National Aeronautics and Space Administration

X-37 C/SiC Ruddervator Subcomponent Test Program

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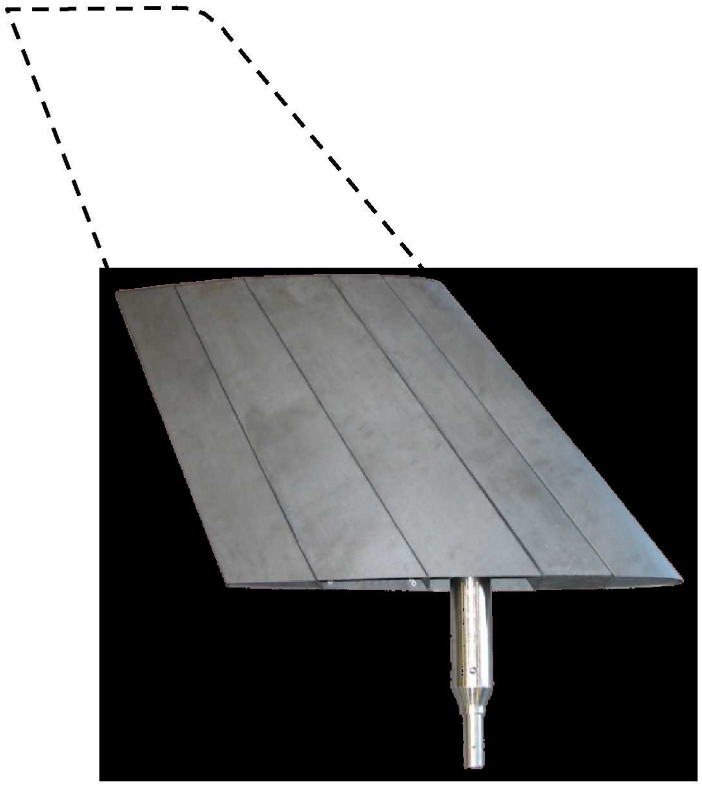
Outline

- Research Objectives
- Project Team
- Test Article Description
- Overall Test Plan
- Thermal-Mechanical Testing
- Mechanical Load Testing
- Summary

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**



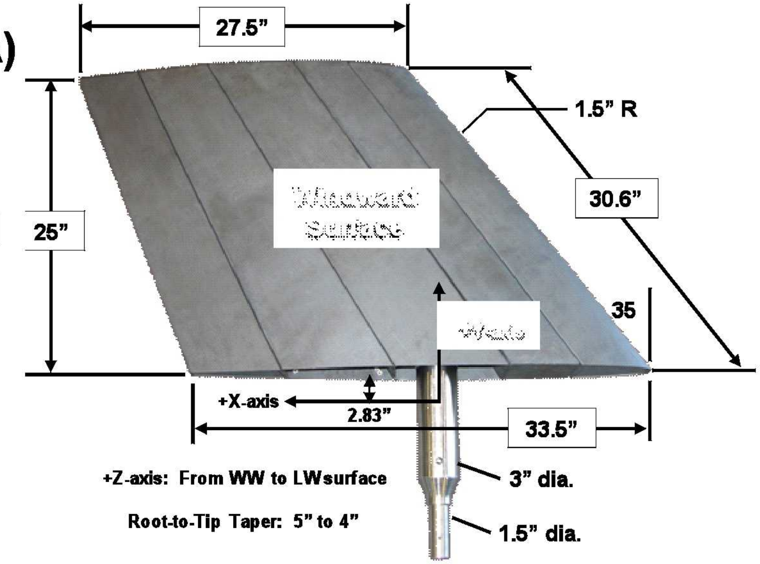
- **Generate database for use by the technical community**

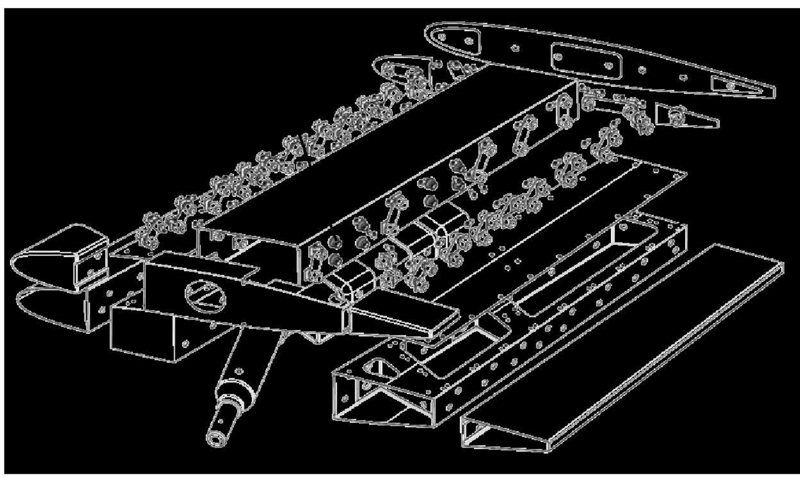
Project Team

NASA Dryden	• Overall project management • Thermal, mechanical, & high-temperature modal survey testing • Thermography testing • High-temperature instrumentation
NASA Langley	• Acoustic, vibration, and modal testing
Materials Research & Design	• RSTA thermal-structural analysis • Pre-test predictions & post-test data correlation
GE CCP GE Research Center	• RSTA modifications and assembly • Thermography test support
LOCKHEED MARTIN	• Requirements definition for hypersonics cruise condition testing

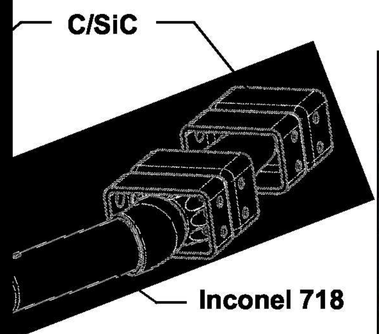
Test Article Description

- **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





Ruddervator Subcomponent Assembly



pindle and Torque Box Assembly

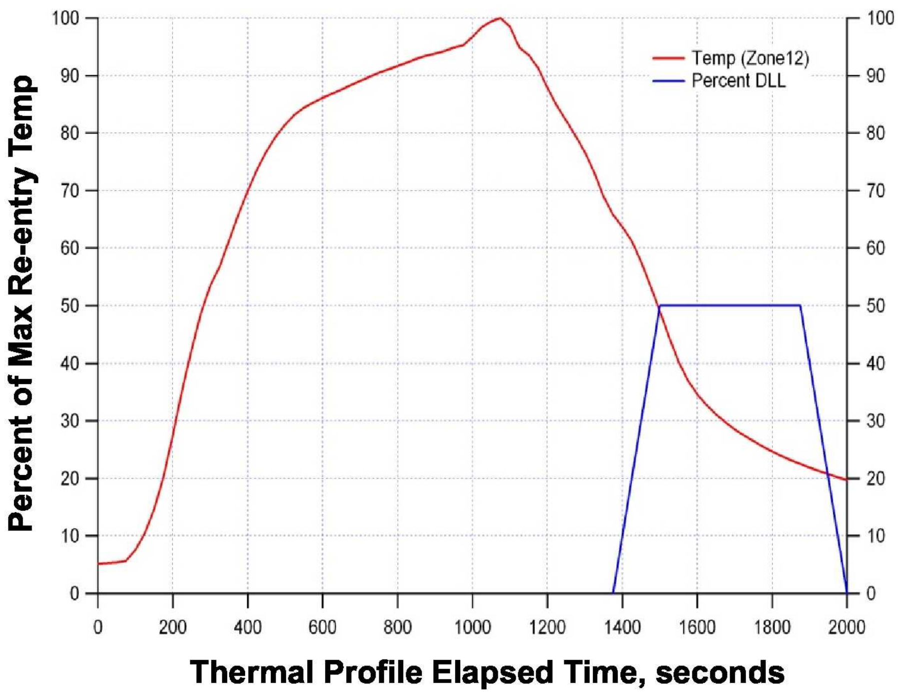
Internal View from Leeward Surface

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**

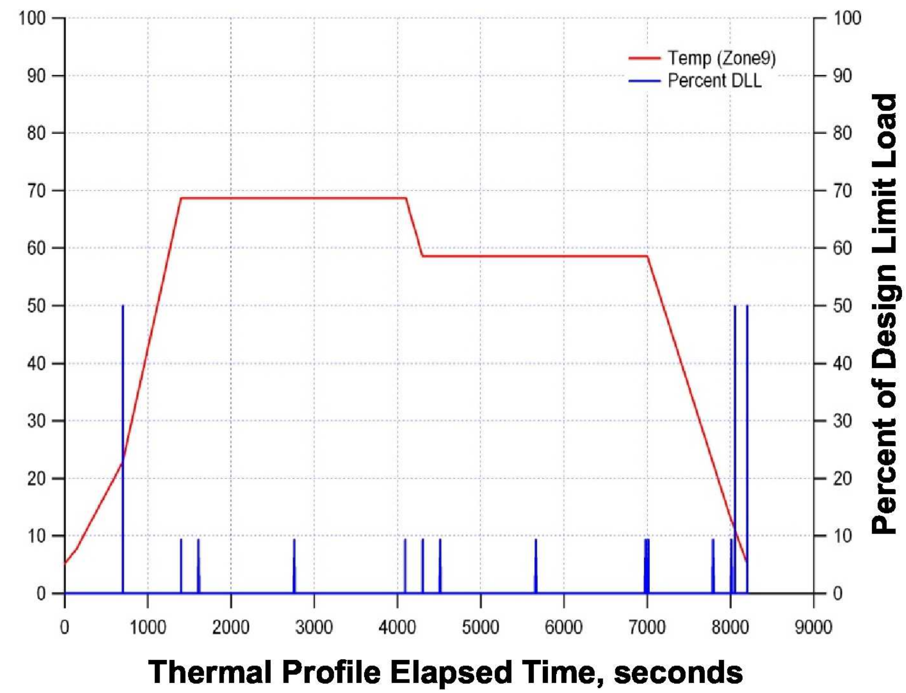
Thermal-Mechanical Testing
Heating and Loading Profiles

