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導電テープテザー技術を用いたPMDデバイス実証の検討

A Study on Post-Mission Disposal Device for Microsatellite Using Electrodynamic Tape Tether Technology

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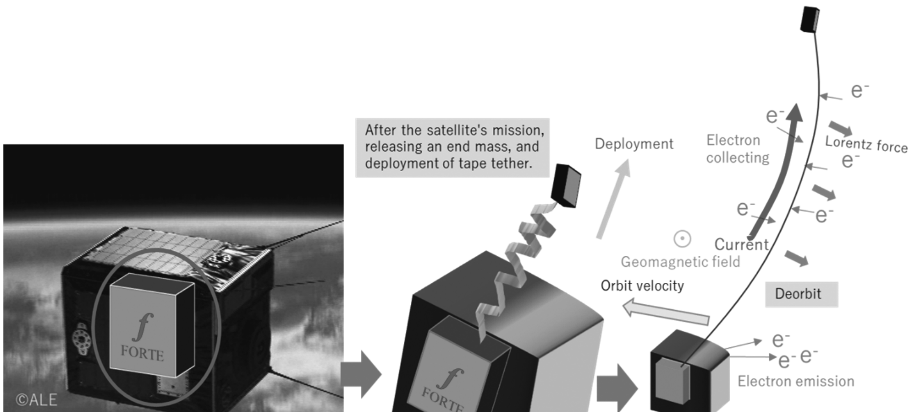
導電テザー技術を用いたPMD（Post Mission Disposal）デバイスの概念検討について紹介する。導電テザーを用いたPMD デバイスは、ローレンツ力と空気抵抗を併用することにより高高度でも高い軌道離脱性能が期待される一方で、その開発には、母衛星ミッションへの負担を軽減するための小型化や安全性の確保、宇宙空間での長期保管などの技術的課題もある。
本発表では、はじめにデバイスのコンセプトを提示し、導電テープテザーその折り畳み収納法や、分離機構、電子源の候補など要素技術の概要を紹介する。次いで簡易計算モデルによる性能の初期検討、特にテープテザーの幅やテザー長さ、軌道高度、軌道傾角の影響についての試算結果を示す。最後に、本デバイスの宇宙実証の機会の候補として、ALE 社の次世代衛星の概要を紹介する。

The authors are conducting research on a post-mission disposal (PMD) device using electrodynamic tether (EDT) technology. This PMD device using EDT expected to have high deorbiting performance even in a high orbit by using both the Lorentz force and atmospheric drag. However, it has technical issues in terms of miniaturization, safety, and long-term storage in space.
This presentation provides the device concept, the concept of tether storage method, deployment system, and electron emitter. In addition, the effect on thrust of tether width, tether length, and orbital inclination angle are shown by numerical analysis using simple models. Finally, a concept on ALE’s next-generation satellite is introduced as opportunity to demonstrate of this PMD device in space.



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渡部研

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Outline

- Introduction
- Concept of the PMD device
- The effect on performance of various parameters
- Conclusions

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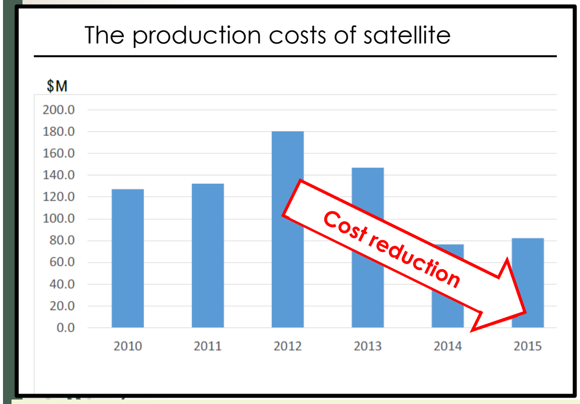
◆ Introduction ~Small/micro Satellite Business~



国内外の宇宙機器・利用産業の市場構造及び動向について（1）平成28年7月28日 内閣府宇宙開発戦略推進事務局http://www8.cao.go.jp/space/comittee/27-sangyou/sangyou-dai2/siryou1-1.pdf

