Challenges with Thermal Protection Material Development and Implementation: Lessons Learned from Recent NASA Experience

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Outline

- TPS Material Use/Fabrication Risks
- Heritage Trap
- TPS Sustainability Challenges
  - Shuttle Examples
  - Proposed Carbon Phenolic Mitigation Strategy
  - PICA
- TPS Material Property Testing Challenges
- Summary

TPS Material Usage/ Fabrication Challenges

- TPS materials generally have no other terrestrial or commercial uses
  - Often NASA TPS materials have no other customers
    - PICA, Avcoat, SLA, etc.,
  - Carbon Phenolic (CP) is a partial exception:
    - Tape Wrapped (TWCP) has DoD TPS and nozzle applications
    - Chop Molded CP (CMCP) is NASA unique
- Manufacturing of TPS materials often utilize(s) specialized techniques with no heritage to other commercial or government processes
- Low flight rates/low volume make it challenging to:
  - Justify improvements such as automation
  - Maintain process expertise, raw material supply chains and infrastructure

Heritage Trap

- Some of the challenges with materials include:
  - Material systems are complex (many constituents)
  - Material interactions with the environment are even more complex
- Once something works, strive not to change it since we don't know how that change may influence performance
  - Long times between material manufacture lead to larger issues with raw material availability
- Having the recipe for a material is not enough.
  - Many TPS materials have a certain "black art" in their manufacturing
  - Must maintain skilled workforce

Heritage Trap

- Quest for heritage can be overdone:
  - More often it's a quest for "heritage-like"
  - Can drive down an unsustainable path:
    - Marginally more "heritage-like" but for limited benefit with a greater supply chain risk
  - At times the perceived reduction in risk by claiming "heritage" may prevent an objective evaluation of the risks of following a non-heritage path

Material Sustainability Challenges

- The 3.5 years of the Crew Exploration Vehicle (CEV) TPS Advanced Development Program (ADP) saw multiple raw material supply issues for multiple materials
- Raw materials used in TPS materials often have:
  - Limited commercial supply base (sole source)
  - Limited commercial uses in non-TPS applications (limited demand)
  - Or volume is too low to interest large industrial partners
- Result can be significant risks to raw material availability and thereby to TPS material manufacturability

Examples: Shuttle Experience - Rewaterproofing

- Dimethylethoxysilane (DMES) is used to re-waterproof Orbiter tiles and blankets prior to every flight.
  - Only effective waterproofing agent that does not cause RTV reversion
- Prior to DMES, 44 other chemicals were reviewed as waterproofing agents and found unable to meet requirements or perform well
  - Qualification testing took over 2 years to complete for the supplier
- The last several years of the Shuttle Program required a very expensive skills-retention program with the manufacturer, Evonik Degussa to keep the line open
  - Required Orbiter to purchase many more bottles than were required to support just to maintain the capability
  - Shelf life of material is only 12 months so lifetime buy was not an option
- Sole source supplier of material has been released due to the end of the Shuttle Program
  - Production line has been closed and dismantled.

Examples: Shuttle Experience – Felt Products

- Strain Isolation Pads (SIP) are used to bond tiles to the aluminum structure and work to prevent structural stresses from damaging the brittle and low strength tile material
  - Sole source manufacturer, Albany International, also manufactures filler bar and Felt Reusable Surface Insulation (FRSI)
- There is no shelf life limit for SIP so a very large stockpile was obtained for Shuttle and future programs
- Because of the end of the Shuttle Program the production line has been closed
  - Although the line has been closed it has not been dismantled

Examples: Shuttle Experience – RTV

- Most TPS components utilize RTV for bonding of the materials to the underlying substrate
  - GE Silicones / Momentive has been the sole source supplier of RTV
- Changes in the supplier of red iron oxide went from a domestic source to a Chinese source in 2007
  - The material went through qualification testing to verify it still met all requirements
- Late 2008 there was an issue with RTV in which the material would not cure, suspected factor was 2 lots of red iron oxide
  - Investigation revealed there are two methods of production of red iron oxide, calcination and precipitation, it was unknown which method the Chinese manufacturer utilizes.
  - The calcination method could introduce variation in particle size, acidity and sulfate concentration
- Boeing / NASA worked with GE / Momentive to identify the issue so that they could work with the Chinese manufacturer to resolve the problem

