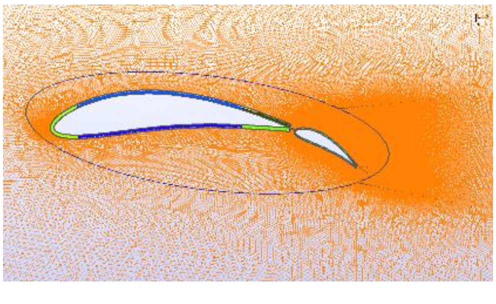
A variable fidelity optimisation procedure for multi-airfoil design

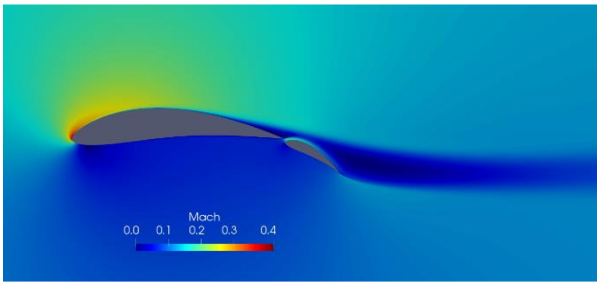
F. F. Semeraro[1), S. Bortolotti[2), M. Boffadossi[2)
[1)Dipartimento di Ingegneria Meccanica, Politecnico di Milano
[2)Dipartimento di Scienze e Tecnologie Aerospaziali, Politecnico di Milano

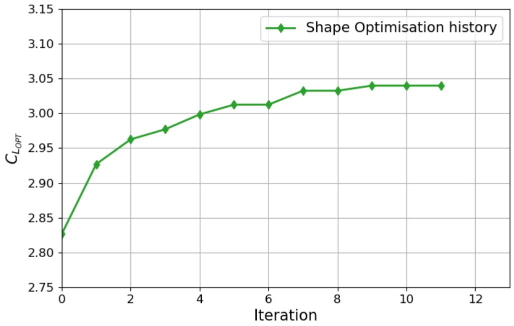
Abstract:

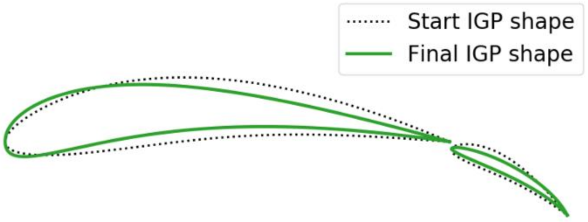
Designing and optimising multi-airfoil configurations require extensive tests in the wind tunnel and computationally expensive CFD simulations. This work proposes an accurate multi-airfoil optimisation procedure based on CFD with variable-fidelity algorithms to reduce the cost related to a pure CFD approach. A fully automated and robust methodology optimises multi-element configurations for the desired objective. CFD calculations are performed after preliminary low-fidelity but faster steps to cut off the number of configurations to be analysed and quickly converge to an optimal solution. This allows for an efficient use of resources, especially when configuration and shape optimisations are conducted simultaneously.

The methodology consists in three major blocks. Geometries and computational grid are built in the first block. Airfoils can be generated either by using known parameterisations or by providing a list of points. Grid generation is a time-consuming activity and requires user experience, especially when complex geometries like multi-element airfoils are concerned. Many details such as wall and wake refinement, farfield size, wall layers and gap description demand several tunings and are usually selected with a trial-and-error procedure. The tool proposed has been optimised on several configurations and generates high quality grids with limited user inputs. Compared to already existing methodologies for airfoil optimisation like the adjoint method, the proposed procedure is convenient because a new grid is generated for each configuration, instead of deforming the starting one. The second step is about CFD simulation. It is performed with compressible RANS and different turbulence models can be selected. The setup has been developed analysing several simulations on single and multi-element configurations. Numerical results have been compared with experimental tests [1], [3], [4]. The optimisation procedure supports several design variables. The user can optimise the shape and the configuration separately or simultaneously. The latter is the most interesting case but entails an increase in the number of design variables. The choice of the IGP [5] methodology allows for keeping a lower number of design variables compared to older parameterisation (i.e. PARSEC, OBF, CST), but with its eight parameters it offers a high degree of control on airfoil shape. During shape optimisation, all the parameters could be used as design variables, but the user can also select a smaller set. For a configuration optimisation, the main design variables are the relative positioning, the angle of attack and the relative chord length of each element. Different optimisation methods are implemented, including Particle Swarm Optimisation (PSO) and Steepest Ascent (or Descent) Optimisation. The procedure supports multi-processing for distributed computing to take advantage of HPC.









To carry out the optimisation without an excessive cost, preliminary evaluations exploit less expensive methodologies like the Hess-Smith panel method or Euler CFD to reduce the number of configurations to be tested with viscous CFD simulations. Furthermore, within these preliminary studies, the Valarezo-Chin criterion [6] is adopted with the Hess-Smith panel method for shortlisting unphysical solutions (i.e. evaluation the pressure coefficient difference between peak and trailing edge values).

To present the feasibility of a CFD optimisation approach based on the previously described methodology, a test case is going to be discussed. It will show the coupled shape and configuration optimisation of a multi-element IGP airfoil configuration for maximum lift.

The flexibility of the tool allows for the implementation of additional optimisation techniques. The procedure is going to be extended to 3D wings with more complex features to further improve the transfer of results to aeronautical and automotive applications. The tool is built in Python3 and connects open-source applications: SU2 for CFD, GMSH for grid generation, ParaView for post-processing.

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