## Aerocapture Technology Needs

**Aerocapture** relies on aerodynamic drag with an atmosphere to achieve orbit capture. This technique is very attractive since it permits spacecraft to be launched from Earth at higher velocities, thus providing a shorter overall trip time, and a shorter capture time. Without aerocapture, a substantial propulsion system would be needed on the spacecraft to perform the same reduction of velocity. Aerodynamic drag can be accomplished by means of rigid aeroshells or by inflatable structures called ballutes (balloon/parachutes). Protection from aerodynamic heating requires careful trajectory selection, a Thermal Protection System (TPS), and monitoring by thermal and pressure sensors. The leading surfaces can be protected by ablation, or by use of high-temperature-resistant, non-ablative materials that offer sufficient insulating ability to protect payloads. The Technology Readiness Level (TRL) for rigid aeroshells is relatively high compared to that for ballutes, but ballutes are viewed as needing long-term, high-priority materials research, more specific to the goals of this NRA. Any technology that reduces mass required for a long-range, long-term mission, significantly increases the payload fraction, which is very desirable, but may fall into a shorter-term, less applicable, development category. Areas that could benefit from research include all materials, including the materials that bond them, the sensors that monitor conditions, and materials needed for deployment.

**Leading Surfaces** (also referred to as Fore Bodies and Heat Shields) experience the brunt of the aerodynamic heating and are mission dependent. Analyses of missions to date identify the following requirements: (1) high temperature operation > 1925° C, (2) high strength (modulus in tens of GPa), (3) high reflectivity in UV, (4) high emissivity in VIS/IR, > 0.9, (5) low mass (less than that of typical carbon composites), (6) anisotropic thermal properties, i.e. high thermal diffusivity parallel to craft mold line, and low thermal diffusivity normal to craft mold line, (7) resistance to reactive atmospheres for non-ablative materials. For ablators, high heat capacity is desired, but typically this coincides with high conductivities. Ablators with lower conductivities (such as an aerogel matrix composite) would be a benefit having priority.

**Bonding Materials** could differ, depending upon location. The higher temperature joint between leading components and insulation is expected to have more stringent thermal requirements, dependent upon the leading component and insulation thermal properties. Requirement is presently > 250° C, or value determined for a specific bond model. The bond must be compatible with materials being bonded over full range of temperature.

**Insulation** requirements include a suite of materials to span high temperature operation to maximum > 1750° C. These materials should have anisotropic thermal properties, i.e. high thermal diffusivity parallel to the craft mold line and low thermal diffusivity normal to the craft mold line. They need high strength (modulus in tens of GPa) and very low density (tens of $kg/m^3$), which is viewed as having a low TRL level at this time.

**Sensors** will need to be embedded in the appropriate materials and locations to measure temperatures from ~1500 – 1700° C, and stresses consistent with launch and re-entry. This could involve sensors fabricated as components within materials.

**Deployables** consist of materials capable of being stored compactly and deployed in space. In particular, deployment of inflatable ballutes in deep space represents a challenging requirement that is given high priority for identification of materials and techniques that could demonstrate feasibility, including the potential for additive layering of heat-resistant aerogels, beads, or other protective materials, before, or after, deployment.

**Science Questions:**

(1) Polymer bonds offer flexibility to accommodate differences in coefficients of thermal expansion, CTE's, but lack high working temperatures. The bonding of metals (e.g. aluminum), ceramics and other dissimilar materials (carbon, aerogels, etc.) that operate over a wide temperature range creates problems with stresses from appreciably different CTE's. Bonding materials need to be identified and processes developed that can satisfy priority requirements over the range of operating conditions and materials to be bonded. In-space fabrication of bonds is viewed as far more difficult than by ground-ops, at this time.

(2) Emissivity is a strong function of the surface, which usually requires measurement for high accuracy, and can change for various reasons. Thermal protection relies on high emissivity reducing leading surface temperatures. Material selections and applications need to account for such conditions, as well as the accepted working temperature, thermal conductivity, specific heat, reflectivity, and other properties.

(3) Priority requirements for strong anisotropy in thermal properties of the materials limit natural bulk materials to those that exhibit such properties, but it appears feasible to investigate multilayer structures that can accomplish anisotropy by having high conductivity layers separated by insulation along the desired low thermal conductivity direction. Bonding then becomes an issue.

(4) Coatings are expendable in the near- to mid-term, but far-term concepts require reusability, which could influence (2). Priority is given to materials development that would result in minimal heat transfer to leading surfaces from ionization (referred to as "non-catalytic"), as well as non-reactive protective coatings.

(5) Level of ablation could be relative, with "non-ablative materials" showing some loss, and small levels of ablation even being designed in. More detailed analyses of selected materials and effects on above questions are needed.

(6) Current TPS's are layered systems of metallic honeycomb sandwich and insulation (densities of 224 $kg/m^3$, or 14 $lbs/ft^3$, and areal densities ranging from 10-26 $kg/m^2$) and are limited to 700 $W/cm^2$. A priority of < 128 $kg/m^3$ (< 8 $lbs/ft^3$) will require materials selection, measurements and analyses to evaluate effects on the other requirements.

(7) The thermal conductivity of a metal correlates with electrical conductivity, which increases with temperature. Oxidation, radiation, or other damages that influence these, or similar properties of other (semiconducting, or dielectric) materials, need accounting for on long missions with exposures that could change material properties.

(8) Ballute requirements are challenging and high priority. The materials must sustain required properties if compacted (creased), long-term (10 years), cold-soaked, exposed to particulate and radiation damage and also when deployed and exposed to very high temperatures and appreciable stresses. Add inflation by low-density gases (He, Ne, H2, etc.) as the means of deployment and the thin containment

walls must be impermeable to these gases, which are being heated within. Selection and testing of materials that can meet these requirements is viewed as being at a very low Technology Readiness Level, conducive to objectives of this NRA. Nondestructive testing and absence of degradation from phase transitions, moisture and other common environmental exposures is required, and a particular interest is expressed in any aerogel-based, or similar, coatings that might enhance the material performance.