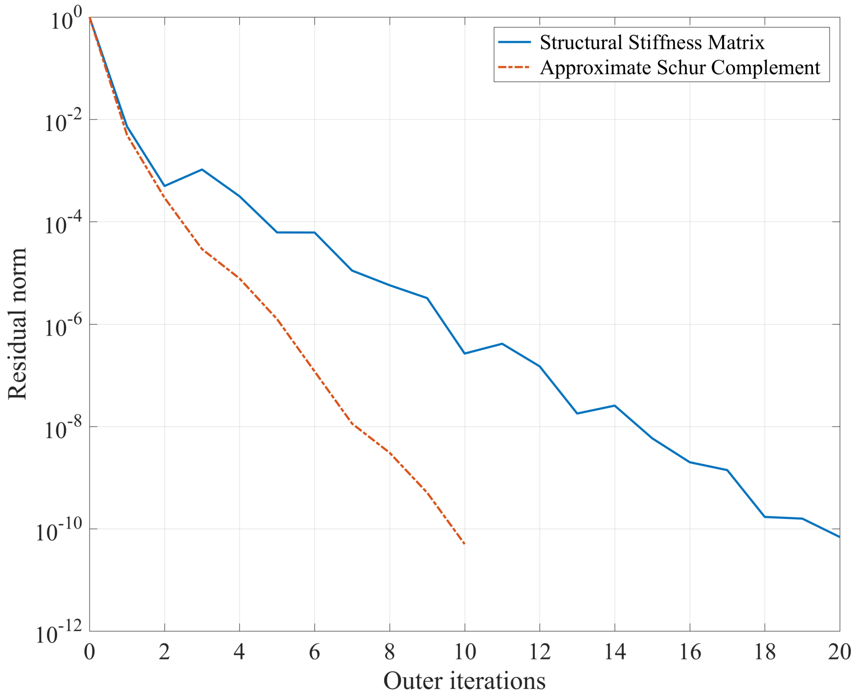

Figure 1: Comparison of convergence behaviour at Mach 0.84

References

[1]Barcelos, M., Bavestrello, H., and Maute, K., "A SchurNewtonKrylov solver for steady-state aeroelastic analysis and design sensitivity analysis," *Computer Methods in Applied Mechanics and Engineering*, Vol. 195, No. 17-18, March 2006, pp. 2050–2069.

[2]Kennedy, G. J. and Martins, J., "Parallel solution methods for aerostructural analysis and design optimization," *Proceedings of the 13th AIAA/ISSMO Multidisciplinary Analysis Optimization Conference, Fort Worth, TX*, 2010.

[3]Kenway, G. K. W., Kennedy, G. J., and Martins, J. R. R. A., "Scalable Parallel Approach for High-Fidelity Steady-State Aeroelastic Analysis and Adjoint Derivative Computations," *AIAA Journal*, Vol. 52, No. 5, May 2014, pp. 935–951.

[4]Blondeau, C., Achard, T., Girodroux-Lavigne, P., and Ohayon, R., "RECENT ACHIEVEMENTS TOWARDS AERO-STRUCTURE GRADIENT COMPUTATION USING HIGH-FIDELITY CFD-CSM IN THE ONERA ELSA SOFTWARE," *International Forum on Aeroelasticity and Structural Dynamics*, 2015.

[5]Saad, Y. and Schulz, H. M., "GMRES: A Generalized Minimal Residual Algorithm For Solving Nonsymmetric Linear Systems," *SIAM J. ScI. STAT. COMPUT.*, Vol. 7, No. 3, July 1986, pp. 856–869.