2nd Generation RLV Airframe Structures and Materials

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- Goals and Objectives
- Structures and Materials Roadmap
- Recent Accomplishments
- Description of NASA-led Tasks
- Summary

Presentation Outline

- Develop and demonstrate verified airframe and cryotank structural design and analysis technologies
  - Damage tolerance, safety, reliability and residual strength technologies
  - Robust nonlinear shell and cryotank analysis technologies
  - High-fidelity analysis and design technologies for local structural detail features and joints
  - High-fidelity analysis technologies for sandwich structures

- Demonstrate low cost, robust materials and processing
  - Polymeric Matrix Composite (PMC) and metallic materials and processing
  - Refractory composite and metallic hot structures materials and processing

2nd Gen Airframe/TPS - Structures and Materials:

Goals and Objectives

- **Develop and demonstrate robust airframe structures and validated integrated airframe structural concepts**
  - **Low cost fabrication and joining**
  - **Operations efficient designs and inspection techniques, NDE**
  - **Scale-up and integrated thermal structural test**
  - **Airframe structures IVHM**
- **Demonstrate low cost, robust repair techniques**
- **Develop verified integrated airframe structural concepts**
  - **Integrated (Primary & cryotank struct./Insulation/TPS) structural concepts**

2nd Gen Airframe/TPS - Structures and Materials:

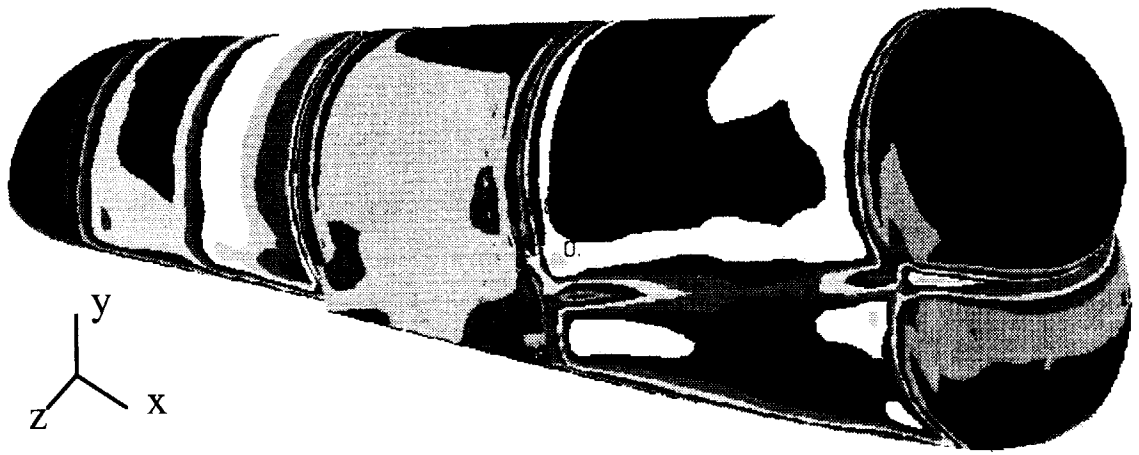
Goals and Objectives - Cont.

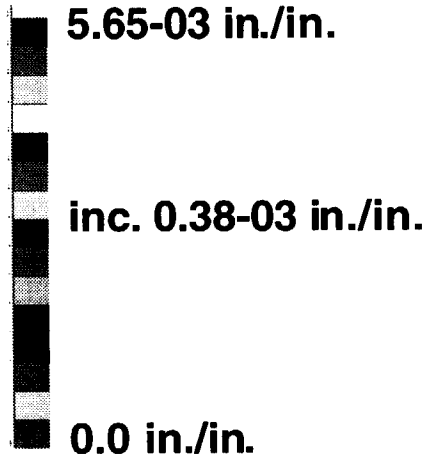
- Plans developed for all structures and materials technology tasks work is being initiated
- High-fidelity nonlinear shell analysis capability under development for response, damage tolerance and residual strength analyses
- Lifecycle and durability testing of materials and structures are currently being conducted
- Tests of curved stiffened composite panel planned for cryo-pressure box test facility
- Cryo-pressure box successfully completed Operational Readiness Review (ORR)
- Developing test capability for Helium permeation under combined temperature and mechanical loads

2nd Gen Airframe/TPS - Structures and Materials:

