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PROBABILISTIC STRUCTURAL ANALYSIS METHODS FOR SELECT SPACE PROPULSION SYSTEM STRUCTURAL COMPONENTS (PSAM)

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The objective of this 5-year contract effort[1] is the development of several modular structural analysis packages capable of predicting the probabilistic response distribution for key structural variables such as maximum stress, natural frequencies, transient response, etc. The structural analysis packages are to include stochastic modeling of loads, material properties, geometry (tolerances), and boundary conditions. As shown in figure 1, the solution is to be in terms of the cumulative probability of exceedance distribution (CDF) and confidence bounds. Two methods of probability modeling are to be included as well as three types of structural models - probabilistic finite-element method (PFEM); probabilistic approximate analysis methods (PAAM); and probabilistic boundary element methods (PBEM).

The purpose in doing probabilistic structural analysis is to provide the designer with a more realistic ability to assess the importance of uncertainty in the response of a high performance structure. PSAM tools will estimate structural safety and reliability, while providing the engineer with information on the confidence that should be given to the predicted behavior. Perhaps most critically, the PSAM results will directly provide information on the sensitivity of the design response to those variables which are seen to be uncertain. Design situations where the performance of the structure strongly depends on variables whose values are uncertain can be identified and corrective steps taken.

The PSAM tools will reflect three levels of user-defined uncertainties, as shown in figure 2. The first level is one in which the uncertainty is from part to part or application to application. Thus, for example, one turbine blade has a different fundamental frequency from a second, randomly selected, blade. The second level of uncertainty reflects the fact that the statistics on loading or material behavior or tolerances may vary from one region of the structure to another. The third, and most detailed, level of uncertainty is within the local behavior of a continuum. In this level, for example, the strains within a structure are to be randomly correlated to the displacement derivatives; the stresses are to be randomly correlated with the strains; and so on.

Three major analysis codes are to be developed following the schedule shown in figure 3. The first of these, the PFEM code, has been under development for just over 2 years. A linear version of that code has been developed (fig. 4). Validation studies have been initiated and the code will be applied this year to an SSME turbine blade analysis. The PAAM modeling effort will not

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[1]Work done under NASA Contract NAS3-24389.

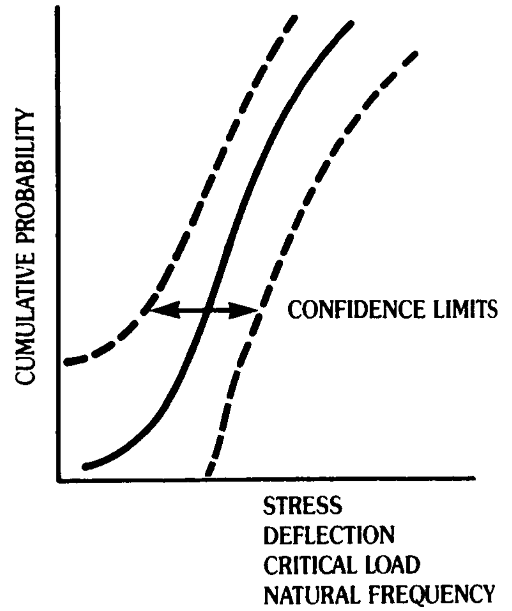
be initiated until FY 88. Following a 1-year study of advanced analysis methods, the development of a probabilistic boundary element code has been initiated. The PBEM code structure will follow that being established for the PFEM code NESSUS.

The current NESSUS (Numerical Evaluation of Stochastic Structures Under Stress) code structure is shown in figure 4. The code currently consists of four major modules: NESSUS/EXPERT, NESSUS/FPI, NESSUS/PRE, and NESSUS/FEM. The EXPERT module provides a user interface to NESSUS to facilitate the development and interpretation of probabilistic data. Fast Probability Integration (FPI) is the currently used reliability estimation algorithm for assessing response distributions and confidence levels. The PRE module reduces random fields with partial correlations to a set of independent random field variables using modal analysis methods. The finite-element method (FEM) module provides a rapid solution method especially developed to perform sensitivity analysis of a structural model. Two subsequent presentations in this same volume will discuss the FPI and EXPERT modules, and then the PRE and FEM modules.

Figure 5 illustrates the team approach being used in the PSAM contract effort. SwRI is responsible for the system integration and code validation efforts, as well as the development of the FPI and EXPERT modules. MARC Analysis Research Corporation is responsible for the FEM and PRE modules. Rocketdyne Division has defined four verification problems and will apply the NESSUS codes to the probabilistic modeling of these applications. Their presentation follows those of SwRI and MARC. Professors Wirsching (University of Arizona) and Atluri (Georgia Institute of Technology) and their graduate students are providing support on the development of advanced reliability and finite-element methods, respectively. Their presentations conclude the set of PSAM presentations.

The goal of the PSAM contract is being attained. A clear methodology for the probabilistic simulation of structural response is established. A linear modeling capability for static and vibrating systems exists and has been forwarded to NASA. The current effort is focusing on a fuller integration of NESSUS/FEM and NESSUS/FPI algorithms in order to more accurately and efficiently define the tails of the distributions. MARC is developing nonlinear solution procedures for probabilistic structures, as well as improving the FEM technology being used. The resulting structural analysis methods are seen to be capable of providing new and very significant insight into the reliable performance of complex structural systems.

PROBABILISTIC DESIGN METHODS WILL SIMULATE "REAL WORLD" STRUCTURAL RESPONSES



DUE TO DESIGN UNCERTAINTIES:

- LOADING
- MATERIAL BEHAVIOR
- GEOMETRY, TOLERANCES
- BOUNDARY CONDITIONS

FIGURE 1.

