C6

デブリ軌道変換用の推進系取付技術について

Mounting Technology of the Propulsion System for De-orbiting Debris

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人類が将来に亘り宇宙開発・利用を持続させていくためにデブリ除去は不可欠なテーマと考えられている。その実施に不可欠な要素技術の一つにデブリをデオービットするための推進系をデブリに取付ける推進系取付け技術が挙げられる。推進系の取付については、各種の方式が検討されているが、デブリのタイプとデオービットの方式により適否が決まるので、これらの条件を定めて、方式を選定する必要がある。ここでは、持続的な宇宙開発・利用に効果的に寄与することを想定して、一回の衝突で多数のデブリを発生させる低軌道周回軌道上のロケット上段部等の大型デブリを、低コストで除去できる方式として、導電性テザー方式を想定して検討している。この方式に対する推進系取付け技術として、ブーム伸展方式、パンチャ打ち込み方式などが候補として挙げられるので、その実現性に向けた課題などの検討を進めている。本プレゼンテーションでは、これらのトレードオフを要約すると共に、その実現性に向けた仕様・課題などにつき講演する。

The removal of the debris is considered to be the inevitable item for the sustainable space development and utilization activities of the mankind. To realize this item, the technology for mounting the propulsion system on the debris to deorbit it is thought indispensable. Various kind of concept on the mounting method are studied today and the selection from them must be made based upon the type of the debris and the method to de-orbit. We are thinking that the most effective targets to be decayed are the large scale debris, such as upper stage of the launching vehicle which had been used to putting the payload satellites on to the orbit, because they may create huge number of small debris at the single collision with other space flying object. We are now studying the Electrodynamics Tether(EDT) method for the deorbit of the above described large scale debris taking into account its feature of low cost and the simpleness. So we are now picking up the various mounting technologies to suit to EDT, such as the boom expanding method and puncher injecting method to study the trade-off and feasibility ,items subject to be solved and so on. In this presentation, current status of the above study and subject to be solved are to be summarized.

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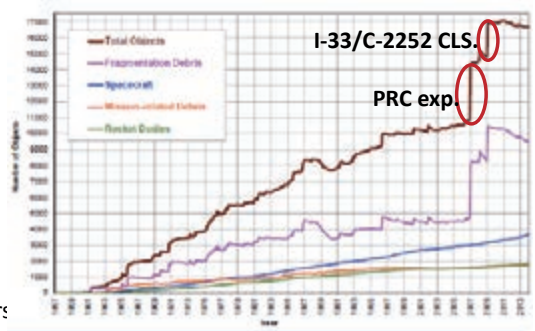
Introduction

- The mounting technology of the propulsion system on the debris is one of the indispensable item for the debris removal.
- The selection of the mounting technology depends strongly on the type of the debris and the method to deorbit.
- Debris of many small size may be the candidates to damage operating satellites, it's **not cost effective** to deorbit them, because there are so many of small debris.

On the hand, **large debris**, such as upper stage of launch vehicle or non-operating large satellites, are candidate to generate a lot of small debris at a single collision.

⇒It is **cost effective** to de-orbit the **large debris** to suppress the increase of debris, especially **upper stage**, and also to progress the standardization of the debris removal because many rockets used PAF.

（e.g. H-ⅡA、Ariane、Delta、Atlas,Soyuz,Proton and others



NASA The Orbital Debris Quarterly News 18-1 (2014, Jan)

Requirements on Mounting of the Propulsion System

- Mount the propulsion system on debris with :
  - approach to the **non-cooperative** debris,
  - existence of the **uncertainty** of the **attitude** and **position** of the debris
  - possibly **tumbling** at the rate of about few degree per second.

  } **Robustness** is needed.
- Transfer large total momentum to debris:
  - with the **uncertainty of position of CG.**
  - △V : a few of 100m/sec to the several tons of debris
- **Cost effective** & **simple** debris removal is needed

⇒**Robustness** with **cost-effective** and **simple method** is strongly desired.

