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PARAMETRIC WEIGHT COMPARISON OF CURRENT AND PROPOSED THERMAL PROTECTION SYSTEM (TPS) CONCEPTS

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Abstract

A parametric weight assessment of advanced metallic panel, ceramic blanket, and ceramic tile thermal protection systems (TPS) was conducted using an implicit, one-dimensional (1-D) thermal finite element sizing code. This sizing code contained models to account for coatings, fasteners, adhesives, and strain isolation pads. Atmospheric entry heating profiles for two vehicles, the Access to Space (ATS) rocket-powered single-stage-to-orbit (SSTO) vehicle and a proposed Reusable Launch Vehicle (RLV), were used to ensure that the trends were not unique to a particular trajectory. Eight TPS concepts were compared for a range of applied heat loads and substructural heat capacities to identify general trends. This study found the blanket TPS concepts have the lightest weights over the majority of their applicable ranges, and current technology ceramic tiles and metallic TPS concepts have similar weights. A proposed, state-of-the-art metallic system which uses a higher temperature alloy and efficient multilayer insulation was predicted to be significantly lighter than the ceramic tile systems and approaches blanket TPS weights for higher integrated heat loads.

Nomenclature

C_p Total Structural Heat Capacity, Btu/ft^2-°R
Q Total Unit Heat Load, Btu/ft^2
q Heat Flux, Btu/ft^2-s
T_{Rad} Radiation Equilibrium Temperature, °F
t Structural or Insulation Thickness, in.
tx1 Inner Insulation Thickness on a TPS Concept, in.
tx2 Outer Insulation Thickness on a TPS Concept, in.
ε Emissivity

Introduction

A number of reusable hypersonic vehicles are being proposed and studied to augment or replace the current Space Shuttle. Proposed vehicles include the Reusable Launch Vehicle (RLV),[1] military spaceplane,[2] spaceplanes for tourism,[3] space trucks,[4] suborbital package delivery vehicles,[5] and hypersonic airbreathing vehicles.[6] One of the key technologies required by all of these vehicles is a reusable, low maintenance, light weight thermal protection system (TPS). Although the primary function of a TPS is to protect the vehicle from the effects of aerodynamic heating, the operational capability and system weight also have significant impact on vehicle performance. For commercial viability, the TPS must contribute to minimizing life cycle costs to enable delivery of commercial payloads at reasonable cost. For military applications, the TPS must enable high performance, rapid response, and rapid turnaround under adverse conditions.

The most extensive experience with reusable TPS is with the ceramic tile and blanket TPS on the Space Shuttle orbiter. Although the orbiter TPS does an excellent job of protecting the vehicle from aerodynamic heating, more than 40,000 work hours[7] are typically expended to refurbish and inspect the TPS between flights. Because of the fragile nature of the orbiter TPS, the orbiter cannot fly through rain, and great care must be taken in routine maintenance to avoid damaging the TPS. Such fragile, high maintenance TPS is clearly unacceptable for future commercial and rapid turnaround hypersonic vehicles.

To achieve the goals of low life cycle cost and rapid turnaround, TPS for future reusable vehicles must be robust and low maintenance, yet efficiently protect

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the vehicles from aerodynamic heating. The TPS must survive the operational environment with minimal refurbishment. That environment includes low- and high-velocity impact (e.g. dropped tools during maintenance procedures and orbital debris, respectively); rain; and aerothermal, acoustic, and thermal-mechanical loads. In addition, the TPS should be easy to inspect, maintain, and repair; should not require waterproofing between flights; and should be rugged and damage tolerant. Of course, an overriding concern for any TPS is system weight. TPS weight is particularly important for single-stage-to-orbit vehicles which have large surface areas requiring thermal protection, and there is generally a tradeoff between TPS durability and weight.

A variety of reusable TPS concepts are being developed to address the requirements of future hypersonic vehicles. Development of improved ceramic TPS is being led by the NASA Ames Research Center.[8] Ceramic tiles, such as alumina enhanced thermal barrier (AETB)[9] with toughened unipiece fibrous insulation (TUFI) and reaction cured glass (RCG) coatings, have been developed to be significantly stronger and more resistant to rain erosion than the current Shuttle tiles. Tailorable advanced blanket insulation (TABI),[10] also developed by Ames, is being proposed as a cheaper more easily integrated and installed replacement for tiles over large areas of future vehicles. Metallic TPS represents another promising alternative reusable concept. Much of the development of metallic TPS is being led by the NASA Langley Research Center (LaRC).[11] Concepts development proceeded from early stand-off heat shields to titanium multiwall concepts (TIMW)[12] to prepackaged superalloy honeycomb sandwich panels (SA/HC).[13] The detailed design and fabrication of the TIMW and SA/HC TPS concepts were performed by Rohr Incorporated (now B. F. Goodrich Aerospace). The SA/HC TPS was further improved and tested under a recent cooperative agreement between McDonnell Douglas Aerospace and the NASA LaRC.[11] A derivative of the SA/HC concept, developed by B. F. Goodrich, is the primary TPS on the windward surface of the X-33,[1] an experimental RLV technology demonstrator vehicle.

