NASA SBIR 2011 Phase I Solicitation

X9 Entry, Descent, and Landing (EDL) Technology

The Entry, Descent, and Landing (EDL) Technology includes developments in Thermal Protection Systems (TPS) and Supersonic Retropropulsion (SRP). The Thermal Protection System (TPS) protects a spacecraft from the severe heating encountered during hypersonic flight through a planetary atmosphere. Supersonic Retropropulsion has been identified in past studies to be enabling for putting human-scale payloads on the surface of Mars. Thermal Protection Systems: In general, there are two classes of TPS: reusable and ablative. Typically, reusable TPS applications are limited to relatively mild entry environments like that of Space Shuttle. No change in the mass or properties of the TPS material results from entry; a significant amount of energy is re-radiated from the heated surface and the remainder is conducted into the TPS material. Ablative TPS materials, in contrast, accommodate high heating rates and heat loads through phase change and mass loss. All NASA planetary entry probes to date have used ablative TPS. Most ablative TPS materials are reinforced composites employing organic resins as binders. In comparison to reusable TPS materials, the interaction of ablative TPS materials with the surrounding gas environment is much more complex as there are many more mechanisms to accommodate the entry heating. Better performing ablative TPS is needed to satisfy requirements of the most severe missions, e.g., Mars Landing from 8 km/s entry and Mars Sample Return with 12-15 km/s Earth entry. Beyond the improvement needed in ablative TPS materials, more demanding future missions such as large payload missions to Mars will require novel entry system designs that consider different vehicle shapes, deployable or inflatable configurations and integrated approaches of TPS materials with the entry system sub-structure. Supersonic Retropropulsion: When decelerating a vehicle to land on a body with an atmosphere, it is generally more mass-effective to take advantage of the natural environment and use atmospheric drag to its full potential, rather than use a propulsion system. This approach works well at Earth where the atmosphere is dense, but the trade is less conclusive at Mars. Recent studies for landing human-scale payloads on Mars (40-60 mt) have shown that using Supersonic Retropropulsion is probably enabling for this challenge. The scale of an aerodynamic decelerator employed in this flight regime would be very large, and presents issues with payload extraction and deployment in the short time available. Since a terminal propulsion system is already needed for these large landers, starting the engines earlier in the descent profile is an attractive solution. Aerodynamic challenges with this approach center around the interaction of the engine plumes with the oncoming supersonic flowfield, and what instabilities this causes for the system. Controlled wind tunnel testing with high-fidelity instrumentation and subsequent modeling of these complex flowfields is key to predicting system behavior. The SRP system will also need to be flight-tested in a relevant environment as part of the technology maturation. Cost-effective, feasible concepts and vehicle configurations for Earth flight tests are needed, to prove feasibility in the near term.

Subtopics

X9.01 Ablative Thermal Protection Systems

Lead Center: ARC

Participating Center(s): GRC, JPL, JSC, LaRC

The technologies described below support the goal of developing higher performance ablative TPS materials for future Exploration missions. Developments are sought for ablative TPS materials and heat shield systems that exhibit maximum robustness, reliability and survivability while maintaining minimum mass requirements, and are capable of enduring severe combined convective and radiative heating, including: development of acreage (main body, non-leading edge) materials, adhesives, joints, penetrations, and seals. Three classes of materials will be required:

- One class of materials, for Mars aerocapture and entry for a rigid mid L/D (lift to drag ratio) shaped vehicle, will need to survive a dual heating exposure, with the first at heat fluxes of 400-500 W/cm^2 (primarily convective) and integrated heat loads of up to 55 kJ/cm^2, and the second at heat fluxes of 100-200 W/cm^2 and integrated heat loads of up to 25 kJ/cm^2. These materials or material systems must improve on the current state-of-the-art recession rates of 0.25 mm/s at heating rates of 200 W/cm^2 and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 1.0 g/cm^2 required to maintain a bondline temperature below 250ÂºC

- The second class of materials, for Mars aerocapture and entry for a hypersonic deployable aerodynamic decelerator, will need to survive a dual heating exposure, with the first at heat fluxes of 100-200 W/cm^2 (primarily convective) and integrated heat loads of 10 kJ/cm^2 and the second at heat fluxes of 30-50 W/cm^2 and heat loads of 5 kJ/cm^2. These materials may be either flexible or deployable.

