Thermal-Mechanical Testing of Hypersonic Vehicle Structures

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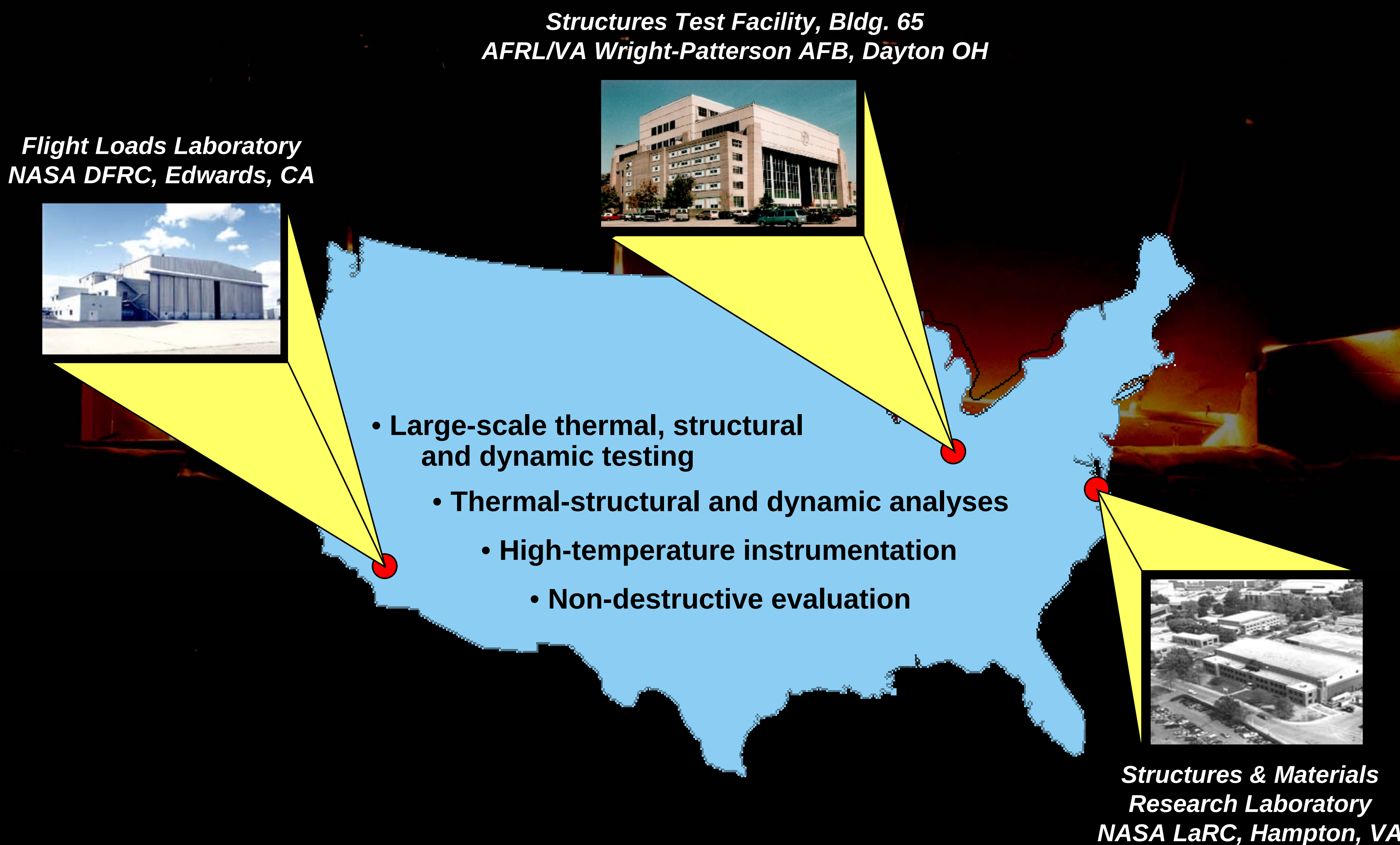
Outline

- 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



NASA Dryden Flight Loads Laboratory

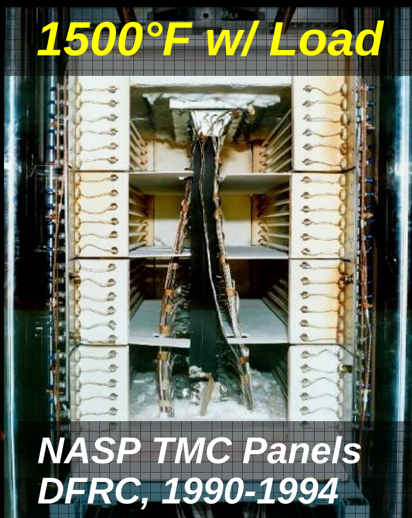
- **General Description**
  - Laboratory for structural and thermal testing of aerospace structures
  - Large high-bay test area (164’ x 120’)
- **Structural Loading Capabilities**
  - Structural loading equipment: load frames, load cells, and hydraulic actuators
  - Aircraft ground vibration and structural 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

