Outline

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Research Objectives

• Evaluate the thermal, structural and dynamic performance of a C/SiC hot-structure component
  – Test under re-entry and hypersonic cruise conditions
  – Acoustic and vibration loading
  – Multi-mission thermal / mechanical cycling
  – Modal survey testing at high temperatures
    • Develop techniques for high-temperature modal survey testing
    • Determine effect of heating on natural frequency and damping response
  – NDE via IR pulsed thermography
    • Identify and track initial defects and damage accumulation throughout testing

• Generate database for use by the technical community
Project Team

- **Overall project management**
- **Thermal, mechanical, & high-temperature modal survey testing**
- **Thermography testing**
- **High-temperature instrumentation**

- **Acoustic, vibration, and modal testing**

- **RSTA thermal-structural analysis**
- **Pre-test predictions & post-test data correlation**

- **RSTA modifications and assembly**
- **Thermography test support**

- **Requirements definition for hypersonics cruise condition testing**
Test Article Description

- C/SiC Ruddervator Subcomponent Test Article (RSTA)
  - Flight-weight truncated full-scale X-37 ruddervator
  - Five C/SiC spar boxes with C/SiC fasteners
  - Inconel 718 spindle with C/SiC torque boxes secured to center spar with Inconel 718 bolts
  - Access panels secured with René 41 screws
Overall Test Plan

• Phase 1: Acoustic and vibration loading to X-37 launch conditions
• Phase 2: Thermal-mechanical testing
  – High-temperature modal survey
  – X-37 re-entry condition with loading to 50% DLL
  – Generic hypersonic cruise condition with loading to 50% DLL
• Phase 3: Mechanical load testing to 100% design limit load
Thermal-Mechanical Testing
Heating and Loading Profiles

X-37 Re-entry

- Higher heating rates over shorter time periods (higher surface temperatures)
- Mechanical loading after peak heating

Generic Hypersonic Cruise

- Lower heating rates over longer time periods (lower surface temperatures)
- Mechanical loading throughout profile
Thermal-Mechanical Testing
Boundary Conditions

- Test in nitrogen purged atmosphere
- Windward and leading-edge surfaces divided into 22 control zones
- Tip and trailing-edge surfaces radiate to chamber
- Leeward and root surfaces radiate to coldplates
- Internal surfaces free to internally radiate
- Internal cavity purged with nitrogen gas
- Spindle constrained axially, radially and rotationally
- Mechanical loads applied via tip loading system
Thermal-Mechanical Testing
Instrumentation

- Fiber optic strain sensors (15)
- Type-K thermocouples (74)
Thermal-Mechanical Testing Instrumentation (cont.)

- High-temperature modal survey instrumentation
  - 14 high-temperature accelerometers (900°F limit)
  - High-temperature force transducer (400°F limit)
Thermal-Mechanical Testing
Overall Test Setup Configuration

Inert Atmosphere Test Chamber

Quartz Lamp Heaters (35)

Heating System

RSTA in Test Chamber for High-Temp Modal Survey Testing
Thermal-Mechanical Testing
High-Temperature Modal Survey Results

• Completed four high-temperature modal survey tests
  – Developed approaches for performing high-temp modal surveys
  – Performed burst random shaking during ramp up and thermal holds

• Exceeded sensing capability of some accelerometers – unable to complete data analysis
Thermal-Mechanical Testing
Re-entry Heating Results

- Successfully applied six re-entry heating thermal cycles (three included loading to 50% DLL during cooldown)
- Typical control performance within 10°F
- Max through-thickness DT »60% of max temp
- Spindle temp reached »60% of max temp
- Bearing temp reached »4% of max temp
Overall good correlation between measured and analytical temperatures for windward and leeward surfaces

Difficulty with correlating spindle area temperatures
Thermal-Mechanical Testing
Re-entry Heating Strain Results

• Overall good thermal cycle repeatability and return to zero for all fiber optic sensors
• Observed repeatable strain shifts in FO101 & FO102 during cooldown
Thermal-Mechanical Testing
Hypersonic Cruise Heating Results

• Successfully applied three hypersonic cruise heating cycles with loading
• Windward surface heated to 70% of re-entry test max temp
• Spindle temp reached »56% of re-entry max
• Outboard bearing reached »6% of re-entry max (slight increase from re-entry test)
Thermal-Mechanical Testing
In-Situ Thermography Setup

- IR thermography for damage detection and tracking initial defects
- In-situ images of the windward, leeward and leading edge surfaces
- Internal surfaces imaged after testing
Thermal-Mechanical Testing
In-Situ Thermography Results

April 2008 (before testing)

March 2009 (after thermal testing)
Mechanical Load Testing
Loading Pad Layout Design

- 100% DLL was applied to the RSTA through pressure loading of the windward surface and tip loading (simulating missing ruddervator section)
- Load pad coverage of windward surface approx. 95%

Load Pad Location Determination from Pressure Load Distribution
Mechanical Load Testing
Loading Profile

Load Rate: 2% DLL per second

Total Up Load

Load to X-37 Re-entry 100% DLL
Thermal-Mechanical Testing
RSTA Strain Gage Instrumentation

- Foil strain gages (31)
  - Leeward surface (12)
  - Windward surface (15)
  - Internal (1)
  - Spindle (3)
Thermal-Mechanical Testing
Deflection Instrumentation

RSTA and Support Fixturing

Spindle and Crank Arm
Thermal-Mechanical Testing
RSTA Boundary Conditions

• Spindle constrained axially, radially and rotationally

• Input Loads
  – Five 2K lbf load cells applying pressure loading to windward surface
  – 5K lbf load cell applying tip load

• Reaction Load
  – 20K lbf load cell measuring reaction load
Mechanical Load Testing
Load Test to 100% DLL Results

- Performed nine load tests to 100% DLL
- No observable decline in structural performance from load cycling
- Excellent repeatability in deflection and strain data
- Noticeable slope change at >60% DLL
Summary

• Completed thermal-mechanical and mechanical load testing
  – 6 re-entry heating tests (3 with loading to 50% DLL), 3 hypersonic cruise tests with loading to 50% DLL and 4 high-temperature modal survey tests
  – 9 tests to 100% DLL

• High-temperature modal survey results were inconclusive due to exceeding capability of some accelerometers

• Overall good correlation between analysis and measured results for windward and leeward surface temperatures

• Generally poor correlation between analysis and measured results for spindle area temperatures

• Excellent test-to-test repeatability in strain and deflection data for 100% DLL testing
Summary

• In-situ thermography images taken before and after thermal testing showed only minor changes in initial defects
  – Final detailed thermography tests scheduled for completion in Oct ‘09

• In process of completing test documentation and test data analysis

• Final reports complete by Dec ’09

• All analysis, test data, test plans, reports, photos, etc. will be made available to the technical community via the CMC Wiki