NASA Shuttle Orbiter Reinforced Carbon Carbon (RCC) Crack Repair Arc-Jet Testing

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to
ASME District E Student Professional Development Conference

April 13, 2007

Background

- Columbia (STS-107)
  - Launched on January 16, 2003 with seven crew members on board
  - Mission ended on February 1, 2003, orbital debris over East Texas
  - Accident occurred due to a breach in the Orbiter wing leading edge thermal protection system caused by External Tank foam debris impact during ascent
- Columbia Accident Investigation Board (CAIB)
  - Investigated, among other things, the re-entry of the shuttle back into atmosphere.
  - Recommended on-flight repairs to the Orbiter heat shield (tiles and Reinforced Carbon-Carbon (RCC))
- NASA developed two major repair techniques for RCC region
  - Plug Repair
    - Larger damage incl. burn-throughs up to 4 in. diameter
    - Flexible 7 in. diameter coated C/SiC cover plates
  - Crack Repair
    - Smaller damage incl. cracks, spalls, gouges
    - Repair material is Non-Oxide Adhesive eXperimental (NOAX) polymer

Objectives of Study

- Test repaired RCC cracked models to see if they survive exposure of the Orbiter re-entry simulated environments at select Orbiter body point locations
- Use models that have been repaired by astronauts in flight as well as on ground in Human Thermal Vacuum chamber
- Perform tests at JSC Arc-Jet Test Position 2 (TP2)
  - Calibration model tests
  - Repaired model tests
- Perform analysis to help assess test data
- Generate test reports

Method of Approach

- Arc-Jet test data
  - Obtain calibration data to establish test conditions representative of orbiter body points during reentry
  - Obtain repaired model data at representative flight conditions in the arc jet, including temperature, pressure, heat flux, and shear.
- Boundary layer analysis
  - Use BLIMPK code to assess heating rates and shear stress on RCC wedge surface
  - Use measured pressure plate data as input to BLIMPK, along with derived stagnation enthalpy based on test data
  - Evaluate heat flux to reference location on plate using pyrometer temperature data and emissivity settings
- Documentation of test results and analysis results
  - Calibration test report
    - Description of models, test conditions, test data (surface pressure, dual-cal probe, arc heater parameters, surface temperatures), boundary layer predictions
  - Repaired model test report
    - Description of models, model photos before and after tests, test data

Orbiter Body Point Locations Showing RCC Nose Cap and Wing Leading Edge (Courtesy of Boeing)

