COMPUTATIONAL STRUCTURAL MECHANICS FOR ENGINE STRUCTURES
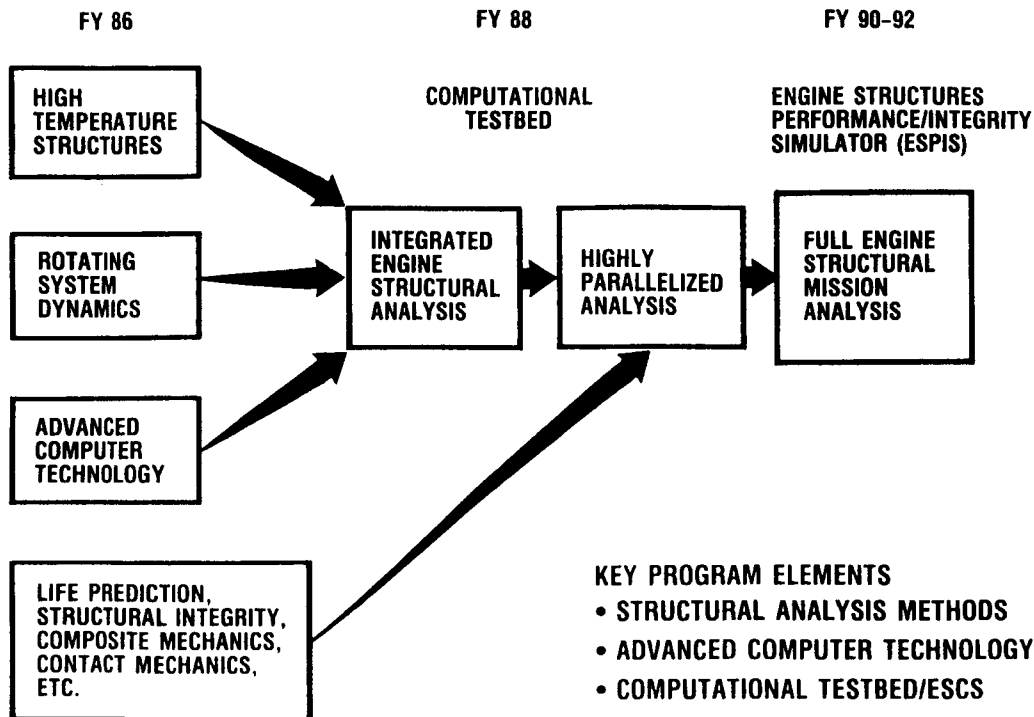
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ABSTRACT

The computational structural mechanics (CSM) program at Lewis encompasses the formulation and solution of structural mechanics problems and the development of integrated software systems to computationally simulate the performance, durability, and life of engine structures. It is structured to supplement, complement, and, whenever possible, replace costly experimental efforts. Specific objectives are to investigate unique advantages of parallel and multiprocesses for reformulating and solving structural mechanics and formulating and solving multidisciplinary mechanics and to develop integrated structural system computational simulators for predicting structural performance, evaluating newly developed methods, and identifying and prioritizing improved or missing methods.

COMPUTATIONAL STRUCTURAL MECHANICS LEADS TO ENGINE STRUCTURES COMPUTATIONAL SIMULATOR (ESCS)

The general content of the Lewis CSM program plan is summarized in the accompanying block diagram. The long-range objective of the program is the full engine structural simulation. It draws on methodology developed under research and development programs and the HOST Program over the past 10 years. This methodology is multidisciplinary and includes high temperature structures specialty analysis methods, rotating system dynamics, advanced components, and durability and life.

FY 86   FY 88   FY 90-92

HIGH   COMPUTATIONAL   ENGINE STRUCTURES
TEMPERATURE   TESTBED   PERFORMANCE/INTEGRITY
STRUCTURES   SIMULATOR (ESPIS)

                    INTEGRATED   FULL ENGINE
ROTATING   ENGINE   HIGHLY   STRUCTURAL
SYSTEM   STRUCTURAL   PARALLELIZED   MISSION
DYNAMICS   ANALYSIS   ANALYSIS ANALYSIS

ADVANCED
COMPUTER
TECHNOLOGY

LIFE PREDICTION,   KEY PROGRAM ELEMENTS
STRUCTURAL INTEGRITY,   • STRUCTURAL ANALYSIS METHODS
COMPOSITE MECHANICS,   • ADVANCED COMPUTER TECHNOLOGY
CONTACT MECHANICS,
ETC.   • COMPUTATIONAL TESTBED/ESCS

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COMPUTATIONAL STRUCTURAL METHODS IDENTIFIED
METHODOLOGY - IMPROVED OR MISSING

An important part of the CSM for engine structures program is the identification of methodology which needs improvement or is missing. This methodology includes several key elements as listed in the accompanying chart. For example, boundary elements for hot fluid and structure interaction is natural since the boundary elements are formulated to match specified surface conditions and satisfy the interior field equations exactly.

