



Quest Thermal Group



Quest Thermal Group/Ball Aerospace Next Generation MLI Products

IMLI

Integrated Multi-Layer Insulation (IMLI) is a next generation ultra-high performance thermal insulation. IMLI uses Discrete Spacer Technology™ to improve thermal performance and predictability and offers significant advantages over traditional MLI and Spray-On Foam Insulation (SOFI).



- IMLI provides improved thermal performance from low conductivity discrete spacers with controlled inter-layer spacing and density, and results in reduced system power and improved cryogenic system life. IMLI measured results show up to 50% less heat leak per layer than traditional MLI.
- Proprietary spacers create a robust, bonded structure that can support dynamic loads.
- Test results show agreement within 10% of SINDA thermal models - *with no correction factors*.
- IMLI can be fabricated using low cost, automated manufacturing processes.
- Modular design enables rapid implementation, installation and easy repairs if damage occurs.
- IMLI products are extensible to a broad range of mission environments and applications.

IMLI technology has been expanded into a family of products to address a broad range of thermal insulation needs, including traditional MLI uses, SOFI replacement, advanced thermal shield systems for cryogenic propellant storage, exposed surfaces of launch vehicles and micrometeoroid shielding.



LVMLI

The product family includes Launch Vehicle MLI (LVMLI), which offers the insulating properties of IMLI with a robust structure and more durable outer layer to withstand aerodynamic launch loads. LVMLI includes more rigid layer separation than IMLI to operate in both the aerothermal launch environment and the ground environment on the pad. LVMLI supports an internal vacuum that increases its insulating capabilities over IMLI, and can enable longer on-orbit coast times for cryogenic upper stages. LVMLI has successfully completed thermal and structural testing, and is ready for additional aerodynamic testing.

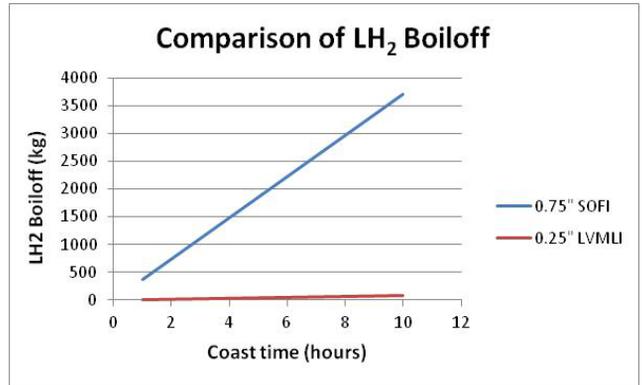
LRMLI

Load Responsive MLI (LRMLI) uses a dynamic spacer and a modular, lightweight vacuum shell to withstand atmospheric loads. LRMLI provides both high thermal performance in-air, and ultra-high performance on-orbit. LRMLI is a SOFI replacement system with substantially higher performance. The LRMLI system is the most durable product in the next generation MLI product family. LRMLI is ideal insulation for LH₂-tanks with in-air operation.



Performance Compared to SOFI

Cryogenic upper stages on launch vehicles have on-orbit coast times limited by propellant boil-off, and LVMLI provides an ideal insulation solution with superior performance. LVMLI has 144x lower heat transfer per thickness than SOFI. For a 200 m² tank, the difference in propellant lost to boil-off is estimated as 3600kg in 10 hours on-orbit. LVMLI mass is estimated as 180kg, SOFI mass is 140kg. As a low-risk path to flight demonstration, LVMLI could be used in conjunction with SOFI to provide both ground hold and long on-orbit coast times.



Thermal performance can be even further improved, as demonstrated by Load Bearing MLI (LBMLI), in which vapor cooled shields are self supported by IMLI spacers, without requiring tank supports or standoffs.

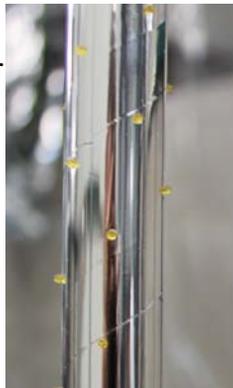


| Insulation Type | Insulation Thickness (cm) | Effective in Air | Area Density (kg/m ²) | Heat Leak in Vacuum (W/m ²), 295 to 77K |
|-----------------|---------------------------|------------------|-----------------------------------|---|
| SOFI | 1.9 | Yes | 0.7 | 231 (700 in air) |
| IMLI | 3.6 (20 layers) | No | 0.82 | 0.41 |
| LVMLI | 0.63 (3 layers) | Yes | 0.9 | 4.8 (29.3 in air) |
| LRMLI | 0.70 (3 layers) | Yes | 2.4 | 4.8 (29.3 in air) |

Other Next Generation IMLI Products:

Wrapped MLI

Wrapped MLI (WMLI) uses custom discrete spacers for reduced heat leak into cryo pipe. WMLI has a measured heat flux 12x less than spiral wrapped traditional MLI, for significantly improved vacuum insulated pipe. WMLI, like IMLI, offers controlled layer spacing and predictable performance.



MMOD IMLI

MMOD-IMLI utilizes IMLI's structural strength to support ballistic layers, providing both thermal insulation and micro-meteoroid and orbital debris protection. MMOD-IMLI has 24% of the mass of a multishock shield with equivalent stopping power, with heat transfer on the order of 0.1 W/m².



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