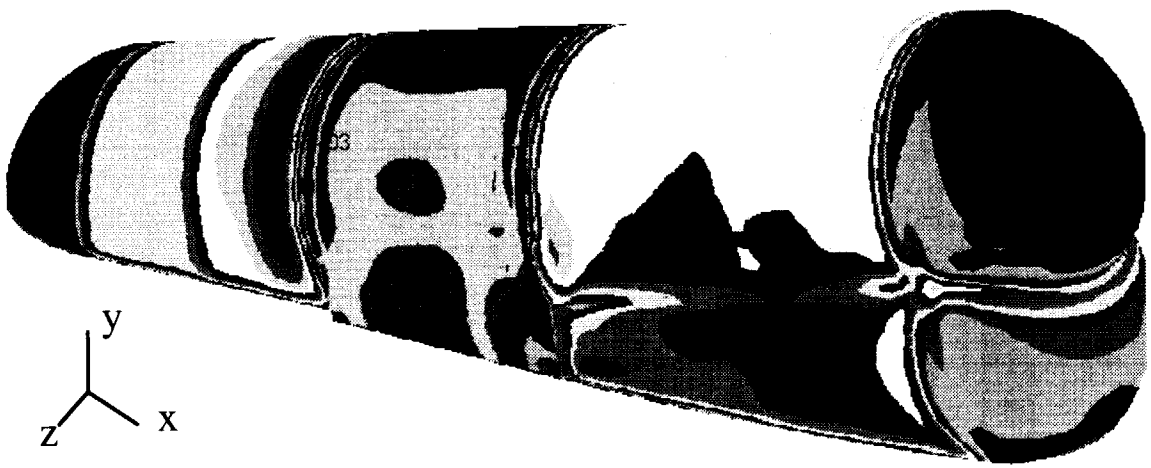
Recent Accomplishments

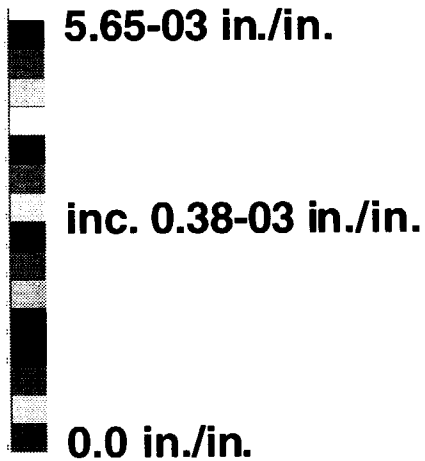
Maximum Principal Strain Plots





Linear Analysis



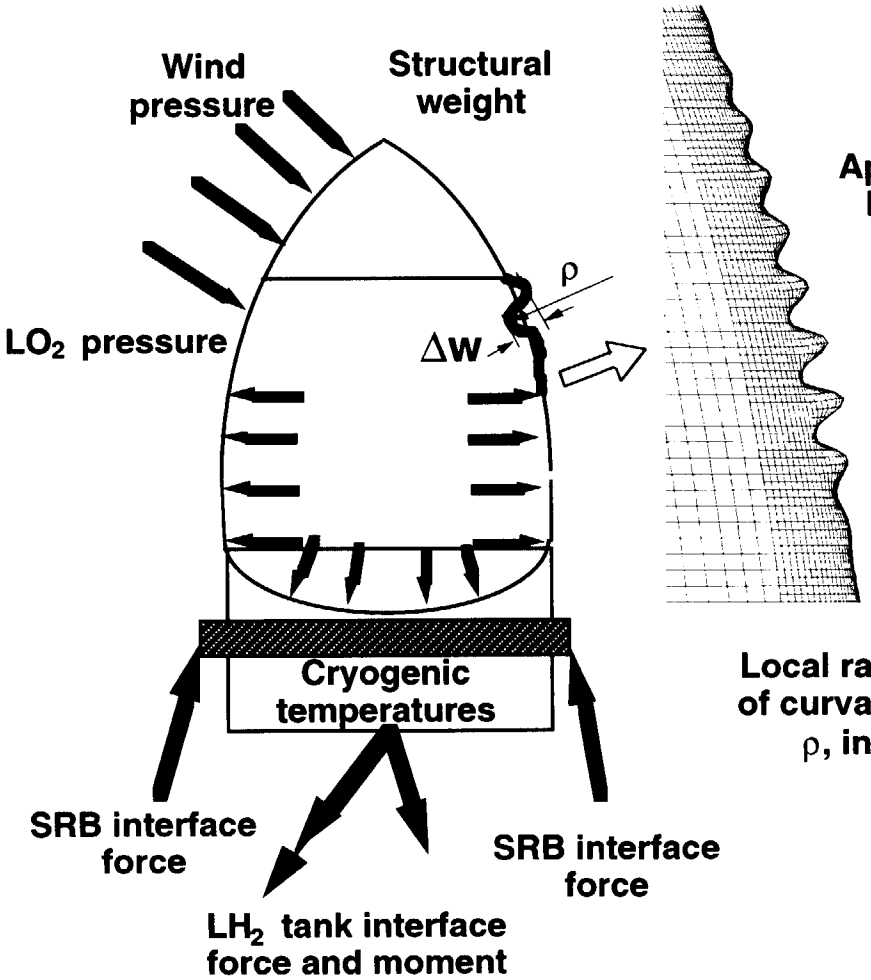


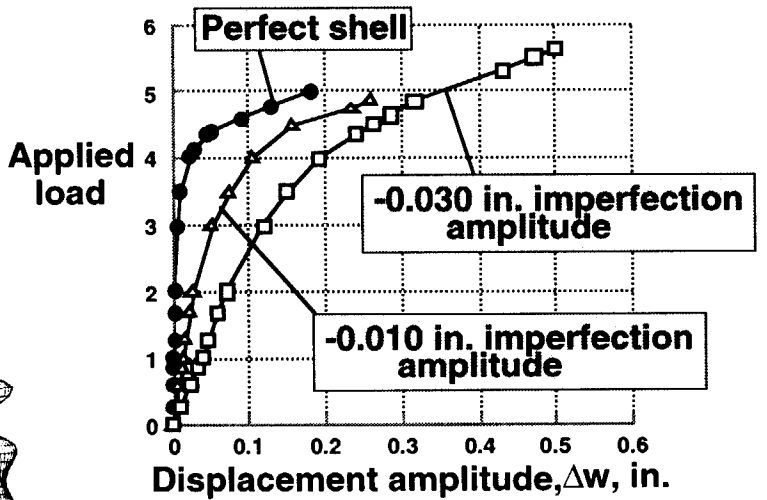
Nonlinear Analysis

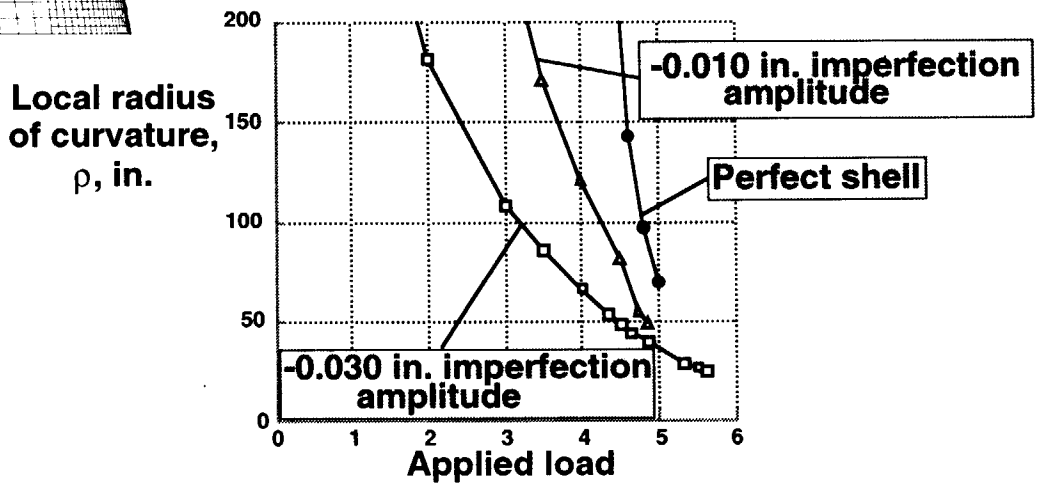
2nd Gen Airframe/TPS - Structures and Materials:

Multi-Lobed Tank Nonlinear Analysis

Space Shuttle Superlightweight External Tank Identifies LO_2 Tank Local Stability Mode

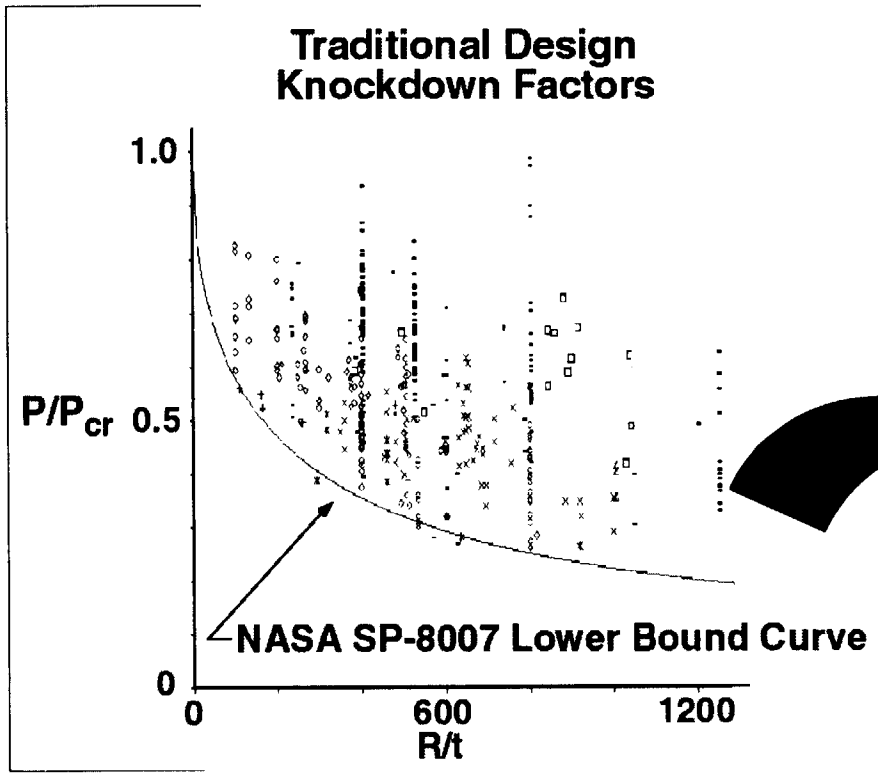






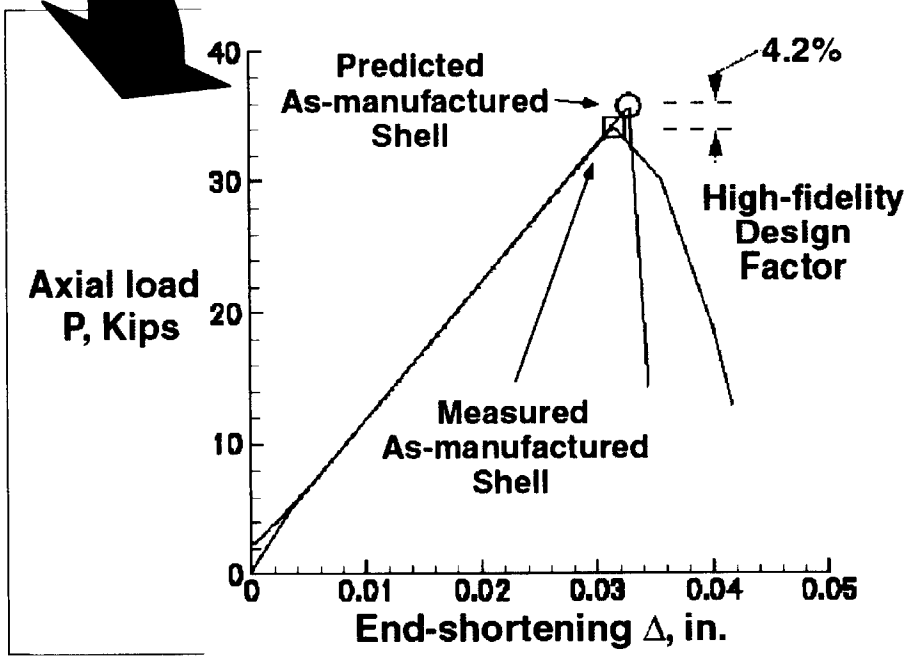
2nd Gen Airframe/TPS - Structures and Materials:

High Fidelity Nonlinear Analysis



Objective: Develop verified high fidelity analysis tools to reduce dependence on tests