- **BOUNDARY ELEMENTS FOR 3-D INELASTIC ANALYSIS**
- **BOUNDARY ELEMENTS FOR HOT FLUID AND STRUCTURE INTERACTION**
- **EFFICIENT HYBRID ELEMENTS**
- **ADAPTIVE TRANSITIONAL FINITE ELEMENTS**
- **COMPUTATIONAL COMPOSITE MECHANICS**
- **COMPUTATIONAL CONTACT MECHANICS**
- **COUPLE COMPUTATIONAL SIMULATION WITH OPTIMIZATION**

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COMPUTATIONAL STRUCTURAL MECHANICS IDENTIFIED METHODOLOGY – ALTERNATIVE

Another important part of the CSM program is to identify alternative method-
ology for computational simulation such as (1) the probabilistic approach
for quantifying the uncertainties with all variables of structural analysis
and design and (2) alternative methods for formulating structural mechanics
problems. Some of the them have already been identified and are listed below

- **PROBABALISTIC OR STOCHASTIC:**
  - **VARIATIONAL PRINCIPLES FOR PROBABILISTIC FINITE ELEMENT**
  - **PROBABILISTIC STRUCTURAL ANALYSIS METHODS**
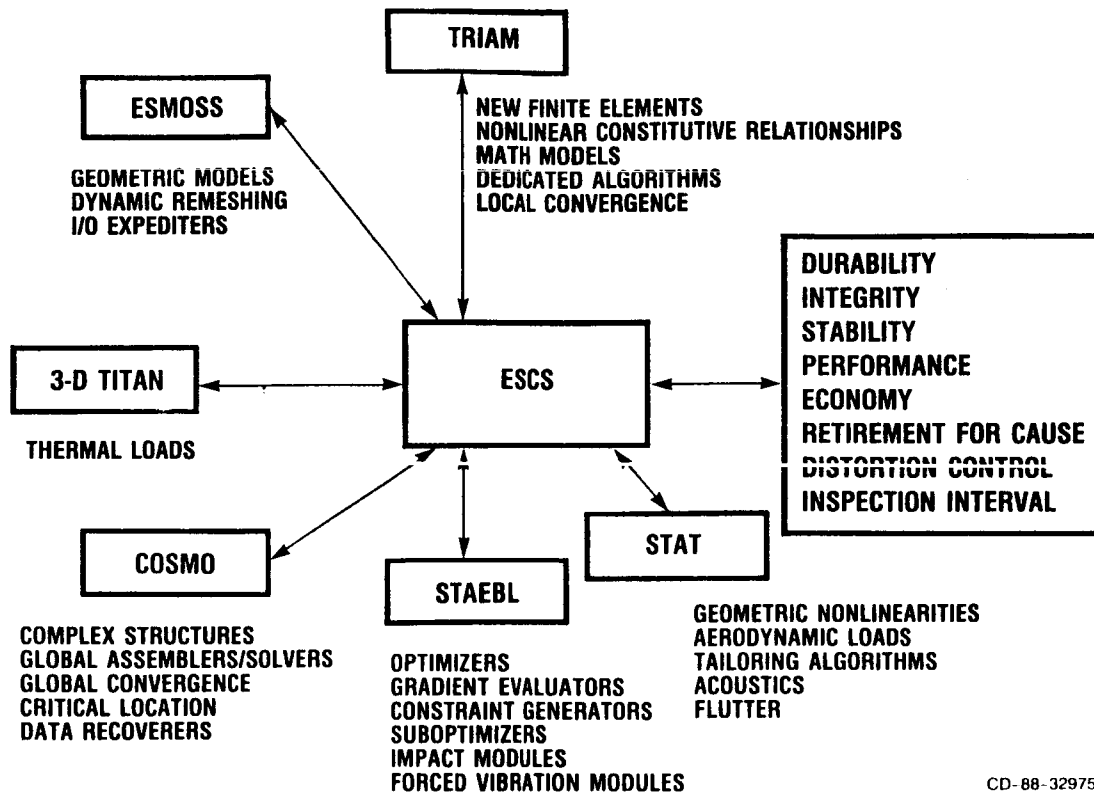 - **PROBABILISTIC FRACTURE MECHANICS**

- **ALTERNATIVE FORMULATIONS:**
  - **MULTIPARALLEL PROCESSORS FOR MULTIDISCIPLINARY MECHANICS PROBLEMS**
  - **SPECIALTY FUNCTIONS FOR SINGULAR MECHANICS PROBLEMS**
  - **COUPLED CONSTITUTIVE RELATIONSHIPS**
  - **DEDICATED EXPERT SYSTEMS**

