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OVERVIEW OF THE NASA PROGRAM IN COMPUTATIONAL STRUCTURAL MECHANICS

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p. 23

NASA COMPUTATIONAL STRUCTURAL MECHANICS

- DEVELOP ADVANCED ANALYTICAL/COMPUTATIONAL METHODS
- EXPLOIT NEWEST AND MOST POWERFUL COMPUTER TECHNOLOGY
- DIRECTED TOWARD VERY LARGE, COMPUTATIONALLY INTENSIVE, MEMORY EXTENSIVE PROBLEMS
- COMPUTATIONAL TESTBEDS TO SERVE AS TECHNOLOGY "INTEGRATORS" TO PROMOTE/ACCELERATE METHODOLOGY RESEARCH AND DEVELOPMENT

NASA Computational Structural Mechanics

NASA has been active in developing computational structural analysis methodology for many years. However, these efforts were typically conducted as elements of broader research and technology programs without a central disciplinary focus. The purpose of developing a formal Computational Structural Mechanics (CSM) program was to provide this focus. This is likely to become particularly important in view of possible revolutionary advances in computing power that may occur with the development of ultra-fast concurrent processor computers with very large internal memory capacities (e.g., 256 Mflops/processor and 256 Mwords of memory for the Cray-2).

In order to meet the anticipated needs in modeling and analysis of advanced aerospace structures, NASA has developed a program focused on computational structural mechanics. The objective of this program is to advance the state-of-the-art in computational analysis to make accurate analysis of very large and complex structural problems routine. This will be accomplished by emphasizing two key areas: (1) the development of advanced analytical methods, extending beyond traditional approaches and, (2) the exploitation of the newest and most powerful parallel/multiprocessor computers available. Computational testbeds will be developed to serve as technology integrators and to promote/accelerate methodology research and development. An additional, and highly desirable, effect of the CSM program would be to influence the design of future hardware and software systems to reflect the needs of structural analysis.

"CSM HISTORY"

LANGLEY

- EXPLORATORY WORKSHOP, APRIL 1984
- PROGRAM ESTABLISHED OCTOBER 1984
  - 12 PROFESSIONALS IN CSM TEAM
  - 7 GRANTS
  - HEAVY EMPHASIS PLACED ON ADVANCED COMPUTING METHODS
  - COMMITMENT TO TESTBED
- TWO PROGRAM DEVELOPMENT WORKSHOPS
  - SEPTEMBER 1984 (INDUSTRY)
  - JUNE 1985 (UNIVERSITY)
- CURRENT STATUS
  - 18 PROFESSIONALS IN CSM TEAM
  - 15 GRANTS
  - 1 MAJOR SUPPORT CONTRACT
  - INITIAL VERSION OF TESTBED OPERATIONAL

LEWIS

- EVOLVED FROM ENGINE STRUCTURES PROGRAM STARTED 1979
- FORMALLY STARTED OCTOBER 1985
  - CONSOLIDATED ADVANCED ANALYSIS CAPABILITY DEVELOPED UNDER BASE R&T AND SYSTEMS TECHNOLOGY PROGRAMS
  - INITIATED PROGRAM IN ADVANCED COMPUTING METHODS
  - LONG RANGE GOAL: FULL ENGINE STRUCTURAL ANALYSIS FOR A MISSION
  - 4 PROFESSIONALS IN STRUCTURES DIV.
  - 2 GRANTS
  - 4 MAJOR ANALYSIS DEVELOPMENT CONTRACTS (SYSTEM TECHNOLOGY)
- CURRENT STATUS
  - 9 PROFESSIONALS IN STRUCTURES DIV.
  - 7 GRANTS
  - SEVERAL ANALYSIS CODES DELIVERED

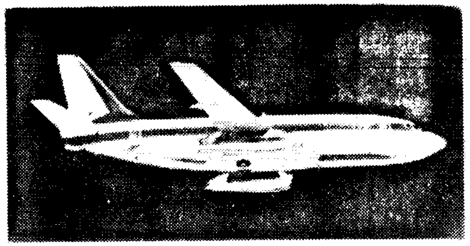
BOTH CENTERS NOW HAVE ACCESS TO A WIDE RANGE OF VERY ADVANCED COMPUTERS

CSM History

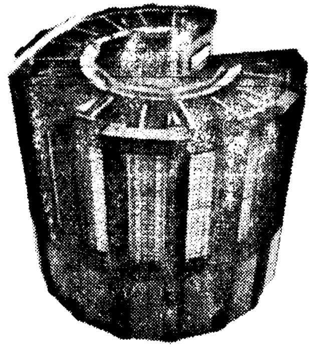
Currently, the CSM effort is being actively pursued by two NASA centers. The Langley Research Center is focusing on airframe structures and large space structures while the Lewis Research Center is focusing on aeronautical and space propulsion structures. Both centers are building on a long history of activity in computational structural analysis and exploiting advanced computers. Lewis was one of the first NASA centers to obtain a supercomputer (first a Cray-1 then a Cray-XMP) and Langley was one of the first to have multi-processor computers (several years ago a specially designed "finite element machine" and more recently a Flex/32). The program is also being heavily supported by the use of the Cray-2 supercomputer (NAS) at the Ames Research Center and will continue to rely on the NAS facilities to provide the leading edge in computer technology.

