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東北大学のデブリ研究の取り組み ～除去テザーの構造，衝突による発光色変調～

Space debris studies in Tohoku University: structures of debris removal tethers, luminescent color modulation

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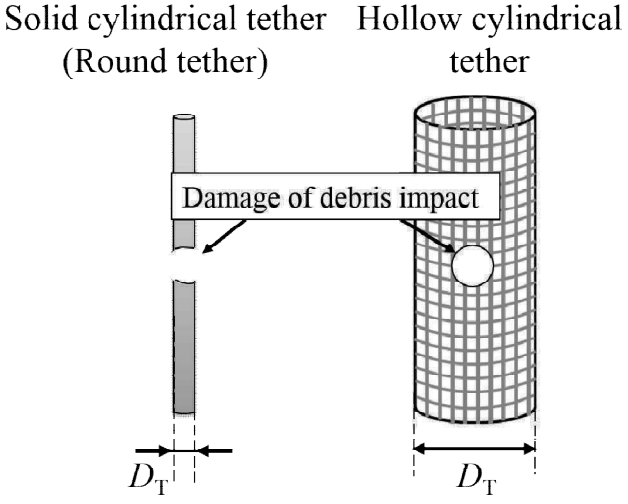
この発表では，東北大学のデブリ研究の取り組みの一部を紹介する．まず，デブリ除去テザーの構造研究を紹介する．図に示す中空円筒メッシュテザー（以下，中空テザー）を提案する．従来の中実円柱テザーと同じ質量で直径を大きくできるため，微小デブリが衝突してもテザーは破断せず，テザーの防御性能を向上させることができる．超高速衝突実験により，中空テザーの性能や損傷形態を明らかにする．円柱テザーと中空テザーの生存確率を比較し，中空テザーの有用性を示す．次に，衝突による発光色変調の研究を紹介する．
宇宙機の異物衝突時に，デブリ衝突修復の為に空気漏れ穴箇所を知らせる表示システムを構築する．急激な温度・圧力上昇をトリガーとして長時間蓄光する光化学物質を宇宙機の与圧壁内側に塗布する想定である．現在，衝突現象で光化学物質がどのように変化するかの実験を行っている．

Space debris studies in Tohoku University are introduced. Firstly, we talk about the use of a hollow cylindrical mesh for an electrodynamic tether to improve its survivability in space. The proposed tether is expected to be used in space missions to remove uncontrollable satellites in orbit. Although the mass of the hollow cylindrical tether is the same as that of a conventional solid and cylindrical (i.e., round) tether, it has a larger diameter, which improves its survivability. To investigate the damage to the proposed hollow cylindrical mesh tether by debris impact, hypervelocity impact experiments were performed by using a two-stage light gas gun. The experimental results confirmed the potentially increased survivability of the proposed hollow cylindrical mesh tether compared to the conventional tether. Secondly, we talk about the luminescent color modulation caused by debris impact. An air-leakage detection system for space-debris impact will be constructed with photochemical materials. We will apply the materials to the pressurized chamber, so that it becomes luminescent due to the rapid increase in temperature and pressure.



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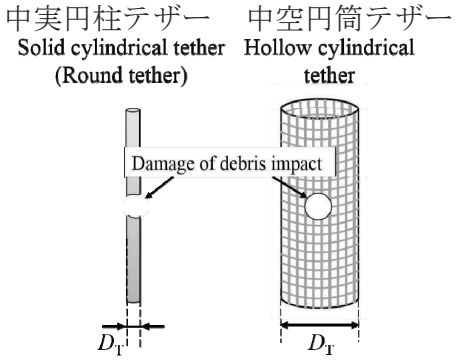
Objectives of tether study

