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COMPUTATIONAL STRUCTURAL MECHANICS FOR ENGINE STRUCTURES

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SUMMARY

The computational structural mechanics (CSM) program at NASA Lewis Research Center encompasses: (1) fundamental aspects for formulating and solving structural mechanics problems and (2) development of integrated software systems to computationally simulate the performance/durability/life of engine structures. It is structured to mainly supplement, complement, and whenever possible replace, costly experimental efforts which are unavoidable during engineering research and development programs. Specific objectives include: (1) investigate unique advantages of parallel and multiprocesses for: reformulating/solving structural mechanics problems and formulating/solving multidisciplinary mechanics problems and (2) develop "integrated" structural system computational simulators for: Predicting structural performances, evaluating newly developed methods, and for identifying and prioritizing improved/missing methods needed. Herein the CSM program is summarized with emphasis on the engine structures computational simulator (ESCS). Typical results obtained using ESCS are described to illustrate its versatility.

INTRODUCTION

NASA Lewis Research Center is conducting extensive research for engine structures with emphasis on advanced structural analysis, structural dynamics, structural aspects of aeroelasticity, and life prediction of turbine engine structures and structural components. These components can be made from conventional materials (used as bill of materials), advanced materials (utectics, directional solidified) and fiber composites. The general objective is to develop the methodology to permit the rational structural design and analysis of components for advanced gas turbine engines as well as the overall engine system. Structural models are developed to provide analysis capability which will assure the structural integrity of the part and to provide the designer with a method of optimizing component designs for maximum performance at minimum weight and cost. Engine system structural models are also developed to analyze the behavior of the entire engine as a complex, interacting dynamic system. The models incorporate overall displacements and distortions as well as component-to-component interactions due to steady-state and transient thermal and mechanical loads. The combined rotating engine structural components under various operating conditions such as takeoff, cruise, maneuver, and landing need to be determined. Fracture mechanics methods specifically related to engines, such as elevated temperature, nonlinear crack growth, and failure prediction methods, are also developed (ref. 1). Fundamental and common to all these developments is the precise geometric and analytical model description of engine structures at several assembly levels from individual parts, through the component, the substructure, and the entire engine.

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Both the precise geometric modeling and the analytical models at the several different levels of the engine structure have resulted in integrated computer programs (refs. 2 and 3). These integrated computer programs are independent, stand along, codes, each with its own input/output formats. A recent research activity identified as Computational Structural Mechanics (CSM) has an objective of integrating these individually integrated multidiscipline codes into one software system (engine structures computational simulator, ESCS) where each discipline-specific code will be a module. The objective of the present paper is to describe the CSM program in general and ESCS in some detail.

COMPUTATIONAL STRUCTURAL MECHANICS

The general content of the CSM NASA Lewis program plan is summarized in figure 1. The long-range objective of the program is the full engine structural simulation. It draws on methodology developed under research and development and HOST programs over a 10 year period (prior to FY86). This methodology is multidiscipline and includes: (1) high temperature structures specialty analysis methods, (2) rotating system dynamics, (3) advanced components, and (4) durability and life.

The present emphasis is in: (1) integrating these codes to computationally simulate the interdisciplinary performance of propulsion structural systems, (2) exploiting new computer hardware systems, and (3) adapting these analyses methods to multiparallel processors.

IDENTIFIED METHODOLOGY-IMPROVED/MISSING

An important part of the CSM for engine structures program is the identification of methodology which needs improvement and/or is missing. This methodology includes the following key elements: (1) boundary elements for three-dimensional inelastic analysis, (2) boundary elements for hot fluid/structure interaction, (3) efficient hybrid elements, (4) adapting transitional finite elements, (5) computational composite mechanics, (6) computational contact mechanics, and (7) couple computational simulation with optimization. For example, a missing technology item is boundary elements for hot fluid/structure interaction is natural, since the boundary elements are formulated to match specified surface conditions and satisfy the interior field equations exactly.

Another missing technology item identified is adaptive transitional finite elements. These types of finite elements are useful in transitioning meshes from three-dimensional to two-dimensional, from a dense local mesh to progressively coarser with distance, or from a higher DOF element to lower.

