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# Multilayer Insulation Material Guidelines

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## Trade Names

Trade names are used in this guidebook to illustrate the use of various commercial materials and not to imply endorsement by the U.S. Government. The trade names are the property of the companies listed here. Trade names should be used only to describe specific products, not as generic terms (for example, not all hook-and-pile fasteners are Velcro brand).

3M Co.: Nextel, Scotch
Chemfab: Beta cloth
E.I. Dupont de Nemours Inc.: Dacron, Kapton, Kevlar, Mylar, Nomex, Nylon, Tedlar, Teflon
Kamen Wiping Materials, Inc.: Rymple cloth
Texwipe Co.: Alpha 10 wipe
Velcro USA, Inc.: Velcro, Hi-Garde

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| | |
|---|---|
| AO | Atomic oxygen |
| BOL | Beginning of life |
| EOIM | Evaluation of Oxygen Interaction with Materials |
| EOL | End of life |
| GSFC | Goddard Space Flight Center |
| HST | Hubble Space Telescope |
| *ISS* | *International Space Station* |
| JSC | Johnson Space Center |
| LDEF | Long-Duration Exposure Facility |
| LEO | Low-Earth orbit |
| MDAC | McDonnell Douglas Aerospace Company (now part of Boeing Co.) |
| M&P | Materials and Processes |
| MLI | Multilayer insulation |
| MSFC | Marshall Space Flight Center |
| MUA | Materials Usage Agreement |
| NASA | National Aeronautics and Space Administration |
| PTFE | Polytetrafluoroethylene |
| *SSF* | *Space Station Freedom* (now *ISS*) |
| STM | Standard material specification |
| STP | Standard processing specification |
| UV | Ultraviolet |

TECHNICAL PUBLICATION

# MULTILAYER INSULATION MATERIAL GUIDELINES

## 1. INTRODUCTION

In general, multilayer insulation (MLI) is a type of high-performance insulator which uses multiple radiation-heat transfer barriers to retard the flow of energy. Individual radiation barriers usually are thin polymer films with vapor-deposited metal on one or both sides. Because it is nearly impossible to design a blanket that reflects 100 percent of incident radiation, an MLI design may range from a few simple blankets to a series of subblankets to fit complex geometries (fig. 1). Typically, each reflector will reflect 90 to 99 percent of radiation. The cumulative effect is that of a nearly 100-percent-effective barrier.

For MLI to be effective, a number of guidelines must be followed in selecting materials, designing them into the spacecraft, and assembling the vehicle.

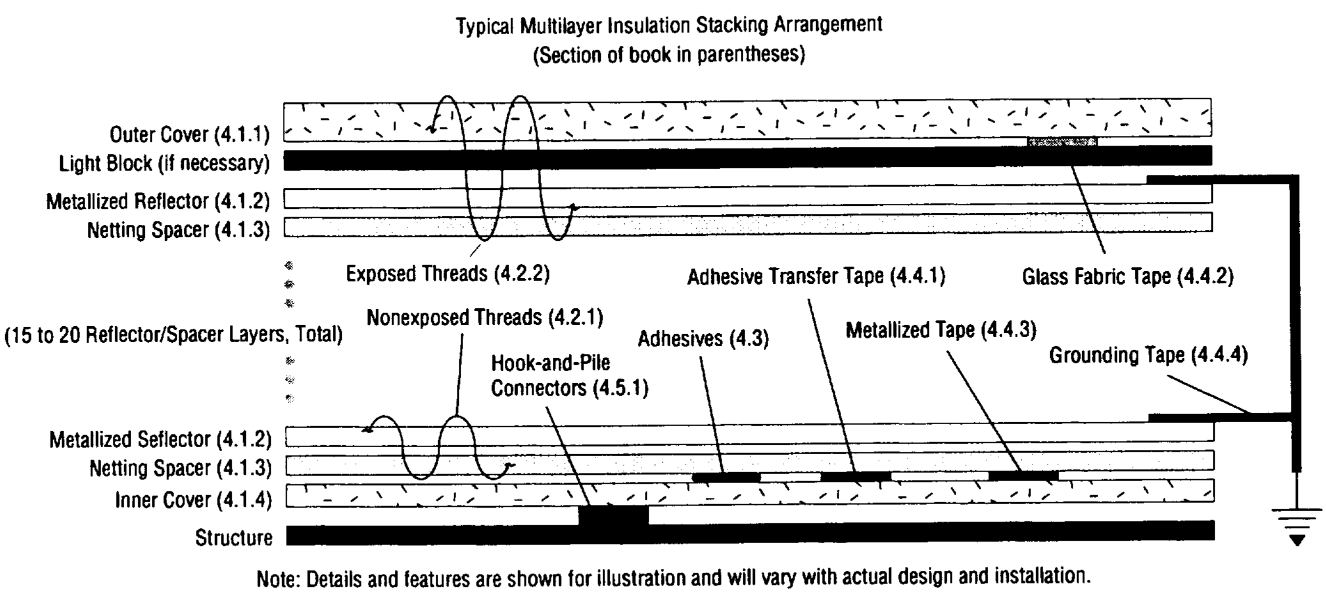


Figure 1. Schematic cross section depicts the key elements of an MLI blanket. Not all elements need be present in every design.

## 1.1 Scope

This document defines the materials approved for and used in previous spacecraft thermal blanket designs. Data from these can be used for future MLI designs on various spacecraft surfaces, whether exposed to the space environment or shielded from direct exposure. Some material data gathered from ground simulations of the space environment are included.

## 1.2 Purpose

The purpose of this document is to provide data on MLI materials used by previous spacecraft such as Spacelab (fig. 2) and the Long-Duration Exposure Facility (LDEF) (fig. 3), and outlines other concerns (fig. 4). The data within this document are presented for information only. They can be used as guidelines for MLI design for future spacecraft provided the thermal requirements of each new design and the environmental effects on these materials are taken into account.

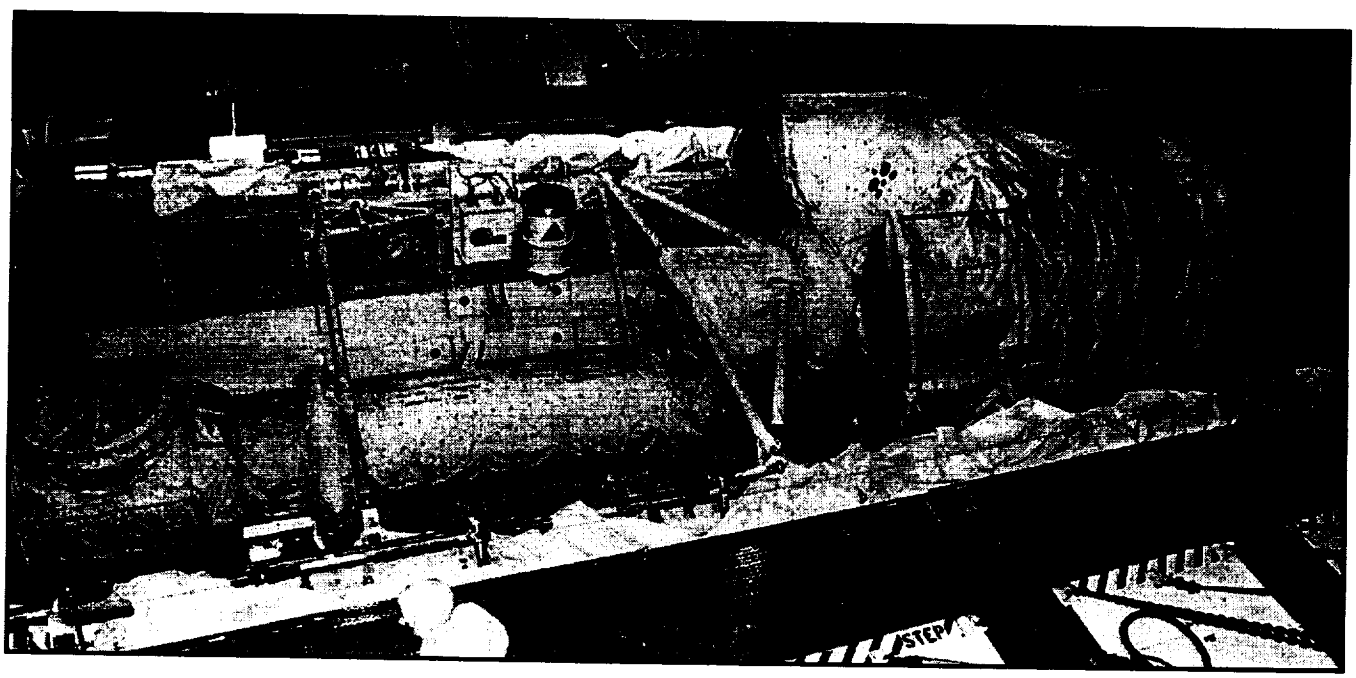

Figure 2. The interior of Space Shuttle *Columbia's* payload bay is seen here with the Spacelab module (right) and crew transfer tunnel (left to center) installed before the vehicle is closed and moved for stacking. Note that virtually everything inside is covered in Beta cloth since the Shuttle orbiter flies, for up to 2 wk at a time, with the payload bay doors open.