Selection of the optimum TPS for a particular vehicle is a complex and challenging task that requires consideration of not only weight, but also operability, maintenance, durability, initial cost, life-cycle cost, and integration with the vehicle structures, including cryogenic propellant tanks. The current paper undertakes a much less ambitious task: weight comparisons among several TPS concepts using a one-dimensional, transient TPS sizing code. Three families of TPS are considered: metallic panels, rigid ceramic tiles, and flexible ceramic blankets. This includes current Shuttle TPS, advanced TPS which have been fabricated and tested, and proposed TPS concepts which incorporate improved materials and designs. For this study, the TPS is assumed to be directly attached to a smooth, adiabatic structure (integration with the cryogenic insulation is neglected) and is sized using entry heating profiles representative of future reusable reentry vehicles. The X-33 metallic TPS is not directly comparable to this configuration, so it is not included in this study. Key parameters, such as total heat load and structural heat capacity, are varied to obtain TPS weight comparisons over a wide range of conditions.

Analysis

This section describes the basic assumptions and analytical methods used in the parametric study of TPS weights. Included are details of the simplified thermal problem analyzed and the one-dimensional TPS sizing code used.

Simplified Thermal Model

The idealized TPS and structure combination considered in this study is shown in Figure 1. This simplified arrangement was selected so that the performance of the various thermal protection systems could be directly compared. The TPS is directly attached to an underlying 0.1 inch-thick aluminum structure. A transient heat flux profile is applied to the outer surface of the TPS, and the inner surface of the structure is assumed to be adiabatic, or perfectly insulated. The structure is limited to a maximum temperature of 300°F, and the minimum required thermal protection system thickness, t, is determined, or sized, to satisfy this temperature limit.

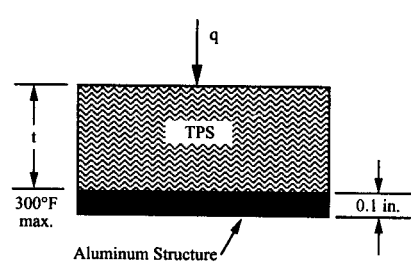

Figure 1. Simplified thermal model of TPS sizing problem.

One-dimensional (1-D) TPS Sizing Code

A thermal protection system sizing code was used to determine the TPS thickness and resulting weight required to maintain the underlying structure below 300°F. The TPS sizing code uses a nonlinear, implicit, one-dimensional, transient, finite element solution technique to compute temperatures throughout the thermal protection system. The code includes thermal and mass models of each TPS concept that account for coatings, adhesives, fasteners, and strain isolation pads. A schematic of the thermal model for Tailorable Advanced Blanket Insulation (TABI) is shown in Figure 2 as an example. Further details concerning the models used for each TPS concept are contained in the following section. In the transient thermal analysis, thermal properties, which may be a function of temperature and pressure, are updated at each analysis time step, and radiation to space is assumed at the surface node. After nodal temperatures are computed, the TPS is resized, and the analysis and resizing are repeated until the temperature of the structure converges to within 2°F of the temperature limit. For TPS concepts using two insulations – such as the original super alloy honeycomb metallic TPS – an additional insulation temperature constraint is added. In general, convergence is achieved in less than six analysis and resizing cycles. Upon convergence, the final TPS insulation thickness and total weight are reported. The validity of the simplifications used in the 1-D thermal models is investigated by comparing the results with those from more elaborate 2-D Engineering Analysis Language (EAL) finite element analyses.[14] Although results from the 2-D analyses are not included in this report, structural temperatures agreed within 5°F of the 1-D results for all the concepts.

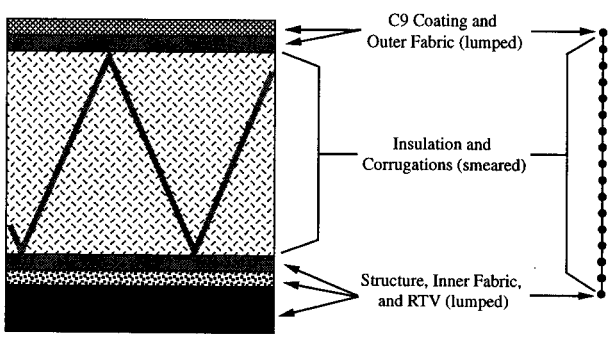

Figure 2. Conversion of a TPS concept to its thermal model.

Thermal Protection System Concepts

The one-dimensional TPS sizing code contains thermal and weight models for each TPS analyzed. A description of each TPS concept and the assumptions used in the analysis are given in this section.

Flexible Ceramic Blankets

Blanket TPS consist of fibrous insulation between outer layers of woven ceramic fabric. The outer fabric layer is coated to stiffen and toughen it, and the blankets are attached to the structure with a layer of room temperature vulcanizing (RTV) adhesive. Blankets have low initial costs, and their flexibility eases installation. The Advanced Flexible Reusable Surface Insulation (AFRSI) blankets used on the Space Shuttle orbiter must be waterproofed after each flight adding considerable maintenance time and expense. Blankets are initially flexible, but the addition of the C-9 coating and exposure to high temperatures make the outer fabric extremely brittle and susceptible to damage. The quilted fabric construction of AFRSI results in a rough exterior surface which increases aerodynamic heating and drag.[15] The Tailorable Advanced Blanket Insulation (TABI) TPS has a smoother surface and an increased temperature capability compared to AFRSI,[10] but TABI also has similar waterproofing and surface brittleness issues as AFRSI. Testing is in progress to evaluate the durability of TABI for use on the windward side of a vehicle, and the concept's scalability to large thicknesses (3-4 inches) needs to be demonstrated. The relatively low emissivities at high temperatures of the blanket fabrics with the C-9 coating limit the heating levels where blanket TPS may be used, but higher emissivity coatings are under development.[10]

