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STRUCTURAL MECHANICS DIVISION RESEARCH AND TECHNOLOGY PLANS FOR FY 1989 AND ACCOMPLISHMENTS FOR FY 1988

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National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665-5225

RESEARCH AND TECHNOLOGY PLANS FOR FY 1989 AND ACCOMPLISHMENTS FOR FY 1988

BY KAY S. BALES

SUMMARY

The purpose of this report is to present the Structural Mechanics Division's research plans for FY 1989 and accomplishments for FY 1988. The work under each branch is shown by RTR Objectives, FY 1989 Plans, Approach, Milestones, and FY 1988 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. There have been significant changes in the organizational structure of the Division effective June 5, 1988. The Division was renamed Structural Mechanics (formerly Structures and Dynamics) and the dynamics work moved into the Structural Dynamics Division (formerly Loads and Aeroelasticity). Thermal Structures and Aerothermal Loads Branches were incorporated into the Division. The Structures Technology Program Office was created with Dr. John G. Davis, Jr., Head. Dr. Larry D. Pinson moved to the Structural Dynamics Division as Assistant Chief. Dr. Michael F. Card returned to Langley from his TDY assignment at Marshall. Dr. Clarence P. Young, Jr., returned to Systems Engineering Division effective February 1, 1989, and Dr. James H. Starnes, Jr., was selected Assistant Chief, SMD, effective March 1, 1989. Dr. Mark S. Shuart was selected Assistant Head, Structural Mechanics Branch, effective April 9, 1989, and Charles J. Camarda was selected Assistant Head, Thermal Structures Branch, effective May 7, 1989.

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

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I ORGANIZATION CHARTS

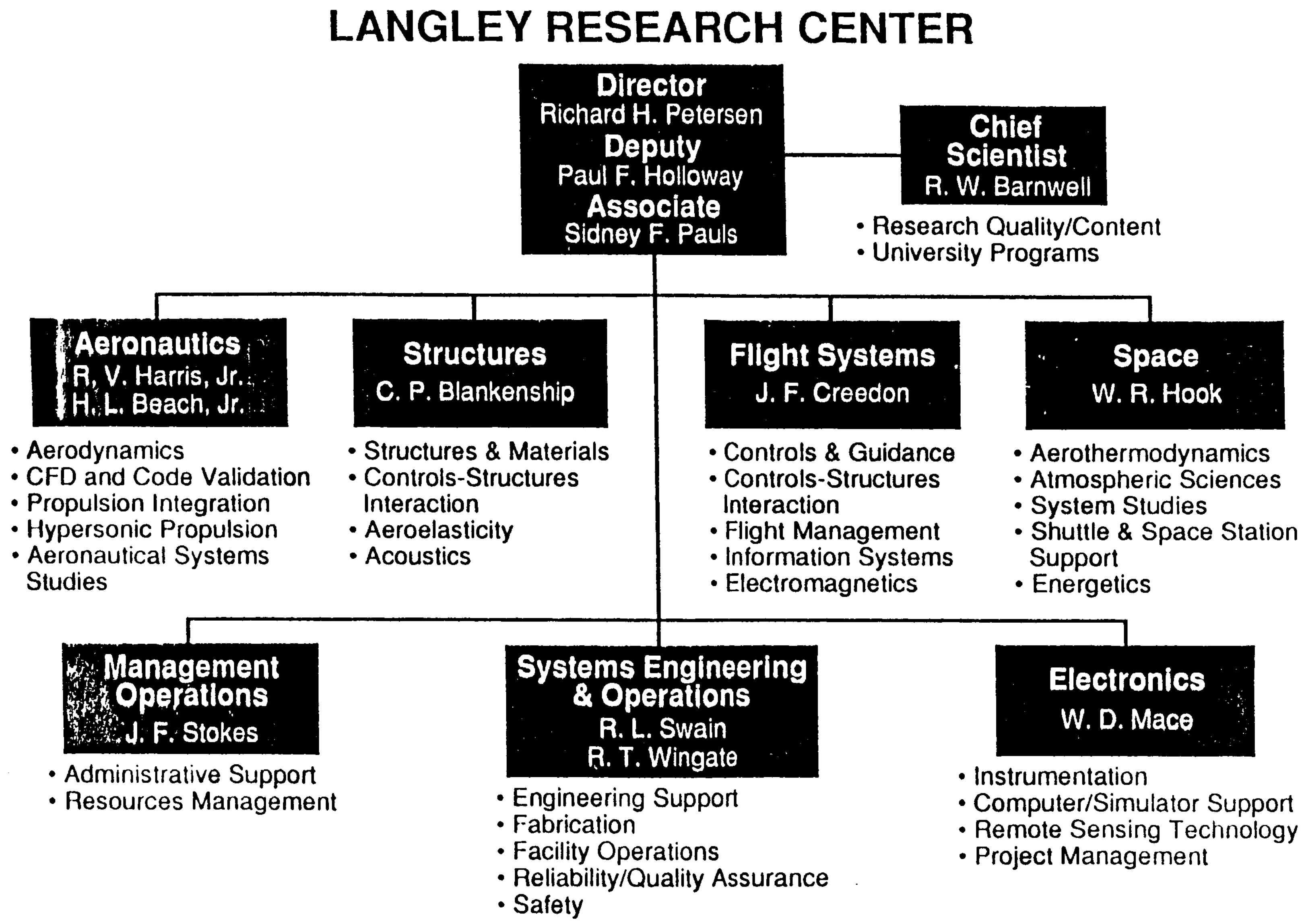
LANGLEY RESEARCH CENTER
Director
Richard H. Petersen
Deputy
Paul F. Holloway
Associate
Sidney F. Pauls
Chief Scientist
R. W. Barnwell
• Research Quality/Content
• University Programs
Aeronautics
R. V. Harris, Jr.
H. L. Beach, Jr.
• Aerodynamics
• CFD and Code Validation
• Propulsion Integration
• Hypersonic Propulsion
• Aeronautical Systems Studies
Structures
C. P. Blankenship
• Structures & Materials
• Controls-Structures Interaction
• Aeroelasticity
• Acoustics
Flight Systems
J. F. Creedon
• Controls & Guidance
• Controls-Structures Interaction
• Flight Management
• Information Systems
• Electromagnetics
Space
W. R. Hook
• Aerothermodynamics
• Atmospheric Sciences
• System Studies
• Shuttle & Space Station Support
• Energetics
Management Operations
J. F. Stokes
• Administrative Support
• Resources Management
Systems Engineering & Operations
R. L. Swain
R. T. Wingate
• Engineering Support
• Fabrication
• Facility Operations
• Reliability/Quality Assurance
• Safety
Electronics
W. D. Mace
• Instrumentation
• Computer/Simulator Support
• Remote Sensing Technology
• Project Management

Figure 1.

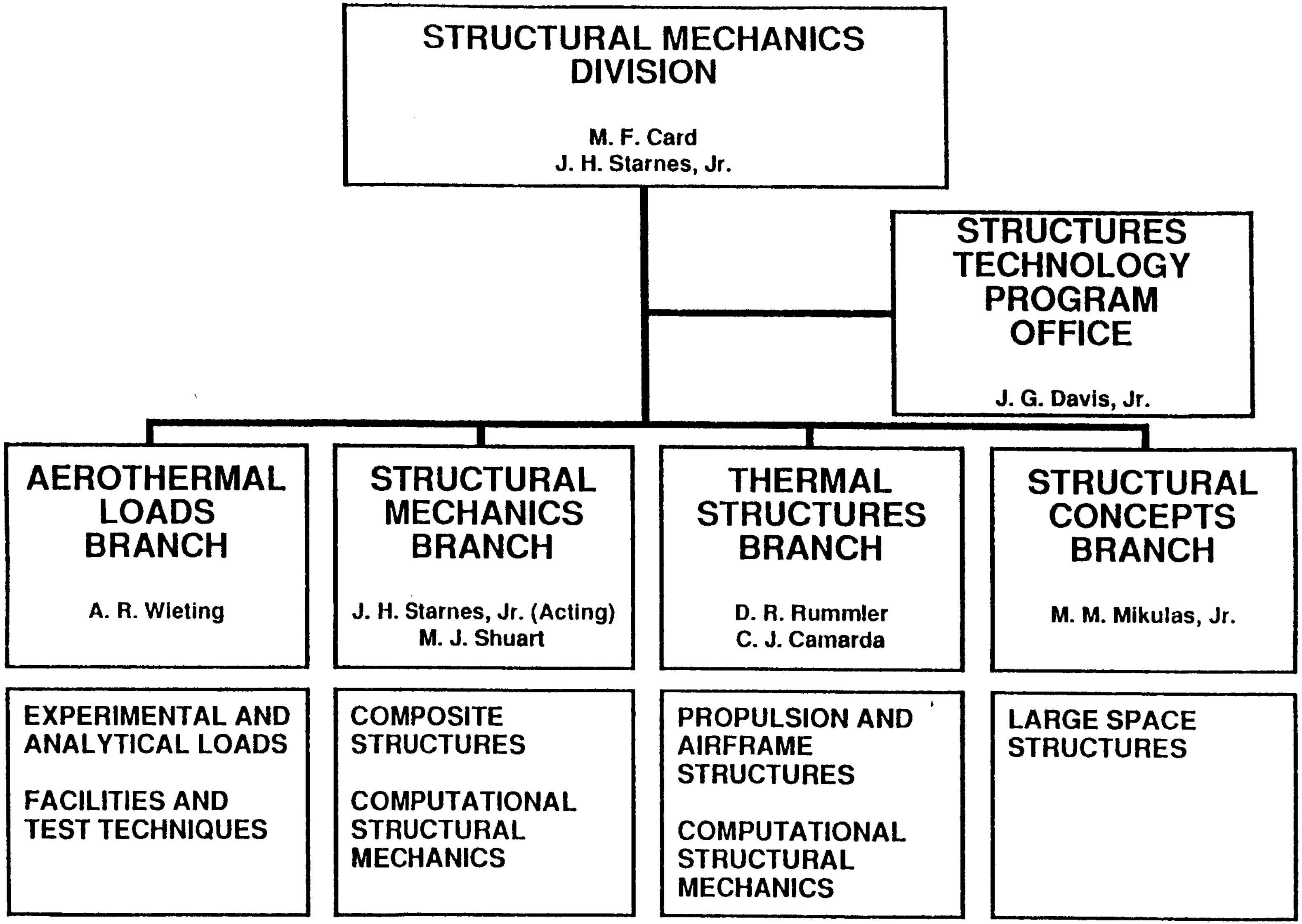
STRUCTURAL MECHANICS DIVISION
M. F. Card
J. H. Starnes, Jr.
STRUCTURES TECHNOLOGY PROGRAM OFFICE
J. G. Davis, Jr.
AEROTHERMAL LOADS BRANCH
A. R. Wieting
STRUCTURAL MECHANICS BRANCH
J. H. Starnes, Jr. (Acting)
M. J. Shuart
THERMAL STRUCTURES BRANCH
D. R. Rummler
C. J. Camarda
STRUCTURAL CONCEPTS BRANCH
M. M. Mikulas, Jr.
EXPERIMENTAL AND ANALYTICAL LOADS
FACILITIES AND TEST TECHNIQUES
COMPOSITE STRUCTURES
COMPUTATIONAL STRUCTURAL MECHANICS
PROPULSION AND AIRFRAME STRUCTURES
COMPUTATIONAL STRUCTURAL MECHANICS
LARGE SPACE STRUCTURES

Figure 2.

II FACILITIES

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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 new. The facility 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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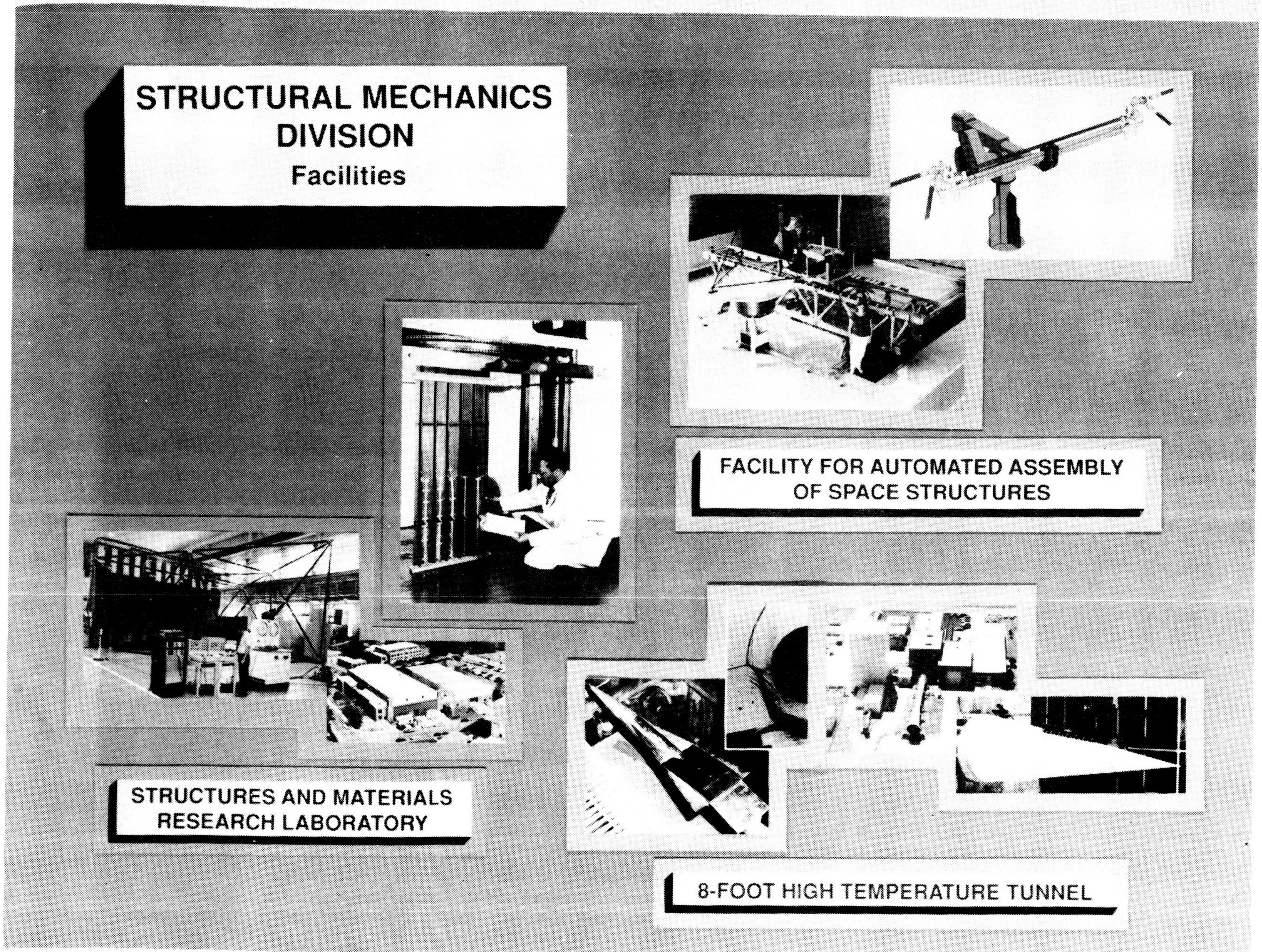

STRUCTURAL MECHANICS DIVISION
Facilities

FACILITY FOR AUTOMATED ASSEMBLY OF SPACE STRUCTURES

STRUCTURES AND MATERIALS RESEARCH LABORATORY

8-FOOT HIGH TEMPERATURE TUNNEL

Figure 3.

III STRUCTURES TECHNOLOGY PROGRAM OFFICE

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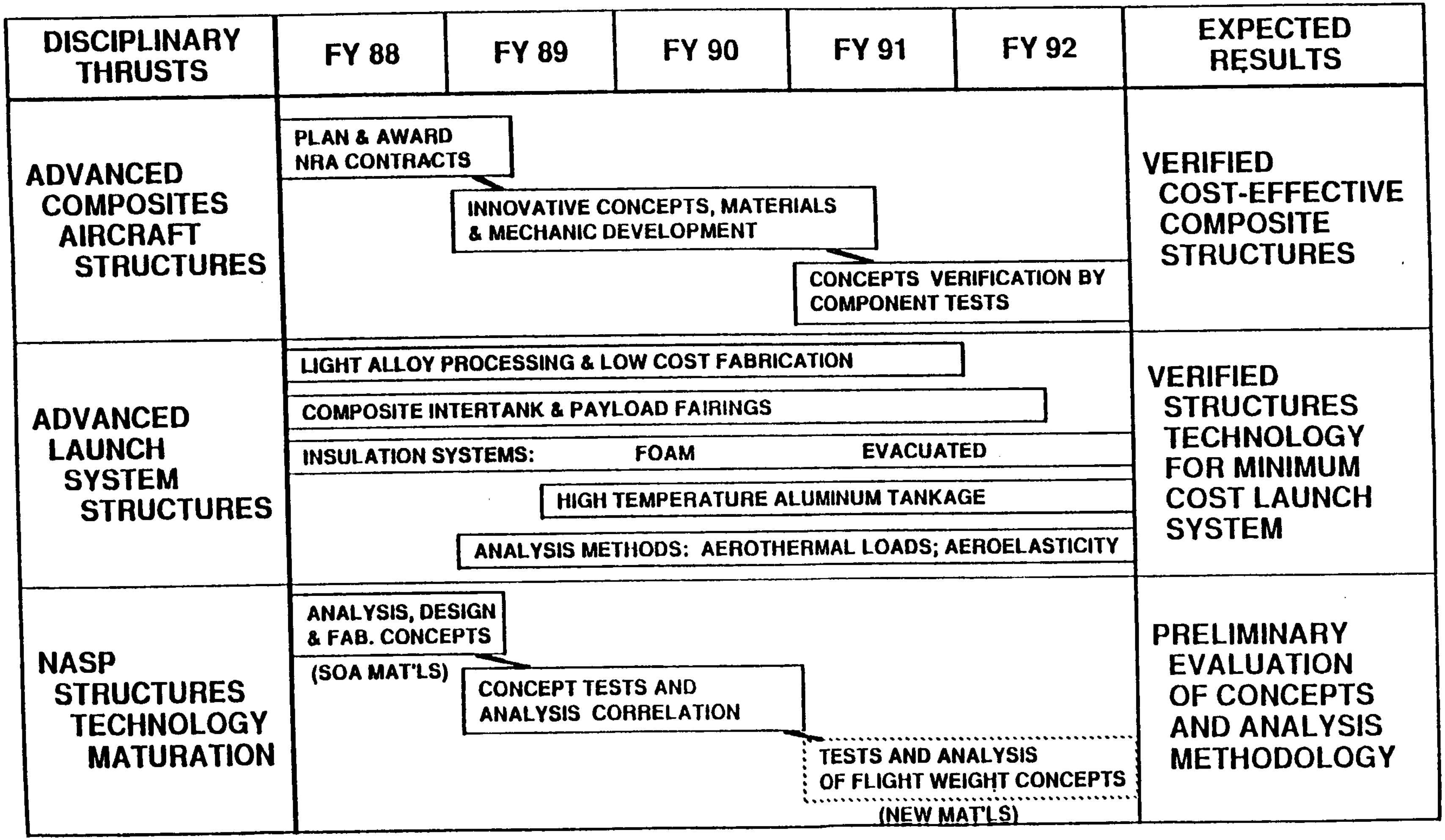
STRUCTURES TECHNOLOGY PROGRAM OFFICE
FIVE YEAR PLAN



DISCIPLINARY THRUSTS

FY 88

FY 89

FY 90

FY 91

FY 92

EXPECTED RESULTS

ADVANCED COMPOSITES AIRCRAFT STRUCTURES

PLAN & AWARD NRA CONTRACTS

INNOVATIVE CONCEPTS, MATERIALS & MECHANIC DEVELOPMENT

CONCEPTS VERIFICATION BY COMPONENT TESTS

VERIFIED COST-EFFECTIVE COMPOSITE STRUCTURES

ADVANCED LAUNCH SYSTEM STRUCTURES

LIGHT ALLOY PROCESSING & LOW COST FABRICATION

COMPOSITE INTERTANK & PAYLOAD FAIRINGS

INSULATION SYSTEMS: FOAM EVACUATED

HIGH TEMPERATURE ALUMINUM TANKAGE

ANALYSIS METHODS: AEROTHERMAL LOADS; AEROELASTICITY

VERIFIED STRUCTURES TECHNOLOGY FOR MINIMUM COST LAUNCH SYSTEM

NASP STRUCTURES TECHNOLOGY MATURATION

ANALYSIS, DESIGN & FAB. CONCEPTS

(SOA MAT'LS)

CONCEPT TESTS AND ANALYSIS CORRELATION

TESTS AND ANALYSIS OF FLIGHT WEIGHT CONCEPTS

(NEW MAT'LS)

PRELIMINARY EVALUATION OF CONCEPTS AND ANALYSIS METHODOLOGY

S[11/07/88]01-

III STRUCTURES TECHNOLOGY PROGRAM OFFICE

This Office was established to provide programmatic leadership and management support for focused structures technology development within the Structures Directorate for hypersonic cruise vehicles, advanced space transportation systems and advanced composite airframes for transport and military aircraft.

The logic chart reflects broad elements that encompass multiple organizations.

RTR 510-02-21-02 Advanced Composite Structures Technology Program

OBJECTIVE:

To develop and verify innovative structural concepts and their associated materials science and structural mechanics technologies that exploit the benefits of advanced organic-matrix composites materials for cost-effective wing and fuselage primary structures for future civil and military aircraft.

FY 1989 PLANS:

- Approval of program plan
- Award NRA contracts
- Hold integration workshops/meetings (DOD, Industry, Universities)
- Update consensus of state-of-the-art for composite primary structures

APPROACH:

Innovative structural concepts that utilize advanced materials, advanced material forms and processing methods, and advancements in structural mechanics will be developed and evaluated. Design and fabrication methodologies will be integrated at the beginning of concept definition and development. Critical structural mechanics, materials and processing problems/issues will be defined on the basis of analytical evaluation of the concepts. Detailed structural mechanics analyses will be performed on areas where large stress gradients are predicted. Coupon, subelement and subcomponent articles will be designed, fabricated and tested to verify the material science and structural mechanics technologies and concept performance.