High fidelity analysis

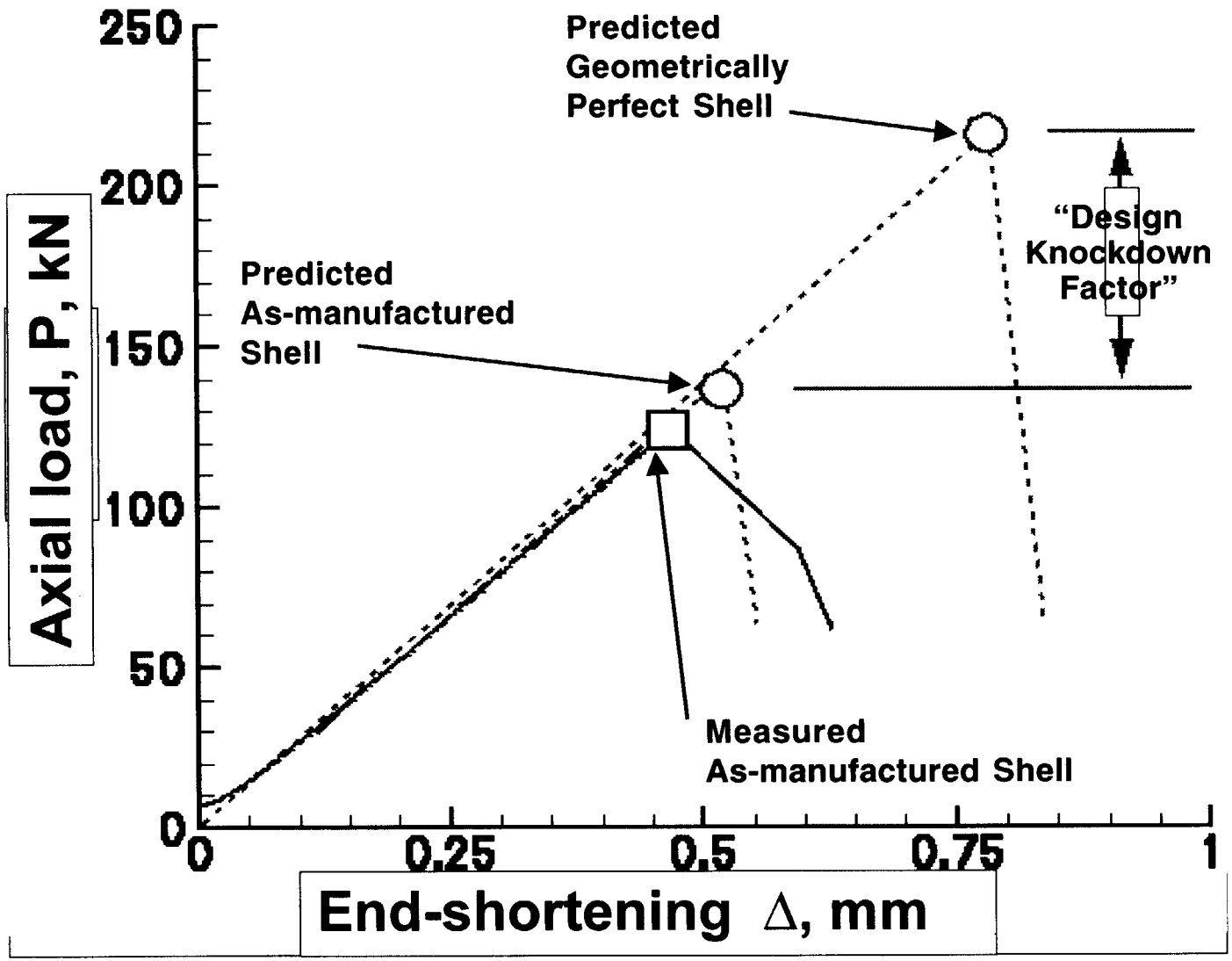


Technologies:

- High fidelity modeling
- Rapid and accurate analysis tools
- Prediction capability for all failure mechanisms
- Progressive failure methods for residual strength
- Intelligent testing approaches

2nd Gen Airframe/TPS - Structures and Materials:

High Fidelity Non-Linear Structural Analysis for Predicting Complex Structural Phenomena

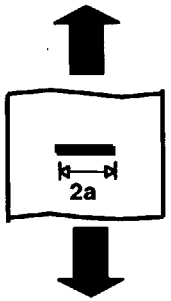


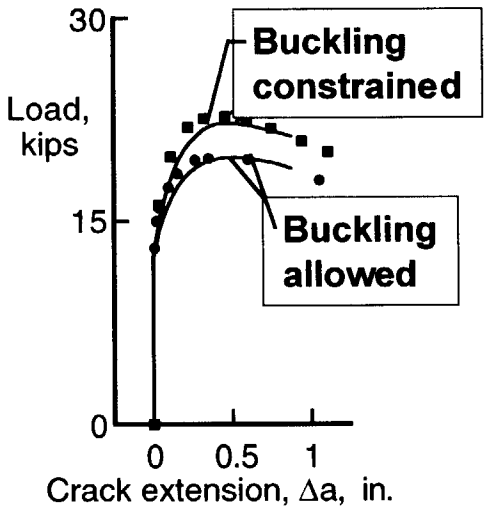
2nd Gen Airframe/TPS - Structures and Materials:

Predicted and Measured Response of a Composite Shell Structure

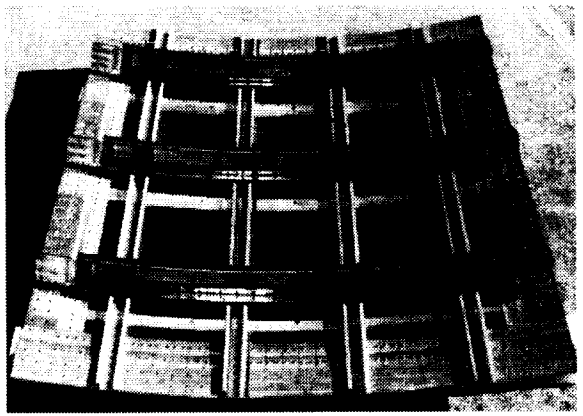
Laboratory Coupons

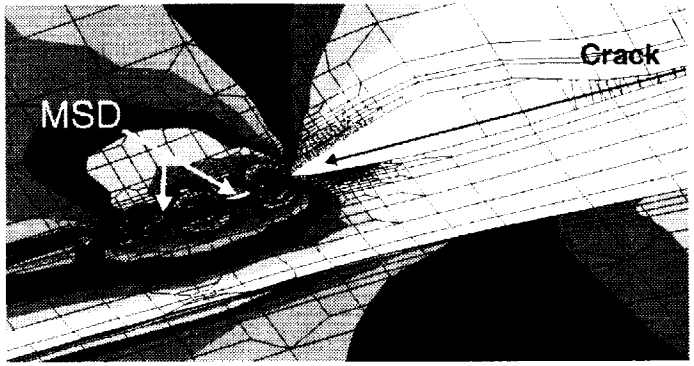
M(T) 12.0 in., 2a = 4 in.

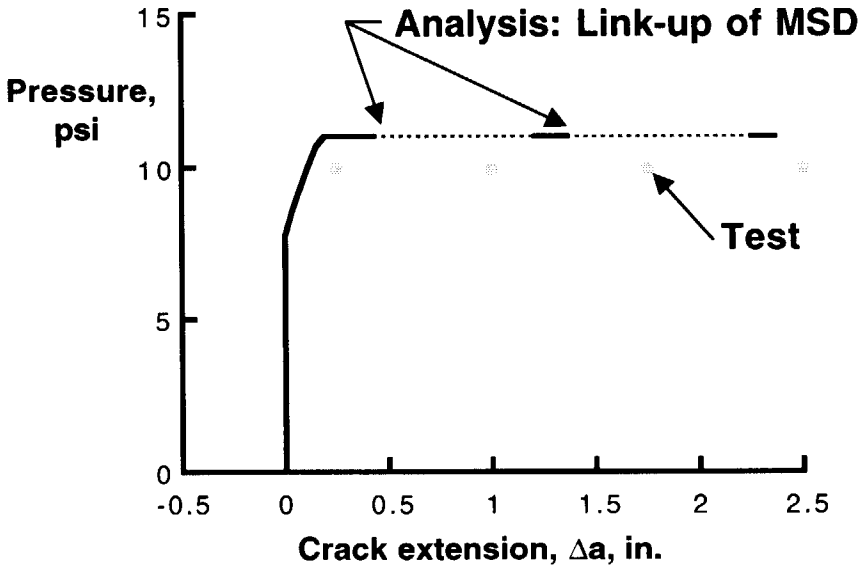




Fuselage Panel with Multiple Site Damage (MSD)