X-37 Re-entry



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

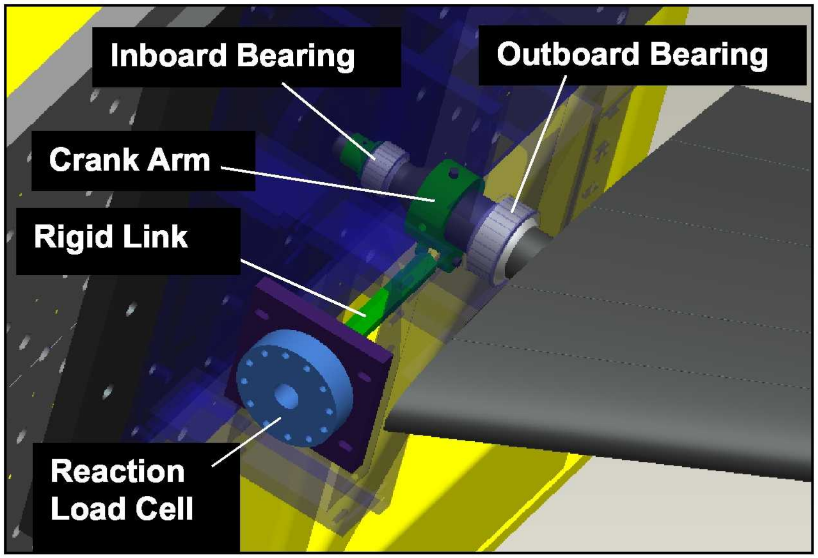
Generic Hypersonic Cruise

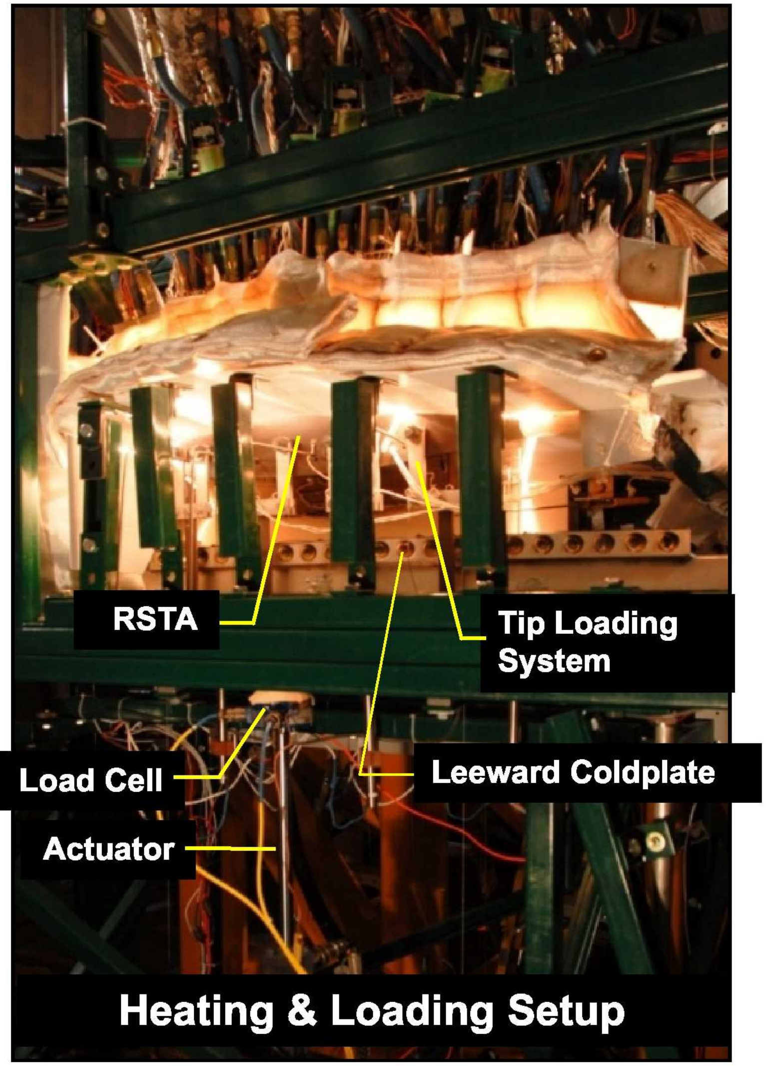


- **Lower heating rates over longer time periods (lower surface temperatures)**
- **Mechanical loading throughout profile**

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

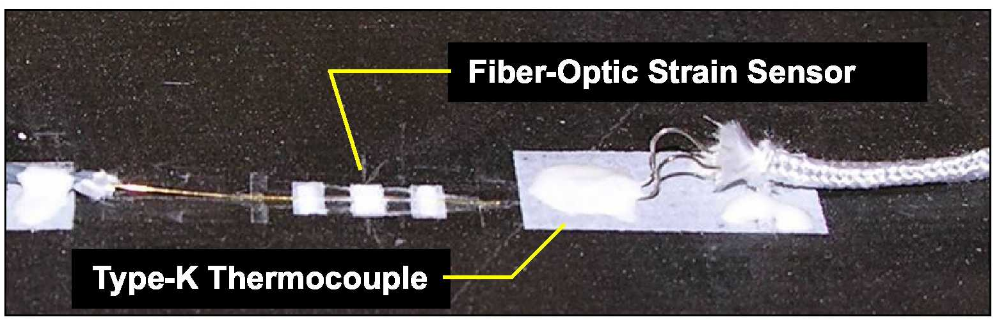


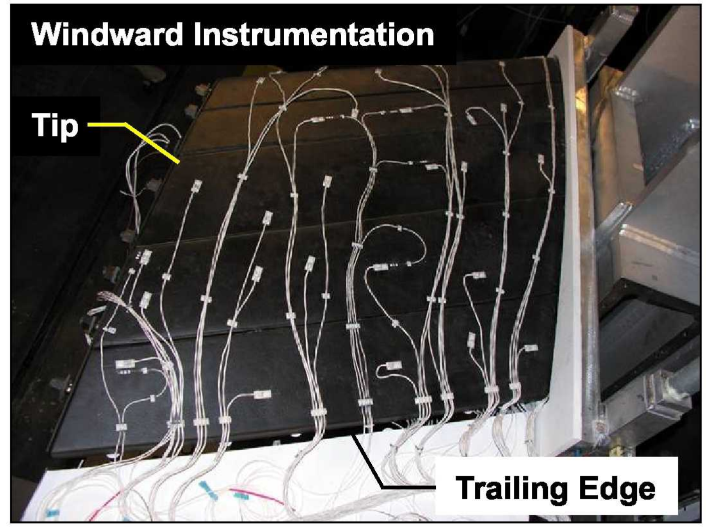


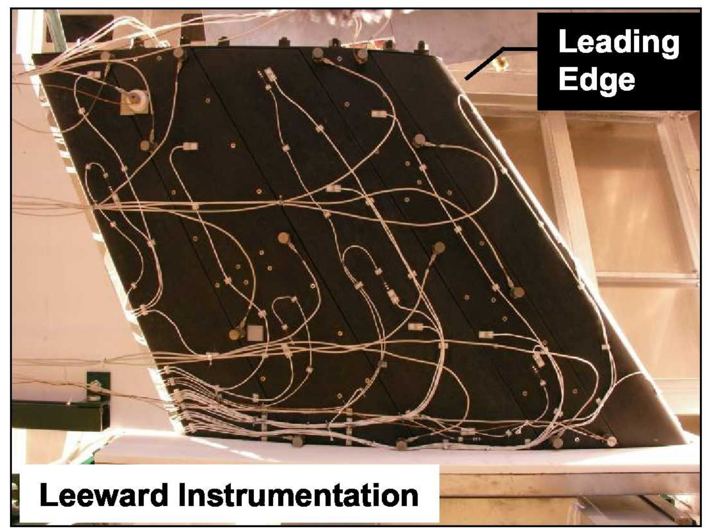
Heating & Loading Setup

Thermal-Mechanical Testing
Instrumentation

- **Fiber optic strain sensors (15)**
- **Type-K thermocouples (74)**

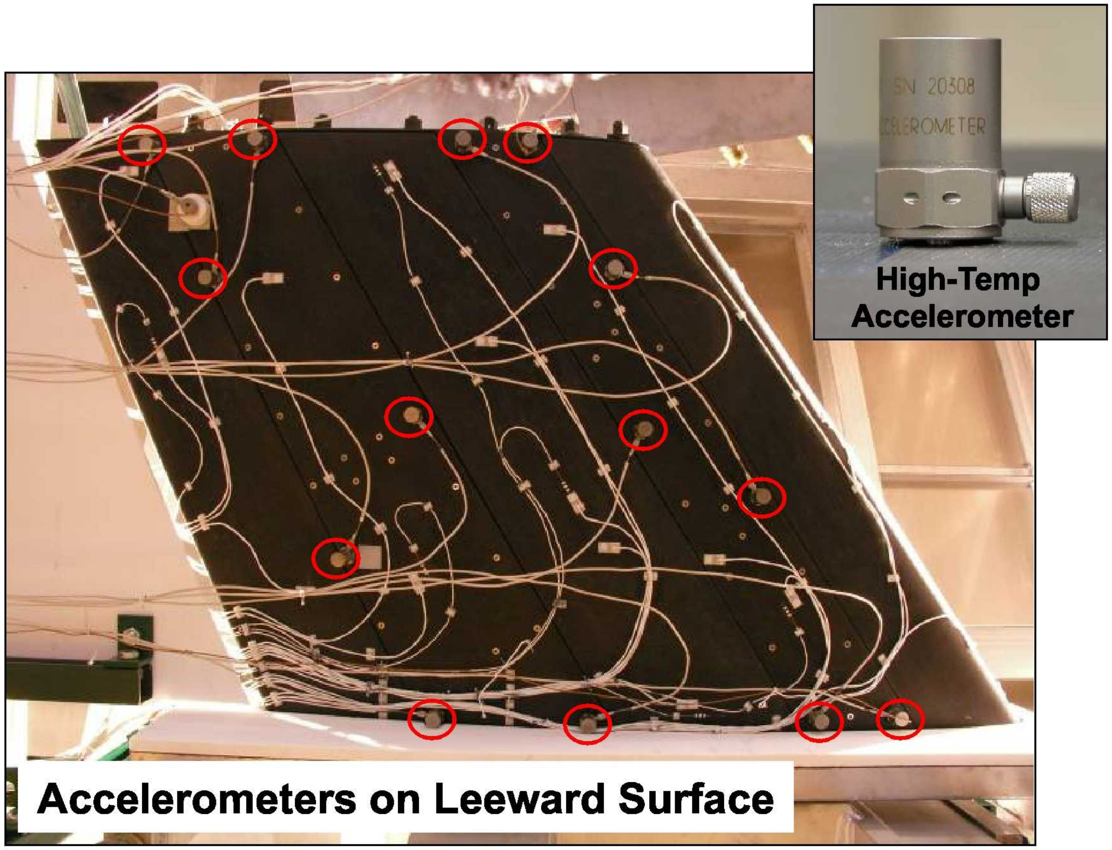






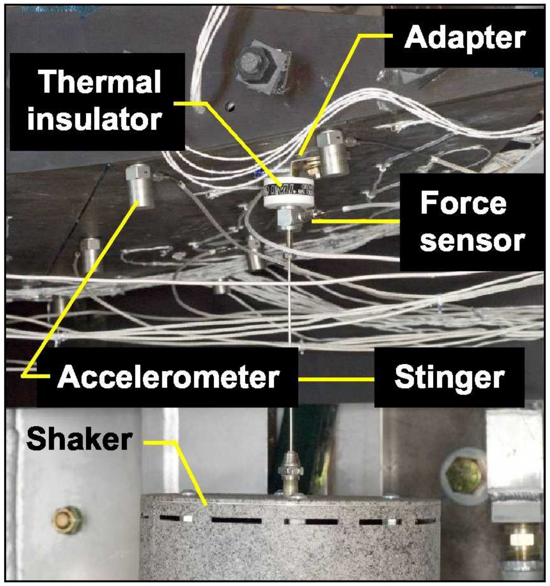
Thermal-Mechanical Testing
Instrumentation (cont.)