Proposals from fifteen contractors have been selected for negotiation to develop new materials, new material forms, characterize new materials, develop and/or evaluate manufacturing methods, develop innovative concepts and to develop the associated structural mechanics foundation.

MILESTONES:

- Program plan approved, February 1989
- Complete award of NRA-87-LaRC-2 contracts, March 1989
- Conduct contractor/Government workshop, April 1989

FY 1988 ACCOMPLISHMENTS:

- Selected fifteen NRA-87-LaRC-2 proposals for negotiation
- Established STPO to manage/coordinate multiple contract efforts

RTR 763-01-41-12 4.8.2 Airframe Seals

OBJECTIVE:

To develop viable seals for control surfaces and doors, develop analytical methods for design, develop manufacturing processes, and verify concepts by analysis and test.

FY 1989 PLANS:

- Complete tests and analysis of in-house and contractor seals specimens at medium temperature Mach 6
- Complete design, thermal analysis, and fabrication of in-house and contractor seals specimens at high temperature

APPROACH:

Coordinate with priced option contractors (4.8.3 and 4.8.4) to provide and utilize analysis methods, identify and resolve design and manufacturing problems, and provide adequate test facilities and techniques.

MILESTONES:

- Complete medium temperature Mach 6 tests, February 1989
- Complete medium temperature Mach 6 test analysis, June 1989
- Complete high temperature test article design, June 1989
- Complete high temperature test article thermal analysis, June 1989
- Complete high temperature test article fabrication, September 1989

FY 1988 ACCOMPLISHMENTS:

- Completed medium temperature test model design
- Completed medium temperature test model blockage tests
- Completed medium temperature test model thermal analysis
- Completed medium temperature test model flow analysis

ALS MATERIALS AND STRUCTURES

FY 1989 PLANS:

ANALYSIS:

- Extend LARCNESS to 3-D
- Prepare structural and dynamic math models of fly-back booster

Al-Li AND ADVANCED PROCESSING:

- Complete design trade-offs to select candidate SPF skin-stiffener concepts
- Select Al alloy compositions for skin and SPF stiffeners

HIGH-TEMPERATURE ALUMINUM:

- Property and process characterization of weldalite and XD weldalite material

INSULATION SYSTEMS:

- Verify performance of internal foam system
- Fabricate and test evacuated H/C insulation

FY 1988 ACCOMPLISHMENTS:

- Program plan approved and resources released

ANALYSIS:

- Adaptive, unstructured mesh generator (LARCNESS) operational for 2-D fluid analysis problems

INSULATION SYSTEMS:

- Cyclic performance of high-temperature (400°F) external foam verified with LHe temperatures

HIGH-TEMPERATURE ALUMINUM:

- Completed extensive property and process characterization Al-Fe-V-Si Alloy

AL-LI AND ADVANCED PROCESSING:

- Superplastic forming of isogrid demonstrated

NASP STRUCTURES TECHNOLOGY MATURATION

FY 1989 PLANS:

PLAN AND COORDINATE TMP:

- Leverage TMP with consortium tasks results
- Keep TMP Director and JPO informed on state-of-the-art
- Push for OGL requests and beyond FY 1990 program
- Highlight NASA laboratory results used by contractors

FY 1988 ACCOMPLISHMENTS:

PLANNED AND COORDINATED TMP:

- Established FY 1989 budget
- Developed team consensus
- Provided technical direction to priced option contracts
- Highlighted technology deficiencies to TMP Director
- Organized and conducted sessions at 4th and 5th symposia
- Reported progress to JPO

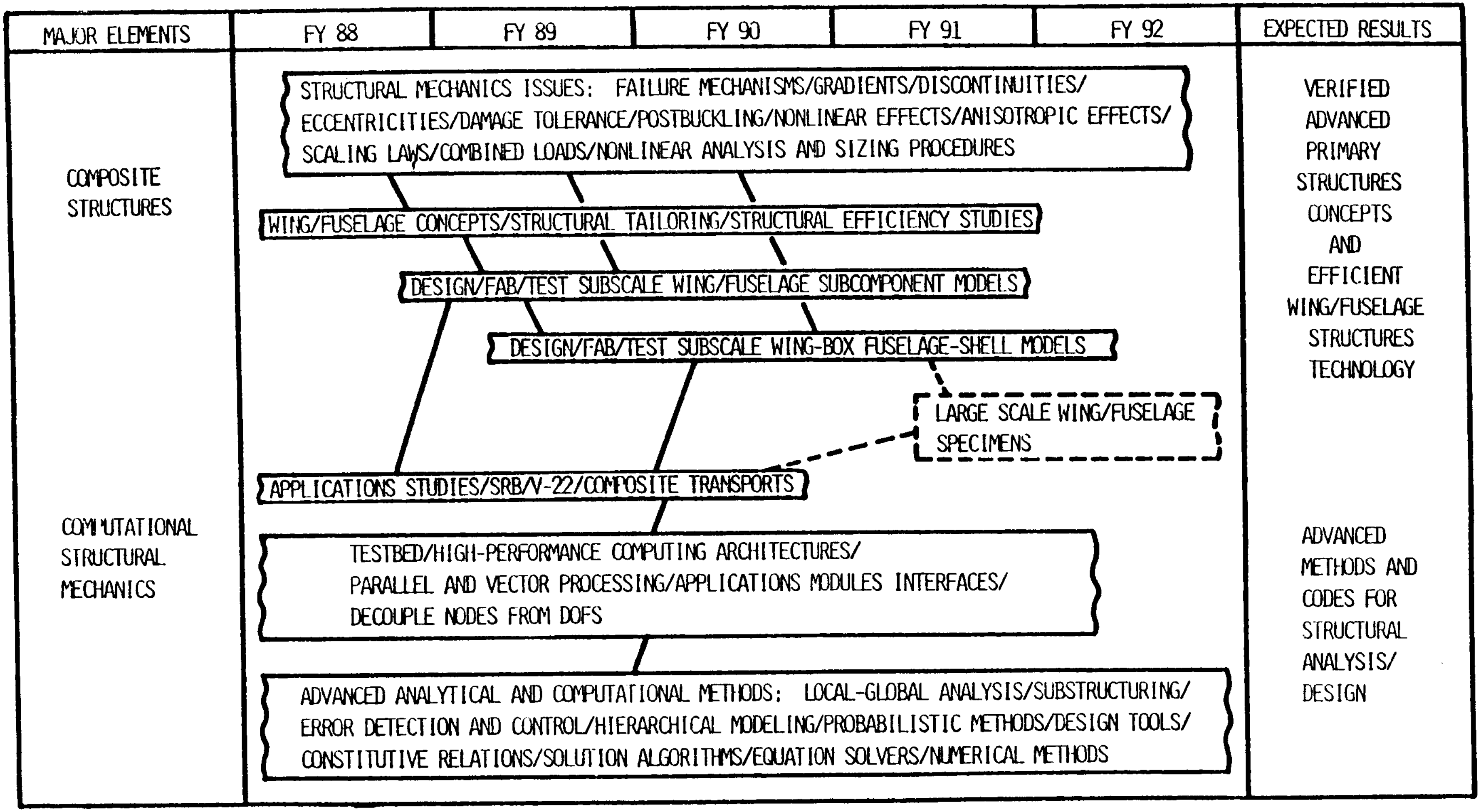
- Supported search for facilities and associated issues

DIRECTED STRUCTURAL CERTIFICATION REQUIREMENTS STUDY:

- Defined areas requiring research and development
- Defined test capability needs

IV STRUCTURAL MECHANICS BRANCH

STRUCTURAL MECHANICS BRANCH



MAJOR ELEMENTS

FY 88

FY 89

FY 90

FY 91

FY 92

EXPECTED RESULTS

COMPOSITE STRUCTURES

STRUCTURAL MECHANICS ISSUES: FAILURE MECHANISMS/GRADIENTS/DISCONTINUITIES/ ECCENTRICITIES/DAMAGE TOLERANCE/POSTBUCKLING/NONLINEAR EFFECTS/ANISOTROPIC EFFECTS/ SCALING LAWS/COMBINED LOADS/NONLINEAR ANALYSIS AND SIZING PROCEDURES

WING/FUSELAGE CONCEPTS/STRUCTURAL TAILORING/STRUCTURAL EFFICIENCY STUDIES

DESIGN/FAB/TEST SUBSCALE WING/FUSELAGE SUBCOMPONENT MODELS

DESIGN/FAB/TEST SUBSCALE WING-BOX FUSELAGE-SHELL MODELS

LARGE SCALE WING/FUSELAGE SPECIMENS

APPLICATIONS STUDIES/SRB/V-22/COMPOSITE TRANSPORTS

VERIFIED ADVANCED PRIMARY STRUCTURES CONCEPTS AND EFFICIENT WING/FUSELAGE STRUCTURES TECHNOLOGY

COMPUTATIONAL STRUCTURAL MECHANICS

TESTBED/HIGH-PERFORMANCE COMPUTING ARCHITECTURES/ PARALLEL AND VECTOR PROCESSING/APPLICATIONS MODULES INTERFACES/ DECOUPLE NODES FROM DOFS

ADVANCED ANALYTICAL AND COMPUTATIONAL METHODS: LOCAL-GLOBAL ANALYSIS/SUBSTRUCTURING/ ERROR DETECTION AND CONTROL/HIERARCHICAL MODELING/PROBABILISTIC METHODS/DESIGN TOOLS/ CONSTITUTIVE RELATIONS/SOLUTION ALGORITHMS/EQUATION SOLVERS/NUMERICAL METHODS

ADVANCED METHODS AND CODES FOR STRUCTURAL ANALYSIS/ DESIGN

IV STRUCTURAL MECHANICS 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. Develops efficient structural concepts that exploit the benefits of composite materials for advanced aircraft structural components. Typical investigations concern stability, strength, damage tolerance, and tailoring of structures made of composite materials. Special emphasis is focused on identification of structural deformations and failure modes, development of verified failure analysis, development of structurally-efficient composite structural concepts, and prediction of nonlinear structural response phenomena. Develops advanced computational structural mechanics analysis methods to exploit predicted future computer hardware architecture. Conceives new static and dynamic test techniques and uses the Structures and Materials Research Laboratory.

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 1989 PLANS:

- Develop modal interaction capability for nonlinear structural analysis

APPROACH:

In FY 1989 emphasis is on anisotropic plate and shell analyses and modal interaction for nonlinear structural analysis. Structural mechanics issues of advanced concepts for composite structural components will be studied analytically and experimentally. Mechanical and pressure 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 equivalence transformation for nonlinear shell problems with multiple modes and expand modal interaction capability for nonlinear structural analysis problems in STAGS, October 1988
- Initiate study of nonlinear materials and viscoelastic effects on compression-loaded composites with discontinuities, January 1989
- Complete development of VICON analysis for curved composite panels with transverse stiffeners, April 1989

- Conduct study of bending boundary layer attenuation lengths for anisotropic structures, June 1989
- Complete study of skin-stiffener interface stress analysis for problems with transverse bending, September 1989
- Complete study of cross-sectional warping of nonlinear stiffened composite panels, September 1989

FY 1988 ACCOMPLISHMENTS:

- Initial study of cross-sectional warping on nonlinear behavior of stiffened composite compression panels indicates that stiffener flange anisotropy causes larger deflections and higher stresses than orthotropic flanges
- Completed SRB ET attachment ring analysis. Identified effect of joint tailoring on bolt failure sequence
- Geometric imperfections included in recontinuization method for error analysis for nonlinear plate problems. Method provides accurate prediction for transverse shear forces as well as error estimates for shear and moments.
- Completed and implemented into STAGS development of equivalence transformation for multiple modes
- Initiated VICON analysis for curved composite panels with transverse stiffeners and studies of anisotropic plates and shells
- Completed preliminary structural efficiency study of composite rib concepts subjected to shear and compression

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 material systems and fabrication procedures for advanced-composite airframe primary structural components.

FY 1989 PLANS:

- Evaluate stiffened thermoplastic compression panel concepts
- Study eccentricity effects caused by stiffener run out in composite compression panels

APPROACH:

In FY 1989 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 and pressure 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:

- Evaluate effectiveness of selective adhesive interleaving concept for increasing residual compression strength of minimum-weight graphite-epoxy laminates with impact damage, November 1988
- Complete evaluation of Protection and Detection System (PADS) for low-speed impact-damage threat to heavily-loaded graphite-epoxy compression panels, December 1988
- Complete design studies of high-aspect-ratio aeroelastically-tailored transport wings and define critical subcomponent test specimens for subsequent fabrication and testing, January 1989
- Evaluate the performance of hat-, blade- and T-stiffened graphite-thermoplastic compression panel specimens. The T-stiffened panels will be made of LaRC-TPI at Langley Research Center, March 1989
- Initiate study of molded graphite-thermoplastic structural details for advanced subcomponent concepts, April 1989
- Develop structurally-efficient stiffener run-out concepts for graphite-epoxy compression panels and fabricate and test specimens to evaluate the concepts, May 1989
- Complete preliminary structural-efficiency study of composite transport-wing ribs subjected to combined compression, shear and fuel pressure loadings. Initiate detailed study of effects of finite-length effects on rib structural efficiency, rib-cover joint-stiffness requirements, and nonlinear effects due to pressure loading, June 1989
- Complete development of POSTOP II postbuckled panel design optimization code that accounts for nonlinear torsional flexural stiffener behavior, July 1989
- Initiate study of structurally-tailored graphite-epoxy cylindrical shells, August 1989
- Complete assembly and test of graphite-epoxy C-130 center-wing-box technology-integration box beam, September 1989

FY 1988 ACCOMPLISHMENTS:

- Successfully fabricated and tested filament-wound, graphite-epoxy geodesically-stiffened spar based on C-130 center-wing-box design. Response predicted analytically
- Fabricated and tested graphite-epoxy three-J-stiffener pultruded wing plank based on C-130 center-wing-box design to evaluate performance and damage tolerance

- Completed design of graphite-epoxy C-130 center-wing-box technology-integration box beam and Critical Design Review held July 13, 1988. Selected design concepts for covers and spars

- Completed SRB ET attachment ring joint analysis and drafted documentation. Initiated analysis of STA-3 test to identify SRB buckling characteristics in bending

- Completed designs of 5 hat-stiffened and 1 blade-stiffened graphite-thermoplastic panels. Fabrication of specimens under way for subsequent testing

- Identified analytically effects of axial compression and external pressure on buckling of thick-walled graphite-epoxy cylindrical shells

- Completed and verified by experiment development of compression failure analysis for multi-directional laminates

- Identified adhesive interleaving as an effective concept for raising the compression strength of graphite-epoxy structures with dropped-ply thickness discontinuities

- Identified stiffener crippling failure mechanisms for graphite-epoxy stiffeners

- Formulated structural tailoring procedure for stiffened composite panels with cutouts

RTR 505-63-01-10 Computational Structural Mechanics

OBJECTIVE:

To develop advanced structural analysis and computational methods that exploit advanced computer hardware, and develop research testbed software system for structural analysis.

FY 1989 PLANS:

- Study error analysis and correction techniques for detailed stress analysis

- Study hierarchical and substructuring structural analysis techniques for aircraft structures

- Develop large-scale modeling plans; e.g., V-22 or composite transport

APPROACH:

In FY 1989 emphasis will be on developing error analysis techniques that can be used to detect and control analysis errors during detailed stress analysis of composite structures. Methods research will emphasize procedures that exploit multiple vector processor computers. To aid in the methods development research, a testbed system will be created. It will consist initially of software for Langley's VAX and FLEX computers and NASA's NAS computers and will then be installed on other powerful multiple vector processor computers for evaluating methods on large, complex problems. This software system will be aimed at the computers and aerospace structural analysis problems of the 1990's and beyond.

MILESTONES:

- Publish program developer's document describing procedure for installing new modules in testbed, January 1989

- Develop and demonstrate a problem decomposition technique suitable for parallel computation of stress distributions in composite structures, May 1989
- Demonstrate prototype of parallel data manager for testbed on new CSM MIMD computer, May 1989
- Demonstrate an error detection and control technique for stress calculations in composite structures, September 1989
- Initiate research program on two new composites focus problems, September 1989

FY 1988 ACCOMPLISHMENTS:

- Documented analysis of SRB aft skirt, SRB/ETA ring, and SRB shell with memorandums, publications, and presentations
- Demonstrated capability to use PATRAN as testbed post processor. Color used to indicate stress intensity
- Developed capability for solving global/local stress analysis problems when deformations are inplane.
- Developed new vector equation solvers for NAS Cray 2 that reduced solution time by up to a factor of 25 compared with existing scaler solver
- Used FORCE (rather than PISCES) to aid transfer of parallel equation solvers from Flex computer to NAS Cray 2. These solvers were then used to carry out performance studies on NAS

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 1989 PLANS:

- Award contracts and grants for structural concepts and structural mechanics innovative primary composite structures

APPROACH:

In FY 1989 emphasis is 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 for future primary structures application and verified experimentally. 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. Subcomponent interaction, failure mechanisms and analyses, damage tolerance and containment, buckling, postbuckling, and other nonlinear effects for these new structural concepts will be studied analytically and experimentally.

Scaling laws for composites will be developed to enable research subscale laboratory models of wing boxes and fuselage shells to be extrapolated to full-scale designs.

MILESTONES:

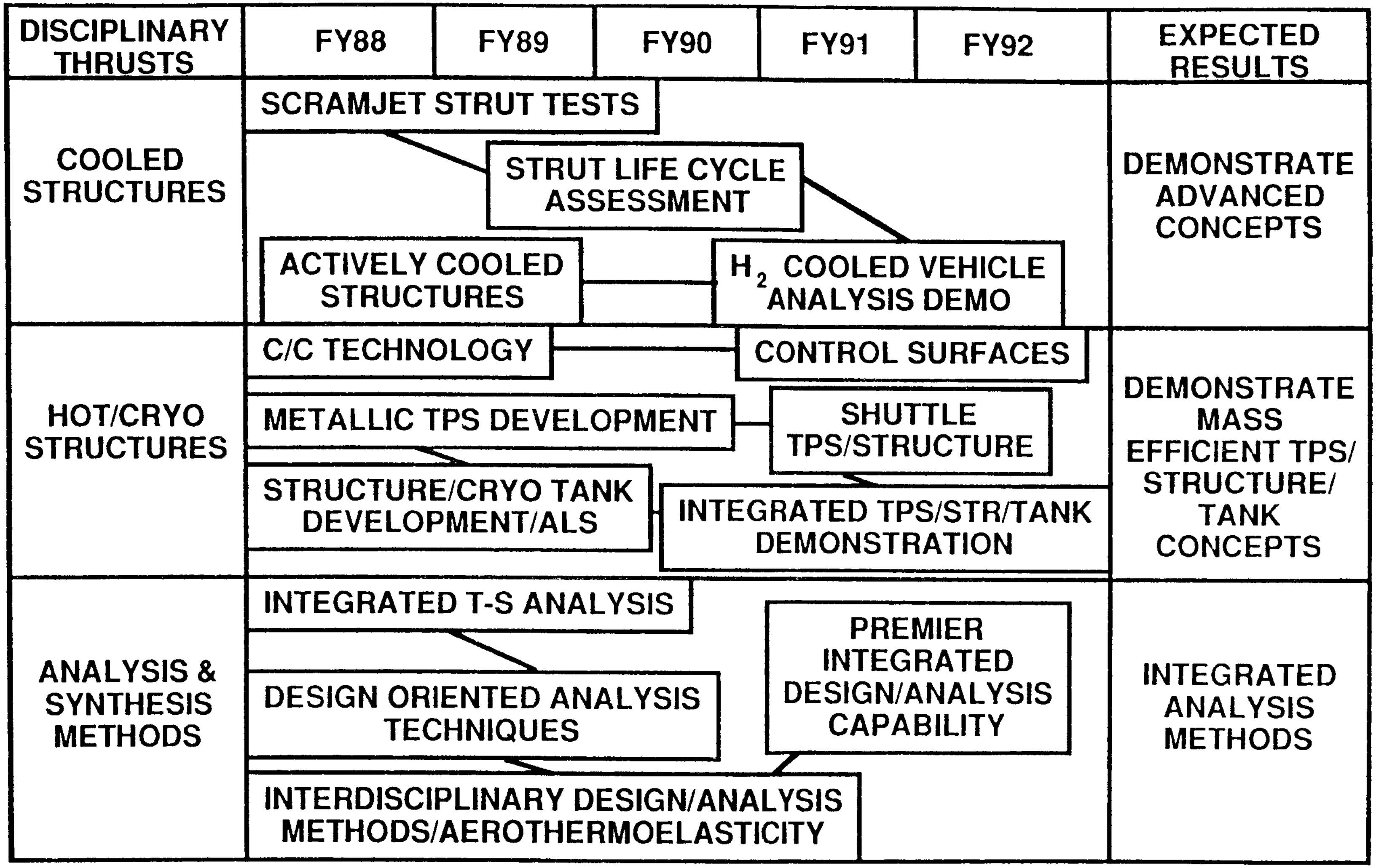
- Award structural concepts and structural mechanics contracts and grants for innovative primary composite structures, June 1989
- Initiate design of advanced rib, spar and cover panel concepts, July 1989
- Initiate design of structurally-tailored advanced concept wing-box models, August 1989
- Initiate design of advanced fuselage frame and shell-wall concepts, September 1989

FY 1988 ACCOMPLISHMENTS:

- Selected fifteen NRA-87-LaRC-2 proposals for negotiation

V THERMAL STRUCTURES BRANCH

THERMAL STRUCTURES
FIVE YEAR PLAN



DISCIPLINARY THRUSTS

FY88

FY89

FY90

FY91

FY92

EXPECTED RESULTS

COOLED STRUCTURES

SCRAMJET STRUT TESTS

STRUT LIFE CYCLE ASSESSMENT

ACTIVELY COOLED STRUCTURES

H_2 COOLED VEHICLE ANALYSIS DEMO

DEMONSTRATE ADVANCED CONCEPTS

HOT/CRYO STRUCTURES

C/C TECHNOLOGY

CONTROL SURFACES

METALLIC TPS DEVELOPMENT

SHUTTLE TPS/STRUCTURE

STRUCTURE/CRYO TANK DEVELOPMENT/ALS

INTEGRATED TPS/STR/TANK DEMONSTRATION

DEMONSTRATE MASS EFFICIENT TPS/ STRUCTURE/ TANK CONCEPTS

ANALYSIS & SYNTHESIS METHODS

INTEGRATED T-S ANALYSIS

DESIGN ORIENTED ANALYSIS TECHNIQUES

PREMIER INTEGRATED DESIGN/ANALYSIS CAPABILITY

INTERDISCIPLINARY DESIGN/ANALYSIS METHODS/AEROTHERMOELASTICITY

INTEGRATED ANALYSIS METHODS

V THERMAL STRUCTURES BRANCH

This Branch conceives structural concepts for future high-speed aircraft and space transportation systems including primary airframe structures, reusable cryogenic tanks, thermal protection systems, for both acreage and stagnation heating areas and structures for airbreathing hypersonic propulsion systems. Verifies promising concepts via analyses and tests in various high temperature and cryogenic facilities. Develops new analysis and test techniques as required to verify advanced concepts.

