C15

レーザ衛星を用いたADRミッションにおける軌道設計
Orbit Design for ADR Mission Using Laser Satellite

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宇宙機やデブリの急激な増加に伴い、能動的デブリ除去（ADR）の必要性も一層高まりつつある。スカパーJSATと理化学研究所は、レーザアブレーションによって得られる推力に着目し、レーザを搭載した衛星をによるADR手法を提案している。本手法の特徴の一つとして、ターゲット物体に対して、物理的な接触が不要という点があげられる。レーザ衛星は、レーザの射程距離内に接近できれば、ターゲット物体のデタンブリングやデオービットを行うことが可能である。そのため、接触型ADRで必要となるターゲット衛星へのドッキングは不要となるが、一方で、レーザ衛星とターゲット物体との相対位置の保持がより重要なタスクとなる。レーザ衛星によるADRミッションは、幾つかのフェーズに分割されるため、それぞれの目的に沿った相対軌道設計が必要となる。本発表では、各フェーズごとの相対軌道について、Hill座標系やROEsを用いて設計し評価した結果を紹介する。

As the number of spacecraft and orbital debris is rapidly increasing, Active Debris Removal is becoming an essential technology to maintain a sustainable space environment. SKY Perfect JSAT and RIKEN are developing a laser equipped ADR satellite which adopts laser ablation technology to generate thrusting force on the target object. This ADR method does not require any physical contact to the target object, which is the remarkable characteristics compared to the widely proposed methods. The laser satellite can perform detumbling and deorbiting of the target object as long as their relative distance is within the laser range. For that reason, docking or capturing is no longer needed for this ADR method. On the other hand, proximity operations need to be considered over the entire mission period. ADR mission provided by Laser satellite can be divided into several phases, such as detumbling phase and deorbiting phase, and each phase requires individual orbit design. This presentation will show the concept of the orbital design for each mission phase and provides the validation results by using Hill coordinate systems and relative orbital elements.

The 10th Space Debris Workshop

C15. Orbit Design for ADR Mission Using Laser Satellite
レーザ衛星を用いたADRミッションにおける軌道設計

