CA250

Arcjet Testing of Advanced Conformal Ablative TPS

Matthew Gasch and Robin Beck
NASA Ames Research Center, Moffett Field, CA, 94035

Parul Agrawal
ERC at NASA Ames Research Center, Moffett Field, CA, 94035

28 January 2014

Outline

CA250

- **Technology Description**
  - Conformal Ablative TPS
  - CA250 Project
- **Arcjet Test Design**
  - SPRITE
- **Results**
  - Temperature Response
  - Recession
  - Thermal Modeling
- **Summary**

Description: Conformal Ablative TPS

- **Substrate: Low density carbon or polymer felts**
  - High strain to failure eliminates need for strain isolation (SIP or large gap) upon attachment to rigid aeroshell (required for PICA & Si-based Tile)
  - Allows for large acreage application (reduced part count)
  - Reduced gaps and gap filler issues present with rigid TPS
  - Near-net-shape fabrication with preferred thermal orientation
- **Resin:** Modified phenolic (CPICA), modified silicone (CSICA), cyanate ester, etc.
- **First developed under Hypersonics EDL Project 2009-11**
  - Patent Pending 13/357,248
- **Transferred to CA250 Project in 2011**

CA250 TPS Project

- **Goal**
  - Development of Conformal PICA (CPICA) to TRL 5 by 2015
- **Activities**
  - 2013: Demonstrate (via ground testing) a conformal ablator capable to at least 250 W/cm^2
  - 2014/15: Demonstrate process/fabrication scale-up via industrial partner
- **Motivation**
  - Commercially available felt systems come in 60-inch wide rolls
    - Larger parts, reduced part count (e.g. 30 pieces CA for MSL size vehicle vs. 120 PICA tiles)
  - Less complex to integrate across a variety of carrier structure
    - Insensitive to surface finish or rigidity of substructure
    - Does not require RTV or other "gap" filler between TPS segments
  - Less expensive "system" to manufacture and integrate

CA250 TPS Project

CA250

- **Goal**
  - Development of Conformal PICA (CPICA) to TRL 5 by 2015
- **Activities**
  - 2013: Demonstrate (via ground testing) a conformal ablator capable to at least 250 W/cm^2
  - 2014/15: Demonstrate process/fabrication scale-up via industrial partner
- **Motivation**
  - Commercially available felt systems come in 60-inch wide rolls
    - Larger parts, reduced part count (e.g. 30 pieces CA for MSL size vehicle vs. 120 PICA tiles)
  - Less complex to integrate across a variety of carrier structure
    - Insensitive to surface finish or rigidity of substructure
    - Does not require RTV or other "gap" filler between TPS segments
  - Less expensive "system" to manufacture and integrate

Test Objectives

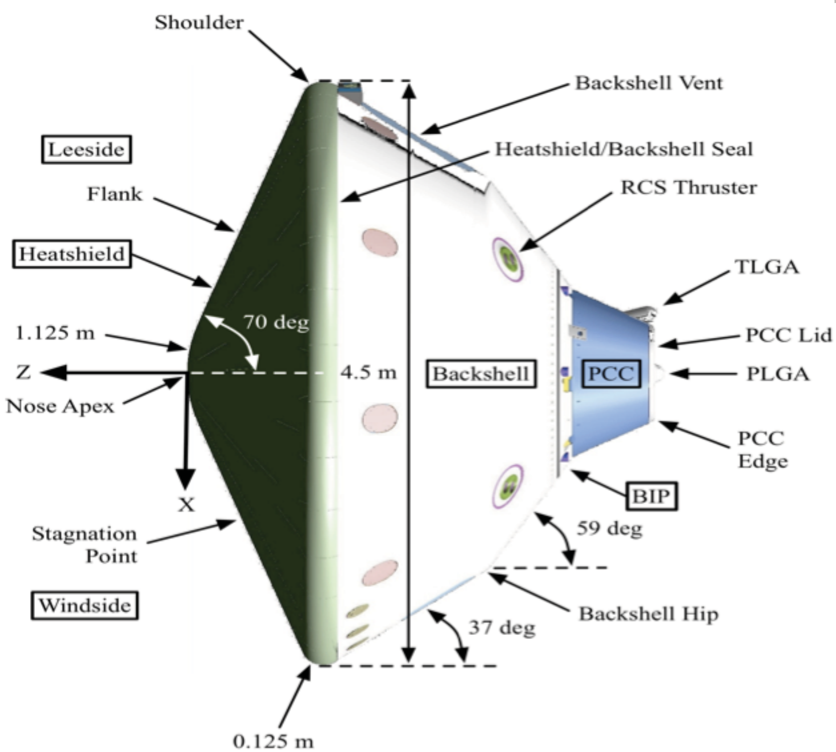
1. Assess the thermal performance of CPICA over a broad range of conditions
2. Develop TPS-C instrumentation for developing and validating thermal response models from TPS materials testing in the arcjet
3. Develop mid-fidelity material response model for CPICA that can predict recession and in-depth temp response in support of mission design and analysis
4. Address how to attach CPICA to a rigid structure while also evaluating seam designs between gore panels

CPICA Material Properties

- **Previous Work 2011-12**
  - Stagnation arcjet tests and screening test with SPRITE geometry 2 conditions
  - Limited material property data
    - Many properties guessed and/or scaled from those of PICA
  - Preliminary ablation and thermal response model developed for use with FIAT
- **Based on new 2013 data, the following were updated**
  - Small changes to
    - Virgin and char densities
    - Elemental composition
  - Preliminary CPICA FIAT model adjusted with new property data
    - Virgin specific heat
    - Virgin and char thermal conductivity
  - Recalculated based on above
    - Pyrolysis gas enthalpy

Aerothermal: MSL Peak Design

MSL Aerothermal Entry Environments	*+3-sigma Value*	*09-TPS-02*	Edquist, JPL D-34661, Rev B	
Location	Peak Heat Rate (W/cm^2)	Peak Shear (Pa)	Peak Pressure (atm)	Peak Heat Load (J/cm^2)
HS Leeside Flank	220.1	393.4	0.246	6103.5
HS Leeside Shoulder	225.7	465.4	0.242	6402.4
HS Leeside Shoulder	203.2	490.2	0.208	5895.3
Stagnation Point	59	5.4	0.332	2604.5
HS Nose Apex	119.2	127.4	0.239	4113.2
HS Windside Shoulder	114.4	216.7	0.242	4136.8
HS Windside Shoulder	103.8	240.5	0.172	3749.7