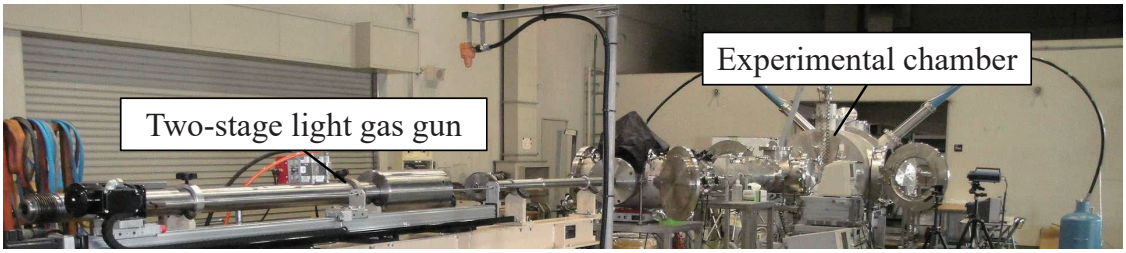
Although the mass of a hollow cylindrical tether is the same as that of a conventional solid and cylindrical (*i.e.*, round) tether, it has a larger diameter, which improves its survivability.
中空円筒テザーであれば，中実円柱テザーと同一質量でありながらも直径を大きくできる．微小デブリに対する衝突耐性の向上が期待できる．



A hollow cylindrical tether is proposed, and is evaluated in terms of impact durability.
中空円筒テザーを提案し，実験などによって微小デブリに対するテザーの衝突耐性を評価する

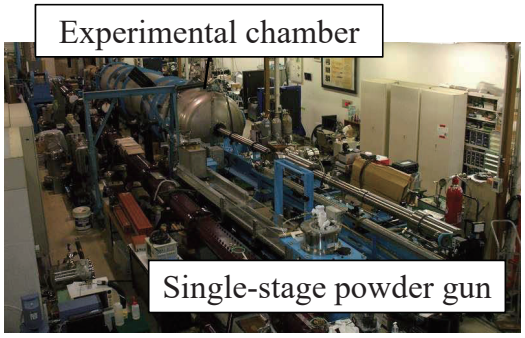
- 複数回生じる複雑な衝突現象を明らかにする．
- 実験により，衝突位置と中空円筒テザーの損傷との関係性を解明する
- 中空円筒テザーの軌道上での生存確率を算出する有効範囲を提案する．
- 中実円柱テザーと中空円筒テザーの生存確率を比較し有用性を示す．

Experimental equipment



Two-stage light gas gun （新型二段式軽ガス銃）
JAXA/ISAS

Single-stage powder gun
（一段式火薬銃）
Tohoku University



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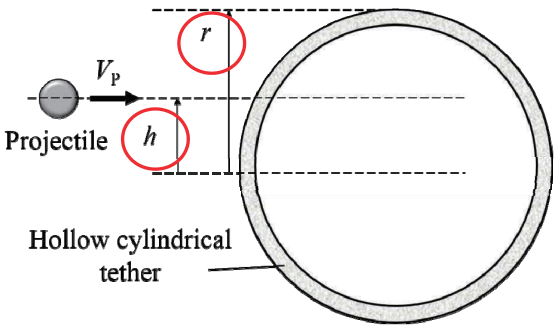
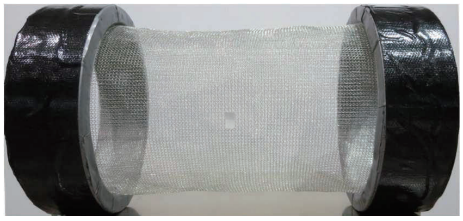
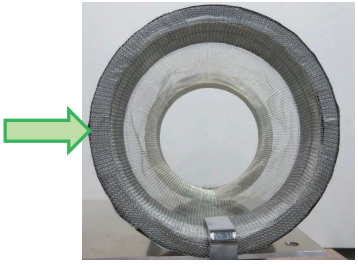
Hollow cylindrical tether







- The impact velocity was set to 7.0 km/s.
- プロジェクタイル球を速度 7 km/sで衝突させる.

- The radius of the hollow cylindrical tether is denoted by r .
- 中空円筒テザーの半径を r とする.

- The distance of the impact point from the center of the tether is denoted by h .
- プロジェクタイル球の衝突位置を，テザー中心からの距離 h とする.