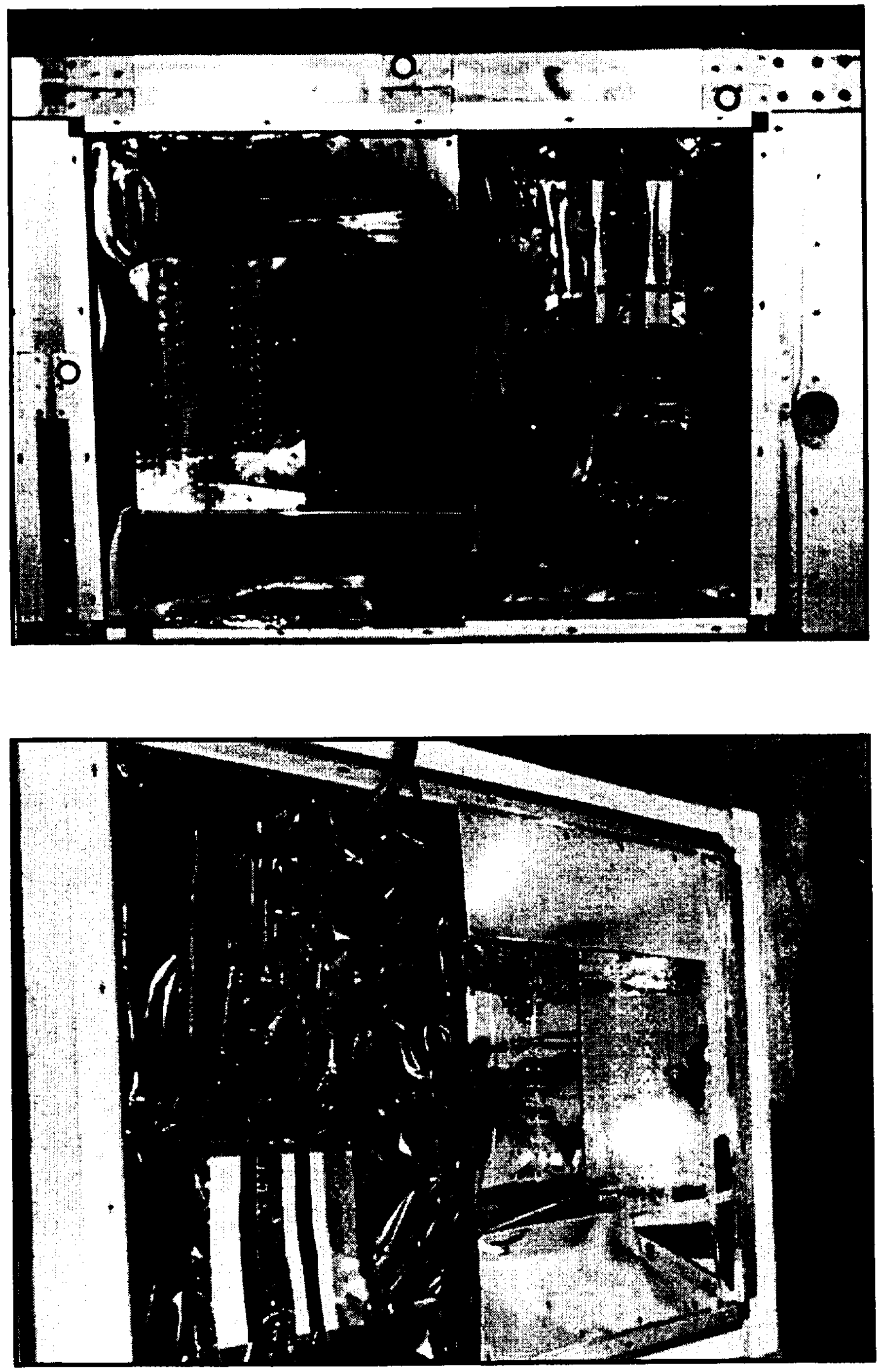

Figure 3. Experiment trays on the LDEF showed varying degrees of damage, depending on their orientation relative to the line of flight, after 69 mo in orbit.

Figure 4. MLI is fragile and easily damaged even under controlled conditions. The MLI covering the Huygens Titan probe was damaged by cooling air that was blown too quickly through the launch vehicle nose fairing. The probe had to be removed so the MLI could be repaired.

## 1.3 Applicability

This document describes various approved MLI designs and lists materials used, with specifications, sources, and available properties. The data are not all-inclusive; i.e., other MLI designs and materials may be available that will perform successfully. This document gives no recommendation, endorsement, or preference, either expressed or implied, concerning materials and vendors used. Regardless of vendor specifications, each design must meet the outgassing requirements of SP–R–0022A and, if involving line-of-sight proximity to sensitive optics, MSFC–SPEC–1443. MLI blankets must be tested for flammability propagation requirements of NHB 8060.1C, but may be tested as an assembly rather than individual material samples.

Wherever possible, the latest manufacturer's specifications are used. These are subject to change without notice, and should be taken as typical and not used in writing design or assembly specifications. The designer should review vendors' latest catalogs and specifications, which are updated frequently, and often contain more data than are presented here. Further, the designer should take into account lessons from new space missions as they are flown. NASA is not responsible for typographical or other errors in the data listed.

# 2. APPLICABLE DOCUMENTS

## 2.1 NASA

| | |
|---|---|
| CR–184245 | MLITEMP—A Computer Program to Predict the Thermal Effects Associated with Hypervelocity Impact Damage to the Space Station MLI |
| MSFC–HDBK–527 | Materials Selection List for Space Hardware Systems |
| MSFC–PROC–1779 | Ultrasonic Weld Procedure for Multilayer Insulation Blankets |
| MSFC–SPEC–1443 | Outgassing Test for Non-Metallic Materials Associated with Sensitive Optical Surfaces in a Space Environment |
| MSFC–STD–506 | Materials and Processes Control |
| NHB 8060.1C | Flammability, Odor and Offgassing Requirements and Test Procedures for Materials in Environments that Support Combustion |
| SP–8013 | Meteoroid Environment Model (Near-Earth to Lunar Surface) |
| SP–8038 | Meteoroid Environment Model (Interplanetary and Planetary) |
| SP–R–0022A | Vacuum Stability Requirements of Polymeric Material for Spacecraft Application |
| TM–100351 | Material Selection Guidelines to Limit Atomic Oxygen Effects on Spacecraft Surfaces |
| TM–104825 | Computer-Based Orbital Debris Environment Model for Spacecraft Design and Observation in Low Earth Orbit |
| TM–104748 | Beta Cloth Durability Assessment for Space Station Freedom Multi-Layer Insulation Blanket Covers |

## 2.2 U.S. Department of Defense

| | |
|---|---|
| MIL–C–20079 | Cloth, Glass; Tape, Textile Glass; and Thread, Glass and Wire-Reinforced Glass |
| MIL–F–21840 | Fastener Tapes, Hook and Pile, Synthetic |
| MIL–P–46112 | Films and Plastic Sheets, Polyester and Polyimide |
| MIL–STD–970 | Standards and Specifications, Order of Preference for the Selection of |
| MIL–T–43636 | Thread, Nylon, Non-melting (Typically replaced by A–A–50195) |

## 2.3 Other U.S. Government

| | |
|---|---|
| FED–STD–209B | Clean Room and Work Station Environments, Controlled Environment |
| L–P–377 | (No title given) |

## 2.4 Other

| | |
|---|---|
| ASTM–B–117 | Method of Salt Spray |
| ASTM–D–257 | Surface Resistivity of Materials |
| ASTM–D–374 | Thickness of Solid Electrical Insulation |
| ASTM–D–882 | Tests for Tensile Properties of Thin Plastic Sheeting |
| ASTM–D–2261 | Tearing Strength of Woven Fabrics by the Tongue (Single Rip) Method |
| ASTM–D–3330 | Peel Adhesion of Pressure-Sensitive Tape at 180° Angle |
| ASTM–D–1000 | Peel Adhesion of Pressure-Sensitive Tape Used for Electrical and Electronic Applications |
| ASTM–D–4030 | Glass Fiber Cord and Sewing Thread |
| ASTM–E–408 | Test Method for Emittance of Surface |
| ASTM–E–490 | Solar Constant and Air Mass Zero Solar Spectral Irradiance Tables |
| ASTM–E–595 | Standard Test Method for Total Mass Loss and Collected Volatile Condensable Materials from Outgassing in a Vacuum Environment |
| ASTM–E–903 | Solar Absorptance, Reflectance, and Transmittance of Surfaces Using Integrated Spheres |
| ASTM–E–5213 | Specification for Polyimide Film |
| ESA PSS–01–701 | European Space Agency MLI Standards |

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| CR | Contractor Report |
| HDBK | Handbook |
| MIL | Military Specification |
| NHB | NASA Handbook |
| PROC | Procedure |
| SP | NASA Special Publication |
| STD | Standard |
| TM | NASA Technical Memorandum |

## 3. GUIDELINES

### 3.1 Applicable Documents

Define and control materials and processes by engineering drawings, specifications, or standards whenever possible. Select U.S. Government and industry specifications in accordance with MIL–STD–970, except that NASA documents shall be considered first in the order of precedence.

### 3.2 Processing

All materials used in making an MLI blanket shall be treated as flight- or program-critical hardware from the time they are received (fig. 5). This requirement extends to all vendors in the manufacturing chain. Do not handle materials with bare hands or expose them to uncontrolled or corrosive environments. Do not pull or unnecessarily wrinkle materials as this may stress the layers and lead to defects that do not appear until after launch.

Separation of the radiation barriers is maintained by lightweight, low-thermal conductivity materials between the reflectors. Avoid tautness of the MLI blankets. MLI requires an atmospheric pressure of $<10^{-5}$ torr to prevent convection and gas conduction between radiation barriers. At pressures $>10^{-5}$ torr, the conductivity of the MLI quickly reverts to approximately the conductivity of air, thus degrading the MLI blanket's protection.

### 3.3 Materials Traceability

Consider organic materials used in the fabrication and assembly of MLI as age life-limited and treated accordingly. Traceability includes documenting the storage and handling conditions from the item of manufacture or receipt through the assembly of the complete vehicle.

The designer will ensure, by way of a Materials Usage Agreement (MUA), that materials used in the fabrication of MLI blanket hardware meet all of the spacecraft materials requirements by considering the nonoperational and operational requirements for the particular application, design engineering properties of the candidate materials, and total program cost effectiveness. These requirements include, but are not limited to, nonoperational and operational thermal limits, loads, fluid environments, charged particles, ultraviolet (UV) radiation, electrical bonding and grounding, contamination, and life expectancy. Ground transportation, storage, handling, and spacecraft on-orbit conditions will also be considered during materials selection.

In general, MLI materials fall into two broad categories of base materials, inorganic and organic, to which various coatings are applied. The primary materials (and principal trade names) are:

Inorganic: Fiberglass woven cloth (Beta cloth)
Organic: Polyester or PET (Mylar), polytetrafluoroethylene or PFTE (Teflon), polyimide (Kapton), polyfluorovinyl or PVF (Tedlar).

(a)

(b)

Figure 5. (a) A technician checks the thickness of MLI components as they are assembled into a complete blanket assembly. Note that she is wearing latex gloves, a hair cover, and safety glasses. T-shaped objects to the rear are large plastic clips (the same as for potato chip bags) to gently hold MLI sets together. Also note that blanket materials farther back on the table are covered with bagging plastic. (b) Two technicians, also wearing gloves and face masks, hold a completed blanket. It includes hook-and-pile fastener strips at top and right, and a neatly stitched cutout strip, from the left side, for a protrusion (Boeing photos).

# 4. SELECTION OF MATERIALS

## 4.1 Standard Blanket Layers

### 4.1.1 Outer Cover

The outer cover material will be resistant to shedding, flaking, and other forms of particulate generation. Outer cover materials that are not opaque to UV radiation will have a metallized reflector layer acting as a light block directly under the outer cover with no separator layer. Outer cover materials which are aluminized will have the aluminized side facing the interior of the blanket. Peel tests should be specified since aluminized Beta cloth can lose its metal coatings with light handling. Where external optical property requirements cannot be met with these listed outer cover materials, an MUA will be submitted to obtain approval for an alternative cover material. Where electrostatic discharge may result in spacecraft electronic systems damage, a conductive coating should be evaluated for an outer cover. The outer cover standard blanket layers are shown in table 1.

A tight weave is essential for long-term durability of Beta cloth in atomic oxygen (AO). NASA TM–104748 contains data on the failure of a looser weave Beta cloth (Sheldahl G414500) to protect underlying layers from AO attack. Looser weave Beta cloth may be acceptable for use in spacecraft areas not exposed to AO.

Prolonged exposure to UV radiation may increase the solar absorptance of Beta cloth if a methylsiloxane agent is used during processing. Less methylsiloxane or a different additive altogether may be used, dependent on flexibility requirements. Batch testing of Beta cloth is recommended where maintenance of optical properties is essential, by an exposure of 500 equivalent Sun hours to UV radiation *in vacuum*, which is sufficient to start the yellowing process. It is essential that the UV radiation testing of Beta cloth be performed in vacuum, otherwise atmospheric bleaching may cancel out any effect of UV. This testing may not be necessary for Beta cloth to be exposed to AO on orbit, since AO will maintain the solar absorptance through bleaching.