COMPUTATIONAL STRUCTURAL MECHANICS

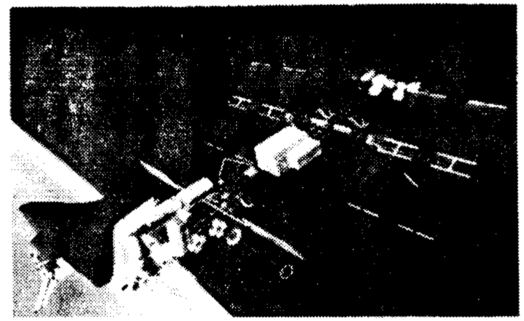
Aircraft Structures



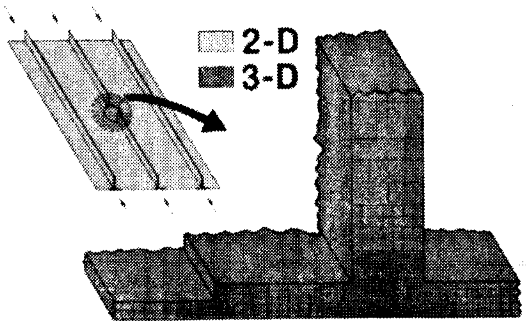
Advanced Architecture Computers

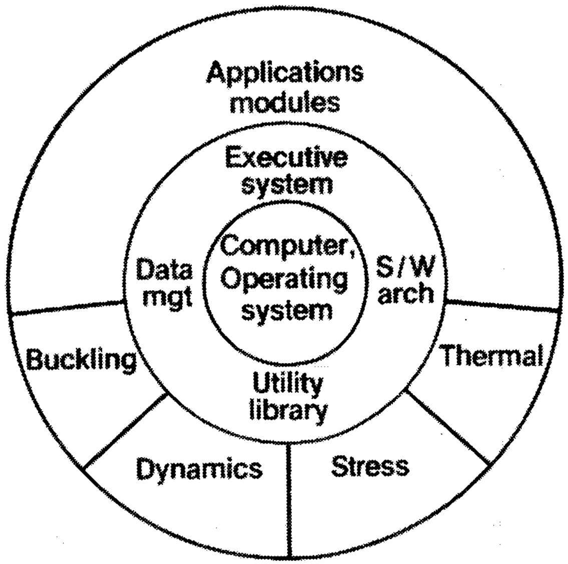


Space Structures

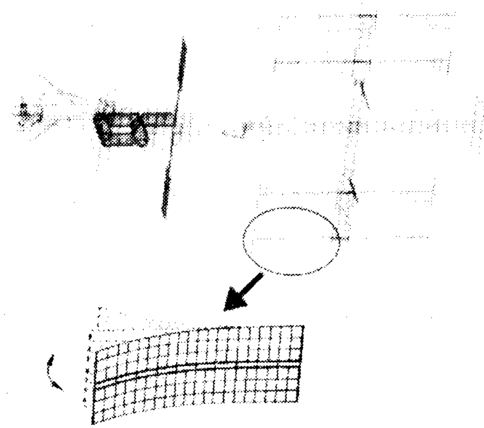


Local 3-D nonlinear stress analysis within larger 2-D analysis model





Transient Dynamics



Computational Structural Mechanics (LaRC)

The NASA CSM program was formally initiated at the Langley Research Center in 1984. An exploratory workshop was held to establish outside support for the program and involve the aerospace community in structuring the program. In October of 1984, an experienced 12-person CSM team composed of structural analysts, computational methods developers and computer scientists was officially established at Langley. The program placed initial emphasis on developing a generic computational testbed, and on developing computing methods for advanced computers and for selected focused application problems. In particular, Langley stressed global/local analysis of composite structures and nonlinear dynamics of deployable space structures. Two subsequent workshops were held, one primarily for industry (September 1984) and one primarily for universities (June 1985). This lead to an increase of funded grants from 7 to 15 and the award of a major technical support contract. The grant activity has proven to be very productive and well coordinated, especially in the area of advanced software systems and computational methods for concurrent processor computers. The addition of the contractual effort has accelerated the development of the testbed. The initial version is currently operational and widely distributed, especially among the CSM participants.

