F1

MLI の微小デブリ防護性能評価

Shielding Effect of MLI against Submillimeter Debris

○東出真澄，平井隆之，黒崎裕久，長谷川直，松本晴久（JAXA）
○Masumi Higashide, Takayuki Hirai, Hirohisa Kurosaki, Sunao Hasegawa, Haruhisa Matsumoto (JAXA)

人工衛星のコンポーネントは，デブリ衝突に対する影響を識別し，衝突リスクが許容されない場合は何らかの防護材を適用する必要性がある．防護材として搭載実績が高いのは ISS のシールド材として使用されているアルミ合金板であるが，無人宇宙機にとっては重量増加の影響が大きい。新たな軽量防護材の研究開発が行われているが，耐宇宙環境性能の評価まで完了している材料は極めて少ない．
そこで本研究では MLI の微小デブリ防護性能を評価し，防護性能を向上させる構成を調べた．中間層に厚みのあるフィルムを使用して MLI 全体の面密度を向上させれば，MLI でも直径 0.1 mm のデブリ貫通を防ぐ効果があることがわかった．最外層に ITO（インジウムすず酸化物）膜を持ったフィルムを使用した場合は模擬デブリがより細かく砕かれた．最外層はデブリ破砕に対する影響が高いと考えられる．また貫通痕の観察結果から，中間層にエンボス加工フィルムを使用すると，防護性能の向上が示唆された．

Components of JAXA’s spacecrafts are identified effects on debris collision before its launch. If the risk is not acceptable, a debris shield is added to the component. An aluminum alloy plate has high reliability since it has been used as a shield of the ISS. For an unmanned spacecraft, however, the effect on the total weight is not ignorable. A lot of light-weight bumpers have been developed before now.
Almost all new bumpers have not finished assessments of protective abilities against space environment. This study investigated shielding effects of MLI blankets. The MLI blanket captured projectiles of 0.1mm in diameter when its areal density was increased by using thick reflectors. If an outer film was covered with ITO (Indium-Tin Oxide), the projectile fractured more. An outer film is considered to influence with fragmentation of debris. Moreover, embossed reflector films seemed to improve shielding effects of a MLI blanket.

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- JMR-002 ロケットペイロード安全標準 English
- JMR-004 信頼性プログラム標準
- JMR-005 品質保証プログラム標準 English
- JMR-006 コンフィギュレーション管理標準 English
- JMR-012 電気・電子・電気機構部品プログラム標準
- JMR-013 品質プログラム標準（基本要求 JIS Q 9100）

2. 技術要求・ガイドライン文書

共通
- JERG-0-001 宇宙用高圧ガス機器技術基準
- JERG-0-017 品質保証プログラム標準 解説書
- JERG-0-039 宇宙用はんだ付工程標準
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ロケット
- JERG-1-007 射場運用安全技術基準 English
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- JERG-1-010 宇宙転用可能部品の宇宙適用ハンドブック（ロケット編）

宇宙機 -- 宇宙機設計標準体系図
- JERG-2-000 宇宙機（人工衛星・探査機）設計標準 English
- JERG-2-023 宇宙転用可能部品の宇宙適用ハンドブック（長寿命衛星編）
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- JERG-2-510 姿勢制御系設計標準 English
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- JERG-2-610 宇宙機ソフトウェア開発標準 English

地上設備
- JERG-3-001 地上設備・装置品質プログラム標準
- JERG-3-003 地上ソフトウェア開発標準 English

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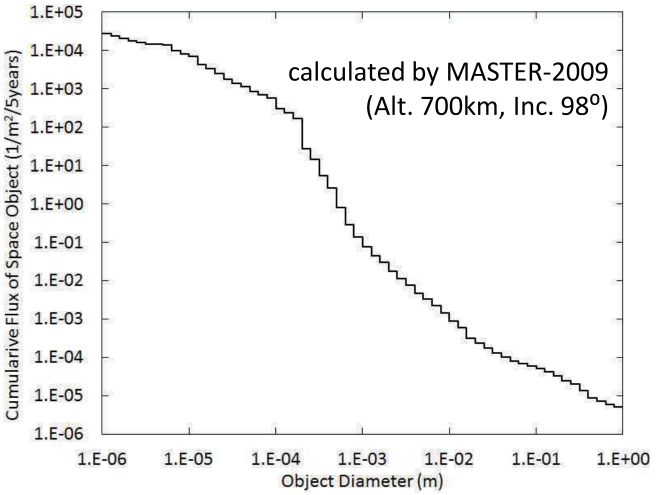
Background

Impact of sub-millimeter debris is a threat of mission failure for LEO satellites.

