The proving ground for multi-layer insulation materials

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Engineers on a constant quest to reduce the weight of space vehicles will look to next-generation materials, replacing metals with fabrics that provide the same thermal and radiation protection while giving the spacecraft a fighting chance of survival outside the Earth's atmosphere. This article will address current materials used, as well as a new generation of high-performing materials.

Most satellites and space vehicles such as the International Space Station (ISS) and the Space Shuttle travel in what is known as Low Earth Orbit (LEO), which is considered to be an orbital band between 100 – 1240 miles above sea level. The most common orbits, however, are between 200 – 250 miles because less energy is required to launch and communications distances are more favorable.

The LEO area is filled with elements we don't find on earth such as atomic oxygen. Atomic oxygen is highly unstable, particularly in this environment, and is a chief source of the degradation of exposed surfaces in space vehicles. At this altitude there is also a high concentration of debris and particles traveling at extremely high speeds relative to that of the vehicle. Even a particle the size of a marble can cause significant damage to a space vehicle.

In addition to the above affects, a spacecraft is also subject to extreme temperature fluctuations as it orbits the Earth. Different parts of the spacecraft may see very hot or cold temperatures during some or all of its "day," which can list minutes or hours depending on its orbit. The sun's radiation combined with the Earth's magnetic fields create a hostile environment for spacecraft systems and instruments, which must still perform flawlessly for the spacecraft's working life.

Thermal and radiant energy and TPS
The sun emits energy in the form of radiation that we on Earth feel as warmth or thermal energy. Our atmosphere protects us from receiving the sun's radiation while retaining enough of it to keep us warm. Spacecrafts operating outside of the atmosphere don't have that protection. They rely on specialized materials referred to as its Thermal Protection System (TPS) to perform this function.

In addition, thermal energy is generated by internal components of a satellite such as batteries, transmitters, computers and other devices. This thermal energy must be emitted so it does not damage the components. Thermal management control systems are an integral part of the design of a satellite. Techniques include passive and active systems. Some active techniques include the use of heaters or refrigerators. Multi-Layer Insulation (MLI) and radiators are other passive techniques.

MLI is a type of thermal protection system (TPS) used on spacecraft, launch vehicles, The Space Shuttle and the International Space Station. MLI insulation is typically found in blanket form and consists of films and fabric constructions ranging from five to forty layers as well as highly specialized tapes used in edge binding and cable wrapping.

The goal of the TPS is to maintain equipment temperatures in very specific ranges during the mission life. Keeping this temperature range allows all electronic equipment, instruments and systems to function in their optimal operating conditions. The most notable example may be the ISS, which has been continuously inhabited since November 2, 2000. **How MLI works**

MLI Blankets consist of multiple layers of highly reflective, low emittance or “E” materials. Similar to “Low E” windows in your house, emittance measures a material’s ability to reflect solar energy. A material that has low emittance properties will have highly reflective properties like a mirror and would deflect heat and specifically in a space environment, solar radiation.

For optimum insulation performance, successive metalized layers are separated by materials with low-thermal conductivity like Nomex or polyester netting. One layer of the MLI structure may reflect as much as 97 percent of incident radiation and adding additional layers decreases absorptance between layers exponentially until it is completely dissipated by the time the energy would reach the protected component.

The simplest way is to support and separate layers using crinkled or embossed film. This ensures that adjacent layers are connected at only a few points. To avoid metal-to-metal contacts of high thermal conductivity, the film must be metalized on only one side.

A more common and more effective method is to separate and support layers of two-side-aluminized film using a thin layer of a poor thermal conductor. Fiberglass material, paper, cloth, and various polymer non-woven or meshes can be used. An additional benefit of this method is that the non-conductive layer provides added puncture resistance and overall creates a more robust construction.

Additionally, the two-side-aluminized films offer lower absorptance because they reflect radiation on both the first and second surface.

Most MLI blankets are based on three foundations, polyester, polyimide or fluorocarbon films. These base materials are metalized, coated, laminated, perforated, crinkled or embossed or some combination to meet different product specifications. For perspective, an MLI film manufacturer could have a product portfolio of over 400 products based on the three aforementioned film types.