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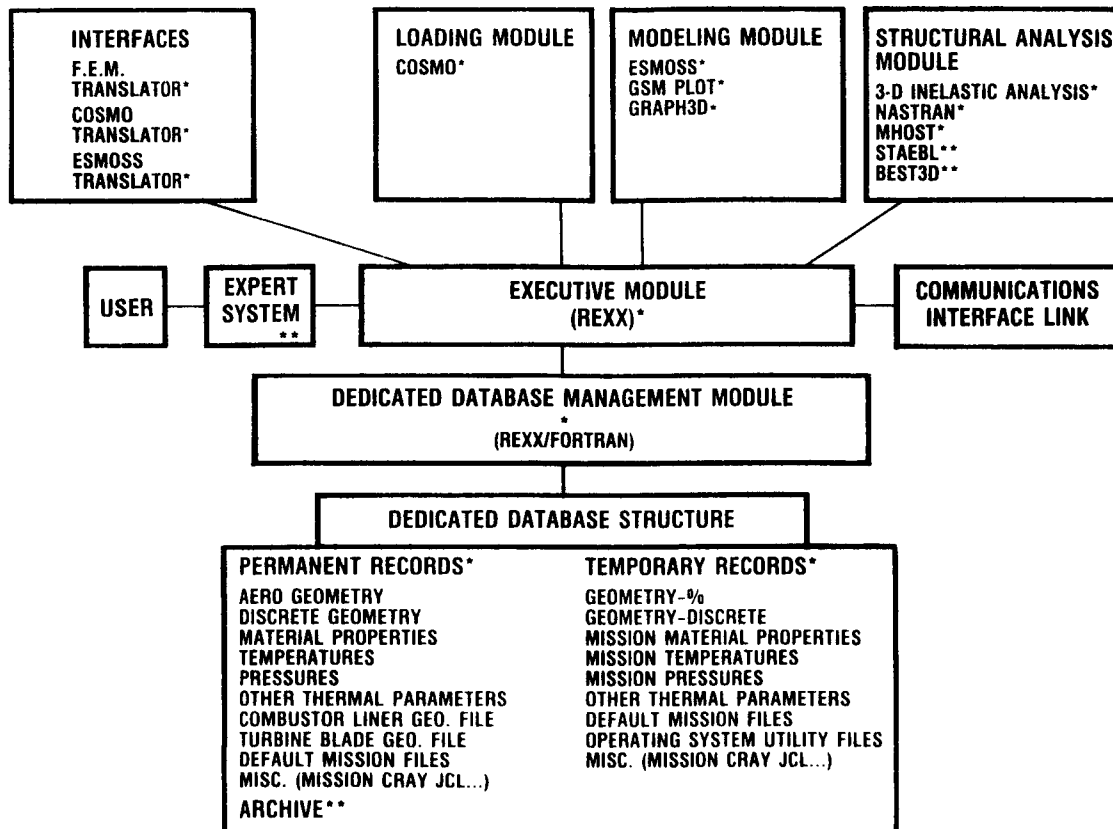## ENGINE STRUCTURES COMPUTATIONAL SIMULATOR (ESCS)

A major part of the 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 as indicated below. ESCS-predicted results will be postprocessed to make assessment of engine structural performance in terms of the items listed in the block at the right.

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                          ┌──────────┐
                          │  TRIAM   │
                          └──────────┘
                              ↕
    ┌──────────┐           NEW FINITE ELEMENTS
    │  ESMOSS  │           NONLINEAR CONSTITUTIVE RELATIONSHIPS
    └──────────┘           MATH MODELS
                           DEDICATED ALGORITHMS
    GEOMETRIC MODELS       LOCAL CONVERGENCE
    DYNAMIC REMESHING
    I/O EXPEDITERS                              ┌──────────────────────┐
                                                │  DURABILITY          │
                                                │  INTEGRITY           │
                                                │  STABILITY           │
    ┌──────────┐       ┌──────────┐             │  PERFORMANCE         │
    │ 3-D TITAN│◄─────►│   ESCS   │◄───────────►│  ECONOMY             │
    └──────────┘       └──────────┘             │  RETIREMENT FOR CAUSE│
                                                │  DISTORTION CONTROL  │
    THERMAL LOADS                               │  INSPECTION INTERVAL │
                                                └──────────────────────┘
                              ┌──────────┐
    ┌──────────┐              │   STAT   │
    │  COSMO   │              └──────────┘
    └──────────┘  ┌──────────┐
                  │  STAEBL  │   GEOMETRIC NONLINEARITIES
    COMPLEX STRUCTURES        └──────────┘   AERODYNAMIC LOADS
    GLOBAL ASSEMBLERS/SOLVERS  OPTIMIZERS       TAILORING ALGORITHMS
    GLOBAL CONVERGENCE         GRADIENT EVALUATORS  ACOUSTICS
    CRITICAL LOCATION          CONSTRAINT GENERATORS FLUTTER
    DATA RECOVERERS            SUBOPTIMIZERS
                               IMPACT MODULES
                               FORCED VIBRATION MODULES
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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 the accompanying chart. The interface module provides the logic to merge different analysis models as well as loading conditions to the analysis models. The analysis module includes advanced analysis methods such as specialty finite elements (three-dimensional inelastic analysis), mixed elements (MHOST), and boundary elements (BEST3-D). It also includes NASTRAN and structures optimization (STAEBL).