### 4.1.2 Reflector Layers

Generally, reflector layers need an outer cover for protection from space environment effects. Organic material is heavily attacked by AO, reducing the effectiveness of the insulation. Most MLI blanket designs call for the reflector layers to be perforated to allow venting during ascent to prevent ballooning. Vent placement is critical for space optics applications to prevent contaminant deposition. If the reflector layers are not perforated, leaving some areas of the blanket unsewn may allow enough venting through the blanket seams. Designers will find references to perforation and porolation (pores) in manufacturers' data sheets. Both terms refer to holes in the reflector layers, made either by a needle (perforation) or a hole punch (porolation). Because many patterns, hole sizes, and hole densities are available, no data are listed here on reflector holes.

## Table 1. Standard blanket layers, outer cover.

| Material | Beta Cloth | Beta Cloth, Aluminized | Tedlar, Reinforced | Kapton, Coated & Backed | Teflon, Backed | Teflon, Coated & Backed |
|---|---|---|---|---|---|---|
| Specification | Rk. MB0135–027 | Rk. MB0135–027 | | | | |
| Description | Fiberglass woven cloth impregnated with PTFE Teflon (500F: no silicone) | Fiberglass woven cloth impregnated with PTFE Teflon with one side aluminized | PVF reinforced with open weave Nomex bonded w/polyester adhesive, one side aluminized | Kapton, transparent indium tin oxide conductive coating and aluminum backing | FEP Teflon, vacuum deposited silver and Inconel backing layers | Teflon, transparent indium tin oxide conductive coating and silver/Inconel backing |
| Vendors | Chemfab | Chemfab, Dunmore | Sheldahl, Dunmore | Sheldahl, Dunmore | Sheldahl, Dunmore | Sheldahl, Dunmore |
| Weave<br>Texture, warp x fill, yarns/cm (/in.)<br>Yarn fiber diam, mm (in.) | Plain<br>32x24 (85x60)<br>0.00004 (0.00016) | Plain<br>32x24 (85x60)<br>0.00004 (0.00016) | N/A | N/A | N/A | N/A |
| Fabric/film thickness, cm (in.) | 0.020 (0.008) | 0.020 (0.008) | 0.01 (0.004) ±20% | [1] | [1] | [1] |
| Weight, gm/cm² (lb/yd²) | 0.0237 (0.44) | 0.0271 (0.5) | – | [1] | [2] | [3] |
| Tensile strength, min.<br>Warp, kg/cm (lb/in)<br>Fill, kg/cm (lb/in) | <br>16 (90)<br>10.7 (60) | <br>16 (90)<br>10.7 (60) | – | – | – | – |
| Elongation at break, % min<br>Warp<br>Fill | <br>6.5<br>2.0 | <br>6.5<br>2.0 | – | <br>70<br>70 | <br>300<br>300 | <br>300<br>300 |
| Tearing strength, kg (lb), min. | 0.82 (1.8) | 0.82 (1.8) | – | – | – | – |
| Useful temp. range, °C (°F)<br>Continuous, min/max<br>Intermittent, min/max | < 204 (400) | < 204 (400) | –72/107 (–100/225)<br><175 (350) | –73/65 (–100/150) | –184/150 (300/300)<br>–184/260 (-300/500) | –73/65 (–100/150) |
| Teflon by weight, % | 17–22 | 17–22 | – | – | – | – |
| Aluminum thickness, Å | – | 350 | – | – | – | – |
| Surface resistivity, Ω/square | – | | | 250,000 | – | 250,000 |
| Solar absorptance (a), min. | 0.45 (white side) | 0.37 (VDA side) | 0.30 | [1] | 0.10 | 0.14 |
| Infrared emittance (e), max. | 0.80 (white side) | 0.30 (VDA side) | 0.80 | [1] | [2] | [3] |
| Environmental compatibility | AO+UV | AO+UV | Short-term AO | Short-term AO<br>Long-term UV | Short-term AO<br>Long-term UV | Short-term AO<br>Long-term UV |
| Flight use | LDEF, OV, *ISS* | EOIM-3, *ISS* | HST, LDEF | – | HST, LDEF | – |

**Weight, solar absorptance, and infrared emissivity for covers of varying thicknesses**

| Thickness, cm (mil) | [1] Kapton gm/cm² (lb/yd²) | [1] Kapton a | [1] Kapton e | [2] Teflon, backed gm/cm² (lb/yd²) | [2] Teflon, backed e | [3] Teflon, coated gm/cm² (lb/yd²) | [3] Teflon, coated e |
|---|---|---|---|---|---|---|---|
| 0.0013 (0.5) | 0.0019 (0.034) | 0.41 | 0.50 | 0.0028 (0.051) | 0.40 | – | |
| 0.0025 (1.0) | 0.0036 (0.66) | 0.44 | 0.62 | 0.0055 (0.10) | 0.48 | – | |
| 0.0051 (2.0) | 0.0071 (0.131) | 0.49 | 0.71 | 0.011 (0.20) | 0.60 | 0.011 (0.20) | 0.60 |
| 0.0076 (3.0) | 0.011 (0.20) | 0.51 | 0.77 | – | | – | |
| 0.0127 (5.0) | 0.019 (0.34) | 0.54 | 0.81 | 0.027 (0.50) | 0.75 | 0.027 (0.50) | 0.75 |
| 0.0191 (7.5) | – | | | 0.055 (0.75) | 0.80 | – | |
| 0.0254 (10.0) | – | | | 0.055 (1.01) | 0.85 | – | |

Also to be considered in designing an MLI blanket is how many reflector layers are needed to achieve the desired thermal effect on the protected surface. Long-term low-Earth orbit (LEO) spacecraft generally use 15 to 20 reflector layers.

The metallized coating shall be 99.99 percent pure metal, vacuum-deposited onto the polymer film substrate with satisfactory adhesion. The coating will be uniform with a bright metallic color and free from significant discoloration. Discolored areas will be evaluated for emissivity standards (use ASTM–E408–71). Minimize scratching of the metallized film during blanket layup and handling.

Table 2 shows the different reflector layers and their characteristics.

Table 2. Reflector layers.

| Material | **Aluminized Kapton** | **Goldized Kapton** | **Aluminized Mylar** | **Polyester** | **Teflon** |
|---|---|---|---|---|---|
| Specification | MDAC-STM0691, Type II, Class 1, Grade A | Rockwell MB0135-038, Type II, Class 1, Grade A | MDAC STM0691, Type II, Class 1, Grade A | – | – |
| Description | Single or double aluminized | Single or double goldized | Double aluminized | Single or double aluminized | Single or double aluminized |
| Vendors | Sheldahl, Dunmore | Sheldahl | Sheldahl, Dunmore | Sheldahl, Dunmore | Sheldahl, Dunmore |
| Thickness, mm (mil)<br>metal, Å | 0.0076–0.127 (0.3–5.0)<br>1,000 | 0.0076–0.127 (0.3–5.0)<br>750 | 0.0051–0.127 (0.2–5)<br>1,000 | 0.00006–0.0013 (0.25–5); 300 | 0.00003–0.0013 (0.1–5); 300 |
| Weight, gm/cm$^2$ (oz/yd$^2$) | | | | – | – |
| 0.0051 mm (0.2 mil) | | | 0.0007 (0.013) | | |
| 0.0064 mm (0.25 mil) | | | 0.00093 (0.017) | | |
| 0.0076 mm (0.3 mil) | 0.0011 (0.020) | 0.0011 (0.020) | | | |
| 0.013 mm (0.5 mil) | 0.0019 (0.034) | 0.0019 (0.034) | 0.0017 (0.031) | | |
| 0.025 mm (1.0 mil) | 0.0036 (0.066) | 0.0036 (0.066) | 0.0033 (0.060) | | |
| 0.051 mm (2.0 mil) | 0.0071 (0.131) | 0.0071 (0.131) | 0.0066 (0.12) | | |
| 0.076 mm (3.0 mil) | 0.011 (0.20) | 0.011 (0.20) | 0.0104 (0.19) | | |
| 0.127 mm (5.0 mil) | 0.019 (0.34) | 0.019 (0.34) | 0.0175 (0.32) | | |
| Temperature, °C (°F) | | | | 260 (500) | 260 (500) |
| Continuous, max/min | –250/+288 (–420/ 550) | –250/288(–420/550 ) | –250/93 (–420/200)[1] | | |
| Intermittent, max/min | –250/+400 (–420/750) | –420/750 (–250/400) | –250/150 (–420/300) | | |
| Absorptance, a (max/typ) | 0.14; 0.12 | 0.30; 0.28 | 0.14; 0.12 | <0.14 | <0.14 |
| Infrared emittance, e | 0.05; 0.03 [2] | 0.04; 0.02 [2] | 0.05; 0.03 [3] | <0.04 | <0.04 |

[1] Temperature range for double-aluminized Mylar may be limited to 120 °C (250 °F) depending on sensitivity of blanket design to shrinkage. Shrinking the blanket before installation is advised.

Typical emittance from noncoated side

| [2] Kapton, single goldized Thickness, cm (in.) | a | e | [3] Mylar, single aluminized Thickness, cm (in.) | a | e |
|---|---|---|---|---|---|
| 0.00076 (0.0003) | 0.31 | 0.50 | 0.00064 (0.00025) | 0.16 | 0.33 |
| 0.0013 (0.0005) | 0.31 | 0.55 | 0.0013 (0.0005) | 0.16 | 0.46 |
| 0.0025 (0.001) | 0.33 | 0.65 | 0.0025 (0.001) | 0.19 | 0.57 |
| 0.0051 (0.002) | 0.34 | 0.75 | 0.0051 (0.002) | 0.23 | 0.72 |
| 0.0076 (0.003) | 0.37 | 0.81 | 0.0076 (0.003) | 0.25 | 0.77 |
| 0.0127 (0.005) | 0.41 | 0.86 | 0.0127 (0.005) | 0.27 | 0.81 |

### 4.1.3 Separator Layers

Place separator layers between each reflector layer and between reflector layers and the inner (a)and outer covers or other surfaces. See table 3 for Dacron and Nomex netting separator layers.

Table 3. Separator layers.

| Material | Dacron Netting | Nomex Netting |
|---|---|---|
| Specification | Rockwell MB0135–042, MDAC–STM0605–03 | |
| Description | 100% polyester fabric mesh[1] | 100% Nomex aramid fabric mesh[2] |
| Vendors | Apex Mills | Stern & Stern Textiles, J.P. Stevens |
| Thickness, mm (in.) | 0.16 ± 0.01 (0.0065 in.±0.0005) | 0.16 ± 0.01 (0.0065 in.±0.0005) |
| Construction<br>Meshes/cm$^2$ (in.$^2$)<br>Denier filaments | <br>7.8±1.2 (50 ± 8)<br>40 | <br>7.9±1.2 (51±8)<br>40 |
| Weight, gm/m$^2$ (oz/yd$^2$) | 6.3 ± 0.85 (0.185 ±0.025) | 6.3 ± 0.85 (0.185±0.025) |
| Burst strength, kg/cm (lb/in.) | 5.625 (10) | 5.625 (10) |
| Temperature range continuous, °C (°F) | –70 +120 (–94 +250) continuous<br>–70 +177 (–94 +350) intermittent | –70 +120 (–94 +250) continuous<br>–70 +177 (–94 +350) intermittent |

[1] Dacron netting may shrink and melt above 177 °C (350 °F)
[2] Nomex netting may contain a phthalate plasticizer added for flexibility. The plasticizer should be removed by chemical means or vacuum bakeout before assembly of the blanket.