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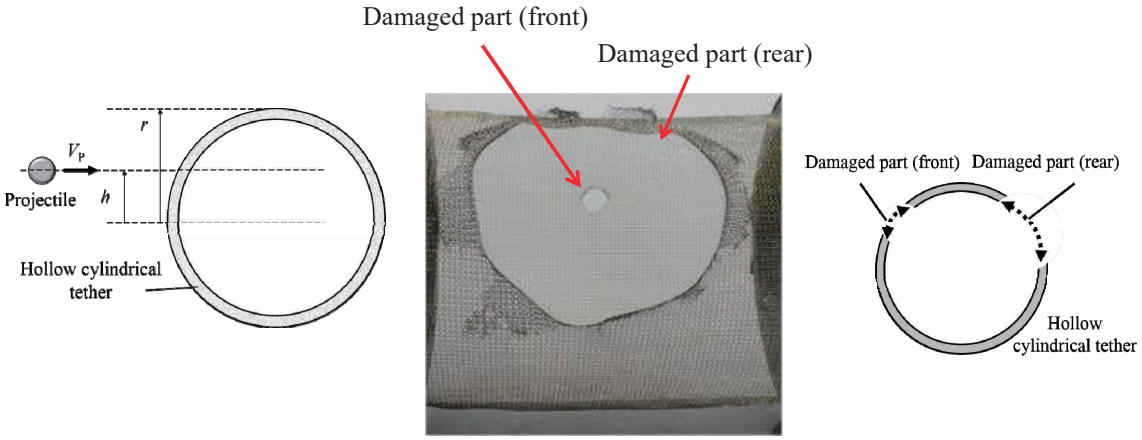
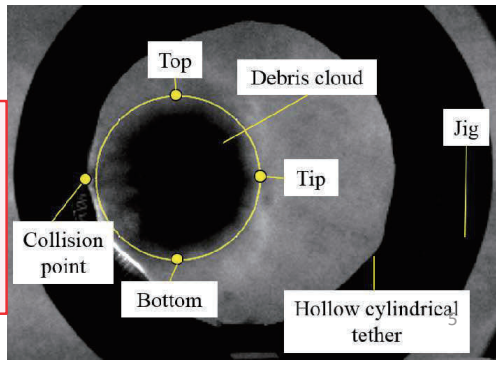
Debris cloud in hollow cylindrical tether



The rear of the hollow cylindrical tether was damaged by debris cloud.

デブリクラウドにより，テザー後方が大きく損傷した.



Debris flux database

We evaluate the survivability of tethers with the employed cumulative debris flux (orbital inclination of 98 degree, year 2000, and altitude of 800 km).

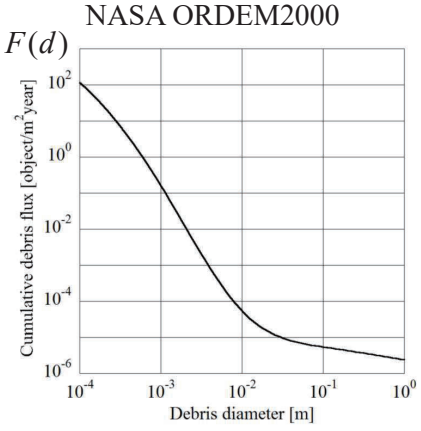
2000年, 高度800 km, 傾斜角98度の軌道上のデブリフラックスに基づいて, 軌道上生存確率を評価する.

$$R_T = -L_T \int_{d_m}^{d_\infty} D_{\mathrm{eff}}(d) \frac{F(d)}{\mathrm{d}d} \mathrm{d}d$$

Effective area of debris (diam. d) 直径dデブリの有効衝突面積

Impact occurrence of debris (diam. d) 直径dのデブリ衝突発生確率

NASA ORDEM2000



d : 直径

Survivability in orbit（軌道上生存確率）

$$P_0 = \exp[-R_T \Delta t]$$

Comparison of survivability in orbit

We evaluate the survivability of tethers with the employed cumulative debris flux (orbital inclination of 98 degree, year 2000, and altitude of 800 km).