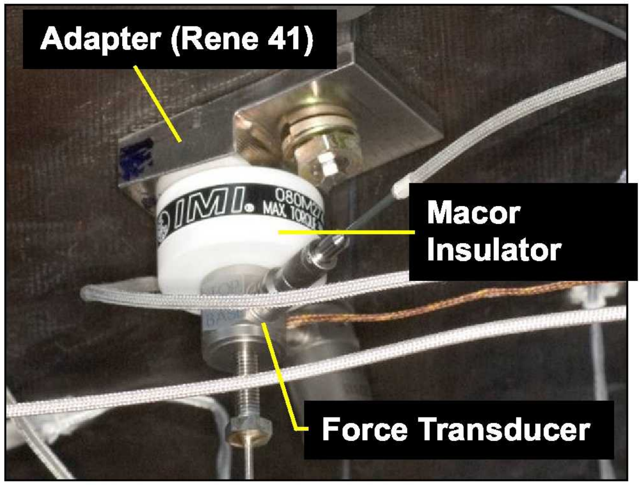
- **High-temperature modal survey instrumentation**
  - 14 high-temperature accelerometers (900°F limit)
  - High-temperature force transducer (400°F limit)



Accelerometers on Leeward Surface

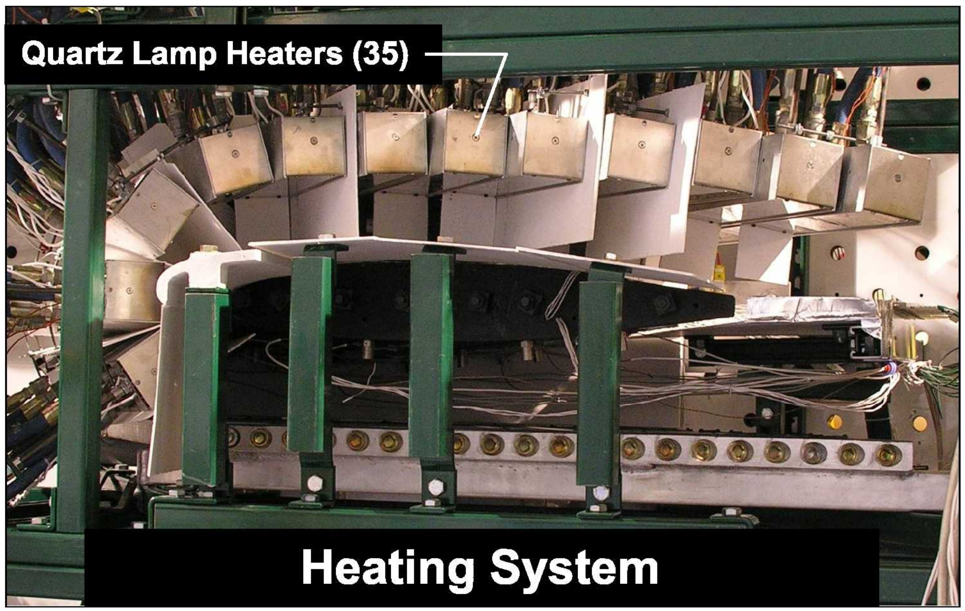
High-Temp Accelerometer

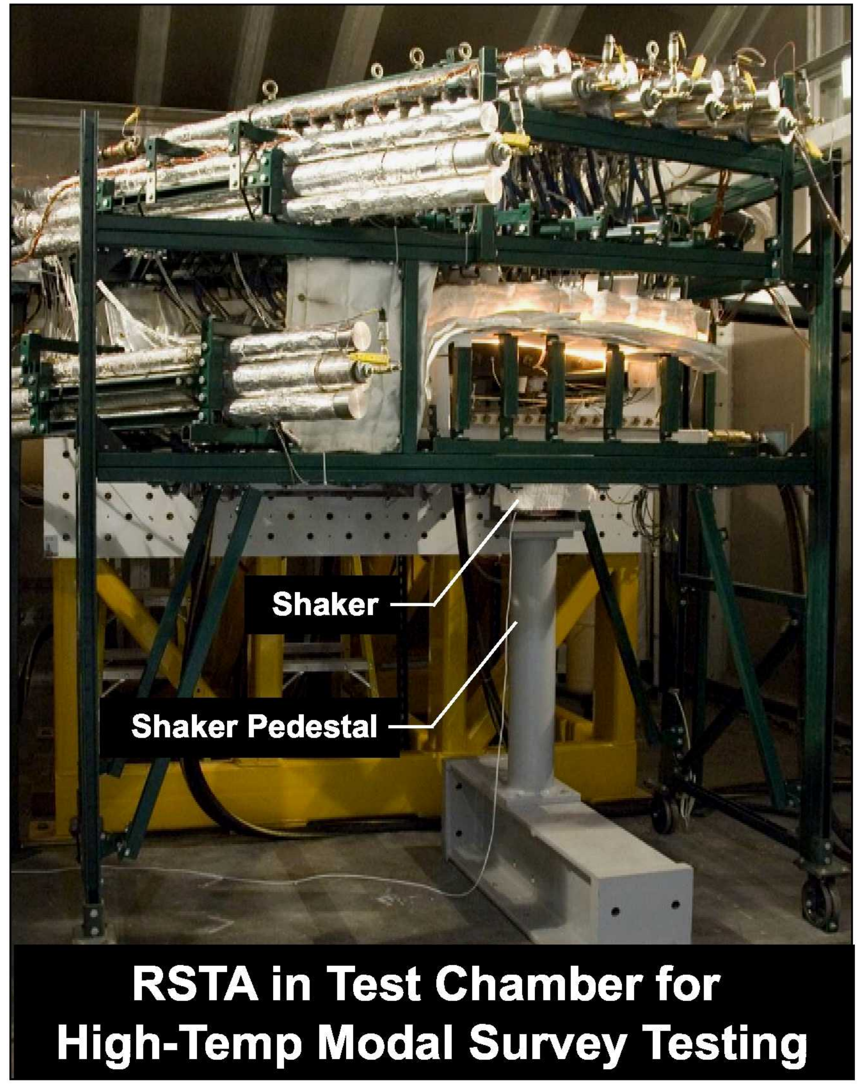




Thermal-Mechanical Testing

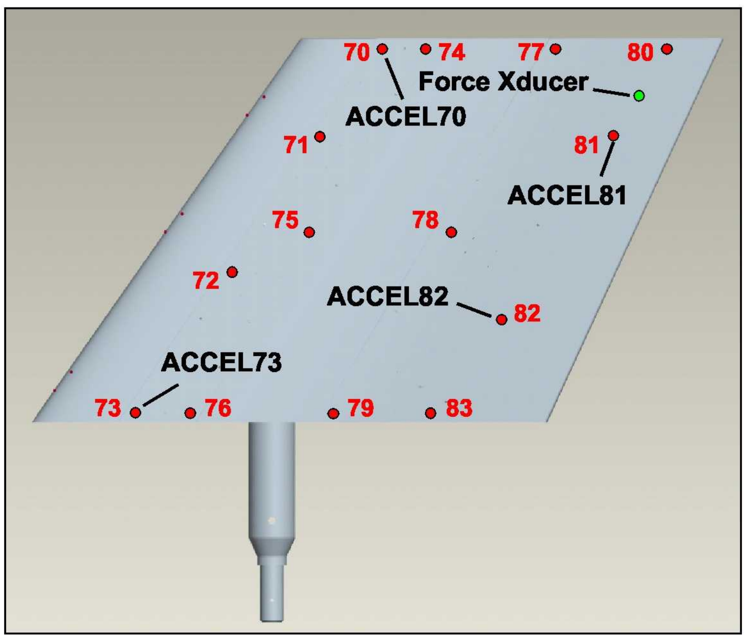
Overall Test Setup Configuration

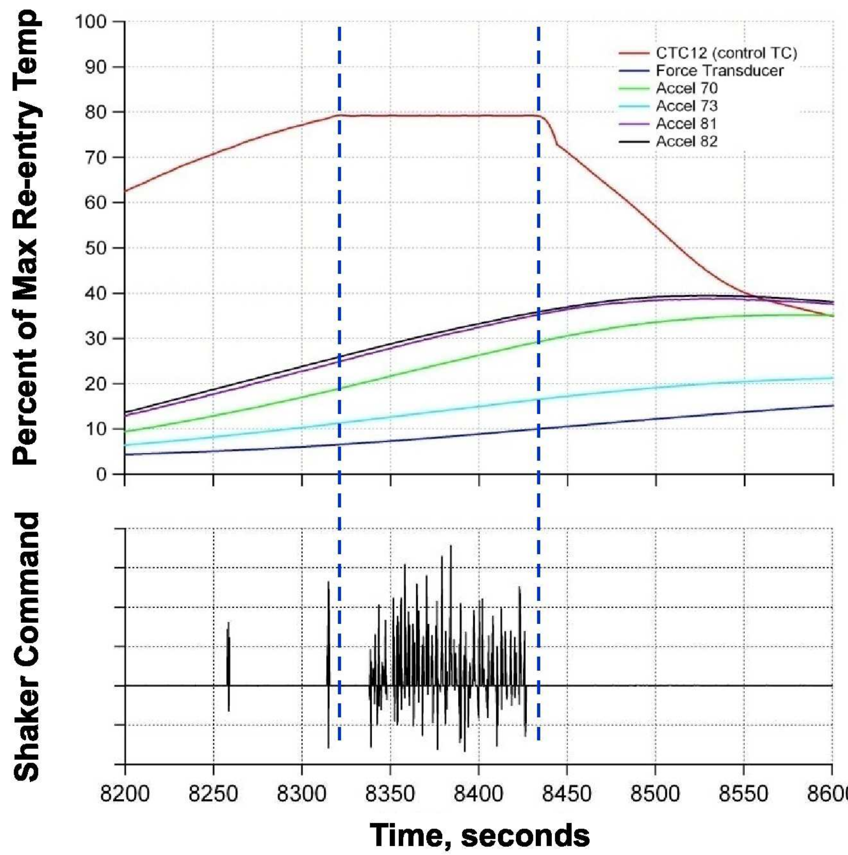




Thermal-Mechanical Testing
High-Temperature Modal Survey Results

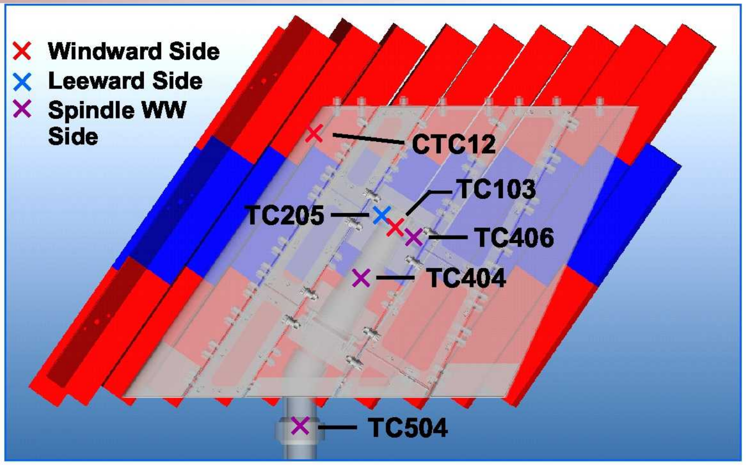
- **Completed four high-temperature modal survey tests**
  - Developed approaches for performing high-temp modal surveys
  - Performed burst random shaking during ramp up and thermal holds
- **Exceeded sensing capability of some accelerometers – unable to complete data analysis**