### 4.1.4 Inner Cover

The inner cover is adjacent to or faces the underlying hardware. This is not always included in MLI designs. The reinforcement in these films and single aluminizations must face the MLI blanket. Mylar film is not recommended for inner cover use because of flammability concerns. Materials with Nomex scrim should be checked for the presence of a phthalate plasticizer sometimes added for flexibility. This plasticizer should be removed through chemical means or baked out if the blanket is to be used with or near sensitive optics. Often, the inner layer is not metallized in order to reduce the chance of an electrical short.

In recent years, vendors have started offering complex laminates comprising reflective, impact-resistant, and structural materials plus several metal coatings, all in a single layer. Because so wide a range is available, only a few are included in table 4. See table 4 for reinforced Kapton inner covers and table 5 for multilaminate inner covers.

## Table 4. Reinforced Kapton inner cover.

| Material | Aluminized | Double Goldized | Glass Reinforced |
|---|---|---|---|
| Specification | MDAC-STM0691, Type II, Class 2, Grade B | Rockwell MB0135-048, Type II, Class 2, Grade B | LAC-22-4448(G); varies with the film and fabric used |
| Description | Polyimide reinforced with aramid (Nomex or equivalent) open weave fabric; 1 or 2-side aluminum | Double goldized polyimide reinforced with aramid (Nomex or equivalent) open weave scrim fabric. | Aluminized polyimde with fiberglass backing |
| Vendors | Dunmore, Complex Plastics | Dunmore, Complex Plastics | Dunmore, Sheldahl |
| Available thicknesses, mm (in.) | 0.013, 0.025, 0.0762 (0.0005, 0.001, 0.003) ± 20% | 0.01 (0.00045) ± 56% | 0.01 (0.00045) ± 56% |
| Metallized thicknesses, Å | 1,000 | 750 | 300 |
| Reinforcement | Leno weave, 6.3x5.9/cm (16 x15/in.) yarn count of 200 denier yarn | Leno weave, 6.3x5.9/cm (16 x15/in.) yarn count of 200 denier yarn | 1070 or 108 fiberglass |
| Ply adhesion, kg/cm (lb/in.) | 0.054 (0.3) | 0.054 (0.3) | 0.18 (1.0) |
| Tear resistance, kg (lb) min avg | 1.4 (3) | 1.4 (3) | 1 (2.2) |
| Tensile strength, kg/cm (lb/in.) | | | |
| Warp | 7.14 (40) | 4.46 (25) | 17.85 (100) |
| Fill | 7.14 (40) | 3.57 (20) | 17.85 (100) |
| Elongation, % avg. | | | |
| Warp | 50 | 9 | 50 |
| Fill | 50 | 5 | 50 |
| Porolation, pinholes/$m^2$ ($ft^2$) (Light visible through 90% of holes) | 145,300±2152 (13,500 ± 200) Open area 3% of surface | 145,300±2152 (13,500 ± 200) | N/A |
| Weight, gm/$m^2$ (oz/$yd^2$) | 50 (1.47) | – | 50 (1.47) |
| Infrared emittance (e) | 0.06 aluminized side 0.4 reinforced side | 0.04 coated side 0.2 coated, reinforced side | <0.04 |

## Table 5. Reinforced multilaminate inner cover.

| Material | Double Nomex Laminate | Kevlar/Kapton Laminate | Lightweight Laminate |
|---|---|---|---|
| Specification | Lockheed Martin/Denver, 0–06149(H) | Lockheed Martin/Denver, 0–06149(H) | Boeing D683–29034–1(D) |
| Description | Aluminum coated | Corrosion resistant, perforated | Aluminum coated, perforated |
| Vendors | Dunmore, Sheldahl | Dunmore, Sheldahl | Dunmore, Sheldahl |
| Layer sequence | Teflon, aluminum coated<br>**Nomex**<br>0.3 Kapton, aluminum coated<br>0.5 FEP, aluminum coated<br>**Nomex**<br>0.3 Kapton, aluminum coated<br>DB–15 corrosion coating | FEP, aluminum coated<br>Kevlar<br>0.5 Kapton, aluminum coated<br>DB–15 corrosion coating | 0.5 Kapton, aluminum coated<br>Nomex, aluminum coated |
| Tensile strength, kg/cm (lb/in.) | 8.0 (45) | 8.0 (45) | 8.0 (45) |
| Tear strength, kg (lb) | 4.5 (10) | 4.5 (10) | 4.5 (10) |
| Material yield, gm/$m^2$ (oz/$yd^2$) | 74 (2.18) | 74 (2.18) | 74 (2.18) |
| Maximum temperature, °C (°F) | <121 (<250) | <121 (<250) | <121 (<250) |
| Emittance (e) | <0.04 | <0.04 | <0.04 |
| Absorptance (a) | <0.14 | <0.14 | <0.14 |

*Aluminum coatings are 350 Å for Dunmore, 1,000 Å for Sheldahl

## 4.2 Thread Selection

### 4.2.1 Thread Selection for Nonexposed MLI Seams

Seams which are not exposed to AO in the LEO environment will be stitched with nonmelting polymeric thread. The thread will be free of wax, paraffin, and other volatile finishes. Table 6 shows the various thread selections.

Table 6. Threads for nonexposed MLI seams.

| Material | Nomex Thread | Nylon Thread | Nylon Thread | Reinforced Kevlar Thread |
|---|---|---|---|---|
| Specification | MIL-T-43636, Type II, Size E | MIL-T-43636, Type I, Size E | MIL-T-43636, Type I, Size F | |
| Description | Aramid, nonmelting, low volatile content thread, no silicone finish | Aramid, nonmelting, low-volatile content thread | Aramid, nonmelting, low-volatile content thread | Polyimide thread w/stainless steel wire reinforcement and Teflon coating |
| Vendors | Synthetic Thread Co. | Synthetic Thread Co. | Synthetic Thread Co. | Alpha Associates |
| Diameter, mm (in.) | 0.41 (0.016) | 0.41 (0.016) | 0.46 (0.018) | 0.43 (0.017) |
| Plies | 3 | 3 | 4 | 3 |
| Twist, turns/cm (in.) | 3.3 (8.5) | 3.3 (8.5) | 3.1 (8) | 3.3 (8.5) |
| Yield, m/kg (ft/lb), max, min | 4167, 4560<br>2813, 3078 (6200, 6784) | 4288, 5980<br>2895, 4038 (6380, 8899) | 3226, 3407<br>2178, 2300 (4800, 5070) | 1988<br>1343 (2959) |
| Breaking strength, kg (lb) | 2.36 (5.2) | 2.36 (5.2) | 3.13 (6.9) | 9.07 (20) |
| Elongation, maximum % | 38 | 38 | 38 | (not available) |
| Maximum operation temp., °C (°F) | <329 (625)<br>25% fail @ 371 (700) | <329 (625)<br>25% fail @ 371 (700) | <329 (625)<br>25% fail @ 371 (700) | <371 (700) |

### 4.2.2 Thread Selection for Exposed MLI Seams

Seams that are exposed to the LEO environment will use thread that is resistant to AO erosion and UV degradation for the anticipated mission life (see table 7). Manufacturing MLI blankets with glass or ceramic thread may be difficult due to sewing needle wear and thread breakage. Where design requirements or manufacturing capabilities do not allow for glass or ceramic thread to be used, organic thread may be used provided that it is protected with an AO-resistant cover. Where possible, metallic yarn will not be used in standard seams because of its tendency to cause heat shorts, although proper blanket design can mitigate this problem. If metallic thread is necessary to comply with electrical bonding requirements, the amount of thread used will be the minimum amount required to meet the grounding requirements and will meet blanket thermal requirements.

An AO-resistant thread was developed by Coats America, but is no longer marketed due to lack of sales. It was developed through a NASA Small Business Independent Research program.

Table 7. Threads for exposed MLI seams.

| Material | Quartz Thread | Glass Thread Coated w/PTFE | Reinforced Glass Thread Coated w/PTFE | Nextel 312, 440 |
|---|---|---|---|---|
| Specification | MIL–C–20079, Type III, Class 3 | MIL–C–20079, Type III, Classes 3 and 4 | MIL–C–20079, Type III, Class 6 | 3M ceramic materials |
| Description | High-temperature quartz thread | Fiberglass coated with PTFE Teflon | Fiberglass reinforced with stainless steel wire and coated with PTFE Teflon | Aluminum borosilicate ceramic thread combined with Rayon |
| Vendors | Alpha Associates, W. F. Lake Corp. | Alpha Associates, W. F. Lake Corp. | Alpha Associates, W. F. Lake Corp. | 3M |
| % weight, other thread | 16 to 24, PTFE | 13 to 16, PFTE | 13 to 16, PTFE | 10, Rayon[1] |
| Temperature range, °C (°F) | –240 to 1,093 (–400 to 2,000) | –240 to+316 (–400 to +600) | –240 to+316 (–400 to +600) | <300 (572) |

[1] Rayon fibers improve sewability. Rayon is susceptible to AO; loss may affect abrasion resistance but not overall strength of the thread. Nextel 312 fibers can withstand temperatures up to 1,204 °C (2,200 °F); Nextel 440 to 1,370 °C (2,500 °F).

**Thread Properties**

| **Quartz Thread** | TFQ–12 | TFQ–18 | TFQ–24 | | |
|---|---|---|---|---|---|
| Diameter, mm (in.) | 0.356 (0.014) | 0.432 (0.017) | 0.508 (0.020) | | |
| Yield, m/kg (yd/lb) | 1982 (2950) | 1327 (1975) | 991 (1475) | | |
| Tensile strength, kg (lb) | 5.44 (12) | 9.07 (20) | 10.89 (24) | | |
| **Glass Thread** | | | | | |
| Diameter, mm (in.) | 0.356 (0.014) | 0.432 (0.017) | 0.533 (0.021) | 0.686 (0.027)* | 0.762 (0.030)* |
| Yield, m/kg (yd/lb) | 1982 (2,950) | 1327 (1,975) | 991 (1,475) | 773 (1,150) | 252 (375) |
| Tensile strength, kg (lb) | 5.4 (12) | 9 (20) | 10.9 (24) | 15.9 (35) | 22.7 (50) |
| **Reinforced Glass Thread** | TFE–12 | TFE–18 | TFE–24 | | |
| Diameter, mm (in.) | 0.36 (0.014) | 0.43 (0.017) | 0.53 (0.021) | | |
| Yield, m/kg (yd/lb) | 2015 (3000) | 1343 (2000) | 1007 (1500) | | |
| Tensile strength, kg (lb) | 5.4 (12) | 9.1 (20) | 10.9 (24) | | |
| **Nextel 312, 440** | AT–21 | AT–28 | AT–32 | BT–28 | BT–32 |
| Diameter, mm (in.) | 0.533 (0.021) | 0.711 (0.028) | 0.813 (0.032) | 0.711 (0.028) | 0.813 (0.032) |
| Yield, m/kg (yd/lb) | 1,007 (1,500) | 672 (1,000) | 504 (750) | 585 (870) | 430 (640) |
| Tensile strength, kg (lb) | 4.5 (10) | 6.4 (14) | 7.3 (16) | 6.4 (14) | 6.4 (14) |

*May not be suitable for sewing

## 4.3 Adhesives

Low-outgassing, silicone-based adhesives meeting the requirements of SP–R–0022A may be used to bond low-temperature fasteners to a structure. These silicone adhesives may not be used on surfaces directly exposed to LEO environment or on surfaces expected to reach temperatures of 204 °C (400 °F) or more. It is recommended after applying adhesive the bond will be allowed to set for at least 24 hr before installation on the hardware. Heat application, up to 66 °C (150 °F), may also be used to improve adhesion.

