Heat Loads Due to Small Penetrations in Multilayer Insulation Blankets

W L Johnson[1], K W Heckle[2], and J E Fesmire[3]

[1]Glenn Research Center, Cleveland, OH, 44135 USA

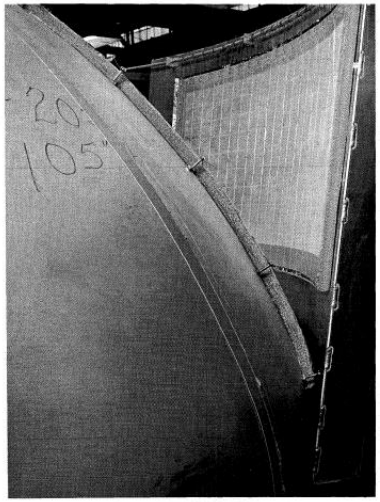
[2]Sierra Lobo, Cryogenics Test Laboratory, Kennedy Space Center, FL 32899 USA

[3]Cryogenics Test Laboratory, Kennedy Space Center, FL 32899 USA

July 10, 2017

Cryogenic Engineering Conference

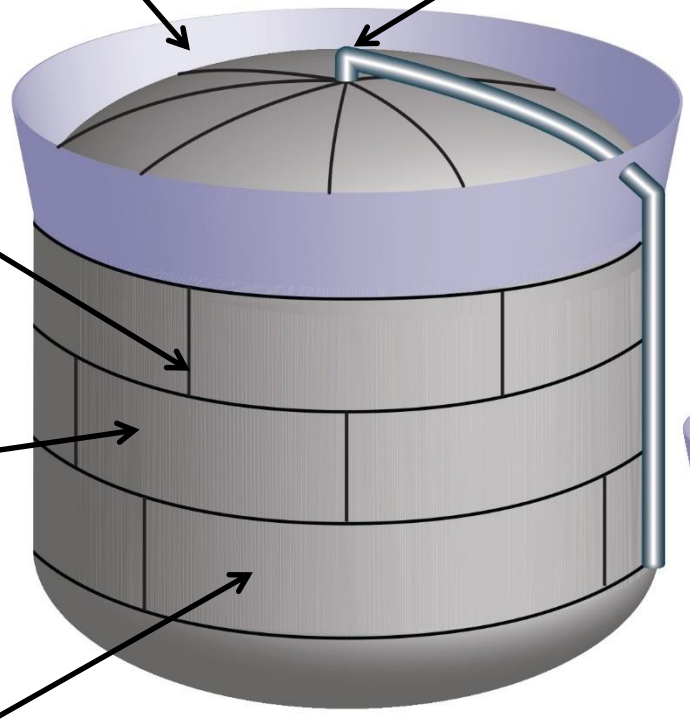
Improved Fundamental Understanding of Super Insulation (IFUSI)



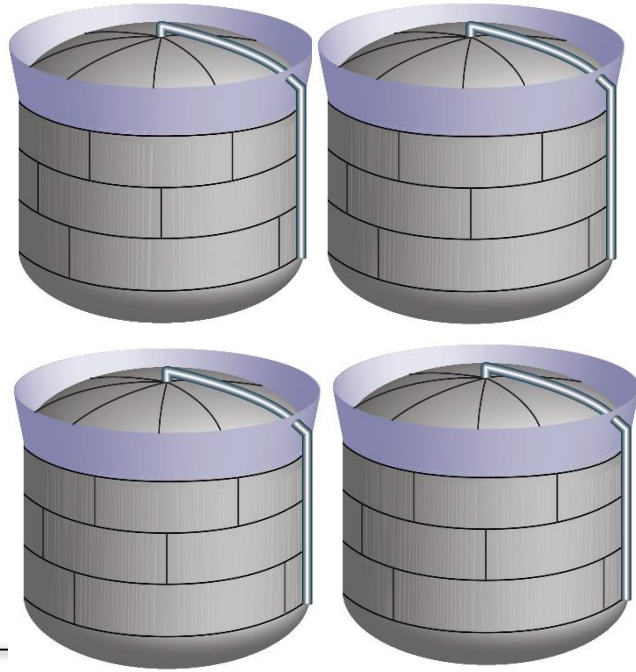
Skirt Integration

Penetration Integration:
- NASA-TP-2012-216315

Seams



Repeatability



MLI Blankets
- Traditional
- SS-MLI
- Hybrid

Tape, Pins & Attachments

Is this really an issue?

