Engineering Risk Analysis Group
Prof. Dr Daniel Straub

Computational Mechanics Group
Prof. Dr Fabian Duddeck

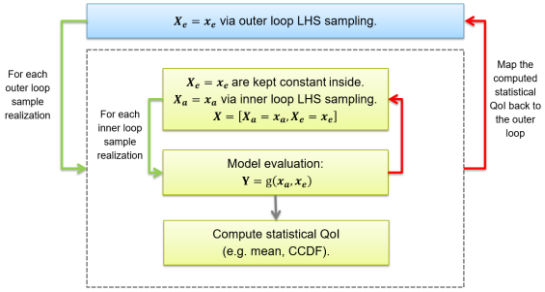
MSc thesis

Mixed aleatory-epistemic uncertainty quantification and sensitivity analysis.

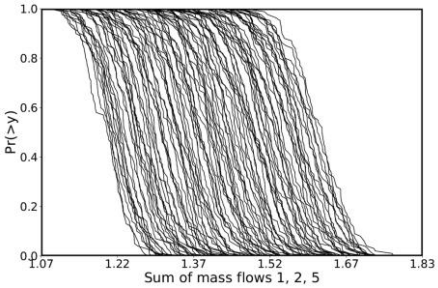
Kamariotis Antonis, January 2019

Background

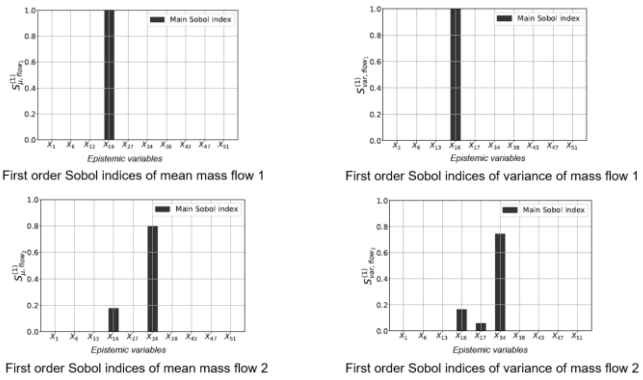
Aleatory uncertainties are due to randomness related to the physical quantities and to the system, and are irreducible. Uncertainties related to lack of knowledge and/or lack of useful data, which are considered reducible, are termed epistemic uncertainties. The focus of this thesis is the computational model input parameter uncertainty. There are different methods for modeling epistemic uncertainty, such as Bayesian probability theory or interval analysis. In most engineering models, both types of uncertainties are present, therefore it is important to find the right tailored methods to do mixed aleatory-epistemic uncertainty quantification and sensitivity analysis. Within the current work, such methods are investigated and applied on a jet engine secondary air system (SAS) model from aerospace engineering.



Nested sampling approach for uncertainty propagation. Aleatory vector X_a. Epistemic vector X_e.



"Horsetail" plot: multiple CCDFs of the response.



Novel expressions for the Sobol indices of a statistical QoI.

Methodology

For the mixed aleatory-epistemic uncertainty quantification two different methods are used. The Interval Valued Probability (IVP) method treats the epistemic variables as intervals, it propagates the epistemic uncertainty by solving an output interval minimization/maximization problem in the epistemic variable bound constrained space, and it computes epistemic bounds on the statistic of interest of the response. The Bayesian approach involves making subjective probability distribution assignments for the epistemic variables, and using stochastic uncertainty propagation techniques (sampling, stochastic expansions) it computes a distribution of the statistic of interest of the response. For sensitivity analysis, an empirical "pinching" strategy was used when using the IVP method, while when using the Bayesian method, either correlation matrices are computed, or a variance-based sensitivity analysis is performed, computing the Sobol indices.

Results

Both methods (IVP, Bayesian) are suitable for mixed aleatory-epistemic uncertainty quantification, as demonstrated on a real high-dimensional engineering model like the SAS. The mathematical structure of the output is different between the two methods, however within this thesis it is shown that Bayesian credible intervals on the statistical QoI of the response can be obtained, which can be compared to the intervals obtained with IVP. Through sensitivity analysis in the mixed uncertainty case, an importance ranking of the epistemic variables is obtained, where the effect of aleatory uncertainty has been integrated out.

Supervised by Univ.-Prof. Dr. Fabian Duddeck
Dr.-Ing. Giulia Antinori
Dr.-Ing. Iason Papaioannou