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Reliability and Confidence Interval Analysis of a CMC Turbine Stator Vane

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Summary

High temperature ceramic matrix composites (CMC) are being explored as viable candidate materials for hot section gas turbine components. These advanced composites can potentially lead to reduced weight, enable higher operating temperatures requiring less cooling and thus leading to increased engine efficiencies. However, these materials are brittle and show degradation with time at high operating temperatures due to creep as well as cyclic mechanical and thermal loads. In addition, these materials are heterogeneous in their make-up and various factors affect their properties in a specific design environment. Most of these advanced composites involve two- and three-dimensional fiber architectures and require a complex multi-step high temperature processing. Since there are uncertainties associated with each of these in addition to the variability in the constituent material properties, the observed behavior of composite materials exhibits scatter. Traditional material failure analyses employing a deterministic approach, where failure is assumed to occur when some allowable stress level or equivalent stress is exceeded, are not adequate for brittle material component design. Such phenomenological failure theories are reasonably successful when applied to ductile materials such as metals. Analysis of failure in structural components is governed by the observed scatter in strength, stiffness and loading conditions. In such situations, statistical design approaches must be used. Accounting for these phenomena requires a change in philosophy on the design engineer's part that leads to a reduced focus on the use of safety factors in favor of reliability analyses. The reliability approach demands that the design engineer must tolerate a finite risk of unacceptable performance. This risk of unacceptable performance is identified as a component's probability of failure (or alternatively, component reliability). The primary concern of the engineer is minimizing this risk in an economical manner.

The methods to accurately determine the service life of an engine component with associated variability have become increasingly difficult. This results, in part, from the complex missions which are now routinely considered during the design process. These missions include large variations of multi-axial stresses and temperatures experienced by critical engine parts. There is a need for a convenient design tool that can accommodate various loading conditions induced by engine operating

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environments, and material data with their associated uncertainties to estimate the minimum predicted life of a structural component.

A probabilistic composite micromechanics technique in combination with woven composite micromechanics, structural analysis and Fast Probability Integration (FPI) techniques has been used to evaluate the maximum stress and its probabilistic distribution in a CMC turbine stator vane. Furthermore, input variables causing scatter are identified and ranked based upon their sensitivity magnitude. Since the measured data for the ceramic matrix composite properties is very limited, obtaining a probabilistic distribution with their corresponding parameters is difficult. In case of limited data, confidence bounds are essential to quantify the uncertainty associated with the distribution. Usually 90 and 95% confidence intervals are computed for material properties. Failure properties are then computed with the confidence bounds. Best estimates and the confidence bounds on the best estimate of the cumulative probability function for R-S (strength – stress) are plotted. The methodologies and the results from these analyses will be discussed in the presentation.