Uncertainty Quantification from an Industrial Perspective

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Summary. This presentation considers uncertainty quantification from an industrial perspective. Some successful methods in the field of stochastic optimization and reliability analysis as well as industrial applications are presented.

1 Content

Deterministic design optimization approaches are no longer adequate for the development of industrial high technology products. Product and process designs often push to the envelope of physical limits to improve performance. In this regime uncertainty originating from fluctuations during fabrication and small disturbances in system operations severely impacts product performance and quality. Design robustness becomes a key issue in optimizing industrial designs.

The design phase of a product or system is characterized by having no direct interaction with data. Here, the methods of uncertainty quantification try to predict confidence intervals for the behavior in the phase of operation. Also optimization and keeping quality limits for products and systems plays an important role in the design phase. Here, special stochastic optimization schemes and reliability analysis must be developed. For an industrial application they have to be designed such that as less function evaluations as possible are needed. The phase of operation is characterized by the interaction with data. For this phase a main task is the callibration of models with incomplete and noisy data. Here, the Bayesian concepts come into play.

We present challenges and solution approaches implemented in our robust design tool RoDeO applied to turbo charger design. In contrast to electricity generating turbines, turbo chargers have to work efficiently not only for one operating point, but for a wide range of rotation frequencies. High computation times for 3D aerodynamic (CFD) and mechanical (FEM) computations, for large sets of frequencies, are a severe limiting factor even for deterministic optimization procedures. Furthermore constrained deterministic optimization cannot guarantee critical design limits under impact of uncertainty during fabrication. Especially, the treatment of design constraints in terms of thresholds for von Mises stress or modal frequencies become crucial. We introduce an efficient approach for the numerical treatment of such absolute reliability constraints that even do not need additional CFD and FEM calculations in our robust design tool set.

A second application concerns the wheel set of a train. For this component (which is the most sensitive part of a train) a life cycle analysis is performed. In real life, such a component is faced by scattering outer impact and abrasion and thus, with a certain probability, the design leads to finite time fatigue resistance in spite it has been designed for infinite time. The underlying physics are the laws of fracture mechanics and crack growth. The failure criteria is the crack size exceeding a given length. The proposed stochastic method is in particular suited for CPU time intensive and large scale physical models. Based on these life time computations also inspection planning can be considered. In doing so we assume that all components are replaced if a crack is detected. The probability of detecting a crack during inspection is itself a random number. Knowing the costs for replacement of components, loss due to the outage during inspection etc., optimal inspection schemes can be derived.

An outlook for further design challenges concludes the presentation.