Testing the potential to offer CAE over the cloud in the SaaS paradigm

FSI optimization of industrial airplanes: the P180 Avanti EVO study

This technical article describes a fluid-structure interaction (FSI) optimization carried out for the P180 Avanti EVO vehicle, a business aircraft designed and manufactured by Piaggio Aerospace. It describes the use of an additional module for the RBF4AERO platform, rbf4aerpFSI, designed and validated to work with both commercial and open source solvers, to conduct the CAE analyses of a set of modifications to the P180's winglet shape. RBF4AERO is the software platform resulting from the EU-funded RBF4AERO project (FP7/2007-2013) to address the highly demanding CAE requirements of aircraft design and optimization to improve aircraft and component performance. The rbf4aeroFSI solver allows designers to perform single- and multi-objective optimization (SOO and MOO) using evolutionary algorithms (EA) assisted by metamodels, while also taking into account the elasticity of the deformable components of interest under steady state conditions using two computation fluid dynamics (CFD) methods: two-way and mode-superposition.

By Emiliano Costa
Rina Consulting

This article describes a fluid-structure interaction (FSI) optimization carried out for the P180 Avanti EVO vehicle, designed and manufactured by Piaggio Aerospace. The study was performed within the framework of Experiment n. 906 of the Fortissimo project, funded by the European Union's Horizon 2020 research and innovation program under grant agreement No. 680481. In particular, it numerically investigated, by means of the mode superposition method, the effect of a set of modifications to the winglet shape, which were applied with a mesh morphing technique based on radial basis functions. The computational fluid dynamics (CFD) analyses were carried out with both commercial (CFD++, ANSYS Fluent) and open-source (SU2) solvers, using the RBF4AERO suite's cross-platform FSI solver.

Background

The RBF4AERO project, which was funded by the EU's Seventh Framework Programme (FP7/2007-2013) under grant agreement n° 605396, aimed to create software (referred to as the RBF4AERO platform) to handle the highly demanding requirements of aircraft design and optimization to considerably shorten the time needed to finalize the computer-aided engineering (CAE) analyses for improving the performance of an aircraft and its components.

Upon completion of the RBF4AERO project, some of the partners, with the support of the Piaggio Aerospace company, agreed to undertake some further exploitation activities.

One of these activities was a submission to participate in the Fortissimo 2 project, being funded by the EU Horizon 2020 research and innovation program under grant agreement n° 680481, with the main objective of offering CAE services using the RBF4AERO platform through the cloud-based Fortissimo Marketplace.

The platform's key elements are tools that existed prior to the RBF4ERO project that were improved and suitably integrated into a single comprehensive working environment over the duration of the project. Specifically, they include the morpher tool (MT) - the commercial standalone version of the RBF Morph technology; the optimization Manager (OM) - employed to run single- and multi-objective optimization (SOO and MOO) problems using evolutionary algorithms (EA) assisted by off-line trained surrogate evaluation models (metamodels); and the in-house developed adjoint solver for the OpenFOAM suite.

The basic function of the platform is to create the parametric of the CAE model through a meshless morphing technique based on radial basis functions (RBF) to enable the computational studies for which the RBF4AERO platform was conceived, which are:

- EA-based optimizations, including constraint SOO or MOO which can be coupled with the FSI option;
- Icing studies;
- Adjoint-morphing coupling optimizations.

The results obtained with the EA-based operational scenarios can be reviewed and post-processed using an embedded post-processing module. Furthermore, the platform can schedule and monitor simulation jobs and supports multi-user and multi-hardware management.

With particular reference to FSI studies, a solver called rbf4aeroFSI was designed, validated and implemented to work with both commercial and open-source solvers. The rbf4aeroFSI solver allows designers to perform SOO or MOO using EA assisted by metamodels, while also taking into account the elasticity of the deformable components of interest under steady state conditions, according to two methods: two-way and mode-superposition. It is worth specifying that the two-way method is based on the exchange of data between the CFD (loads) and the computational structural mechanics (CSM) (displacements) models, whilst the mode-superposition method is based on the importation of the natural modes and frequencies of the deformable parts, with the calculation of the modal forces and the actual displacement being performed directly in the CFD model.

