

PROBABILISTIC STRUCTURAL ANALYSIS METHODS FOR  
SELECT SPACE PROPULSION SYSTEM COMPONENTSS20-39  
19877H.R. Millwater and T.A. Cruse  
Southwest Research Institute  
San Antonio, Texas

The Probabilistic Structural Analysis Methods (PSAM) project developed at SwRI integrates state-of-the-art structural analysis techniques with probability theory for the design and analysis of complex large-scale engineering structures. PSAM is currently in the fifth year of a five year contract. An advanced efficient software system (NESSUS) capable of performing complex probabilistic analysis has been developed. NESSUS contains a number of software components to perform probabilistic analysis of structures. These components include: an expert system, a probabilistic finite element code, a probabilistic boundary element code and a fast probability integrator. The NESSUS software system is shown in figure 1.

An expert system is included to capture and utilize PSAM knowledge and experience. NESSUS/EXPERT is an interactive menu-driven expert system that provides information to assist in the use of the probabilistic finite element code NESSUS/FEM and the fast probability integrator (FPI). Figure 2 summarizes the expert system menu structure.

The NESSUS system contains a state-of-the-art nonlinear probabilistic finite element code, NESSUS/FEM, to determine the structural response and sensitivities. A broad range of analysis capabilities and an extensive element library is present. A summary of the current analysis capabilities include static, eigenvalue, harmonic, random vibration, and buckling analyses. A variety of random variables are available such as geometry, loads, material properties, temperatures, boundary conditions, harmonic excitation, power spectral density input, etc. In addition, special algorithms have been developed and implemented to efficiently perform sensitivity computations required for probabilistic structural analysis. A summary of the current code capabilities is presented in figure 3.

A fast probability integrator (FPI) has been developed to efficiently perform probabilistic analysis. Fast probability integration is an approximate technique which offers significant advantages over traditional Monte Carlo methods particularly in the low probabilities of failure typically found in structural engineering. FPI contains a number of features and options which are summarized in figure 4.

A probabilistic boundary element analysis program (PBEM) is available in the NESSUS system as an alternative to the finite element code. For many types of analyses, the boundary element method offers significant efficiency and accuracy advantages over finite elements. PBEM is a robust three-dimensional nonlinear boundary element code. The current capabilities of the code are: linear elastic and plastic analyses with temperature dependent materials, time dependent loading, and normal mode vibration.

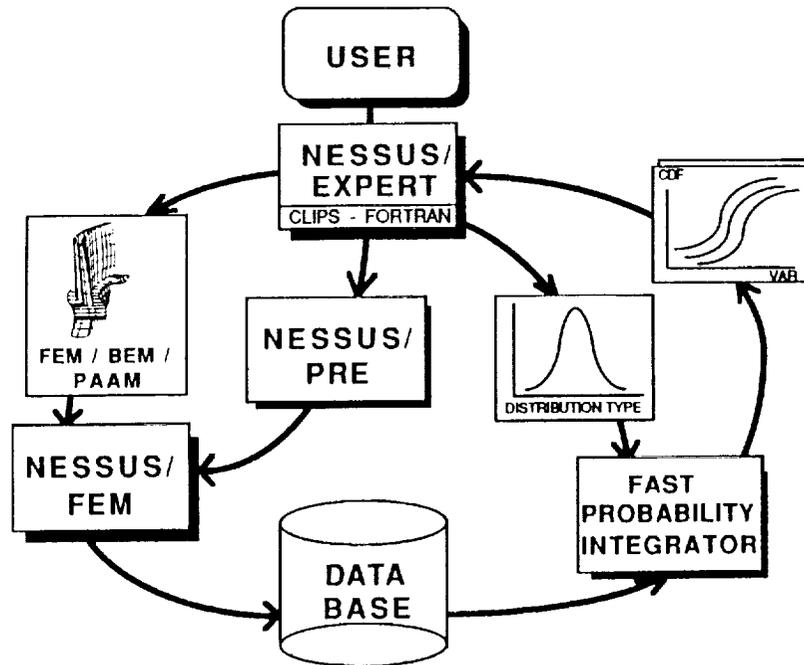
NESSUS has been validated on a number of small-scale problems where the exact solution can be determined. Figure 5 is a finite element model for a notched plate. The primary random variable is the radius of the notch and the response variable is the probabilistic stress concentration. Figure 6 demonstrates the random vibration capabilities of NESSUS. The random variables include the Power Spectral Density acceleration, the structural damping and the PSD cutoff frequency. The response variable is the root-mean-square tip displacement. In both cases, excellent agreement is found between the NESSUS solutions and exact solutions. In general, NESSUS has been validated for a number of capabilities including: static stress analysis, eigenvalue, buckling, harmonic excitation and random vibration.