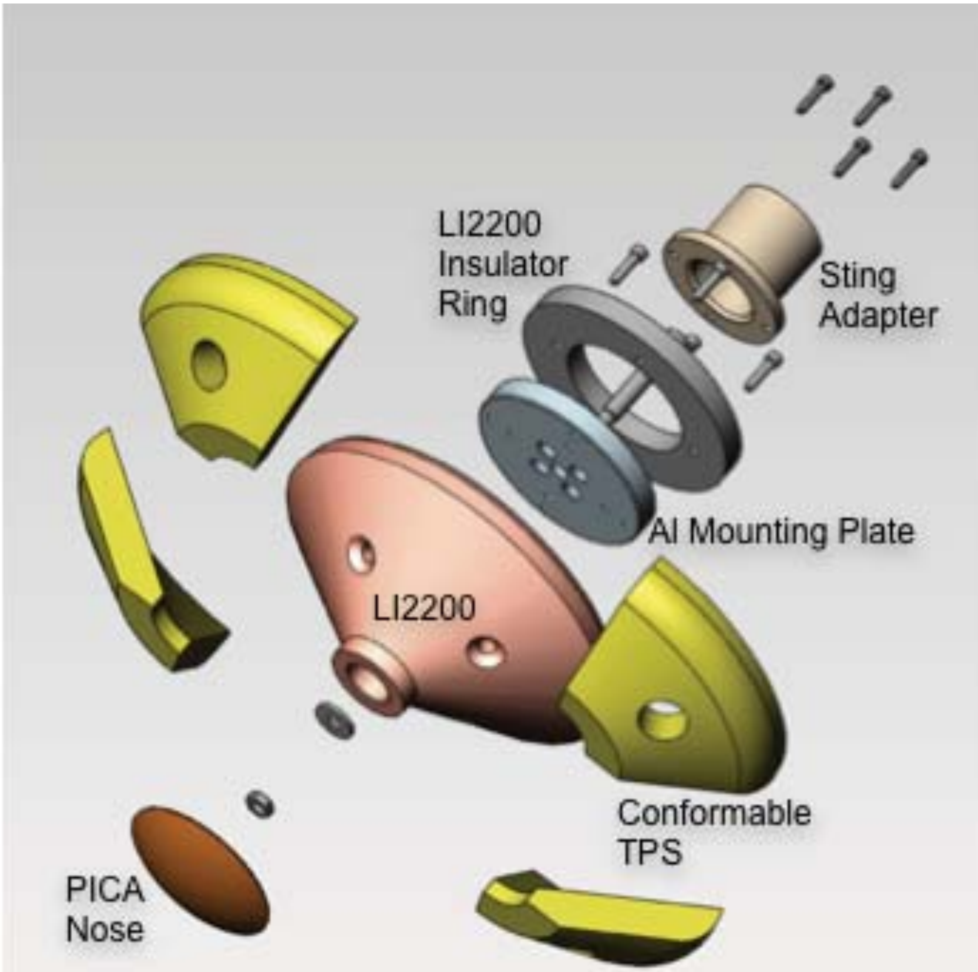


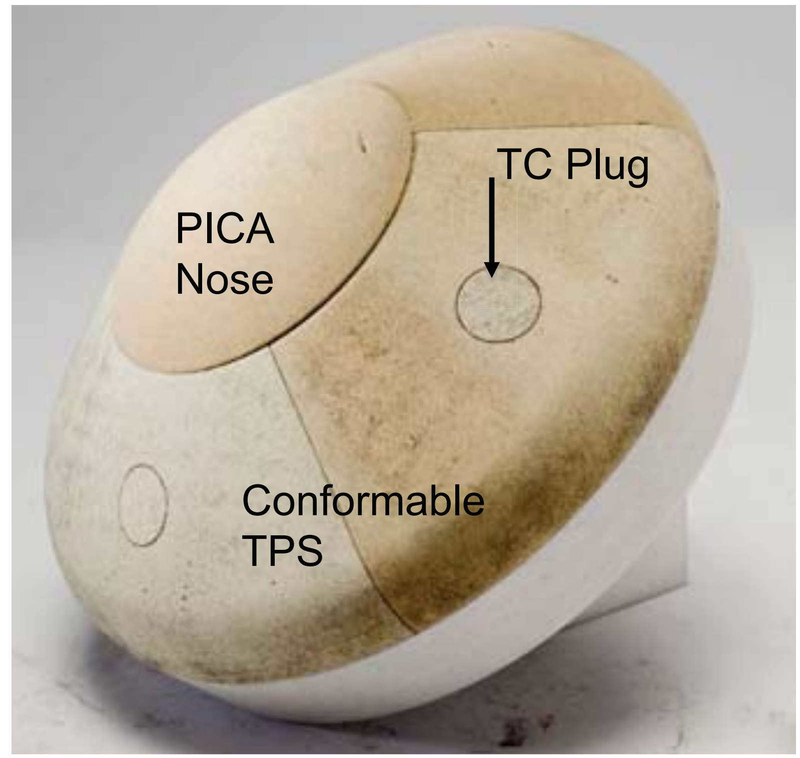
250 W/cm^2,
0.33 Atm,
490 Pa Shear

CA250

SPRITE Test Article Detail

SPRITE[1] – Small Probe Reentry Investigation for TPS Engineering



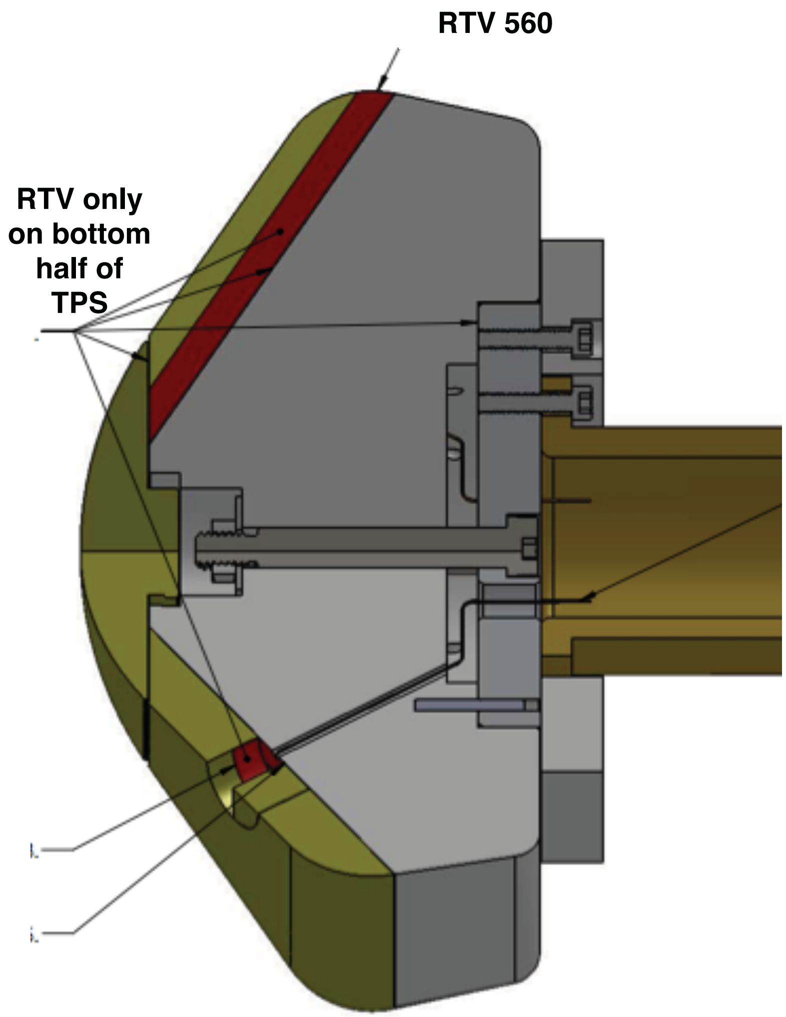


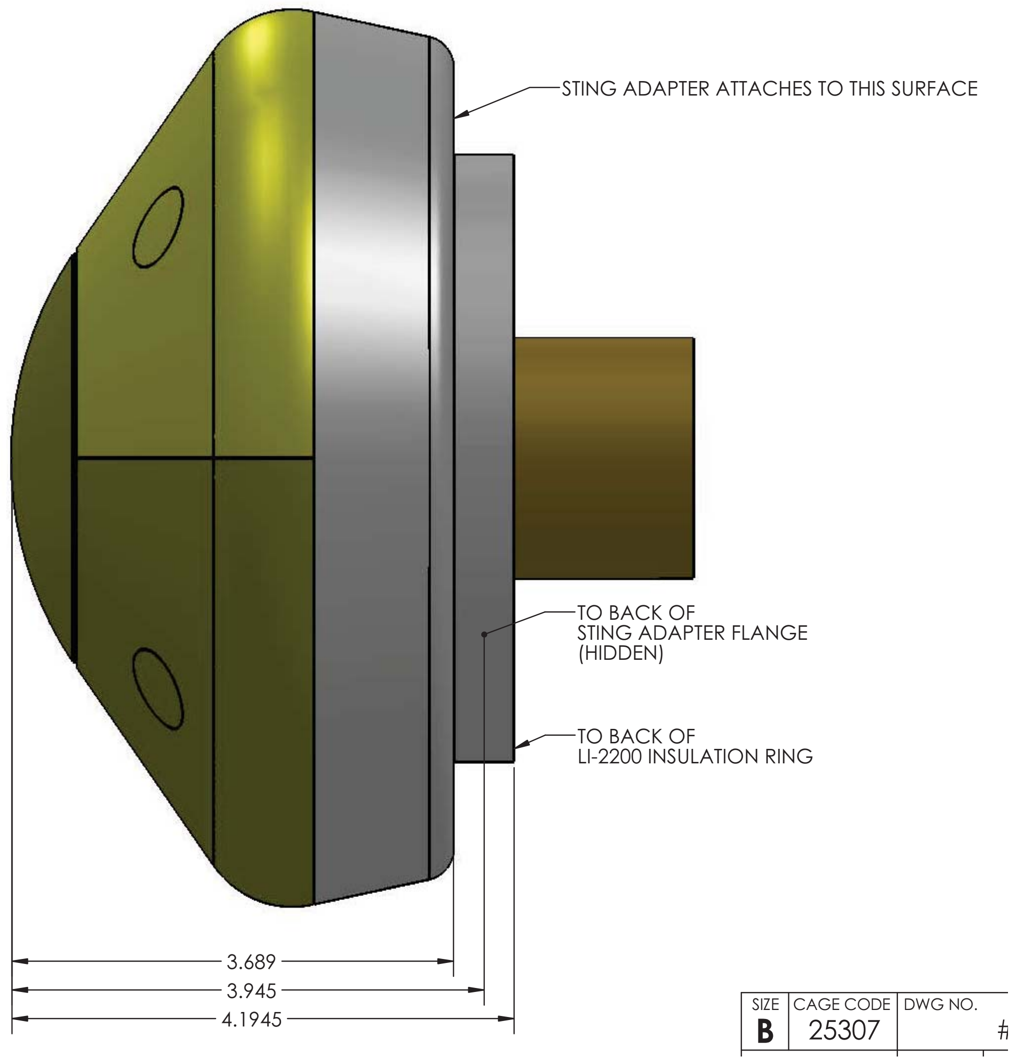
- 8-inch diameter
- 55^0 sphere cone

[1]Empey, D. M., Skokova, K.A., Agrawal P., Swanson G., Prabhu, D.K., Peterson K. H., and Venkatapathy E., "Small Probe Reentry Investigation for TPS Engineering (SPRITE)", proceedings , 8th International Planetary Probe Workshop, Portsmouth, VA, 6-10 June 2011.

