Multiobjective Optimisation of a Compressor Stator using a 3D B-Spline Parameterisation

Sam Duckitt and Chiara Bisagni

Delft University of Technology, Delft, 2629 HS Netherlands

Shahrokh Shahpar

Rolls-Royce plc., Derby, DE24 8BJ, United Kingdom

With ever stricter emissions targets and a relentless demand for efficiency improvements, optimisation has become an indispensable tool in the design of gas turbine engines. Traditionally most studies focus on increasing the performance of fan, compressor and turbine blades but it is now common to find optimisation applied to secondary air systems in an effort to further improve overall engine efficiency. Wherever this optimisation is performed in the engine, it inevitably becomes a multidisciplinary endeavor. Compressor blades for example are required to have high aerodynamic efficiency but must also withstand considerable static and dynamic structural loads. Arriving at an optimal design is therefore very challenging since satisfying these objectives results in conflicting requirements.

In this study we focus on a multiobjective optimisation of the TU Berlin TurboLab stator blade. The first objective is to minimise total pressure loss between CFD inlet and outlet whilst keeping the mass flow at $9.0 \pm 0.1 kg/s$. The second is to minimise the flow angle deviation at the CFD outlet from the axial direction. Three operating points are accounted for, where the inlet whirl angle is allowed to vary $\pm 5°$ from its nominal value of $42°$. This leads to a multipoint optimisation problem where a weighting of 50% is assigned to the nominal operating condition and 25% to the two off design points. There are also a number of mechanical constraints which will be described during the presentation.

A novel approach has been developed to parameterise the blade with B-spline control points. The idea is to use a smaller set of 'design control points' which only approximate the true geometry. When these points are moved during the optimisation process, they produce a displacement field which can be mapped to the original geometry, generating a new design. This concept is illustrated in Figure 1(a) for a simple 2D aerofoil geometry, where 2 control points are displaced (highlighted with arrows). Compared to directly using the control points required to represent the geometry, this approach drastically reduces the number of design variables whilst maintaining a very large design space.

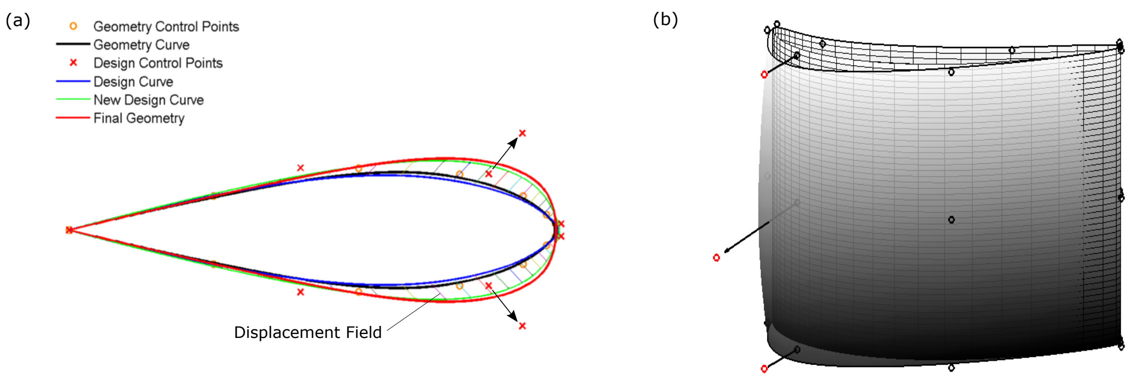

Figure 1: (a) 2D illustration of B-Spline parameterisation method (b) Perturbing the TU Berlin stator blade design by moving 3 control points (red)

Figure 1(b) shows the TU Berlin stator blade approximation (solid grey) and a new design which is achieved by displacing 3 control points (red). The approximate 'design' geometry is represented by 3 radial sections at the hub, tip and mid-span. Each section has 10 control points which gives 30 control points for the whole blade. Each control point is free to move in two directions but due to constraints such as keeping a constant chord, the number of design variables for each section can be reduced to 10. This results in a total of 30 design variables for the optimisation.

The optimisation is performed making use of the Rolls-Royce SOPHY system.[2] Using the given boundary and flow conditions, HYDRA[3] is used for the CFD solver. The optimisation technique used in this study was the trust based, Meta-Assembly Method (MAM) from the SOFT[2] library. This reduces the number of computations necessary for large scale optimisations by using localised design of experiments (DoE) that can be dynamically moved. The results from a generation of simulations (chosen by DoE) are taken and the sub-optimal point then calculated. The search then moves to near this point, where a new generation is created and the process repeated until an optimum design is found.

To assess the efficacy of the B-spline parameterisation method, a comparison is made against a Free-Form-Deformation (FFD) optimisation. The advantages and pitfalls of the approach will be thoroughly discussed during the presentation.

References

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[3] Lapworth, L., *'Hydra CFD: A Framework for Collaborative CFD Development'* , International Conference on Scientific and Engineering Computation, Singapore, 2004.