IDENTIFIED METHODOLOGY - ALTERNATE

Another important part of the CSM program is to identify methodology for the computational simulation such as: (1) probabilistic simulation for quantifying the uncertainties in structural response associated with all variables/parameters of structural analysis/design and (2) alternate methods/approaches for formulating structural mechanics problems. Those identified to date are:

(1) probabilistic/stochastic: variational principles for probabilistic finite element, probabilistic structural analysis methods, and probabilistic fracture mechanics; and (2) alternate formulations: multiparallel processors for multidiscipline mechanics problems, specialty functions for singular mechanics problems, coupled constitutive relationships, and dedicated expert systems.

The development of probabilistic structural analysis methods constitute an extensive multi-institute program (ref. 4). This extensive program also includes the development of dedicated expert systems. Multifactor coupled constitutive relationships are a part of another recently initiated program because these relationships are essential in the computational simulation of high temperature composites and composites for superconductors.

ENGINE STRUCTURES COMPUTATIONAL SIMULATOR

A major part of the NASA Lewis CSM program is the development of engine structures computational simulator (ESCS). ESCS integrates discipline specific methodology and computer codes developed under research and technology programs indicated in the periphery blocks in figure 2. ESCS predicted results are post processed to make assessment of engine structural performance in terms of the requirements listed in the block at the right in the figure.

As already mentioned, each computer code identified in the periphery blocks was developed to be stand-alone and transportable. These codes, in essence, are the discipline modules required to perform the requisite multidiscipline analyses within the framework of the simulator. The integration of these types of codes require an especially coded executive module and interfacing modules. The executive module controls the program execution and the communication between the different discipline modules.

ESCS SOFTWARE SYSTEM ARCHITECTURE

ESCS is modular with an expert system driven executive module. It includes interfacing modules, a database and its manager. A schematic of the ESCS present status configuration is shown in figure 3. The interfacing modules provide the logic to merge different discipline analysis models as well as loading conditions for the system analysis models. The analysis modules include advanced analysis methods such as specialty finite elements (three-dimensional inelastic analysis), mixed elements (MHOST) (ref. 5), and boundary elements (BEST3D) (ref. 5) as well as thermal and gas dynamic analyses. They also include NASTRAN and structures optimization (STAEBL) (ref. 6). The dedicated database has a permanent and a temporary record part. The temporary part is designed to handle proprietary data that the user can erase after he completed his analysis.

ESCS is configured to computationally simulate the structural performance of engine structures: (1) subcomponents, (2) components, (3) subassemblies, (4) assemblies, and (5) integrated systems for mission specified requirements. These are shown in figure 4 from bottom left to top right, respectively.

An important part of current research activities deals with the logistics and solution algorithms for handling large problems. For example: how do we simulate the whole engine and still have a manageable model with respect to: (1) size, (2) global response, and (3) local detail? New methods of substructuring, superelement, and telescoping finite elements are attractive alternatives.

It is worthy of note that undertaking the development of a software system of the magnitude of ESCS provides opportunities to identify research activities for the solution of large multidiscipline, dynamically interacting problems.

SOME TYPICAL RESULTS

Typical results obtained using ESCS are described to illustrate its versatility and potential to computationally simulate the integration and interaction of the participating multidisciplines. The results described include: (1) loads simulation, (2) the structural dynamic response of a bladed rotor, (3) blade tip displacements at three different flight conditions, and (4) blade tip displacements throughout a mission.

Loads Simulation

The loads on the blades (temperatures, pressures, and rotating speeds) are determined by an engine loads module (COSMO (ref. 7) in the ESCS schematic, fig. 3). This module is based on engine thermodynamics. The temperatures and pressures are predicted on the surface at user selected span stations. A typical example for temperatures is illustrated in figure 5. The blade surface temperatures have been unfolded for three-dimensional plotting presentation. Pressures and other local loads can be similarly represented.

Blade Tip Displacements

As was previously mentioned, the structural response can be predicted throughout the mission. Representative results for blade-tip radial displacement are shown in figure 6 at identifiable stages during the flight mission due to corresponding pressures, temperatures, and centrifugal loadings. These types of results can be obtained for any point in the component included in the simulation. The significance of having integrated, interdisciplinary structural response throughout the mission is that: (1) all dynamic interactions are properly accounted for; (2) results for stress/strain are suitable for durability/life assessments; and (3) results for global displacements, frequencies and/or instabilities can be used to design active controls.