CA250

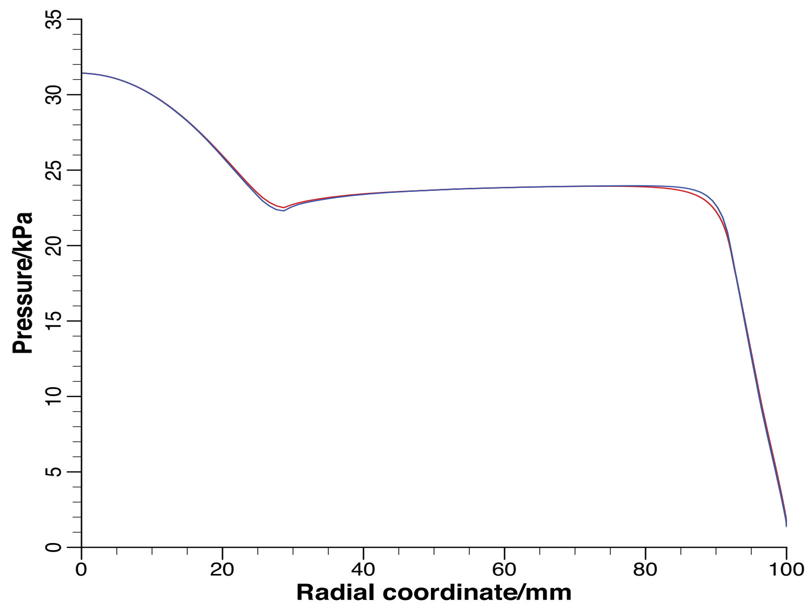
SPRITE Test Article Detail Cont.

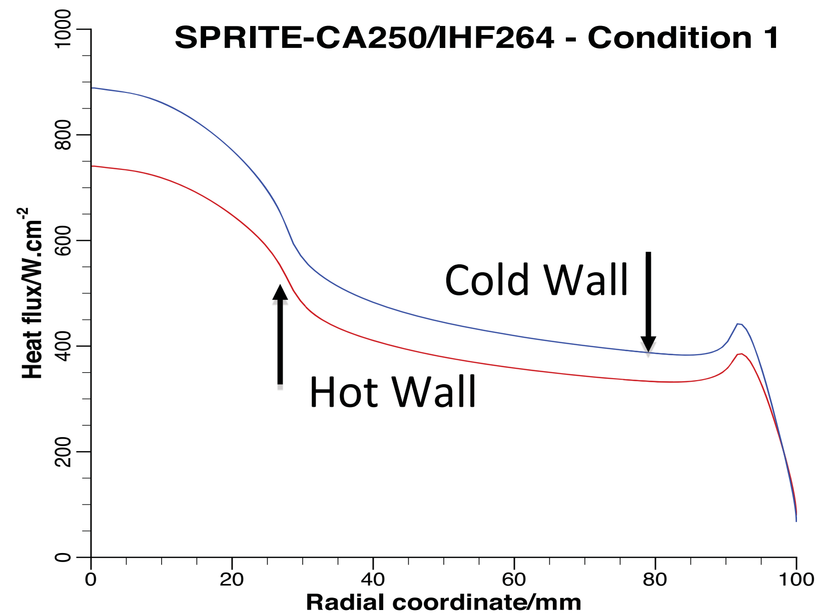


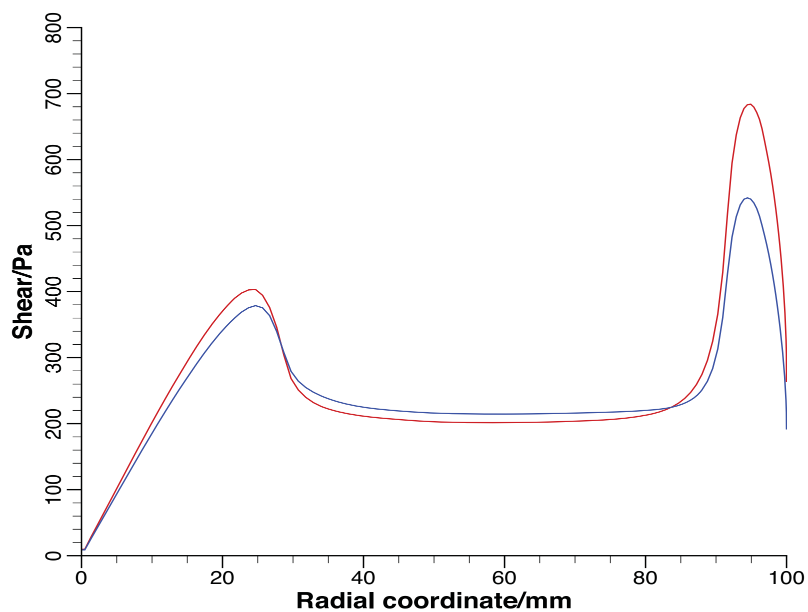


CA250

Pre-Test CFD







<u>High Condition "MSL+"</u>

~ 400 W/cm^2, ~ 24 kPa Press. ~ 210 Pa shear on Flank and ~ 550 Pa shear On 0.8" R_b corner

CFD - Dinesh Prabhu

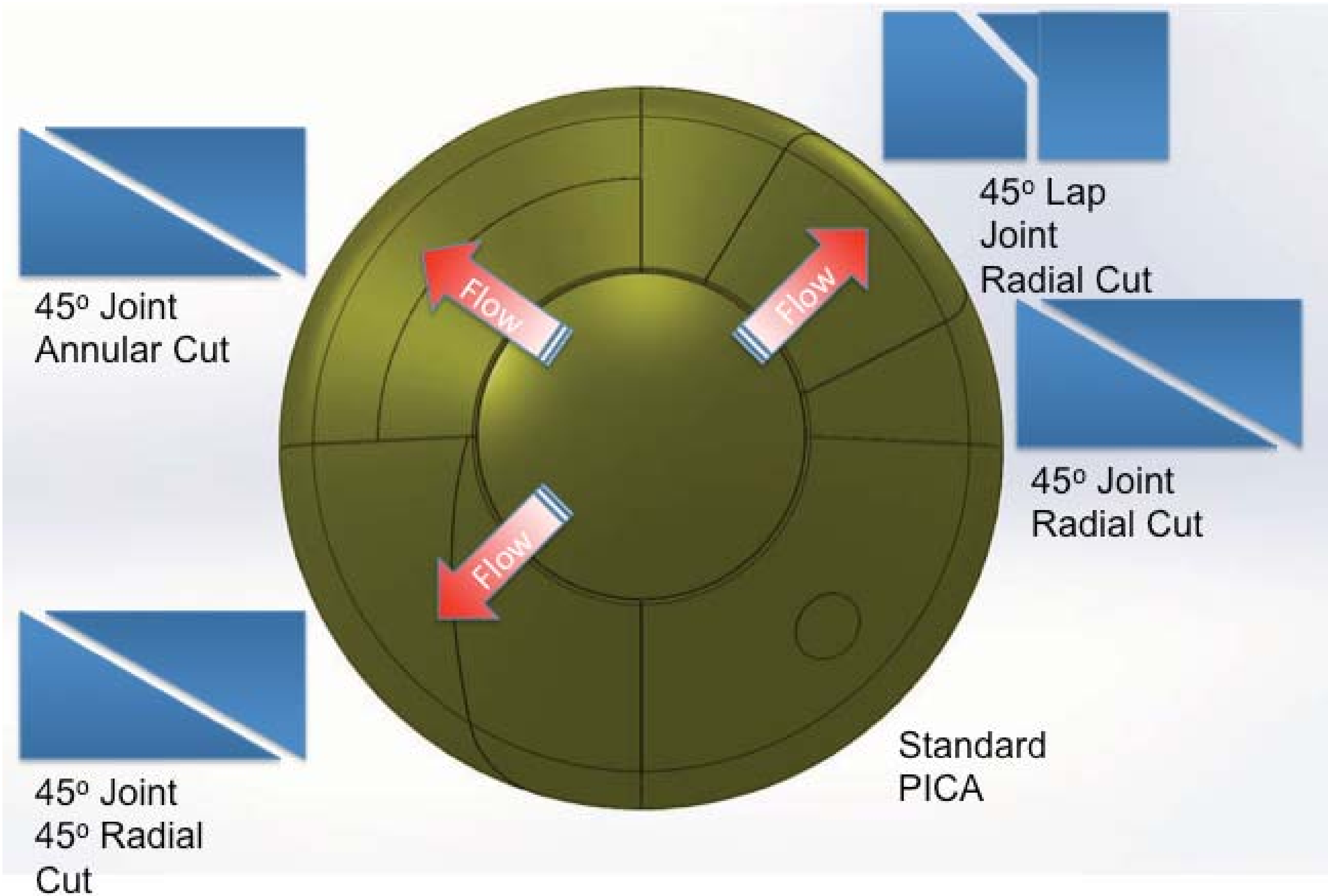
Test Description

- 8 Articles tested at 4 conditions: 40, 150, 180 & 400 W/cm^2
- Standard rigid PICA & CPICA: both 0.5-inch thick & $0.28 g/cm^3$
- 4-inch hemispherical calorimeters were used to characterize the flow
- 4 TR models had TC plugs in each TPS segment at depth of: 0.15, 0.30 & 0.50-inch
- 4 seam models had TC plug in PICA segment and TC's at 0.50-inch behind CPICA segments

