C11

スペースデブリ発生防止用導電性テザーシステムとその実証

Electrodynamic Tether System for Space Debris Prevention and its Demonstration

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宇宙利用が急速に加速する昨今、衛星打ち上げ機会と小型衛星需要の増加、メガコンステレーションの台頭により、スペースデブリ対策としてミッション終了後の衛星の速やかな軌道離脱（PMD: Post Mission disposal）は宇宙の持続的な開発に重要な技術として位置づけられている。
ALE と JAXA では導電性テザー(EDT: Electrodynamic Tether)を用いた PMD デバイスによる軌道離脱の技術実証を目的とした事業協同実証(J-SPARC)を行っており、2021 年の打ち上げを計画している。EDT は地球磁場とテザーに流れる電流の相互作用によるローレンツ力と空気抵抗を推進力として軌道離脱を行うため、地球磁場の影響する広範囲の軌道に存在する衛星に有効である。
開発した PMD デバイスは軌道降下時間を大幅に短縮することが可能なため今後のスペースデブリ対策の一つとして効果的である。本講演では現在開発を行っている PMD デバイスと数値解析による軌道降下への影響及びミッション概要について紹介する。

The rapid growth of space utilization, increase in demand for small satellites and their launch opportunities, and the rise of mega-constellations means an increased threat from space debris. Considering the current situation, Post-Mission Disposal (PMD) is considered to be important technique for the prevention of space debris and sustainable space development.
ALE and Japan Aerospace Exploration Agency (JAXA), as a part of the JAXA Space Innovation through Partnership and Co-creation (J-SPARC) project, are developing a PMD device using an Electrodynamic tether (EDT) to demonstrate the de-orbit of satellites. In this project, we are planning to launch a satellite equipped with a PMD device in 2021. The EDT is effective for satellites in a wide range of orbits within the Earth's magnetic field. It uses Lorentz force, an interaction between the Earth's magnetic field and electrical current flowing through the tether and atmospheric drag, to decrease the time needed to de-orbit.
Our developed PMD device is able to significantly reduce the time required for the satellite to reenter the atmosphere. It can be utilized as a countermeasure for the prevention of space debris. This paper provides details of the developed PMD device, the numerical analysis of de-orbit, and the mission overview.

Electrodynamic Tether System for Space Debris Prevention and Its Demonstration

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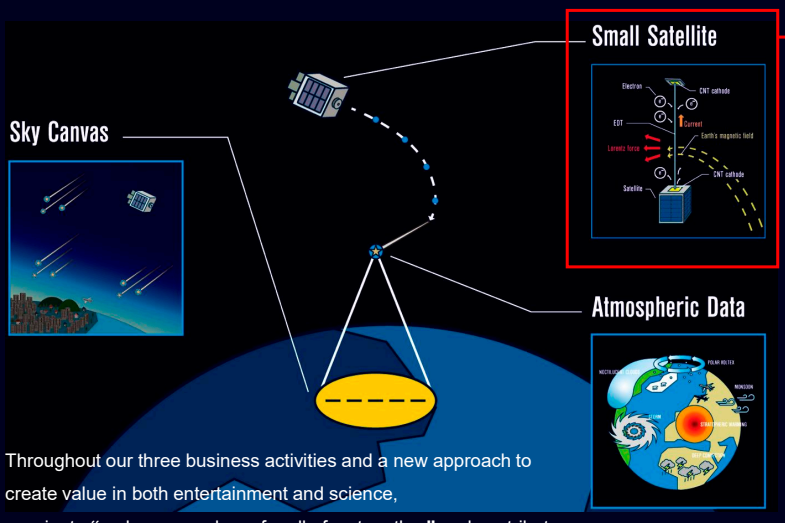
Feb. 26th, 2021 9th Space Debris Workshop