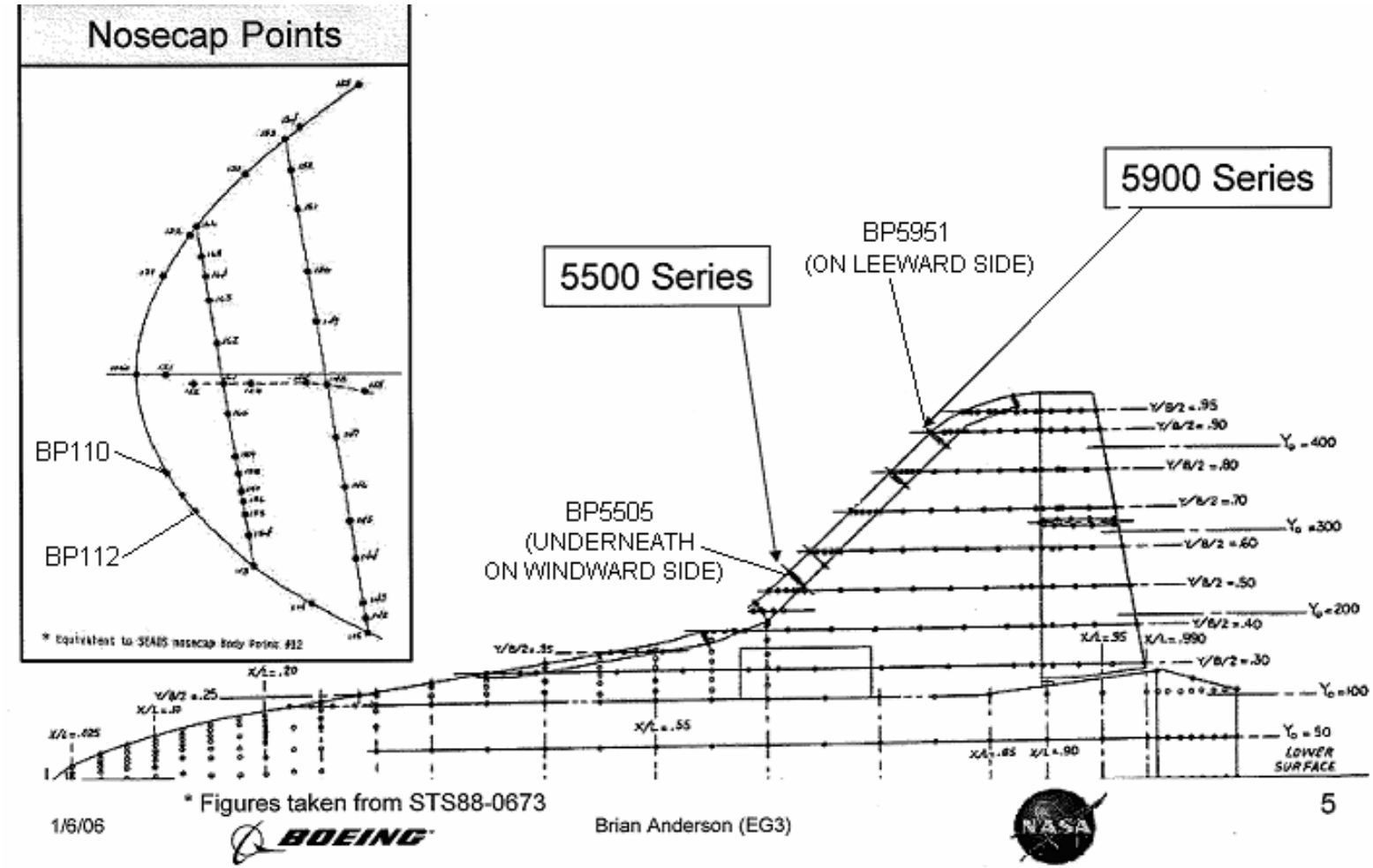
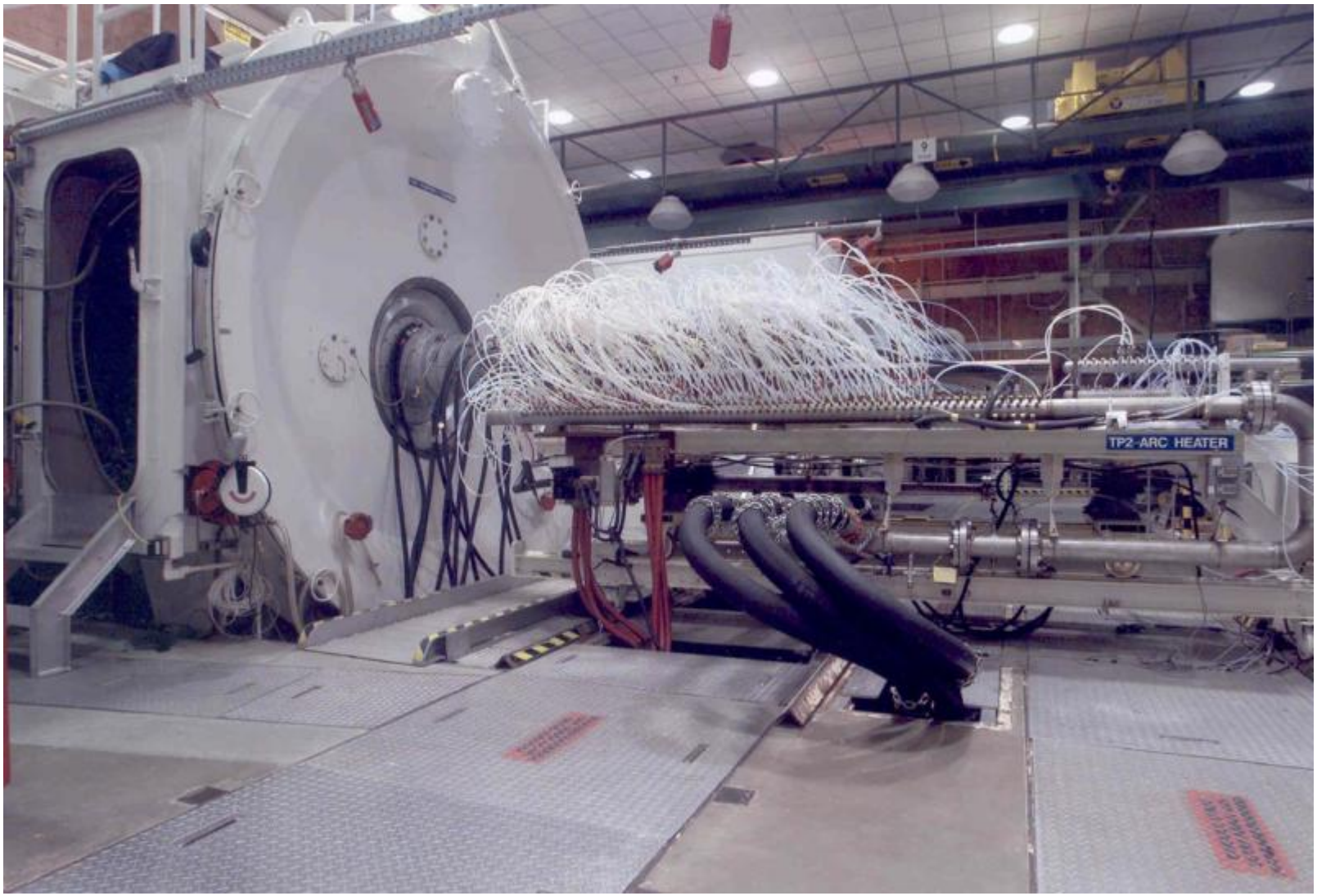