November 30th, 2022

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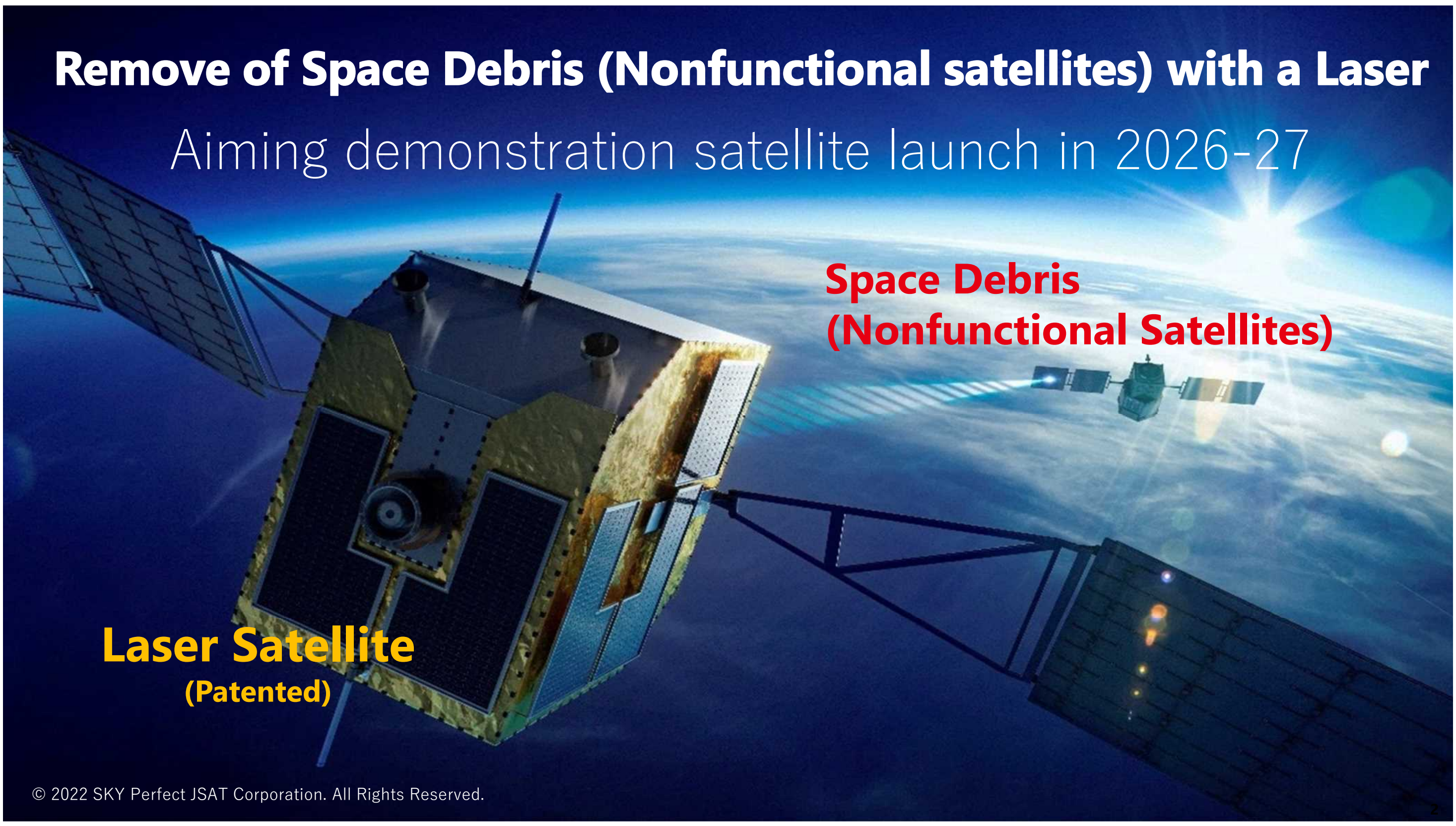
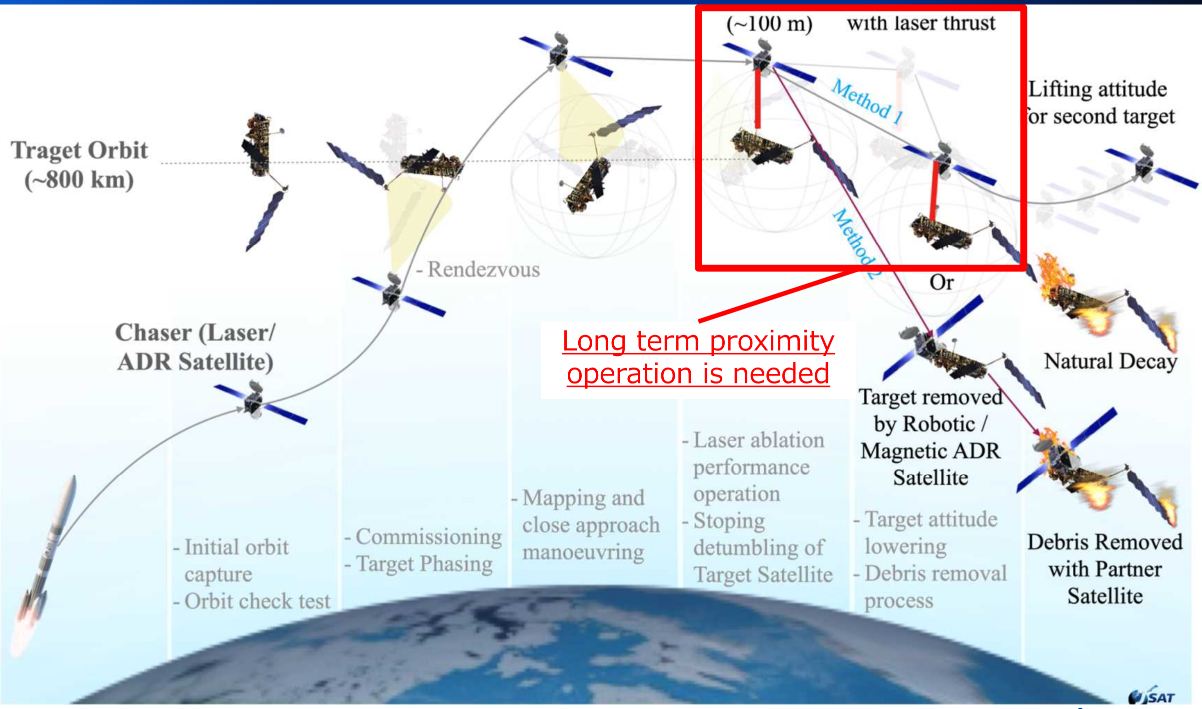


Mission Scenario for ENVISAT case (IAC 2022)