- The third class of materials, for Mars return, will need to survive heat fluxes of 1500-2500 W/cm^2, with radiation contributing up to 75% of that flux, and integrated heat loads from 75-150 kJ/cm^2. These materials, or material systems must improve on the current state-of-the-art recession rates of 1.00 mm/s at heating rates of 200 W/cm^2 and pressures of 0.3 atm and improve on the state-of-the-art areal mass of 4.0 g/cm^2, required to maintain a bondline temperature below 250ÂºC.

In-situ heat flux sensors and surface recession diagnostics tools are needed for flight systems to provide better traceability from the modeling and design tools to actual performance. The resultant data will lead to higher fidelity design tools, risk reduction, decreased heat shield mass and increases in direct payload. The heat flux sensors should be accurate within 20%, surface recession diagnostic sensors should be accurate within 10%, and any temperature sensors should be accurate within 5% of actual values.

Non Destructive Evaluation (NDE) tools are sought to verify design requirements are met during manufacturing and assembly of the heat shield, e.g., verifying that anisotropic materials have been installed in their proper orientation, that the bondline as well as the TPS materials have the proper integrity and are free of voids or defects. Void and/or defect detection requirements will depend upon the materials being inspected. Typical internal void detection requirements are on the order of 6-mm, and bondline defect detection requirements are on the order of 25.4-mm by 25.4-mm by the thickness of the adhesive.

Advances are sought in ablation modeling, including radiation, convection, gas surface interactions, pyrolysis, coking, and charring. There is a specific need for improved models for low and mid density as well as multi-layered charring ablators (with different chemical composition in each layer). Consideration of the non-equilibrium states of the pyrolysis gases and the surface thermochemistry, as well as the potential to couple the resulting models to a computational fluid dynamics solver, should be included in the modeling efforts.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.

X9.02 Advanced Integrated Hypersonic Entry Systems

Lead Center: ARC

Participating Center(s): GRC, JPL, JSC, LaRC

The technologies below support the goal of developing advanced integrated hypersonic entry systems that meet the longer-term goals of realizing larger payload masses for future Exploration missions.

Advanced integrated thermal protection systems are sought that address:

- Thermal performance efficiency (i.e., ablation vs. conduction).
- In-depth thermal insulation performance (i.e., material thermal conductivity and heat capacity vs. areal density).
- Systems thermal-structural performance.
- System integration and integrity.

Such integrated systems would not necessarily separate the ablative TPS material system from the underlying sub-structure, as is the case for most current NASA heat shield solutions. Instead, such integrated solutions may show benefits of technologies such as hot structures and/or multi-layer systems to improve the overall robustness of the integrated heat shield while reducing its overall mass. The primary performance metrics for concepts in this class are increased reliability, reduced areal mass, and/or reduced life cycle costs over the current state of the art.

Advanced multi-purpose TPS solutions are sought that not only serve to protect the entry vehicle during primary planetary entry, but also show significant added benefits to protect from other natural or induced environments including: MMOD, solar radiation, cosmic radiation, passive thermal insulation, dual pulse heating (e.g., aero capture followed by entry). Such multi-purpose materials or systems must show significant additional secondary benefits relative to current TPS materials and systems while maintaining the primary thermal protection efficiencies of current materials/systems. The primary performance metrics for concepts in this class are reduced areal mass for the combined functions over the current state of the art.

Integrated entry vehicle conceptual development is sought that allow for very high mass (> 20 mT) payloads for Earth and Mars entry applications. Such concepts will require an integrated solution approach that considers: TPS, structures, aerodynamic performance (e.g., L/D), controllability, deployment, packaging efficiency, system robustness/reliability, and practical constraints (e.g., launch shroud limits, ballistic coefficients, EDL sequence requirements, mass efficiency). Such novel system designs may include slender or winged bodies, deployable or inflatable entry systems as well as dual use strategies (e.g., combined launch shroud and entry vehicle). New concepts are enabling for this class of vehicle. Key perormance metrics for the overall design are system mass, reliability, complexity, and life cycle cost.

Advances in Multidisciplinary Design Optimization (MDO) are sought specifically in application to address combined aerothermal environments, material response, vehicle thermal-structural performance, vehicle shape, vehicle size, aerodynamic stability, mass, vehicle entry trajectory/GN&C (Guidance, Navigation and Control), and cross-range, characterizing the entry vehicle design problem.

Technology Readiness Levels (TRL) of 2-3 or higher are sought.