RTR 505-63-31-03 Hypersonic Structures

OBJECTIVE:

To develop and evaluate actively cooled structural concepts for hydrogen-fueled scramjet engines which operate at speeds in excess of Mach 5, and to develop high-temperature test capability.

FY 1989 PLANS:

- Complete fabrication of flight-weight strut

APPROACH:

In FY 1989 emphasis is on performance of actively cooled structures. Fabricate under contract a full-size, flightweight fuel-injection 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. Reactivate actively cooled test stand (ACTS) apparatus for glycol-cooled structural testing. Develop LH2 capability for active cooling.

MILESTONES:

- Complete fabrication of flightweight strut, June 1989
- Complete testing of stainless steel strut, September 1989

FY 1988 ACCOMPLISHMENTS:

- Reactivated ACTS apparatus
- Completed Rockwell International Corp. cooled panels tests
- Designed heat exchanger specimen for National Bureau of Standards (NBS) tests
- Completed fabrication of copper calibration strut

RTR 505-80-31-01 4.2.4.2 Engine Walls

OBJECTIVE:

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

FY 1989 PLANS:

Develop actively cooled apparatus at NIST (National Institute of Standards and Technoloyg) (formerly National Bureau of Standards) and complete initial tests

APPROACH:

In FY 1989 emphasis will be on developing the capability to test engine heat exchanger specimens at NIST. After completion of detailed analysis of candidate concepts, an engine wall 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 LeRC. Fabricate and test flightweight engine strut which includes actively cooled walls.

MILESTONES:

- Complete initial pin-fin heat exchanger testing, March 1989
- Initiate channel heat exchanger tests, June 1989
- Complete initial flow tests on strut, September 1989

FY 1988 ACCOMPLISHMENTS:

- Delivered engine heat exchanger thermal/structural optimizer code to engine companies
- Developed heat exchanger test apparatus at NBS
- Designed nozzles for film cooling experiments to maximize engine cooling effectiveness

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 1989 PLANS:

- Complete thermoelastic tests on curved TPS panels

APPROACH:

For FY 1989 the primary emphasis will be on the performance of passively cooled thermal structures. Perform studies of attractive structural concepts and validate 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 (thermal protection system) TPS concepts, June 1989
- Demonstrate improved transfinite element-thermostructural analysis, June 1989
- Develop radiation element for hierarchical conduction elements, June 1989

FY 1988 ACCOMPLISHMENTS:

- Delivered improved view factor analysis code
- Refurbished and upgraded ACTS; completed Rockwell International Corp. water cooled panel tests
- Completed design and fabrication of test fixture for thermal stress tests of curved TPS panel at Dryden Flight Research Facility
- Completed finite element model (FEM) for curved TPS

RTR 506-49-11-05 Thermostructural Concepts for Planetary Entry Vehicles

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 1989 PLANS:

- Complete equivalent shell analysis development

APPROACH:

In FY 1989 emphasis will be on development of equivalent shell analysis. Support in-house studies to identify critical structures and materials technologies. Perform studies of attractive thermostructural concepts.

MILESTONES:

- Complete development of conceptual weight analysis code, June 1989
- Initiate vehicle conceptual studies, June 1989
- Complete first version of "SMART" vehicle systems analysis, September 1989

FY 1988 ACCOMPLISHMENTS:

- Completed design study of heat-pipe-cooled leading edges for hypersonic vehicles
- Designed and initiated fabrication of a Shuttle II leading edge heat pipe

RTR 506-80-31-01 4.6.1 Control Surfaces for Very High Temperatures

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 1989 PLANS:

- Fabricate and test carbon/carbon control surface subcomponents

APPROACH:

In FY 1989 the primary emphasis is on design and fabrication of a carbon/carbon control surface test article. 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 detail analysis and design, December 1988
- Initiate complete fabrication of full-scale segment, March 1989
- Define test and evaluation plan, September 1989
- Fabricate and test subelement components, September 1989

FY 1988 ACCOMPLISHMENTS:

- Completed concept design study of control surfaces
- Initiated high-temperature carbon/carbon fastener program
- Initiated detailed design and analysis of control surface concept
- Completed tests and analysis of carbon/carbon stiffened compression panels and shear panels

RTR 506-80-31-04 and RTR 763-01-41-18 4.7.6 Mechanics of Hot Structures

OBJECTIVE:

To develop improved analytical capability to predict local and global temperature distribution in vehicle structure and to predict structural response to combined thermal and mechanical loads.

FY 1989 PLANS:

- Complete thermal discretization study

APPROACH:

In FY 1989 emphasis is on the development of approximate analysis codes for conceptual vehicle studies. Systematically refine analytical model to hypersonic aircraft structures and determine the level of detail necessary to get usable results. Develop improved thermal/structural analysis capability, including the effects of joints. Verify improved methods by comparing results with available test results.

MILESTONES:

- Complete initial development of structural finite elements for LIFTS, September 1989

- Complete global thermal stress analyses mods for "SMART"
- Complete thermal stress discretization study

FY 1988 ACCOMPLISHMENTS:

- Developed Sizing and Optimization Language (SOL) to improve implementation of formal thermostructural optimization
- Demonstrated feasibility of equivalent plate theory application to fuselage structure
- Version 1.0 of METCAN released by NASA LeRC for metallic matrix composite analysis
- Developed 3-D hierarchical conduction element in SPAR

RTR 763-01-41-13 4.5.1 Cryogenic Insulation

OBJECTIVE:

To define the cryogenic insulation design requirements and criteria necessary to meet the NASP mission and develop an insulation system to meet the requirements.

FY 1989 PLANS:

- Complete developmentof high delta T thermal conductivity apparatus

APPROACH:

In FY 1989 emphasis is on development of a high delta temperature calorimeter. Determine insulation requirements for each wall configuration under consideration. Candidate insulations include existing cryogenic foams, evacuated superinsulations, and evaluated multiwall and new ideas such as fibrous insulations with reflectively coated fibers. Insulations will be studied in detail to select the most promising. Manufacturing developments effort will include small test items to address key issues. If evacuation is necessary, considerable effort may be required to develop techniques to fabricate foil encapsulated insulations which maintain an acceptable thermal conductivity over the life of the vehicle. Panel sized specimens will be fabricated and subjected to cyclic thermal and structural tests.

MILESTONES:

- Complete initial liquid hydrogen conductivity tests of evacuated honeycomb, March 1989
- Complete manufacturing development of cryo insulation system, September 1989

FY 1988 ACCOMPLISHMENTS:

- Developed thermal conductivity apparatus for cryogenic (LHe) insulation systems tests (NBS)
- Established feasibility of evacuated, foil gage honeycomb cryogenic insulation

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 actively cooled design concepts.

FY 1989 PLANS:

- Complete design of carbon/carbon refractory metal heat pipe

APPROACH:

In FY 1989 emphasis is on the design of a carbon/carbon heat pipe. Design, fabricate and test a carbon/carbon refractory metal heat pipe leading edge. Verify analytical methods by testing a 6-ft. liquid metal heat pipe designed for Shuttle II by McDonald Douglas Corp. (MDC)

MILESTONES:

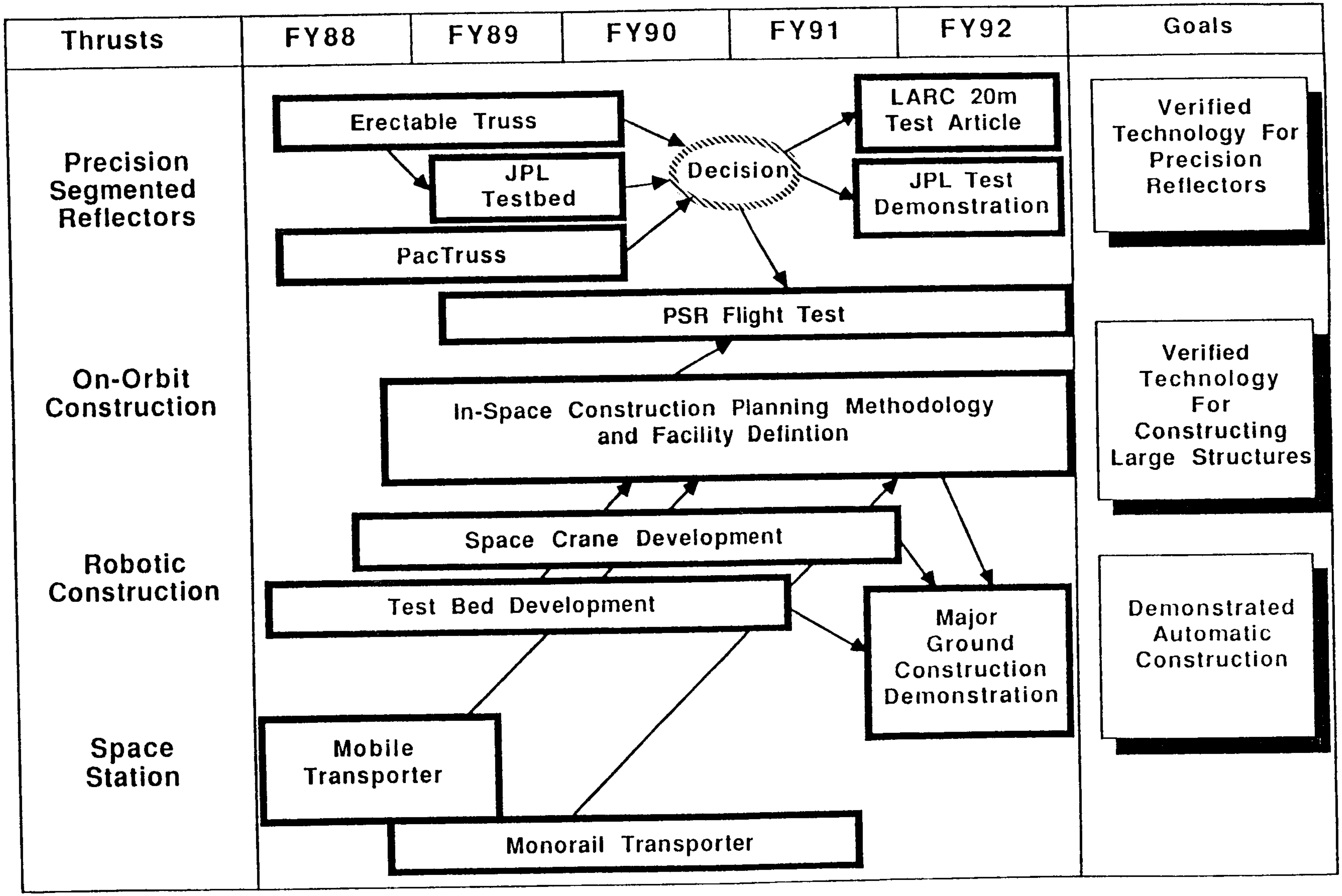
- Initiate testing of MDC heat pipe, March 1989
- Complete design, September 1989
- Begin fabrication, September 1989

FY 1988 ACCOMPLISHMENTS:

- FY 1989 new start

VI STRUCTURAL CONCEPTS BRANCH

ADVANCED SPACE CONCEPTS



VI STRUCTURAL CONCEPTS BRANCH

This Branch develops structures technology required to design future space systems including platforms, antennas, and space station. Research encompasses structural concepts, packaging, deployment, erection, and in-space construction. 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 1989 PLANS:

- Support NASA JSC WETF (Weightless Environmental Training Facility) Mobile Transporter simulator tests
- Conduct truss accuracy analysis and design studies
- Conduct automated assembly tests of precision reflector truss

APPROACH:

In FY 1989 the main focus will be static and dynamic testing of a two-ring truss robotically constructed of 2-meter struts. Individual joints will also be tested and all results will be correlated with analysis. Continued emphasis will be placed on computer-aided design aids for structures.

MILESTONES:

- Static and dynamic tests of robotically assembled truss, February 1989
- Correlation of above test results with analysis, April 1989
- Fabricate and test all-composite erectable joint, June 1989
- Develop concept for a monorail astronaut mover, September 1989

FY 1988 ACCOMPLISHMENTS:

- Completed, installed, and tested a Mobile Transporter simulator for JSC WETF
- Completed ground test of Mobile Transporter
- Completed 1-g tests of Mobile Transporter
- Installed Mobile Transporter in NASA MSFC Neutral Buoyancy Simulator (NBS)
- Conducted simulated 0-g test in MSFC NBS
- Developed 1-inch robotic compatible joint for automated assembly of high accuracy truss support structures

RTR 585-01-31-01 Precision Reflector Structures

OBJECTIVE:

To develop deployable and erectable structural concepts for precision reflectors.

FY 1989 PLANS:

- Fabricate 2-ring erectable truss with dynamic and accuracy tests and provide to Jet Propulsion Lab (JPL)
- Fabricate 2-ring PACTRUSS

APPROACH:

In FY 1989 the main focus will be fabrication and testing of segments of an erectable and deployable PACTRUSS support structure. Also, a 2-ring erectable truss will be supplied to JPL as a testbed experimental article. NASTRAN analyses will be made of both test articles and results compared with test results.

MILESTONES:

- Complete 2-ring erectable truss, March 1989
- Complete PACTRUSS deployable segment, March 1989
- Complete erectable LaRC tests, May 1989
- Complete PACTRUSS LaRC test, July 1989
- Complete correlation with NASTRAN, September 1989

FY 1988 ACCOMPLISHMENTS:

- Held first technical interface meeting at JPL
- Initiated ASTRO PACTRUSS design task
- Developed new stepped PACTRUSS concept for eliminating deployment hard points
- Designed and fabricated two "zero-free play" deployable joints for PACTRUSS; testing initiated
- Developed erectable truss design
- Developed 1-inch erectable joint design

RTR 591-22-11-01 Requirements for Pathfinder

OBJECTIVE:

To define structural and operational requirements for generic, heavily loaded mechanical joints. The joints will be used to assemble large spacecraft components on-orbit.

FY 1989 PLANS:

- Complete definition of Pathfinder focus problem

APPROACH:

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:

- Develop first draft of Pathfinder requirements document, June 1989

FY 1988 ACCOMPLISHMENTS:

- Conducted first Pathfinder on-orbit construction inter-Center advisory group meeting in Washington, D. C.
- Made Code Z mission study data dump to on-orbit construction advisory group at LaRC
- Conducted on-orbit construction advisory group FY 1989 planning meeting in Washington, D. C.

RTR 591-22-21-01 Construction Concepts

OBJECTIVE:

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

FY 1989 PLANS:

- Develop space crane design and fabricate articulated joint

APPROACH:

A study will be performed to size the aerobrake support truss. Concepts for constructing the support truss will be developed and evaluated based on design-for-construction criteria. Space cranes will be required to assemble the 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:

- Complete definition of 100-meter space crane, June 1989

FY 1988 ACCOMPLISHMENTS:

- FY 1989 new start

RTR 591-22-31-01 Joining Methods

OBJECTIVE:

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

FY 1989 PLANS:

FY 1989 PLANS:

- Develop joint design for 200,000-pound aerobrake strut

APPROACH:

Identify design concepts which meet the aerobrake support truss structural and construction requirements. 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 1989

FY 1988 ACCOMPLISHMENTS:

- FY 1989 new start

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

OBJECTIVE:

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

FY 1989 PLANS:

- Develop testbed for evaluating heavily-loaded mechanical joints

APPROACH:

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. A testbed will be developed for testing joint strength, stiffness, and ease of assembly.

MILESTONES:

- Define testbed requirements and complete testbed design, May 1989

FY 1988 ACCOMPLISHMENTS:

- FY 1989 new start

VII AEROTHERMAL LOADS BRANCH

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, the Aerothermal Arc Tunnels (20 and 5 MW), and the 7-Inch High Temperature Tunnel.

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 1989 PLANS:

- Document experimental results of Chine gap heating, and turbulent boundary layer characterization
- Validate analysis tools with experimental data for swept cylindrical leading edge, swept shock-on-lip, axial compression corner, and hypersonic vehicle (Mach 20) and fighter
- 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 1989 a major milestone is the development of aposteriori error estimates for adaptive h and p finite element 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:

- Initiate development of combined h and p adaptive methods for finite element analysis of aerothermal loads in high-speed flows, December 1988
- Develop Taylor-Galerkin implicit finite element algorithm for unstructured grids, March 1989
- Develop aposteriori error indicators for adaptive meshing and hierarchical methods for finite element fluid mechanics, June 1989
- Calibrate entropy variable based finite element algorithm on experimental and analytical shock-shock interaction results, September 1989

FY 1988 ACCOMPLISHMENTS:

- Implemented new finite element adaptive unstructured meshing procedures in LMSC page code, "Adaptive Computational Methods for Aerothermal Heating Analysis," LMSC-HEC PR F225772 December 1987
- Documented experimental aerothermal results for split elevon as NASA TP
- Acquired VAX host computer to support experimental and analytical programs
- Developed implicit algorithm and adaptive grid technique for accurate prediction of heat transfer rates. Incorporated LARCNESS code. "A Point Implicit Unstructured Grid Solver for the Euler and Navier Stokes Equations," AIAA Paper No. 88-0036, January 1988
- Completed tests of turbulent boundary layer characterization in 8'HTT
- Calibrated adaptive Runge-Kutta finite element scheme for the Euler and Navier Stokes equation for shock-on-lip phenomena through comparison with experiment. "Application of Finite Element and Remeshing Technique to Shock Interference on a Cylindrical Leading Edge," AIAA Paper No. 88-0368, January 1988
- Implemented real gas chemical equilibrium model in Runge-Kutta Euler code, AIAA Paper No. 88-0036

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 1989 PLANS:

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

APPROACH:

In FY 1989 a major milestone is the extension of LIFTS to three-dimensional thermal and structural analysis and the inclusion of the LARCNESS CFD algorithm. 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.

MILESTONES:

- Incorporate LARNCESS fluid algorithm into LIFTS, December 1988
- Extend LIFTS thermal and structural capability to three dimensions, March 1989
- Evaluate implementation of viscoplasticity in LIFTS, September 1989
- Develop and validate model to account for the effects of temporal and spatial free stream nonuniformities on stagnation point heating in incompressible flow, September 1989

FY 1988 ACCOMPLISHMENTS:

- Coupled flow-thermal-structural analysis of aerodynamically-heated, hydrogen cooled leading edges with shock-on-lip with LIFTS code. "Flow-Thermal-Structural Study of Aerodynamically Heated Leading Edges," AIAA Paper No. 88-2245-CP, April 1988
- Prototype three-dimensional adaptive unstructured remeshing technique demonstrated. "Finite Element Euler Computations in Three Dimensions," AIAA Paper No. 88-0032, January 1988
- Two-dimensional unstructured grid enhancement technique developed; stability and dispersion properties identified. "An Adaptive Quadrilateral and Triangular Finite Element Scheme for Compressible Flows," AIAA Paper No. 88-0033, January 1988

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

OBJECTIVE:

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

FY 1989 PLANS:

- Complete shakedown of transpiration cooled nozzle and oxygen

APPROACH:

In FY 1989 a major milestone is the shakedown of the 8'HTT. 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:

- Complete verification of DAS software for Modcomp, March 1989
- Complete development of VAX software for data reduction and verify, March 1989
- Overhaul elevator cylinder and complete change to new hydraulic oil, March 1989
- Complete shakedown of transpiration cooled nozzle and oxygen, June 1989
- Initiate shakedown of Mach 4 and 5 nozzles and mixer, September 1989

FY 1988 ACCOMPLISHMENTS:

- Completed aerothermal tests of Government NASP baseline vehicle, turbulent boundary layer study, and DoD shroud removal studies
- Completed checkout of Modcomp DAS
- Completed development and initiated verification of DAS software for Modcomp
- Verified, through use, the structural integrity of the 8'HTT water cooled approach section

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

OBJECTIVE:

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

FY 1989 PLANS:

- Integrate existing controls with new controls
- Build spare platelets for transpiration cooled nozzle

APPROACH:

A major milestone for FY 1989 is fabrication of a partial set of spare platelets for the transpiration cooled nozzle. 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:

- Fabricate spare platelet stacks for backup air transpiration cooled nozzle, March 1989

FY 1988 ACCOMPLISHMENTS:

- Awarded contract for upgrade to 8'HTT control system

RTR 506-80-31-05 4.7.4 Detailed 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 data base for accurate prediction of aerothermostructural loads required to reduce design margins.

