FY01 and Beyond Program Plan

POC: Dave Bowles
3rd Gen Airframe Program Manager
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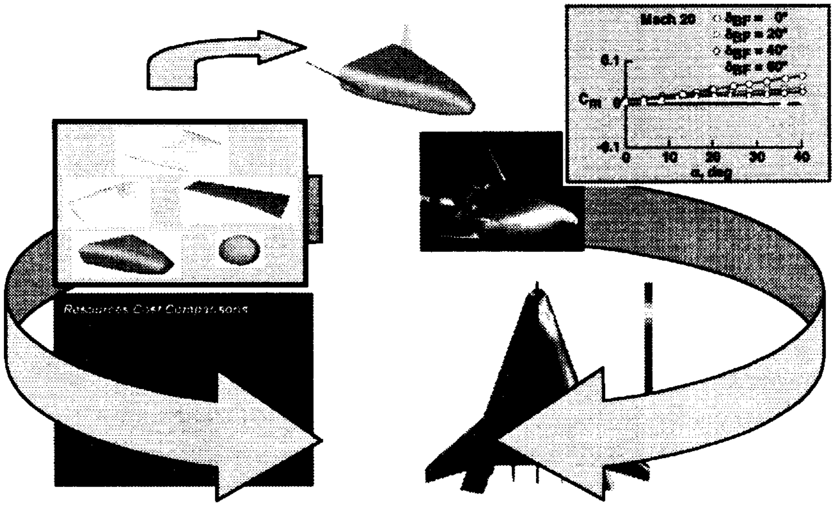
- **Project Scope:**
  - Develop and demonstrate 3rd generation airframe technologies that provide significant reductions in cost of space transportation systems while dramatically improving the safety and higher operability of those systems.

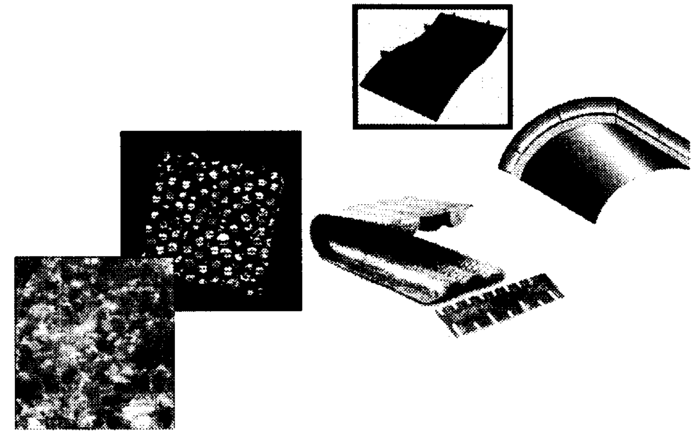
- **Supports Goal 9**
  - Earth-to-Orbit (Goal 9): Conduct research and technology development and demonstrations which will enable U.S. industry to increase safety by four orders of magnitude (loss of vehicle/crew probability less than 1 in 1,000,000 missions) and reduce costs by two orders of magnitude ($100's per pound) within 25 years.

3rd Gen Airframe/TPS:

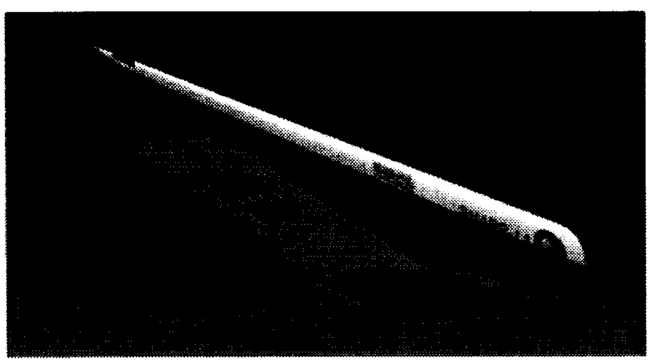
Project Description



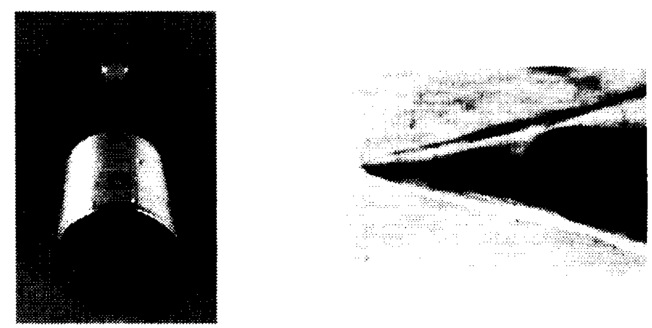
Integrated Airframe Design
(LaRC Lead)



Int. Thermal Structures & Materials
(LaRC Lead)



Thermal Protection Systems
(ARC Lead)



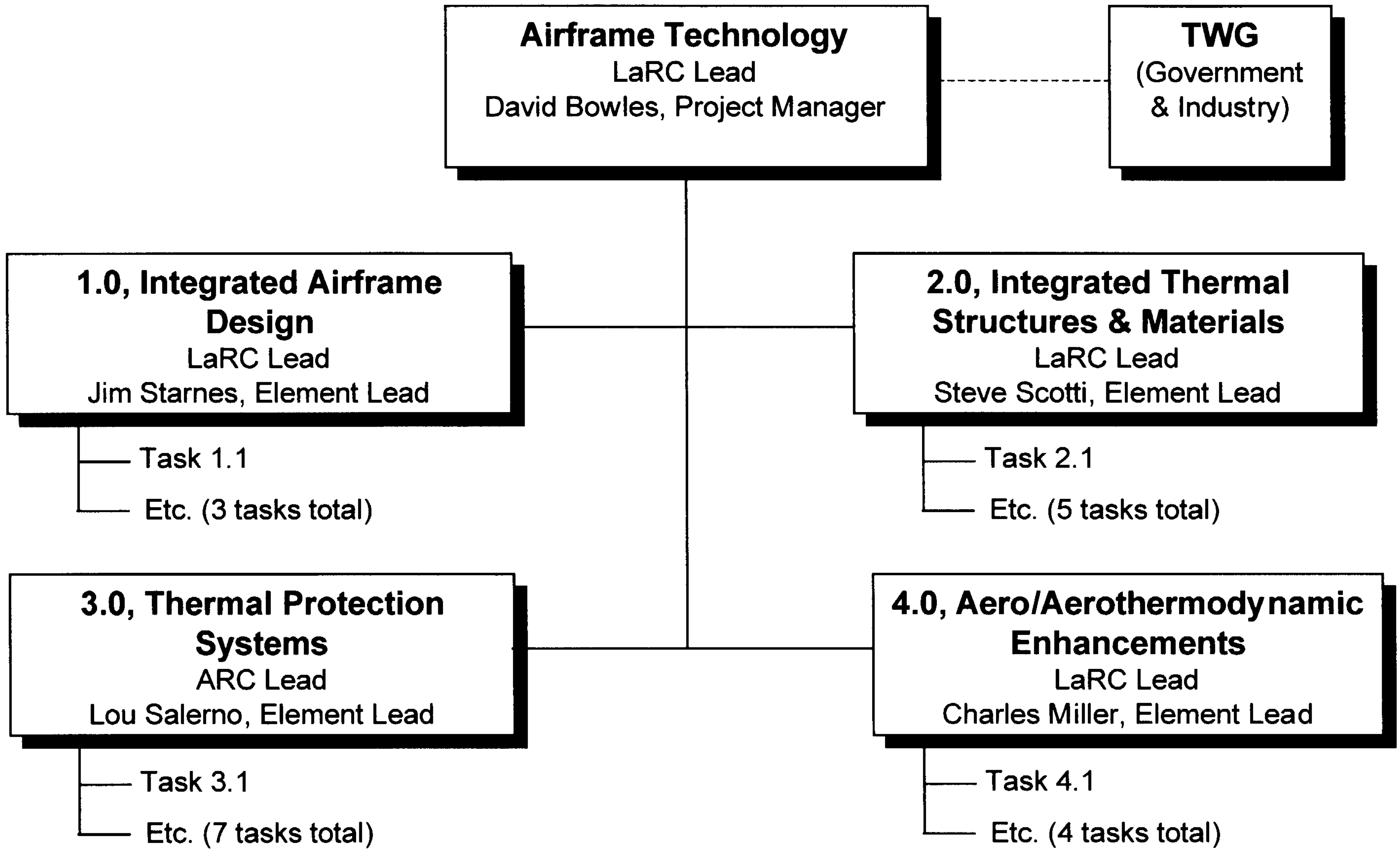
Aero/Aerothermo Enhancement
(LaRC Lead, No FY00 Funding)

3rd Gen Airframe/TPS:

Airframe Technology Elements

3rd Gen Airframe/TPS:

Airframe Organization and WBS



- **Integrated Design & Analysis**
  - Dr. James H. Starnes
  - (757) 864-3168
  - j.h.starnes@larc.nasa.gov
- **Integrated Thermal Structures & Materials**
  - Dr. Stephen J. Scotti
  - (757) 864-5431
  - s.j.scotti@larc.nasa.gov
- **Thermal Protection Systems**
  - Dr. Louis J. Salerno
  - (650) 604-318
  - lsalerno@mail.arc.nasa.gov
- **Aero/Aerothermodynamic Enhancements**
  - Dr. Charles G. Miller
  - (757) 864-5221
  - c.g.miller@larc.nasa.gov

3rd Gen Airframe/TPS:

Element Lead Contact Information

3rd Gen Airframe/TPS:

Technical Working Group (TWG)

1. **Dave Bowles (Acting Chair), Project Manager, LaRC**
2. **Jim Starnes, Integrated Airframe Design Element Lead, LaRC**
3. **Steve Scotti, Integrated Thermal Structures and Materials Element Lead, LaRC**
4. **Lou Salerno, Thermal Protection Systems Element Lead, ARC**
5. **Charles Miller, Aero/Aerothermal Enhancement Element Lead, LaRC**
6. **Frances Hurwitz, GRC**
7. **Pete Rodriguez, MSFC**
8. **Jason Hatakeyama, Boeing**
9. **Derek Townsend, Lockheed Michoud**
10. **Ravi Deo, Northrup-Grumman**
11. **Mike Stropki, DoD (alternate Dan Cleyrat)**
12. **Tom Dragone- OSC**
13. **Roger Kimmel, DoD**

Ex-Officio:

1. **Marshall Merriam ARC**
2. **Partha Dasgupta, GRC**
3. **Gaspare Maggio, SAIC**

TWG Scope

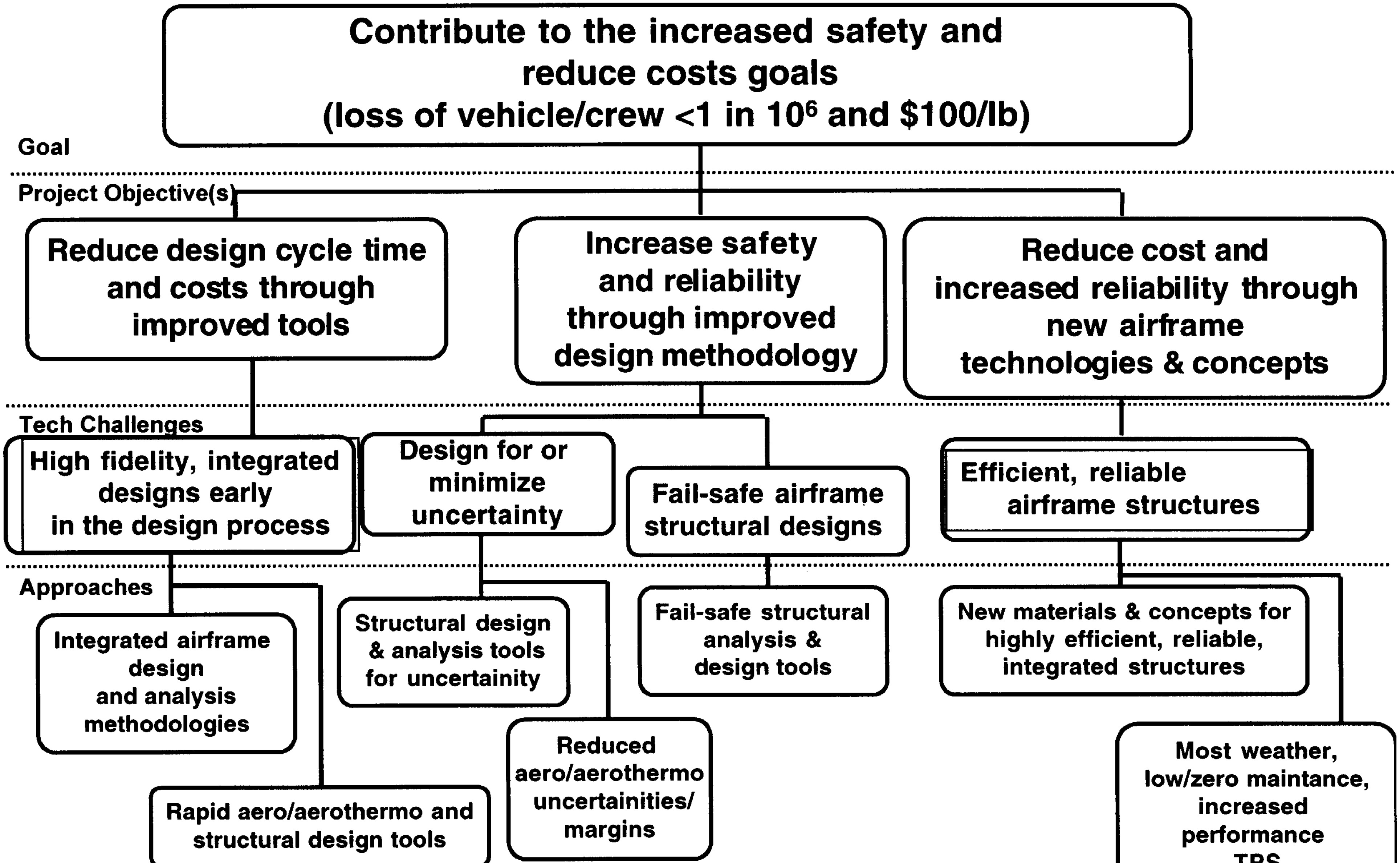
- **Government and Industry participants**
- **Primary responsibilities**
  - Review technical progress and results (annual?)
  - Recommend technical priorities
  - Foster coordination with industry and other government agencies

3rd Gen Airframe/TPS:

Top Level Budget Summary

3rd Gen Airframe/TPS:

Task Structure and Leads



3rd Gen Airframe/TPS:

Goals, Objectives, Challenges, Approaches

- **Goal:**
  - **Reduced Cost ($100/lb)**
  - **Increased Safety (LOC/LOV 1 in 10^6)**
- **Challenge:**
  - **How to meet both simultaneously?**
- **Strategy:**
  - **Requires paradigm change**

Conventional Paradigm:	***New Paradigm:***
Cost $\downarrow$ ***Safety*** $\downarrow$	***Cost*** $\downarrow$ ***Safety*** $\uparrow$

