C01

デブリ除去衛星システムの概念検討

Concept study of a debris removal spacecraft

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JAXA では低軌道の混雑軌道に存在するロケット上段等の大型デブリを除去するデブリ除去システムを検討している。比較的 TRL の高い技術を組み合わせた除去方法として、デブリに剛結合して電気推進により軌道降下させ、大気密度が高くなってきた高度から大気抵抗を積極的に利用し、軌道降下に必要な推薬量を削減したシステムを検討している。本講演では電気推進を使用した宇宙機システムのトレードオフを実施した結果を報告する。電気推進機はその必要電力が大きいほど、推力は大きく、また寿命も長くなる性質がある。宇宙機システムにとっては必要電力が小さく、適当な推力をある期間発揮できるのが望ましいため、デブリ除去のミッション期間に最適な性能の電気推進機が存在する。

JAXA is studying the active debris removal systems to reduce the relatively large debris, i.e. large upper stage, in the crowded region of LEO. The authors are studying the system consists of the relatively high TRL technologies, and the electric propulsion is considered as a main device for the orbital decay with rigid fixation at the debris. To reduce the required propellant mass, the atmospheric drag is positively utilized where the air density becomes high as the altitude decays. The present study shows the result of some system trade-offs with consideration of the electric propulsion and the air drag. The electric propulsion has the characteristics that produces higher thrust and longer life as the required input power is bigger. However, it is preferable from the spacecraft system cost and mass viewpoint that EP has smaller power consumption and the appropriate life. Therefore, the optimum electric propulsion sizes are found from the debris removal mission duration.

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Concept study of a debris removal spacecraft

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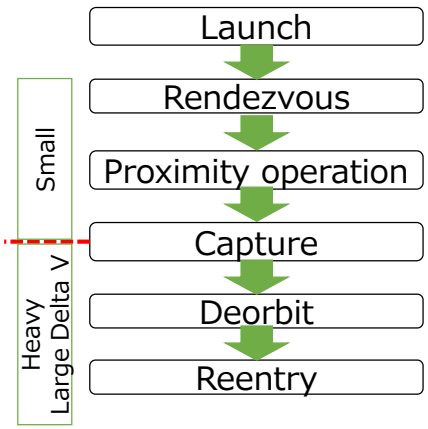
Concept of ADR Operation



Launch into LEO

Rendezvous to uncooperative target

Look around the target and go to capture point

Capturing target

Today's topic

Big issue, but not today's topic

Study Object

- Consider electric propulsion (EP) as a main propulsion device on ADR spacecraft for decaying the debris altitude
- EP consumes certain amount of the spacecraft power demand at operation
  - Less EP power demand leads to smaller spacecraft size
- The decay duration depends on the EP thrust, which is related to EP power requirement
  - Higher EP power shortens the mission duration
- System study is conducted to find appropriate EP and ADR spacecraft size (mass and power)

3

Presentation Outline

- System Study Assumptions
- Deorbit scheme
- System design simulation and results
- Summary

4

System Study Assumptions

- Target debris is a large rocket body flying in LEO
  - Environmental criticality is seemed to be large
    - Both probability of collision and mass are large
  - Target mass is assumed to be 3000kg for this study
- The first demonstration mission will be carried out around 570 to 600km altitude
  - To reduce the environmental deterioration if the mission unfortunately go wrong
- 1 ADR spacecraft removes 1 debris
- Launch with other spacecraft into SSO
  - Avoid to leave additional debris at launch as possible
  - Maximum allowable weight of the spacecraft will be about 500kg for first demonstration

