PUBLISHABLE SUMMARY

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Project acronym: HIPERLAM

Project title: High-Fidelity and High-Performance Laminar Wing Optimization

Funding Scheme: JTI Clean-Sky

Date of latest version of Annex I against which the assessment will be made:

Date of modifications in negotiation phase	**2012-07-09**
Date of amendment	**2013-09-17**

Periodic report: **1st**

Period covered: **22 months from 2012-09-01 to 2014-07-01**

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Objectives

In air transport, low aircraft fuel consumption is a major objective for designers because it directly reduces aircraft exploitation costs and environmental impact. Aircraft aerodynamic shape optimization is an activity that, similarly to aeroelasticity, investigates and develops methods for aircraft design. The specific objective of this discipline is to find geometries of aircraft, per component or for the entire design, that reduce the drag, or increase the glide, or improve other figures of merit that have an impact on fuel consumption. *Natural Laminar Flow design (NLF)* refers to aerodynamic shape optimization that aims at reducing a major part of the drag, e.g. the viscous drag, through delaying the transition from laminar to turbulent flow; the larger the laminar area of the flow on a wing, the lower the amount of drag due to air viscosity. Natural laminarity of the flow refers to the fact that this is a passive control technique, e.g. it only relies on the shape at design, in contrast to other approaches that involve activation of devices during flight, so called active flow control.

The overall goal of HIPERLAM is to progress on the development of high performance numerical methods for NLF design using Computational Fluid Dynamics (CFD). High performance refers here to the level of fidelity of the models and to the ability to deal with large simulations and design space, so called large scale optimization. Large scale optimization involving CFD in particular is a developing activity coupling gradient-based algorithms of optimization and adjoint technique that allows calculating gradients efficiently for the functions that are optimized, such as drag or other figures of merit and constraints. This goal is achieved through four development activities: development of adjoint equations for turbulence models coupled to the Reynolds Averaged Navier-Stokes equations (RANS), development of Radial Basis Functions (RBF) for the deformation of the CFD grid in the volume, comparison of methods for deforming geometries, e.g. shape parameterization, and development of a database technique in order to initialize stability computations that otherwise lacks robustness.

Performed work

The technical work took place in two work packages: *Development of methods* (WP2) and *Validation and demonstration* (WP3).

- A continuous adjoint of the Spalart-Almaras (SA) one equation turbulence model has been derived following a continuous approach and a preliminary version has been implemented in the development version of the CFD code Edge. In the objective of improving the quality of design results, alternative boundary conditions for the flow solver were tested in an attempt to reduce numerical oscillations that penalize the use of standard unstructured CFD in 3D design applications, in particular when it is coupled to boundary layer stability analysis.
- Two approaches of wing parameterization have been compared, an approach describing the wing as airfoils and a Free-Form Deformation (FFD) algorithm developed in collaboration between FOI, within its HIPERLAM activities, and Brno University in the framework of the European project CEDESA [1][2].
- RBF mesh deformation, earlier studied in the context of optimization [3], was implemented in the development version of the CFD code Edge and compared to standard methods used in aeroelasticity and aerodynamic shape optimization (Laplace smoothing and spring analogy).

- A database for *efficient initialization of stability computations* has been generated and implemented in Matlab. It includes data for both Tollmien–Schlichting (TS) and Crossflow (CF) perturbations without distinguishing between the cases.

Main results and status

- The development and testing work on adjoint turbulence models contribute to the development of the adjoint RANS equations in Edge. A quantitative result of this work is that the tests carried out here contributed to adapt the solver (line-implicit method and multigrid) that greatly improved the convergence for the adjoint Navier-Stokes equations (Figure 1). Further work is required on the adjoint equations of the turbulence models in order to solve the adjoint RANS equations and not only the adjoint NS equations.

