Aerospace Europe Conference 2023
Joint 10th EUCASS – 9th CEAS Conference

Abstract #XXX *(to be filled by the organizers)*
Preferred Topics: AEROFLIPHY / CFDMPS
Corresponding author: LIU Xinying
e-mail of corresponding author: xinying.liu@zhaw.ch
Type: Oral
Status of corresponding author: Regular

Title

Numerical optimisation of single-/multi-element aerofoils using gradient-based methods

Authors

Xinying LIU [1], David ANDEREGG [2], Marcello RIGHI [3], Leonardo MANFRIANI [4]*

** Corresponding author*
[1] Senior research associate & project lead, Zurich University of Applied Sciences, Technikumstrasse 71, 8401 Winterthur, Switzerland, xinying.liu@zhaw.ch
[2] Research associate, Zurich University of Applied Sciences, Technikumstrasse 71, 8401 Winterthur, Switzerland, david.anderegg@zhaw.ch
[3] Professor, Zurich University of Applied Sciences, Technikumstrasse 71, 8401 Winterthur, Switzerland, marcello.righi@zhaw.ch
[4] Professor, Zurich University of Applied Sciences, Technikumstrasse 71, 8401 Winterthur, Switzerland, leonardo.manfriani@zhaw.ch

Abstract

The paper presents a review of aerofoil optimisation activities at the Zurich University of Applied Sciences by using high-fidelity gradient-based tools. Two optimisation chains have been applied in research projects with industrial partners in a wide range of fields including wind energy systems, motorsport, and aeronautical engineering.

ADflow, an open-source Reynolds-averaged-Navier-Stokes (RANS) CFD solver including discrete adjoint method [1], was used in the first optimization chain, in which RANS equations are solved on structured multiblock and overset grids. The aerofoil geometry was parameterised by using free-form deformation (FFD) application. The optimisation studies were carried out using the open-source framework OpenMDAO [2] developed by NASA. It allows to write components describing a certain part of a system and manages its interaction with other systems. OpenMDAO is particularly useful for efficiently computing derivatives across computational models, which we relied on in this work for gradient-based design optimisation. The Spalart–Allmaras turbulence model [3] was used in the first optimisation process.

The second optimisation process was driven by the commercial finite-volume CFD solver ANSYS Fluent with the same mesh topology. To compute the derivates of an observation of the flow surrounding the aerofoils, the discrete adjoint approach was adopted in ANSYS Fluent with the aim of providing shape-sensitivity data in the present applications. The problem of shape parameterization of entire aerofoils is therefore reduced to a problem of the parameterization of changes in the aerofoil shape. In the mesh morphing process, the designated deformation regions of used structured mesh were manipulated via displacements applied a set of control points. The user-defined motions that result in the displacements of the control points (each involving a parameter value and other directional settings) were then applied to the mesh as a smooth deformation by using the tensor product of Bernstein polynomials. A generalized k-ω two-equation (GEKO) turbulence model [4] implemented in ANSYS was used in this optimisation process.

To validate the 2D numerical results, experimental test campaigns were conducted in different subsonic wind tunnels in Switzerland, like the large subsonic wind tunnel of the Federal Institute of Technology in Zurich, and the Automotive Wind Tunnel Emmen at RUAG. 2D drag measurements were carried out by measuring the accurate velocity profiles downstream of the model using Constant Temperature Anemometry (CTA).

For the sake of publishing the applications without showing confidential information, some independent optimisation benchmarking cases with similar objectives and constraints are studied in this paper. The paper gives a brief description of both optimisation chains, followed by the optimisation setups of the selected case studies, and by discussions based on the numerical and experimental data.

The goal of the present paper is to demonstrate the versatility and usefulness of the two high-fidelity gradient-based methods used at ZHAW for aerofoil design. While most of the aforementioned tools were developed and implemented previously, this paper is more related to application and analysis, addressing common concerns of gradient-based optimisation approach and provides practical suggestions to the aerofoil designers applying both optimisation processes.

References

[1] Mader, C. A., Kenway, G. K. W., Yildirim, A., and Martins, J. R. R. A., “ADflow—An open-source computational fluid dynamics solver for aerodynamic and multidisciplinary optimization,” Journal of Aerospace Information Systems, 2020. https://doi.org/10.2514/1.I010796.

[2] Gray, J. S., Hwang, J. T., Martins, J. R. R. A., Moore, K. T., and Naylor, B. A., “OpenMDAO: An Open-Source Framework for Multidisciplinary Design, Analysis, and Optimization,” Structural and Multidisciplinary Optimization, Vol. 59, 2019, pp.1075–1104. https://doi.org/10.1007/s00158-019-02211-z.

[3] Spalart, P., and Allmaras, S., “A one-equation turbulence model for aerodynamic flows,” 30th aerospace sciences meeting and exhibit, 1992, p. 439.

[4] Menter, F. R., Lechner, B., and Matyushenko, A., “Best Practice: Generalized k-ω Two-Equation Turbulence Model in ANSYS CFD (GEKO),” TECHNICAL REPORT ANSYS, 2019.