Conformal Ablative Thermal Protection Systems (CA-TPS) for Venus and Saturn Backshells

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1: Background

CA-TPS: The Problem – The Solution

The Problem

- NASA requires TPS ablator advances (TA14.3.1) to significantly lower the areal mass of TPS concepts, demonstrate high entry environment capability, demonstrate high reliability, demonstrate improved manufacturing consistency and lower cost
  - Current SOA materials require complicated installation techniques and/or high touch labor costs

SOA

- Limited number of certified TPS materials available
- PICA tile on rigid heatshields is limited by small size billet manufacturing and low strain-to-failure resulting in high tile count and gaps with filler designs
- Honeycombed concepts (AVCOAT) require extensive touch-labor, large curing ovens, and complicated NDE

MSL: 113 PICA Tiles

MSL: 27 different tile drawings

EFT-1 Orion: ~320,000 cells filled by hand

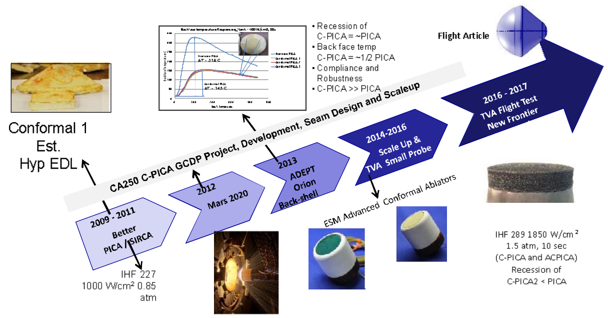
The Solution

- Develop a high strain-to-failure TPS capable to ~250 W/cm2 to allow for easier application and reliable thermal protection
  - Successfully tested at **~400 W/cm2 in shear**
  - Successfully tested at **1850 W/cm2, 1.5 atm in stagnation**
- Utilizing flexible reinforcement, parts can be molded and then infused, resulting in a near-net shaped composite with higher strain-to-failure and lower thermal conductivity than SOA materials made on a rigid reinforcement and machined to shape
  - New material can be made in larger sizes, directly bonded to a wide selection of aeroshells without the need for strain isolation pads or gap fillers (reduced installation costs)

2: Key Performance Parameters

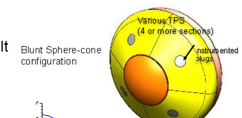
Conformal Ablators Key Performance Parameters	Category *Definition*	State-of-the-Art Value	TRL 5 Threshold/ Goal	Justification
KPP-C1	**Survivable for MSL-like and COTS aerothermal environments** *Capability required for future Mars and COTS missions*	PICA: >250 W/cm , 0.33atm, 490 Pa shear	250 W/cm2 / >500 W/cm2	Current goal for Conformal Ablator is to meet MSL-like conditions while satisfying COTS heat shield conditions
KPP-C2	**Strain to Failure** *Material property that provides an indication of compliance when bonded to an underlying structure*	PICA (<<1%) Avcoat (~1%)	>1% / > 2%	High strain to failure and use of felts for substrates enables factor of >10 reduction in heat shield parts count
KPP-C3	**Manufacturing Scalability** *Assesses the likelihood that the technology concept will successfully scale to the large sizes required by mission architectures*	20" x 40" PICA max tile size (1m cast monolithic)	1m x 1m / 2m x 2m	Eventual application will require large panels, seams, and close-outs. Heat loads define ablator thickness. The MDU, arcjet testing, and analysis will prove scalability of the ablator to full scale
KPP-C4	**Response Model Fidelity** *Ability to reliably and repeatably predict the thermal response of the material to the applied environments*	Mean: bias error 30%, Time to peak error: 30% Recession error: 150%	Mean bias error < 40% / 10% Time-to-peak error < 40%/ 10% Recession error < 50% / 25%	Working from low to mid to high fidelity models - need the ability to estimate thicknesses for target mission design

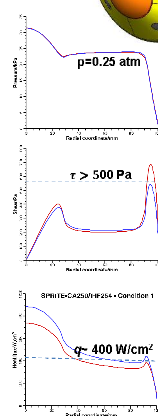
3: Conformal Ablator TPS Development

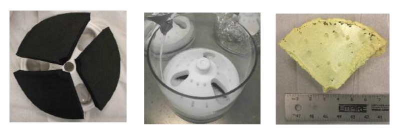


New TPS Shear Testing Approach

- Heritage shear test configurations (cooled-copper wedges) result in non-representative pressure gradients and often dissimilar flow fields
- New blunt sphere-cone (small probe) design results in flight-like gradients and similar flow fields
- Objectives of the test:
  - Demonstrate moldability of conformable ablators on a curved structure at MSL-type and COTS LEO conditions or beyond
  - Demonstrate advanced instrumentation of conformable ablators and measure in-situ temperature data for the development of a material response model
  - Gather recession and back-face temperature data on conformable ablators in a representative heating, pressure *and* shear environment for verification and validation of materials requirements.
  - Investigate different seam designs
  - Compare materials on a single arc jet model

