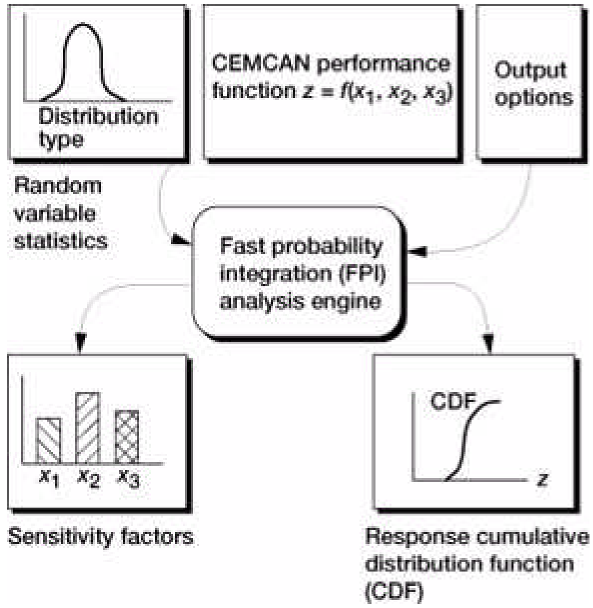
Design Tool Developed for Probabilistic Modeling of Ceramic Matrix Composite Strength

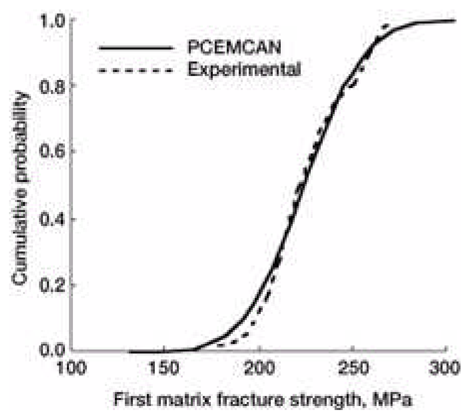
Ceramic matrix composites are being evaluated as candidate materials for many high-temperature applications such as engine combustor liners for the High-Speed Civil Transport (HSCT). They are required to have an assured life of several thousand hours. Estimating the reliability of these components is quite a complex process and requires knowledge of the uncertainties that occur at various scales. The properties of ceramic matrix composites (CMC) are known to display a considerable amount of scatter due to variations in fiber/matrix properties, interphase/coating properties, bonding, amount of matrix voids, and many geometry- and fabrication-related parameters such as ply thickness and ply orientations. The objective of this research effort is to account for these uncertainties in a formal way by probabilistically analyzing both the stiffness- and strength-related properties of CMC's. In current deterministic approaches, uncertainties are usually accounted for by safety factors. This approach often yields overly conservative designs, thereby reducing the potential of many advanced composite materials.

Work is underway at the NASA Lewis Research Center to incorporate the probabilistic distribution of material-behavior and fabrication-related parameters into the micromechanics and macromechanics of CMC's. The primary objective of this work was to develop an efficient computational design tool that could account for all the uncertainties in a more rigorous and formal manner, providing overall composite properties and their probabilistic distributions.

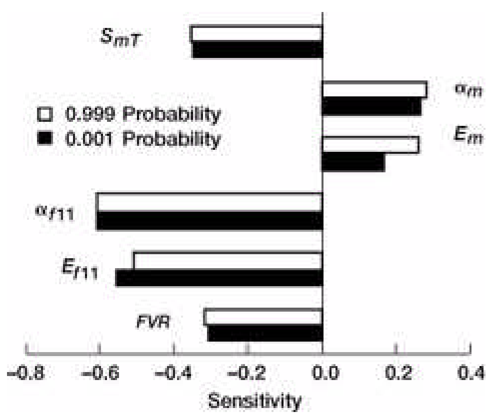


Fast probability integration input and output.

Therefore, we combined the CMC analysis embedded in the CEMCAN (Ceramic Matrix Composite Analyzer) computer code with the fast probability integration (FPI) techniques available in the NESSUS (Numerical Evaluation of Stochastic Structures Under Stress) code. CEMCAN provides functional relationships that tie the constituent properties and other geometry- and fabrication-related parameters to the overall composite properties. Fast probability integration is used to perform probabilistic analyses by utilizing the properties generated by CEMCAN. The results are cumulative distribution functions (CDF's) and probability density functions (PDF's) for the ply and laminate properties of the CMC. This technique is more efficient than a standard Monte-Carlo technique, where a large number of simulations are needed to generate a cumulative distribution function. The probabilistic sensitivities of the output variables with respect to inherent scatter in basic variables are obtained as a byproduct of the fast probability integration analyses. This provides very useful information to design and test engineers in evaluating the importance of variables that control the scatter in an overall property. The accompanying figures show sample results from the analyses.



Comparison of the first matrix cracking strength cumulative-distribution-function simulation (PCEMCAN, Probabilistic Ceramic Matrix Composite Analyzer) with the experimental data for a $[0]_8$ SCS-6/RBSN composite laminate.



Sensitivity of the first matrix cracking strength to the primitive random variables of a $[0]_8$ SCS-6/RBSN composite laminate. Matrix tensile strength, S_{mT}; fiber coefficient of thermal expansion, a_{f11}; fiber longitudinal modulus, E_{f11}; fiber volume ratio, FVR.

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