TO: Aerospace Community

FROM: NASA Ames Research Center (ARC)

SUBJECT: Request for Information: TPS Materials for Mars EDL
Response requested by Friday, August 14

PLEASE NOTE: This is a request for information only and does not constitute a commitment, implied or otherwise, that NASA Ames will take procurement action in this matter. Further, neither NASA Ames nor the Government will be responsible for any cost incurred in furnishing this information. NASA is issuing this Request for Information to gain a better understanding of industry capabilities and to assess the current state of the technology. Responses to this RFI are to be submitted by Friday, August 14. Electronic responses, in either Microsoft Office or Adobe (PDF) format, are preferred.

RFI Description and Requirements

The National Aeronautics and Space Administration invites you to submit a response to this inquiry, to assist in planning for the long-lead development of a Thermal Protection System (TPS) for future exploration missions to Mars. The Entry, Descent, and Landing (EDL) Technology Development Project (TDP) is actively pursuing design development and maturation of thermal protection system materials capable of withstanding the severe thermal heating loads associated with aerocapture and entry into the Mars environment. Development of this EDL TPS would be considered as both a major technological advancement for the eventual human exploration to Mars and a potential future upgrade to the thermal protection systems for the Orion Crew Exploration Vehicle. Upon review of the written responses to this RFI, NASA may conduct one-on-one exploratory meetings with industry to further discuss their TPS concepts.

This RFI will focus on materials applied to either of the two TPS concepts for Mars EDL: an ellipsled rigid aeroshell TPS and a flexible/deployable aeroshell decelerator. The specified requirements for each system are provided within the narrative and tables below. This RFI will consider materials at any technology readiness level, as defined in Appendix C.

EDL Concept #1: Ellipsled Rigid Aeroshell TPS

The rigid aeroshell TPS concept is required to survive two heating pulses, the first during aerocapture into Mars orbit, and the second during entry into the Mars atmosphere for descent and landing onto the Mars surface. In addition, this rigid aeroshell TPS concept is required to minimize TPS mass in order to maximize

payload mass. The aerocapture and entry phases could be separated by as much as six months. The ellipsled concept consists of an approximately 10 meter diameter by 30 meter long body with three general regions of thermal heating: the backshell (lowest heating), nose cone (mid heating), and heatshield (highest heating). Figure 1 depicts the ellipsled rigid aeroshell TPS concept. This RFI focuses only on the heatshield, or windward side of the ellipsled, where the highest heating will occur, and seeks any TPS concept capable of handling long duration heat load during aerocapture followed by entry from Mars orbit. Examples of TPS concepts envisioned by the project team for the rigid aeroshell application include multilayer (e.g., ablator over insulator or ablator over ablator), warm structure, and conformable systems. Non-tiled (monolithic) TPS concepts are strongly preferred.

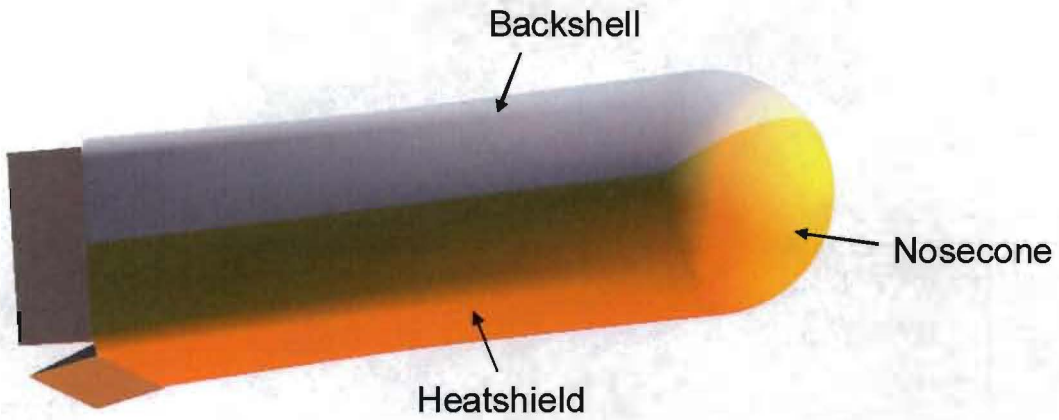

Figure 1: Ellipsled Rigid Aeroshell TPS Concept

Upon arrival at Mars via a trans-Mars injection from Low Earth Orbit (LEO), the ellipsled undergoes an aerocapture maneuver to both reduce the vehicle velocity and bring it into Mars orbit. Estimated heating rates for the aerocapture maneuver are shown in the table below. Once in Mars orbit (up to six months), the ellipsled will then enter the Mars atmosphere at hypersonic velocities, and the heatshield will be jettisoned at approximately M=5. Table 1 shows the estimated entry environments.

