

Thermal-Mechanical Testing of Hypersonic Vehicle Structures



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Santa Barbara, CA
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Outline

- ◆ U.S. Laboratories for Hot Structures Testing
- ◆ NASA Dryden Flight Loads Laboratory
- ◆ Hot Structures Test Programs
- ◆ Typical Sequence for Hot Structures Testing
- ◆ Current Hot Structures Testing
- ◆ Concluding Remarks



U.S. Laboratories for Hot Structures Testing

Structures Test Facility, Bldg. 65
AFRL/VA Wright-Patterson AFB, Dayton OH



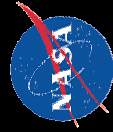
Flight Loads Laboratory
NASA DFRC, Edwards, CA



- Large-scale thermal, structural and dynamic testing
- Thermal-structural and dynamic analyses
- High-temperature instrumentation
- Non-destructive evaluation



Structures & Materials
Research Laboratory
NASA LaRC, Hampton, VA



NASA Dryden Flight Loads Laboratory

◆ General Description

- Laboratory for structural and thermal testing of aerospace structures
- Large high-bay test area (164' x 120')

◆ Structural Loading Capabilities

- Structural loading equipment: load frames, load cells, and hydraulic actuators
- Aircraft ground vibration and structural mode interaction testing
- 84 channels of hydraulic load control

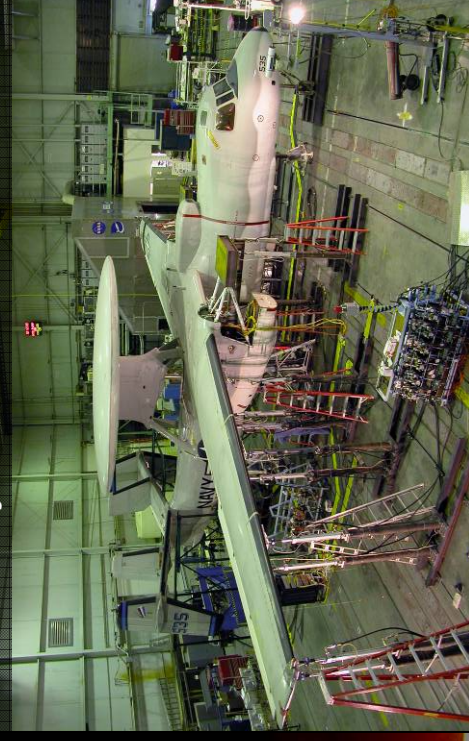
◆ Thermal Loading Capabilities

- Vacuum furnaces, low and high temperature chambers, liquid and gaseous nitrogen supply systems
- Quartz lamp and graphite element heating
- 20 MW of available power
- 4000 gal of liquid nitrogen storage for cryogenic testing
- Potential for 512 channels of thermal control

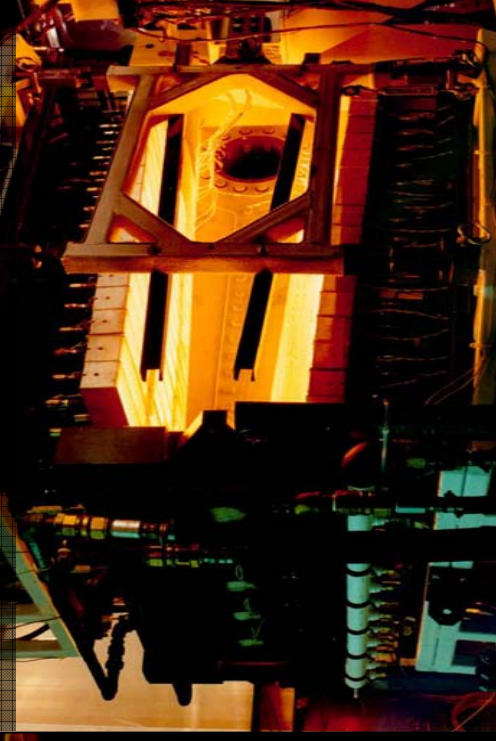
◆ Data Acquisition Capabilities

- Potential for 1280 channels of data acquisition

E2C Hawkeye Loads Calibration Test



C/C Elevon Thermal/Structural Test



NASA Dryden Flight Loads Laboratory



Proof Loading



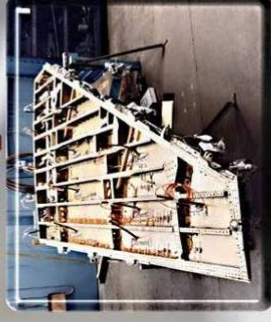
Loads Calibration



Ground Vibration Testing



Moment of Inertia



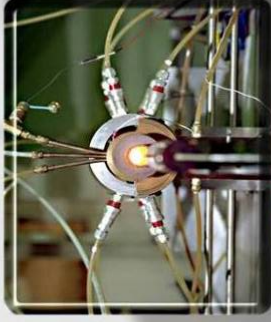
Strain Gage Installation



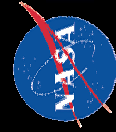
Aerodynamic Heating Simulation



Thermostructural Testing

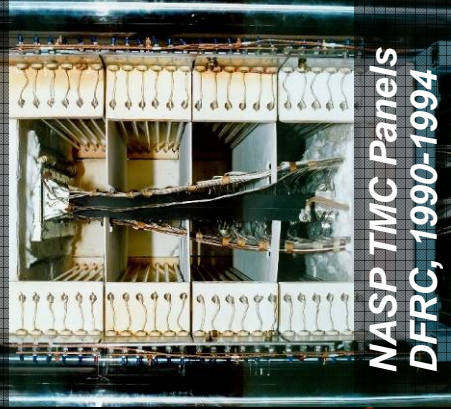


High-Temp Instrumentation



Hot Structures Test Programs (1990's)

