C05

耐AOコーティングによるCFRPからのイジェクタの低減
Reduction in Ejecta from CFRP by Atomic Oxygen Protective Coating

○西田 政弘，高原 秀征（名古屋工業大学），古田 尚正，
岩瀬 賢明（東亞合成），東出 真澄，石田 雄一（JAXA）
○NISHIDA Masahiro, TAKAHARA Hideyuki (Nagoya Institute of Technology), FURUTA Naomasa,
IWASE Yoshiaki (Toagosei), HIGASHIDE Masumi, ISHIDA Yuichi (JAXA)

炭素繊維強化複合材料（CFRP）は宇宙機にも多く使われているが，飛翔体が超高速衝突すると，多くの破片（イジェクタ）が飛散する．耐原子状酸素（AO）コーティングを塗布することで，イジェクタを低減しつつ，バンパーとしての性能は同等もしくは向上するようなデブリバンパーを目指して，研究している．その結果を報告する．

Carbon fiber reinforced plastic (CFRP) plates are widely used in spacecraft. When projectiles strike them at very high velocities, many fragments (ejecta) were scattered. Our group proposed AO coating/CFRP to reduce ejecta from CFRP and to keep or improve bumper performance. We would like to report some results of AO coating/CFRP.

第9回 スペースデブリワークショップ
2021年2月24日～26日オンライン

耐AOコーティングによるCFRPからのイジェクタの低減

Reduction in Ejecta from CFRP by Atomic Oxygen Protective Coating

○西田政弘，高原秀征（名古屋工業大学）
古田尚正，岩瀬賢明（東亞合成株式会社）
東出真澄，石田雄一（宇宙航空研究開発機構）

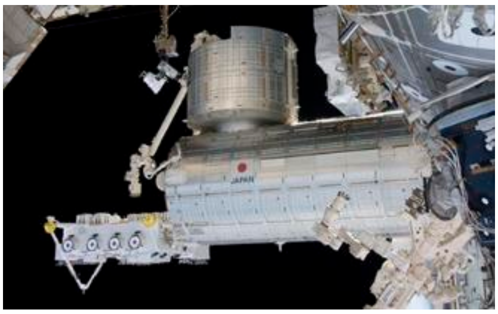
Masahiro Nishida, Hideyuki Takahara (Nagoya Institute of Technology)
Naomasa Furuta, Yoshiaki Iwase (Toagosei Co., Ltd.)
Masumi Higashide, Yuichi Ishida (JAXA)

1

International Space Station

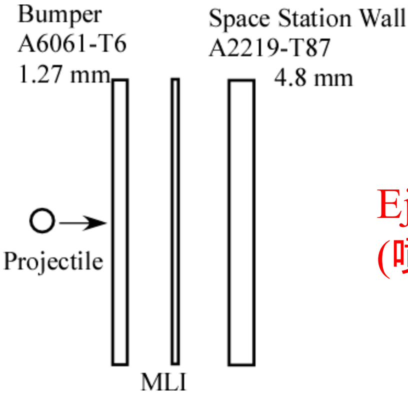
Courtesy of NASA
http://spaceflight.nasa.gov/gallery/images/shuttle/sts-127/html/s127e011212.html

JEM "KIBOU"

