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STRUCTURAL MECHANICS DIVISION RESEARCH AND TECHNOLOGY PLANS FOR FY 1990 AND ACCOMPLISHMENTS FOR FY 1989

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National Aeronautics and
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Langley Research Center
Hampton, Virginia 23665

RESEARCH AND TECHNOLOGY PLANS FOR FY 1990 AND ACCOMPLISHMENTS FOR FY 1989

BY KAY S. BALES

SUMMARY

The purpose of this report is to present the Structural Mechanics Division's research plans for FY 1990 and accomplishments for FY 1989. The work under each branch is shown by RTR Objectives, FY 1990 Plans, Approach, Milestones, and FY 1989 Accomplishments. Logic charts* show elements of research and rough relationship to each other. This information is useful in program coordination with other government organizations in areas of mutual interest.

ORGANIZATION

The Langley Research Center is organized by directorates as shown on figure 1. The Structures Directorate includes Structural Mechanics Division, Materials Division, Structural Dynamics Division, and Acoustics Division. The Structural Mechanics Division consists of four branches and one program office as shown on figure 2. James L. Pittman was selected Assistant Head, Aerothermal Loads Branch, effective December 3, 1989. There have been some changes in the organizational structure of the Division effective April 22, 1990, as follows: Dr. Donald R. Rummler was appointed Assistant Division Chief; the Thermal Structures Branch was abolished and the work merged with the Aircraft Structures Branch (formerly Structural Mechanics Branch) with Dr. James H. Starnes, Jr., Head, and Dr. Mark J. Shuart and Charles J. Camarda, Assistant Heads; the Computational Mechanics Branch was established, incorporating the work of the Computational Structural Mechanics Group, with Dr. Jerrold M. Housner appointed Head; and the Structural Concepts Branch was renamed Spacecraft Structures Branch.

FUNCTIONAL STATEMENT

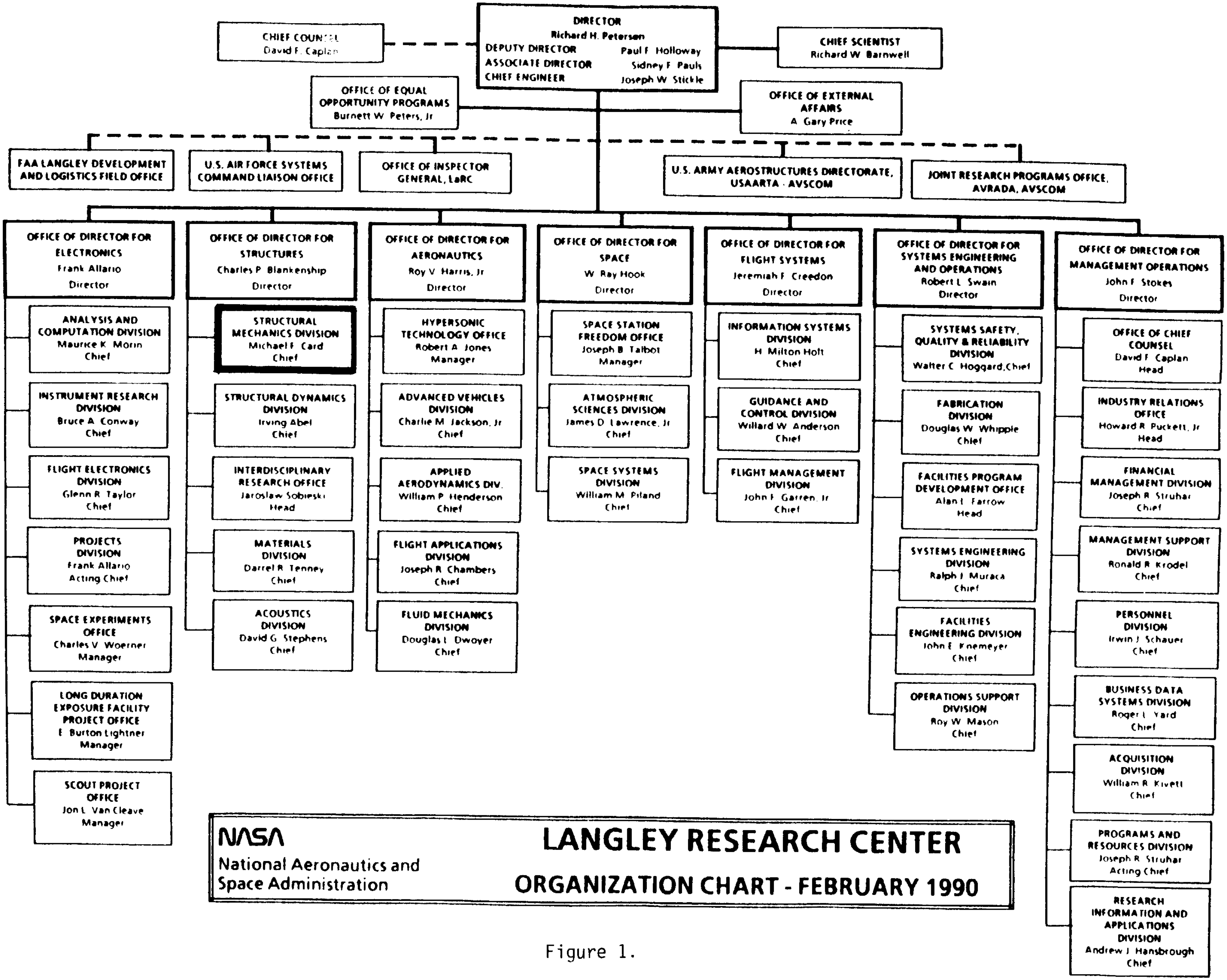
The Division conducts analytical and experimental research to provide structural concepts which meet functional requirements of advanced atmospheric and space flight vehicles. Develops and validates analytical methods of predicting stresses, deformation, structural strength, thermal loads and various thermoelastic phenomena. Develops and evaluates structural configurations embodying new material systems and/or advanced design concepts for general application and for specific classes of new aerospace vehicles. Develops and validates advanced structural analysis methods. Provides program support for structures technology programs in advanced composites research, hypersonic aircraft and advanced launch vehicles. Uses a broad spectrum of test facilities and develops new research techniques. Test facilities include the Struc-

* Updated version reflecting reorganization is not available for all branches

tures and Materials Laboratory, the 8-foot High Temperature Tunnel, the Aerothermal Arc Tunnels, the 7-inch High Temperature Tunnel, and the Automated Assembly Facility.

TABLE OF CONTENTS

I ORGANIZATION CHARTS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SPACE SYSTEMS DIVISION
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LANGLEY RESEARCH CENTER
ORGANIZATION CHART - FEBRUARY 1990

Figure 1.

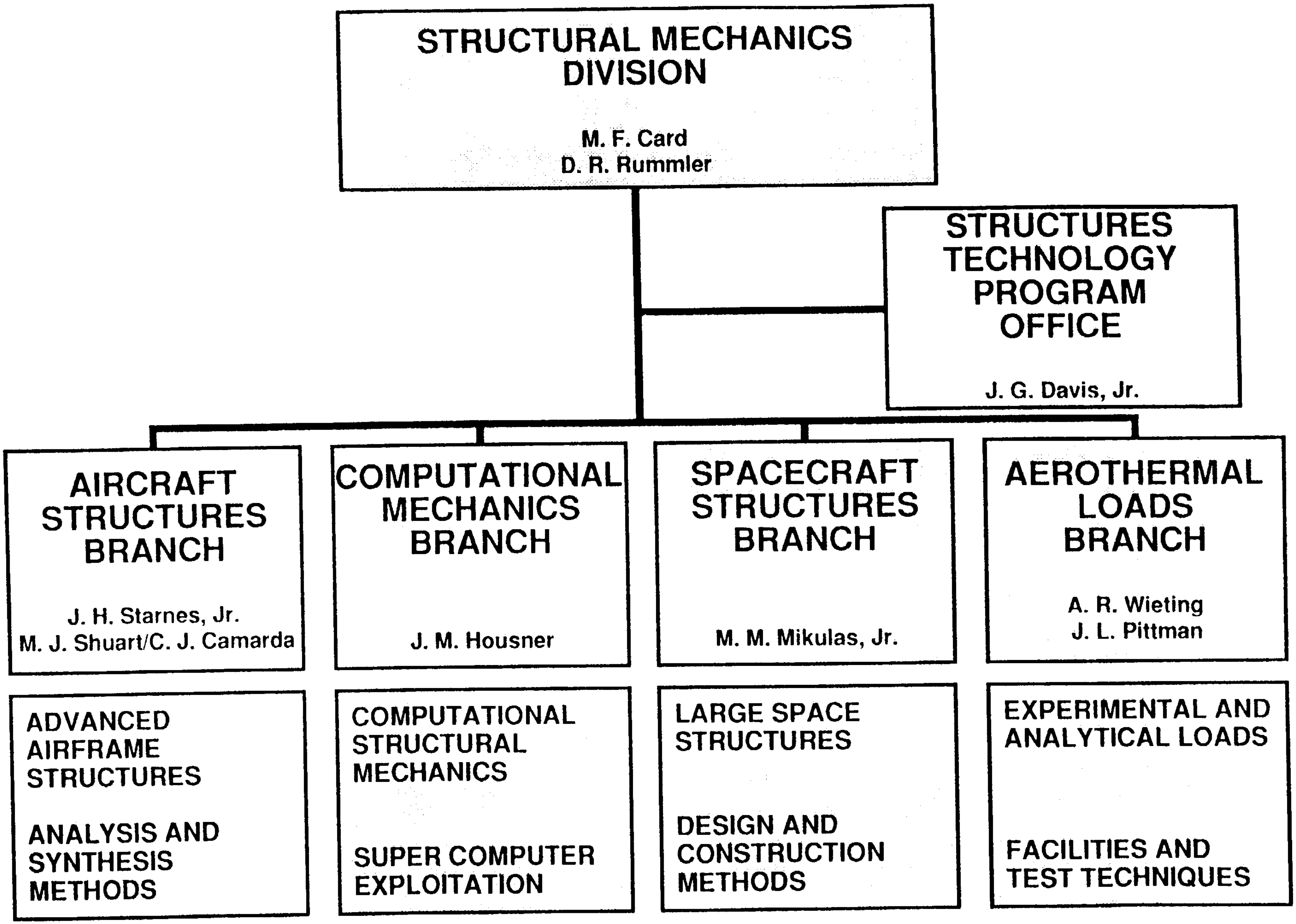
STRUCTURAL MECHANICS DIVISION
M. F. Card
D. R. Rummler
STRUCTURES TECHNOLOGY PROGRAM OFFICE
J. G. Davis, Jr.
AIRCRAFT STRUCTURES BRANCH
J. H. Starnes, Jr.
M. J. Shuart/C. J. Camarda
COMPUTATIONAL MECHANICS BRANCH
J. M. Housner
SPACECRAFT STRUCTURES BRANCH
M. M. Mikulas, Jr.
AEROTHERMAL LOADS BRANCH
A. R. Wieting
J. L. Pittman
ADVANCED AIRFRAME STRUCTURES
ANALYSIS AND SYNTHESIS METHODS
COMPUTATIONAL STRUCTURAL MECHANICS
SUPER COMPUTER EXPLOITATION
LARGE SPACE STRUCTURES
DESIGN AND CONSTRUCTION METHODS
EXPERIMENTAL AND ANALYTICAL LOADS
FACILITIES AND TEST TECHNIQUES

Figure 2.

II FACILITIES

II FACILITIES

The Structural Mechanics Division has two major facilities to support its research (shown in figure 3).

The Structures and Materials Laboratory equipment includes a 1,200,000 lb. capacity testing machine for tensile and compressive specimens up to 6-feet wide and 18-feet long; lower capacity testing machines of 300,000, 120,000, 100,000 and 10,000 lb. capacity; torsion machine of approximately 60,000 in.-lb. capacity; hydraulic and pneumatic pressurization equipment; and vertical abutment-type backstop for supporting and/or anchoring large structural test specimens.

The Aerothermal Loads Branch operates the 8-Foot High Temperature Tunnel (8'HTT) which is a unique hypersonic Mach 7 blowdown wind tunnel with an 8-ft. diameter test section (uniform temperature test core of 4 feet) that uses products of combustion (methane and air under pressure) as the test medium. The tunnel operates at dynamic pressures of 250 to 1800 psf, temperatures of 2400 to 3600^{o}R and Reynolds numbers of 0.3 to 2.2 x 106/ft. The tunnel is used to test 2-D and 3-D type models to determine aerothermal loads and to evaluate new high temperature structural concepts. A major CoF item is under way to provide Mach 4 and 5 capability and oxygen enrichment for the test medium. This is being done primarily to allow the tunnel to test models that have hypersonic air-breathing propulsion applications.

Other facilities in the Aerothermal Loads Branch include the 7-Inch High Temperature Tunnel (7"HTT) and two Aerothermal Arc Tunnels. The 7"HTT is a nearly 1/12th scale of the 8'HTT with basically the same capabilities as the larger tunnel. It is used primarily as an aid in the design of larger models for the 8'HTT and for aerothermal loads tests on subscale models.

The two Aerothermal Arc Tunnels (20 MW and 5 MW) are used to test models in an environment that simulates the flight reentry envelope for high-speed vehicles such as the Space Shuttle. The amount of usable energy to the test medium in these facilities is 9 MW and 2 MW. The 5 MW is a three-phase AC arc heater while the 20 MW is a DC arc heater. Test conditions such as temperature, flow rate, and enthalpy vary greatly since a variety of nozzles and throats are available and model sizes are different (3-in. diameter to 1-ft. x 2-ft. panels).

The Automated Assembly Facility (also shown in figure 3) is composed of a robot arm, a planar X-Y motion base platform, and a rotating motion base. The facility hardware was designed as a ground based system to permit initial evaluation of in-space assembly concepts. The facility also has an integrated video subsystem to permit the operator to view, at close range, the operations of the robot and end-effector.

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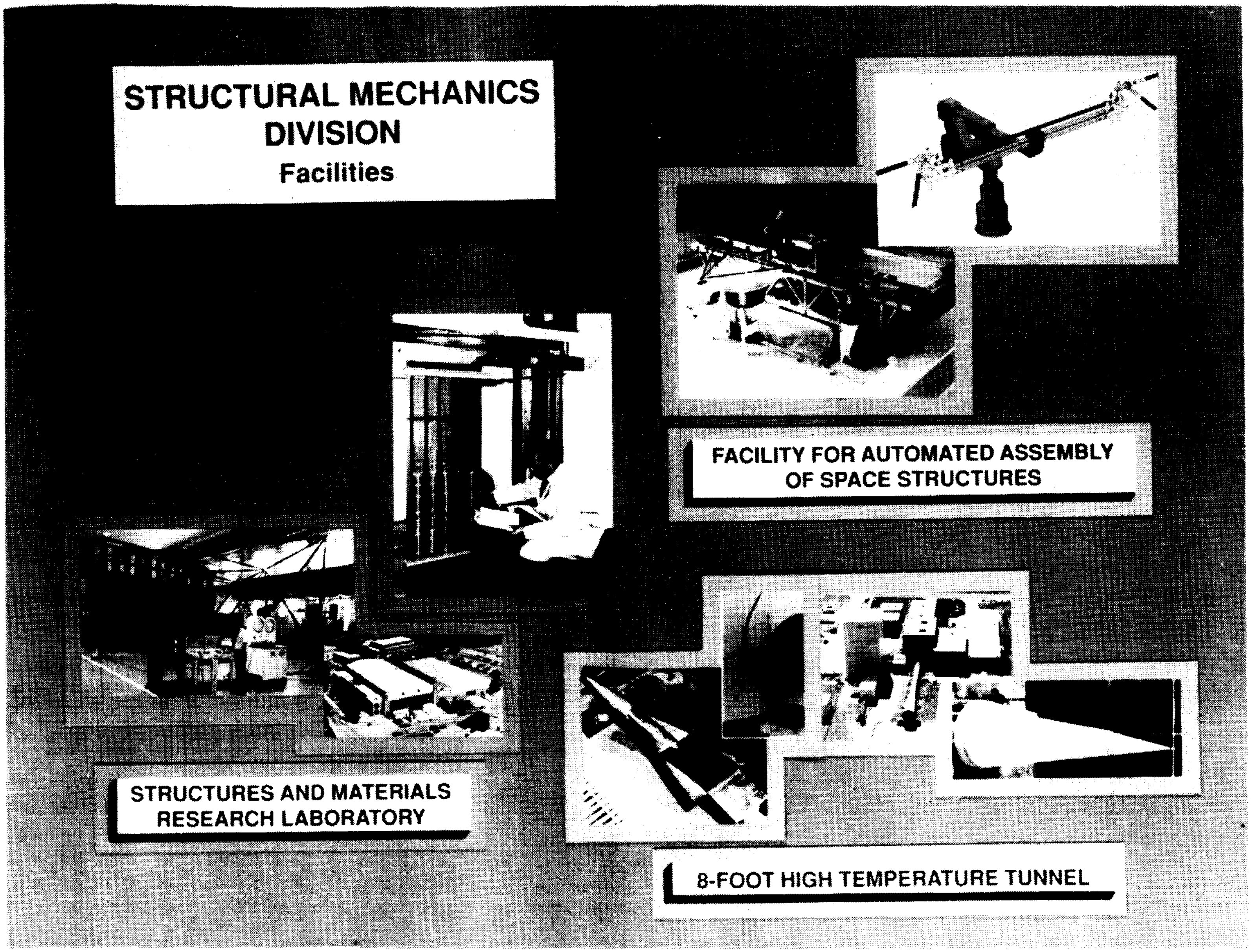
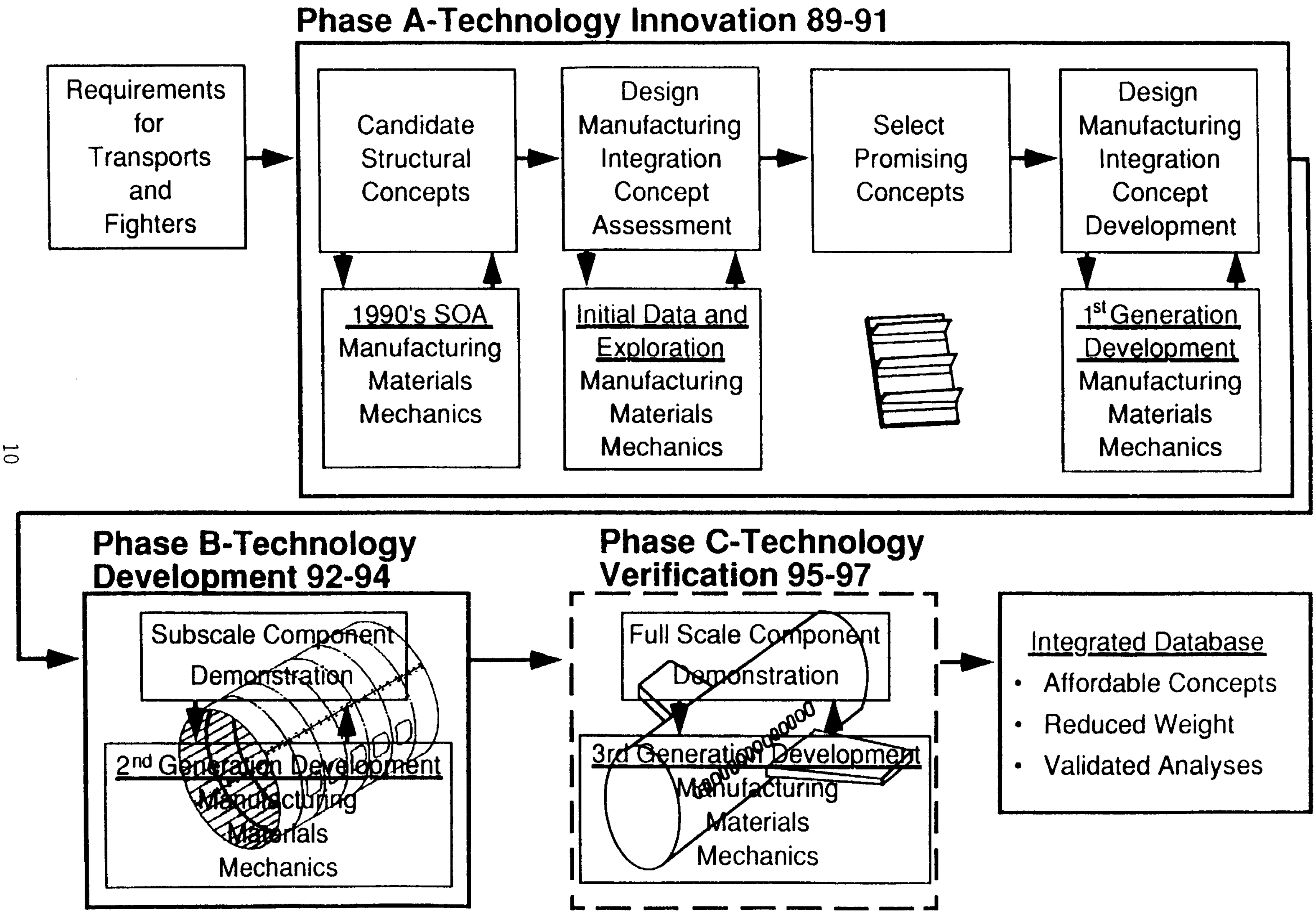


Figure 3.

III STRUCTURES TECHNOLOGY PROGRAM OFFICE

ACT Program Logic Chart



III STRUCTURES TECHNOLOGY PROGRAM OFFICE

This Office provides programmatic leadership and management support for focused structures technology development within the Structures Directorate for advanced composite airframes for transport and military aircraft and future focused technology programs in aeronautics and space. Serves as the focal point for technical and programmatic interchanges on focused technology activities with research organizations within NASA, other government agencies, and industry.