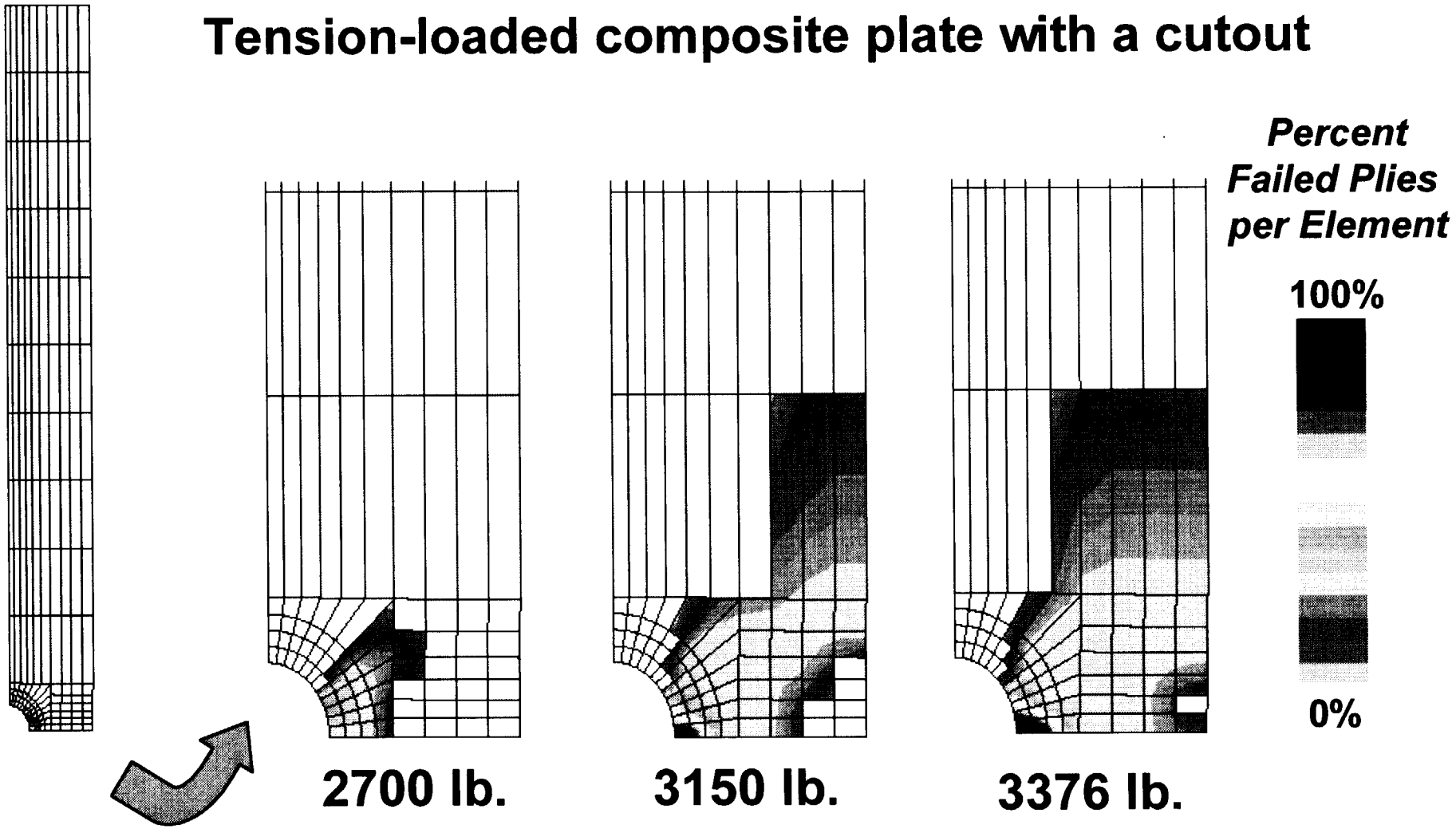




2nd Gen Airframe/TPS - Structures and Materials:

Applying Advanced Methods for Residual Strength Predictions

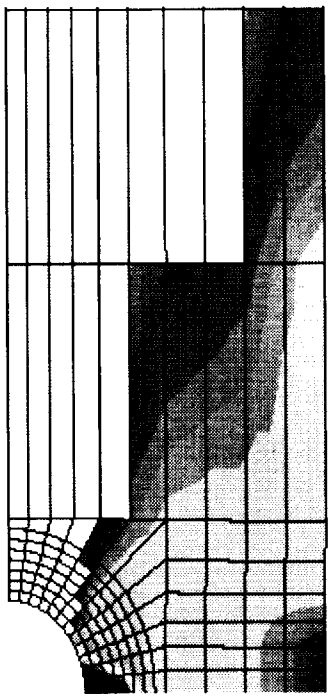
Tension-loaded composite plate with a cutout



2nd Gen Airframe/TPS - Structures and Materials:

Progressive Failure Analysis

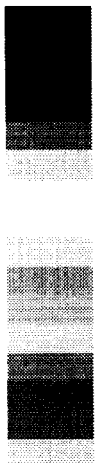
Maximum load solution for a composite plate with a cutout



3430 lb.

Percent Failed Plies per Element

100%



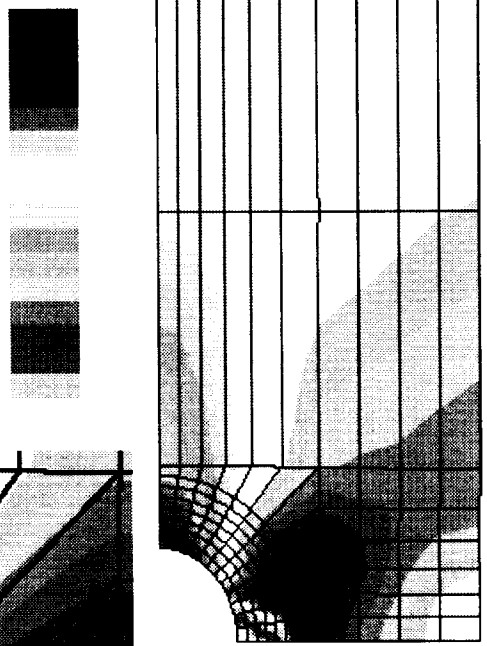
0%

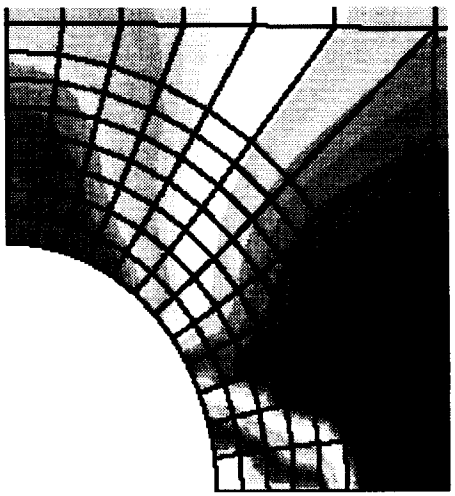
Longitudinal Stress Distribution in Outer 0-deg. Ply

4.013E+05 psi

Inc. 1.442E+04 psi

2.164E+05 psi

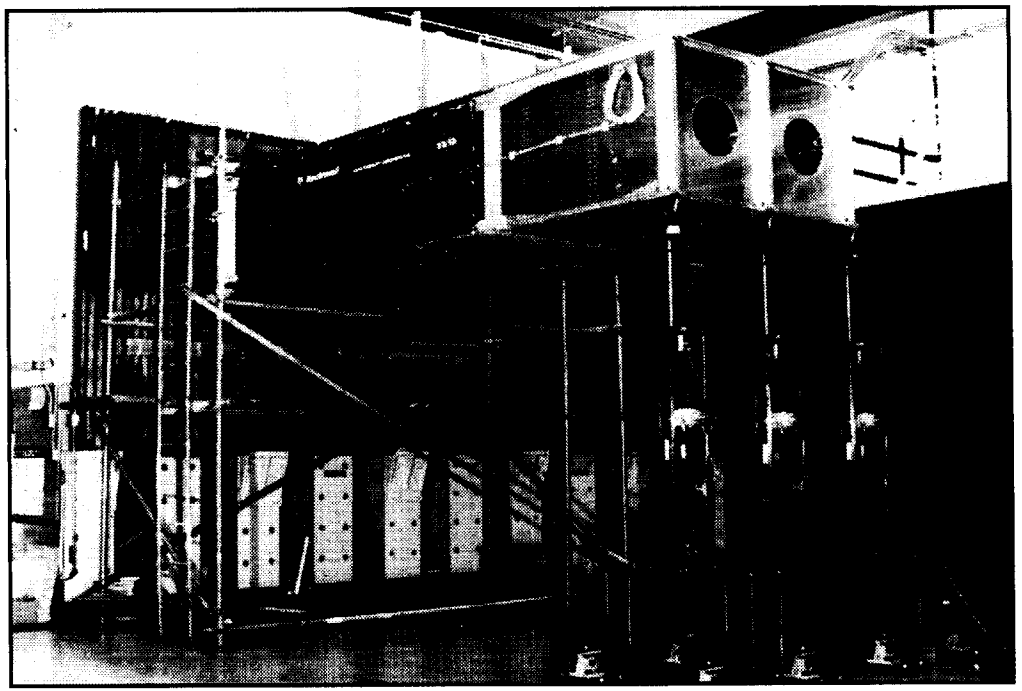




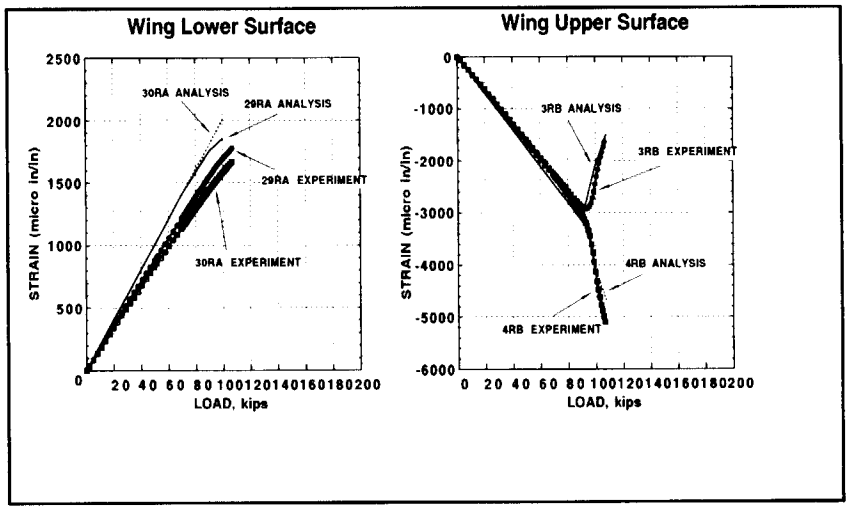
2nd Gen Airframe/TPS - Structures and Materials:

Progressive Failure Analysis - Cont.