### 4.4 Adhesive Tape

All pressure-sensitive adhesive (PSA) tape used on the outer covers or environmentally exposed surfaces of MLI blanket assemblies will be tacked every 2.5 to 5 cm (1 or 2 in.) with an AO-resistant thread. All tape used on the external surfaces of inner covers which are not exposed to LEO environment may be hand-tacked every 2.5 to 5 cm (1 or 2 in.) with nylon thread. A hard rubber roller or equivalent is recommended for applying pressure during tape application.

#### 4.4.1 PSA Tape, Plain

Adhesive transfer tapes may be applied to thin films where a good bond is ensured. Table 8 lists specifications for plain PSA tape.

Table 8. PSA tape, plain.

| Material | Scotch Adhesive Tape, 3M Y966 | Scotch Adhesive Tape, 3M 9460 | Scotch Adhesive Tape, 3M Y9473 | Tedlar Tape |
|---|---|---|---|---|
| Specification | - | - | - | - |
| Description | Polyimide w/966 PSA | Polyimide w/9460 PSA | Polyimide w/9473 PSA | Tedlar film w/3MY966 PSA |
| Vendors | 3M, Dunmore | 3M, Dunmore | 3M, Dunmore | Complex Plastics, Dunmore |
| Substrate film thickness, mm (in.) | 0.05 (0.002) | 0.05 (0.002) | 0.25 (0.01) | 0.1 (0.004) |
| Maximum operation temp., °C (°F)<br>Continuous<br>Intermittent | 160 (<320) | <br><150 (300)<br><260 (500) | - | <br>149 (300)<br>260 (500) |
| Peel adhesion, 90° @ 1m/min (1 ft/min.)<br>Aluminum, gm/cm (oz/in.)<br>Stainless steel<br>Acrylic plastic<br>Polycarbonate | <br>-<br>547 (49)<br>-<br>- | <br>1,340 (120)<br>1,407 (126)<br>1,273 (114)<br>1,005 (90) | - | 547 (49) |
| Flight | HST | - | - | - |

#### 4.4.2 PSA Tape, Glass or Glass Fabric Impregnated

A contact-adhesive-backed, glass-fabric tape can be used on the outer cover and any seams stitched with organic thread that need AO protection (table 9). It is desirable to have tape with optical properties identical to those of the outer cover, but tape with different optical properties may be used as long as the performance of the entire blanket is not significantly degraded.

#### 4.4.3 PSA Tape, Metallized

A contact-adhesive-backed metallic tape may be used on the reflective layers and the inner cover of the MLI blanket provided that it meets the optical property requirements of the blanket (table 10). The metallic foil will be dead soft, uniform, clean, and free of corrosion. Neither the liner nor the foils will be wrinkled or buckled. The adhesive coat shall be smooth and uniformly applied, without voids, streaks, or foreign materials.

Table 9. PSA tape, glass fabric.

| Material | Teflon (PTFE)-Impregnated Glass Cloth Tape | | | Polyimide |
|---|---|---|---|---|
| | Plain | Aluminized | Goldized | Aluminized |
| Specification | MDAC STM0692 | MDAC STM0692 | Rockwell MB0135–059 | LMC LAC24–4686 & 4687 |
| Description | w/3M 5451 silicone PSA | Aluminized on one side, 3M Y966 acrylic PSA | Gold coated on one side, 3M Y966 acrylic PSA | w/108 fiberglass, 966 PSA, 1st or 2nd coating |
| Vendors | Sheldahl | 3M, Sheldahl, Dunmore | Sheldahl | Dunmore, Sheldahl |
| Widths, cm (in.) | 2.54, 5.08 (1, 2) | 2.54, 5.08 (1, 2) | 2.5, 5.1, 7.6, 10.2 (1, 2, 3, 4) | – |
| Substrate film thickness, mm (in.) | 0.15 (0.006) | 0.08 (0.0032 ) ± 10% | 0.08 (0.0032 ) ± 10% | 0.18 (.007) |
| Weight, gm/m$^2$ (oz/yd$^2$) | 9.15 (27) | – | – | – |
| Tensile strength, kg/cm (lb/in.) | 12.5 (70) | 2.14 (12) | 2.14 (12) | 000 (24K psi) |
| Elongation, % max. | – | 10 | 10 | – |
| Unwind force, gm/cm (oz/in.) | – | 447 (40) | 447 (40) | – |
| Panel adhesion, gm/cm (oz/in.) | 391 (35) | 447 (40) | 447 (40) | 279 (25) |
| Temperature range, °C (°F)<br>Continuous<br>Intermittent | –73 to +204 (–100 to +400)<br><260 (500) | – | – | <149 (<300) |
| Infrared emittance, ε, max | – | 0.04 | 0.04 | 0.14 (1st) 0.39 (2nd) |
| Absorptance, α, max | – | – | – | 0.04 (1st) 0.62 (2nd) |
| Resistance, Ω/square | – | – | – | ≤250,000 |

Table 10. PSA tape, metallized.

| Material | Kapton, Aluminized | Kapton, Goldized | Mylar | Teflon |
|---|---|---|---|---|
| Specification | MDAC STM0695, Type I | Rockwell MB0135–050, Type II, 3M 848 | Dunmore | Dunmore |
| Description | Polyimde film, 3M 966 PSA, aluminum coating | Polyimde film, 3M 848 PSA, gold coating | Polyethylene teraphthalate film, PSA alumium coat. | PFTE w/aluminum 2nd surface |
| Vendors | Dunmore, Sheldahl | 3M, Sheldahl | Complex Plastics, Sheldahl, Dunmore | Dunmore, Sheldahl |
| Thickness, mm (in.)<br>Substrate<br>Total | 0.013–0.025 (0.0005–0.001)<br>0.064–0.076 (0.0025–0.003) | 0.025 (0.001)<br>0.051 (0.002) | – | 0.051 (0.002)<br>0.102 (0.004) |
| Tensile strength kg/cm (lb/in.) | 4.64 (26) | 4.64 (26) | – | – |
| Unwind force, gm/cm (oz/in.) | – | 447 (40) | – | – |
| Adhesion, gm/cm (oz/in.) | 279-447 (25–40) | 145 (13) | – | 279 (25) |
| Infrared emittance, ε | 0.04 (See 1) | 0.04 | 0.05 | <0.04 |
| Absorptance, α | 0.14–0.39 | – | – | <.0.14 |

[1]Type III Kapton tape has the same requirements except that there is no requirement for emissivity. Kapton tape is also available in 0.013 mm (0.0005 in.) thickness.

### 4.4.4 Conductive Tape

A PSA tape with conductive adhesive may be used in conjunction with a grounding strap to ground the layers of an MLI blanket. The tape is folded between the metallized reflective layers. See section 7.1 for grounding concerns. Optical property requirements are not as important as the conductive properties of the tape. See table 11 for conductive tape characteristics.

Table 11. Conductive tape.

| Material | Aluminum Tape | DM-106, DM-140 | M006061 |
|---|---|---|---|
| Specification | - | - | - |
| Description | PSA w/conductive particles[1] | Black E7 polyimide with 966PSA[2] | Black E7 polyimide with 966PSA[3] |
| Vendors | 3M | Dunmore | Dunmore |
| Thickness, mm (in.)<br>Substrate film<br>Total | 0.102 (0.004) | 0.025 (0.001)<br>0.076 (0.003) | 0.025 (0.001)<br>0.076 (0.003) |
| Tensile strength, kg/cm (lb/in.) | - | 3,022 (17,000) | 3,022 (17,000) |
| Unwind force, gm/cm (oz/in.) | - | - | - |
| Adhesion, gm/cm (oz/in.) | - | 279 (25) | 279 (25) |
| Resistance, Ω/square | $<10^9$ | $<4 \times 10^9$ | $<10^9$ |
| Infrared emittance, ε | 0.05 (max) | >0.81 | >0.81 |
| Absorptance, α | - | <0.95 | <0.95 |

[1]Must be baked out before flight
[2]Available with aluminum coating
[3]Available with 9703 conductive PSA (M006061).

## 4.5 Fasteners

The layout of the fasteners of an MLI blanket assembly shall be specified on the assembly drawings.

### 4.5.1 Hook-and-Pile Fasteners

Hook-and-pile fasteners may be used to attach MLI blanket joints and assemblies. The hooks may be attached to the structure or the MLI blanket by approved adhesives applied to the fastener tape. Hook fasteners may also be attached mechanically, such as riveting, to the spacecraft, provided that structural stress and fatigue factors are considered. The pile fastener may be sewn to the blanket or attached by ultrasonic welding using an approved adhesive. This weld operation shall be through the entire blanket to inhibit inner layer shifting.

Flammability requirements limit the use of hook-and-pile fasteners to a maximum of 930 $cm^2$ (12 $in.^2$) per application with at least 5 cm (2 in.) separation in all directions from other applied hook-and-pile fasteners.

**4.5.1.1 Organic Hook-and-Pile Fasteners.** Flight experience indicates that hook-and-pile fasteners made from organic materials may be used on surfaces that will not be directly exposed to the LEO environment for more than a few hours. When designing these fasteners for an LEO environment, allow 6–12 mm (0.25–0.5 in.) overhang of the blanket assembly to prevent AO erosion, either through direct contact or scattering. A major contractor required 5 cm (2 in.) flaps of Beta cloth for *International Space Station* blankets. Hook-and-pile fasteners are generally available in 2.5-cm (1-in.) widths but may also be available in widths of 1.6 cm (0.625 in.), 1.9 cm (0.75 in.), 3.8 cm (1.5 in.), and 5 cm (2 in.). To prevent unraveling, do not slit fastener tapes lengthwise or trim selvage edges. Fastener tapes may be slit widthwise for forming into an arc or adjustment around a protrusion. Table 12 lists various organic hook-and-pile fasteners.

Table 12. Organic hook-and-pile fasteners.

| Material | **Astro Velcro Fastener** | **Nomex Fasteners** | **Nylon Fasteners** | **Polyester Fasteners** |
|---|---|---|---|---|
| Specification | MIL–F–21840 | MIL–F–21840, Type I, Class 2 | MIL–F–21840, Type II, Class 1 | MIL–F–21840, Type II, Class 3 |
| Description | Hook fastener tape of polyester hooks on Beta glass ground, pile fastener tape of Teflon loops on Beta glass ground | Hook fastener tape made of Nylon hooks on Nomex ground, pile fastener tape of 100% Nomex | Hook and pile fastener tapes made of nylon | Hook-and-pile fastener tapes made of polyester |
| Vendors | Velcro USA Inc. | Velcro USA Inc., Aplix | Velcro USA Inc., Aplix | Velcro USA Inc., Aplix |
| Hook and loop filament size, mm (in.) | 0.2 (0.008) | 0.17 (0.007) | 0.2 (0.008) | 0.2 (0.008) |
| Hooks/linear cm (in.) | 110 (280) | 112 (285) | 100 (255) | 75 (191) |
| Hook tape breaking strength, kg (lb) min | N/A | 70.3 (155) | 56.7 (125) | 72.6 (160), 100 pile |
| Loop tape breaking strength, kg (lb) min | N/A | 65.3 (144) | 45.4 (100) | 54.4 (120), 100 pile |
| Composite shear strength, kg (lb) min | 6.8 (15) | 6.8 (15) | 6.8 (15) | 10.8 (24) |
| Composite peel strength, kg (lb) min | 0.40 | N/A | N/A | N/A |
| Temperature range, °C (°F) | –57 to +93 (–70 to 200) | | | |
| Comments | | Recommended for high temperature applications | | OK for a few cycles of UV or chemical interaction |

Data for these materials are given for 2.5-cm- (1-in.-) wide tapes. Hooks are generally placed every four picks on the ground fabric, loops are every three picks. Composite shear strength is tested with 7.6 cm (3 in.) overlap of hook-and-pile tapes.