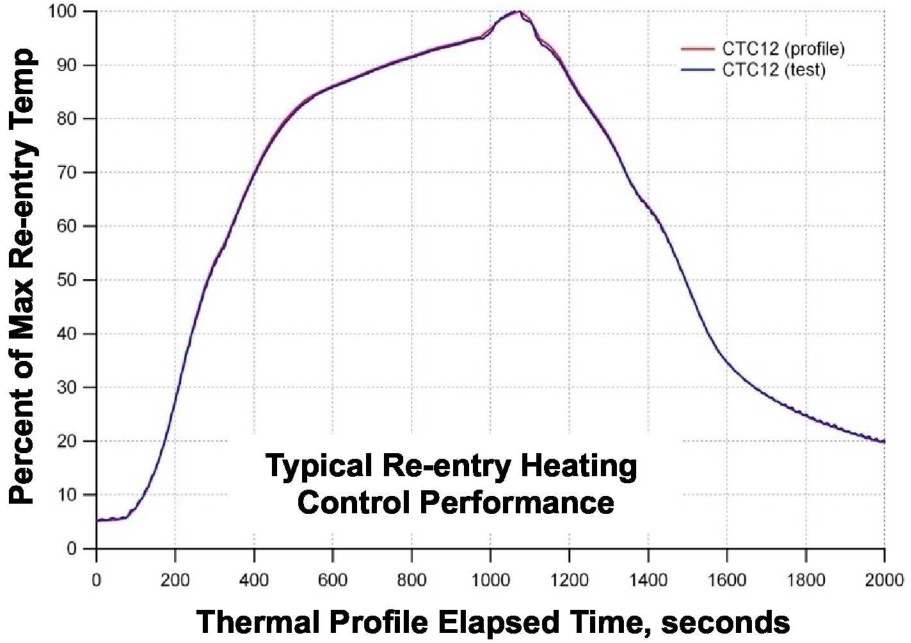


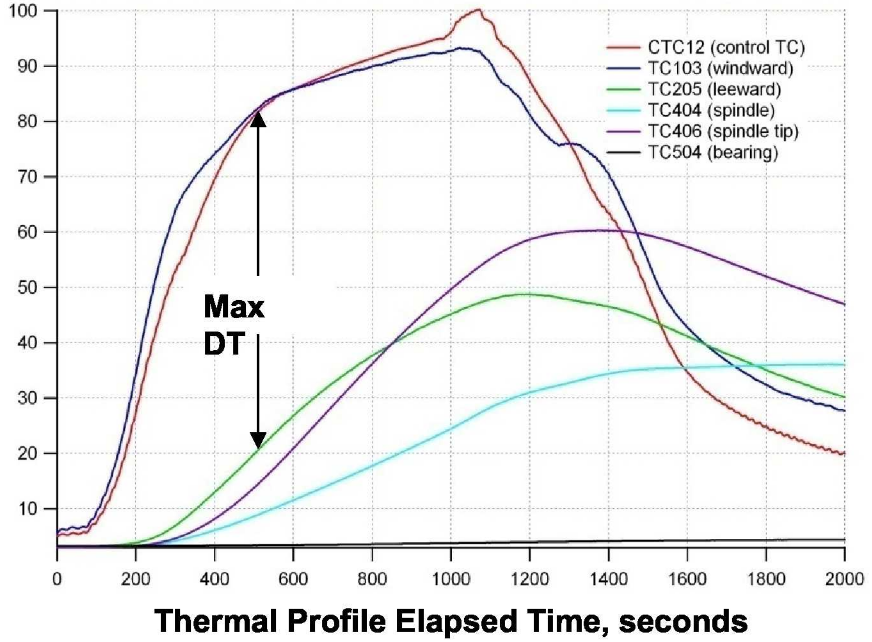


Thermal-Mechanical Testing
Re-entry Heating Results

- 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

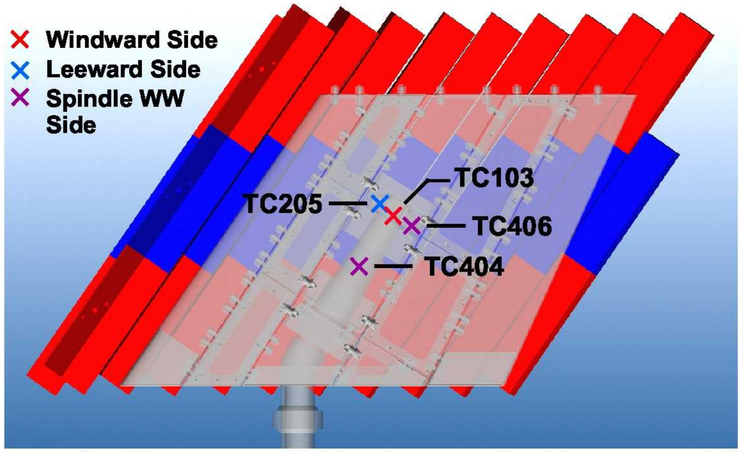


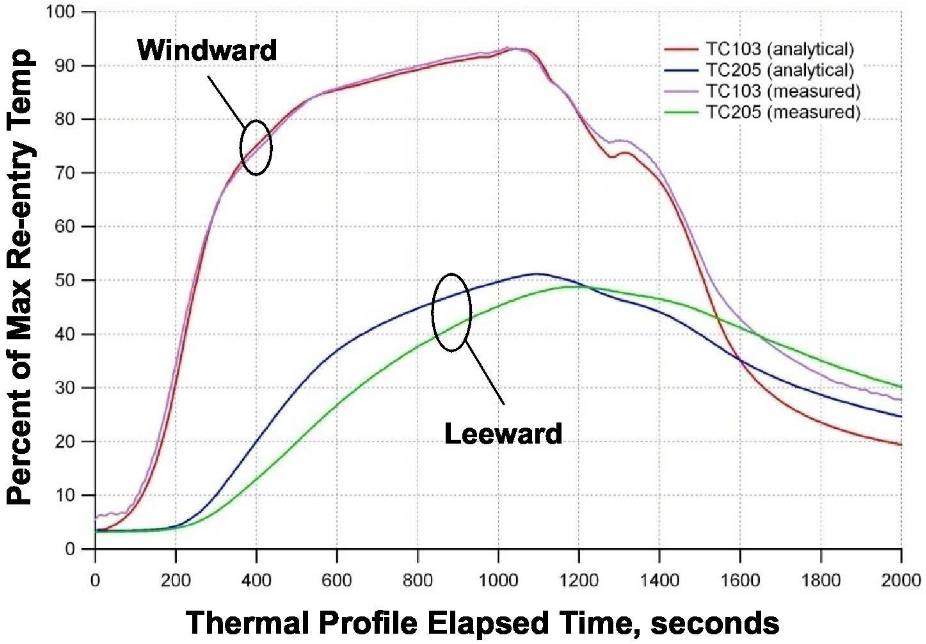


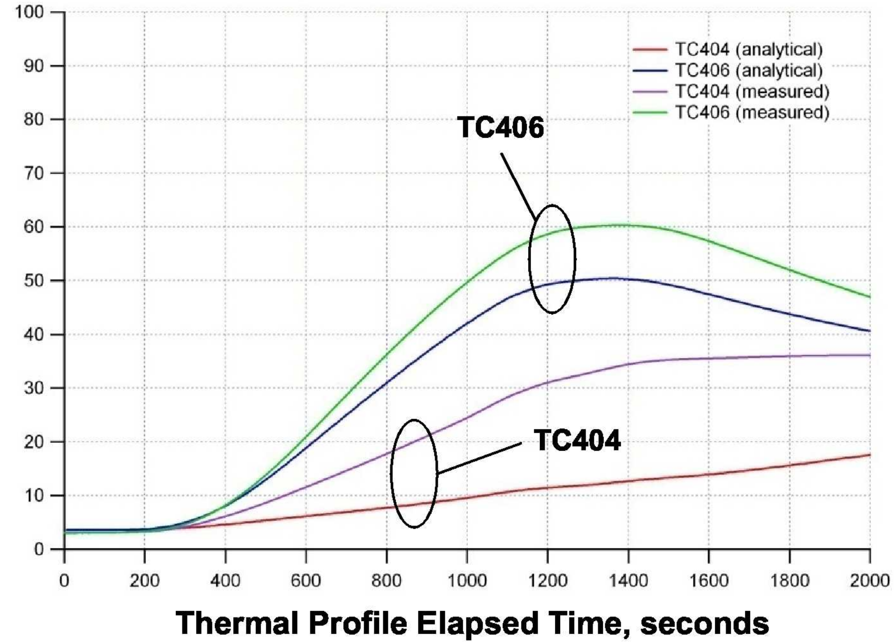


Thermal-Mechanical Testing
Re-entry Heating Comparisons to Analysis

- **Overall good correlation between measured and analytical temperatures for windward and leeward surfaces**
- **Difficulty with correlating spindle area temperatures**

