Conformal Ablative TPS for New Frontier Venus and Saturn Missions - A New Technology Solution in Development

Ethiraj Venkatapathy
Robin A. Beck
NASA Ames Research Center.

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Pioneer-Venus back shell used an ablative TPS known as “ESM”
- Unsupported chemically foamed, fiber filled RTV silicone elastomer with density of $35 \pm 3 \text{ lb/ft}^3$
- Found no evidence that ESM has been made or used since P-V

Venus in situ missions, depending on design and entry parameters, could experience $\sim 250 \text{ W/cm}^2$ of heat-flux on the back shell
- Tiled PICA for MSL is designed for $\sim 250 \text{ W/cm}^2$ (seams and gap filler)

The goal of Conformal Ablative TPS Project is to make an ablative TPS material that is more mass efficient with better mechanical properties

Conformal TPS material development success to-date
- More mass-efficient than flight tested PICA by $\sim 40\%$
- Better mechanical properties (higher strain to failure) than PICA
- Robust for conditions relevant for Venus back shell
- Manufacturing scale-up in progress to make large molded panels
- Potential flight test in FY16/FY17 to provide data at relevant conditions for Venus missions and also ground to flight traceability

Lighter back shell means significant system mass savings

Advocacy from VEXAG for Conformal TPS to be offered as New Technology
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<th>Conformal Ablators Key Performance Parameters</th>
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| **KPP-C1**                                 | Survivable for MSL-like and COTS aerothermal environments  
*Capability required for future Mars and COTS missions* | PICA: >250 W/cm², 0.33 atm, 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: 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 |
Conformal Ablative TPS Advanced Arc Jet Testing
Thermal Response and Seam Behavior

Flank Heating ~400 W/cm², 30 s, Shear ~200 Pa on Flank, ~500 Pa at Shoulder

Thermal Response Test Model
Standard PICA

Seam Evaluation Test Model
Standard PICA

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

Thermal Response Analysis Model Developed
Conformal Ablative TPS Advanced Structural Property Testing

3-Point Bend Tests

- PICA failure < 360 lb, ROC ~ 18”
- Conformal failure > 1,200 lb, ROC ~ 35”

4-point bend tests

- PICA failure < 750 lb, ROC ~ 145”
- Conformal no failure at 1,500 lb, ROC < 65”

- Flexible reinforcement results in much better performance
Manufacturing Scale Up Efforts

- **Felt Scale-Up**
  - 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 carbonized to ~3”
  - C-PICA thick felt phenolic impregnation has been very successful

- **Part scale up – Design and build a Pathfinder 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

Removing Part from the Mold
Small Probe Development with Terminal Velocity Aerospace (TVA)

- Small probe vehicle flight vehicle design
- TVA responsible for entire design
  - Ames responsible for TPS selection and sizing
- Ames hardware
  - Backshell TPS bonded to carrier structure
    - RF transparent Silica/silicone (C-SIRCA)
    - In-depth instrumentation included
  - Heatshield TPS bonded to carrier structure
    - Conformal Ablative TPS
    - 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
Conformal Ablative TPS Mission Infusion Efforts

Arc Jet Test Article Design and Build
- Vehicle and arc jet test article configuration iterations completed
  - Trajectory analyses performed, environments defined, TPS sizing completed
- TPS parts designed
- TPS processing molds designed and manufactured
- Segments processed and machined
- Test articles assembled and ready for testing

Flight Article Design

Arc jet test article design

Arc jet test article

- TVA tested their mock-up in balloon-drop out of Tillamook, Oregon
  - Charred RF transparent conformal ablator flew
  - Transmission was successful
Conformal Ablative TPS Summary

NASA Ames Research Center has developed a conformal ablator that:

• Can deliver better overall performance than PICA and with less weight - every pound saved can increase science payload
  - Is more compliant than PICA
    • More robust to structural deflections
    • Should be able to be directly bonded to an aeroshell and installed without gap filler
  - Could be used on the backshells of high energy planetary entry vehicles
• Is not constrained to current manufacturing PICA dimensions and can deliver parts 1.5 x 1 m or larger, significantly reducing part count
• Will reduce installation “touch labor” and associated cost relative to PICA or AVCOAT
• Will be flight tested in late FY16 - early FY17

NASA will deliver a TRL 5 material capable of at least 400 W/cm² by the middle of FY16.