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PROBABILISTIC STRUCTURAL ANALYSIS VERIFICATION STUDIES

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The space propulsion system components are subjected to complex mechanical and thermal loading. Typically, these components are analyzed using the state of the art deterministic methodologies in linear and nonlinear structural analysis domain. The components are then designed using a factor of safety approach. The purpose for doing a probabilistic structural analysis of space propulsion system components has been explained in one of the earlier papers on PSAM appearing in this same volume.

During the first year and part of the second year of the contract, identification and definition of environments and analysis techniques that are used to analyze the typical space propulsion system components were discussed and presented (Ref. 1). The basic objective of the verification efforts is to apply the probabilistic structural analysis methods developed and implemented in NESSUS (Numerical Evaluation of Stochastic Structures Under Stress) code to typical space propulsion components (Figure 1). The chosen typical components are turbine blade, high pressure duct, Lox post, and transfer tube liners. Since analysis options of increasing levels of sophistication are implemented in NESSUS incrementally, the verification efforts are also tailored to have increasing levels of sophistication during the progression of the contract. The current released version of the code is limited to linear structural analysis.

Considering turbine blade component first, several simple verification studies were conducted. The studies exercised the solid element type, typical random variables, and various solution strategies. The results of the simple verification studies (Ref. 2) aided in establishing confidence in the code, identified its limitations in user interface, finite element and analysis deficiencies. The studies conducted on simple models so far indicate that for the chosen random variables and their normal range of perturbation found in practice, the implemented solution strategies were adequate. On the other hand, the studies also showed that when the perturbations were large, in the context of doing a sensitivity analysis over a wide range, the implemented solution strategies did not converge, and in some cases divergence occurred. The divergence or slow convergence issue has been addressed in the development of fully integrated probabilistic structural analysis package that causes the reformulation of the system equations as needed for convergence.

The studies included geometry perturbation (variations in tilt angle), material orientation perturbation ($\pm 10°$), material property perturbation and load (centrifugal load, pressure, temperature) perturbations. The studies resulted in improved user interfaces and hastened the implementation of more advanced solid elements that behave better in a variety of stress fields including temperature gradients.

Several simple verification studies have been conducted on frequency extraction of the perturbed structure using perturbation technique, which is of special interest in turbine blade components. Based on the review of results, strategies for improvements in accuracy and a reduction in computing time to obtain the frequencies of perturbed structure are being sought.

A solid finite element turbine blade model, representative of blades found in space propulsion system components, has been generated and is currently being exercised (Figure 3). A basic set of random variables, consistent with first cut design requirements, have been identified (Figure 3). These random variables will be used in the study to determine the probability density function (PDF) of stress at critical areas and the PDF of frequencies. Some of the other important random variables such as variables contributing to the damper effectiveness, dynamic pressure, support conditions and transient conditions that are necessary for the final design are not considered in the initial exercise.

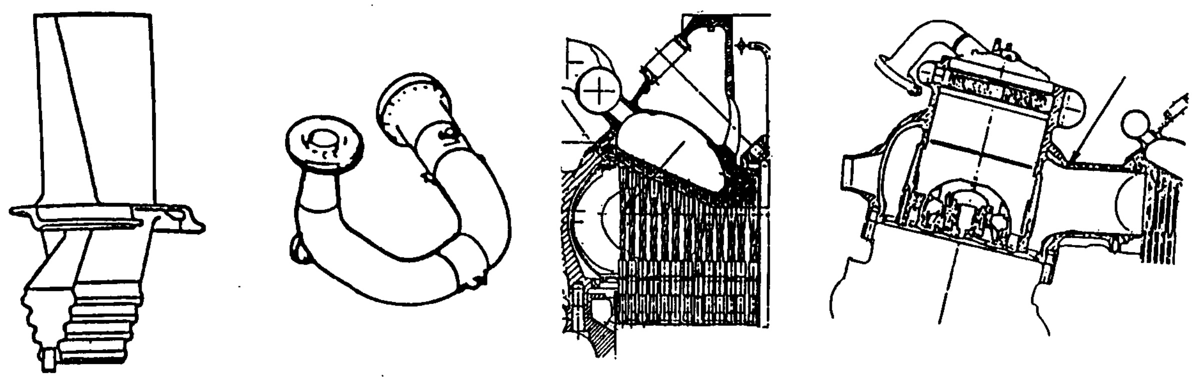
Following the turbine blade analysis, verification efforts on other typical components such as high pressure ducts (Figure 4), Lox post (Figure 5), and transfer tube liners (Figure 6) will follow. The random variables and solution types have been carefully chosen to exercise and verify a wide range of analysis options and element types that are being developed in NESSUS and also in determining the probabilistic response of primary component specific design parameters.

References

1. Probabilistic Structural Analysis Methods for Select Space Propulsion System Components (PSAM). First Annual Report, NASA Contract NAS3-24389, March 1986.
2. Probabilistic Structural Analysis Methods for Select Space Propulsion System Components (PSAM). Second Annual Report, NASA Contract NAS3-24389, November 1986.

VERIFICATION ANALYSES
OBJECTIVE

TO APPLY THE METHODS DEVELOPED TO THE ANALYSIS OF
TYPICAL SPACE PROPULSION SYSTEM COMPONENTS



TURBINE BLADE | HIGH PRESSURE DUCT | LOX POST | TRANSFER TUBE LINER

FIGURE 1.