1500°F w/ Load



NASP TMC Panels
DFRC, 1990-1994

2000°F w/ Load



NASP C/C Wing Box
AFRL, 1992

1200°F w/ Load



NASP TMC Panel
Joint Test
LaRC, 1993

1200°F w/ Load



NASP TMC Splice Joint Panel
AFRL, 1993

900°F w/ Load

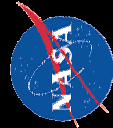


NASP TMC Side Shear Panel
DFRC, 1995

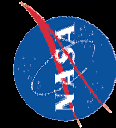
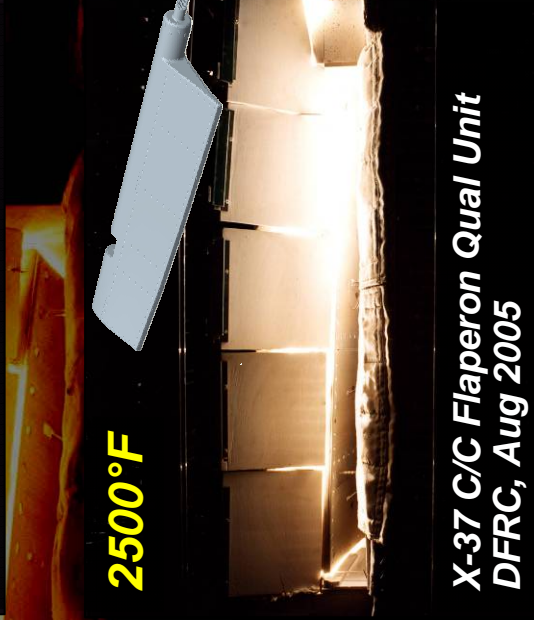
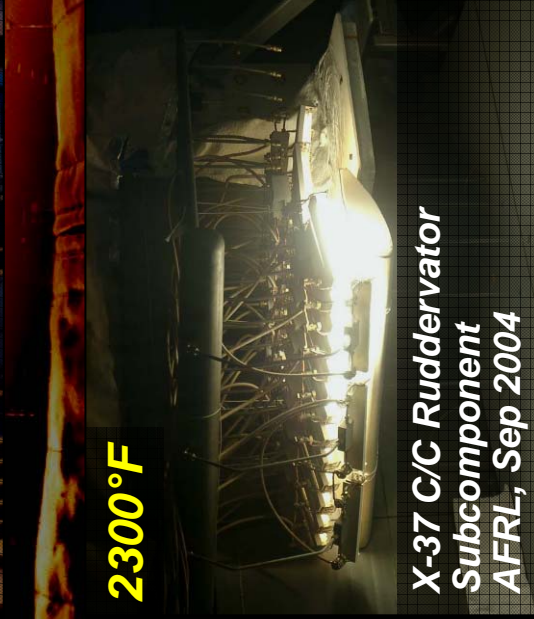
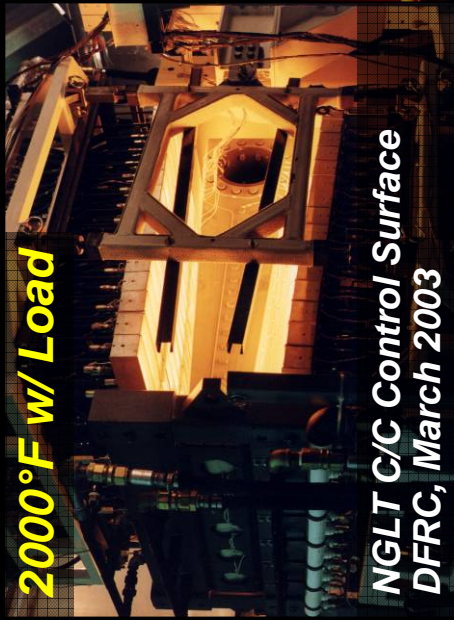
2250°F w/ Load



AFRL C/C Wing Box
AFRL, 1999

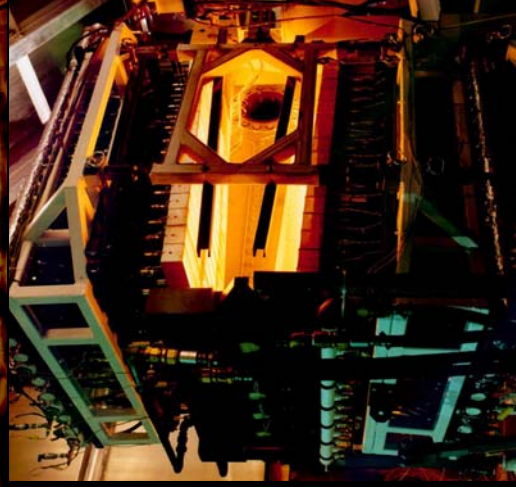
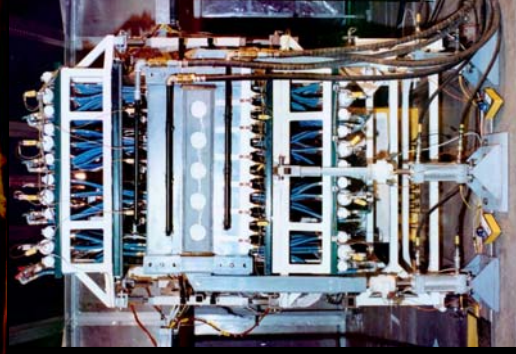
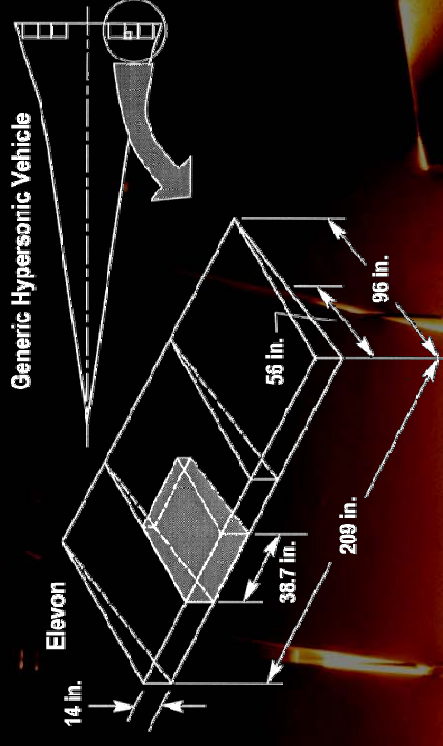