Advanced Flexible Reusable Surface Insulation (AFRSI) – Advanced Flexible Reusable Surface Insulation was developed as a partial replacement for Felt Reusable Surface Insulation (FRSI) and Low Temperature Reusable Surface Insulation (LRSI) on the Space Shuttle orbiter. It is easier to maintain and install, and it possesses a maximum operational temperature of 1200°F.[16] The AFRSI concept modeled in this paper is composed of an outer fabric with C-9 coating, 6 lb/ft^3 Q-fiber felt insulation, and an inner fabric layer, and it is attached to the structure with RTV adhesive (Fig. 3). The weight and analysis models are based upon a 30 inch by 30 inch sample.

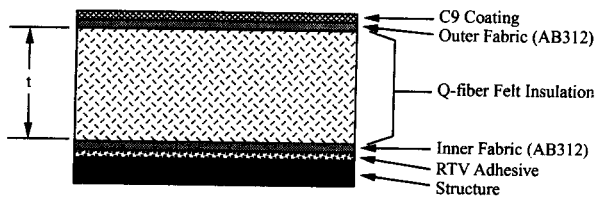

Figure 3. Depiction of the AFRSI thermal protection system.

Tailorable Advanced Blanket Insulation (TABI) – Tailorable Advanced Blanket Insulation was developed by the NASA Ames Research Center as an improvement to the AFRSI currently certified on the Space Shuttle orbiter. Integrally woven corrugations provide higher strength and a higher operational temperature (2200°F) than AFRSI.[17] TABI is being proposed for use on the windward side of reentry vehicles and is composed of an outer ceramic fabric with C-9 coating, 6 lb/ft^3 Q-fiber felt insulation, ceramic fabric corrugations, and a fabric inner layer. It is attached to the structure with RTV adhesive (Fig. 4). The weight and analysis models examine a 30 inch by 30 inch sample.

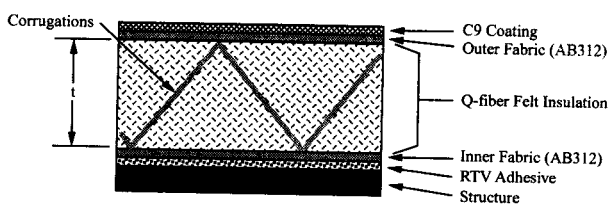

Figure 4. Depiction of the TABI thermal protection system.

Rigid Ceramic Tiles

Rigidized ceramic insulation tiles are used over the major portion of the Space Shuttle orbiter where temperatures range from 1300 to 2300°F. Tiles have the highest temperature capabilities of the various TPS concepts considered in this study. The basic orbiter tile system is composed of a ceramic tile, a nomex (nylon) felt strain isolation mounting pad, and RTV adhesive. The LI-900 (9 lb/ft^3) and LI-2200 (22 lb/ft^3) tiles are coated on five sides to improve the surface emissivity and toughness. Due to the brittle nature and low strength of tiles, ceramic tile TPS must be isolated from the thermal and mechanical strains of the underlying structure. This is accomplished by the felt strain isolation pad (SIP). The tiles have been susceptible to impact damage, and have required waterproofing after each flight.[18] These inspections, repairs, and waterproofing are time consuming and costly. Improved tile systems are under development which offer increased temperature capabilities and improved strength and durability. An example of this is the alumina enhanced thermal barrier (AETB) tile with the toughened unipiece fibrous insulation (TUFI) coating.[9]

LI-900 (RSI) Tiles – LI-900 tiles are an all-silica, rigid, fibrous insulation system with a maximum operational temperature of 2300°F,[19] and they are used extensively on the Space Shuttle orbiter. The 6 inch by 6 inch rigid tile has a protective and emittance enhancing reaction cured glass (RCG) coating applied to the exposed surfaces, a densified region at the attachment to improve strength, and a strain isolation pad (SIP). It is attached to the structure with RTV adhesive (Fig. 5).

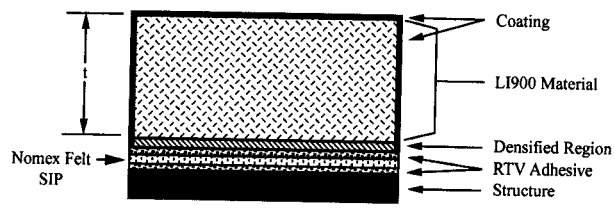

Figure 5. Depiction of the LI-900 thermal protection system.

Alumina Enhanced Thermal Barrier (AETB) Tiles with TUFI Coating – The AETB ceramic tile with TUFI coating was developed at the NASA Ames Research Center as an improvement to the LI-900 tile. The AETB tiles demonstrate higher strength, added durability, and have a maximum operational temperature of 2500°F.[18] The system is composed of an 8 inch by 8 inch AETB ceramic tile that is coated with TUFI and mounted on a strain isolation pad or SIP (Fig. 6). A tile density of 8 lb/ft^3 (AETB-8) is included in this study.

