Space Technology Mission Directorate
Game Changing Development Program

National Aeronautics and Space Administration

Boeing: Arc Jet Exposure of Ablative Non-Oxide CMC TPS for Planetary Probe and Sample Return Applications

NASA making its unique testing facilities available to promote commercial space.

STATUS QUO

Several heritage TPS materials have limitations of high fabrication and installation costs as well as raw material obsolescence issues (closed factories, environmental protection rules)

NEW INSIGHTS

- Lack of sufficient TPS options can be mission limiting therefore this work offers a risk mitigation in demonstrating an alternative to aging and potentially obsolete heritage TPS materials such at SLA, Avcoat and C/SiC
- New technologies utilize advances in TPS fabrication techniques and resin systems and sustainable approaches that are not dependent on NASA to maintain

PROBLEM / NEED BEING ADDRESSED

Development of new TPS materials that can replace old heritage systems which suffer from high fabrication and installation costs as well as raw material obsolescence issues

TASK DESCRIPTION/APPROACH

- NASA provided arc jet sample design & CFD support and arc jet test time of stagnation and shear models
- Boeing provided 3 commercial TPS materials for NASA testing:
  - BLA: medium density ablator for low heat flux applications
  - BPA: medium density ablator for moderate to high heat flux applications
  - Non-oxide high temperature ceramic composite for structurally integrated TPS (SITPS)
- NASA oversaw arc jet model testing and data transfer to Boeing

QUANTITATIVE IMPACT

- Developing and certifying new TPS materials is costly and requires access to unique facilities
- Expanded commercial TPS material options allowing NASA and industry to improve understanding of TPS performance for planetary probe and sample return applications

TASK GOAL

- Verify the performance of commercially made TPS materials in a relevant entry environment via arc jet testing and thereby increase the TRL of these new systems from 3 to 4.

Technology Infusion Plan:

BLA №18 baselined on CST-100 under Commercial Crew Program. Potential applications for BLA and BPA for planetary exploration: Mars, Venus, Earth Return

Boeing Families of Ablators

Boeing Lightweight Ablator (BLA)

- BLA № 18
  - Medium density w/thermal additives
  - Baselined on CST-100
- BLA № 21
  - Higher density w/thermal additives
- BLA № 22
  - Higher density (no additives)

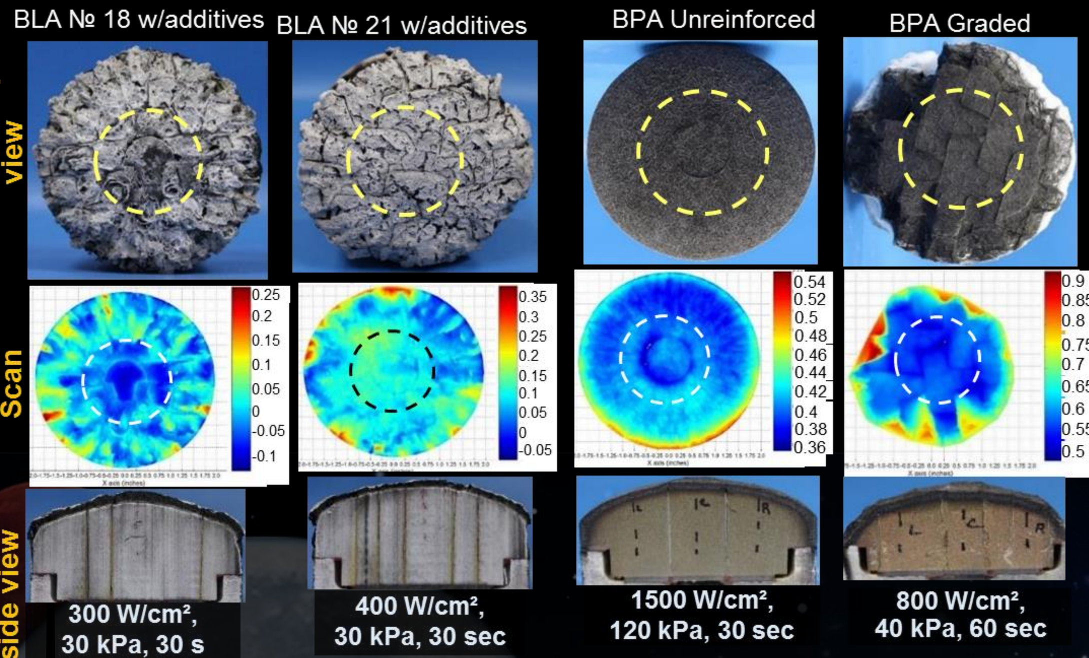
Boeing Phenolic Ablator (BPA)