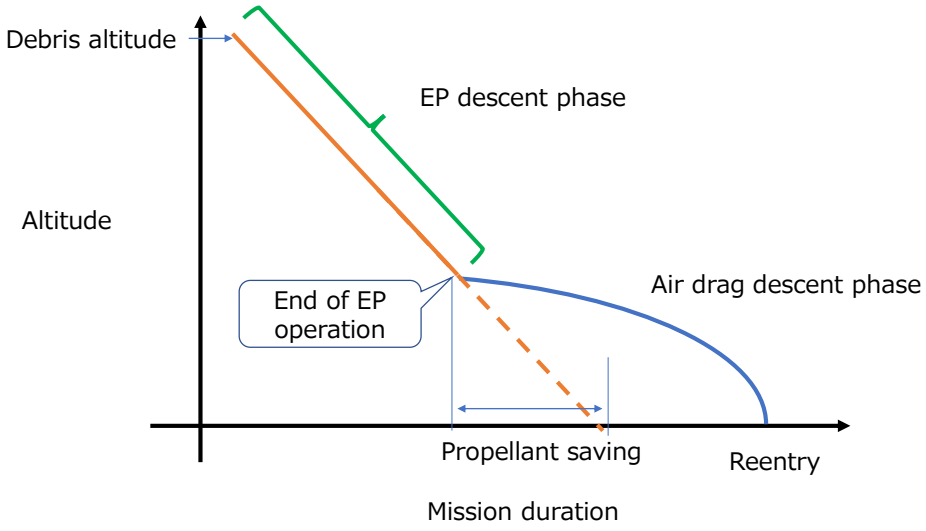
5

Deorbit scheme

- Hall thruster and Ion engine are candidates of the main propulsion to descent altitude at first
  - EP descent phase
- After some altitude descent by EP, the debris attitude is controlled to utilize the atmospheric drag as possible
  - Air drag descent phase
  - To reduce the propellant mass
  - ACS Actuators: RW, torquer, chemical thruster
- The descent duration (from capture to reentry) will be in a year or some

6

Deorbit profile



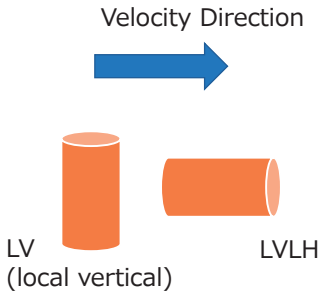
7

System design simulation

- The EP descent phase requires high power demand and power is the main factor of spacecraft size and mass
- Purpose
  - Find appropriate EP size, spacecraft total mass and power demand
- Fixed parameters
  - Debris mass: 3000 kg
  - Space craft Bus power demand: 700W
    - If EP requires 600W, total spacecraft power demand is 1300W
  - EP generates thrust continuously during EP descent phase
    - Spiral orbit transfer

8

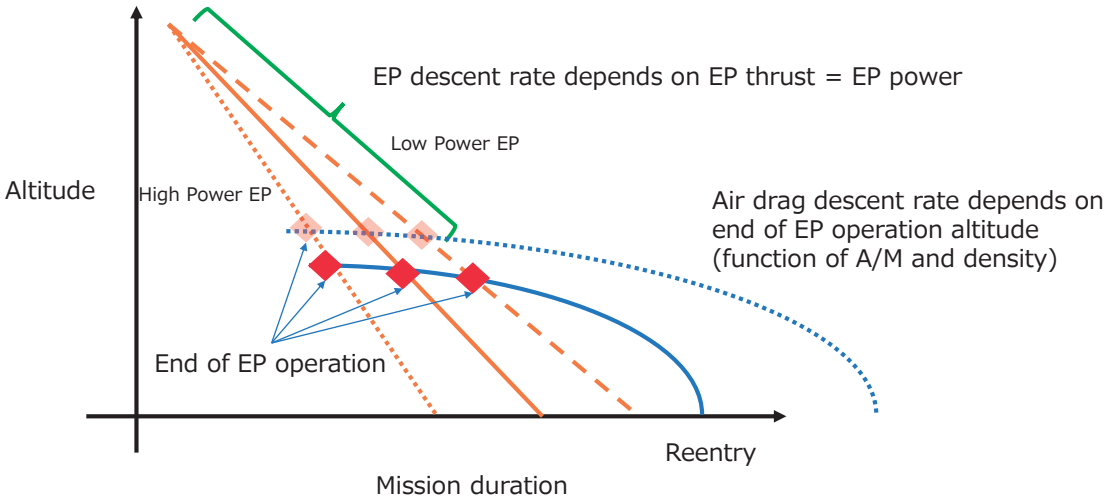
System design simulation



- System model
  - SMAD satellite cost model (SSCM)
    - Satellite mass is a function of total power demand
    - Satellite cost is a function of satellite mass
  - NRL-MSISE-00 (atmosphere)
    - Averaged in 1km altitude bin
    - Cd(2.0), Area for LV, Area for LVLH are fixed
  - EP performances (Thrust, Isp, PPU input power, PPU mass)
    - Hall thruster (estimated from BHT-600, SPT-50M, etc.)
      - Thrust 33 mN, Isp=1750s @ 600W
      - Small thruster has shorter life
      - Life = 200 days for 550W or lower, 330 days for above 550W
    - Ion Engine (based on HAYABUSA2 ion engine), life is over 40,000 hrs
      - Thrust 15.4 mN, Isp=3200s @ 600W
    - EP assumed to be developed/modified to accommodate with ADR requirement
  - Xe tank mass
    - Function of volume, estimated from several CFRP wrap tank datasheet