Our business activities



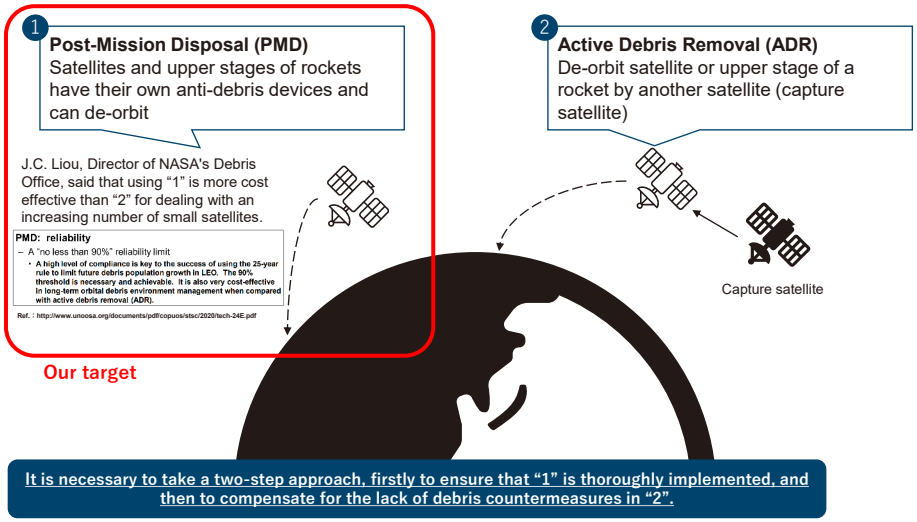
Throughout our three business activities and a new approach to create value in both entertainment and science,
we aim to **"make space closer for all of us together"** and contribute to the **sustainable development of humankind**.

ALE, together with JAXA (Japan Aerospace Exploration Agency) has developed a space debris disposal device using Electrodynamic tether (EDT), enabling prompt deorbit of satellites after the completion of their mission.

- Forces satellites, rockets or other parts of spacecrafts to lower their altitude into Earth's atmosphere.
- Prevents space debris accumulation, even if the satellites, rockets and other parts of the spacecrafts loses their power supply.

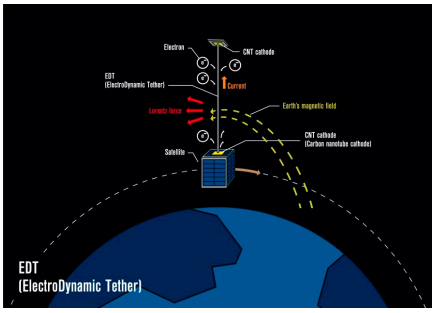
Approach to Space Debris

For future launches, we will take measures to debris disposal before they are launched.
For satellites that are already in orbit, we will launch another satellite.



It is necessary to take a two-step approach, firstly to ensure that "1" is thoroughly implemented, and then to compensate for the lack of debris countermeasures in "2".

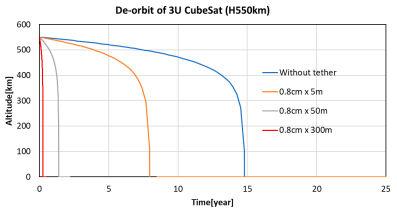
EDT De-orbit Mechanism

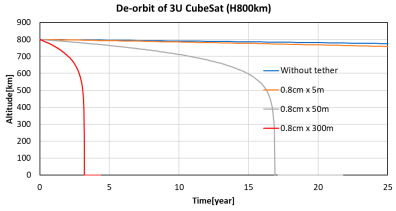


- **Lower attitude in LEO (~800 km)**
  Atmospheric drag is effective for de-orbiting. Large cross section generates large thrust.
- **Higher attitude in LEO (800~ km)**
  Low air density does not much contribute to de-orbiting. Emitting electrons enhances electromagnetic force and de-orbiting.

Large objects (satellite, part of rocket) also can de-orbit by electron emission.