RLV wing box test setup



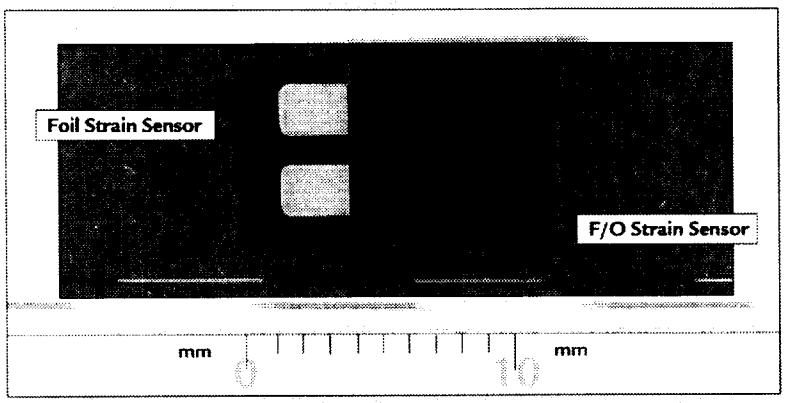
Measured and calculated strains on an RLV wingbox upper and lower surfaces

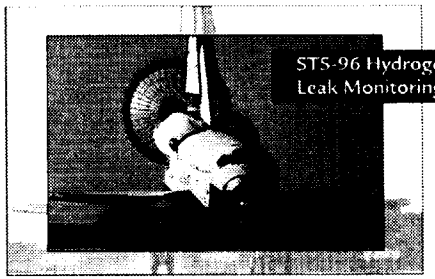


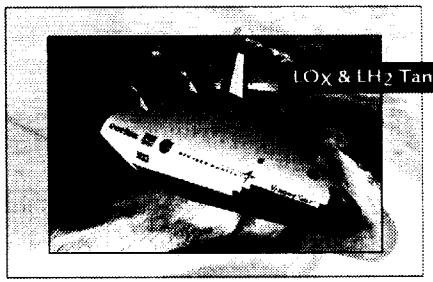
2nd Gen Airframe/TPS - Structures and Materials:

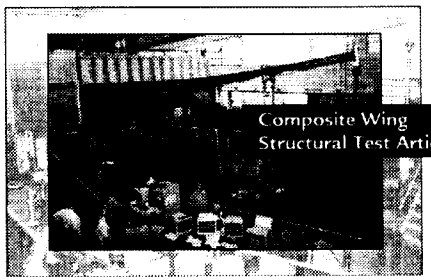
X-33 Phase I Graphite Composite Wing Box Design Validation Test

Distributed Fiber-Optic (F/O) Sensing for Structures IVHM



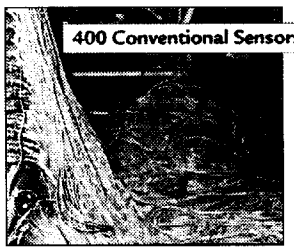


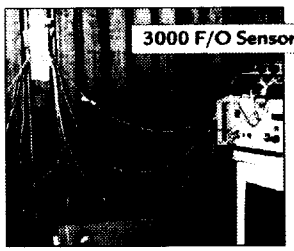




High Density Structural Sensors

- 10,000 Sensors < 1 pound
- Strain, Temperature, & Hydrogen (Propellant Leaks)
- Future Research - Vibration, Shape, Acoustic Emission, Chemistry (Corrosion)
- < $10/Sensor





2nd Gen Airframe/TPS - Structures and Materials:

Distributed Fiber Optic Sensing

Capabilities:

Loads

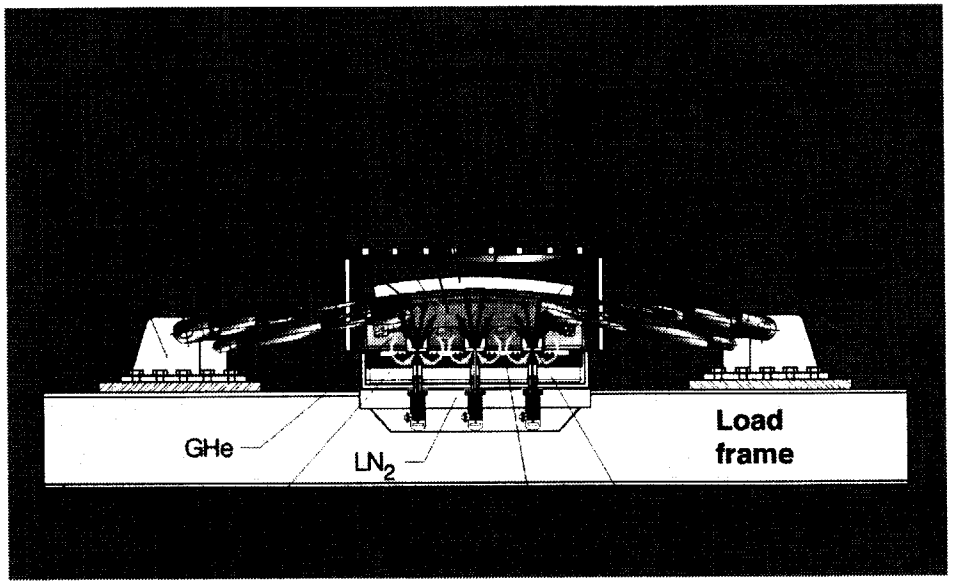
- Bi-axial tension is applied
- Max. axial load is 450 kips
- Max. internal pressure is 45 psig
- Internal cooling to -400°F
- Internal heating to 250°F
- External heating to 1000°F

Geometry

- Panel size is 65 in. x 76 1/2 in.
- Panel radii from 130 in. to 266 in. (80 in. is possible)
- Panels can have internal and external ring frames and stringers