Improvement of small/micro satellite technology
Low cost and commoditization

⇩

Growth of Small/Micro Satellite Business

Consternation plan using micro-satellites
超小型衛星群による運用プラン例

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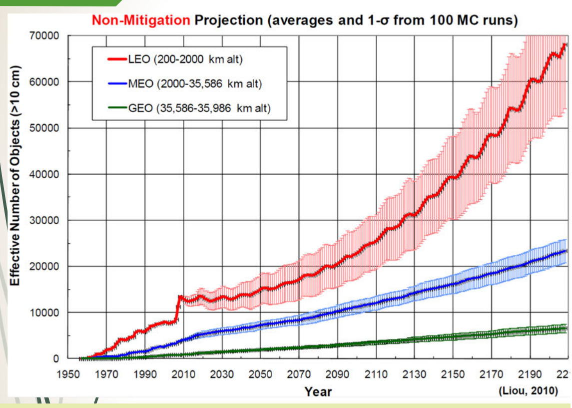
◆ Introduction ~Space Debris~



The Near-Earth Orbital Debris Problem and the Challenges for Environment Remediation
J.-C. Liou, PhD, https://ntrs.nasa.gov/search.jsp?R=20120012893

The growth of Micro-satellite Business and Concept of Micro-satellite Mega Constellation plan

⇩

Concern about mass production of space debris from the post mission satellites

⇩

The needs for development of Space Debris prevention technology

Space Debris is "Environment issues" in the future.
宇宙デブリは、新しい時代の「環境問題」

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The Significance and Research Purpose of PMD Device for Micro Satellite

- Concern about increased debris due to the launching of a large number of micro-satellites
  超小型衛星の打ち上げ拡大によるデブリ増加の懸念
- Needs for development of Post Mission Disposal (PMD) technology for micro satellite
  超小型衛星用PMD技術開発のニーズ
- Technical issues: Down sizing, Safety, and Long-term storage in space,,,
  技術的課題：小型化、安全性、宇宙での長期保存

- **Proposal of concept of PMD device using EDT Technology**
  導電テザー技術を用いたPMDデバイスの提案
- **Feasibility Study on the PMD device**
  システムの初期検討

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FORTE

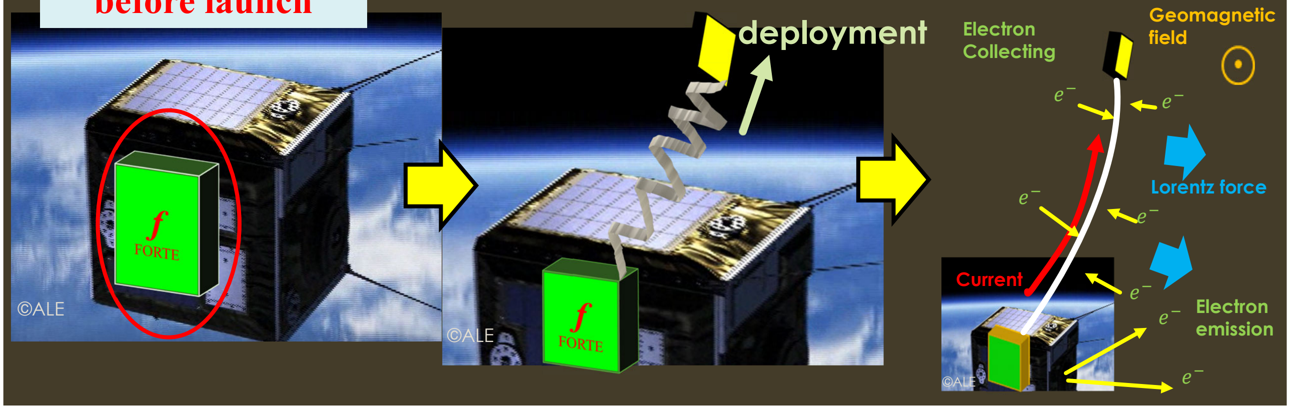
Foldaway Re-entry assist Tether deployment module