	Cold Wall Heat Flux (W/cm^2)	Pressure (atm)	Shear (Pa)	Exposure Duration (s)
Condition 1	400	0.25	210	30
Condition 2	180	0.15	120	60
Condition 3	150	0.07	100	80
Condition 4	40	0.09	60	100

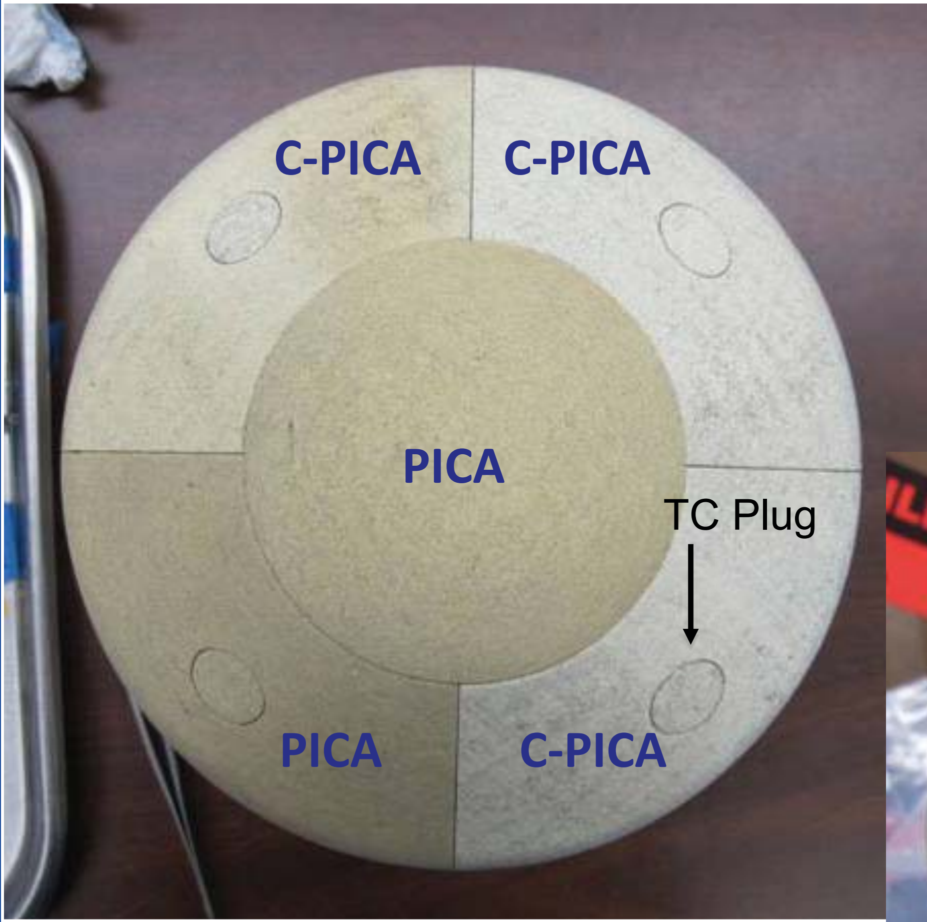
CA250

Detail: Seam Models



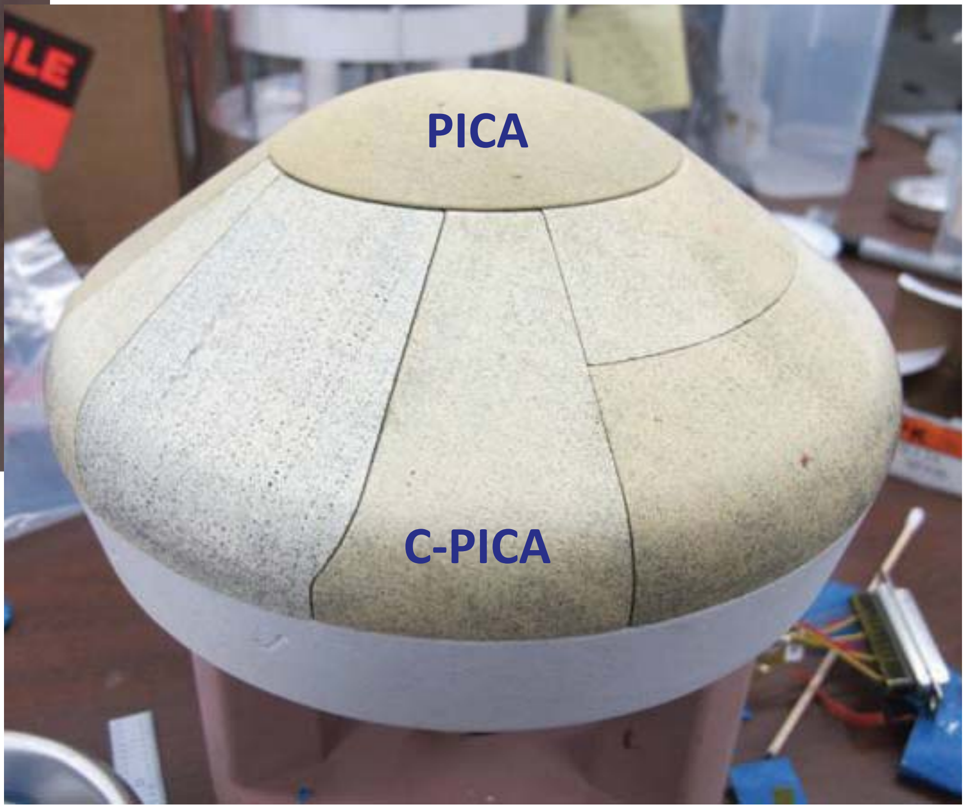
