# Adjoint-driven Aerodynamic Optimization of a Compressor Stator using CAD-based and CAD-free Parameterizations

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**Long Abstract**

## Introduction

This work presents the results of an adjoint-driven aerodynamic optimization study conducted on the TU Berlin TurboLab Stator benchmark test case [1]. Both CAD-based and CAD-free parameterizations are considered leading to a comparison between two different optimization attempts. The CAD-based approach requires the computation of derivatives w.r.t. the CAD design parameters, which is achieved by linking the adjoint surface sensitivities with the model's geometric sensitivities. It is advantageous regarding the incorporation of the manufacturing constraints of the case and, since the optimization output is already in CAD format, the optimum blade can be straightforwardly manufactured without any further post-processing. On the other hand, the CAD-free approach uses all the model's surface mesh nodes as design parameters, which are perturbed according to the smoothed adjoint surface sensitivities. This offers more freedom to the shape of the blade. Then, a mesh morpher is used to propagate the boundary displacements to the interior of the CFD domain. Both methods are applied to the turbomachinery test case, where a multi-objective multi-point problem is considered.

## 1. Methods

In order to perform gradient-based optimization using a CAD-based parameterization, the sensitivities of the model's boundary w.r.t. the design parameters have to be computed. Differentiating the underlying parameterization of the CAD software to obtain these geometric sensitivities is usually not an option within an industrial environment, where closed-source commercial CAD tools are widely used. In this work, the stator blade is parameterized through the Rolls-Royce in-house aerofoil design software Parablading [2], which uses an approved design parameterization [3,4]. This is based on a superposition of camber-line angle and thickness distributions to create the blade design sections, in conjunction with a profile stacking approach to generate the 3D blade shape. Additionally, the blade is described as a set of NURBS patches, which allows to maintain a CAD representation of the stator during the whole optimization process. The geometric sensitivities for each design parameter are calculated using finite differences between discrete representations of the CAD geometry.

The in-house compressible CFD solver HYDRA [5] is employed to predict the 3D flow, solving the steady RANS equations with Spalart-Allmaras turbulence model, and its corresponding discrete adjoint is used to compute the sensitivity map. More specifically, the adjoint solver provides the volume sensitivities (i.e. the change in objective function w.r.t. a volume mesh node perturbation) at a CPU cost which is similar to that of one primal/flow calculation [6,7]. The surface sensitivities are obtained using the inverse operation of a spring-based mesh deformation algorithm on the volume sensitivities. Finally, the total gradient w.r.t. the CAD parameters is computed as the inner product between the geometric sensitivities and the adjoint surface sensitivities.

As an alternative, a CAD-free parameterization is also considered in this work. It uses all the surface mesh nodes as design parameters, which represents the richest design space the CFD can evaluate. However, since the surface nodes can move independently, the implementation of a smoothing algorithm is required to prevent the generation of oscillatory shapes during the optimization. This is achieved here by applying a Gaussian filter [8] on the raw surface sensitivities provided by the adjoint solver. The smoothed sensitivities are used to perturb the boundary of the blade and a mesh morpher (either based on linear elasticity [9] or inverse distance [10]) is employed to deform the volume CFD mesh, in order to close the optimization loop.

Both approaches are applied to the turbomachinery test case, where the goal is to optimize the blade w.r.t. the total pressure loss over a prescribed incidence range, while achieving an axial flow at the stator exit.

**References**


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