COMBINING AN OPENFOAM-BASED ADJOINT SOLVER WITH RBF MORPHING FOR SHAPE OPTIMIZATION PROBLEMS ON THE RBF4AERO PLATFORM

E.M. PAPOUTSIS-KIACHAGIAS[1], K.C. GIANNAKOGLOU[1], S. PORZIANI[2], C. GROTH[3]
' M.E. BIANCOLINI[3], E. COSTA[2], M. ANDREJAŠIČ[4],
[1], *National Technical University of Athens, Parallel CFD & Optimization Unit, Greece*
vaggelisp@gmail.com, kgianna@central.ntua.gr
[2], *D'Appolonia S.p.A., Viale Cesare Pavese, 305 - 00144 Rome, Italy*
stefano.porziani@dappolonia.it, emiliano.costa@dappolonia.it
[3], *University of Rome Tor Vergata (UTV), Italy*
corrado.groth@uniroma2.it, biancolini@ing.uniroma2.it
[4], *PIPISTREL d.o.o. Ajdovščina, R&D, Department of Aerodynamics*
matej.andrejasic@pipistrel.si

Keywords: *OpenFOAM®-based Continuous Adjoint Solver, RBF-based Morphing, Shape Optimization, RBF4AERO Platform*

During the last years, CFD-based aerodynamic shape optimization has been attracting the interest of both academia and industry. The constituents needed for executing an automated shape optimization loop include the flow solver, the geometry parameterization (the parameters of which act as the design variables), an optimization method capable of computing the optimal values of the design variables and a way to adapt (or regenerate) the computational mesh to each candidate solution. OpenFOAM® can play an important role in such a framework by both including a set of CFD solvers that can be used to evaluate the quality of each candidate solution and by providing a base for developing (parts of) the other constituents of the optimization loop.

Funded in the Aeronautics and Air Transport (AAT) research thematic area of the EU 7th Framework Programme (Grant Agreement no. 605396), the RBF4AERO Project aims at developing the RBF4AERO Benchmark Technology, namely a numerical platform conceived to face the requirements of top-level aeronautical design studies such as multi-physics and multi-objective optimization, fluid-structure interaction (FSI), adjoint-driven optimization and ice accretion simulation. Based on the RBF mesh morphing technique, such a numerical platform allows to significantly boost the aerodynamic design process and a relevant impact is then expected in the ever-growing technological demand posed by aeronautical manufacturers in relation to the performance and reliability of aircrafts constituting components. To demonstrate the general validity and the effective usage of the RBF4AERO platform in the industrial field, one of its capabilities envisaging the adjoint-morphing coupling is, herein, described for a car aerodynamics and an aircraft optimization problem.

In the presented studies, the *simpleFoam* solver of OpenFOAM®-2.2.1 is used to numerically solve the incompressible Navier–Stokes equations for turbulent flows.

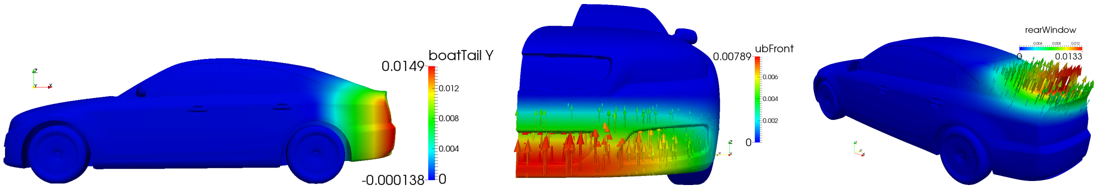
Shape parameterization techniques can be divided into two categories, i.e. those parameterizing only the surface to be optimized and those which also deform the surrounding nodes of the interior mesh. A method representative of the latter category is based on Radial Basis Functions (RBFs). The great advantage of the this category is that the interior of the computational mesh is also deformed, avoiding, thus, costly re-meshing and allowing the initialization of the flow field from the solution obtained in the previous optimization cycle, since the mesh topology is preserved. In this paper, a number of parameters controlling the positions of groups of RBF control points are used as the design variables, using technology and methods developed in the context of the RBF Morph software [1].

During the last years, the adjoint method for computing sensitivity derivatives (SD) of objective functions w.r.t. a set of design variables is becoming increasingly popular, due to having a cost per optimization cycle that does not scale with the number of design variables. In this work, a continuous adjoint solver, implemented in-house based on OpenFOAM®-2.2.1, is used to compute the necessary SD. The adjoint code takes into consideration the differentiation of the turbulence model PDEs and the law of the wall, [2, 3] to increase the accuracy of the computed sensitivities.