Sub-millimeter projectile impact data on spacecraft component are not enough to debris protection design for spacecraft.

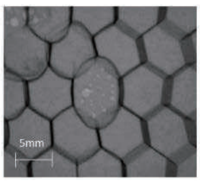
Ref. 東出, 工業材料, 2014.

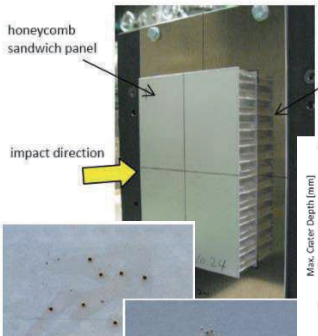


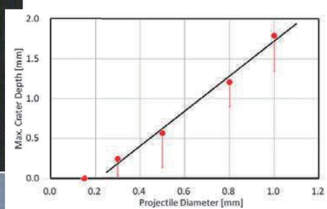
JAXA is summarizing examples of hypervelocity impact experiment and numerical simulation data on the Space Debris Protection Design Manual (JERG-2-144-HB001).

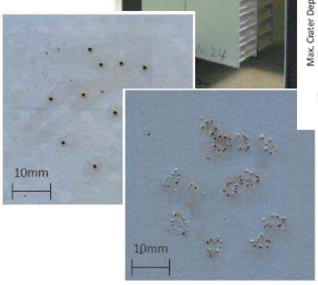
Vulnerability of Spacecraft Component

Ref. Higashide et al., Trans. JSASS Aerospace Tech. Japan, 2012.



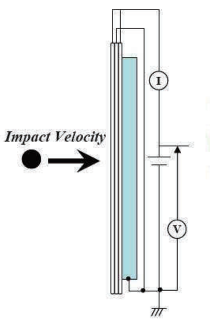


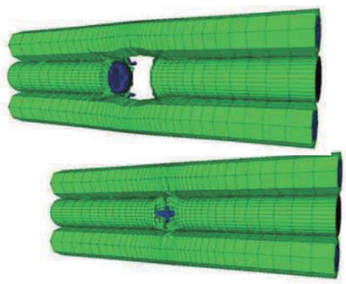




Projectiles larger than 0.3mm in dia. were perforated a honeycomb sandwich panel

Ref. Nitta et al., Trans. JSASS Aerospace Tech. Japan, 2010.






Impacts of projectiles larger than 0.3mm in dia. showed negative effects on power harnesses

Spacecraft components are vulnerable against small debris impacts
→ Critical components are protected if the collision risk is not acceptable

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Debris Shielding Material

Bumper shield installed on the ISS
→ Inducing weight increase of spacecraft because its main material is aluminum alloy

Ref. 東出 他, 遊星人, 2015.

Bumper shield made of high-strength fiber woven
→ Having high protective ability & flexible structure
→ Having restrictions for use (temperature, radiation, etc.)

Multi layer insulation (MLI) blankets are normally installed on out-side of spacecraft
→ Can MLI blankets shield spacecraft from sub-millimeter debris impacts?

Past Research of MLI blankets

Ref. Lambert , Adv. Space Res., 1997.

Lambert conducted the experiments on MLI blankets (22 ply) put on the aluminum plate (2 mm in thickness).
Ballistic limit energies were investigated when aluminum spheres impacted at 6 km/s.

Table 1. Relative performances of MLI in front of aluminium plates

Configuration	Surface density (g/cm^2)	Ballistic limit energy at 6 km/s (J)	Projectile diameter (mm)	Surface density of aluminium to defeat same energy (g/cm^2)	k_∞ (Eq. 1)
Aluminium	0.56	9	0.71	0.56	0.42
Aluminium + MLI	0.62	25	0.99	0.81	0.32
Aluminium + 2 MLI	0.68	85	1.49	1.26	0.23
Aluminium + 3 MLI	0.73	125	1.70	1.43	0.21
Aluminium + MLI + 10 mm spacing	0.62	45	1.21	1.01	0.26

↑Projectile diameter (mm)

Energy absorption by MLI blanket was confirmed against impacts of approximately 1 mm projectiles.

→ Shielding effect of MLI is also expected against sub-millimeter debris impact.

