C02

デブリ除去に必要な要素技術の実証衛星と システム実証衛星の実現性検討

Feasibility Study of Active Debris Removal Satellite for Key Technology Demonstration and System Demonstration

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近年、スペースデブリの増加が大きな問題として認識されており、解決策の一つとしてデブリを積極的に除去するデブリ除去衛星の研究がなされている。特に、混雑軌道にあるロケット上段は、衝突時の影響が大きいことから、除去対象のデブリとして検討がなされている。
当社は、デブリ除去の方法として、導電性テザー(EDT)を使用した方法を提案している。これは、デブリ除去衛星により、ロケット上段の PAF 開口部に EDT を取り付け、軌道遷移させる方法である。この方法では、非協力ターゲットであるロケット上段への接近技術、EDT を取り付けるための捕獲技術、EDT による減速技術の 3 つのキーとなる要素技術がある。それぞれの要素技術には技術的課題があるため、各技術の軌道上実証をした上でデブリ除去衛星のシステム実証へ進むことで、デブリ除去衛星の早期かつ低コストでの実現が期待できる。
本発表では、デブリ除去に必要な要素技術の軌道上実証を目的とした超小型衛星と、システム実証を目的とした小型衛星のシステム検討結果について発表する。なお、デブリ除去の要素技術実証のため、当社で独自開発中の超小型衛星「DRUMS」についても紹介する。

Recently, a growth of space debris has been recognized as a significant problem and Active Debris Removal (ADR) has been studied as one of the solution for it.
To remove upper stages of rocket in congestion orbit is most effective because of it is large volume and mass, so it is considered as one of the targets for ADR mission.
Kawasaki Heavy Industries proposes ADR mission which uses Electrodynamic tether (EDT) attached on PAF (Payload Attachment Fitting) of the upper stage of rocket. In this mission, there are three key technologies, “non-cooperative rendezvous”, “capturing PAF” and “deorbit by EDT”. However each technology has technical problems and it is difficult to verify them on the ground. So it is necessary to verify them in orbit as a step for ADR satellite.
This paper describes the satellite system studies for verifying the key technologies and ADR system. It also describes Kawasaki Heavy Industries’ micro size satellite “DRUMS ; Debris Removal Unprecedented Micro-Satellite ” used for verification of ADR key technologies.

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OUTLINE

1. Background
2. Feasibility Study for "EDT Demonstration Satellite"
3. Feasibility Study for "Non-Cooperative Rendezvous Demonstration Satellite"
4. Development of KHI's micro size satellite **"DRUMS"**
5. Summary

1. Background

- Active Debris Removal (ADR) is necessary to stabilize the growth of space debris.
- The upper stages of rocket have been remaining on orbit as space debris, and the number of it is so large.

-> For this problem, KHI proposes ADR mission which uses **Electrodynamic tether (EDT)** attached on PAF of the upper stage of rocket.

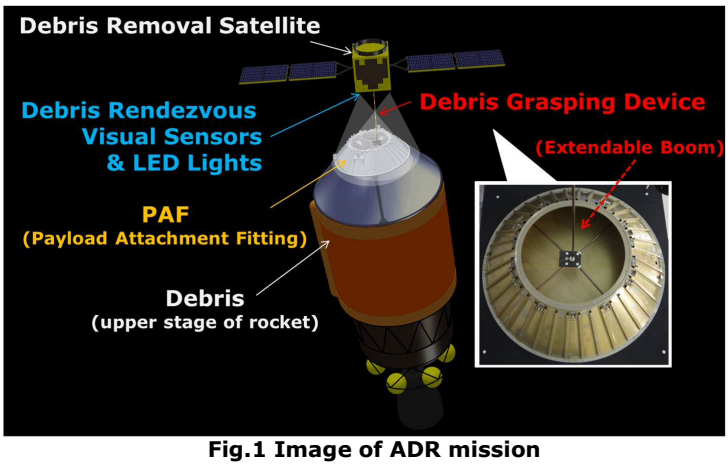
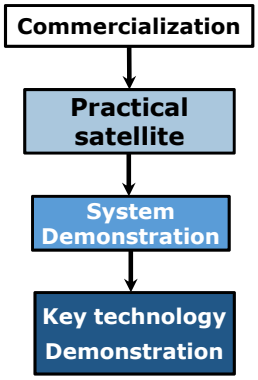


