

Multi-Environment MLI: Lightweight Supported Vacuum Shells

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Multi-Environment MLI

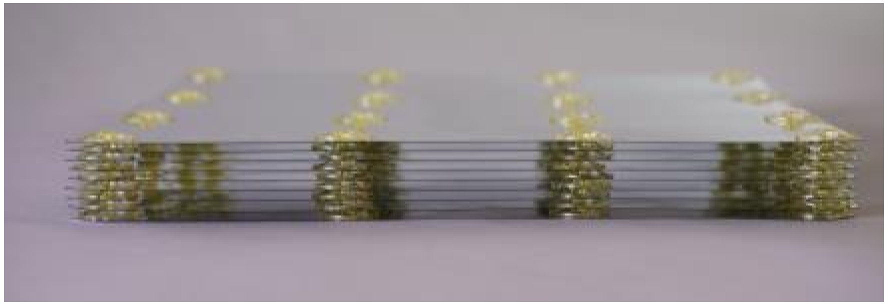
- NASA is developing concepts for In-Situ propellant surface liquefaction and storage on Mars and the moon.
- Mars' atmosphere means conventional MLI requires a heavy vacuum shell.
- New technology needed includes effective cryocooling and high performance, low mass thermal insulation in a soft vacuum.
- Discrete Spacer Technology, developed by Quest Thermal and Ball Aerospace, offers unique structural capabilities for multilayer insulation.

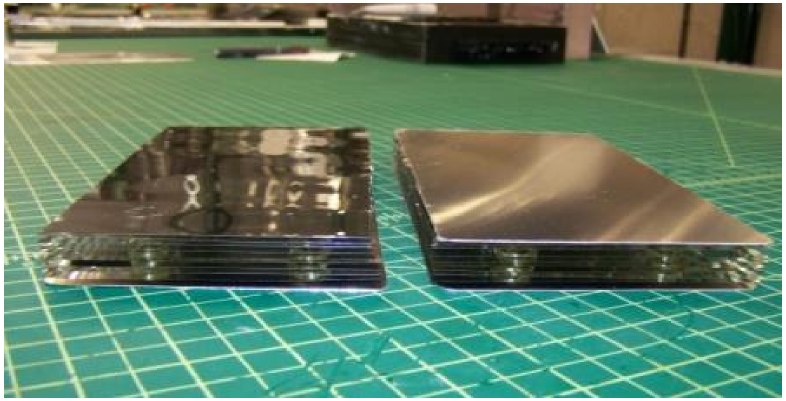
Multi-Environment MLI

- Integrated MLI (IMLI) uses discrete spacers to support various loads, such as the 4.7torr external atmospheric pressure on Mars, and up to 90psi.
- MEMLI uses a thin, lightweight, supported vacuum shell combined with IMLI, designed to operate at Mars surface pressure.
- The MEMLI ventable/sealable vacuum shell is GN_2 purged prelaunch, vented during in-space cruise, then sealed for on-Mars use with LOX (90K) or LCH4 (110K) tanks.

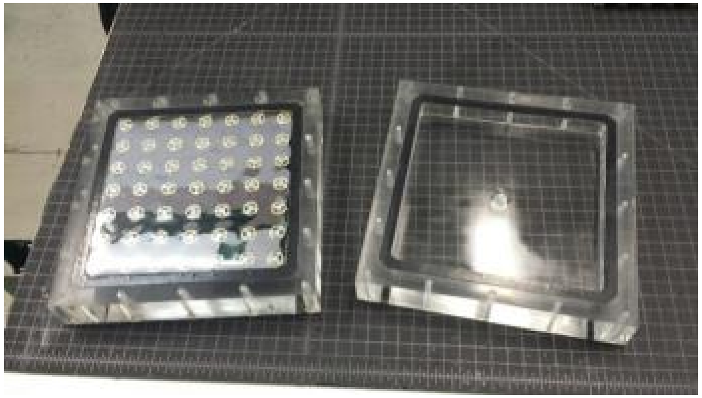
Initial NASA goals were:

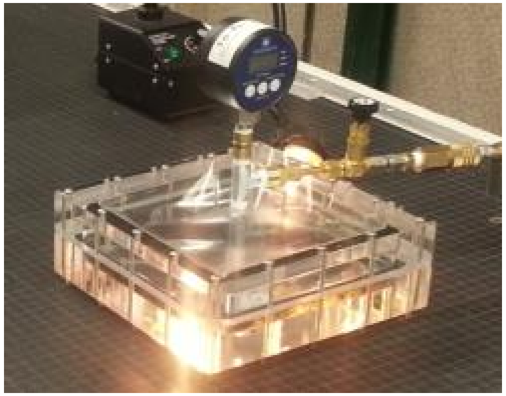
- <1.0 W/m^2 on-Mars (90K – 210K)
- <0.5 W/m^2 in-space (90K – 210K average boundary temperatures)
- < 230 W/m^2 prelaunch (90K – 295K)