RTR 510-02-11-02/510-02-21-02/510-02-31-01 Advanced Composite Structures Technology Program

OBJECTIVE:

To develop an integrated technology data base that provides impetus for cost effective use of advanced composite materials in the primary structures of future aircraft.

FY 1990 PLANS:

- Hold Cost Prediction and Reporting Workshops
- Focus BCA and LASC on most promising cost effective concepts
- Hold Design/Manufacturing Integration Workshop
- Hold Common Structural Components for Cost and Weight Comparison Workshop
- Develop First Technical Executive Summary Report
- Appoint ACT Program Steering Committee
- Conduct Program Review
- Hold NASA/DOD Innovative Manufacturing Research Workshop
- Hold First Technical Conference

APPROACH:

Phase I - Technology Innovation - The first phase of the ACT program is about 30 months in duration and will promote innovative research in several key areas. Participants in this phase include the aircraft industry, government scientist and engineers, universities with strong composites background and the composite materials industry.

Early emphasis will be on development of advanced material systems that offer opportunities for improved toughness and lower cost. Opportunities for advancements in areas of toughened thermosets, thermoplastic/thermoset hybrids, new pregpregging concepts such as powder-coated tow, and resin-fiber interphase properties will be examined in depth. These studies will be conducted in parallel with research to provide a scientific basis for the understanding and prediction of laminate failures, damage propagation and residual strength. Analytical developments that accurately predict postbuckling behavior, structural stability in the presence of eccentric loadings, and the influence of impact damage on pressurized structure and stochastic models for life prediction will be pursued with emphasis on utilization in the integrated design/manufacturing process.

A second emphasis in Phase I that has high promise for affordable technology is in the areas of innovative fabrication methods and unique material forms. Current studies with woven preforms, knitted fabric, stitching, and comingled fiber/matrix interweaves show significant improvements in damage tolerance as well as potential for reduced fabrication cost. Significant attention will be given to techniques for low cost fabrication such as advanced fiber placement, thermoforming, and resin transfer molding.

A third emphasis in Phase I is innovative structural concepts that effectively use the advantages of composites in airframe structural configurations. Attention will be given to structural mechanics methodology necessary to understand and predict accurately the response to failure of these innovative structural concepts.

All of the material forms, fabrication processes and methods, and structural concepts will be properly characterized by standard tests at the laminate, element and subcomponent levels. Analyses of these test data will provide the rationale for selection of materials, fabrication methods and structural concepts that merit further development in Phase II.

Phase II - Technology Development - This phase of the ACT program is expected to require approximately 30 months and will concentrate on the development and analysis of a component level test matrix of sufficient magnitude to serve as a basis for an integrated technology data base. An integrated technology data base is essential for design, fabrication and certification of advanced composites in future aircraft.

Tests at the component level representative of aircraft substructure (frames, panels, shells) and structural elements (joints, cutouts, local details, clips) will provide initial data required to assess advances in weight and cost effectiveness in areas of materials, material forms, fabrication methods and innovative structural concepts. These test data also will permit initial benchmark assessment of analytical tools used in design, performance, and structural life predictions.

A major emphasis in Phase II is the integration of design and fabrication disciplines. Within the airframe contracts design and fabrication teams will work to develop cost-effective composite structures through the definition of new efficient structural arrangements, shapes, elements and components that are amenable to lowcost fabrication. The component test program will address most substructure elements of both heavily-loaded wings and fuselages for transport aircraft and mission driven aircraft. In each area test data will be used to conduct trade-off asessments of fabrication cost against vehicle performance.

MILESTONES:

Materials and Processes

- Demonstrate 6-axis fiber placement methodology (Hercules), October 1989
- Complete fatigue characterization of woven laminates (RI), February 1990
- Demonstrate rubber-toughened 350^{o}F resin system, May 1990
- Develop powdered tow preg suitable for weaving (BASF), July 1990
- Complete single and multifilament interphase tests (Utah (B)), August 1990

Structural Mechanics

- Validate 3-D model to characterize impact damage of thermoset laminates (Stanford), October 1989
- Complete theoretical development for wing aeroelastic tailoring (Cal-Davis), July 1990
- Complete experiment/analysis correlation of ordered staple material, (Delaware) August 1990

Structural Concepts Verification

- Complete design of isogrid fuselage concept for FPT demonstration (LASC), October 1989
- Select concepts for Thermo-X fabrication demonstration (Sikorsky), October 1989
- Complete Thermo-X concept evaluation tests (Sikorsky), January 1990
- Complete ranking of innovative wing concepts (LASC), April 1990
- Complete tests of innovative spar designs using textile preforms (GAC), May 1990
- Complete wing subcomponent tests to demonstrate resin transfer molding technology (DAC), June 1990
- Demonstrate advanced material placement and flexible automation for low cost assembly (BCA), August 1990

Technology Transfer

- Technology review at 8th DOD/NASA/FAA Conference, December 1989
- 1st NASA/Industry mini-workshop, December 1989
- 2nd NASA/Industry Mini-workshop, March 1990
- Conduct first ACT program review and conference, September 1990

FY 1989 ACCOMPLISHMENTS:

Management

- Program Plan approved
- Developed MICS report

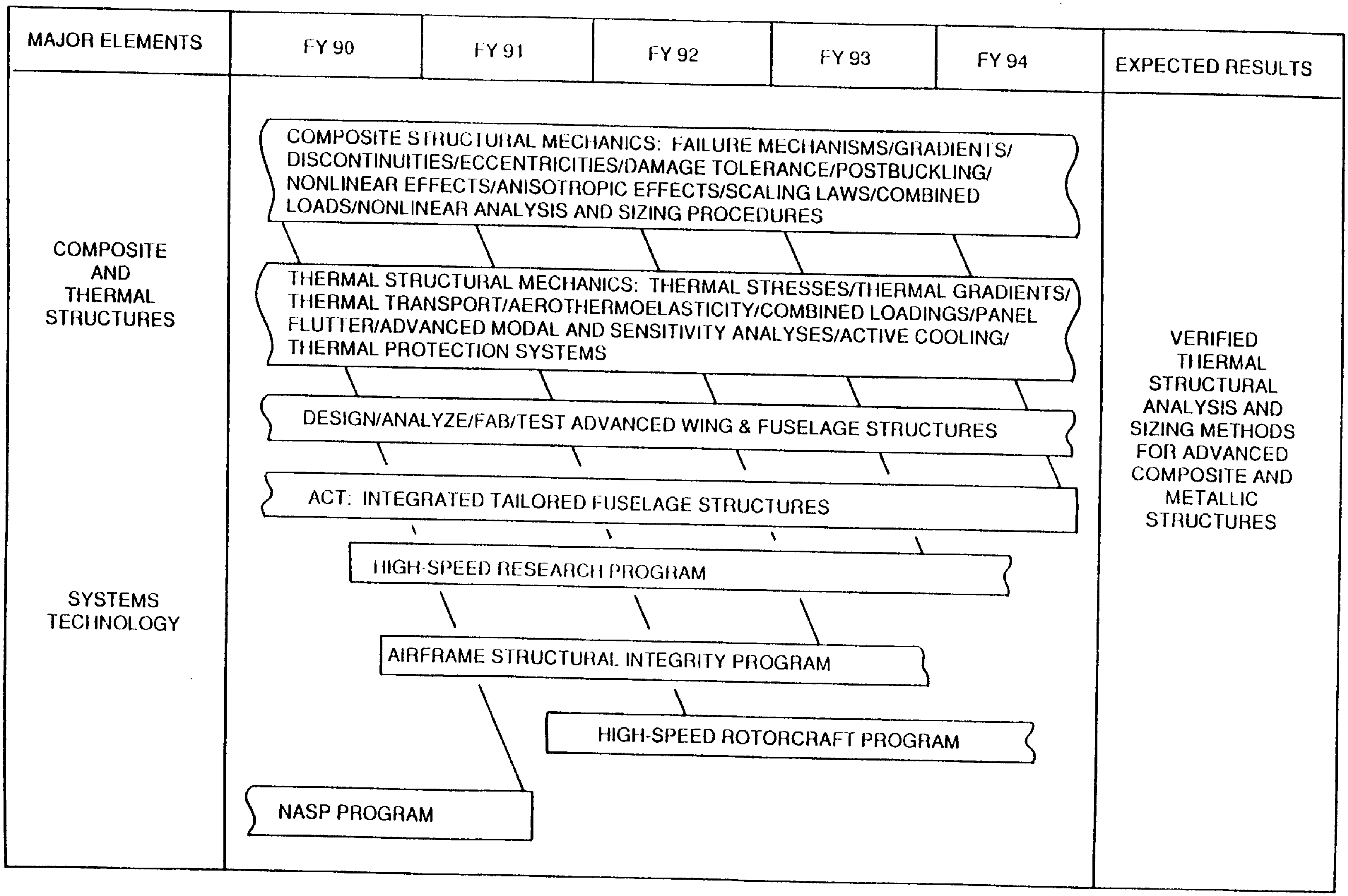
- Awarded NRA Contracts to Boeing, Lockheed, McDAC, Northrop, Grumman, Sikorsky, Dow, Hercules, BASF, Rockwell, U. of Utah (B), U. of Utah (N), U. of Delaware, Stanford U. and U. of California (Davis)
- Held 1st Industry Review/Integration Workshop
- Executive Summary approved
- Structural materials manufacturing initiative coordinated with Air Force

Technical

- Verified quality of automated tow placement fabricated laminates
- Demonstrated scale-up of Resin Transfer Molding process
- Evaluated fatigue response of stitched RTM specimens
- Identified candidate structural concepts

IV AIRCRAFT STRUCTURES BRANCH

AIRCRAFT STRUCTURES BRANCH



IV AIRCRAFT STRUCTURES BRANCH

This Branch conducts analytical and experimental research on the response of complex structures subject to static and dynamic loads. Explores basic behavior, develops advanced methods of analysis and design, and confirms validity of analysis by conducting tests of elements and large-scale structural models at room temperature and at high and low temperatures, as required. Develops efficient structural concepts for future low-speed and high-speed aircraft that exploit the benefits of advanced composite and metallic materials.

Typical investigations include primary airframe structural behavior and concepts, stability, strength, damage tolerance, tailoring of structures made of composite materials, thermal protection systems, reusable cryogenic tanks, cooled structural concepts, and thermal effects on structural behavior. Special emphasis is focused on identification of structural deformations and failure modes, development of structurally-efficient composite and metallic structural concepts, and prediction of nonlinear and linear response phenomena due to mechanical, pressure and thermal loads.

Conceives new static and dynamic test techniques and uses the Structures and Materials Research Laboratory, the Thermal Structures Laboratory (in progress), and various high temperature and cryogenic facilities.

RTR 505-63-01-08 Mechanics of Composite Structures

OBJECTIVE:

To develop structural mechanics technology required for verified design of structurally-efficient, damage-tolerant advanced-composite airframe structural components and to formulate advanced analysis methods to predict static and dynamic nonlinear response and ultimate strength of composite structures.

FY 1990 PLANS:

- Study effects of curvature on modal interaction for nonlinear structures
- Study bending boundary layer attenuation on composite panels

APPROACH:

In FY 1990 emphasis is on anisotropic plate and shell analyses, modal interaction for nonlinear structural analysis, and thermal effects on composite structures. Structural mechanics issues of advanced concepts for composite structural components will be studied analytically and experimentally. Mechanical, pressure and thermal loads representative of wing and fuselage components will be considered. Methods will be developed for predicting strength, stiffness, buckling and postbuckling behavior of composite components including those with local gradients, discontinuities, eccentricities and damage. Procedures will be developed that predict large deformations and 3-D stresses in flat and curved composite panels. Failure mechanisms will be identified and analytical models for predicting failure will be developed and compared with failure criteria.

MILESTONES:

- Initiate development of VICON.OPT for optimizing stiffened panels and cylinders including material constraints and effects of bending produced by pressure and imperfections, October 1989
- Initiate study of buckling behavior of shear-loaded specially orthotropic plates with cutouts, October 1989
- Conduct study of bending boundary layer attenuation lengths for anisotropic composite shells, January 1990
- Conduct study of curvilinear fiber placement on the buckling resistance of plates with cutouts, April 1990
- Conduct study of nonlinear materials and viscoelastic effects on compression-loaded composites with discontinuities, June 1990
- Conduct analysis of the buckling behavior of composite plates subjected to non-uniform thermal environments, June 1990
- Complete study of higher-order transverse shear deformation theories for the postbuckling of long, thick, orthotropic plates with initial imperfections and subjected to compression loading, September 1990

FY 1989 ACCOMPLISHMENTS:

- Completed equivalence transformation for nonlinear shell problems with multiple modes and operational in STAGS
- Developed VICON analysis for curved composite panels with transverse stiffeners
- Identified effects of stacking sequence on inplane gradient attenuation for flat composite plates
- Initiated study of curvilinear fiber placement for composite plates with cutouts and described effects of curvilinear fiber placement on composite plate tensile strength
- Extended to cylindrical shells recontinuization method for error analysis and submitted to COSMIC computer program for error analysis

RTR 505-63-01-09 Advanced Composite Structural Technology/Concepts

OBJECTIVE:

To develop verified composite structural mechanics and design technologies, and structural concepts needed to realize the improved performance, structural efficiency, and cost-effective advantages offered by new materials systems and fabrication procedures for advanced-composite airframe primary structural components.

FY 1990 PLANS:

- Evaluate stiffened thermoplastic compression and shear panel concepts
- Verify eccentricity effects caused by stiffener runout in composite compression panels

APPROACH:

In FY 1990 emphasis is on evaluating structurally-tailored wing-box subcomponent design concepts and thermoplastic panel concepts. Advanced structural mechanics, design technology, and concepts for primary structures applications will be developed and evaluated for structural efficiency, damage tolerance and improved performance. The effects of design constraints, such as those imposed by aeroelastic tailoring and laminar flow requirements, will be included in the design of new structural concepts for aircraft components. Mechanical, pressure, and thermal loads representative of wing and fuselage structural components will be considered. Structural mechanics issues peculiar to these new design concepts will be studied and selected concepts will be evaluated experimentally.

MILESTONES:

- Initiate studies of skewed stiffener orientations for tailoring composite compression panels, October 1989
- Initiate studies of advanced composite fuselage concepts for primary aircraft structures, November 1989
- Complete study of interlaminar stress distributions for unsymmetric laminates subjected to thermal or mechanical loadings, December 1989
- Complete development of POSTOP II postbuckled panel design optimization code that accounts for nonlinear torsional-flexural stiffener behavior, January 1990
- Complete evaluation of hat- and blade-stiffened graphite-thermoplastic compression panel specimens, January 1990
- Conduct evaluation of the effects of crossovers for filament-wound panels with cutouts, with impact damage, or loaded into the postbuckling range, April 1990
- Conduct experiments for composite laminates with cutouts and subjected to cylindrical bending to validate analysis and observe failure modes, April 1990
- Conduct detailed study of effects of finite-length on rib structural efficiency, rib-cover joint stiffness requirement, and nonlinear effects due to pressure loading, June 1990
- Evaluate performance of NACA-Y stiffened crippling and compression panel specimens, June 1990
- Conduct design studies of aft-swept, high-aspect-ratio, aeroelastically tailored transport wings including comparison to metal designs, July 1990
- Conduct analyses and optimization studies of structures using sandwich construction, including the effects of impact damage, September 1990

FY 1989 ACCOMPLISHMENTS:

- Developed closed form solution for determining stresses in anisotropic plates with cutouts and subjected to bending/twisting moments
- Completed study of TEM hat-stiffened panels and results show TEM structures 20-40 percent more structurally efficient than similar aluminum structures

- Completed experimental program for determining the effects of impact damage and cutouts on the response of graphite-epoxy shear web

- Demonstrated that Protection and Detection System (PADS) and interleaving is effective without significant (large) weight increases

- Designed forward-swept graphite-epoxy wing box with aspect ratio of 12. Studies indicated that a four-spar wing box may be more structurally efficient than the conventional two-spar wing box

- Initiated cooperative program with NASA-MSFC to study the effects of impact damage and cutouts on the response of filament-wound composite shell structures

RTR 510-02-21-01 Advanced Composite Structures Technology Augmentation

OBJECTIVE:

To exploit the benefits of advanced composites for transcentury aircraft primary structural applications by providing the enabling structures technology and the necessary scientific basis for verified innovative structurally-efficient, cost-effective structural concepts..

FY 1990 PLANS:

- Conduct preliminary design and optimization studies for innovative composite structures

- Conduct HSR and composite airframe structural analysis studies

- Initiate design of combined load testing capability for large airframe structures

APPROACH:

In FY 1990 emphasis will be on development of innovative wing and fuselage subcomponent concepts and related structural mechanics technology. Innovative structural concepts that exploit the benefits of advanced composites and lend themselves to cost-effective fabrication procedures will be developed and verified experimentally for future primary structures application. Structural mechanics technologies will be developed including analysis, design and test methodologies for structurally-tailored and structurally-efficient wing and fuselage components and subcomponents with local gradients, discontinuities and complex mechanical and aerodynamic loadings.

MILESTONES:

- Initiate design of combined load testing capability for composite wing and fuselage structures, October 1989

- Initiate design of advanced fuselage frame and tailored shell-wall concepts, January 1990

- Conduct parametric studies for efficient designs of geodesic-stiffened compression panels for Hercules to fabricate under their ACT contract, April 1990

- Award advanced structural concepts and structural mechanics contracts and grants for new innovative primary composite structures for transcentury aircraft concepts, July 1990

- Evaluate performance of geodesic-stiffened spar web, August 1990

- Evaluate performance of unstiffened graphite-thermoplastic shear webs with circular cutouts and bead-stiffened graphite-thermoplastic shear webs, August 1990

FY 1989 ACCOMPLISHMENTS:

- Developed analysis/optimization procedure for geodesic-stiffened spar web design concepts

- Initiated studies for filament-wound shell concepts and for analysis of fuselage pressurization

- Four contracts awarded (U. California-Davis, U. Delaware, Northrop, Lockheed) from NRA-87-LaRC-2 proposals (also cited under Structures Technology Program Office accomplishments)

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RTR 505-63-31-03 Engine/Airframe Structural Concepts

OBJECTIVE:

To develop and validate, through analysis and test, efficient structural concepts and thermal management techniques critical to the design of hypersonic vehicle engine and airframe structures.

FY 1990 PLANS:

- Complete fabrication of flightweight strut

APPROACH:

In FY 1990 emphasis is on development of design-oriented and application-oriented analysis tools and the fabrication of the flightweight fuel-injection strut. Fabricate in-house a full-size, flightweight strut for a scramjet engine concept. Wind-tunnel test the strut in-house under actual combustion conditions. Fabricate and test in-house a similar copper strut for measuring the thermal and pressure load environment in the tunnel. Define insulation requirements for engine/airframe structures with emphasis on cryogenic fuel tank structures.

MILESTONES:

- Complete fabrication of flightweight strut, June 1990

- Complete testing of stainless steel strut, September 1990

- Incorporate in CSM Testbed the advanced transient structural analysis method, September 1990

- Complete CFD solution for oscillating coolant heat exchanger, September 1990

FY 1989 ACCOMPLISHMENTS:

- Fabricated and delivered to NIST for testing a 3-in. x 8-in. pin-finned heat exchanger test article
- Completed liquid-metal forced-convection CFD analysis
- Completed thermal parametric study and optimization of carbon-carbon/heat-pipe wing leading edge

RTR 506-43-31-04 Thermal Structures for STS

OBJECTIVE:

To develop and validate, through analysis and test, efficient structural concepts and thermal management techniques critical to the design of future space transportation systems (STS).

FY 1990 PLANS:

- Complete thermoplastic tests on curved TPS concept

APPROACH:

In FY 1990 the primary emphasis will be on the completion of curved metallic TPS tests. Studies of attractive structural concepts will be performed and validated via tests. Support in-house studies to identify critical structural material research requirements. Effort will be focused on improved thermal analysis methods and test techniques with combined thermal-mechanical loads.

MILESTONES:

- Complete thermoelastic tests of curved metallic TPS (thermal protection system) concepts, December 1989
- Demonstrate improved transfinite element-thermostructural analysis, December 1989
- Complete gap heating TPS analysis, June 1990

FY 1989 ACCOMPLISHMENTS:

- Completed new, improved version of vu-factor computation code (VU-II), and sent to COSMIC PC and mainframe versions
- Completed 1-D and 2-D transfinite element code and delivered VAX version
- Completed study on thermal effects of flutter in the postbuckled region using 1-D beam finite elements
- Completed elementary heat-soak tests of curved TPS

RTR 506-43-71-04 Design and Analysis Methodology

OBJECTIVE:

To develop efficient design-oriented thermostructural analysis methods suitable for application to hypersonic vehicle airframe and engine structures.

FY 1990 PLANS:

- Complete development of 3D, flux-based thermal finite element

APPROACH:

In FY 1990 emphasis will be on thermoealstic global buckling and coordinating with LeRC on research to be done on component life cycle predictions. Systematically refine analytical models of hypersonic vehicle structural components and determine the level of model detail necessary to predict thermostructural behavior.

MILESTONES:

- Complete development of Taylor-Galerkin nodeless variable finite elements for transient thermal analysis, April 1990
- Initiate component life cycle predictions research, July 1990
- Determine level of FEM modeling required to predict thermal/mechanical global buckling, July 1990
- Complete tests at DFRF on thermoelastic performance of curved TPS, September 1990

FY 1989 ACCOMPLISHMENTS:

- FY 1990 new start

RTR 506-43-71-05 Combined Thermo/Mechanical Test Methodology

OBJECTIVE:

To develop methods and procedures to perform multiaxial thermo/mechanical testing of hypersonic vehicle components at the airframe panel level (size).