Structural Dynamic Response

The structural dynamic response of blades assembled in a bladed rotor is different than that of an individually simulated blade. The dynamics motion of a bladed rotor determined using ESCS is shown in figure 7 at take-off conditions. Although results are not shown here, the same model was used to determine frequencies and compared with those obtained using single blades at unloaded and loaded conditions. A similar model was used to determine the dynamic response under bird impact loading conditions.

Blade Tip Displacement at Three Flight Conditions

As was already mentioned the ESCS executive module couples the loads module with the analysis-modeling module and with the analysis module through module-communication links and proceeds to determine the component structural response at the preselected times during the mission. Results from such an analysis for the displacements of a turbine blade are shown in figure 8 for three mission conditions.

The important point to be made is that only one user used the simulator; he initiated the analysis with input information typical for preliminary designs, and obtained the detailed results shown in the figure. The total continuous connect time was about 3 hr with a CPU of about 1 hr. This compares to about 2 man-months by using the traditional approach and illustrates the effectiveness of the simulator in the usage of professional time.

ESCS LONG RANGE OBJECTIVE AND ANTICIPATED BENEFITS

The long range objective of ESCS is to provide a computational simulation that parallels and replaces, in part, the current development methods which make extensive use of experimental procedures. The parallel between ESCS and the current development procedures are depicted in figure 9. ESCS will minimize the effort expanded from initial design to engine builds and will often result in more cost effective engine builds for the same engine performance.

Anticipated benefits include: (1) reduced time development and cost, (2) fewer development engine builds, (3) longer life components, (4) reduced life cycle costs on components, (5) reduced component and engine weight, (6) improved engineering productivity, (7) increased performance, and (8) increased reliability. Engine manufacturers have cost estimates for each of these items based on their own experience. Suffice it to say that each item runs into multimillion dollars and takes several years to ascertain its reliability in order to meet qualification and certification requirements.

CONCLUSIONS

The computational structural mechanics program at NASA Lewis Research Center is described in general. The development of the engine structures computational simulator (ESCS), a major part of the computational structural mechanics program, is described in some detail. The details were limited to: (1) objectives, (2) integrated, interdisciplinary content, and (3) typical results obtained. These results show promise that an ESCS software system is attainable and lend credence to projections on potential long-range simulation capabilities and anticipated benefits.

REFERENCES

1. "Engine Structures - A Bibliography of Lewis Research Center's Research for 1980-1987," NASA TM-100842, 1988.

2. Chamis, C.C., "Integrated Analysis of Engine Structures," NASA TM-82713, 1981.

3. Chamis, C.C. and Johns, R.H., "Computational Engine Structural Analysis," NASA TM-87231, 1986.

4. Chamis, C.C., "Probabilistic Structural Analysis Methods for Space Propulsion System Components," NASA TM-88861, 1986.

5. Wilson, R.B., Bak, J.J., Nakazawa, S., and Banerjee, P.K., "On 3-D Inelastic Analysis Methods for Hot Section Components," PWA-5940-36, Pratt and Whitney Aircraft, East Hartford, CT, 1986, NASA CR-175060.

6. Brown, K.W., "Aero/Structural Tailoring of Engine Blades (Aero/STAEBL)," PWA-5774-82, Pratt and Whitney Aircraft, East Hartford, CT, 1988, NASA CR-180805.