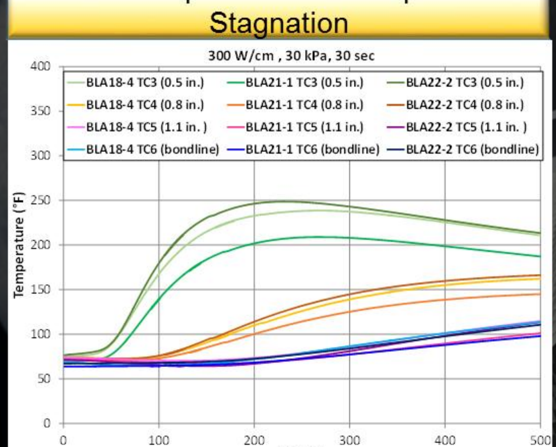
- Standard (BPA-S)
  - Medium density in reinforcement core
- Graded Density (BPA-G)
  - Low bulk density in reinforcement core
- Unreinforced (BPA-U)
  - Medium density (no core)

Ablator Test Matrix

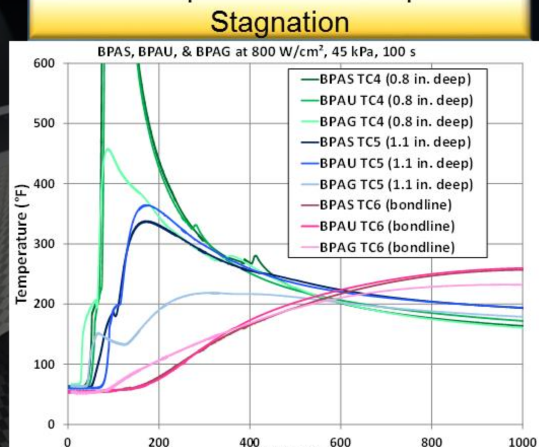
	Heat Flux (W/cm²)	Pressure (kPa)	BLA №18 1" core	BLA №18 3/8" core	BLA №21 1" core	BLA №21 3/8" core	BPA-S	BPA-U	BPA-G
Stagnation	130	30	x						
	200	30	x						x
	300	30	x		x				
	400	30			x				
	450	50						x	x
	600	40						x	x
	800	40					x	x	x
	1000	50						x	x
	1500	120					x	x	x
Shear	150	20	x	x					
	400	30			x	x	x	x	x

Ablator Stagnation Test Results





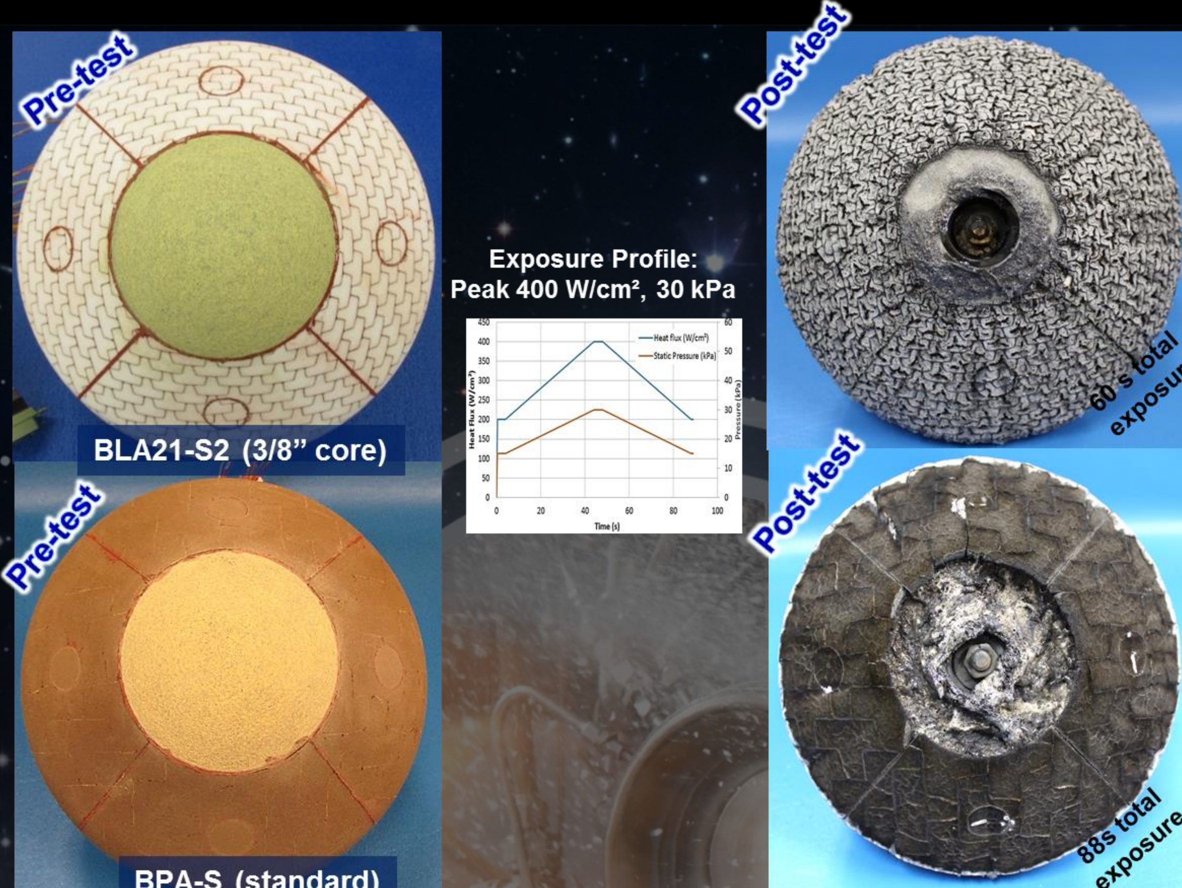
- Higher density formula with additives shown to result in lowest bondline temperature