FY 1990 PLANS:

- Develop with Dryden Flight Research Facility test plans for Boeing tank

APPROACH:

In FY 1990 the primary emphasis is on design and analysis of a biaxial panel test apparatus. In-house analytical and experimental studies to identify viable thermomechanical testing methods and procedures will be supported.

MILESTONES:

- Complete preliminary and analysis of biaxial panel test apparatus, February 1990
- Design, fabricate and test photoelastic model of panel test apparatus, August 1990
- Complete final design of biaxial panel test apparatus, September 1990

FY 1989 ACCOMPLISHMENTS:

- FY 1990 new start

RTR 506-49-11-05 Thermostructural Concepts for Planetary EntryVehicles

OBJECTIVE:

To develop and validate, through analysis and test, efficient structural concepts and thermal management techniques critical to the design of future planetary entry vehicles.

FY 1990 PLANS:

- Complete equivalent plate frame analyses development

APPROACH:

In FY 1990 emphasis is on implementation of the equivalent shell formulation. In-house studies to identify critical structures and materials technologies will be supported. Studies of attractive thermostructural concepts will be performed.

MILESTONES:

- Complete implementation of equivalent shell formulation, June 1990
- Implement arbitrary frame shapes capability into "SMART," June 1990
- Complete first version of "SMART" vehicle systems analysis, September 1990

FY 1989 ACCOMPLISHMENTS:

- Extended equivalent plate methodology to equivalent frame for non-axisymmetric cross sections
- Completed formulation of equivalent shell for non-axisymmetric fuselage cross sections

RTR 763-01-41-21 4.3.1 Airframe Leading Edges

OBJECTIVE:

To develop innovative wing heat-pipe-cooled leading edge concepts for NASP-type vehicles which offer substantial benefits such as reduced mass or increased reliability over other cooled design concepts.

FY 1990 PLANS:

- Complete design of carbon-carbon refractory metal heat pipe
- Initiate startup tests of McDonnell Douglas & Corp. (MDC) heat pipe

APPROACH:

In FY 1990 the main emphasis is on the fabrication of a 6-ft. liquid metal heat pipe at Los Alamos. A carbon-carbon/refractory metal heat-pipe leading edge will be designed, fabricated, and tested. Analytical startup predictions will be verified by testing a 6-ft. liquid metal heat pipe designed for Shuttle II by MDC.

MILESTONES:

- Complete thermostructural analysis of carbon-carbon/refractory metal heat pipe leading edge, September 1990

- Fabricate 6-ft. liquid metal heat pipe at Los Alamos National Labs, September 1990

FY 1989 ACCOMPLISHMENTS:

- Established thermal feasibility of a carbon-carbon/refractory metal internally radiation cooled heat pipe
- Initiated thermostructure design/analysis of a carbon-carbon/refractory metal heat pipe
- Completed heat pipe startup prediction computer program

RTR 763-01-41-24 4.4.2 Actively Cooled Panels

OBJECTIVE:

To conduct structural and thermal analysis on candidate actively cooled concepts using material properties for advanced material systems and to conduct tests on selected surface heat exchanger structural concepts.

FY 1990 PLANS:

- Develop actively cooled test apparatus (National Institute of Standards and Technology (NIST)); complete initial tests

APPROACH:

In FY 1990 emphasis is on completion of the initial pin-fin heat exchanger testing. After completion of detailed analysis of candidate concepts, an actively cooled panel concept will be selected for testing. Surface heat exchanger specimens will be tested at NIST to determine heat transfer and pressure drop characteristics, and an engine wall configuration will be tested in a hot gas rocket test stand at NASA Lewis Research Center. Fabricate and test flightweight engine strut which includes actively cooled walls.

MILESTONES:

- Complete initial pin-fin heat exchanger testing (NIST), September 1990
- Initiate channel heat exchanger design, September 1990

FY 1989 ACCOMPLISHMENTS:

- Completed construction and calibration of high heat flux, heat transfer apparatus
- Initiated rocket exhaust testing of LaRC impingement cooled leading edge at LeRC

RTR 763-01-41-25 4.6.1 Control Surfaces

OBJECTIVE:

To develop and demonstrate materials, fabrication, joint designs and fastening techniques, design and analysis, testing and nondestructive inspection methods required to construct the least weight movable control surface.

FY 1990 PLANS:

- Fabricate and test carbon-carbon control surface

APPROACH:

In FY 1990 the main emphasis is to complete fabrication of the control surface test component (CSTC). A control surface for NASP vehicle configuration will be selected for the focal point of this effort. Performance requirements will be defined. Preliminary designs will be developed for several candidate concepts and the best concept will be selected. A development and evaluation program will be defined and initiated to develop the required design and fabrication technology. A full-scale segment of the control surface design will be fabricated and tested to verify the adequacy of the concept.

MILESTONES:

- Complete bonding of rib-stiffened control surface shell, January 1990
- Complete fabrication of carbon/carbon fasteners, June 1990
- Complete fabrication of CSTC, July 1990
- Initiate room temperature mechanical tests of CSTC at DFRF, September 1990

FY 1989 ACCOMPLISHMENTS:

- Completed detailed design of CSTC
- Initiated fabrication of CSTC
- Completed layup and initial cure for CSTC and all subcomponents

V COMPUTATIONAL MECHANICS BRANCH

COMPUTATIONAL MECHANICS BRANCH

Major Elements	FY89	FY90	FY91	FY92	FY93	Expected Results
Computational Structural Mechanics	Testbed/high-performance computing architectures/ parallel and vector processing/integrated multiple-method analyses					**Advanced Methods And Validated Codes For Structural Analysis/ Design**
	Advance analytical and computational methods: local-global analysis/ error detection and control/rapid approximate analyses/design methods/ progressive failure analyses/constitutive relations/solution algorithms/ numerical methods					

V COMPUTATIONAL MECHANICS BRANCH

This Branch was established effective April 22, 1990. Conducts analytical research in the development of advanced computational methods for predicting the response of complex aerospace vehicles subject to static and dynamic loads using new and evolving computer hardware and software technology. Developed methods to utilize the physics of structural mechanics and materials behavior. Special emphasis is placed on modeling methods for predicting composite component failure and iintegrity, micro-to-macro response behavior, nonlinear structural response, and integrated thermal, mechanical and dynamics behavior. New equation solvers are developed to enhance computational efficiency of new or existing methods on present and future computer systems using modern software architecture. Developed analytical methods are validated through experiments performed by other organizations and through other analyses.

RTR 505-63-01-10 Computational Structural Mechanics

OBJECTIVE:

To develop advanced structural analysis/design methodology that exploits new and emerging high-performance computers to reduce the design cycle time for new airframe structures or for modification of existing airframes.

FY 1990 PLANS:

- Demonstrate adaptive refinement analysis capability in CSM Testbed
- Develop specifications for multiple-method analysis framework
- Prototype integration of rapid-approximate and finite-element analysis methods
- Perform large-scale structural analysis studies of composite airfract, e.g., assess structural arrangements for high speed research (HSR)

APPROACH:

In FY 1990 emphasis will be on demonstrating automatic error detection and control during large-scale analysis of complex structural components. Advanced static and dynamic structural analysis/sizing methods wil be integrated into a multiple-method analysis capability. Methods development research will include rapid approximate techniques for parametric studies, the development of global/local modeling methodology with error control, and the development of solution techniques that exploit vector/parallel processing on advanced computers. Advanced methods will be assessed by carrying out validation studies on complex aerospace structures.

MILESTONES:

- NASA LaRC, LeRC and Headquarters agree on plan for major CSM workshop involving focus problems, January 1990
- Extend advanced equation solvers to problem sizes exceeding main memory (i.e., out-of-core-solvers), March 1990

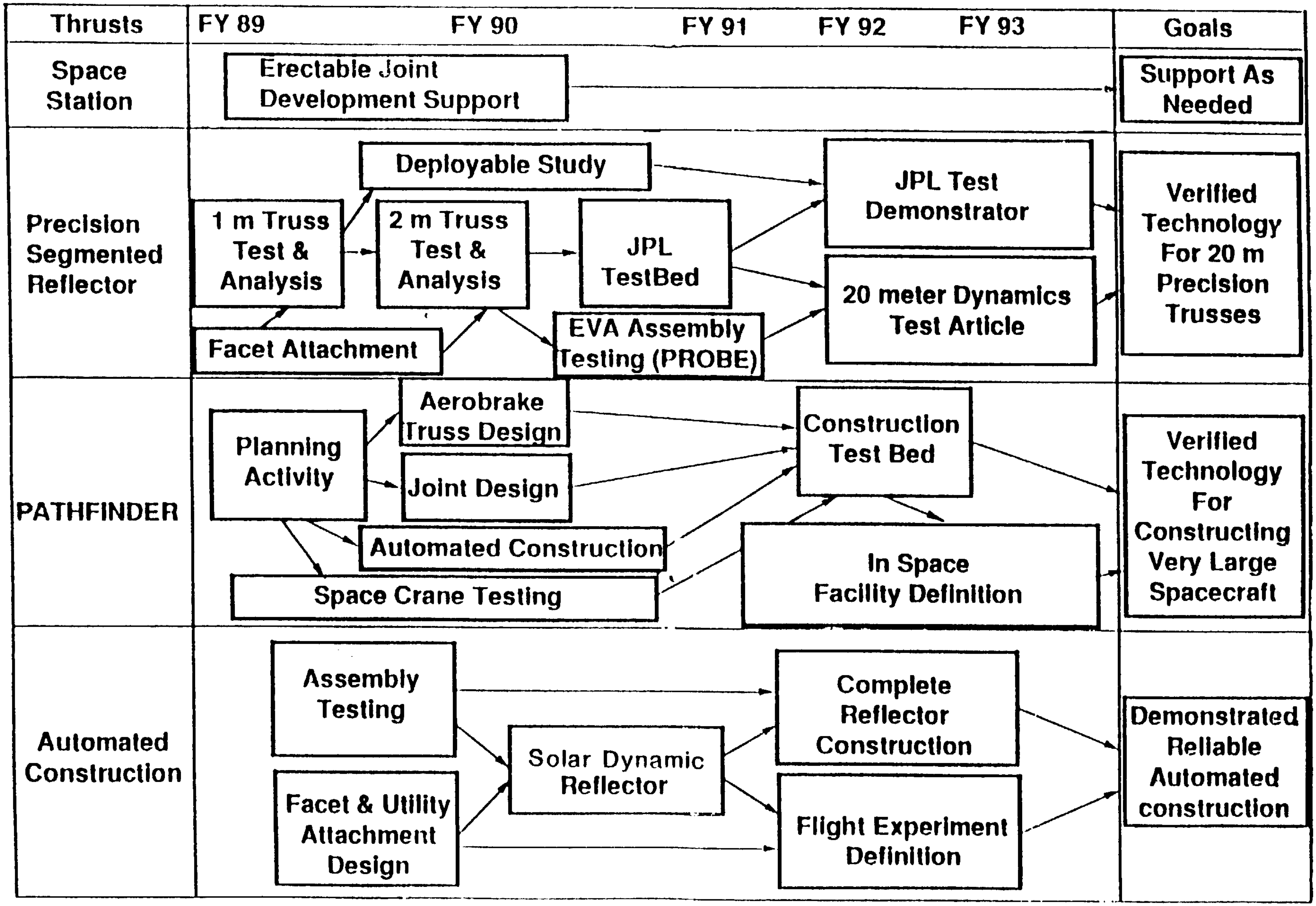
- Hold training workshop for potential CSM Testbed users, and release Testbed to selected participants, March 1990
- Establish preliminary software design for implementing multiple method solution strategy in Testbed, August 1990
- Perform preliminary structural analysis of wing for high-speed civil transport using rapid-approximate analysis and Testbed finite-element model, August 1990
- Demonstrate automatic error detection and control during large-scale analysis of complex structural subcomponent, August 1990

FY 1989 ACCOMPLISHMENTS:

- Developed CSM Program Plan
- Procured powerful parallel/vector computer; fully operational one day after installation
- Error detection method demonstrated on simple problems. Software design document for adaptive refinement procedure delivered by Lockheed
- Nine volumes of Testbed documentation published
- Automated techniques developed and used to assess performance of finite elements.
- State-of-the-art parallel/vector equation solvers demonstrated on Cray 2
- Advanced finite elements (developed in-house, by grantees, and by contractor) installed in Testbed using generic element processor
- Developed and tested ring analysis formulation for rapid-approximate analysis method for fuselage structures; formulation for skin representation being implemented

VI SPACECRAFT STRUCTURES BRANCH

SPACECRAFT STRUCTURES BRANCH



VI SPACECRAFT STRUCTURES BRANCH

This Branch develops technology required to design advanced space structures systems including antennas, space station, aerobrakes, as well as launch vehicles. Research encompasses structural concepts, packaging, deployment, EVA and robotics in-space construction and advanced composite structures. Theoretical work is supported by hardware development and experimental research.

RTR 506-43-41-02 Advanced Space Structural Concepts

OBJECTIVE:

To develop deployable and erectable structural concepts and associated design technology for antenna and reflector structures and for space station.

FY 1990 PLANS:

- Continue definition of Precision Reflector Orbital Build Experiment (PROBE)
- Develop and demonstrate panel attachment for automated construction
- Test and evaluate titanium truss joints for automated construction

APPROACH:

In FY 1990 a major thrust will be to design, fabricate and test a composite erectable joint. A second thrust will be to design, fabricate and robotically install hexagonal panels on the robotics truss. Continued emphasis will be placed on computer-aided analysis and design aids for structures.

MILESTONES:

- Design and fabricate a 1-in.-diameter composite joint, February 1990
- Design and fabricate hexagonal panels for robotics truss, March 1990
- Develop design for a monorail astronaut mover, September 1990

FY 1989 ACCOMPLISHMENTS:

- Completed and assembled robotic truss
- Tested robotic truss for frequencies and surface accuracy
- Developed computer analysis for selective arrangement of truss members to improve surface accuracy
- Defined truss reflector flight experiment and presented to NASA Headquarters Code M
- Completed 0-g mobile transporter tests in NASA MSFC Neutral Buoyancy Simulator (NBS) and documented results
- Modified the NASA JSC mobile transporter simulator which was subsequently used by astronauts for truss assembly trade studies

RTR 590-33-31-01 Precision Reflector Structures

OBJECTIVE:

To develop deployable and erectable structural concepts for precision reflectors.

FY 1990 PLANS:

- Complete testing of 1-meter strut length, 2-ring JPL testbed truss
- Fabricate 2-meter strut length, 3-ring precision segmented reflector (PSR) truss for dynamic testing
- Complete 1-g astronaut construction testing of PSR-type reflector

APPROACH:

In FY 1990 the main focus will be to fabricate and test two 2-meter-long strut truss reflectors. One reflector will be used for dynamics testing and the other will be used for neutral buoyancy construction simulation testing. A second 1-meter-long strut truss reflector will be designed for JPL and fabrication will be initiated. NASTRAN analyses will be correlated with test results.

MILESTONES:

- Complete 2-ring LaRC dynamic test article, February 1990
- Complete design of second generation JPL truss, March 1990
- Complete 2-ring NBS test article, July 1990
- Complete LaRC structural tests, September 1990

FY 1989 ACCOMPLISHMENTS:

- Developed and verified independently geometry of erectable testbed (TB) truss design
- Fully developed NASTRAN model of TB
- Generated geometry of revised (2.4m focal length) TB truss
- Finalized design of erectable truss joint hardware
- Completed NASTRAN analysis of revised TB truss; three variations of model transmitted to JPL
- Shipped selected TB truss components to JPL
- Awarded composite strut manufacture contract
- Completed manufacture and inspection of TB truss node
- Thermal analysis indicates potential truss accuracy improvements through tailoring of individual strut CTE's
- Received composite struts for TB and length setting begun; fabricated truss base support

RTR 591-22-11-01 Requirements for Pathfinder

OBJECTIVE:

To define structural and operational requirements for large future spacecraft.

FY 1990 PLANS:

- Develop In-Space Assembly Data Handbook

APPROACH:

The main emphasis in this area is to develop an "In-Space Assembly Data Handbook." A study will be conducted to (1) collect vehicle and mission descriptions from various NASA sources; (2) define structural and operational requirements for mechanical joints, such as loads, stiffness, component alignment, separation tolerances, and assembly time; and (3) identify existing and emerging mechanical joint technologies which enable on-orbit construction and identify the vehicle locations where mechanical joints may be applied.

MILESTONES:

- First draft of Assembly Data Handbook, May 1990

FY 1989 ACCOMPLISHMENTS:

- Task given to Astro Aerospace Corp. to initiate assembly data handbook
- Interface meeting held with NASA Headquarters Code Z

RTR 591-22-21-01 Construction Concepts

OBJECTIVE:

The two primary focus problems of the Pathfinder In-Space Assembly and Construction Program will be a large reentry spacecraft and a space crane. In this task, construction concepts for the aerobrake support truss, which is part of the focus problem, and the space crane will be developed and validated.

FY 1990 PLANS:

- Fabricate and test 1/5-scale space crane model

APPROACH:

In FY 1990 the major emphasis is to develop and evaluate actuators and structural concepts for large space cranes. A study will be performed also to size the aerobrake support truss. A 2-D space crane mockup will be designed and fabricated to serve as a testbed for evaluating crane actuator and articulating joint concepts. Concepts for telerobotic assembly sequence planning, which can be applied to an aerobrake support truss, will be developed.

MILESTONES:

- Fabricate 1/5-scale crane model, February 1990
- Document aerobrake study, March 1990

FY 1989 ACCOMPLISHMENTS:

- Developed and fabricated full-scale movable joint for crane
- Completed aerobrake sizing study

RTR 591-22-31-01 Joining Methods

OBJECTIVE:

To design heavily-loaded mechanical joint concepts for the aerobrake support truss.

FY 1990 PLANS:

- Fabricate and test heavily-loaded aerobrake joint concept

APPROACH:

In FY 1990 the main emphasis is to identify, design, and fabricate a first generation joint for heavily-loaded space truss structures. Design concepts which meet the aerobrake support truss structural and construction requirements will be identified. The joint concepts will be assessed for ease of assembly, structural efficiency, reliability, and ease of automated assembly. Candidate joints will be selected for fabrication.

MILESTONES:

- Fabricate a first generation heavily-loaded mechanical joint concept, April 1990

FY 1989 ACCOMPLISHMENTS:

- Task given to Boeing to survey existing joints for heavily-loaded applications

RTR 591-22-41-01 Concepts/Technology Validation

OBJECTIVE:

To develop a testbed for evaluating heavily-loaded mechanical joints.

FY 1989 PLANS:

- Conduct trade study on competing aerobrake structural concepts

APPROACH:

In FY 1990 the main emphasis is to design and develop a testbed for evaluating heavily-loaded joints for construction ease. Test methodology will be developed for testing heavily-loaded mechanical joints. The methodology will assure that all joint concepts are compared and assessed on an equal basis.

MILESTONES:

- Define testbed requirements and complete testbed design, December 1989
- Fabricate a testbed, September 1990

FY 1989 ACCOMPLISHMENTS:

- Task given to Sparta/EMA to study active suspension for space crane
- Developed requirements and preliminary design for a joint assembly testbed

VII AEROTHERMAL LOADS BRANCH

AEROTHERMAL LOADS

FIVE YEAR PLAN

DISCLIPINARY THRUSTS	FY 89	FY 90	FY 91	FY 92	FY 93	EXPECTED RESULTS
EXPERIMENTAL	GAPS/WAVY SURFACES/ PROTUBERANCES					DETAILED DESIGN DATA BASE
	COMPRESSION/AXIAL CORNER FLOWS					
	SHOCK-SHOCK/SHOCK BOUNDARY LAYER					
	MASS ADDITION FLOW EFFECTS					VALIDATED CODES
	NASA/INDUSTRY/DOD COOPERATIVE STUDIES					
ANALYTICAL	EULER ALGORITHMS					
	NAVIER-STOKES COMPRESSIBLE FLOW ALGORITHM					
	ADAPTIVE TECHNIQUES					INTEGRATED ANALYSIS CAPABILITY
	INTEGRATED FLUID-THERMAL-STRUCTURAL					
FACILITIES AND TEST TECHNIQUES	OPERATION, MAINTENANCE, AND ENHANCEMENT					EFFICIENT RELIABLE FACILITIES AND TEST TECHNIQUES
	HIGH TEMPERATURE INSTRUMENTATION					
	8' HTT MODIFICATION/AIR BREATHING PROPULSION					

VII AEROTHERMAL LOADS BRANCH

This Branch conducts analytical and experimental research to identify and understand flow phenomena and flow/surface intereaction parameters required to define detailed aerothermal loads for thermal protection system and structural designs for high-speed flight vehicles. Devises and evaluates techniques for testing in high-energy true-temperature wind tunnels. Develops fluid-thermal-structural analysis methods and applies them to support experimental aerothermal loads investigations and to evaluate new structural concepts. Operates the 8-Foot High Temperature Tunnel (8'HTT), the Aerothermal Arc Tunnels (20 and 5 MW), and the 7-Inch High Temperature Tunnel (7"HTT).

The Experimental Facilities and Techniques Section of this Branch directs the operation and maintenance and effects improvements of equipment and operational techniques of the above-named facilities. Improves wind-tunnel technology, test techniques, and instrumentation for experimental determination of aerospace vehicle aerothermal loads, structural performance characteristics, and airbreathing engine performance. The prime purpose of this Section is the continued safe and efficient operation of these highly complex, high energy facilities.

RTR 506-40-21-01 Aerothermal Loads

OBJECTIVE:

To define aerothermal loads for important viscous dominated flows including mass addition cooling, with emphasis on effects of surface roughness and 3-D structural interactions. Develop database and methodology for accurate prediction of aerothermostructural loads required to reduce design margins.

