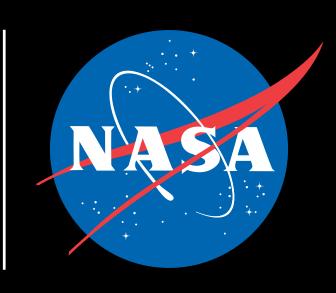
Space Technology Mission Directorate Game Changing Development Program

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.

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

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

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

 NASA oversaw arc jet model testing and data transfer to Boeing

TPS (SITPS)

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

- 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
- 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.

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

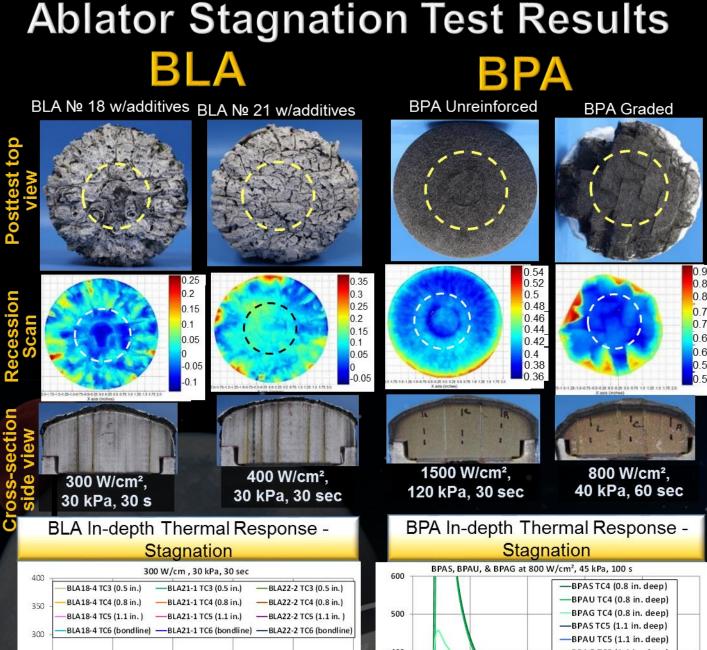
 Higher density (no additives) **Boeing Phenolic Ablator (BPA)**

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)



		ADIATO	1000	MIGITI	_					
		Pressure	BLA N±18		BLA N⊵21		92	7	ų	
	Heat Flux [W/cm²)	(kPa)	1" core	3/8" core	1" core	3/8" core	BPA-S	BPA-U	BPA-G	
sar Stagnation	130	30	х							
	200	30	x						×	
	300	30	х		х					
	400	30			х					
	450	50						x	х	
	600	40						х	х	
	800	40					х	х	х	
	1000	50						x	х	
	1500	120					х	x	х	
	150	20	×	x						
Shear	400	30			х	x	x	х	х	



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

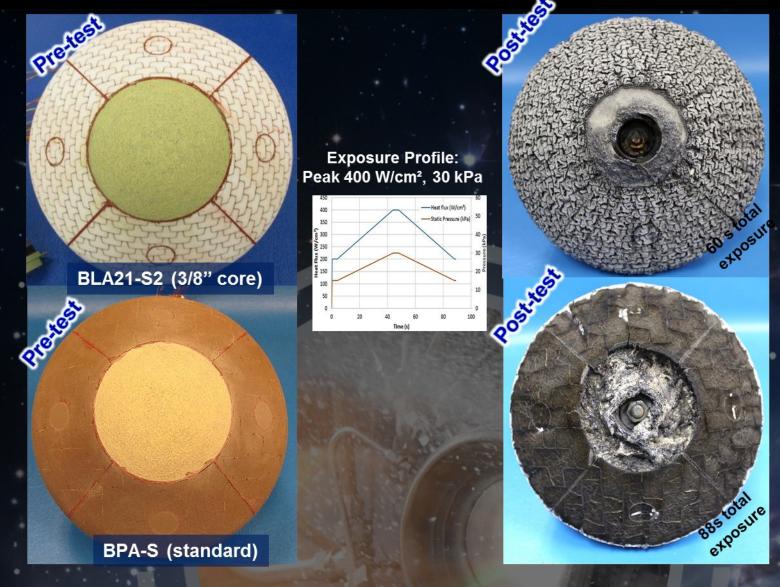
BPAG TC5 (1.1 in. deep) -BPAS TC6 (bondline) BPAU TC6 (bondline)