Main objectives of Experiment 906

In Fortissimo Experiment n. 906, known as "Cross-Solver Cloud-based Tool for Aeronautical FSI Applications", the proposed aeronautical application consisted of the aero-elastic optimization of the winglet of the P180 Avanti EVO (see Fig. 1), a business aircraft designed and manufactured by Piaggio Aerospace.

The FSI optimization

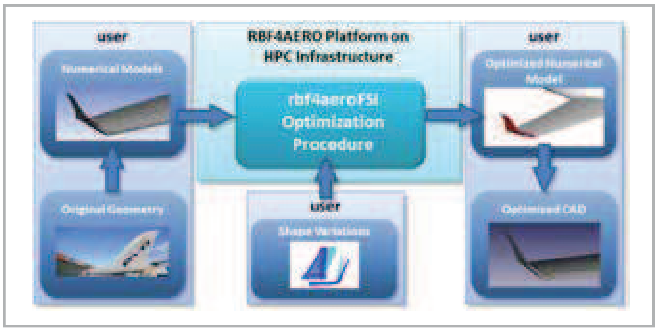

Fig. 1 - Workflow of the proposed FSI optimization

Shape modifications

The three shape modifications executed are twist, cant and sweep angles. In particular, the twist angle variation concerns the rotation of the winglet tip around the trailing edge while maintaining a fixed root, the cant angle shape modification changes the winglet angle with respect to the wing, whilst the sweep angle geometrical variation is achieved by translating the winglet position along the wing chord.

The RBF set-up controlling the surface mesh is shown in Fig. 2, where the red area on the left represent the moving points, while the green areas do not change their position during morphing. Fig. 2 (right) shows the final position of the source points, amplified 10 times to ease comprehension. The portion of the winglet between the moving and the fixed points is left free to deform by morphing.

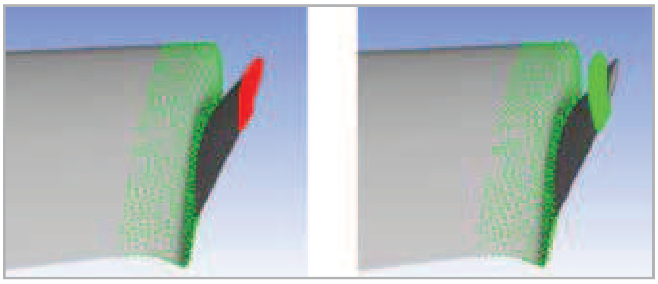

Fig. 2 - Winglet twist angle RBF set-up for surface mesh morphing

The RBF set-up that manages the volume mesh provides for the definition of a domain in which the morphing action is delimited. Due to degradation of cell quality from the morphing, combinations of the created shape modifications were verified by evaluating the quality of the resulting mesh in the range of variations of the selected angles.

Mesh and CFD model set-up and results for the baseline case

An unstructured hybrid computational grid with about 21 million cells was generated according to the specifications and settings typically used by Piaggio Aerospace to create a medium precision grid. In particular, a surface mesh formed by triangular elements was generated only from the imported CAD model. Then a series of layers was inflated from the surfaces to properly resolve the boundary layer to finally generate the tetrahedral cells in the remaining portion of the simulation volume. The transonic cruising conditions commonly used by Piaggio Aerospace were selected to perform the CFD simulations included in the FSI optimization. In particular, the flow regime enabled the identification of the main settings to be assigned in the CFD set-up, such as the angle of attack, the Mach number and the altitude conditions, while the influence of the engine was simulated through the correct boundary conditions being applied to the inlet and outlet.

