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PROBABILISTIC FE-ANALYSIS OF COOLED HIGH PRESSURE TURBINE BLADES – PART A: HOLISTIC DESCRIPTION OF MANUFACTURING VARIABILITY

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Modern high pressure turbine (HPT) blade design stands out due to high-grade complexity comprising three-dimensional blade features, multi-passage cooling system (MPCS) and film cooling to allow for progressive thermodynamic process parameters. During the last decade, probabilistic design approaches became increasingly important in turbomachinery to incorporate uncertainties such as geometric variations caused by manufacturing scatter.

Within this scope, the first part of this two-part paper introduces parametric models for cooled turbine blades that allow for probabilistic FE analysis taking geometric variability into account to aim at sensitivity and robustness evaluation. The statistical database is represented by a population of more than 400 blades whose external geometry is captured by optical measurement techniques and 34 blades that are digitized by computed tomography (CT) to record the internal geometry and the associated variability, respectively. Based on this, parametric models for airfoil, endwalls, wedge surfaces and MPCS are presented.

The parametric airfoil model which is based on traditional profile theory is briefly described. In this regard, a methodology is presented that enables to adapt this airfoil model to a given population of blades by means of Monte-Carlo based optimization. The endwall variability of hub and shroud are parametrized by radial offsets that are applied to the respective median endwall geometry. Wedge surfaces are analytically represented by planes. Variations of the MPCS are quantified based on the radial distribution of cooling passage centroids. Thus, an individual MPCS can be replicated by applying adapted displacement functions to the core passage centroids. For each feature that is considered within the present study, the accuracy of the parametric model is discussed with respect to the variability that is present in the investigated blade population and the measurement uncertainty.

The parametrization of the investigated blade population is associated with a comprehensive statistical analysis to reveal the parameter correlation structure and probability density function (PDF). This is required for a reliable probabilistic analysis that is shown in the second part of this paper.

Keywords: Probabilistic analysis, FE analysis, uncertainty quantification, manufacturing variation, real geometry effects