- **Supports re-entry of satellite by Atmospheric drag and the Lorentz force**
- **Post Mission Disposal (PMD) Device**

① Install "FORTE" **before launch**

②At post mission, release an end-mass and **deploy** the tape tether

③Deorbit



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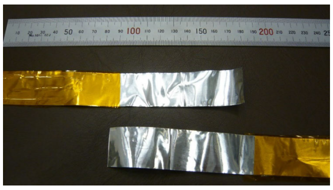
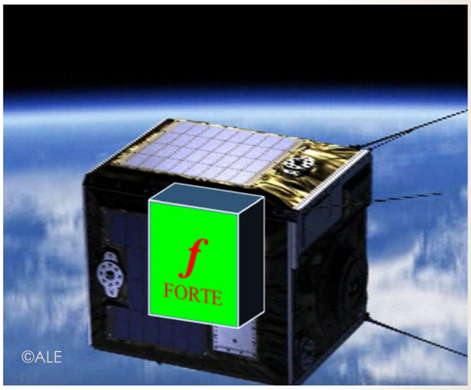
◆ Concept of the PMD device

Size：$x_f \times y_f \times z_f$ [mm]
Weight：M_f [kg]

Start at N years later(After the mission)
Complete Deorbit in D days

Simple system and Using Tape Type Tether





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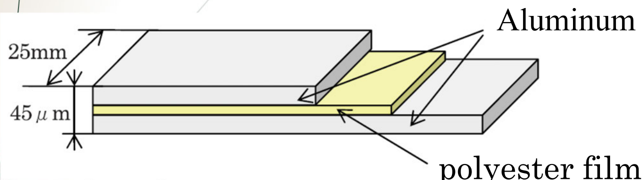
◆ Concept of the PMD device
~Tape Tether and Folding Concept~

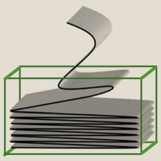
テープテザーと折りたたみ収納設計案



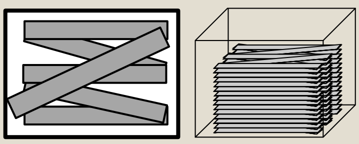
Tether materials：ALPET
(polyester film and aluminum, sandwich structure)
Tickness:45μm
Density:2.4g/m (w25㎜)

Folding concept

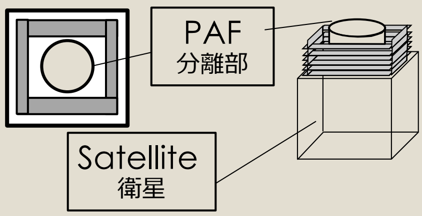
Single type Folding
単段折り



Cross Shift Folding
クロスシフト折り



Surround Folding
囲み折り



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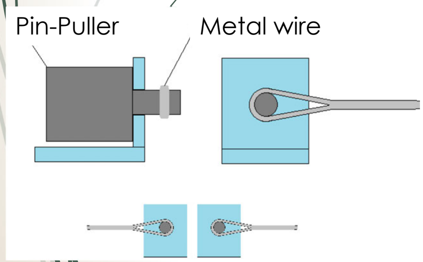
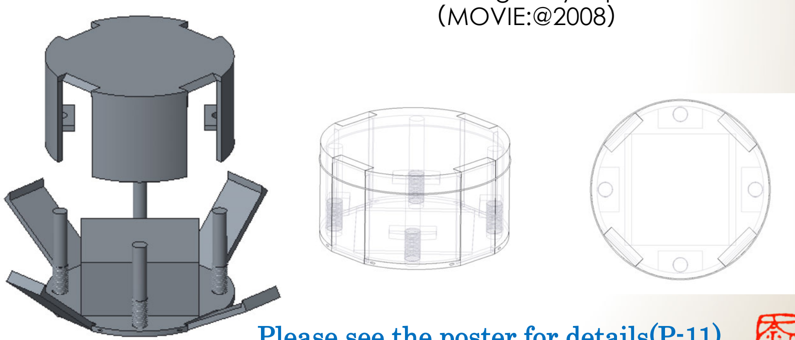
◆ Concept of the PMD device ~Deployment System Plan~

- Deployment system has clamps and **metal wire** which holds an end-mass
- Releasing an end-mass by **Pin-Puller**.
- Give initial velocity by **Spring force**.