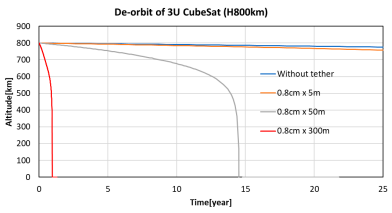
Atmospheric drag effect

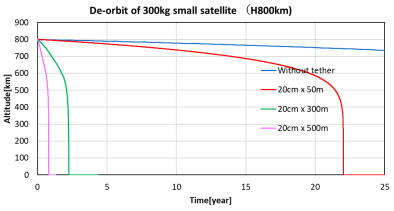




Electromagnetic force applied

(Atmospheric drag + Electromagnetic force)

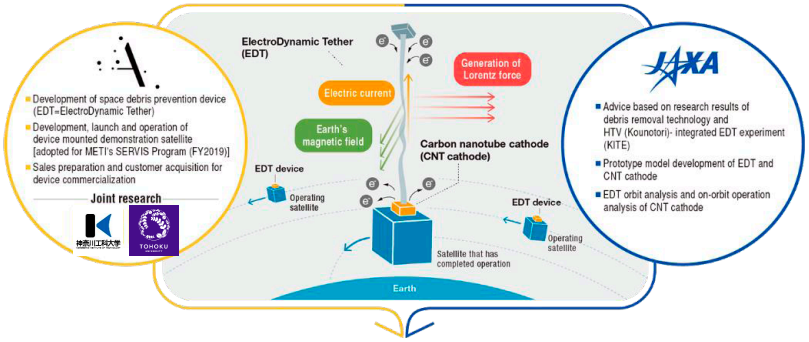




Collaboration with JAXA

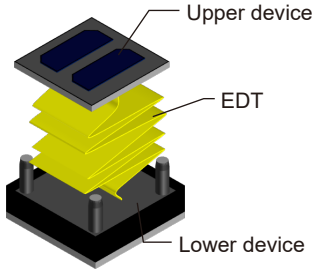
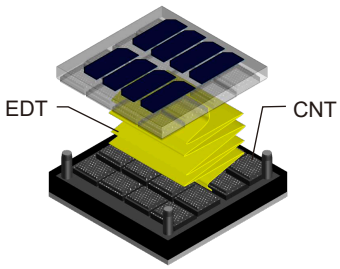
Minimizing the risk of first on-orbit demonstration through collaboration with JAXA, which has knowledge and technique of EDT.

The project members are collaborating with us, and we will utilize their knowledge and experience to further enhance the technology.



Extend conductive tether from EDT device mounted on microsatellite and de-orbit.
Mitigate the generation of space debris thereby contributing to sustainable space development.

Product Overview

	Standard Model	Carbon Nanotube Model
Appearance		
Function	● After deploy tether, Atmospheric drag and weak electromagnetic force are generated to de-orbit. ● Deploy tether by bus command and timer.	● After deploy tether, Atmospheric drag and weak electromagnetic force are generated to de-orbit. ● Deploy tether by bus command and timer. ● CNT electron emitter accelerates de-orbiting.

Proposal for Space Debris Disposal

Our Electrodynamic Tether (EDT) can solve the challenges and reinforce the efficiency of satellites operation.

EASY ATTACHMENT TO SATELLITES

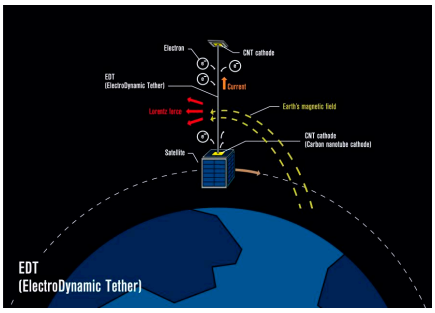
Our EDT is **very small** device cheap.

FOCUS ON EACH MISSIONS

Our EDT is designed to be **particularly reliable for de-orbiting**.