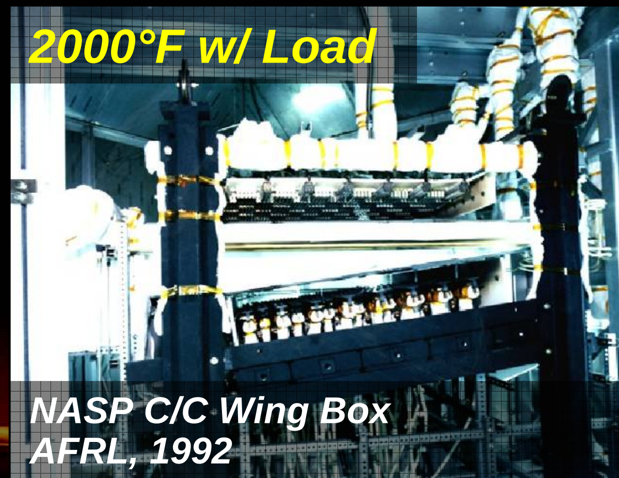
C/C Elevon Thermal/Structural Test

NASA Dryden Flight Loads Laboratory

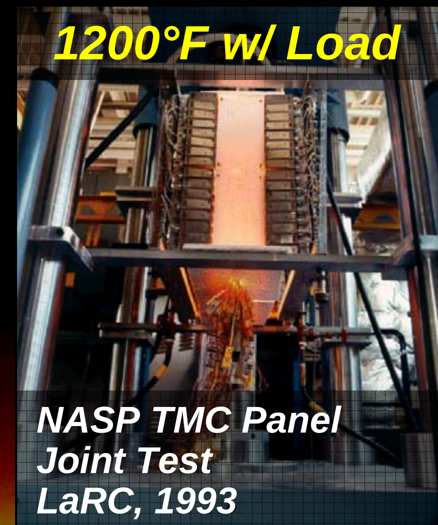
Hot Structures Test Programs (1990's)



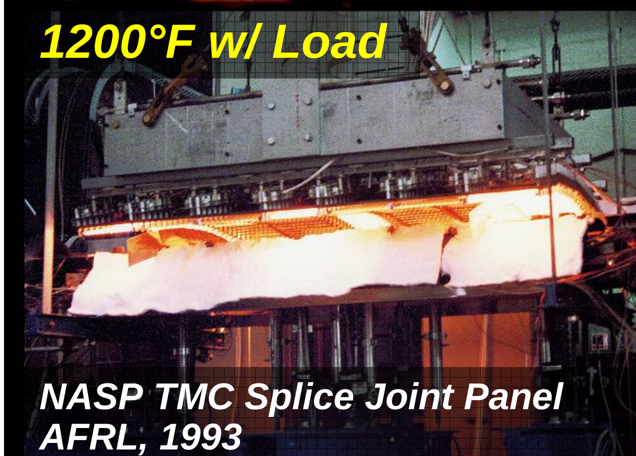
NASP TMC Panels
DFRC, 1990-1994



NASP C/C Wing Box
AFRL, 1992



NASP TMC Panel
Joint Test
LaRC, 1993

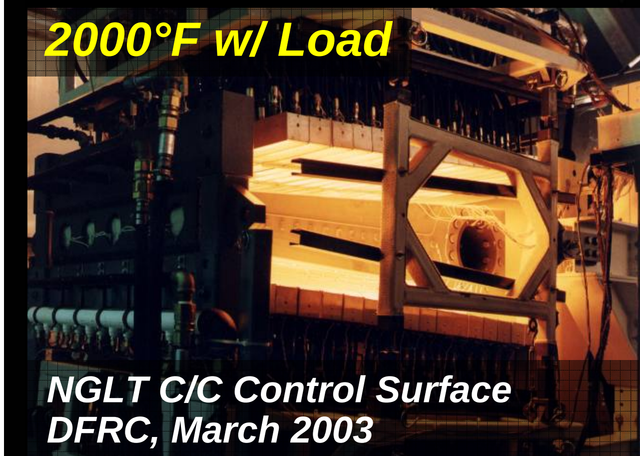


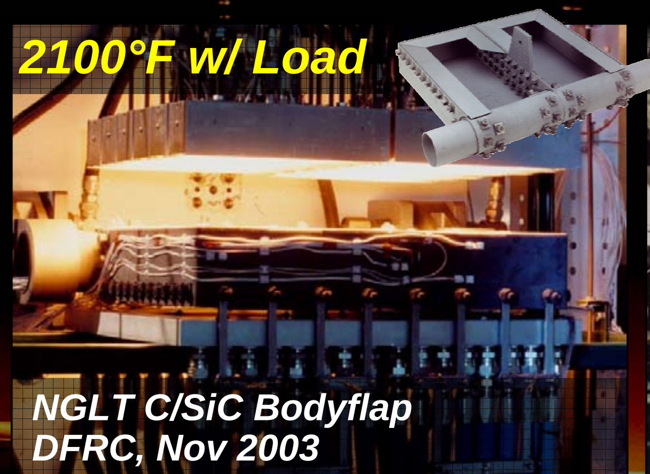
NASP TMC Splice Joint Panel
AFRL, 1993

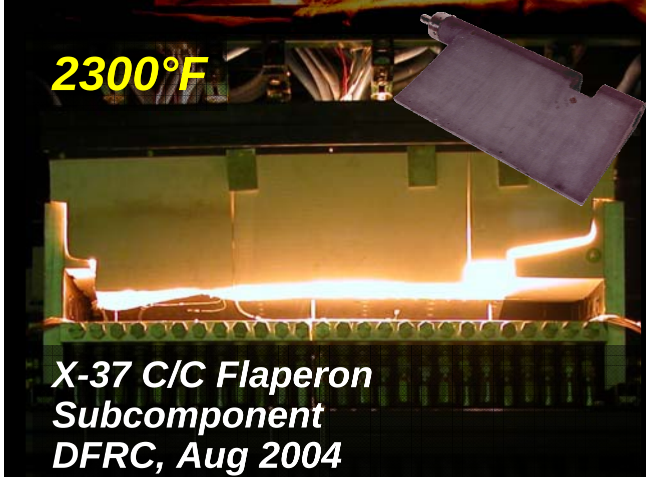
NASP TMC Side Shear Panel
DFRC, 1995

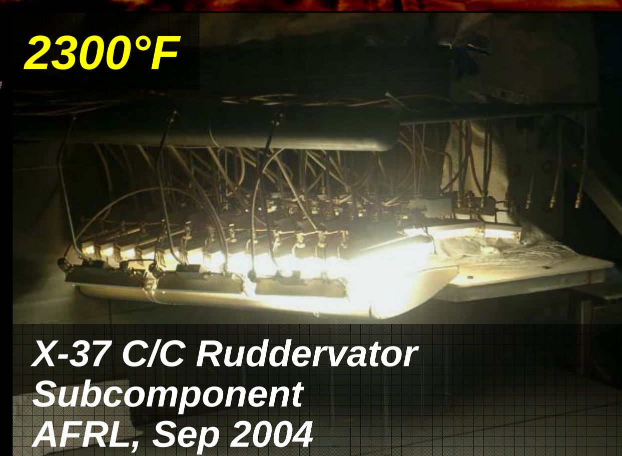
AFRL C/C Wing Box
AFRL, 1999

Hot Structures Test Programs (2000's)



