Preliminary design optimization of a hybrid regional aircraft wing using a multifidelity approach

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Keywords : *Design optimization, Gradient-based optimization, Multi-point aerostructural optimization, Adjoint methods, Distributed electric propulsion, Regional aircraft*

1 Context

Against the backdrop of environmental footprint concerns, the study of electric power for aircraft propulsion systems has shown interest for hybrid architectures in limiting airborne emissions and noise levels while opening up a vast design space for electric propulsion architectures. These architectures being new, special tools for the study of preliminary design trade-offs have to be developed. The work presented in this paper focuses on the development of a design tool for a hybrid regional aircraft's wing. It has been conducted during a six-month internship at AURA AERO, an emerging aircraft manufacturer founded in 2018 whose ambition is to design and manufacture aerobatic and regional hybrid aircraft. The Experimental Design Office develops a 19 passenger regional aircraft, which key features - high aspect ratio [1], distributed propulsion and distributed batteries - make its wing non-common, thus requiring the development of a dedicated design tool.

2 Problem

Aircraft design means finding the best trade-off between the various disciplines at stake : aerodynamic efficiency, mass breakdown, handling qualities... In this work, the focus is on the wing aerostructural optimization, where a trade-off has to be found between aerodynamic performances and the structural sizing while minimizing the generated drag, with design variables being the wing planform geometry and the distributed structural mass over wingspan. This trade-off is a fundamental one for aircraft design since aerodynamic performances are better

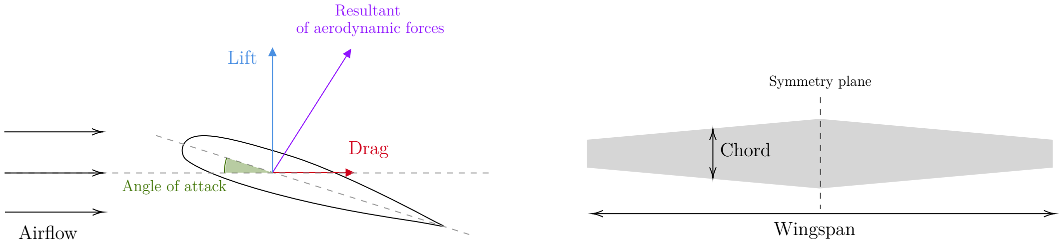

FIG. 1 – Left, airfoil lift and drag generation from the angle of attack with the airflow. Right, the wing planform geometry (seen from above).

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[1] The aspect ratio $AR = \frac{b}{c_{MAC}}$ is the ratio of the wingspan over the mean aerodynamic chord c_{MAC}, *i.e.* the average of the chord over the entire wingspan

when the aspect ratio increases but the structure required to withstand the corresponding loads sees its mass increase with the aspect ratio. Since the energy consumption for an aircraft decreases with its aerodynamic performances but increases with its total mass, a trade-off has to be found.

The designed optimization tool has several operational requirements : *computational efficiency*, which enables the exploration of numerous design configurations ; *modularity*, as the ability to build the design by assembling modules together and *explainability*, which means getting insight into the optimal design configuration characteristics. Design optimization complying to these requirements has been studied for the last two decades and gave birth to Multidisciplinary Design Optimization (MDO) as an active research field. Efficient gradient-based optimization has been the key to deal with scalability and explainability. Automatic differentiation (AD) as well as the development of adjoint methods [2] for the computation of a model's derivatives manage to make gradient-based methods both efficient and applicable to any model. The OpenMDAO Python-based framework [1] enables the developement of models benefiting from the previous features. Into such a framework, the architecture now plays the key role in the performance, since model evaluation - and thus derivative evaluation thanks to AD - requires to call system solvers on submodules to converge couplings involved in models.

3 Methodology

We build two wing models with increasing level of fidelity (or precision) :
— (A) : Prandtl's lifting line for the aerodynamics, simple beam model for the structure
— (B) : VLM for the aerodynamics, FEM on a skeleton of beams for the structure and a Rankine-Froude propeller flow model for the blowing effect.

Model B is built on the basis provided by OpenAeroStruct [3], which is a wing aerostructural optimization tool developed in the OpenMDAO framework. We perform multi-point aerostructural optimization, *i.e.* we evaluate the wing model on several flight conditions and build an objective function as a combination of the performances of these different cases.

4 Results

From the engineering point of view, both models gave results to quantify the influence of the wingspan and the structural mass distribution on the generated drag as well as how battery positions help improving the wing's performances by reducing the bending moment in flight.

From the research point of view then, the models demonstrated the performance of MDO applied to the design of a more challenging kind of aircraft design problem. With different couplings involved (*aeroelastic* between aerodynamic loads and structure deformation, *aero-propulsive* between the thrust generated by propellers and the aerodynamic response of the wing) the models developed are still able to find optimal designs with aerodynamic meshes of 30 points, structural meshes of 10 points, 8 engines and 20 non-structural point masses in about a minute of computation, enabling wing configuration exploration at a low cost.

References

[1] Justin S. Gray, John T. Hwang, Joaquim R. R. A. Martins, Kenneth T. Moore, and Bret A. Naylor. OpenMDAO : an open-source framework for multidisciplinary design, analysis, and optimization. *Structural and Multidisciplinary Optimization*, 59(4) :1075–1104, March 2019.

[2] John Hwang. A modular approach to large-scale design optimization of aerospace systems. 01 2014.

[3] John P. Jasa, John T. Hwang, and Joaquim R. R. A. Martins. Open-source coupled aerostructural optimization using python. *Structural and Multidisciplinary Optimization*, 57(4) :1815–1827, February 2018.