Hot Structures Test Programs (2000's)



Hot Structures Test Programs

- ◆ **NASP / NGLT Carbon-Carbon Elevon (2003)**
 - Concept validation test of a flight-weight C/C hot structure component
 - Fabricated in 1989 for the NASP Tech Mat program
 - Simultaneous heating and loading to 2000°F and 100% DLL in nitrogen atmosphere
 - 128 quartz-lamp heaters (32 control zones)
 - Approximately 1.5 MW of electrical power
 - **Instrumentation**
 - 50 thermocouples and 54 strain gages (first hot structure application of fiber optic strain sensors)



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Test at 2000°F & 100% DLL

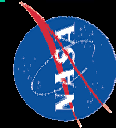
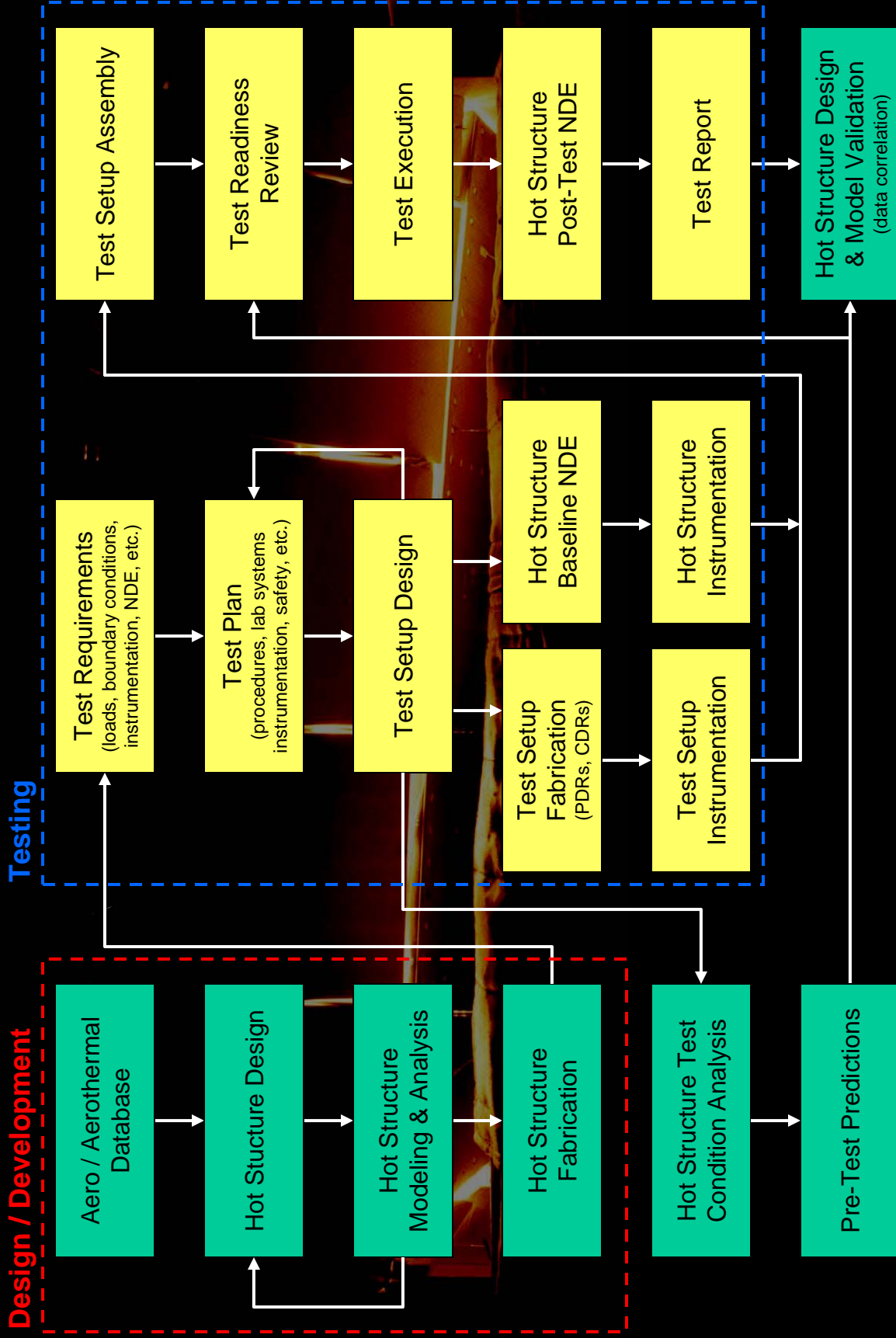