Graded density configuration offers better insulation as well as weight

Ablator Shear Test Results



Ablator Sphere-cone Articles - Pre-test



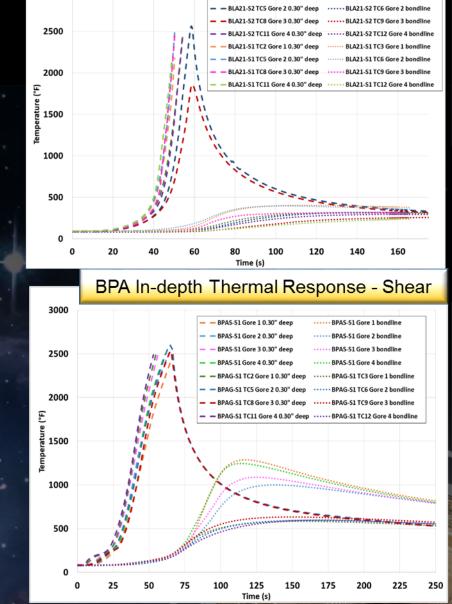
· Risk of configuration-induced flow anomalies in wedge holder retired by changing test article geometry

Shear In-depth Temperature Response

- · 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

BLA № 21 In-depth Thermal Response - Shear

· Useful data collected on most test articles despite PICA recession



Smoother char surface

Minimal difference in in-

depth temperatures for

2 core sizes

with 3/8" core in BLA

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/cm²BLA char layer recession exceeds material swell Thermal performance additives reduce the recession rate
- **BPA** Recession Rate **BLA Recession Rate** ■ BPA-9 BPA-U ■ BLA № 22

Ablator Expanded Design Space Base heat shield environment Planets Entry Backshell environment (Blunt Body) Note that backshell environments can be 75% 90% more benign depending on configuration NASA HEEET pability falls in this range Ablator known capability before test series 1.E+02 1.E+03 1.E+04 1.E+05 Peak Heat Flux (W/cm²)

Carbon/SiC Laminate Shear Tests

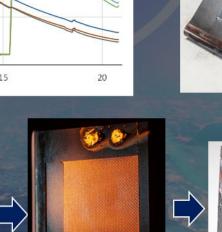
C-SiC Test Matrix

	O-SIO TEST WATTA						19-1. 2000 1 ,		
	Sample ID	Pyrometer Temp (°F)	Exposure Duration (s)	Avg Heat Flux (W/cm²)	Avg Press (kPa)		300 sec 74 W/cm², 2.8 kPa		
-	19-1	2596	300	74	2.8	Sec. 1			
1:	19-2	2690 2845	60 60	93 111	4.1 4.8				
N.	20-1	2845	415	= 0	-		NI JO		
	20-2	2505	167	93	4.1			F	
	20-3	2728	135	93	4.1		Pre test		
	20-4	2711	90	111	4.8				
3000		C/SiC TI							
Temperature (F) 2000 2000			-20-2 TC 1 -20-2 TC 2 -20-2 TC 3 -20-1 TC 1				In-test	des laminas con	
1000 500			—20-1 TC 2 —20-1 TC 3 —M668L_e08 —M190H_e08	JC21					

20-3: 2700°F 135 sec 93 W/cm² 4.1 kPa

Pre test

-M190R2_E1





Post test



requirements

 Advanced TRL of new formulation Graded density configuration reduces bulk density by 26% while maintaining similar thermal capabilities

Capability to withstand shear loads up to 250 Pa has been demonstrated

The scalable BPA 2017 formulation has been verified for heat flux up

Successful arc jet testing to planetary probe and

sample return mission relevant conditions completed

• Density and reinforcement core size can be tailored to mission applications

• 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

to 1500 W/cm² and heat loads up to 80 kJ/cm²

Boeing TPS

Capabilities

Expanded

- Reinforcement configuration can be selected based on application
- 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