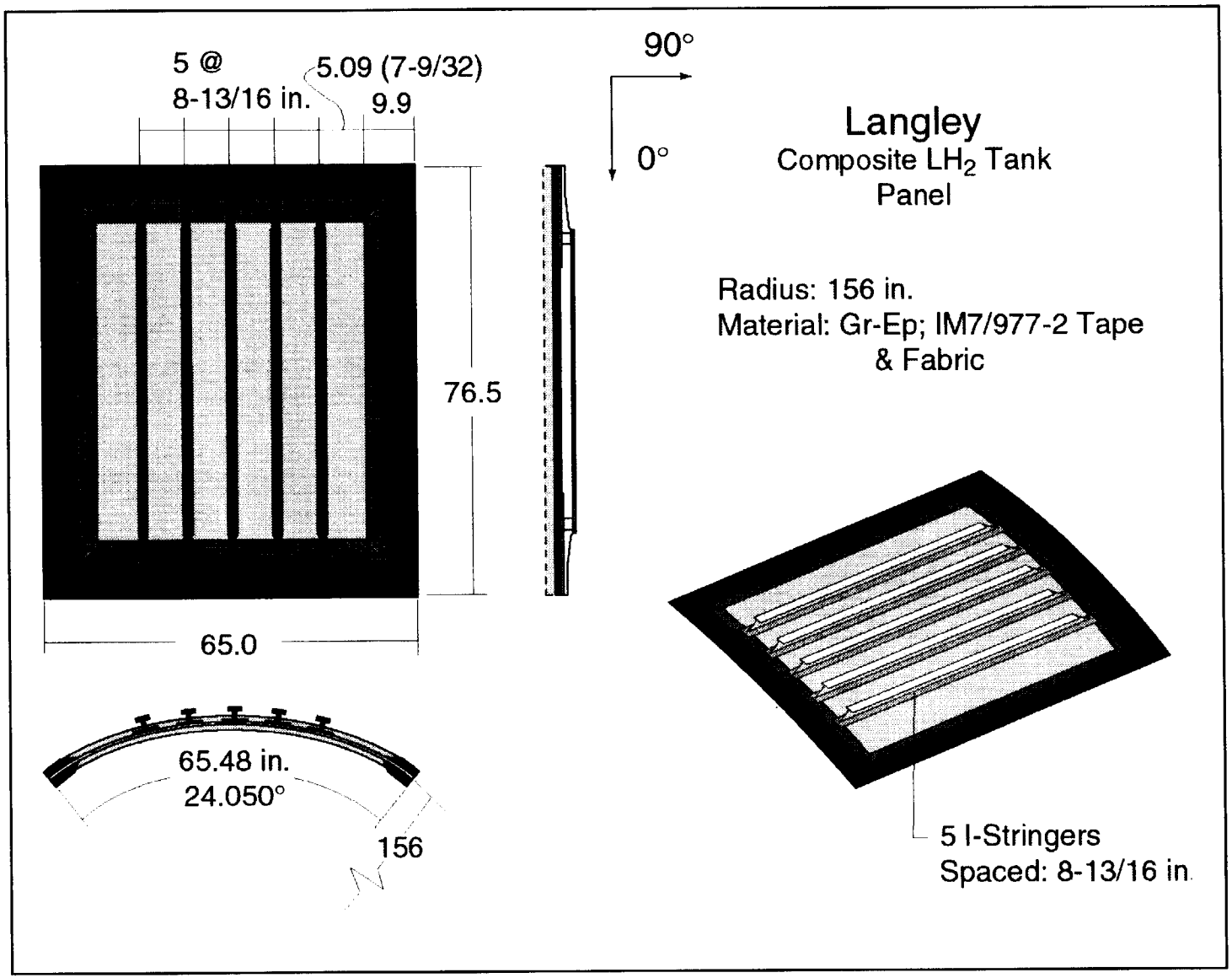
Benefit

- Full-scale tank features
- Testing at subcomponent costs



2nd Gen Airframe/TPS - Structures and Materials:

Cryogenic Pressure Box Facility

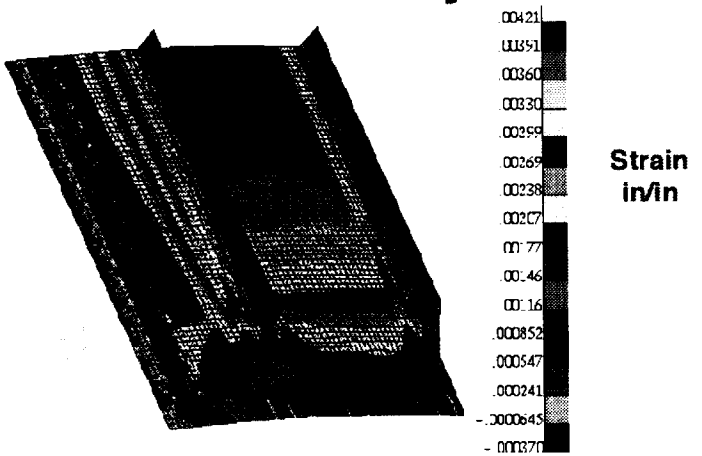


2nd Gen Airframe/TPS - Structures and Materials:

Cryogenic Pressure Box Panel

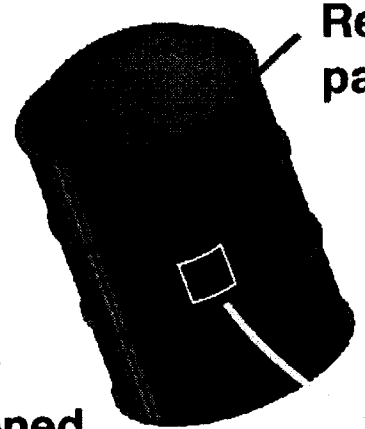
- Combined thermal and structural analysis
- Traceable solutions to flight articles

Structural Analysis



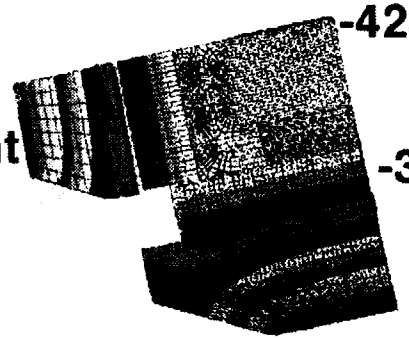
Full sized articles

Tank geometry modelled as a cylinder



Graphite-Epoxy
Externally stiffened
LH_2 tank

Thermal Analysis



2nd Gen Airframe/TPS - Structures and Materials:

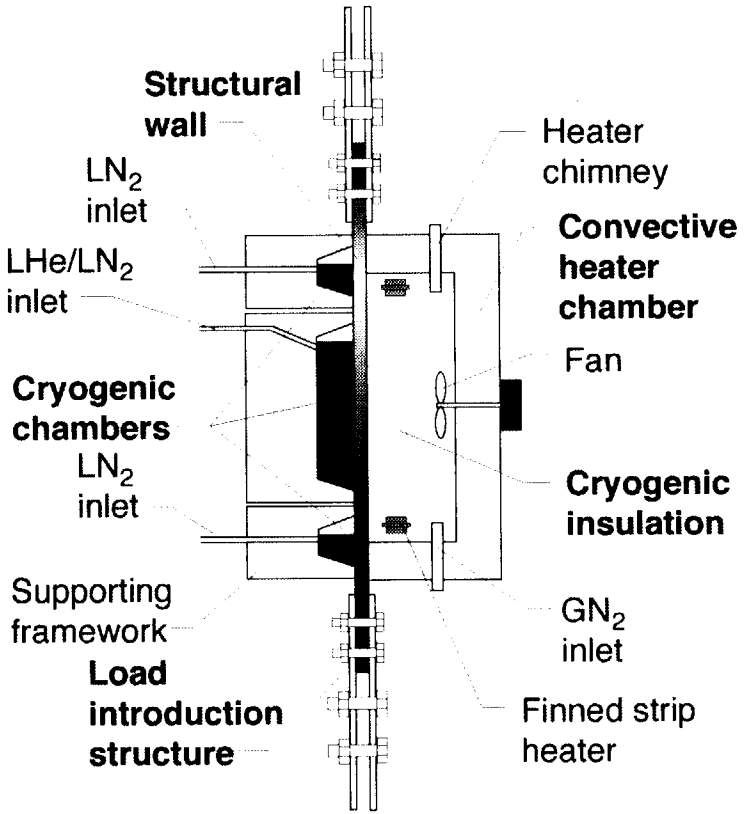
Correlation of Analysis to Test

- Any honeycomb material can be foam filled - Korex, Nomex, Graphite, etc.
- Honeycomb cell size from 1/8" and larger can be foam filled.
- Honeycomb core thickness from 1/4" and larger.
- Foam densities ~2.6 pcf.

2nd Gen Airframe/TPS - Structures and Materials:

TEEK Foam Filled Honeycomb Materials

Cross-Section of fixture



Specimens

Substrate: 1' x 2' & 1' x 4'

Min. Temp.

-423˚F (Cryo. side)
10˚F (Foam surface)

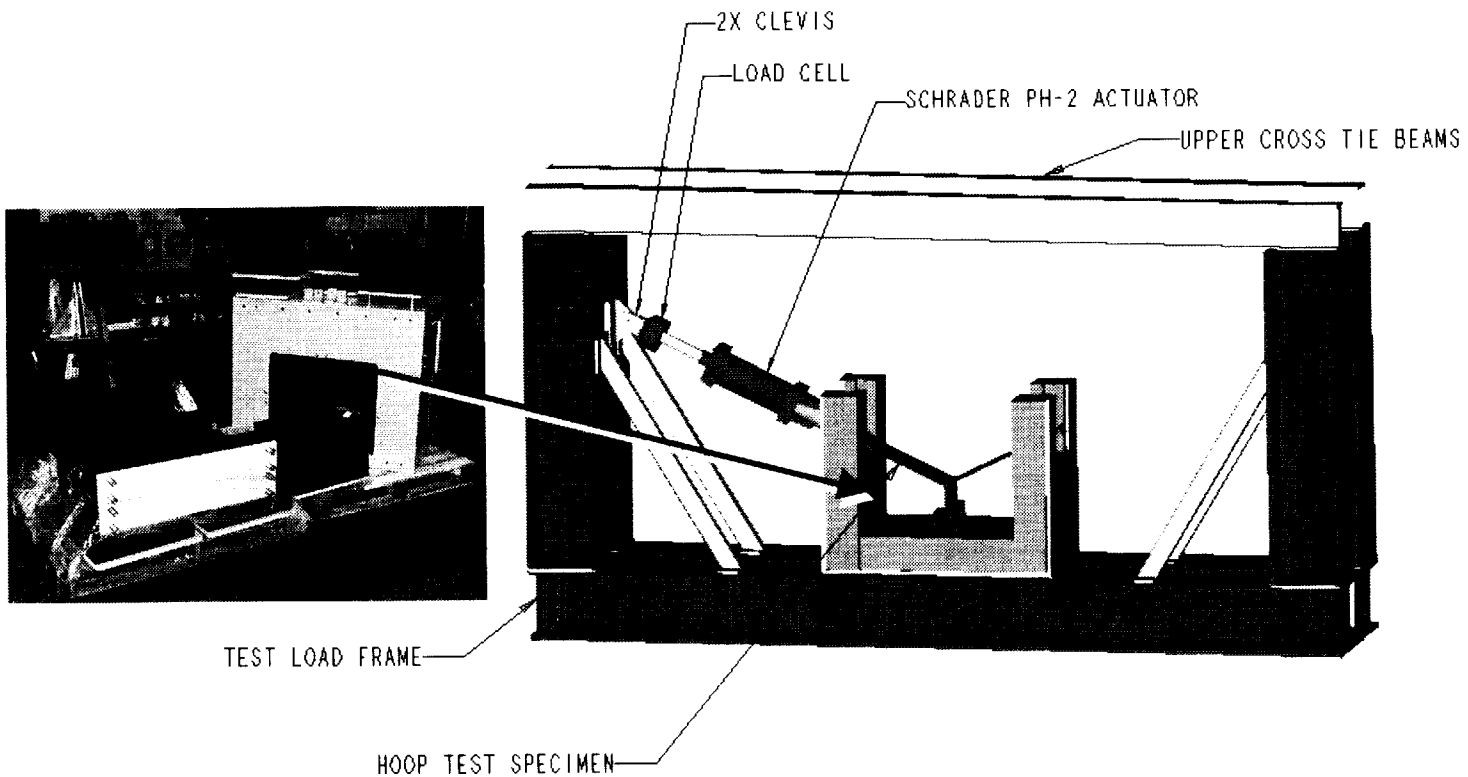
Max. Temp.