INTERFACES	LOADING MODULE	MODELING MODULE	STRUCTURAL ANALYSIS MODULE
F.E.M. TRANSLATOR* COSMO TRANSLATOR* ESMOSS TRANSLATOR*	COSMO*	ESMOSS* GSM PLOT* GRAPH3D·	3-D INELASTIC ANALYSIS* NASTRAN* MHOST* STAEBL** BEST3D**

USER	EXPERT SYSTEM **	EXECUTIVE MODULE (REXX)*	COMMUNICATIONS INTERFACE LINK

DEDICATED DATABASE MANAGEMENT MODULE
*
(REXX/FORTRAN)

DEDICATED DATABASE STRUCTURE

PERMANENT RECORDS*	TEMPORARY RECORDS*
AERO GEOMETRY DISCRETE GEOMETRY MATERIAL PROPERTIES TEMPERATURES PRESSURES OTHER THERMAL PARAMETERS COMBUSTOR LINER GEO. FILE TURBINE BLADE GEO. FILE DEFAULT MISSION FILES MISC. (MISSION CRAY JCL...) **ARCHIVE****	GEOMETRY-% GEOMETRY-DISCRETE MISSION MATERIAL PROPERTIES MISSION TEMPERATURES MISSION PRESSURES OTHER THERMAL PARAMETERS DEFAULT MISSION FILES OPERATING SYSTEM UTILITY FILES MISC. (MISSION CRAY JCL...)

*—PRELIMINARY VERSION AVAILABLE

**—TO BE INSTALLED

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ESCS CONFIGURED FOR ENGINE STRUCTURES FROM COMPONENT TO ENGINE

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 below from bottom left to top right, respectively.
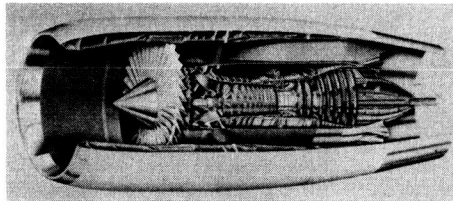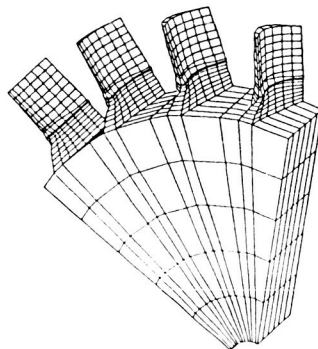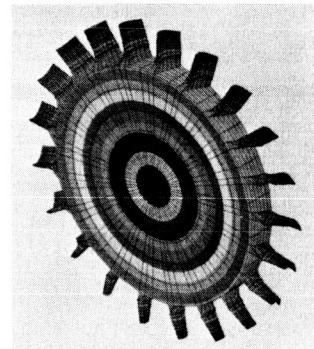
ENGINE
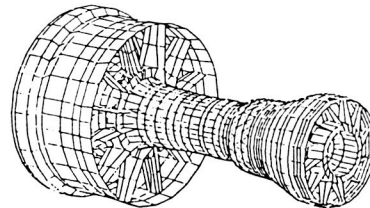
FINITE ELEMENT MODEL
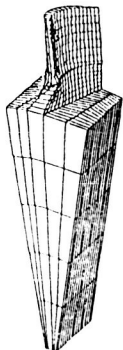
BLADE