Hot Structures Test Programs

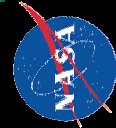
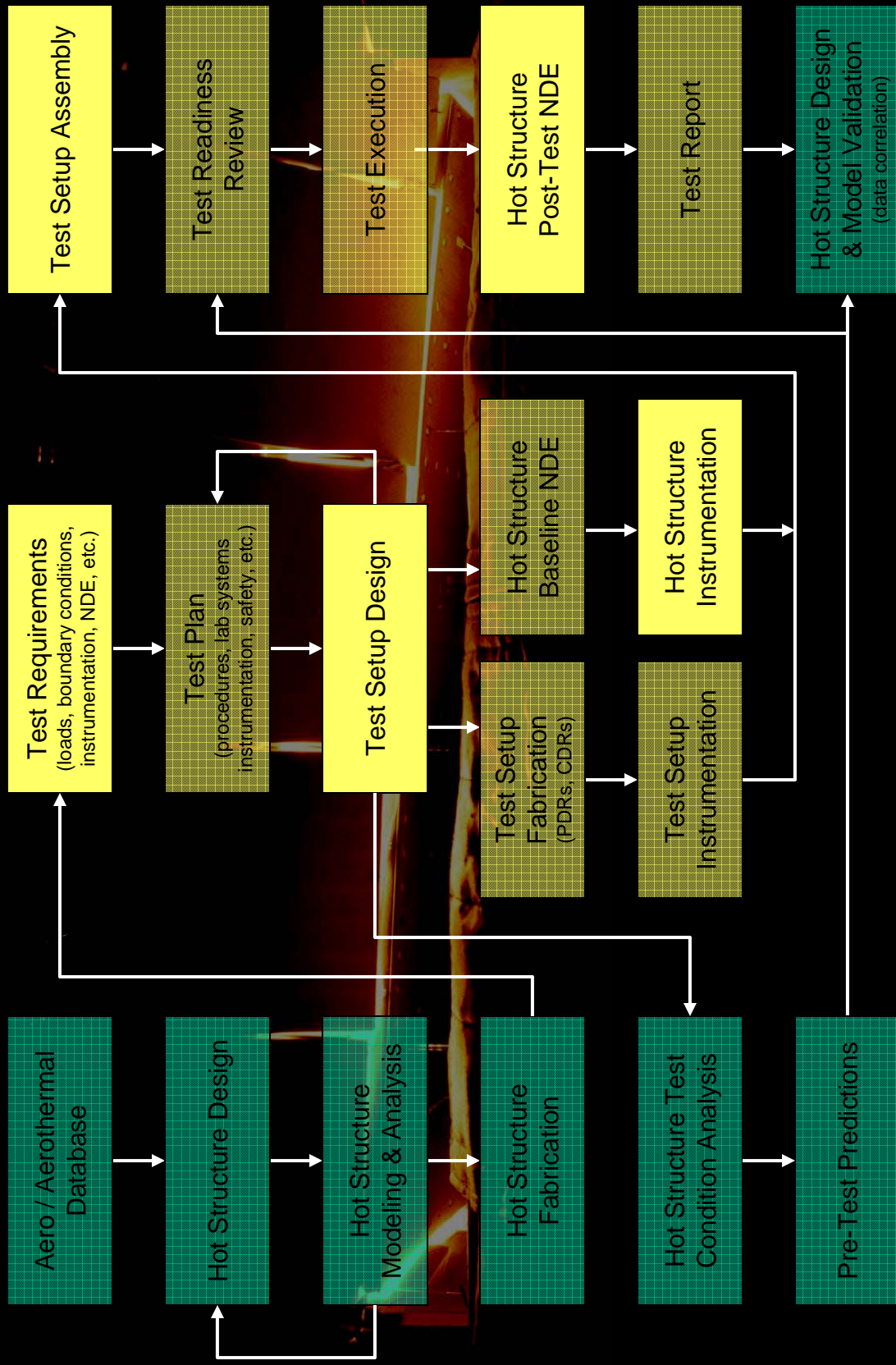
- ◆ X-37 Carbon-Carbon Flaperon (2005)
 - Thermal & mechanical qualification test of a flight design C/C hot structure control surface
 - Tested in nitrogen purged atmosphere
 - 35 quartz lamp heaters (18 control zones)
 - Instrumentation
 - 82 thermocouples channels (124 on test setup)
 - 14 fiber-optic strain sensors
 - 12 deflection measurements
 - Key test challenges
 - Bonding high-temp instrumentation to C/C
 - Achieving desired boundary conditions



Typical Sequence for Hot Structures Testing



Typical Sequence for Hot Structures Testing



Test Requirements Definition

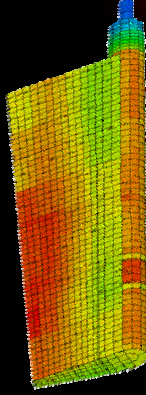
- ◆ Test article description (material, size, type, etc.)
- ◆ Type of test (proof, acceptance, qualification, validation, research)
- ◆ Type of loading (thermal, mechanical, dynamic, combined)
- ◆ Boundary condition definition
- ◆ Type of heating system (quartz lamp, graphite)
- ◆ Type of test atmosphere (purged, air, level of O₂)
- ◆ Test matrix definition (test sequence)
- ◆ Instrumentation (type, number, location)
- ◆ Handling requirements
- ◆ Inspection requirements
- ◆ Documentation requirements



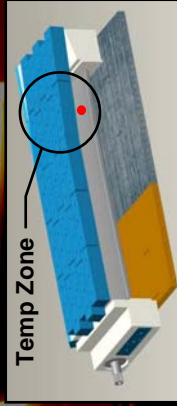
Test Setup Development

- ◆ Goal: Design test setup to simulate desired boundary conditions
 - Heating system to meet desired temperature distribution
 - Mechanical loading system to meet desired pressure distribution