FY 1990 PLANS:

- Validate analysis tools with experimental data for swept shock-on-lip and axial compression corner
- Develop implicit time marching scheme
- Improve triangle adaptive unstructured remeshing scheme for 3-D
- Evaluate higher order elements for CFD (Computational Fluid Dynamics)

APPROACH:

In FY 1990 the major emphasis is the continued improvement and development of finite element fluid-thermal-structural procedures for adaptive h and p methods. Detailed flow field and surface distributions of pressures, temperatures, skin friction, and heat flux in laminar and turbulent flow will be obtained experimentally and analytically for viscous interacting flows attendant to generic configurations such as leading edges, gaps, corners, protuberances, wavy surfaces, and engine inlets. Design, fabricate, and/or test simulated leading edge models, simulated compression surfaces, corners, slot film cooling and transpiration cooled, and other viscous interacting models.

MILESTONES:

- Complete phase change paint corner flow tests in LaRC Mach 6 facility, February 1990
- Document experimental aerothermal results for chine gap heating in NASA TP, March 1990
- Document tests of turbulent boundary layer characterization in the 8-ft High Temperature Tunnel in Master's Thesis by November 1989, and in NASA TP, April 1990

FY 1989 ACCOMPLISHMENTS:

- Initiated development of combined h and p adaptive methods for finite element analysis of aerothermal loads in high-speed flows
- Developed Taylor-Galerkin implicit finite element algorithm for unstructured grids
- Developed a posteriori error indicators for adaptive meshing and hierarchical methods for finite element fluid mechanics
- Developed adaptive remeshing technique that utilizes only structured quads in boundary layer and primarily unstructured quads in the inviscid region. Developed new error indicators to identify the edge of the boundary layer

RTR 506-43-31-03 Integrated Fluid-Thermal-Structural Analysis Methods

OBJECTIVE:

To develop advanced fluid-thermal-structural analysis methods for predicting the coupled nonlinear behavior of aerospace structures under combined fluid, thermal, and mechanical loads.

FY 1990 PLANS:

- Extend adaptive unstructured grid enhancement to thermal and structural analysis
- Evaluate constitutive relationships/algorithms for nonlinear structural behavior

APPROACH:

In FY 1990 the major emphasis is the evaluation of adaptive remeshing procedures for steady state thermal and structural analysis. Analytical developments are focused on improved integrated fluid-thermal-structural analysis capability. Continue development of 2-D and 3-D integrated finite elements and apply to practical space transportation vehicles (Shuttle II, NASP). Initiate/develop, in-house and under grant, finite element analysis capability focused on compressible viscous interactions and unified viscoplastic theory. Principal application focus will be to develop the capability to include surface interaction effects on steady and unsteady viscous flows about complex vehicle components including wing and fin leading edges and body junctions, protuberances, mass addition cooling, and control surfaces. Develop and perform thermal structural component tests to validate numerical methods.

MILESTONES:

- Develop prototype adaptive remeshing technique for steady state heat conduction and thermal stress analysis, May 1990
- Develop and implement non-equilibrium air chemistry model for LARNCESS, June 1990
- Evaluate quadrilateral unstructured/structured remeshing procedure for separated flow, June 1990

FY 1989 ACCOMPLISHMENTS:

- Incorporated LARCNESS fluid algorithm into LIFTS and evaluated on several problems
- Extended LIFTS thermal and structural capability to three dimensions
- Evaluated implementation of viscoplasticity models in finite element codes with adaptive time stepping
- Developed and validated model to account for the effects of temporal and spatial free-stream nonuniformities on stagnation point heating in incompressible flow
- Calibrated entropy variable based finite element algorithm on experimental and analytical shock-shock interaction results
- Developed "linear flux" technique that eliminates need for numerical integration. Evaluation shows improved accuracy and 4.5 time decrease in CPU time to calculate element stiffness matrix

RTR 506-43-31-05 Aerothermal Test Facilities and Test Methods

OBJECTIVE:

To provide test facilities required to support development of aerothermal loads experimental database, advanced thermostructural concepts, and ram/scramjet engines.

FY 1990 PLANS:

- Complete shakedown of transpiration cooled nozzle and oxygen

APPROACH:

In FY 1990 the major thrust is the completion of the shakedown of the 8'HTT to bring the facility back on line for research. Test generic configurations to provide database for thermal structural design and validation of prediction techniques. Test advanced TPS under radiant heating, and under aerothermal conditions in Aerothermal Loads Branch complex to verify thermal structural performance. Maintain high enthalpy facilities in ALB complex required for the determination of critical aerothermal loads for structural design and verification and certification of advanced thermostructural and air-breathing engine concepts.

MILESTONES:

- Improve response time of oxygen sensor control device for 8'HTT, February 1990
- Complete verification of DAS/Host software for Modcomp, March 1990

- Verify, through use, structural integrity of the 8'HTT air transpiration cooled nozzle and predict optimal airflow requirements at Mach 7, May 1990

- Establish uniformity of LOX mixing through nozzle exit flow survey, June 1990

- Establish nozzle exit flow profiles for modified 8'HTT at Mach 7, June 1990

FY 1989 ACCOMPLISHMENTS:

- Completed first phase verification of DAS software for Modcomp

- Completed and verified first phase development of VAX software for data reduction

- Added 7"HTT to new Modcomp DAS/Host system

- Completed NASP/Boeing transpiration cooled leading edge test in 20 MW Aerothermal Arc Tunnel

RTR 506-43-31-06 8-Ft. High Temperature Tunnel Spray Bar

OBJECTIVE:

To develop an improved fuel spray bar for both methane and oxygen operation of the 8'HTT.

FY 1990 PLANS:

- Develop new fuel injector for 8'HTT

APPROACH:

The main thrust for FY 1990 is the development of a new LOX/CH4 fuel spray bar for the 8'HTT. Analytically determine fundamental flow features and experimentally evaluate spray bar concepts in the 7"HTT. Design and fabricate the best concept for the 8'HTT.

MILESTONES:

- Complete evaluation of lifted flame concept, November 1989

- Modify existing fuel spray bar for methane operation during shakedown, January 1990

- Provide correlation between analysis and experiment of lifted flame concept, June 1990

FY 1989 ACCOMPLISHMENTS:

- Awarded contract to fabricate spare platelet stacks for backup air transpiration cooled nozzle

- Completed incorporation of non-modified 8'HTT system controls into new control system

RTR 763-01-41-19 4.7.4 Local Aerothermal Loads

OBJECTIVE:

To define detailed aerothermal loads for important viscous dominated flows including heat transfer, skin friction and pressure with emphasis on effects of surface roughness, 3-D structural interactions, mass addition, and real gas effects. Develop a database for accurate prediction of aerothermostructural loads required to reduce design margins.

FY 1990 PLANS:

- Complete tests in Calspan and Langley tunnels for glancing shock boundary layer interaction, slot-cooled model with shock wave interaction, and axial corner model with impinging shock wave

- Document results for slot-cooled model with shock wave interaction, transpiration cooled leading edge with shock-on-lip, and turbulent boundary layer characterization

- Fabricate and instrument perpendicular fuel injector model, and axial corner flow model

APPROACH:

In FY 1990 major thrusts will be the extension of the 2-D adaptive unstructured remeshing technique to three dimensions, and the completion of the slot film cooling and the transpiration cooled leading edge tests in the Calspan shock tunnels. Detailed flow field and surface distributions of pressure, temperatures, heating rates, and skin friction in laminar and turbulent flow will be obtained experimentally for leading edges, corners, protuberances, mass additional cooling concepts, and engine inlets.

MILESTONES:

- Complete tests in Calspan 48"HST and data reduction for slot film cooling including shock interaction effects, December 1989

- Complete data reduction and documentation of transpiration cooled leading edge shock-on-lip study, March 1990

- Evaluate ENSA algorithm on compression corner flow and shock-on-lip data, June 1990

- Document results from slot film cooling study, June 1990

- Develop finite-element PNS method for unstructured meshes, September 1990

FY 1989 ACCOMPLISHMENTS:

- Completed first phase of experiment and documented experimental results of tests for supersonic film cooling with shock interaction

- Completed test on transpiration cooled leading edge with shock-shock interaction and documented results

VIII ACCOMPLISHMENT HIGHLIGHTS

AIRCRAFT STRUCTURES BRANCH

HIGH-ASPECT-RATIO CONFIGURATION OPTIMIZED FOR AEROELASTICALLY-TAILORED WINGBOX

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Grant NAG1-168

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May 1989
RTOP 505-63-01
Code RM WBS 28-2

Research Objectives: To exploit the unique properties of composite materials by using structural tailoring to enable structurally-efficient, forward-swept, high-aspect-ratio wing designs and to demonstrate an integrated multidisciplinary approach for conducting aircraft structures design.

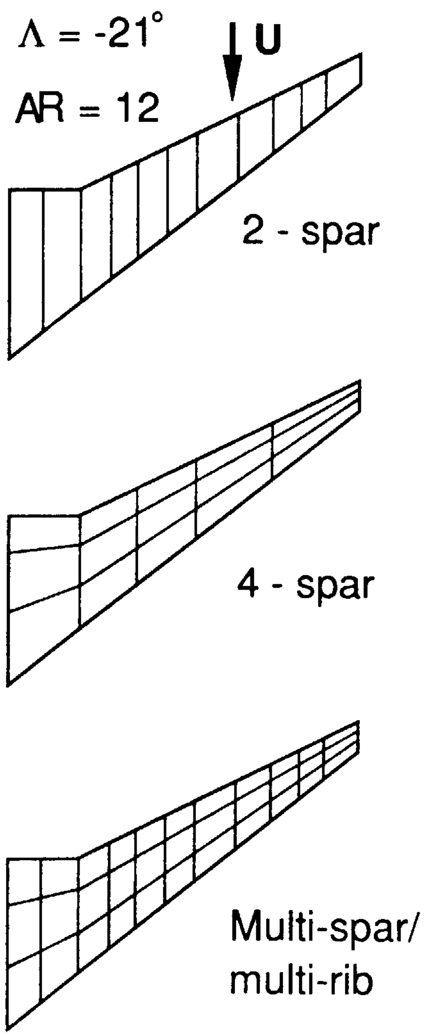
Approach: A high-aspect-ratio, forward-swept wing configuration was selected for study, and three wingbox models with different interior structural configurations were developed. The wingbox models are shown on the left side of the attached figure. An integrated multidisciplinary procedure consisting of an aerodynamic analysis with aeroelastic corrections, a structural analysis, and a structural optimization algorithm was used for this study. Minimum-weight wingbox structures that satisfy the loading conditions and design constraints (see figure) were obtained.

Accomplishment Description: Optimized weights for the 2-spar, 4-spar, and multi-spar/multi-rib wingboxes are shown on the right of the figure. Results are presented for wingboxes modeled with IM7/8551-7 damage-tolerant graphite-epoxy material and for wingboxes modeled with an improved material having stiffness and strength properties that are 20 percent greater than the respective properties for the IM7/8551-7 material. The results show that the conventional 2-spar wingbox is the heaviest of the wingboxes studied. This wingbox satisfies all requirements using thick tailored cover panels. The 4-spar and multi-spar/multi-rib wingboxes are approximately 45 percent and 50 percent lighter, respectively, than the 2-spar wingbox. These wingboxes combine an efficient internal structure with tailored cover panels to achieve feasible lightweight designs. The 4-spar wingbox appears to be the best of the wingboxes studied since it has approximately the same weight as the multi-spar/multi-rib wingbox but is a much simpler design than the multi-spar/multi-rib wingbox.

Significance: Current minimum-weight designs for transport aircraft have 2-spar wingbox metallic structures. The results of this study show that the 4-spar wingbox is significantly lighter than the conventional 2-spar wingbox for this high-aspect-ratio wing configuration and indicate that new, structurally-efficient wing internal structures concepts are possible by exploiting the benefits of composite materials. Wingboxes modeled with the improved material are approximately 20 percent lighter than wingboxes modeled with the IM7/8551-7 material. This difference suggests that emerging and future high-stiffness composite materials will enable desirable new concepts and configurations for aircraft structures.

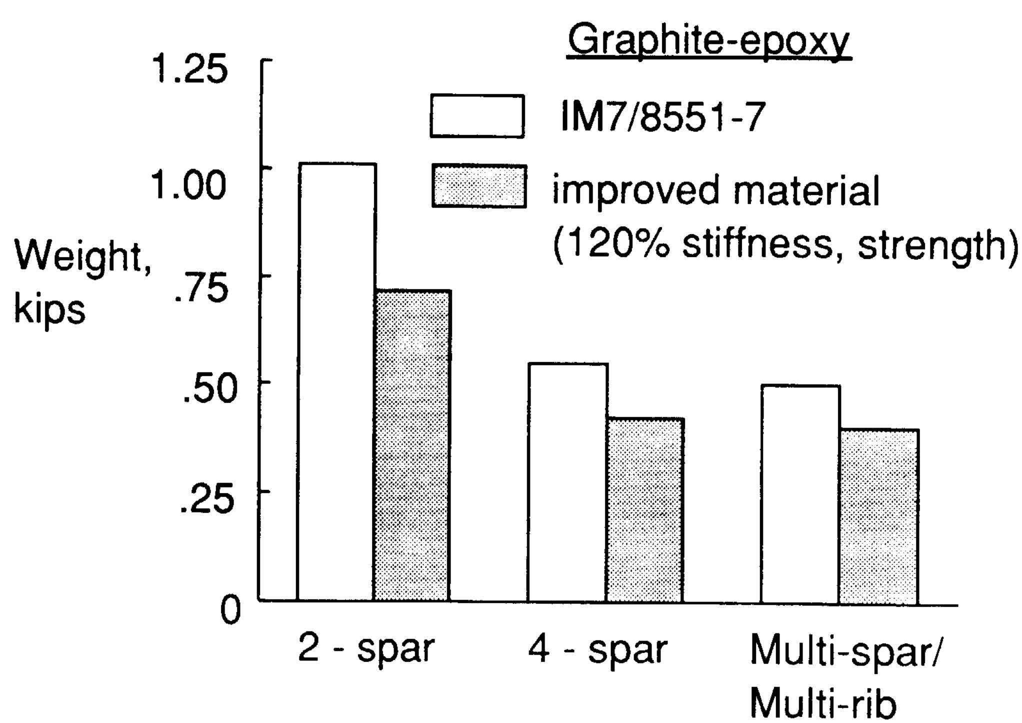
Future Plans: Analyze an aft-swept, high-aspect-ratio wing configuration.

HIGH-ASPECT-RATIO CONFIGURATION OPTIMIZED FOR AEROELASTICALLY-TAILORED WINGBOX



<u>Loading conditions</u>
2.5 G maneuver
gust up

<u>Design constraints</u>
maximum strain
minimum gage
tip twist $\leq 0^{\circ}$



STIFFENED CARBON-CARBON COMPRESSION PANELS FABRICATED, TESTED, AND ANALYZED

James Wayne Sawyer
Thermal Structures Branch
Ext. 45432 June 1989
RTOP 506-80-31
Code RS, WBS 60-1

Research Objective: To develop the technology required to design, fabricate and predict the performance of lightweight stiffened carbon-carbon compression panels for National Aero-Space Plane applications.

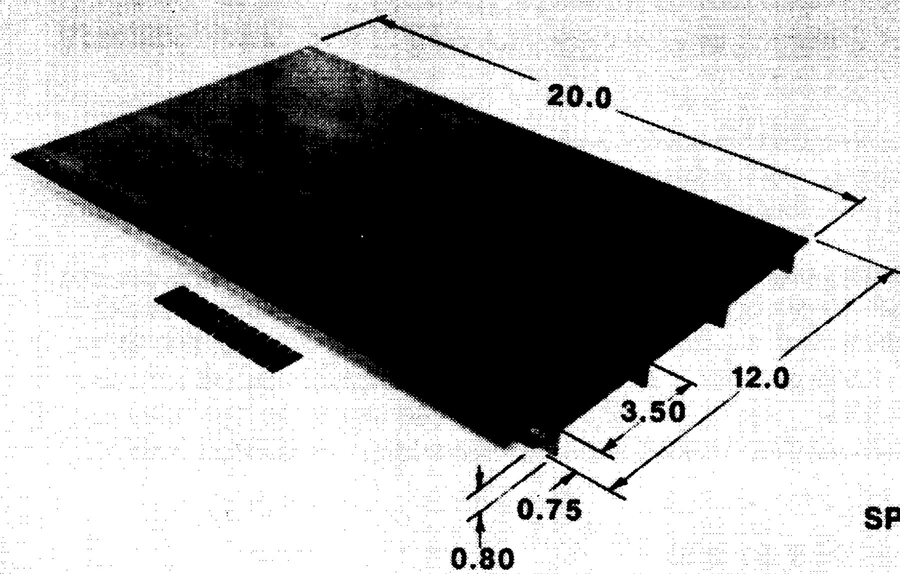
Approach: Typical carbon-carbon compression panels were designed, fabricate, analyzed, and tested. Optimum lightweight compression panel designs were determined and a panel design was selected to fabricate, test and analyze. Experimental and analytical results were compared. The results demonstrated the design, fabrication, and structural capability of stiffened carbon-carbon panels under compression loading and determined the dominant failure mode.

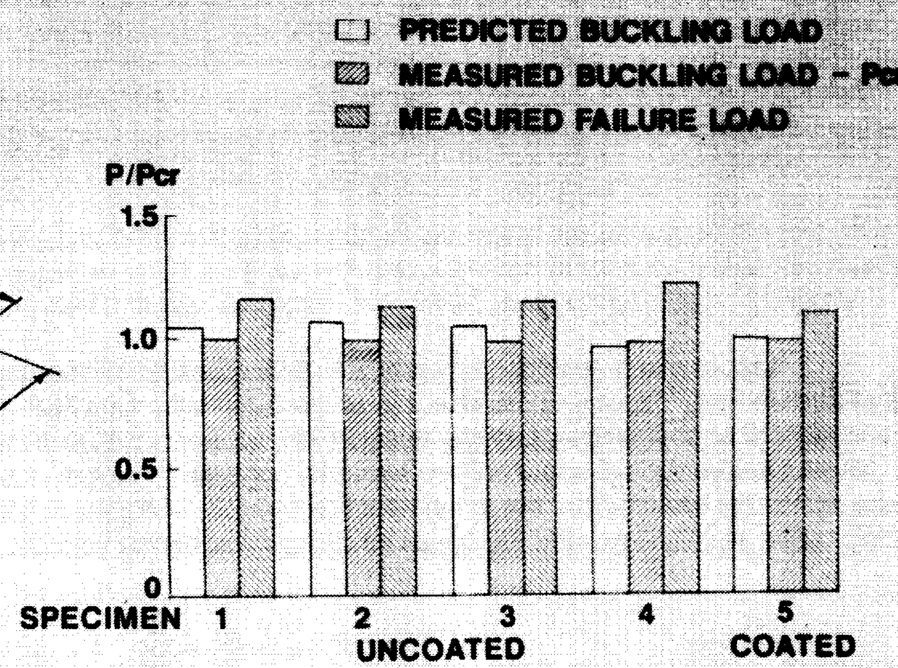
Accomplishment Description: Five coated and uncoated carbon-carbon blade-stiffened compression panels were designed, fabricated, tested, and analyzed. A typical uncoated panel is shown in the figure. Fabrication trials and experimental results showed that carbon-carbon panels with integral stiffeners can be successfully fabricated using 6 plys of woven fabric in a two-dimensional 0/90 degree cross-ply layup configuration. Experimental and analytical buckling results normalized by the measured buckling load are shown on the graph for both coated and uncoated panels. Experimental results show that local skin buckling does not cause panel collapse and that ultimate failure occurs at loads 10 to 20 percent above the buckling load. Separation of the stiffeners from the panel skin was not a problem even though the two-dimensional carbon-carbon material has low interlaminar strength properties and was anticipated to produce a relatively weak attachment of the stiffener to the skin. Comparison of the experimental and analytical results shown on the graph for the panels indicates that conventional finite element analysis procedures adequately predict the onset of skin buckling for both coated and uncoated blade-stiffened compression panels.

Significance: The demonstrated capability to design, fabricate, and predict the performance of carbon-carbon stiffened compression panels provides confidence for use of carbon-carbon materials in advanced structural components. Carbon-carbon structures technology may provide part of the enabling technology needed for advanced high-temperature aircraft and spacecraft.

Future Plans: A full scale segment of a elevon control surface for the NASP is being designed, fabricated and tested to further develop the technology required to apply carbon-carbon materials to advanced structures.

STIFFENED CARBON-CARBON COMPRESSION PANELS FABRICATED, TESTED, AND ANALYZED





DEVELOPMENT OF ADVANCED MODAL METHOD FOR TRANSIENT STRUCTURAL ANALYSIS
(FORCE DERIVATIVE METHOD)

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Ext. 45185
September 1989
RTOP 506-80-31 Code RM /WBS 60-2

Research Objective: Calculating the transient response of complex aerospace structures which are approximated by large, discrete finite element models can be computationally expensive. Popular methods for reducing the size of the problem are the modal methods which use the natural vibration modes as a set of reduced basis vectors. Two such methods are the mode-displacement method (MDM) and the mode-acceleration method (MAM). For structural problems which have closely-spaced frequencies (e.g. large-area truss-like space structures), convergence of the solution is typically very slow using either of these two methods. The purpose of the present study was to develop an improved modal method which would converge to an accurate solution using few modes.

Approach: A new, higher-order, modal method was developed which converges faster (i.e. using fewer modes) than, previous, lower-order methods such as the MDM or MAM methods. The new method successively integrates-by-parts the convolution integral form of the response and is called the force-derivative method (FDM) because it produces terms which are related to the forcing function and its time derivatives.