FY 1989 PLANS:

- Complete tests in Calspan and Langley tunnels for Mach Nos. 11-19 swept leading edge shock-on-lip, transpiration cooled leading edge with shock-on-lip, slot cooled model with shock wave interaction, and axial corner model with impinging shock wave
- Complete upgrade Reynolds and Mach No. capability of Calspan 48"HST (Hypersonic Shock Tunnel)
- Document results of NASP baseline vehicle aerodynamics - NASP/Boeing, and Mach 8 swept leading edge
- Fabricate and instrument perpendicular fuel injector model, and axial corner flow model

APPROACH:

In FY 1989 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:

- Implement and calibrate Baldwin-Lomax algebraic turbulence model in LARCNESS code, December 1988
- Implement and calibrate real gas chemical equilibrium model in LARCNESS code, December 1988
- Complete tests in Calspan 48"HST and data reduction for slot film cooling including shock interaction effects, December 1988
- Complete data reduction and documentation of transpiration cooled leading edge shock-on-lip study, March 1989
- Complete upgrade to Calspan 48"HST for increased Mach and Reynolds number range, March 1989

- Complete axial compression corner with shock interaction tests with ceramic model/phase change paint at LaRC, reduce data, and document, March 1989
- Document 8'HTT aerothermal loads test results for baseline NASP vehicle, March 1989
- Demonstrate three-dimensional adaptive unstructured grids with inviscid analysis of NASP vehicle and viscous swept shock-shock interaction model, March 1989
- Document results from slot film cooling study, June 1989
- Initiate design, fabrication, and instrumentation of metallic axial compression corner model for shock tunnel tests in FY 1990, June 1989
- Design, fabricate, and instrument axial compression model for corner shock interaction aerothermal loads tests in the Calspan 48"HST in FY 1990, September 1989
- Complete following tests in Calspan shock tunnels: (a) 3-D laminar separation from interacting flows in an axial compression corner, and (b) flat plate/swept compression wedge, September 1989
- Fabricate wall fuel injection model for tests in FY 1990, September 1989

FY 1988 ACCOMPLISHMENTS:

- Documented experimental results of shock-on-lip tests at Mach Nos. 11-19 including effects of multiple shock interaction. "Studies of Aerothermal Loads Generated in Regions of Shock/Shock Interaction in Hypersonic Flow," AIAA Paper No. 88-0477, January 1988
- Designed and fabricated ceramic axial compression corner model which simulates engine compression ramps and control surfaces
- Completed aerothermal loads tests of NASP baseline vehicle in NASA LaRC 8'HTT
- Designed, fabricated, instrumented, and initiated tests of film cooled model with shock interaction in the Calspan 48"HST
- Contract awarded to Calspan for transpiration cooled leading edge shock-on- lip study and upgrade to Calspan 48"HST for increased Mach and Reynolds number range

VIII ACCOMPLISHMENT HIGHLIGHTS

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STRUCTURAL MECHANICS BRANCH

STAGS POSTPROCESSOR COMPUTES TRANSVERSE SHEAR STRESS RESULTANTS

Gaylen A. Thurston, Blake Avery[1], Kathleen A. Tallieu[2] and Rajaram Sistla[3]
Structural Mechanics Branch
Ext. 3524   October 1987
RTOP 505-63-11
Code RM   WBS 56-1

Research Objective: To compute transverse shear stress resultants in postbuckled composite plates using discrete numerical results from the STAGS finite-element code.

Approach: Shear resultants are computed from a "recontinuized" solution for the transverse equilibrium equation. The "recontinuization" procedure accurately determines continuous solutions to governing nonlinear differential equations by using discrete numerical results from finite element codes as initial approximations to the solutions.

Accomplishment Description: The STAGS code returns discrete, numerical results for displacements and stress resultants. A "recontinuized" solution is computed by a postprocessor as part of the error analysis and correction of the discrete results. The upper four figures show a typical blade-stiffened panel in compression, the finite-element grid, and the postbuckled deflection pattern. Recontinuized results are shown in the lower four figures for the center section of the panel indicated as plate 2 in the upper figures. The contour plot for the continuous solution for the bending stress resultant M compares well with the plot generated from the discrete STAGS data for M_x. The STAGS code does not compute values for the transverse shear stress resultants Q_x and Q_y so they were computed by the postprocessor and are also plotted as part of the recontinuized solution. The recontinuized solution is derived by solving for the deflection W in the transverse equilibrium equation,

$$D_{11} W_{,xxxx} + 2(D_{12} + D_{66}) W_{,xxyy} + D_{22} W_{,yyyy} = (N_x W_{,xx} + N_{xy} W_{,xy} + N_y W_{,yy})_0$$

The solution starts with the term in parentheses with the zero subscript on the right-hand side of the equation given as discrete STAGS output data. The term is approximated by a continuous trigonometric interpolation formula that passes through the discrete data points. The resulting partial differential equation indicated above is solved for W and the stress resultants computed from W using plate theory. The continuous solution W also satisfies discrete boundary conditions from STAGS data at node points on the boundary of the plate unit. The solution for W tends to oscillate about the boundary points which indicates that the continuous solution requires more numerical analysis near the boundary.

Significance: Failure predictions for composite panels require accurate, detailed analysis that provides transverse shear stress resultants. Failure due to transverse shear is observed in composite panels while the same failure mode is not common for metal panels.

Future Plans: Perform error analysis on recontinuized solution. Modify collocation method for satisfying boundary conditions to a least-squares method and compare results from the two methods.

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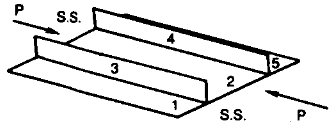
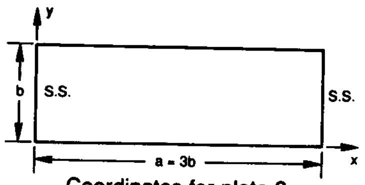
[1] PRC/Kentron, [2] Unisys Co., [3] AS&M, Inc.

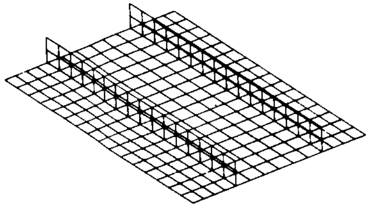
STAGS POSTPROCESSOR COMPUTES TRANSVERSE SHEAR STRESS RESULTANTS



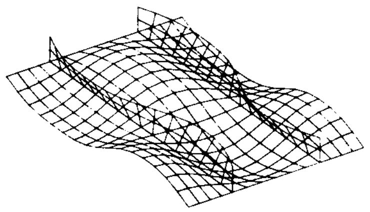
Stiffened panel in compression



Coordinates for plate 2

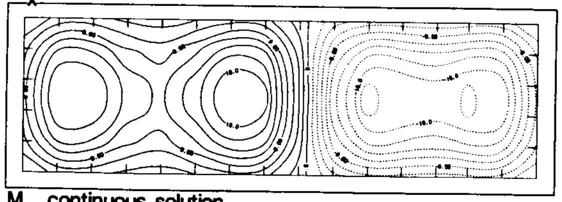


Finite element grid

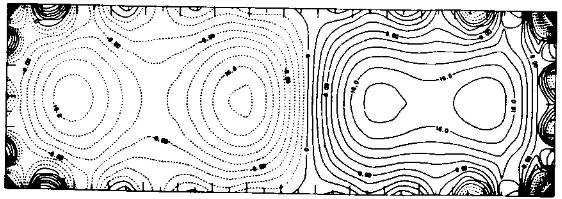


Postbuckled deflection pattern

M_x, from STAGS

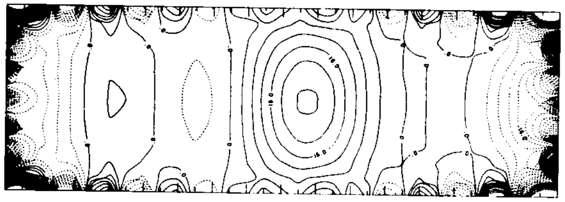


M_x, continuous solution

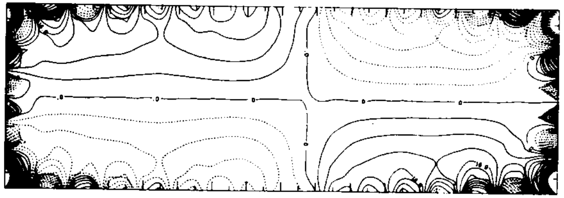


Bending stress resultant, M_x

Q_x



Q_y



Transverse shear stress resultants
continuous solution

PARALLEL ALGORITHM REDUCES COMPUTATION TIME FOR SOLVING EIGENVALUE PROBLEMS

Susan W. Bostic
CSM Group, Structural Mechanics Branch
Extension 2506
November 1987
RTOP 505-63-01
Code RM WBS 56-2

Research Objective

To develop a parallel algorithm for solving eigenvalue problems with modern or future multiprocessor computers.

Approach

The algorithm is based on the Lanczos method, which consists of a series of substitutions and transformations that reduce the original large problem to a small, easier-to-solve problem. The solution to the small problem gives accurate approximations to a few of the eigenvalues of the original problem. The major computational tasks in the method are the decomposition of the stiffness matrix, a step necessary in the transformation of the original problem, and a forward/backward solution, which enables the problem to be reduced to the smaller, simpler form. These two time-consuming calculation steps have been parallelized, so that multiple calculations are performed concurrently on a number of processors. The parallel algorithm has been implemented on a FLEX/32 multiprocessor computer.

Accomplishment Description

The new algorithm was used to perform a free vibration analysis of the blade-stiffened graphite-epoxy panel with a circular cutout shown in the figure. The speedup obtained on up to 16 processors for each step and for the total solution is shown in the figure. The theoretical maximum speedup is the speedup obtainable if all processors were working at 100 percent efficiency and the workloads were completely balanced. On one processor, the decomposition of the matrix took 63 percent of the time and the forward/backward solution steps took 33 percent of the time. On eight processors, a speedup of 7.9 was obtained for the decomposition step, and a speedup of 4.2 was obtained for the forward/backward solution step resulting in a speedup for the total solution of 5.0. The speedup plot shows that using more than eight processors was not productive for this problem. As the amount of calculation to be performed on each processor decreases, the percentage of sequential calculations increases and the parallel overhead computational effort associated with communication between processors also increases.

Significance

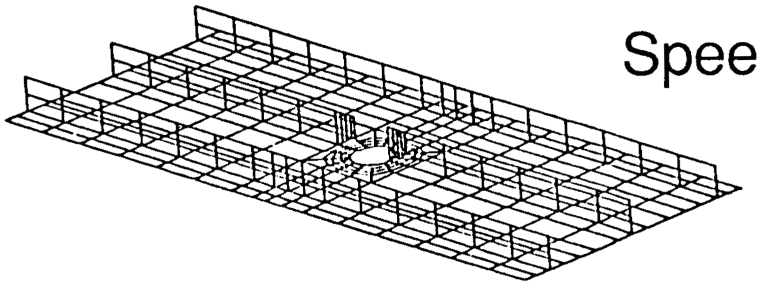
The computation time for the solution of large-scale structural vibration problems can be significantly reduced by performing calculations in parallel on a multiprocessor computer. The efficient use of resources is dependent on the amount of computation to be performed and varies from task to task as well as being dependent on the overall problem size and the hardware/software environment.

Future Plans

The existing sequential steps in the parallel Lanczos algorithm will be parallelized and the method will be applied to larger problems. Timing results will be analyzed in order to determine how to achieve the best speedups for various types and sizes of problems on multiprocessor computers.

PARALLEL ALGORITHM REDUCES COMPUTATION TIME FOR SOLVING STRUCTURAL EIGENVALUE PROBLEMS

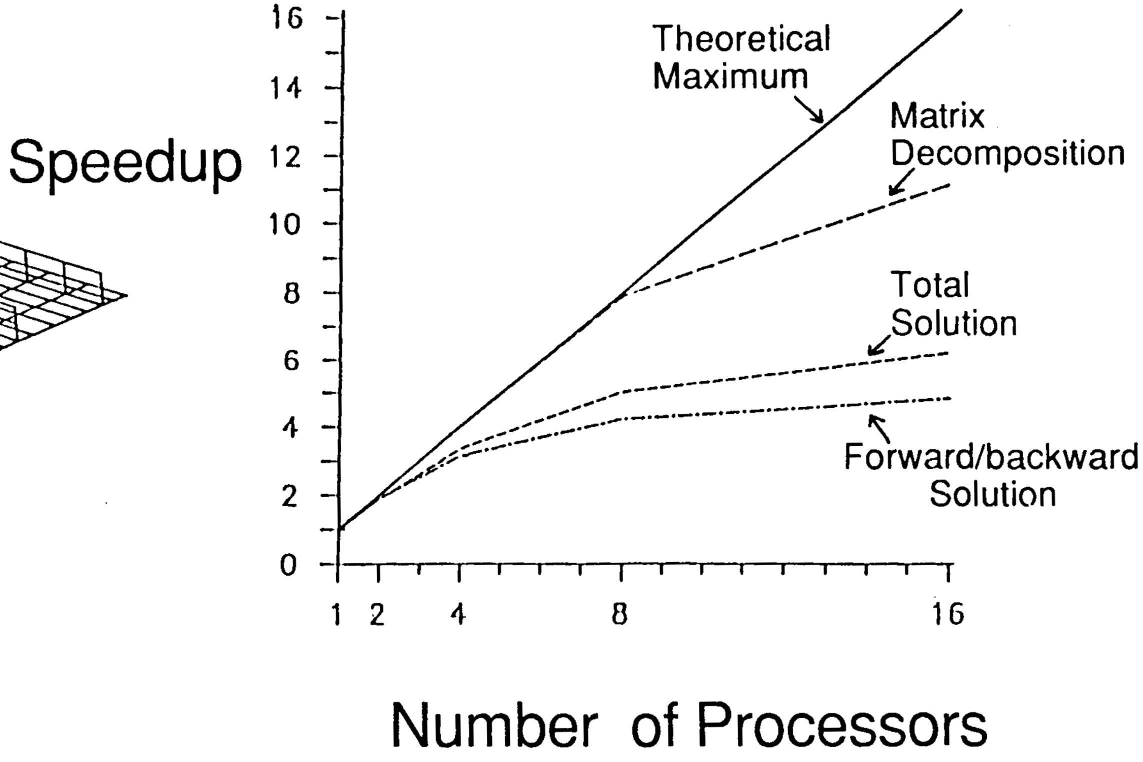
Example: Free vibration analysis of blade-stiffened graphite-epoxy panel



Finite Element Model

648 Degrees of Freedom

Semi-bandwidth of 135



STRUCTURAL ANALYSIS OF AFT SKIRT

Norman F. Knight, Jr. and Joseph E. Walz
Structural Mechanics Branch Structural Dynamics Branch
Ext. 4892 Ext. 4424

RTOP 554-14-21 November 1987
Code RM WBS 56-2

Research Objective:
To assess the adequacy of the USBI baseline shell model of the SRB aft skirt for stress analysis and redesign.

Approach:
Obtained the USBI baseline shell finite element model from MSFC using the SPAN network. Due to the complexity of the MSC/NASTRAN model, the Ames CRAY XMP/48 computer was used for analysis, and Mladen Chargin and Ken Hamm of Ames provided expertise in the use of MSC/NASTRAN. Postprocessing of results was accomplished using PDA/PATRAN on Langley and Ames computers. Detailed drawings were obtained from USBI, and PATRAN was used to verify the model geometry. A critique of the baseline shell model, suggested changes to the modeling strategy, and the stress analysis results obtained using both the baseline model and a modified model were forwarded to MSFC.

Accomplishment Description:
The MSC/NASTRAN shell model of the SRB aft skirt was interrogated using PDA/PATRAN. Cross checks between the model geometry and the engineering drawings were made. Several geometry errors and modeling discrepancies were identified and the critique was forwarded to MSFC/USBI. Detailed, local models for use in the redesign and new detailed, global models for use in recertification of the SRB aft skirt have also been evaluated. Stress analyses of these models have been completed. The von Mises stress distribution for the outer surface of the aft skirt section with posts 7 and 8 is shown on the slide. Using a postprocessing software package, like PATRAN, an analyst is quickly informed of high stress areas. Using the IVBC-3 maximum compression loads, negative margins of safety were predicted based on an elastic stress analysis at ultimate load.

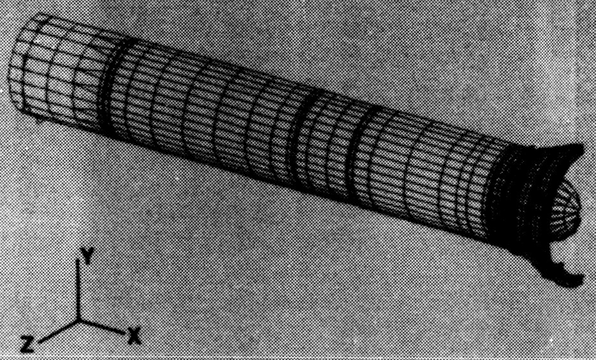
Significance:
The independent assessment of the USBI baseline shell model has provided a better analysis model for the SRB aft skirt. USBI is currently developing a detailed recertification model which will resolve other modeling uncertainties. In the interim, the revised baseline shell model is being used by USBI for the aft skirt redesign.

Future Plans:
Assure that the finite element models being used for the SRB aft skirt analysis and redesign are accurate and adequate.

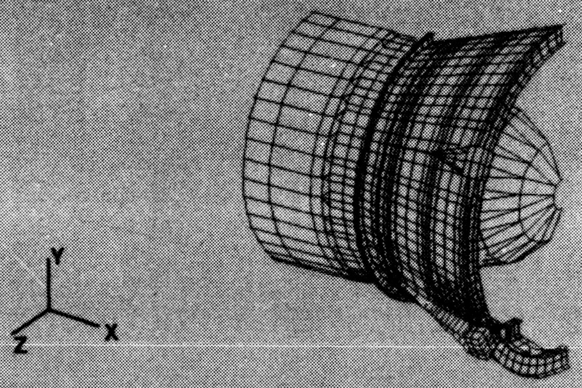
NASA
L-87-9541

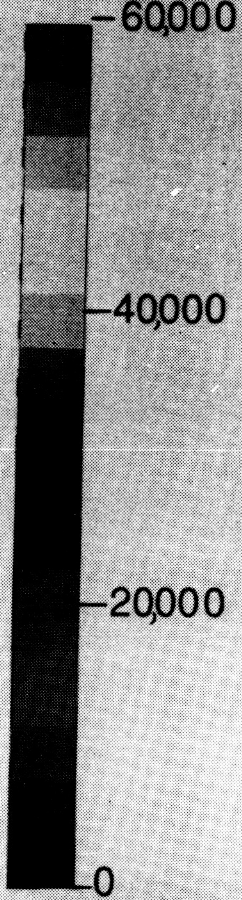
STRUCTURAL ANALYSIS OF AFT SKIRT

Finite element model of structural test article



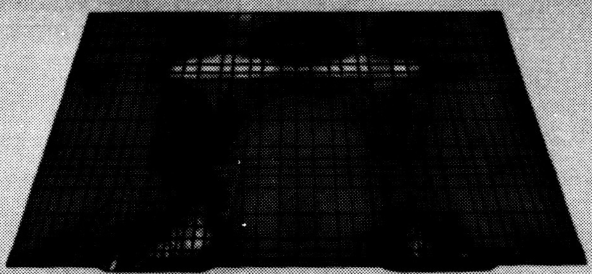
Close-up of aft skirt model





von Mises stress, psi

Von Mises stress distribution



Close-up of post 8

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

NONLINEAR SHELL RESPONSE OF SRB/ETA RING INTERFACE DETERMINED FOR SELECTED STS 51-L PRE-LIFTOFF LOADS

Norman F. Knight, Jr.
Structural Mechanics Branch
Ext. 4892

RTOP 554-14-21 December 1987
Code RM WBS 56–2

Research Objective:
To determine the nonlinear shell response of the SRB/ETA ring interface subjected to selected STS 51-L pre-liftoff loads.

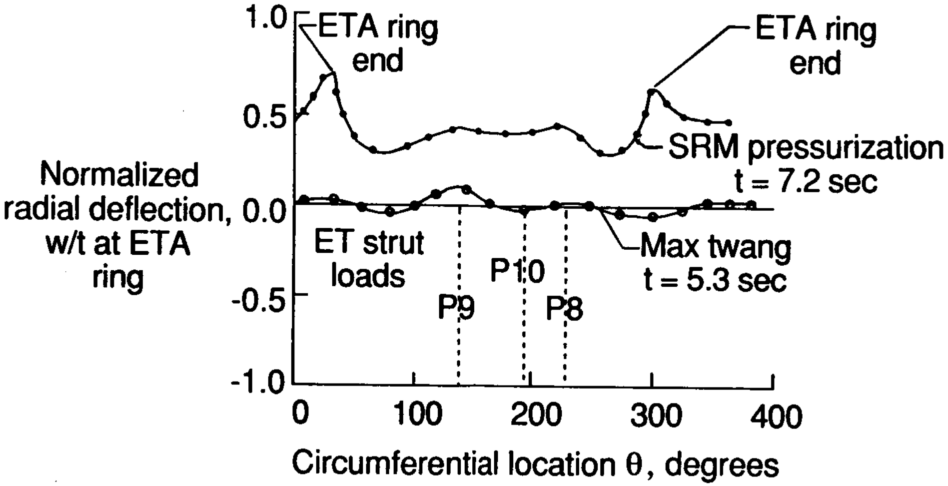
Approach:
The SRB/ETA ring interface models were developed using the STAGSC-1 finite element computer code and executed on the NAS computer system. These models are based on the original STS 51-L geometry configuration. The SRB/ETA ring interface model includes the complete ETA ring, a portion of the SRM aft attachment segment including a factory joint, and a portion of the aft center segment including a field joint as indicated on the right side of the figure. The total length of the model is 136 inches. The field and factory joints are modeled by using equivalent stiffness joints instead of detailed models of the joint. As such, the effect of local joints on the shell response is included; however, local joint behavior (i.e., gap motion) can not be obtained from these global models. Global shell behavior of the SRB/ETA ring interface can be obtained using an equivalent stiffness joint, and an evaluation of nonlinear effects such as shell collapse and ovalization can be performed. These analyses included the asymmetric loads resulting from the aft ET strut loads and the equivalent shell loads derived from the JSC reconstructed flight loads for STS 51-L.

Accomplishment Description:
Nonlinear analyses of the SRB/ETA ring interface model using the reconstructed loads for time $t=5.3$ and 7.2 seconds after SSME ignition have been performed. The nonlinear radial deflections at the ETA ring normalized by the nominal SRB case thickness (0.479 inches) are shown in the upper left of the figure as a function of circumferential location around the SRB. Time $t=5.3$ seconds corresponds to the time at which maximum bending occurs and has been referred to as "max twang". At this time, the SRM is unpressurized since it has not yet been ignited. The ET strut loads at maximum bending result in an asymmetric radial deflection pattern; however, the amplitudes of these deflections are small compared to either the nominal shell thickness or the radial deflections caused by internal pressure loading only. Time $t=7.2$ seconds corresponds to the time at which the SRM reaches full pressure and liftoff occurs. The deformed geometry of the entire model shown in the lower left of the figure correspond to the loading case at $t=7.2$ seconds which includes SRM pressurization. At SRM pressurization, the overall shell response is dominated by the effects of the internal pressure, and the effect of the ET strut loads is secondary.