ROTOR SECTOR

ROTOR STAGE

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ESCS HAS MODULE FOR LOADS

The loads on the blades (temperatures, pressures, and rotating speeds) are determined by an engine loads module (COSMO in the ESCS schematic). This module is based on engine thermodynamics. The temperatures and pressures are predicted on the surface at user-selected span stations. The accompanying chart is a typical example for temperatures. The blade has been unfolded for 3-D plotting presentation. Pressures and speeds can be similarly represented.
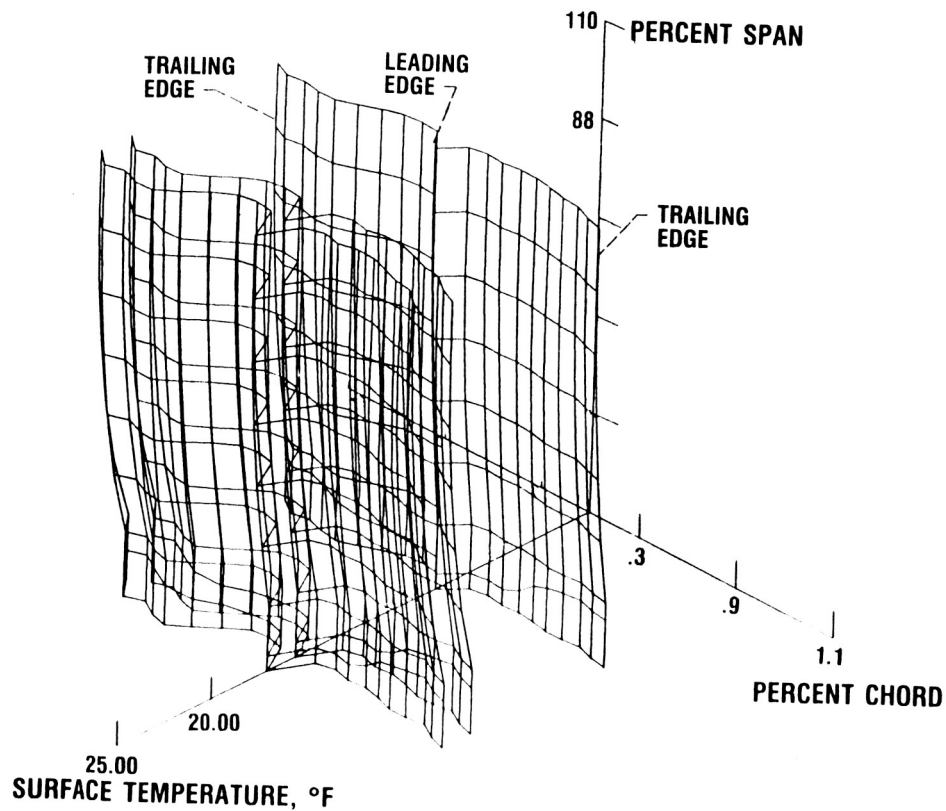
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DEFORMATION OF TURBINE BLADE UNDER FLIGHT
CONDITIONS - A SAMPLE ESCS CASE

The ESCS executive module couples the loads module with the analysis-model-
ing module and with the analysis module through module-communication links
and proceeds to determine the blade structural response at the preselected
times during the mission. Results from such an analysis for the displace-
ments of a turbine blade are shown below for three mission conditions.

TAKEOFF
GROUND IDLE
(PRE-TAKEOFF)
STATIONARY
IDLE

Z

Y

X
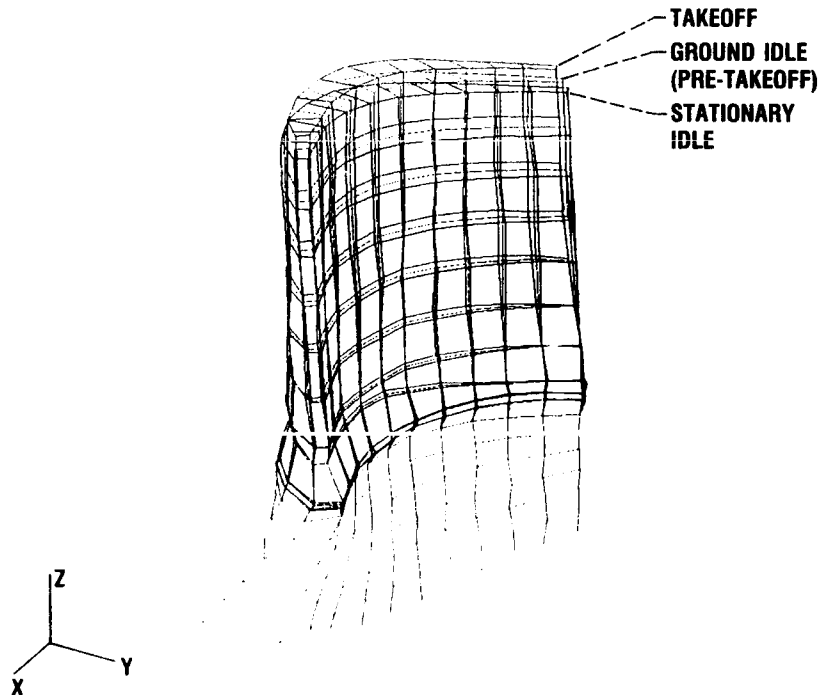
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ESCS ANALYSIS MODULES – PREDICTION COMPARISONS

ESCS has two finite-element analysis modules at its present status – MSC/NAS-
TRAN and MHOST. Results predicted by these two analysis modules are com-
pared in the accompanying chart. The predicted results for the blade air-
foil displacements from the two analysis modules for combined mechanical and
thermal loads are indistinguishable.

