Thermal Performance Analysis of a Multilayer Honeycomb Heat Shield for Re-Entry Capsules

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***Abstract*—Re-entry capsules experience severe aerodynamic heating during atmospheric descent, making an effective Thermal Protection System (TPS) essential for protecting the vehicle and its internal components. This study investigates a lightweight five-layer TPS consisting of an outer ablative layer, adhesive layers, a hexagonal honeycomb core, inner insulation, and a metallic structural plate. Five different material combinations are evaluated to examine their influence on heat transfer and inner-wall temperature under representative re-entry conditions. A detailed three-dimensional honeycomb geometry is developed and analyzed using steady-state thermal simulations in ANSYS. The outer surface is subjected to a representative temperature of approximately 2060 K, while cabin-side convection is applied at the inner surface. The simulated temperature distributions and depth-wise thermal gradients are compared with NASA reference data for validation. The results show that all five configurations significantly reduce the external temperature, producing inner-wall temperatures in the range of approximately 320–780 K. Among the tested configurations, Combination 5 provides the lowest inner-surface temperature, demonstrating the benefit of combining a low-conductivity ablative material with a Nomex honeycomb core. The results highlight the importance of material selection and honeycomb-core design in achieving effective thermal protection while maintaining low structural mass.**

***Index Terms*—Thermal Protection System (TPS), Re-entry Capsule, Aerodynamic Heating, Honeycomb Core, Ablative Material, Thermal Analysis, ANSYS, Heat Transfer, Nomex Honeycomb, Thermal Insulation.**

I. INTRODUCTION

Re-entry capsules are exposed to extremely high temperatures during atmospheric descent because of intense aerodynamic heating. A reliable Thermal Protection System (TPS) is therefore essential to protect the vehicle and its internal components. Lightweight multilayer TPS designs incorporating honeycomb cores are particularly attractive for small return capsules because they can provide strong thermal resistance without adding excessive structural mass. In this work, a five-layer heat shield comprising an outer ablative layer, adhesive layers, a hexagonal honeycomb core, and an inner structural plate is evaluated under representative re-entry conditions. Five material combinations are compared to examine how the selection of the ablative material, core, adhesives, and inner structure affects heat transfer through the shield. The main objective is to identify the configuration that most effectively limits the temperature reaching the inner wall. Steady-state thermal simulations are performed and the resulting temperature-depth profiles are compared with NASA reference data for validation.

II. MATERIALS AND METHODOLOGIES

The heat shield is represented as a five-layer Thermal Protection System made up of an outer ablative layer, a high-temperature adhesive, an 80-mm hexagonal Nomex honeycomb core, a second adhesive layer, and an inner metallic structural plate. Five different material combinations are considered by changing the ablative surface, honeycomb core, adhesive, and inner structural sheet. This allows the thermal behaviour of the alternative designs to be compared under the same boundary conditions. A complete three-dimensional honeycomb geometry is used so that heat conduction through the individual cells can be represented more realistically than with a homogenized core model. The geometry is then analyzed in ANSYS using a steady-state thermal model. The outer surface is subjected to a representative re-entry temperature of approximately 2060 K, while convection on the inner surface is used to represent cabin-side cooling. For each material

combination, the temperature field, inner-surface temperature, and temperature variation through the shield thickness are obtained. These results are subsequently compared with NASA reference temperature profiles to assess the validity of the modelling approach.