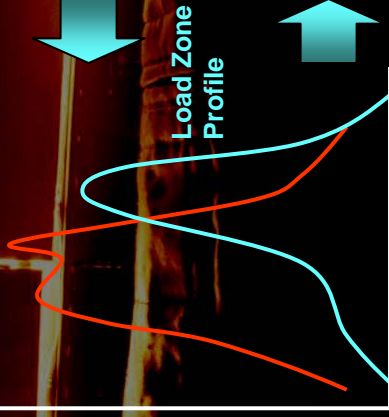
Heating System



Temperature Distribution



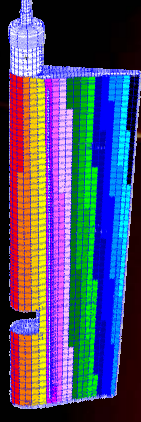
Temp Zone Profile



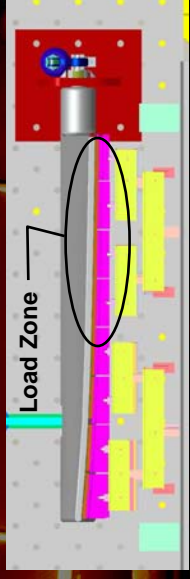
Load Zone Profile

Time

Mechanical Loading System



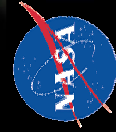
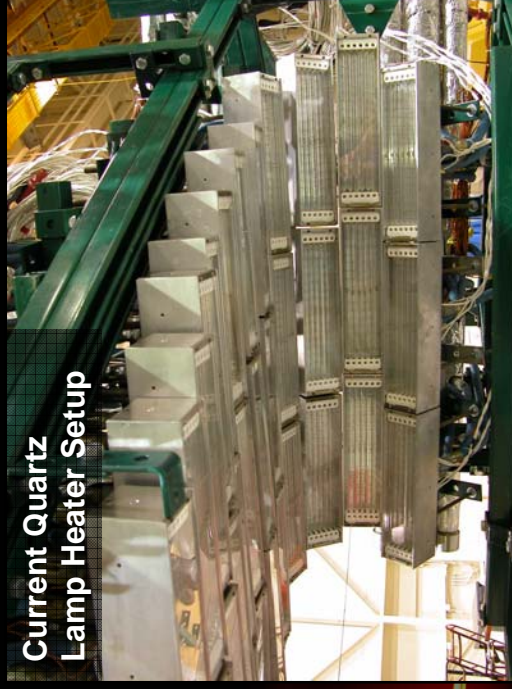
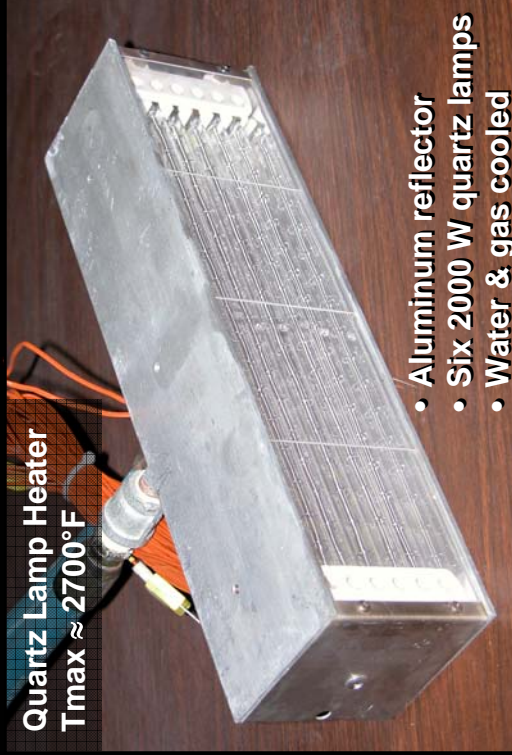
Pressure Distribution



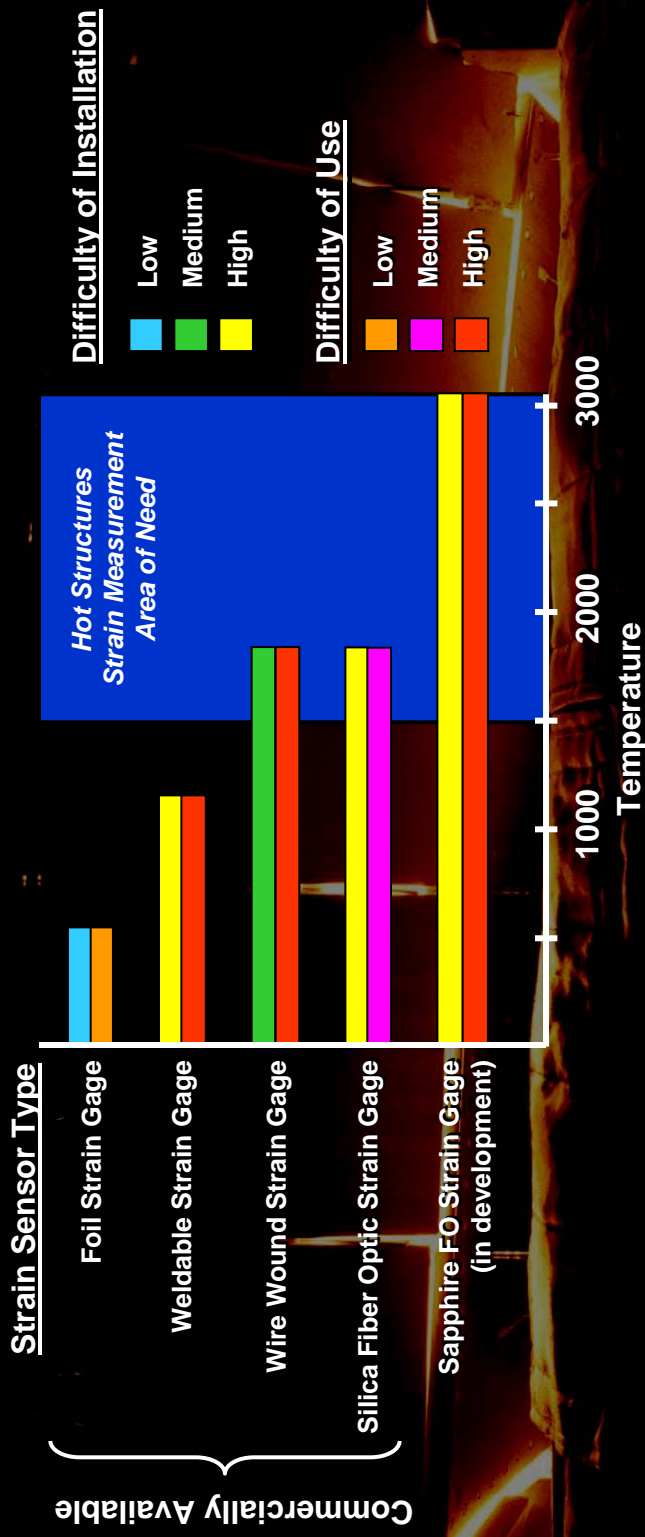
- ◆ Perform a test condition analysis to include real boundary conditions
 - Provides more representative pre-test predictions
 - Provides best correlation between test data and analysis



Test Setup Development



High-Temperature Instrumentation



◆ Issues

- Hot structures are utilizing advanced materials that operate at temperatures that exceed current ability to measure structural performance
- Robust strain sensors that operate accurately and reliably beyond 1800°F do not exist

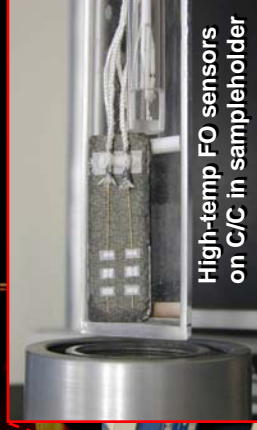
◆ Implications

- Hinders ability to validate analysis and modeling techniques
- Hinders ability to optimize structural designs