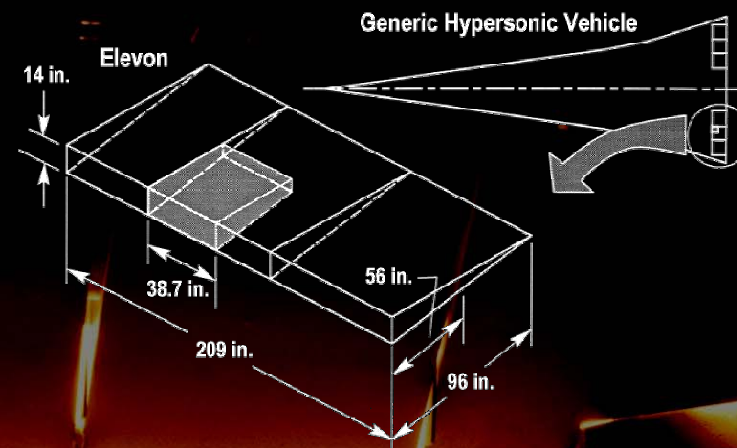


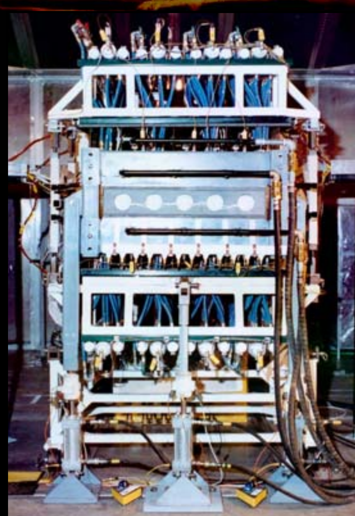


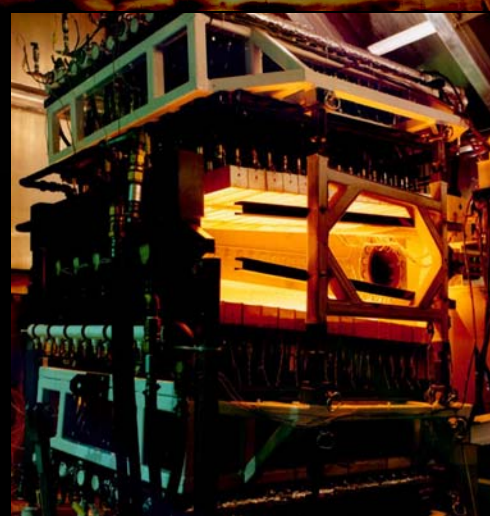


Hot Structures Test Programs

- 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)