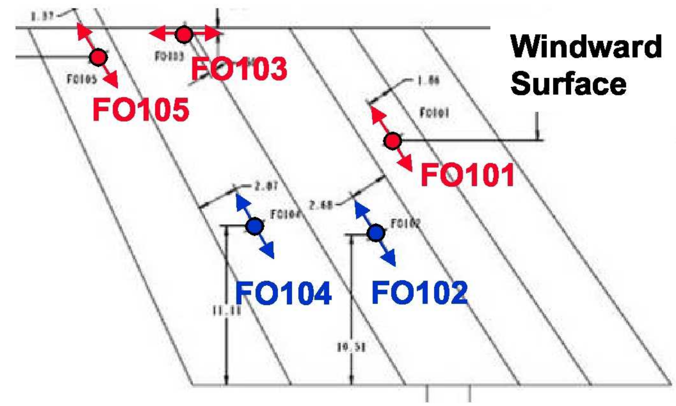


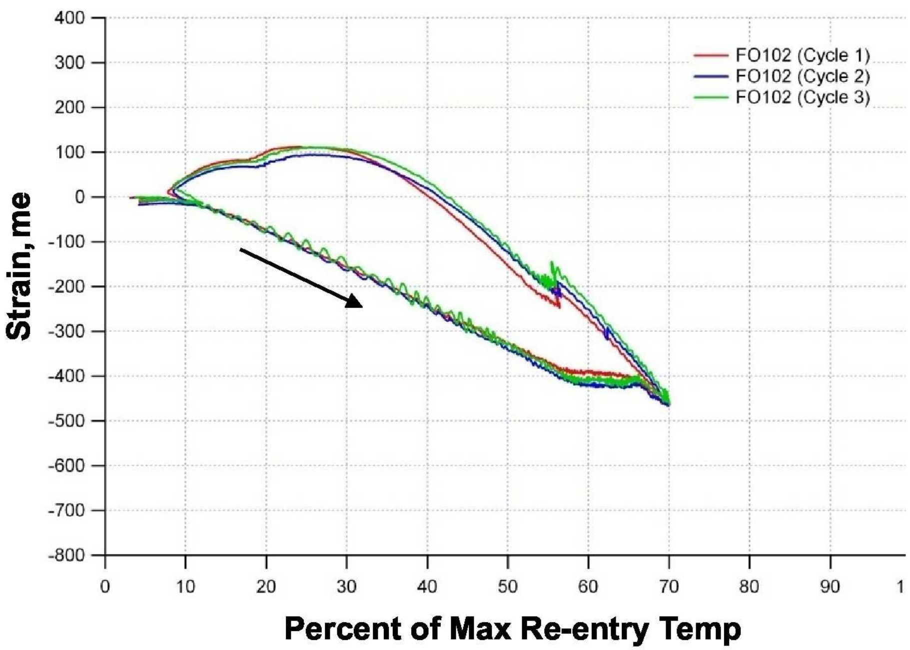


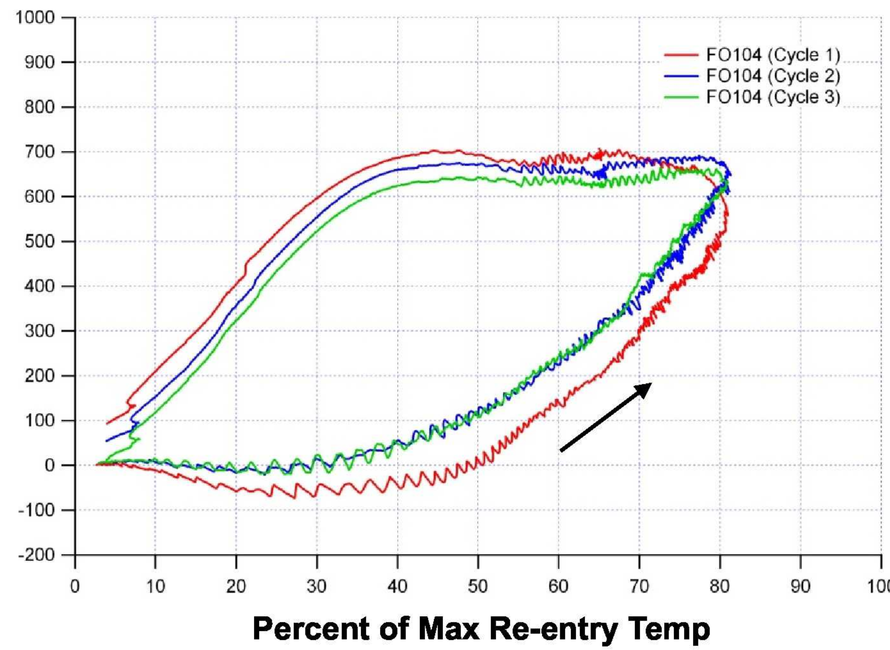


Thermal-Mechanical Testing
Re-entry Heating Strain Results

- **Overall good thermal cycle repeatability and return to zero for all fiber optic sensors**
- **Observed repeatable strain shifts in FO101 & FO102 during cooldown**