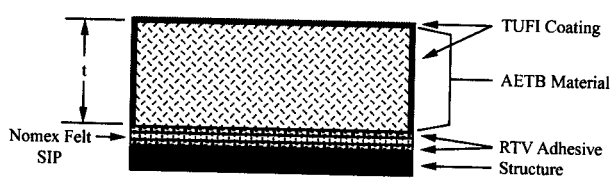

Figure 6. Depiction of the AETB thermal protection system.

Metallic Panels

Development of metallic thermal protection systems has been led by the NASA Langley Research

Center (LaRC). The metallic TPS concepts considered in this study consist of foil-gage metallic box encapsulating lightweight, fibrous ceramic insulation. The box rests upon an RTV and nomex felt edge support system to prevent flow from beneath the panels and is attached to the structure with mechanical fasteners. High temperature superalloys are used in the hottest regions, and titanium alloys are used in lower temperature applications to reduce weight. The outer face of the box is constructed of a honeycomb sandwich to increase load carrying capability and durability. The weight of the metallic box is offset to some extent by the low density, efficient fibrous insulations used. The inherent ductility of the metallic materials used offers the potential for a more robust TPS, and the design can be easily modified to improve durability. In addition, the encapsulated designs are inherently waterproof, and the mechanical fasteners allow for easy removal and reattachment.[11] Metallic TPS panels do not, however, have the extensive flight history of the tiles and blankets, and the initial costs are expected to be high due to the required tooling. In addition, the spacecraft structure may require special design features to accommodate the mechanical fasteners.

Superalloy Honeycomb Metallic (SA/HC) TPS – The superalloy honeycomb (SA/HC) metallic TPS panels have been fabricated and have undergone extensive testing. The SA/HC metallic TPS incorporates lightweight insulation (Q-fiber and Cerrachrome) between two metallic honeycomb sandwich panels[13] (Fig. 7). The outer sandwich is made of Inconel 617 (IN617), and the inner sandwich panel is made of titanium, and the system has a maximum operational temperature of 1800°F to 2000°F (actual maximum temperature depends on loads and required life). The 12 inch by 12 inch sandwich panels are connected by 0.003 inch thick beaded IN617 sidewalls.

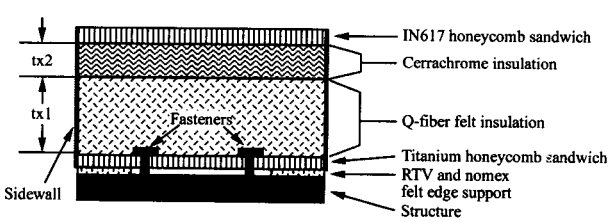

Figure 7. Depiction of the Superalloy Honeycomb metallic Thermal Protection System.

Second Generation Superalloy Honeycomb Metallic (SA/HC2) TPS – The second generation superalloy honeycomb (SA/HC2) metallic TPS has been developed as an improvement to the superalloy honeycomb system. The layout of the SA/HC2 system is similar to the SA/HC, but it incorporates a lighter weight, higher temperature insulation (Saffil), and the structural weight has been reduced by replacing a 9 inch by 9 inch center section of the lower titanium sandwich with a thin foil[11] (Fig. 8). Both of these modifications reduce weight compared to the SA/HC concept. These 12 inch by 12 inch panels which have been fabricated and tested have a predicted maximum operational temperature of 1800°F to 2000°F.

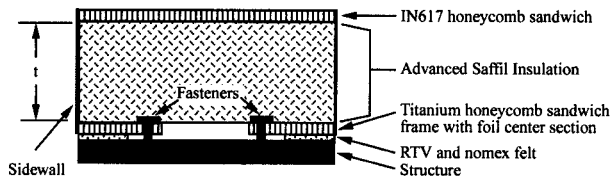

Figure 8. Depiction of the second generation superalloy honeycomb metallic Thermal Protection System.

Titanium Honeycomb Metallic (TI/HC) TPS – The titanium honeycomb (TI/HC) metallic TPS concept is a reduced weight metallic TPS concept for lower temperature applications. The 12 inch by 12 inch TI/HC TPS panel replaces the IN617 components of the SA/HC2 concepts with titanium members (Fig. 9). The material change, which has not been rigorously analyzed or tested, results in a weight savings of 0.37 lb/ft^2 as compared to the SA/HC2 TPS.

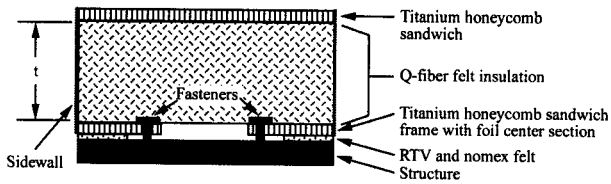

Figure 9. Depiction of the Titanium Honeycomb metallic thermal protection system.

