1 Multi-Layer Insulation (MLI)

1.1 Damage Mode

Numerous mission support hardware systems and their spares are maintained outside of the habitable volume of the International Space Station (ISS), and are arranged covered by a multi-layer insulation (MLI) thermal blanket which provides both thermal control and a measure of protection from micrometeoroids and orbital debris (MMOD).

The NASA Hypervelocity Impact Technology (HVIT) group at the Johnson Space Center in Houston Texas has assessed the protection provided by MLI in a series of hypervelocity impact tests using a 1 mm thick aluminum 6061-T6 rear wall to simulate the actual hardware behind the MLI. HVIT has also evaluated methods to enhance the protection provided by MLI thermal blankets. The impact study used both aluminum and steel spherical projectiles accelerated to speeds of 7 km/s using a 4.3 mm, two-stage, light-gas gun at the NASA White Sands Test Facility (WSTF).

1.2 Impact Experiments

In this work, twenty-two impact experiments have been performed with aluminum and steel projectiles with five different combinations of MLI areal density and wall separations. The nominal MLI configuration has an outer and inner layer of Teflon coated glass fabric (beta cloth) and nineteen aluminized-polyimide reflective layers separated by twenty polyester mesh layers with a total areal density of 0.086 g/cm^2. The first four configurations use this MLI with separations of 50.8, 101.6 and 152.4 mm between the back of the MLI package and the front of the rear wall. These different shield configurations are arranged as shown in Figure 1.2-1 where the separation, as marked, is varied for the configurations. A pre-impact photograph of a representative 152.4 mm experimental target is shown in Figure 1.2-2.

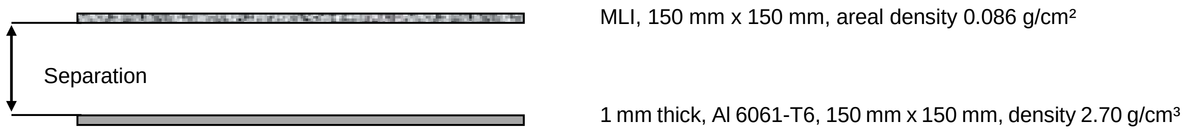

Figure 1.2-1 MLI double wall shield

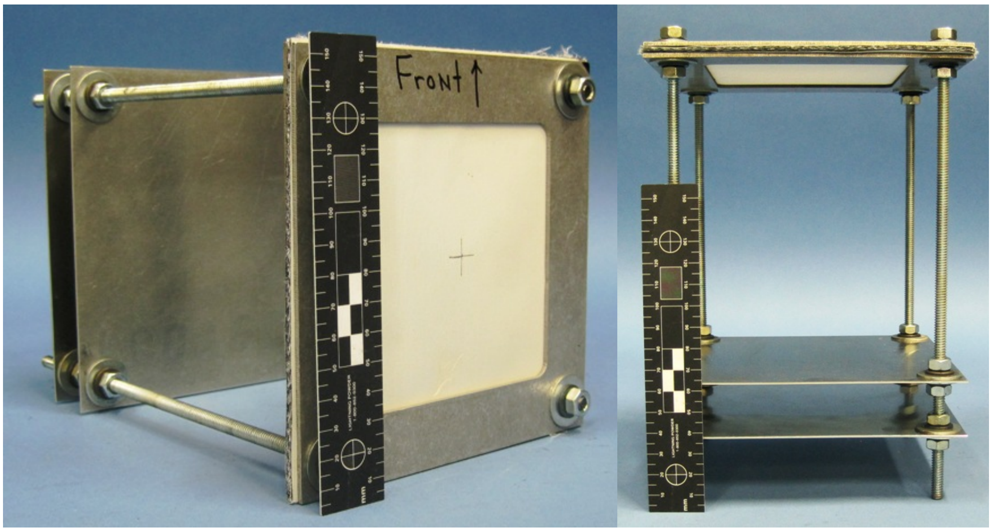

Figure 1.2-2 Pre-impact photograph of a typical 152.4 mm configuration target

In addition to the nominal MLI package, another MLI configuration with the inner beta cloth layer removed with a resulting areal density of 0.059 g/cm^2 was also included in the test matrix. This modified MLI package was tested with the single separation distance of 50.8 mm between the back of the MLI and the front of the rear wall as shown in Figure 1.2-3.