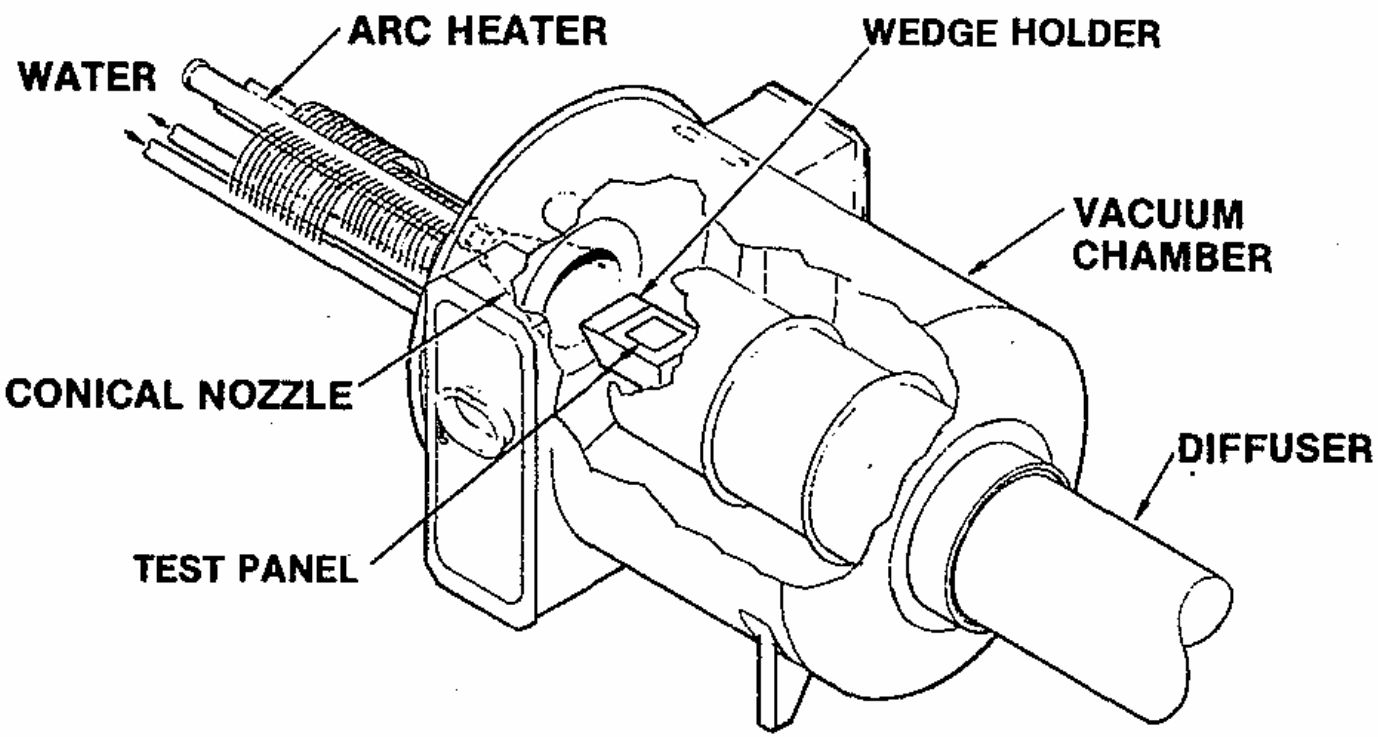