- **Paradigm change achieved by**

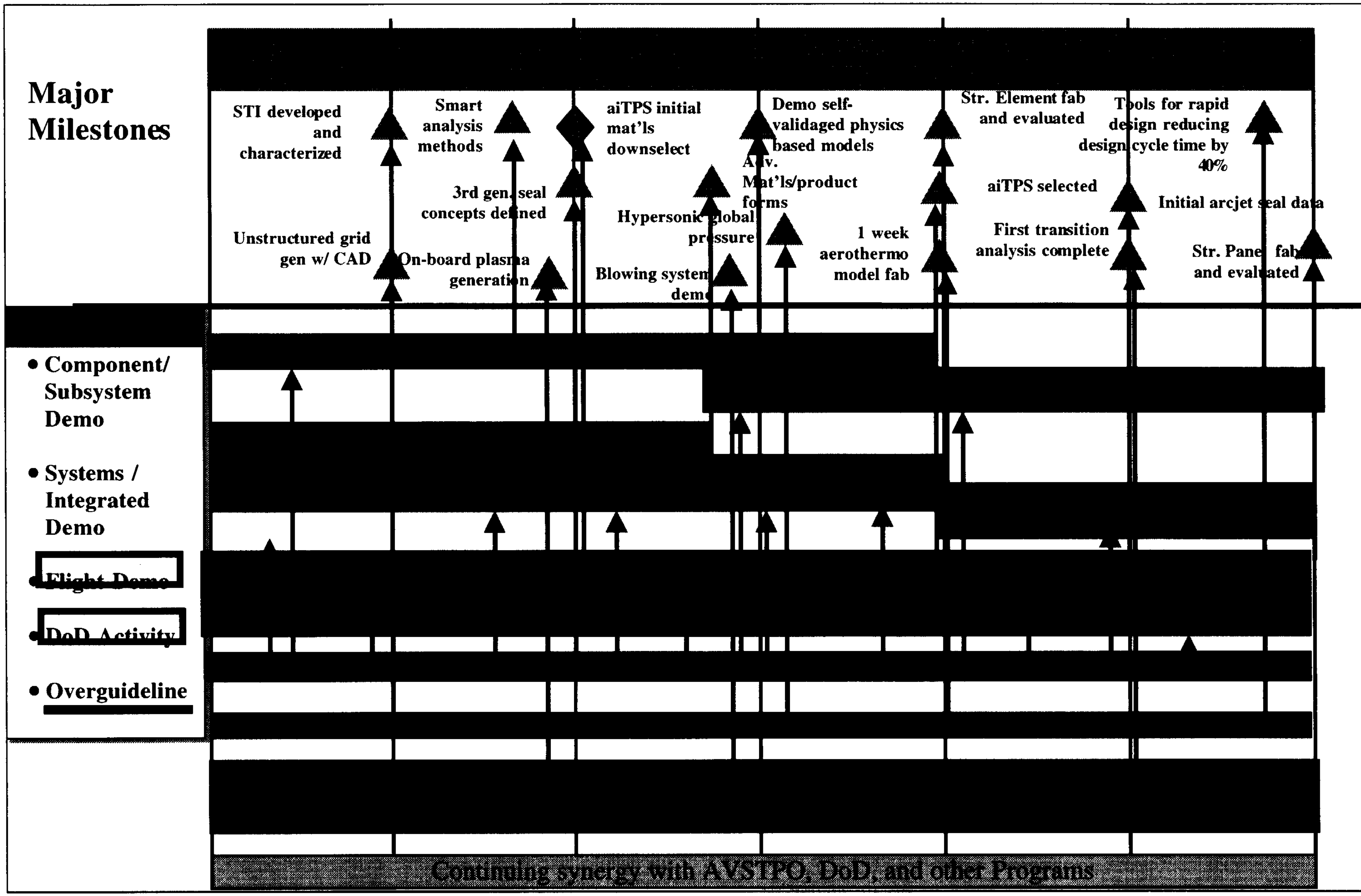
Inherent Reliability through Robust Designs

Advanced Airframe Technologies Allow Robust Designs at Reduced Weights

- ***High fidelity, reliability based analysis and design methodologies***
- ***Advanced materials and structural concepts***

3rd Gen Airframe/TPS:

Strategy for Meeting the Goals

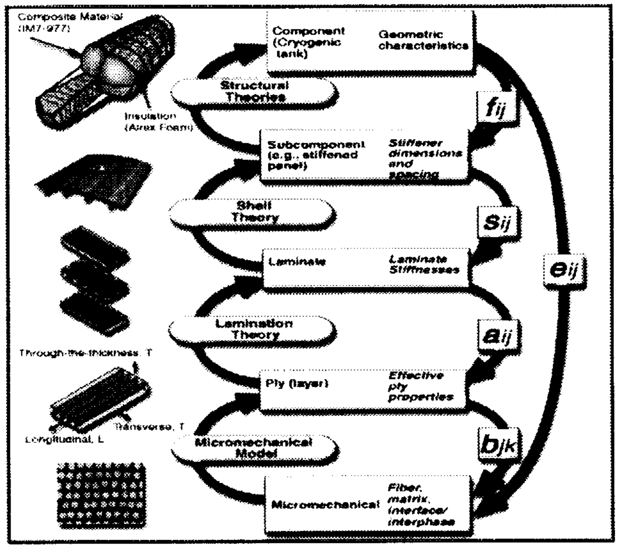


3rd Gen Airframe/TPS:

Project Roadmap

3rd Gen Airframe/TPS:

Integrated Airframe Design



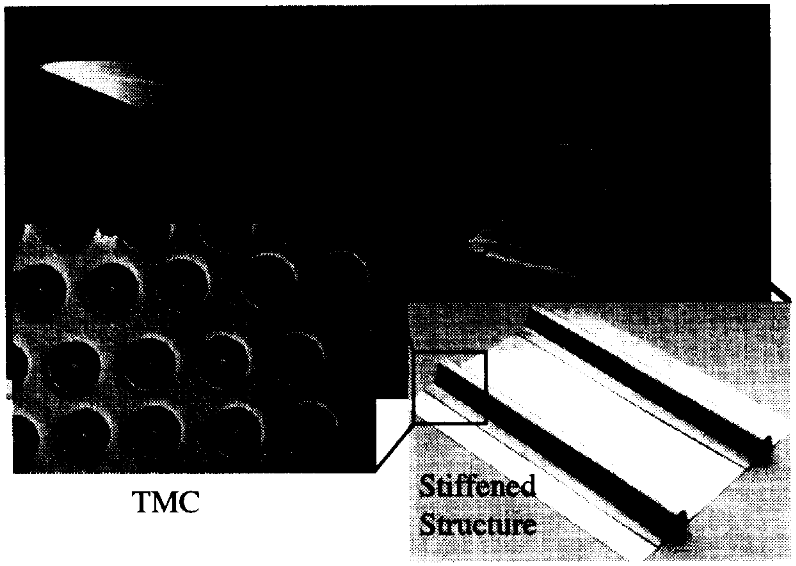
- Integrated advanced design and analysis methods that reduce design cycle time
- Airframe structural design and analysis methods that relate risk, cost and performance
- Verified fail-safe structural design and analysis methods that increase reliability

- Goals
  - Contribute to 100x cost reduction and 10, 000x safety improvement goals
- Objectives
  - Develop integrated airframe design and analysis technologies to reduce design cycle time by 40% and design cost
  - Develop verified fail-safe structures design and analysis technologies that increase the reliability by an order of magnitude and increase performance

- Major FY01 / 02 Products
  - Parametric studies to identify key parameters (9/01)
  - Develop "smart" analysis methods that can automatically account for uncertainties (9/02)
- Major FY03 - 06 Products
  - Develop high-fidelity physics-based analysis methods for predicting coupled thermal-structural response (9/03)
  - Structural design and sizing for residual strength (9/04)
  - Rapid, hierarchical analysis (9/06)

3rd Gen Airframe/TPS:

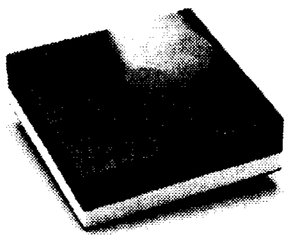
Integrated Thermal Structures and Materials

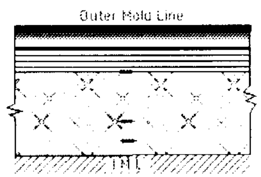


- Goals
  - Contribute to 100x cost reduction and 10, 000x safety improvement goals
- Objectives
  - Efficient and reliable hot wing structures with low maintenance and fabrication costs
  - Efficient and reliable conformal cryotank structures with low maintenance and fabrication costs

- Ultra-high properties over extended temperature ranges for both hot wing and conformal cryotank structures
- Large-scale fab of structures into high-efficiency/reliable/functional component hardware for both hot wing and conformal cryotank structures
- Thermal & thermal-structural concepts including control/accommodation of temperatures and thermal stresses

- Major FY01 / 02 Products
  - Select constituents and processes (9/01)
  - Advanced adhesives for non-autoclave processing (9/02)
  - MMC and Al-Mg-Be materials characterization (9/02)
- Major FY03 - 06 Products
  - Integrated airframe concepts defined and assessed (12/02)
  - TMC fiber/matrix interaction studies (9/03)
  - Advanced cryogenic insulation (9/03)
  - MMC and Al-Mg-Be cryogen compatibility (9/03)
  - Structural elements made of adv materials fab and evaluated (9/04)
  - Structural panels made of adv mat'ls (9/06)





STI Exploits Embedded Phases of Nanostructural or Energy Transport Control Materials into Tiles, Blankets, and other TPS to isolate and control cryopumping, radiation, convection, and conduction

- Goals
  - Increased TPS safety, reliability, operability, and decreased cost
- Objectives
  - Necessary ground development and characterization
  - Development and demonstration of highly reusable TPS with extended life cycle capabilities, including most weather flight capability and fail-safe performance
  - Assessment, simulation, and prediction of TPS degradation and failure

- Higher temperature lower density systems
- Improved operating margins
- Fault tolerant systems
- Most weather capability
- Low/zero maintenance

- Major FY01 / 02 Products
  - Superthermal Insulation materials development and characterization (9/01)
  - Initial aiTPS materials downselection (9/02)
  - 3rd gen seal concepts defined (9/02)
- Major FY03 - 06 Products
  - Completed initial arcjet testing of seal concepts (9/05)
  - MITAS graded layer systems for mechanical/thermal test (9/06)

3rd Gen Airframe/TPS:

Thermal Protection Systems

- Goals
  - Contribute to 100x cost reduction and 10, 000x safety improvement goals
- Objectives
  - Reduce time for aero/aerothermo design of aerospace vehicles (factor of 20 by 2010)
  - Reduce aero/aerothermo uncertainties/margins and enhanced performance by 10x

- **Decrease ground-based facility testing time by a factor of 20**
- **Develop aerothermo multidisciplinary techniques**
- **Decrease CFD prediction times by a factor of 30**
- **Determination and control of boundary layer transition**
- **Flow control or modification of flow environment**

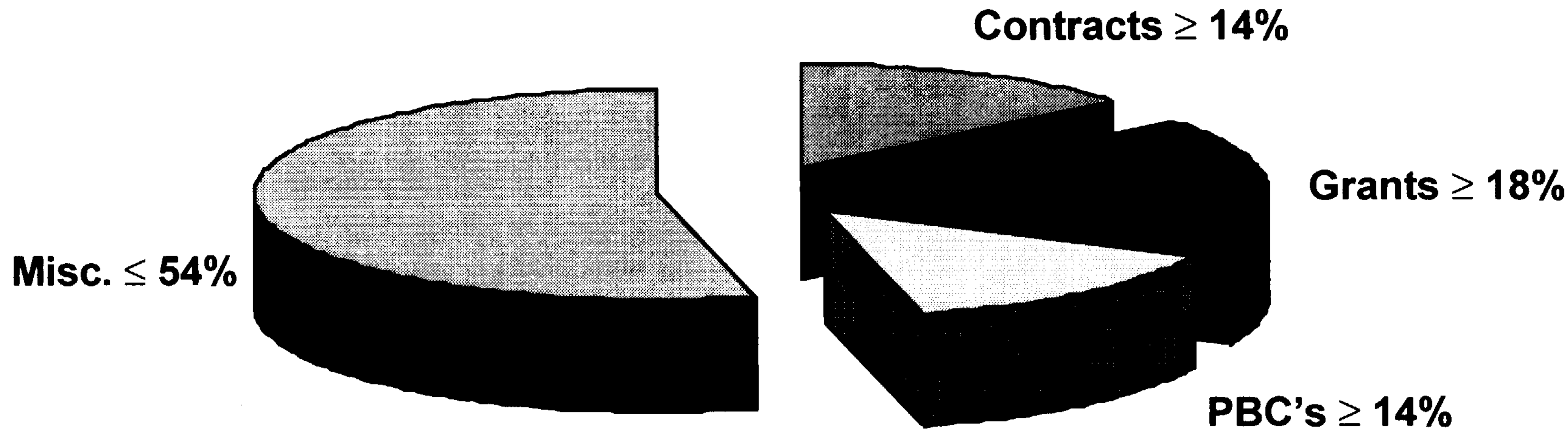
- **Major FY01 / 02 Products**
  - **Unstructured grid generation with CAD (10/01)**
  - **Low shrinkage metal model casting (12/01)**
- **Major FY03 - 06 Products**
  - **High resolution image acquisition (12/02)**
  - **Automated 3-D image mapping software (12/03)**
  - **1 week aerothermo model fab (9/04)**
  - **First transition analysis complete(12/05)**
  - **Tools for rapid design reducing design cycle time by 40% (6/06)**

3rd Gen Airframe/TPS:

Enhanced Aero/Aerothermo

- Varies across elements and tasks
  - University grants (existing and new)
  - Existing task assignment contracts
  - Specific RFPs ?
  - In-House (facilities, materials, equipment, PBC's, etc.)