TRAILING EDGE

LEADING EDGE
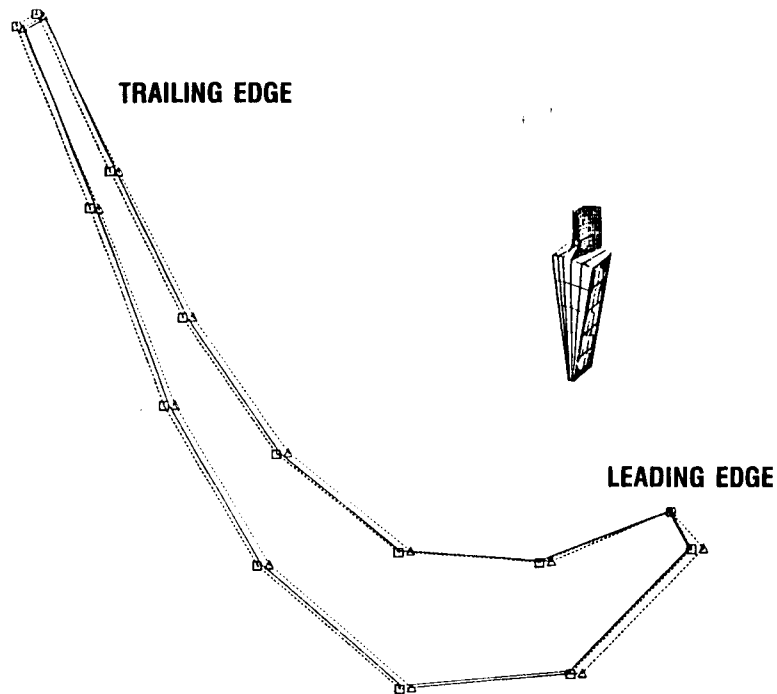
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ESCS postprocesses analysis results for computer graphics display. Examples include a single component in this chart at three stages during the mission: ground idle, takeoff, and cruise. The dynamic motion of the blade is assessed by comparing it with the reference state (stationary position in the figure).