CA250

Pre-Test Images

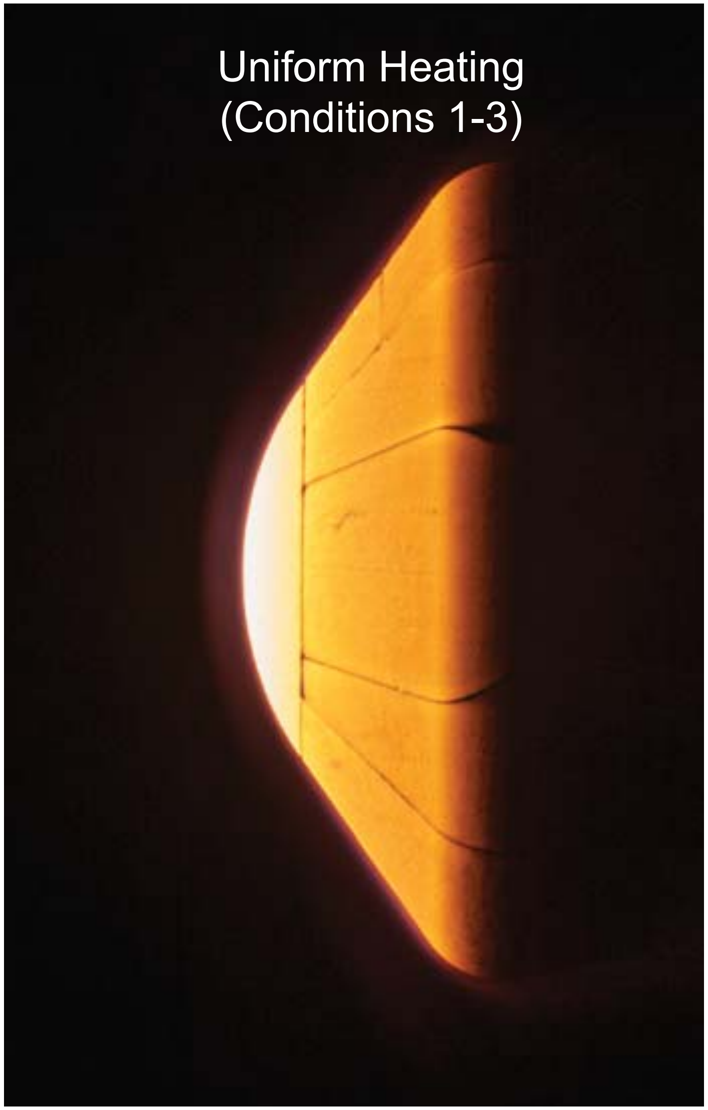


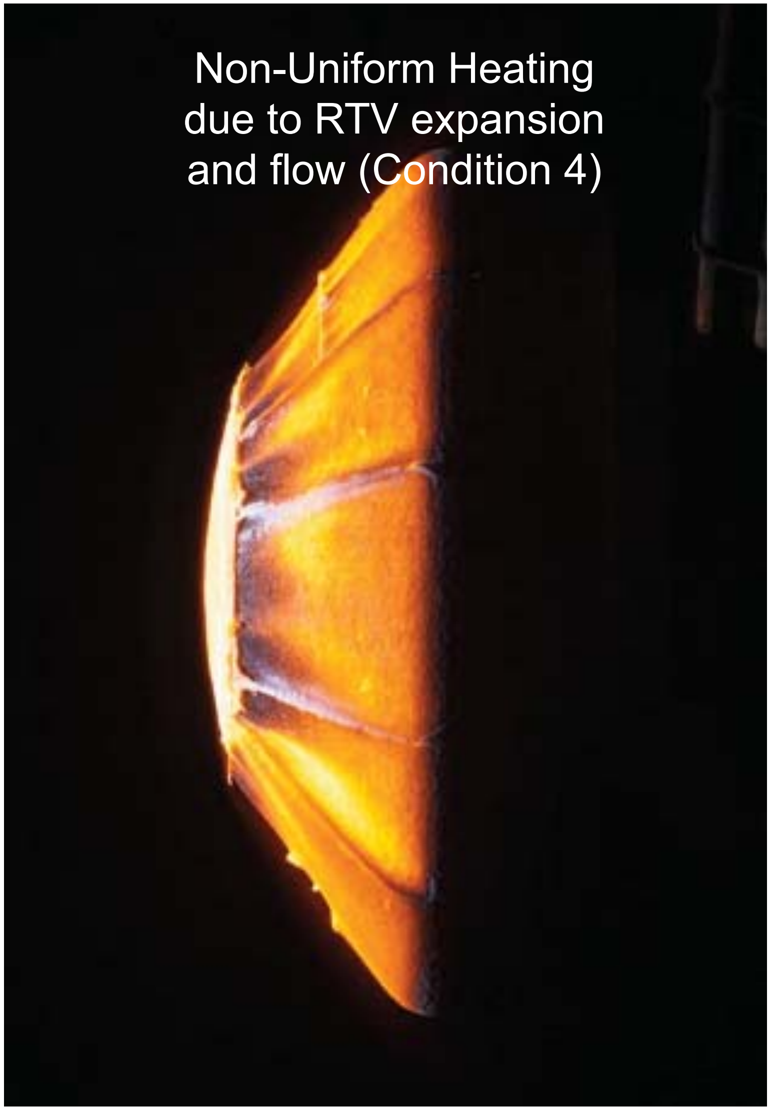
Thermal Response Model

Seam Model



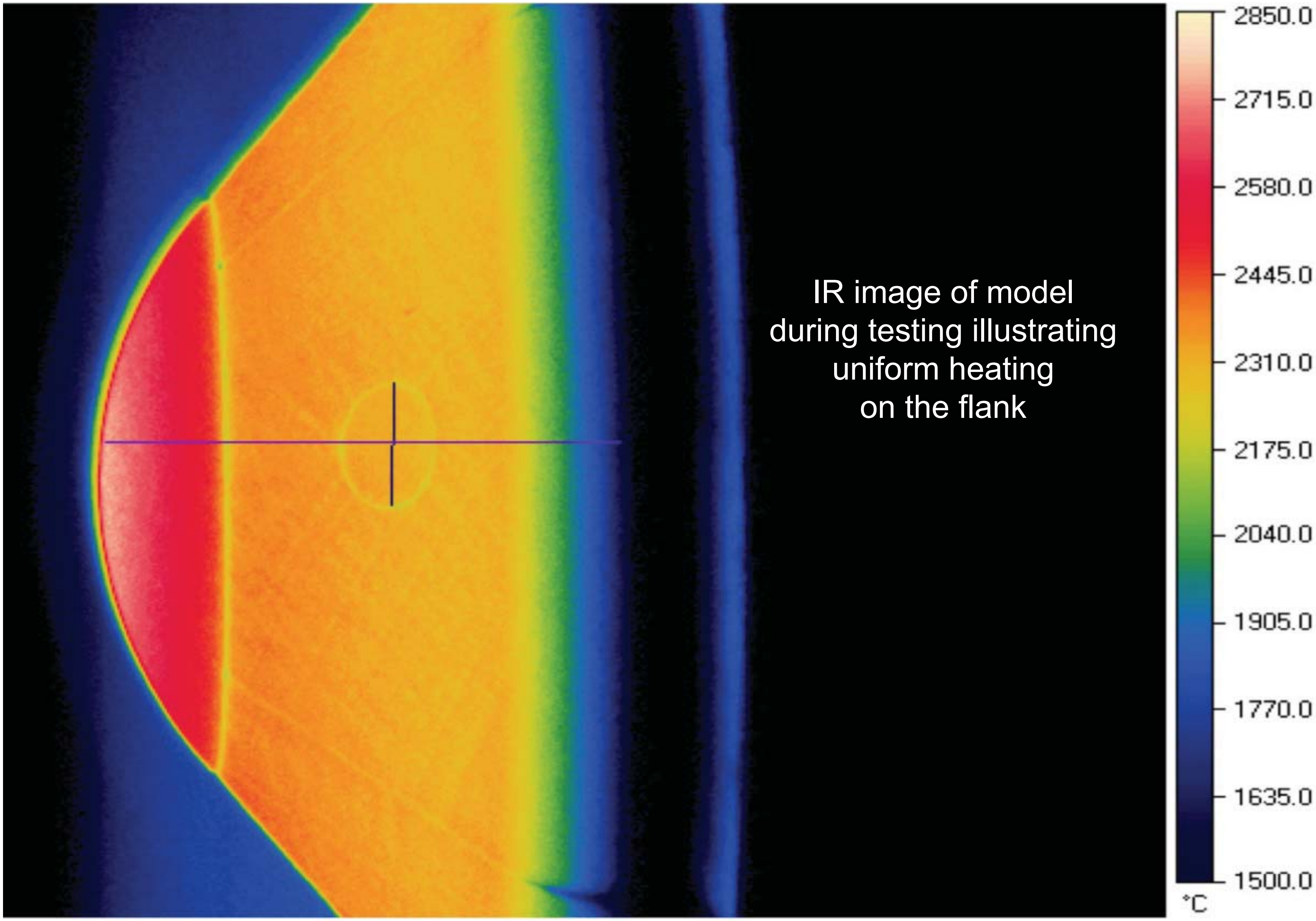
Models During Testing





CA250

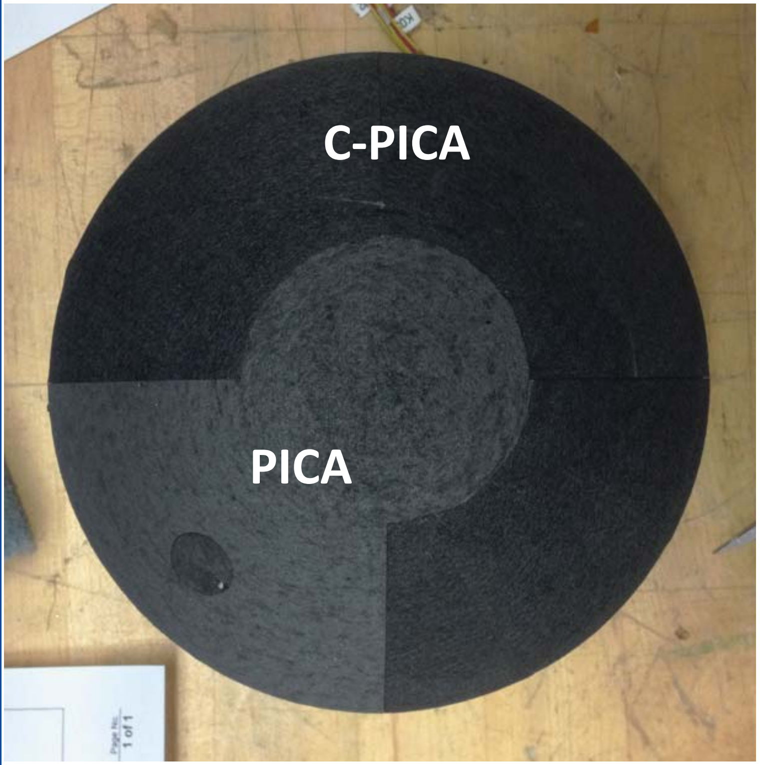
Model During Testing @ 400 W/cm^2 on flank