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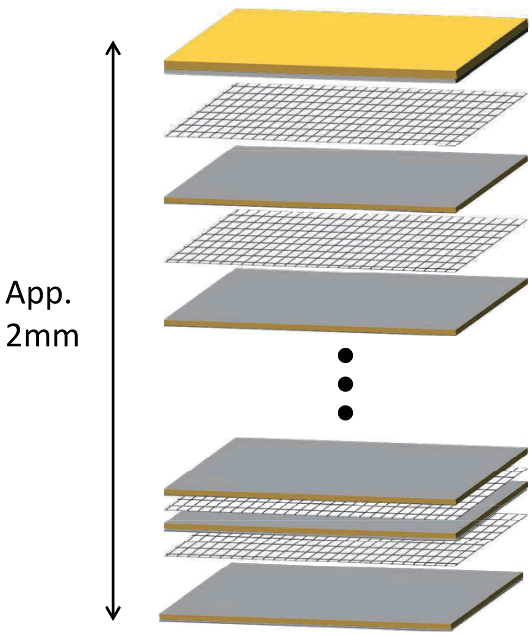
Objective

Investigate shielding effects of MLI blankets against sub-millimeter debris impacts

Tested specimens:

- Typical MLI blankets installed on LEO satellites
- MLI blanket consisting of embossed films

Example of MLI Stracture



Outer layer :
Aluminized polyimide film
(with radiation coating)

Reflector layer :
Aluminized polyester film,
Aluminized polyimide film
(several layers)

Separator :
Plastic mesh

Inner layer :
Aluminized polyimide

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Tested MLI Blankets

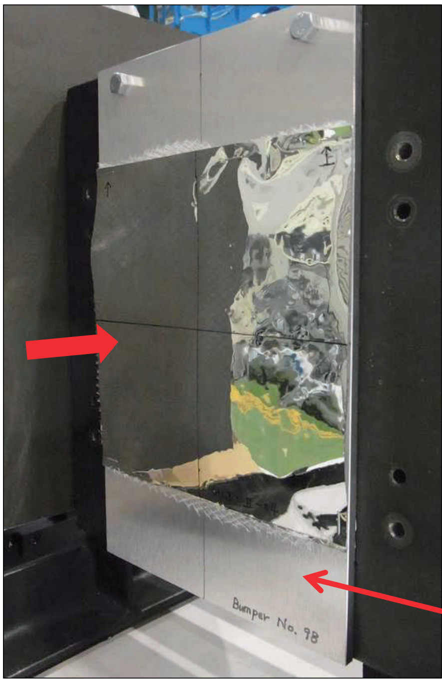
ID	MLI - I	MLI - II	MLI - III	MLI - IV	MLI - V
Weight	268 g/m^2	229 g/m^2	315 g/m^2	154 g/m^2	268 g/m^2
Outer	Single Aluminized Polyimide, **50µm**	Double Aluminized Polyimide, 25µm	Single Aluminized Polyimide, 25µm	Double Aluminized Polyimide, 25µm	**ITO** Coated Aluminized Polyimide, 50µm
Reflector	Double Aluminized Polyester				
	6µm, 10ply	6µm, 10ply	**12µm**, 10ply	6µm, **6ply**	6µm, 10ply
Separator	Polyester Mesh				
Inner	Double Aluminized Polyimide, 25µm				

ITO: Indium-Tin Oxide, Use for holding lower surface potential

Experimental Conditions

Impact velocity
6 km/sec

Projectiles
SUS304, Sphere
d_p=0.1mm, 0.3mm



4 corners of a blankets were fixed on an aluminum alloy plate

Inner layer roughly contacted on surface of an aluminum alloy plate

Aluminum alloy plate
A2024-T3, t=5mm

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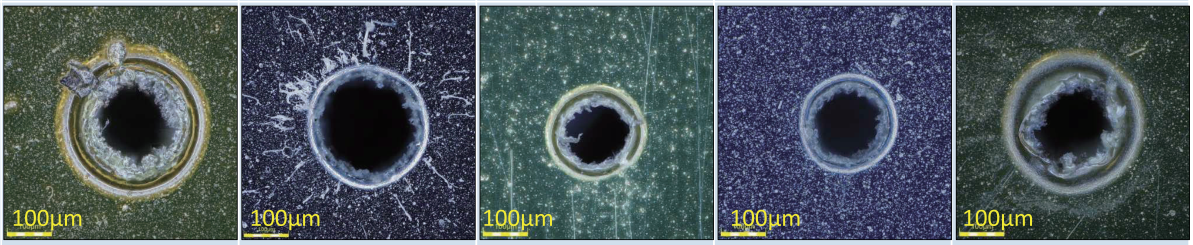
Results