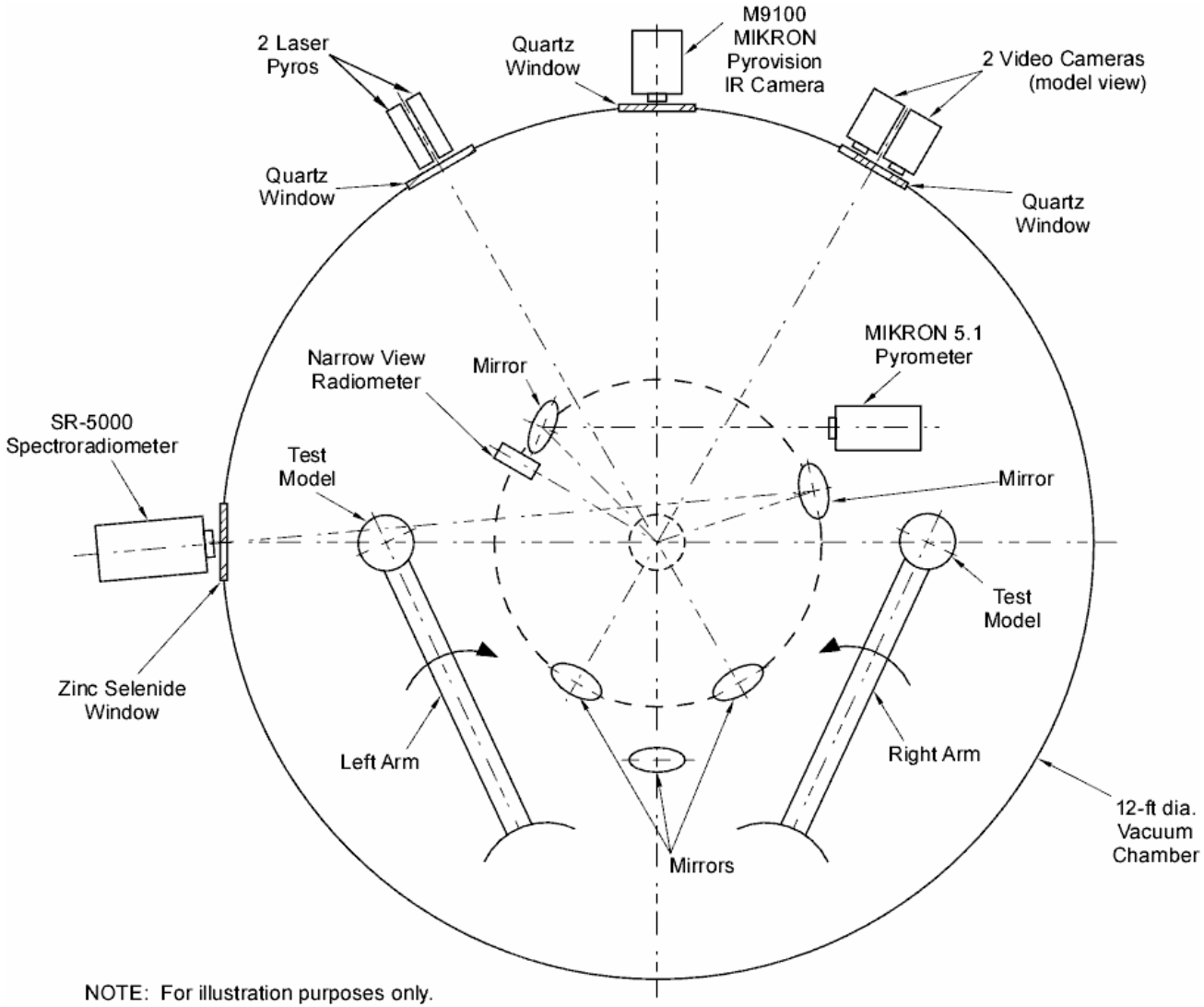
Photo of Test Position 2 (TP2) at JSC Arc-Jet Facility