7. McKnight, R.L., "Component Specific Modeling," NASA CR-174925, 1985.

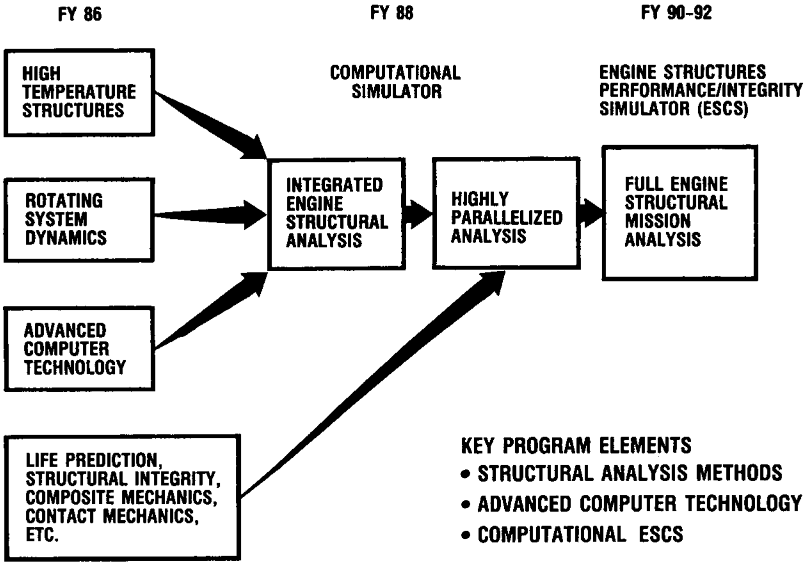


FIGURE 1. - COMPUTATIONAL STRUCTURAL MECHANICS.

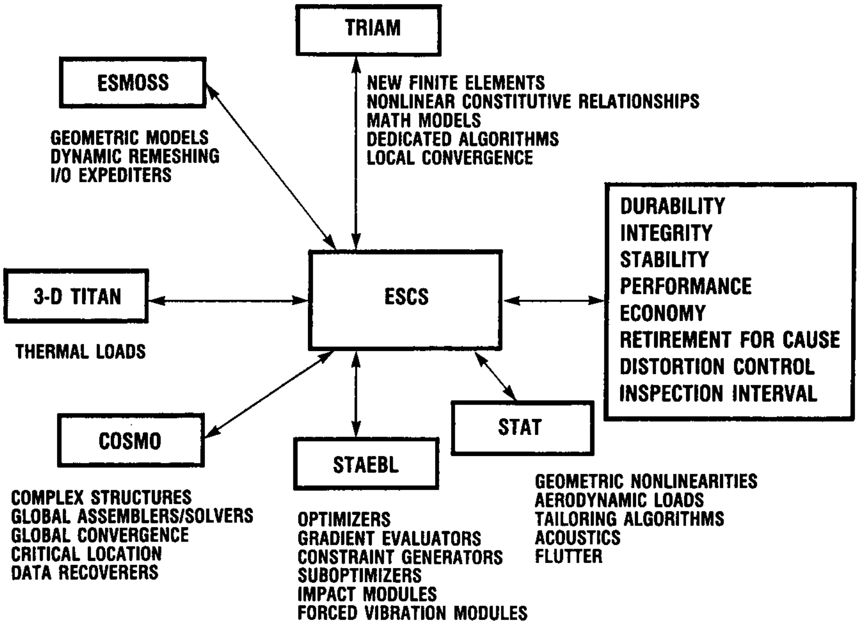
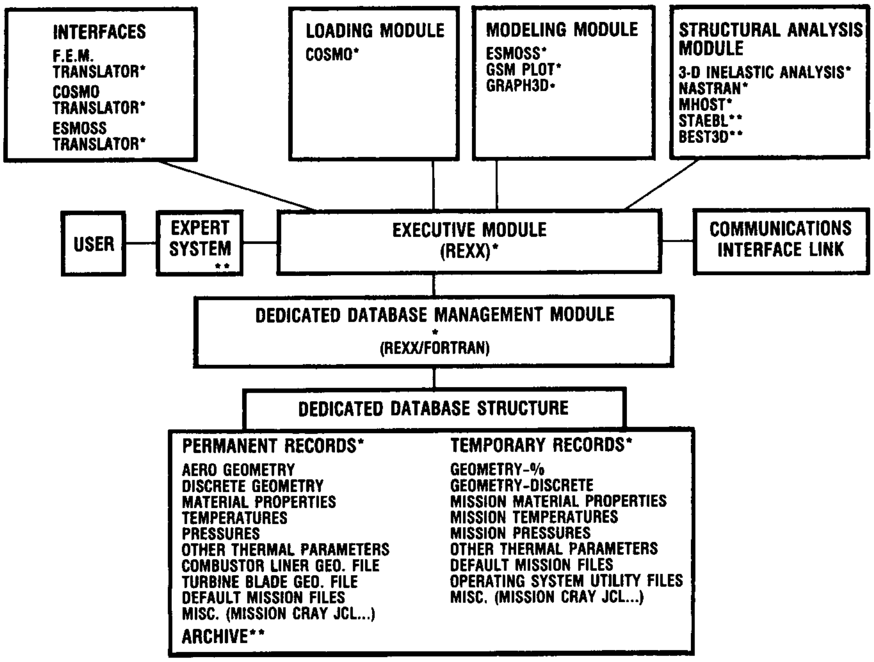


FIGURE 2. - ENGINE STRUCTURES COMPUTATIONAL SIMULATOR, ESCS.