- Graded density configuration offers better insulation as well as weight savings

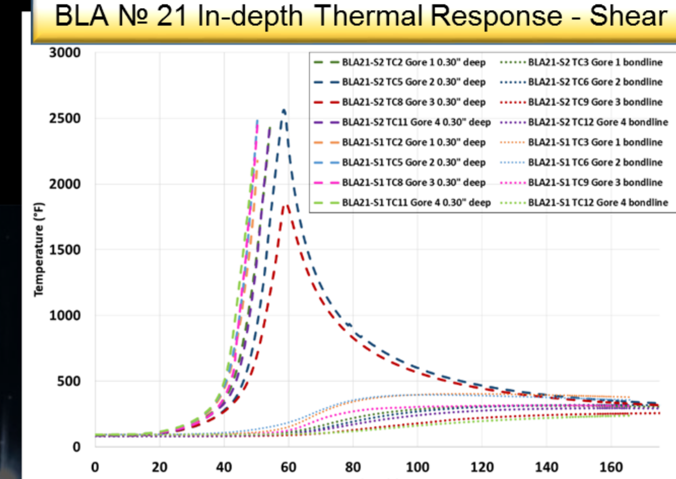
Ablator Shear Test Results

Ablator Sphere-cone Articles – Pre-test

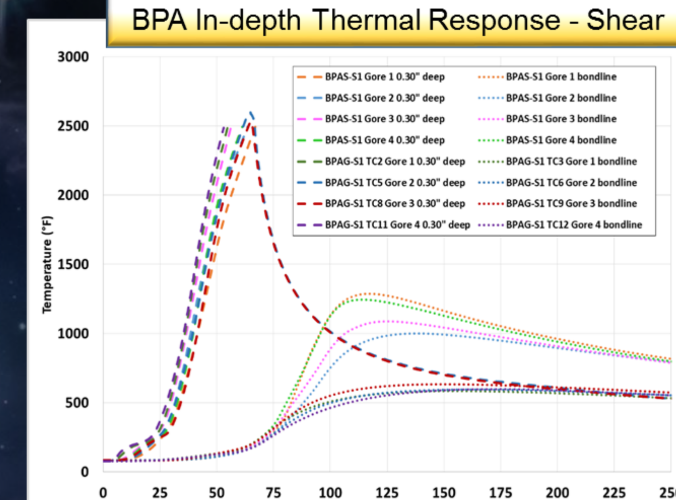


Shear In-depth Temperature Response

- Risk of configuration-induced flow anomalies in wedge holder retired by changing test article geometry
  - Sphere-cone configuration eliminated cooled holders and adjacent dissimilar materials
  - Ablator recession was more uniform without unexpected channeling on all materials
- PICA nose cap receded due to long ramp to temperature
  - CFD showed little effect on conditions on ablator flank
  - Useful data collected on most test articles despite PICA recession