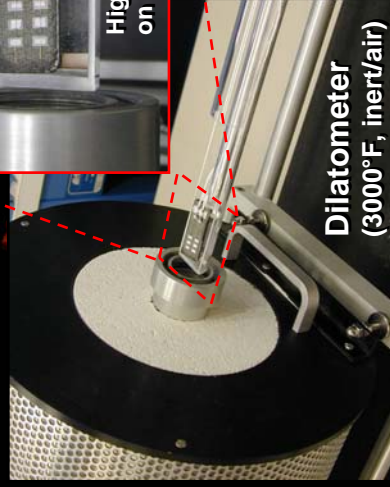


High-Temperature Instrumentation

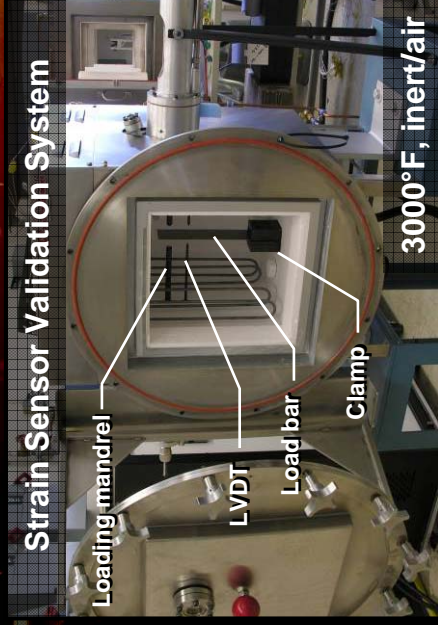
- ◆ **Goal: Provide valid strain and temperature data to analysts**
 - Supports FEM and thermal-structural analysis validation
- ◆ **Key Issue: Develop attachment techniques for strain & temperature sensors on hot structure materials (superalloys, C/C, C/SiC, etc.)**
- Validate attachment techniques through characterization testing



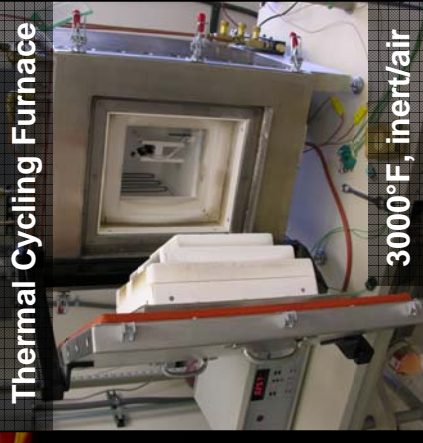
High-temp FO sensors on C/C in sampleholder



Dilatometer (3000°F, inert/air)



Strain Sensor Validation System



Thermal Cycling Furnace

Typical Systems for Sensor Validation Testing

High-Temperature Instrumentation

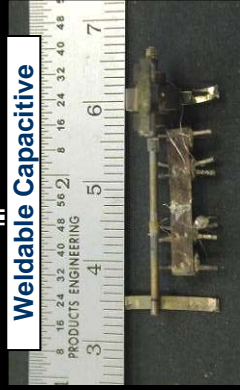
Evolution of Hot-Structure Strain Measurements



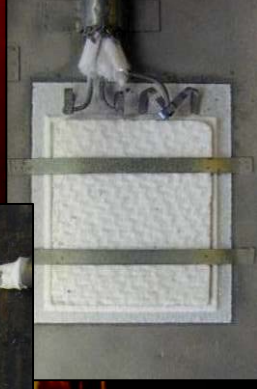
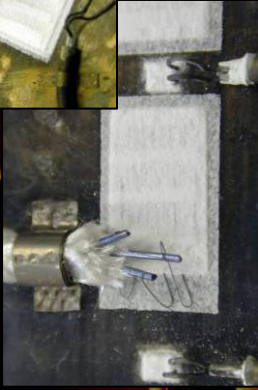
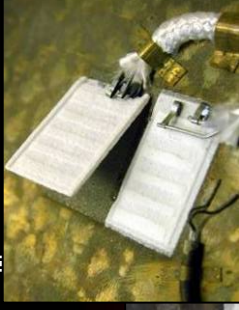
1960-1970

1980-1990

>2000



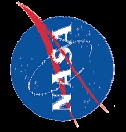
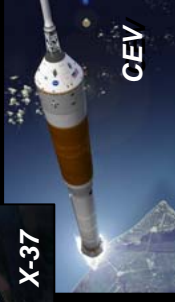
Large thermal outputs and measurement uncertainties