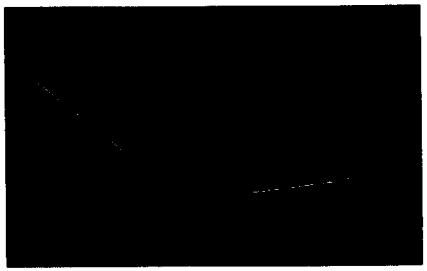
250˚F (Cryo. side)
450˚F (Foam surface)

Max. Load: 110 kips

2nd Gen Airframe/TPS - Structures and Materials:

Thermal/Mechanical Tension Test





Hoop Y-joint

Axial Y-joint

Specimens

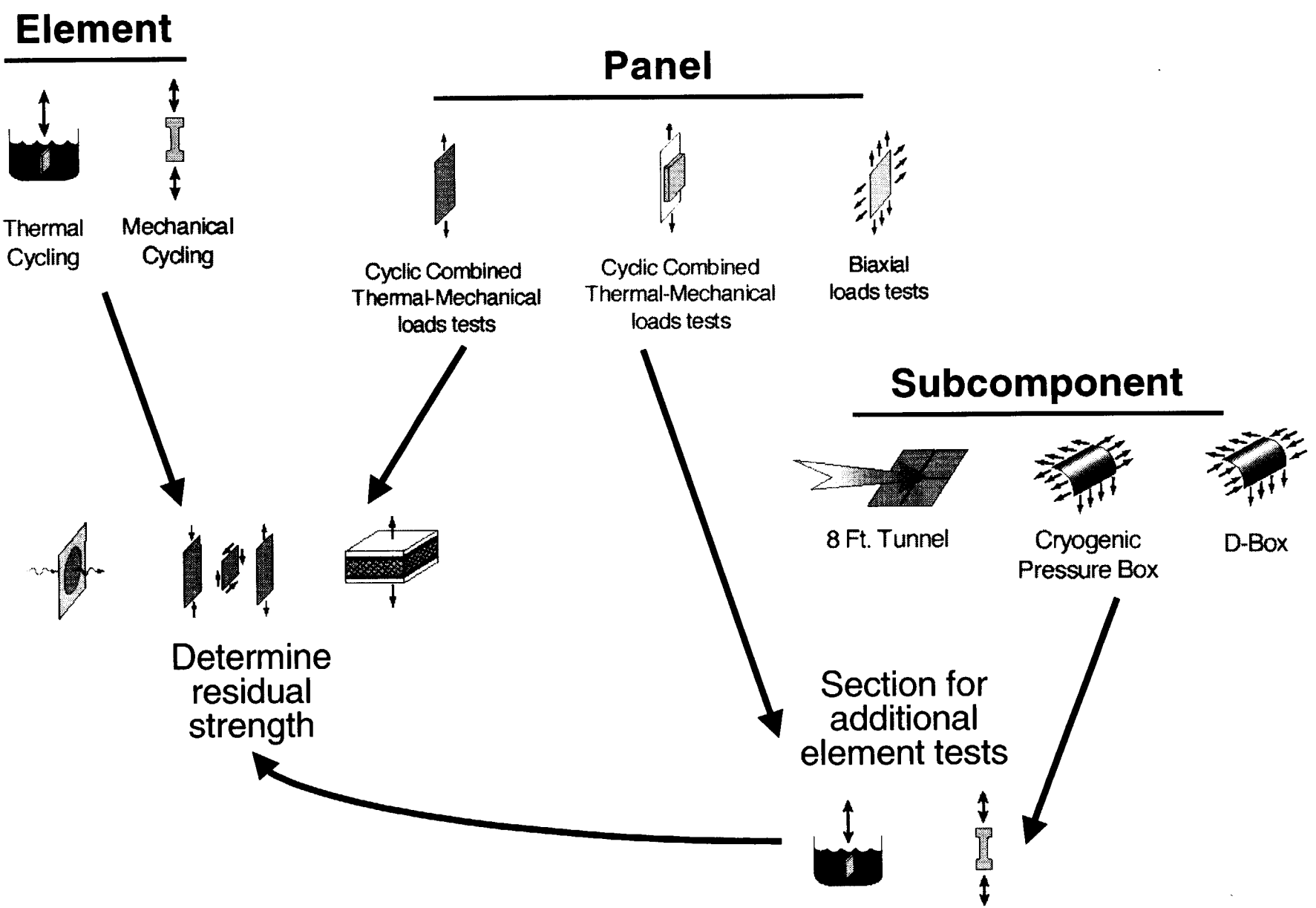
2 Hoop Tension Y-Joints
Arm-to-Barrel step joint
2 Axial Tension Y-Joints
Axial and Arm-to-Barrel step joint

Test Plan

10 Thermal Cycles (-423°F to +250°F)
Pull to failure at -423°F
Record failure load, failure mode

2nd Gen Airframe/TPS - Structures and Materials:

Hoop & Axial Y-Joint Tests



2nd Gen Airframe/TPS - Structures and Materials:

Materials in Structural Applications

- **NASA's Thermal Protection System (TPS) Technologies**
  - RLV Focused Projects
  - Recent or Emerging Technologies
- **NASA's TPS Research, Development & Testing Capabilities**
  - TPS Development Approach
  - Laboratories
  - Modeling
  - Databases
  - Test Facilities
- **TPS POC**

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TPS Technologies & Capabilities

- **Constituents and Fabrication Techniques for Metallic TPS** - *LaRC*
  - Advanced joining techniques
  - Surface property characterization
  - Durable, lightweight coating development
- **Metallic TPS Concepts** - *LaRC*
  - Improved metallic TPS concepts
  - Lower risk, subsurface panel-to-panel seals, cooler subsurface attachments
- **Advanced Durable Blanket TPS** - *ARC Partnership w/ Industry*
  - Lower fabrication and maintenance unit costs
  - Suitable for application to windward vehicle surfaces
- **High Temperature Integrated Structures** - *LaRC Partnership w/ Industry*
  - Structurally integrated high temperature wing design
  - Reduced manufacturing costs and improved load bearing characteristics

RLV Focused Project of the ASTP

- **Durability**
  - TUFI & White TUFI on AETB Ceramic Tiles - *ARC*
  - Structural Seals & Thermal Barriers - *GRC*
  - Toughened LI-900 - *ARC*
  - Metallic Sandwich Panel TPS - *LaRC*
  - Metal Covered Ceramic Blankets (DurAFRSI) - *ARC*
  - CMC Covered Ceramic Tiles - *LaRC*
  - Advanced Durable Ceramic Blankets - *ARC with Industry Partner*
- **Lower Thermal Conductance**
  - Reduced Conductivity AETB Ceramic Tiles - *ARC*
  - Nano-Phase Ceramic Insulations - *ARC*
    - Aerogel & other xerogel composites