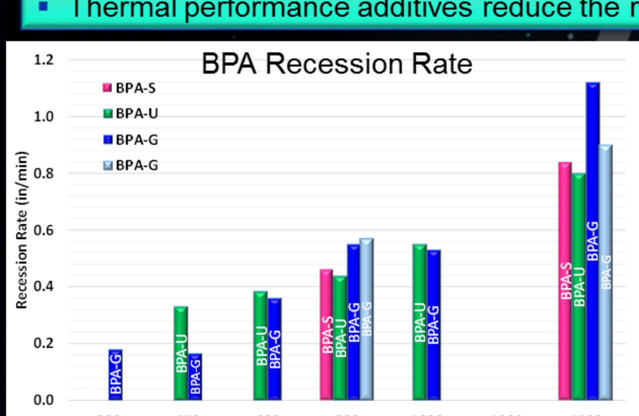
- Smoother char surface with 3/8" core in BLA
- Minimal difference in in-depth temperatures for 2 core sizes

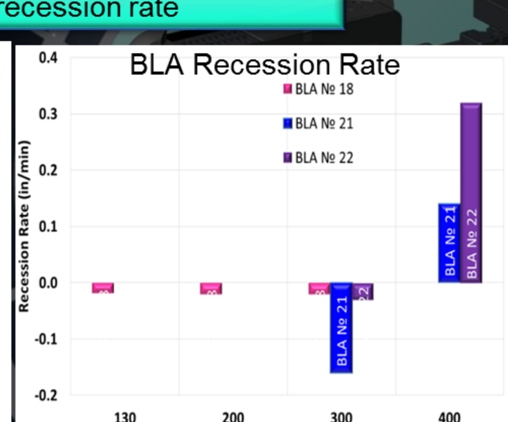


- Graded density and unreinforced BPA withstood shear as well as standard configuration
- Lower in-depth temperatures observed for graded density configuration

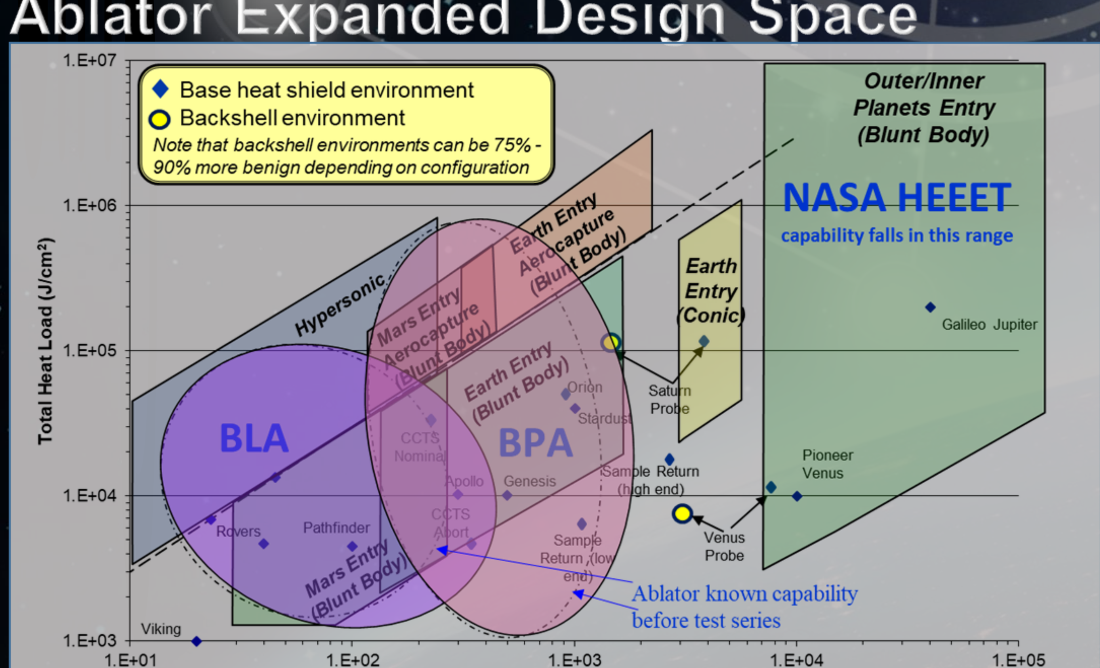
Ablator Recession

- BPA Recession rate has expected dependence on heat flux
- Unreinforced BPA material recesses same amount as reinforced configurations - unexpected.
- BLA material swell prior to charring is equal to or greater than char layer recession under 400 W/cm² = no recession
- At 400 W/cm² BLA char layer recession exceeds material swell
- Thermal performance additives reduce the recession rate