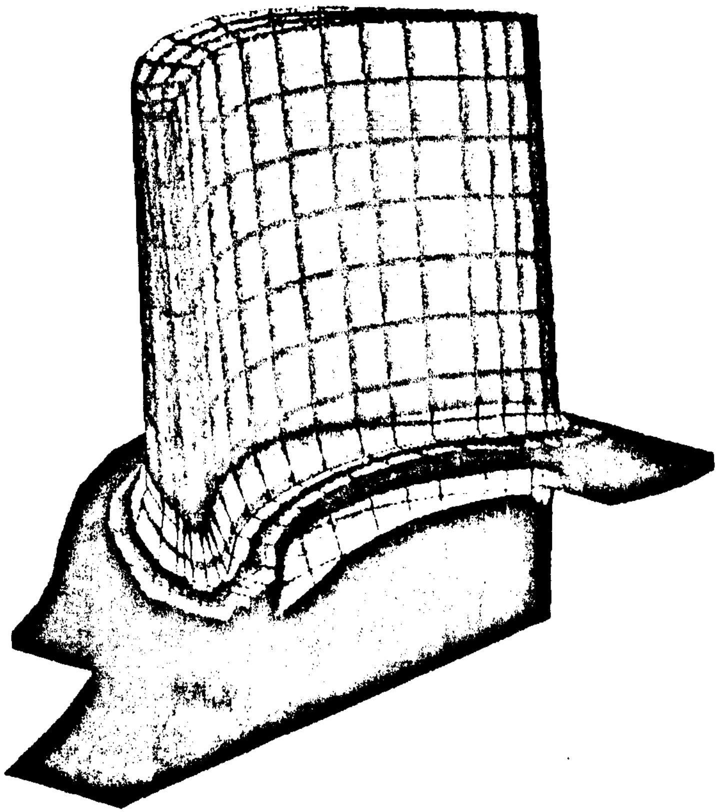
STRUCTURES DIVISION

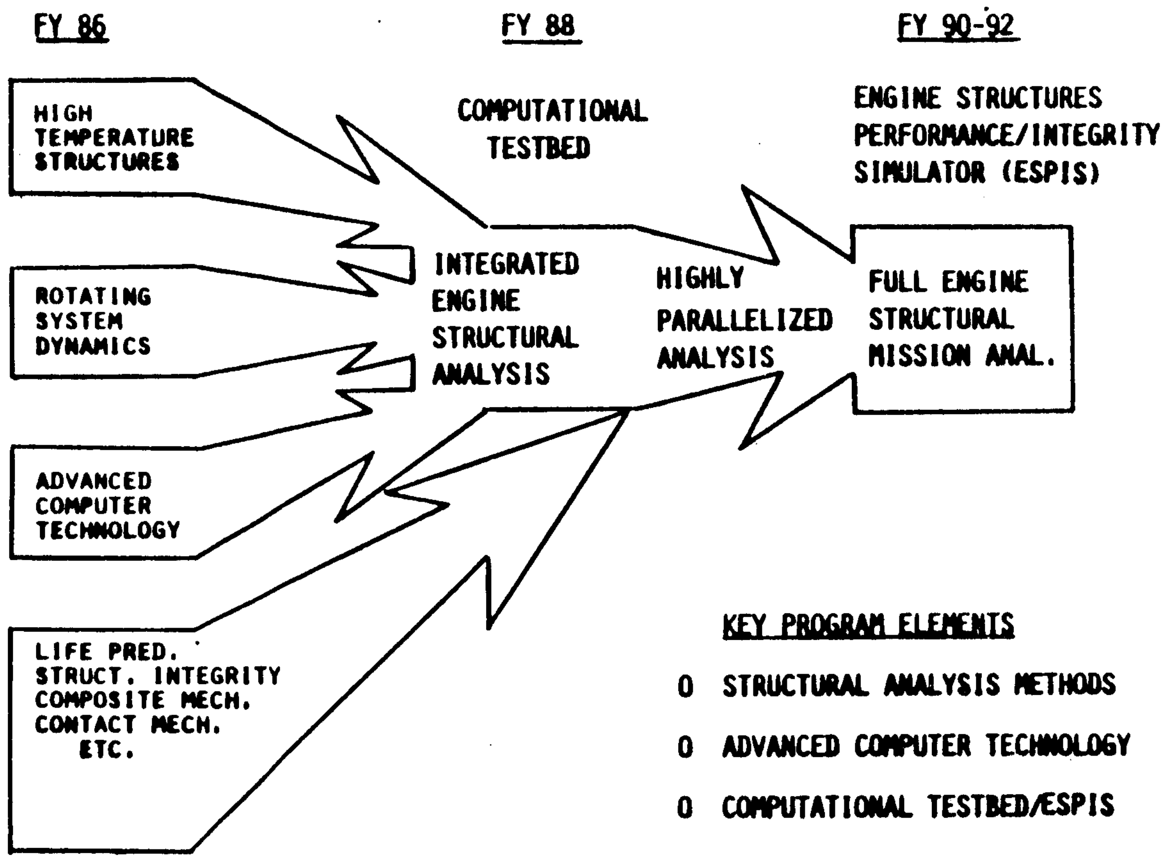
ADVANCED CONCEPTS & APPLICATIONS BRANCH

AEROSPACE TECHNOLOGY DIRECTORATE

NASA Lewis Research Center

COMPUTATIONAL STRUCTURAL MECHANICS





KEY PROGRAM ELEMENTS

0 STRUCTURAL ANALYSIS METHODS

0 ADVANCED COMPUTER TECHNOLOGY

0 COMPUTATIONAL TESTBED/ESPIS

Computational Structural Mechanics (LeRC)

While the CSM program at the Lewis Research Center "officially" began in 1985, Lewis had a well developed internal program in computational structural mechanics which was part of a broader engine structures program that began about 1978. Elements of these activities were consolidated into the CSM program which established a long-range goal of developing computational capability to enable detailed structural analyses of complete engine models to be conducted over complete mission cycles, routinely. The program emphasized development of advanced analytical methods, a strength of the engine structures program, and initiated an activity directed at exploiting advanced parallel/multi-processor computers. Initially, the CSM program was supported by the equivalent of 4 researchers. It funded 2 grants and benefited from the results of several on-going activities, including 4 major contracts to develop advanced analytical methods. Currently, there are effectively 9 researchers working on CSM at Lewis; 7 grants are funded; and the research contracts have delivered advanced computer codes covering inelastic finite element analysis, nonlinear boundary element analysis and probabilistic structural analysis.