NESSUS TO HAVE THREE LEVELS OF MODELING SOPHISTICATION

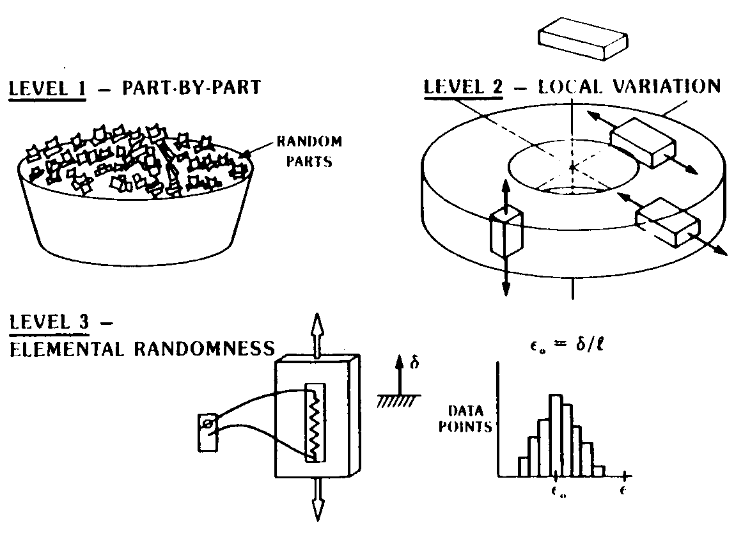


FIGURE 2.

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OF POOR QUALITY

PSAM EFFORT INVOLVES THREE MAJOR ANALYSIS CODES (NESSUS)

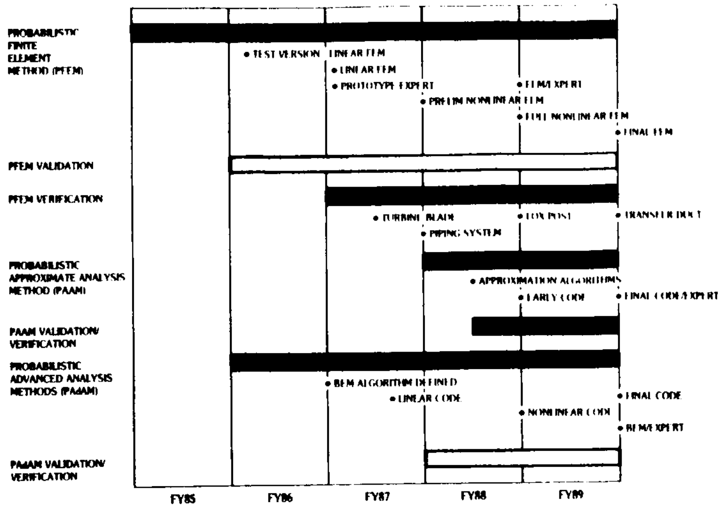
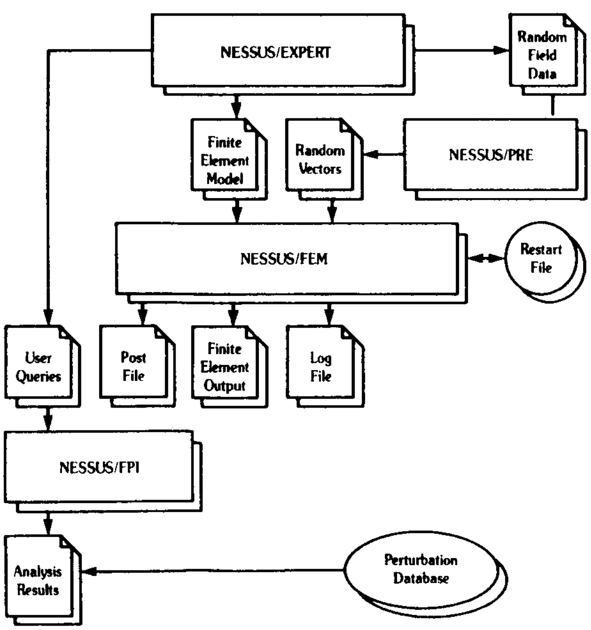


FIGURE 3.

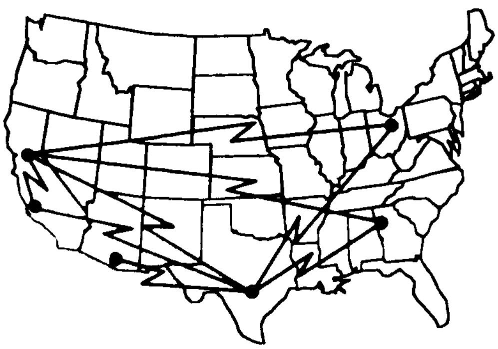
PSAM INTEGRATES FEM TECHNOLOGY WITH PROBABILISTIC METHODS



- NESSUS/FEM COMPUTES SENSITIVITY DATA
- NESSUS/PRE ANALYZES CORRELATION MODELS
- NESSUS/EXPERT PROVIDES USER INTERFACE
- NESSUS/FPI COMPUTES PROBABILISTIC RESULTS

FIGURE 4.

PSAM IS A TEAM EFFORT



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- PROBABILISTIC METHODS
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MARC ANALYSIS RESEARCH CORP.

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ROCKETDYNE DIVISION

- VERIFICATION STUDIES
- VERIFICATION APPLICATIONS

PROF. PAUL WIRSCHING (UNIV. OF ARIZONA)

- ADVANCED RELIABILITY METHODS
- STATISTICAL MODELING

PROF. SATYA ATLURI (GEORGIA TECH)

- HYBRID FEM DEVELOPMENT
- STOCHASTIC MECHANICS MODELING

FIGURE 5.