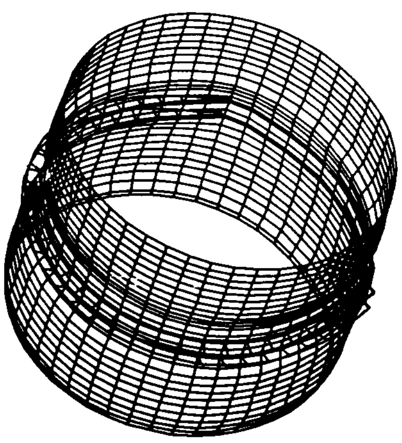
Significance:
Two STS 51-L pre-liftoff, time-consistent loading cases have been considered. The loading component which has been shown to significantly affect the shell deflection patterns is the SRM internal pressure. The ET strut loads at maximum bending result in an asymmetric radial deflection pattern with amplitudes that are small compared to either the nominal shell thickness or the radial deflections caused by internal pressure loading only. At SRM pressurization, the overall shell response has been shown to be dominated by the effects of the internal pressure.

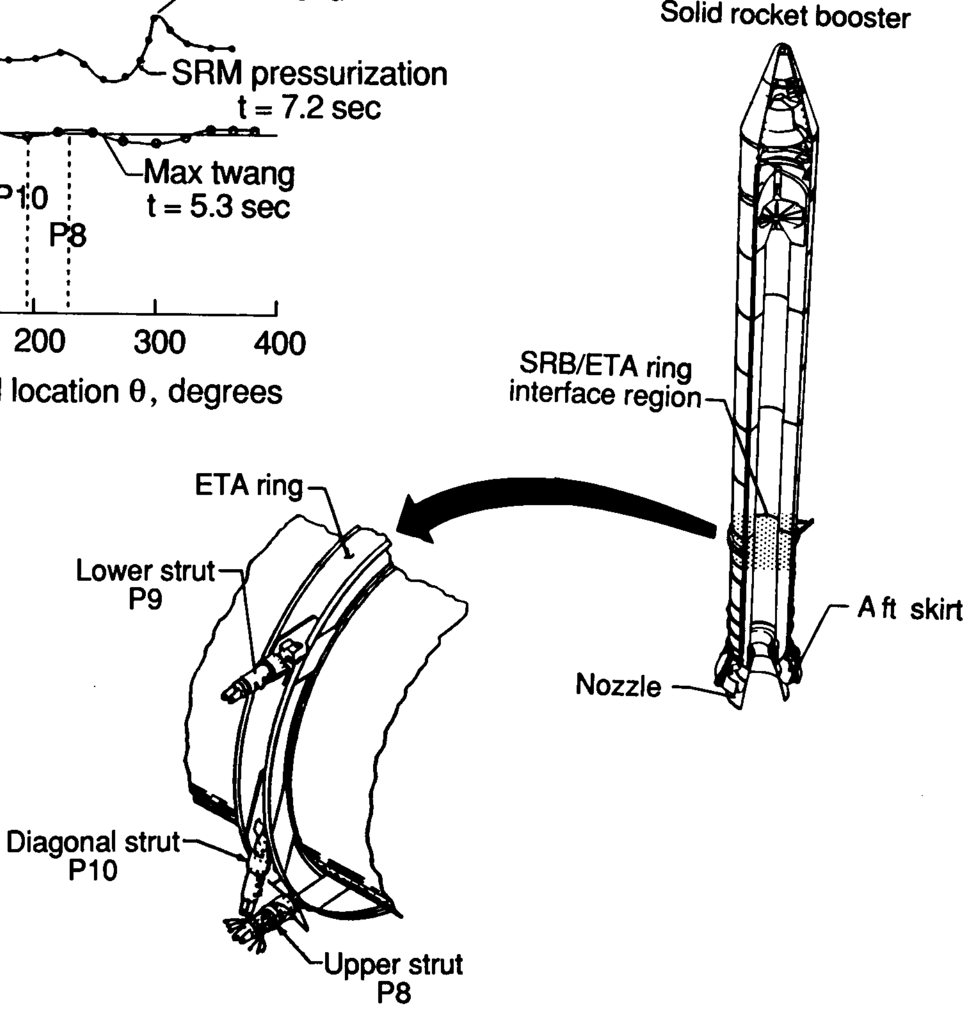
Future Plans:
Document results in NASA TM 89164.

NONLINEAR SHELL RESPONSE OF SRB/ETA RING INTERFACE DETERMINED FOR SELECTED STS 51-L PRE-LIFTOFF LOADS



Deformed geometry





CAPTURE TANG CLEARANCES GREATLY AFFECT JOINT PRESSURE SEAL REDUNDANCY

Michael P. Nemeth and Melvin S. Anderson
Structural Mechanics Branch/Old Dominion University, SDD
Ext. 4052 April 1988
RTOP 554-14-21
Code RM WBS 56-2

Research Objective: To determine the effects of capture tang initial clearances on redesigned solid rocket motor (RSRM) field joint pressure seals.

Approach: Structural deformations of the RSRM field joint with capture tang were obtained by using an influence coefficient method to simulate contact between adjacent shell walls. Parametric studies were performed using the axisymmetric shell-of-revolution analysis code FASOR and an in-house computer program for determining the contact forces and resulting joint displacements.

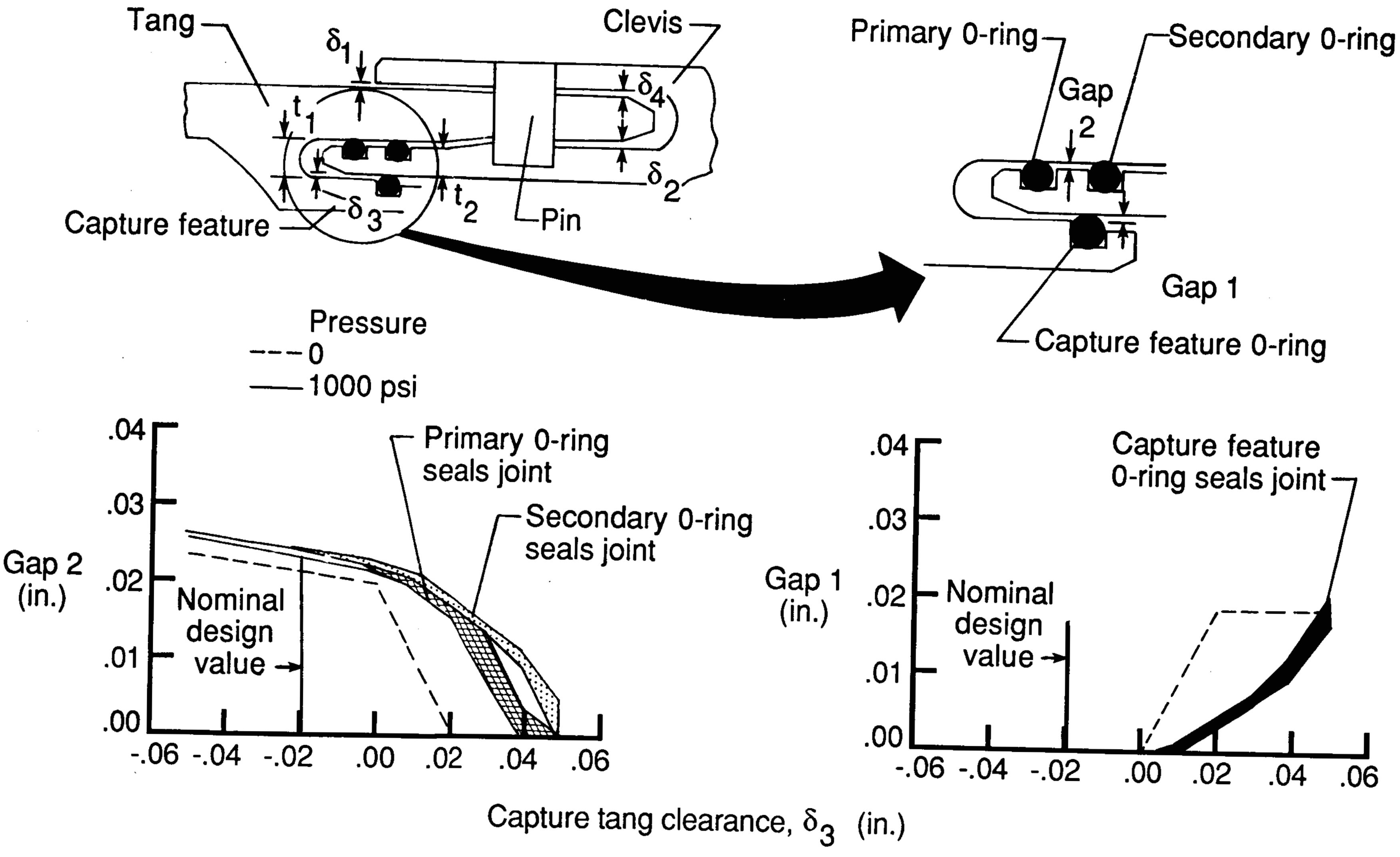
Accomplishment Description: The chart indicates the effect of initial clearances on the joint displacements at the capture tang O-ring, and between the primary and secondary O-rings, resulting from loads introduced by joint assembly and from 1,000 psi pressure loading. Pressure distribution results for the capture tang O-ring sealing the joint, the primary O-ring sealing the joint, and the secondary O-ring sealing the joint are presented. The joint details and four joints clearances $\delta_1, \delta_2, \delta_3$, and δ_4 are shown in the upper figures. The nominal capture tang interference fit design value for the RSRM is given by $\delta_3 = -0.02$ inches. Joint displacements at the capture tang O-ring and between the primary and secondary O-rings are referred to as Gap 1 and Gap 2, respectively. Hatched areas in the lower figures indicate results for values of δ_1 and δ_2 ranging between 0 and 0.05 inches. The results are independent of clearances δ_4 and nearly insensitive to all variation in clearances except for that of δ_3.

The lower figures indicate the absolute O-ring gaps as a function of the joint clearances for the nominal capture feature dimensions $t_1 - t_2 = 0.02$ inches. The dashed curves represent the unpressurized assembly conditions and the solid curves the 1,000 psi pressurized conditions. The difference between the dashed and solid curves indicates the gap changes that the O-rings must track during motor pressurization. When the capture tang O-ring seals the joint (lower right figure), Gap 1 remains zero (metal-to-metal fit) during motor pressurization if an interference fit is used. For values of $0 < \delta_3 < 0.045$ the capture tang O-ring seals the joint at larger absolute gaps but is always compressed during motor pressurization. If the capture tang O-ring fails, the results indicate (lower left figure) that the remaining O-rings must always expand to track the gap changes during motor pressurization. The results also indicate that these O-rings seal the joint at substantially larger absolute gaps (Gap 2) than the capture tang O-ring when $\delta_3 < 0$, but are only required to track gap changes on the order of 0.005 inches during motor pressurization. When $0 < \delta_3 < 0.03$, the primary and secondary O-rings seal the joint at smaller absolute gaps but are required to track larger gap changes during motor pressurization. As δ_3 increases beyond 0.03, the joint prestress induced at assembly leads to a metal-to-metal fit between the inside surface of the tang and the clevis, which results in all three O-rings having smaller gaps to track during motor pressurization.

Significance: The results can be used to predict RSRM joint performance trends on the basis of absolute gap size or change in gap the O-rings must track. The results also suggest the operating conditions of the joint associated with nonconcentric assembly.

Future Plans: Document results in a NASA technical paper.

CAPTURE TANG CLEARANCES GREATLY AFFECT JOINT PRESSURE SEAL REDUNDANCY



GENERAL FAILURE THEORY FOR COMPRESSION-LOADED LAMINATES VALIDATED BY EXPERIMENTS

Mark J. Shuart
Structural Mechanics Branch
Ext. 2813 July 1988
RTOP 505-63-01
Code RM WBS 56-1

Research Objective

To validate a general theory for predicting the strength and failure mode of compression-loaded, multi-directional composite laminates.

Approach

A general failure theory for predicting the strength and failure mode for compression-loaded, multi-directional laminates has been developed. The theory uses a nonlinear analysis for predicting accurately laminate stresses and strains, and this analysis includes the effects of out-of-plane ply waviness, inplane fiber waviness, and fiber-scissoring. The results from the nonlinear analysis are input to a maximum stress/maximum strain failure criterion to predict the laminate compressive strength. The stress or strain component that satisfies the failure criterion also indicates the laminate failure mode. A series of $[\pm\theta/\mp\theta]_{6S}$ laminates having $0° \leq \theta \leq 90°$ where θ is the ply orientation were tested, and experimental results for compressive strength and failure mode from these laminates were compared with the failure theory's predicted results.

Accomplishment Description

Laminate compressive strength as a function of ply orientation is shown in the attached figure for $[\pm\theta]_S$-class AS4/3502 laminates where θ is the ply orientation. The laminate compressive strength is dominated by three failure mechanisms: interlaminar shearing due to out-of-plane ply waviness; inplane matrix shearing at the fiber/matrix interface; and matrix compression when the matrix material is the principal load-carrying constituent. The stress associated with each failure mechanism is calculated, and the lowest or critical stress is the predicted laminate compressive strength. This strength is plotted as a solid line on the figure. The theory predicts that interlaminar shearing initiates laminate failure for $0° \leq \theta \leq 15°$, that inplane matrix shearing initiates laminate failure for $15° \leq \theta \leq 50°$, and that matrix compression initiates failure for $50° \leq \theta \leq 90°$. Experimental results are plotted as symbols on the figure. The theoretical and experimental results show good agreement for $\theta < 45°$ and show excellent agreement for $\theta \geq 45°$.

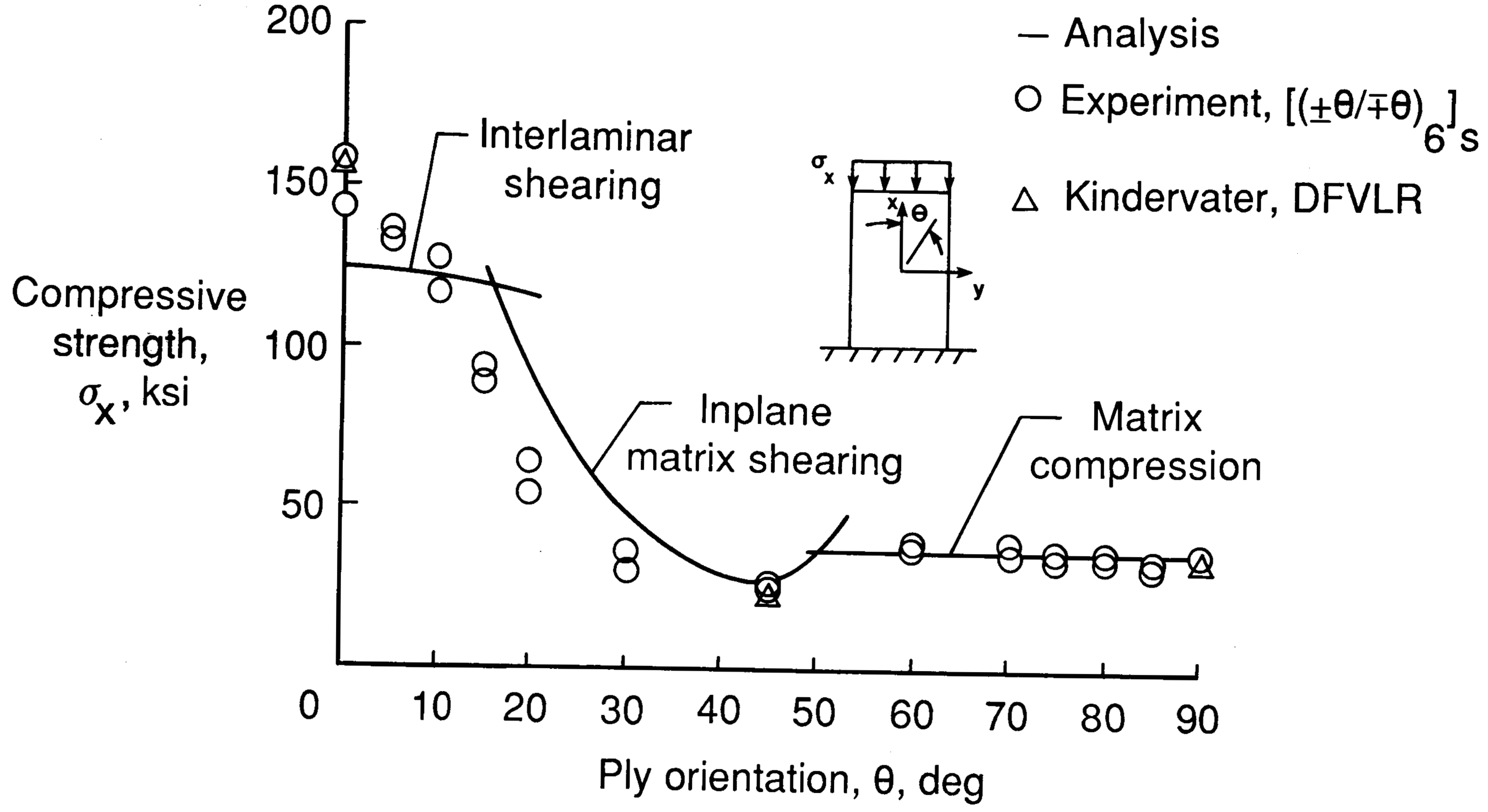
Significance

The dominant compression failure mechanisms for multi-directional laminates have been identified, and the corresponding failure theory has been validated by tests.

Future Plans

Document the results of this study.

GENERAL THEORY FOR COMPRESSION-LOADED LAMINATES VALIDATED BY EXPERIMENTS



STRUCTURAL CONCEPTS BRANCH

TAPERED ENDS FOR SPACE SHUTTLE SOLID ROCKET BOOSTER/EXTERNAL TANK ATTACHMENT RING REDESIGNED

Martin M. Mikulas, Harold G. Bush, John T. Dorsey,
W. B. Fichter, and Mark S. Lake
Structural Concepts Branch
Extension 2414 October 1987
554-14-21 WBS 55-2
Code M

Research Objective: To develop a cross sectional area taper profile for the ends of the Space Shuttle Solid Rocket Booster (SRB)/External Tank Attachment (ETA) ring that exhibits all positive margins of safety in attachment bolt loads and stresses.

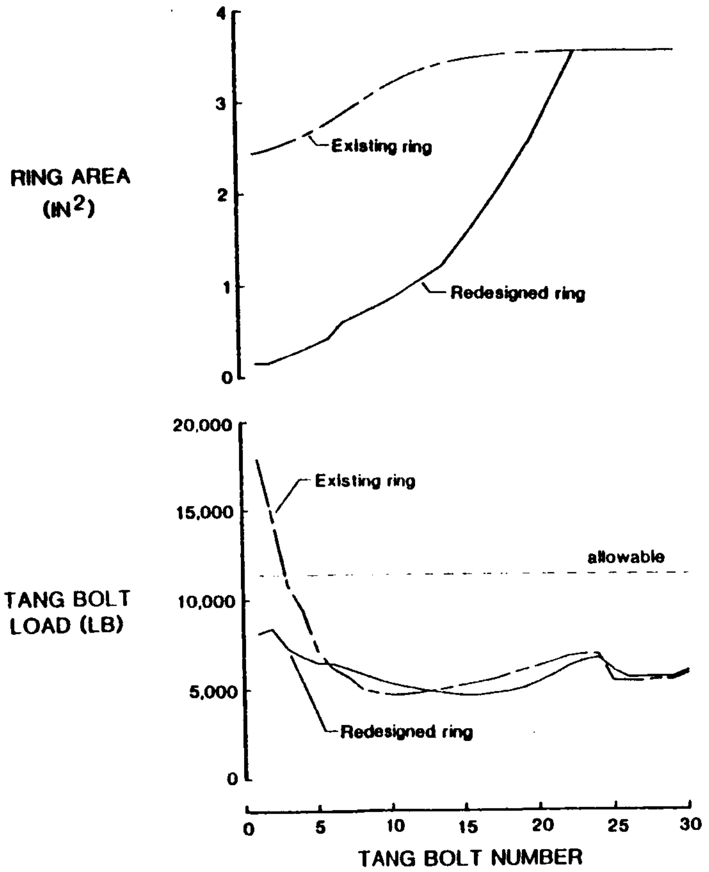
Approach: A one-dimensional linear representation of the ring, tang bolts, and case wall was developed to efficiently calculate an initial taper profile for the ring area. Numerous iterations on the ring area profile using detailed finite element analysis led to a final design which exhibited all positive margins of safety in bolt loads and ring web stresses.

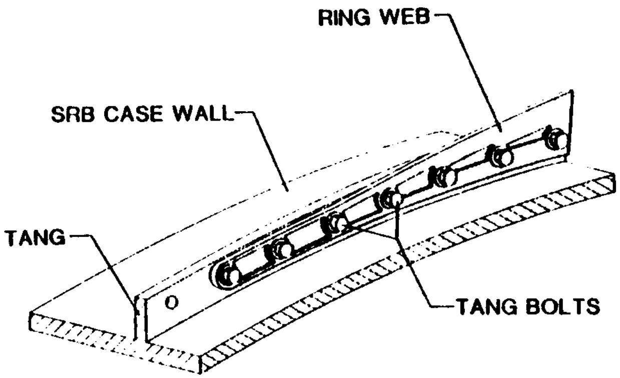
Accomplishment Description: The existing SRB/ETA ring design, which extends about 270 degrees around the circumference of the SRB case wall, provides insufficient cross sectional tapering at the ring ends. Consequently, shear failure has occurred in the bolts which attach the ring to tangs on the SRB case walls in both recovered flight boosters and ground test boosters. The attached figure compares the geometry of the tapered end of the existing ring (lower right) to the end of the redesigned ring (upper right) and the graph in the upper left compares the cross sectional area profiles of the two rings for the first 30 tang bolts. The area at the end of the ring had to be significantly reduced to prevent tang bolt failures. The effect of this area reduction is seen in the lower left-hand plot, which shows the tang bolt load distributions for both designs during the worst case flight loading condition. Analysis of the existing design shows negative margins of safety on the first few bolts which is consistent with the failures that have occurred. Improved area tapering in the redesigned ring lead to greatly reduced end bolt loads and all positive margins of safety.