FY01 Funding Distribution (Net $7.76M)



3rd Gen Airframe/TPS:

Acquisition Strategy

3rd Gen Airframe/TPS:

Risk Management

- **Overall Project Level Risks**

  Objective: Develop and demonstrate 3rd generation airframe technologies that provide significant reductions in cost of space transportation systems while dramatically improving the safety and higher operability of those systems

  - Risk:
    - Uncertainty in funding and budget reduction constraints
  - Risk Mitigation Strategy:
    - Use Descope plan within budget constraints
  - Risk:
    - Lack of good systems analysis to identify technology cost/benefit trades
  - Risk Mitigation Strategy:
    - Develop systems analysis to conduct cost/benefit trades
    - Utilize TWG to help set technology priorities
  - Risk:
    - High risk technologies, all of which might not proceed as planned
  - Risk Mitigation Strategy:
    - Use multiple technical approaches where feasible

- Solid Technical Plan in Place
- Strong Intercenter Team (ARC, GRC, LaRC, MSFC)
- Looking Forward to Industry/Academia Input and Participation

3rd Gen Airframe/TPS:

FY01 Summary Comments

3rd Gen Airframe/TPS:

FY00 Research Highlights

- **Focus on those activities that will be continued/built upon in FY01**
- **Topics include**
  - **Integrated Design and Analysis**
    - Damage Tolerance & Repair
    - Safe Structures Design Technology
  - **Integrated Thermal Structures & Materials**
    - Resins for transfer molding or infusion processing
    - Nonautoclave processable adhesives
    - Automated Tape Placement Device with e-beam cure
  - **Thermal Protection Systems**
    - Quick Processed, Low Cost Erosion Resistant TPS
    - SmarTPS
    - Advanced High Temperature Structural Seals
    - UHTC Sharp Leading Edges
    - High Temperature Felt TPS

Integrated Design and Analysis Overview

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- **PMC Damage Tolerance & Repair**
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    - Dr. Tom S. Gates
    - (757) 864-3400
    - t.s.gates@larc.nasa.gov
- **Safe Structures Design Technologies**
  - **POC:**
    - Dr. Damodar R. Ambur, NASA LaRC
    - (757) 864-3449
    - d.r.ambur@larc.nasa.gov

3rd Gen Airframe/TPS:

Integrated Design and Analysis

PMC Damage Tolerance and Repair
Goals & Objectives

- Develop methodology for assessing the effects of manufacturing defects
- Develop damage tolerance criteria and damage tolerance database for RLV cryogenic tank structures
  - impact
  - pressure leakage
  - cryogenic permeation
  - validated damage prediction tools
- Develop repair technology

PMC Damage Tolerance and Repair
Current Program Status

- Initiated in FY1999 as Bantam Damage Tolerance Program
- Continued as PMC Damage Tolerance Program during FY2000 with reduced funding level
- Needs continuation to address technology issues that will limit composites application to cryogenic tank structures

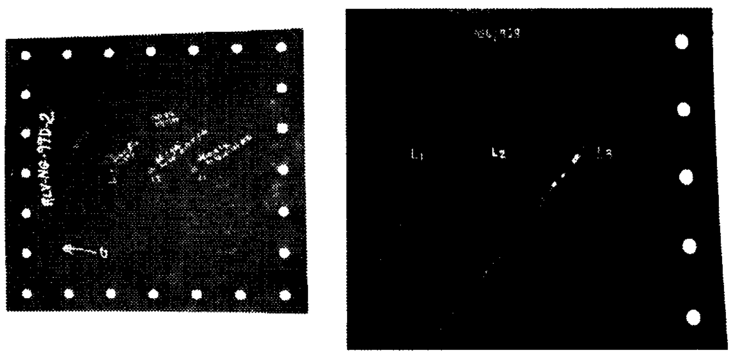
PMC Damage Tolerance and Repair
Current Technical Status

- **FY1999:**
  - Established damage tolerance requirements (impact, pressure leakage, cryogenic permeation)
  - Fabricated and impact tested flat and curved thin-skin panels made of different material forms
  - Conducted impact damage tolerance tests for damage resistance and barely visible damage (BVID); developed a 0.05 in. dent depth BVID criterion
  - Developed analytical methods to predict the impact response and damage resistance for curved, thin laminated composites
- **FY2000:**
  - Assessed existing repair methods for stiffened-skin and sandwich constructions
  - Developed analysis methods for optimally sizing bolted and bonded anisotropic patch repairs
  - Completed compression-after-impact strength tests on three material forms
  - Developed analytical models and methods to assess the critical size of delaminations for combined loading conditions
  - Assessed mixed-mode fracture toughness for IM7/977-2 and AS4/PEEK material systems at cryogenic temperatures
  - Conducting pressure leakage threshold tests

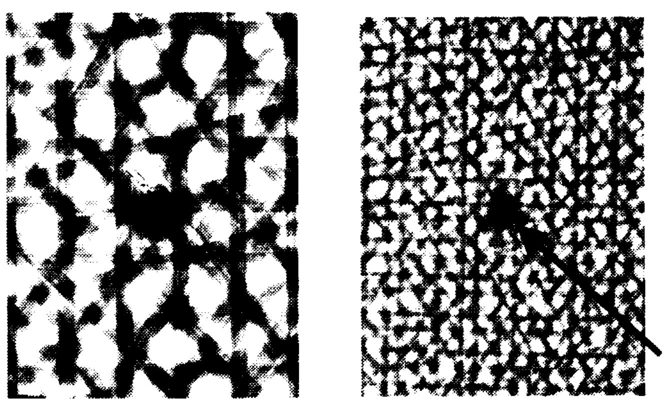
PMC Damage Tolerance and Repair

ENERGY THRESHOLDS FOR BARELY VISIBLE IMPACT DAMAGE OF CURVED THIN LAMINATES MADE OF DIFFERENT MATERIAL FORMS

Criterion: 0.05-in. dent depth

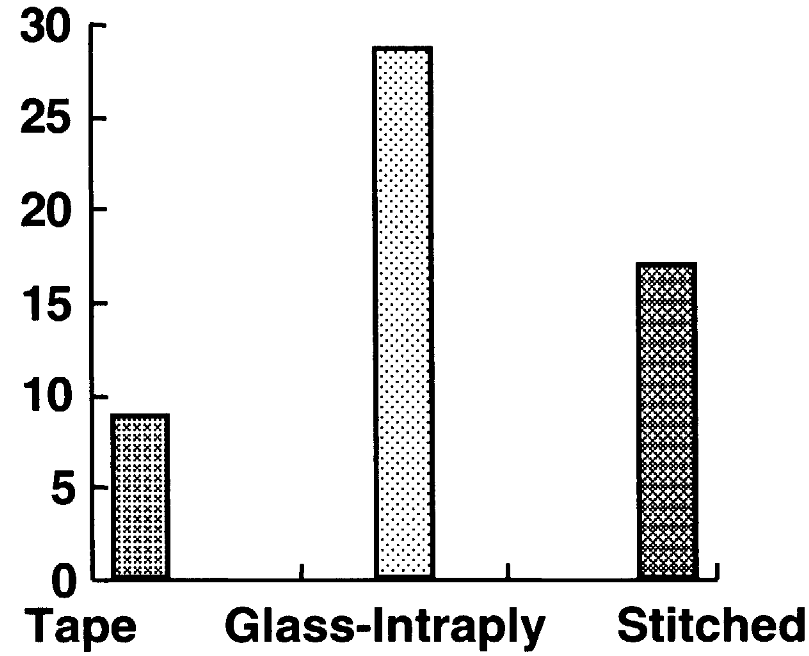


Pre-impregnated tape material



Back-surface fiber splitting

Graphite-glass intra-ply material



3rd Gen Airframe/TPS:

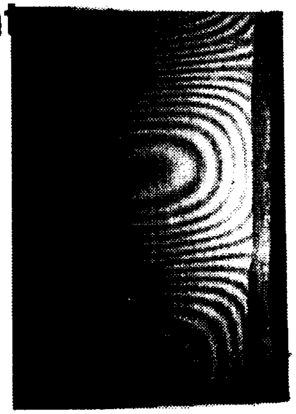
Integrated Design and Analysis

PMC Damage Tolerance and Repair

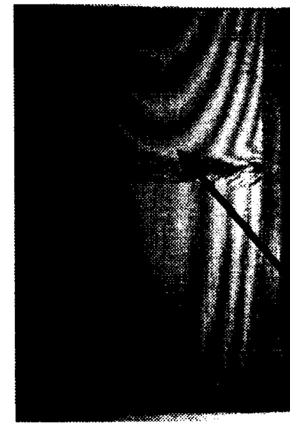
TYPICAL COMPRESSION RESPONSE AND FAILURE OF 16-PLY-THICK CURVED PLATES LOADED IN COMPRESSION

Displacement con

Failed specimen



Undamage d



Failure location

Impact damaged

Impact damage location

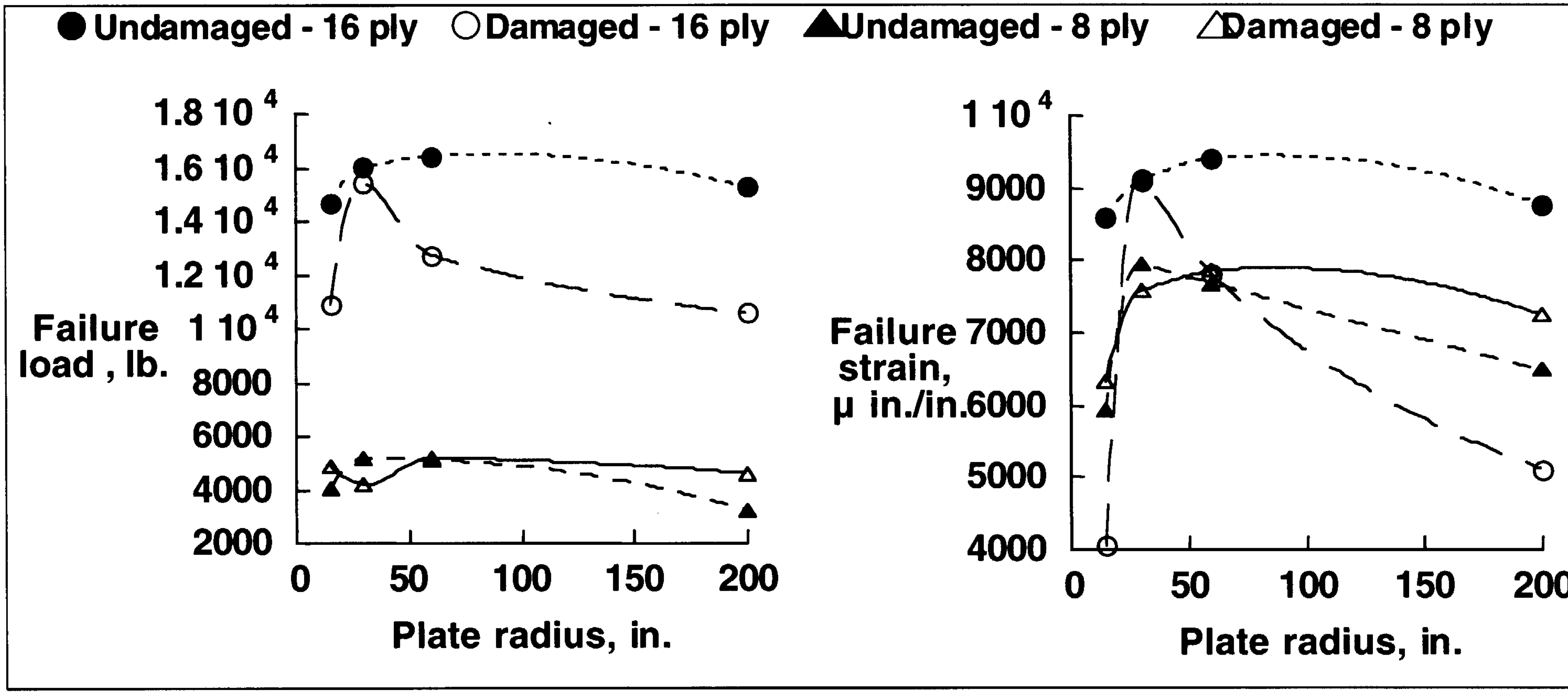
3rd Gen Airframe/TPS:

Integrated Design and Analysis

PMC Damage Tolerance and Repair

COMPARISON OF COMPRESSION-AFTER-IMPACT STRENGTH RESULTS FOR CURVED THIN PLATES

AS4-3502 Prepreg Tape Material

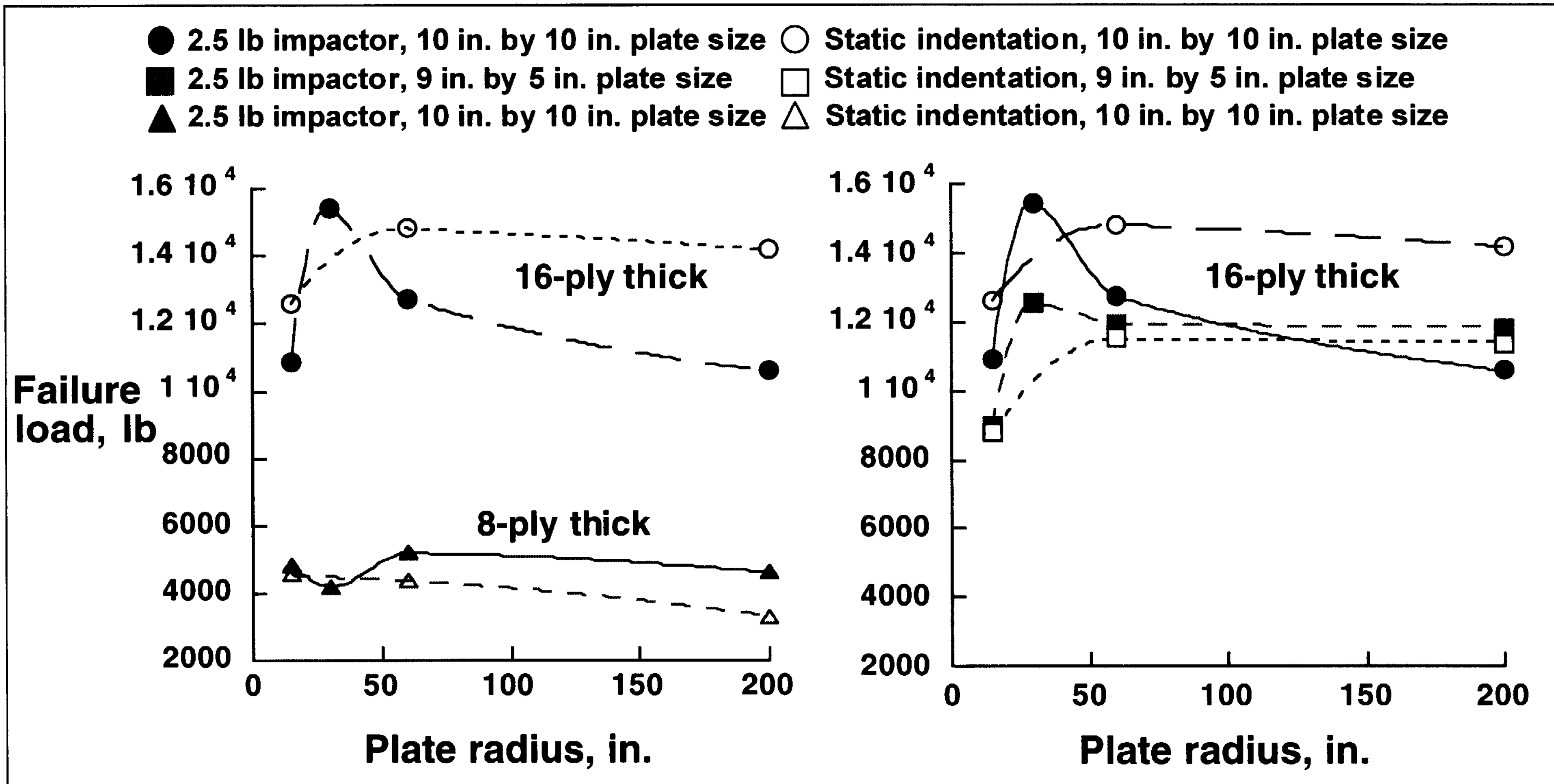


3rd Gen Airframe/TPS:

Integrated Design and Analysis

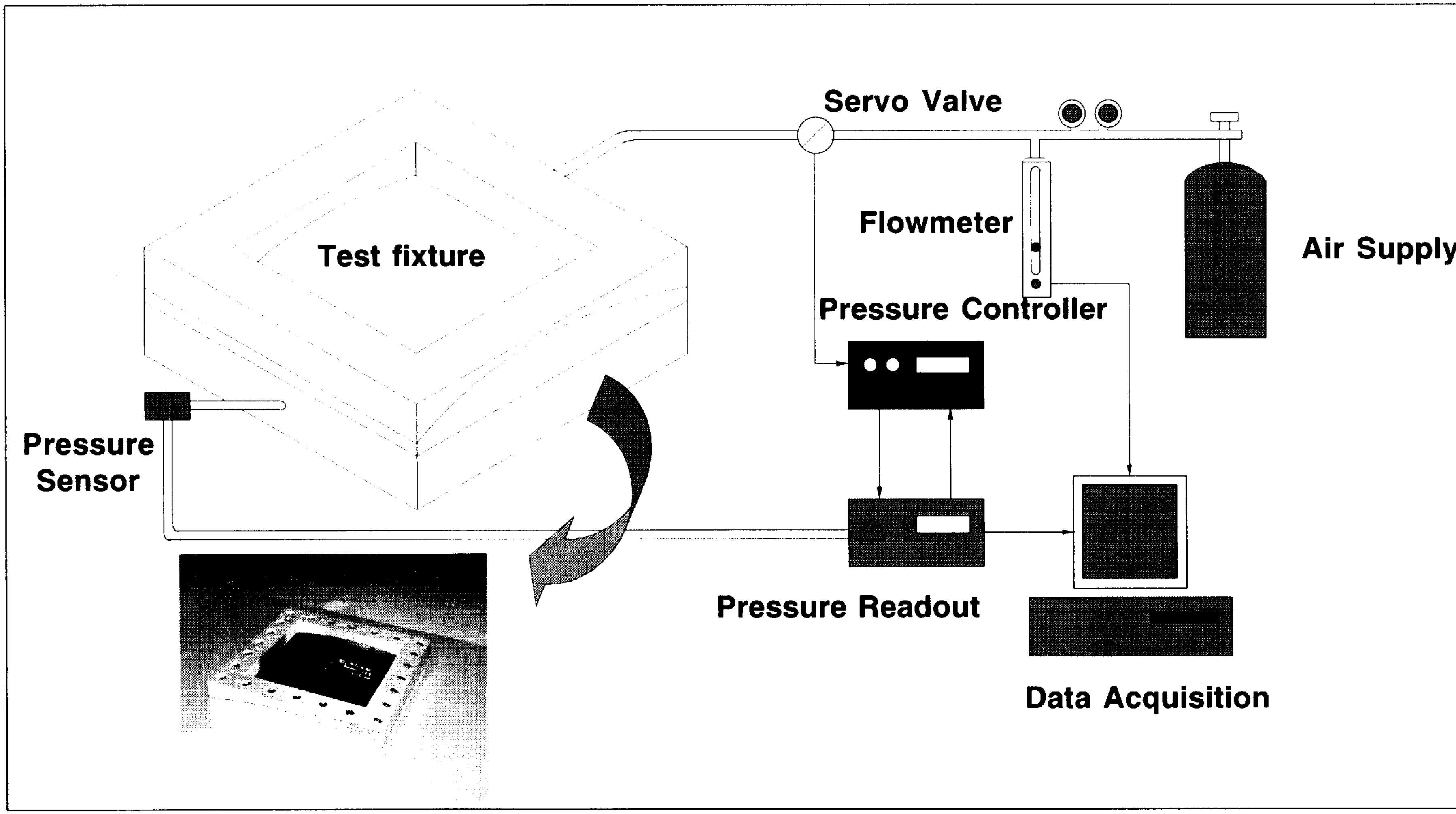
PMC Damage Tolerance and Repair

COMPARISON OF RESIDUAL STRENGTH RESULTS FOR PLATES SUBJECTED TO DROPPED-WEIGHT IMPACT AND STATIC INDENTATION DAMAGE



PMC Damage Tolerance and Repair

SCHEMATIC DIAGRAM OF TEST SET-UP FOR PRESSURE LEAKAGE TESTS



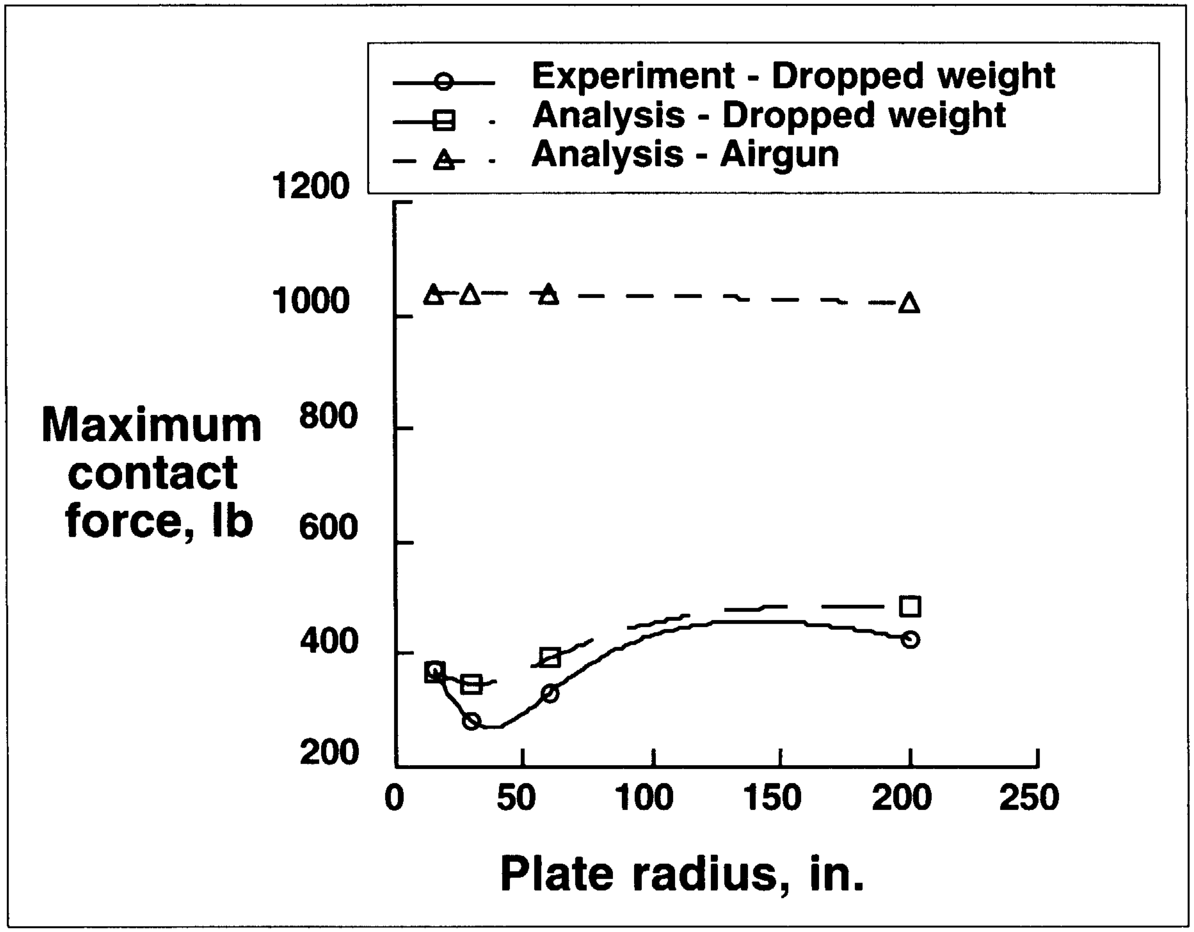
PMC Damage Tolerance and Repair

SUMMARY OF ANALYTICAL EFFORTS

- Impact response of thin curved laminates
- Finite element analysis to assess critical manufacturing defect size for combined mechanical and thermal loaded structures
- Methods for optimizing bonded and bolted repairs

PMC Damage Tolerance and Repair

DEVELOPED NONLINEAR ANALYSIS METHOD FOR ACCURATELY DETERMINING IMPACT RESPONSE AND DAMAGE INITIATION

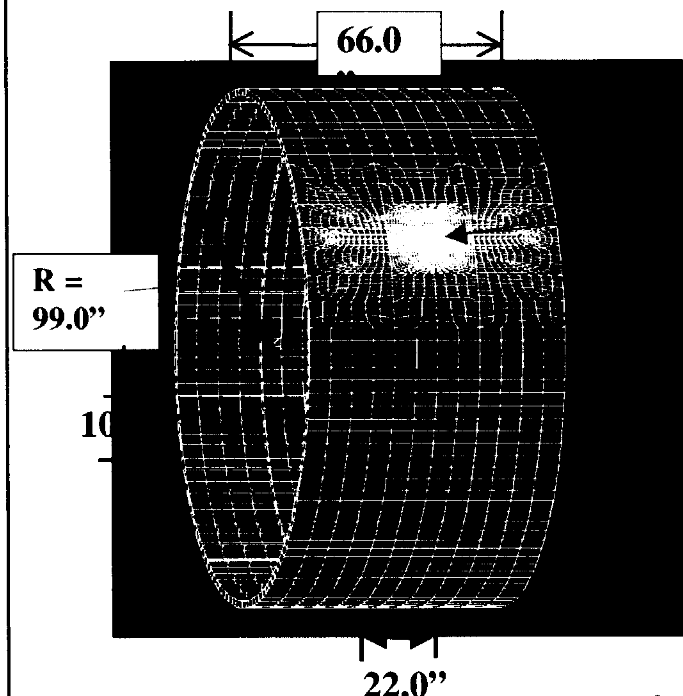


PMC Damage Tolerance and Repair

DELAMINATION GROWTH STUDIES

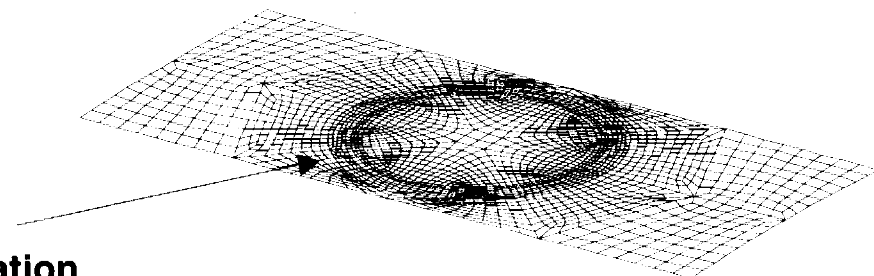
Modeling and Analysis Approach

Global model



- **Number of elements: 10,664**
- **Dof: 64,314**

Local model



- **Number of elements: 7,784**
- **Dof: 46,548**

Virtual crack closure technique to determine strain energy release rates.

Parametric studies with combined mechanical, thermal and internal pressure loading conditions.

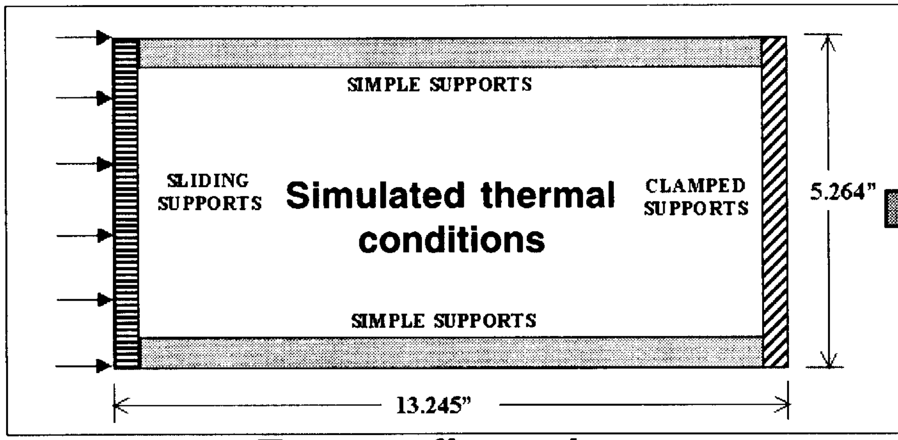
- **Critical delamination size and location.**
- **Stiffened skin and sandwich constructions.**

3rd Gen Airframe/TPS:

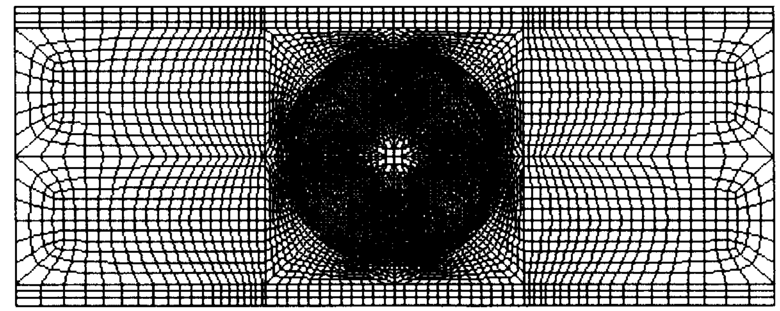
Integrated Design and Analysis

PMC Damage Tolerance and Repair

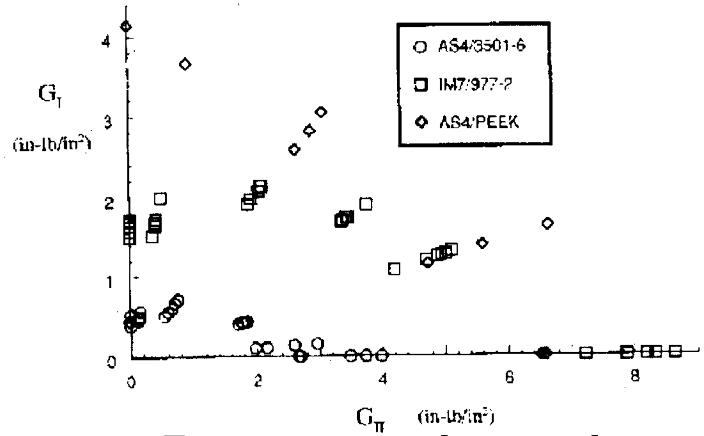
APPROACH FOR DELAMINATION GROWTH VERIFICATION TESTING



Test configuration



Finite element model



Fracture toughness data

Experimental verification of the critical size and location of delaminations

3rd Gen Airframe/TPS:

Integrated Design and Analysis

PMC Damage Tolerance and Repair

NEAR-TERM PLANS

- Conduct pressure leakage tests on laminates made from different material forms
- Complete compression-after-impact strength tests on laminates made from different material forms
- Complete delaminated panel compression tests at cryogenic temperatures to verify criticality of the effects of defects

- PMC Damage Tolerance & Repair
  - POC - Dr. Damodar R. Ambur/Dr. Tom S. Gates, NASA LaRC
- Safe Structures Design Technologies
  - POC - Dr. Damodar R. Ambur, NASA LaRC

3rd Gen Airframe/TPS:

Integrated Design and Analysis

Safe Structures Design Technologies

Goals and Objectives

- Develop validated second generation nonlinear progressive failure analysis method for composite structures subjected to combined mechanical loads
- Develop non-deterministic analysis and design methods that bound manufacturing uncertainties
- Conduct sensitivity analyses for manufacturing uncertainties
- Develop and demonstrate 3rd. generation progressive failure analysis method that includes combined mechanical and thermal load effects and delaminations
- Develop design and analysis relationships between structural weight and reliability for composite structures subjected to combined mechanical and thermal loads
- Develop hybrid deterministic and non-deterministic analysis and design methods that account for uncertainties at the material, structures, and mission levels
- Conduct hierarchical sensitivity analyses and identify design trends for multiple length scales subjected to combined loads

Safe Structures Design Technologies

- Current Program Status
  - Initiated in FY2000
  - Efforts continue under the 3rd Generation RLV Program
- Current Technical Status
  - Developed analytical methods and algorithms for using the current damage progression methods to predict the response of nonlinearly deformed structures
  - Conducted progressive damage verification tests on a compression-loaded composite cylinder
  - Conducting progressive damage verification tests on a composite panel subjected to nonlinear deformation with in-plane shear loading
  - Initiated tools development for predicting delamination initiation and growth

Safe Structures Design Technologies

MECHANICS TECHNOLOGY FOR PROGRESSIVE FAILURE ANALYSIS

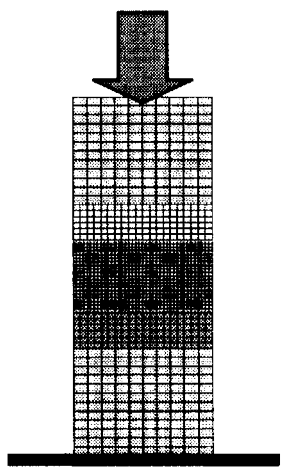
- Embed progressive failure criteria and material degradation models with robust nonlinear structural mechanics solver STAGS
- Provide progressive damage capability coupled with large displacement, large rotation deformation states for laminated composite structures
- Provide traditional and state variable damage models
  - Maximum strain with ply discounting
  - Crack density based criteria for failure and degradation
  - User interfaces include ABAQUS/UMAT
- Incorporate artificial damping feature to mitigate non-convergence problems in re-establishing equilibrium
- Establish consistency between first and second variations for the energy functional
- Enhance visual depiction of progressive damage simulation
- *Increased design robustness through evaluation of extreme loading conditions and understanding possible composite structures failure scenarios*

3rd Gen Airframe/TPS:

Integrated Design and Analysis

Safe Structures Design Technologies

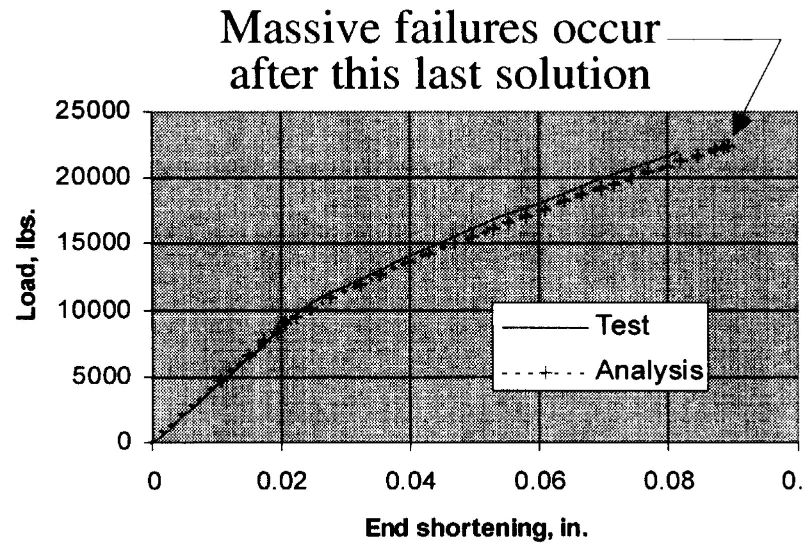
COMPRESSION-LOADED POSTBUCKLING COMPOSITE PANEL



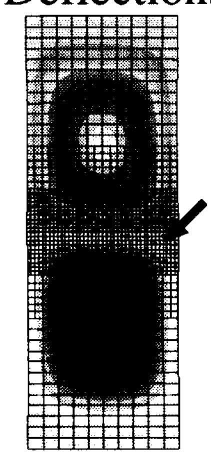
24-ply Graphite-epoxy orthotropic laminate

Starnes & Rouse, AIAA Paper 81-0543

Failure load =21,910 lbs
End shortening at failure = 0.0818 in.

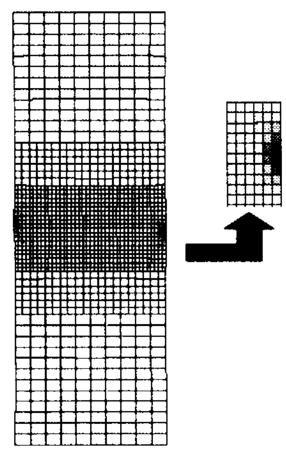


Out-of-plane Deflections



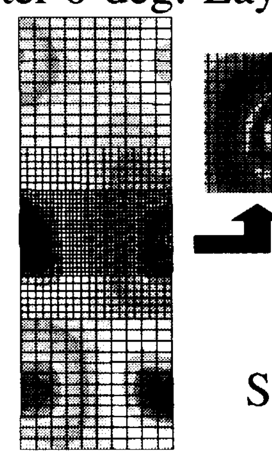
Node Line in Buckle Pattern

Percent Failed Plies



Close-up of Failed Region

Inplane Shear Stress in Outer 0-deg. Layer



Close-up Showing Stress Relief

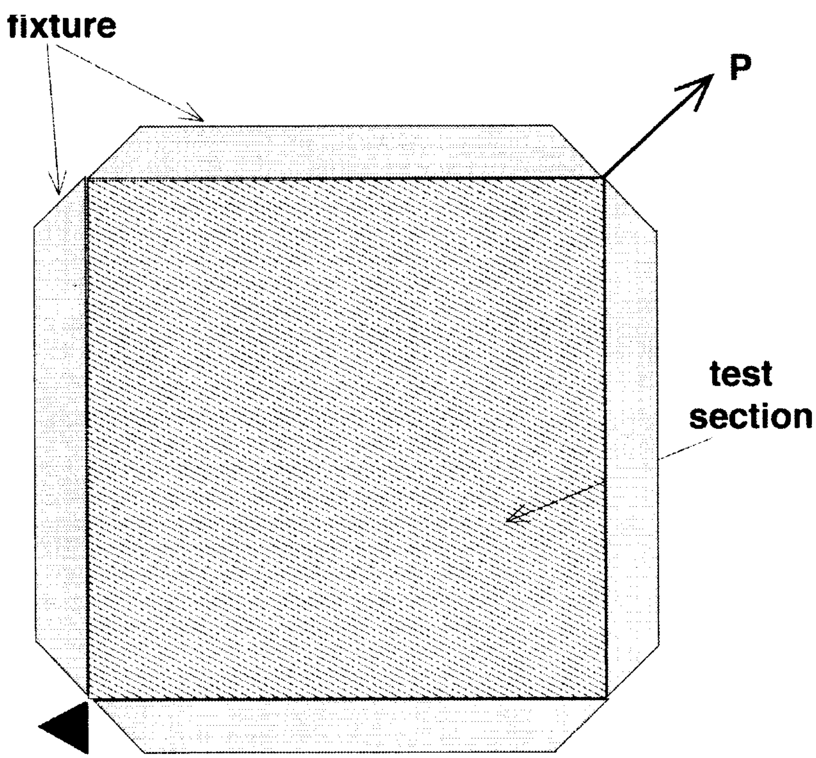
3rd Gen Airframe/TPS:

Integrated Design and Analysis

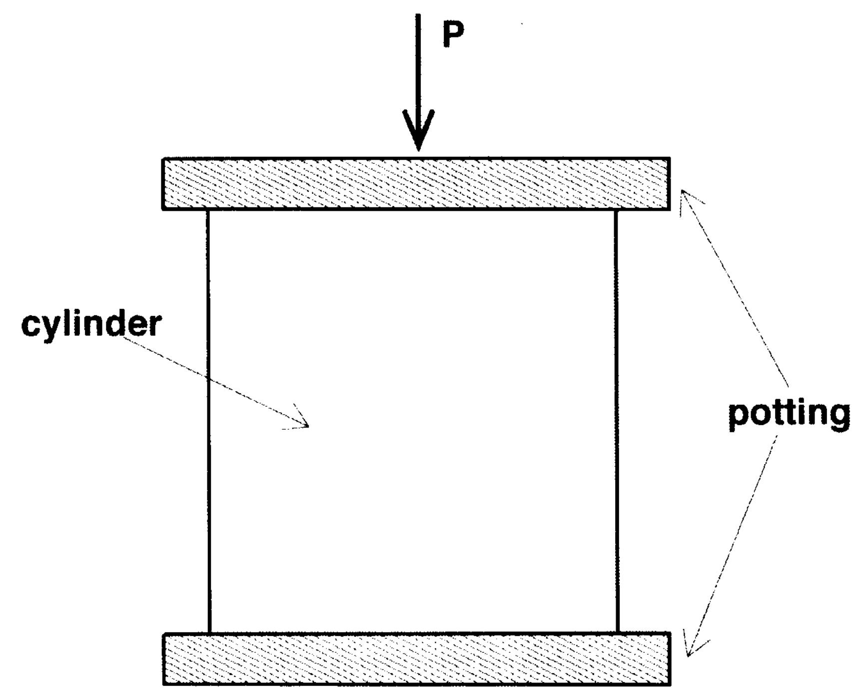
Safe Structures Design Technologies

CORRELATION OF PROGRESSIVE FAILURE ANALYSIS RESULTS
FOR PANELS AND SHELLS

Stiffened and Unstiffened Panels
Loaded in a Picture Frame



Cylinders in Axial Compression



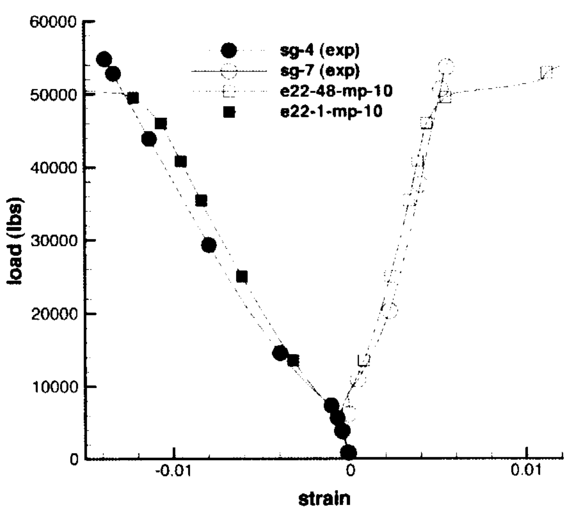
Safe Structures Design Technologies

UNSTIFFENED PANEL LOADED IN PICTURE FRAME SHEAR

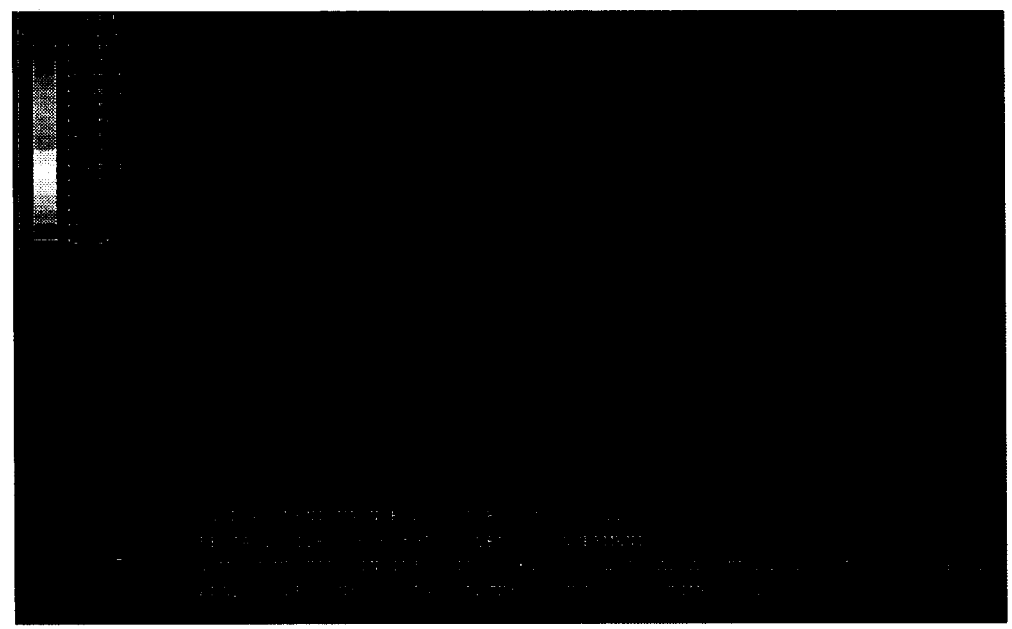
- **Panel size: 12-in. by 12-in.; Thickness: 0.0896-in.**
- **Stacking sequence is [± 45/0/90]$_{2s}$**
- **E_{11} = 18.5 Msi, E_{22} = 1.67 Msi, G_{12} = 0.87 Msi, G_{13} = 0.87 Msi, G_{23} = 0.258 Msi, μ_{12} = 0.3**
- **X_T = 0.233 Msi, X_C = 0.21 Msi, Y_T = 0.0147 Msi, Y_C = 0.0287 Msi, SC = 0.02975 Msi**

Failure Load:
54,807 lbs - Test
54,447 lbs - Analysis

Strain Normal to Fiber Direction on Top and Bottom Surfaces at Center of Test-Section



Map of Matrix Failure Region



3rd Gen Airframe/TPS:

Integrated Design and Analysis

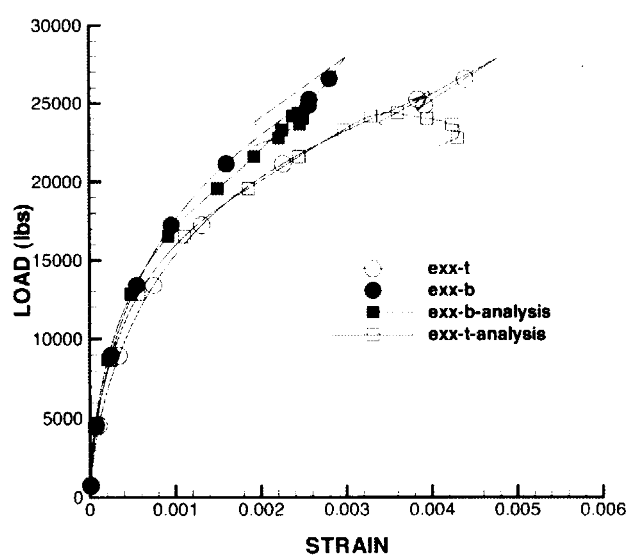
Safe Structures Design Technologies

BEAD-STIFFENED PANEL LOADED IN PICTURE FRAME SHEAR

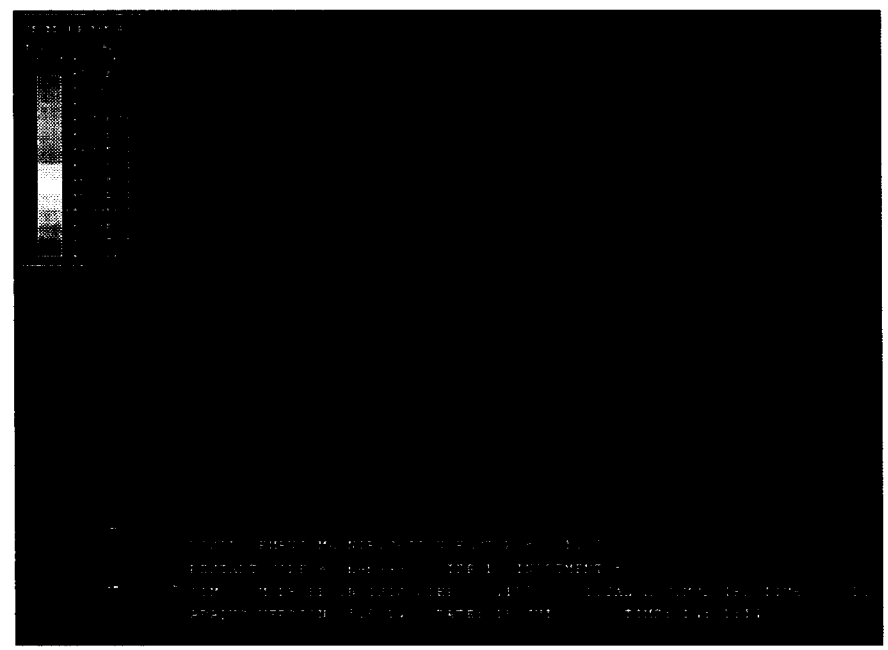
- Panel size: 12-in. by 12-in.; Thickness: 0.08-in.
- Stacking sequence is $[\pm 45/\pm 45/0/\pm 45/90]_s$
- $E_{11} = 18.0$ Msi, $E_{22} = 1.50$ Msi, $G_{12} = 0.82$ Msi, $G_{13} = 0.82$ Msi, $G_{23} = 0.82$ Msi, $\mu_{12} = 0.3$
- $X_T = 0.30$ Msi, $X_C = 0.20$ Msi, $Y_T = 0.013$ Msi, $Y_C = 0.031$ Msi, $SC = 0.027$ Msi

Failure Load:
27,936.9 lbs -Test
26,995.9 lbs -Analysis

Axial Strain on the Top and Bottom Surfaces at Center of Panel



Map of Matrix Failure Region



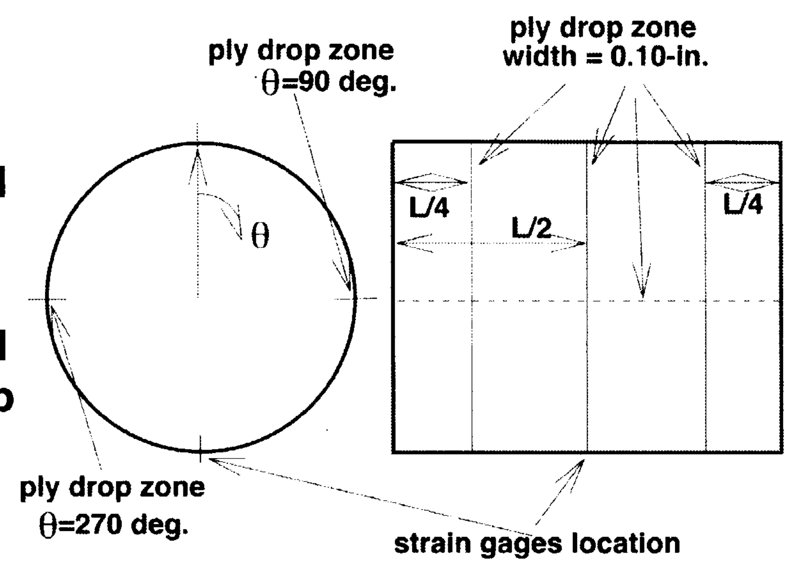
3rd Gen Airframe/TPS:

Integrated Design and Analysis

Safe Structures Design Technologies

EFFECTS OF MANUFACTURING UNCERTAINTIES ON COMPOSITE CYLINDER AXIALCOMPRESSION RESPONSE

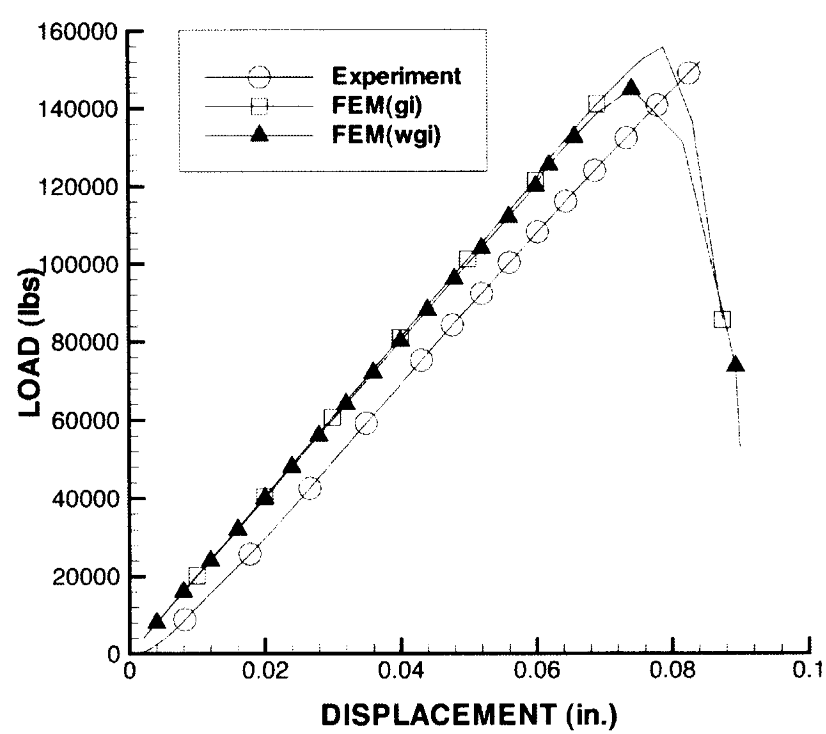
- Cylinder is 16.0-in. long; 16.0-in. diameter
- Laminate is $[\pm 45/0/90]_{2s}$ and 0.08-in. thick
- $E_{11} = 19.0$ Msi, $E_{22} = 1.450$ Msi, $G_{12} = 0.814$ Msi, $G_{13} = 0.814$ Msi, $G_{23} = 0.55$ Msi, $\mu_{12} = 0.3$
- $X_T = 0.156$ Msi, $X_C = 0.156$ Msi, $Y_T = 0.00725$ Msi, $Y_C = 0.0145$ Msi, $SC = 0.010826$ Msi
- Two models were considered:
  - Model 1:
    - Measured geometric imperfection modeled
    - 7,560 elements; 4-noded
  - Model 2:
    - Measured geometric imperfection modeled
    - Laminate imperfection modeled as ply drop
    - 10,692 elements; 4-noded



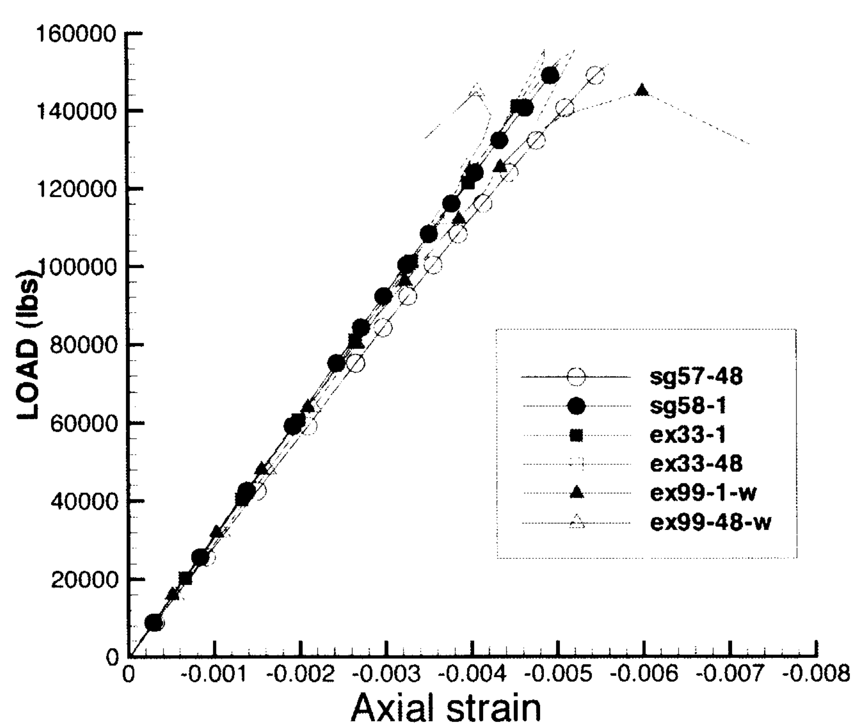
Safe Structures Design Technologies

EFFECT OF MANUFACTURING UNCERTAINTIES ON COMPOSITE CYLINDER AXIAL COMPRESSION RESPONSE (Contd.)

Load Vs. End-shortening Results



Load Vs. Axial Strain Results



3rd Gen Airframe/TPS:

Integrated Design and Analysis

Safe Structures Design Technologies

EFFECT OF MANUFACTURING UNCERTAINTIES ON COMPOSITE CYLINDER AXIAL COMPRESSION RESPONSE (Contd.)

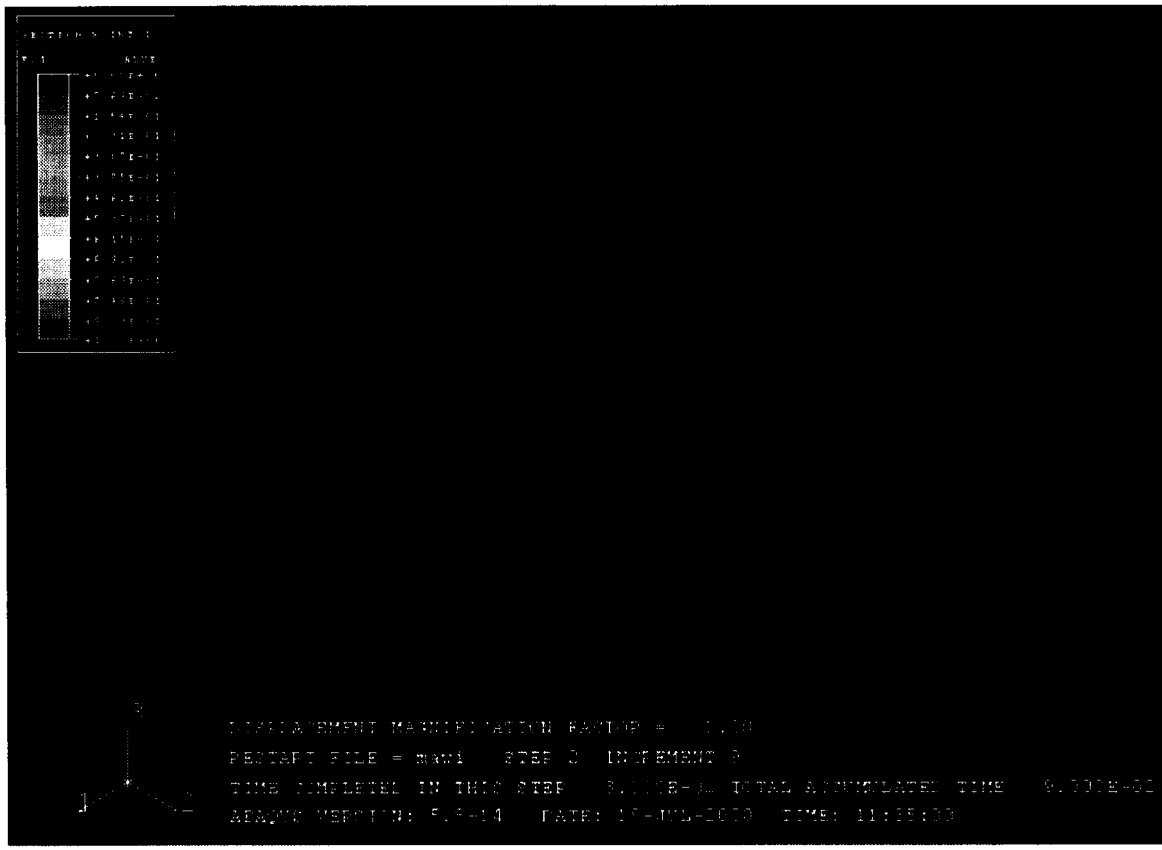
Map of Failure Region for Model 1

Safe Structures Design Technologies

EFFECT OF MANUFACTURING UNCERTAINTIES ON COMPOSITE CYLINDER AXIAL COMPRESSION RESPONSE (Concluded)

Map of Failure Region for Model 2

Failure modes and damage region results obtained using Model 2 compare well with experimental results



