P10

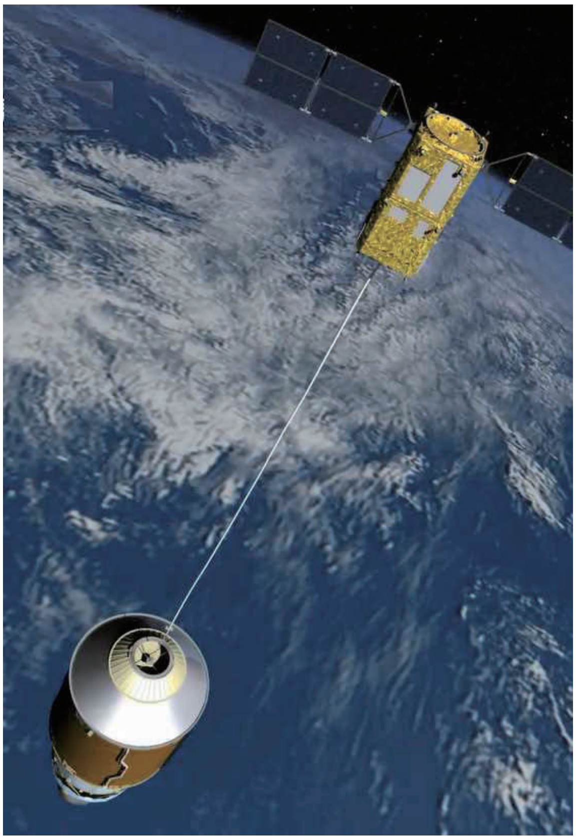
デブリ除去のための導電性テザー推進技術について

Electrodynamic Tether Propulsion Technology for Active Debris Removal

○壹岐賢太郎、河本聡美、大川恭志（JAXA）
○Kentaro Iki, Satomi Kawamoto, Yasushi Ohkawa (JAXA)

デブリ増加の問題を解決する有効な手段として、混雑する地球周回低軌道からの既存デブリの除去が挙げられる．低コストでのデブリ除去を実現するため、JAXA では高効率推進系である導電性テザー（EDT）によるデオービット技術の研究開発を進めている．将来のデブリ除去システム実証では、実際にデブリに接近し推進系を取り付けて軌道降下させるが、EDT 要素技術実証フェーズに比べてEDTの大型化・大電流化が必要となる．本稿ではデブリ除去に用いる EDT の原理および特徴を紹介し、また将来のデブリ除去システム実証に備えて、EDT システムのキーとなる要素の特性およびデブリ除去システム実証におけるテザー伸展や EDT 推進によるデオービットについての数値解析結果について論じる．

The increase in the amount of orbital debris has been becoming a serious problem for human space activities. One effective strategy to suppress space debris growth is an active removal of already existing large debris in the crowded low earth orbits. Toward the realization of cost-effective active debris removal (ADR) in the lower earth orbits, the Japan Aerospace Exploration Agency (JAXA) has been conducting research and development of an electrodynamic tether (EDT) as a very promising candidate of propulsion for deorbiting in ADR. EDT can generate sufficient thrust for orbital transfers without the need for propellant by utilizing interactions between the Earth's magnetic field and currents through the tether. In order to remove large debris objects with the mass of about 1-3 tons in the crowded regions (altitude of 800–1000 km), EDT requires a tether length of 5–10 km and several ampere of current. This paper describes the fundamentals of the electrodynamic tether including its advantages and disadvantages for ADR. In addition, for the preparation of the ADR system demonstration, we will introduce the characteristics of the key EDT system components, and the results of the numerical simulations of tether deployment and deorbit by EDT thrust using our system.

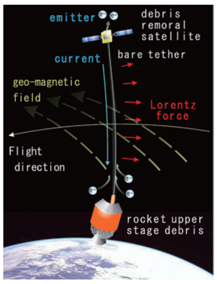


Electrodynamic Tether Propulsion Technology for Active Debris Removal

Kentaro Iki, Satomi Kawamoto, Yasushi Ohkawa (JAXA)

1. EDT System for ADR

Electrodynamic tether (EDT) is a very promising candidate for a deorbit propulsion in Active Debris Removal (ADR) system



Advantages

- Simplicity
- High efficiency
- Ease of attachment to debris
- No requirement for thrust vector control

Disadvantages

- Long mission duration (several months to a year)
- Possibility of tether being severed
- Collision risk with other satellites or debris
- Difficulty of controlled reentry

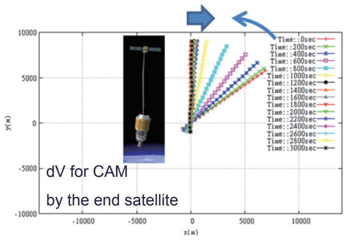
2. Countermeasures for disadvantages

a) Possibility of tether being severed
adopting a reinforced net-type tether

b) Collision risk with other satellites or debris
shifting the orbital phase of the end DRS and the other operational satellites by utilizing thruster on the end satellite or by switching the current on and off

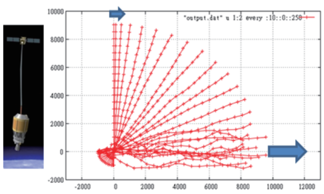
*DRS : Debris Removal Satellite

c) Difficulty of controlled reentry
a controlled reentry will be conducted by utilizing the chemical propulsion on the DRS after the DRS reaches a low enough altitude by EDT thrust



b) Collision Avoidance Manuever (CAM)