**4.5.1.2 Metallic Hook-and-Pile Fasteners.** Metallic hook-and-pile fasteners (table 13) may be used on surfaces that will be exposed to AO for longer times than organic fasteners. These fasteners shall meet thermal requirements. Metallic hook-and-pile fasteners will not be considered for more than 10 peel cycles. If the fastener is expected to exceed 10 peel life cycles, then a combination of organic and metallic hook-and-pile fasteners may be used where the organic material is not exposed to AO. However, this combination has a lower adhesion strength and will require more adhesion area to fulfill strength requirements.

Table 13. Metallic hook-and-pile fasteners.

| Material | **Hi-Garde Stainless Steel Fastener** |
|---|---|
| Specification | MIL–F–21840 |
| Description | Hook-and-pile fastener tapes made of noncorrosive metal |
| Vendors | Velcro USA Inc. |
| Hook size, mm (in.) | 0.1 (0.004) |
| Hooks/linear cm (in.) | 98 (250) |
| Hook tape breaking strength, kg (lb) min | 45.4 (100) |
| Loop tape breaking strength, kg (lb) min | 45.4 (100) |
| Composite shear strength, kg (lb) min | 6.8 (15) |
| Temperature range, °C (°F) | –40 to +427 (–40 to +800) |

### 4.5.2 Laces and Hand Ties

In many cases it is necessary or desirable to attach MLI blankets to each other or to a spacecraft by hand ties or laces. Laces should be taut and have no slack that will let the blanket shift and expose protect areas or break away. Neither should the laces be pulled so tight as to cause the blanket to bunch or pucker. At their ends, the laces should be tied off in a square knot that is snugged down to the fabric (note: a granny, which resembles a square knot, is unacceptable). The tips of the laces shall be protected to ensure that they do not unravel.

Laces should attach to the MLI blanket either by cloth or other loops attached to the exterior of the blanket, or by metal grommets that penetrate the blanket. In the latter case, the blankets to be attached in this manner should be designed so a flap of material passes over the two edges that are to be laced, thus ensuring that the gap between the laces or the blanket does not allow sunlight or gases to pass through. The covering flap should then be secured in place.

Holes for the laces shall be protected with aluminum grommets which provide a firm grip on the blanket and prevent tears from propagating from the hole. The grommets are coated, if necessary, to protect MLI fibers or films where they are punctured. See table 14 for flat and round braid lacing tapes and tie cords.

Table 14. Lacing tapes and tie cords.

| Material | **Flat Braid** | **Round Braid** |
|---|---|---|
| Specification | See below | See below |
| Description | PTFE coated before braiding | PTFE coated before braiding |
| Vendors | W.F. Lake | W.F. Lake |
| Yield, m/kg (yd/lb) | 446–872 (220–432) | 730–2332 (360–1150) |
| Thickness, mm (in.) | 0.2–0.5 (0.007–0.018) | N/A |
| Width, mm (in.) | 3.2–1.2 (0.125–0.47) | N/A |
| Diameter, mm (in.) | N/A | 0.7–1.2 (0.027–0.047) |
| Break strength, kg (lb) | 68.1–18.1 (150–40) | 36.3–22.7 (80–50) |
| Elongation, % | <5 | <5 |
| Temperature, °C (°F) | –240 to 288 (–400 to 550) | –240 to 288 (–400 to 550) |

Applicable specifications:

MIL–T–43435B; MIL–C–20079H
Martin STM–F–411, 417, 420
Lockheed 25–4066A
Boeing BAC 5170, 5157
Hamilton Standard 539769
General Electric 932A224
U.S. Navy 17773A1118A007X

# 5. FINISHING

## 5.1 Seams

Minimize the total length of seam in a blanket assembly to limit the reduction in blanket thermal efficiency by heat shorts (the thread will conduct heat from the surface of the MLI blanket to the interior structure). Seal edges of blankets by either adhesive transfer tape or by ultrasonic welding. Ensure that welds have no discontinuities, and carefully trim off welding residuals, threads, and netting strands.

Continuous stitch lines (fig. 6) are best when the blanket configuration permits. Recommended stitch length is four to eight stitches per inch (about one every 3 to 6 mm (0.12 to 0.24 in.)). If the thread breaks or runs out in the middle of a stitch line, back up ≈25 mm (1 in.) and restart the stitch line. The new stitch line will be restarted in a previously made needle hole to reduce blanket perforations. At the end of a stitch line, backstitch ≈13 mm (0.5 in.) to secure the seam.

Figure 6. Several reflectors' layers are stitched to make a complete blanket (photo courtesy of Boeing).

## 5.2 Billowing

Buttons may be used to sew the inner layer of the blanket to the outer layer to prevent billowing and ripping. This is necessary with large blanket assemblies and will not be considered necessary for equipment geometries of 15.2 cm (6 in.) diameter or less, such as fluid lines and equipment supports. Use buttons made of UV- and AO-resistant materials, according to the environment expected. Buttons may be fixed by a flat, braided Kevlar or Nomex cord, or equivalent.

## 5.3 Tie Downs

Tie downs employ straps or clamps to fasten intersecting blanket assembly terminations to the surrounding structure or equipment. Tie down materials will be protected from the space environment unless they are made of resistant materials.

# 6. ENVIRONMENTAL EFFECTS ON MULTILAYER INSULATION

## 6.1 Atomic Oxygen

AO erodes most organic materials and will react with a number of metals and other inorganic materials (fig. 7). The requirements for materials exposed to AO and AO reaction rates are given in NASA TM–1000351. All materials susceptible to AO erosion in structural applications, including stitching, buttons, and groundings, shall be shielded from AO. MLI blanket surfaces which are exposed to AO shall be made of AO-resistant materials that will maintain the thermal design requirements for the life of the blanket.

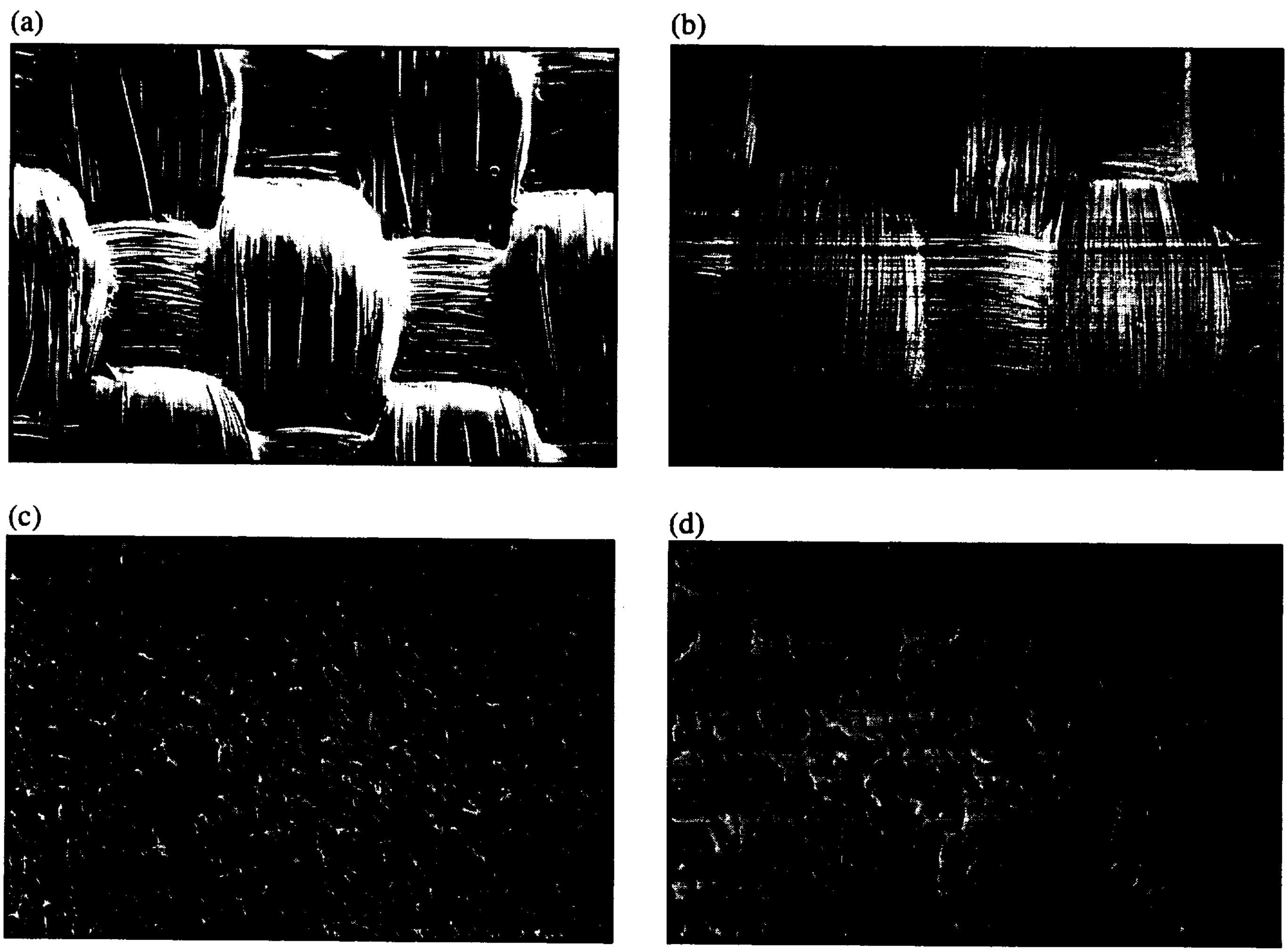


Figure 7. AO erosion is readily seen in scanning electron microscope images. Beta cloth (a) before and (b) after exposure to AO. Note that the Teflon coating has been eroded, but that the glass fibers remain intact. Samples of (c) Kapton and (d) silverized Teflon are shown after exposure to AO on LDEF.

## 6.2 Ultraviolet Radiation

Long-term exposure to UV radiation has been shown to cause significant changes in optical and mechanical properties for various materials. Materials that will be exposed to UV radiation shall not embrittle or show significant change in optical or mechanical properties for the life of the material. Note that UV radiation combined with AO can cause reactions that might not take place in the presence of AO or UV alone. In effect, the energies from both sources are additive.

## 6.3 Meteoroid/Orbital Debris Impacts

Exposed MLI blankets may be hit by micrometeoroids and orbital debris which may penetrate the entire assembly and expose the underlying surfaces (fig. 8). Designers must consider whether to minimize impacts with shielding or to allow for thermal performance degradation due to impacts. The amount of damage to an MLI blanket during a mission may be calculated using NASA TM–104825 for orbital debris impacts and NASA SP–8013 for meteoroid impacts. NASA SP–8038 may be used for predicting meteoroid impacts for an interplanetary mission. Computer models, such as MLITEMP, have been developed to predict insulative deterioration due to impact damage.