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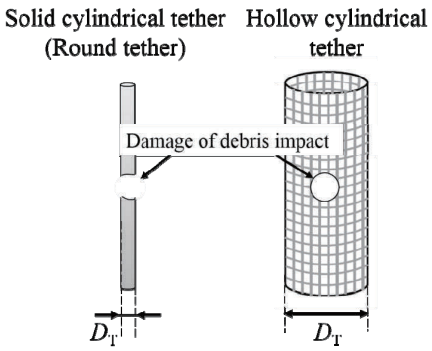
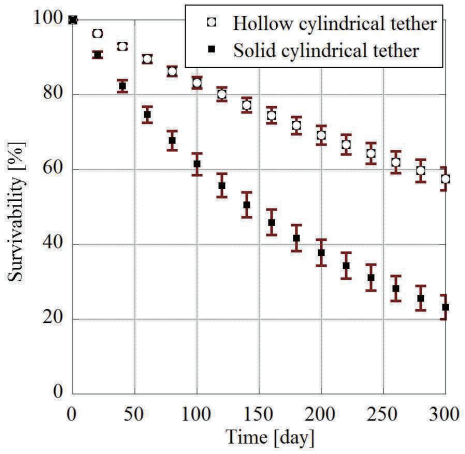
中実円柱テザー　中空円筒テザー





- Hollow cylindrical tether has high durability against debris impact, and has high survivability in orbit.
- 中空円筒テザーの衝突耐性と生存確率の高さが示された.

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Introduction: study of luminescent color modulation (発光色変調)

What is the problem?

・Current debris shield can endure only small-sized debris.

▼

・Large-sized debris can penetrate the pressurized wall, resulting in air-leakage from a through-hole.

▼

・Big impact may cause blackout of electricity (停電).

▼

・It is necessary to display air-leakage holes **even in the dark**.
暗闇の中でも衝突による空気漏れ穴を表示することは重要だ.

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Air-leakage detection

Photoluminescent substance (発光物質)

・Crews should detect and fix the air-leakage holes in complete darkness.

▶ Photoluminescent substance can help them to detect easily.

・Two factors that make the substance luminescent:

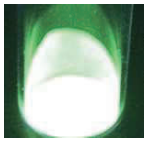
Photo-response (光反応): storing ambient light
Stress-response (応力反応): high pressure or temperature.
→ Caused by debris impacts

Raw material

Stress response →

Photolominescent substance

Photo-responce
Stress-response →



Luminescent

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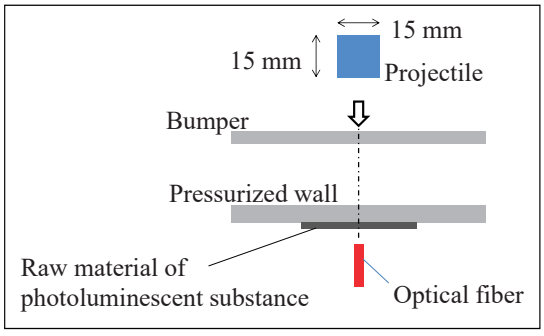
Hypervelocity impact experiments

Purpose and experimental setup

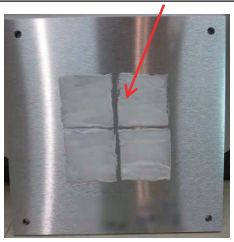
・We used single-stage powder gun to shoot a cylindrical projectile.

・The raw material was coated with back side of pressurized wall.

Single-stage powder gun



Raw material of photoluminescent substance



Back side of pressurized wall

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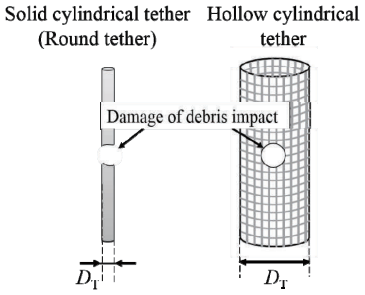
Conclusions of studies in Tohoku Univ.

- A hollow cylindrical tether was proposed, and was evaluated in terms of impact durability.
- The cylindrical tether was shown to have high durability and survivability.

- 中空円筒テザーを提案して，実験などによって微小デブリに対するテザーの衝突耐性を評価した．
- 中空円筒テザーの衝突耐性の高さと生存確率の高さが示された．



- Luminescent color modulation caused by debris impact is studied.
- We will construct a system to display air-leakage holes even in the dark.

- デブリ衝突で生じる発光色変調を研究している．
- 暗闇の中でも衝突による空気漏れ穴を表示するシステムの構築が目標である．

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