ID	MLI - I	MLI - II	MLI - III	MLI - IV	MLI - V
Mark	**Thick outer film**	**Standard**	**Thick reflectors**	**Half layers**	**ITO outer film**
Weight	268 g/m^2	229 g/m^2	315 g/m^2	154 g/m^2	268 g/m^2
Outer	Single Aluminized Polyimide, **50µm**	Double Aluminized Polyimide, 25µm	Single Aluminized Polyimide, 25µm	Double Aluminized Polyimide, 25µm	ITO Coated Aluminized Polyimide, 50µm
Reflector	6µm, 10ply	6µm, 10ply	**12µm**, 10ply	6µm, **6ply**	6µm, 10ply
0.3mm	Perforation				
0.1mm	Perforation	Perforation	**Non Perforation**	Perforation	Perforation

Damage of Outer Films (0.1mm)

ID	MLI - I	MLI - II	MLI - III	MLI - IV	MLI - V
Mark	Thick outer film	Standard	Thick reflectors	Half layers	ITO outer film
Outer film	Single Aluminized Polyimide, **50µm**	Double Aluminized Polyimide, 25µm	Single Aluminized Polyimide, 25µm	Double Aluminized Polyimide, 25µm	ITO Coated Aluminized Polyimide, 50µm

Front surface



Aluminized surfaces were observed around perforated holes in the cases of single aluminized outer films.
→ Back surface or 2nd layer (reflector surface)

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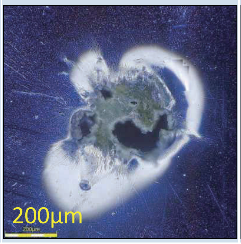
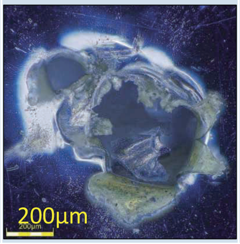
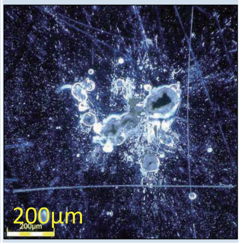
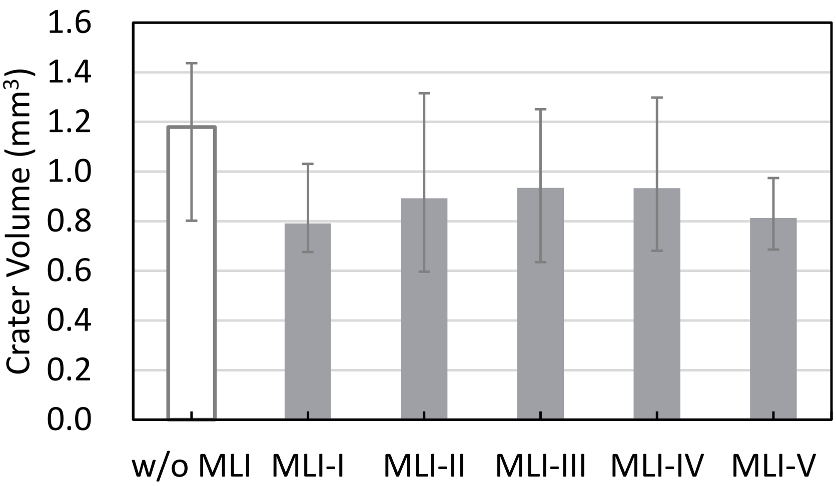
Damage of Inner Films (0.1mm)

ID	MLI - I	MLI - II	MLI - III	MLI - IV	MLI - V
Mark	Thick outer film	Standard	Thick reflectors	Half layers	ITO outer film
Inner	Double Aluminized Polyimide, 25µm				
Back surface			Non Perforation		

Perforated holes were larger than outer layers.
On the film of MLI-V, groups of smaller holes were observed.
→ ITO coating seems to contribute fragmentation of a projectile.

Crater Volume (0.3mm)

All MLI blankets were perforated by impacts of 0.3 mm projectiles
→ Measure volumes of craters on aluminum plates behind the blankets



MLI blankets seem to have effects to reduce by about 20% of impact energies.