The above-mentioned tools are combined in order to form a single OpenFOAM® code able to execute an automated optimization loop, applied to two shape optimization problems, namely (a) the minimization of the drag force exerted on the surface of the DrivAer model developed by the Institute of Aerodynamics and Fluid Mechanics of TU Munich, [4], and (b) the maximization of the lift-to-drag ratio of a lightweight glider.

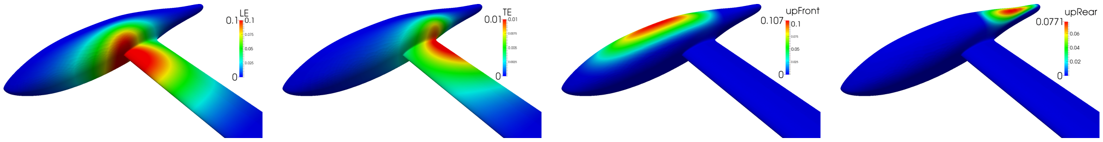
Six RBF-based design variables are used to parameterize the shape of the DrivAer car model. The parts of the car surface influenced by the design variables are depicted in fig. 1. After executing 15 steps of an adjoint-based optimization loop, a reduction of $\sim 7\%$ in drag is observed. A comparison of the pressure field plotted over the back side of the initial and optimized cases is presented in fig. 3(a).

Regarding the glider case, 4 design variables are used to parameterize its shape, fig. 2, targeting the maximization of the lift-to-drag ratio in a high farfield flow angle of 10^o. An increase of 15% is observed in the objective function, caused by 10% drag reduction and a 4% lift increase. A comparison between the near-wall velocity magnitude for the initial and optimized cases is depicted in figs. 3(b) and 3(c).



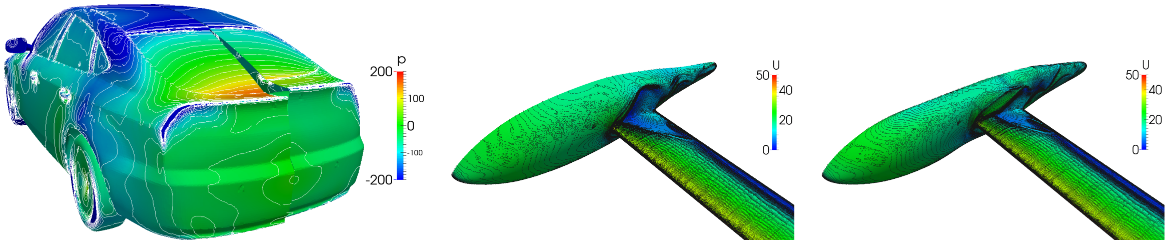
(a) boat tail (b) underbody front (c) rear window

Figure 1: DrivAer shape optimization: Part of car surface controlled by the three of the six shape deformation parameters and the corresponding deformation velocities (i.e. how the surface will be displaced for a unitary change on the design variables).



(a) (b) (c) (d)

Figure 2: Glider shape optimization: the magnitude of the deformation velocity for the four design variables parameterizing the glider shape. The first two parameterize the wing-fuselage junction close to the leading and trailing edges, while the second two affect parts of the upper glider surface. All design variables are allowed to vary within certain limits in order to prevent the generation of non-manufacturable solutions.



(a) (b) (c)

Figure 3: (a) Initial (right) and optimized (left) DrivAer geometries, coloured based on pressure. Lowering the rear window, creating a spoiler at the end of the trunk and creating a boat-tail shape for the rear side lead to an increased pressure at the rear part of the car, contributing to drag reduction. Near wall velocity isolines, plotted on the glider surface for the initial (b) and optimized (c) geometries. It can be observed that the low velocity area close to the trailing edge has been considerably reduced.

References

[1] M. Biancolini, "Mesh morphing and smoothing by means of radial basis functions (RBF): A practical example using Fluent and RBF Morph," in *Handbook of Research on Computational Science and Engineering: Theory and Practice (2 vol)*, 2011, pp. 347–380.

[2] A. Zymaris, D. Papadimitriou, K. Giannakoglou, and C. Othmer, "Continuous adjoint approach to the Spalart-Allmaras turbulence model for incompressible flows," *Computers & Fluids*, vol. 38, no. 8, pp. 1528–1538, 2009.

[3] E. Papoutsis-Kiachagias and K. Giannakoglou, "Continuous adjoint methods for turbulent flows, applied to shape and topology optimization: Industrial applications," *Archives of Computational Methods in Engineering, to appear*, 2016.

[4] A. Heft, T. Indinger, and N. Adams, "Experimental and numerical investigation of the DrivAer model," in *ASME 2012, Symposium on Issues and Perspectives in Automotive Flows*, Puerto Rico, USA, 8-12 July 2012, pp. 41–51.