Lessons Learned from Shuttle

- Programs are able to better deal with supply chain issues because of longer term focus
  - Projects on the other hand are not able to
- Impact of Shuttle going away is not fully understood by the TPS community

Challenge of Sustainability vs Optimized Performance

- Material developers are striving to produce materials with improved performance
  - Can result in selection of new raw materials with limited supply chain
- Given the long intervals between missions, sustainability of raw material supply chain should factor into choice of constituents
  - Marginal improvement in material performance may not be worth the long term sustainability risk
- Expect changes in raw material suppliers and the need to recertify the material.

Material developers need to pay attention to sustainability along with performance.

How do we deal with NASA-Unique TPS product lines?

- NASA assumes the risk of ensuring material availability and has mitigated this by:
  - Subsidizing the costs of maintaining critical components/materials
  - Accepting the risk of restarting the manufacturing line when needed
    - A cost and schedule risk for one-off planetary missions
  - Commit to a lifetime buy of raw materials
    - Lifetime buy for a one-off mission is ONE
  - Manufacture finished component for lifetime use (stockpile)
- A challenge for unique one-off planetary missions, there is no long term program such as Shuttle to consistently cover these costs

Decadal Survey recently recommended Technology investment in order to develop new capabilities or maintain critically needed capabilities.

The Challenge for Planetary Exploration due to Vanishing Carbon Phenolic Manufacturing Capabilities

- Carbon phenolic TPS
  - Enables Venus lander and probe missions, and Saturn, Neptune and Uranus probe and Aerocpature missions – Missions Prioritized in the current Decadal Survey
  - Mars Sample Return Earth Return Capsule
    - Baseline TPS is heritage CP
- Aeroshell, 45^0 sphere cone, is the preferred shape for all these missions except for MSR EEV.
- Examples:

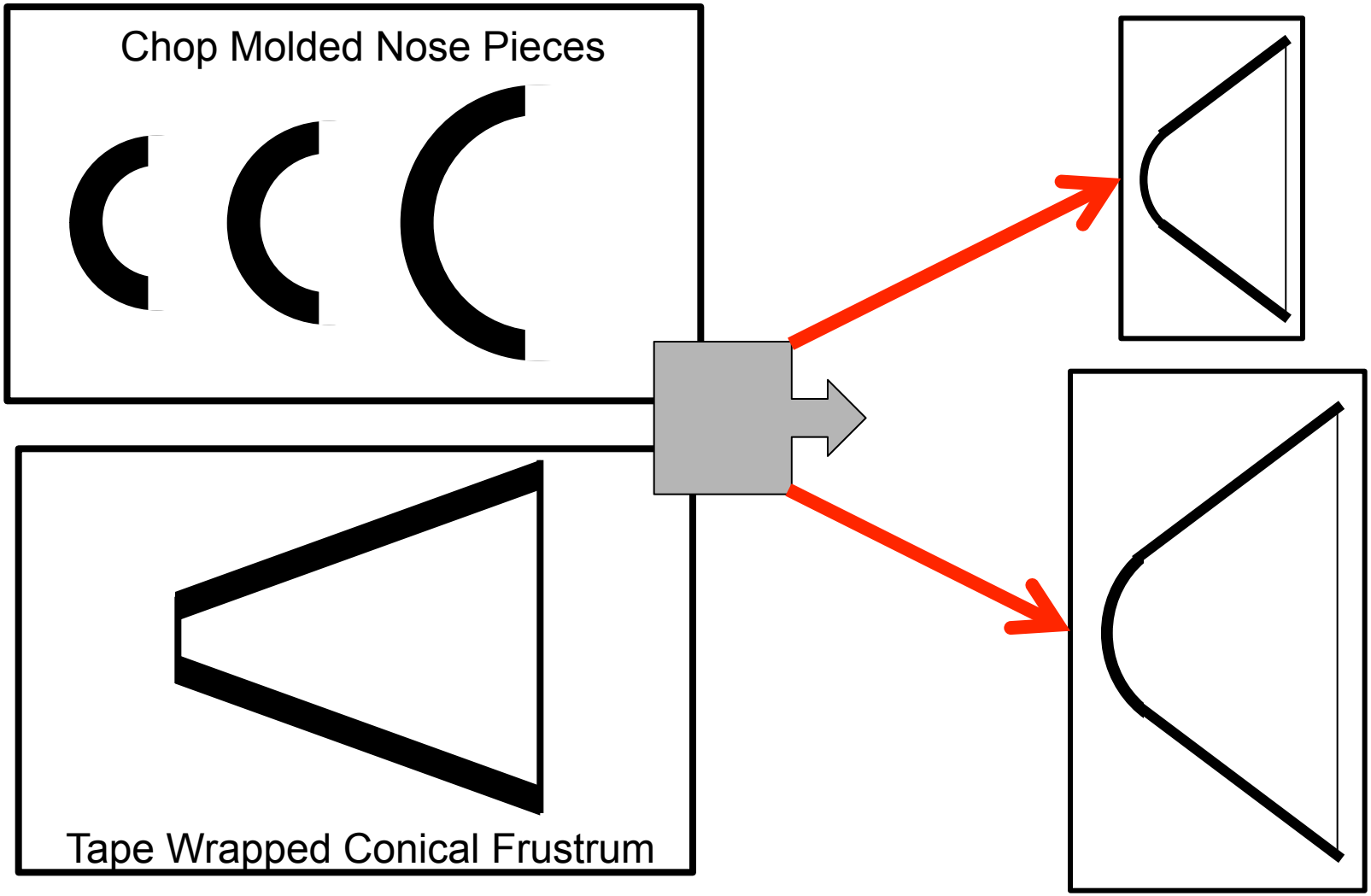
Destination	Mission Studies	Mission Timeline	TPS	Heatshield Size, m	Quant.
Venus	NF Class Lander	2020 - 40	Alt CP	~2.5	1
	Discovery Class Ballon	2020 - 40	Alt CP	(2.0 - 2.5)	1
	Flagship	2020 - 40	Alt CP	(2.5 - 3.5)	1
Saturn	Probes	2020 - 40	Alt CP	~1.3	1
Uranus	Probes	2020 - 40	Alt CP	~1.3	1
Neptune	Probes	2020 - 40	Alt CP	~1.3	1
Mars Sample Return	Earth Return Capsule	2024 (?)	Heritage CP	1.1	3
			Flight Hardwares =		9
			EDU and Spares =		9
			Total =		~ 20

- In support of one of the planetary missions, we will need to revive, recertify and manufacture flight hardware.

Vanishing Carbon Phenolic Capability: Make Parts Now and Store, Assemble as Needed

Make Parts NOW and Store

Integrate during Project Phase



CP Strategy Risk

- Once CP is stockpiled there is no driving need for TPS community to maintain capability/knowledge
  - After “x” years we’re back in the same situation that currently exists
  - Risk stifling innovation into alternate CP materials with superior reentry performance or better availability