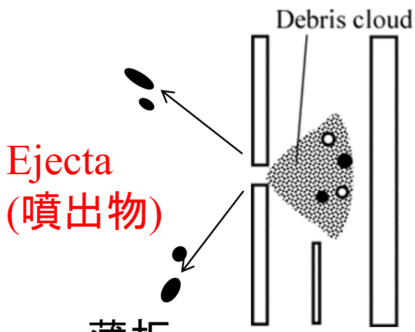


Courtesy of JAXA
http://www.jaxa.jp/projects/iss_human/kibo/index_j.html

Bumper shield



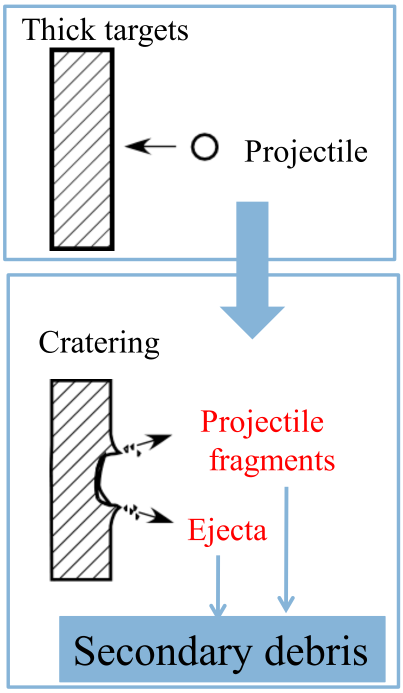
Whipple shields



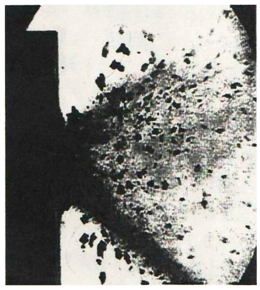
Thin plate perforation

2

Penetration into Thick Plates

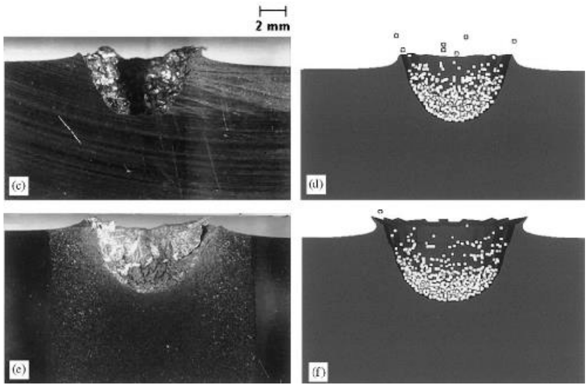


Composition of ejecta



Numata, Kikuchi, Sun, Kaiho, Takayama, Proc JSSW, (2006), pp. 221-222.

Projectile fragments and ejected materials



Murr, Int. J Impact Eng., (2006), pp. 1981-1999.

Flux of Space Debris

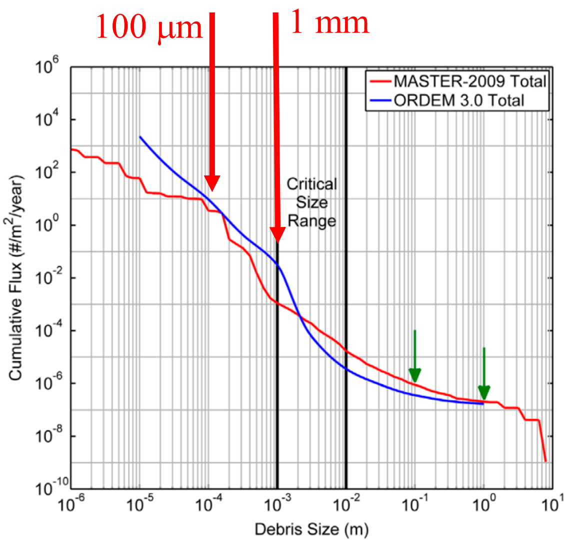


Fig. 1. ORDEM 3.0 and MASTER-2009 orbital debris fluxes for the ISS orbit in 2014.

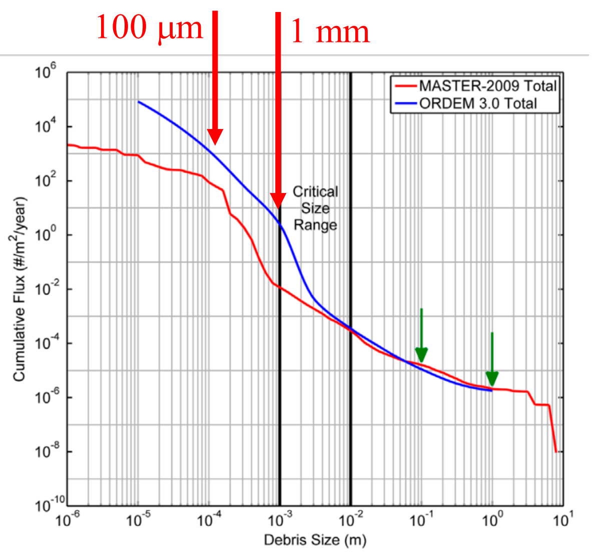


Fig. 4. ORDEM 3.0 and MASTER-2009 orbital debris fluxes for the SSO orbit in 2014.