Fig.1 Image of ADR mission

1. Background

- To put ADR into practice, we should solve some technical problems which are difficult to demonstrate on the ground.
- To commercialize ADR, these demonstration should be done with low cost.

-> the demonstration by a **low cost and small satellite** is one of solution.



- The flow of this study is shown in the following.

a. Assuming ADR mission
b. Arranging the functional requirements
c. Picking up the technical problems which should be demonstrated on orbit (these are "Key technologies")
d. Setting mission requirements for the demonstration satellite
e. Studying feasibilities of the demonstration satellite

Fig.2 Flow of requirement

1. Background

- Mission sequence of ADR using "EDT" is shown in the following.
- There are 3 key technologies.

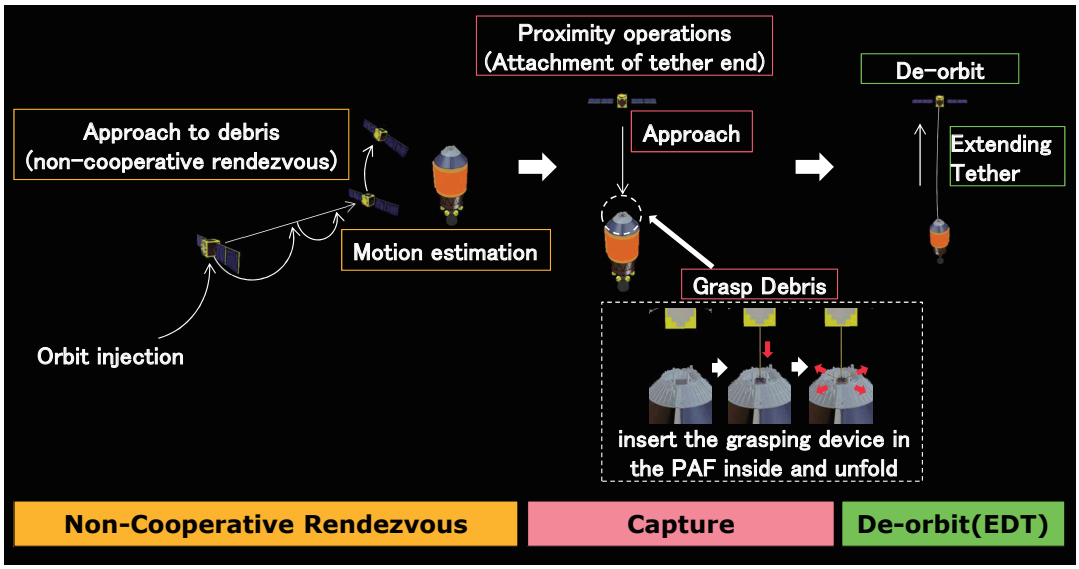


Fig.3 Mission sequence of ADR using EDT

2. Feasibility Study for EDT Demonstration Satellite

2.1 Mission requirement

- Mission requirement of this satellite is to demonstrate "De-orbit(EDT)" on orbit.