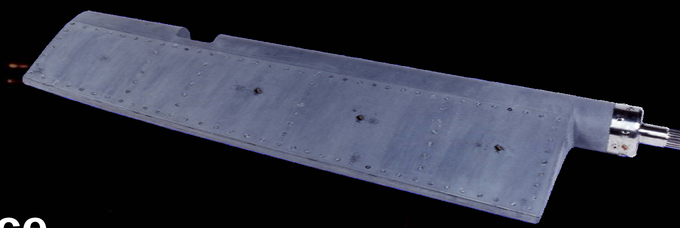




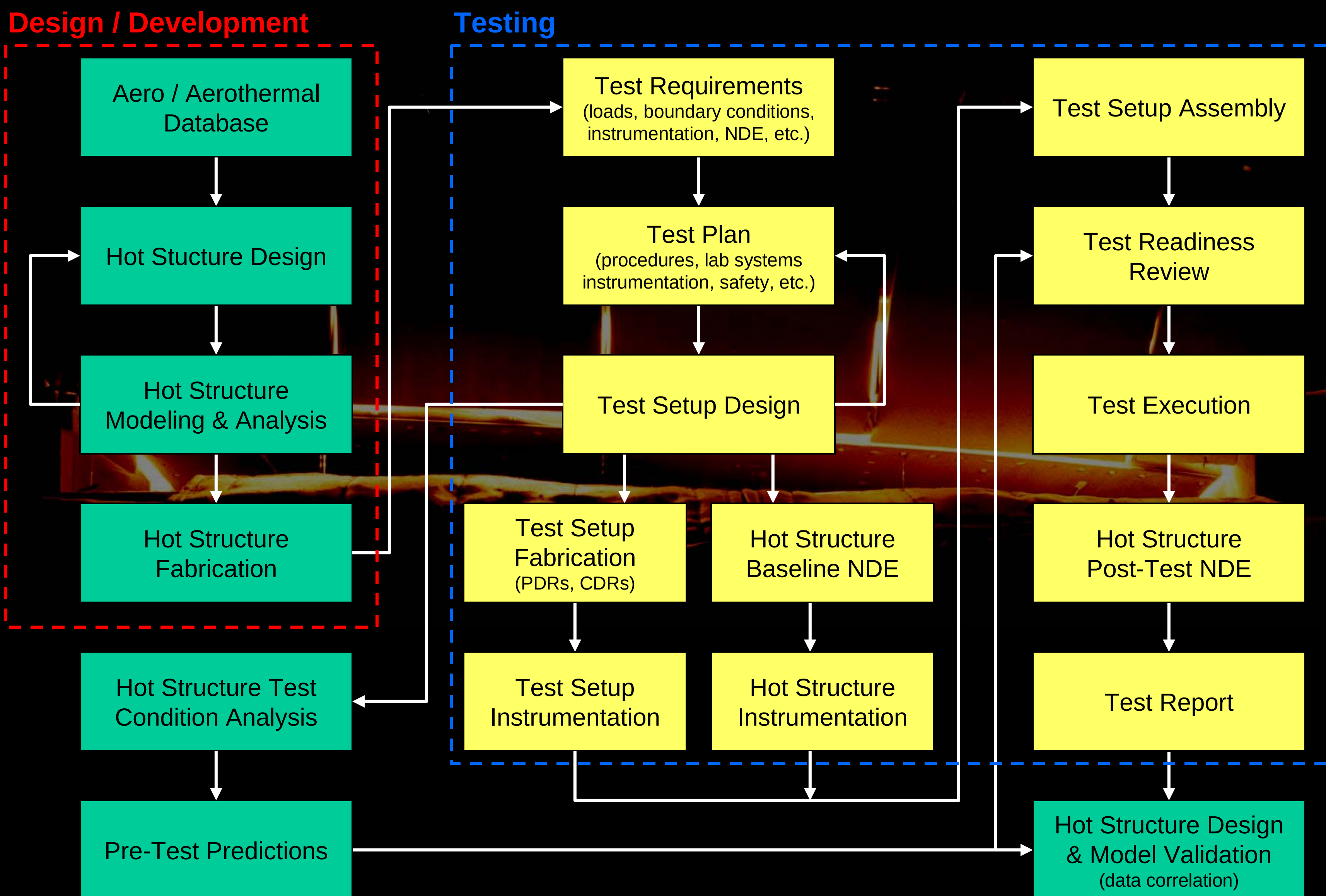
Test at 2000°F & 100% DLL

Hot Structures Test Programs

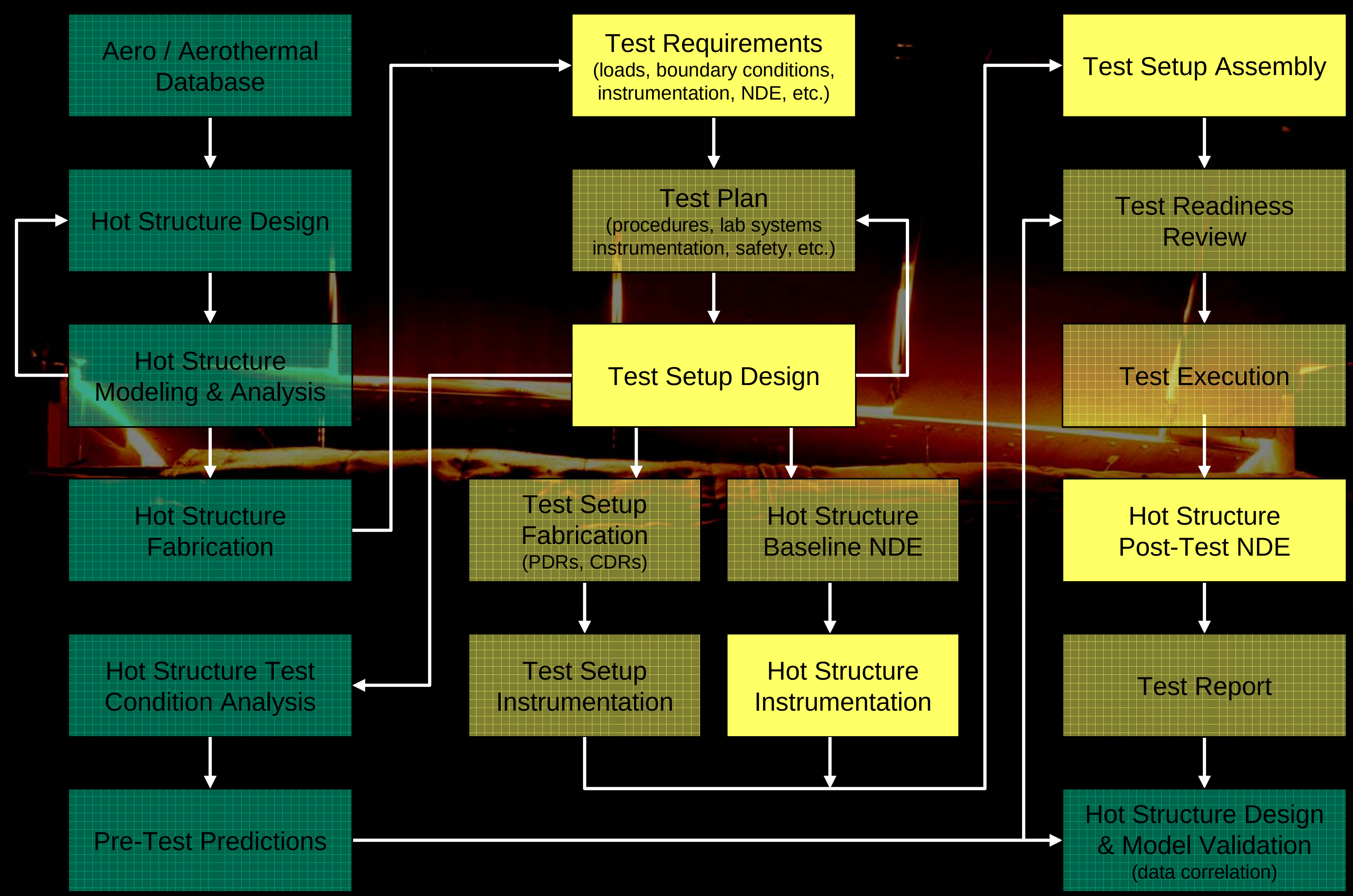
- X-37 Carbon-Carbon Flaperon (2005)
  - Thermal & mechanical qualification test of a flight design C/C hot structure control surface
  - Tested in nitrogen purged atmosphere
  - 35 quartz lamp heaters (18 control zones)
  - Instrumentation
    - 82 thermocouples channels (124 on test setup)
    - 14 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