Note that much of the orbital debris problem is generated by launch vehicles and satellites and may be expected to get worse over the next few decades as satellite launch rates increase. Debris can range from fragments released during staging down to paint chips and bits of insulation that flake off during service life. Designers thus carry the obligation to ensure that MLI materials contribute as little as possible to the problem as they degrade during operation.

Blankets under shielding may experience damage by impacts through the shield with accompanying debris and plasma spray. Place blankets as close as possible to the meteoroid/debris shield to minimize damage to the blanket.

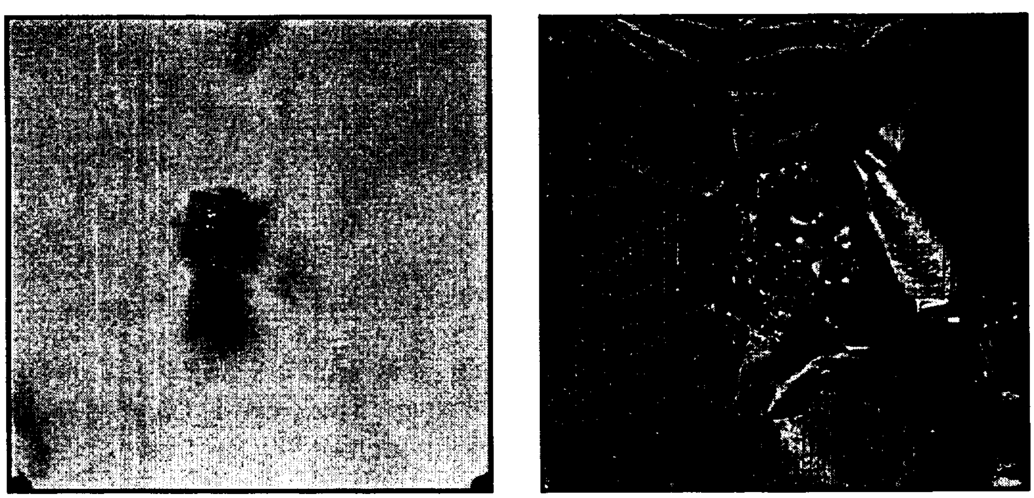

Figure 8. Multilayer insulation is easily penetrated by high-speed debris, as in this ballistic test of a panel using a sample of Space Station materials. Lightweight, slower debris poses a greater hazard to MLI which can erode with long exposure, especially when coupled with AO and UV effects. These views cover a width of ≈15 cm (6 in.).

Long-term spacecraft may need allowances for eventual replacement of MLI blanket assemblies to maintain thermal performance. Designers should consult the operational experience of astronauts and cosmonauts who have participated in extravehicular repair missions. For example, the repair of the Solar Maximum Mission saw the crew patch the goldized Kapton on the telescope section after cutting into it to replace an electronics unit. On the second Hubble Space Telescope servicing mission (fig. 9), the astronauts noticed several areas of eroded MLI on the spacecraft exterior. They applied patch kits that had been supplied for such an event. Other lessons to consult include the design for replacement of larger units, including the use of heavier connectors and fasteners. In some cases it may be more desirable to replace a module (possibly by robot) and repair the details inside the station or after the element is returned to Earth.

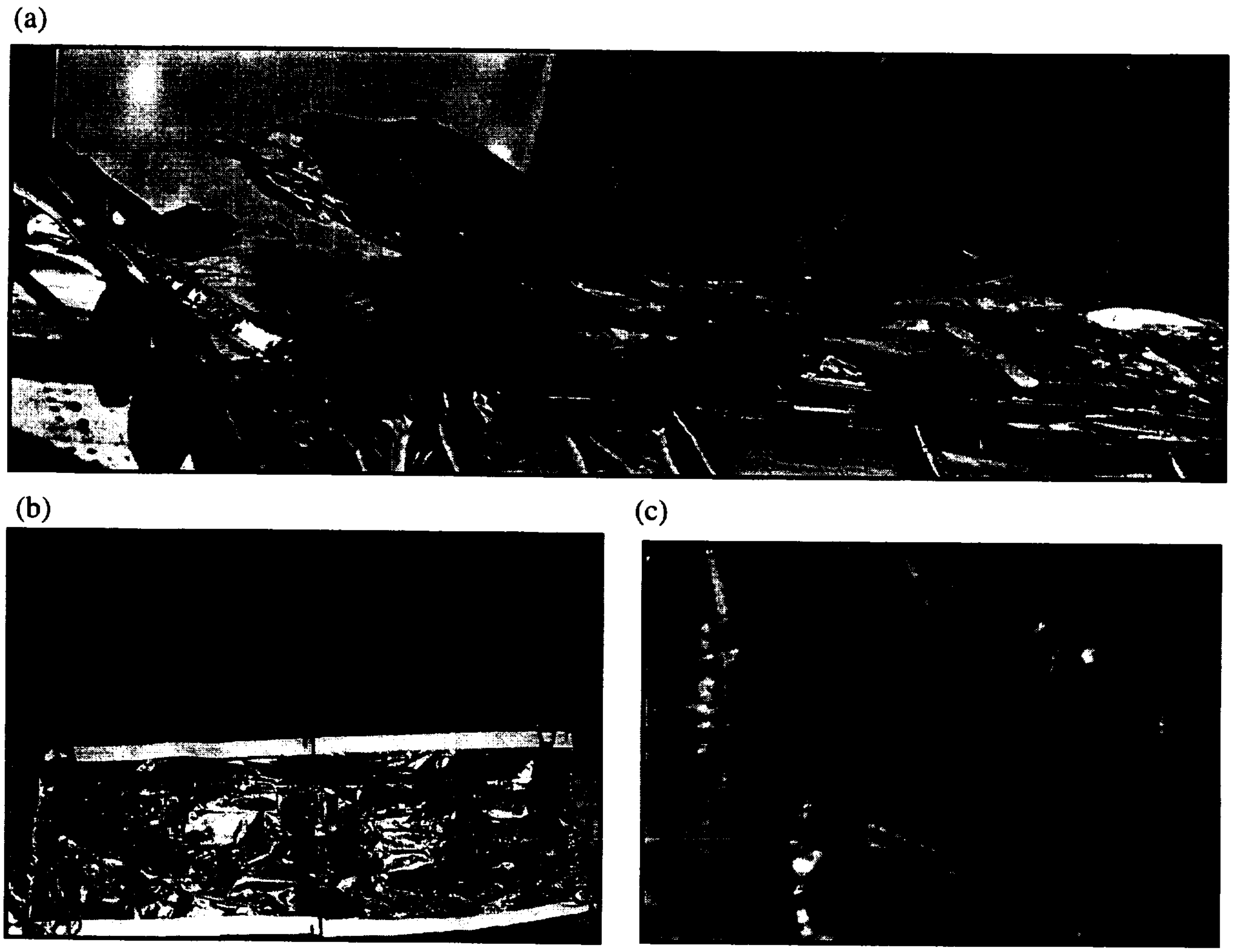


Figure 9. To protect areas where the MLI had degraded in orbit (a), astronauts applied MLI repair patches (b) to the exterior of the Hubble Space Telescope (c) during the January 1997 servicing mission (STS–82). Such repair techniques will become more common with expanded operation of long-duration spacecraft and the availability of humans or robots to maintain them.

## 6.4 Contamination Control

Construction and assembly of MLI blankets shall meet the contamination control plan of the spacecraft. The work area where assembly, disassembly, or testing of MLI blankets is accomplished shall have minimal dust, particulate material, and condensate fumes. All tools, equipment, templates, holding fixtures, or other structures which may contact the MLI shall be cleansed before use with a solvent having a nonvolatile residue not exceeding 0.02 g/L. Solvents shall be compatible with the component materials so that the materials are not damaged by normal cleaning operations. Work table surfaces shall have clean protective covers when not in use. MLI blankets shall be handled with clean white gloves or powder-free latex gloves suitable for clean room use. Workers shall wear clean laboratory smocks and practice good housekeeping in the work area. Foot coverings shall be worn when working above the MLI blankets or blanket installations and shall be removed when leaving the overhead location and replaced when returning to the overhead location. Templates shall be used whenever possible during blanket fabrication.

Blankets shall be inspected for contamination before flight. Observed contaminations may be removed by dry-wiping with a clean room wipe (Rymple cloth, Alpha 10 wipe, or other purified wiping cloth) and vacuuming contaminants as required. When Beta cloth is used as an outer cover, vacuum with a brush attachment in the direction of the fabric's warp. Cloth warp is in the direction of the raised fibers and may be determined using a $\times 30$ microscope. Some manufacturers may place an alignment thread showing the direction of the warp. A clean room wipe moistened with an appropriate solvent may also be used to clean MLI blankets. However, avoid excessive wiping, cleaning, and solvent use. Replace blanket assemblies that have been permanently degraded by contamination.

Because most launch sites are next to a beach, the MLI designer should be aware of the potential exposure of MLI to salt spray and other corrosive agents. (Even inland launch sites have corrosion problems comparable to those near beaches.) Most spacecraft will be handled inside clean rooms or in environmental capsules for transit to the launch pad and installation on the launch vehicle. The Space Shuttle has ventilation panels on the sides of the payload bay. While the bay normally is ventilated with dry air, the potential exists for sea air or vehicle exhaust to enter the bay. MLI designs should take into account potential exposure to airborne corrosion.

## 6.5 Outgassing

All finished MLI blanket assemblies shall meet the outgassing requirements of SP–R–0022A. Materials that do not meet outgassing requirements shall undergo a component bakeout prior to assembly. The recommended bakeout should comply with MSFC–SPEC–1238.

## 6.6 Plasma Effects

The presence of plasma (ionized gas) at LEO (<5,000 km (3,100 mi)) presents a medium for surface and differential charging that can result in considerable potential difference between remote locations dependent on the conductivity of the interconnecting materials. This can lead to static electric discharges between the spacecraft and the ambient plasma, or between partially insulated elements of the spacecraft. The final result can be severe damage to key electrical components, possibly resulting in loss of the spacecraft.

# 7. OTHER CONCERNS

## 7.1 Electrical Bonding and Grounding

The number of grounding assemblies required depends on the size of the MLI blanket and the environment. Blankets <1 $m^2$ (10.8 $ft^2$) in area may not require grounding. Two grounds shall be provided for each blanket assembly >1 $m^2$ (10.8 $ft^2$) in area, with additional grounds for blankets larger than 4 $m^2$ (43.2 $ft^2$) in area. Grounding assemblies shall not keep blankets from meeting thermal requirements. Ground locations shall be at least 2.54 cm (1 in.) away from other fasteners (fig. 10), and the blanket assembly may not be welded together in the grounding area.

An example of a grounding assembly follows. Other designs may also be acceptable, providing they meet the grounding and thermal requirements. Resistance through the assembly will be <1 Ω.

Cut away the spacer netting in a 2.54-cm (1-in.) square. Apply grounding tape, such as aluminum tape with conductive adhesive, continuously, accordion-style, between each blanket layer. Wrap the tape around the inner and outer cover to complete a grounding path through the entire blanket. Additional tape may be used to minimize contamination to the surrounding surfaces through venting or particulate generation. Punch a hole through all layers of the blanket and the tape before placing the grounding bolt. Preferred materials for grounding bolts and washers are brass or corrosion-resistant steel (CRES) without surface coating, though alodined aluminum has been used. The bolt passes through a flat washer, an eyelet terminal, the blanket, another flat washer, a lock washer, and a lock nut. Crimp a single conductor wire (of length to be specified in the engineering drawing) to the eyelet terminal and then attach it to ground. The grounding wire will be 22 gauge and insulated by Teflon or as specified in the engineering drawing. Torque the bolt and lock nut assembly to 7 to 9 in.-lb.

