



# **An Overview of NASA's Current Materials Development Efforts for Mars EDL**

**Robin A. S. Beck**  
**Matthew Gasch**  
**Anthony Calomino**

**Presented at IPPW-8 EDL Short Course**  
**June 4, 2011**  
**Portsmouth, VA USA**

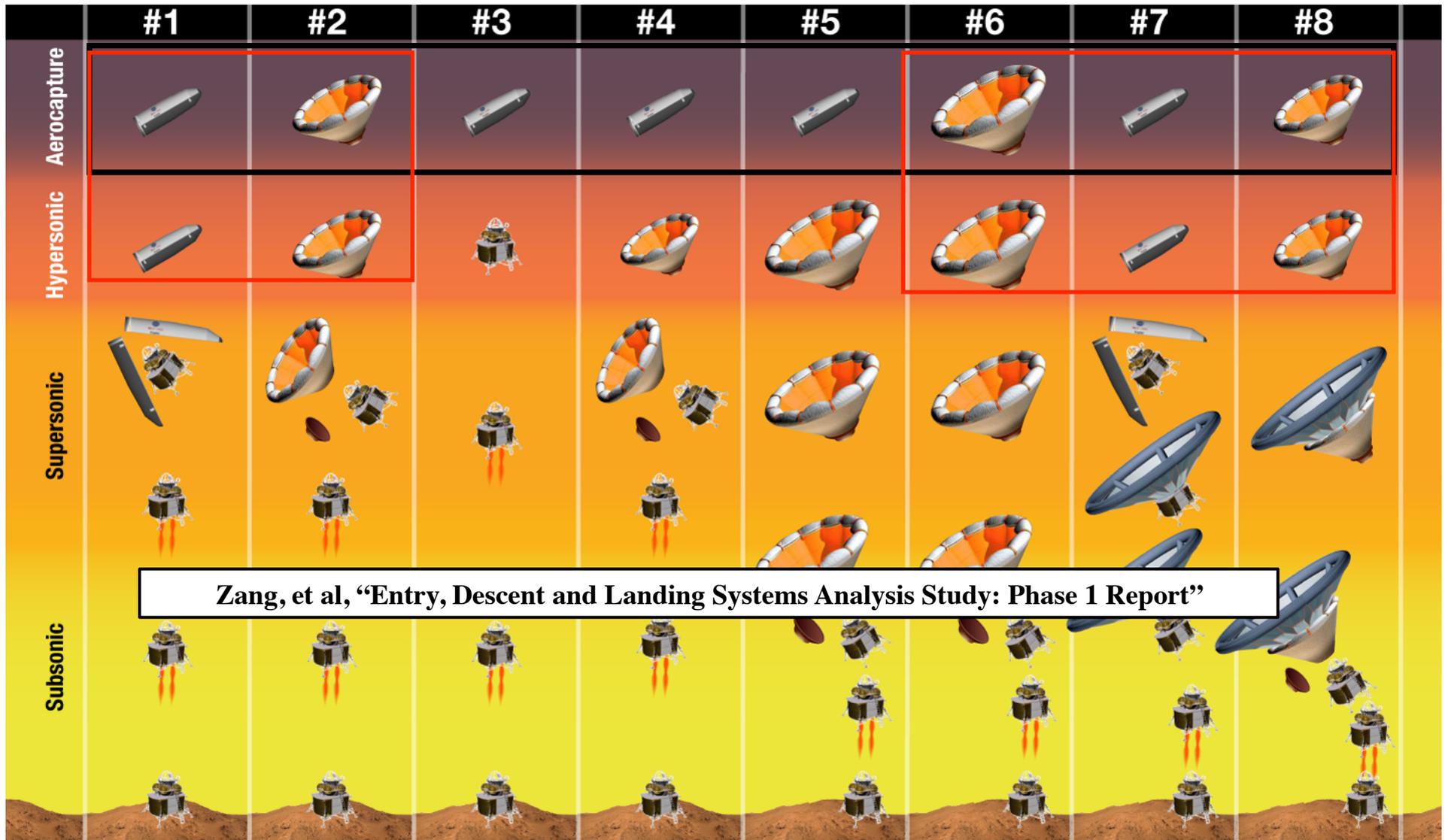


# Overview

- **Mission scenarios for exploration class missions to Mars**
- **Requirements for material advancements**
- **Flight environments and material goals**
- **Materials under development at NASA**
- **Modeling challenges**
- **Summary**