Significance: The redesigned SRB/ETA ring shows substantial improvement in performance over the existing design in greatly reduced web-to-tang bolt loads and improved stress margins of safety.

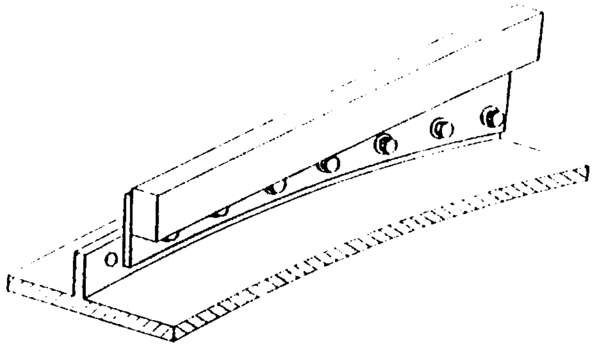
Future Plans: The redesigned ring is being further developed for flight qualification testing under a cooperative agreement with NASA Marshall Space Flight Center.

TAPERED ENDS FOR SHUTTLE SRB/ETA RING REDESIGNED





REDESIGNED RING END



EXISTING RING END

TECHNICAL OPPORTUNITY FOR PENINSULA STUDENTS (TOPS)
CONDUCT 1-G ASSEMBLY TEST OF TRUSS STRUCTURE

Judith J. Watson
Structural Concepts Branch
Ext. 2414   October 1987
RTOP 506-43-41
Code RM   WBS 55-2

Research Objective: Twenty-three gifted students from high schools within the six school district area were selected to participate in a student program which investigated a few components of the Space Station. In a series of semiweekly sessions during May the students were given the opportunity to examine and interact with the Space Station components: computer modeling, human factors, automation and technology, and structural concepts.

The objective of the structural concepts sessions was to provide the students with an opportunity to develop assembly procedures and to participate in the construction of a 9-foot bay of erectable truss structure.

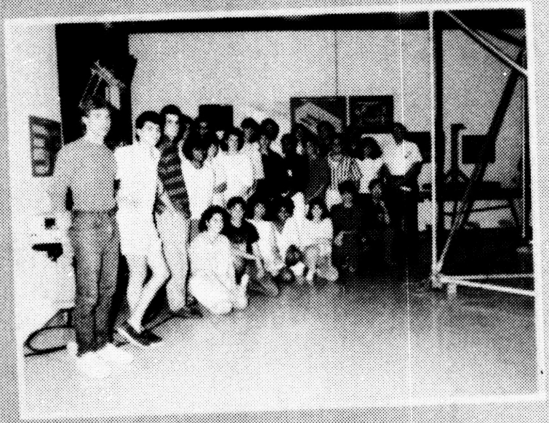
Approach: Two bays of 9-foot truss structure with the mobile work station, quick-attach joint design were made available to the students from the Structural Concepts Branch. The students were organized into teams to represent the various areas of a flight experiment, i.e., astronauts, principle investigators/design, project managers, safety, data collection, equipment, communication, and mission control. Each team interacted with advisors from Langley. The students were required to develop their own assembly procedures, flight rules and procedures, and safety requirements. They conducted three assembly tests; one, a pre-test, by the principle investigators, and two, flight simulations, by the student astronauts. They used video cameras and stop watches to record assembly times for analysis.

Accomplishment Description: The students, using four "astronauts", assembled one bay of structure in 8.65 minutes for the first assembly and 7.08 minutes for the second assembly. They interacted with "mission control" and solved problems (real and advisor induced) as they arose in a professional manner.

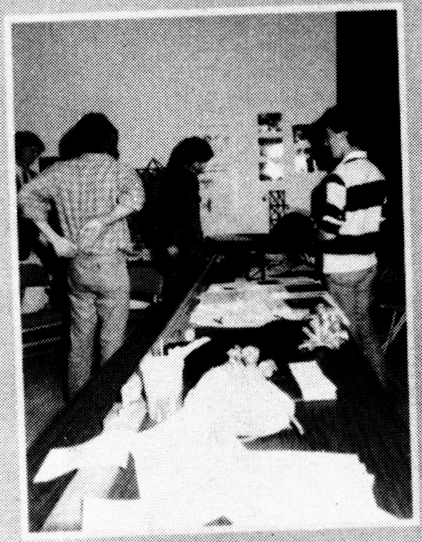
Significance: The project gave the students insight into the real world of experimentation. They were required to learn about problem solving, team work, and program management to successfully complete their objectives.

Future: Next year a similar project for high school students will be developed by the education programs specialist at LaRC. Consideration is being given to a possible neutral buoyancy test.

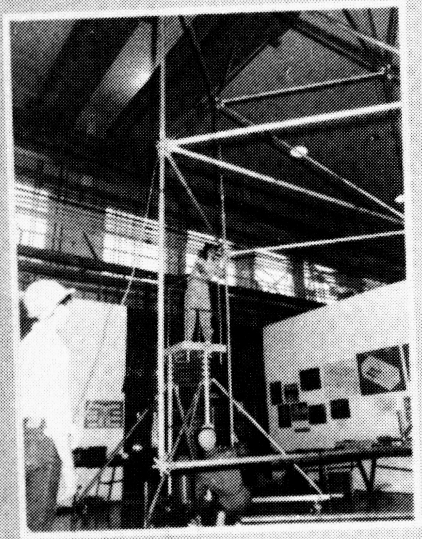
TOPS HIGH SCHOOL STUDENTS CONDUCT 1-G ASSEMBLY TEST OF TRUSS STRUCTURE



TOPS participants



"Principal investigators" develop assembly sequence with "Astronauts"



"Astronaut" crew assembles truss structure

1-G Mobile Platform Developed for Simulating Space Station Assembly

Harold G. Bush, Judith J. Watson, and Walter L. Heard, Jr.
Structural Concepts Branch Ext. 2498, 2414, and 2608
Richard E. Wallsom, J. Kermit Jensen, and James E. Phelps
PRC/Kentron Incorporated Ext. 2891, 2319, and 2414
RTOP 506-43-41
Code RM WBS 55-2
February 1988

Research Objective: To develop a test device which simulates the operation (in 1-g and neutral buoyancy) of the mobile platform proposed for Space Station assembly.

Approach: A platform was constructed which simulates space operation of the mobile platform by moving along the assembled truss structure in one-bay increments. Supporting the platform from a tower and moving the lighter weight truss permitted building the platform and ancillary man-moving arms sufficiently robust for 1-g operation (see attached figure). The tower will also support the mobile platform when it is installed in the MSFC Neutral Buoyancy Facility (NBF).

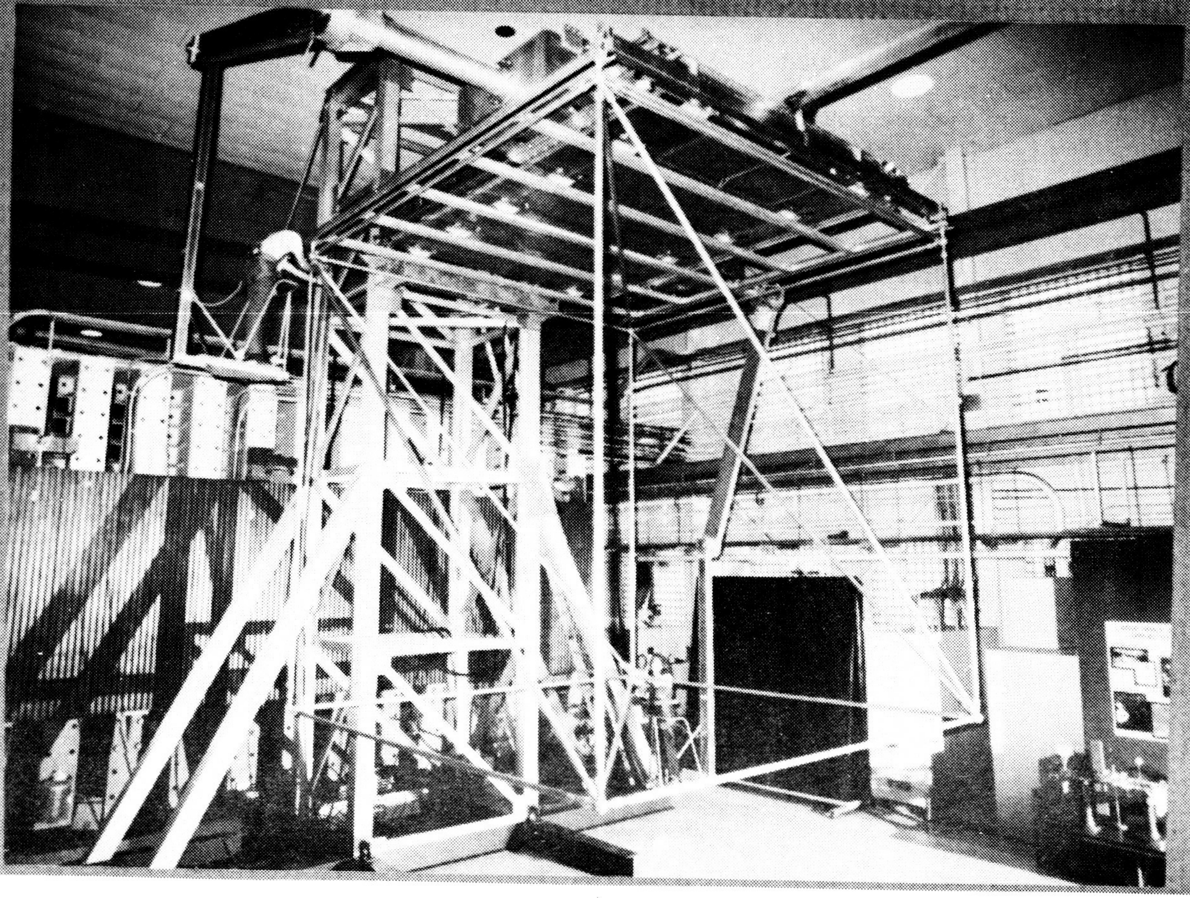
Accomplishment Description: An assembly test device has been designed, fabricated and installed in Building 1148 Structures and Materials Laboratory. This platform partially simulates operation of the mobile platform. It is capable of linear truss assembly but cannot turn corners - either horizontally or vertically as proposed for the flight version. It is hydraulically powered for both 1-g and underwater use. The arms are capable of positioning subjects within a planar work envelope on two sides of the truss structures. The drawbar simulates incremental movement of the mobile platform on the truss by translating the truss structure (supported by secondary rails in 1-g). The position of each test subject is currently controlled by an individual remotely located operator who responds to verbal commands from the test subject. Two strut cannisters (not shown) will be positioned on the platform to present truss elements to the subjects in a realistic manner.

Significance: The mobile platform simulator will permit realistic examination of structural assembly problems in both 1-g and simulated 0-g environments. In addition to timelines, tests will provide early operational information for the preferred arrangement and design of flight hardware for the truss and assembler system.

Future Plans: One-g testing and check-out of the mobile platform assembler will be completed at LaRC by mid April 1988. Simulated 0-g (neutral buoyancy tests) will be performed at MSFC during May and June 1988. Astronauts, as available, will be included in both the 1-g and neutral buoyancy tests.

L-87-11,997

I-G MOBILE PLATFORM DEVELOPED FOR SIMULATING SPACE STATION ASSEMBLY



SPACE STATION TRUSS CONSTRUCTION METHOD DEMONSTRATED IN NEUTRAL BUOYANCY TESTS

Walter L. Heard, Jr.; Harold G. Bush; Mark S. Lake
Richard E. Wallsom; and J. Kermit Jensen
Structural Concepts Branch
Ext. 2608, 2498, and 2414
RTOP 506-43-41 May 1988
Code RM WBS 55-2

Research Objectives: To perform checkout tests of the Simulated Mobile Transporter and initiate a long term test program in the Johnson Space Center's Weightless Environment Training Facility (WETF) to: (1) obtain astronaut observations of the Mobile Transporter concept proposed by LaRC for extra vehicular activity (EVA) assembly of Space Station; (2) support and encourage astronaut familiarization and neutral buoyancy training in EVA assembly of full scale Space Station truss hardware; (3) develop EVA assembly procedures; and (4) determine EVA assembly rates.

Approach: Use the Simulated Mobile Transporter designed for operation in the WETF and astronaut crews of two test subjects each to repeatedly assemble 3-bay segments of the 5-meter Space Station truss. Use stowage canisters sized to accommodate all struts and nodes required for Space Station construction First Flight. Record all operations on audio/video tapes. Debrief astronaut crews after each test.

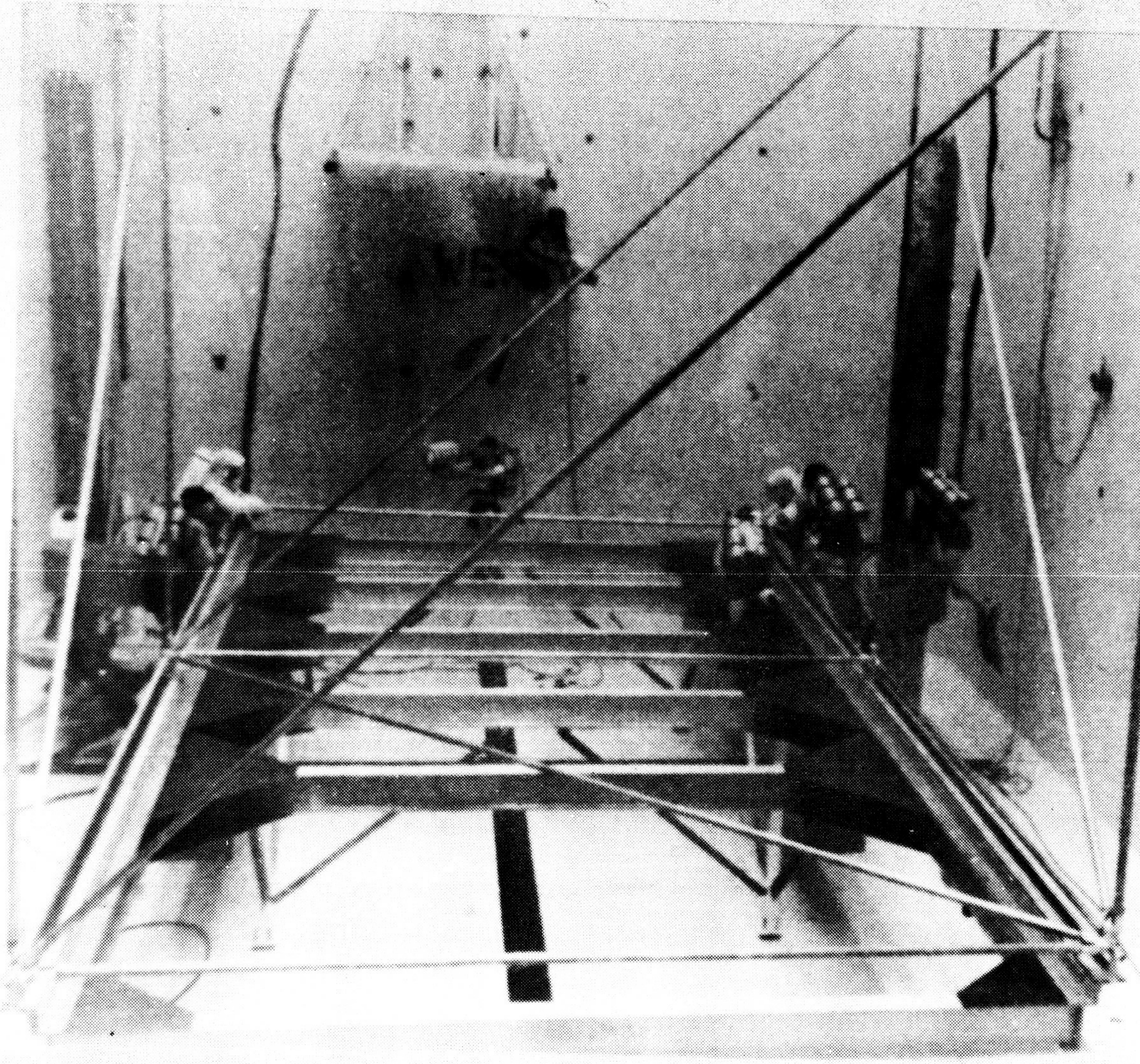
Accomplishment Description: Four truss assembly tests were performed during the week of December 7, 1987. The astronaut test subjects were: Jerry Ross, Sherwood Spring, Pierre Thuot, David Low, James Buchli, Mark Lee, and William Shepherd. Ross and Spring are the most highly experienced in performing neutral buoyancy testing, and are the only astronauts with actual EVA structural assembly experience. Although these tests were performed primarily to check out the hardware, the assembly times by Ross and Spring averaged 14 minutes for the first bay (18 struts) and 9 minutes for all other bays (13 struts each). Astronaut observations are: (1) the assembly procedure is intuitive, (2) the diagonal (longer) struts should be conspicuously marked, (3) the spacing between stowed struts is tight but adequate for access with the pressure suit glove, (4) use of only two strut/node canisters and their placement requires a large amount of "up and down" motion to access the material supply, and (5) hardware tethering remains to be addressed.

Significance: The Simulated Mobile Transporter permits realistic examination of structural assembly of Space Station truss structure, and enables early communication between astronauts and engineers for preferred design refinements. In addition, realistic assembly rates can be determined for scheduling construction of Space Station.

Future Plans: Integrated tests with various Space Station components (utilities, Crew and Equipment Translation Aid, Alpha Joint) will be conducted in the WETF in May 1988.

NASA
L-88-1892

EVA ASSEMBLY TEST OF SPACE STATION TRUSS IN NEUTRAL BUOYANCY



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REVISED PACTRUSS DESIGN ELIMINATES DEPLOYMENT HARD POINTS FOR DOUBLY-CURVED REFLECTOR TRUSS

Timothy J. Collins and Martin M. Mikulas, Jr.
Structural Concepts Branch
Ext. 2414 and 2551

RTOP 585-02-31 June 1988
Code RM WBS 55-2

Research Objective: To develop a reliably deployable, high precision, PACTRUSS-type truss structure. The PACTRUSS structure has been proposed as a design for the primary support structure of space-based Precision Segmented Reflectors (PSR) such as the Large Deployable Reflector (LDR).

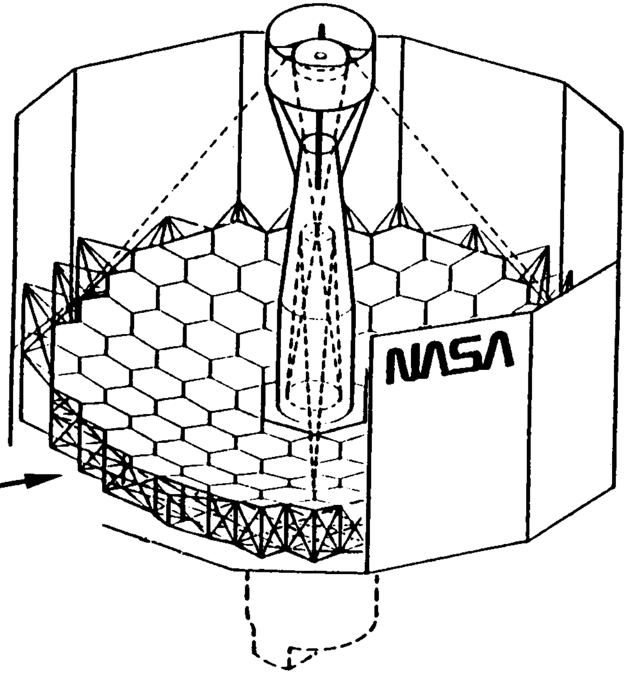
Approach: Through in-house conceptual design studies and a contract with Astro Aerospace Corporation, with John M. Hedgepeth as principal investigator, deployment analyses were conducted for several different PACTRUSS concepts. Computer programs were written for the purpose of generating various truss designs and for handling the deployment analysis of each structure.

Accomplishment Description: The original PACTRUSS design consisted of a doubly-curved truss structure with a surface that matched the contour of a parabolic reflector (see Figure). The uppermost truss nodes of this original PACTRUSS design were constrained to lie on a parabolic curve which was offset from the reflective surface by a constant standoff distance. Extensive analysis of this design showed that intolerable lockup conditions or hard points occur during deployment. To overcome the lockup problem a revised PACTRUSS design was formulated. In this design, alternate bays of the PACTRUSS are not allowed to deploy past the horizontal position. This results in a structure that has a step-like profile. For this revised PACTRUSS, a doubly-curved parabolic surface is achieved by adding extensions to the basic truss at those nodes which do not naturally lie on the desired parabola. Deployment analyses for the new PACTRUSS concept exhibited no tendency for lockup and no significant member straining.

Significance: Analysis of the new PACTRUSS design indicates that a doubly-curved support structure can be reliably deployed. Because of its self deploying nature and its relatively small stowage volume, PACTRUSS is an attractive option for the large deployable reflector or for precision segmented reflectors in general.

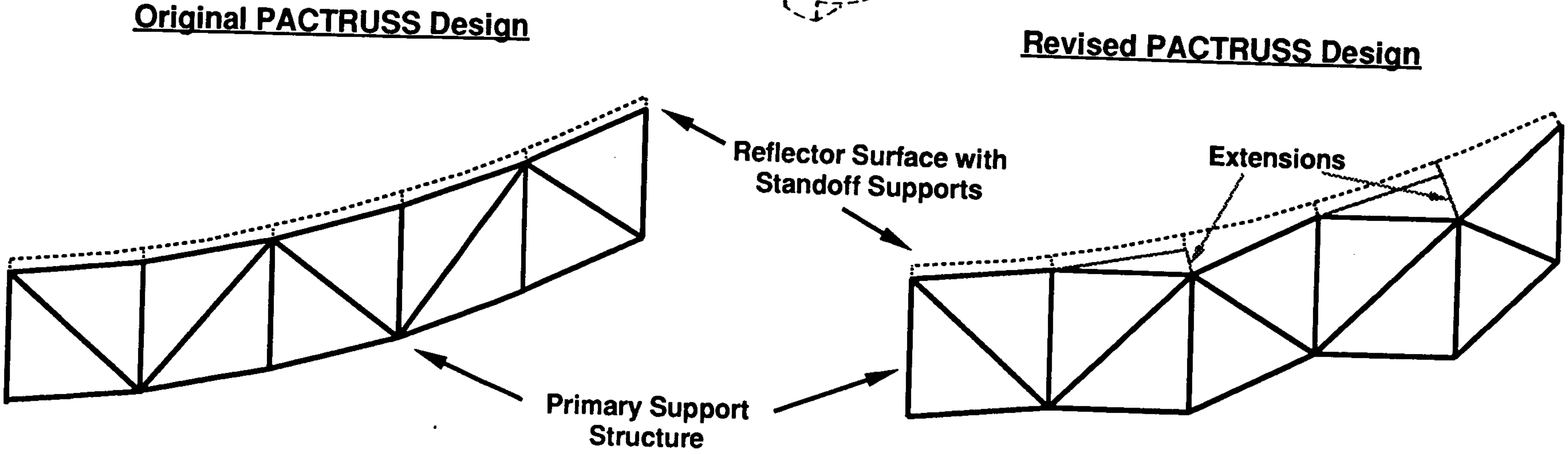
Future Plans: Final PACTRUSS configurations that meet the requirements for a JPL Test Bed experimental program are currently being generated. Finite element models are currently being developed for the different truss designs in order to determine their structural and dynamic characteristics.