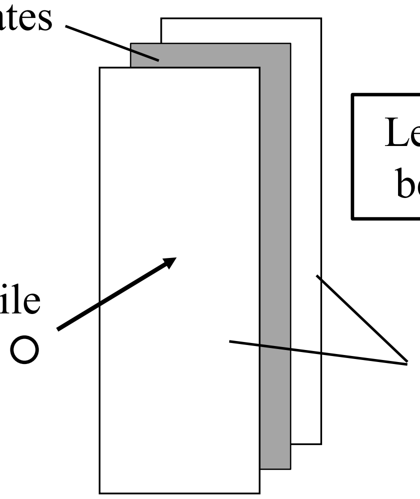
P. H. Krisko, S. Flegel, M. J. Matney, D. R. Jarkey, V. Braun, ORDEM 3.0 and MASTER-2009 modeled debris population comparison, Acta Astronautica, Vol. 113, 2015, pp. 204-211.

Purpose：Reduction of Ejecta（イジェクタの低減）

1) Coating / CFRP plates（コーティング / CFRP板）
（宇宙科学に関する室内実験シンポジウム2020，材料学会講演会2020電通大）

2) Organic fiber reinforcement composites（有機繊維補強複合材料）
（宇宙科学に関する室内実験シンポジウム2019，M&M2019材料力学カンファレンス九大，第8回スペースデブリワークショップ2018）

=> Poster presentation



Earlier Studies of Debris Shielding (1/2)

PBI coating/CFRP

Polybenzimidazole (PBI):
Atomic Oxygen Protective Coating

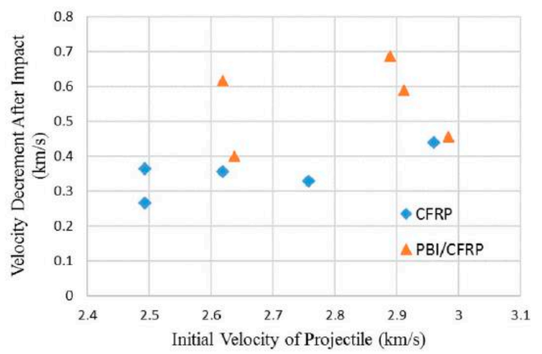
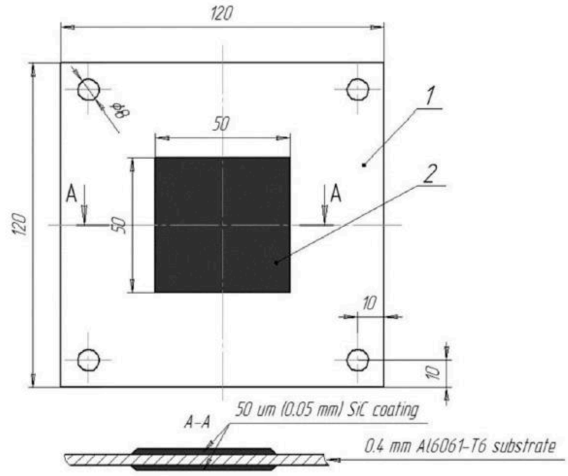


Fig. 5. Velocity decrement of the projectile after impact with CFRP and PBI/CFRP.

Sarath Kumar Sathish Kumar, et al., Polybenzimidazole (PBI) film coating for improved hypervelocity impact energy absorption for space applications, Composite Structures 188 (2018) 72–77

SiC coating/Al



Aleksandr Cherniaev, Igor Telichev, Sacrificial bumpers with high-impedance ceramic coating for orbital debris shielding, International Journal of Impact Engineering, 119 (2018) 45–56

Earlier Studies of Debris Shielding (2/2)

