Thermal Performance Testing of Cryogenic Multilayer Insulation with Silk Net Spacers

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Background

- Early MLI systems from the 1960s and early 1970s used silk netting to achieve the best thermal performance
  - Silk netting thoroughly tested in "Lockheed Report" (NASA-CR-134477)
  - Due to large expense and scarcity, most applications moved to dacron/polyester netting
  - Lockheed continued to manufacture spaceflight cryogenic dewar insulation using silk netting
    - Due to spaceflight heritage of performance
    - Costs for small dewars not large compared system thermal requirements
- At the 2013 Space Cryogenics Workshop, Lockheed Martin (ATC) and NASA personnel came to agreement for testing
  - Both sides wanted test data to compare between systems that were tested similar conditions (same calorimeter, same boundary conditions, same layers, same layer density, etc)
  - Lockheed to provide silk netting from remaining stock
  - NASA used netting to fabricate blankets, install on Cryostat-100, perform testing

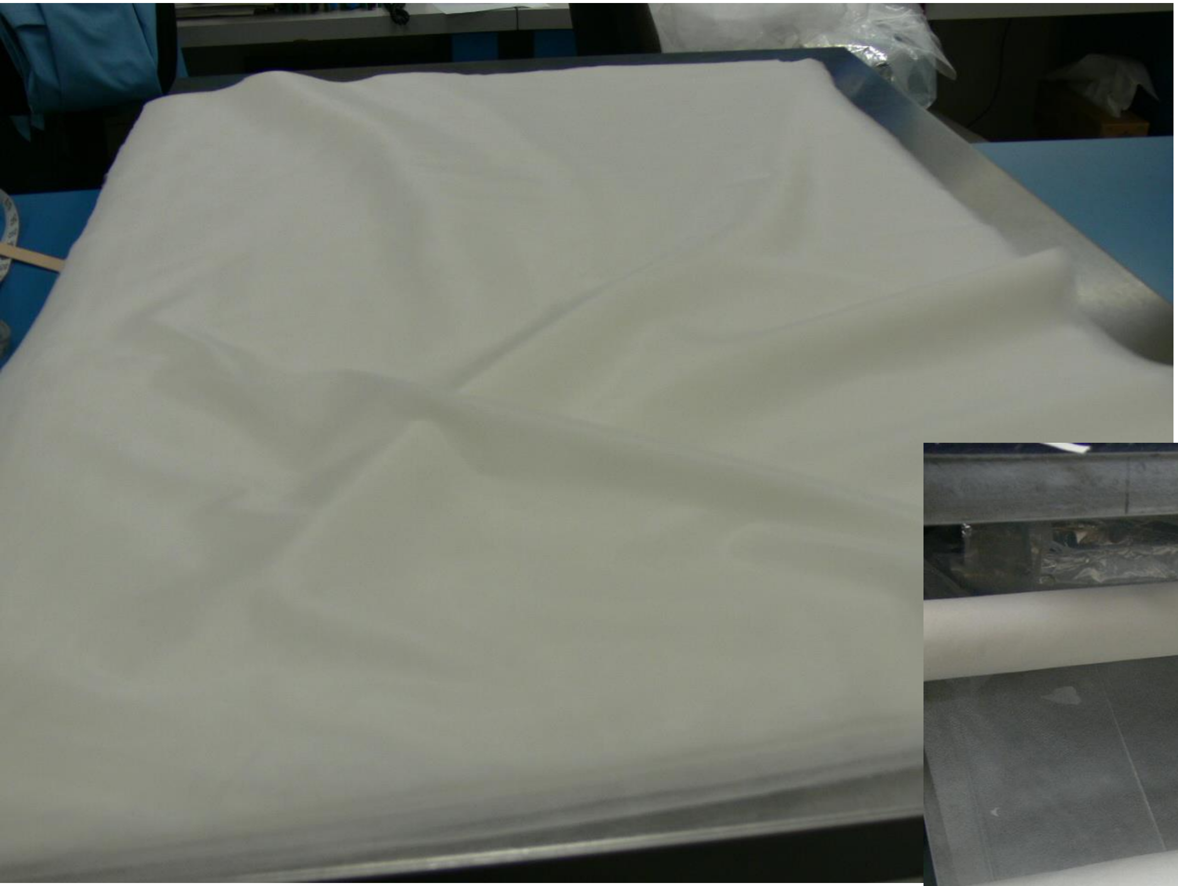
Test Approach

- Build silk netting blankets in manner consistent with previous test articles using double aluminized mylar and polyester netting
  - Multiple Warm Boundary Temperatures (WBT)
    - 293 K, 305 K, 325 K
  - Multiple Cold Vacuum Pressures (CVP)
    - High Vacuum (10^{-6})
    - No Vacuum (760 Torr)
- Compare data to existing data sets previously tested at KSC using polyester netting
  - Use same double aluminized Mylar for consistency

