P12

テザー牽引を用いたデブリ除去衛星の初期検討
—数値シミュレーションによる設計パラメータやモデルの影響評価—
Satellite active debris removal using tethered tug
-Evaluation of design parameters and modeling by numerical simulations-

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本研究では、ロケット上段などの大型デブリを対象としたテザー牽引を用いたデブリ除去について検討する。デブリ除去手法のひとつとして、スラスタなどの推進系を持った衛星とデブリをテザーによって連結し牽引する手法が、各国で検討されている。この際の挙動に関して、デブリ除去系を離散質点としてモデル化し数値シミュレーションによって解析する。先行研究では2質点モデルを用いたものや深宇宙を想定したものなど簡易的な解析が主である。そこで本研究では、まず離散質点モデルの質点数の影響について比較を行う。さらにスラスタ推力、テザー剛性、テザー長さの設計パラメータおよび初期姿勢が、系の挙動に対してどのように影響するかを評価する。

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Active Debris Removal Using Tethered Tug
– Evaluation of Design Parameters and Modeling by Numerical Simulations –

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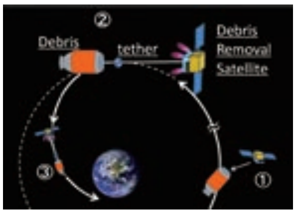
1. Introduction & Purpose

[1] NASA Orbital Debris Program Office, Orbital Debris Quarterly News volume 18January 2014.

The amount of space debris has been rapidly increasing, and Active Debris Removal (ADR) is needed.

■ **Tethered Tug**

- ☐ The removal satellite, which is connected to debris by a tether, performs de-orbit maneuver using thrusters
- ☐ Possible to perform a controlled re-entry
- ☐ Possible to use at the lower enough altitude after de-orbiting by Electrodynamic Tether
- ☐ Prior researches evaluate the system's motion by a simplified model such as 2 point masses connected by a spring



Analysis and Evaluation of Design Parameters and Modeling using Multiple Mass Model

2. Numerical Simulation

Simulation Flow

Initial State → Thruster ON → (if ΔV=100 [m/s]) → Thruster OFF

■ **Tether model**

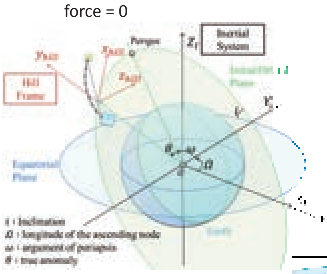
- ☐ Multiple mass point model
- ☐ Connected with spring and damper
- ☐ When compressed, restoring force = 0

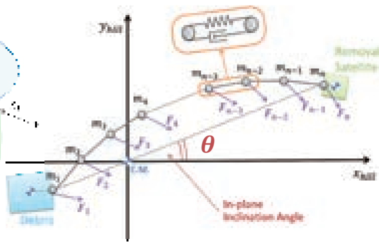
■ **Debris Removal Satellite model**

- ☐ Small satellite 1m class (360kg)
- ☐ Attitude controlled

■ **Debris model**

- ☐ H-2A rocket upper stage (mass: 3000kg, height: 800km)
- ☐ Considering attitude motion



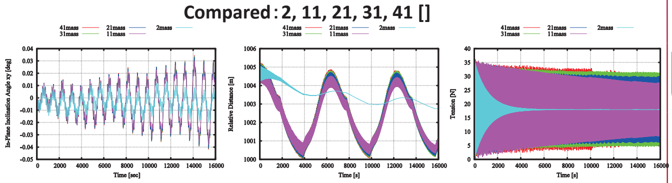


3. Design Parameters & Modeling

<Nominal value>
Number of point mass : 21 , Young's modulus : 14 [GPa] , Length : 1.0 [km] , Thruster force:20 [N]

■ **Number of point mass**

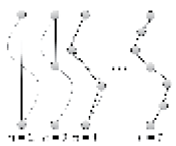
Compared : 2, 11, 21, 31, 41 []



＜Considered Causes＞

In case of 2 mass,

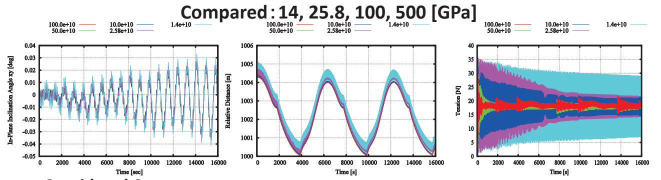
- ☐ Reconstruction of tethered structure is imperfect.
- ☐ Propagation of longitudinal vibration does not occur.



<Result>
11 to 21 point masses are appropriate considering computational cost

■ **Rigidity (Young's modulus E)**

Compared : 14, 25.8, 100, 500 [GPa]



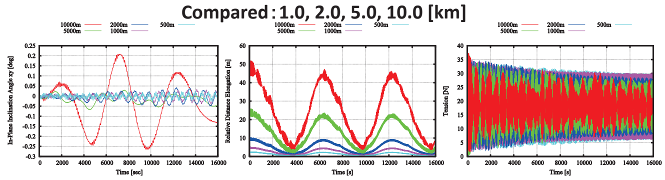
<Considered Causes>

- ☐ Higher E = larger spring constant k → faster oscillation decay
- ☐ E does not influence maximum tension

＜Result＞
High rigidity is preferred.

■ **Length**

Compared : 1.0, 2.0, 5.0, 10.0 [km]



＜Considered Causes＞

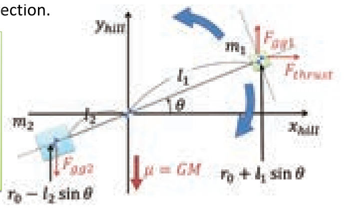
- ☐ Same E → Same elongation rate
- ☐ Lower k → gradual oscillation spread (low natural frequency)
- ☐ Longer Length produces higher gravity gradient → unstable in tangential orbital direction.

Maximum Length before θ divergence

$$l_{max} = \frac{F_{thrust} \cdot {r_0}^3}{3\mu} \cdot \frac{m_1 + m_2}{m_1(m_2 - m_1)}$$

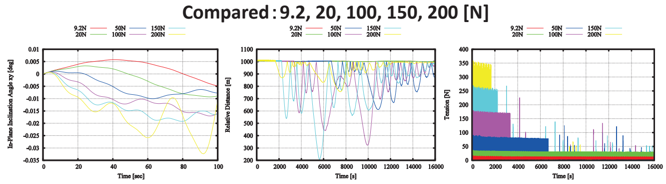
＜Result＞

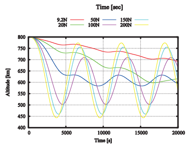
- Tether length must be shorter than l_{max}
- Optimum length : minimum length that can keep distance for avoiding collision



■ **Thrust force**

Compared : 9.2, 20, 100, 150, 200 [N]





＜Result＞

- Minimal thrust required by mission (such as for controlled re-entry) is preferred

4. Conclusion

The behavior of tethered tug were evaluated using design parameters of number of point mass, tether length, tether rigidity, thrust.

＜Future Research＞

- **Realistic initial conditions**
- Young's modulus is known to be nonlinear → **modeling nonlinear spring**
- Possibility of collision between debris and satellite without thrust control when the thrust is off → **Thrust control using such as Input Shaping**

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