An industry ready approach to characterization and reduction of manufacturing uncertainties

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Significant research and development effort has been dedicated over the past few years to the improvement of uncertainty propagation and robust or reliable optimization techniques. A variety of uncertainty propagation methods spanning from advanced sampling methods like multi-level Monte-Carlo, over various Polynomial chaos based method to perturbation techniques were significantly advanced to address in the order of ten uncertainties in industrial applications [Hirsch *et al.* (2018)]. All these methods, however, rely on the correct characterization of input uncertainties, which in general is a difficult task.

In particular characterizing the manufacturing variability of for example turbomachinery blades remains challenging. One possibility is to measure hundreds of manufactured blades and in this way sample the surface variability resulting from the manufacturing process. This is, on the one hand, expensive and time consuming and, on the other hand, not always applicable, for example for customized designs, which are either unique or comprise of only one or two machines. In this case, insufficient geometry samples are available. Büche *et al.* (2018) show a path to extract an estimation of manufacturing variability from technical norms, which define the allowable manufacturing tolerances typically in clearly defined tolerance classes from coarse to fine.

In the current work, the approach described by Büche *et al.* (2018) forms the basis for the characterization of input uncertainties of a high pressure turbine. Manufacturing tolerances are attributed to engineering design parameters describing the blade shape. In general, such a model or a CAD design will consist of hundreds of lengths, angles and radii. However, a direct treatment of the O(100) uncertainties is still out of reach on industrial scale for state-of-the-art uncertainty propagation techniques. An alternative form design space reduction techniques [Diez *et al.* (2015)], which aim at maintaining the freedom in the geometrical variability, but at a lower computational cost. The number of effective uncertain variables is reduced.

A Latin Hypercube Sampling is performed sampling up to thousands of geometries from uniform- and beta-distributed random variables. On this basis, the covariance of the geometry is calculated and a Principle Component Analysis (PCA) is applied. The resulting Eigen modes for various retained reconstruction accuracies are analyzed and discussed.

In a second step, the uncertainties resulting from the reduction are propagated and compared to the results of the full parametric uncertain problem for the four classes of accuracy defined in the applied technical norm. The uncertainties in the reduced problems correspond to the retained modes and are Gaussian distributed, while the eigenvalues are the variance of these Gaussian distributions.

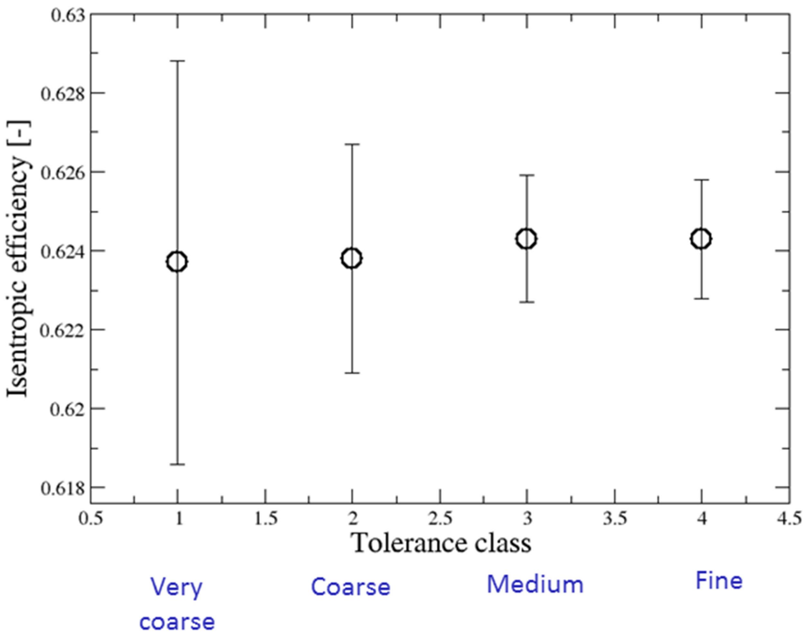

Figure 1: Comparison of mean value and standard deviation of isentropic efficiency for the 4 defined tolerance classes. The bars correspond to ±σ.

The results of the UQ simulations are discussed and compared. Figure 1 shows the evolution of the mean value and standard deviation of the isentropic efficiency for the four tolerance classes defined in the technical norm. As one could expect, the spread of the predicted result reduces with more narrow tolerance classes. It is very interesting to observe that from a practical engineering point of view there is no relevant difference in prediction for the two most narrow tolerance classes 'medium' and 'fine'. This can be exploited in an inverse robust design optimization setting, where the largest allowable tolerance is sought for, while respecting a minimum performance (constraint).

The further, scaled sensitivity derivatives of the various studied problems are compared and the reduced problems are compared with the initial non-reduced problem. This work constitutes an industry ready approach for the characterization and reduction of manufacturing uncertainties.

References

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