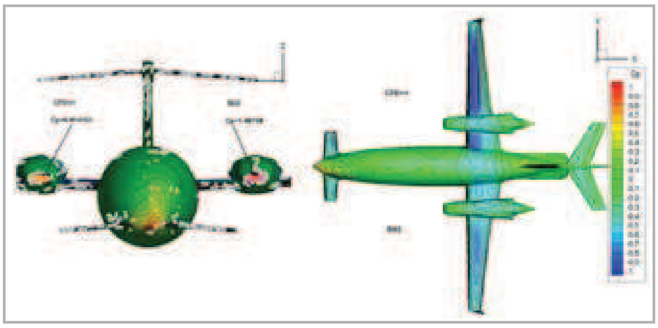

Fig. 3 - CFD results obtained for the baseline configuration of the P180 model

Fig. 3 from the front (left) and bottom (right) view respectively, depicts the comparison between the distribution of the pressure coefficient (Cp) over the surfaces of the aircraft obtained with SU2 and CFD++ in stable cruising conditions.

The fully developed solution generated for the baseline configuration was used to initialize the calculation of each design point (a baseline shape variant) of the FSI optimization, thus saving computing time.

CSM model and model analysis results

The CSM model includes the central parts of the aircraft. This model and its position and space with respect to the CAD model is shown in Fig. 4. While the winglets are modelled in detail down to the composite material used, the rest of the model is simplified by using plates and beams for the wing, and rigid elements for the engines, and by using spring elements to connect the wing and fuselage, maintaining the two extremes of the fuselage fixed.

Since the surfaces of the wet CFD and CSM did not match, it was impossible to achieve an FSI optimization using the standard two-way method. However, by exploiting the meshless property of the morpher tool, it was possible to interpolate the structural displacements to propagate them on the CFD mesh with a good level of accuracy. For this reason, the modal superposition method, which provides for the incorporating of structural modes in the CFD model, was chosen to implement the FSI analysis. According to this method, the FSI is solved as a reduced order method in which the structural behaviour of the system is condensed using a chosen number of modes, also called retained modes, each of which allows a single degree of freedom problem to be solved directly in the CFD solver.

Fig. 4 - The CSM model and its position with respect to the CAD model

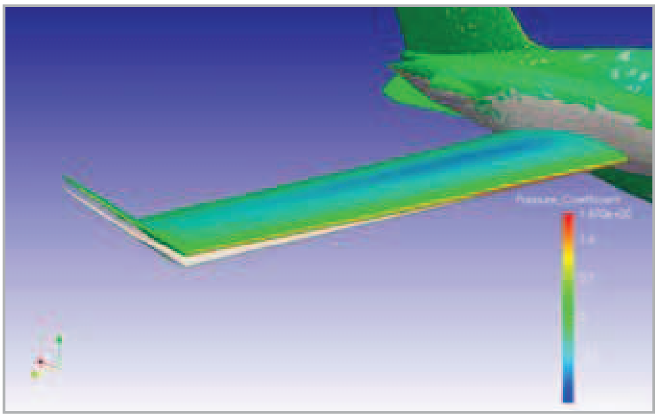

Fig. 5 - Comparison between the baseline (bottom-grey) and the deformed configuration

The first 30 modal shapes in particular were extracted, but most of them were discarded as being relative to the local vibrational modes of the plates. The modal shapes extracted from the CSM solver were used to generate a shape parameter for each one, adopting a similar strategy for the set-up of the RBF solutions to the one followed for the shape modifications previously detailed.

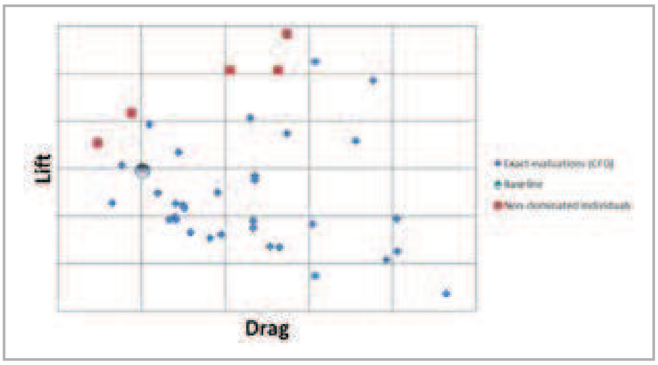

Fig. 6 - Main optimization outputs. Front of the non-dominated solutions together with all the candidate solutions evaluated during the optimization.