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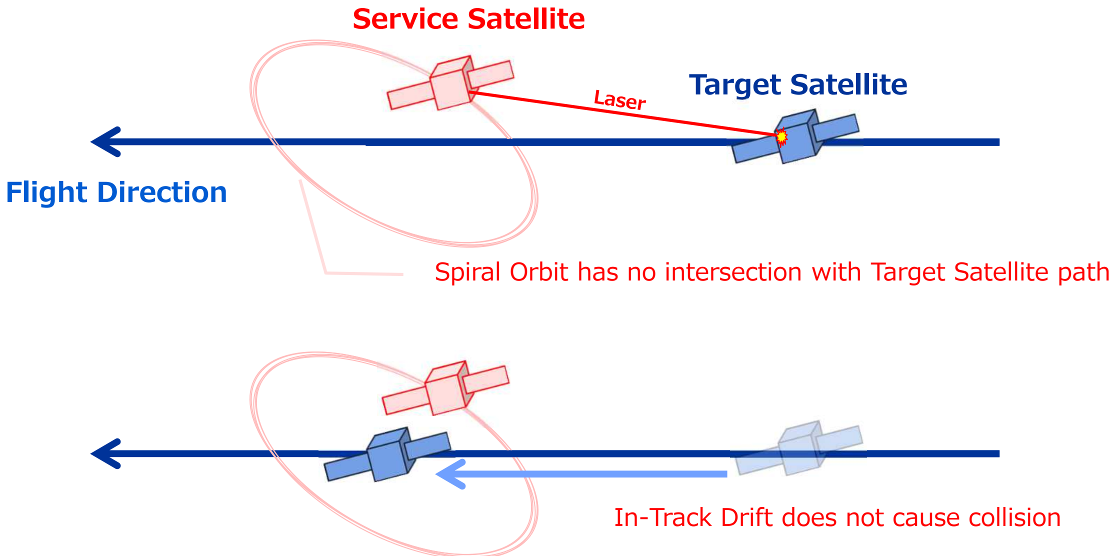
Proximity Operation by Spiral Orbit

Safer operation can be provided by Spiral Orbit strategy



This presentation provides the progress on the Spiral Orbit Designing for Laser ADR mission

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Spiral Orbit Design

Relative Orbital Elements (ROEs) can be used for spiral orbit designing

ROEs: Delta between two orbital elements of Target and Service satellites

$$\delta\alpha = \begin{bmatrix} \delta a \\ \delta\lambda \\ \delta e_x \\ \delta e_y \\ \delta i_x \\ \delta i_y \end{bmatrix} = \begin{bmatrix} \Delta a/a \\ \Delta u + \Delta\Omega \cos i \\ \Delta e_x \\ \Delta e_y \\ \Delta i \\ \Delta\Omega \sin i \end{bmatrix}$$

Specific ROEs combination gives a specific relative elliptical orbit on Hill coordinate system (see right figure).

By adjusting (aδe, aδi, aδλ)[m], the desired relative orbit can be obtained

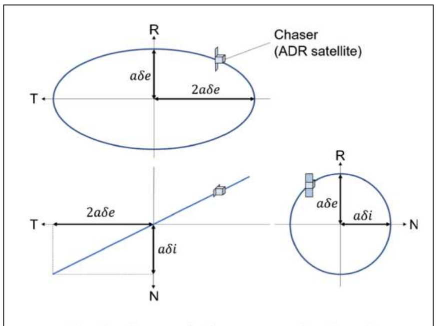
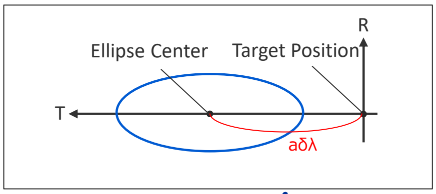
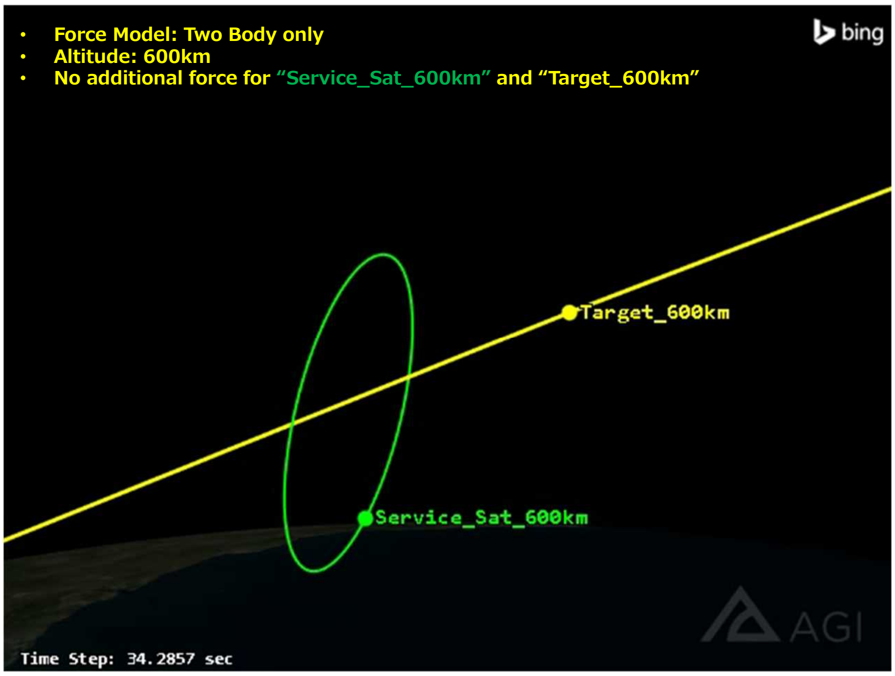