Advanced Metallic Honeycomb (AMHC) TPS – The Advanced Metallic Honeycomb thermal protection system (AMHC) is being proposed at the NASA LaRC as an improvement to the superalloy honeycomb metallic system. It incorporates an advanced, low conductivity Internal Multiscreen Insulation (IMI) between an outer PM2000 honeycomb sandwich and a thin titanium facesheet on the bottom[11] (Fig. 10). A box frame that runs along the outer edges is attached to the lower facesheet. The frame and bottom facesheet configuration

replace the honeycomb sandwich to reduce structural weight, and a PM2000 honeycomb replaces the Inconel 617 honeycomb panel because it has the potential to increase the maximum operational temperature up to 2000°F to 2200°F and has a lower density. The 12 inch by 12 inch system is fastened to bosses on the structure with a quick release spring. This new fastening configuration will allow the TPS to be examined and repaired much more quickly. It is important to note that no detailed design has been performed on this concept, and the multilayer insulation properties are predicted from analytical models.

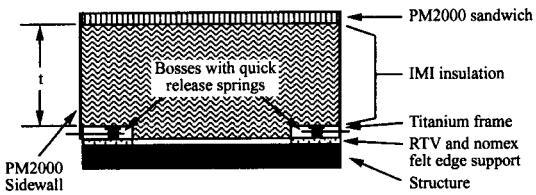

Figure 10. Depiction of the Advanced Metallic Honeycomb thermal protection system.

Parameters Investigated

Heat Load

The TPS concepts are sized using variations of the baseline heat flux profiles for the Access to Space (ATS) rocket-powered single-stage-to-orbit (SSTO) reference vehicle[19] and a proposed Reusable Launch Vehicle (RLV). Two different vehicles are investigated to broaden the applicability of the results. The heat flux profiles for two specific locations on each of these two vehicles are shown in Figure 11 and Figure 12. Heat flux profiles for surface locations with peak radiation equilibrium temperatures of approximately 1100°F and 1850°F are chosen on each vehicle to provide heating rates suitable for a range of TPS concepts. The reference body points investigated for the ATS are shown as body points A and B on Figure 11, while the RLV reference points are shown as body points A and B on Figure 12.

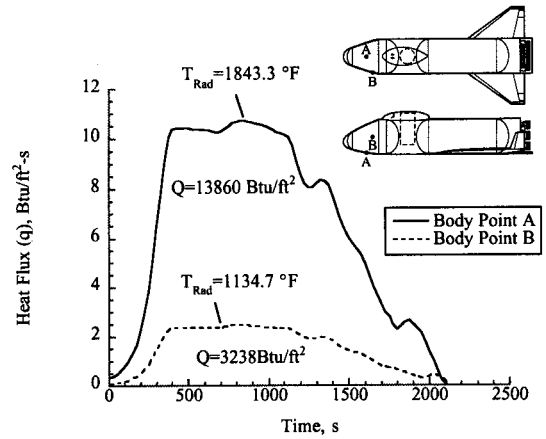

Figure 11. Heat Flux profiles for ATS body points.

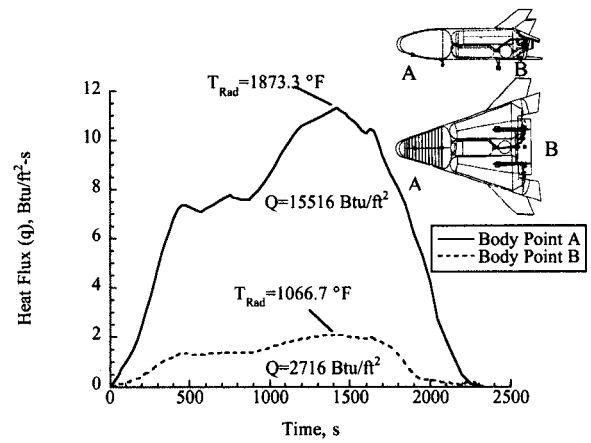

Figure 12. Heat flux profiles for RLV body points.

The influence the total heat load has on TPS weight is investigated by varying the magnitude of the heat flux and the integrated time from 0.25 to 2.0 times the reference heat profiles. When the integrated time is varied, the radiation equilibrium temperature remains constant (Table 1). In this study, all TPS concepts are

Table 1. Heat Load Range (Integrated Time Scaled)

	0.25 x Baseline Profile		Baseline Profile		2 x Baseline Profile	
Heating Profile	Heat Load(Q) Btu/ft²	T_{Rad} °F	Heat Load (Q) Btu/ft²	T_{Rad} °F	Heat Load (Q) Btu/ft²	T_{Rad} °F
ATS-A	3460	1843	13860	1843	27720	1843
ATS-B	810	1135	3238	1135	6476	1135
RLV-A	3879	1873	15516	1873	31032	1873
RLV-B	679	1067	2716	1067	5432	1067

Table 2. Heat Load Range (Heat Flux Magnitude Scaled)

Heating Profile	0.25 x Baseline Profile		Baseline Profile		2 x Baseline Profile	
	Heat Load(Q) Btu/ft^2	T_{Rad} °F	Heat Load (Q) Btu/ft^2	T_{Rad} °F	Heat Load (Q) Btu/ft^2	T_{Rad} °F
ATS-A	3460	1169	13860	1843	27720	2279
ATS-B	810	668	3238	1135	6476	1434
RLV-A	3879	1190	15516	1873	31032	2315
RLV-B	679	620	2716	1067	5432	1356

Table 3. Structural Heat Capacity Range

Heating Profile	0.25 x Baseline Capacity	Baseline Capacity	2 x Baseline Capacity
	Heat Capacity (C_P) Btu/ft^2-°R	Heat Capacity (C_P) Btu/ft^2-°R	Heat Capacity (C_P) Btu/ft^2-°R
ATS-A	0.082	0.327	0.654
ATS-B	0.082	0.327	0.654
RLV-A	0.082	0.327	0.654
RLV-B	0.082	0.327	0.654

considered only within their temperature limits. When the magnitude of the heat flux is expanded, the maximum radiation equilibrium temperature varies within the parametric range (Table 2). In some instances, the temperature exceeds the TPS temperature limit, and TPS weights are not calculated in these cases. All other parameters are held at the baseline values.