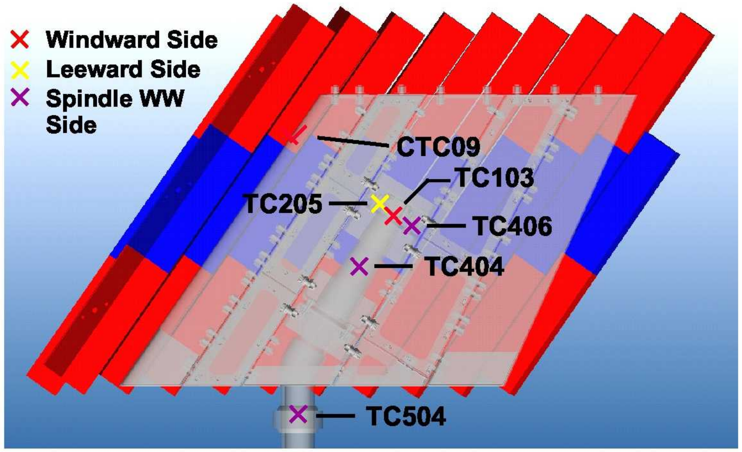


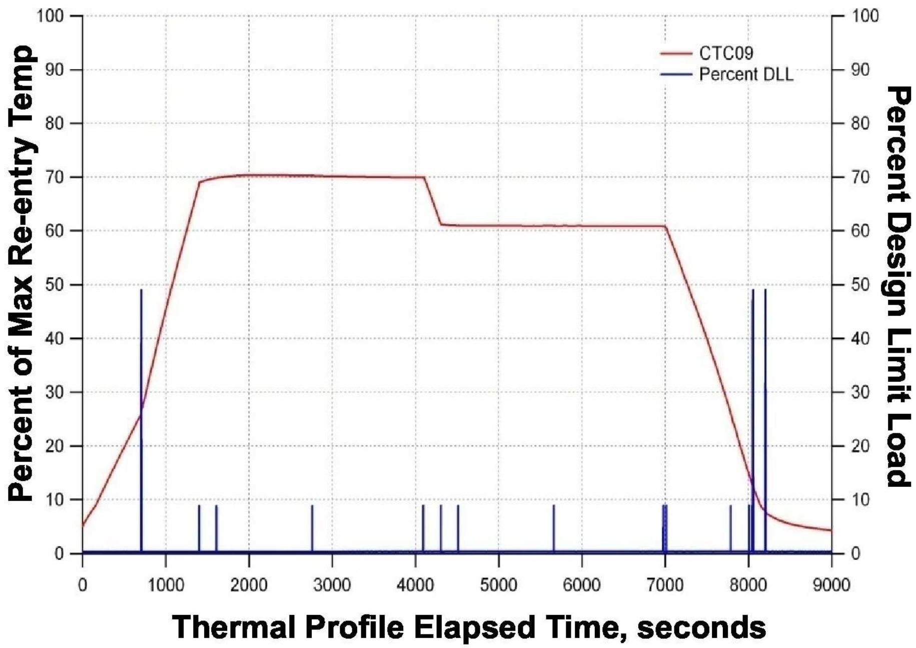


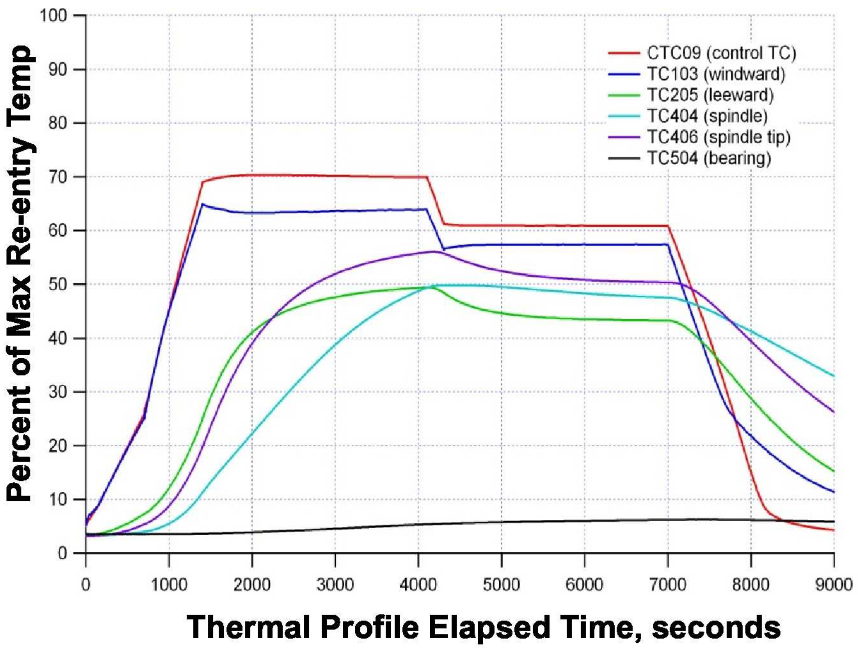


Thermal-Mechanical Testing
Hypersonic Cruise Heating Results

- **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)**

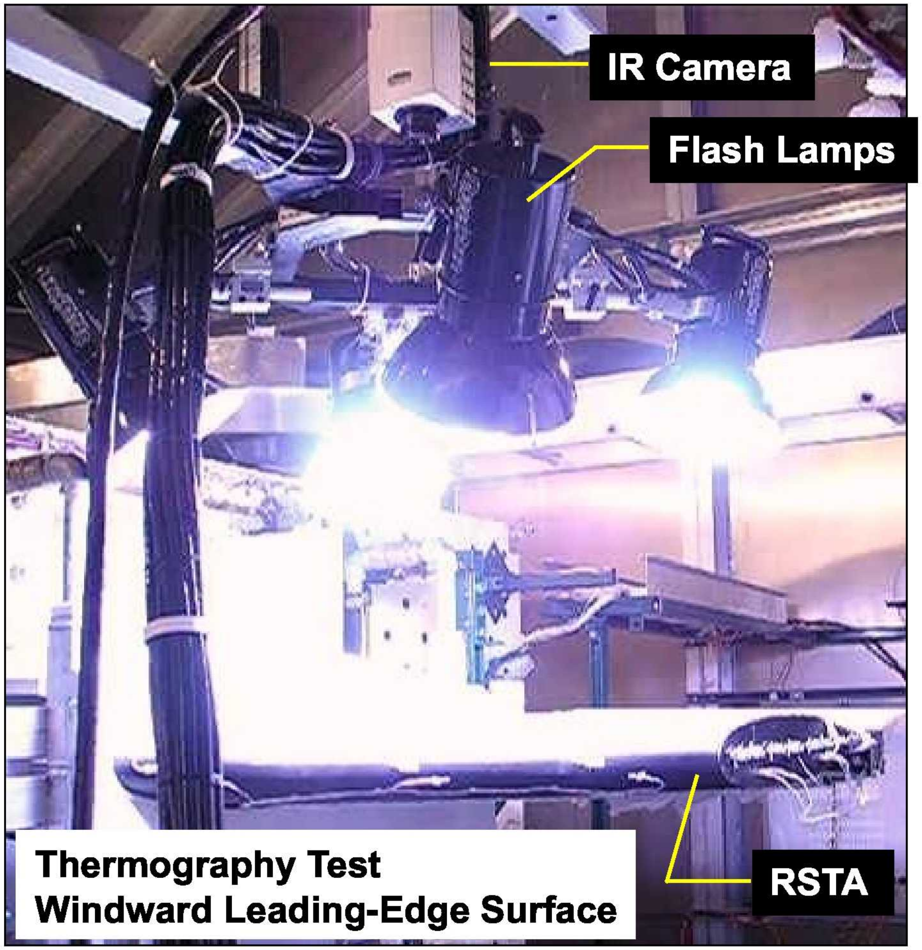






Thermal-Mechanical Testing
In-Situ Thermography Setup

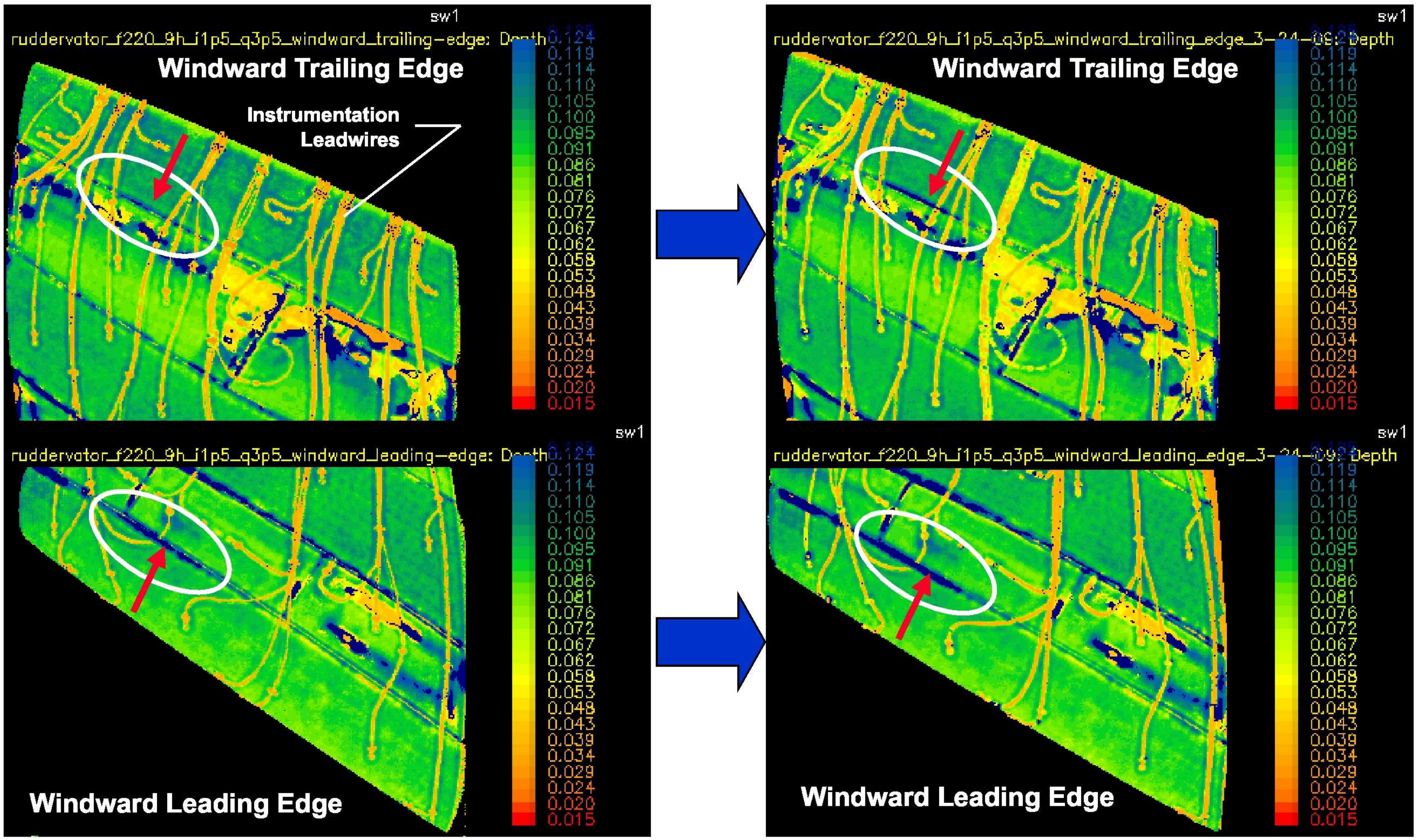
- IR thermography for damage detection and tracking initial defects
- In-situ images of the windward, leeward and leading edge surfaces
- Internal surfaces imaged after testing



Thermography Test
Windward Leading-Edge Surface

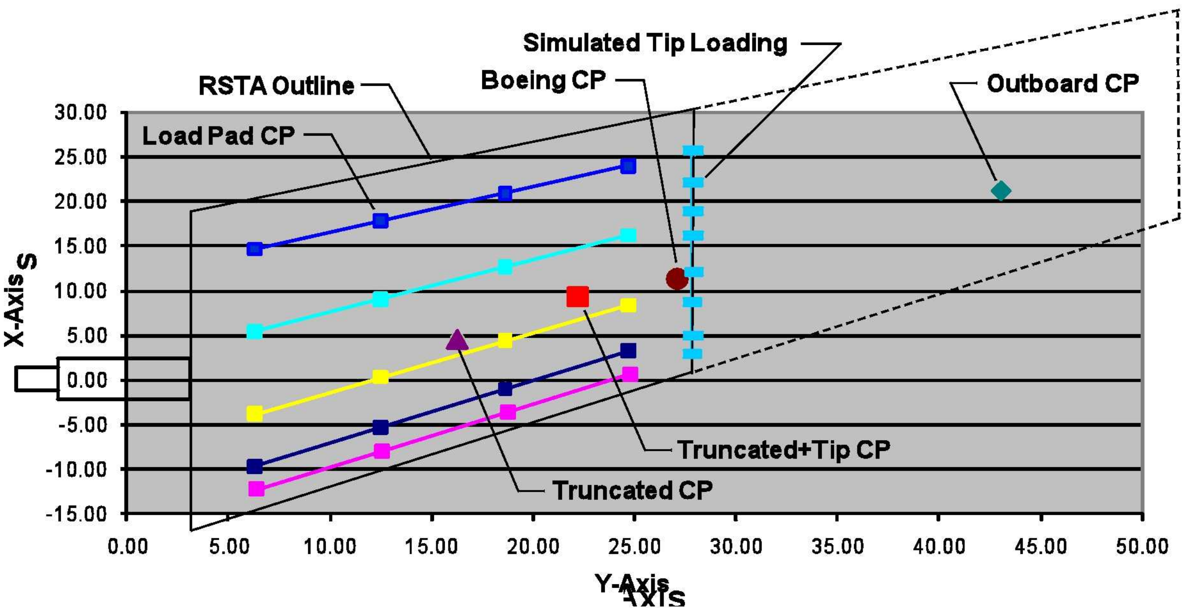
Thermal-Mechanical Testing
In-Situ Thermography Results

April 2008 (before testing) **March 2009 (after thermal testing)**

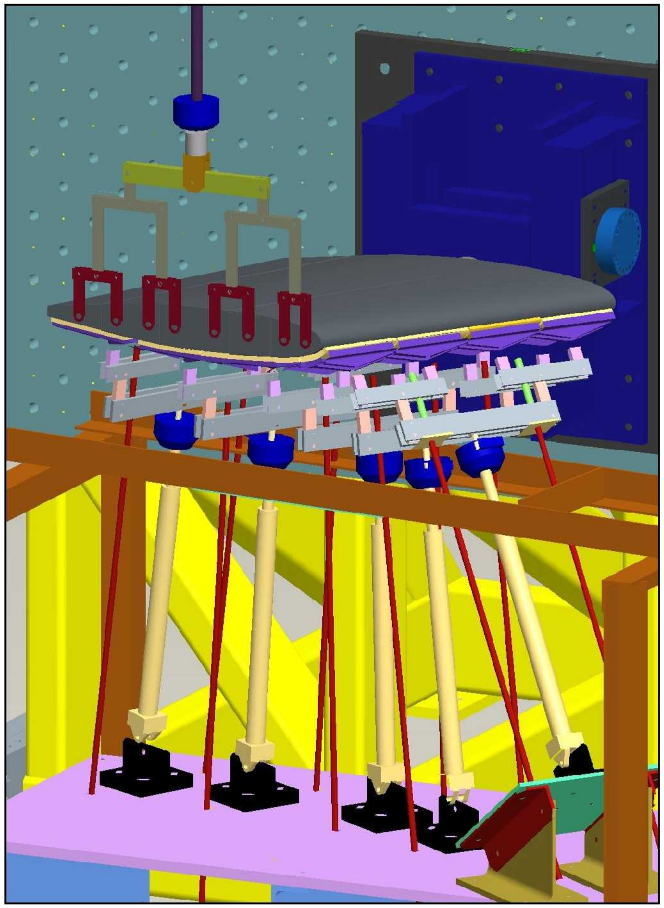


Mechanical Load Testing
Loading Pad Layout Design

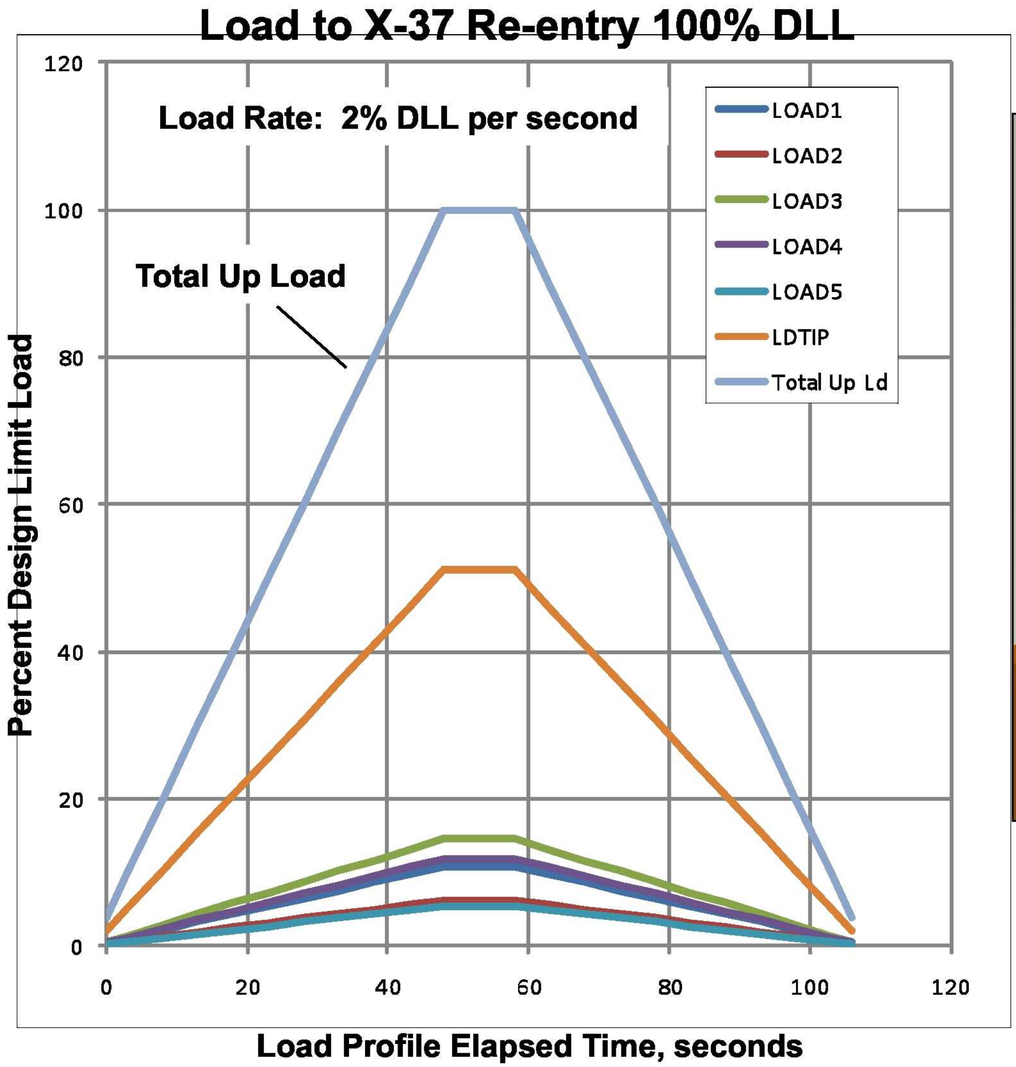
- **100% DLL was applied to the RSTA through pressure loading of the windward surface and tip loading (simulating missing ruddervator section)**
- **Load pad coverage of windward surface approx. 95%**