Micro gravity Experiment (MOVIE:@2008)





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Please see the poster for details(P-11)

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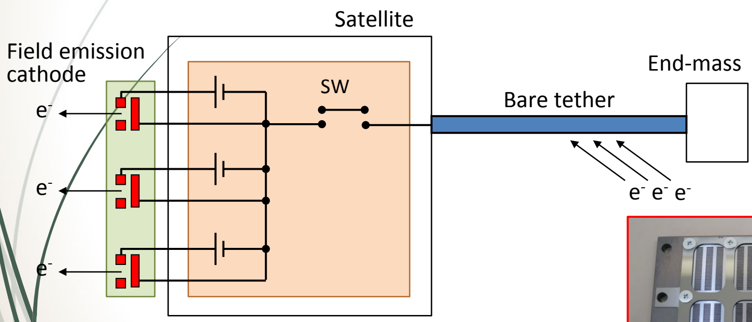
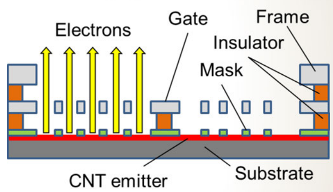
EDT System and Electron Emitter

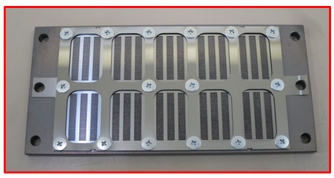
- Simple system is important for PMD
- "Bare tether" and "Field emission cathode (FEC)" might be simplest combination for forming EDT system
- Flight proven cathode technology for KITE is applicable



EDT System Schematic



Structure of Field Emission Cathode


Field Emission Cathode for KITE

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◆ The effect on performance of various parameters

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➡ The effect on performance of tether width, and orbital inclination angle are shown by numerical analysis

- Electron collection model
  2D-OML theory

$$j_{2D-OML}(x) = \frac{en_p}{\pi}\left(\frac{2e\phi(x)}{m_e}\right)^{\frac{1}{2}}$$

$$\phi(x) = v_{emf}x - r_t\int_0^x J_t(x)dx$$

- Plasma model：IRI2016
- Geomagnetic field：IGRF-12（10×10）
- Atmosphere model：NRLMSISE-00

○Analysis parameter
Tether length[m]:900
Tether width[mm]:25,50,100
Tether thickness[μm]:45
Tether material：ALPET102510

Weight of mother satellite[kg]:70
Weight of end-mass[kg]:4
Size of mother satellite[cm]:60×60×80

Current upper limit [mA]:40
Number of point mass:40

Orbital inclination angle [deg]:0,50,98.4

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◆ The effect on performance of various parameters

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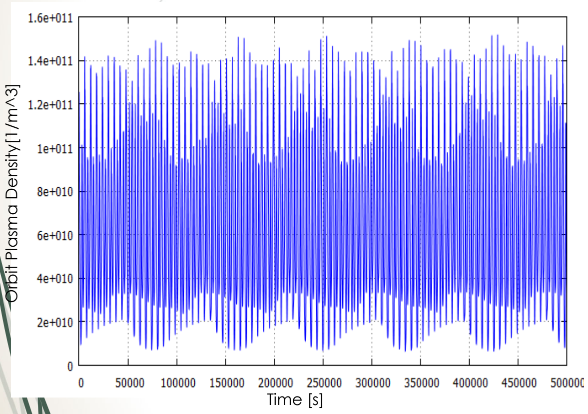
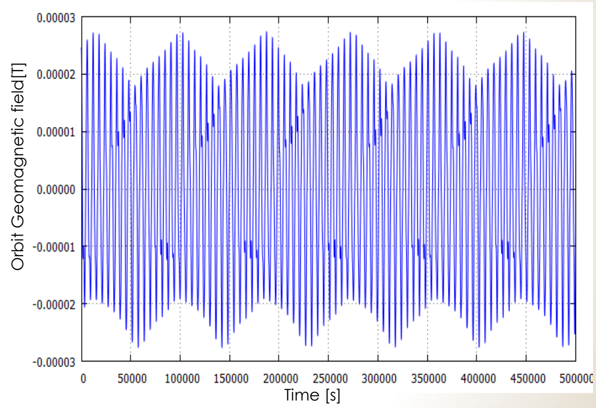
➡ Plasma density and geomagnetic field(out-of-plane)

