Multidisciplinary Robust Design Optimization of LPT Vane Clusters

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Reduction of emissions, weight and vibrations while increasing efficiency are the goals for the design of advanced civil aircraft engines. To achieve these goals, each component of the engine needs to be optimized. The guide vane (Fig. 1) is the crucial component for the low pressure turbine (LPT) design, responsible for optimal direction of the gas flow to act on the rotor blades.

The design of the vane cluster is driven by multiple disciplines, such as aerodynamics, thermal-mechanics, structure and damage mechanics. These disciplines are coupled, and the optimal design in one discipline may lead to the failure in other disciplines. Multidisciplinary analysis (MDA) and optimization (MDO) are aimed to satisfy conflicting multidisciplinary constraints and improve the overall performance of the guide vane.

First part of the research project is aimed to establish the automatic process for the vane cluster shape modification and MDA (Fig. 2). The total computation time for a single deterministic design point evaluation is within 2-3 hours range. Concerning high-dimensional (30-60 variables) design space, MDO based on true simulations is not a sensible option. Thus, surrogate modeling is used for model reduction.

Global sensitivity analysis is used prior to optimization for the variable screening [1]. Both correlations analysis and advanced non-linear techniques, such as Elementary Effects and Variance Decomposition are used to identify input-output relations. Surrogate models are used for the complex non-linear sensitivity analysis.

Fig. 1: Vane cluster.
As was mentioned before, surrogate-based approaches are of the main interest for the optimization. To get high accuracy of the optimal solution while maintaining low number of true evaluation, efficient adaptive strategy is being developed, based on EGO method [2]. The method uses the Gaussian Process (GP) surrogate models, which provide not only the approximation, but also expected model variance. This is used to construct efficient adaptive refinement criteria, such as Expected Improvement [2]. The methods toolbox is implemented in Python and successfully applied for the vane cluster shape optimization [3].

Next to that, uncertainties in load conditions, as well as manufacturing tolerances should be considered, so that final optimal design will satisfy robustness requirements. Sampling based techniques, applied onto the GP surrogate models are used to assess the reliability w.r.t presented constraints and robustness of the objective function. Efficient adaptive refinement criterion, proposed originally for the Efficient Global Reliability Analysis (EGRA) [4] is employed together with the Subset Simulations technique for the efficient surrogate-based reliability analysis.

Finally, a novel adaptive surrogate-based approach is introduced which is inspired by the EGO method and inverse reliability analysis, and is aimed to find the global robust optimum of expensive black-box systems. The aforementioned method was successfully used for multidisciplinary robust design optimization of the vane cluster [5].

Main results:
- Automated process chain for multidisciplinary analysis of vane clusters, including aerodynamic, thermal structural and damage analysis.
- Global sensitivity analysis and variable screening for expensive high-dimensional vane cluster MDA based on response-surface methods [1].
- Efficient global MDO of the vane cluster using adaptive surrogate-based methods [3].
- Novel adaptive surrogate-based method for the Multidisciplinary Robust Design Optimization of the vane cluster [5].

References