Design Optimization of a High-Pressure Turbine Blade using Generalized Polynomial Chaos (gPC)

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Gas turbine engines for aerospace applications have evolved dramatically over the last 50 years through the constant pursuit for better specific fuel consumption, higher thrust-to-weight ratio, lower noise and emissions all while maintaining reliability and affordability. This paper addresses one facet of this inter-disciplinary optimization problem – optimal design of a turbine blade. An existing Rolls-Royce High Work Single Stage (HWSS) turbine blisk provides a baseline to demonstrate the optimal aerodynamic design of a turbine blade. The optimization problem maximizes stage efficiency, for the high-pressure stage turbine, using turbine aerodynamic rules as constraints. The function evaluations for this optimization are surrogate models built from detailed 3D steady Computational Fluid Dynamics (CFD) analyses. To perform the optimization, this paper presents the generalized polynomial chaos (gPC) method – which is commonly associated with uncertainty quantification – as a viable option for sampling and constructing polynomial approximations. To reduce computational costs, the optimization uses response surfaces generated by fitting the results from the engineering toolset at a prescribed set of trial points. Instead of using traditional DoE techniques, like fractional factorial designs, the gPC method provides the trial points through sparse grid sampling. Also the gPC toolbox developed as part of this research effort facilitates construction of the response surfaces for the blade optimization via the stochastic collocation technique. The paper describes the design optimization concept, introduces basic gPC theory, provides detailed CFD results and concludes with an interpretation of the design optimization effort that results in a new aerodynamic shape for the turbine blade. The efforts are aimed at advancing the usability and impact of high-fidelity tools in the design process using automation and optimization with the focus of improving stage efficiency of the high work single stage turbine. To the best of the authors' knowledge, this paper is a first in applying gPC methods to generate surrogate models for design optimization in an industry level turbomachinery problem.