Recent or Emerging Technologies

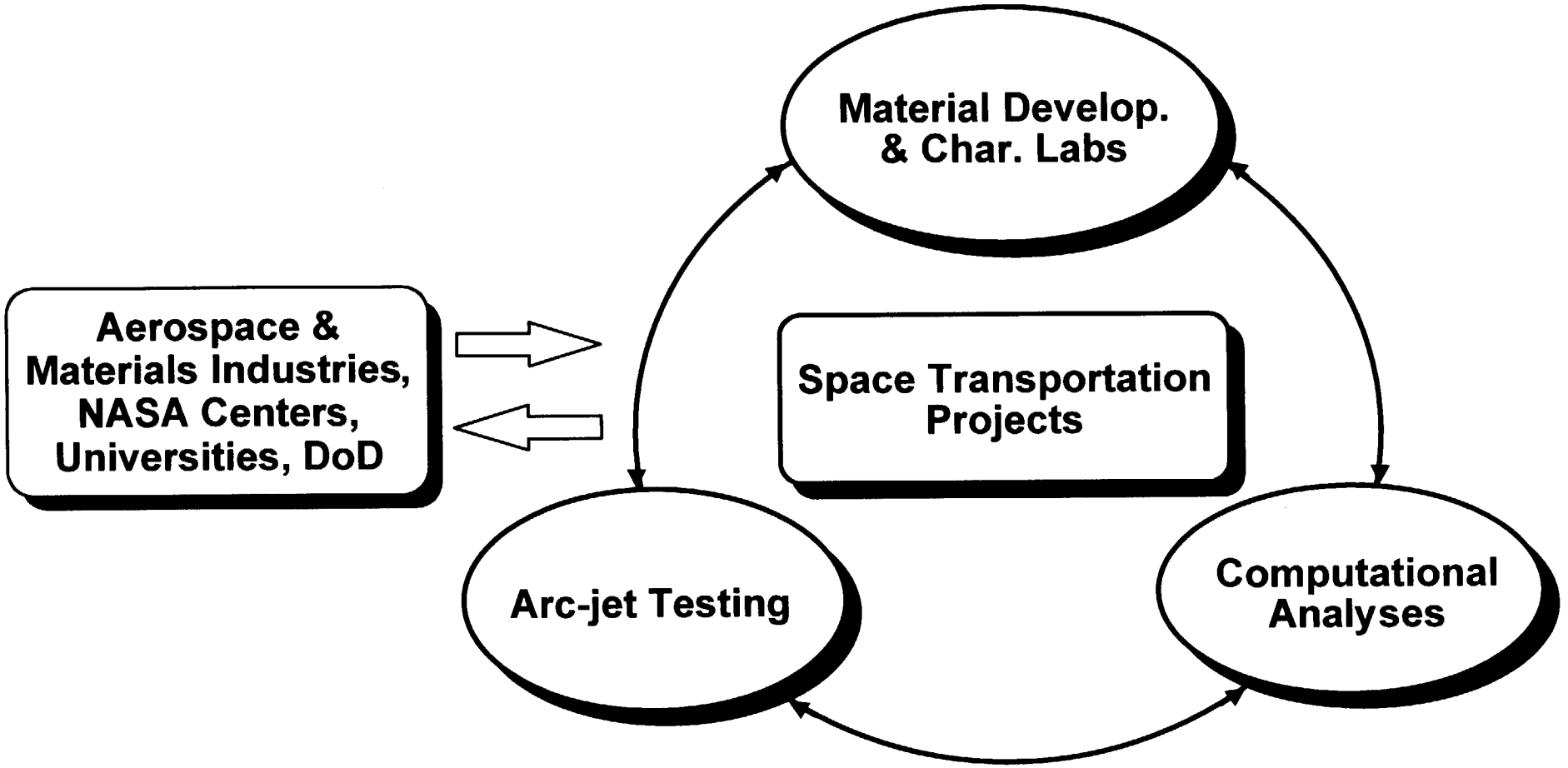
♦ Higher Temperature Capability

- Ultra-High Temperature Ceramics - *ARC, GRC, LaRC*
  - including Zr & Hf based ceramic composites
- High Temperature Seals - *GRC*
- Heat Pipe Cooled Leading Edges - *LaRC*
- TUFI-HT, Ultra-TUFI on AETB Ceramic Tiles - *ARC*
- Higher Temperature Coatings for CMCs - *JSC, LaRC*
- Light-weight Ceramic Ablators - *ARC*
  - SIRCA, PICA, SPLIT

♦ Lower TPS Life Cycle Costs

- TPS Health Monitoring Techniques - *ARC, KSC, & Industry Partners*
  - Remote scanning with distributed passive sensors
- Organo-ceramic Materials - *ARC*
  - QUIC-Fix, QUIC-Stick, QUIC-TUFI
- Higher-Temperature Felts - *ARC*
- Integral Cryogenic Insulation / TPS - *ARC, MSFC*

Recent or Emerging Technologies, ctd.



A Synergistic, Multidisciplinary Approach, Combining National Arc-jet Facilities, Material Development Labs, and Analysis Capabilities

Extensive Industry Interaction, Collaboration and Technology Transfer

TPS Development Approach

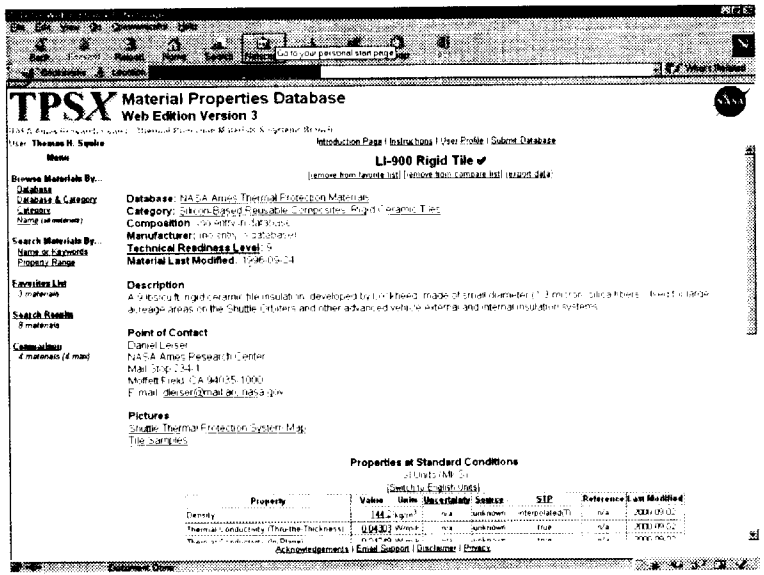
- **Materials Development & Characterization Laboratories**
  - *ARC, GRC, JSC, LaRC*
    - Material Processing & Optimization
    - Material Structure Analysis
    - Thermo-mechanical Properties
    - Thermo-chemical Stability
    - Optical Properties
    - Heat Transfer Properties

- **Modeling** - *ARC, GRC, LaRC*
    - Vehicle Flow Environments, Aerodynamic & Aerothermal Predictions
    - TPS Material Response Analysis & Sizing
    - Ground Test Facility Flow Characterization for Optimal Testing
    - Test Model Design Optimization
    - Post-test Data Analysis & Interpretation

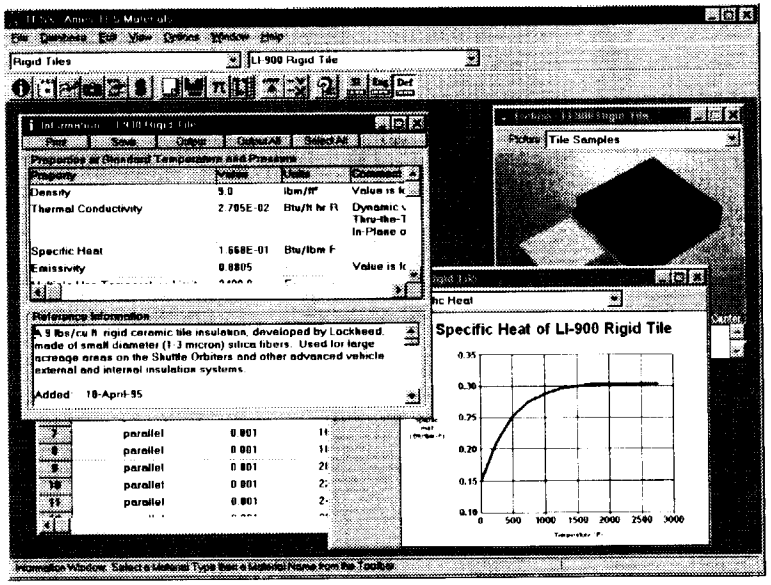
Material & Analytical Capabilities

http://tpsx.arc.nasa.gov

- TPS*X* is an engineering design tool that provides material property and performance data on a variety of thermal protection system materials.
- TPS*X* contains data on over 500 materials and allows users to search, display and output the information in several formats .
- TPS*X* is available as a downloadable Windows program and on the Web.
- TPS*X* has nearly 1000 registered users and the web site receives ~1200 hits per week.



TPS*X* Web Edition



TPS*X* Windows Program

Space Transportation Technology Workshop - Airframe Section

Thermal Protection Systems Expert & Material Property Database

- **Arc Jets**
  - ARC, JSC
- **Radiant Heating Facilities**
  - ARC, JSC
- **Wind Tunnels**
  - ARC, LaRC, MSFC
- **Aircraft-based Testbeds**
  - DFRC
- **Impact Durability Assessment**
  - ARC
- **Vibro-acoustic Facilities**
  - ARC, LaRC

Test Facilities