The application of NESSUS to SSME components is being conducted under the verification phase of PSAM. The four selected components are shown in figure 7. Each component exercises a different capability of NESSUS. Presently, verification studies of the turbine blade and the HPOD have been completed. The turbine blade model exercises the static stress analysis and natural frequency capabilities of NESSUS. The HPOD model exercises the random vibration capabilities.

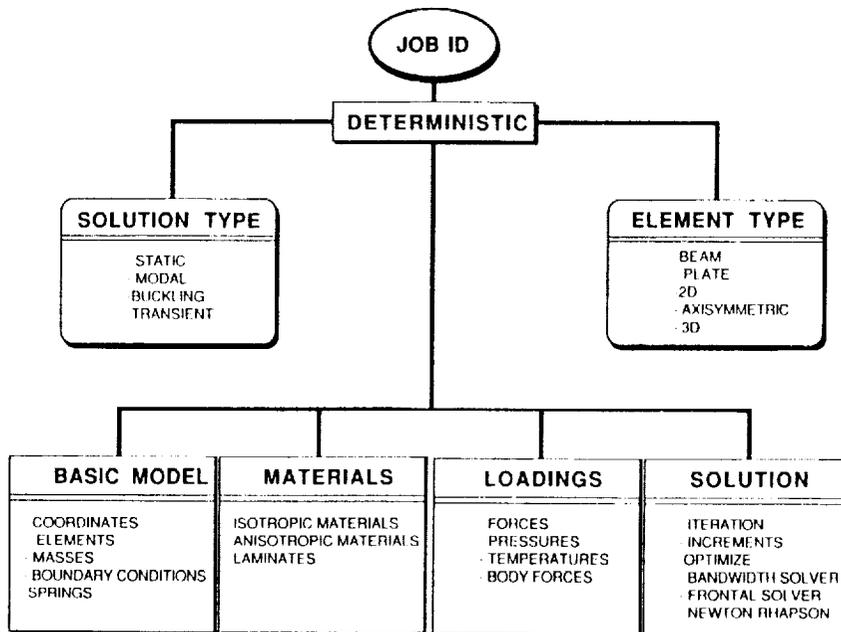
Graphical interfaces between NESSUS and pre- and post-processors have been developed to enhance data interpretation. Figure 8 is a contour plot of the probability of exceeding 80,000 psi stress for the turbine blade. This plot can be used to quickly determine critical areas which can then be examined more accurately with further computations.

NESSUS is currently being extended into transient and nonlinear material and geometric problems. Random variables will include initial accelerations, displacements, velocities and nonlinear parameters such as yield stress and hardening parameters.