JSC Conical Nozzle Arc-Jet Configuration

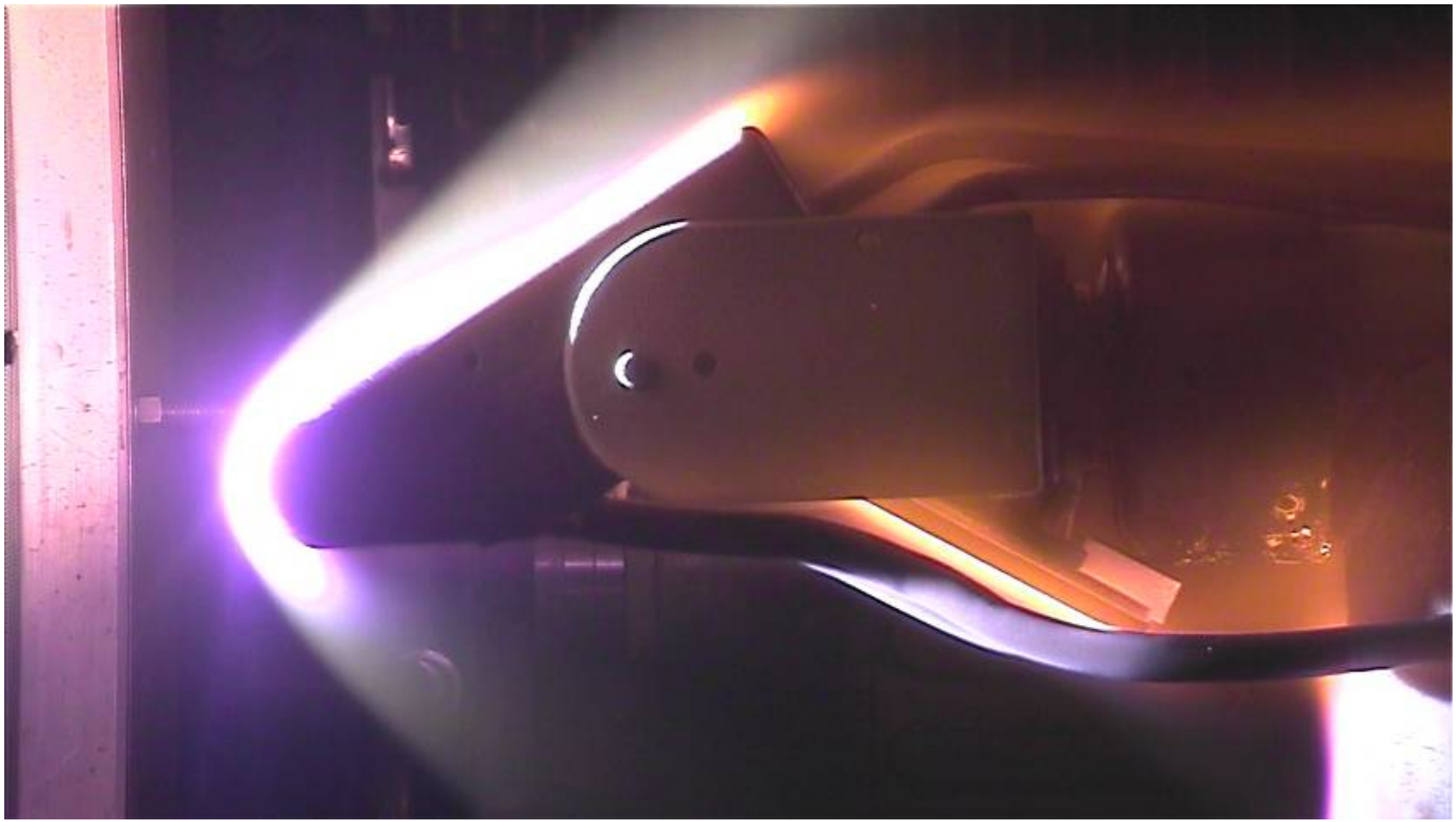


Test Set-up for TP2



RCC Calibration Model in Wedge Holder Before Testing

Shock Wave Around Blunted Wedge at 30º Angle of Attack

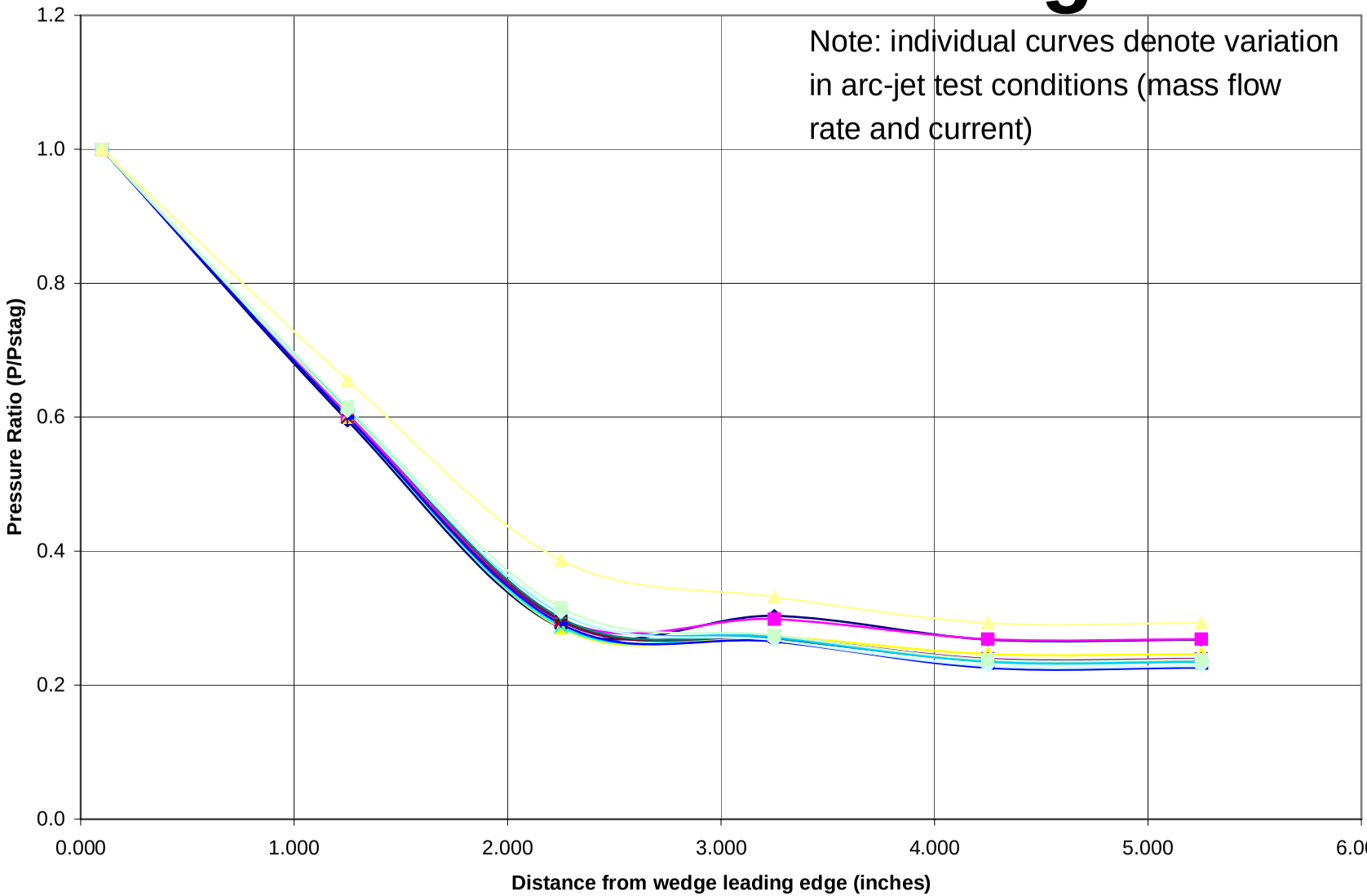


Dual-Cal Probe to Measure Stagnation Heat Rate and Pressure

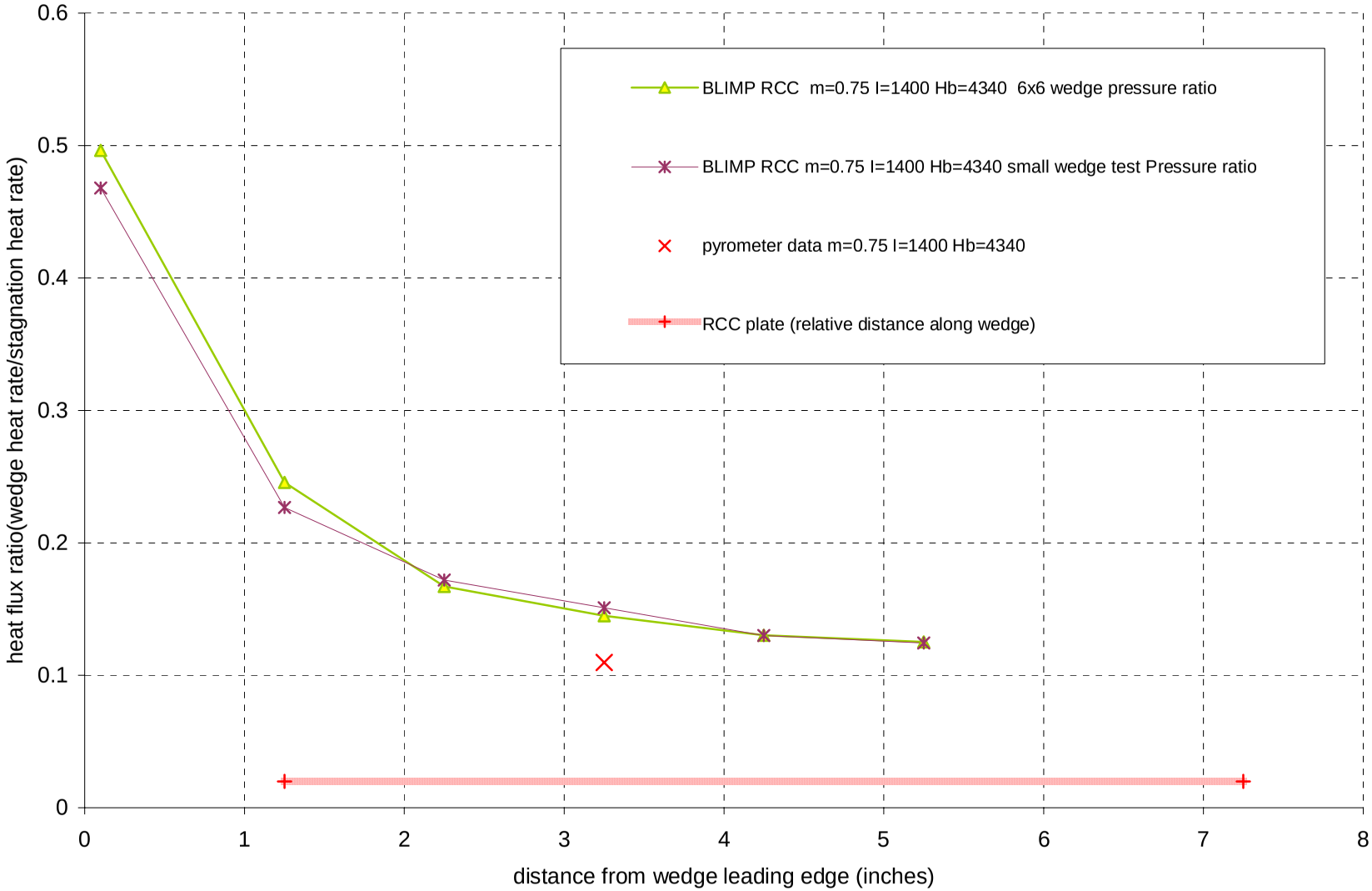
Predictions of Boundary Layer Properties on Wedge Holder

- Boundary Layer Integral Matrix Procedure - Kinetic (BLIMPK) code used
- BLIMPK calculates surface heating rates and shear stresses, plus other properties across boundary layer
- Chemical non-equilibrium around wedge with ¾” wedge leading edge radius
- Required inputs to BLIMPK code:
  - Stagnation enthalpy, based on measured stagnation pressure and heating rate (Hiester-Clark relation)
  - Measured pressure ratio distribution along wedge
  - Measured stagnation pressure
  - Surface emissivity of 0.89