9

System design simulation



10

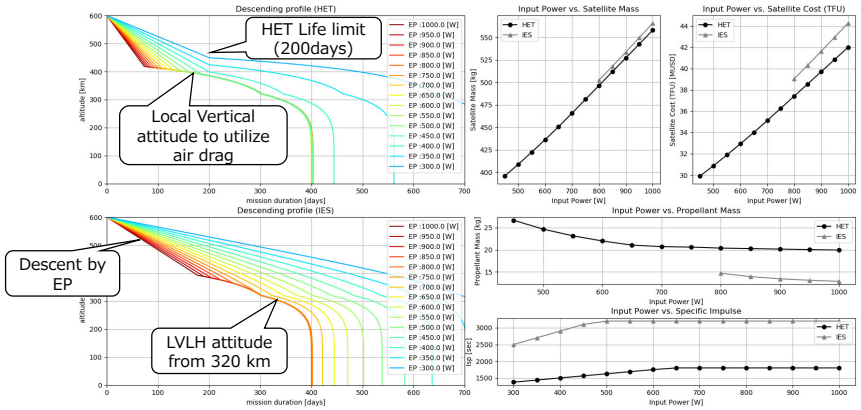
Simulation Steps

1. Specify EP performance with PPU_input, EP_type
   - Function G(PPU_input, EP_Type)
     - Return thrust, Isp, EP_mass, EP_life
     - Assume: Thrust is linear function of PPU_input
     - Assume: Isp is trapezoidal shape function of PPU input
2. Descent profile calculation function
   - Function H(EP_off_height, PPU_input, EP_type, duration)
     - Calculate descent profile with EP and air drag
     - Return final height at the end of duration
3. Calculate EP_off_height for fixed PPU_input, EP_type, and duration
   - Optimize function H(obtain: EP_off_height;
     fixed: PPU_input, EP_type, duration, final height)
     - Obtain EP_off_height and EP_operating_duration, prop_mass
4. Calculate Spacecraft mass and cost
   - Function SSMC_TFU(PPU_input, prop_mass, EP_mass)
     - Calculate EPS mass with PPU_input and bus_demand(=700W)
     - Calculate Bus mass with SSMC (ratio of satellite/EPS) plus prop_mass and EP_mass
     - Calculate Bus cost with SSMC (linear relation to bus mass)
     - Calculate TFU cost with SSMC (function of Bus cost and Bus mass)
       - Incl. IAT, Program level, Launch and orbital operations support

11

Simulation Results

Debris mass:3000kg, Spacecraft mass:about 500kg, Circular orbit altitude: 600km, Descent duration 400 days case

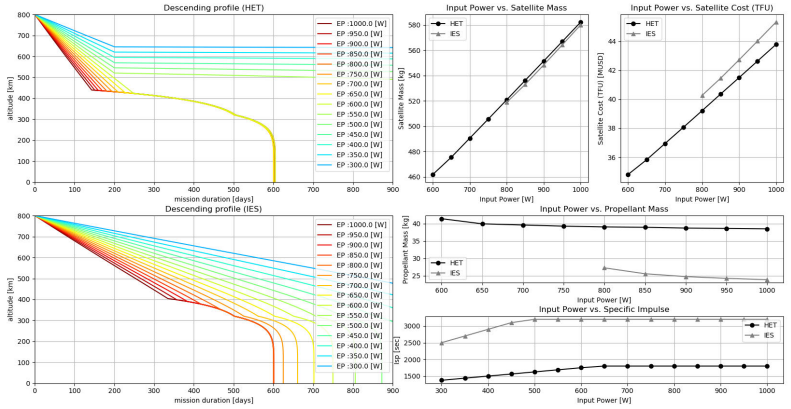


Hall thruster which is higher thrust to power ratio to Ion engine, can satisfy less PPU input power, less cost and mass

12

Simulation Results

Debris mass:3000kg, Spacecraft mass:about 500kg, Circular orbit altitude: 800km, Descent duration 600 days case



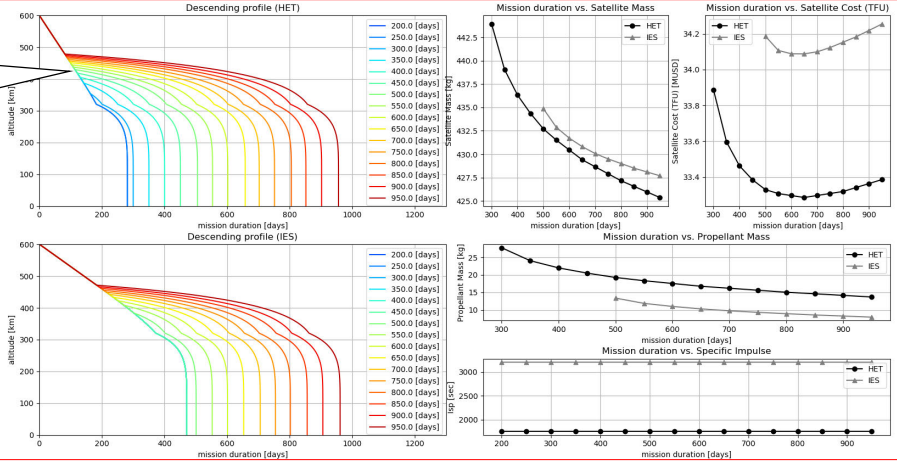
Hall thruster which is higher thrust to power ratio to Ion engine, can satisfy less PPU input power, less cost and mass