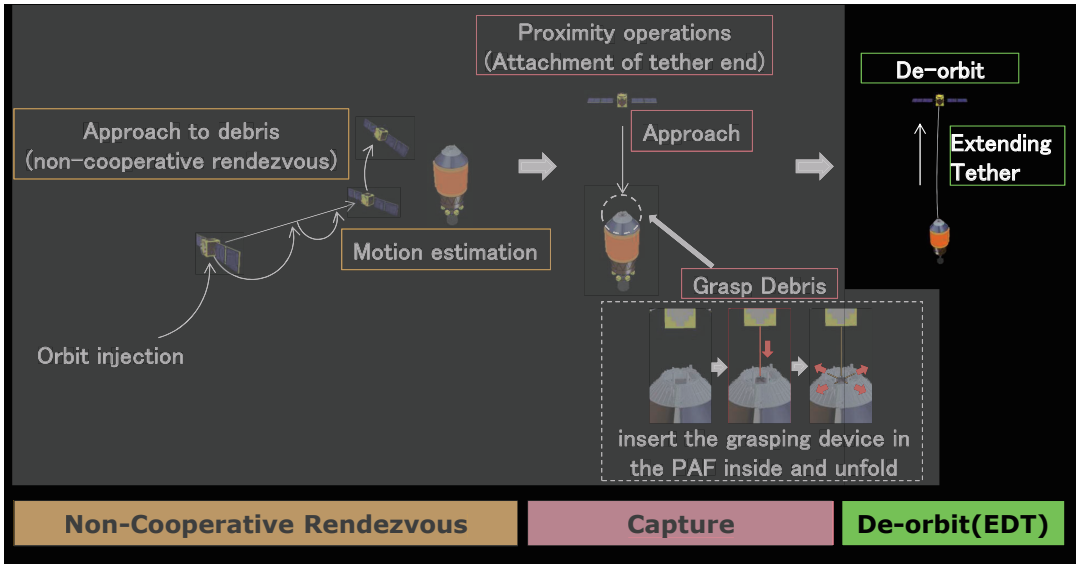


Fig.4 Mission requirement for EDT demonstration satellite

2. Feasibility Study for EDT Demonstration Satellite
2.1 Mission requirement

■ Mission sequence of "De-orbit(EDT)" is shown in the following.
- Swing will occur by gravity and Coriolis force in "3.Extend the main tether".
- And it is difficult to simulate the swing dynamics between extendable booms, tether and debris. => Demonstration on orbit is needed.

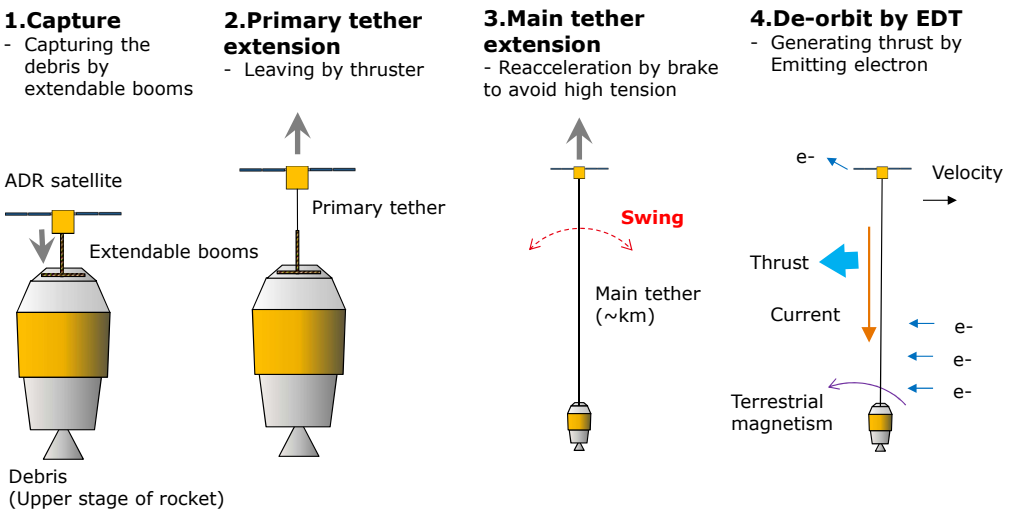


Fig.5 Mission sequence for capture and de-orbit

2. Feasibility Study for EDT Demonstration Satellite
2.2 Requirements

■ The mission requirements of EDT demonstration satellite are shown in the following.
- Demonstrating the EDT theory
- Measuring the swing date
- Satellite mass < 60kg

■ The functional requirements for the satellite are shown in the following.

