Ongoing TPS Development at NASA Ames Research Center

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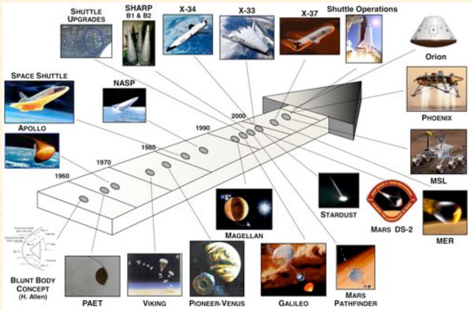
ARC TPS Legacy

- Every U.S. spacecraft that has entered the atmosphere has had some development or testing performed at NASA-Ames
- NASA-Ames is capable of handling all stages of TPS development from conception, material properties investigations, and modeling, to fabrication, testing and small scale end product delivery or technology transfer
- Ames is continually improving existing materials and developing new materials. This work will enable safer, faster missions for access to space and to explore the solar system



Some Examples of ARC Developed TPS

Tiles and Coatings

- Effort started in 1970's by ARC to provide NASA with TPS materials and processing expertise
- Successfully developed TPS materials including LI-2200, RCG, FRCI, Gap Fillers between RSI tiles, AFRSI, AETB, and TUFI that are used on all of the Orbiters
- Other surface treatment approaches and tile derived TPS concepts including HETC, TUFI-HT, ROCCI and TUFROC have been developed for higher temperature applications on future Reusable Launch Vehicles (RLVs)


Shuttle Flight Testing of LI-900/ RCG vs AETB-8/TUFI in Base Heatshield Undamaged After Three Flights

SIRCA

- SIRCA is an insulative, ablative TPS material that is machinable to custom shapes and applied directly to the spacecraft.
- SIRCA was developed in the1990s at NASA Ames, and was a TPS choice for Mars Pathfinder, X-34 and Mars '03
- Both Mars Exploration Rovers used SIRCA. For this mission NASA ARC:
  - performed afterbody aerothermal environment predictions.
  - manufactured 35 SIRCA billets for the Backshell Interface Plate & Transverse Impulse Rocket System (TIRS) Cover TPS
  - performed arc jet testing & SIRCA thermal response analyses


Arc Jet test of SIRCA TIPS Cover at NASA ARC

PICA

- PICA was developed at NASA ARC in the 1980s. PICA's low density (~ 0.27g/cm^3), coupled with efficient ablative capability at high heat fluxes, made it an enabling technology for the Stardust mission.
- At the time of the Stardust mission, PICA was a developmental material, with no previous flight heritage. NASA ARC transferred the PICA process to Fiber Materials, Inc. (FMI) & the PICA heatshield was manufactured at FMI
- A tiled PICA heatshield is used on MSL and is a backup TPS option for CEV

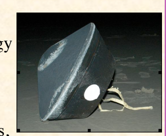


Image of the sample return capsule post flight with PICA as the forebody TPS.

New Materials Development Approaches

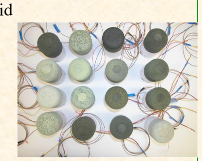
- NASA Ames is focused on qualifying and certifying TPS for current missions and on developing new TPS for upcoming missions
- Three broad levels of development approach considered:
  - Advanced development: characterization & modeling of down-selected materials
  - Intermediate development: tailoring materials
  - Initial development: novel concepts/designing materials

Heritage vs. New Materials

- Projects like to use heritage materials with proven performance:
  - Risk reduction strategy
  - Several low density (< 0.3 g/cm^3) and high density (> 1 g/cm^3) ablative TPS solutions have flight heritage
  - Technology gaps exist with current heritage materials
- ***As missions become more demanding, we will need higher capability materials — necessary to have a robust research and development program for both reusable and ablative materials***

New Rigid TPS Development
Advanced PICA Approaches

- Developed a family of ablator materials in the low- to mid density range with improved performance over PICA
- Tailor composition (for example, phenolic loading, Fiberform™/phenolic ratio)
- Include additives to enhance certain properties in PICA variants for specific mission scenarios:
  - Increased char strength
  - Reduced recession
  - Improved oxidation resistance


Series of arc jet PICA variant models prior to testing

Mid Density CMCP

- Fully dense Carbon Phenolics are good TPS options in extreme conditions –
  - Used at very high heat fluxes and high pressure conditions
  - least favorable in terms of density
- Processing of fully dense carbon phenolics (including Chop Molded Carbon Phenolics (CMCP)) was optimized in the 1960s.
- For intermediate conditions (peak heat flux of 1,000 to 10,000 W/cm^2 and stagnation pressures of 1.0 to 8.0 atm) it is necessary to reduce the density of fully dense CMCP materials to make them more efficient
- Our recent efforts have focused on lowering the density of CMCP ablators while still maintaining good mechanical and thermal performance.
  - Systems developed had densities ranging from 0.8 to 0.9 g/cm^3. This yields a ~40% reduction in density compared to fully dense systems. Reductions in density were achieved by incorporation of additives compatible with the base carbon phenolic system

Pre test arc jet image of a 0.86 g/cc CMCP sample

Post test arc jet image of a 0.86 g/cc CMCP sample.

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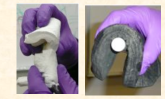
New Conformal/Flexible TPS Development
Flexible PICA and SIRCA

Flexible versions of PICA and SIRCA are currently under development at ARC

Applications for flexible TPS include:

- TPS deployed to form a large, blunt shape providing aerodynamic drag during hypervelocity atmospheric flight, while surviving heating from the bow shock wave that envelops the body. These hypersonic inflatable aerodynamic decelerators (HIADs) are one approach for the delivery of a large payload to the surface of Mars
- TPS used for large aeroshells where deployment is by a mechanical means rather than inflation
- TPS bonded directly to the substructure to replace rigid TPS and overcome challenges with rigid TPS that include gap fillers, tile size, and stringent requirement on carrier structure stiffness to minimize deflection in rigid systems
- Candidate systems have been processed and are currently going through a series of screening tests that include thermal, mechanical and relevant environment screening (arc jet, LHMEL)


Flexible SIRCA Flexible PICA


Pre and post test flexible PICA tested in the JSC arc jet facility at 526 W/cm^2, 0.35 atm and a 20 sec exposure


Pre and post test flexible SIRCA tested LHMEL at 114.6W/cm^2 with a 20 sec exposure

Graded Ablators Development

- For missions with high heat flux, a lower overall mass can be obtained if the TPS composition changes from a carbon-based ablator at the heated surface to an insulator near the inner surface
- A graded material approach eliminates the need for joints and/or bonding agents between material plies
- Monolithic graded ablator tiles and graded ablator in honeycomb (H/C) are being evaluated
- ARC experimental effort to date has focused on better optimizing processing
- A modeling effort is also in process as current response models are inadequate for graded (and multi-layer) ablators
- Preliminary results from arc jet testing of these materials is encouraging


Monolithic graded ablator


Graded ablator in H/C


Pre and post arc jet tested graded ablator (graded from a carbon phenolic OML to a silica phenolic IML). Tested at 440 W/cm^2, 27.7kPa atm and a 30 sec exposure

Summary

- TPS materials have special requirements for successful development and require a thorough understanding of:
  - Chemistry / Materials Science
  - Modeling
  - Design
  - Testing
- Operating environment determines type and choice of materials
- New materials being developed:
  - Enabling for better, more efficient vehicle design and performance
  - Improving safety
  - Withstanding high heat fluxes/environments (outer planets)
- NASA-Ames is working to make significant contributions in TPS material development for future space missions