①thrust for rotating tether from vertical to horizontal

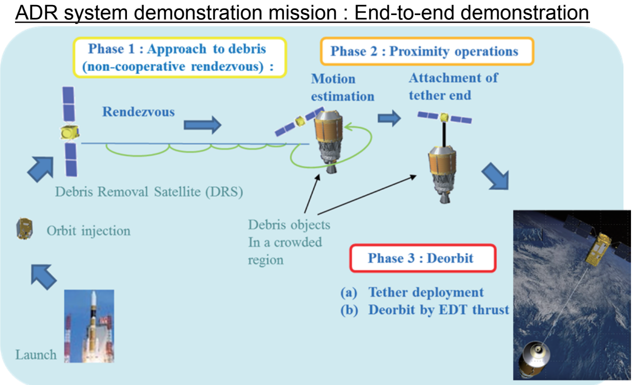


②large thrust burn for reentry

c) Controlled reentry

3. Mission Sequence

ADR system demonstration mission : End-to-end demonstration



Debris Removal Satellite (DRS)

- approaches the non-cooperative target debris
- attaches the end of EDT to the target debris as proximity operations
- transfers the debris to lower orbit by EDT thrust

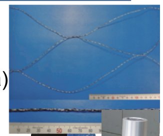
An example of ADR system demo.

- Target : H-IIA rocket upper stage debris (orbit : 620 km alt. and 98° inc.)
- Tether : 5-km-long tether installed in DRS

EDT requires a tether length of 5–10 km and several amperes of current for removing large debris objects with the mass of about 1-3 tons

4. Components of EDT system for ADR

Net- type bare tether

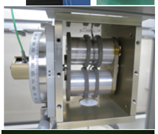


- high resistance against the tether being severed
- simple electron collector (from the ambient plasma)
- withstand load : 160 N , current level : 1 A

Spool-type reel

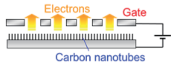
- tether is wound and stored in the DRS
- The spool reels are combined :
  - Inside spool reel : simple and low deployment friction
  - Outside spool reel : greater deployment friction

Braking mechanism (applying tether tension)



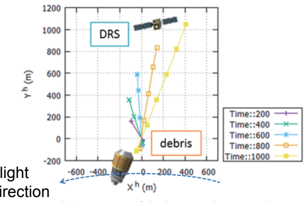
- To suppress tether libration by applying tension
- To decelerate deployment velocity
- Gradual braking from immediate to termination

Field Emission Cathode (FEC)

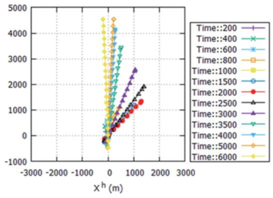


- an active electron emitter for current driving
- electron emitter : carbon nanotube (CNT)

5. Tether deployment simulation (example)

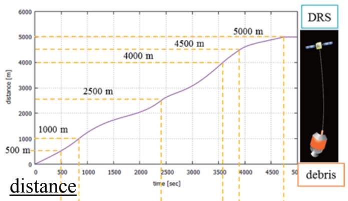


(a) Beginning of deployment (~1000 sec)

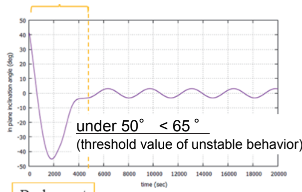


(b) Deployment phase (~6000 sec)

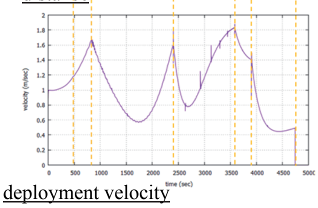
Change in the form of tether



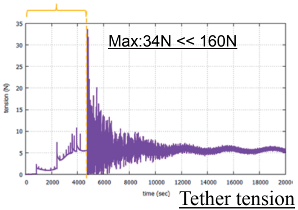
distance



In-plane libration angle



deployment velocity

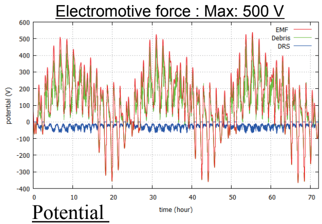


Tether tension

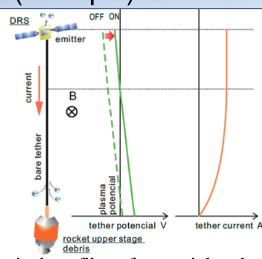
under 2.0 m/s by changing braking force for deceleration effectively in stages

6. Current driving simulation (example)

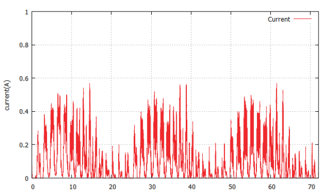
Electromotive force : Max: 500 V



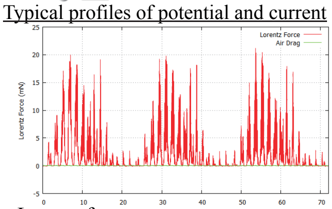
Potential



Typical profiles of potential and current



Current Max 0.6 A



Lorentz force 10 mN order