Test Matrix

KSC Test #	Layers	Layer Density (lay/cm)	Mean Area (m^2)	WBTs (K)	Vacuum Levels (mTorr)	MLI Mass (g)
A177	20	8.98	0.343	293, 305, 325	HV, 760000	287.7
A178	20	13.6	0.330	293	HV, 0.1, 1	201.7
A179	10	13.0	0.318	293	HV, 0.1, 1	105

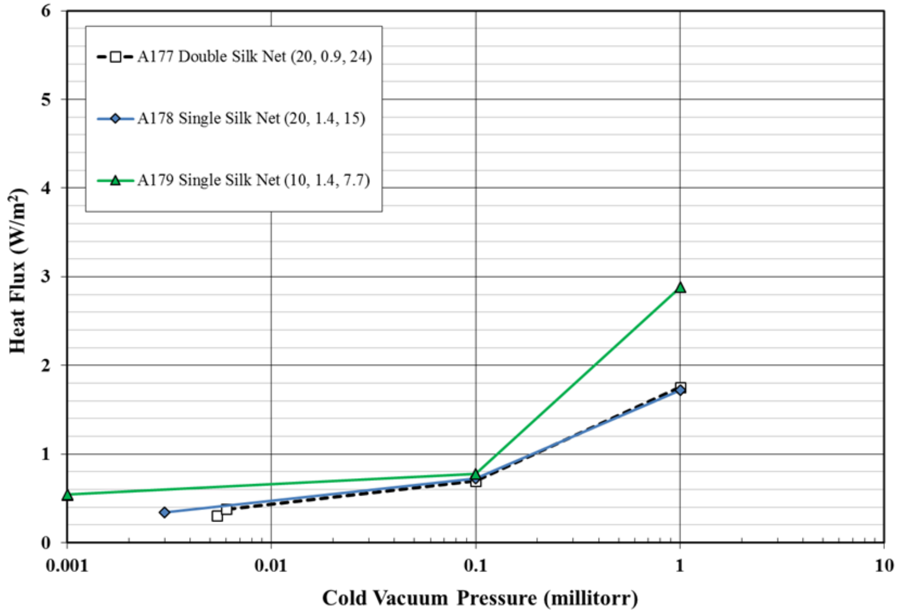
Silk Netting Preperations



Installation on Cryostat 100

Test Results

Test Series	CVP (Torr)	WBT (K)	Q (W)	k_e (mW/m/K)	q (W/m^2)
A177	$5*10^{-6}$	293.4	0.105	0.033	0.304
	$6*10^{-6}$	293.3	0.130	0.041	0.377
	$1*10^{-4}$	292.5	0.240	0.114	0.696
	$1*10^{-3}$	293.1	0.604	1.00	1.75
	760	284.0	68.9	22.9	200
	$4*10^{-6}$	305.4	0.140	0.042	0.406
	$4*10^{-6}$	325.8	0.185	0.051	0.536
A178	$3*10^{-6}$	293.2	0.113	0.023	0.342
	$1*10^{-4}$	293.0	0.239	0.050	0.724
	$1*10^{-3}$	293.2	0.569	0.117	1.72
A179	$2*10^{-6}$	292.3	0.171	0.019	0.538
	$2*10^{-6}$	292.0	0.172	0.019	0.541
	$1*10^{-4}$	293.5	0.246	0.028	0.774
	$1*10^{-3}$	292.8	0.917	0.103	2.884



Performance Modelling

Lockheed Martin Flat Plate Equation (4-14), NASA CR-134477

$$q = \underbrace{\frac{C_s (z)^{2.56} T_m}{n+1} (T_H - T_c)}_{\text{Conduction}} + \underbrace{\frac{C_r \varepsilon_{RT}}{n} (T_H^{\ 4.67} - T_C^{\ 4.67})}_{\text{Radiation}}$$