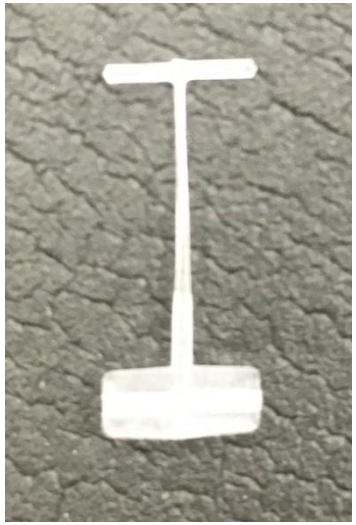
ATV 1 (Joules Verne) incident

- During launch, more power draw required than expected, was traced to blanket disengagement.
- Root causes came down to improper structural attachment
- AIAA-2010-6197

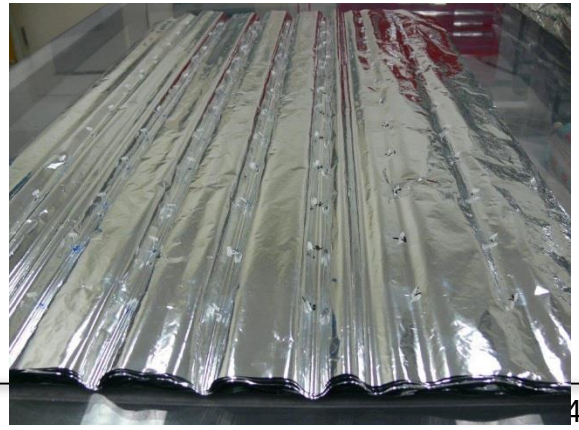
Nylon Tag Testing

- **Nylon tags have long been used to hold MLI together**
- **Installed 56 pins into an existing 10 layer LB-MLI blanket**
  - Individual pins have a really small heat load (~0.9 mW each)
  - Needed repeatable MLI coupon to do initial test and pinned test
  - Pin spacing ~ 3 inch
- **Blanket Heat flux (KSC – Cryostat 100):**
  - A164 July 2012[1]: 0.92 W/m^2
  - A191 March 2015: 1.04 W/m^2
  - Was also used in Hybrid MLI testing[2] (A174, A175, A181, A182)
- **Predicted disturbance:**
  - Variable tag geometry
  - 20 node conduction model (NIST nylon props): 0.5 mW/tag
  - Direct radiation through hole: 8 μW/tag

Cold side



Hot side

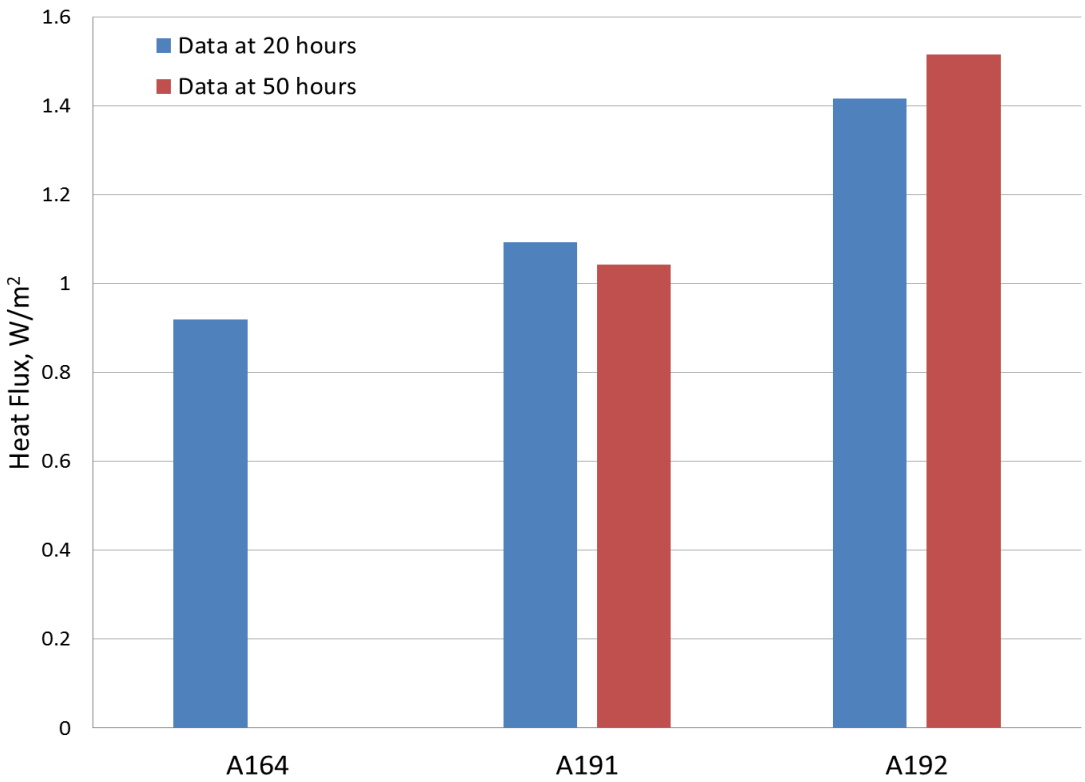


[1]Johnson, W.L., Heckle, K.W., and Hurd, J. **"Thermal coupon testing of Load-Bearing Multilayer Insulation"**, *AIP Conference Proceedings 1573*, pg. 725, 2014.
[2]Johnson, W.L., Fesmire, J.E., and Heckle, K.W., **Demonstration of Hybrid Multilayer Insulation of Fixed Thickness Applications**, *IOP Conf. Ser.: Mater. Sci. Eng.* **101** 012015, 2015.

