Parametric-Adjoint Optimization using OpenFOAM and CAESES

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Today, the optimization of flow-exposed geometries is typically undertaken by means of coupling parametric modeling (variable geometry) and Computational Fluid Dynamics (CFD). An approach that is finding more and more interest in the industry is based on solving the adjoint RANS equations for selected objective functions (like drag and lift) and subsequently deforming the mesh in a parameter-free approach. This approach often makes it difficult to bring the modifications back into the CAD process. Combining parametric and parameter-free solutions, however, is an emerging technique that helps to effectively optimize shapes without leaving the CAD domain of the model, making it easier to integrate in the overall design process.

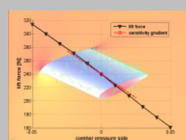
On the basis of the Computer Aided Engineering (CAE) software CAESES developed by FRIENDSHIP SYSTEMS AG and OpenFOAM, a parametric-adjoint approach will be presented. The approach is built on concatenating so-called “design velocities” and “adjoint shape sensitivities”. Design velocities yield the regions of influence for a given model’s parameters from a purely geometric point of view. Meanwhile, adjoint shape sensitivities show where and how changes of the surface affect the objective. Overlaying the surface distributions of both the design velocities and the adjoint shape sensitivities results in so-called “parametric sensitivities”. These help to understand the importance of all parameters within the chosen model.

In addition to solving the adjoint RANS equations - the derivation of which requires considerable effort - the calculation of adjoint shape sensitivities can also be realized by utilizing Algorithmic Differentiation. This technique allows to automatically differentiate numerical models on a source code level, thus leading to greater flexibility with respect to the implementation of new solvers, objectives and boundary conditions. Also higher order derivatives can be computed using this method. A version of OpenFOAM which has been differentiated by Algorithmic Differentiation has been developed by RWTH Aachen University and was coupled with CAESES for this case study.

The approach will be demonstrated on a practical shape optimization example.

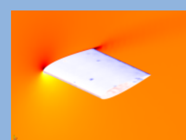
$$\frac{\partial J}{\partial \alpha_n} = \sum_k \frac{\partial J}{\partial n_k} \frac{\partial n_k}{\partial \alpha_n} \frac{A_k}{A_{avg.}}$$

CAESES



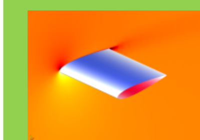
Sensitivity, here camber of pressure side

OpenFOAM



Adjoint sensitivities

CAESES



Design velocity, here camber

Red: Push in Blue: Pull out