REVISED PACTRUSS DESIGN ELIMINATES DEPLOYMENT HARD POINTS FOR DOUBLY-CURVED REFLECTOR TRUSS



Large Deployable Reflector (LDR) 20-Meter Baseline Concept

Deployable PACTRUSS-Type Primary Support Structure



Original PACTRUSS Design

Revised PACTRUSS Design

Reflector Surface with Standoff Supports

Extensions

Primary Support Structure

NONLINEAR RESULTS INDICATE THAT THE LINEAR ANALYSIS USED IN THE DESIGN OF THE ETA RING IS CONSERVATIVE

John T. Dorsey
Structural Concepts Branch
Ext. 2892 August 1988
RTOP 554-14-21
Code M WBS 55-2

Research Objective: The research was performed to aid the LaRC redesign effort for the Space Shuttle 270-degree External Tank Attach (ETA) Ring (shown at the top of the figure). The three objectives of this research were: 1) to provide global ring stresses as input for more detailed ring redesign analyses; 2) to understand and assess the relative importance of the rocket motor axial and circumferential loading components (due to motor pressurization) on ring stresses; 3) to determine the effect of geometric nonlinearities on ring stresses.

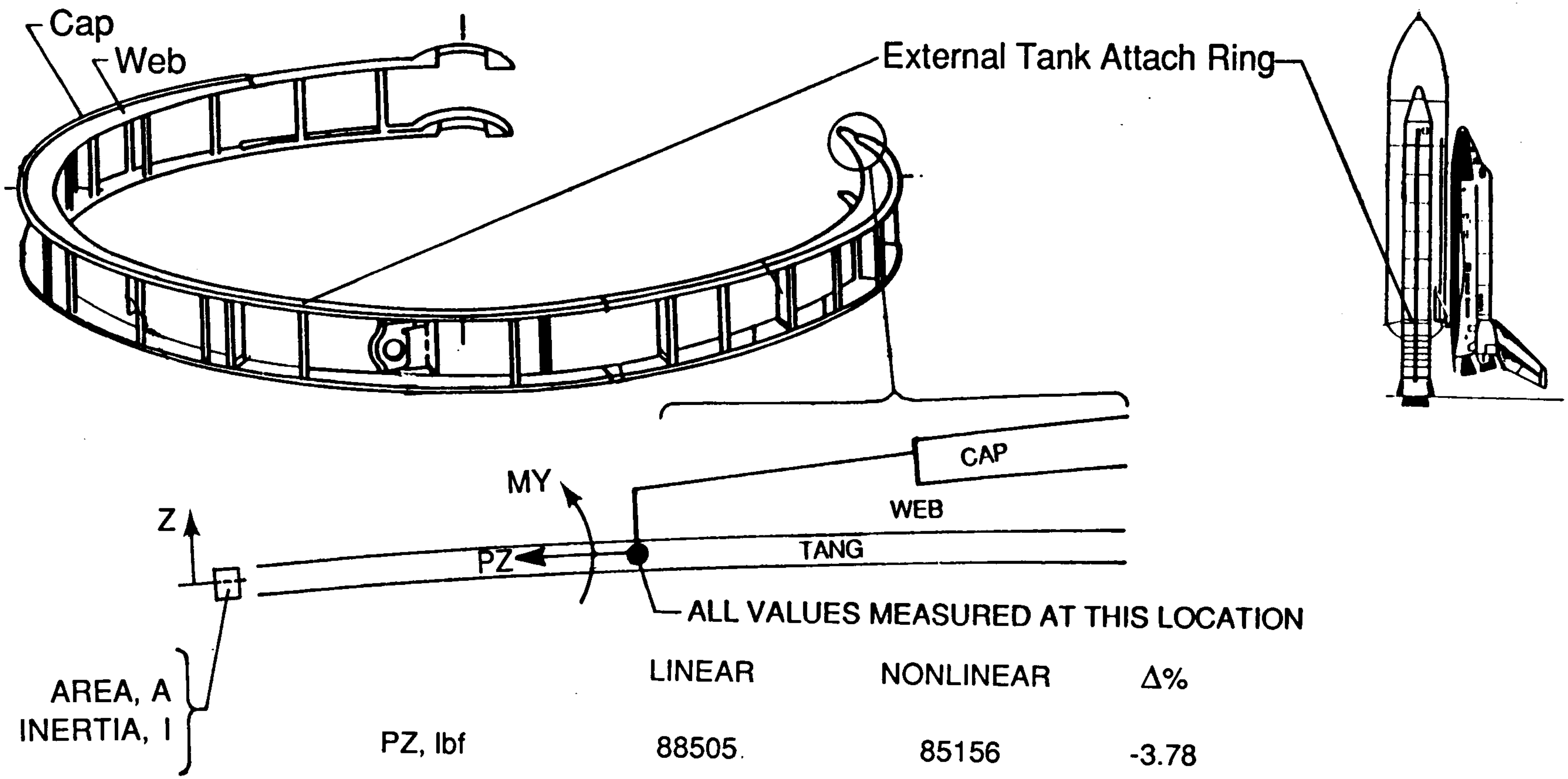
Approach: A finite element model of the original 270-degree ETA ring and neighboring Solid Rocket Motor (SRM) case wall was constructed. Ring deflections and stresses due to an internal pressure of 912 psi were determined (at the ETA ring location) using linear analysis as well as large deflection nonlinear analysis.

Accomplishment Description: The nonlinear analysis generally gave higher membrane stresses (maximum of 7 percent) in the ETA ring web, and the lowly stressed portions of the tang, but gave lower stresses in the the highly stressed portions of the tang. The results at the bottom of the figure show the maximum total stress in the tang at one end of the web. The nonlinear solution gives a 3.8 percent reduction in the tang axial load, and a 13.5 percent reduction in the tang bending moment. The resulting maximum stress in the tang outer fiber was reduced by 7.5 percent in the nonlinear solution.

Significance: This analysis indicated that the linear analysis being used in design, is conservative in the highly stressed portion of the ETA ring.

Future Plans: The LaRC effort successfully redesigned the 270-degree ETA ring to have all positive margins of safety. Plans are to certify the redesigned 270-degree ring and replace the current 360-degree ring and regain approximately 400 lbm of Shuttle payload capability.

NONLINEAR RESULTS INDICATE THAT THE LINEAR ANALYSIS USED IN THE DESIGN OF THE ETA RING IS CONSERVATIVE



	LINEAR	NONLINEAR	Δ%
PZ, lbf	88505	85156	-3.78
MY, in-lbf	15457	13378	-13.45
σ^*_{MAX}, ksi	218.5	202.1	-7.53

$^*\sigma = \frac{PZ}{A} + \frac{MY \times Z}{I}$: $A=.6616\ in^2$ $Z=.827\ in$ $I=.1508\ in^4$

SPACE STATION TRUSS ASSEMBLY WITH MOBILE TRANSPORTER DEMONSTRATED IN 1-G TESTS

Judith J. Watson, Mark S. Lake, Harold G. Bush, and Walter L. Heard Jr.
Structural Concepts Branch
J. Kermit Jensen and Richard E. Wallsom
PRC Kentron, Inc.
Ext. 2414, 2608, 2494 September 1988
RTOP 506-43-41
Code RM WBS 55-2

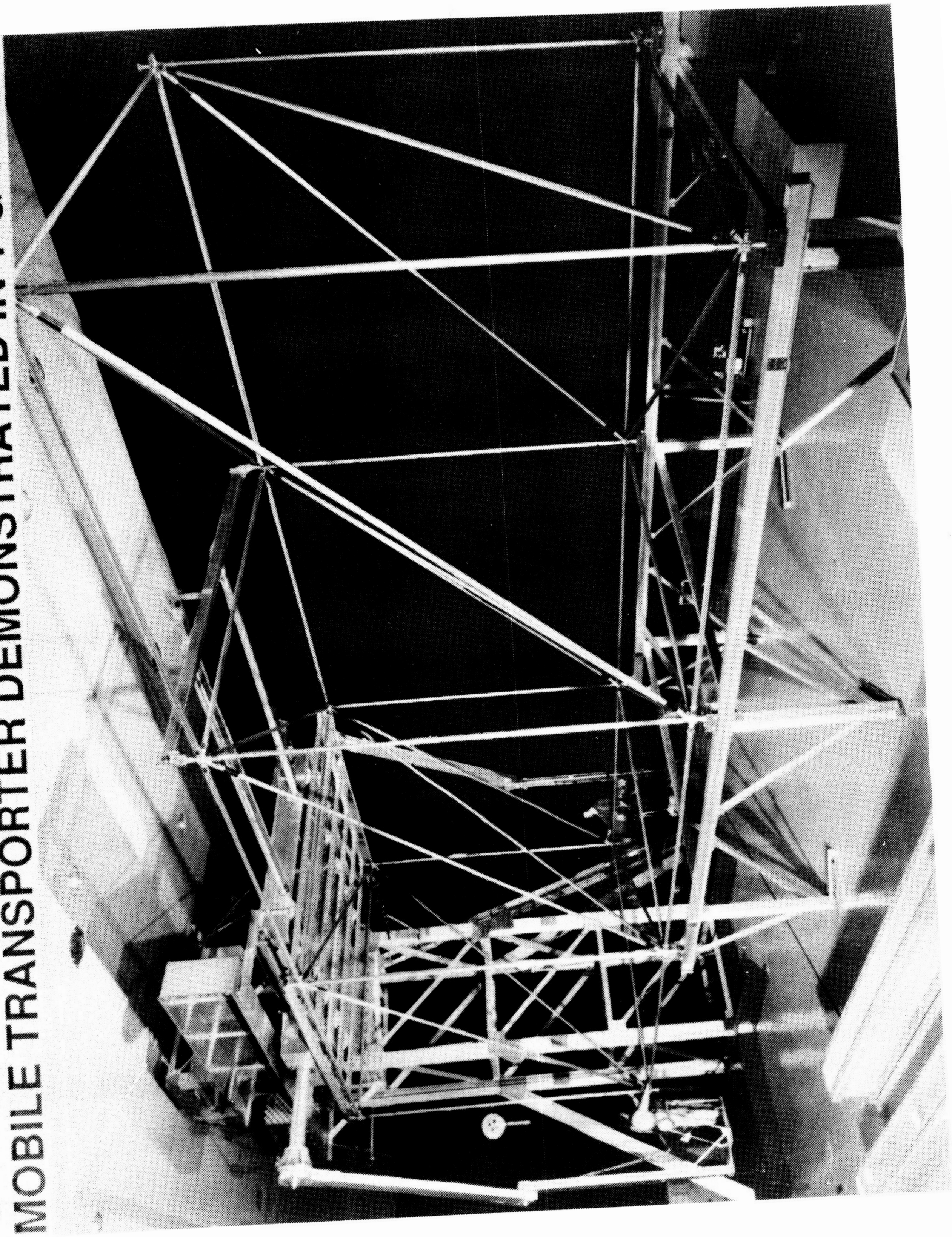
Research Objectives:
To develop procedures and determine 1-g assembly time to be used in conjunction with neutral buoyancy assembly time for prediction of EVA assembly time of Space Station truss structure using the Mobile Transporter method of assembly.

Approach:
Use crews of two test subjects each to perform timed assembly tests of a 3-bay segment of Space Station size truss structure according to various assembly procedures, using the LaRC Mobile Transporter hardware.

Accomplishment Description:
Procedural development tests were completed at LaRC during the first two weeks in March. Timed assembly tests by LaRC engineers were completed during the latter two weeks. The average time to assemble three bays (44 struts) was 15.3 minutes for a unit assembly time of 20.9 s/strut. Astronauts Col. Sherwood Spring and Maj. James Voss supported the LaRC tests by performing one training assembly test and one timed assembly test.

Significance:
The 1-g assembly test results indicate rapid assembly rates are possible with the Mobile Transporter/EVA method for Space Station assembly. Assembly procedures have been refined and test subjects trained for subsequent neutral buoyancy tests. Astronauts are now familiar with Mobile Transporter method of assembly.

Future Plans:
Truss assembly tests with integrated utility trays will be conducted with test subjects in scuba and in Extravehicular Mobility Units (EMU's) in the Neutral Buoyancy Simulator at the Marshall Space Flight Center in May-June, 1989. Results will be formally documented.



SPACE STATION TRUSS ASSEMBLY WITH
MOBILE TRANSPORTER DEMONSTRATED IN 1-G TESTS

AEROTHERMAL LOADS BRANCH

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COWL AEROTHERMAL LOADS AMPLIFIED BY SHOCK-ON-LIP AND LARCNESS IN GOOD AGREEMENT WITH MACH 8 EXPERIMENT

Ken Morgan, Rajiv Thareja, and Allan R. Wieting, Ext. 3423
Aerothermal Loads Branch
RTOP 506-40-21

Research Objective: Validate the Langley Adaptive Refinement Code NaviEr-Stokes Solver (LARCNESS) finite element analysis code's ability to predict the shock-on-lip amplified aerothermal loads on a scramjet engine cowl by comparison with the experimental data of Wieting, Holden, and Glass for incident shock heating on a blunt cylindrical leading edge. Demonstrate the ability of the adaptive unstructured remeshing capability to capture the complex flow physics of a Type IV shock interaction with a high degree of accuracy on a reduced computational grid.

Approach: Compute the flow field and aerothermal loads on the 3-inch diameter cylinder experimental model in Mach 8.03 flow with a 12.5° turning angle shock forming a Type IV supersonic-jet interaction (fig.1) with the LARCNESS code. LARCNESS utilizes an adaptive unstructured remeshing technique developed by Peraire and Morgan which begins with an approximately uniform triangular mesh in the essentially inviscid region and a stretched rectangular mesh in the near wall region (to encompass the boundary layer). Computations are initiated on this initial mesh until the flow features are well defined. Then utilizing one or more of the computed flow field gradients (such as density, Mach number, etc.) the triangular meshed inviscid region is remeshed to place smaller elements in the regions of high gradients and larger elements in regions of small gradients. The near wall rectangular mesh is maintained constant in the stretched direction, normal to the wall, and refined parallel to the wall to match the triangular mesh. Computations are then continued on the new mesh and the remeshing process repeated. Three remeshing cycles provided excellent definition of the Type IV shock interaction with the adapted grid conforming to the flow field physics as seen by comparing the experimental schlieren photograph (fig. 1) with the final adapted grid (fig. 2).

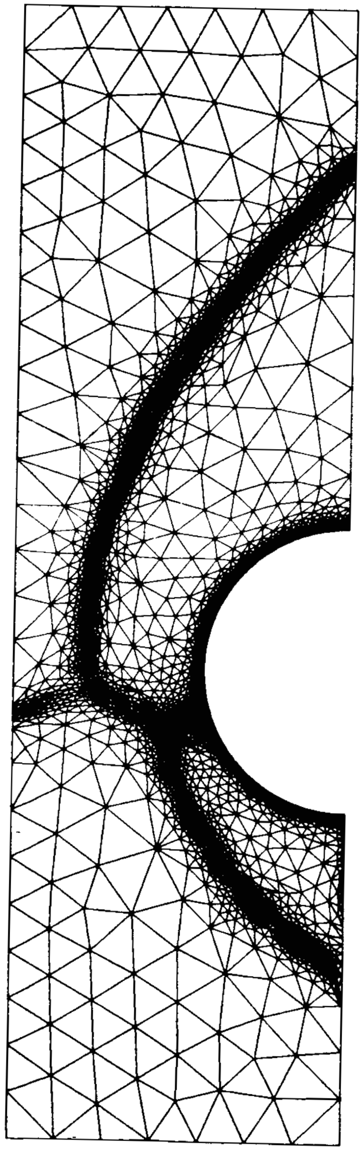
Accomplishments: LARCNESS captured the complex Type IV supersonic jet interaction with 8800 grid points (other codes require on the order of 20,000 grid points) and elements that vary in size by a factor of 1000:1. Wall pressure and heating rate distributions, normalized by the undisturbed (no incident shock) stagnation point level, and plotted as a function of the circumferential position, θ, on the cylinder (positive values of θ are on the upper half of the cylinder) are shown in figure 2. The computational results capture the sharp peaks of the locally amplified loads and are in good agreement with the experimentally measured values.

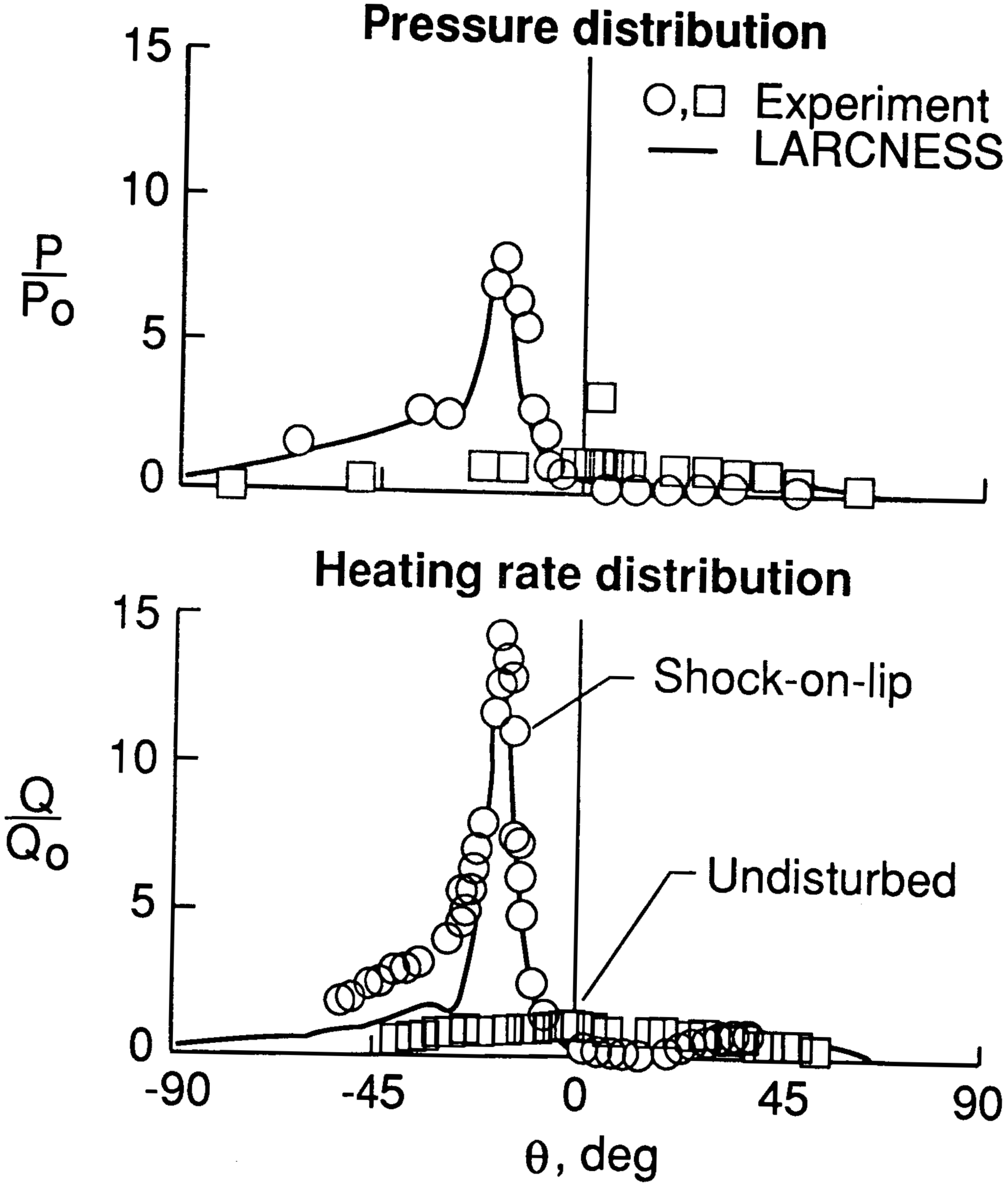
Significance: The flight environment for the AeroSpace Plane is too severe to simulate in ground based facilities, hence validated codes will have to be relied upon to predict the environment and performance of candidate cowl leading edges with shock wave interference heating. At Mach 16 the vehicle bow shock wave traverses the cowl lip and amplifies the undisturbed stagnation point heating rate by a factor of 27, which results in a heating rate between 30,000 and 100,000 BTU/ft^{2}sec depending on the flight corridor and leading edge radius.

Future Plans : Extend LARCNESS to three dimensions, add chemical equilibrium air option, and turbulence models.