R1:Grasping Device
R2:Equipments of EDT
(ex. Tether, Electron resource, Langmuir probe)
R3:Equipments of Monitoring the tether swing

-> Satellite mass > 60kg

■ It is necessary to decrease the mass while satisfying the mission requirements. As a result, we satisfied it as follows.

R1:Grasping Device
-> Only 1 extendable boom (5 booms @ full configuration)
R2:Equipments of EDT
-> Length of tether is 1km (5km @ full configuration)
R3:Equipments of Monitoring the swing
-> Monitoring by 1U Cubesat

2. Feasibility Study for EDT Demonstration Satellite
2.3 Configuration

■ Satellite's specifications and configuration are shown in the following.

Table1 Specification

Item	Spec.
Mass[kg]	60
Power(BOL) [W]	62.7
Size[mm]	600×600×800
Attitude Control	before mission:Earth-oriented 3axis control Mission:No-control
Communication	S-band (for communication with grand station) UHF-band (for communication with Cubesat)
Orbit[km]	600@SSO

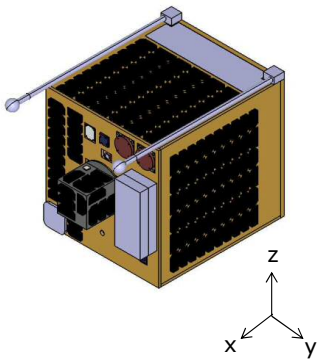


Fig.6 Configuration(Launch)

2. Feasibility Study for EDT Demonstration Satellite
2.4 Mission sequence

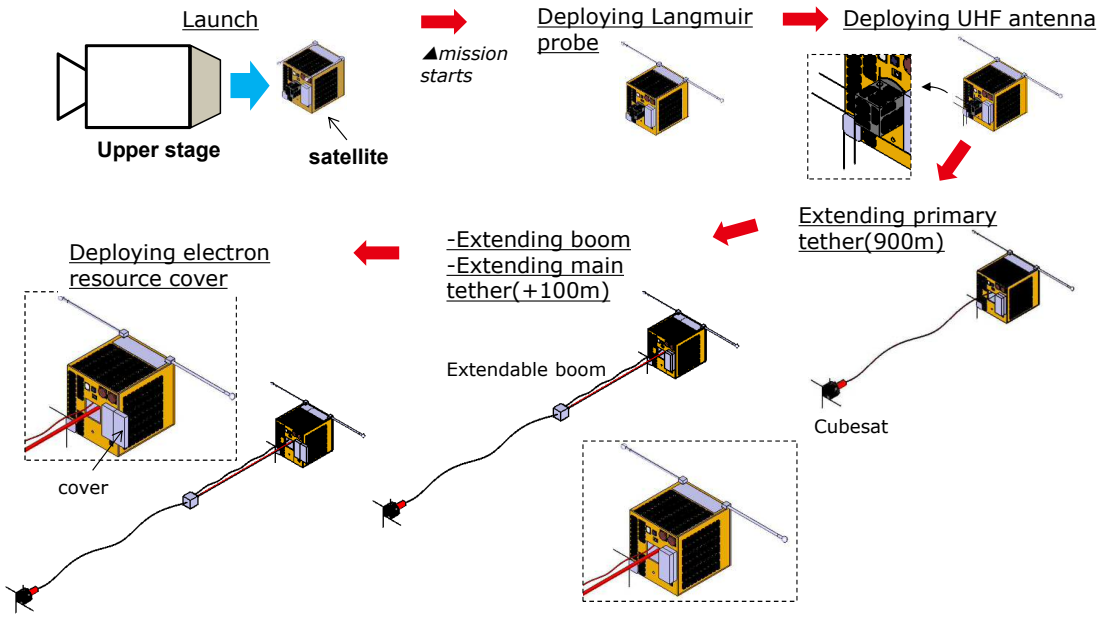


Fig.7 Mission sequence of EDT demonstration satellite

2. Feasibility Study for EDT Demonstration Satellite

2.5 Mission equipment

■ Mission equipment are shown in the following.