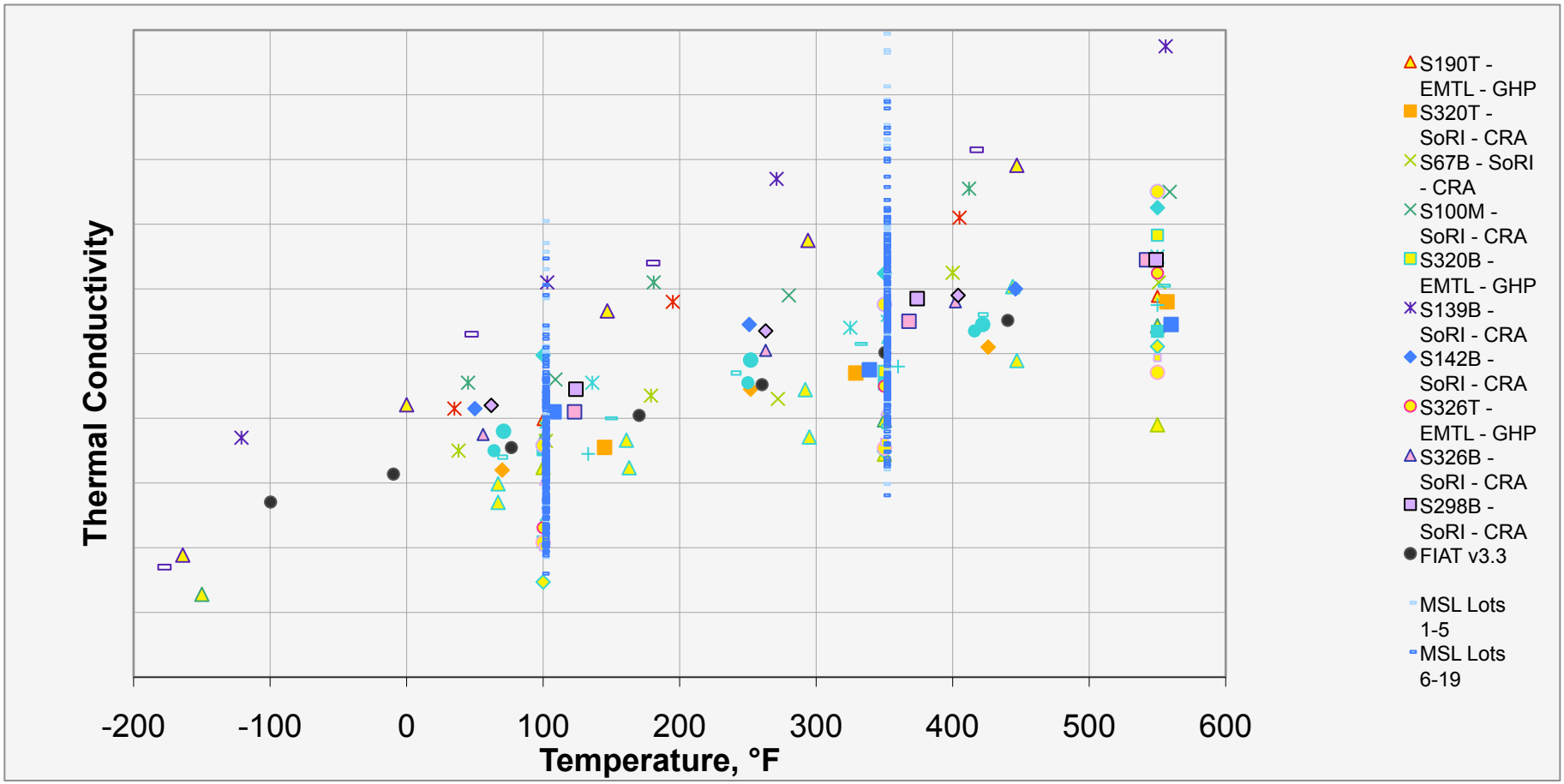
PICA Risks

- Given that Orion downselected to Avcoat and MSL heat shield fabrication is complete, FMI is no longer manufacturing PICA
- For the next few years material restart is a relatively low risk
  - FMI corporate knowledge will be retained for near term
  - NASA developed a substantial PICA corporate knowledge between Orion and MSL
- In the medium to long term material restart **may** become an issue
- Space X's PICA-X potentially provides a medium to long term solution
  - However, it may not be possible for a mission to utilize PICA-X as a drop in replacement for FMI PICA

Challenges in Material Characterization: Lessons learned

- Given the non-traditional nature of TPS materials there is often limited experience in characterizing material properties
  - Adaptations must be made to standard test techniques to account for material architectures
- Verification and Validation testing at more than one facility can prove invaluable
  - Differences in measured properties raise issues
  - In-house characterization experience is crucial
- Material properties can be strong functions of temperature, humidity, pressure, etc…
- Generally there are few opportunities to optimize material properties/variability (live with what you get)