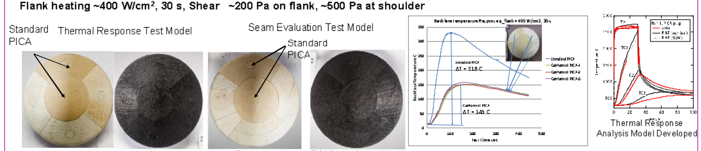






C-PICA has similar recession and much lower thermal penetration than PICA

Flank heating ~400 W/cm², 30 s, Shear ~200 Pa on flank, ~500 Pa at shoulder



All seams were well behaved, even 90° butt joints between test segments

C-PICA has much better performance in flexure testing than PICA

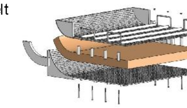
3-point bend tests | **4-point bend tests**

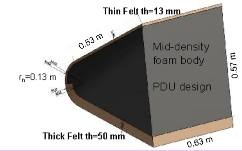
Felt Scale-up successful for thick C-PICA – 4" Rayon Felt yields ~3" Carbon Felt

- State of the art for carbon felt ~1.0-in thick, density 0.8-1.0 g/cm³ resulting in ~0.5" finished part
- Desire for thicker and higher density felt led to working with a felt vendor to make 4" rayon-based white goods, which would carbonize to ~3"

5: Demonstration of Scale-Up of C-PICA

- **Part scale up – Design and build a prototype demonstration unit (PDU)**
  - Objective is to demonstrate scale up of impregnation for different felt thicknesses, handling, machining and assembly of large parts
  - Metallic molds designed and fabricated
  - First large, thick felt part produced for evaluation
  - Changes recommended and second part underway



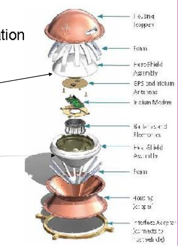


Removing Part from the Mold

Cores removed for material evaluation

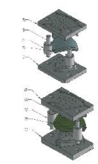
6: Conformal Ablator Mission Infusion – Small Probe Development with Terminal Velocity Aerospace

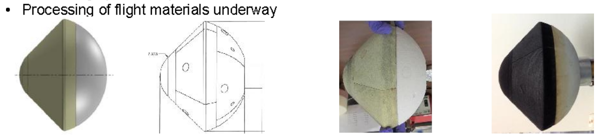
- Small probe vehicle designed for break-up evaluation
- TVA responsible for entire design
  - Ames responsible for TPS selection, sizing, manufacturing, instrumentation and installation for initial arc jet models and test flight vehicles
- Ames hardware
  - Backshell TPS bonded to carrier structure
    - RF transparent Silica/silicone (C-SIRCA)
    - In-depth instrumentation included
  - Heatshield TPS bonded to carrier structure
    - C-PICA
    - In-depth instrumentation included
- Remaining hardware is TVA's responsibility
- Designed for heating at ~400 W/cm² on the nose, 200 W/cm² on the flank, 20 W/cm² on backshell
  - Heatshield thickness ~0.9" (using thick felt)
  - Backshell thickness ~0.35"
- Flight manifest: from Station in late FY16



Progress to date:

- Vehicle and arc jet test article configuration iterations completed
  - Trajectory analyses performed, environments defined, TPS sizing completed
- TPS parts designed for arc jet and flight
- TPS processing molds designed and manufactured
- Segments for arc jet test articles processed, machined, instrumented, assembled and tested
- Processing specs completed
- Processing of flight materials underway





Flight Article Design | Arc Jet Model Design | Arc Jet Model – Pre-test | Arc Jet Model – Post-test

7: Work to Go: Advancing C-PICA from TRL5 to TRL6 for New Frontiers Venus Backshell Applications

- Why C-PICA for backshells?
  - Pioneer-Venus used a material called ESM - no longer made. Backshell heating should be ~250 W/cm² to require a capable ablator– alternates: PICA, C-PICA, PhenCarb, BPA
  - C-PICA is very mass efficient, with high strain to failure easier to integrate unlike PICA, and use of RTV as the gap-filler will meet the requirements of integration. Molded to shape is another big advantage. Large panels will reduce the cost of touch labor and integration challenges.
- TRL 5 to 6 will be minimal
  - MDU with curved panels, structural testing, moderate amount of testing for thermo-structural properties and tailored arc jet testing for qualification
  - Large curved panel molding and resin infusion, machining and integration to achieve desired gap width tolerance.
  - Can be accomplished in 1-2 years.

8: Acknowledgements

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- Arc jet testing performed by the NASA Ames TSF Branch
- Thick rayon felt manufactured by American Felt and Filter Company (AFFCO) and carbonized by Fiber Materials Inc (FMI)
- Scaled panel processed by the Ablatives Laboratory at Applied Research Associates Inc.