CURRENT MAJOR AREAS OF EMPHASIS

LANGLEY

- TESTBED DEVELOPMENT
- GLOBAL/LOCAL ANALYSIS
- NONLINEAR TRANSIENT DYNAMICS
- ADVANCED FINITE ELEMENT ANALYSIS
- PARALLEL PROCESSING
- APPLICATION STUDIES (AS A PART OF IN-HOUSE ACTIVITIES)

LEWIS

- ENGINE STRUCTURES COMPUTATIONAL SIMULATOR DEVELOPMENT
- INELASTIC FINITE ELEMENT ANALYSIS
- NONLINEAR BOUNDARY ELEMENT ANALYSIS
- PROBABILISTIC STRUCTURAL ANALYSIS
- NONLINEAR TRANSIENT DYNAMICS
- TRANSPUTER SYSTEMS

Current Major Areas of Emphasis

The major areas of emphasis in the CSM program cover a broad spectrum of advanced analytical methods, computational methods and focused applications. At the center are computational testbeds intended for use by NASA, active CSM participants and by outside users. The testbeds will serve to integrate the methodology being developed across the program and provide access to NASA-developed technology by interested researchers. The generic testbed being developed by Langley is UNIX-based and is currently available on VAX, Cray and Flex computers within NASA and will be extended to other computers in the future. The initial version has been widely distributed among participants in the NASA CSM program and can be supplied, upon request, to other organizations wishing to use it. The testbed being developed at Lewis is more focused on applications related to engine structures and is not currently intended for distribution. However, it will be accessible to selected outside users through NASA.

Advanced analytical capability is being developed for transient and nonlinear dynamics, advanced finite element analysis, nonlinear boundary element analysis and probabilistic structural analysis and global/local analysis. All of these capabilities are currently being incorporated directly into the testbeds and/or exist as complete stand-alone computer codes. In addition, fundamental methods are being developed for conducting structural analyses on multi-processor computers, including eigenanalysis, solutions to systems of linear equations and basic matrix operations. These techniques will be incorporated into the structural analysis methods as they, in turn, are developed for concurrent processor computers. These methods also form part of the effort to make the testbeds easily adaptable to general classes of multi-processor computers.

AREAS OF FOCUSED APPLICATION

- COMPOSITE STRUCTURES
  - MECHANICS AND FAILURE MECHANISMS
  - BUCKLED/POST-BUCKLED BEHAVIOR
- NONLINEAR HIGH-TEMPERATURE STRUCTURAL ANALYSIS
  - AIRCRAFT ENGINE STRUCTURES
  - SPACE SHUTTLE MAIN ENGINE
  - (HYPERSONICS AIRCRAFT STRUCTURES)
- SYSTEM DYNAMICS
  - LARGE AMPLITUDE TRANSIENT MOTION (DEPLOYABLE SPACE STRUCTURES)
  - HIGH SPEED (ROTATING) ENGINE STRUCTURES
- TIRE MECHANICS

Areas of Focused Application

A strong motivating factor for developing the CSM program was the need for large-scale advanced analytical capability in several areas of activity within NASA including basic research and systems technology. These areas serve to focus the CSM activities on current problems which can benefit immediately from newly developed capability, provide realistic problems and experimental data with which to develop and validate new capabilities, and expose strengths and weaknesses to guide the program in the future.