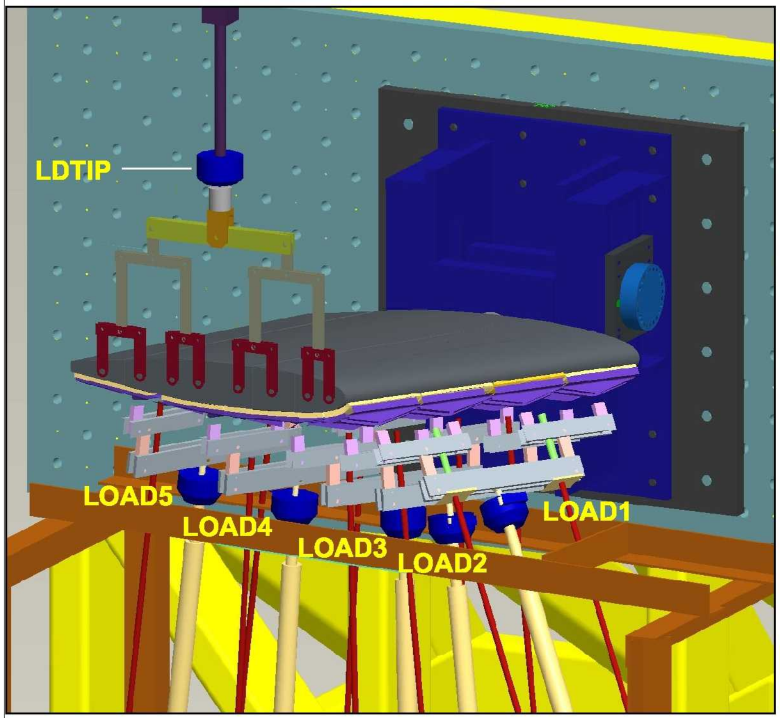


Load Pad Location Determination from Pressure Load Distribution



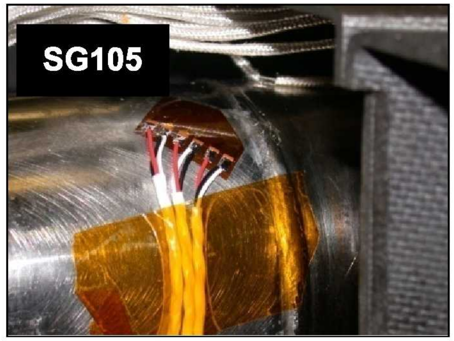
Mechanical Load Testing
Loading Profile

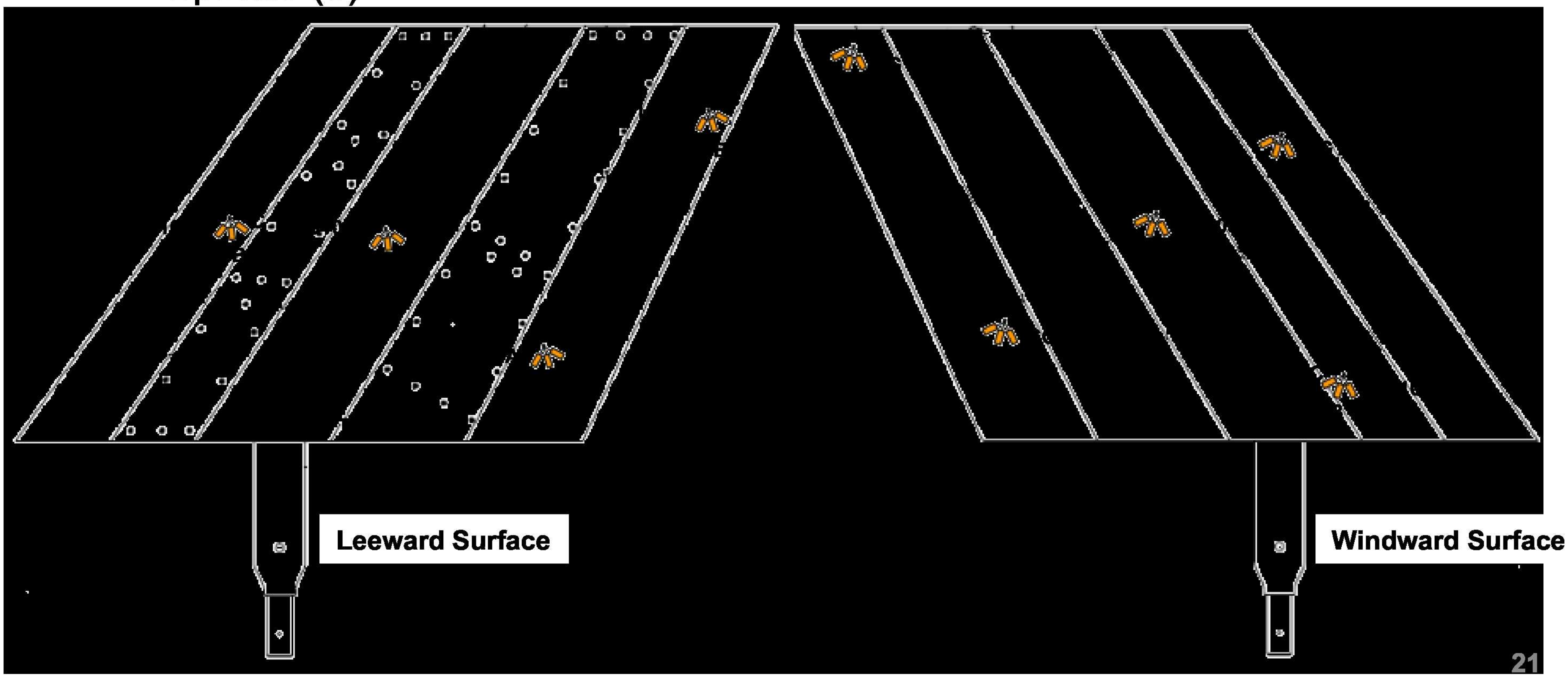




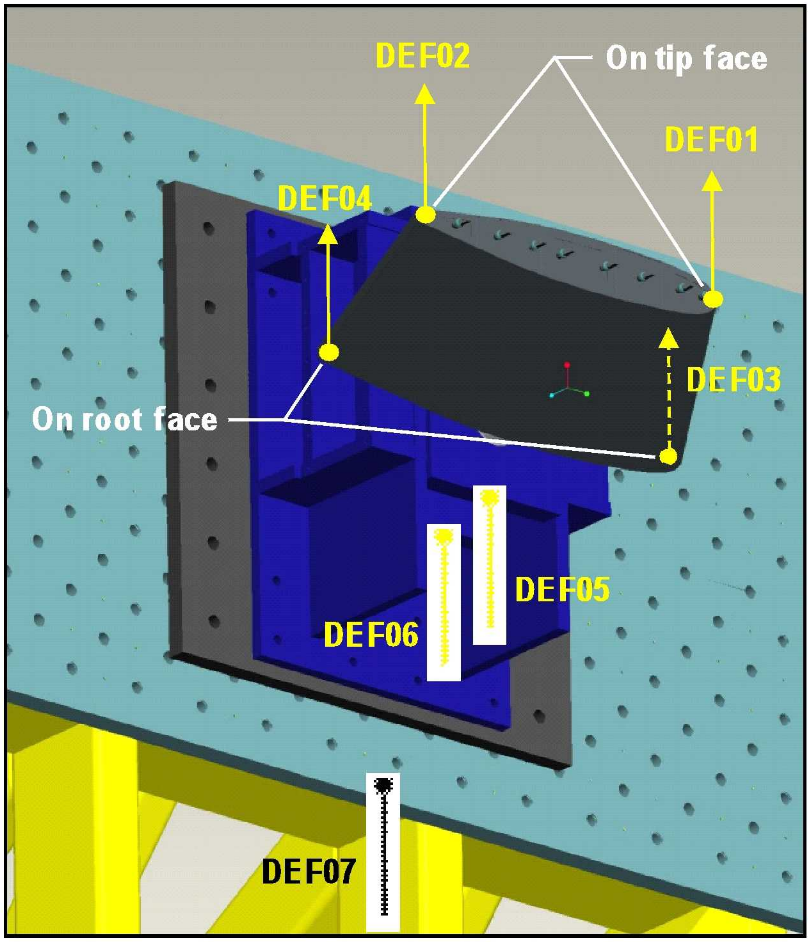
Thermal-Mechanical Testing
RSTA Strain Gage Instrumentation

- **Foil strain gages (31)**
  - Leeward surface (12)
  - Windward surface (15)
  - Internal (1)
  - Spindle (3)