13

Simulation Results

Debris mass:3000kg, Spacecraft mass:about 500kg, Circular orbit altitude: 600km, PPU input power 600W. Cost includes 3 person operation cost.

EP off altitude is varied by mission duration

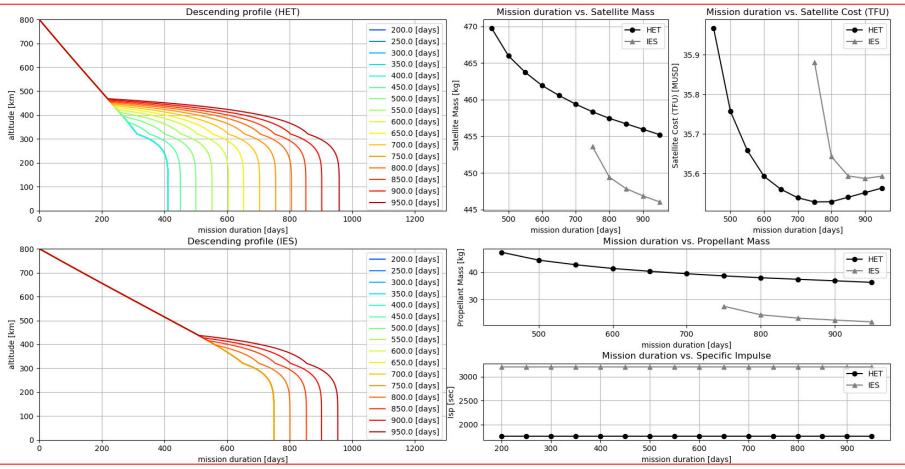


Hall thruster is preferable from mass and cost perspective.
There is optimum mission duration because of operation cost.

14

Simulation Results

Debris mass:3000kg, Spacecraft mass:about 500kg, Circular orbit altitude: 800km, PPU input power 600W. Cost includes 3 person operation cost.

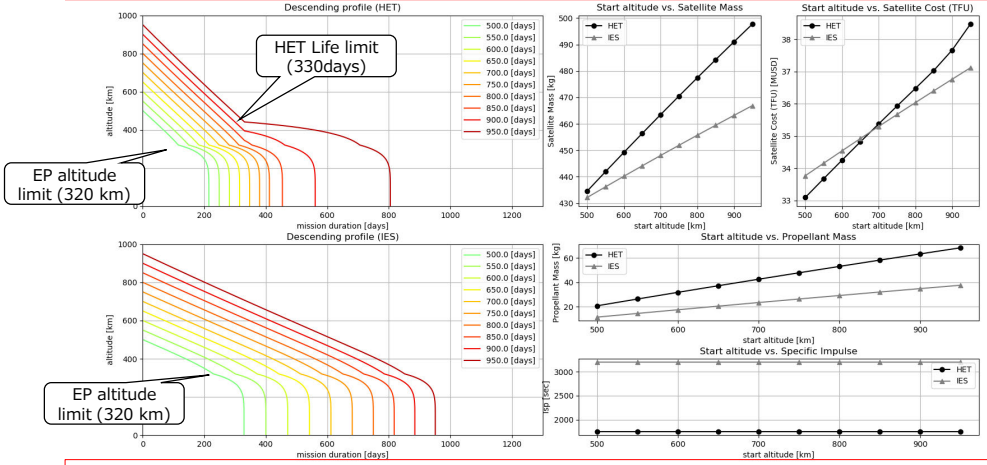


IES system mass is lighter, but Hall thruster is preferable from cost perspective. There is optimum mission duration because of operation cost.

15

Simulation Results

Debris mass:3000kg, Spacecraft mass:about 500kg, Circular orbit altitude: 500-950km, PPU input power 600W. Cost includes 3 person operation cost.



IES system mass is lighter.
Cost depends on the start altitude.

16

Summary

- System simulations have been conducted and the EP size range has been studied
  - The smaller in size and power but longer life is preferable
  - Hall thruster seemed to be a better candidate in EP than Ion engine from the cost perspective
- The EP can be adopted to be a main propulsion device on the ADR spacecraft for decaying the debris altitude
  - Conventional size with air drag assistance