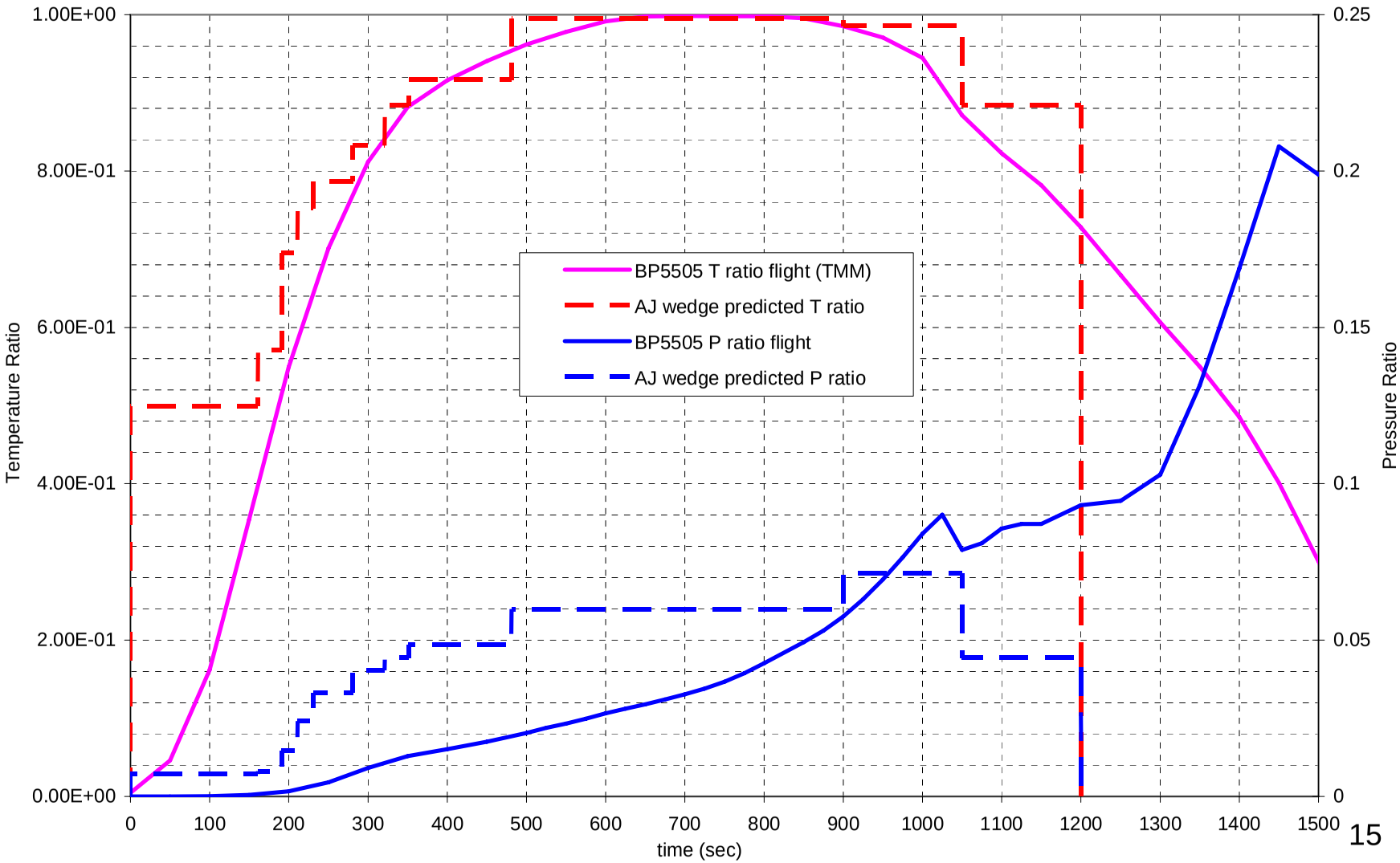
Pressure Ratio vs. Distance on Wedge



Heat Flux Ratio vs. Distance on Wedge



Flight and Arc-Jet Temperature and Pressure Ratios for BP5505



Description of NOAX Repair Material

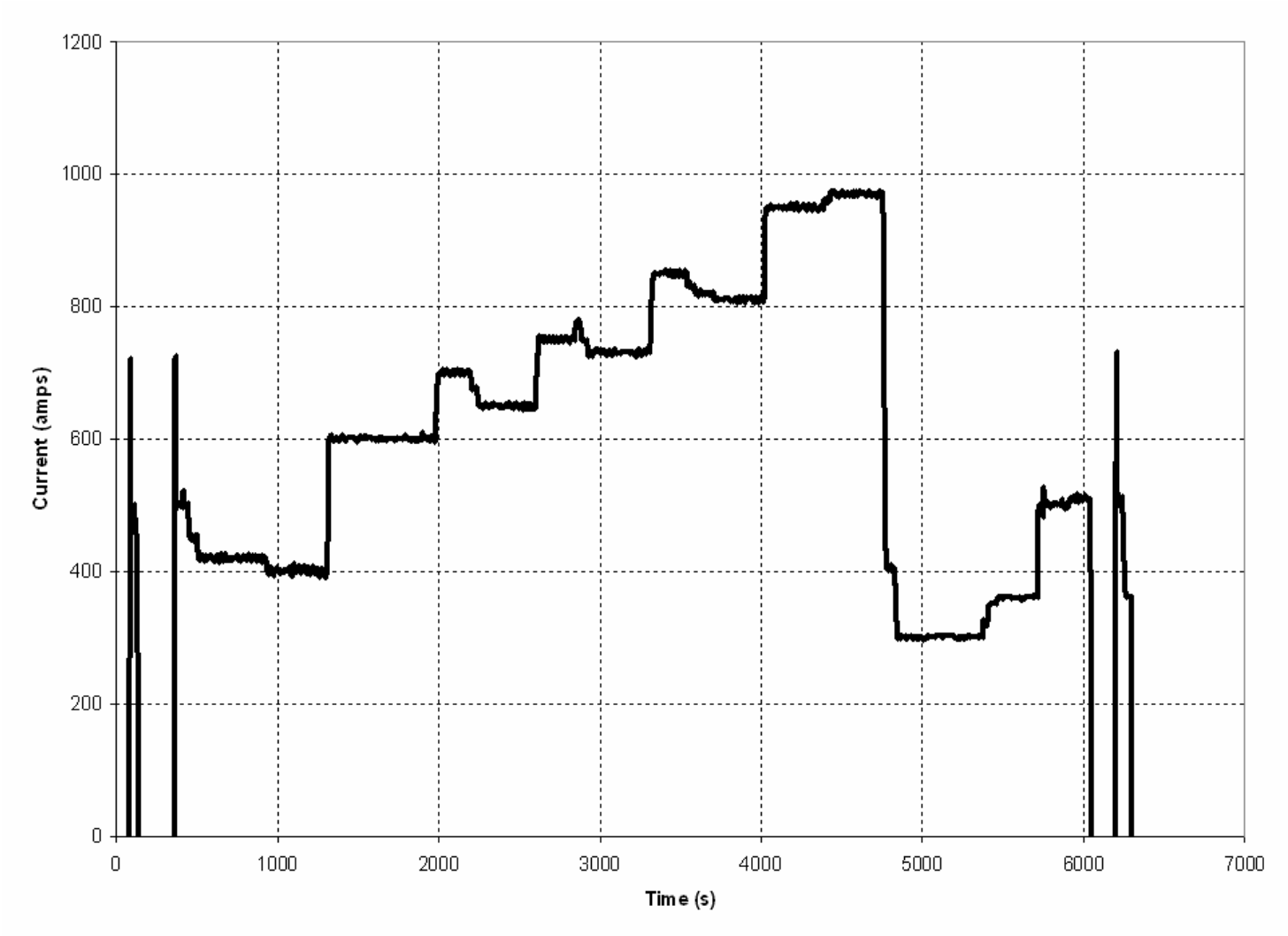
- Non-Oxide Adhesive eXperimental (NOAX) is NASA's choice of material for RCC crack repair concept
- Has been successfully flown and demonstrated on recent shuttle flights
- Has also been applied in Human Thermal Vacuum (HTV) chamber at JSC
- NOAX uses pre-ceramic polymer sealant impregnated with carbon-silicon carbide powder
- Designed to fix damage caused by small pieces of foam falling of redesigned External Tank, ice, and MMOD impacts
- Used to refill cracks or coating losses up to 0.02 in. wide, and 4 inches long