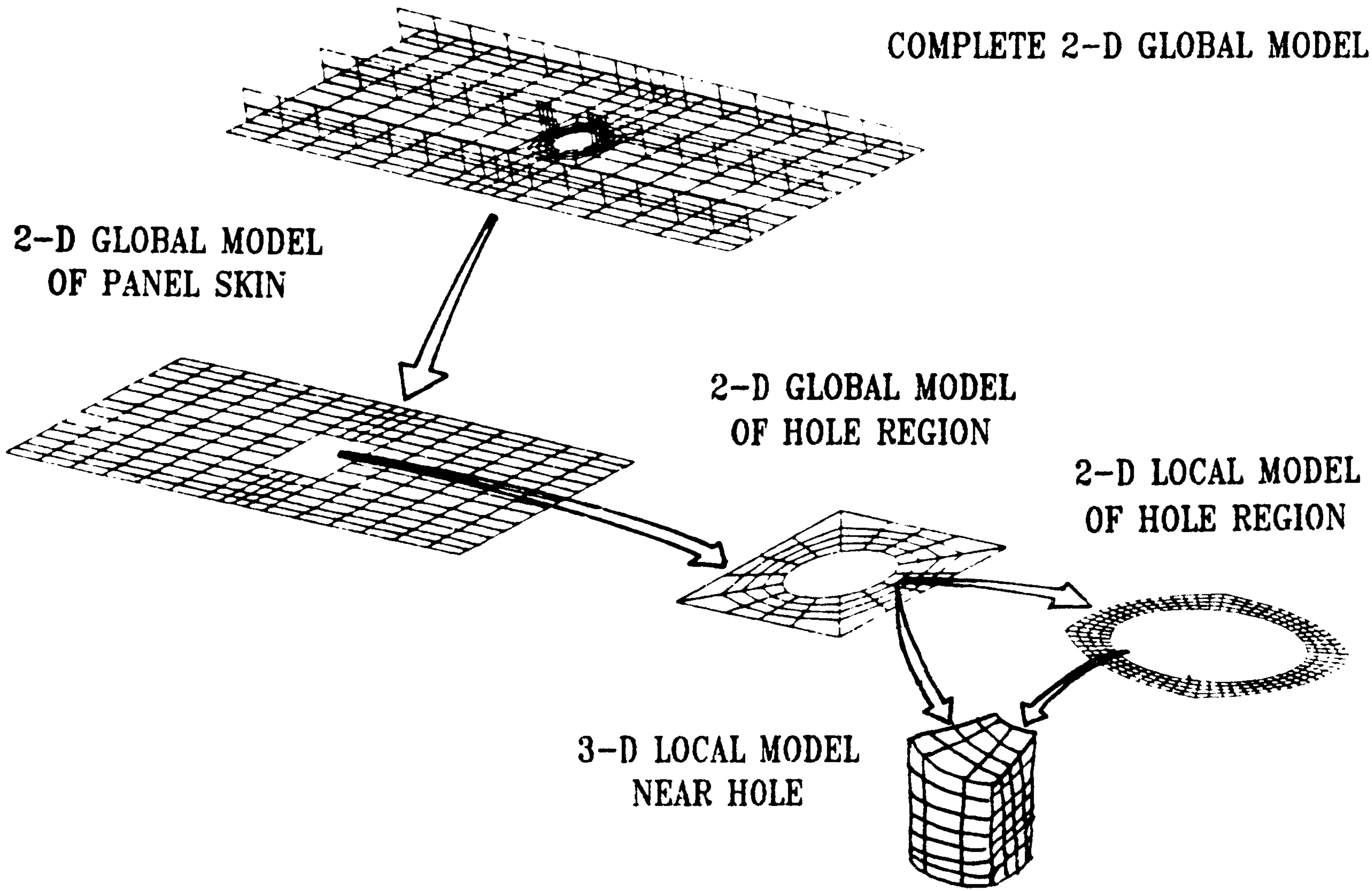
An area common to both centers is analysis of composite structures. CSM supports basic research in developing computational methods for predicting properties of composite materials, describing failure mechanisms and analyzing behavior of composite structures including buckled and post-buckled behavior. At Langley, particular emphasis is being placed on analysis of composite structures in order to develop methods for global/local analysis. The activity is coordinated with basic structures research at Langley. It is currently focused on analyzing a stiffened panel as a realistic generic structure, but also due to the availability of good validation data. Lewis is placing a strong emphasis on the analysis of complex high-temperature structures for propulsion systems (e.g. turbine blades). This element of the program is benefiting significantly from systems technology programs directed toward aircraft engine structures and space shuttle main engine durability. The former has produced advanced inelastic finite element and boundary element analysis capability while the latter is focusing on probabilistic structural analysis. Both centers are likely to become more involved in multi-disciplinary problems with the development of hypersonic vehicles.

In the area of dynamics, both centers have applications involving transient nonlinear dynamics. Langley is focusing on the deployment of flexible space structures such as large trusses. This supports their role in the evolutionary development of the Space Station and in developing fundamental concepts for large space structures. Langley also has a smaller activity directed toward analyzing the dynamics of tires for aerospace vehicles. Recently, they have been heavily involved in analyzing tire wear on the space shuttle. The CSM dynamics program at Lewis is currenly concentrating on rotation engine structures and is coordinated with the high-temperature structures program.

The applications of CSM technology and the areas of fundamental research are strongly influenced by the existing and long-range needs of NASA and the general aerospace community. The general approach has been, and will continue to be, to develop capability based on long-range needs but to emphasize applications to current relevant problem areas.