CA250

Post-Test – 400 W/cm^2, 30 sec

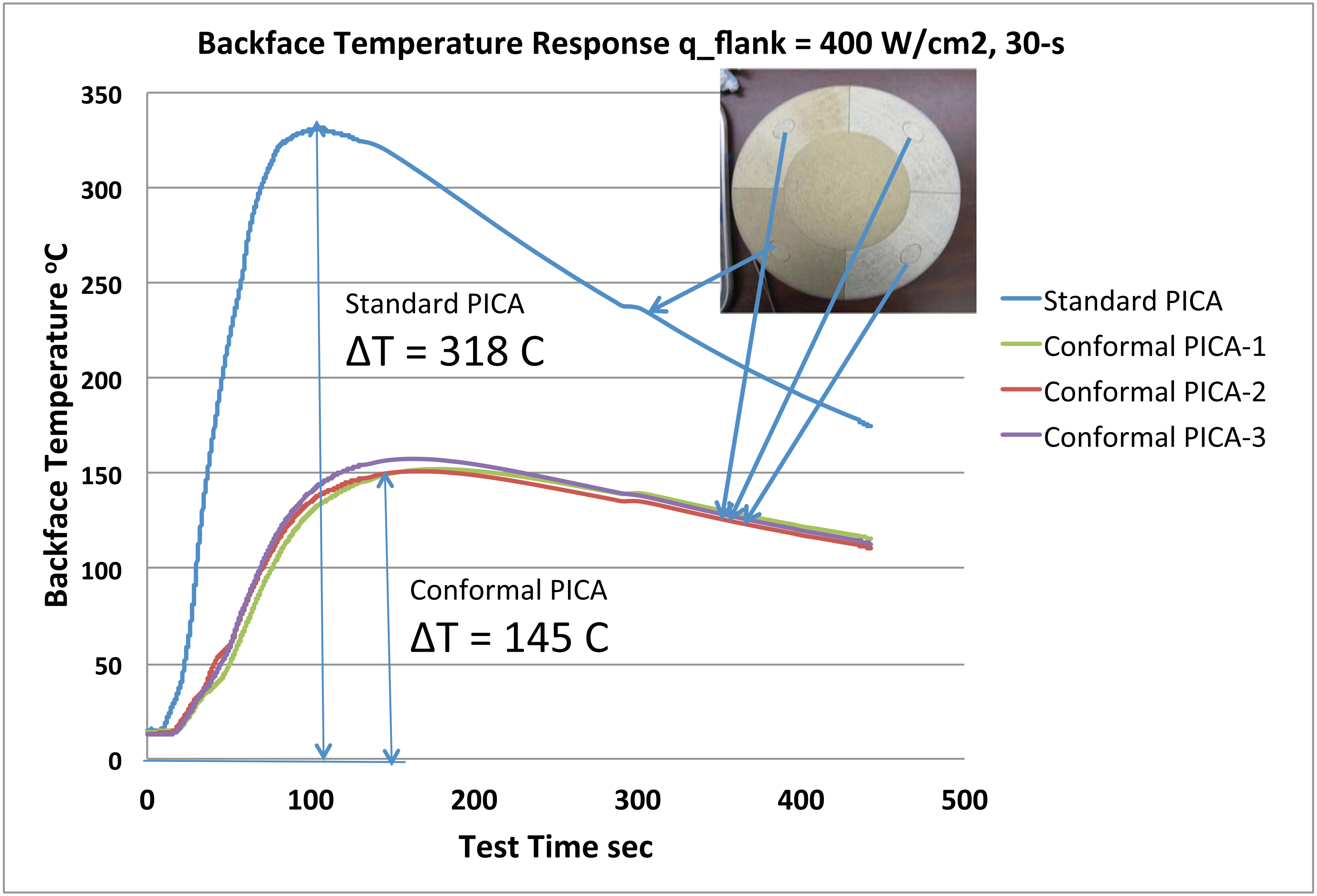
CA250



Thermal Response Model

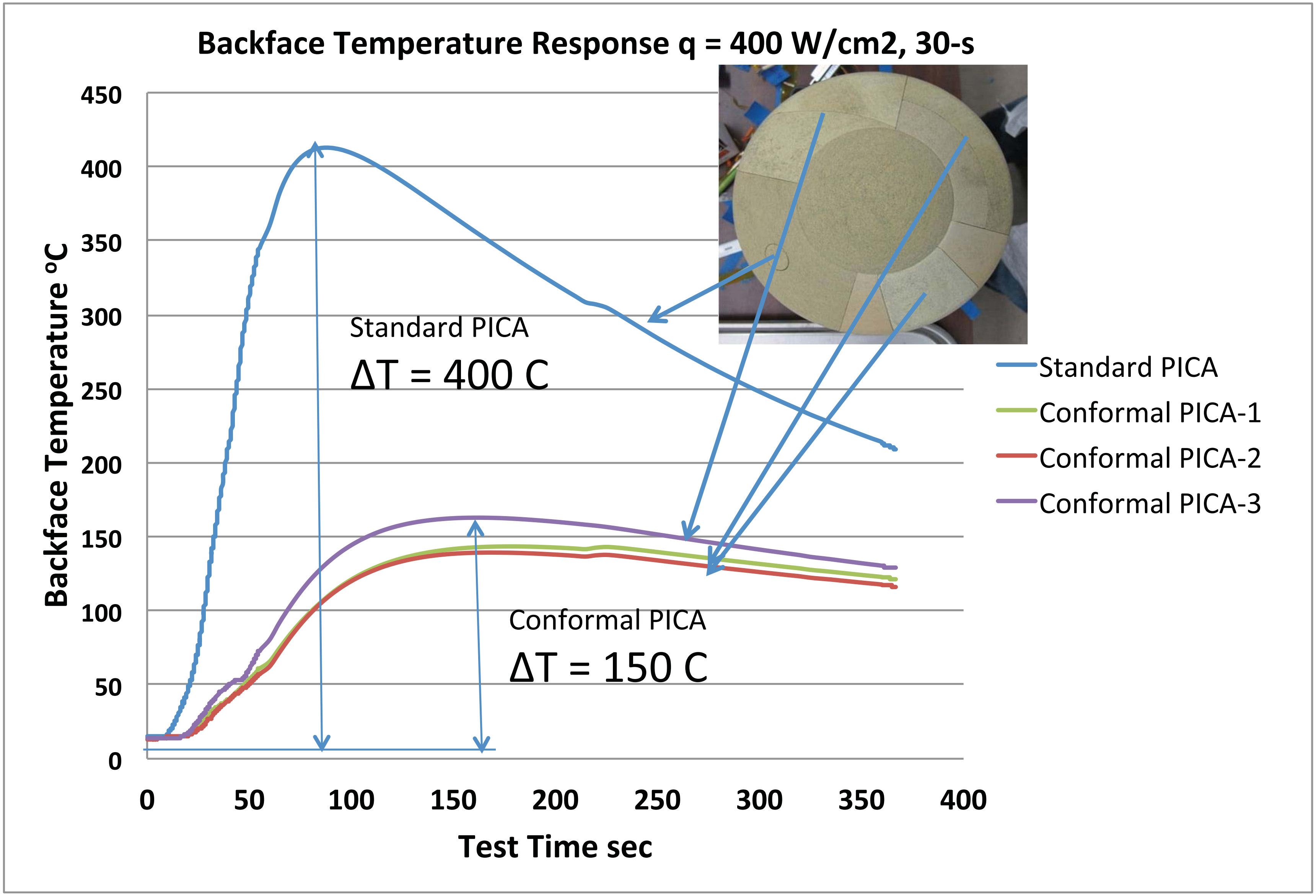
Seam Model

Backface Temp – TR Model



CA250

Backface Temp – Seam Model



CA250

CA250

Post-Test Thermal Response

	400 W/cm^2 – 30 sec.				
	Surface Temp	PICA		C-PICA	
		0.30”	0.50”	0.30	0.50”
Temp C	2361	1039	373	677	151
Std. Dev.	25	124	57	23	9

	180 W/cm^2 – 60 sec.				
	Surface Temp	PICA		C-PICA	
		0.30”	0.50”	0.30	0.50”
Temp C	1945	1222	513	1028	215
Std. Dev.	27	57	76	24	15

	150 W/cm^2 – 80 sec.				
	Surface Temp	PICA		C-PICA	
		0.30”	0.50”	0.30	0.50”
Temp C	1924	1378	683	1158	273
Std. Dev.	22	29	1	45	18

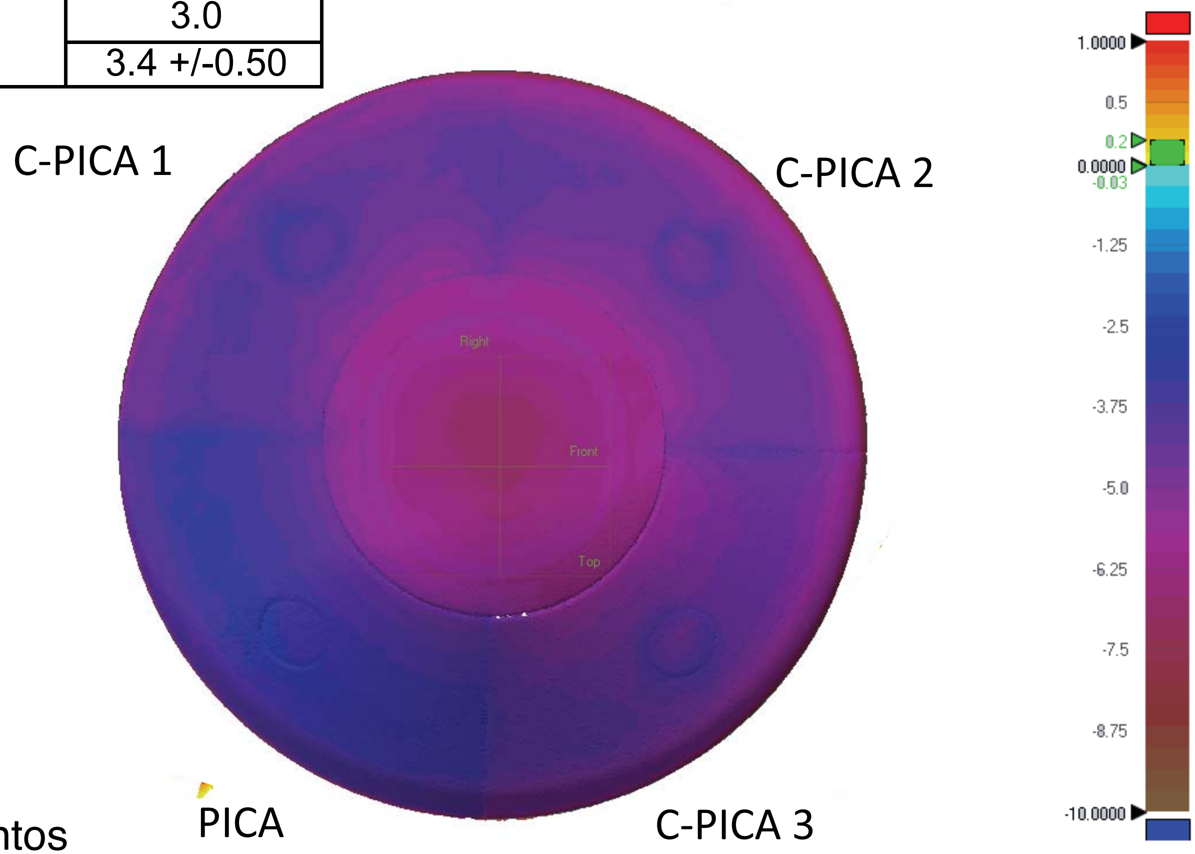
	40 W/cm^2 – 100 sec.				
	Surface Temp	PICA		C-PICA	
		0.30”	0.50”	0.30	0.50”
Temp C	1374	966	485	628	213
Std. Dev.	15	66	14	33	10

