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
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
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)**

- **1600°F w/ Load**: NASP TMC Panel Joint Test LaRC, 1993
- **2250°F w/ Load**: AFRL C/C Wing Box AFRL, 1999
- **1200°F w/ Load**: NASP TMC Panel Joint Test LaRC, 1993
- **1700°F w/ Load**: AFRL C/C Wing Box AFRL, 1999
- **900°F w/ Load**: NASP C/C Wing Box AFRL, 1992
- **2000°F w/ Load**: NASP TMC Side Shear Panel DFRC, 1995
- **1500°F w/ Load**: NASP TMC Panels DFRC, 1990-1994
- **1200°F w/ Load**: NASP TMC Splice Joint Panel AFRL, 1993
Hot Structures Test Programs (2000's)

2400°F w/ Load
X-37 C/SiC Flap Subcomponent
DFRC, May 2004

2300°F
NGLT C/C Control Surface
DFRC, March 2003

2100°F w/ Load
NGLT C/SiC Body Flap
DFRC, Nov 2003

2000°F w/ Load
X-37 C/C Control Surface
DFRC, May 2005

2500°F
X-37 C/C Flap Subcomponent
AFRL, Sep 2004

2300°F
X-37 C/SiC Flap Subcomponent
DFRC, Aug 2004

2200°F
X-37 C/C Ruddervator Subcomponent
AFRL, Sep 2004

2100°F w/ Load
X-37 C/C Flap Subcomponent
DFRC, Aug 2004

2000°F w/ Load
X-37 C/C Flap Subcomponent
DFRC, Aug 2004
**Hot Structures Test Programs**

  - 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

Design / Development

- Aero / Aerothermal Database
- Hot Structure Design
- Hot Structure Modeling & Analysis
- Hot Structure Fabrication
- Hot Structure Test Condition Analysis
- Pre-Test Predictions

Testing

- Test Requirements (loads, boundary conditions, instrumentation, NDE, etc.)
- Test Plan (procedures, lab systems instrumentation, safety, etc.)
- Test Setup Design
- Test Setup Fabrication (PDRs, CDRs)
- Hot Structure Baseline NDE
- Test Setup Instrumentation
- Hot Structure Instrumentation

- Test Setup Assembly
- Test Readiness Review
- Test Execution
- Hot Structure Post-Test NDE
- Test Report
- Hot Structure Design & Model Validation (data correlation)
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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

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**

**Quartz Lamp Heater**
- Tmax ≈ 2700°F
- Aluminum reflector
- Six 2000 W quartz lamps
- Water & gas cooled

**Graphite Heater**
- Tmax ≈ 3200°F

**Current Quartz Lamp Heater Setup**

**Graphite Heater Evaluation Test (3100°F)**
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

- Flame-Sprayed Resistive
- Weldable Resistive
- Weldable Capacitive

1980-1990

- Improved temperature-compensation using flame-sprayed resistive gages
- Improved measurement accuracy applying Silica and Sapphire EFPI Technology

>2000

- Large thermal outputs and measurement uncertainties
- Improved temperature-compensation using flame-sprayed resistive gages
- Improved measurement accuracy applying Silica and Sapphire EFPI Technology

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High-Temperature Instrumentation

Fiber Optic Strain Sensor Installation
- Gold-coated silica fiber (125 micron)
- Nextel overbraid
- Ceramic cement
- Plasma/Rokide thermal sprayed basecoat
- Max use ≈ 1850°F

Thermocouple Installation
- Rokide flame spray
- Plasma spray (2 mils)
- Plasma/Rokide thermal sprayed basecoat
- C/SiC
- Ceramic cement
- Max use ≈ 2500°F
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
Objective: Test a C/SiC Ruddervator Subcomponent under relevant thermal, mechanical & dynamic loading

Supports NASA ARMD Hypersonics Material & Structures Program


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
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