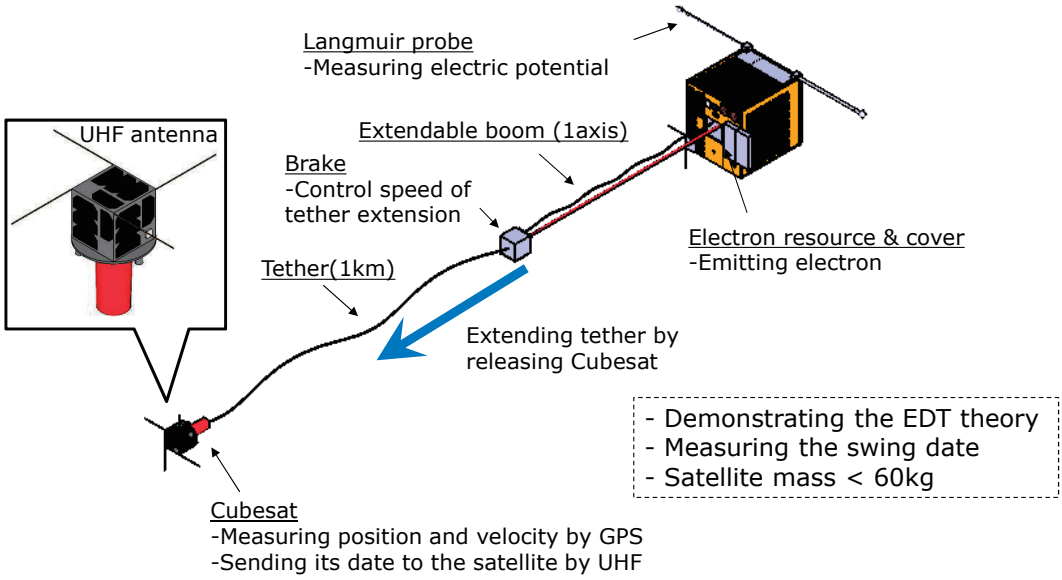


Fig.8 Mission equipment

3. Feasibility Study for Non-Cooperative Rendezvous Demonstration Satellite

3.1 Mission requirement

■ Mission requirement of this satellite is to demonstrate "Non-Cooperative Rendezvous" and "Motion estimation" on orbit.

