Next Generation Multilayer Insulation with Discrete Spacer Technology

Part 2: New applications and thermal insulation designs

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Editor's note: The original development of Integrated MLI was described in part one (Cold Facts Vol. 32 No. 1), along with several variants using Discrete Spacer Technology to create insulation with unique properties. Part 2 describes more recent insulation developments.

Thermal insulation is used all around us and opportunities for advanced insulation for aerospace and terrestrial applications are quite interesting. Integrated MLI (IMLI) and variants are not necessarily the best solution for all cryogenic insulation applications but they offer the opportunity for improved performance, structural strength and the unique capability to precisely engineer insulation with novel properties for new mission requirements.

The Quest Thermal and Ball Aerospace team has developed advanced launch vehicle specific insulation systems to improve upon the spray on foam insulation (SOFI) used on launch vehicle cryopropellant tanks. Launch Vehicle MLI (LVMLI) uses the robustness and strength of discrete spacers to form a ruggedized IMLI structure potentially strong enough to survive launch loads on exposed cryotank sidewalls. Current Centaur sidewall insulation is SOFI, with a heat flux of approximately 230 W/m^2. The team's 2.5 layer LVMLI prototype survived simulated aerodynamic ascent forces. It has 3.5 W/m^2 heat leak, 68 times lower than SOFI, and 33 percent of the mass of SOFI. LVMLI requires vacuum for good performance and as such is designed for in-space operation.

Load Responsive MLI (LRMLI, described in Part 1) can operate both in-air and in-space, but requires the insulation internal space to be pumped down to hard vacuum. With this limitation in mind, the team began designing two new launch vehicle insulation systems that would not require mechanical pumping.

Cellular Load Responsive MLI (CLRMLI) is a novel technology with a cryopumping cellular core containing Load Responsive MLI layers. CLRMLI self-evacuates via cryocondensation or cryosorption (depending on cryogen and temperature) when in contact with cryogenic propellant tanks, allowing high thermal performance both in-air and in-space. The cellular structure provides damage tolerance, and internal LRMLI layers support atmospheric pressure with a lightweight laminate vacuum shell layer. CLRMLI dramatically outperforms SOFI both in-air and in-space. Compared to SOFI's 230 W/m^2 heat flux, CLRMLI first generation prototypes have a measured heat flux of 11 W/m^2 in vacuum and 46 W/m^2 in-air. Quest demonstrated the feasibility of CLRMLI in SBIR Phase I, reaching TRL 4, and is now in Phase II R&D. SINDA-like thermal modeling predicts second generation CLRMLI should have 8 W/m^2 in-space and 27 W/m^2 in-air (77 K, 295 K, 1.5 cm).

Launch Vehicle-Load Responsive MLI prototype ready for thermal testing (polymer laminate vacuum shell visible). *Image: Quest Thermal Group*

Another new launch vehicle system, Vacuum Cellular MLI (VCMLI), uses a thin self-evacuating dual layer vacuum cell honeycomb for thermal insulation in-air, with exterior LVMLI layers for excellent performance in-space. VCMLI can replace SOFI with a high performance, robust system that provides 76 percent lower heat leak in-air and 98 percent lower heat leak in-space than SOFI.

An interesting (and fun) aspect of these new insulation technologies is that we can engineer these systems to modify their properties. Four-layer VCMLI provides a different operational trade-off than CLRMLI, with 4.7 W/m^2 in-space and 42 W/m^2 in-air, offering better performance in-space and still preventing icing pre-launch. Heat leak through the cellular structure, heat leak through the internal or external radiation barriers and strength of outer skins are each adjustable for specific applications. Ball Aerospace and Quest have a current VCMLI development program funded by the US Department of Defense to begin further testing and integration into a launch vehicle for increased payloads and coast time capabilities. The benefits are clear, but as these technologies are currently at TRL 3 to 5, more development and testing are required.

Quest Thermal is also working on two new insulation systems with potential to help meet NASA cryogenic fluid management goals. The 2015 NASA thermal management roadmap has goals for passive and active thermal control, including load responsive insulation that can support broad area coolers or vapor-cooled shields and low thermal conductivity structural supports, for reduced or zero boiloff. As acreage tank MLI improves, conductive heat leak through tank supports such as skirts and struts has become more important, and reducing heat load through these support elements is a productive area for innovation.

Quest has developed and tested novel Vapor Cooled Structure MLI (VCSMLI) with custom shaped discrete spacers that create a lightweight vapor transport layer for vapor cooling. VCSMLI uses discrete spacers and

IMLI to provide robust insulation that intercepts heat load conducted through tank supports. VCSMLI models predicted a 45 percent reduction in total tank and support heat leak for a skirt mounted tank, and 57 percent reduction in skirt alone heat leak. A VCSMLI prototype achieved a 41 percent reduction in heat leak by using vapor cooling through a lightweight vapor layer applied directly to tank supports and integrated with IMLI insulation. Application of VCSMLI to the Advanced Common Evolved Stage (a cryo upper stage) could reduce heat flux into the LH_2 tank from 10,900W to 3,400W, and VCSMLI integrated with Quest LVMLI is modeled to further reduce heat flux to 755W.

VCSMLI Phase II development is beginning and will increase technical maturity by optimizing the design and testing in more relevant environments to include larger tanks, tank strut supports and LH_2 tanks. VCSMLI could prove very useful for reducing heat flux into skirt mounted cryotanks such as those on the Delta Cryogenic Second Stage, Vulcan or SLS cryogenic upper stages.

Another interesting insulation system developed for NASA was to provide an effective Mars thermal control strategy, insulating LCH_4 storage tanks during the cruise phase to Mars and for LCH_4 ISRU storage tanks on Mars surface. NASA provided challenging thermal goals, including <1 W/m^2 heat flux on-Mars surface, <0.5 W/m^2 in-space, better than SOFI thermal performance in-air prelaunch and low mass.

A hybrid system (LV-LRMLI) using Launch Vehicle MLI (very good in space) with inner layers of a modified LRMLI (very good in-air and on-Mars) enclosed in a ventable and sealable lightweight vacuum shell was developed. Various spacers and geometries—with different structural strength and solid heat conductance—offer unique capabilities to custom engineer thermal solutions. For on-Mars operation with a low atmospheric pressure (600 Pa), the team designed spacers with adequate structural strength to support a polymer laminate vacuum shell with low external on-Mars load while minimizing heat flux. LV-LRMLI prototypes were fabricated and thermal performance measured with boundary temperatures of 77 K and 295 K, with the heat flux for LCH_4 tanks calculated to be 127 W/m^2 in-air, 1.0 W/m^2 on-Mars surface condition (4.5torr CO_2) and 0.25 W/m^2 in-space. This system provides unique thermal properties, with very good thermal performance in Mars atmosphere for future Mars missions.

Noting the long adoption cycle for aerospace applications, Quest Thermal is currently developing commercial grade superinsulation, based on our discrete spacer technology, initially focusing on home and commercial appliances like refrigerator/freezers (RF). Quest High Performance MLI (HPMLI) uses a new spacer designed for low cost and full time in-air use; a 0.22" thick panel is expected to have a heat flux of 2.4 W/m^2. State-of-the-art RF insulation is polyurethane foam, which for 1" thick insulation has about 22 W/m^2. HPMLI could lead to highly energy efficient appliances. Prototypes are currently in development and discussions have begun with appliance manufacturers. **www.questthermal.com** ■