Improved temperature-compensation using flame-sprayed resistive gages

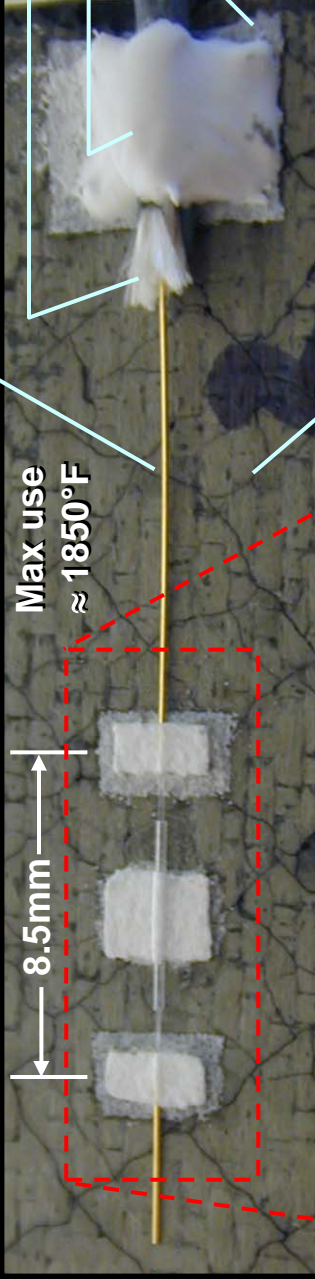


Improved measurement accuracy applying Silica and Sapphire EFPI Technology

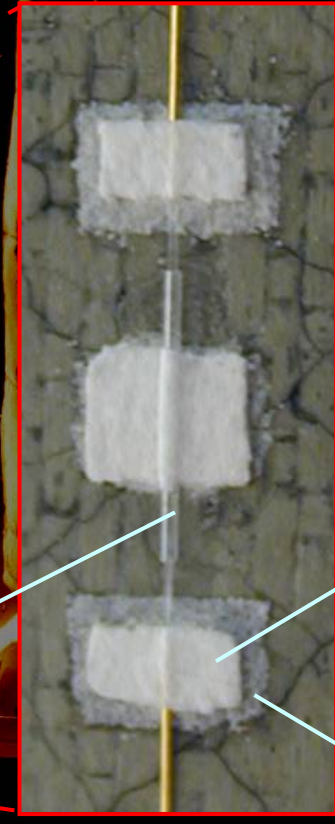
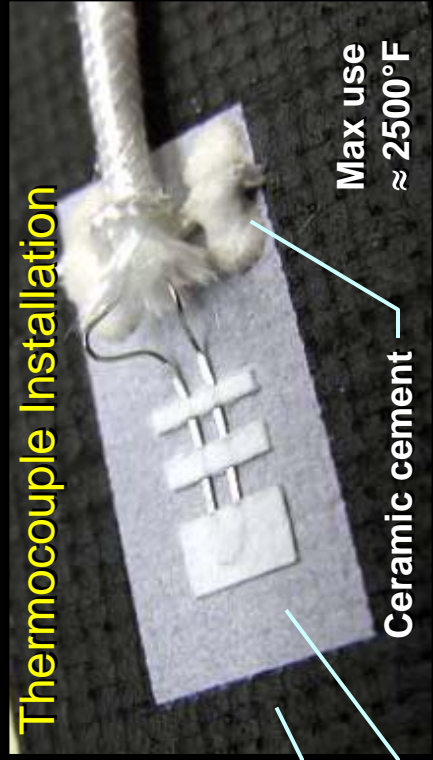


High-Temperature Instrumentation

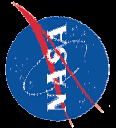
Fiber Optic Strain Sensor Installation



Plasma/Rokide basecoat

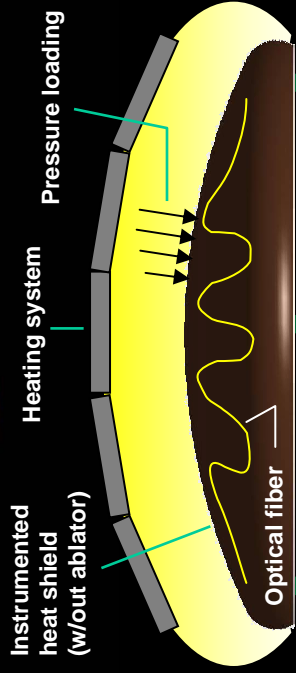


C/SiC

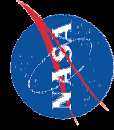
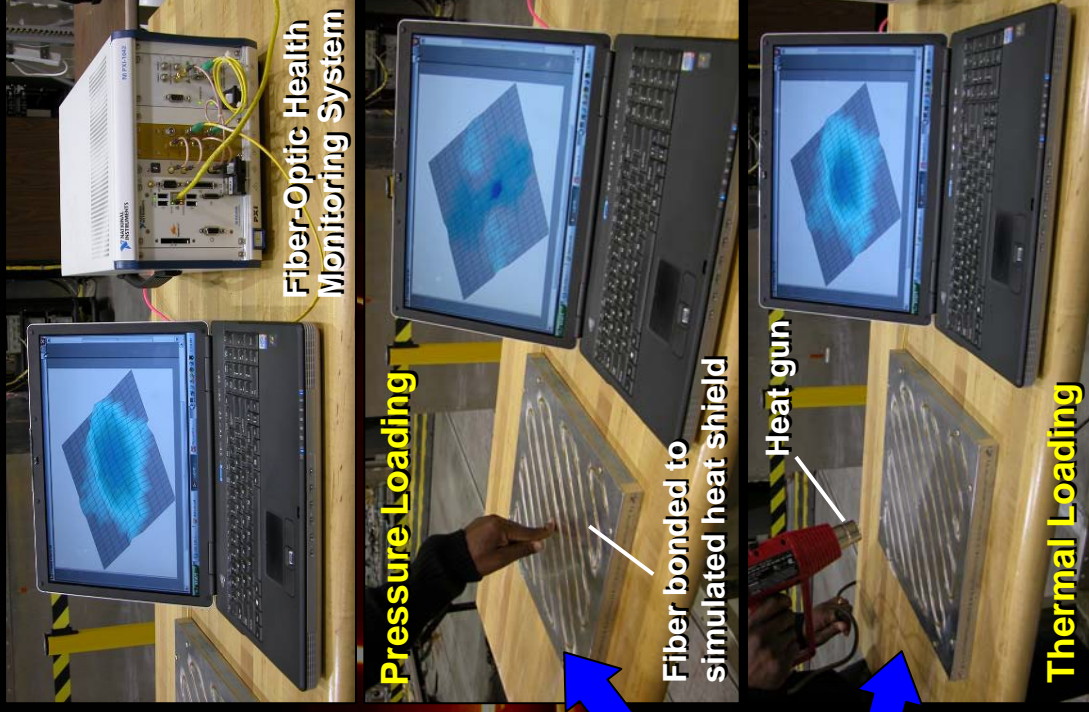


High-Temperature Instrumentation

- ◆ Dryden advanced fiber-optic measurement system for heat shield health monitoring
 - Simultaneous strain and temperature measurements
 - Flight system currently available
 - 480 sensors per optical fiber
 - 2-fiber mode at 35 sps
 - 4-fiber mode at 20 sps
 - Flight testing on Predator B in Sep '07