Aerothermal Entry Environments-Rigid	
Peak Total Heat Rate (Aerocapture)	500 W/cm^2
Peak Aerocapture Heat Rate (Convection)	450 W/cm^2
Peak Aerocapture Heat Rate (Radiation)	130 W/cm^2
Peak Heat Rate (Entry)	130 W/cm^2
Peak Entry Heat Rate (Convection)	130 W/cm^2

Peak Entry Heat Rate (Radiation)	20 W/cm^2
Total Heat Load (Aerocapture + Entry)	80 kJ/cm^2
Heat Load (Aerocapture)	55 kJ/cm^2
Heat Load (Entry)	25 kJ/cm^2
Peak Pressure	
Peak Pressure (Aerocapture)	45 kPa
Peak Pressure (Entry)	25 kPa
Peak Shear Force	
Peak Shear Force (Aerocapture)	700 Pa
Peak Shear Force (Entry)	300 Pa

Table 1: Aerothermal Entry Environments for Rigid Aeroshell

EDL Concept #2: Deployable Aeroshell Decelerators

A potentially more mass efficient, but less developed, method for Mars EDL is application of a deployable aeroshell decelerator system. Expected to be much lighter than the rigid aeroshell solution, the deployable aeroshell system requires the use of flexible TPS materials. With the deployable system, the spacecraft would deploy a large heatshield (approximately 20-40 m in diameter) prior to the aerocapture maneuver, as shown in Figure 2. This deployable aeroshell decelerator would be used for both aerocapture and entry maneuvers. Attributes of interest include in-situ rigidization and various methods for deployment (inflation, mechanical, etc.). TPS concepts envisioned include ablative fabrics and flexible materials treated with coatings or impregnants to reduce catalycity and/or increase re-radiation efficiency. Table 2 lists the aerothermal entry requirements for a deployable aeroshell system.

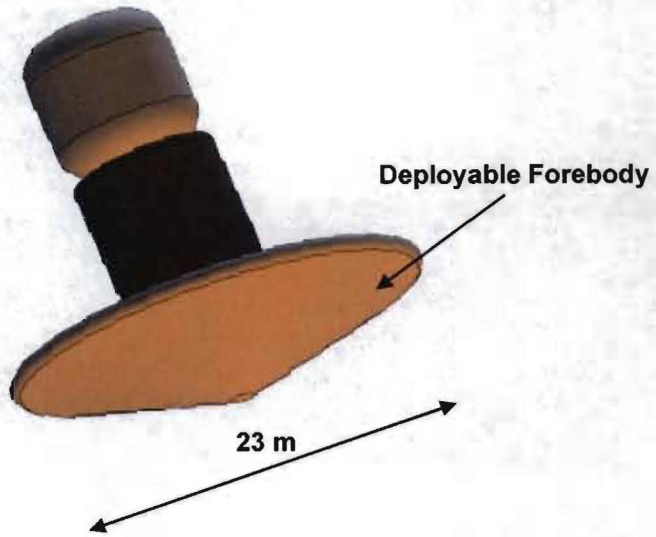

Figure 2: Example of a Deployable Aeroshell Decelerator Concept

Aerothermal Entry Environments- Deployable	
Peak Heat Rate (Aerocapture)	110 W/cm^2
Peak Aerocapture Heat Rate (Convection)	90 W/cm^2
Peak Aerocapture Heat Rate (Radiation)	60 W/cm^2
Peak Heat Rate (Entry)	30 W/cm^2
Peak Entry Heat Rate (Convection)	30 W/cm^2
Peak Entry Heat Rate (Radiation)	0 W/cm^2
Total Heat Load (Aerocapture + Entry)	14 kJ/cm^2
Heat Load (Aerocapture)	10 kJ/cm^2
Heat Load (Entry)	4 kJ/cm^2
Peak Pressure	
Peak Pressure (Aerocapture)	14 kPa
Peak Pressure (Entry)	10 kPa
Peak Shear Force	
Peak Shear Force (Aerocapture)	90 Pa
Peak Shear Force (Entry)	60 Pa

Table 2: Aerothermal Entry Environments for Deployable Aeroshell

Guidelines for RFI Response

The specific objective of this RFI is to request information identifying and describing potential heatshield materials at any TRL (as defined in Appendix C) applied to either of the TPS concepts above. Comments/responses are requested to the following topics below.

1. System Description

Describe the candidate TPS system (referencing either of the TPS concepts listed in the requirements section), including thermal protection materials, surface coatings, bonding agents or adhesives, insulating layers, surface encapsulation or any other substance or mechanism between the outer mold line and the carrier structure. Present conceptual material stackups of all TPS components. For each component material, complete the Appendix A material properties template for known values, including TRL; if unknown, state "unknown" or state "N/A" for properties that are not relevant for a particular type or component of a particular TPS. Cite the basis for all material property values (measured or inferred). If available, provide details of complete ground testing and flight heritage for the system and individual

components as described in Appendix B, particularly at conditions of peak heating rate shown for the different categories of materials above.