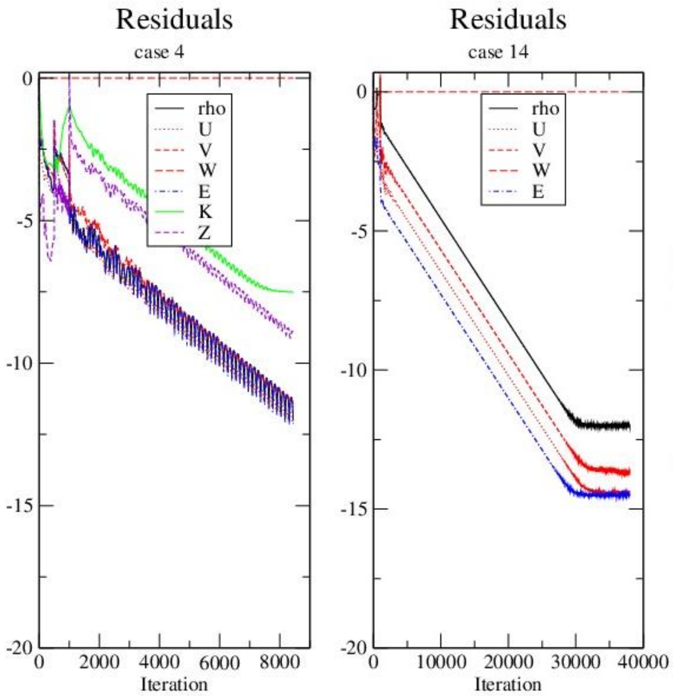


Figure 1 - Edge (CFD) solver convergence: on the left the residual of the RANS equations (Menter SST k-Omega model), on the right the residuals of the adjoint Navier-Stokes equations based on the flow solution obtained on the left (frozen viscosity approximation).

- The evaluation of two approaches of wing parameterization concerned their performance and properties on 3D design problems. Results on the FFD (Figure 2) were presented in two AIAA papers [1][2]. Also the comparison of the OPTLAM method and the FFD indicates trends that can help users to make a better use of the methods (Figure 3).

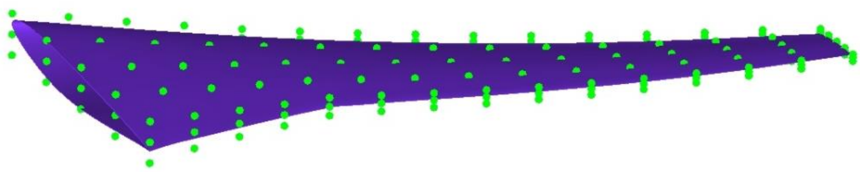


Figure 2 - An FFD lattice around the CRM wing

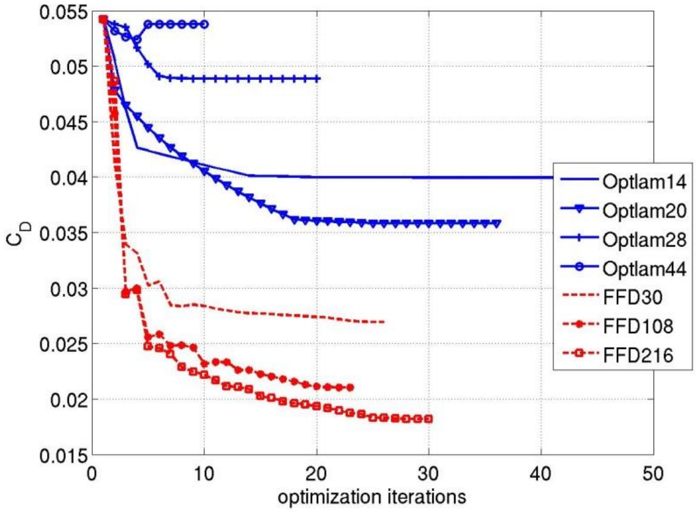
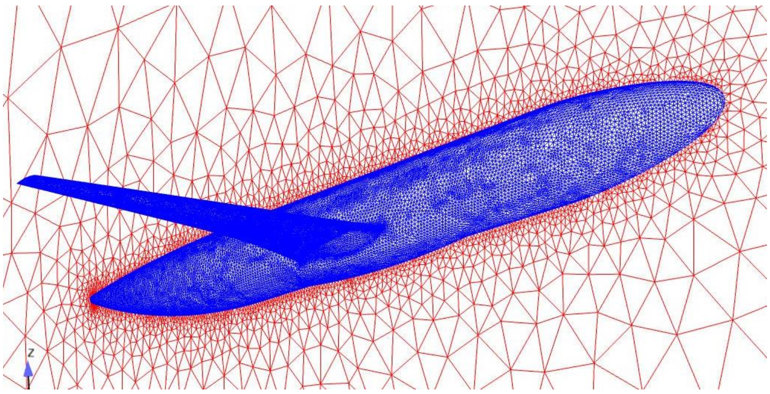