Ti-Al nylon impedance-graded materials

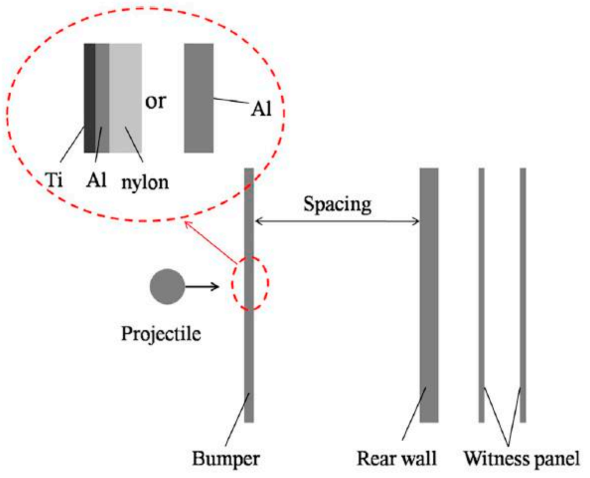


Fig. 1. Experiment schematic diagram.

Zhang P.L., et al., Study of the shielding performance of a Whipple shield enhanced by Ti-Alnylon impedance-graded materials, International Journal of Impact Engineering 124 (2019) 23–30

Kevlar/ FRP

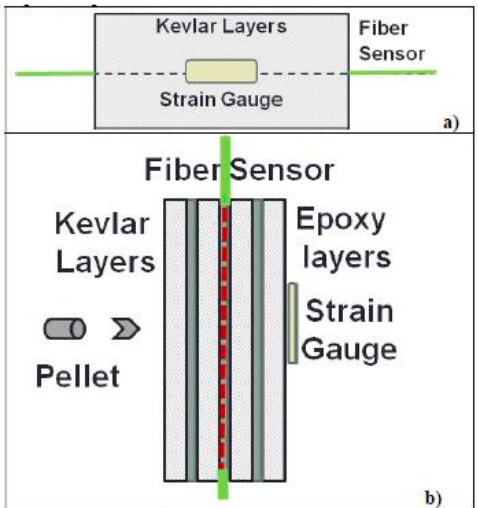


Figure 6, Four layers Kevlar/Epoxy, a) Top Front View; b) Cross Section Side View Strain Gauge and FBG (example Shot #79)

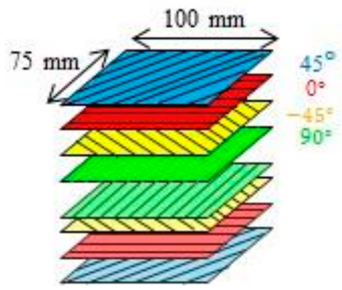
Emile Haddad, et al., Mitigating the effect of space small debris on COPV in space with fiber sensors and self repairing materials, Proc. ECSSMET (2018)

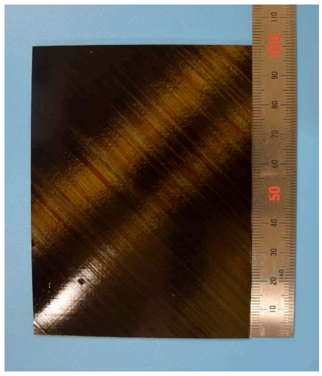
Atomic oxygen（AO）protective coating / CFRP plates

（耐原子状酸素コーティング/CFRP板）

Polyimide CFRP

Polyimide CFRP（Prepreg from JAXA*）
Size：75 mm × 100 mm
Thickness: 1.0 mm（8 ply）
Quasi-isotropic [45°/0°/−45°/90°]s
（擬似等方性）



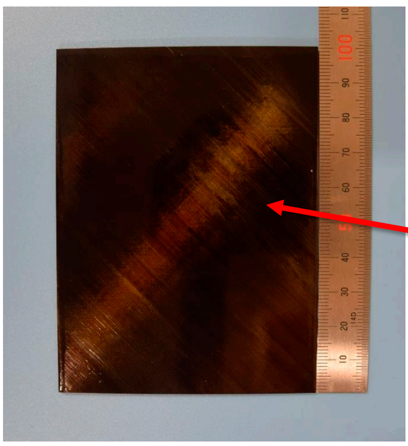


* 石田雄一，耐熱高分子基複合材（耐熱 CFRP）の適用技術研究，日本航空宇宙学会誌, 68(2), 2020, pp. 38-42.
Miyauchi, M., Ishida, Y., Ogasawara, T. and Yokota, R., Highly soluble phenylethynyl-terminated imide oligomers based on KAPTON-type backbone structures for carbon fiber-reinforced composites with high heat resistance, Polymer J., 45, 2013, 594-600.