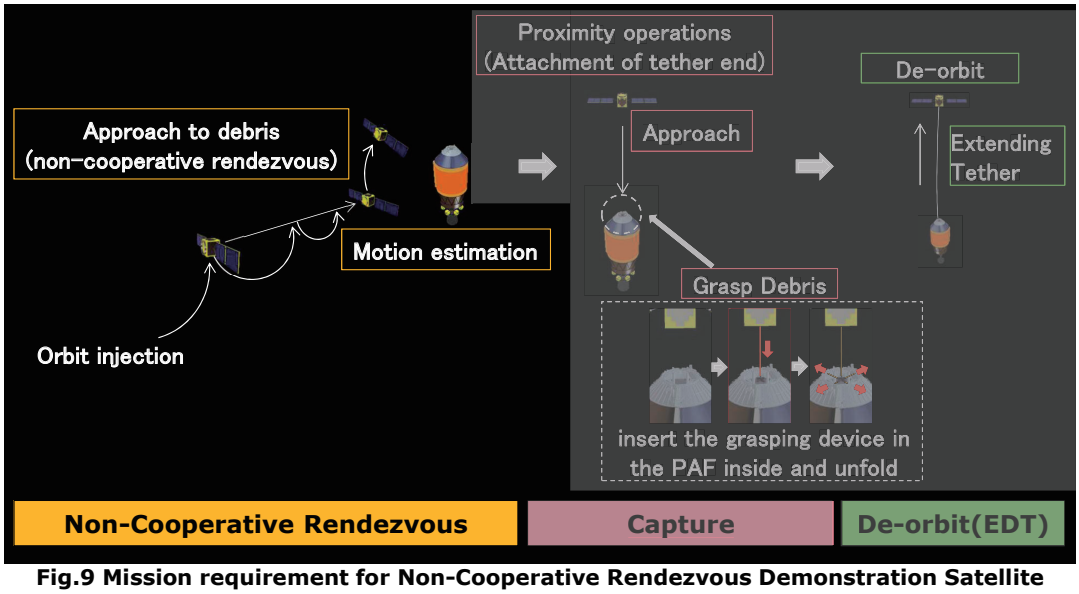


Fig.9 Mission requirement for Non-Cooperative Rendezvous Demonstration Satellite

3. Feasibility Study for Non-Cooperative Rendezvous Demonstration Satellite

3.2 Configuration

■ Satellite's specifications and configuration are shown in the following.

Table2 Specification

Item	Spec.
Mass[kg]	96
Power(BOL)[W]	472
Size[mm]	Launch：620×770×664 On orbit：620×3890×664
Attitude Control	Before mission：Sun-oriented 3axis Control Mission：Target-oriented 3axis Control
Communication	S-band 64kbps(downlink)/4kbps(uplink)
Orbit[km]	600@SSO

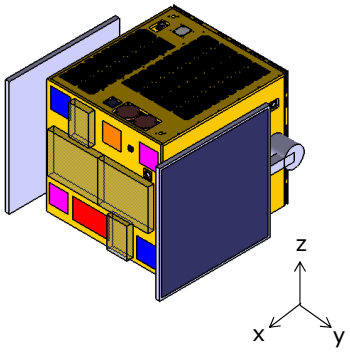


Fig.10 Configuration(Launch)

3. Feasibility Study for Non-Cooperative Rendezvous Demonstration Satellite

3.2 Configuration

■ Configuration on orbit are shown in the following.

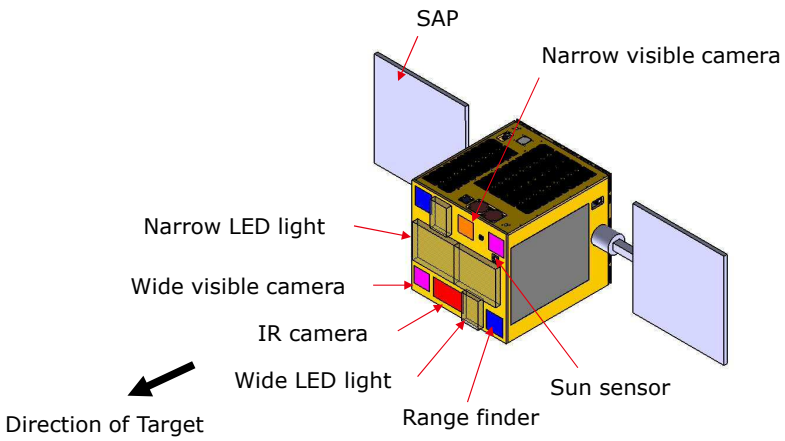


Fig.11 Configuration on orbit

4. Development of KHI's micro size satellite "DRUMS"

4.1 Mission requirement

- Mission requirement of DRUMS is to demonstrate "Capture" and "Vision-based Navigation" on orbit.