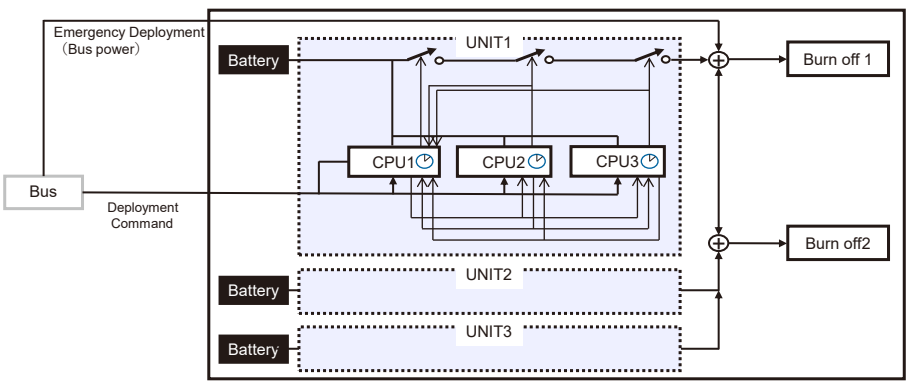
AUTONOMOUS AND RAPID DE-ORBITING

Our EDT **works independently** and enables each satellites to be **de-orbited automatically and rapidly** even if the satellite system is faulted.



Secure Deployment

- Never deploy during the launch and Securely deploy after the mission.
  - ・・・Triple Redundancy Decision System and Triple redundant operating system.
  - ・・・Tether can be deployed by **Bus command**, **Timer**, and **Bus Power.**
  - ・・・Autonomously deploy the tether by independent power supply even if the spacecraft has suffered an unrecoverable fault.
    ⇒Energy saving and long-time driving circuit.
  - ・・・Highly reliable burning off system with double redundancy.
- Can be package in a small size, even for CubeSat



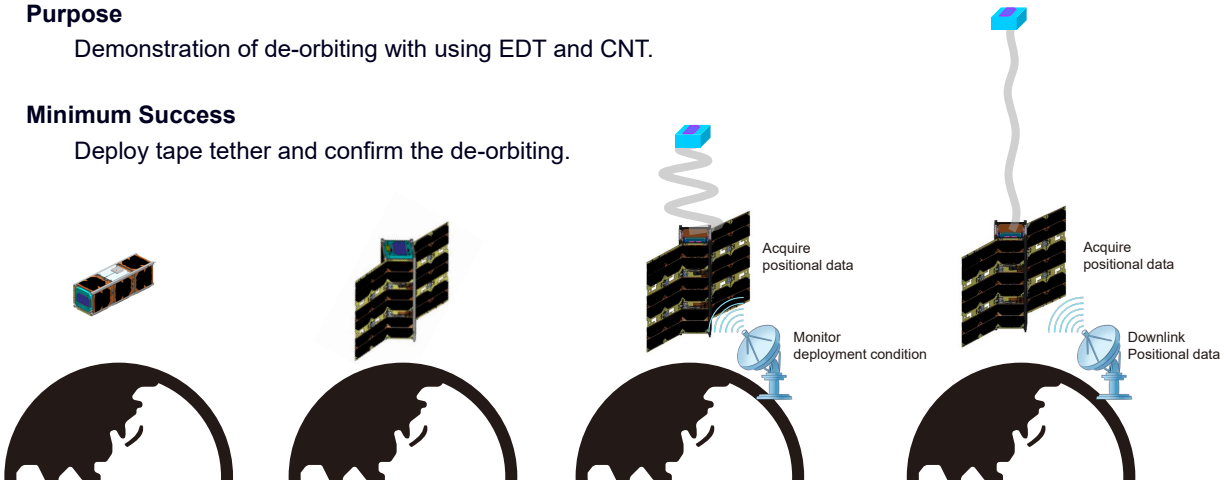
EDT-sat Project

Purpose

Demonstration of de-orbiting with using EDT and CNT.

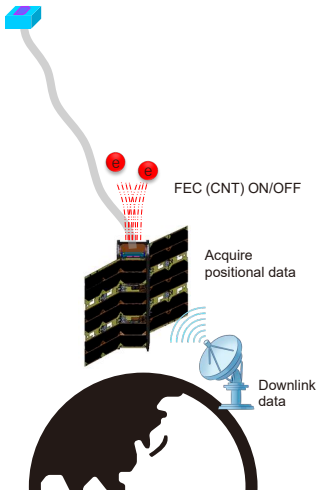
Minimum Success

Deploy tape tether and confirm the de-orbiting.



0: Earth orbit 1: Attitude control 2: Start to deploy tether 3: Complete tether deployment

EDT-sat Project



Full Success

Confirm the change of de-orbiting performance by ON/OFF of CNT electron emitter.