PICA Through-Thickness Thermal Conductivity

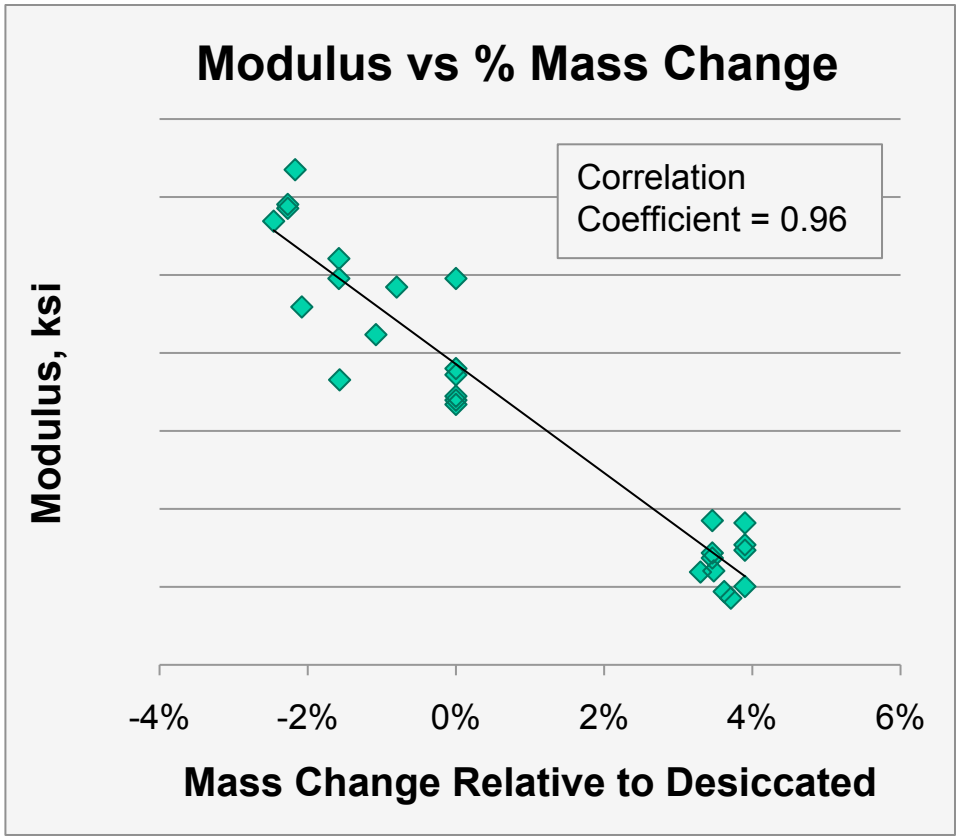


- Testing performed at Southern Research Institute & EMTL using guarded hot plate and comparative-longitudinal heat flow techniques
- Large range in measured conductivity makes thermal response model development challenging, affects thermal margin and heat shield thickness/mass

From Jay Feldman

Avcoat Modulus Sensitivity

- Avcoat modulus *highly sensitive* to humidity & volatiles content
- Vacuum exposure on orbit may reduce the volatiles content of Avcoat
- Orion needs to test material at a post-orbit-like condition
- Orion may need to utilize different mechanical properties for orbit & launch conditions



From Jay Feldman

Summary

- TPS materials offer many challenges:
  - High cost and long duration of material certification limits TPS options in NASA inventory
  - Sustainability issues include: limited flight rates and limited uses beyond TPS
  - Focus on achieving “heritage-like” can lead to unintended/ unanticipated risks
- Material developers need to keep sustainability in mind when considering raw material choices
- Proposed stockpiling CP materials for future missions once certification of alternate CP has been achieved
  - Stockpiling has its own risks including stifling innovation
- Significant challenges may exist in material property testing due to unique nature of some TPS materials