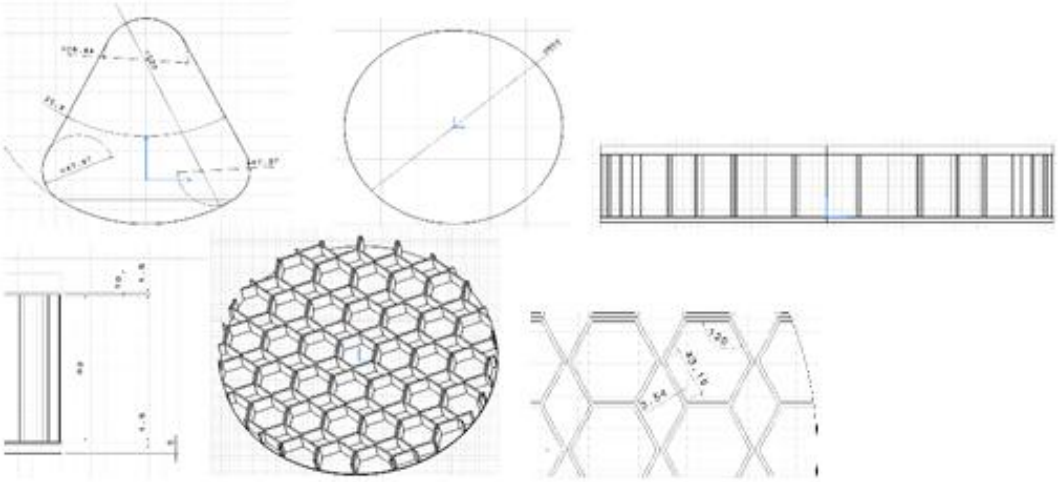

Figure 1: Design geometry and honeycomb layout

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Table 1: Materials used in each layer for the different TPS combinations

Layer	Combination 1	Combination 2	Combination 3	Combination 4	Combination 5
Outer Ablative Layer	PICA	Avcoat	Carbon Phenolic	Avcoat	PICA-LD
Adhesive Layer	High Temp Epoxy	Ceramic filled epoxy	Polymide Adhesive	Silicon RTV	Low-k adhesive
Honeycomb Layer	Nomex	Aluminium	Nomex	Fiberglass honeycomb	Nomex
Inner Insulation	Silica Aerogel	Silica fiber mat	Carbon Felt	Silica aerogel	Aerogel + fiber hybrid
Inner Structure	Titanium	Stainless Steel	Titanium	Stainless Steel	Titanium

Table 2: Enthalpy and Entropy Change per Unit Area

Combination	ΔHarea (J/m²)	ΔSarea (J/m²K)	Remarks
1	1.17×10^8	1.30×10^5	Light, efficient insulation path
2	2.05×10^8	2.27×10^5	High thermal storage; heavy system
3	1.36×10^8	1.50×10^5	Balanced behaviour
4	2.07×10^8	1.50×10^5	Very high inertia; mass penalty
5	1.17×10^8	1.30×10^5	Same capacity as Combination 1 but better protection

III. RESULTS AND DISCUSSION

The steady-state simulations show a substantial reduction in temperature across all five TPS configurations. An external temperature of about 2060 K is reduced to inner-wall temperatures ranging from approximately 320 to 780 K. Among the configurations investigated, Combination 5 produces the lowest inner-surface temperature. Its improved performance is associated with the low-conductivity ablative material and the Nomex-based honeycomb core. The temperature profiles also display the

expected behaviour of a multilayer TPS: a pronounced temperature drop occurs through the ablative layer, followed by comparatively slower heat conduction through the honeycomb region. The depth-wise temperature distributions show close agreement with the NASA reference data, supporting the reliability of the modelling procedure. Overall, the results demonstrate that both material selection and core architecture have a significant effect on heat attenuation. For small re-entry capsules, lightweight ablative-honeycomb systems provide an effective balance between thermal protection and structural mass.

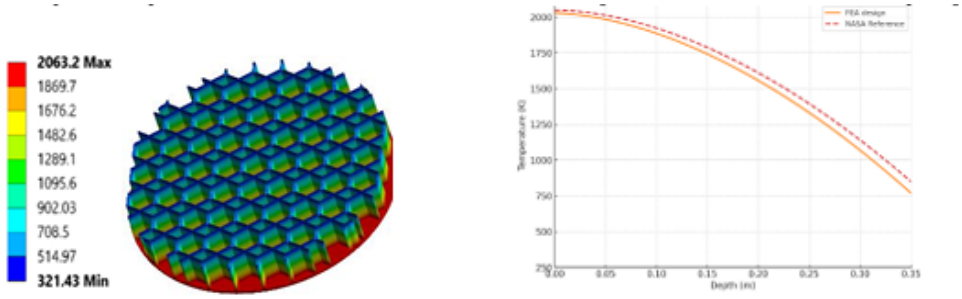

Figure 2: ANSYS simulation of hexagonal honeycomb heat shield and validation with NASA reference data

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