The resistance from any ground assembly to the spacecraft structure must be <1 Ω. The resistance from any aluminized surface to ground will be <5,000 Ω.

## 7.2 Installation Requirements

Where possible, MLI installation shall take place in an area designated strictly for this purpose, or in a common work area where other tasks are excluded for the duration of the MLI installation. Normally, installation will be done in a clean room certified as meeting the requirements of the most sensitive equipment exposed during the process. For example, a spacecraft exterior can tolerate a wider range of conditions than a telescope's optics. The lead installer will inspect the MLI and the MLI's documentation to ensure that the correct components are being installed, and that they have been properly stored and handled.

Before starting an MLI installation, the lead technician or engineer will review the design with the installation team and with a representative of the engineering design office. The lead installer will ensure that all workers are properly trained and certified for the task, including making repairs, should the MLI be damaged during installation. The lead installer will also ensure that the installation steps are properly recorded and documented, including photography and videotaping, as appropriate.

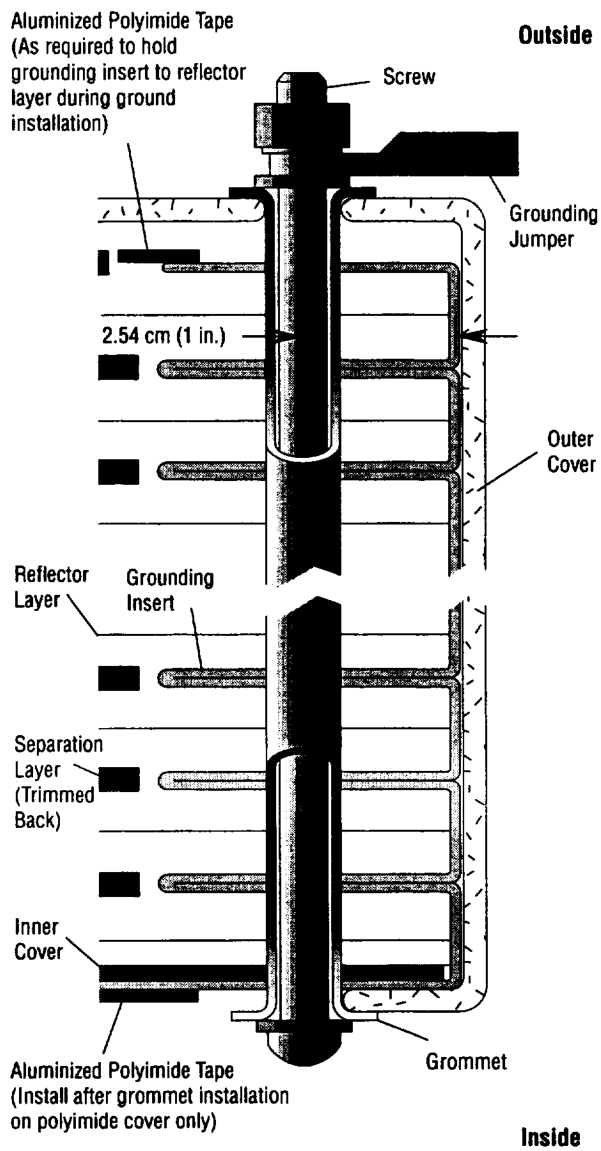


Figure 10. Electrical grounding straps are required to ground MLI layers to the primary structure on spacecraft that may build up a static charge. In this design for the *International Space Station*, the aluminized polyimide layers are electrically connected by aluminum foil (the grounding insert), and a metal grommet through the blanket connects the layers to the ground strap (from a Boeing drawing).

### 7.3 Venting Requirements

MLI blankets shall be designed so that all gases trapped between layers can vent within 48 hr of launch. The design of vent paths and of holes between each layer of the MLI is left to the designer since each situation will be unique. The 48-hr requirement is set to match the initial on-orbit period when a spacecraft is allowed to outgas before full activation. This ensures that high voltage is not applied in the presence of trace amounts of gas that would support arcing and thus the short-circuiting of the spacecraft.

The blanket design must also prevent bubbles from being trapped and then outgassing later (i.e., gas flow makes the layers billow so they fold and obstruct a passage).

In designing the MLI for venting, the designer shall be mindful of the need to ensure that the vent paths do not inadvertently provide return paths for sunlight, AO, or gases vented by the spacecraft.

## 7.4 Cutouts or Protrusions

To allow for protrusions, cut the blanket assembly with a sharp scalpel. Take care to minimize tearing of the blanket materials since tears can weaken the blanket or allow light to penetrate the MLI assembly (this, in effect, cancels part of the blanket in the area that is penetrated). If a cutting template is used, the template will be made of noncontaminating material. Firm pressure on the template during cutting will prevent layer slippage. Ultrasonically weld or tape the exposed edges with aluminized polyimide tape. Additional stitching with approved thread may be required around the protrusion.

When slitting is required, simultaneously weld and slit the blanket with the appropriate ultrasonic welder. Offset slits by at least 5 cm (2 in.) to minimize the effect of slitting on blanket performance.

## 7.5 Storage

Unpackage raw materials in the clean room or clean room airlock just before blanket fabrication. When not in use, cover or bag these materials to maintain cleanliness.

When not being worked, such as during nonworking hours, cover blankets in fabrication with noncontaminating plastic sheets, such as bagging materials approved by the contamination control plan. Purge all finished blankets with dry nitrogen and double-bag them with heat-sealed edges for storage. The bagging material must be a minimum of 0.15 mm (0.006 in.) thick. Any blanket identification must be visible through the storage bag, or the bag shall be properly labeled with the part number of the fabricated blanket. Do not open bags containing flight hardware blankets in any environment other than a clean room or other environmentally controlled area, as specified in the contamination control plan.

While in storage, maintain the blankets in a low-humidity, temperature-controlled environment. The recommended storage temperature is 15–27 °C (59–81 °F). Desiccant packs and a humidity indicator may be used between the inner and outer storage bags.

When removed from storage, inspect the bags for structural integrity, and the blanket for visible signs of deterioration such as loose particles or discoloration.

## 7.6 Repair

Repair cuts, abraded areas, and other defects of the reflective layers of an MLI blanket with aluminized or goldized tape (sec. 4.4.3). Damaged areas of the outer cover may be repaired with Teflon-impregnated glass cloth tape (sec. 4.4.2), provided that the optical property requirements are met. Large amounts of damage will be cause for rejecting the blanket for spacecraft use.

## 7.7 Other Hazards

Designers should be aware that the moving parts of a spacecraft can displace or tear a section of MLI blanket (fig. 11) if the blanket is in the path of the mechanism. While designers normally take care to avoid such interference, the natural flexibility of MLI blankets may allow them to shift.

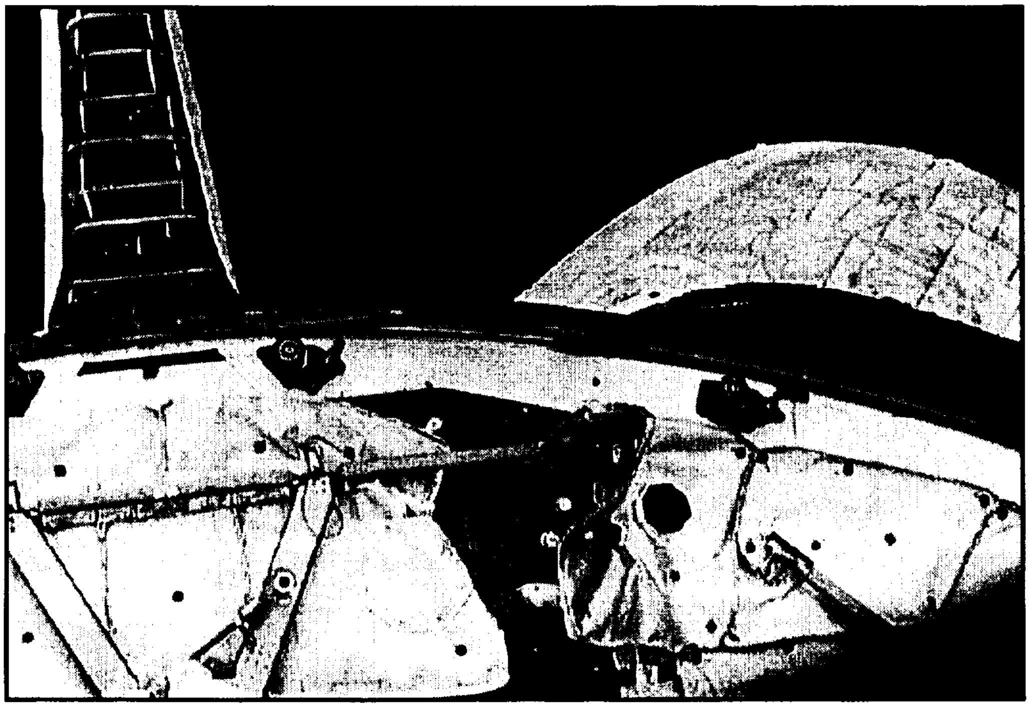

Figure 11. Beta cloth-covered MLI in the aft end of the Space Shuttle payload bay was pulled out of position by the payload bay door mechanism. The underlying spacecraft structure was not damaged, but the event highlights the potential for damage with moving equipment.

Further, ground support equipment can be a hazard to MLI if not properly used. In late 1997, the Huygens probe on the Cassini spacecraft had to be removed for repairs to the MLI covering the heat shield. Fans blowing cool air through the launch vehicle nose shroud were set too high, and the air flow pulled and ripped the MLI. Making all personnel aware of the potential for damage to the MLI can help avoid damage.

## 7.8 Cryogenic Insulation

In addition to protecting spacecraft exteriors, MLI also is used to insulate cryogenic fluids for long durations in space. NASA's Lewis Research Center has developed a Supplemental Multilayer Insulation Research Facility which provides a small-scale test bed for cryogenic experiments in a vacuum environment. The facility is capable of simulating a Space Shuttle launch pressure profile, a steady space vacuum environment of $1.33\times10^{-4}$ N/m$^2$ ($1.3\times10^{-6}$ torr), warm-side boundary temperatures between 111 and 361 K (200–650 R), and a typical lunar day-night temperature profile. Details are available in NASA TM–106991.

## 8. VENDORS

Vendors are listed for the convenience of the reader in contacting known suppliers of MLI blankets and components. Inclusion in the list is neither a NASA endorsement nor a guarantee that the supplier's goods will meet your specific needs. While every effort has been made to include all MLI vendors, some may have been inadvertently left out. We will be glad to add them to the list as these guidelines are updated.

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http://www.aplix-usa.com

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http://www.ChemFab.com/

Brady USA
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*Multilayer Insulation Material Guidelines* provides data on multilayer insulation materials used by previous spacecraft such as Spacelab and the Long-Duration Exposure Facility and outlines other concerns. The data presented in the document are presented for information only. They can be used as guidelines for multilayer insulation design for future spacecraft provided the thermal requirements of each new design and the environmental effects on these materials are taken into account.

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