TITLE: *TPS Materials and Costs for Future Reusable Launch Vehicles*

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Abstract:
There is considerable interest in developing new reusable launch vehicles (RLVs) for reducing the cost of transporting payload to and from orbit. This work reviews thirteen candidate thermal protection system (TPS) options currently available for RLVs. It is useful to begin with the current **Shuttle** TPS layout as a reference. The nose cap and wing leading edge , which reach the highest temperatures, are made of reinforced carbon-carbon (RCC) that is protected from oxidation by an external coating (about 0.020" thick) of silicon-carbide. Most of the windward surface is 9 lb/cubic ft ceramic tiles (LI-900) with a thin (about 0.012") coating of Reaction Cured Glass (RCG). The leeward side of the vehicle is covered largely by AFRSI, a quilted ceramic blanket, and FRSI, a polyamide felt. These four materials can be considered first generation reusable TPS. Since the time of the **Shuttle** design, considerable progress has been made advancing TPS technologies in terms of thermal performance, robustness, and cost. For each of the major systems, a second generation ceramic TPS has been developed, tested, and characterized. Metallic-based systems have also been developed. For applications requiring RCC in the past, advanced carbon-carbon (ACC) is now available. This material has better mechanical properties, somewhat higher temperature capability to 2900F and greatly increased oxidation resistance. New carbon fiber reinforced silicon-carbide matrix composites (C/SiCs) have shown additional improvement in properties over ACC with use temperatures to 3000F and above. For rigid tiles, NASA Ames has made two significant advancements. The first is a **tile** substrate called Alumina Enhanced Thermal Barrier, or AETB, that incorporates alumina fibers for improved dimensional stability at high temperatures, to 2600F and above. This material can be made to densities as low as 8 lb/cubic ft. The second is a coating preparation called Toughened Uni-piece Fibrous Insulation, or TUFT, that penetrates about 0.1 in. into the **tile** substrate. The resulting composite, with a functionally gradient density near the surface, provides orders of magnitude increased **damage** resistance compared with RCG coated LI-900, with only a small weight increase. The TPS that combines these two developments is called AETB-8/TUFI and has been adopted for high **damage** areas on the Shuttles. Two notable developments have occur-red in flexible ceramic blanket technology. The first is aluminoborosilicate-based fibers with use temperatures of 2200F and above," in comparison to quartz and silica fiber used in AFRSI which have multi-use temperature limits of 1200 to 1400F. Blankets incorporating these new high temperature fibers are referred to as AFRSI-HT. The second is an integral weaving techniques that produces a fluted core blanket with a smoother surface and greater resistance to aero-acoustic noise, to levels as high as 170 dB. This Ames innovation is called Tailorable Advanced Blanket Insulation, or TABI. Finally, for felt-based TPS, Boeing is developing Polybenzimidazole Blanket Insulation, or PBI, with a multi-use temperature limit of 1000F and above, in contrast to **Shuttle** FRSI which has a multi-use temperature limit of about 700F. 1.6 NASA Langley and BF Goodrich (formerly Rohr Corp.) have led the development of metallic-based TPS. This activity uses essentially three approaches: metallic tiles which encase a fibrous ceramic batting in a box fabricated largely from metallic honeycombs, typically Nickel based alloys; metallic honeycomb sheets, made of Nickel-based alloys, incorporating a fibrous back-side insulation

encapsulated in a metallic foil bag, providing reduced weight; and metallic multi-wall, which is comprised of dimpled Titanium metal sheets, which are stacked and then diffusion bonded at contact points to form the TPS. The Nickel-based systems can be used up to temperatures of about 1800F, and the Titanium system to about 100F. These thirteen TPS materials have pros and cons to their usage in terms of temperature capability, weight, initial cost, and maintenance. Carbon-carbon and C/SiC systems have the highest temperature capability but are relatively expensive and heavy, requiring significant time, expertise, and costly facilities and tools for design and fabrication. Second generation ceramic tiles are relatively light, durable, simple to fabricate and easy to install; however, waterproofing is a concern. Blankets and felts are light, simple, inexpensive, and easy to install over curved vehicle surfaces, but durability and waterproofing are concerns. Metallics are robust and appear to have eliminated waterproofing, but they tend to be heavy and relatively expensive, requiring costly facilities and tools. If thin metal sheets are used to reduce weights, then issues arise from possible metal fatigue and corrosion caused by thermal cycling, pressure oscillations, and environmental exposure. For application to future RLVs, system analyses show that a significant component of the vehicle life cycle cost is from the TPS; however, it is difficult to quantify and to compare the potential savings of advanced systems without performing full vehicle designs using each of the different options. Because this entails a considerable effort and also tends to submerge TPS cost impacts under unrelated vehicle design assumptions, there is a clear need for a simpler quantitative method to evaluate the cost impact of different TPS options. To this end, this work introduces a TPS life-cycle cost parameter which is easily computed and applicable to generic RLVs.

Major Subject Terms:
COST REDUCTION • INSULATION • LIFE CYCLE COSTS • MECHANICAL PROPERTIES • REUSABLE LAUNCH VEHICLES • THERMAL PROTECTION • HEAT SHIELDING

Minor Subject Terms:
FABRICATION • HONEYCOMB STRUCTURES • LOW COST • OXIDATION RESISTANCE • POLYBENZIMIDAZOLE • SILICON CARBIDES • TILES • CERAMICS

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