Use of Parallel Coordinates for Post-Analyses of Multi-Objective Aerodynamic Design Optimisation in Turbomachinery

by

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Abstract

A novel approach for the post-analysis of design optimisation processes is suggested. The technique is based on the parallel coordinates representation of multi-dimensional design spaces. By applying this methodology, the geometrical characteristics of optimum turbomachinery blade shapes responsible for improved behaviour of crucial flow characteristics can be identified and classified according to their impact on the overall turbomachinery efficiency. Hence, geometrical features are directly associated with physical flow characteristics in highly complex aerodynamic domains. The main objective of the present approach is to reveal physical mechanisms, responsible for highly efficient turbomachines, to researchers and designers that can be ascertained by no other means.

Preliminary exploration of the suggested technique for qualitative design optimisation post-analysis demonstrates the ability to derive useful physical information through engineering optimisation. The same approach can be directly applied to any type of real-world design optimisation problem. Indeed it has already been extended to the analysis of an entire 7-stage axial Intermediate Pressure Compressor preliminary design described with 45 design parameters representing the compressor annulus, distribution of the pressure ratio in the stages, the blade lengths, number of blades and the exit flow angles from the stators. The surge margin and the isentropic efficiency of the system are considered as objectives for optimisation.

The value of such parallel coordinates analysis of the optimum design configurations in the optimisation of a stator compressor row can be summarised as follows: sweep and lean are responsible for the control of the amount of flow separation, while blade thickness distribution along the span and camber are responsible for the restriction of the development of secondary losses. An appropriate combination of those

geometrical characteristics is shown to produce robust optimum blade shapes exhibiting good behaviour over a range of flow features critical to the performance of the turbomachine. In contrast, a bad combination is shown to produce unstable behaviour of the optimum configurations to some of the most important flow characteristics that were not considered during the optimisation process. However, the efficiency of the optimiser is directly responsible for the intelligent blending of all the beneficial geometrical attributes.

If we visualise all the candidate design vectors explored during the optimisation process, we can identify the discontinuities, infeasible regions and non-linear behaviour of the design space under investigation. Hence, a better understanding of the complex morphology of the design landscape can be achieved.

Furthermore, the existing Parallel Coordinates analysis technique can also be extended and deployed directly inside the computational design process, in a pro-active way, to enhance the intelligence of the computational design system.