Solar Sails

Critical Requirements/Needs

Solar sails use the momentum transfer from reflected light to provide a propulsion force. The sun deposits approximately 9 Newtons per square kilometer at 1 Au . The low mass sail requires nano-thin materials (submicron thickness) coatings that must be tear and wrinkle resistant, deployable and because of the close approach to the sun requires surviving severe thermal (temp = 500C at 0.1 AU) and radiation (ultraviolet + low energy charged particles <100 KeV) environments over a mission life of 10-15 years within 0.1 AU. Ultimate goals are to survive the extremely hostile thermal environment (2000 C) and cosmic radiation flux at 3 solar radii. Sail surfaces facing toward the sun need high reflectivity coatings and surfaces facing away from the sun need high emissivity coating to shed heat. The goals are 0.99 reflectivity and emissivities ranging from 0.9 to 0.99.

Current polymeric material designs are approximately 2 µm thick, with sail material density of about $10g/m^2$ and psi and temperature capability is 180-200 C is currently undergoing environmental testing. The current state of the art is Al for reflective coatings with reflectivity of 0.9 and Cr for emissive coating with an emissivity of 0.8. Current polymeric sails disintegrate under extreme radiation exposure. Metal foils also suffer radiation damage. There is no sun close-approach material currently available.

The sail material is supported by masts and a control boom is needed perpendicular to sail. Support booms/masts must be deployable from payload package. Graphite coilable booms represent the current state of the art (20-25 $grams/m^2$ for the structure) and provide unique, repeatable deployment capability and have been flight-proven. The near term goal is 12-15 g/m^2 areal density (including support structure but not including boom, science package & bus). The long-term goal for an interstellar probe (417 meter hexagon) is an areal density of 1 to 0.5 g/m^2 (including support structure) for the 90,000 m^2 sail. Key requirement is to reduce mass of boom design while maintaining rigidity/structural integrity.

Key Science Issues

Polymers in current designs are degraded by the radiation and cannot withstand the temperatures that are anticipated.

1. Is it possible to develop a higher temperature and radiation hard polymeric material which might include highly crosslinked thermoset composites rigidized after deployment by thermal curing, UV curing, etc.
2. Concepts that might also include self healing materials would be of interest.

For near-term designs, the reflectivity might be sacrificed for radiation exposure resistance, higher temperature capability, and high emissivity. Alternatively, a very high refelectivity, radiation hard sail material with current state of the art emissivity might be suitable.

1. Radiation hardened materials with high emissivity and reflectivity over the range of temperature (to 500 C) are required. What is the metal coating thickness required for high reflectivity? What refractory radiation hard materials exist with high emissivity and reflectivity? How can the necessary knowledge base of radiation hard materials for emissivity and reflectivity for solar sail applications be developed and measured?
2. How might surface morphological texturing be utilized to achieve higher emissivity of the surface?
3. Increasing the reflectivity achieves two important advantages. The efficiency of the sail increases and the amount of absorbed energy converted to heat decreases. Can the ideal reflectivity (0.99) be approached with nanoscale dielectric multiplayer photonic band gap materials approaches?

Ceramics are ideal for high temperatures. Can a ceramic polymer composite (polymer with ceramic precursors) be developed that while unfired is sufficiently flexible, but after deployment, and firing (with heat from the sun), leaves a ceramic that very stable at the high temperatures.

1. How might polymer-ceramic composites be fired in-situ producing a thin ceramic membrane?
2. Can ceramic-polymer composites that fire to thin ceramic films be fabricated with suitable high reflectivity and high emissivity surfaces *in situ*?

The development of deployable lightweight rigid booms is of interest.

1. What alternate methods might be developed for support structure fabrication? Aerogels have high strength at very low weight. Is there a way to fabricate Aerogel beams in situ for structural supports?
2. Are inflatable structure concepts practical for solar sails?