## Overview of the NESSUS System



## NESSUS/EXPERT Menu System



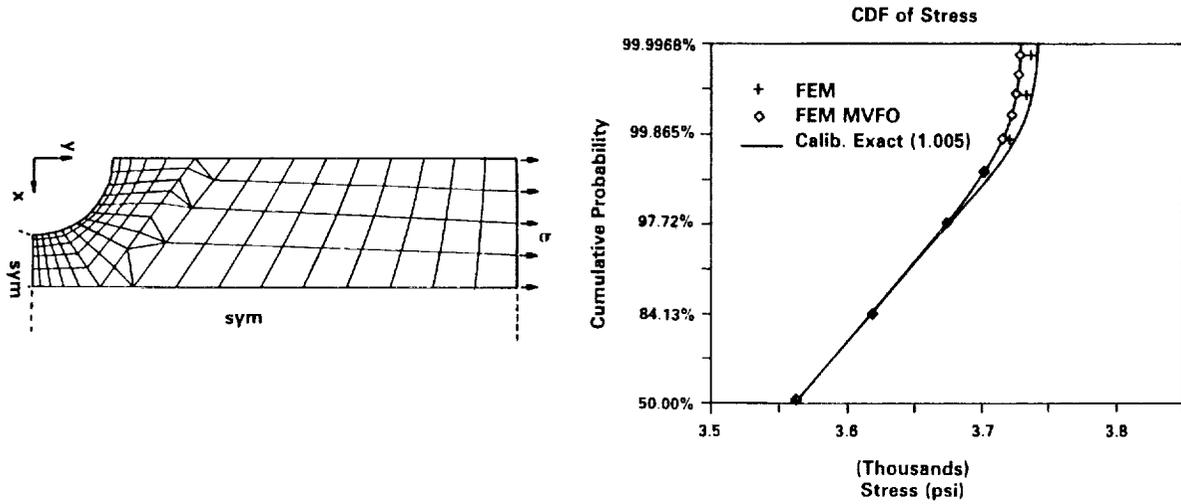
## NESSUS/FEM Capabilities

ANALYSIS TYPES	ELEMENT LIBRARY	RANDOM VARIABLES
STATIC	BEAM	GEOMETRY
NATURAL FREQUENCY	PLATE	LOADS
BUCKLING	PLANE STRESS	FORCES
HARMONIC EXCITATION	PLANE STRAIN	PRESSURES
RANDOM VIBRATION	AXISYMMETRIC	TEMPERATURES
TRANSIENT DYNAMICS	3D SOLID	MATERIAL PROPERTIES
	3D ENHANCED SOLID	ELASTIC MODULUS
		POISSON'S RATIO
		SHEAR MODULUS
		ORIENTATION ANGLE
<u>NONLINEAR</u>		
<u>MATERIAL</u>		
<u>GEOMETRY</u>		