Atomic Oxygen（AO）Protective Coating

Coating
Sil-sesqui-oxane derivative
（シルセスキオキサン誘導体）
（Toagosei）
Thickness 5 μm, 20 μm

Composition formula $[(RSiO_{1.5})_n]$, intermediate material of inorganic silica $[SiO_2]$ and organic silicone $[(R_2SiO)_n]$
Density 1.14 g/cm^3
Storage modulus 1×10^9 Pa (1 Hz, 0°C)



Atomic oxygen（AO）protective coating

bar-coating method
⇒ Ultraviolet curing

Thickness 20 μm
=> Areal density 1.58% up

Sil-sesqui-oxane Derivative

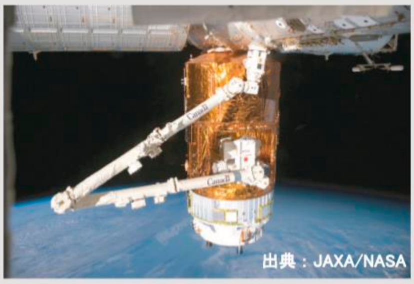


写真１　ポリイミドフィルム使用例（写真中央琥珀色光沢部）
ISSに取り付けられた「こうのとり」３号機

写真３　ポリイミドフィルムに対するプラズマアッシャー試験
簡易耐AO試験、15時間照射後

古田尚正，北村昭憲，鈴木浩，石澤淳一郎，木本雄吾，田村高志，シルセスキオキサン誘導体「光硬化型SQ シリーズ」の宇宙用材料への応用～耐原子状酸素コーティングの開発～，東亞合成．研究年報TREND (2013)

SQ series (1 - 2 μm)/ polyimide film (50 μm)

図２　AO照射による質量変化

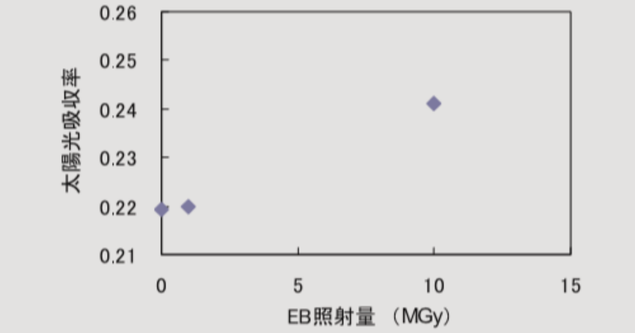


図３　EB照射による太陽光吸収率変化

Experimental Condition

Shot No.	Impact velocity [km/s]	Coating thickness [μm]	Areal density [g/cm^2]
J-417	3.24		0.1705
J-413	3.17	5	0.1712
J-414	3.11	20	0.1732

Thickness 20 μm
=> Areal density 1.58% up

Experimental Setup (1/2)