Structural Heat Capacity

To investigate the effect the structural heat capacity, C_p , has on TPS weight, the structural thickness of the underlying tank wall is varied from 0.025 inch to 0.2 inch from the reference value of 0.10 inch. This corresponds to a structural heat capacity range from 0.082 Btu/ft^2-R to 0.654 Btu/ft^2-R from the reference value of 0.327 Btu/ft^2-R (Table 3).

Results

Weights are calculated for the TPS concepts previously described versus integrated heat load as several parameters are varied. Thicknesses corresponding to calculated weights are shown for each concept. Although results were calculated for both the ATS and RLV trajectories, weights agree within 7% for a given integrated heat load. Therefore, only the results for the ATS are shown. The benefits of applying additional improvements to the AMHC TPS concept are also assessed.

Dependence of TPS Weight on TPS Thickness

Figures 13 and 14 summarize TPS weight as a function of insulation thickness for each concept. Figure 13 is a plot of the TPS concepts for use at relatively low temperatures (less than 1400°F) while Figure 14 shows TPS concepts for use at higher temperatures. For reference, two TPS concepts (TABI and LI-900) are plotted in both figures. For a given TPS thickness, the weight is calculated using a formula within the 1-D sizing code. The metallic TPS panels in this study have fixed weight inner and outer surfaces. Increasing thick-

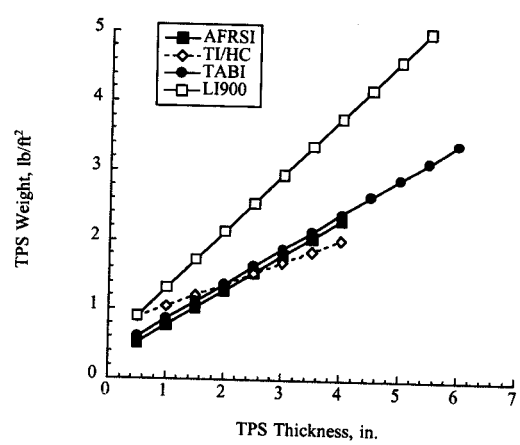

Figure 13. Lower temperature TPS versus TPS thickness.

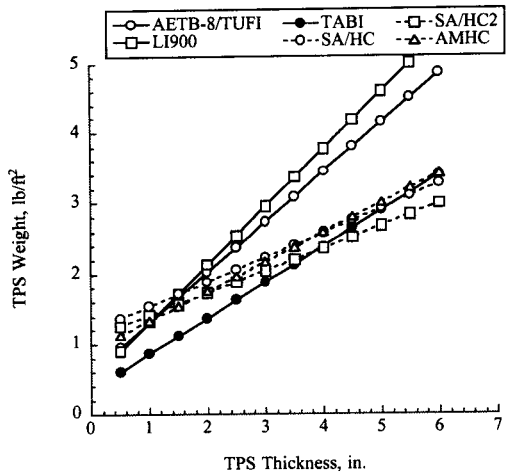

Figure 14. Higher temperature TPS weight versus TPS thickness.

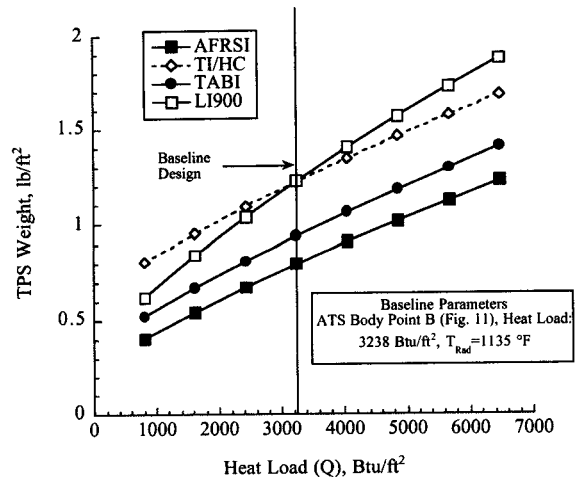

Figure 15. Lower temperature TPS weight versus heat load with scaled time.

ness results primarily in adding additional efficient, non load-bearing insulation. Therefore, as seen in Figures 13 and 14, metallic TPS tends to be heavier than other concepts for small thicknesses but increases less in weight as thickness increases. This same trend can be seen in the following weight comparisons. Metallic TPS tends to be more efficient for higher integrated loads.