# EDL-SA Mars Exploration Architectures



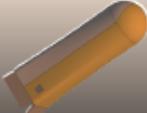
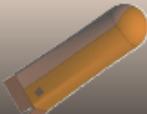


# Material Advancement Required

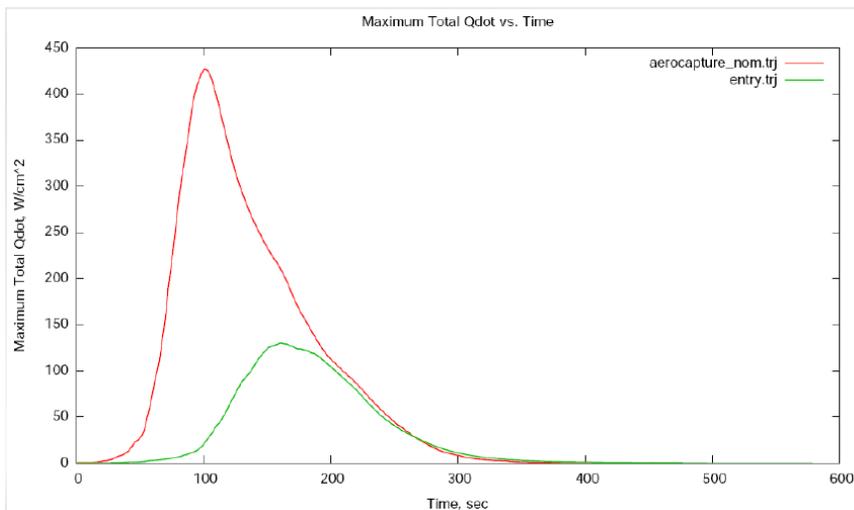
- **Development of lighter weight thermal protection material systems is required to support either mid L/D rigid systems or hypersonic inflatable/deployable aerodynamic decelerators**
- **All 8 EDL architectures require ablative materials for aerocapture based on original geometric limitations**
  - Studies of much larger HIADs allow for insulative flexible materials currently being studied under Fundamental Aerodynamics (Hypersonics)
- **5 of 8 architectures require dual pulse materials**
  - Both for rigid and flexible materials
- **Advancement in materials modeling required to support concepts under consideration**
  - Multi-layer or graded rigid ablators with varying resins
  - Multi-layer insulative flexible materials
  - Ablative flexible materials