Orbital inclination angle 98.4° Altitude 800㎞





Plasma density and geomagnetic field are periodically fluctuating

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◆ The effect on performance of various parameters

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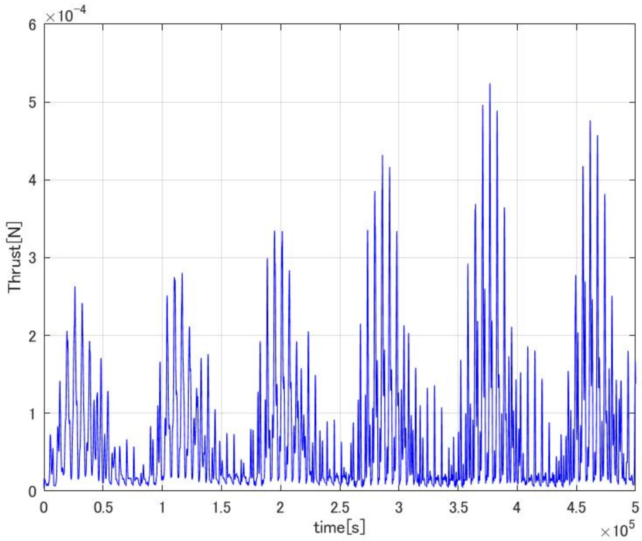
➡Time fluctuation of thrust

(Orbital inclination angle 98.4° Altitude 800km Tether length 900m)



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◆ The effect on performance of various parameters

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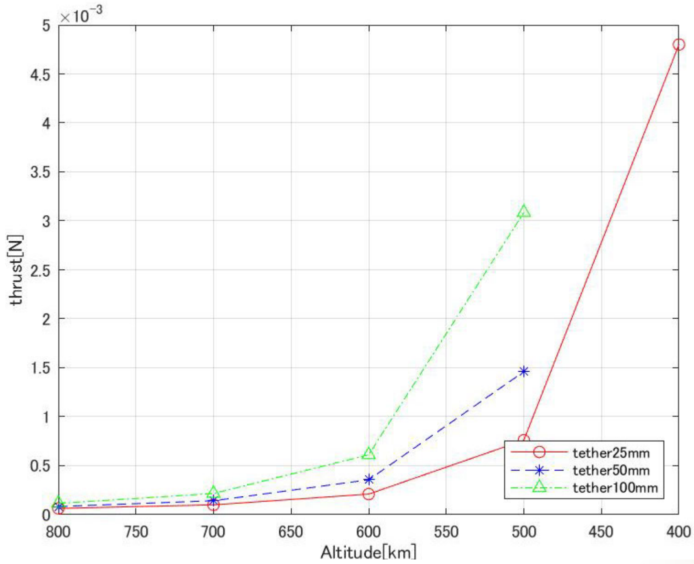
➡The effect on thrust of tether width

(Orbital inclination angle 98.4° Tether length 900m)



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◆ The effect on performance of various parameters