The films are the base layer for TPS and are selected for a few key properties including physical, thermal, electrical and chemical. See chart below for data.

Key Properties of Aluminum-Coated Polyester, Polymide, and Fluorocarbon Films			
	Polyester	Polyimide	Fluorocarbon
Physical Properties	@ 25°C (77°F)	@ 23°C (73°F)	@ 23°C (73°F)
Density	1.4 g/cc	1.42 g/cc	2.13-2.14 g/cm^2
Thickness	25 gauge (6.3 microns)	100 gauge (25 microns)	200 gauge (50 microns)
Yield	576 ft^2/lb	136 ft^2/lb	45 ft^2/lb
Tensile Strength	28,000 PSI/1972 kg/cm^2	24,000 PSI/1690 kg/cm^2	2,500 PSI 176 kg/cm^2
Thermal Properties			
Thermal Conductivity	6.1 x 10^{-3} Watts cm^{-1}°C^{-1}	6.1 x 10^{-3} Watts cm^{-1}°C^{-1}	1.94 x 10^{-3} Watts cm^{-1}°C^{-1}
Specific Heat	.28 (cal/gm/ °C)	.28 (cal/gm/°C)	.28 (cal/gm/°C)
Solar Absorptance	≤ 0.14	≤ 0.14	≤ 0.14
Emissivity	0.035 (avg)	0.035 (avg)	0.035 (avg)
Service Temperature (nom.)	-250°C +150°C	-250°C + 204°C	-150°C +150°C
Outgassing	% TML < 1.0% %CVCM < 0.1%	% TML < 1.0% %CVCM < 0.1%	% TML < 1.0% %CVCM < 0.1%
Electrical Properties			
Resistivity, Ohms/ □	< 1.0 Ω / □	< 1.0 Ω/ □	< 1.0 Ω/ □
VDA Thickness Angstroms	≤ 300 Å	≤ 300 Å	≤ 300 Å
Chemical Properties			
Moisture Absorption 50% R.H. @ 25°C (77°F)	1.0% (nominal)	4.0% (max)	1.0% (nominal)

Some MLI blankets use coated films in addition to metalization. Various coatings are used for corrosion resistance, controlling emittance and bonding dissimilar substrates together.

New technologies

External insulation materials are sensitive to electromagnetic interference (EMI), particularly in LEO and medium earth orbit (MEO) due to EMI from the Van Allen radiation belt. Existing metallic coatings that are clear and electrically conductive (Less than 1000 ohms per square), and used to dissipate the charge build-up, have been used but are subject to cracking and handling damage. Next generation polymer based coatings can be incorporated into MLI blankets to improve the flexibility of the insulation allowing for more robust construction.

Other new technologies are constantly being tested for use in space vehicles, for example:

- Integration of new film barrier technologies in combination with advanced composites, including nano-fibers and 3-D woven materials, are applied for their ability to produce very strong, thick materials.
- Combination of solar energy modules as an active insulation component with the passive MLI that insulates without using electrical or other forms of power.
- Use of advanced barrier coatings to further prevent electrical interference and oxidation of components in LEO.

Steady growth in satellite applications and work on the ISS over the coming years will serve as a proving ground for optimization of current MLI materials as well as this new generation of specialized materials. The intent of these materials is to provide more reliable, long term service, while at the same time enhancing the performance of the space vehicle and its instruments throughout its life. The challenge will be to provide coated films and fabrics with improved thermal resistance, optical and physical protection properties at the same or less weight as current materials used, and thereby enabling engineers to apply them to areas where only heavier materials have worked in the past.

About the author:

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Corporation, Art Mallett, Jr. leads the team that develops innovative materials for the aerospace industry, including DunShield ESD and aircraft Thermal Acoustic Insulation. He holds a bachelor of science in aerospace engineering from the Florida Institute of Technology (FIT) and is a member of the American Institute of Aeronautics and Astronautics (AIAA). Art regularly participates and speaks at AIAA events, most recently speaking about “Advances In Materials for Multi-Layer Insulation” at the AIAA Space 2011 Conference in September 2011.

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