Dependence of TPS Weight on Heat Load (Time Integration Scaled)

The influence the total heat load has on TPS weight is first investigated by scaling the integrated exposure time of the TPS to the baseline heating profile from 0.5 to 2 times the reference exposure time (Table 1). For the lower heating profile, TPS weights are shown on Figure 15. From these plots, it is apparent that the ceramic blanket concepts (AFRSI and TABI) are the lightest concepts. LI-900 and TI/HC have nearly the same weight at the baseline heating. As the heat load decreases, LI-900 becomes the lighter of the two concepts, and as the heat load increases, TI/HC becomes lighter than LI-900.

For the higher heating profile, TPS weight versus heat load is plotted on Figure 16. From these plots, AMHC is the lightest TPS concept over about 90% of the parametric range. In addition, SA/HC and SA/HC2 are lighter than all the tiles as the heat load increases above the reference heat profiles, while LI-900 is lighter than the SA/HC and the SA/HC2 as the heat load decreases below the reference heat profiles. If SA/HC and SA/HC2 are compared to AETB-8/TUFI,

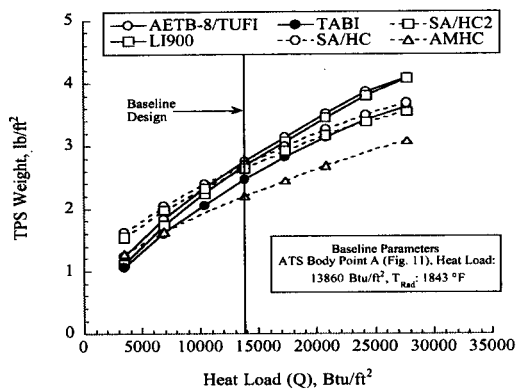

Figure 16. Higher temperature TPS weight versus heat load with scaled time.

the figures indicate that the metallic panels are lighter over the majority of the range. Finally, TABI is heavier than AMHC over a majority of the range, and lighter than the tiles.

Dependence of TPS Weight on Heat Load (Maximum Heat Flux Scaled)

The influence the total heat load has on the TPS weight is also investigated by scaling the magnitude of the heat flux profile from 0.5 to 2 times the reference heat flux profile (Table 2). For the lower heating profile, TPS weights are shown on Figure 17. The trends from this figure are the same as seen in Figure 15 except AFRSI and TI/HC can only be used up to the point where their maximum allowable temperatures are not exceeded.

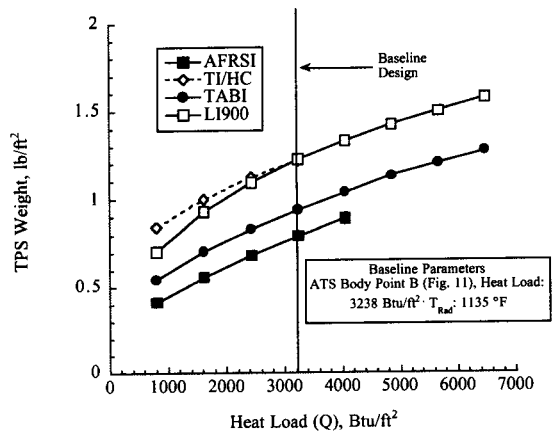

Figure 17. Lower temperature TPS weight versus heat load with scaled heat flux.

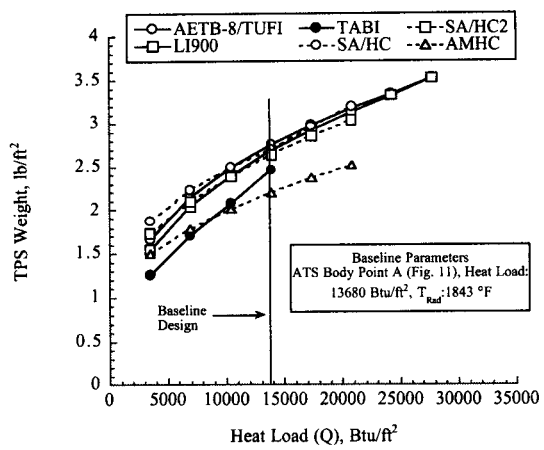

Figure 18. Higher temperature TPS weight versus head load with scaled heat flux.

For the higher heating profile, TPS weight versus heat load is plotted on Figure 18. The trends are the same as seen in Figure 16. TABI and AMHC are the lightest TPS concepts over their useful temperature range. LI-900, AETB-8, SA/HC2, and SA/HC have comparable weights over most of the parametric range, but the tiles are the only concepts capable of operation over the entire heating range.

Dependence of TPS Weight on Structural Heat Capacity

To investigate the effect that total structural heat capacity, C_p, has on TPS weight, the heat capacity was varied as shown in Table 3. The baseline heat flux profile used for each body point examined. For the lower heating profile, TPS weights are shown on Figure 19. From this plot, it is apparent that the ceramic blanket concepts (AFRSI and TABI) are the lightest concepts. LI-900 and TI/HC have nearly the same weight at the baseline. As C_P increases, LI-900 becomes the lighter of the two concepts. However as C_P decreases, TI/HC becomes lighter.

