Constrained Multi–Objective Optimization of the TU Berlin TurboLab Stator using Continuous Adjoint

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An adjoint–based optimization study carried out on the benchmark test–case TU Berlin TurboLab Stator of the 11th international conference on Numerical Optimisation methods for Engineering Design (ASMO UK/ISSMO/NOED2016) is presented. Gradient–based non–linear programming by the Method of Moving Asymptotes (MMA), is used to produce a new stator shape with improved aerodynamic performance. The computational cost is made independent of the number of design variables using the continuous adjoint to compute flow sensitivities. A differentiated in–house turbomachinery row parameterization software is included in the loop. The design variables are NURBS curve coefficients, used as input of the parameterization, which ensure smooth shape changes during the optimization, despite the great number of degrees of freedom. In order to reduce the optimization turnaround time the in-house primal and adjoint solvers are implemented to run on a cluster of Graphics Processing Units (GPUs). For the same reason, costly re–meshing steps are avoided by using Radial Basis Functions (RBFs) to deform the grid accordingly to the updated shape of the flow domain in each cycle of the optimization loop.

I. Introduction

The primary objective of this abstract is to present a workflow for the parameterization and constrained optimization of turbomachinery rows. The test case is a stator in a measurement rig at the TU Berlin in the TurboLab at the Chair for Aero Engines.

II. Optimization Strategy

The stator has been re–parameterized through an in-house turbomachinery row parameterization software, which has been differentiated to support the gradient–based optimization. This strategy allows to maintain a CAD representation of the row during the whole process.

Constraints are specified on the geometry and they are treated as either bounds to the design variable values or constraint functions of the optimization problem. Since two objective functions are considered, a set of non–dominated solutions is sought.

The flow model is based on the Navier–Stokes equations for incompressible flows, using the pseudo–compressibility approach introduced by Chorin.[1] The continuous adjoint method for incompressible flows, with a fully differentiated turbulence model, is used.[2] Both primal and adjoint solvers are implemented on a cluster of NVIDIA Graphics Processing Units (GPUs).[3]

Geometric sensitivities $\delta \mathbf{x}/\delta \mathbf{b}$, which stand for the ratio of boundary displacements $\delta \mathbf{x}$ over the corresponding variation in any of the CAD parameters $\delta \mathbf{b}$, are computed by differentiating the parameterization software. Based on the chain rule of eq. 1, these are combined with the gradients of the objective functions $\mathcal{F}_i$ with respect to (w.r.t.) the displacements of the blade or casing nodes $\delta \mathbf{x}$, as computed by the adjoint method. The outcome is the gradient of the objective functions w.r.t. the variation of any CAD parameters

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$$\frac{\delta \mathcal{F}_i}{\delta \mathbf{b}} = \frac{\delta \mathcal{F}_i}{\delta \mathbf{x}} \frac{\delta \mathbf{x}}{\delta \mathbf{b}} \tag{1}$$

which can be used to change the shape of the stator and casing during the optimization. In fig.1 an example of adjoint and geometric sensitivities is shown.

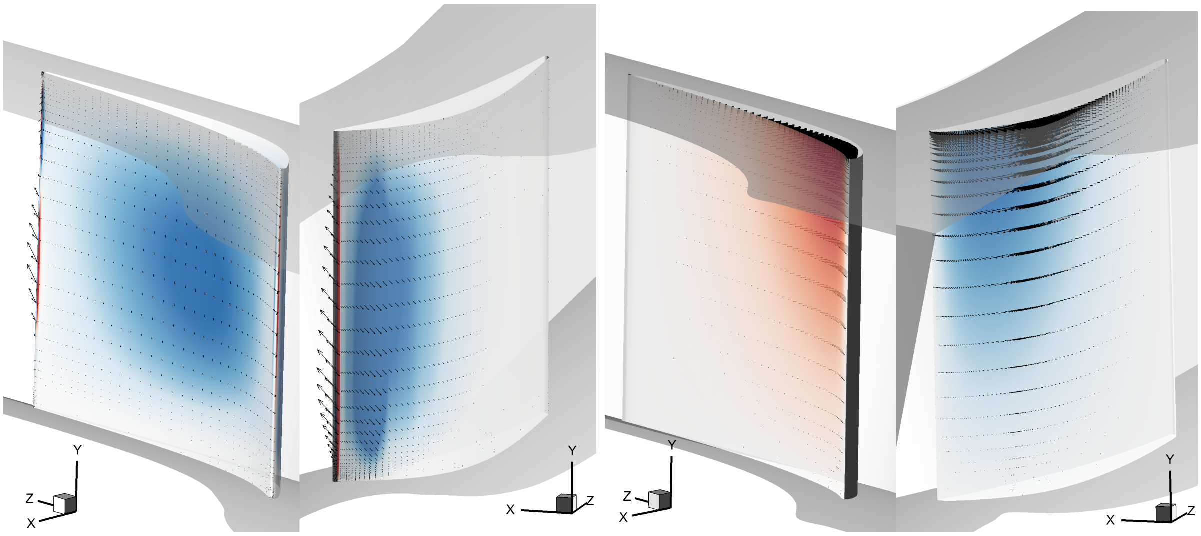

Figure 1. Adjoint sensitivities $\delta\mathcal{F}_i/\delta\mathbf{x}$ of the blade w.r.t. one of the objective functions. The blade is coloured based on the adjoint sensitivities in the normal direction $\delta\mathcal{F}_i/\delta\mathbf{x}\ \mathbf{n}$, whereas arrows represent the actual adjoint sensitivities $\delta\mathcal{F}_i/\delta\mathbf{x}$ (left). Geometric sensitivities $\delta\mathbf{x}/\delta b$ of the blade w.r.t. one of the design variables. The stator blade is coloured according to the geometric sensitivities in the normal direction $\delta\mathbf{x}/\delta b_i\mathbf{n}$, whereas arrows represent the actual geometric sensitivities $\delta\mathbf{x}/\delta b_i$ (right). For both figures, red colour denotes inwards (towards the solid) displacement, whereas blue outwards.

In order to adapt the mesh to the new shape at each optimization cycle RBFs are employed. With the RBF model the deformation is treated as a scattered data interpolation where surface node displacements are smoothly interpolated at the internal nodes.[4] The new surface grid, which corresponds to the new geometry, is obtained by inverting and displacing nodes in the NURBS parametric space (u, v). Special care is taken in case of trimmed surfaces.

The optimization is driven by the MMA: in this method, in each cycle of the optimization, a convex subproblem approximating the objective function is generated. The "moving asymptotes" are upper and lower bounds defined on each design variable, used to regulate the convergence of the method.[5]

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References

[1]Chorin, A., *A numerical method for solving incompressible viscous flow problems*, Journal of Computational Physics, 2–1, 12–26, New York, 1967.

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

[3]Asouti,V.G., Trompoukis, X. S., Kampolis and Giannakoglou, K. C. *Unsteady CFD computations using vertex–centered finite volumes for unstructured grids on Graphics Processing Units*, International Journal for Numerical Methods in Fluids, 67(2), 232-246, 2011.

[4]Buhmann, M., *Radial basis functions: theory and implementations*, Cambridge University Press, Cambridge, 2003.

[5]Svanberg, K., *The method of moving asymptotes – A new method for structural optimization*, International Journal for Numerical Methods in Engineering, 24, 359-373, Stockholm, 1987.