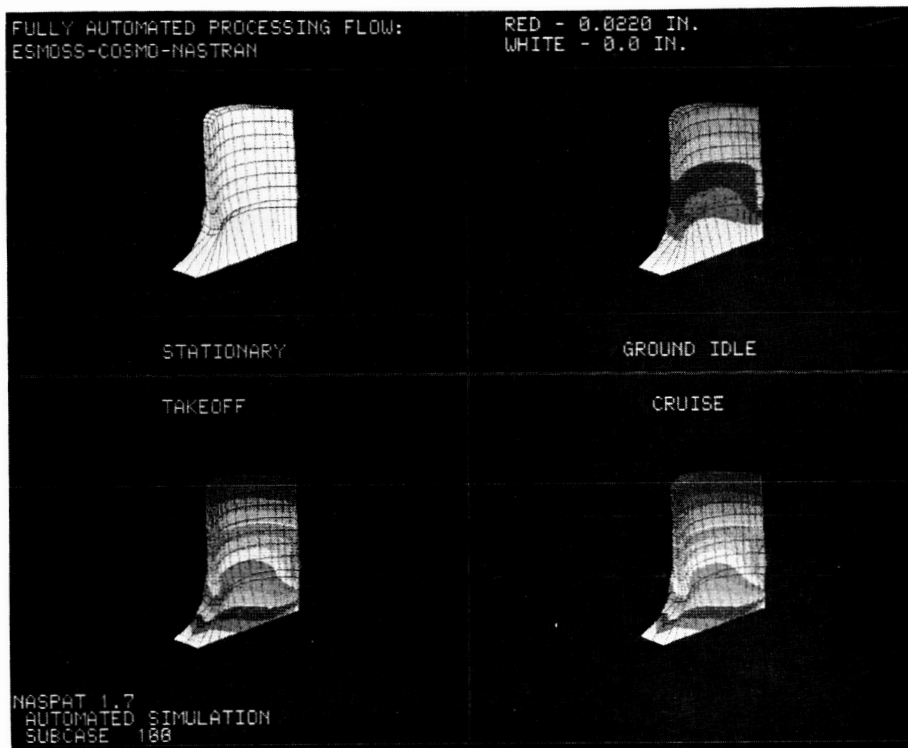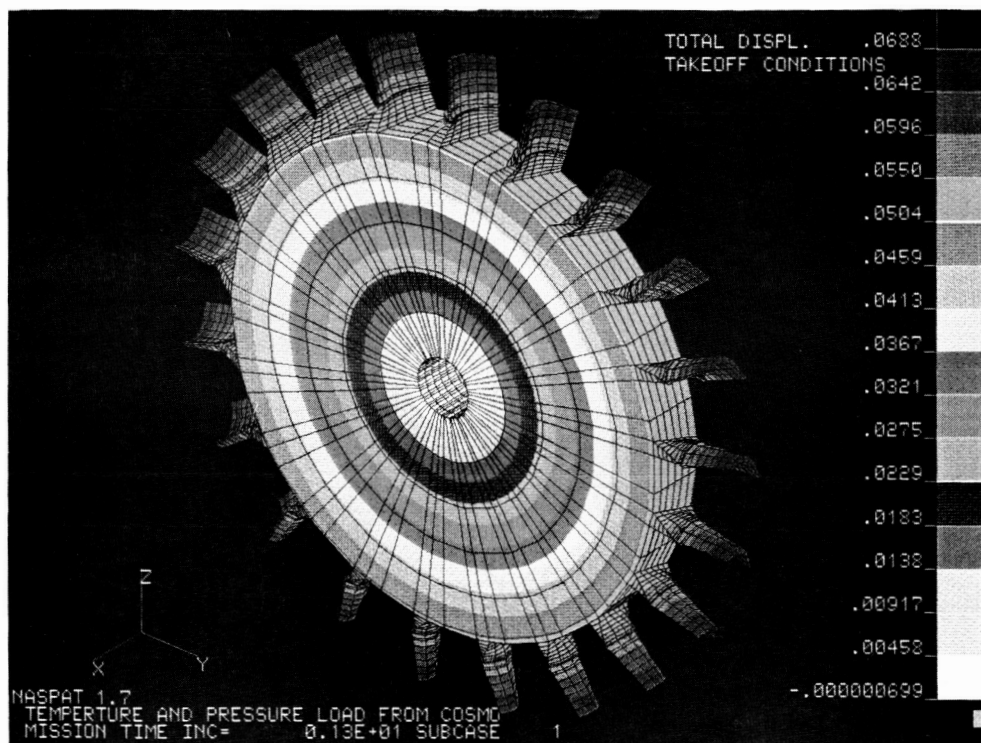
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The structural dynamic response of blades assembled in a bladed rotor is different from that of an individually simulated blade. The dynamic motion of a bladed rotor determined using ESCS is shown below at the takeoff conditions.
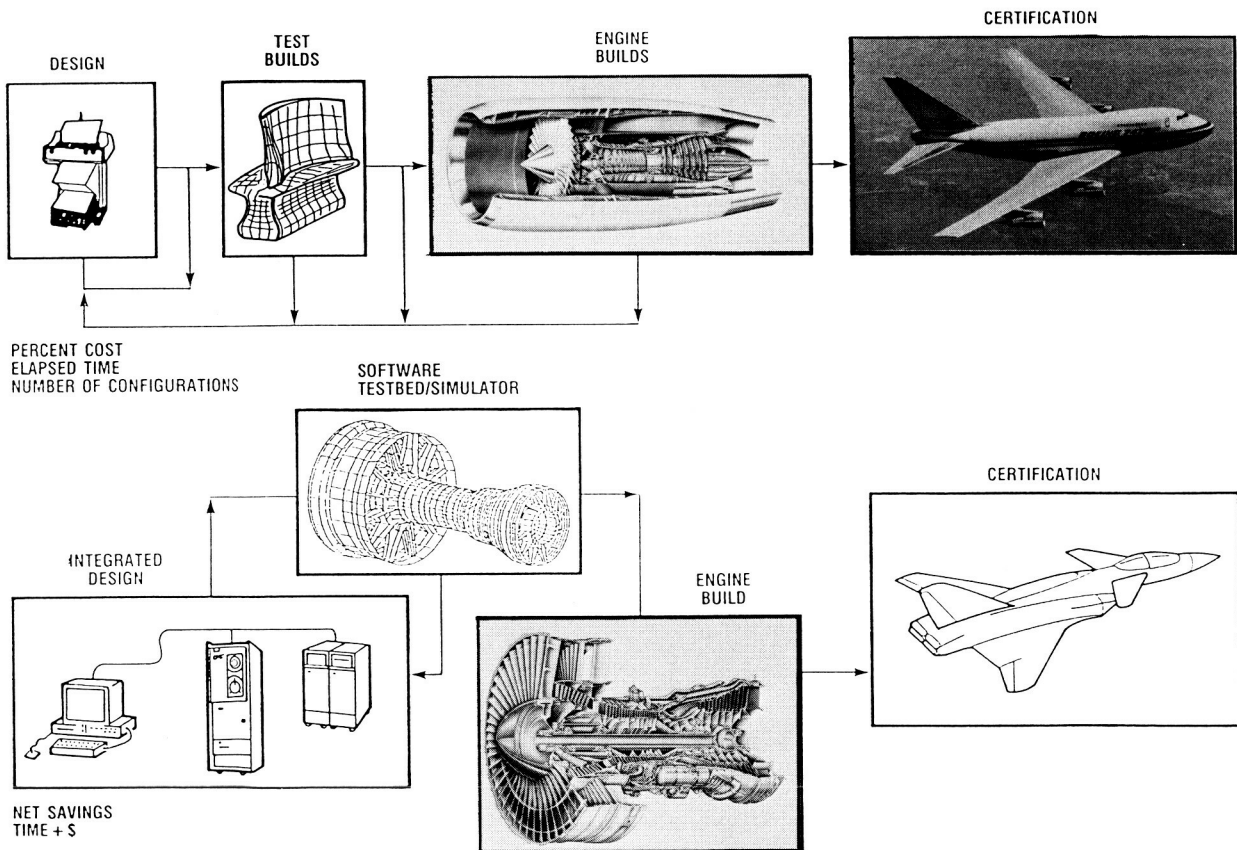

