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Multi-Point Aerodynamic Optimization of a Flexible Transport Aircraft Wing using an Aeroelastic Adjoint Method

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INTRODUCTION

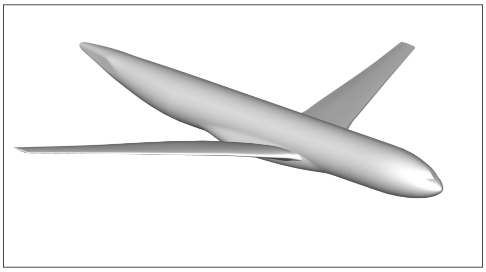
To achieve optimal overall performance of a transport aircraft over its complete mission, the aerodynamic design of its wing must consider the variations of operating conditions the aircraft will encountered. During the cruise segment, such variations have several origins: cruise speed variations motivated by operational reasons (imposed arrival time by the ATM), variation of the aircraft weight as the fuel is burnt along the mission, intentional cruise altitude changes. To account for this variability of the operating cruise condition and optimize the aircraft accordingly, a natural approach consists in performing a multi-point optimization of the aerodynamic performance. This consists in solving an optimization problem which objective function is for example a linear combination of the aerodynamic performances at several flight conditions. In this work, it is proposed through applications considering a modern civil aircraft wing, to highlight the advantages of multi-point flexible wing optimization in comparison to single point rigid optimizations.

AIRCRAFT CONFIGURATION CONSIDERED

The glider version of the Airbus XRF1-v1 configuration, representative of a modern wide-body transonic transport aircraft, is used in this work. The XRF1 configuration is presented in Figure 1.

AERODYNAMIC NUMERICAL SIMULATION AND OPTIMIZATION TECHNIQUES

The RANS equations closed with the Spalart-Allmaras turbulence model are solved with the ONERA CFD software elsA [1]. Evaluation of the aerodynamic performance of the aircraft is done using a farfield drag extraction approach implemented in the ONERA FFD72 software [2]. The RANS adjoint equations, with either a linearization of turbulence model or with the “frozen” eddy-viscosity assumption are solved to obtain the sensitivities of the aerodynamic performance with respect to the wing shape parameters. To account for the aeroelastic wing deformations, a version of the elsA code that coupled aerodynamic loads with a structural model of the wing based on an equivalent beam is used [3]. A system of both structural and aerodynamic adjoints is solved to evaluate the gradient of aerodynamic performance sensitivity on the wing at its aeroelastic equilibrium [3]. Gradient-based optimization techniques are used to solve the different aerodynamic, single or multi-point, optimization problems considered in this work. CONMIN and DOT gradient optimizers have been used within the DAKOTA toolkit [4]. A summary of the workflow for the optimizations in presented in Figure .



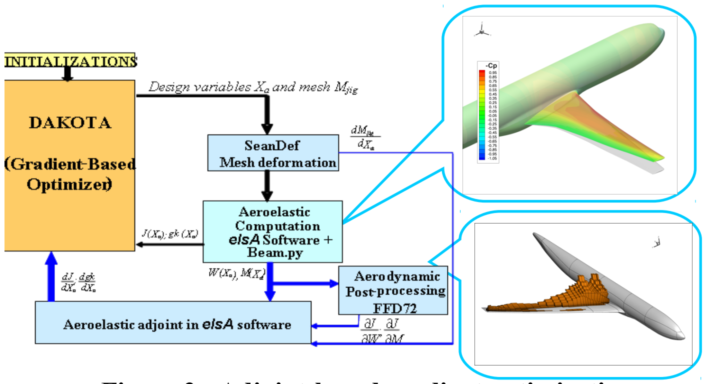


Figure 1 -View of the XRF1 aircraft configuration used in this work.

Figure 2 - Adjoint-based gradient optimization system based on aeroelastic CFD (elsA) and Dakota optimization library.