Figure 3 - Comparison of parameterizations (airfoils as in a previous project Optlam, or FFD) applied on the shape optimization of a civil aircraft (geometry from OPTLAM), for which a coarse mesh us shown below. Here the drag is minimized under constraints on the lift and volume. The number of parameters varied from 14 to 44 for the parameterization of the wing as airfoils ("Optlam") and from 30 to 216 for the parameterization with FFD.



- The main result on the RBF-based mesh deformation is a quite general implementation in Edge allowing varying the type and characteristics of the RBF: selection (sampling algorithm) of the control points, type of base function and shape factor. All tests showed that it allows achieving much better quality in mesh deformation than using standard algorithms (Laplace smoothing and spring analogy). Those two standard methods failed to deform meshes in the majority of the cases.

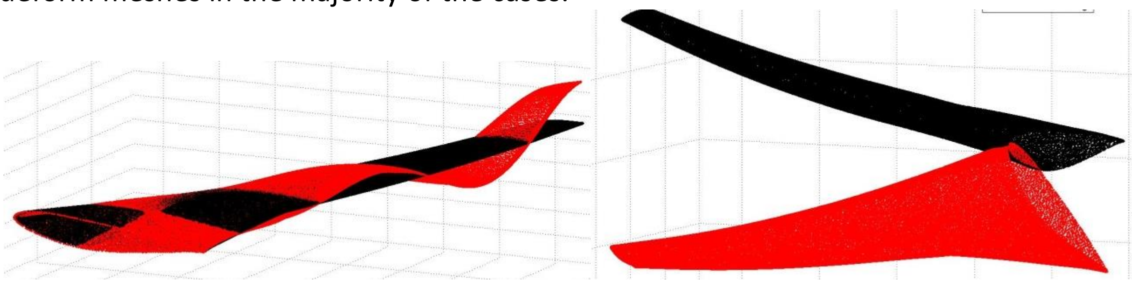


Figure 4 – Two among the test cases of deformations of the geometry (harmonic type on the left, pure rotation on the right) to test the performance of the mesh deformation algorithms (RBF, Laplace smoothing, spring analogy)

Expected impact

The algorithms developed or improved here in the context of aerodynamic shape optimization with CFD benefit to the development of aircraft design methods for all users of the CFD code Edge, but can also have a positive impact on aero-elasticity using Edge or similar CFD programs:

- Linearization of the flow equations, as in the derivation of the adjoint RANS equations, is also used for the development of frequency domain solvers of the flow equations which are useful for aero-elastic analysis.
- Fast and reliable mesh deformation schemes, such as the RBF implemented here, are needed in both disciplines.

Presentation and availability of the results

Two AIAA papers were presented at the conference SciTech 2014 on the work carried out on shape parameterizations [1][2]. The FFD code was produced in Matlab and will become available as an open source project.

All developments in Edge, that are validated, are available to all beneficiaries of the code that is distributed by FOI. Here it concerns a new Radial Basis Function (RBF) method for mesh deformation and improvements of the adjoint Navier-Stokes (NS) solvers.

[1] O. Amoignon, J. Navratil and J. Hradil, Study of parameterizations in project CEDESA. In 52nd Aerospace Sciences Meeting. AIAA, 2014

[2] O. Amoignon, J. Hradil and J. Navratil, A numerical study of adaptive FFD in aerodynamic shape optimization. In 52nd Aerospace Sciences Meeting. AIAA, 2014

[3] S. Jakobsson and O. Amoignon, Mesh deformation using radial basis functions for gradient based aerodynamic shape optimization, Computers and Fluids Volume: 36, Issue: 6, July, 2007, pp. 1119-1136.