*TC’s at 0.15-in not listed as they all burned out

Post-Test Recession

Material	Heat Flux (W/cm^2)	Exposure Time (s)	Recession* (mm)
PICA	400	30	2.8
C-PICA			3.5 +/-0.17
PICA	180	60	4.1
C-PICA			4.7 +/-0.04
PICA	150	80	4.0
C-PICA			4.7 +/-0.37
PICA	40	100	3.0
C-PICA			3.4 +/-0.50

Laser Scan of Post-Test Model

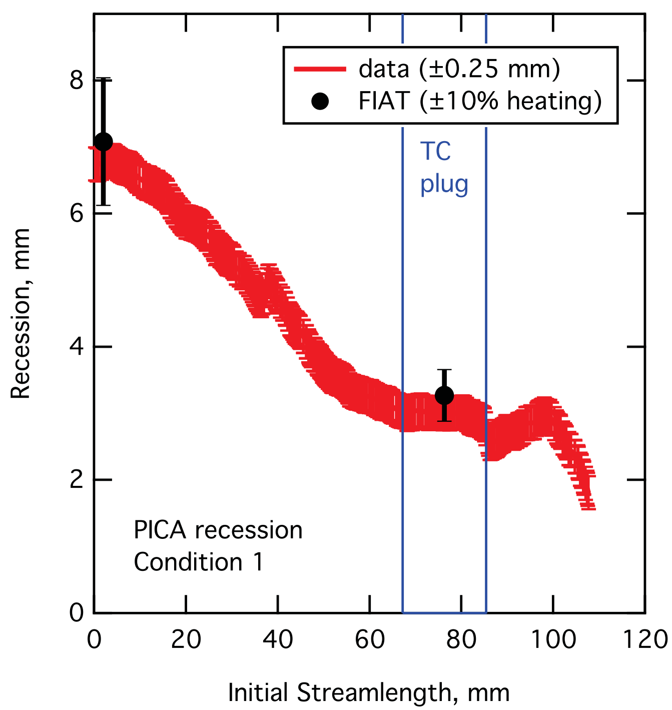


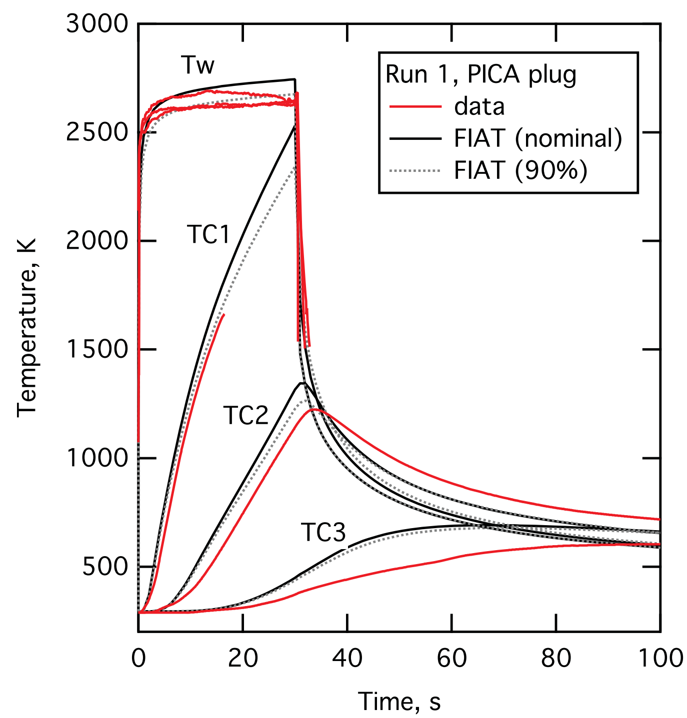
CA250

PICA Calculations – Condition 1

- **FIAT run with ±10% of nominal heating**
  - Recession was ok at both nose and TC plug
  - Temperatures matched fairly well for Tw, TC1, and TC2
  - Could not match time TC3 response in this test series

*Temperature predictions for nose <u>not</u> shown (no data acquired)



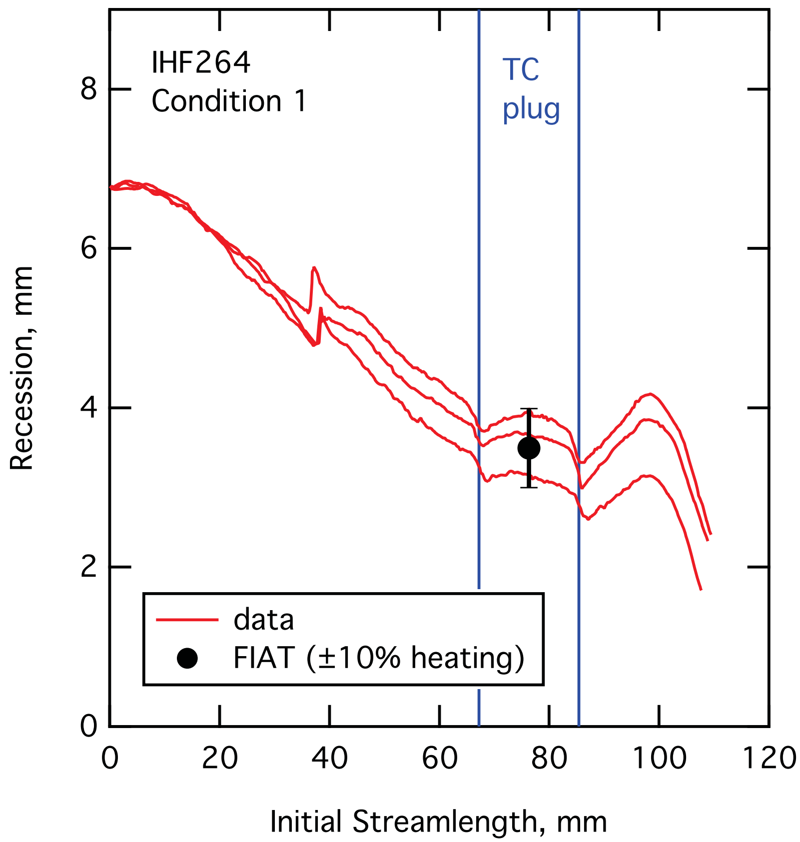


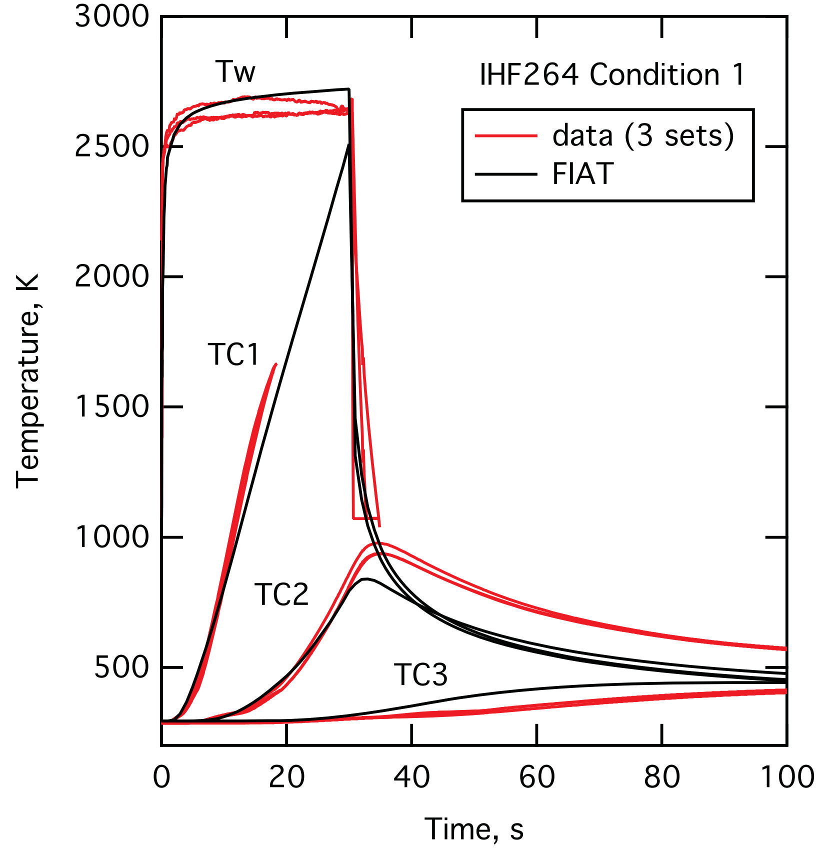
CA250

CPICA – Condition 1

CA250

- Recession, Tw, and TC1 match model well
- Model a bit low for TC2, but high for TC3