LARCNESS IN GOOD AGREEMENT WITH MACH 8 EXPERIMENT

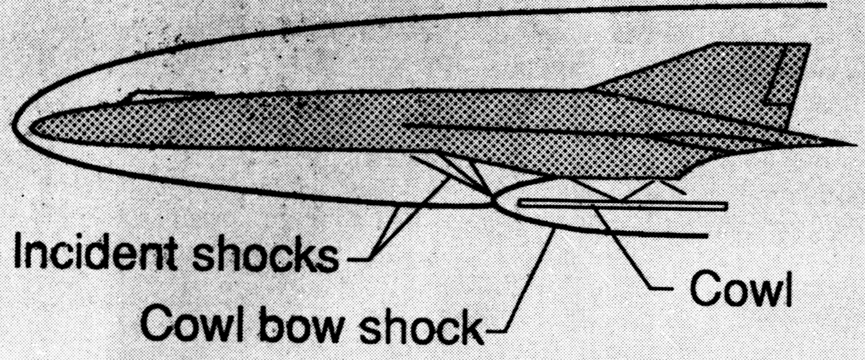
Adapted grid



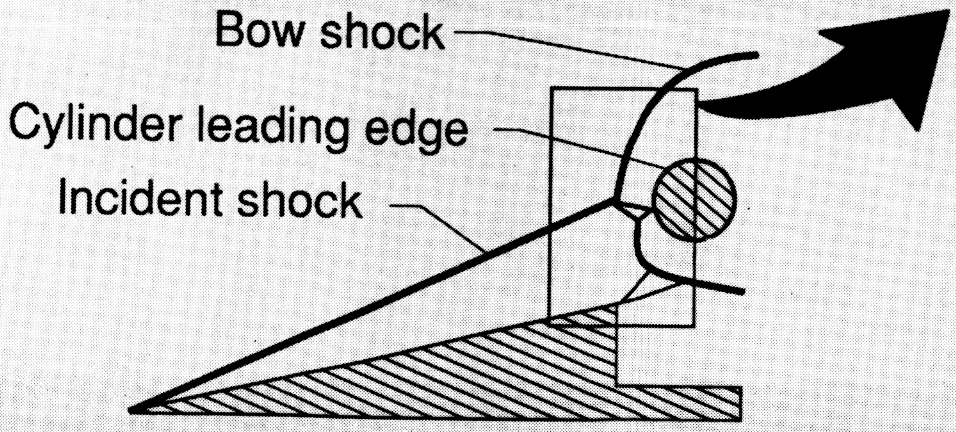


SHOCK-ON-LIP IMPINGEMENT ON COWL LEADING EDGE

Vehicle schematic



Experimental configuration



Schlieren

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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.

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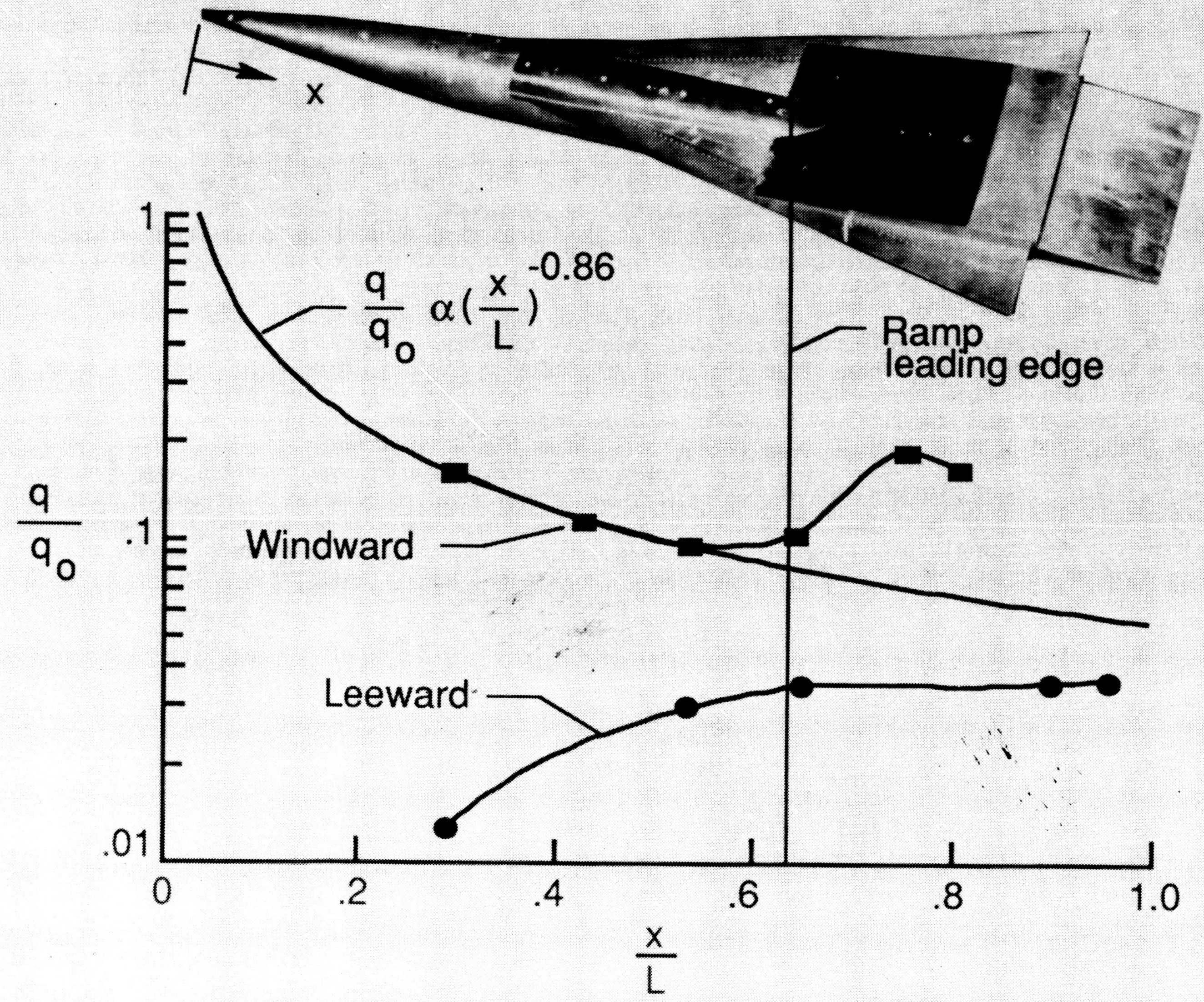
*Now assigned to Structures Directorate Office

NASP AEROTHERMAL LOADS MEASURED IN 8' HTT AT MACH 7



THERMAL SUPERCONDUCTING MATERIALS REDUCE TEMPERATURES, GRADIENTS AND STRESSES

Pramote Dechaumphai
Aerothermal Loads Branch
Extension 3155

RTOP 506-43-31
Code RM WBS 57-1

Research Objective: Leading edges for hypersonic vehicles experience intense stagnation point pressures and heating rates which are a challenge to the designer. For engine leading edges, these intense loads can be amplified by an order of magnitude when the leading edge bow shock is impinged upon by an oblique shock wave, which causes intense localized heating and attendant severe temperatures levels and gradients. The design of a cowl lip to survive this environment is one of the major challenges for the National Aero-Space Plane. Hydrogen impingement cooled leading edges are candidate concepts if the temperature levels and gradients can be reduced to an acceptable level.

Approach: The Langley Integrated Fluid Thermal Structural (LIFTS) analyzer is used to investigate the benefits of internal fins and thermal superconducting materials for reducing thermal gradients and stresses by increasing the thermal energy absorption by the hydrogen coolant and increasing circumferential diffusion. LIFTS predicts the external heating and structural heat transfer to the coolant using finite element methods. A 0.25 inch diameter leading edge is subjected to transient shock wave interference heating typical of acceleration of the X30 through Mach 16 which causes the vehicle nose bow shock to sweep across the engine cowl leading edge from an outboard to an inboard position, which creates the shock-on-lip interference pattern shown in the lower left figure. The interference heating rate reaches a peak value of 30,000 BTU/ft^2 sec. at about 22° below the horizontal centerline of the leading edge. The inner surface is convectively cooled by the direct impingement of the sonic hydrogen jet stream with an inlet temperature of 50°R and pressure of 1000 psia. Internal tapered fins around the circumference of the leading edge increase the effective convection area by a factor of 2.5. The physical area is increased five times, but because the fins are not isothermal the fin efficiency factor is 50%. Copper and beryllium are the candidate thermal superconducting materials because they provide significantly higher thermal conductivity than nickel, the baseline unfinned concept. The peaks of the thermal conductivity for copper and beryllium, which occur at 20°R and 70°R, are approximately 300 and 80 times higher than the nickel, respectively, as shown in the upper right figure.

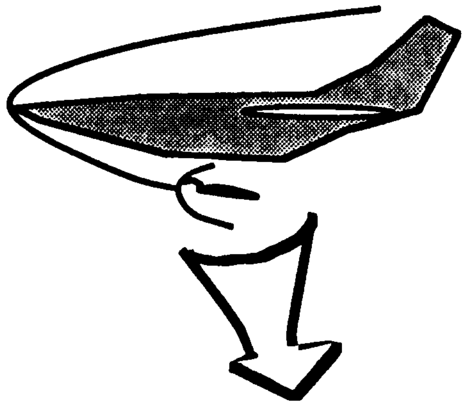
Accomplishment Description: The peak temperature, where the shock interference occurs, was reduced from 2500°R for the nickel to 1000°R for the beryllium, and to 766°R for the copper as shown in the lower right figure. The circumferential temperature gradient was also reduced significantly, but still results in an axial stress level about 100 ksi even for the copper. Since this stress level exceeds the material elastic limits, the design is cycle lift limited.

Significance: The demonstration has shown the viability of hydrogen impingement cooled leading edges over a wider range of aerothermal loading and the NASP contractors are revisiting this concept.

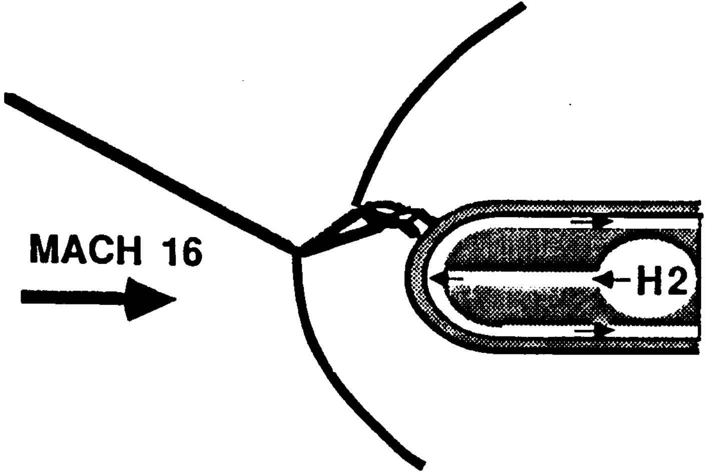
Future Plans: Modify LIFTS to improve the computational fluid dynamics module, to more efficiently calculate the loading, and extend the thermal-structural modules to three dimensions. Continue studies to develop an acceptable cowl lip design.

THERMAL SUPERCONDUCTING MATERIALS REDUCE TEMPERATURES, GRADIENTS, AND STRESSES

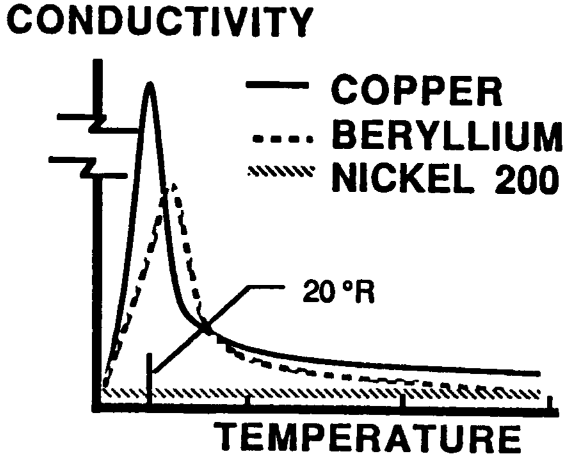
HYPERSONIC VEHICLE



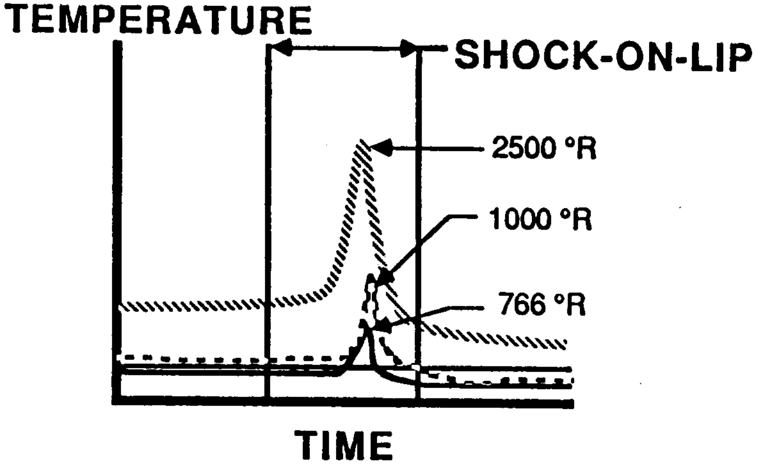
SHOCK-ON-LIP



THERMAL SUPERCONDUCTIVITY



TEMPERATURE HISTORY



IX PUBLICATIONS AND PRESENTATIONS

IX PUBLICATIONS AND PRESENTATIONS

The FY 1988 accomplishments resulted in a number of publications and presentations. They are listed below as Formal Reports, High-Nmbered Technical Memorandums, Contractor Reports, Journal Articles and Other Publications, Meeting Presentations, Technical Talks, Computer Programs, Tech Briefs, and Patents.

Formal Reports

Camarda, C. J.; and Riley, M. F.: Application of Formal Optimization Techniques in Thermal/Structural Design of a Heat-Pipe-Cooled Panel for a Hypersonic Vehicle. NASA TM-89131, October 1987

Glass, C. E.; and Hunt, L. R.: Aerothermal Tests of Quilted Dome Models on a Flat Plate at a Mach Number of 6.5. NASA TP-2804, May 1988

Lake, M. S.; and Wu, K. C.: Preliminary Investigation of Stability of a Fin-Stiffened Slender Strut. NASA TM-4034, April 1988

Noor, A. K.; and Mikulas, M. M., Jr.: Continuum Modeling of Large Lattice Structures - Status and Projections. NASA TP-2767, February 1988

Nowak, R. J.: Gas-Jet and Tangent-Slot Film Cooling Tests of a 12.5 Degree Cone at Mach Number of 6.7. NASA TP-2786, May 1988

High-Numbered Technical Memorandums

Bales, K. S.: Structures and Dynamics Division Research and Technology Plans for FY 1988 and Accomplishments for FY 1987. NASA TM-100585, May 1988

Blosser, M. L.: Thermal Stress in High Temperature Cylindrical Fasteners. NASA TM-100611, May 1988

Dechaumphai, P.; Thornton, E. A.; and Wieting, A. R.: Fluid-Thermal-Structural Study of Aerodynamically Heated Leading Edges. NASA TM-100579, April 1988

Dorsey, J. T.: Structural Analysis of the Space Shuttle Solid Rocket Booster/External Tank Attach Ring. NASA TM-100510, January 1988

Gillian, R. E.; and Lotts, C. G.: The CSM Testbed Software System: A Development Environment for Structural Analysis Methods on the NAS CRAY-2. NASA TM-100642, September 1988

Greene, W. H.; and Haftka, R. T.: Computational Aspects of Sensitivity Calculations in Transient Structural Analysis. NASA TM-100589, April 1988

Jegley, D. C.: An Analytical Study of the Effects of Transverse Shear Deformation and Anisotropy on Natural Vibration Frequencies of Laminated Cylinders. NASA TM-100554, January 1988

Jegley, D. C.: An Analytical Study of the Effects of Transverse Shear Deformation and Anisotropy on Buckling Loads of Laminated Cylinders. NASA TM-100508, October 1987

Knight, N. F., Jr.; Gillian, R. E.; and Nemeth, M. P.: Preliminary 2-D Shell Analysis of the Space Shuttle Solid Rocket Boosters. NASA TM-100515, March 1988

Lucas, S. H.; and Scotti, S. J.: The Sizing and Optimization Language (SOL) - A Computer Language for Design Problems. NASA TM-100565, April 1988

McComb, H. G., Jr. (Compiler): Redesign of Solid Rocket Booster/External Tank Attachment Ring for the Space Transportation System. NASA TM-100476, October 1987

Raju, I. S.; and Fichter, W. B.: A Finite-Element Alternating Method for Two-Dimensional Mode-I Crack Configurations. NASA TM-100616, May 1988 (SES 88-89)

Sawyer, J. W.: Investigation of Test Techniques for Measuring Interlaminar Shear Strength of Two-Dimensional Carbon-Carbon Composites. NASA TM-100647, September 1988

Sawyer, J. W.: Effects of Impact Damage and Holes on Compression Strength of Two-Dimensional Carbon-Carbon Composites. NASA TM-89150, October 1987

Scotti, S. J.; Martin, C. J., Jr.; and Lucas, S. H.: Active Cooling Design for Scramjet Engines Using Optimization Methods. NASA TM-100581, March 1988

Watson, J. J.; and Heard, W. L., Jr.: A 60-Meter Erectable Assembly Concept for a Control of Flexible Structures Flight Experiment. NASA TM-100497, February 1988

Wieting, A. R.; Dechaumphai, P.; Bey, K. S.; Thornton, E. A.; and Morgan, K.: Application of Integrated Fluid-Thermal-Structural Analysis Methods. NASA TM-100625, May 1988

Contractor Reports

Barkey, D. A.; and Madan, R. C.: Manual for Program PSTRESS: Peel Stress Computation. NASA CR-178408, December 1987 (McDonnell Douglas Corporation, NAS1-17970)

Madan, R. C.: Composite Transport Wing Technology Development. NASA CR-178409, February 1988 (NAS1-17970, McDonnell Douglas Corporation)

Rankin, C. C.: Consistent Linearization of the Element-Independent Corotational Formulation for the Structural Analysis of General Shells. NASA CR-178418, January 1988 (NAS1-18101, Lockheed Missiles and Space Company, Inc.)

Sensmeier, M. D.; Griffin, O. H., Jr.; and Johnson, E. R.: Static and Dynamic Large Deflection Flexural Response of Graphite- Epoxy Beams. NASA CR-4203, March 1988 (NAG1-343, Virginia Polytechnic Institute and State University)

Journal Articles and Other Publications

Camarda, C. J.; and McGowan, D. M.: (Subject sensitive, title omitted). NASP TM-1022, June 1988 (Special Document)

Card, M. F.; and Starnes, J. H., Jr.: Current Research in Composite Structures at NASA's Langley Research Center. Sadhana, Volume 11, Parts 3 & 4, December 1987, p. 277-298

Davis, J. G., Jr.: (Subject sensitive, title omitted). NASP TM-1017, May 1988

Davis, J. G., Jr.; and Dixon, S. C.: Beyond Simulation. Aerospace America, July 1988, Volume 26, No. 7, p. 38-42

Greene, W. H.; Knight, N. F., Jr.; and Stockwell, A. E.: Structural Behavior of the Space Shuttle SRM Tang-Clevis Joint. Journal of Propulsion and Power, Volume 4, No. 4, July - August 1988, p. 317-327

Haftka, R. T.; and Starnes, J. H., Jr.: Stiffness Tailoring for Improved Compressive Strength of Composite Plates with Holes. AIAA Journal, Vol. 26, No. 1, January 1988, p. 72-77

Holden, M. S.; Wieting, A. R.; and Glass, C. E.: (Subject sensitive, title omitted). NASP CR-1014, May 1988 (Special Document)

Knight, N. F., Jr.; and Starnes, J. H., Jr.: Postbuckling Behavior of Selected Curved Stiffened Graphite-Epoxy Panels Loaded in Axial Compression. AIAA Journal, Vol. 26, No. 3, March 1988, p. 344-352

Nemeth, M. P.: Buckling Behavior of Compression-Loaded Symmetrically Laminated Angle-Ply Plates with Holes. AIAA Journal, Vol. 26, No. 3, March 1988, p. 330-336

Noor, A. K.; and Mikulas, M. M., Jr.: Continuum Modeling of Large Lattice Structures: Status and Projections. In Large Space Structures: Dynamics and Control, S. N. Atluri and A. K. Amos, eds., Springer-Verlag, 1988, p. 1-34

Thurston, G. A.; and Stein, P. A.: An Experiment for Determining the Euler Load by Direct Computation. Experimental Mechanics, Volume 28, No. 1, March 1988, p. 70-76

Thurston, G. A.; Reissner, J. E.; Stein, P. A.; and Knight, N. F., Jr.: Error Analysis and Correction of Discrete Solutions From Finite-Element Codes. AIAA Journal, Volume 26, No. 4, April 1988, p. 446-453

Meeting Presentations

Blosser, M. L.: Thermal Stress in High Temperature Cylindrical Fasteners. Presented at the AIAA, ASME, et al., 29th Structures, Structural Dynamics and Materials Conference, April 18-20, 1988, Williamsburg, Virginia. AIAA Paper No. 88-2246-CP

Bonnani, D. L.; Johnson, E. R.; and Starnes, J. H., Jr.: Local Crippling of Thin-Walled Graphite-Epoxy Stiffeners. Presented at the AIAA, ASME, et al., 29th Structures, Structural Dynamics and Materials Conference, April 18-20, 1988, Williamsburg, Virginia. AIAA Paper No. 88-2251-CP

Bostic, S. W.; and Fulton, R. E.: Vibration Analysis Using a Parallel Lanczos Method. Presented at the ASCE National Convention on Parallel and Distributed Processing in Structural Engineering, May 9-13, 1988, Nashville, Tennessee. In Proceedings, Parallel and Distributive Processing in Structural Engineering Session

Camarda, C. J.: (Subject sensitive, title omitted). Presented at the Fourth National Aero-Space Plane Technology Symposium, February 17-19, 1988, Monterey, California. In NASP CP-4027, Volume VI, p. 157-188

Camarda, C. J.: Thermostructural Applications of Heat Pipes for High-Speed Aerospace Vehicles. Presented at the Third International Heat Pipe Symposium, September 12-14, 1988, Tsukuba City, Japan. In Proceedings, p. 348-357

Card, M. F.; and Starnes, J. H., Jr.: Current Research in Composite Structures at NASA's Langley Research Center. Presented at the Indian Institute of Technology, Aeronautical Society of India, et al., International Conference on Composite Materials and Structures, January 6-9, 1988, Madras, India. In Composite Materials and Structures, K. A. V. Pandalai, ed., Academy of Sciences, Bangalore, India, 1988, p. 5-26

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16. Abstract

This paper presents the Objectives, FY 1989 Plans, Approach, and FY 1989 Milestones for the Structural Mechanics Division's research programs. FY 1988 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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