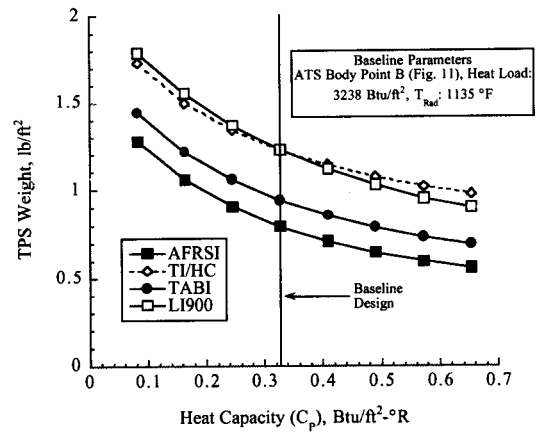

Figure 19. Lower temperature TPS weight versus structural heat capacity.

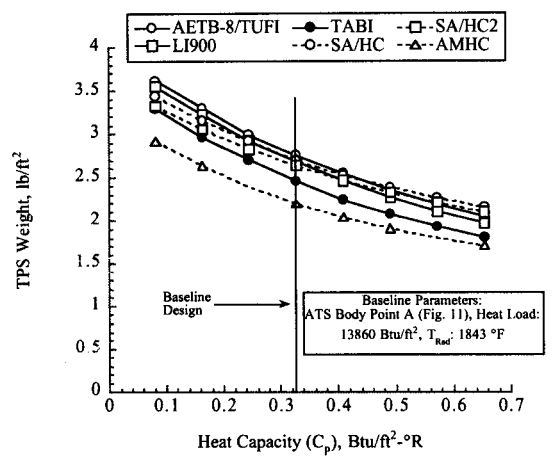

Figure 20. Higher temperature TPS weight versus structural heat capacity.

For the higher heating profile, TPS weights versus structural heat capacity are plotted on Figure 20. From this plot, AMHC is the lightest TPS concept over the parametric range while TABI is the second lightest. Once again, LI-900, AETB-8, SA/HC2, and SA/HC have comparable weights over the parametric range.

AMHC TPS Weight Improvement Estimate

Two additional improvements to the AMHC TPS offer the potential for further weight savings: a higher emissivity coating and larger panels which would have less heat shorts per unit area. To obtain an upper bound to the projected weight savings, the weight of the coating was neglected, and the panel was not resized for increased structural loads (this is beyond the scope of the current study). The weights for the AMHC baseline panel, the panel with the high emittance coating (0.85), the larger (18 inch-square) panel, and the larger panel with the high emittance coating are shown in Figure 21. The combined improvements may reduce the weight by as much as 13 percent.

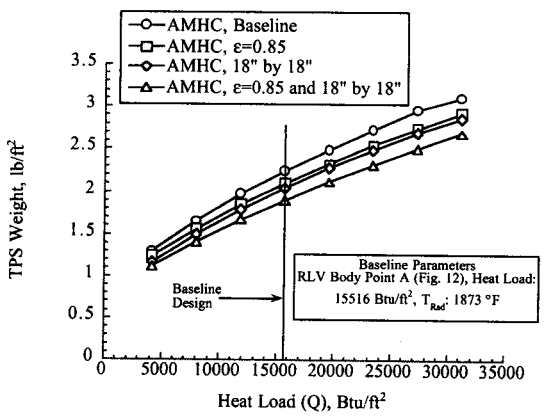

Figure 21. Potential AMHC weight savings due to design improvements.

Conclusions

A parametric weight assessment of advanced metallic, ceramic blanket and ceramic tile thermal protection systems (TPS) was conducted using an implicit, one-dimensional (1-D) finite element sizing code. TPS concepts were sized for heating profiles from two vehicles, the Access to Space (ATS) rocket-powered single-stage-to-orbit (SSTO) vehicle and a proposed Reusable Launch Vehicle (RLV), to investigate whether TPS weight comparison trends varied with trajectory. The applied heat load and structural heat capacity were varied to compare the weight of TPS concepts over a wide range of conditions.

For the two trajectories considered, TPS weight agreed within 7% for a given integrated heat load. Therefore the trends identified in this study may not be unique to the trajectories considered.

Among the TPS concepts considered for the lower temperature regime, several trends were observed. The blanket TPS concepts are lighter than competing concepts for almost all conditions considered. AFRSI is the lightest, and TABI is only slightly heavier. At the baseline conditions, Titanium Honeycomb panels (TI/HC) and LI-900 tiles are approximately the same weight. As the heat load increased or the structural heat capacity decreased, the TI/HC became lighter. However, as the heat load decreased or the structural heat capacity increased, the LI-900 became lighter.

For the higher heating profiles, the AMHC metallic concept is generally the lightest concept, while TABI is generally the second lightest. Much of the efficiency of the AMHC results from the use of multilayer internal insulation. In addition, the LI-900 tiles, the AETB-8 tiles, the Superalloy Honeycomb (SA/HC) and Advanced Superalloy Honeycomb (SA/HC2) metallic concepts had comparable weights over the parametric ranges. In general, the metallic concepts perform better with increasing integrated heat load due to the low density fibrous insulations used in these concepts, but the tiles have a higher temperature capability.

This study has compared TPS weights for several concepts over a wide range of conditions. Although low weight is a very important parameter, it is only one of several competing requirements for future TPS, including durability, operability, rapid turnaround, low maintenance, and low life cycle cost. Metallic TPS, which are shown to be weight competitive with other TPS concepts in this study also have the potential to better meet the additional requirements of future TPS. The AMHC metallic concept appears to be very promising, but this concept requires additional design work and experimental verification of its performance.

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