*—PRELIMINARY VERSION AVAILABLE

**—TO BE INSTALLED

FIGURE 3. - SIMULATOR ARCHITECTURE OF THE SOFTWARE SYSTEM.

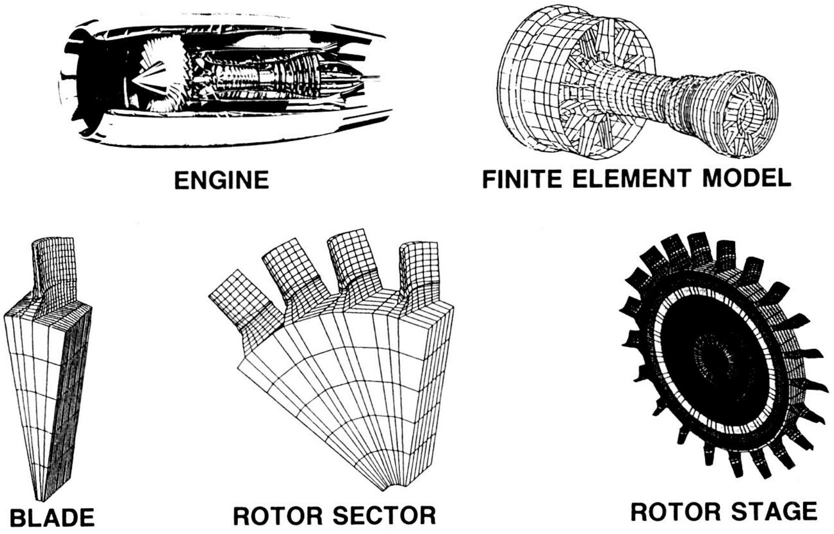


FIGURE 4. - ENGINE STRUCTURES COMPUTATIONAL SIMULATOR.

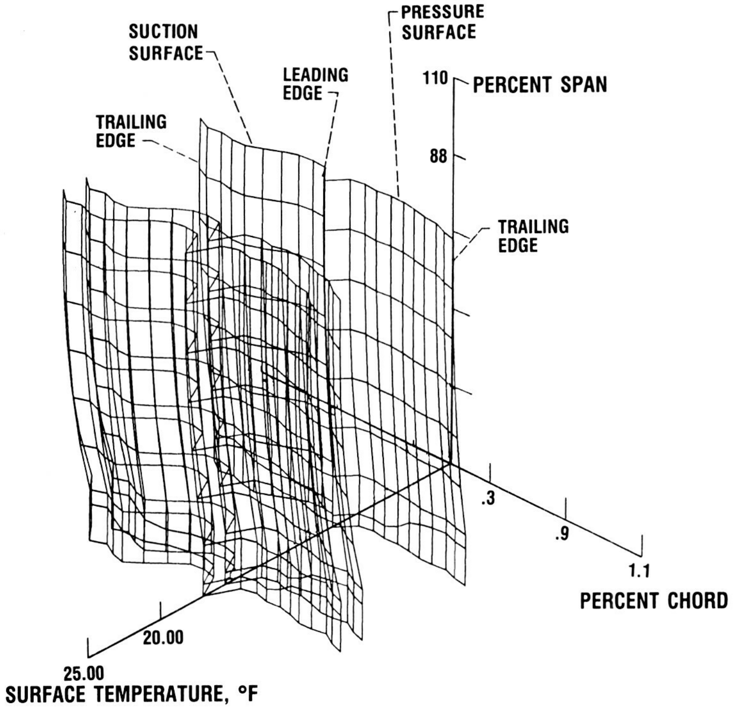


FIGURE 5. - SURFACE TEMPERATURE PROFILE FOR TURBINE BLADE.