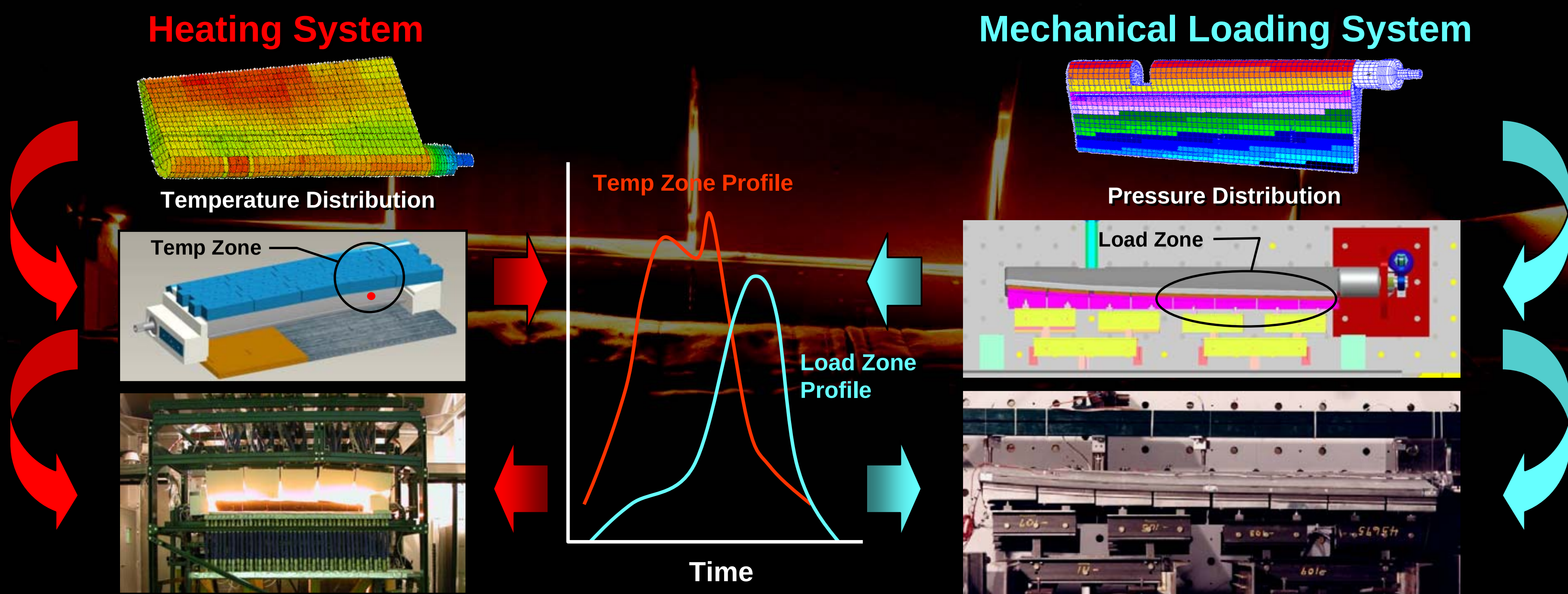


Test Requirements Definition

- 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 O_2)
- Test matrix definition (test sequence)
- Instrumentation (type, number, location)
- Handling requirements
- Inspection requirements
- Documentation requirements