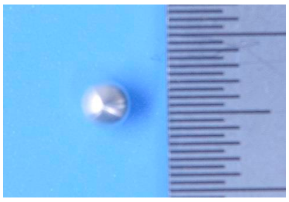
Two stage gas gun

JAXA/ISAS

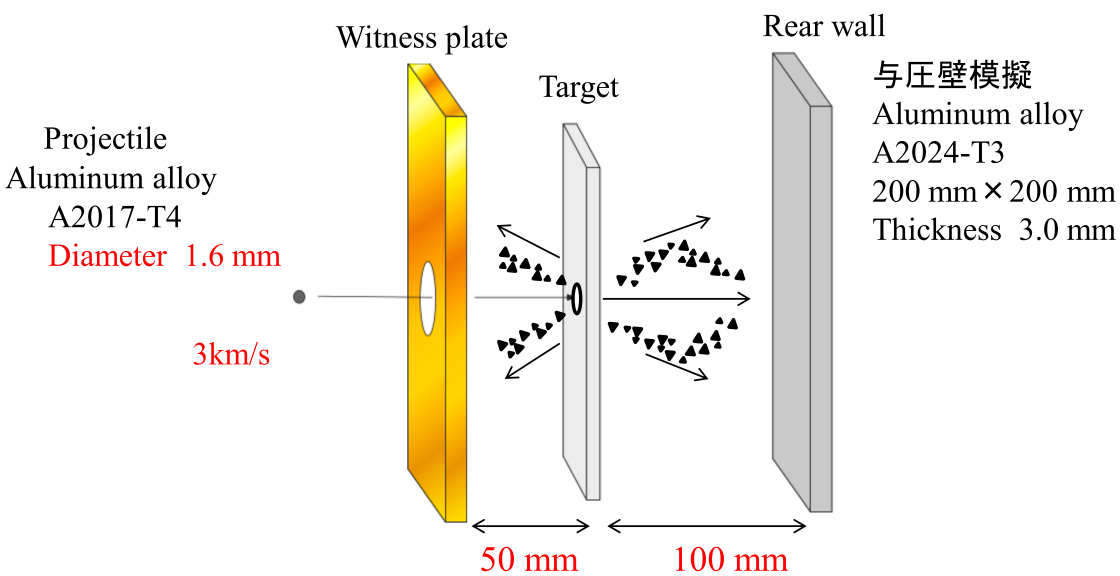
Impact velocity
2 km/s – 7 km/s

N. Kawai, K. Tsurui, S. Hasegawa, E. Sato, Rev Sci Instrum 81 (11) (2010) 115105.

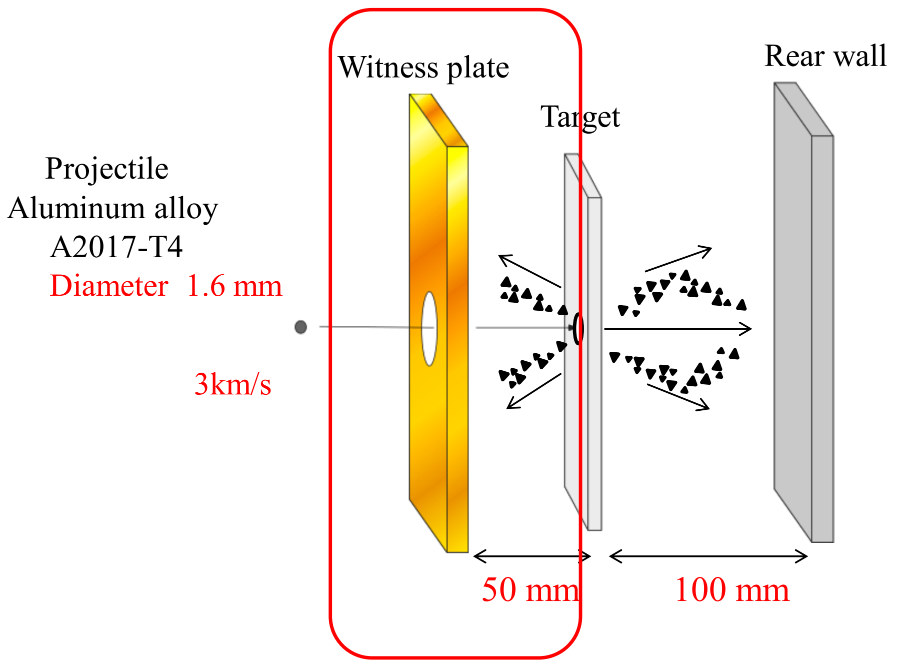
Projectile
Aluminum alloy sphere
A2017-T4
Diameter: 1.6 mm
(3 km/s)