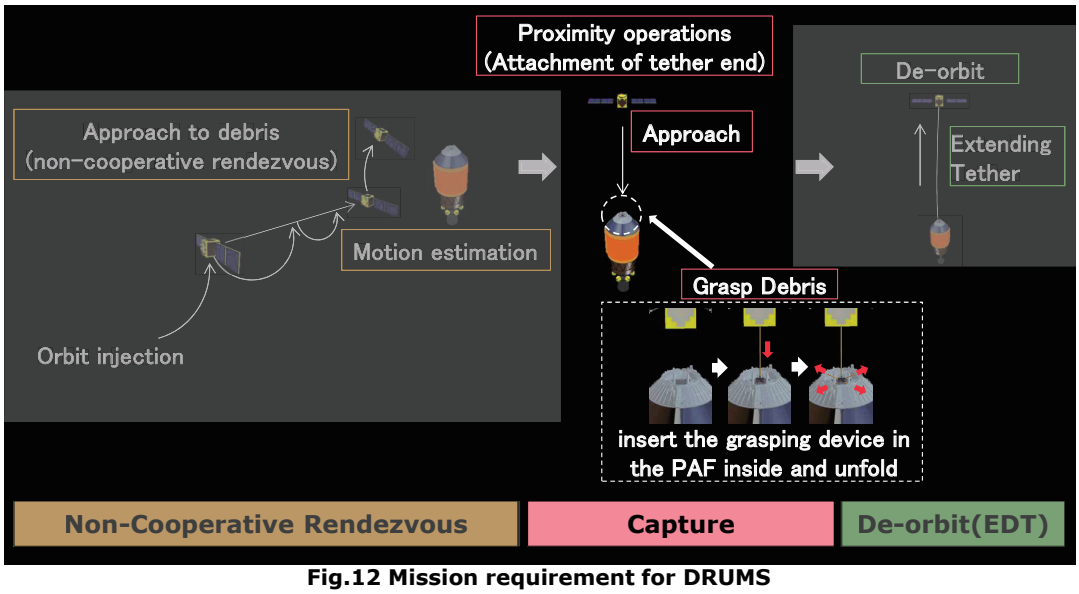


Fig.12 Mission requirement for DRUMS

4. Development of KHI's micro size satellite "DRUMS"

4.2 Configuration

- Satellite's specifications and configuration are shown in the following.
- We have been developing this satellite to get the integration technology of satellite and demonstrating ADR technology on orbit.

Table3 Specification

Item	Spec.
Name	DRUMS (Debris Removal Unprecedented Micro-Satellite)
Mass[kg]	65
Size[mm]	600 × 600 × 800
Orbit[km]	500(TBD)@SSO

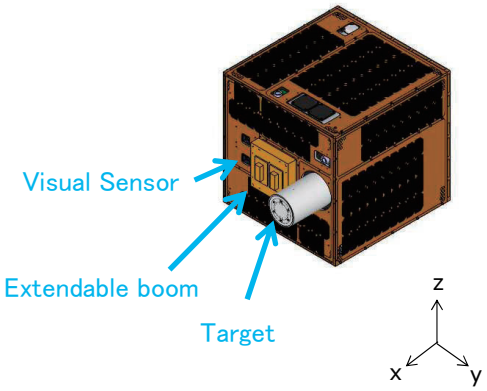


Fig.13 Configuration(Launch)

4. Development of KHI's micro size satellite "DRUMS"
4.3 Mission sequence

- A mission requirement is to demonstrate the sensor system for an approach(leaving) to a non-cooperative target and the capture system on orbit.
- DRUMS releases a small non-cooperative target and leaves from it
- After that, it start to approach and touch to the target by the extendable boom.