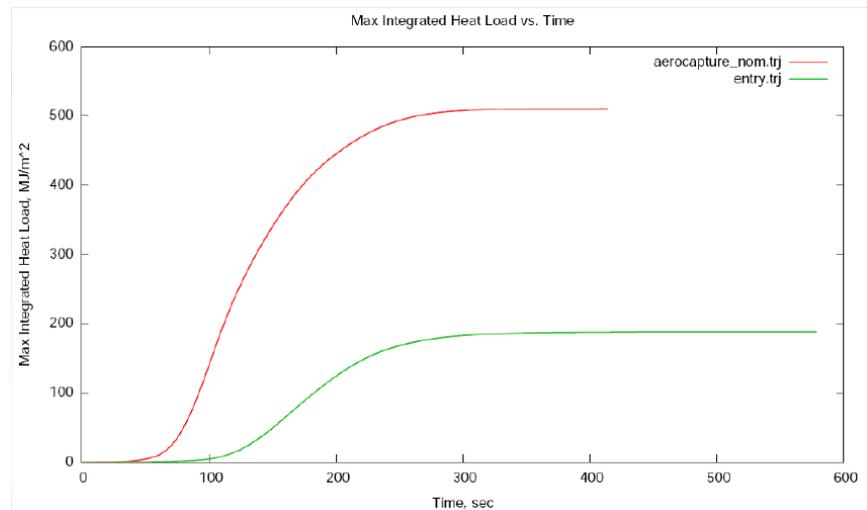
# Rigid Mid L/D Heating Environments

|                                                                                   |                                                                                                                                                                                              |                    |
|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
|  | <p><b>AoA: 55°</b></p> <p><b>Peak Heating: 430 W/cm<sup>2</sup></b></p> <p><b>Peak Shear: 554 Pa, @ 406 W/cm<sup>2</sup></b></p> <p><b>Peak Pressure: 35 kPa, @ 206 W/cm<sup>2</sup></b></p> | <b>Aerocapture</b> |
|  | <p><b>AoA: 55°</b></p> <p><b>Peak Heating: 130 W/cm<sup>2</sup></b></p> <p><b>Peak Shear: 301 Pa, @ 80 W/cm<sup>2</sup></b></p> <p><b>Peak Pressure: 25 kPa, @ 25 W/cm<sup>2</sup></b></p>   | <b>Entry</b>       |

**Maximum Heat Flux**



**Maximum Integrated Heat Load**





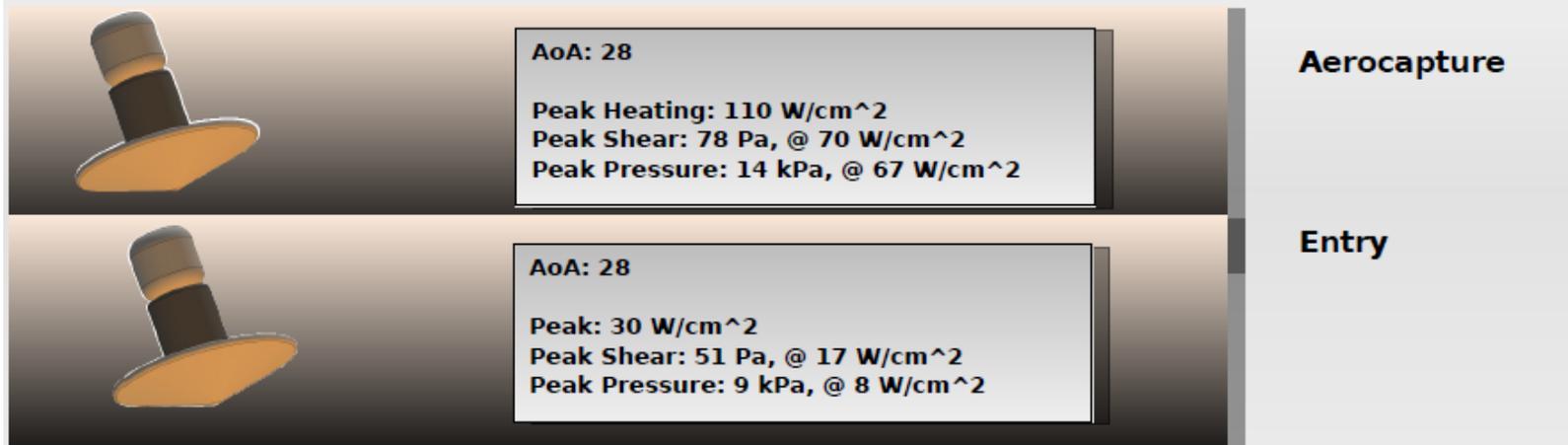
# Rigid TPS Material Goals

- **Current analysis of peak heating location on rigid TPS for the state-of-the-art material (PICA)**
- **Threshold areal density is 75% of the PICA areal density**
- **Goal areal density is 50% of the PICA areal density**
- **Approaches considered:**
  - Dual or multiple layers of dissimilar materials
    - Ablator over insulator
    - Ablator A over ablator B/C/D/E....
  - Layers of similar materials of different densities (co-cured)
- **“Monolithic” design**
  - Cured directly on aeroshell
  - Honeycomb system
  - Very large pieces manufactured and bonded with robust bond verification approach
  - No small tiles with gaps