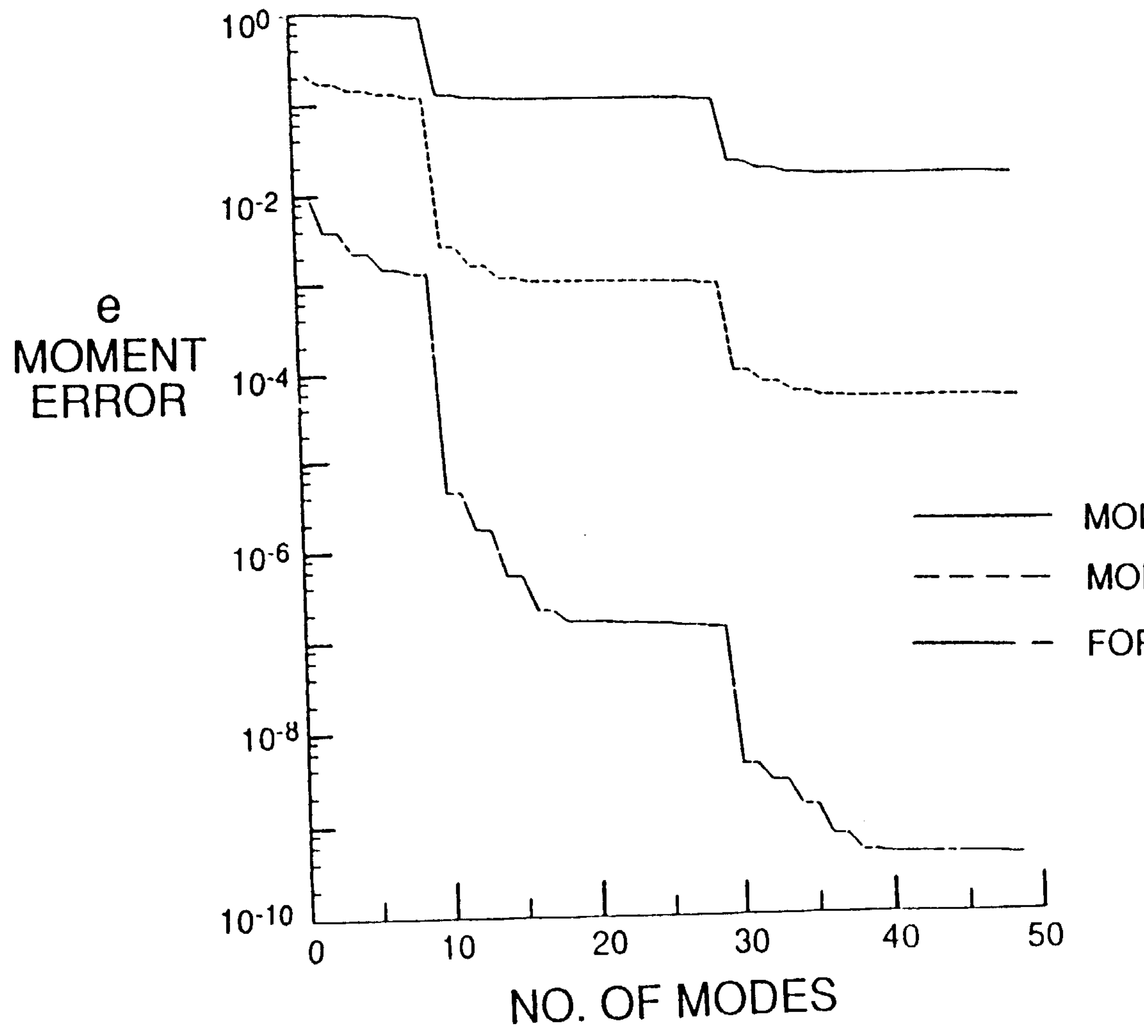
Accomplishment Description: The FDM enables a unified method for developing higher-order modal methods, beginning with the zeroth- and first-order methods (MDM and MAM respectively) and continuing as high as necessary, providing a suitable analytic description of the forcing function is available. The FDM was found to be more accurate than either the MDM or MAM methods. In particular, for problems in which there are a large number of closely spaced frequencies (e.g. large-area truss-like space structures) the FDM is very effective in representing the important, but otherwise neglected, higher modes. A uniform load distribution, whose magnitude varies as a quintic function of time, was applied to a 10-span, simply-supported beam with proportional damping (fig. 1). The multispan beam has closely-spaced frequencies occuring in groups of ten. As shown, the moment error for the FDM method is two orders-of-magnitude less than the MDM method and one order-of-magnitude less than the MAM method. The FDM converged to an accurate solution using only one mode as compared to ten modes for the MAM and 49 modes for the MDM.

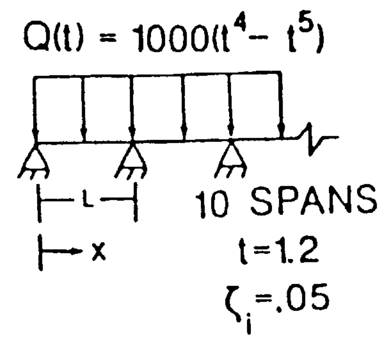
Significance: The FDM can reduce the size of very large, complex dynamic problems significantly to enable efficient solutions for displacements and stresses. Coupling this reduction technique with new methods for sensitivity calculations can greatly reduce the computational expense for transient structural optimization.

Future Plans: Higher-order methodologies for solving non-proportionally-damped structural problems as well as thermal problems are currently being developed and evaluated. Future plans include the incorporation of the FDM method into NICE-SPAR and its evaluation for large, complex thermal and structural dynamic problems.

DEVELOPMENT OF ADVANCED MODAL METHOD FOR TRANSIENT STRUCTURAL ANALYSIS (FORCE DERIVATIVE METHOD)

MULTISPAN BEAM WITH UNIFORM LOAD DISTRIBUTION





53

COMPUTATIONAL MECHANICS BRANCH

NEW EQUATION SOLVER REDUCES STRUCTURAL ANALYSIS TIME

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Structural Mechanics Branch, SMD, Ext. 2040
and
Eugene L. Poole and Andrea L. Overman
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RTOP 505 - 63 - 01 November 1988
Code RM WBS 56 - 2

Research Objective:
To reduce structural analysis time so that large-scale, complex problems can be solved rapidly enough for the results to be useful to designers.

Approach:
A new, faster method for solving large systems of equations has been developed. The method is designed to take advantage of the architecture of the Cray-2. Specifically, the method uses the vector capability and local memory of the Cray-2 plus several coding, storage, and matrix decomposition techniques. The method provides computation rates in excess of 100 Mflops (millions of floating point operations per second).

Accomplishment Description:
To test the new method, it was installed in a large finite element structural analysis code, denoted the CSM Testbed, and used to analyze a large problem involving the Space Shuttle SRB. The new solver was 10 times as fast as the early, Testbed, sparse matrix solver and was 9 times as fast as an industry standard LINPACK Choleski solver (for banded systems) available in the Cray math libraries. These reductions in times to solve the large system of equations (54,870) reduced the analysis time by a factor of 2. With the new solver, the time spent solving the finite element equations is reduced from 53% of the total analysis time to only 9% of the total analysis time.

Significance:
The new equation solver allows a substantial reduction in structural analysis time. Techniques used to accomplish that goal point the way toward further improvements in structural analysis computational efficiency not associated with solving equations.

Future Plans:
Document the method and results in NASA CR-4159 and use the same general approach to improve computational efficiency in other areas of structural analysis.

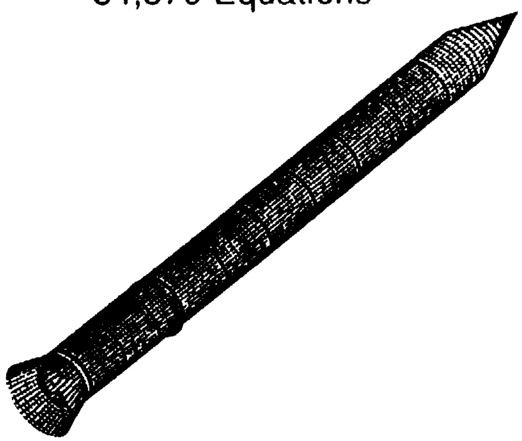
NEW EQUATION SOLVER REDUCES STRUCTURAL ANALYSIS TIME

All Analyses on NAS Cray-2

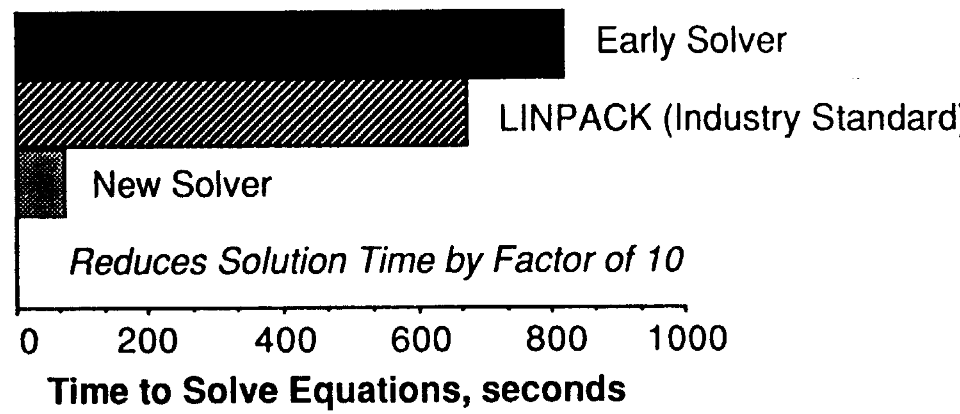
SRB Finite Element Analysis

K u = f

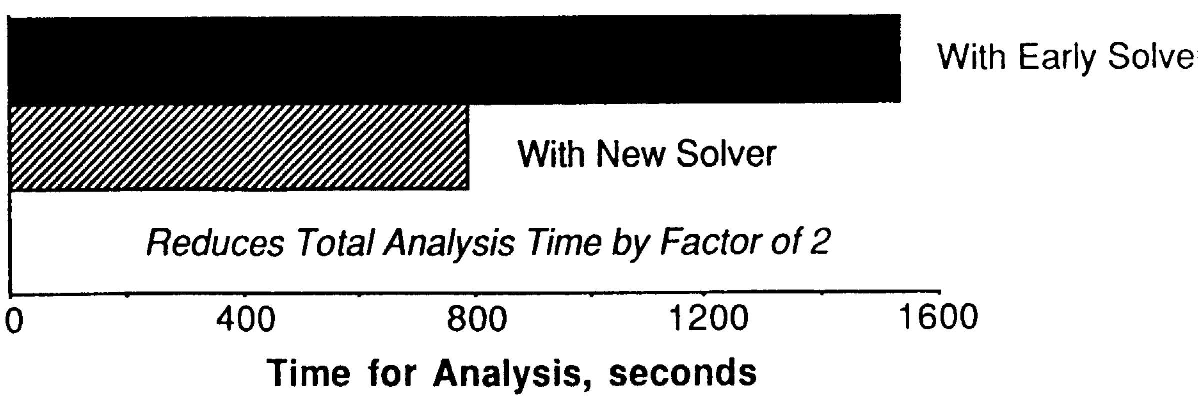
54,870 Equations



Comparison of Equation Solvers



Comparison of Total Analysis Times



VECTORIZED LANCZOS VIBRATION ANALYSIS ALGORITHM DEVELOPED TO EXPLOIT NAS CRAY 2

Susan W. Bostic
CSM Group, SMB, SMD
Ext. 42910
RTOP 505-63-01 March 1989
Code RM WBS 56-2

Research Objective:
Reduce computation time for vibration analysis by exploiting the architectures and high performance of advanced computers.

Approach:
Develop and implement an efficient, reliable eigensolver based on the Lanczos procedure for parallel/vector computers. Test the eigensolver by performing vibration analysis of a high speed transport model on the NAS CRAY 2 supercomputer.

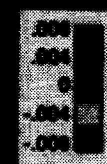
Accomplishment Description:
The strength of the Lanczos algorithm is that the few eigenvalues of interest can be found with a minimum amount of computation by transforming the original large problem into a small easier-to-solve problem. Previous work demonstrated speedups over a sequential solution when implemented on a FLEX/32 parallel computer with twenty processors. Current results reflect the reduction in computation time by optimizing the algorithm for implementation on the NAS CRAY 2 vector computer.The Lanczos eigensolver has been installed in the CSM testbed to provide a general purpose capability for performing large-scale vibration analysis. This new capability has been used to analyze a high speed transport model with 4518 degrees of freedom. This model has been used in preliminary design studies of this vehicle. In the figure, the second vibration mode is shown (1.5 hz). The color chart at the right indicates the normalized deflection. The color on the figure indicates the magnitude of the deflection normal to the surface. The Lanczos eigensolver found the ten smallest eigenvalues and eigenvectors of the system in less than two seconds. The normalized frequency results agreed with those found using the original testbed vibration capability, EIG, a Stodola procedure not optimized for vector machines. Using the testbed EIG processor, more than 17 seconds were required for the analysis.

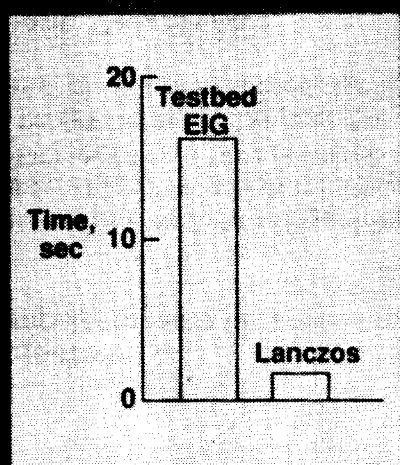
Significance:
A computationally efficient vibration analysis capability has been developed and implemented in the CSM testbed for general purpose use. Significant reduction in computation time has been demonstrated by optimizing algorithms for high performance computers.

Future Plans:
The Lanczos algorithm is being installed on a two-processor CONVEX and will be optimized to run in a parallel/vector mode. Demonstration of the capability on larger models is planned.

VECTORIZED LANCZOS VIBRATION ANALYSIS ALGORITHM DEVELOPED TO EXPLOIT NAS CRAY 2

High Speed Transport Model With 4518 Degrees Of Freedom





Smallest 10 eigenvalues

Testbed EIG	Lanczos
.10620	.10620
.23928	.23926
.65018	.65018
.81332	.81332
1.39620	1.39620
2.19910	2.19910
3.30600	3.30600
3.65280	3.65280
4.62550	4.62530
4.74630	4.74490

ORDER-OF-MAGNITUDE REDUCTION IN SRB SOLUTION TIME

Olaf O. Storaasli
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Ext. 42927
RTOP 505-63-01 March 1989
Code RM WBS 56-2

Research Objective:
Reduce the computation time for static structural analysis by exploiting the parallel and vector capabilities of supercomputers.

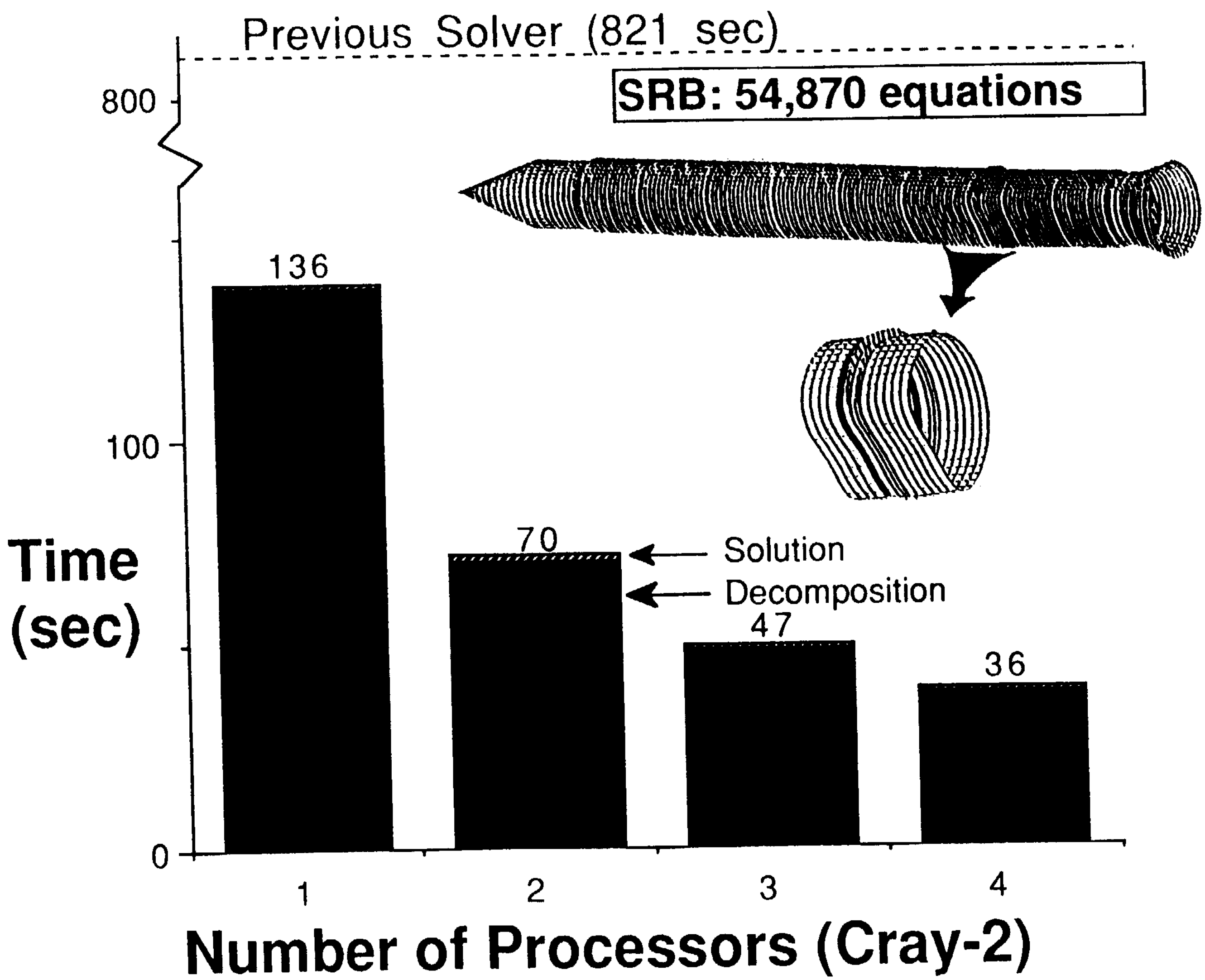
Approach
Develop, implement and test an efficient, reliable equation solver for linear static structural analysis. The method is based on a skyline Choleski algorithm which minimizes the memory used. The computationally intensive portions of this algorithm (in a triple-nested DO loop) can be optimized to exploit both the parallel and vector features offered by modern supercomputers. The method is programmed to be portable (without changes) across shared-memory supercomputers (Cray-2, Cray-YMP, Convex 220), and is written in a modular fashion to permit its use in other engineering applications.

Accomplishment Description:
Current equation solvers on high-performance supercomputers are either highly vectorized (but machine-dependent) and/or have only limited parallel capability. The strength of the Parallel Skyline Choleski method is that it achieves optimum performance by full use of parallelism (triple-nested DO loop) as well as vectorization for the innermost loop. This results in an order-of-magnitude reduction in computation time. In addition, the skyline storage scheme used (only terms under the skyline are stored), requires a minimum of memory. This permits the solution of even larger structural analysis problems than other storage schemes can offer. The code has been implemented on Flexible, Encore, Alliant, Sequent, Cray-2, Cray-YMP and Convex 220. This machine portability was accomplished by using a new concurrent FORTRAN language (Force) which requires no changes in the code and yet achieves optimum compilation which enhances algorithm performance. In the attached figure, a static analysis of the Space Shuttle Solid Rocket Booster is presented to investigate the effects of local bending in the neighborhood of the O-ring seals. The solution time for the model, which took 821 seconds to solve on the Cray-2 by a widely-used code, now is reduced to 136, 70, 47 and 36 seconds using 1, 2, 3, and 4 processors, respectively.

Significance:
A computationally efficient, yet portable, parallel/vector equation solver has been developed and implemented on different high-performance supercomputers for general purpose use. Significant reductions in computation time and memory requirements have been demonstrated for large-scale problems.

Future Plans:
The Parallel Skyline Choleski solver is being incorporated in transient response and eigenvalue analysis procedures.

ORDER-OF-MAGNITUDE REDUCTION IN SRB SOLUTION TIME



SPACECRAFT STRUCTURES BRANCH

SPACE STATION TRUSS ASSEMBLY WITH MOBILE TRANSPORTER DEMONSTRATED IN SIMULATED 0-G TESTS

Judith J. Watson, Walter L. Heard, Jr., Harold G. Bush, and Mark S. Lake
Structural Concepts Branch
J. Kermit Jensen, Richard E. Wallsom, and James E. Phelps
PRC Kentron, Inc.
Ext. 2414, 2494, 2608 October 1988
RTOP 506-43-41 Code RM

Research Objectives:
To develop and demonstrate in simulated 0-g the procedures and assembly rates for EVA construction of the Space Station truss structure using the Mobile Transporter with astronaut positioning devices (APD).

Approach:
Install the Mobile Transporter in the MSFC Neutral Buoyancy Simulator and use test subjects in Shuttle pressure suits (Extravehicular Mobility Units) to perform timed assembly tests of a 3-bay segment of Space Station size truss structure with and without utility tray installation. Set the translation rate for the truss and the APDs at approximately 1 ft/sec.

Accomplishment Description:
Fourteen test runs were conducted using subjects in EMUs during the months of May and June. A total of eight subjects participated in the testing including LaRC engineers, astronauts Sherwood Spring and Jay Apt, and Ralph Weeks (NASA HQ, Code MD),and Steve Porter (JSC, Crew and Thermal Systems Division). Preliminary results indicate three bays (44 struts) of Space Station truss with integrated utility trays can be assembled in 20 minutes (27 seconds/strut) using the Mobile Transporter concept.