Pre-test and Post-test Photos for NOAX RCC Crack Repair

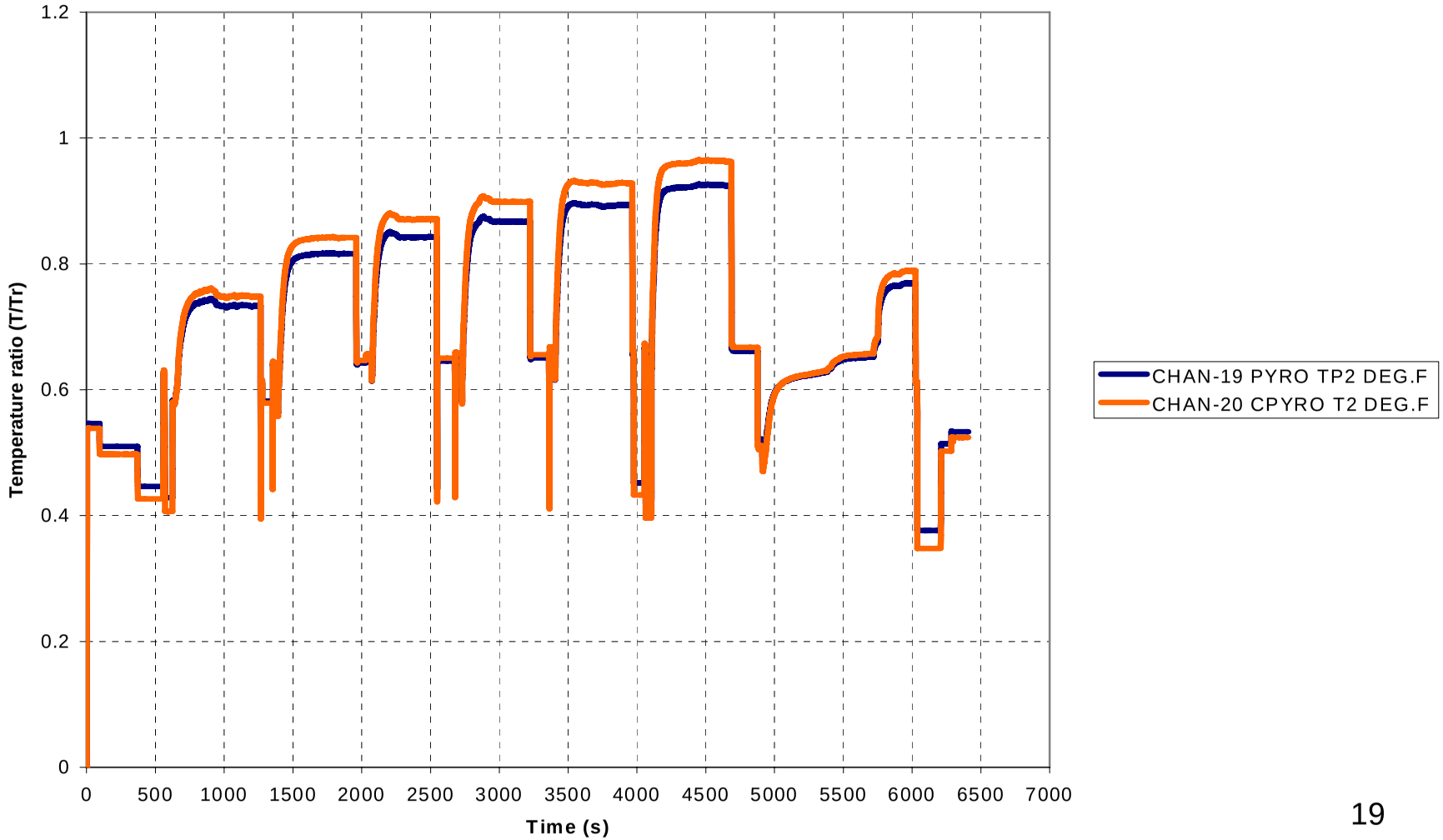
Pre-test

Post-test

Arc-Current Variation with Time for RCC Calibration Run



Pyrometer Surface Temperature Ratio vs. Time for RCC Calibration Run



Summary

- This NASA study demonstrates the capability for testing NOAX-repaired RCC crack models in high temperature environments representative of Shuttle Orbiter during reentry.
- Analysis methods have provided correlation of test data with flight predictions.
- NOAX repair material for RCC is flown on every STS flight in the event such a repair is needed.
- Two final test reports are being generated on arc-jet results (both calibration model runs and repaired models runs)