Test Series	Net	No. Layers (n)	Layer Density (Layer/cm) (z)	T_{hot} (K) WBT	q measured (mW/m2)	Q predicted (mW/m2)
A177	Double layer	20	8.51	293.4	304	310
A177	Double layer	20	8.51	305.4	405	370
A177	Double layer	20	8.51	325.8	536	490
A178	Single Layer	20	13.60	293.2	342	404
A179	Single Layer	10	13.02	292.3	538	759
A179	Single Layer	10	13.02	292.0	541	756

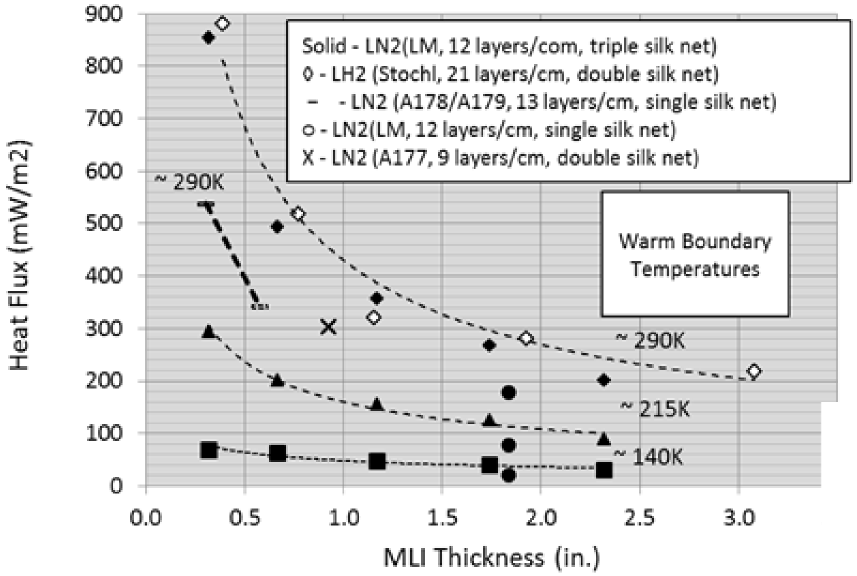
Mass and Heat Load Comparison

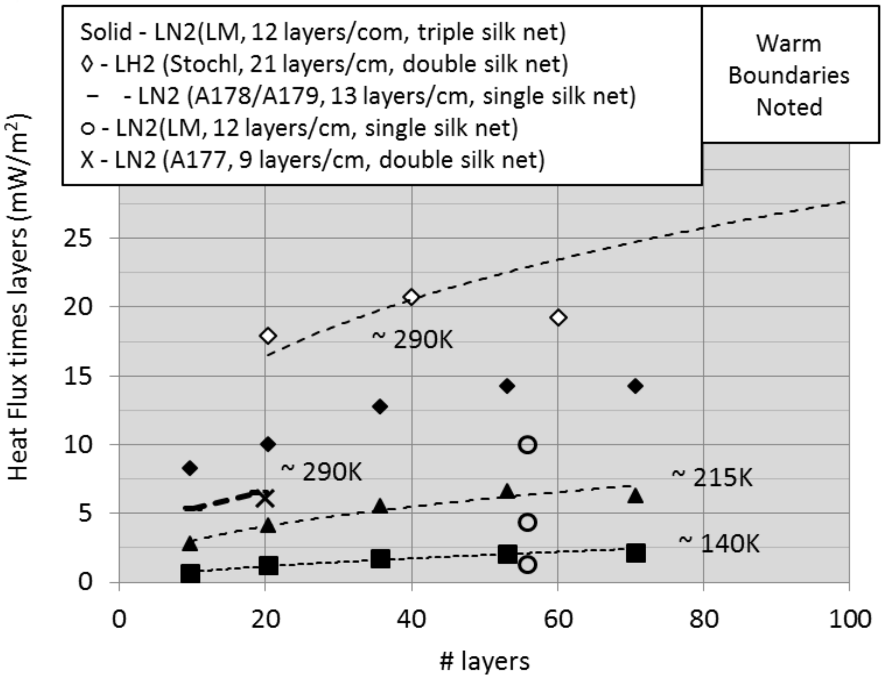
Layers	10 Layers	20 Layers	20 Layers (double netting)
Silk netting heat flux (W/m^2)	0.54 (A179)	0.34 (A178)	0.31 (A177)
Polyester netting heat flux (W/m^2)	1.00 (MN154)	0.68 (MN152) 0.37 (60 layers, MN143)	0.53 (MN159) 0.39 (40 layers, MN139)
Polyester fabric heat flux (W/m^2)	0.89 (MF145)		
LB-MLI* heat flux (W/m2)	0.92 (MX164)		0.41 (MX142)

