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Abstract:

Aim of the PhD project is the evaluation of several stochastic methods with respect to their applicability for the uncertainty quantification of a coupled flow-thermo-mechanical model of a jet engine low pressure turbine rotor. Stochastic methods to quantify uncertainty are well established in literature, however their application for the multidisciplinary design of a low pressure turbine rotor is not common. In fact, the design of a new part is usually based on a deterministic model. The stochastic analysis is comprised of a sensitivity analysis followed by an uncertainty analysis. The sensitivity analysis is performed to gain a better understanding of the coupled flow-thermo-mechanical system robustness, to identify the important variables and to reduce the number of design parameters which will be used in the optimization. The uncertainty analysis using probability distributions derived from the manufacturing process, allows to predict the effect of the input uncertainties on the life duration of the rotor. The flow system models the Secondary Air System of the aircraft engine, which performs essential tasks mosts of them related to cooling or sealing applications. It is represented as a succession of chambers, with finite volume, linked by complex flow passages (holes, ducts, pipes, seals, discs) which possess their own pressure loss characteristics. The thermal system models the heat conduction, convection phenomena between surface and fluids, and the radiation phenomena which take place inside the low pressure turbine rotor. The temperature field is used to compute the stresses due to thermal and dynamic loads, which are then used to produce an estimate of life expectancy. The flow-thermo-mechanical system inputs, which primarily consist of geometric characteristics as well as of the performance parameters are varied in a certain range ($\pm x\%$ from nominal value) on the basis of the manufacturing tolerances. Using some knowledge on the system, physically meaningful dependencies among the inputs (among performance parameters as well as among some of the geometric features) has been introduced before the sensitivity analysis starts. In order to simulate the system the remaining independent input variables are sampled uniformly within their range of variation. A review of the most common sampling methods is performed. The study shows that some of the sampling methods cannot be recommended since they produce spurious correlations between independent input variables.

With regards to the sensitivity analysis, many literature sources state that the Pearson correlation method is only valid for linear models when assessing the importance of input variables. As the coupled flow-thermo-mechanical system might behave non-linearly and interactions among the different parameters should be also determined, non parametric variance based methods are introduced to make up for the limitations of the correlation method. Following the result of the study, it is recommended to combine the correlation computation with a non parametric variance based method.

Once the main players have been identified, uncertainty quantification analysis is performed. There are mainly two kinds of uncertainty: epistemic uncertainty, which is reducible to a lack of knowledge, and aleatory uncertainty, which is due to random variability inherent in nature. In this work we are interested in the quantification of aleatory uncertainty. This aim can be fulfilled by using sampling methods, i.e

by generating sets of samples according to the probability distribution of the uncertain variables and by mapping them into corresponding sets of response functions. The probability distribution of the input variables can be determined by using measurement data or by making some assumptions. Due to the lack of measurements, a normal probability distribution has been assigned to the input variables. The mean is given by the input parameters' nominal value and the standard deviation by the parameter variation, which for the geometric parameters corresponds to the manufacturing tolerances and it amounts to $\pm 3\sigma$. For what concerns the performance parameters, at the beginning of the analysis an estimate of the variation based on experience was given. However, it resulted to be too inaccurate and it led to erroneous results. Therefore the estimation has been refined and in the new definition it corresponds to a $\pm 2\sigma$ variation. Additionally, correlations (which were neglected in the first approximation) among the different performance parameters has been introduced by using the Iman and Conover modification of the Latin Hypercube sampling technique. Probably a more rigorous definition would be given by the copula theory, which will be objective of future investigations. The introduction of correlations among some of the input parameters requires a new investigation of the sensitivity analysis methods. This is due to the fact that both the EE and the Sobol methods assume the independence of the input parameters.

The objective of the uncertainty analysis is to check the robustness of the system which can be measured by assessing that the current solution differs from the nominal one, i.e. from the design intent solution, less than $\pm 3\sigma$. As first, the probability distribution of the output variables is identified through an Anderson-Darling test. Almost all the responses results to be normally distributed, hence a t-test is performed to check if the sampled mean is equal to the nominal solution. The confidence level chosen for the test is 95%. The result of the test, is that the nominal value lies between the first and third quartile, i.e. inside a $\pm 1\sigma$ variation, which proves the robustness of the system.

The next step is the optimization. Life expectancy is one of the objective functions to be optimized. In addition, the amount of cooling air employed by the SAS should be minimized as well as the temperature gradient between bore and rim locations in every turbine stage. Additionally, the parameters which represent the system topology are affected by uncertainties due to manufacturing tolerances, engine-to-engine variations and ambient conditions. Thus, in order to include the uncertainties, a probability distribution is assigned to each parameter and the optimization is performed in the frame of robustness, i.e. it should be assured that the optimized solution remains relatively unchanged when exposed to uncertain conditions. Therefore, the optimization problem is not only multidisciplinary, but also multi-objective, since both the mean and variance of the objective function have to be minimized. Since the simulation of the physical system is computationally quite demanding, Monte Carlo methods for the computations of robustness measures are not affordable. A faster method, based on sparse polynomial chaos expansions, is implemented instead to guarantee higher efficiency.

Short biography –

I studied Mathematics at the University of Padua gaining my Bachelor degree in 2009 and my Master degree in 2012. I have been always interested in the application of mathematics to real life problems. I am currently PhD student at the Technische Universität in Munich and my research project is the robust design and optimization of a low pressure turbine rotor. The project is part of the LuFo aeronautics research programme funded by the German Federal Ministry of Economics and Technology and it is supported by the MTU-Aero Engines and the Technische Universität München.