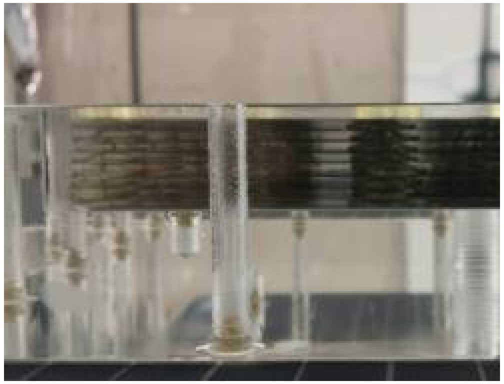




MEMLI coupon testing





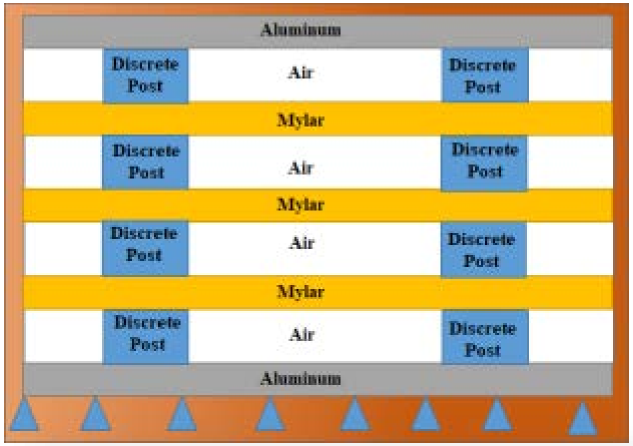


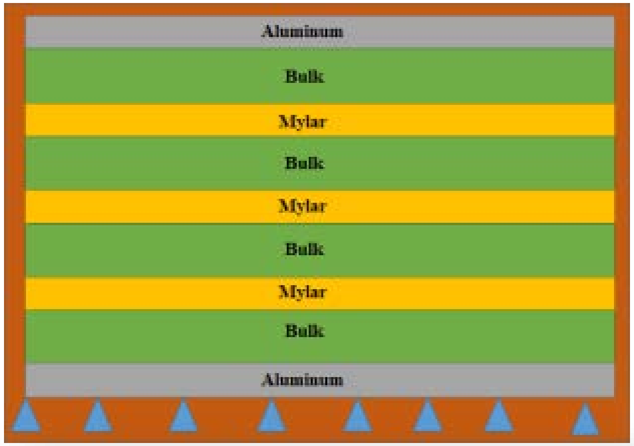
- Coupons were built and tested for structural strength with different spacers, grid spacings, layers, vacuum shells; to optimize for operation at Mars atmospheric pressure (4.7 torr).
- Shell and layer deformation and interlayer spacing were evaluated at up to 4x Mars atmospheric pressure.
- Structural analysis and testing indicated the lower heat leak IMLI spacer could support 10 or 15mil 6061 Al vacuum shells at 5 torr pressure.

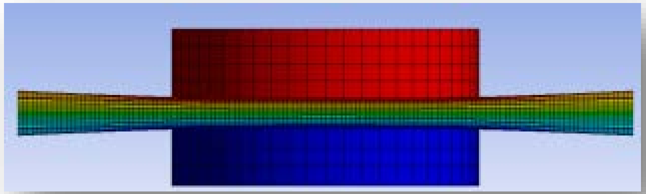
IMLI modeling

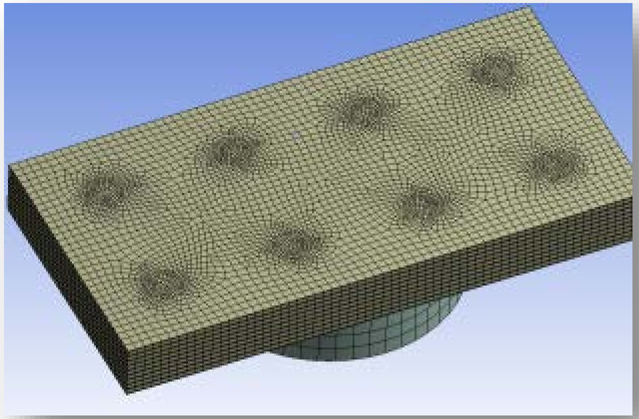
IMLI models created in ANSYS

- Full FEA models of IMLI are complex
  - Spacer deformation modes
  - Point stress failure in layer films
  - Spacers act as springs, film layers are not rigid, meshing difficult
- IMLI modeled two ways
  - Bulk material with orthotropic core
  - Posts modeled as discrete objects