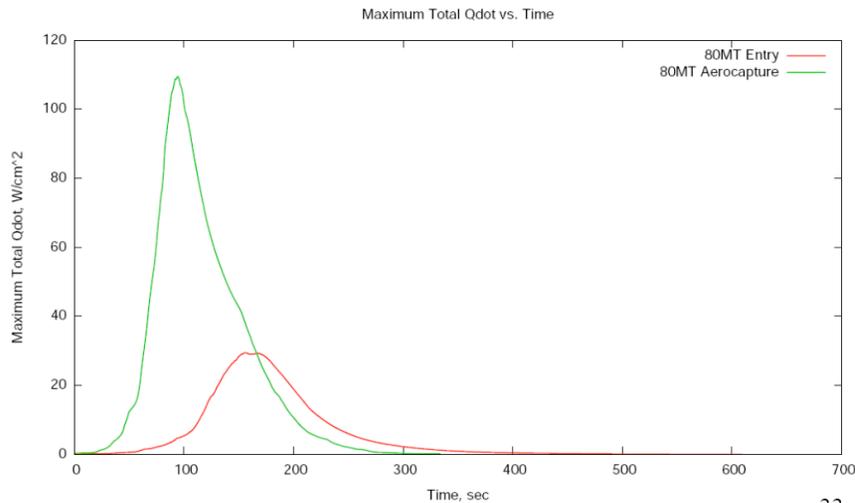


# Deployable Heatshield Heating Environments

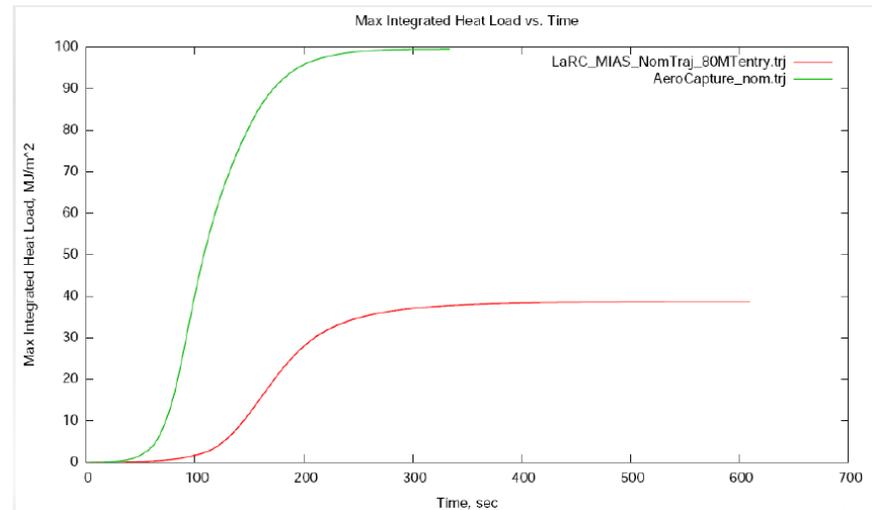
Based on 23-m Diameter Deployable



Maximum Heat Flux



Maximum Integrated Heat Load





# Deployable Materials Goals

- **Develop flexible high heat flux capable materials ( $q \sim 120 \text{ W/cm}^2$ )**
  - Current state-of-the-art insulative flexible materials survivable at  $q < 30 \text{ W/cm}^2$
- **Approach to flexible ablative materials development**
  - MIAS-class “onion-skin” ablators
  - Shuttle-derived flexible insulators (with improvements)
  - Impregnated fabrics
  - In-situ rigidized materials
  - Low catalycity, radiation reflective coatings
- **Approach to deployables**
  - Rigid yet stowable in 10x30m fairing
  - Light weight
- **Much lower TRL starting point for these ablative concepts**
- **Alternative: design with larger diameter (50-80-m) and reduce heating to allow for use of insulative flexible material systems**



# Rigid Graded/Multi-Layer Ablators

**Benefit:** Enables thermally optimized TPS systems that offer weight savings over current TPS

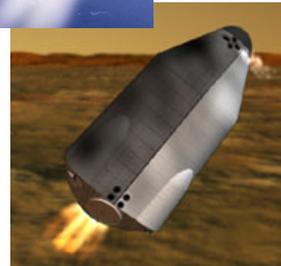
**Technical Approach:** Fabrication of graded TPS as a monolithic or incorporated within a honeycomb construction, incorporating optimized resin (enhanced char yield), reflective, insulation (shock layer), and endothermic additives. Includes Competitive procurement from industry.

**Infusion Plan:** Rigid TPS for mid L/D vehicle to enable human Mars exploration and block upgrade option for NASA or COTS Multi Purpose Crew Vehicle.

## Key Challenges:

Fabrication of mission-tailored ablator families that will utilize existing commercially available constituent materials for polymer matrix, enhancement additives, and reinforcement substrates that achieve weight/density competitive systems.