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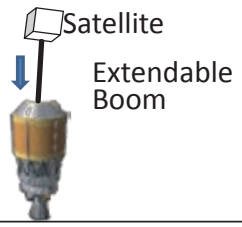
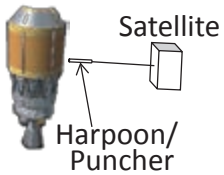
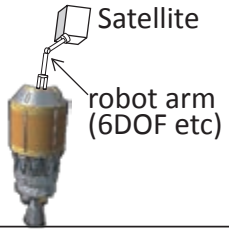
Mounting Technology of Propulsion System(1/2)

Items \ Method	Extendable Boom Hooking	Harpoon/Puncher Penetrating	Robotics Arm Grasping
Concept to Capture			
Method	Boom are extended into PAF of debris to hook it.	Harpoon/Puncher is lodged in the body of debris to capture it	Robotics arm on satellite grasps debris.
Merit	Easy to test. Need not precise position and attitude information.	Easy to test. Need not precise position and attitude information.	Flight exp. of robot. Perform. test :easy. Retry possible.
De-merit	Appligable only to PAF.	Risk of generation of small paticles.	Precise estimation of motion needed. High cost ,heavy
Remark	Upper stage of many rocket using PAF.	Reduction of reaction force at fire of hapoon/puncher is needed.	Several mechanism at side of PAF may obstruct the roperation.

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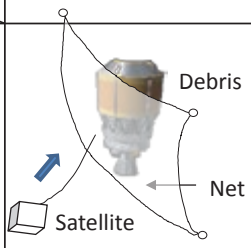
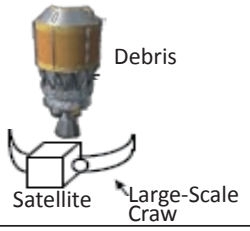
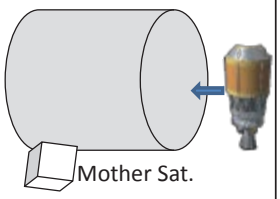
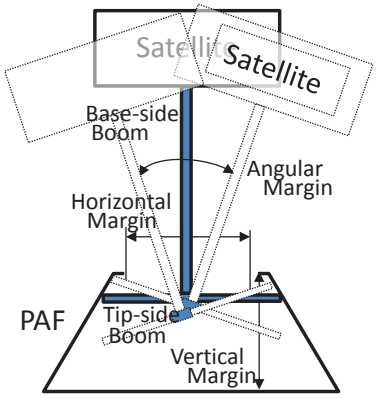
Mounting Technology of Propulsion System(2/2)

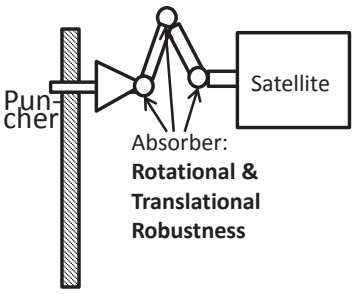
Item \ Method	Net Wrapping	Large-Scale Craw Grasping	Mother sat. pulling in
Concept to Capture			
Method	Net thrown to debris wrapping the debris.	Large-scale craw mounted on satellite grasps the debris to capture	Mother sat. pulling in debris thru the mouth
Merit	Adaptable for tumbling and nutating small debris.	Effective for small debris	Small debris may be easy to be pulled in.
De-merit	Not easy to analyze and test performance	Needs large craw mechanism	Large debris cannot be pulled in.
Remark	Not easy to capture large debris(upper stage of rocket or large sat.)	Not easy to capture large debris(upper stage of rocket or large sat.)	Not easy to capture large debris(upper stage of rocket or large sat.)

Robustness of Propulsion Mounting System

Ⅰ. Extendable Boom

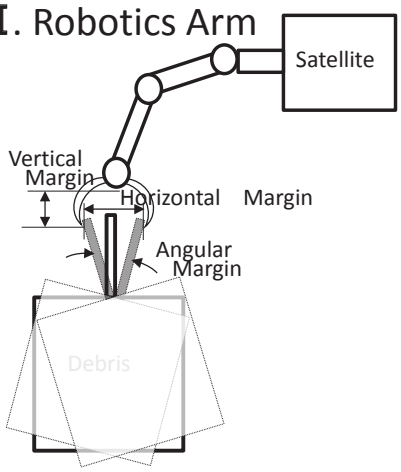


Ⅱ. Puncher



Outer Wall of Debris

Ⅲ. Robotics Arm



Robustness \ Type	Ⅰ. Extendable Boom	Ⅱ. Puncher	Ⅲ. Robotics Arm
Transverse Robustness	Horizontal & Vertical Margin	Transverse Adjustable Range	Horizontal & Vertical Margin
Rotational Robustness	Angular Margin	Rotational Adjustable Range	Angular Margin

Extendable Boom Capturing(1/2) Debris Capturing Concept

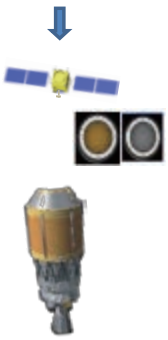
① Estimate the relative attitude and position of debris analyzing the pictures of PAF.