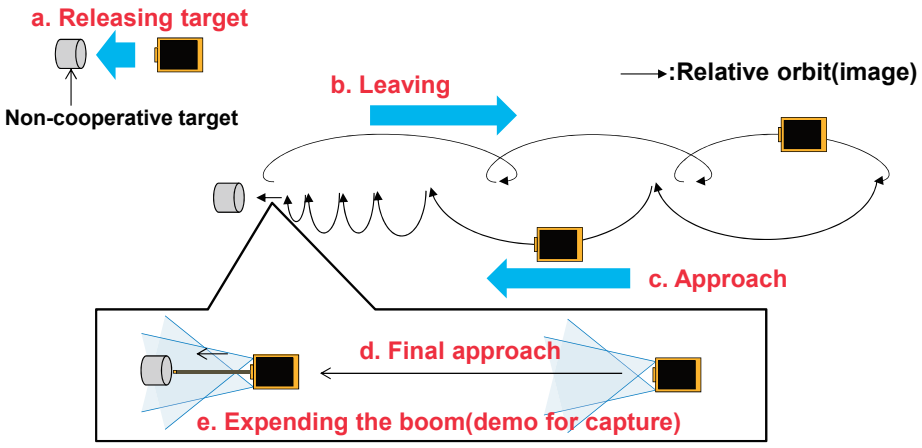


Fig.14 Mission sequence of DRUMS(1/2)

4. Development of KHI's micro size satellite "DRUMS"
4.3 Mission sequence

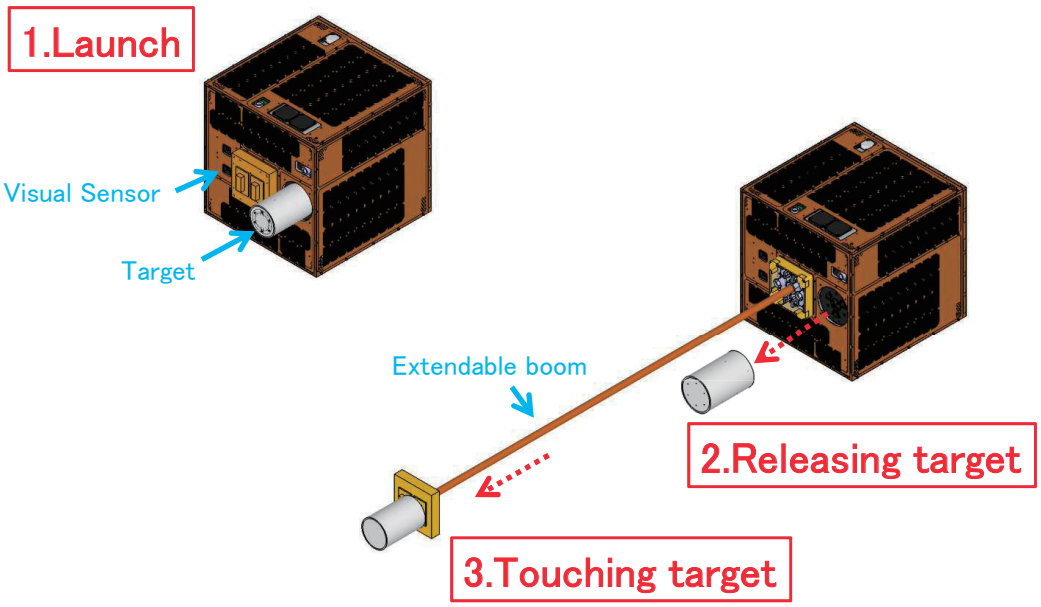


Fig.14 Mission sequence of DRUMS(2/2)

5. Summary

- KHI proposes ADR mission which uses Electrodynamic tether (EDT) attached on PAF of the upper stage of rocket.
- To put ADR into practice, we should solve some technical problems which are difficult to demonstrate on the ground.
- To commercialize ADR, these demonstration should be done with low cost.
- We showed the results of small demonstration satellite's design.
  - EDT Demonstration Satellite
  - Non-Cooperative Rendezvous Demonstration Satellite
- We showed KHI's micro size satellite "DRUMS" for ADR demonstration.

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