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ESCS SAMPLE RESULTS FOR FLIGHT MISSION SIMULATION

The structural response can be predicted throughout the mission. Representative results for blade-tip radial displacement are shown graphically at identifiable stages during the flight for 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 structured response throughout the mission is that all dynamic interactions are properly accounted for, and the stress-strain results are suitable for life assessments.
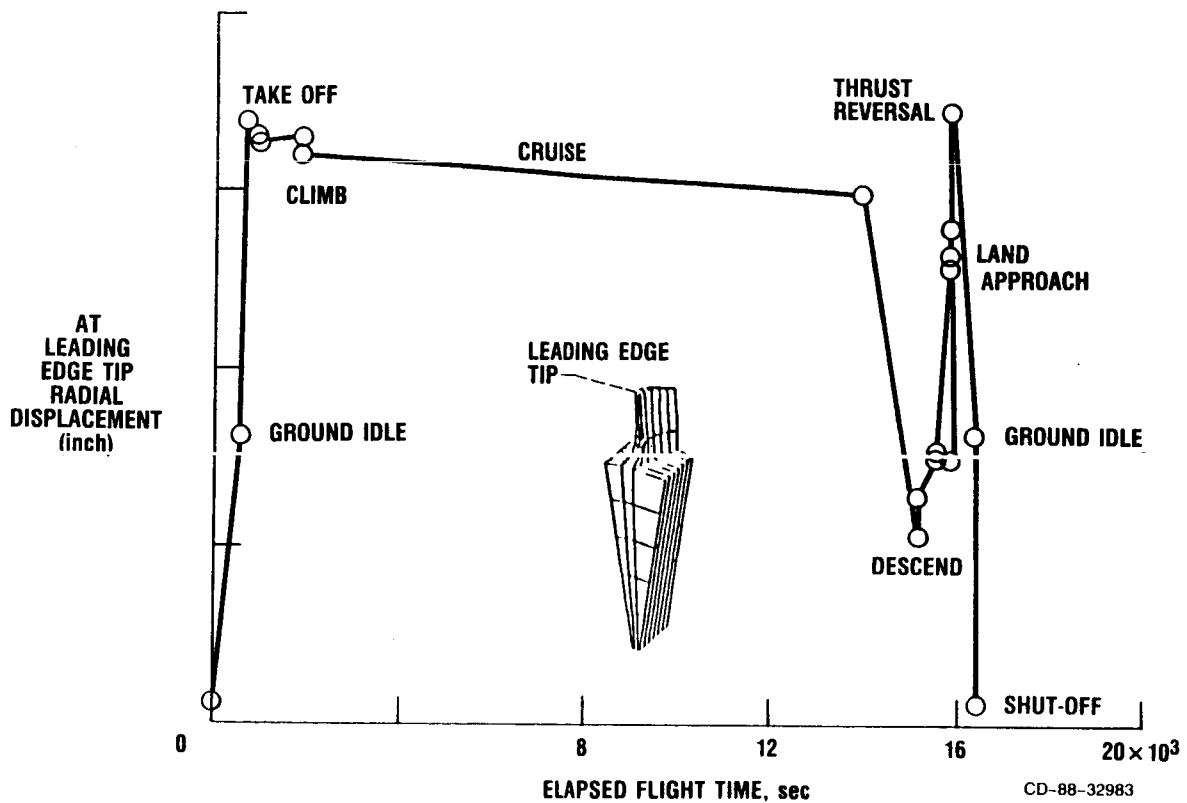
ESCS LONG RANGE OBJECTIVE REVISITED

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

DESIGN → TEST BUILDS → ENGINE BUILDS → CERTIFICATION

PERCENT COST
ELAPSED TIME
NUMBER OF CONFIGURATIONS

SOFTWARE
TESTBED/SIMULATOR

INTEGRATED
DESIGN

ENGINE
BUILD

CERTIFICATION

NET SAVINGS
TIME + $

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ESCS ANTICIPATED BENEFITS

The anticipated benefits to aerospace industry of having and exercising ESCS are summarized in the accompanying chart using qualitative terms. Engine manufacturers have cost estimates for each of the items in the chart based on their own development experience. Suffice it to say that each item runs into multimillions of dollars

- **REDUCED DEVELOPMENT TIME AND COSTS**

- **FEWER DEVELOPMENT ENGINE BUILDS**

- **LONGER LIFE COMPONENTS**

- **REDUCED LIFE CYCLE COSTS ON COMPONENTS**

- **REDUCED COMPONENT AND ENGINE WEIGHT**

- **IMPROVED ENGINEERING PRODUCTIVITY**

- **INCREASED PERFORMANCE**

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