ANALYSIS OF SINGLE POINT RIGID WING SHAPE OPTIMIZATION RESULTS

In the first part of this paper, the results of single-point, rigid, aerodynamic optimizations will be presented and analysed, highlighting the impact of gradient algorithm and gradient accuracy on the results.

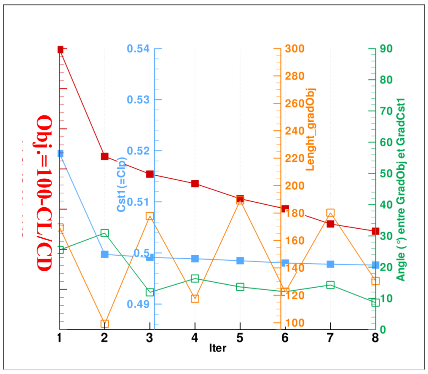


Figure 2: History of functions of the single point (at CL=0.5) rigid optimization.

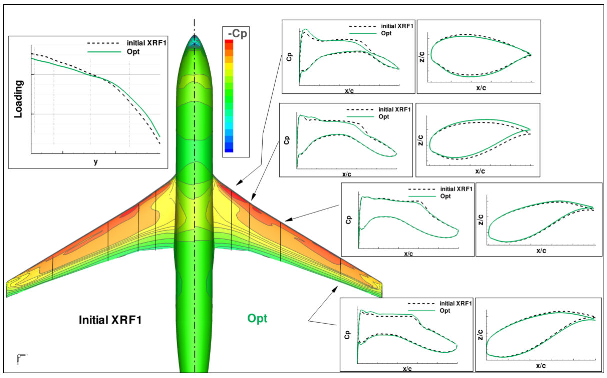


Figure 3 – Aerodynamic analysis of the single point (at CL=0.5) rigid optimization.

ANALYSIS OF MULTI-POINT FLEXIBLE WING SHAPE OPTIMIZATION RESULTS

In the second part of this paper, the results of multi-point, flexible, aerodynamic optimizations will be presented and analysed. A comparison to the results of single-point and rigid optimization will be used to illustrate the interest of multi-point and the necessity of aeroelastic optimization.

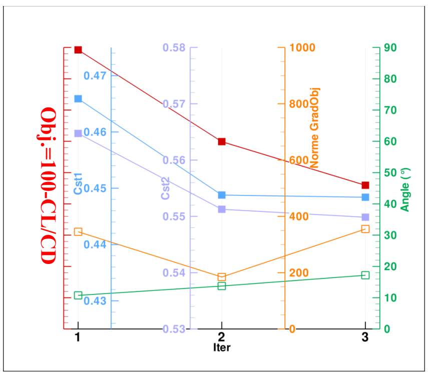


Figure 4: History of functions of the multi-point (at CL=0.45&0.55) flexible optimization

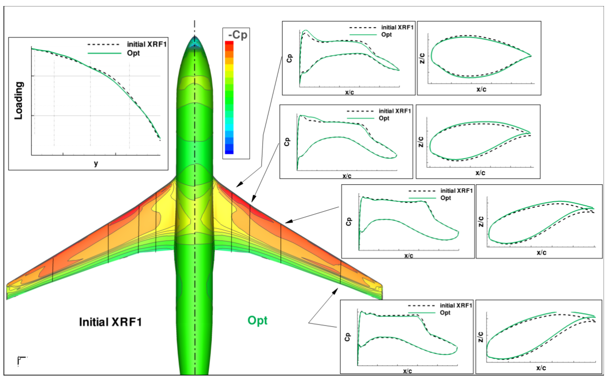


Figure 5 – Aerodynamic analysis at CL=0.55 of the multi-point (at CL=0.45&0.55) flexible optimization

CONCLUSION

In this paper, an analysis of the results of different single-point and multi-point aerodynamic wing optimizations considering or not the wing flexibility is presented. This work illustrates the importance of designing the wing for a range of operating conditions and not for a single flight condition. Moreover, the necessity of accounting for the aeroelastic wing deformations in the context of multi-point optimizations is highlighted.

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