②-1 Extend the base-side extendable boom to the center of PAF at the position of 1.5m away from PAF.

-2 Extend the 4 tip-side extendable booms radially toward circle of PAF.

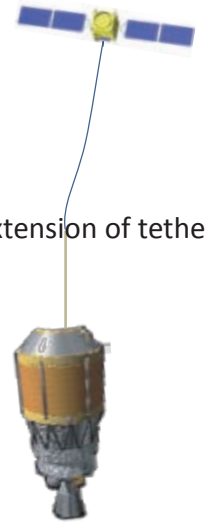
③ Making sure of the completion of extension of booms to be fixed at hem of PAF, the satellite escape extending the tether.

Concept of Extendable Boom on Satellite



①Estimation of attitude and position of debris

② Extension of booms



③ Extension of tether

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Extendable Boom Capturing(2/2) Capturing Feasibility

- Preliminary feasibility of extendable boom capturing of debris was evaluated as follows by the conceptual study :
  - ✓ Alignment requirement of position : ±100 mm along X-axis(long axis of debris)
    : ±200 mm across X-axis
    attitude : no limitation around X-axis
    : ±5 deg. around Y & Z-axis
  - ✓ Approaching velocity of debris: 0 ~ 100 mm/sec. along X-axis
  - ✓ Angular velocity of debris ;±1 deg./sec. around all-axis
- Preproduction sample of boom and extension mechanism was manufactured and evaluated to be :
  - ✓ Basic feasibility of the extendable boom for debris capturing was evaluated.
  - ✓ Some characteristics of boom were find to be improved:
    - ➢ review the extension method of tip side boom to reduce the stress on base-side boom
    - ➢ review the manufacturing process to improve the quality
    - ➢ Increase the stiffness of boom for future mission

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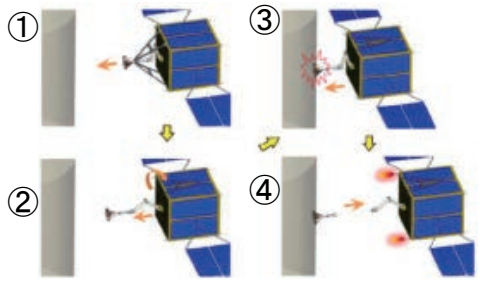
Harpoon/Puncher Penetrating(1/2) Debris Capturing Concept

Ⅰ. Concept of debris capturing (Arm + Puncher Method)



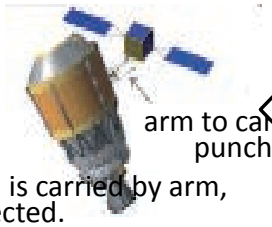
①: Identification of debris motion

②: Puncher arming

③: Capture and penetration of the debris wall

④: Make sure of fixed and then escape

Ⅱ. Reduction of reaction force on satellite at fire



arm to carry puncher

Puncher is carried by arm, then injected.
(Firing by booster is not needed.)
The reaction force is reduced by absorber in arm
(Arm + Puncher method)

Reduction of reaction Force is necessary.

<Candidate>
- Arm+Puncher
- Soft release + Puncher
- Improved Harpoon

Reaction force caused at Harpoon firing may damage satellite mechanical part.

⇒It must be reduced

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Harpoon/Puncher Penetrating(2/2)

Affirmation of the Penetration thru. the Debris Wall

The penetration of the Harpoon/Puncher through the debris wall was evaluated preliminarily :

◆ Collision model study

Possibility of penetration at collision of harpoon/puncher to debris wall was studied to be evaluated in order-level validity.

◆ Preliminary experimental feasibility study

Feasibility was studied by preliminary experiment to be evaluated the penetration of harpoon/puncher to be able. to penetrate the outer wall of debris.

◆ Further studies are to be carried out to evaluate more precise modeling to make sure of the penetration.

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Further to be Studied

Following task are going to be carried out :

<Extendable boom>

Characteristics of boom are to be improved:

- to improve the quality of extension and holding.
- to increase the stiffness for future mission.

<Harpoon/Puncher>

Further studies and tests to evaluate more precise model of penetration to make sure of penetration.

<Debris Removal System >

Further studies are to be carried out on:

- countermeasure for the electric discharge at the contact of satellite with debris of different charge level.
- ensure of communication link at flyaround and capturing .
  electlic power
  thermal balance
  and other system budget

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