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Title

Multi-fidelity Multidisciplinary Analysis Methodology for Preliminary Design of Ultra-high Aspect Ratio Strut Braced Wing Aircraft

Authors

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Abstract

The increasing pressure on the civil aviation industry towards sustainability has been a driving force in incremental technological innovations and design choices to optimize the efficiency of a modern airliner. However, the exploration of novel aircraft designs, such as the ultra-high aspect ratio strut-braced wing (UHARSBW) configuration, that departs from the traditional fuselage and cantilever wing design is required to find more significant gains in aircraft efficiency [1]. In order to realize the full potential of these novel aircraft design concepts, a holistic multidisciplinary analysis (MDA) must be undertaken in the preliminary design phase of the aircraft to enable global optimization. The importance of employing MDA is especially pertinent for the UHARSBW design concept due to the strong dependencies between the aerodynamic and structural effects caused by the high aspect ratio wings and the non-linear aerodynamic effects appearing in the transonic flow regime caused by the strut-wing interactions.
Within the MDA process, the prohibitive computational cost of relying solely on high-fidelity analysis tools, such as RANS CFD simulation, calls for the utilization of multi-fidelity surrogate modelling strategies. This paper will investigate the MDA performance using multi-fidelity aerodynamic simulations applied to the case of the UHARSBW aircraft concept to serve a similar role to that of Airbus Industries A321-LR. The MDA process is constrained by the top-level aircraft requirements of 7400km sizing range, 18tn sizing payload, 23tn maximum payload and cruise Mach number of 0.78, with further structural requirements, which include the 2.5g pull-up manoeuver and -1.5g taxing bump loading.
Unified top-level geometric design parameters are defined to parameterize the aerodynamic and structural models. Commercial structural analysis software, NASTRAN, is utilized for the FEM analysis with internal structural details within the wing. The structural model developed optimizes the sizing of internal structures such as skin, stringers and ribs thickness to minimize the weight of the aircraft structure. Furthermore, the flutter analysis is conducted within the structural analysis model using the doublet lattice method to ensure the flutter constraint is fulfilled. Athena Vortex Lattice (AVL), a vortex lattice method solver, is utilized as a low-fidelity aerodynamic analysis tool, whilst the SU2 Euler CFD solver is selected as the high-fidelity alternative. The two aerodynamic solvers serve to construct a multi-fidelity model, which was then coupled with the structural solver to perform the MDA. The aerodynamic surrogate model, coupled with the structural model, is constructed to capture the non-linear aerodynamic effects observed by the high-fidelity solver, which the low-fidelity method lacks but can capture the trends of lift and induced coefficients. The results and performance of the MDA processes based on pure high-fidelity, pure low-fidelity and multi-fidelity aerodynamic models are analyzed and compared to one another.

The first section of this paper defines the design mission and constraints. The second section details the parametric model generation and each model's simulation chain. The third section describes the MDA process and analyses the results and performances of each MDA case based on the different fidelity models. Finally, the possible integration of the MDA process in the global optimization of the preliminary design of UHARSBW aircraft is explored, and future expansion of design considerations is discussed.

References

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