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Multiphysics Optimization of an Aircraft Winglet via CFD–FEM Coupling and Radial Basis Function Mesh Morphing

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Objectives

The installation of winglets on aircraft wings allows contributing in drag reduction and thus in reducing fuel consumption, with clear advantages in long range cruising. The working principle consists in recovering energy from the tip vortex to generate a force with a component in the forward direction. Their efficiency is then related to the intensity of the vortex. For this reason the benefit of winglets is more evident in highly loaded wings but with the drawback to introduce an increase in the global wing bending moment. This aspects render winglet aerodynamic design a particularly complex structurally constrained problem requiring a coupled aero-structural assessment. The objective of this is to develop a numerical methodology for the multi-physics optimization of an aircraft winglet, capable of simultaneously accounting for aerodynamic performance and structural constraints.

Methodology

The proposed approach is based on the coupling of CFD and FEM analyses and on the use of Radial Basis Function (RBF) mesh morphing techniques for geometric parametrization. Starting from a baseline configuration, the winglet geometry is smoothly modified through a morphing approach that simultaneously updates both the CFD and FEM models, enabling the generation of multiple design variants while preserving mesh quality and avoiding costly remeshing procedures. For each morphed configuration, a fluid–structure interaction (FSI) analysis is performed by iteratively coupling the aerodynamic and structural solvers until convergence is achieved. In this framework, aerodynamic loads are computed on the current deformed configuration and transferred to the structural model, whose response in turn updates the geometry used for the flow solution. This ensures a fully consistent aero-structural evaluation, in which both aerodynamic performance and structural response are assessed on the converged deformed state. The optimization process is then carried out by considering both aerodynamic and structural objectives and constraints.

Results

The methodology is applied to an industrial case study developed in collaboration with Leonardo Aircraft Division, focusing on the optimization of a winglet for a light aircraft. The results demonstrate the capability of the proposed approach to efficiently explore the design space and identify improved configurations with respect to the baseline design. In particular, a reduction in aerodynamic drag is achieved while maintaining structural responses within acceptable limits, confirming the effectiveness of the multi-physics framework.

Conclusions

The study shows that the integration of RBF-based geometric parametrization with coupled CFD–FEM analyses provides a consistent and efficient framework for aero-structural winglet optimization. The proposed methodology represents a valuable tool for integrated aeronautical design, enabling a systematic trade-off between aerodynamic performance and structural integrity. The approach can be further extended to more complex configurations and industrial applications characterized by high design variability.

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