Incorporation of additives for tailored densities, thermal insulation or for radiation reflection requires the development of adequate process staging to maintain good ablator performance.



## Near Term Development Schedule:

**FY11:** Identification of advanced resin for thermally enhanced properties, begin process scale-up for fabrication of medium-scale test samples to support arcjet testing.

Graded Ablator 1-Ablative system graded from an insulator to an ablator. Demonstrated fabrication to 8x8-inch size. Characterization of thermal and mechanical properties complete.

Round 2 screening complete, Round 1 development of 3 FY10 screening materials complete.



# Advanced Conformal Ablators (Semi-rigid)

## Technical Approach:

Processing of conformable ablative systems using polymer impregnation of various flexible substrate systems including carbon felt, organic felts, woven carbon mats/fabric, etc.

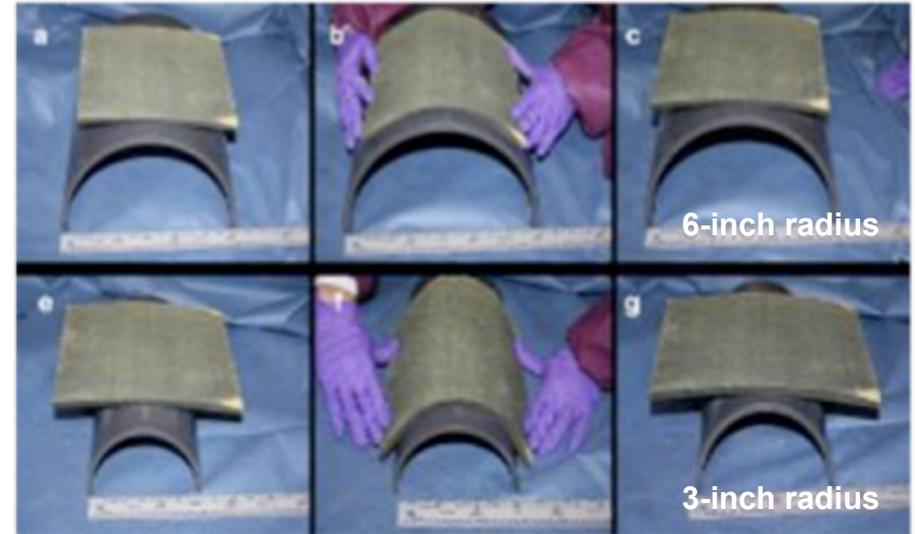
Chemical modification of resin systems to increase flexibility of the polymer and to increase endothermic capacity of the system.

**Infusion Plan:** Semi-Rigid TPS for mid L/D vehicle to enable human Mars exploration and/or block upgrade option for NASA or COTS Multi Purpose Crew Vehicle.

## Key Challenges:

Fabrication of mission-tailored ablator families that will utilize existing commercially available constituent materials for polymer matrix, enhancement additives, and reinforcement substrates that achieve weight/ density competitive systems.

Incorporation of additives for tailored densities, thermal insulation or for radiation reflection requires the development of adequate process staging.



## Development Status/Schedule:

**FY11:** Conformal Ablator 1-Flexible fibrous substrate infiltrated with modified flexible resin. (12x12-inch) Lab-scale demonstration of a conformal system capable of bending over 12-inch diameter. Characterization of physical and mechanical properties complete. Thermal performance wrt PICA baseline established.

**FY12:** Identify advanced resin incorporating heat resistant molecules or endothermic properties.

**FY13:** Conformal Ablator 2-Conformal ablation 1 system modified with flexible polymer resin and reflective additives processed for additional radiative heat protection.



# Insulative Flexible Thermal Protection Systems

**Description:** Advance technology readiness level of Insulated and transpiration cooled flexible thermal protection systems, structural configurations and performance models.

**Technical Approach:** Develop and mature TRL of materials, manufacturing, and models for flexible heat shields comprised of outer refractory fabrics, pliable low density insulators, high temperature gas barriers, and high temperature structural fabrics.