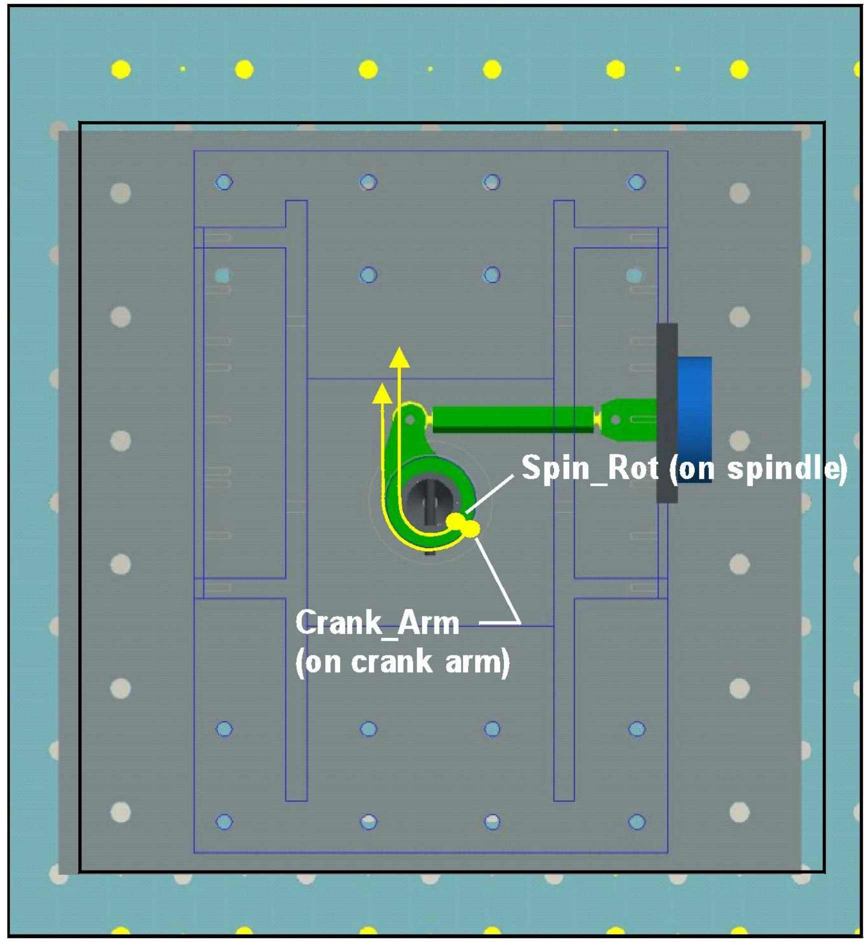




Thermal-Mechanical Testing
Deflection Instrumentation



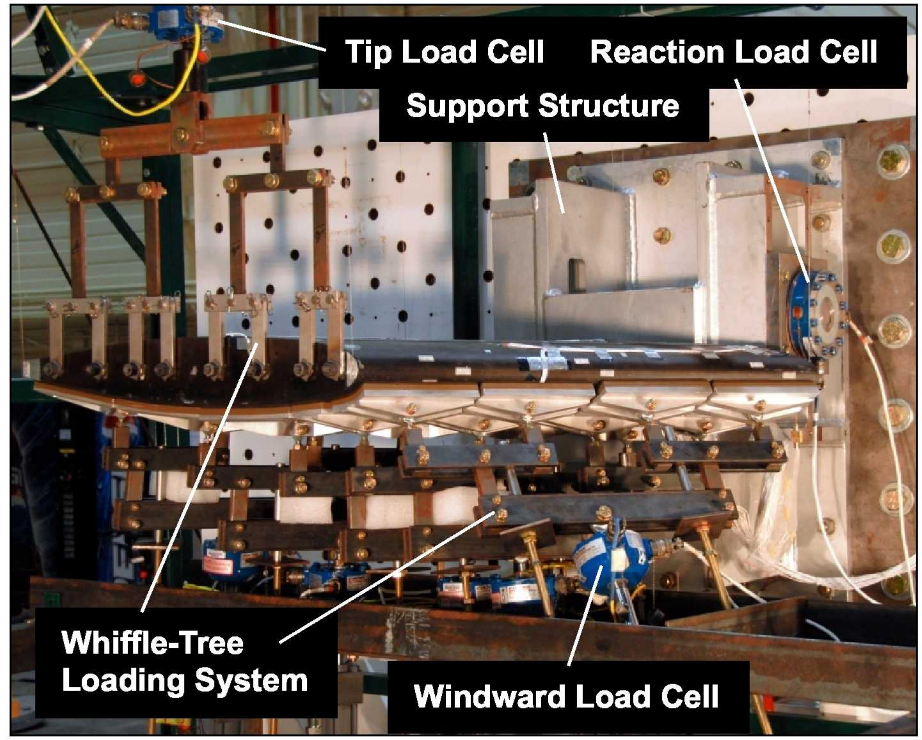
RSTA and Support Fixturing

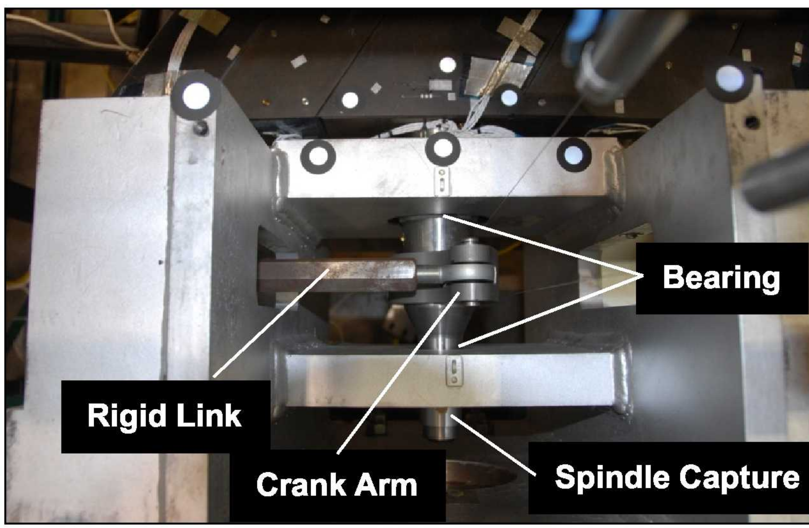


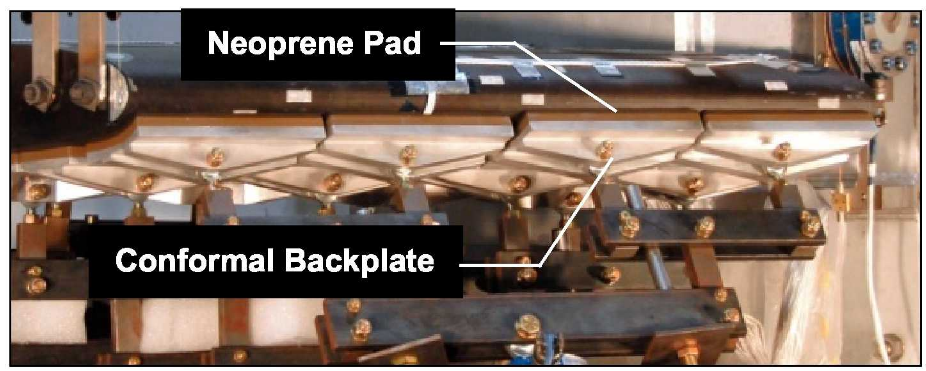
Spindle and Crank Arm

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

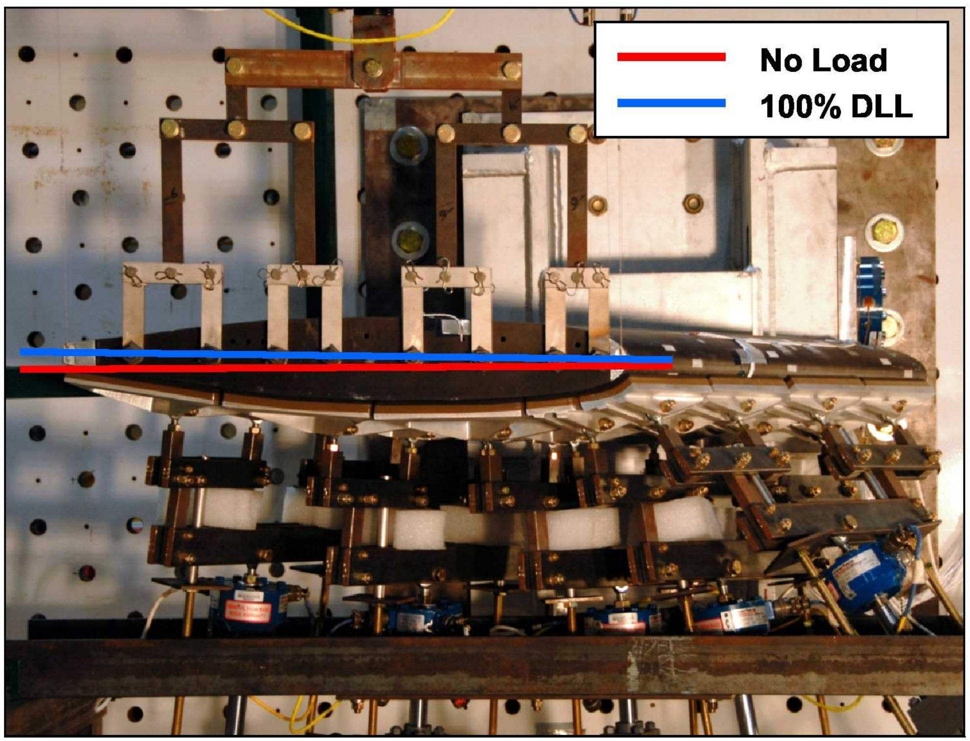


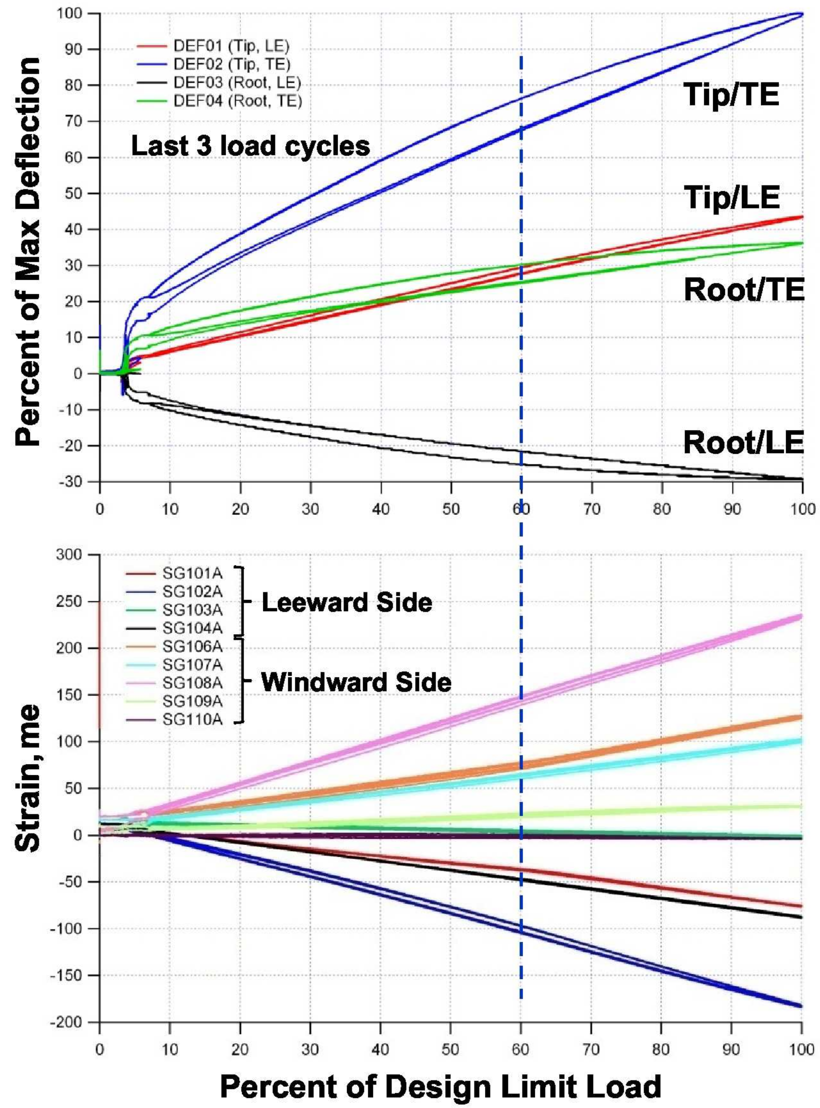




Mechanical Load Testing
Load Test to 100% DLL Results

- **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**