2. Design Rationale
Provide rationale for the TPS material being discussed. Explain the basis for suggesting the system as a candidate for further development and application for Mars EDL.

3. Performance Testing
If available, provide any study results or data that supports the TPS materials and systems ability to withstand operating environments including on-orbit radiation and thermal cycling.

This preliminary information is being made available for planning purposes only, subject to FAR Provision 52.215-3, entitled "Request for Information or Solicitation for Planning Purposes." It does not constitute a Request for Proposal, and it is not to be construed as a commitment by the Government to enter into a contract, nor will the Government pay for the information submitted in response to this request.

Although all comments received will be carefully reviewed and considered for inclusion in a later action, the initiators of this request make no commitment to include any particular recommendations.

All information received in response to this RFI that is marked Proprietary will be handled and protected accordingly. As applicable, NASA will likely provide Proprietary information to its support service contractors who are under an obligation to keep third-party Proprietary information in confidence. By submitting a response to this RFI, the responder is deemed to have consented to release of Proprietary information to such NASA support service contractors. Responses to the RFI will not be returned.

Appendix A. Material Properties

- The properties listed in the following table do not constitute a comprehensive set. Respondants are free to add other important properties as appropriate, or state "N/A" for properties that are not relevant for a particular type or component of a particular TPS.
- If a property value is applicable, but unknown, state "unknown".
- For properties that vary as a function of material direction or environmental parameters (e.g. temperature, pressure) provide a table of the property values as a function of all governing parameters.
- The basis, or source, for each value must be provided, e.g. test measurements, analytical predictions and published data.
- Supply a separate set of tables for each material.

Vendor Name		
Concept Design		
Material		
TRL for Material		
Material Property	**Nominal Value**	**Basis/source**
Physical and Chemical		
Virgin material density (g/m^3)		
Char density (g/m^3)		
Virgin material composition (constituents and mass fractions)		
Heat of formation, virgin material (J/g)		
Heat of formation, char (J/g)		
Elemental composition, virgin material		
Elemental composition, char		
Thermal Gravimetric Analysis (TGA) data in inert gas		
Porosity, virgin material (%)		
Porosity, char (%)		
Recombination coefficient for oxygen		
Recombination coefficient for carbon dioxide		
Catalytic efficiency in dissociated carbon dioxide		
Thermal		
Specific heat, virgin material (J/g-K)		
Specific heat, char (J/g-K)		
Thermal conductivity, virgin material (W/m-K)		
Thermal conductivity, char (W/m-K)		
Coefficient of thermal expansion, virgin material (cm/cm/°C)		
Coefficient of thermal expansion, char (cm/cm/°C)		
Optical		
Total hemispherical emissivity, virgin material		
Total hemispherical emissivity, char		
Spectral reflectivity, virgin material		
Spectral reflectivity, char		
Structural		
Tensile modulus (kPa)		
Compressive modulus (kPa)		
Shear modulus (kPa)		
Ultimate tensile strength (kPa)		
Ultimate compressive strength (kPa)		
Ultimate shear strength (kPa)		

Appendix B. Material and System Heritage

Provide ground testing and flight heritage at conditions of peak heat fluxes or greater (include pressure and enthalpy test conditions for each cited heating rate) and total heat loads indicated for each TPS category. Provide steady-state recession rate data (cm/s) reported with specification of heat flux (W/cm^2), enthalpy (MJ/kg) and pressure (kPa) for each test; include surface temperature (K) if recorded.

Appendix C. TPS Technology Readiness Level Guidelines

TRL	Guidelines
TRL-1	Basic principles observed and reported.
TRL-2	Technological concept and/or application formulated, lab samples made, environment for possible application defined.
TRL-3	Analytical and experimental critical function and/or characteristic proof-of-concept, initial test; i.e., arc jet, thermal cycling demonstrate proof-of-concept.
TRL-4	Component and/or breadboard validation in laboratory environment; detailed testing of materials at temperature and under appropriate atmosphere.
TRL-5	Component and/or breadboard validation in relevant environment, such as arc jet for thermal and structural test at temperature environment.
TRL-6	System/subsystem model or prototype demonstration in a relevant environment (ground or space) subjected to adequate testing to demonstrate flight readiness.
TRL-7	System prototype demonstration in a space environment.
TRL-8	Actual system completed and "flight qualified" through test and demonstration (ground or space).
TRL-9	Actual system "flight proven" through successful mission operations.