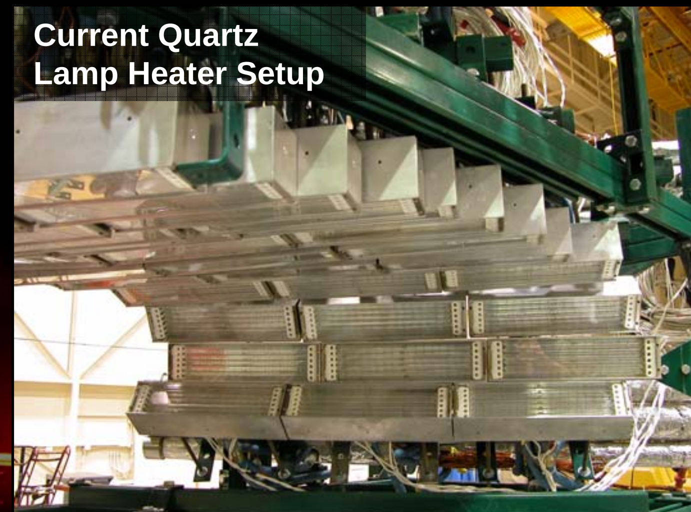
Test Setup Development

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

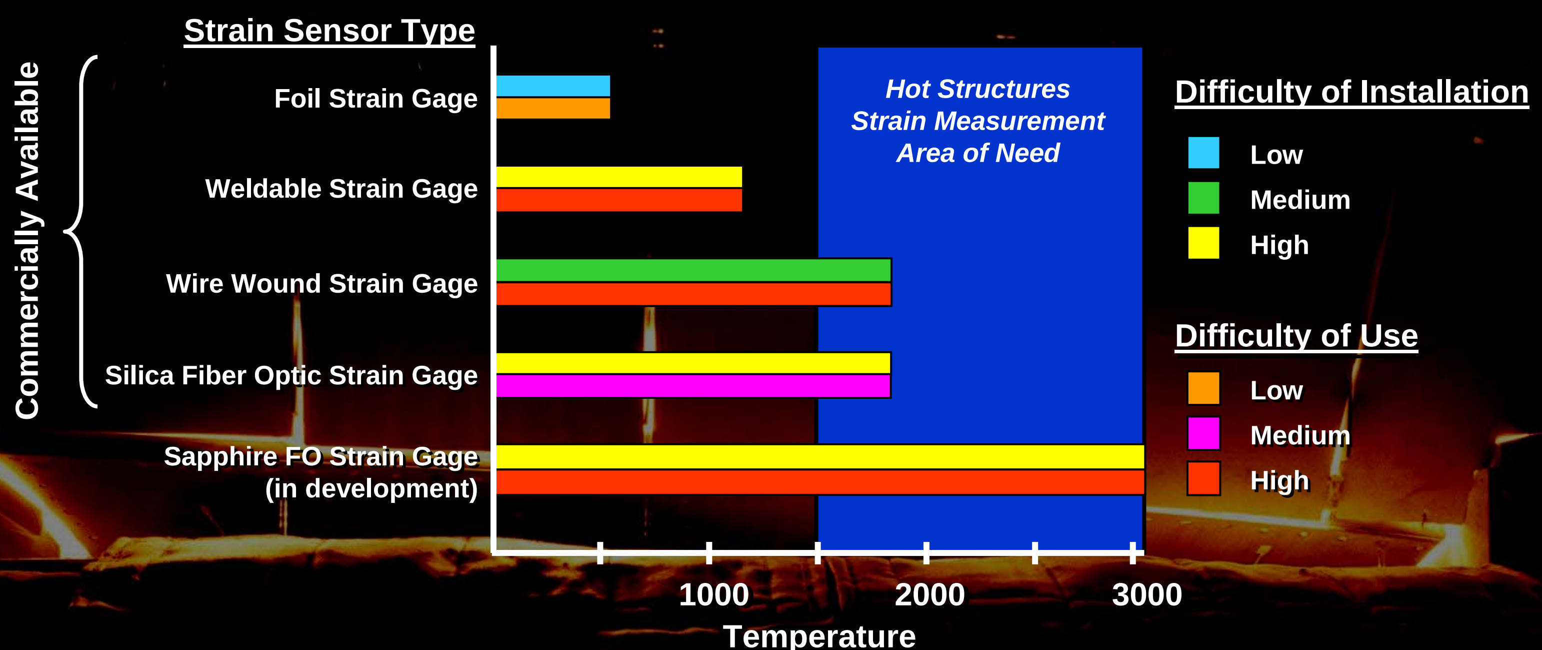


- Perform a test condition analysis to include real boundary conditions
  - Provides more representative pre-test predictions
  - Provides best correlation between test data and analysis

Test Setup Development



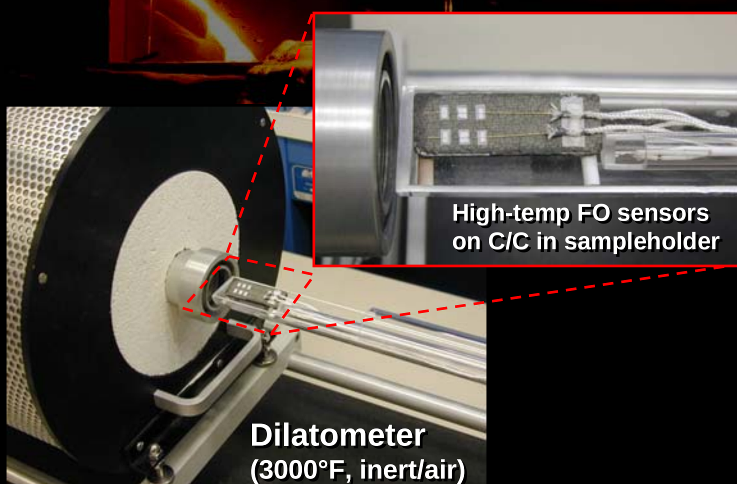
High-Temperature Instrumentation

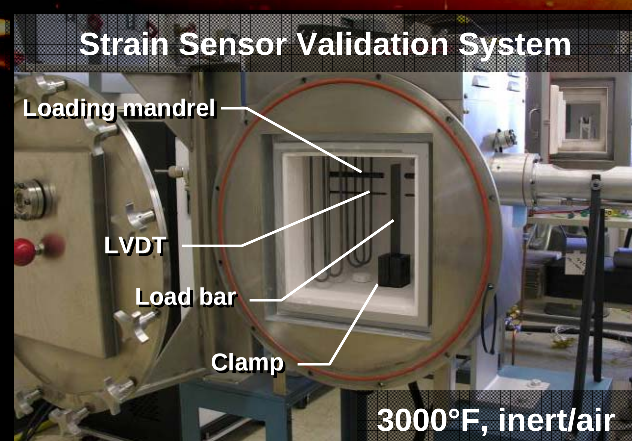


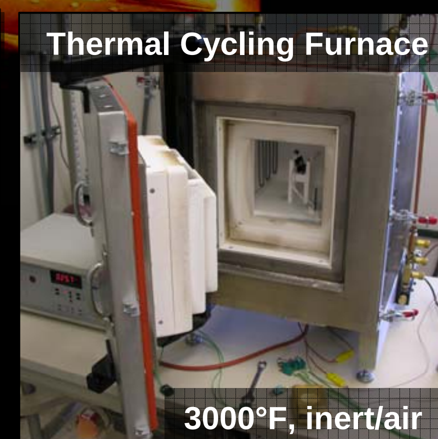
- **Issues**
  - Hot structures are utilizing advanced materials that operate at temperatures that exceed current ability to measure structural performance
  - Robust strain sensors that operate accurately and reliably beyond 1800°F do not exist
- **Implications**
  - Hinders ability to validate analysis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