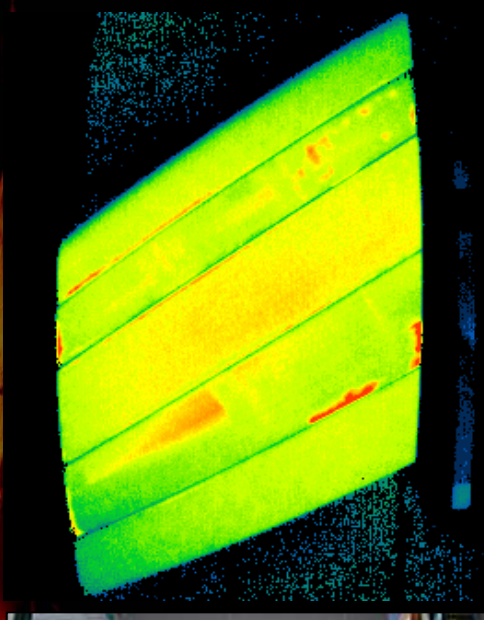
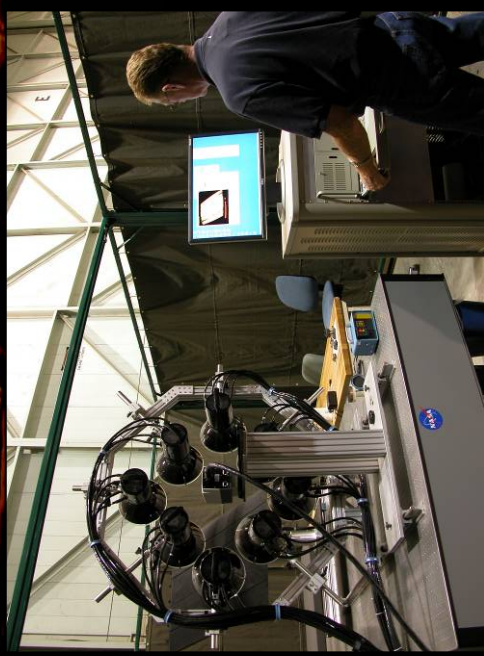


Proposed Ground Validation Test of Heat Shield Health Monitoring System



Hot Structures NDE

- ◆ NDE is an essential part of any hot structures test program
 - Must be able to detect, locate, identify and track defects / damage to fully characterize the hot structure component under test
- ◆ IR Pulsed Thermography NDE for high-temperature composite structures (C/C, C/SiC)
 - Locates and maps material delaminations and porosity
 - Locates precise depth of defect
 - Technique improvements are required to better characterize damage in C/C & C/SiC materials
 - Currently looking to develop standards with engineered defects

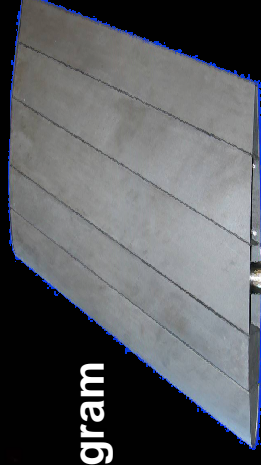


Current Hot Structures Testing

- ◆ **Objective:** Test a C/SiC Ruddervator Subcomponent under relevant thermal, mechanical & dynamic loading
- ◆ **Supports NASA ARMD Hypersonics Material & Structures Program**
- ◆ **Partners:** NASA Dryden, Langley, Glenn, Lockheed-Martin, Materials Research & Design, GE Aviation

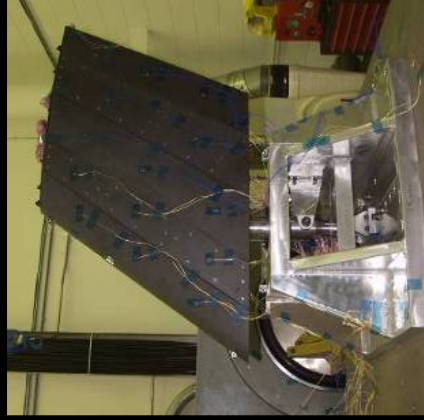
◆ Test Phases

- Phase 1: Acoustic-Vibration Testing (LaRC) – completed
- Phase 2: Thermal-Mechanical Testing (DFRC) – in design / fab
- Phase 3: Mechanical Testing (DFRC) – in design / fab
- Phase 4: Thermal-Acoustic Testing (LaRC) – in design

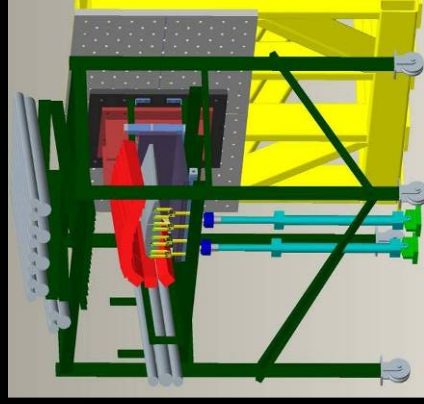


C/SiC Ruddervator Subcomponent

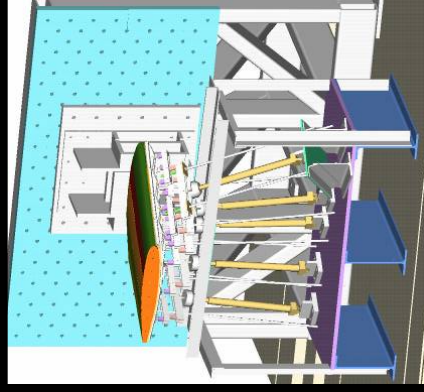
Phase 1



Phase 2



Phase 3



Phase 4



Concluding Remarks

- ◆ **Hot structures are currently finding applications on real vehicles**
- ◆ **Current structural sensing technologies do not meet the peak temperature requirements for hot structure applications**
 - Innovative sensors are needed
 - Advanced sensor attachment techniques are required
 - Sensor characterization and validation is required
- ◆ **Improved NDE techniques and engineered standards are required to better detect and identify damage in C/C & C/SiC materials**
- ◆ **U.S. laboratories must maintain core competencies to effectively meet imminent demands for hot structures testing**