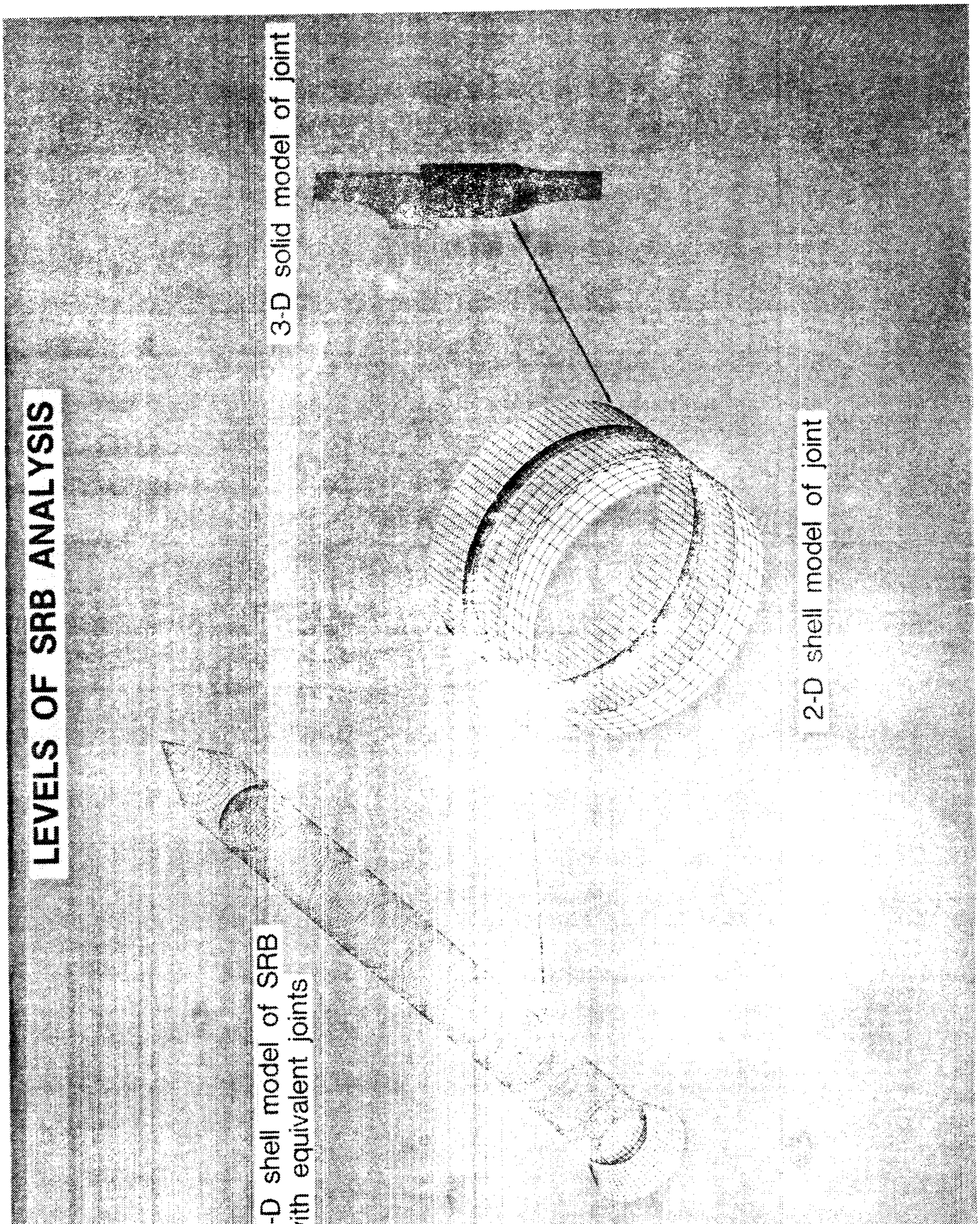
GLOBAL/LOCAL ANALYSIS OF CSM FOCUS PROBLEM

METHODS AND APPLICATIONS



Global/Local Analysis of CSM Focus Problem

An example of a focused CSM application problem at Langley is the stiffened composite panel with a hole. This structure is typical of aircraft structures and is being studied as part of the Langley structures program in order to understand and predict buckling/post-buckling behavior and failure mechanisms. The particular region of study is the area around the hole, especially near the discontinuity at the stiffener. The object of the CSM effort is to avoid large, highly detailed models of the entire structures, by developing methods to "converge" on the hole by moving from a relatively sparse global 2-D model, to a local 2-D model, to a "small" detailed 3-D model that accurately represents thickness effects. In following this process, it is extremely important to assure that each higher level model contains enough information for accurate transition to a more local model. This may require additional intermediate models and some iteration, but the goal of CSM is to assure a desired level of accuracy with a minimal level of computational effort and to do this in an automated manner requiring a minimal amount of intervention. This capability is being incorporated into the testbed and will also serve as a focused problem for developing concurrent processing methods. More significantly, it will be further integrated into a generic global approach to analyzing very large structural problems such as an entire airframe.



ORIGINAL PAGE
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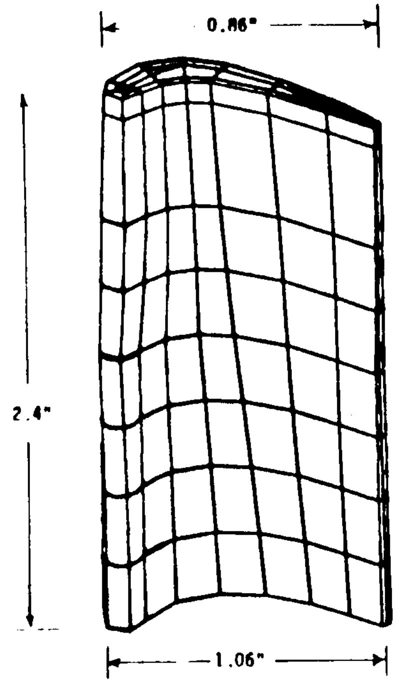
Levels of SRB Analysis