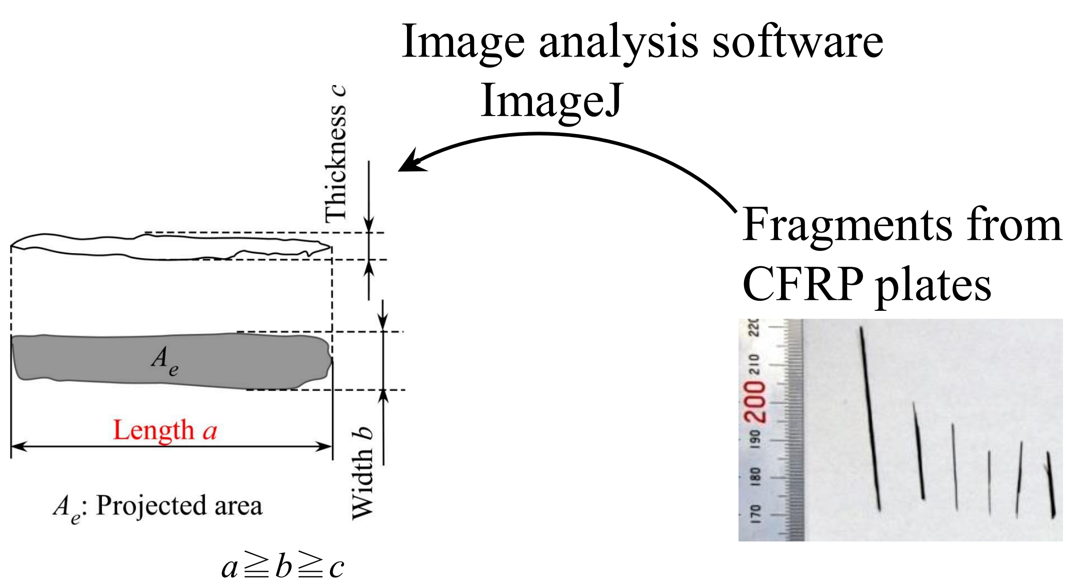
Experimental Setup (2/2)



Results of Ejecta

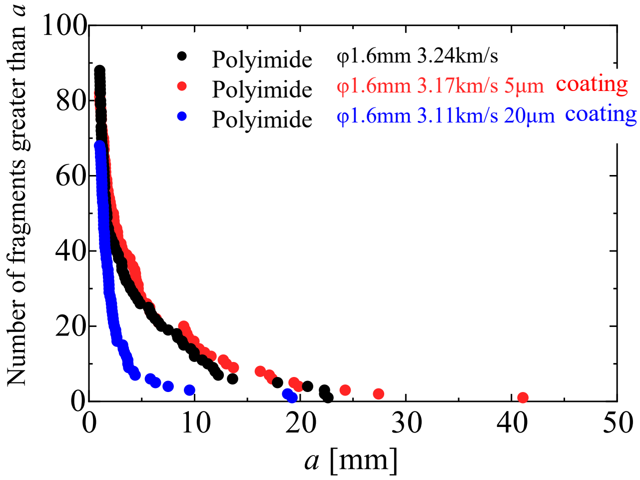


Evaluation of Ejecta (Direct method)



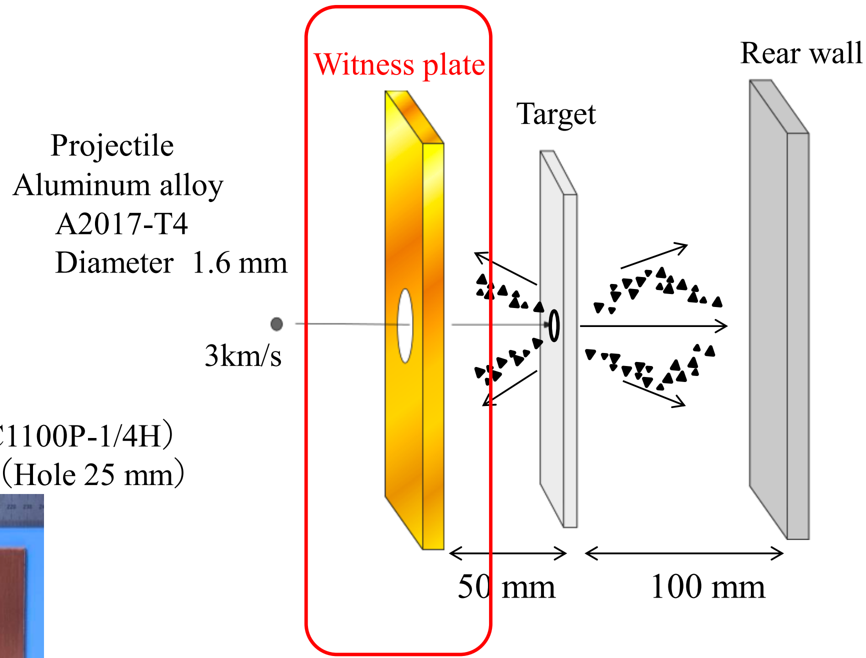
Main target : $a \geqq 1$ mm

Results by Direct Method (Cumulative number distribution of ejecta)

