Passive Thermal Control Challenges for Future Exploration Missions

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Background

• The President’s recently announced vision refocuses attention to exploration;

• Emphasis shifts from Earth orbit operations to travel to the Moon, establishing a lunar base, and an eventual journey to Mars;

• Humans went to the Moon during Apollo, but only for short stays – a different set of challenges arises when we consider going to the Moon to stay for extended periods;

• Humans have yet to visit Mars but work on advanced programs has identified some key challenges associated with sending humans to Mars.

NOTE: This presentation will focus only on passive thermal control – thermal protection (entry-related technologies) will be covered in a separate presentation.
General

• *Improved Thermo-optical Coatings:*
  • Low solar absorptance to infrared emittance ratio ($\alpha/\varepsilon$) – potential use on radiators;
  • Inexpensive – some current low $\alpha/\varepsilon$ coatings are very expensive;
  • Easy to apply;
  • Resistance to property changes (due to ultra-violet radiation);
  • Resistance to atomic oxygen;
  • Long lifetime with stable properties;
  • Can be easily maintained (in lunar- or martian-dust environment);
  • Variable/user specified optical properties.

• *Thermal Instrumentation:*
  • Inexpensive;
  • Reliable;
  • Robust.
General (Continued)

- **Cryogenic Boil-Off:**
  - Improved storage of cryogens for prolonged periods.

- **Insulation/Isolation Technologies:**
  - Vacuum panels;
  - Use of aerogels;
  - Multi-Layer Insulations (MLI);
  - Thermal Compartments;
  - Thermal Switches.

- **Lunar Day/Night Survival:**
  - Lunar days and nights each last ~two weeks;
  - Extreme temperatures during lunar day (> +250 deg F);
  - Lunar soil reaching high temperatures in prolonged sunlight;
  - Lunar nighttime produces surface temperatures < -300 deg F
Electronics

• With further miniaturization of electronics components, power density and the associated challenges of electronics heat dissipation will provide new challenges -- Potential needs include power reductions that keep pace with electronics miniaturization;

• Improved means of heat transfer from electronics components:
  • Gap Fillers;
  • Gaskets;
  • Improved interface conductance.

_Involvement by the thermal community is critical early in the development process._
Analysis

- Improved modeling of systems;

- Potential for large model sizes

- Improved modeling of electronics components;

- Improved thermal environment characterization;
  - Planet/moon surface environments, atmospheric extinction, diffuse sky heating components;
  - Improved convective heat transfer calculations for Mars surface;

- Improved compatibility with concurrent engineering tools:
  - Thermal $\rightarrow$ Structural;
  - CFD $\rightarrow$ Thermal;
  - Orbit $\rightarrow$ Thermal;
  - Etc.

- Thermal Analysis of Inflatable Structures
Environment Characterization

• Lunar and Martian Orbit Environments:
  • Lunar albedo and infrared emission;
  • Martian albedo and infrared emission.

• Mars Surface Environments:
  • Atmosphere optical depth and dust storm characteristics;
  • Diffuse sky solar and infrared heating components;
  • Detailed wind profiles;
  • Atmospheric temperature profiles near the surface.
Testing

*Facilities to support large-scale thermal-vacuum testing for lunar- and martian surface environments are needed:

- Solar simulation;
- CO2 environment at low pressure (for martian surface simulation);
- Lunar and Mars surface simulation.
Wrap-up

• Expect additional technical challenges to arise as an architecture for exploration matures;

• Key aspects of passive thermal control arise as a consequence of spacecraft integration:
  • Utilizing waste heat from one system to accommodate the needs of another system;
  • The entire system must function successfully as a unit.