SIMPLE VERIFICATION STUDIES
OBJECTIVES

- SHAKEOUT OF ANALYSIS METHODS/CODE/USER OPTIONS
- SELECTION AND EXERCISE OF COMPONENT SPECIFIC KEY RANDOM VARIABLES ON SIMPLISTIC MODELS
- RESULTS IN IDENTIFICATION OF LIMITS AND IMPROVEMENTS IN

· ELEMENT TECHNOLOGY	· ALGORITHIMIC BEHAVIOR	USER INTERFACE
· SOLID ELEMENT ENHANCEMENTS	· CONVERGENCE AND ACCURACY	· IMPROVEMENTS IN INPUTS
· TEMPERATURE GRADIENT MODELING	· STIFFENING OR SOFTENING STRUCTURE	· SOLUTION STRATEGY RECOMMENDATION

FIGURE 2.

TURBINE BLADE ANALYSIS

- RANDOM VARIABLES
  - GEOMETRY
  - MATERIAL ORIENTATION
  - MATERIAL PROPERTIES
- STEADY STATE
  - CENTRIFUGAL LOAD
  - TEMPERATURE
  - STATIC PRESSURE AND ΔP
- RESPONSE VARIABLES
  - CENTRIFUGAL STRESS AND PRESSURE STRESS
  - FREQUENCY

- 3-D SOLID MODEL

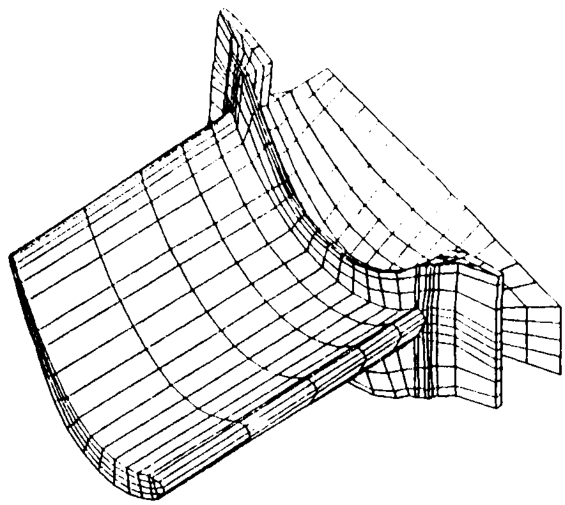


FIGURE 3.

HIGH PRESSURE DUCTS

- DYNAMIC ANALYSIS WILL BE EMPHASIZED
- RANDOM VARIABLES
  - DAMPING
  - SUPPORT VIBRATION
  - ACCELERATION
  - GIMBAL
  - MISALIGNMENT
- RESPONSE VARIABLE
  - STRESS AT CRITICAL AREAS

- 3-D LINE ELEMENT MODEL

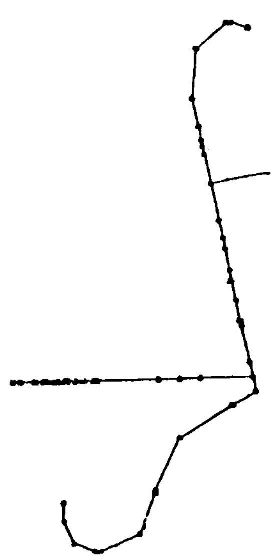
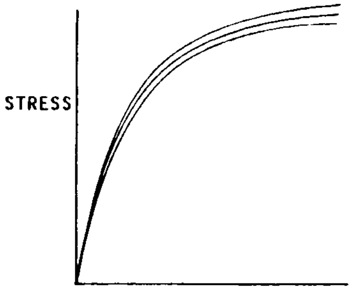


FIGURE 4.

LOX POST ANALYSIS
STATIC MATERIAL NONLINEAR ANALYSIS

- RANDOM VARIABLES
  - STRESS-STRAIN LAW



  - TEMPERATURE
- RESPONSE VARIABLE
  - TOTAL INELASTIC STRAIN AT CRITICAL AREAS

- 2-D AXISYMMETRIC MODEL

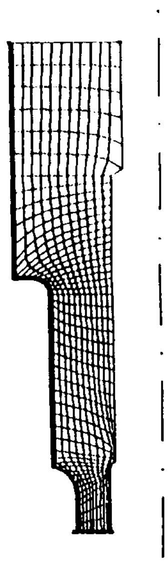


FIGURE 5.

TRANSFER TUBE ANALYSIS
STATIC GEOMETRIC NONLINEAR ANALYSIS

- RANDOM VARIABLES
  - MATERIAL PROPERTIES
  - THICKNESS
  - NODAL COORDINATES
  - BOUNDARY CONDITION FLEXIBILITY
  - TEMPERATURE
- VARIABLE TO BE DETERMINED
  - BUCKLING LOAD

- 3-D THIN SHELL MODEL

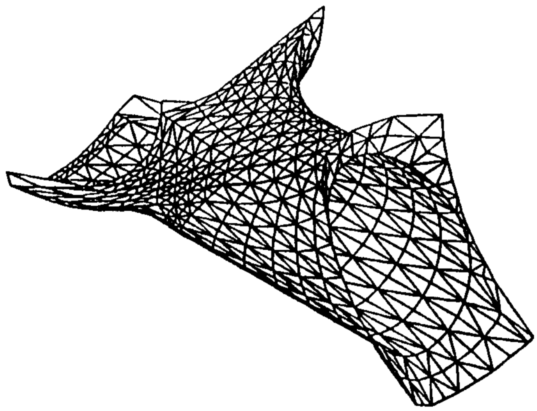


FIGURE 6.