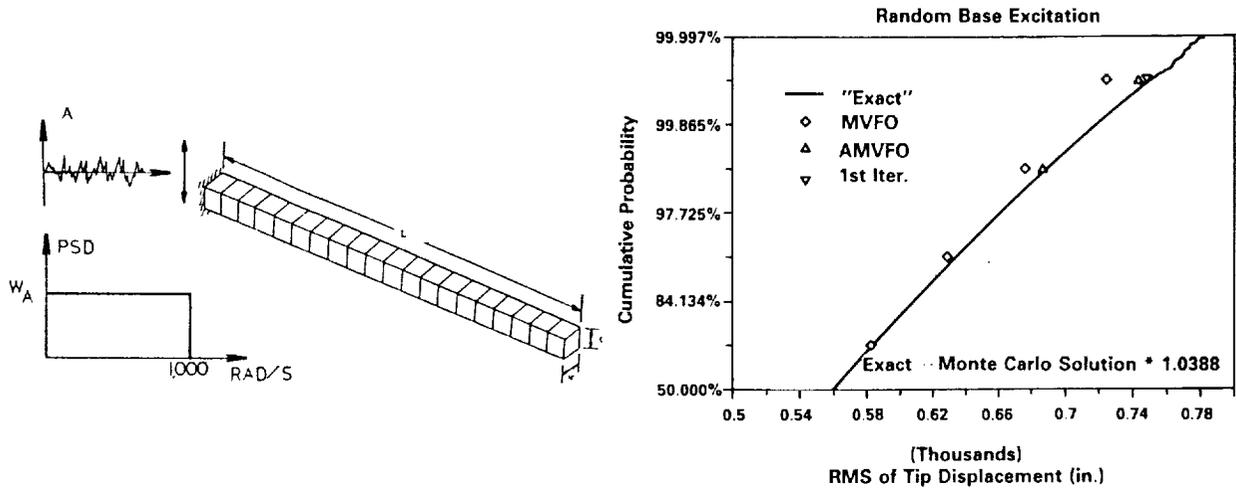
## NESSUS/FPI Capabilities

- **Advanced Mean Value First Order Method**
- **Linear and Quadratic G Function Approximation**
- **Confidence Levels**
- **Sensitivity Factors**
- **Empirical Distribution Functions**
- **Full Library of Standard Distribution Functions**
- **Harbitz Method Monte Carlo**

# Stress Concentration Analysis



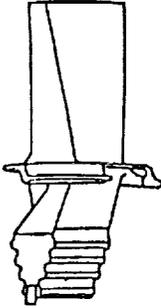
# Random Vibration Analysis of Cantilever Beam



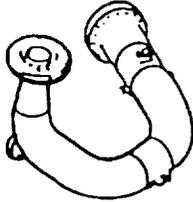
# Verification Analyses

---

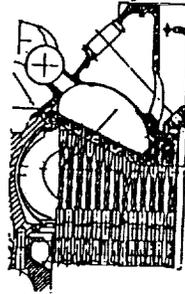
---



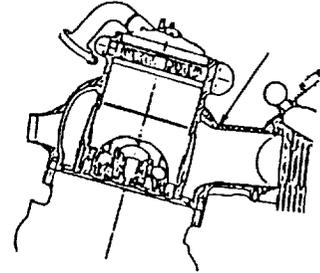
Turbine Blade



High Pressure Duct



LOX Post

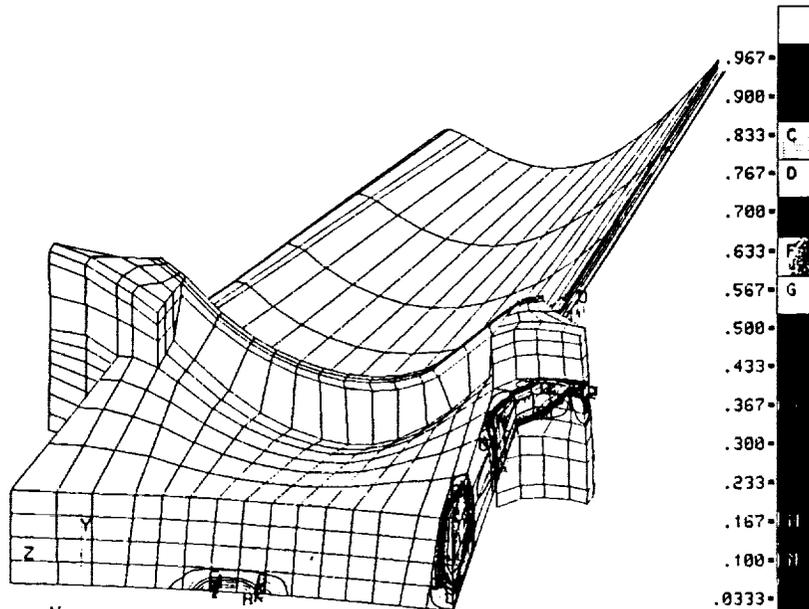


Transfer Tube Liner

## Turbine Blade Analysis

---

---



PROB. ANALYSIS - MAT. ORIEN, ELASTIC CONSTANTS AND GEOMETRY AS RANDOM  
EFFECTIVE STRESS - PROB. OF EXCEEDING 80000 PSI