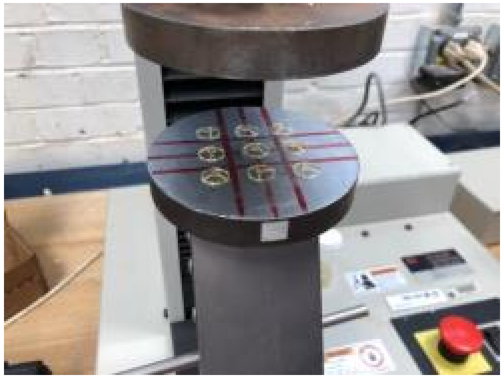






Structural modeling & testing

- NASA collaborated to develop a structural FEA model and do testing of the vacuum shell/IMLI system.
- Work done by Glenn & Marshall folks (Ariel Dimston, Amy Stalker, Wes Johnson, James Smith, D. Plachta).
- Testing performed at room temp and LN_2 temp
  - Compression, shear, bending
- Test data compared to FEA model results



IMLI modeling and testing

- Goal was to structurally model IMLI and get results matching testing.
- Material properties characterized by bulk layer method and by discrete post method.
- Initial error comparison was about 21%.
- Once anchored (using test results to refine the FEA model), agreement between model and measured properties was quite good with 1 to 5% error.
- Methods were developed that correctly model and characterize complex IMLI systems, improving understanding of MEMLI.

Method	Deflection	% Error
Compression Test	0.08784 [in]	measured
Bulk Layer (FEA)	0.08687 [in]	1.10%
Discrete Posts (FEA)	0.08336 [in]	5.10%

MEMLI 50L prototype

Thin wall vacuum shell

- MEMLI prototype was designed, built & installed on 50L 14" diameter 40" length test tank
- Vacuum shell was 16mil 6061-T6 aluminum
- New vacuum shell seaming and welding methods developed
- New fabrication and inspection processes developed

MEMLI 50L Test Article

MEMLI prototype

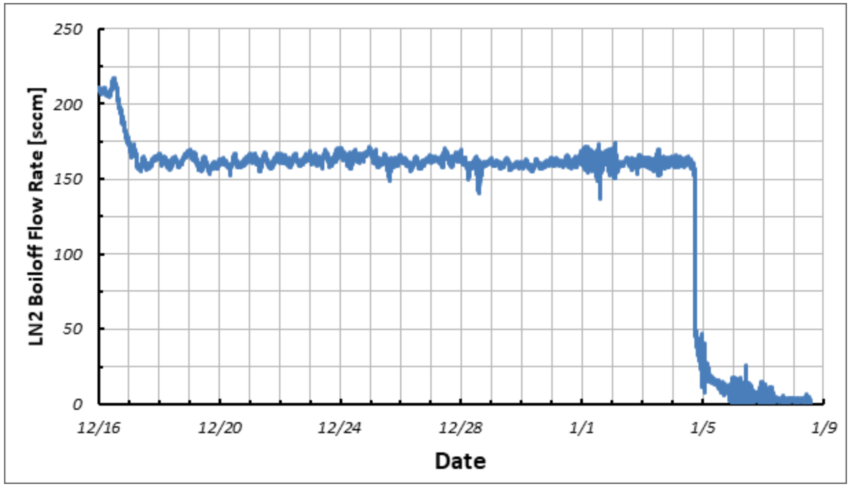
- 10 layers of IMLI and Vacuum Shell installed on tank
- Custom vacuum closeouts for vacuum shell
- Custom remote valve to vent/seal the vacuum space
- Ready for a long term (6 month) test of all mission phases

MEMLI Long Term Test

- ***Tests simulate Mars mission environments***
- ***Launch to Cruise Phase – vacuum shell valve open to space***

- ***In-space cruise thermal performance:***
  - ***0.505 W/m^2 (77K - 295K), e* = 0.00118***
  - ***0.126 W/m^2 (90K – 210K), calculated from e****