Test matrix

Test Series	# layers [n]	Thickness [x] (mm)	Layer Density [z] (layers/mm)*	Effective Area [A_e] (m^2)	CVP Tested (torr)	Warm Boundary Temperature (K)	# pins
A164	10	16.5	0.54	0.334	~10^{-6}	~293	0
A191	10	15.2	0.59	0.331	~10^{-6}	~293	0
A192	10	15.1	0.60	0.331	~10^{-6}	~293	56

Results



Test Series (Data Time)	CVP (Torr)	WBT (K)	Q (W)	k_e (mW/m/K)	q (W/m^2)
A164	$5x10^{-6}$	291.7	0.31	0.072	0.92
A191 (20 hrs)	$2x10^{-5}$	292.4	0.37	0.078	1.11
A191 (50 hrs)	$2x10^{-5}$	293.0	0.35	0.074	1.04
A192 (20 hrs)	$7x10^{-6}$	293.3	0.47	0.099	1.41
A192 (50 hrs)	$7x10^{-6}$	292.4	0.51	0.106	1.51

Test Results Analysis

- **Total heat to the blanket (with 56 tags): 0.51 W**
  - 0.35 W through blanket
  - 0.16 W (+/- 0.025) residual (i.e. through tags)
- **Predicted load: 45 mW**
- **Measured heat load is 3.5 x predicted heat load**

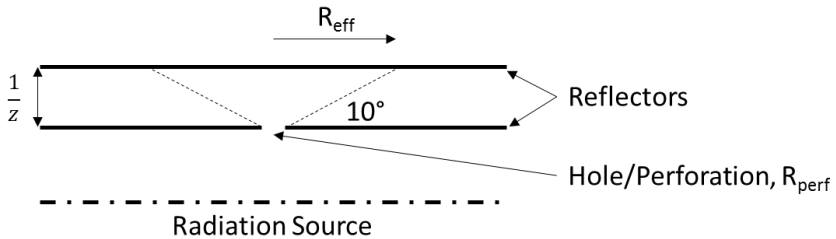
- **Similar to Arthur D. Little, Inc results from 1966[3]**
  - Single 0.8 mm nylon pin through 10 layers MLI (1.0 mm diameter hole)
  - Predicted heat load of 0.3 mW
  - Measured change in heat load of ~ 3 mW, which was the experimental error

- **Need revised model**

[3]Black, I.A, Glaser, P.E., Reid, R.C., "Heat Loss Through Evacuated Multilayer Insulation Penetrated By a Low-Conductivity Pin", Bull. IIR, Annex 1966-2, 233-243 (Meeting Of Commission 2, Trondheim, Norway, Jun 22-24, 1966)

Revised model

- **Based on perforations model developed for MHTB large perforations, the radiation through a perforation is not limited to direct radiation[4]**
- **Instead the effective radiation area is defined by a 10 deg angle**
- **Using layer density as the spacing for LB-MLI, this can be extrapolated to a tag hole.**



$$\theta = 10\ deg = 0.175\ rad$$

$$r_{eff} = \frac{1}{z\cos\theta} + r_{perf}$$

$$A_{eff} = \pi r_{eff}^2$$

$$\dot{Q} = A_{eff}\varepsilon_{layer}\sigma\left(T_h^4 - T_c^4\right) + \int \frac{A}{dx}\int k dT$$

- **Revised model estimates 3.6 mW per tag on recent testing (~30% more than actual)**
- **Revised model estimates 3.6 mW heat load for tag & hole in ADL test**

[4]Fox, E.C., Keifel, E.R., and McIntosh, G.L., et.al. "Multipurpose Hydrogen Test Bed System Definition and Insulated Tank Development", Martin Marietta Astronautics, NASA CR-194355, July 1993.

Conclusions

- **Completed testing on an MLI blanket with multiple small penetrations.**
- **Results show that heat load much more than conduction only.**
- **Analytical approach with combined radiation and conduction shows uncertainty less than 30%.**
  - Change in vacuum level may account for difference

Test Series	Hole Radius (mm)	# layers	Layer Density (lay/mm)	Q_{hole} (mW)	Q_{pin} (mW)	Q_{total} (mW)	Q_{meas} (mW)
A192	0.5	10	0.6	3.1	0.52	3.6	2.0-2.8
Black [9]	0.5	10	1.3	3.3	0.3	3.6	~3