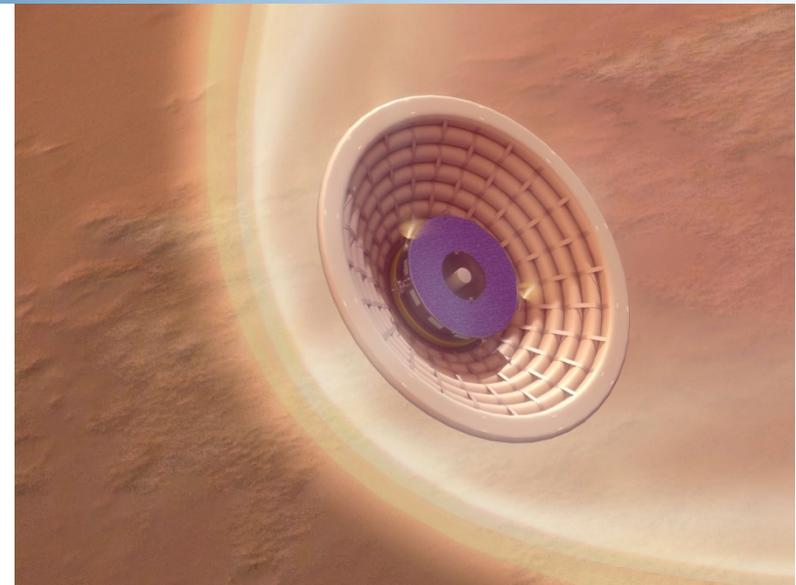
**Infusion Plan:** Sub orbital and orbital flight tests supported by flight relevant ground-based testing and model validation.

**Key Challenges:**

Extend capability to  $>100 \text{ W/cm}^2$

Increase integrated heat load capability

Establish validated system design tools



**Development Schedule:**

**FY11:** Mature system fabrication methods and validate flight relevant performance of  $20\text{W/cm}^2$  through ground testing.

**FY12:** Extend thermal performance to  $50\text{W/cm}^2$  and validate  $20\text{W/cm}^2$  capability through sub-orbital flight testing.

**FY13:** Extend thermal performance to  $75\text{W/cm}^2$  and validate flight relevant performance of  $50\text{W/cm}^2$  through ground testing.



# Ablative Flexible Thermal Protection Systems

## Technical Approach:

Formulate, fabricate and procure from industry a series of ablative flexible materials designed to withstand heat fluxes in excess of 100 W/cm<sup>2</sup> consisting of fabrics or felts impregnated with various polymers.

Test at representative conditions and down-select best material systems.

Further maturation of best materials with systematic testing to measure materials properties and response. Develop materials models for best TPS for use in system design.

## Infusion Plan:

Low  $\beta$  deployable decelerators for higher energy planetary entry vehicles

Replacement candidate for traditional rigid TPS for Block upgrade to Orion and/or COTS vehicles

## Key Challenges:

Materials performance in shear may require additional outer higher strength material or treatments

Instrumentation of flexible ablatives is challenging in that the sensors must themselves be flexible and extremely low mass

Innovative methods for joining and/or bonding materials will be required in order to manufacture very large systems



## Development Schedule:

**FY10** – Initial in-house concept development; experimentation with varying substrates and polymers; creation of new materials; thermal, aerothermal, transmission, structural screening of materials

**FY11** – Continued in-house materials improvements, and refinements; procurement of vendor supplied concepts; screening materials in thermal, aerothermal, transmission, structural and CO<sub>2</sub> environments; development of instrumentation sensors, downselection for materials maturation

**FY12** – Third round of materials development and screening; maturation of “best” FY10 and 11 materials; materials response testing and modeling; joining concept

**FY13-16** – Materials maturation and TRL advancement 12



# Materials Analysis Modeling Needs

- **Rigid Ablators:**
  - Varying materials with depth
  - Varying resin systems
  - Mixing of pyrolysis gases in depth
  - Surface reactions
- **Flexible insulators**
  - Varying thickness due to compression
  - Contact resistance between layers
  - Transpiration cooling effects
  - FSI (fluid/surface interactions effects on heating)
- **Flexible ablators**
  - Varying thickness due to compression (effects density, properties)
  - Possible varying materials with depth, varying resin systems
  - FSI (fluid/surface interactions effects on heating)



# Summary

- **NASA is busy developing new, more complex materials**
- **Modeling these new material and their unique behaviors will be challenging**
- **We are looking to the modeling community (inside and outside NASA) to meet these challenges**