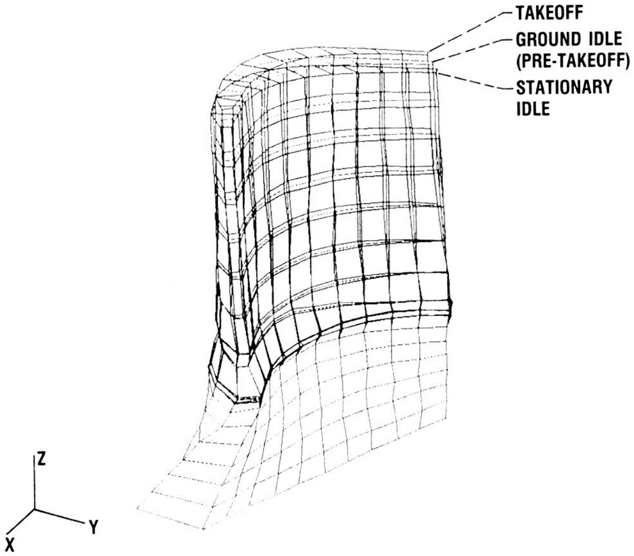


FIGURE 6. - DEFORMATION OF TURBINE BLADE UNDER FLIGHT CONDITIONS.

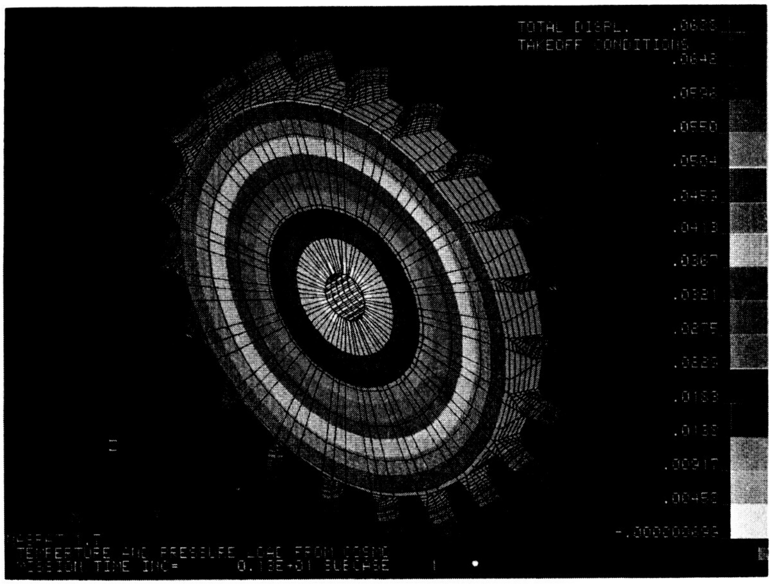


FIGURE 7. - STRUCTURAL DYNAMIC RESPONSE OF A BLADED ROTOR.