Extra Success

Measure the tether position and confirm the effect of Lorentz force.

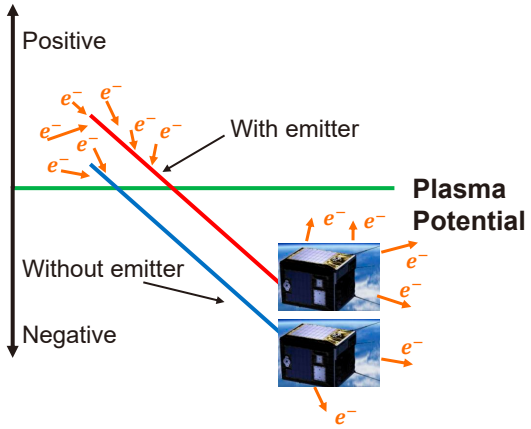
Performance Evaluation

Electron emitter

- Apparatus for emitting electrons into space.
- Installed on the end of the tether where the potential is negative.

More electrons can be collected from the tether surface, thereby increasing the current flowing.

- ✓ Can shorten the time required for deorbiting.
- ✓ Reduce the risk of debris collision during PMD device operation.
- ✓ Collision avoidance maneuver may be possible.



Performance Evaluation

Model

- ✓ • Tether model: Lumped mass model connected by springs and viscous dampers
- ✓ • Electron collection model: 2D-OML theory
- ✓ • Ion collection model: 2D-OML and Orbital velocity
- ✓ • Plasma model：IRI2016
- ✓ • Geomagnetic field：IGRF-12（10×10）
- ✓ • Atmosphere model：NRLMSISE-00
  ※ Average projected area is 2 / π of the tether width.

Conditions

Tether type: Tape type tether

Tether dimension: Parametric

Tether material: Metal plated polyimide film

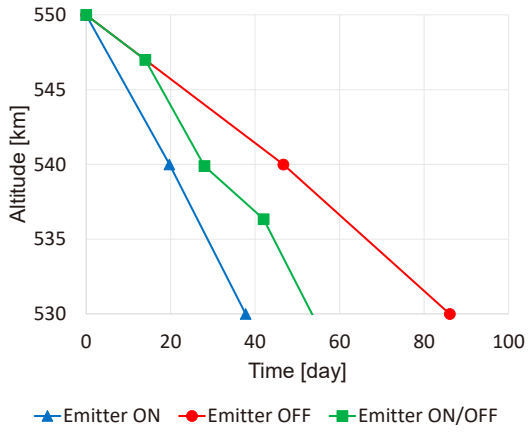
Electron emitter: With or Without

Maximum emission current: 10[mA]

Weight of satellite:5[kg]

Size of satellite:10[cm]×10[cm]×30[cm]

Case Study



※ OML available ratio: about 50%
※ The solar activity was assumed to minimal.
※ FEC(CNT) ON/OFF：
The case of assuming electron emitter was turned on/off every two weeks.

In this case, clearly, orbital descent ratio is differed between with and without an electron emitter.

The effect of EDT can be confirmed by orbital descent ratio.

- The performance obtained varies depending on the tether dimensions, orbital parameters, and other factors.
- By making such evaluations, the specifications of the tether and electron emitter can be determined for such electrodynamic tether requirements as orbital conditions, weight, and deorbit time.

Conclusions

- We developed PMD (Post-Mission disposal) device using EDT, which can be securely deployed in orbit.
- Our developed PMD device obtains the thrust from atmospheric drag and electromagnetic force.
- Atmospheric drag is dominant in lower attitude and electromagnetic force is effective in higher attitude.
- Secure tether deployment system utilize for redundant system functioning for a long time at low power consumption.
- Numerical analysis showed that our developed EDT can reduce the time of required to reenter the atmosphere even if it's in lower attitude.
- The demonstration of EDT-sat is planned to launch in FY2021.

Acknowledgment

- This work is supported by JAXA Space Innovation through Partnership and Co-creation (J-SPARC).
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ALE Co., Ltd.