Recently, the CSM group at Langley provided extensive support in advanced structural modeling and analysis to the NASA shuttle re-design effort presenting some of the most detailed analysis yet conducted on the shuttle solid rocket booster (SRB) cases. They produced and analyzed a highly detailed, 83000 degree-of-freedom shell model of the entire rocket motor; a more refined model of a section near the clevis-tang joint; and a highly refined 14000 degree-of-freedom, 3-D model of a narrow segment about the clevis joint including the shear pin. This last model can also account for some of the frictional nonlinearities that can arise from pin case contact and can be further used to transfer these effects to the full model of the SRB. This analysis required the full resources of a Cray-XMP.

This was a "crash" effort and used the best analytical tools currently available. Its significance is not so much in what was accomplished but in the amount of human and computational effort that was required to do it. The fact that a very knowledgeable CSM team was in place at Langley greatly contributed to the success of this task. However, it clearly demonstrated the need for highly streamlined, computationally efficient methods for attacking problems such as these on a routine basis. CSM will continue to develop, in part, by selecting problems such as these for focused applications.

NONLINEAR STRUCTURAL ANALYSIS OF AN AIR-COOLED TURBINE BLADE

(SIMPLIFIED)



SIMPLE STRUCTURAL MODEL
VERY COMPLEX MATERIAL MODEL
THERMAL AND CENTRIFUGAL LOADING

418 NODES
173 ELEMENTS
20 SEC./LOAD STEP
200 STEP/MISSION CYCLE
5 - 10 CYCLE/SIMULATION

5 - 10 HOURS ON CRAY-XMP

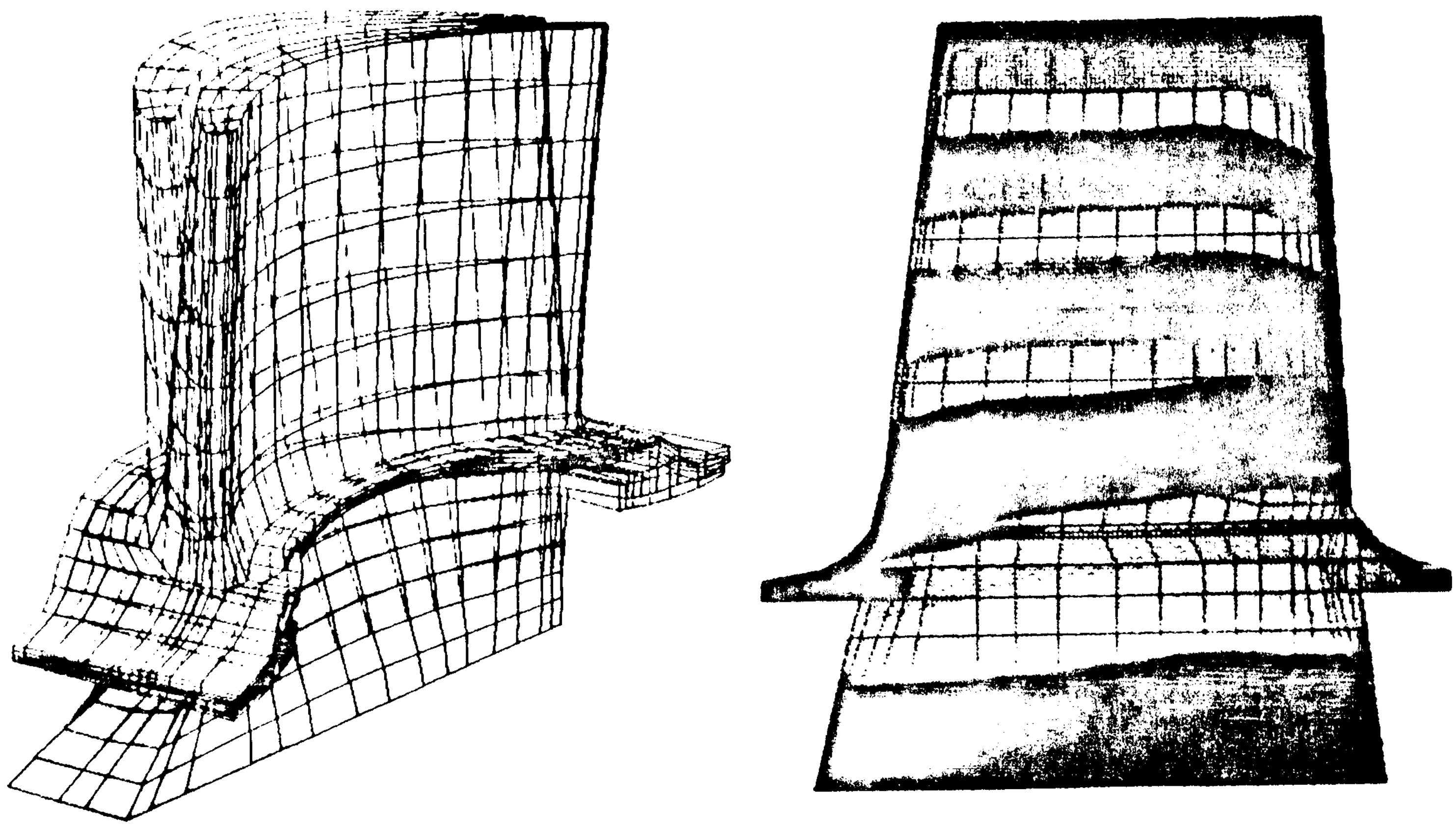
MORE REALISTIC MODELS - 2000 NODES, 1000 ELEMENTS
" DAYS OF COMPUTER TIME ? "