Safe Structures Design Technologies

NEAR-TERM PLANS

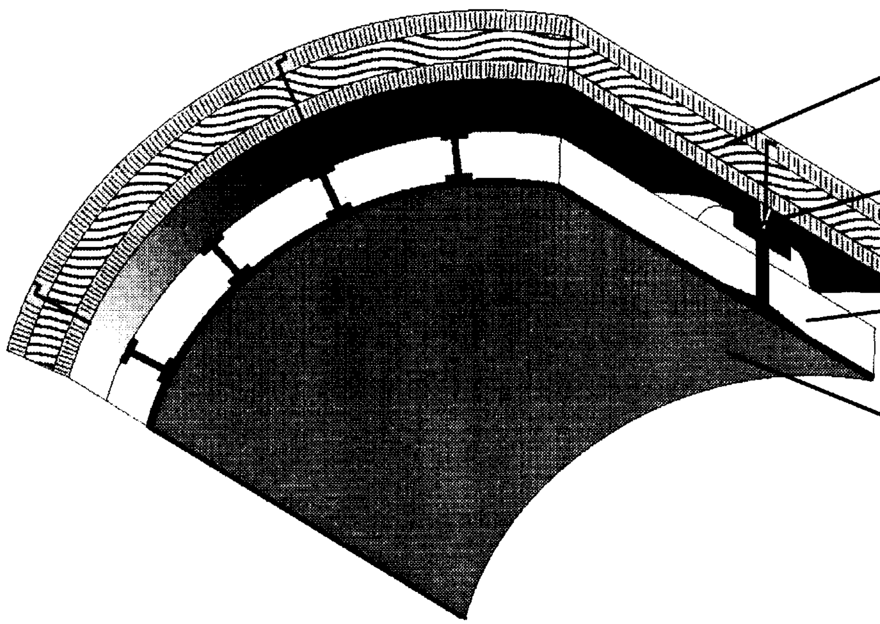
- Conduct inplane shear tests on stiffened and unstiffened panels
- Correlate analytical and experimental results
- Continue efforts to validate the decohesion element for simulating the delamination failure mode
- Incorporate decohesion element into STAGS finite element analysis code

Integrated Thermal Structures & Materials Overview

Dr. Brian Jensen
NASA Langley Research Center
(757) 864-4271
b.j.jensen@larc.nasa.gov

- **Resins for transfer molding or infusion processing**
  - **POC:**
    - Paul M. Hergenrother
    - (757) 864-4270
    - p.m.hergenrother@larc.nasa.gov
- **Nonautoclave processable adhesives**
  - **POC:**
    - Dr. Brian J. Jensen
    - (757) 864-4271
    - b.j.jensen@larc.nasa.gov
- **Automated Tape Placement Device with e-beam cure**
  - **POC:**
    - Harry L. Belvin
    - (757) 864-9436
    - h.l.belvin@larc.nasa.gov

High Temperature RLV Tank Concept



TPS:
SA/HC (LaRC Metallic tile)

Support Structure:
Gr-Poly lattice

Cryogenic insulation:
LaRC TEEK™ foam panels
E-Beam cured adhesive

Tank wall:
Externally stiffened Gr-Poly
Liquid Crystal Polymer (LCP) coating

- Resins for transfer molding or infusion processing
  - POC - Paul M. Hergenrother, NASA LaRC
- Nonautoclave processable adhesives
  - POC - Brian J. Jensen, NASA LaRC
- Automated Tape Placement Device with e-beam cure
  - POC - Harry L. Belvin, NASA LaRC

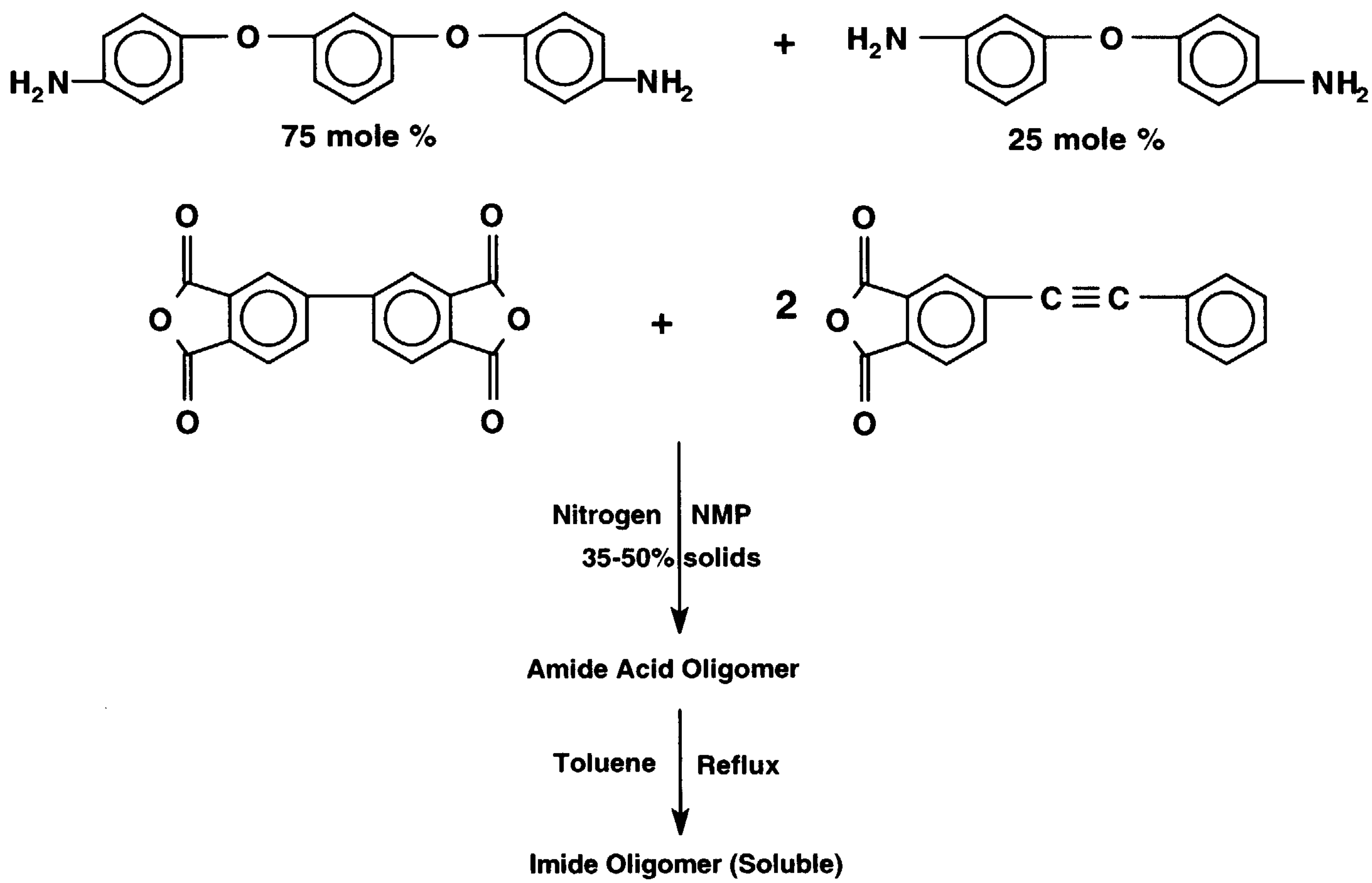
3rd Gen Airframe/TPS:

Int. Thermal Structures and Materials

Accomplishments, RTM/RI Resins

- LaRC prepared 5 resins with Tgs as high as 625°F, <1% volatiles, moderate toughness and low melt viscosity and sent to Boeing or Lockheed Martin
- GRC prepared 4 resins with Tgs as high as 700°F, <10% volatiles and low melt viscosity and sent to Boeing
- Boeing successfully fabricated 2' x 2' x 36 ply composites by resin infusion (RI) of stitched preforms from all NASA supplied resins
- Lockheed Martin successfully fabricated 13" x 14" x 16 ply composites by resin transfer molding (RTM) from all NASA supplied resins

Chemistry of PETI-298



Calculated Mn 750 g/mole = PETI-298

3rd Gen Airframe/TPS:

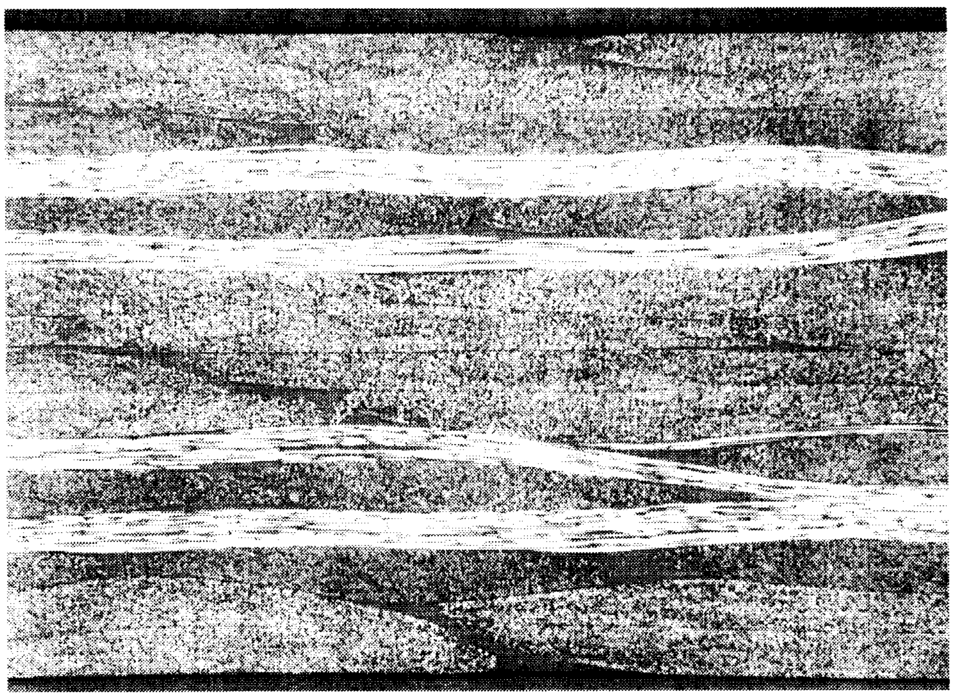
Int. Thermal Structures and Materials

Comparison of PETI Oligomers Prepared From 1,3,3 and 1,3,4 - APB

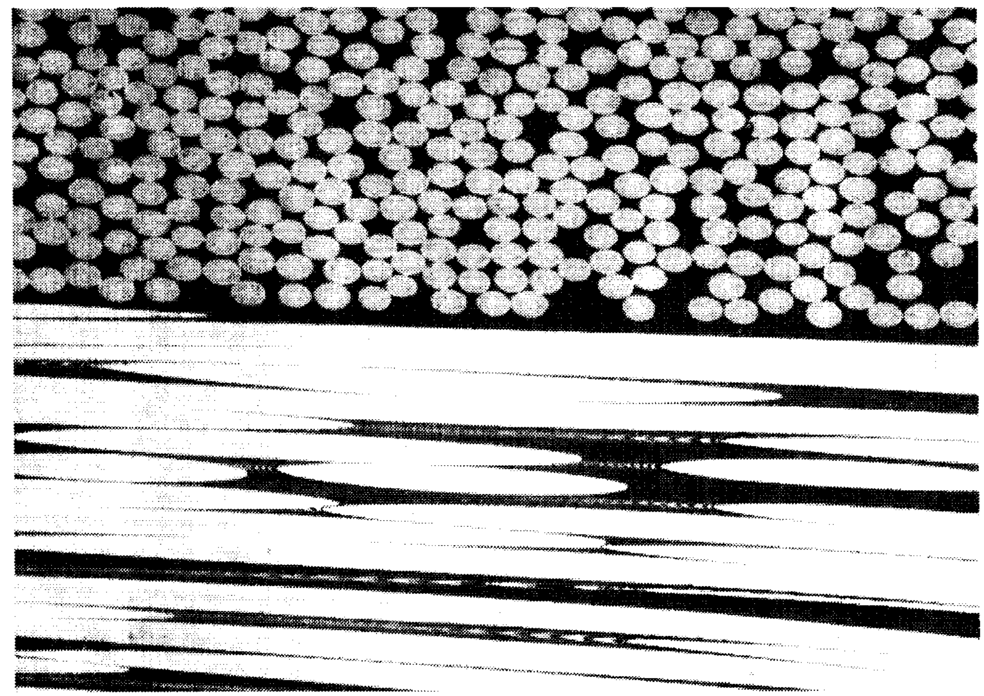
APB Diamine	Calculated Mn, g/mole	Glass Transition Temp., °C Initial	Glass Transition Temp., °C Cured*	Melt Viscosity @ 280°C, poise
1,3,3	750	132	258	1-6
1,3,3	1250	151	244	5-15
1,3,4	750	139	298	6-13
1,3,4	1250	165	285	10,000**

* Cured 1 hour at 371°C
**Viscosity dropped to ~30 poise at 325°C

Photomicrographs of PETI-298 Laminates Fabricated Via RTM

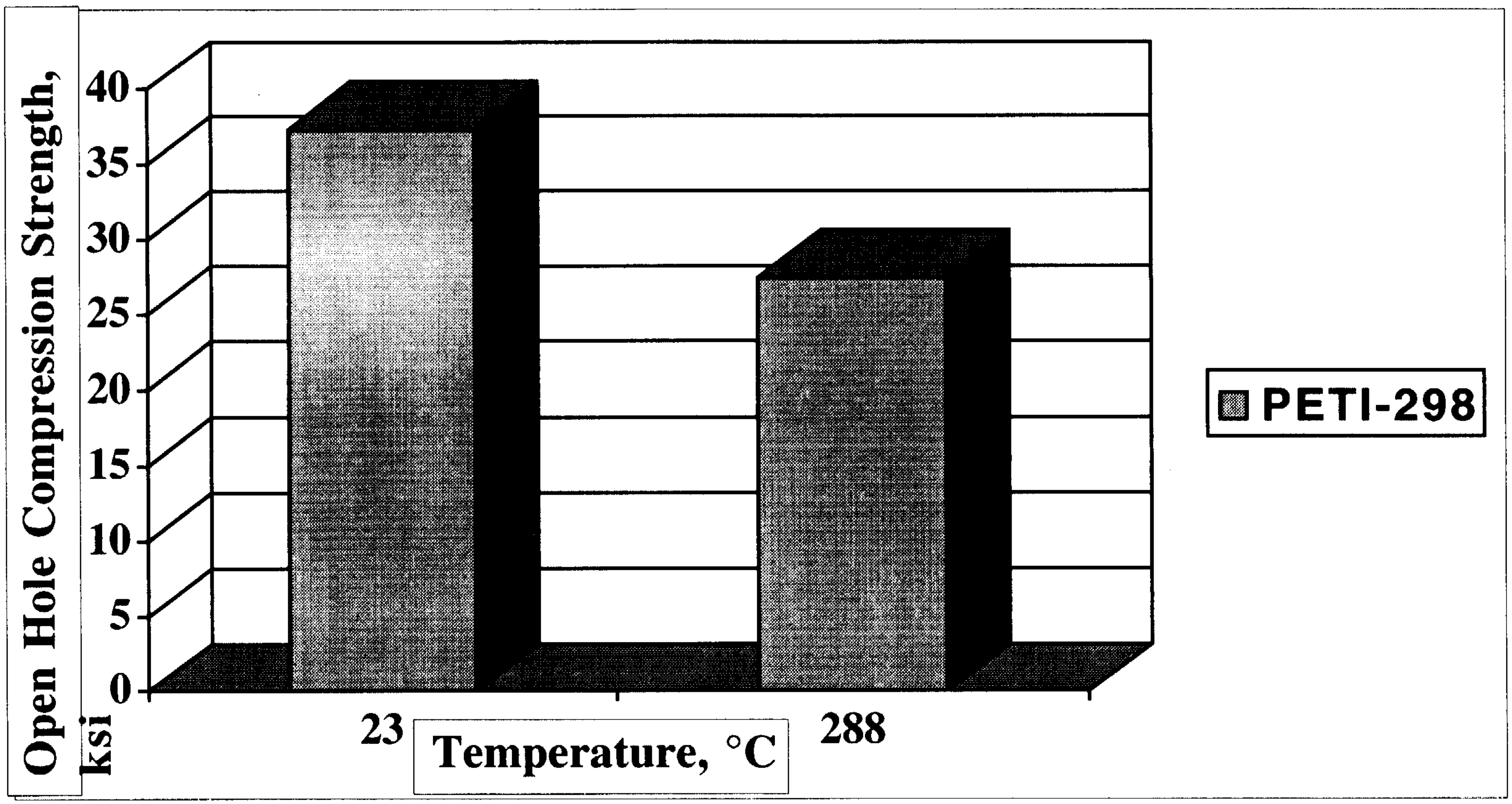


25 x Magnification



400 x Magnification

Mechanical Properties of AS-4/PETI-298 Fabric Composites Fabricated Via Resin Transfer Molding (8 ply)