*Load Bearing MLI (spacers are polymer support posts, not netting or fabric)

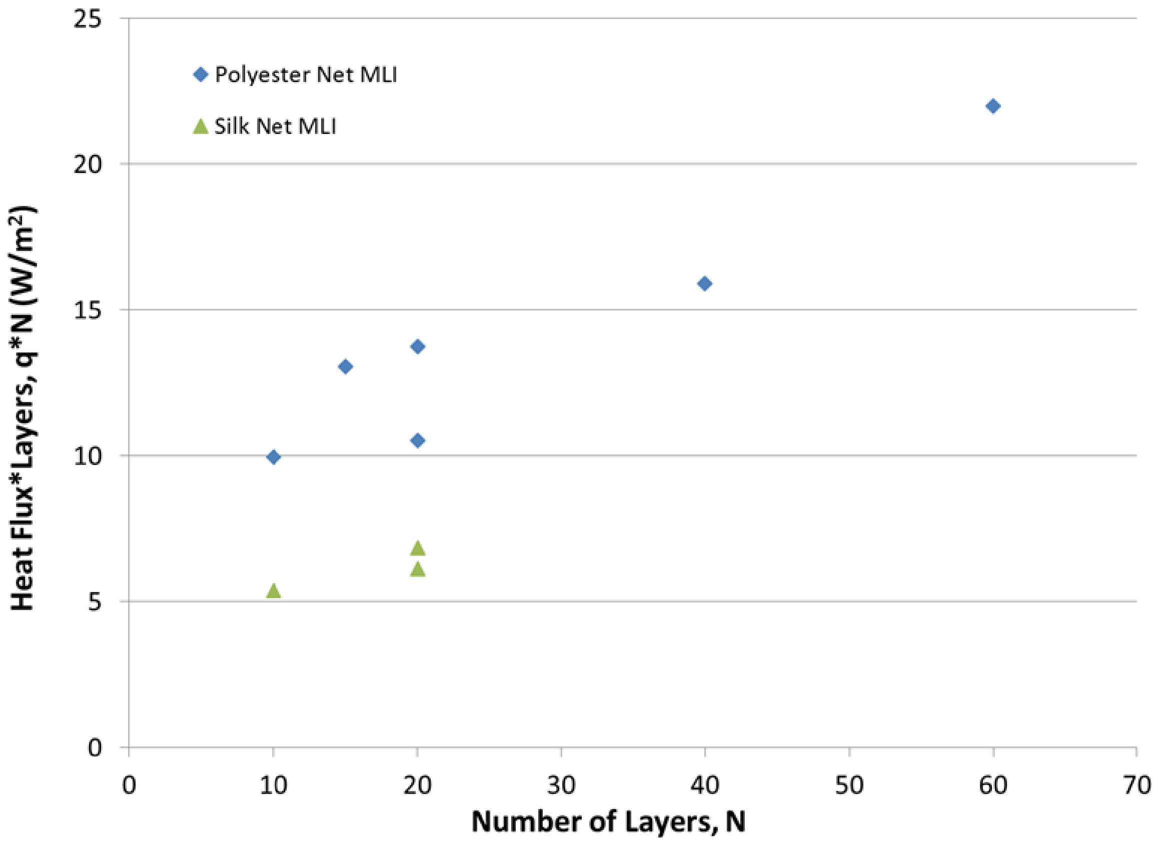
	Polyester Netting	Silk Netting
20 layers (single spacer)	231 g	202 g
10 layers (single spacer)	111 g	105 g

Comparison with Lockheed Data





Heat Flux variations with # Layers



Conclusions

- Testing completed on silk netting based MLI blankets between 293 K and 78 K.
- Data compares well to previous Lockheed test data, which was at a slightly higher layer density
- Silk netting shows significant improved performance over polyester netting and fabric testing at KSC
- Silk netting shows similar trends as dacron netting
  - Scale factor increases with thickness
  - Indicates heat flux not directly linear with # layers
- No significant mass difference