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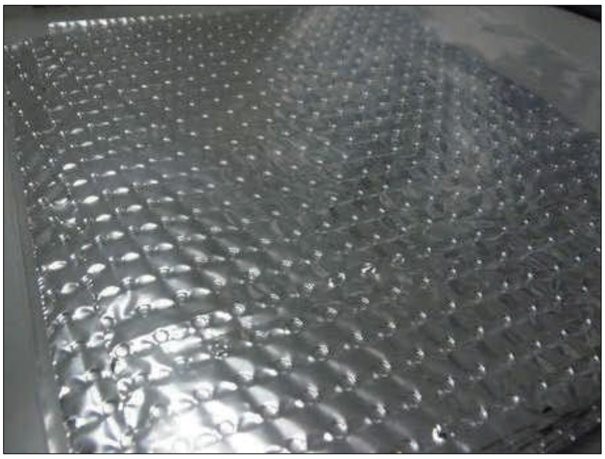
Embossed Refrector

Embossing: Method for making concavo-convex pattern



Merits:

Separators are not used because contacting area between layers is quite small due to embossed pattern

→ Acceptable temperature does not depend on separator material

→ Workability is improved

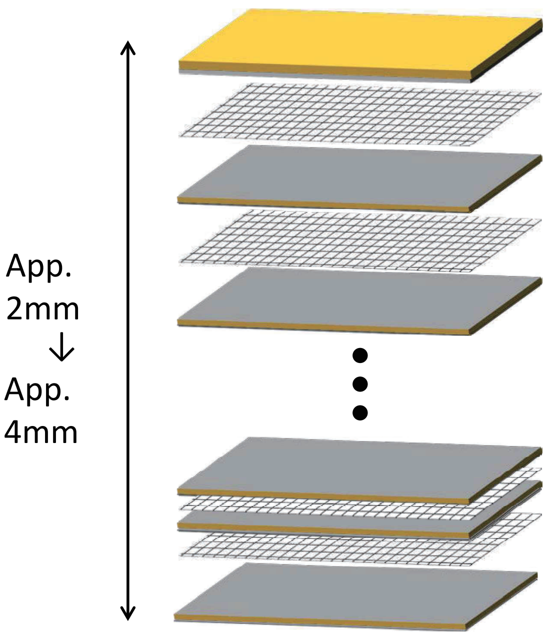
Demerits:

Cost is higher

Total thickness of the blanket becomes thick due to embossed pattern

→ Can it induce higher shielding effects?

Structure of Embossed MLI blankets



Outer layer :
Aluminized polyimide film
(with radiation coating)

Reflector layer :
Embossed Aluminized polyester film,
Embossed Aluminized polyimide film
(several layers)

~~Separator :
Plastic mesh~~

Inner layer :
Aluminized polyimide

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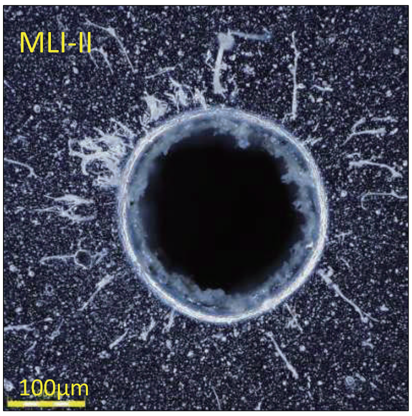
Tested MLI

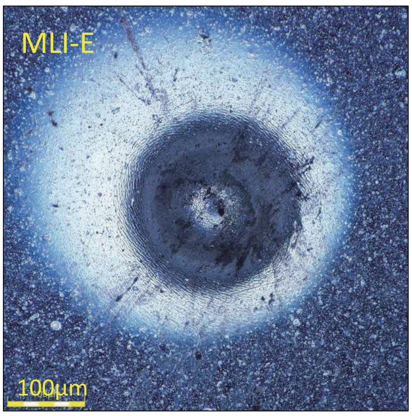
ID	MLI - II	MLI-E
Weight	229 g/m^2	239 g/m^2
Outer	Double Aluminized Polyimide, 25μm	
Reflector	Double Aluminized Polyester Film, 6μm, 10ply	**Embossed** Double Aluminized Polyester Film, 350-400μm, 10ply
Separator	**Polyester Mesh**	None
Inner	Double Aluminized Polyimide, 25μm	

Impact Test Result

0.1 mm projectiles did not perforate the embossed MLI blanket
→ Showed high shielding effect

Measurement of crater volumes on the aluminum plate is ongoing





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Summary

As a result of hypervelocity impact experiments for 6 kinds of MLI blankets, shielding effect of the MLI blankets were found against sub-millimeter projectile impacts.

- Projectiles of 0.1 mm in diameter were captured in the MLI blanket made from thick reflectors (12 μm) and one from embossed reflectors.
- ITO coating of outer layer seemed to improve shielding effects because projectiles were fractured to smaller fragments.
- MLI blankets can reduce 20% of projectile impact energies.
- Use of embossed films as reflector material can improve shielding effects against sub-millimeter debris impact.

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