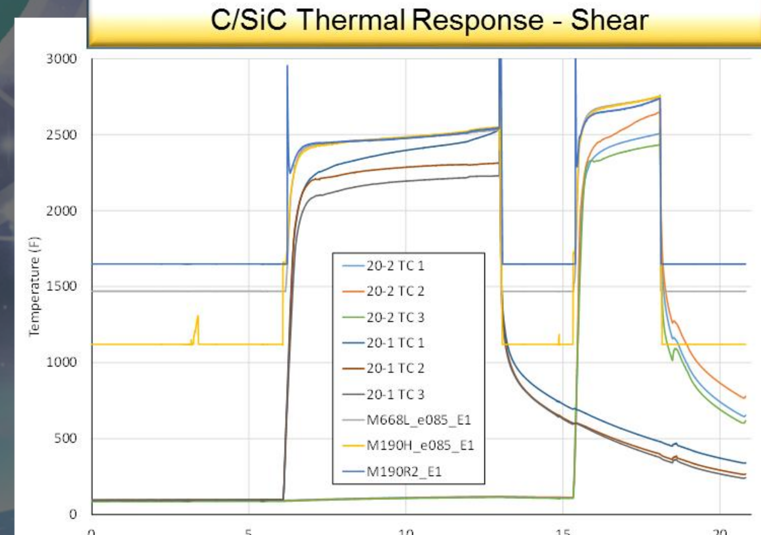
Ablator Expanded Design Space



Carbon/SiC Laminate Shear Tests

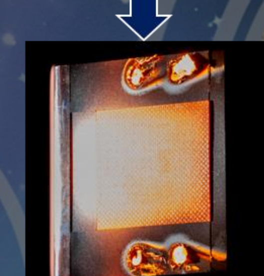
C-SiC Test Matrix

Sample ID	Pyrometer Temp (°F)	Exposure Duration (s)	Avg Heat Flux (W/cm²)	Avg Press (kPa)
19-1	2596	300	74	2.8
19-2	2690 2845	60 60	93 111	4.1 4.8
20-1	2845	415	-	-
20-2	2505	167	93	4.1
20-3	2728	135	93	4.1
20-4	2711	90	111	4.8



19-1: 2600°F, 300 sec 74 W/cm², 2.8 kPa

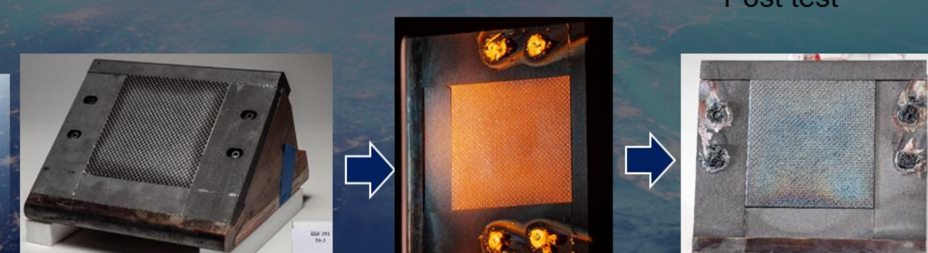
Pre test



In-test

Post test

20-3: 2700°F 135 sec 93 W/cm² 4.1 kPa



Pre test In-test Post test

Boeing TPS Material Capabilities Expanded

Successful arc jet testing to planetary probe and sample return mission relevant conditions completed

- The design space for the BLA family of materials has been expanded to heat flux up to 500 W/cm² and heat loads up to 12 kJ/cm²
  - Capability to withstand shear loads up to 370 Pa
  - Density and reinforcement core size can be tailored to mission applications
- The scalable BPA 2017 formulation has been verified for heat flux up to 1500 W/cm² and heat loads up to 80 kJ/cm²
  - Capability to withstand shear loads up to 250 Pa has been demonstrated
  - Advanced TRL of new formulation
  - Graded density configuration reduces bulk density by 26% while maintaining similar thermal capabilities
  - Reinforcement configuration can be selected based on application requirements
- Advanced the TRL of Boeing fabricated C/SiC laminate materials through successful testing at conditions representative of hypersonic flight for approximately 7 minutes
  - Longer duration testing suggested for future efforts
  - Alternative material to graphite edge closeouts will need to be used due to erosion during long durations

Annual Program Review at NASA Glenn, Task Poster Session September 26, 2018

Boeing PIs: Michelle Chaffey, Jon Courter NASA Representative: Susan White