Optimization results

In relation to the optimization analysis, a two-objective optimization was run by selecting the drag function as the objective to minimize and the lift function as the objective to maximize in exploring the three shape modifications between +/-15°. As for the optimization settings, the full factorial method was selected to apply to the 27 design points identified from the exact CFD-based evaluations resulting from the design of experiment (DoE). Other settings concerned setting the child population size to 60 and the parent population size to 20, while the elite size was set to 5, the maximum number of exact evaluations was set to 40 and the maximum approximations was set to 500. Fig. 5 shows the comparison between the baseline (bottom-grey) and the deformed configuration (colored-top) of the wing for the baseline configuration. Fig. 6 shows the optimization's most important output, namely the distribution of the exact evaluations which highlight both the baseline configuration and the non-dominated individual configurations in different colors (the data set is confidential). As can be seen, the FSI optimization showed that there is room to effectively optimize the winglet in stable cruise conditions. Since non-dominated individual configurations can be generated using known combinations of shape modifications, one of these can be then identified as the optimal configuration to improve the aircraft's cruising performance.

Conclusions

Using the case of the winglet of a mid-sized business aircraft in cruise conditions, the RBF4AERO platform's effectiveness to perform a highly automated optimization study, while also accounting for the effect of the wing's elasticity, was demonstrated. This optimization was undertaken by adopting the mode superposition method, even though the wet surfaces of the CFD and FEM models did not match. This study showed the margins for improving the aerodynamic efficiency of an industrial vehicle, since the mesh morphing methodology can help to optimize the shape of the winglet in order to achieve, for instance, a reduction in fuel consumption during flight. The RBF4AERO platform confirmed itself to be a potential numerical means of offering CAE services over cloud infrastructures such as the Fortissimo Marketplace in the software as a service (SaaS) paradigm.

Acknowledgments

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The paper full version and related references are available in the Proceeding of the International CAE Conference 2019 at http://proceedings2018.caeconference.com/sessions.html#aero

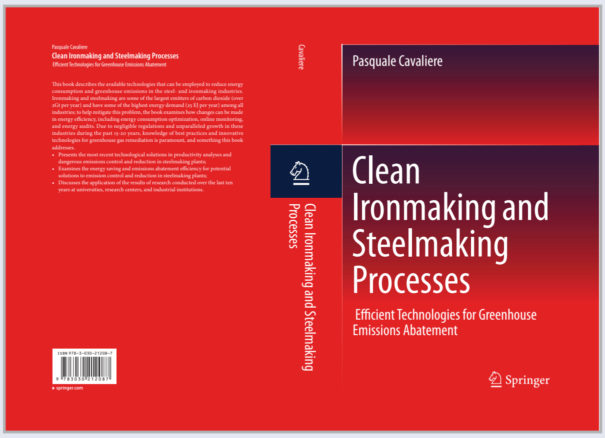
For more information
Emiliano Costa - Rina Consulting
emiliano.costa@rina.org

New book on clean ironmaking now available for pre-order

Provides best practices and innovative technologies for greenhouse gas remediation

A new book entitled "Clean Ironmaking and Steelmaking Processes - Efficient Technologies for Greenhouse Emissions Abatement" by Pasquale Cavaliere, professor of metallurgy at the University of Salento in Italy, is now available for pre-order from Springer International publishing.

This book describes the available technologies that can be employed to reduce energy consumption and greenhouse emissions in the steel- and ironmaking industries. These producers are some of the largest emitters of carbon dioxide (over 2Gt per year) and have some of the highest energy demand (25 EJ per year) among all industries. To help mitigate this problem, the book examines how changes can be made in energy efficiency, including energy consumption optimization, online monitoring, and energy audits.



The author presents the most recent technological solutions in productivity analyses and dangerous emissions control and reduction in steelmaking plants. He examines energy saving and emissions abatement efficiency for potential solutions and he discusses the application of the results of research conducted over the last ten years at universities, research centers, and industrial institutions.

"The unparalleled growth of these industries coupled with the negligible regulations governing them has made the best practices and innovative technologies for greenhouse gas remediation vitally important, which is what I have provided in this book," states Cavaliere.

To pre-order the book, visit www.springer.com/gp/book/9783030212087.