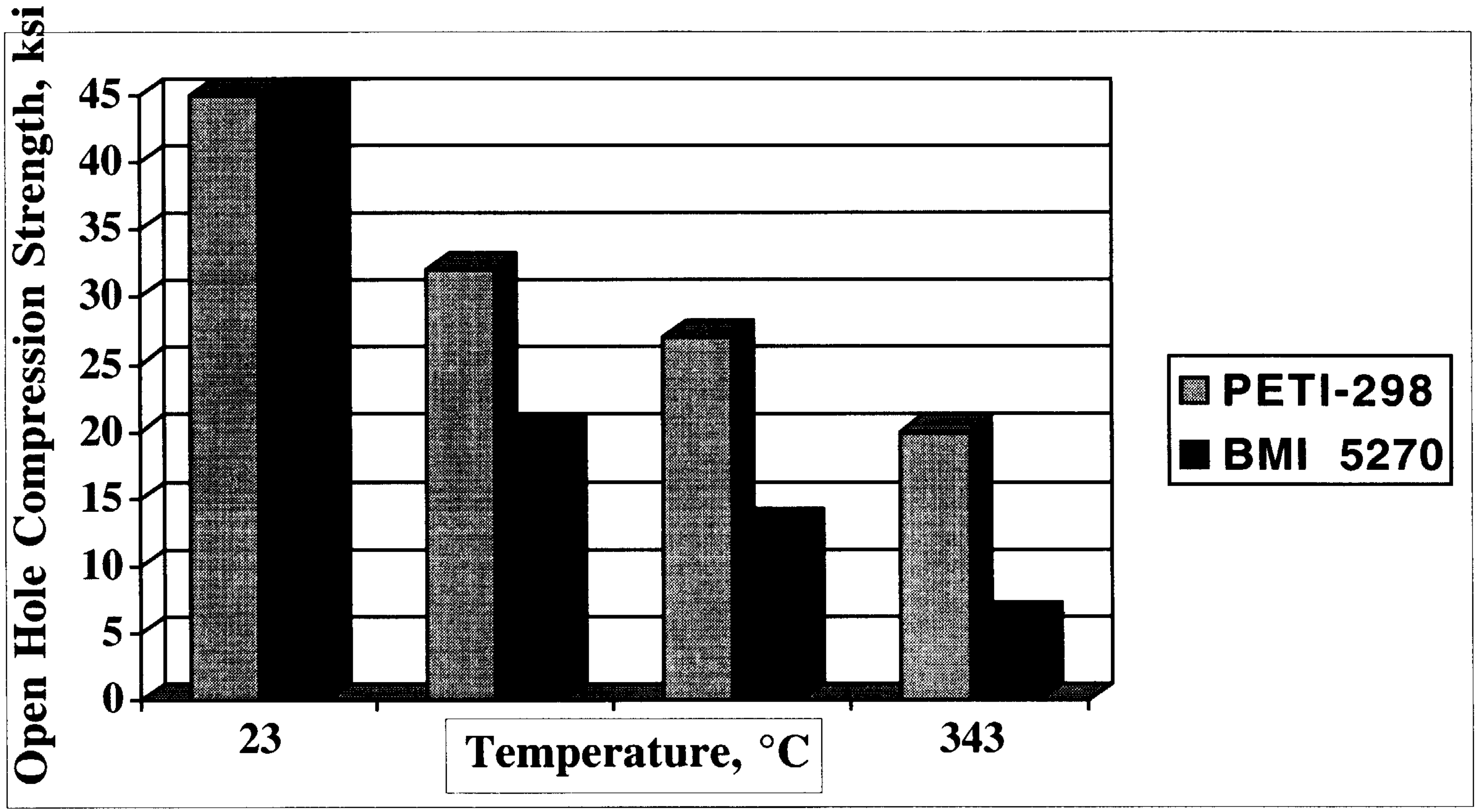
PETI-298 cured 1 hr @ 370°C, Tg = 302°C (8 ply AS-4 fabric)

Un-notched Compression Strength at 23°C = 60 ksi

3rd Gen Airframe/TPS:

Int. Thermal Structures and Materials

Mechanical Properties of IM-7 PETI-298 Stitched Composites Fabricated Via Resin Infusion (36 ply)



PETI-298 cured 1 hr @ 370°C, postcured at 370°C, Tg = 338°C (Panel 36 ply x 22"x 22", stitched)

BMI 5270 cured 4 hr @ 190°C, postcured at 232 and 260°C , Tg = 299°C

- Resins for transfer molding or infusion processing
  - POC - Paul M. Hergenrother, NASA LaRC
- Nonautoclave processable adhesives
  - POC - Brian J. Jensen, NASA LaRC
- Automated Tape Placement Device with e-beam cure
  - POC - Harry L. Belvin, NASA LaRC

3rd Gen Airframe/TPS:

Int. Thermal Structures and Materials

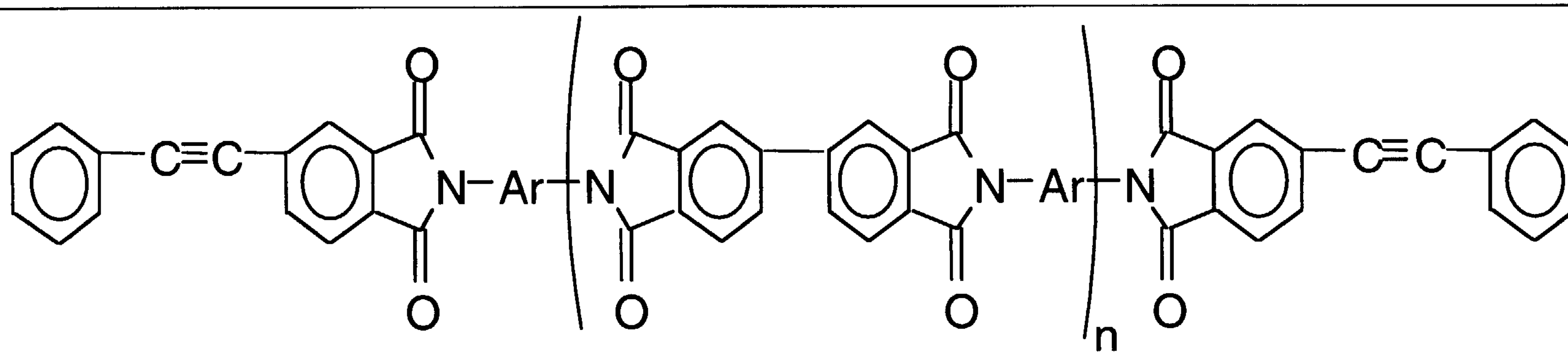
Accomplishments, LaRC PETI-8

- Developed and supplied to Cytec Fiberite several non-autoclave processable adhesives.

- LaRC PETI-8 is a phenylethynyl terminated polyimide adhesive which has low melt viscosity and excellent melt stability at temperatures below 300°C, allowing the production of excellent adhesive bonds under vacuum bag pressure, without the need for external pressure normally supplied by an autoclave. Heating at 316°C for 8 hours provides excellent titanium to titanium tensile shear strengths from 75°F to at least 350°F and excellent flatwise tensile strengths at 75°F.

- Plan to continue work on adhesives which do not require an autoclave for processing. Concentrate on vacuum bag / oven processing, hot melt adhesives and the use of e-beam radiation to cure advanced adhesives. Optimize the properties of LaRC PETI-8 by studying various formulations of the adhesive tape and various cure conditions.

LaRC PETI-8



Titanium to Titanium Tensile Shear Strengths

Required	Achieved
5000 psi at 75° F	**7400 psi**
3500 psi at 350° F	**6200 psi**

Flatwise Tensile Strength (Composite Skins over Titanium core)

Required	Achieved
1000 psi at 75° F	**1370 psi**

Bonding Conditions:

Vacuum Bag Only Pressure, 316°C, 8 hour hold, 5V CAA surface treatment

Cytec Fiberite Results for PETI-8 Bonding

Evaluated 550°F, 575°F and 600°F cycles from 4-12 hours under vacuum bag only pressure for several different formulations. Shown are results for 600°F, 4 hour cycle.

PETI-8 Tensile Shear Strength	75°F	350°F
Titanium substrate, CAA Anodized	7000 psi (min.)	5000 psi (min.)
PETI-5 composite substrate (interlaminar failure at both test temperatures)	5500 psi	4500 psi

PETI-8 Flatwise Tensile Strength	75°F
2024 Al face sheets, FPL etched, 3/16" Ti core	1800 psi

Cytec currently preparing two 2' x 2' PETI-5 composite panels to be bonded together as a wide area specimen.

- Resins for transfer molding or infusion processing
  - POC - Paul M. Hergenrother, NASA LaRC
- Nonautoclave processable adhesives
  - POC - Brian J. Jensen, NASA LaRC
- Automated Tape Placement Device with e-beam cure
  - POC - Harry L. Belvin, NASA LaRC

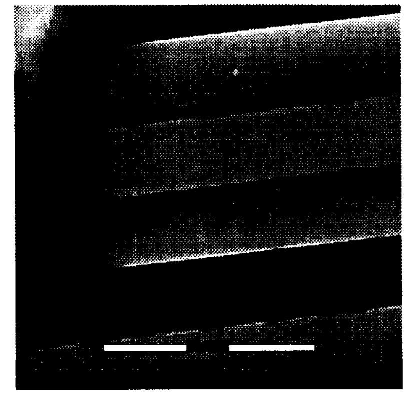
3rd Gen Airframe/TPS:

Int. Thermal Structures and Materials

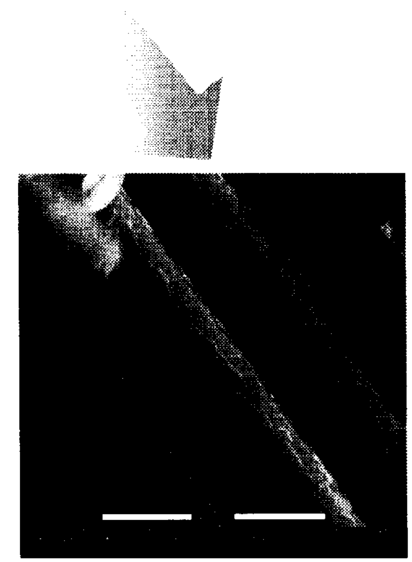
Accomplishments, ATP with E-Beam Cure

- GRC has Cooperative Agreement with Kent State University to study e-beam irradiation of polyimide thin films. (Shows little effect on mechanical properties or Tg)
- GRC has Cooperative Agreement with University of Delaware to study new e-beam curable resins. (Extent of cure dependent on molecular mobility)
- GRC in-house e-beam curable resin development. (Diels-Alder trapping of quinodimethane intermediates formed under radiation)
- LaRC and Boeing developing a tape laying machine with e-beam cure-on-the-fly processing. Undergoing acceptance testing at Boeing and will be shipped to LaRC when facilities are ready.

- **Products/ Benefits/Payoff:**
  - Validate the cause of low performance in E-beam cured graphite/epoxy composites and investigate methods for improving their performance through the use of novel sizings or resin additions.
  - The goals are to:
    - Positively identify the deficiencies causing reduced properties in E-beam cured composites
    - Identify and demonstrate the best method for performance improvement
  - Improved performance of E- beam composites will enable out-of-autoclave fabrication of large cryo tanks. Higher performance of these materials directly reduces RLV vehicle weight.



E-Beam Cured Cat-B



Thermally Cured 8552

3rd Gen Airframe/TPS:

Int. Thermal Structures and Materials

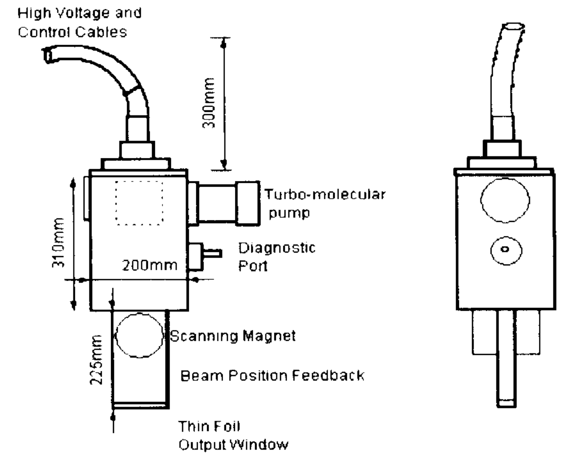
E-beam Gun Head from Electron Solutions, Inc.
E-beam Gun Head from Electron Solutions, Inc.
Boeing Tape Laying Gantry

- Description

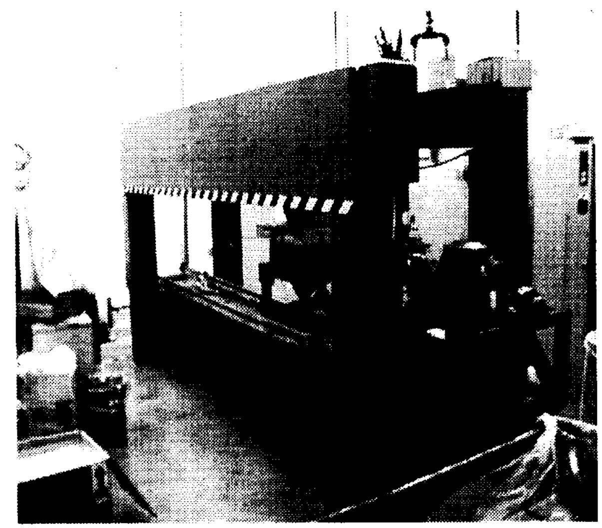
This task will design, fabricate and deliver a tape laying device capable of laying E-beam "cure-on-the-fly" (COTF) prepreg for material evaluations.

- **Products/ Benefits/Payoff:**

COTF E- beam curing will enable out-of-autoclave fabrication of RLV cryo tanks which will substantially reduce overall vehicle weight.



E-beam Gun Head from Electron Solutions, Inc.



Boeing Tape Laying Gantry

3rd Gen Airframe/TPS:

Int. Thermal Structures and Materials