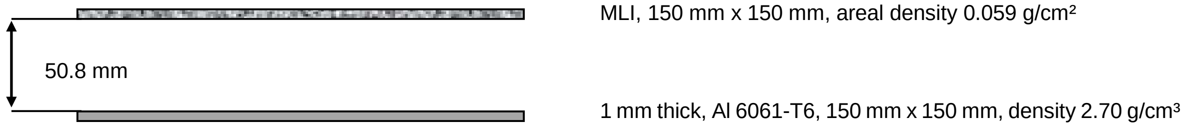

Figure 1.2-3 Lightweight MLI double wall shield

1.3 Experimental Conditions and Results

The MLI experimental impact conditions are summarized in Table 1.2-1. Any detached spall or perforation of the Al 6061-T6 rear wall is considered a failure of the shield. Aluminum (Al 2017-T4) and stainless steel 440C spherical projectiles were used in the tests.

Table 1.2-1 MLI shield impact conditions.

Test #	MLI Density (g/cm^2)	Wall Separation (mm)	Projectile Material	Projectile Diameter (mm)	Impact Obliquity (°)	Impact Speed (km/s)	Test Result
HITF11218	0.086	50.8	Al2017	1.0	0	7.00	Pass
HITF11224	0.086	152.4	Al2017	2.0	0	6.97	Fail
HITF11225	0.086	152.4	Al2017	1.8	0	6.91	Pass
HITF11227	0.086	101.6	Al2017	1.9	0	7.01	Pass
HITF11231	0.059	50.8	Al2017	1.2	0	6.99	Pass
HITF11232	0.059	50.8	Al2017	1.4	0	6.95	Fail
HITF11248	0.059	50.8	Al2017	1.3	0	7.00	Pass
HITF11273	0.086	50.8	Al2017	1.7	0	6.93	Fail
HITF13253	0.086	50.8	SS440C	0.8	45	7.06	Fail
HITF13254	0.086	50.8	SS440C	0.6	45	4.95	Fail
HITF13255	0.086	50.8	SS440C	0.8	0	6.82	Fail
HITF13256	0.086	50.8	SS440C	0.6	45	7.16	Pass
HITF13258	0.086	152.4	SS440C	1.0	0	7.11	Fail
HITF13259	0.086	152.4	SS440C	0.89	45	7.10	Fail
HITF13260	0.086	152.4	SS440C	0.6	45	4.46	Fail
HITF13261	0.086	152.4	SS440C	0.8	0	7.15	Pass
HITF13262	0.086	152.4	SS440C	0.7	45	6.42	Pass
HITF14001	0.086	50.8	SS440C	0.75	0	7.03	Pass

1.4 Recommendation for MMOD risk reduction

Toughened thermal blankets have been developed that greatly improve protection from hypervelocity micrometeoroid and orbital debris (MMOD) impacts as described by Christiansen and Lear in “Toughened Thermal Blanket for Micrometeoroid and Orbital Debris Protection”. This blanket arrangement can be used for significant improvement of MLI performance even when there is no separation between the MLI and the critical component. Three types of materials were added to the thermal blanket to enhance its MMOD performance: (1) disrupter layers, near the outside of the blanket to improve breakup of the projectile, (2) standoff layers, in the middle of the blanket to provide an area or gap that the broken-up projectile can expand, and (3) stopper layers, near the back of the blanket where the projectile debris is captured and stopped. Hypervelocity impact tests performed on the candidate toughened thermal blanket configurations at NASA WSTF and at the University of Dayton Research Institute showed significant improvement of MLI performance. From these tests the best disrupter materials has been found to be beta cloth and fiberglass fabric. Polyimide open-cell foams provide a light-weight means to increase the blanket thickness and improve MMOD protection. The best stopper material is Spectra™ 1000-952 or Kevlar™ KM2-705.

1.5 References

Christiansen, E. L. and Lear, D. M. “Toughened Thermal Blanket for Micrometeoroid and Orbital Debris Protection”, Procedia Engineering, **103**, 73-80 (2015).