Significance:
Results of the simulated 0-g tests indicate that EVA constuction of the Space Station truss and integratied utility trays using the Mobile Transporter with astronaut positioning devices is an efficient, rapid and reliable assembly method. The attachment of the integrated utility trays to the truss structure had no significant impact on the truss assembly rate, which was 1/2 the nominal 60 seconds/strut assembly rate currently used for prediction of on-orbit construction of Space Station.

Future Plans:
Results of the test will be formally documented. Further studies involving the Mobile Transporter hardware are under investigation.

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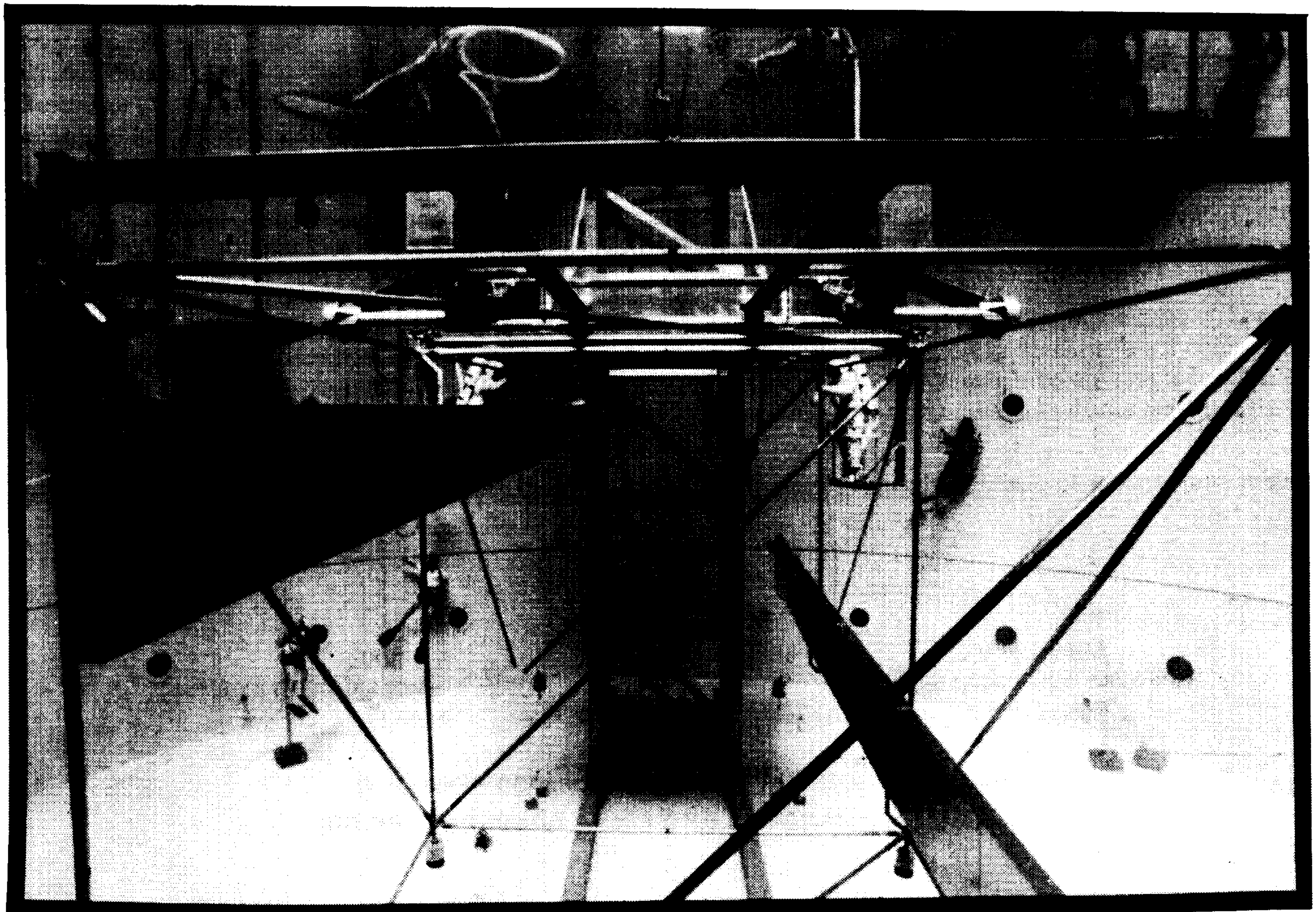
SPACE STATION TRUSS ASSEMBLY WITH MOBILE TRANSPORTER DEMONSTRATED IN SIMULATED 0-G TESTS



Member Exchange Procedure Developed for Improving Surface Accuracy in Truss Reflector Structures

William H. Greene
Structural Concepts Branch, SMD
Ext. 2608

Raphael T. Haftka *
Virginia Polytechnic Institute
(703) 961-4860

February 1989
RTOP 506-43-41
Code RM WBS 42-2

Research Objective: To reduce the surface errors in truss reflector backup structure caused by length errors in the individual members.

Approach: Finite element models of tetrahedral truss structures with arbitrary sets of member errors were developed. The problem of finding an optimal arrangement of members in the truss is a combinatorial problem that requires the evaluation of a very large number of configurations. Since the brute force approach to this analysis is not computationally feasible, an efficient method was developed to calculate the effect of exchanging pairs of members which requires only about a dozen arithmetic operations per exchange.

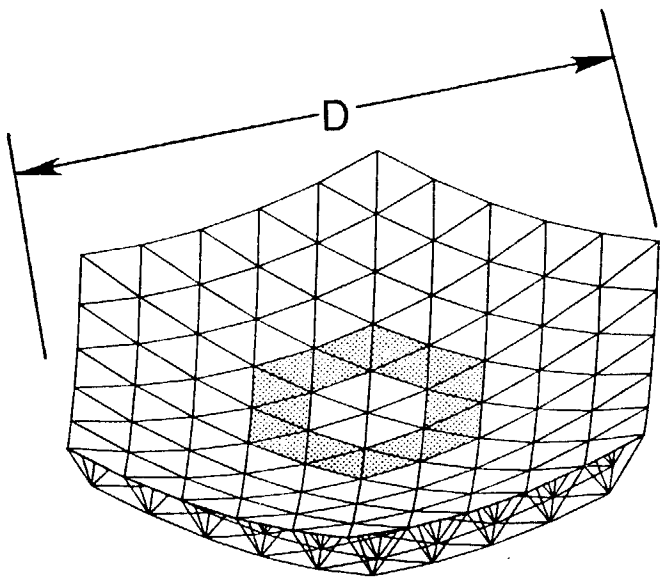
Accomplishment Description: The procedure has been applied to 2- and 5-ring (shown in the figure) tetrahedral trusses. The manufacturing errors in the truss member lengths were generated as normally distributed random numbers with a mean value of zero and a sigma of 5×10^{-5} in/in. In both cases the surface error parameter was reduced by more than two orders of magnitude from the value shown in the figure for the trusses with arbitrary member arrangement. The figure shows that trusses assembled with an arbitrary member arrangement fail to meet current accuracy requirements for the Precision Segmented Reflector (PSR) while the trusses with the improved arrangement easily meet this requirement. Other studies indicate that it is possible to simultaneously reduce both the surface error and built-in residual forces in the truss.

Significance: Previously it was assumed that achieving very accurate surfaces in truss reflectors required that the individual members be manufactured extremely accurately. The current studies suggest that it may be possible to construct very accurate trusses using members manufactured to only standard tolerances, thus resulting in significant savings in fabrication costs.

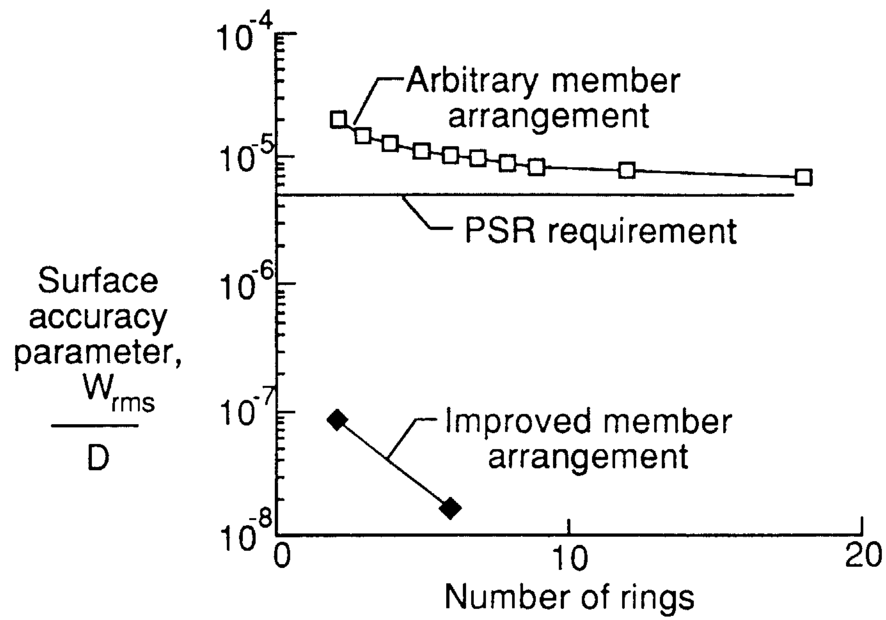
Future Plans: This technique wil be applied to precision truss structures being built in the Structural Concepts Branch as part of the PSR activity.

*Supported by Interdisciplinary Research Office Grant NAS1-224

MEMBER EXCHANGE PROCEDURE DEVELOPED FOR IMPROVING SURFACE ACCURACY IN TRUSS REFLECTOR STRUCTURES



5-ring tetrahedral truss reflector backup structure



COMPARISON OF SURFACE ACCURACY MEASUREMENTS WITH FUTURE MISSION REQUIREMENTS AIDS IN ERROR BUDGET ANALYSIS

Marvin D. Rhodes and Martin M. Mikulas, Jr.
Structural Concepts Branch
Ext. 43121 and 43102
April 1989
RTOP 506-43-41
Code RM

Research Objective: Characterize the truss substructure accuracy requirements for large precision space antennas.

Approach: The error budget for precision antenna surfaces is frequently divided arbitrarily between the reflector surface panels and the supporting substructure. An evaluation of measured results from high quality test hardware permits estimates of the achievable accuracy of both the panels and the substructure. It also provides insight into the requirements for the panel actuator control system.

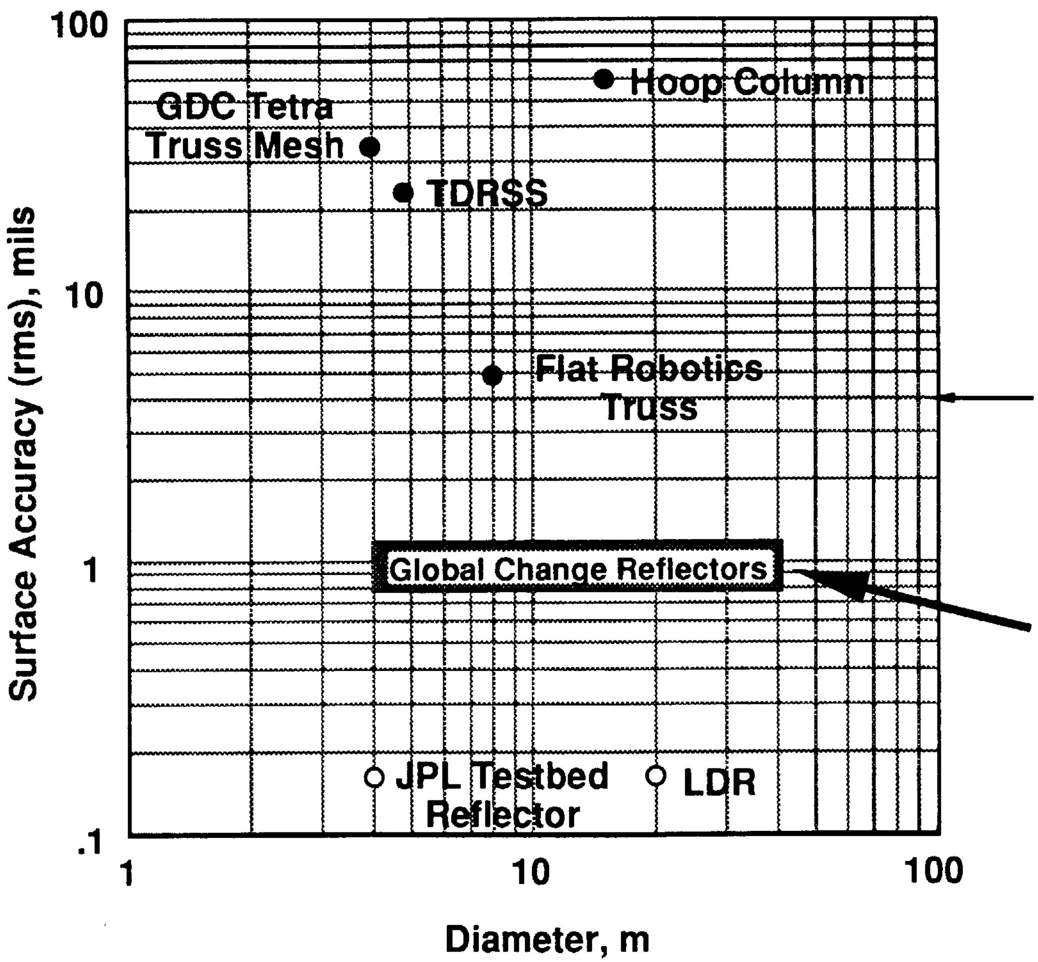
Accomplishment Description: Shown on the attached figure are the RMS measurement results from data taken from the surface of three antennas with diameters between 4 and 15 meters. The requirements for future systems such as the 4-meter-diameter JPL test bed reflector which is a part of the PSR program and the 20-meter-diameter LDR program are also shown. It is apparent that the requirements for future systems are approximately 300 times higher than the measured values on current antennas. Global change reflectors proposed for study of the Earth's atmosphere also require much higher surface accuracy than that currently achieved.

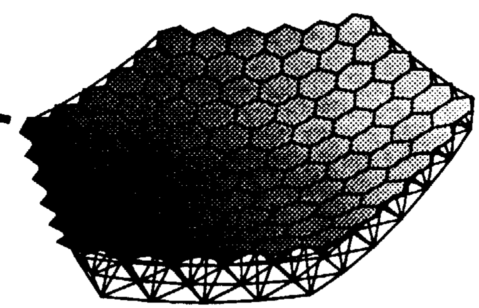
Recently a planar tetrahedral truss with 2-meter members was fabricated to evaluate the potential for automated assembly using a robot arm. This truss was fabricated using conventional processes and the components were measured to determine the variation in length between the members. The struts had length errors between ± 0.005 inch. The assembled truss was measured to determine the RMS accuracy with respect to a best-fit plane for the top 19 nodes. This represents the first measurements made on a moderate size truss and the results indicate significant improvement over the three antennas.

Significance: Many of the large antennas proposed for future space applications will incorporate a truss substructure that has a high stiffness and very accurate node locations for mounting the reflector panels. This study puts the truss requirements for these antennas in perspective by comparing developed antennas and truss hardware with requirements for proposed missions. It provides confidence that trusses for future missions can meet the accuracy need using conventional fabrication procedures.

Future Plans: Fabricate and test a two-ring doubly-curved truss for the JPL PSR ground test bed system that will meet or exceed the requirements for the global change reflectors.

TWO RING ROBOTIC TEST TRUSS EXHIBITS 5 MIL RMS SURFACE ACCURACY





DEPLOYABLE STIFFENERS PERMIT SIGNIFICANT INCREASE IN STRUT BUCKLING LOAD WITH SMALL MASS AND STOWED VOLUME PENALTIES

Mark Lake
Structural Concepts Branch
Extension 4-3114 August 1989
RTOP 506-43-41 WBS 42-2

Research Objective: To evaluate the mass savings offered by using curved, deployable stiffeners to increase the buckling load of slender struts for large space structure applications.

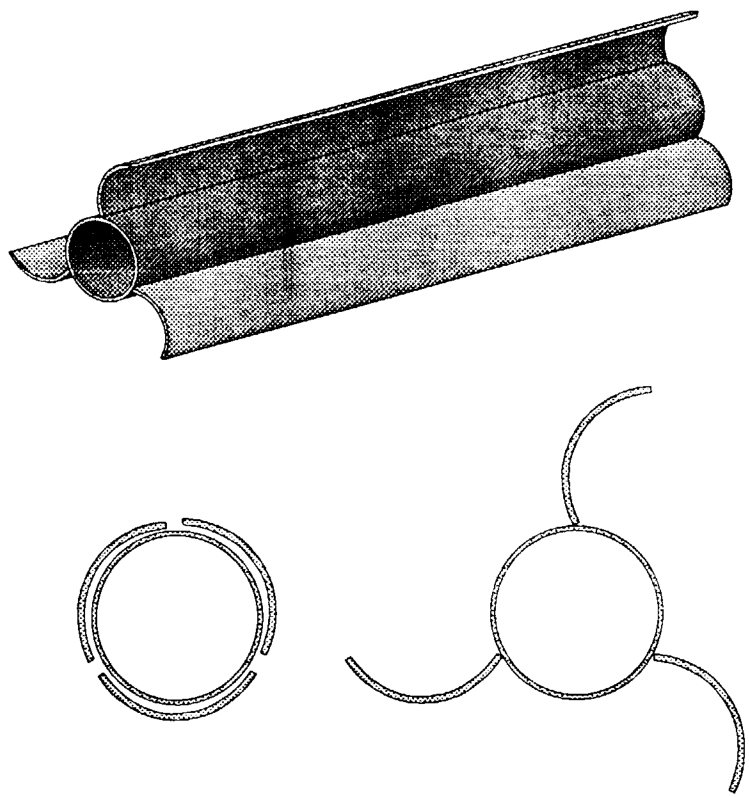
Approach: Extensive numerical analysis of Euler column buckling and local stiffener buckling performed previously, has indicated that stiffened strut designs having reasonable stiffener thicknesses will exhibit Euler buckling as their fundamental stability mode. Therefore, mass and buckling load estimates can be based on cross-sectional area and moment of inertia calculations, respectively. Assuming thin walled cross sections, approximate expressions were determined for area and moment of inertia. These expressions are linear with respect to the stiffener thickness. Using these expressions, mass versus buckling load trends were studied by monotonically increasing stiffener thickness.

Accomplishment: Truss components in large space structures must have low mass and stowed volume for efficient transport to orbit. This consideration leads to the use of very long slender struts which have low buckling loads. The addition of curved, deployable stiffeners was found to greatly improve the buckling load of the strut with small mass and stowed volume penalties. The attached figure shows an isometric view of a portion of a stiffened strut, cross-sectional views of the strut with stiffeners stowed and deployed, and a plot of the mass savings associated with deployable stiffeners. From the drawings, it is evident that the stowed stiffeners would add little volume to the strut. The plot shows approximate normalized strut mass versus normalized buckling load. The mass savings of the stiffened strut is demonstrated by comparison to the strut with increased wall thickness. The mass savings is significant for large increases in strut buckling load, even assuming the mass of stiffener attachment and deployment mechanisms to be 50 percent of the mass of the unstiffened strut.

Significance: It is conceivable that a strut with deployable stiffeners could be used in place of simple cylindrical struts in any erectable or deployable space structure, because these stiffeners have an insignificant effect on stowed volume. Addition of the deployable stiffeners allows a more efficient way of improving strut buckling load than simply increasing the strut wall thickness. The simplified mass versus buckling load relationship allows quick, first iteration design calculations to be performed.

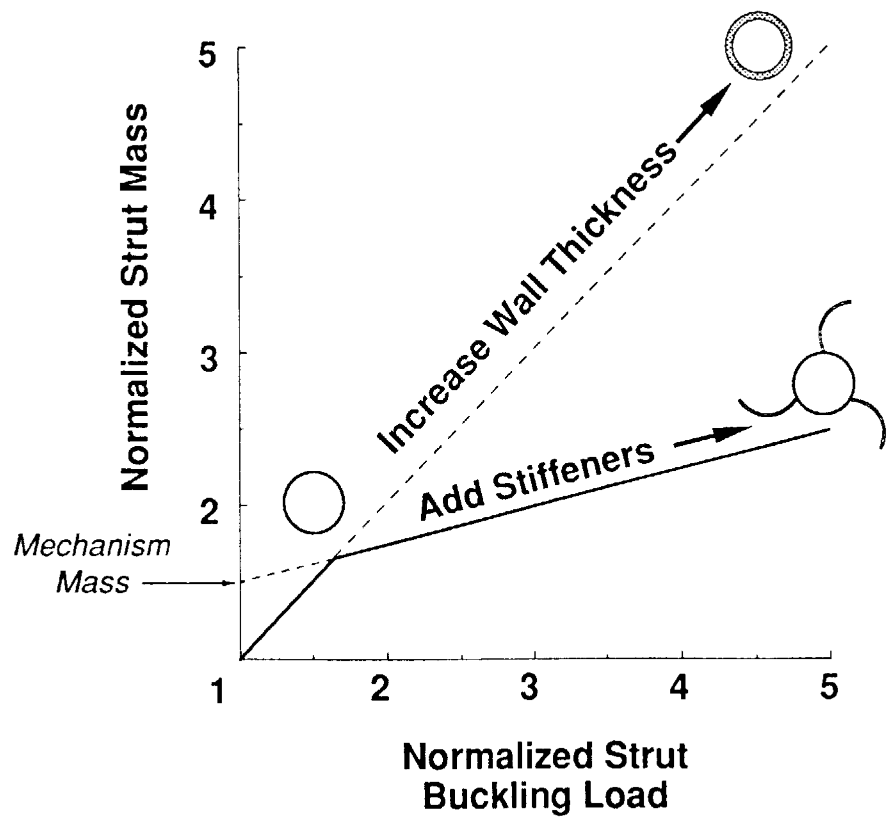
Future Plans: Results of an extensive stability design study of this strut concept which has been performed will be published in a NASA Technical Memorandum.