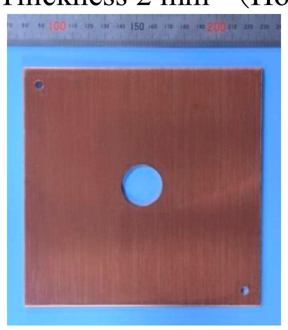


No.	Impact velocity [km/s]	Coating thickness [μm]	Areal density [g/cm²]	Number of ejecta over 1 mm
J-417	3.24		0.1705	88
J-413	3.17	5	0.1712	82
J-414	3.11	20	0.1732	68

Results of Ejecta



ISO 11227
Witness plate
（copper plate：C1100P-1/4H）
Thickness 2 mm （Hole 25 mm）

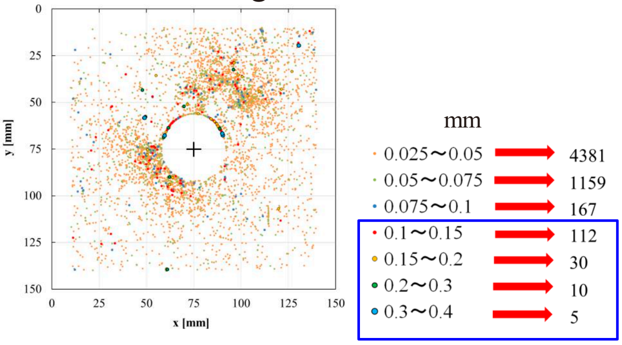


Epoxy CFRP (Toray, P13080F-3: Matrix 3800-2, Fiber M60JB) 2.41 km/s

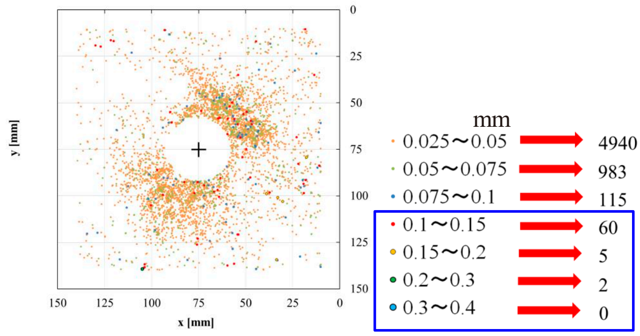
Nishida et al., Proceedings of 7th European Conference on Space Debris, (2017)

Results by Witness Plates (ISO 11227)

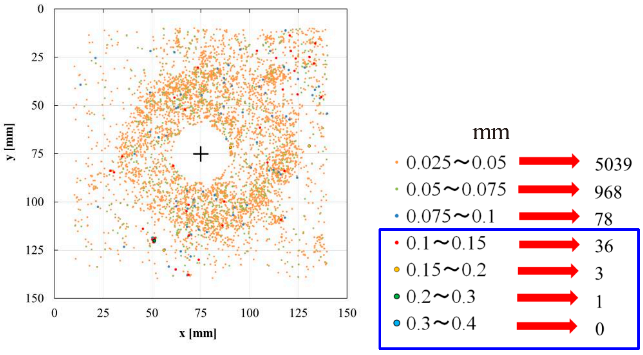
Without coating 3.24 km/s



5 µm coating 3.17 km/s



20 µm coating 3.11 km/s



Conclusions

1. Shielding performance : Similar
2. Forward ejecta : Decrease
3. Effects of coating thickness : Unclear
4. Future plans :
   1） Reproducibility
   2） Effects of space environment
   3) Mechanism

Acknowledgments

本研究を進めるにあたり，コーティングに関しまして，名古屋工業大学 栗山 晃 特任教授に，アドバイスいただきました．

本実験にあたり，宇宙航空研究開発機構 宇宙科学研究所 スペースプラズマ共同研究設備を利用しました．ここに記して謝意を表します．本研究は，JSPS 科研費19K04072の助成を受けたものです．