Typical Systems for Sensor Validation Testing

High-Temperature Instrumentation

Evolution of Hot-Structure Strain Measurements

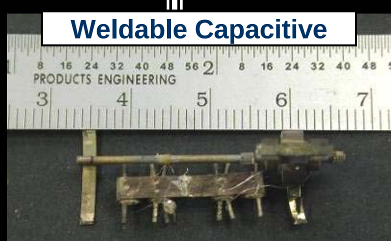
1960-1970 | **1980-1990** | **>2000**

1960-1970

Flame-Sprayed Resistive

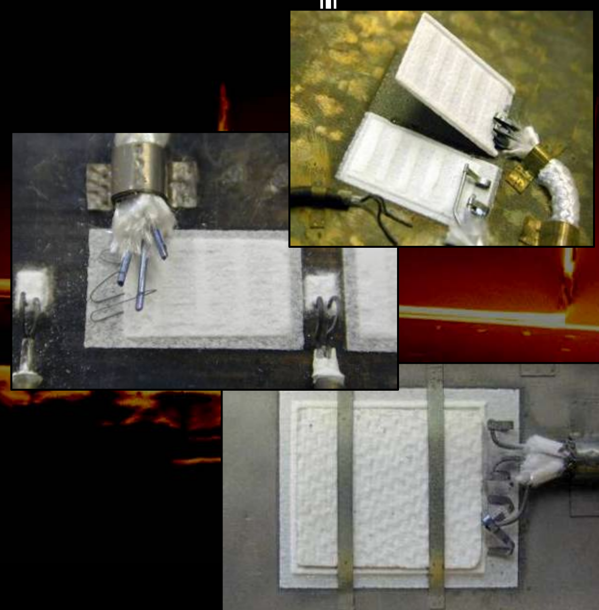
Weldable Resistive

Weldable Capacitive



Large thermal outputs and measurement uncertainties

1980-1990



Improved temperature-compensation using flame-sprayed resistive gages

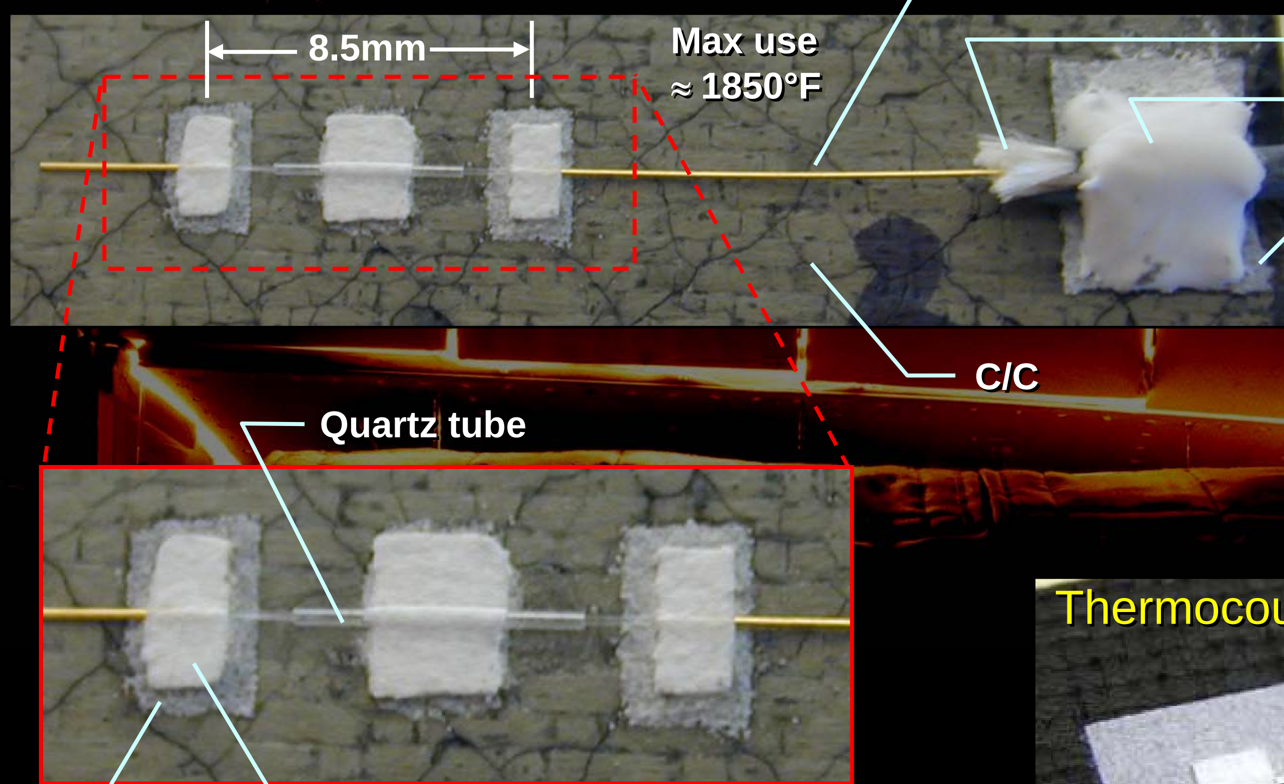
>2000

Fiber-Optic Strain Sensor

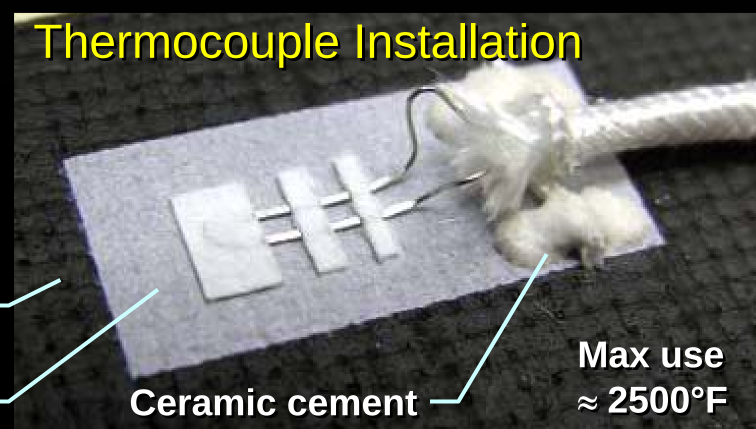
Improved measurement accuracy applying Silica and Sapphire EFPI Technology