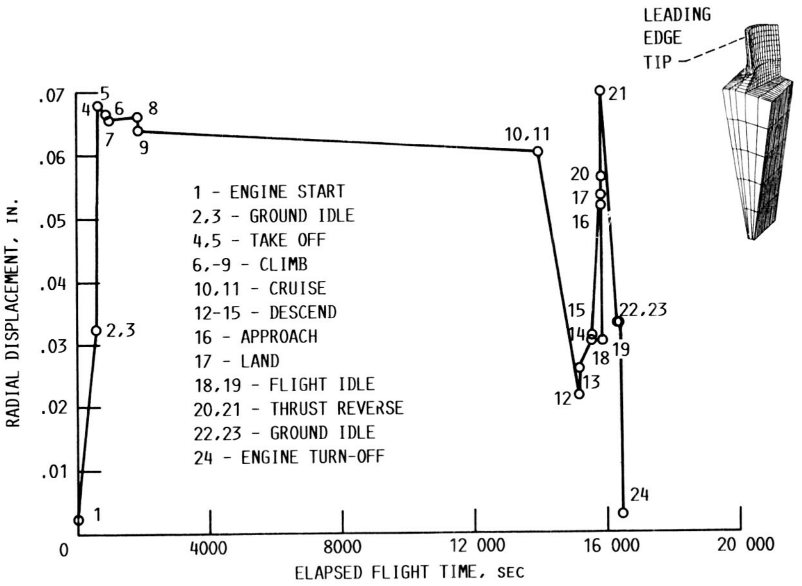
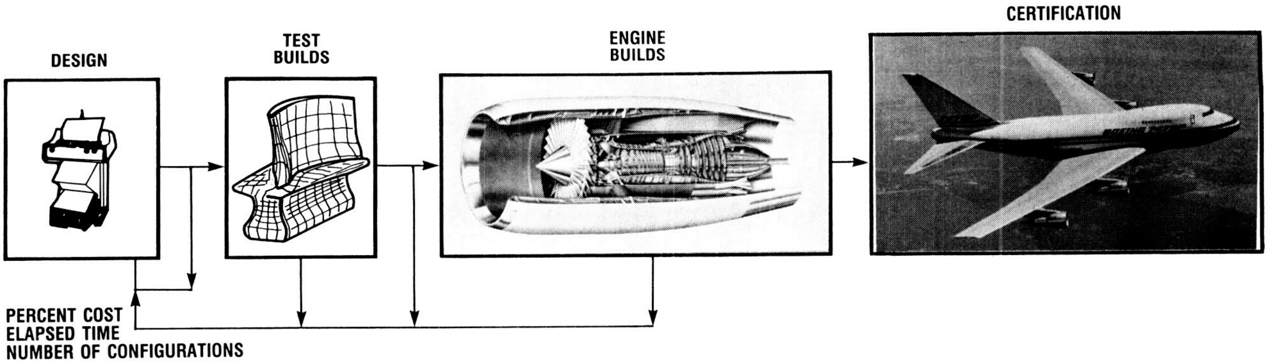
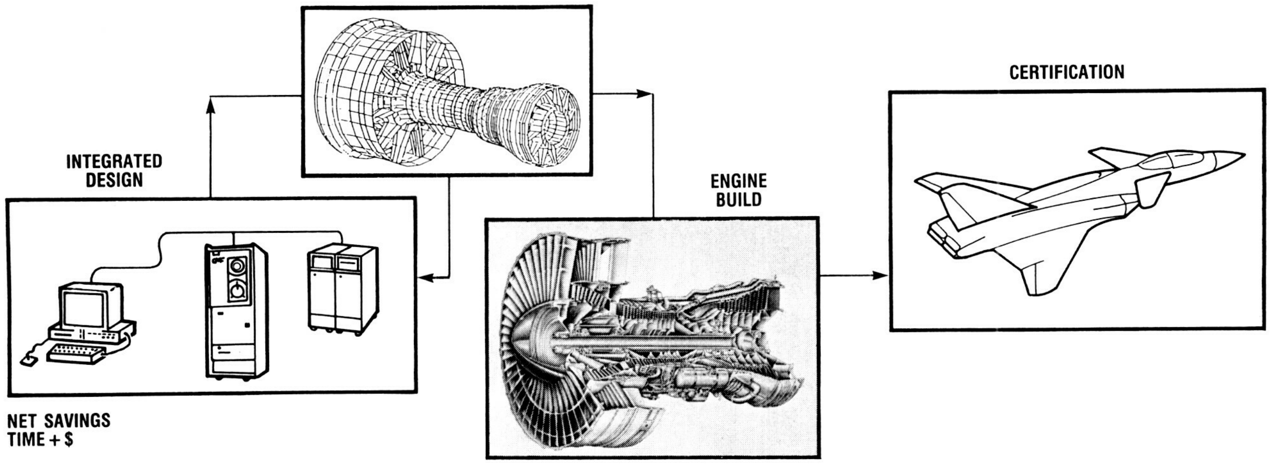


FIGURE 8. - ESCS SAMPLE RESULTS FOR FLIGHT MISSION SIMULATION.



(A) CURRENT DEVELOPMENT METHOD.



(B) COMPUTATIONAL SIMULATION METHOD.

FIGURE 9. - PARALLEL BETWEEN CURRENT DEVELOPMENT AND COMPUTATIONAL SIMULATION METHODS.

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16. Abstract

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17. Key Words (Suggested by Author(s))
Structural analysis; Stress analysis; Multidiscipline; Finite elements; Mixed elements; Boundary elements; Computer codes; 3-D analysis; Nonlinear analysis; Transient analysis

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