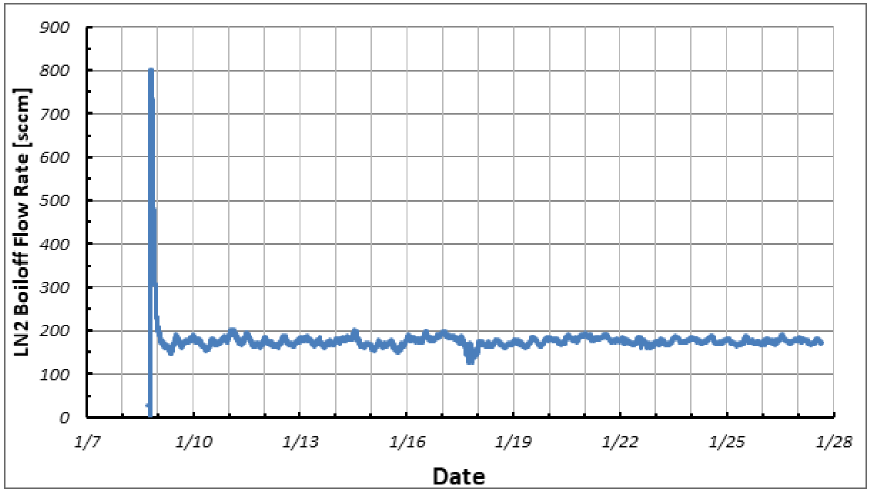
Avg flow rate [sccm]	160
Avg flow rate [L/min]	0.160
Avg vacuum [mbar]	2.46E-06
Vacuum shell surface area [m^2]	1.32
Log mean surface area	1.223
Measured heat leak [W]	0.617
Measured heat flux [W/m^2]	0.505 [at 77K – 295K]
e*	0.00118
Calculated heat flux [W/m^2]	0.126 [for 90K – 210K]



MEMLI Long Term Test

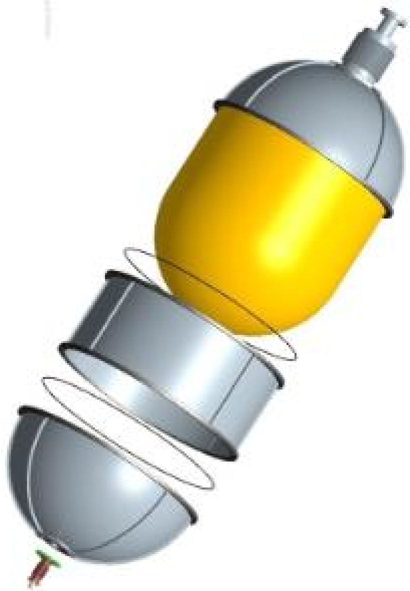
- ***Mars surface phase – vacuum shell closed, 5 torr CO_2 in chamber***
- ***Mars surface thermal performance:***
  - ***0.577 W/m² (77K - 295K), e* = 0.00135***
  - ***0.144 W/m² (90K – 210K), calculated from e****
  - ***MEMLI vacuum remained at E-6 torr over 4 months***

Avg flow rate [sccm]	183
Avg flow rate [L/min]	0.183
Avg vacuum [mbar]	4.6E-06
Vaccum Shell surface area [m²]	1.32
Log mean surface area	1.223
Measured heat leak [W]	0.706
Measured heat flux [W/m²]	0.577 [at 77K – 295K]
e*	0.00135
Calculated heat flux [W/m²]	0.144 [for 90K – 210K]



MEMLI 400L Test Article

- Next test article is a mid-scale 400L hemispherical dome tank
- Purpose is to mature fabrication processes and develop new on-tank thin vacuum shell welding and bonding processes
- 30” diameter, 15” barrel length, hemispherical ends
- Gore sections for domes
- Rolled barrel sections
- Girth rings at dome to barrel interfaces
- Vacuum shell 6061 Al 16mil supported by IMLI blanket



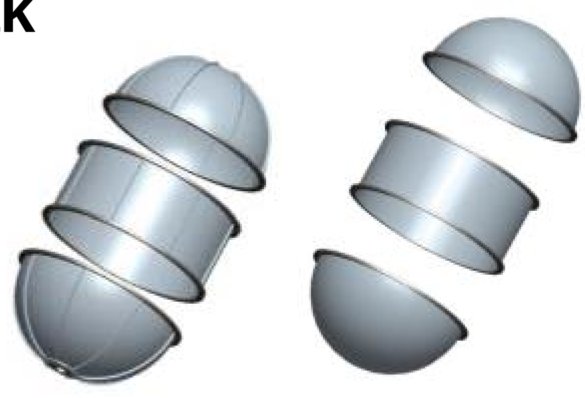
MEMLI vs conventional vacuum shell comparison

Sized for NASA test tank 49” diameter x 77” height for Mars surface operation.

MEMLI (0.016” Al)	Conventional MLI (0.08” SS)
17.7 kg	82.7 kg
10 layer IMLI	10 layer netting MLI
0.126 W/m^2	0.34 W/m^2
$e^* = 0.0012$	$e^* = 0.0032$

A good Figure of Merit is Mass * heat leak

2.2 $kg*W/m^2$	28 $kg*W/m^2$



MEMLI technology summary

- MEMLI technology allows thin, lightweight supported vacuum shells for soft vacuum applications, such as Mars surface or stratospheric balloon operation.
- MEMLI offers a 78% reduction in mass, and a 92% reduction in [heat leak * mass] over conventional MLI methods.
- MEMLI continues to look promising for Mars surface liquefaction and storage, with a next ground test in planning for a 1400L 4’ diameter cryotank.

Questions?

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