High-Temperature Instrumentation

Fiber Optic Strain Sensor Installation

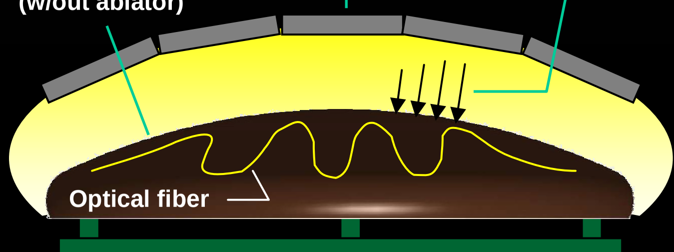


Thermocouple Installation

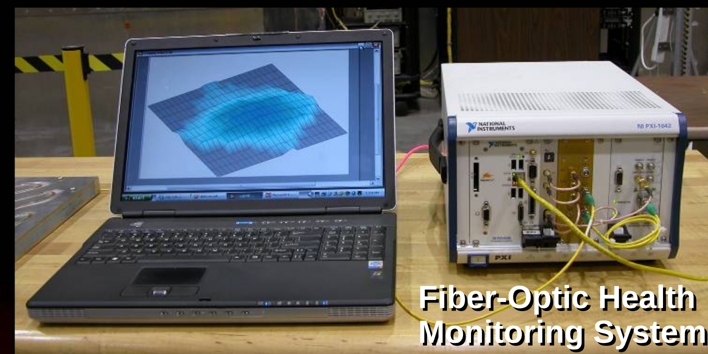


High-Temperature Instrumentation

- 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

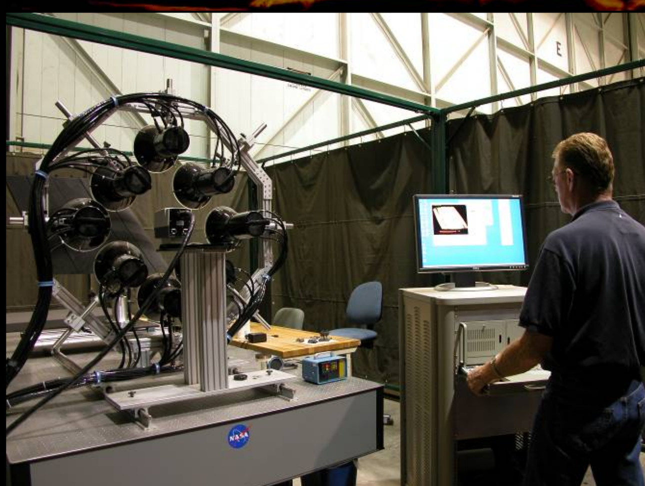


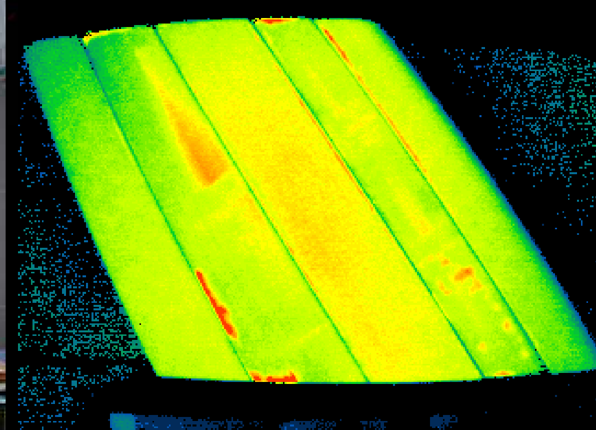
Proposed Ground Validation Test of Heat Shield Health Monitoring System



Hot Structures NDE

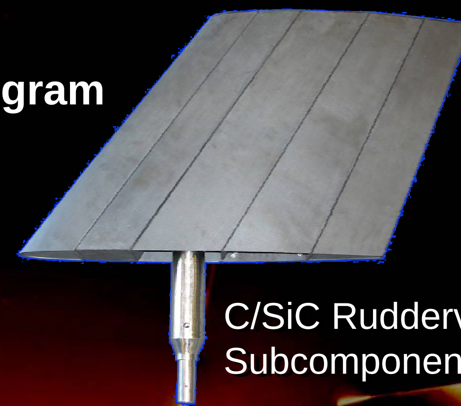
- NDE is an essential part of any hot structures test program
  - Must be able to detect, locate, identify and track defects / damage to fully characterize the hot structure component under test
- IR Pulsed Thermography NDE for high-temperature composite structures (C/C, C/SiC)
  - Locates and maps material 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





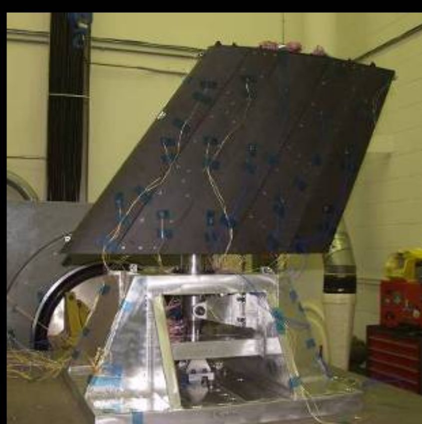
Current Hot Structures Testing

- **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

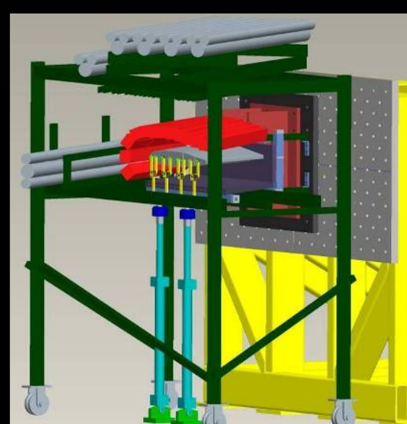


C/SiC Ruddervator Subcomponent

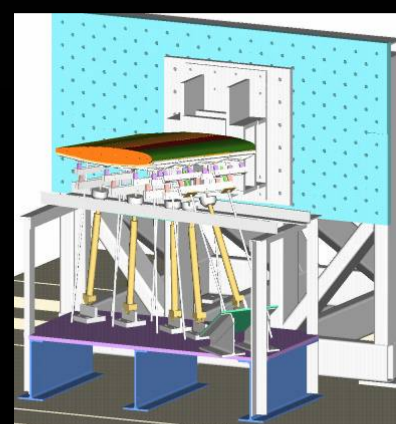
Phase 1



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**