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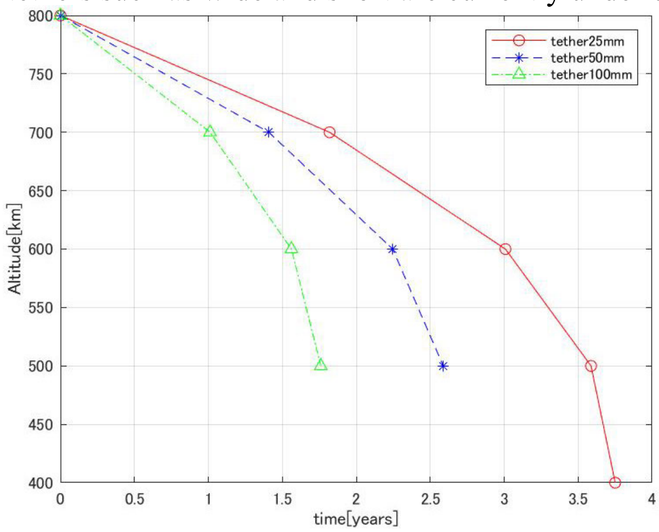
The effect on thrust of tether width

(Orbital inclination angle 98.4° Tether length 900m)

※Other types of tethers such as wide and short are currently under consideration



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◆ The effect on performance of various parameters

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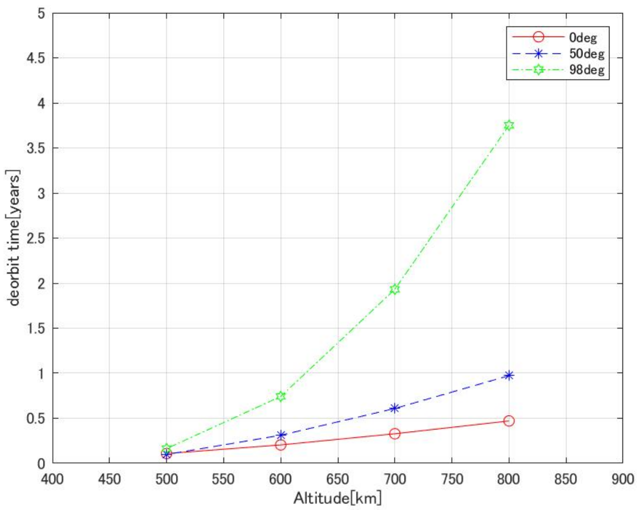
The effect on deorbit time of Orbital inclination angle

(Tether width 25mm Tether length 900m)



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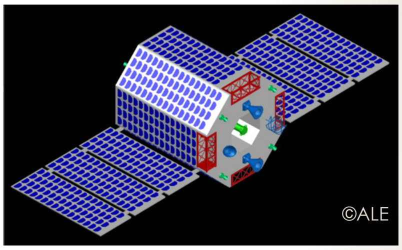
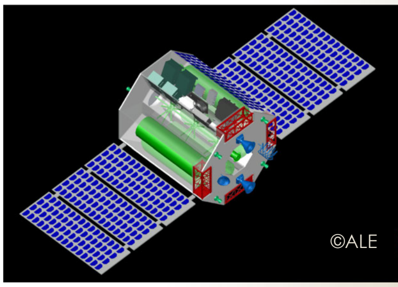
ALE’s next-generation satellite

ALE次世代衛星

One of the demonstration experiment candidates in space

Size and weight size weight	W908xD783xH1000 100kg
Attitude determination and control method	3-axis stabilization
Sensors	Star sensor(x2), IMU(3x3axes) Earth sensor(x2) Magnetometer(2x3-axes) GPS receiver(x2) Sun sensors(x4)
Actuators	Reaction wheels(x4) Magnetic torquers(3axes)
Release system	High pressure gas system 3000 particles
Thruster	TBD





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◆ Conclusions

- Proposed the PMD device for micro-satellite using EDT

  超小型衛星向けのEDTを利用したPMDデバイスを提案した。

- Feasibility Study on technologies about the PMD device is started (deployment system and folding storage method)

  分離展開機構、折り畳み収納法など要素技術の初期検討を開始した。

- Examined the effect on performance of tether width and orbital inclination angle.

  テザー幅や軌道傾斜角がデオービット性能に与える影響を検討した。

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