Nonlinear Structural Analysis of an Air-Cooled Turbine Blade

An example of computational structural mechanics at Lewis Research Center is the analysis of advanced turbomachinery turbine blades. These components are geometrically very complex and are subjected to severe thermomechanical loading from centrifugal force, with rotational speeds as high as 36000 RPM; thermal loads, with temperatures ranging from -450^{o}F in liquid hydrogen fueled rockets to over 2500^{o}F in aircraft gas turbine engines; and gas pressure loads as high as several hundred pounds force. In future propulsion systems, rotational speeds and pressure forces could double and temperatures may exceed 4000^{o}F. Furthermore, materials characteristics can become very nonlinear in critical locations during normal operation and both loads and material behavior can vary over the component in a non-deterministic manner requiring that the analysis be performed probabilistically.

Analysis of a simplified structural model incorporating a single complex load case and nonlinear material behavior requires about 20 sec. of computing time on a Cray-XMP computer. However, a complete analysis of the blade requires that it be analyzed over several simulated mission cycles, consisting of 100-200 separate load steps per cycle, in order to determine the cumulative effects of extended use. This would take 5-10 hours of computer time and, as such, analysis of this type is rarely done.

SSME HPFTP - FIRST STAGE TURBINE BLADE
SINGLE CRYSTAL BLADE DYNAMICS
MODE 1 - FREQUENCY 4487 HZ



SSME HPFTP - First Stage Turbine Blade

The more realistic model of a turbine blade shown contains 1025 solid elements and 1575 nodes and is representative of turbine blades in rocket engine turbopumps and aircraft gas turbine engines. (Actually, modern aircraft gas turbine blades have internal cooling passages and can be much more complex than the model shown.) Depending on the severity of the loads, a complete structural analysis for a single loads case requires about 1-5 minutes of computer time on a Cray-XMP and is performed routinely. However, a detailed analysis of this blade model over several mission cycles could take well over 100 hours of computer time. The goal of CSM at Lewis is to make analysis of this type routine and, ultimately, to extend computational capability to the point of analyzing entire engine configurations in detail. Projections of increases in computing power over the next ten years indicate that this is likely, but it will have to be done by developing new, innovative approaches to basic structural analysis as well as exploiting the most powerful computers available. The computational testbed will facilitate this process and the analytical methods currently under development are the first step toward this goal.

SIGNIFICANT NASA COMPUTERS AVAILABLE TO CSM

- CRAY-2 – NUMERICAL AERODYNAMIC SIMULATOR (NAS-AMES)
- CRAY-XMP – LEWIS AND AMES
- FLEX/32 – LANGLEY
- TRANSPUTER SYSTEM (67 PROCESSORS) – LERC (ALSO POSSIBLY LARC)
- RIAC (RESEARCH INSTITUTE FOR ADVANCED COMPUTING) – AMES
  - CONVEX C1
  - SEQUENT BALANCE 2000
  - ALLIANT (TO BE DELIVERED)
  - INTEL iSPC HYPERCUBE
  - CONNECTION MACHINE CM2 (TO BE DELIVERED)
  - DATA FLOW MACHINE (TO BE DELIVERED)
  - PRINCETON "NAVIER-STOKES" MACHINE (TO BE DELIVERED)
- PROPOSED SUPER-MINICOMPUTERS – LANGLEY AND LEWIS
- AMDAHL MAINFRAME COMPUTERS – LEWIS AND AMES
- IBM 3033 – LEWIS
- VPS-32 – LANGLEY
- SEVERAL VAX
- MPP – GODDARD

Significant NASA Computers Available to CSM

NASA has a wide range of advanced computers available to the CSM program, including Cray-2 and Cray-XMP supercomputers and a variety of the most modern concurrent processing computers. These are in addition to powerful computer resources available at Langley and Lewis. Furthermore, the NAS computer facility at Ames will continue to provide the most powerful computers available by maintaining state-of-the-art supercomputers. In the next few years, the Cray-2 will become the "second" computer at the center when a newer one, at least 4 times faster, is acquired. This process is planned to be repeated every 2 years thereafter with at least 2 generations of supercomputers available concurrently. Also, the Research Institute for Advanced Computing (RIAC) at Ames will maintain an array of advanced concurrent processor computers. While RIAC is intended as a part of a broader computer science research activity its computers are available to CSM researchers through the "NASnet" networking system. These extensive resources are considered to be one of the major strengths of the CSM program. They will allow researchers to work on an exceptionally broad range of computer architectures and be assured ready access to the most powerful supercomputers.