DEPLOYABLE STIFFENERS PERMIT SIGNIFICANT INCREASE IN STRUT BUCKLING LOAD WITH SMALL MASS AND STOWED VOLUME PENALTIES



STOWED

DEPLOYED



AEROTHERMAL LOADS BRANCH

NASP AEROTHERMAL LOADS MEASURED IN 8' HTT AT MACH 7

David E. Reubush*
Aerothermal Loads Branch, SMD
Ext. 2325
RTOP 763-01-41 December 1988
Code RN WBS 60-4

Research Objective: Obtain heat transfer measurements on a realistic, large scale model of a "NASP-like" configuration for turbulent boundary layer conditions to verify computational techniques.

Approach: Conduct cooperative (with Boeing) experimental investigation in the Langley 8-Foot High Temperature Tunnel of a 1/20-scale model of a modified version of the configuration known as the "government baseline," which is shown in the attached figure. The model was instrumented with 52 heat transfer gauges of various types depending on the space available in the model and the anticipated heat transfer rates. The distribution of the heat transfer instrumentation on the configuration was biased toward the upper surface or lee side of the vehicle (for positive angles of attack) since the prediction of lee side heat transfer is significantly more difficult than that for the windward side which is shown in the figure.

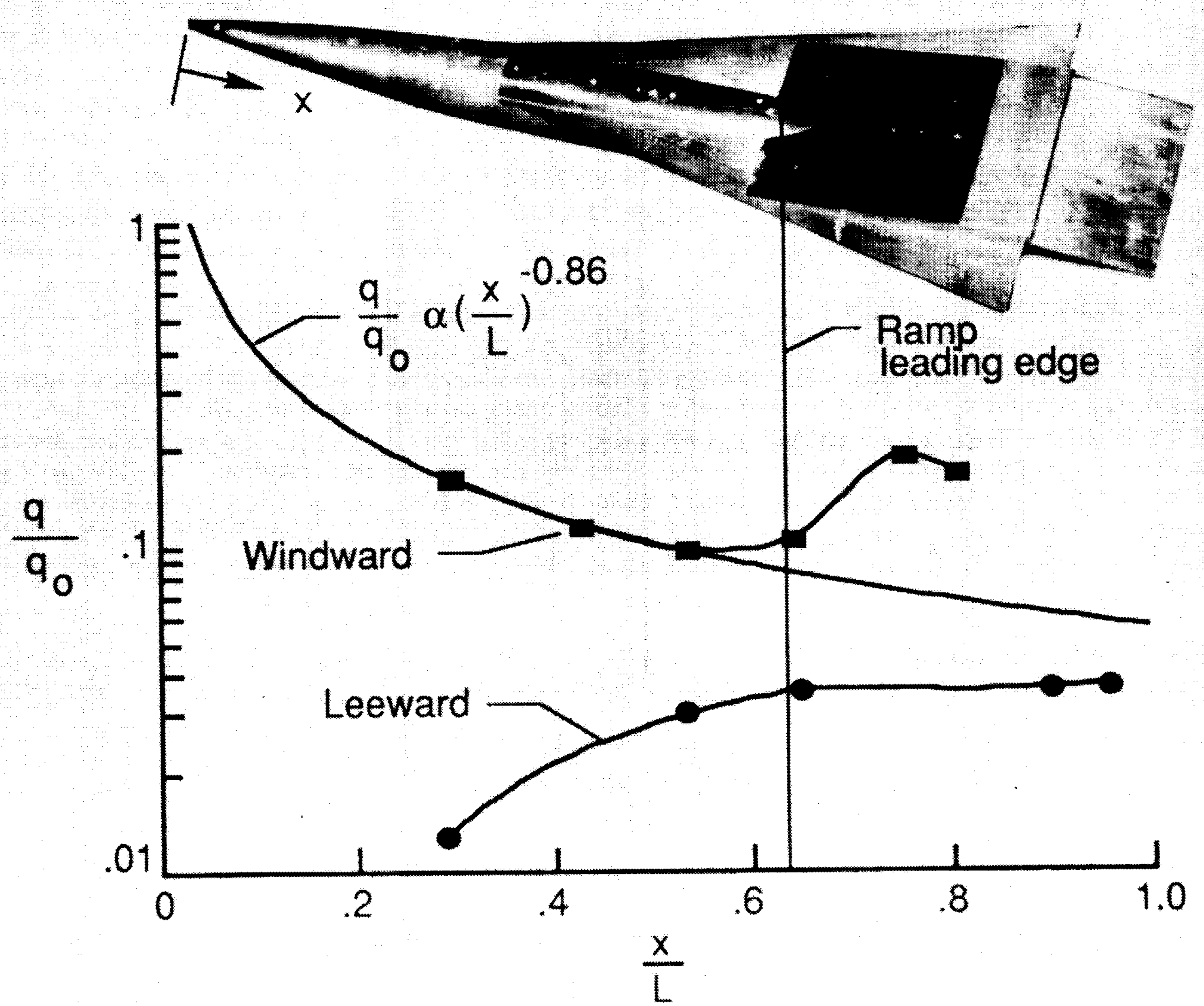
Accomplishment Description: A total of nine runs were made with tunnel combustor pressure varied from about 1000 psi to 2500 psi (most runs) and a combustor temperature of 3200°R. The Reynolds number varied from 0.6 million per foot to 1.6 million per foot. At the low Reynolds number condition the model angle of attack was either 0 or 3 degrees while at the high Reynolds number condition the model angle of attack was varied from 0 to 14 degrees. A typical heat transfer distribution on windward and leeward fuselage (nondimensionalized by the stagnation point heat transfer for a sphere of 1 foot radius) is shown in the figure. The experimental data for the bottom centerline (windward side) varies logarithmically with distance similar to turbulent heating levels. The heating level increases as the flow passes over the ramp. Leeward heating rises to approach the windward heating levels on the trailing surfaces.

Significance: The flight environment for the Aero-Space Plane is too severe to simulate in ground based facilities, hence validated codes will have to be relied upon to predict the environment and performance of the candidate configurations (particularly at the very high Mach numbers). Quality experimental data are required to validate the codes.

Future Plans : Document results and compare the experimental heat transfer data with theory.

*Now assigned to Structures Directorate Office

NASP AEROTHERMAL LOADS MEASURED IN 8' HTT AT MACH 7



LEADING EDGE SWEEP REDUCES COWL SHOCK-ON-LIP PRESSURE AND HEATING RATE

Christopher E. Glass
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Ext. 4441
RTOP 506-80-31 MARCH 1989
CODE RF WBS 60-4

Research Objective: Experimentally investigate the effect of leading edge sweep on the peak shock-on-lip pressure and heating rate from a shock-shock interference pattern that results in a "Type IV" supersonic jet impingement (Shown schematically in the upper right of the figure).

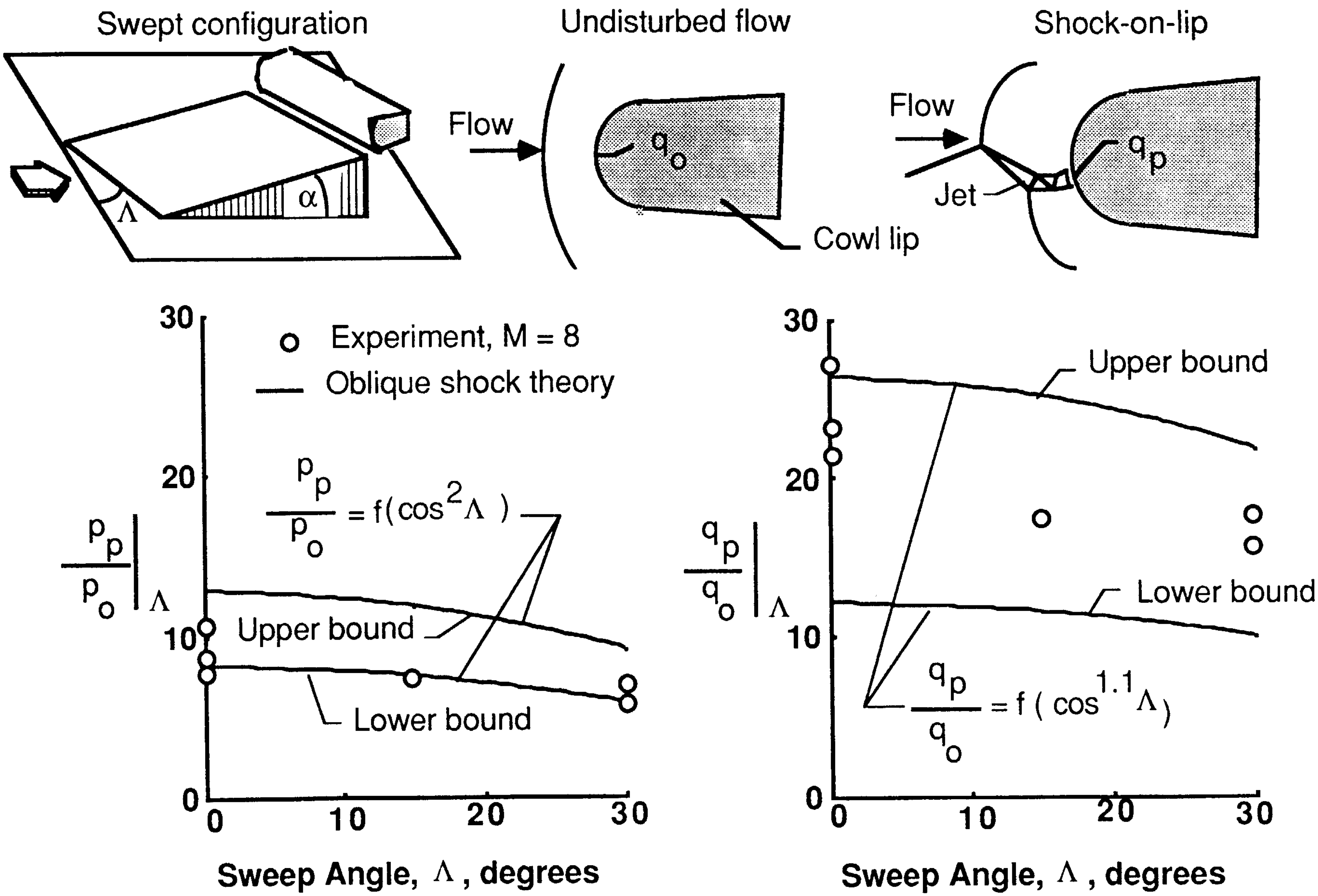
Approach: An experimental study was conducted on a swept shock interference model (upper left of the figure) in the Calspan 48" HST through a grant with Calspan-University of Buffalo Research Center (CUBRC). The model consisted of an incident shock generator wedge at angle-of-attack, α, of 12.5° and a 3-inch diameter cylinder. The wedge and cylinder were swept at the same angle, Λ, of 0°, 15°, and 30°. The peak pressure and heating rate occur in a very narrow localized region on the cylinder surface. Hence, the wedge and cylinder were translated horizontally and vertically with respect to each other to produce various types of interference patterns and to create the severest interference Type IV supersonic jet impingement pattern. The cylinder was instrumented with 24 pressure transducers and 32 thin-film platinum thermometers. The densely spaced instrumentation was rotated into the jet impingement region to accurately define the surface pressure and heating rate distribution. The tests were made at Mach 8, freestream Reynolds number of 1.5×10^6 per foot, dynamic pressure of 800 psf, and total temperature of 2800 °R.

Accomplishments: Results from six tests are shown in the figure. The experimental peak pressure, p_p, and peak heating rate, q_p, are normalized by swept cylinder undisturbed flow (no shock interference as shown in the upper center of the figure) stagnation line pressure, p_o, and heating rate, q_o, respectively for the given test condition. The undisturbed flow stagnation pressure varies with $\cos^2\Lambda$ (Newtonian) and the undisturbed heating rate varies with $\cos^{1.1}\Lambda$ (Beckwith and Gallagher). The curves labeled upper bound and lower bound represent an extrapolation of pressure and heating rate calculated from oblique shock theory for the 0° swept Type IV jet impingement using the same cosine functional relationships as the undisturbed case. The normalized experimental data are bracketed by these upper and lower theoretical predictions and, in general, normalized pressure follows the $\cos^2\Lambda$ variation and normalized heating rate follows the $\cos^{1.1}\Lambda$ variation, therefore predicting the trend as a function of sweep angle. If the experimental data were normalized by unswept stagnation line values, peak pressure and heating rate would decrease with $\cos^4\Lambda$ and $\cos^{2.2}\Lambda$, respectively. Hence, sweeping the leading edge 30° would reduce the peak heating rate by 25%.

Significance: Baseline data and correlation for prediction of peak shock-on-lip pressure and heating rate on swept leading edges.

Future Plans: Document in an AIAA conference paper, a Master's thesis, and a NASA paper; Compare with three-dimensional CFD Navier Stokes predictions. Obtain additional data at Mach 11 - 19 in Calspan 48" HST.

LEADING EDGE SWEEP REDUCES COWL SHOCK-0N-LIP PRESSURE AND HEATING RATE



COALESCED MULTIPLE SHOCK-ON-LIP INCREASES HEAT TRANSFER RATE AMPLIFICATION

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RTOP 506-80-31 APRIL 1989
CODE RF WBS 60-4

Research Objective: Hypersonic airbreathing engine performance is maximized when the oblique shock waves used to compress the external air flow intersect the engine cowl, i.e. shock-on-lip. These oblique shock waves emanate from the vehicle nose and engine inlet ramps and their number is dependent on the vehicle design and mission. The objective of this study was to experimentally determine (1) the heating rate distribution resulting from two oblique shock waves coalescing at their intersection point with the blunt bow shock wave from a cylindrical leading edge, (2) the peak heat transfer rate amplification above the undisturbed (no oblique shock wave) stagnation heat transfer rate and (3) the change from a single oblique shock interaction.

Approach: Conduct a cooperative experimental study with the Calspan-University of Buffalo Research Center (CUBRC) in the Calspan 48" HST using an existing shock interference model. Modify the wedge shock generator to accommodate a second wedge to generate the second oblique shock wave. Turn the Mach 8 free stream flow through a 7.5° wedge angle and then through a 5° wedge angle to obtain a total turning angle of 12.5°, which corresponds to the flow turning angle of the single oblique shock interaction. Position the wedges and cylinder to allow the two oblique shock waves to coalesce at their intersection point with the bow shock wave from the cylinder as shown in the center of the figure.

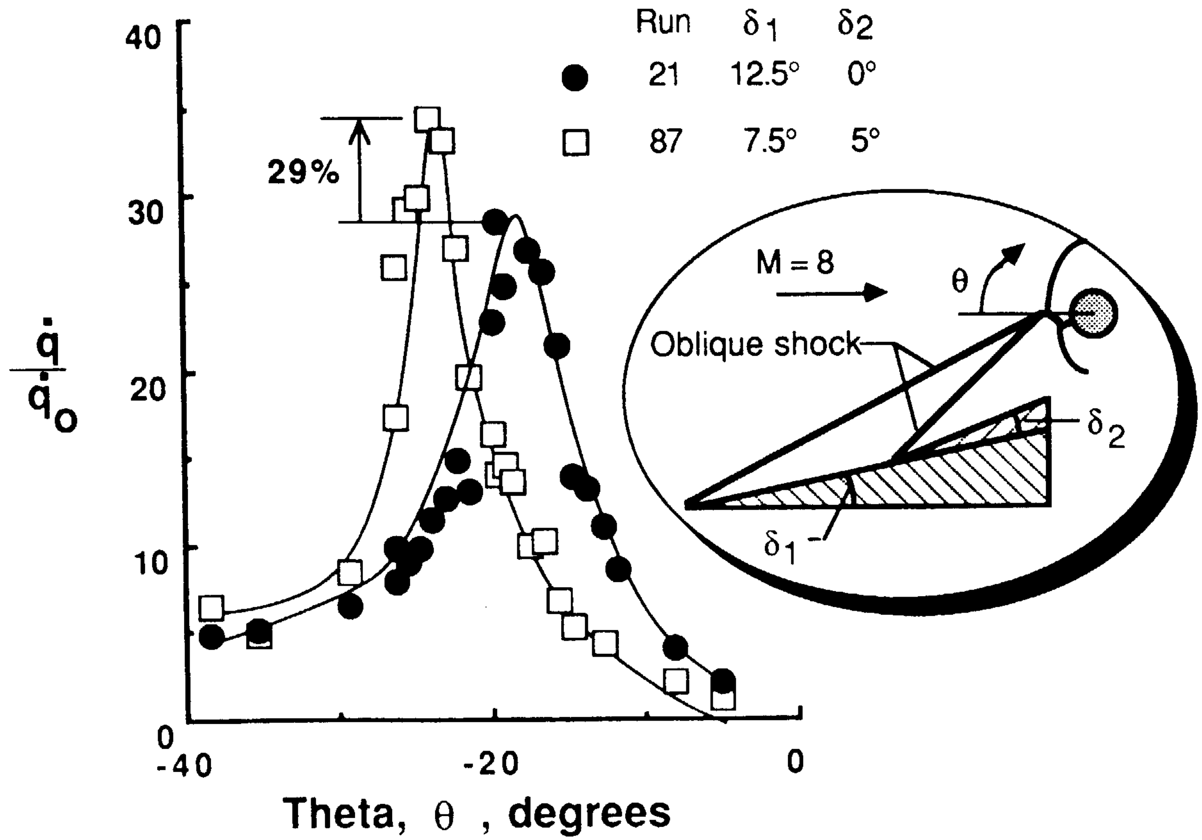
Accomplishment: Schlieren photographs of a single and dual shock-shock interaction, which result in supersonic jet interference patterns, are shown on the right of the figure. The local heat transfer rates, $\dot{q}$, normalized by the undisturbed stagnation point heat transfer rate, $\dot{q}_o$, are plotted as a function of angular position, θ, from the undisturbed flow stagnation point. The distributions are similar indicating that the supersonic jet interference pattern is essentially unchanged. The location of the peaks differ by ~ 4° because the flow behind the dual shock has a higher pressure than that of the single oblique shock wave, hence undergoes less turning at the bow shock wave intersection point. Most importantly the peak heat transfer rate amplification ratio increases 29% from 28 to 36.

Significance: First data on multiple shock-on-lip aerothermal loads for design of engine cowl lips.

Future plans: Results have been documented in AIAA paper No. 88-0477. Use data to benchmark CFD prediction capability prior to predicting flight environment.

COALESCED MULTIPLE SHOCK-ON-LIP INCREASES HEAT TRANSFER RATE AMPLIFICATION

Heat Transfer Rate Distribution



q_o = undisturbed flow stagnation heat transfer rate

Schlieren

Run 21
Single oblique shock

Run 87
Dual oblique shock

INTEGRATED FLUID-THERMAL-STRUCTURAL ANALYZER DEMONSTRATES HEAT TRANSFER/DEFORMATION COUPLING

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June 1989

RTOP 506-43-31
Code RM WBS 60-3

Research Objective: Design of leading edges for hypersonic vehicles that experience intense stagnation point pressures and heating rates depends on accurate prediction of the aerodynamic flow, the structural temperature response, and the structural deformations and stresses. Significant coupling occurs between the aerodynamic flow field, structural heat transfer, and structural response creating an interdisciplinary interaction. Understanding the fluid-thermal-structural interaction is important for the design of leading edges to survive such severe aerothermal environment.

Approach: The Langley Integrated Fluid-Thermal-Structural (LIFTS) analyzer is used to investigate the interdisciplinary interaction of an aerodynamically heated leading edge under simulated test environment. The LIFTS analyzer employs a finite element method to solve: (1) the Navier-Stokes equations for the flow solution, (2) the energy equation of the structure for the temperature response, and (3) the equilibrium equations of the structure for the structural deformation and stresses. A schematic of a proposed experimental set up of a 0.25-inch diameter, three inch long and 0.1-inch thick leading edge is shown in the upper left figure. The leading edge is initially exposed to the undisturbed Mach 5.25 flow (position A) behind the oblique shock generated by the free stream Mach 8 flow. After one minute, the leading edge is raised instantaneously to the predetermined position B to produce the type IV shock-shock interference pattern which results in a supersonic jet impingement normal to the leading edge surface causing intense stagnation point pressure and heating rate. The fluid analysis is first performed to predict the flow behavior and aerothermal loads on the leading edge when it is at the position A. An adaptive mesh refinement technique is used in the fluid analysis to minimize number of unknowns. The finite element flow model and flow Mach numbers are shown in the lower left figure. The predicted aerodynamic heating rate is in excellent agreement with the Fay and Riddell solution as shown in the upper right figure. This heating rate causes the leading edge temperature to increase nonuniformly resulting in the leading edge bending upward as shown in the centered right figure. As mentioned, the deformed leading edge is raised to the predetermined position B at one minute to produce the type IV shock-shock interference pattern. Because of the leading edge deformation, the type IV interference pattern does not occur. The deformed shape results in the type III interference pattern as shown in the figure. The heating rate distribution shown in the lower right figure reflects this type III interference pattern and the high leading edge surface temperature. The peak heating rate is caused by the shear layer/boundary layer interaction and the minimum heating rate is at the nose of the leading edge where the temperature is maximum.