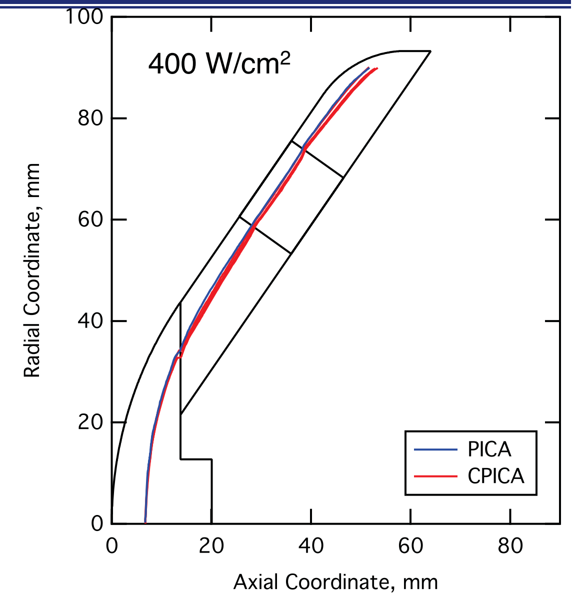
Summary

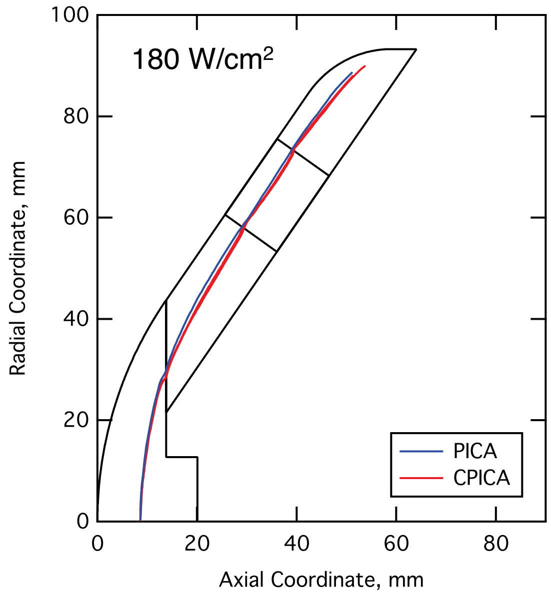
- Fabricated CPICA using commercially available carbon felt
- Demonstrated applicability of CPICA on a curved structure at range of conditions from 40-400W/cm^2
  - MSL-heat flux, pressure and shear
- Demonstrated advanced instrumentation of CPICA and gathered in-situ temperature & recession data in a representative shear environment
- Evaluated 5 seam designs between CPICA gores
  - All designs performed well
  - TPS performance not affected by any particular seam design
- CPICA material response model created based on new arcjet and thermal property data
  - Developed a mid-fidelity model that compares favorably with recession and temperature data
  - Errors tend toward over-prediction of surface recession and/or in-depth temperature, to be investigated

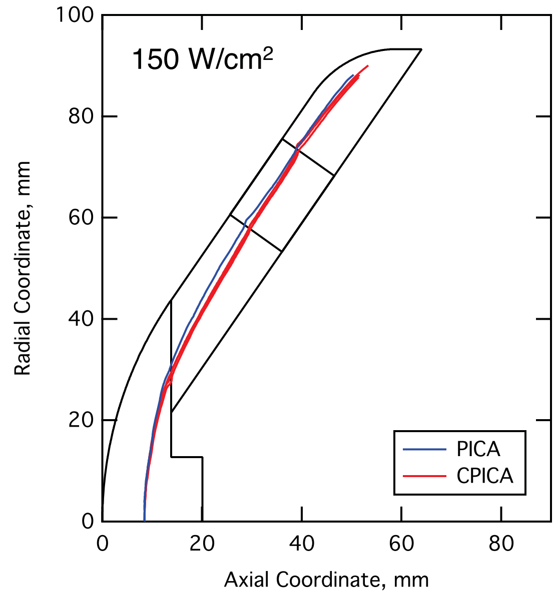
CA250

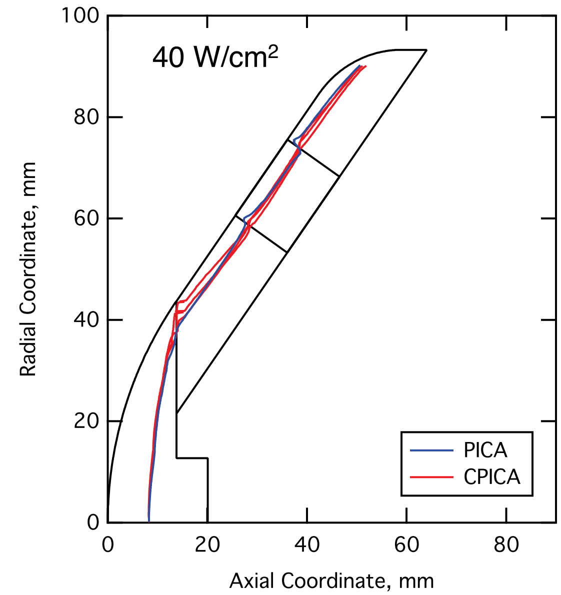
Initial and Ablated Shapes

- Models were scanned to get post-test shape in bisecting plane of each quadrant
- Although shape change around nose is significant, did not affect conditions on flank



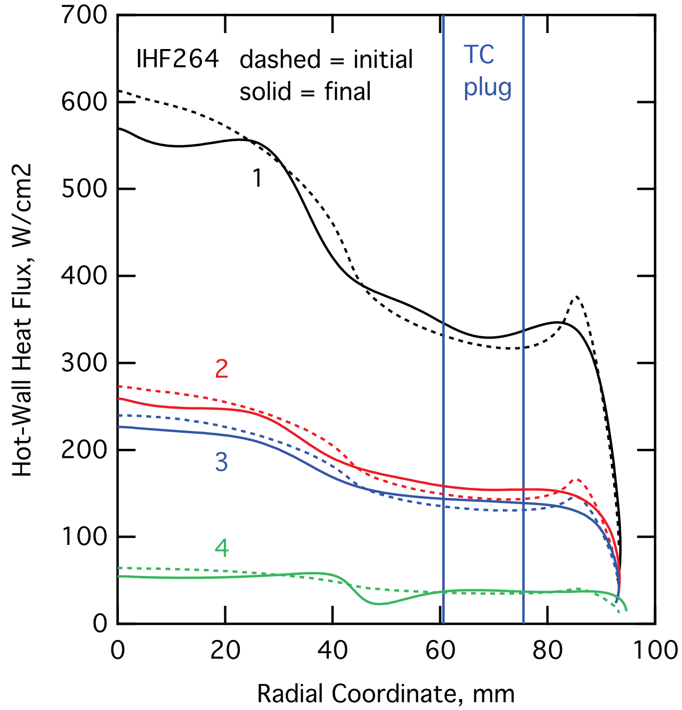


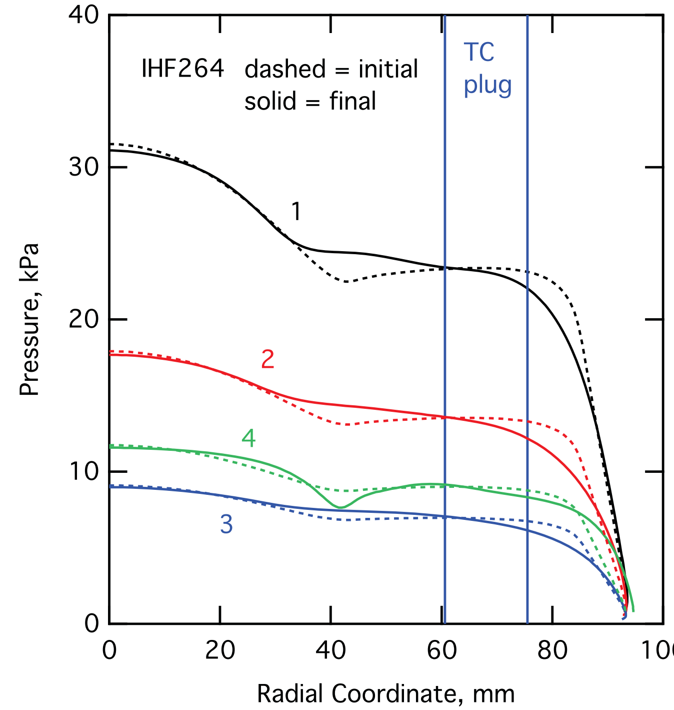




DPLR – Pre & Post-Test

- **For each arc jet condition, DPLR was run using the initial shape and the smoothed final shape**
  - Results show only a small change in pressure and heat flux at the TC plug as a result of shape change





CA250

CFD - Dinesh Prabhu