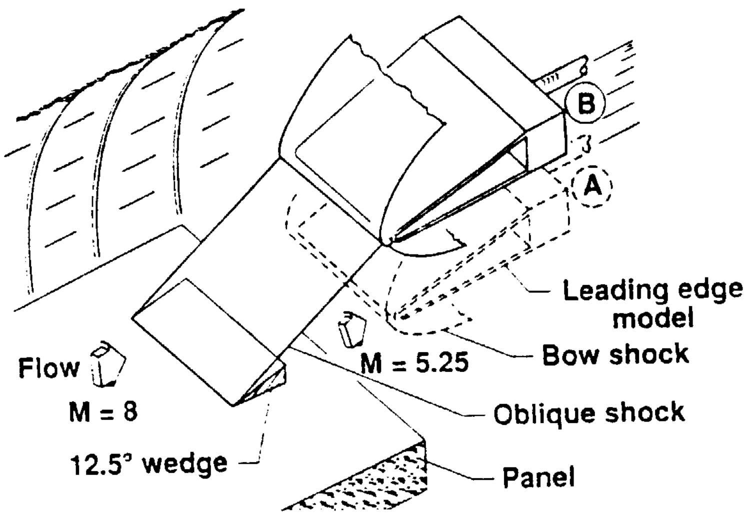
Accomplishment Description: The demonstration has shown the capability of the integrated fluid-thermal-structural analysis approach to provide solutions to complex aerothermostructural behavior and the interdisciplinary interaction.

Significance: The integrated fluid-thermal-structural result underlines the importance of the interdisciplinary interaction that must be taken into account in the design and testing of the aerodynamically heated leading edges subjected to shock-shock interference loading.

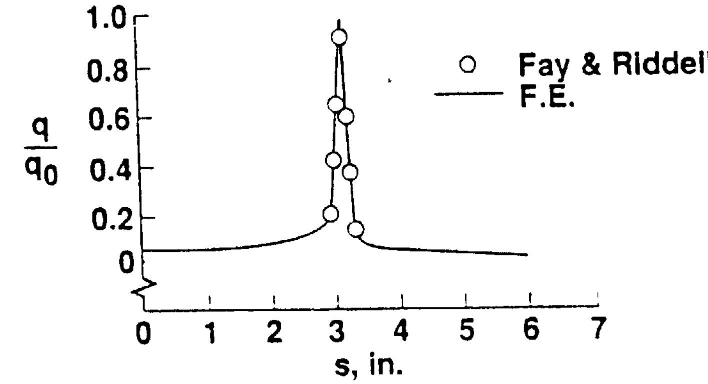
Future Plans: Modify LIFTS to improve the structural analysis module which includes the adaptive mesh refinement capability and implementation of unified viscoplastic theory. Apply current computational fluid dynamics module to other structural configurations such as sharp leading edges and compression corners.

INTEGRATED FLUID-THERMAL-STRUCTURAL ANALYZER DEMONSTRATES HEAT TRANSFER/DEFORMATION COUPLING

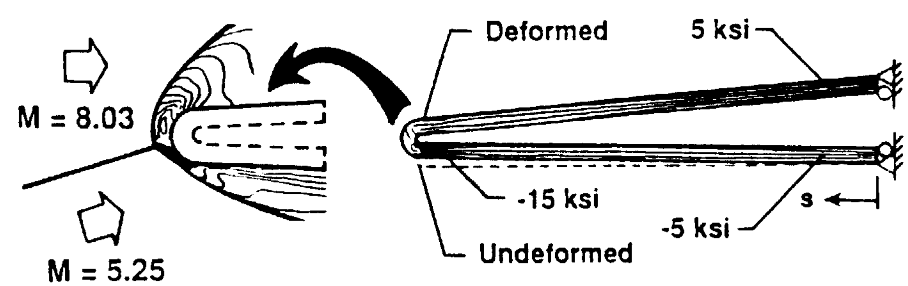
Experimental configuration



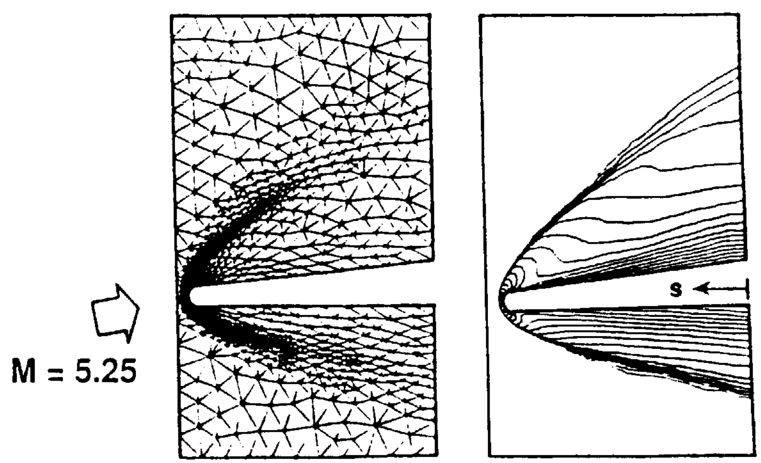
Surface heating rate (Position A)



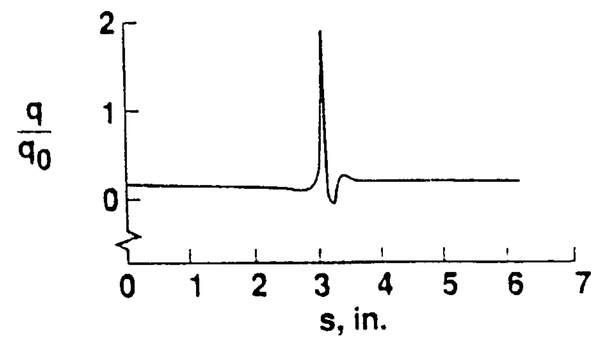
Tangential stress on deformed leading edge at position B with type III interference pattern



Adaptive flow mesh and Mach number contour



Surface heating rate (Position B)



COWL LEADING EDGE LOADS REDUCIBLE TO ACCEPTABLE LEVELS

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RTOP 506-80-31   July 1989
CODE RF   WBS 60-4

Research Objective: Hypersonic airbreathing engine performance is maximized when the oblique shock waves used to compress the external air flow intersect the engine cowl, which creates a shock-on-lip condition. This condition is shown schematically on top of the figure. These oblique shock waves emanate from the vehicle nose and engine inlet ramps and create a supersonic jet shock wave interference pattern that impinges on the leading edge amplifying the pressure and heat transfer rates. The objective of this parametric study was to determine the effect of cowl leading edge sweep and flow deflection angle on the peak heat transfer rate.

Approach: The design or reference heat transfer rate to a 1/8th inch diameter, unswept cowl leading edge for Mach 16 flight at a dynamic pressure of 2000 psf was determined analytically. The flow turning angle, δ, is assumed to be 10° for this reference condition. The peak heat transfer rates for other flow turning angles were predicted with the EASI (Equilibrium Air Shock Interference) code, which has been calibrated on experimental data at Mach 8 to 16. The effect of leading edge sweep, Λ, was determined by assuming that the peak heat transfer rate varies with the $(\cos \Lambda)^{2.2}$ as shown experimentally by Glass.

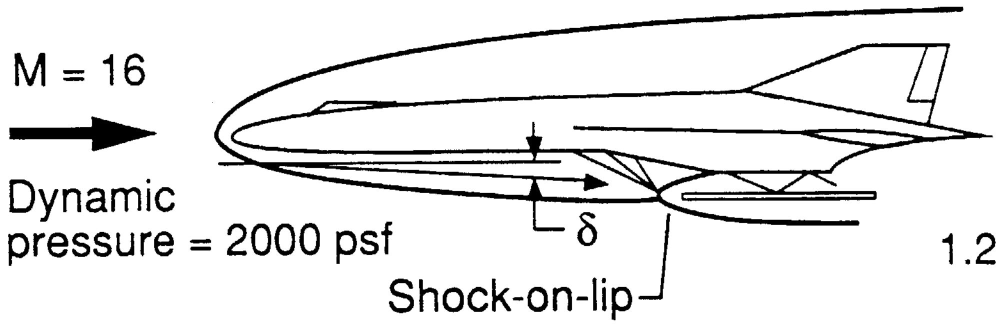
Accomplishment: The effect of flow turning angle, δ, and leading edge sweep angle, Λ, is shown in the carpet plot on the right of the figure. The filled symbol represents the reference heat transfer rate or NASP design condition of 70,000 Btu/ft^2-sec., which is five times the maximum level in the Space Shuttle Main Engine. For the NASP, the flow deflection angle is expected to be in the 5° to 8° range which would reduce the reference heat transfer rate up to 25%. Sweeping the leading edge 45° would reduce the reference heat transfer rate an additional 45% for a total reduction of 70%. The resulting heat transfer rate would then be approximately 28,000 Btu/ft^2-sec, which is still severe but more acceptable. However, sweeping the leading edge will create either a spherical tip or a notch which would still be subjected to the higher heat transfer rates.

Significance: This study identifies possible design trades that can reduce the cowl leading edge heat transfer rates to levels for which viable design concepts have been identified.

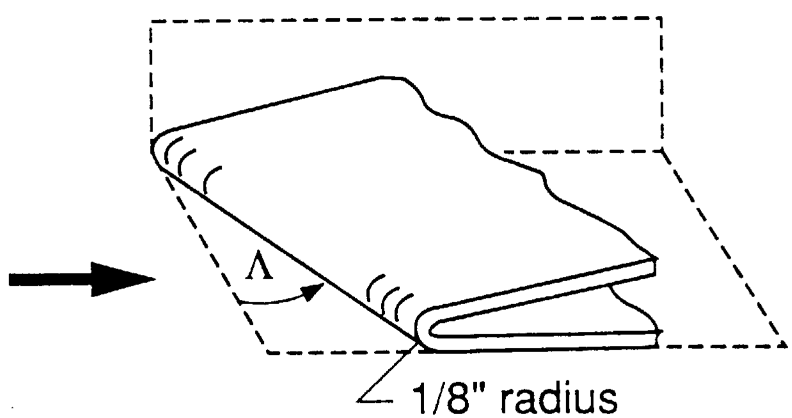
Future plans: Results have been documented in NASP paper No. 8, which was presented at the 6th National Aero-Space Plane Technical Symposium in Monterey, CA., April 24-28, 1989.

COWL LEADING EDGE LOADS REDUCIBLE TO ACCEPTABLE LEVELS

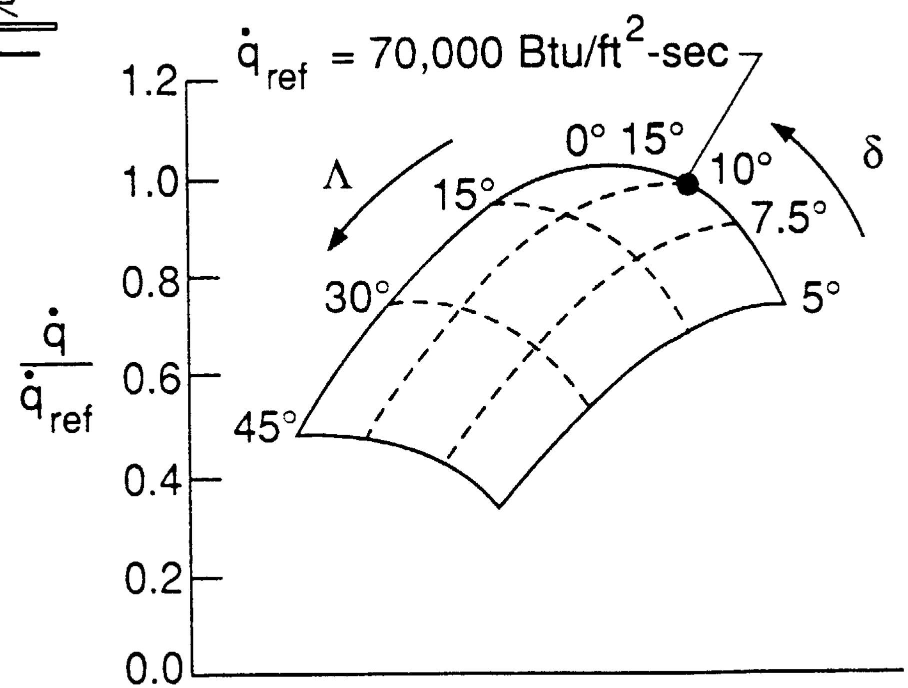
Flow deflection angle



Cowl leading edge sweep



Design heat transfer rate



DISCRETE LONGITUDINAL GAP FILLERS REDUCE CIRCUMFERENTIAL GAP HEAT LOADS

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RTOP 506-40-21
CODE RF WBS 60-4
JULY 1989

Research Objective: The gaps between reusable surface insulation tiles on the Shuttle cause local flow disturbances that have been studied extensively on flat surfaces. Important parameters including gap width, gap length, and flow angularity and their effects on local and total heat transfer rates have been identified. However, the effect of surface pressure gradients, which occur naturally on curved surfaces, have not been quantified. In general, pressure gradients would cause greater flow ingestion into the tile gaps and augment the aerothermal loads. Consequently, many of the Shuttle tile gaps are filled to circumvent this problem, but this approach costs in weight and labor. The objective of this study was to experimentally determine gap heat transfer rates and the effect of gap fillers in reducing the heating rates.

Approach: The Curved Surface Test Apparatus has been developed as a generalized test model for the Langley 8' High Temperature Tunnel (8' HTT). The model is representative of the forward portion of a lifting body and the complex, three-dimensional flow field around this body has been defined experimentally and analytically. An extensive array of simulated tiles was installed over the aft portion of one side of the model as shown in the figure. Thin-wall, metallic heat-transfer tiles were installed in the location, high-lighted in red, adjacent to pressure instrumented solid tiles to determine the aerothermal loads in the tile gaps. The instrumented circumferential tile gap of interest is also illustrated in the figure. Tests were at Mach 6.6, a total temperature of 3400 °R, Reynolds numbers of 0.4 to 1.5 x 10^6 per foot, and angles of attack of 7° , 10°, and 13°, which provided a pressure gradient range. Discrete gap fillers, such as those illustrated in the longitudinal gaps which provided a continuously open circumferential gap, (shown in yellow) allowed the effect of gap fillers to be assessed.

Accomplishments: Heat transfer rates and pressures were obtained on the surface and at gap half depth to identify the effect of pressure gradient on the gap aerothermal loads. Discrete gap fillers provided insight into the mechanisms that resulted in the increased heating rates. The most significant result of the study was that the longitudinal gaps, which are more closely aligned with the external flow than the circumferential gaps, tend to channel the flow into the circumferential gaps. This increased flow raises the gap heat transfer rates. When the longitudinal gaps are blocked as illustrated, the circumferential gap heating relative to the no gap filler reference circumferential heating rate, $\dot{q}_{ref}$, is reduced by an order of magnitude as shown in the graph in the figure.

Significance: The results suggests that the circumferential gap fillers on the shuttle may be unnecessary, hence could be removed, providing more payload and reduced maintenance.

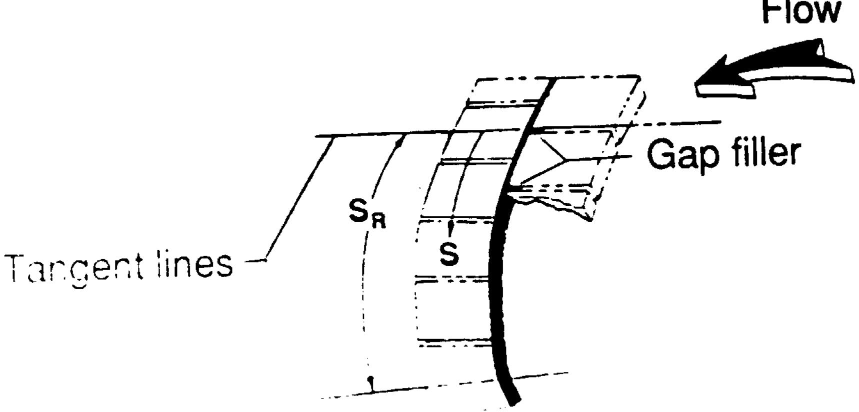
Future: Test results are being documented in a formal NASA publication.

DISCRETE LONGITUDINAL GAP FILLER REDUCE CIRCUMFERENTIAL GAP HEAT LOADS

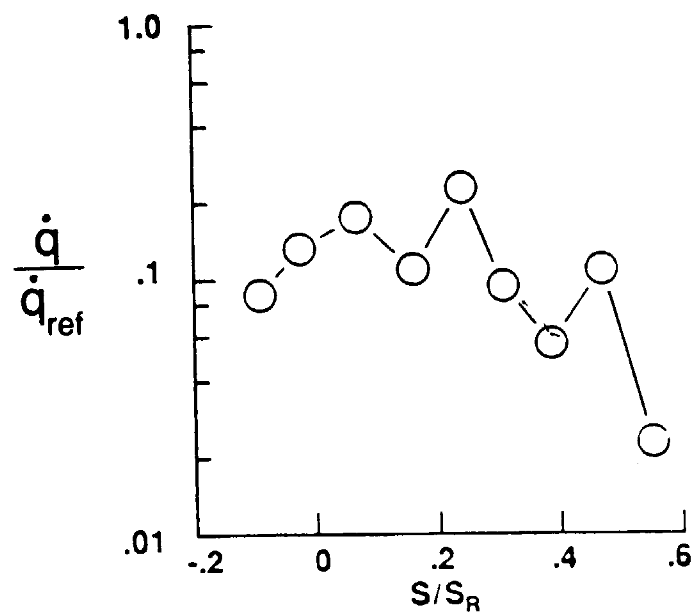
LaRC 8'HTT, M = 6.6, α = 10°

Model

Tile Array



Circumferential Gap Heating Distribution



IX PUBLICATIONS AND PRESENTATIONS

IX PUBLICATIONS AND PRESENTATIONS

The FY 1989 accomplishments resulted in a number of publications and presentations. They are listed below as Formal Reports, High-Numbered Technical Memorandums and Conference Publications, Contractor Reports, Journal Articles and Other Publications, Meeting Presentations, Technical Talks, Computer Programs, Tech Briefs, Patents, and Special Documents (NASP).

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Stroud, W. J.; Housner, J. M.; Tanner, J. A.; and Hayduk, R. J. (Editors): Computational Methods for Structural Mechanics and Dynamics. NASA CP-3034, Part 1, May 1989

Stroud, W. J.; Housner, J. M.; Tanner, J. A.; and Hayduk, R. J. (Editors): Computational Methods for Structural Mechanics and Dynamics. NASA CP-3034, Part 2, May 1989

Sutter, T. R.; and Bush, H. G.: A Comparison of Two Trusses for the Space Station Structure. NASA TM-4093, March 1989

Young, C. P., Jr.; and Gloss, B. B. (Compilers): Second Workshop on Cryogenic Wind-Tunnel Models - Design and Fabrication. NASA CP-3010, October 1988

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Bush, H. G.; Lake, M. S.; Watson, J. J.; and Heard, W. L., Jr.: The Versatility of a Truss Mounted Mobile Transporter for In-Space Construction. NASA TM-101514, November 1988

Camarda, C. J.; and Haftka, R. T.: Development of High-Order Modal Methods for Transient Thermal and Structural Analysis. NASA TM-101548, February 1989

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Dorsey, J. T.; and Mikulas, M. M., Jr.: Preliminary Design of a Large Tetrahedral Truss/Hexagonal Heatshield Panel Aerobrake. NASA TM-101612, September 1989

Greene, W. H.; and Gray, C. E., Jr.: Structural Analysis of a Thermal Insulation Retainer Assembly. NASA TM-101580, July 1989

Greene, W. H.; and Haftka, R. T.: Reducing Distortion and Internal Forces in Truss Structures by Member Exchanges. NASA TM-101535, January 1989

Jackson, L. R.: An Accelerator Airplane Concept for Single-Stage-to-Orbit Flight. NASA TM-101563, September 1989

Jegley, D. C.: Effect of Adhesive Interleaving and Discontinuous Plies on Failure of Composite Laminates Subject to Transverse Normal Loads. NASA TM-101507, January 1989

Knight, N. F., Jr.; Gillian, R. E.; and Nemeth, M. P.: Nonlinear Shell Analyses of the Space Shuttle Solid Rocket Boosters. NASA TM-101546, January 1989

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Watson, J. J.; Heard, W. J., Jr.; Bush, H. G.; Lake, M. S.; Jensen, J. K.; Wallsom, R. E.; and Phelps, J. E.: Results of EVA/Mobile Transporter Space Station Truss Assembly Tests. NASA TM-100661, November 1988

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Hedgepeth, J. M.: PACTRUSS Support Structure for Precision Segmented Reflectors. NASA CR-181747, June 1989 (NAS1-17536, Astro Aerospace Corporation)

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Ho, T.; Matza, E. C.; Medford, J. E.; and Watabe, S.: Design Concept Study for NASP Control Surface. NASA CR-181713, November 1988 (NAS1-18462, LTV Missiles and Electronics Group)

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Blosser, M. L.; Nowak, R. J.; and Rothgeb, T. M.: Thermal-Structural Tests of a Water/Glycol Cooled Aluminum Panel. Presented at the NASA Workshop on Correlation of Hot Structures Test Data With Analysis, November 15-17, 1988, ARC-Dryden, Moffett Field, California

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Collins, T. J.; and Fichter, W. J.: Support Trusses for Large Precision Segmented Reflectors; Preliminary Design and Analysis. Presented at the SPIE 1989 Technical Symposium on Optics, Electro-Optics, and Sensors, March 27-31, 1989, Orlando, Florida

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15. Supplementary Notes

16. Abstract

This paper presents the Objectives, FY 1990 Plans, Approach, and FY 1990 Milestones for the Structural Mechanics Division's research programs. FY 1989 Accomplishments are presented where applicable. This information is useful in program coordination with other governmental organizations in areas of mutual interest.

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