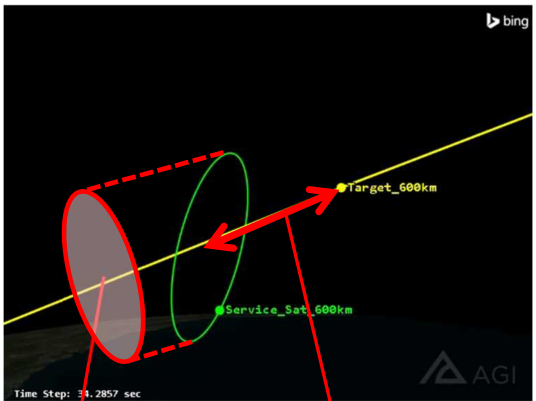
Fig. 6. Concept of e/i-vector separation ($\delta a = 0$).

Takahiro SASAKI, Yu NAKAJIMA, Toru YAMAMOTO, Proximity Approaches and Design Strategies for Non-Cooperative Rendezvous, TRANSACTIONS OF THE JAPAN SOCIETY FOR AERONAUTICAL AND SPACE SCIENCES, 2021, 64 巻, 3 号, p. 136-146



Example of Spiral Orbit Design

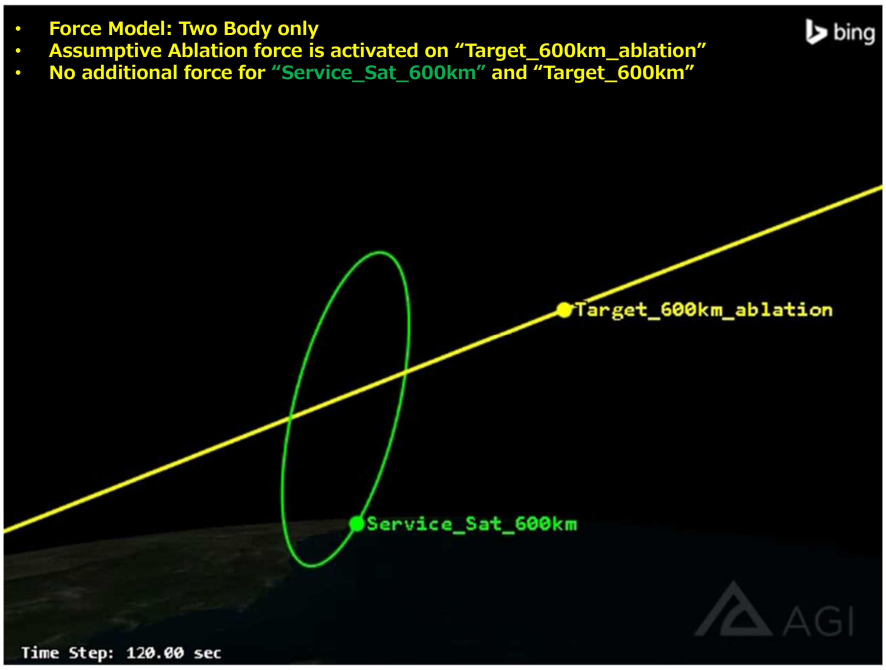


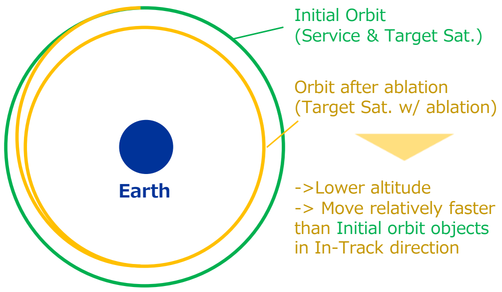


Distance between Target and Center of ellipse＝100m

R-N plane radius ＝30m

Orbit Change Caused by Ablation Force





Ablation Force gradually changes the target object orbit.

Service satellite needs to perform thrusting to keep the relative position.

Follow-up Maneuver during Detumbling & Deorbiting

Previous research* found the **Equation for Ablation & Maneuver Planning**
-> Which contributes to defining finite propulsion and Laser ablation planning to keep relative orbit.

*Isobe, S., Yoshimura, Y., Hanada, T., Itaya, Y., Fukushima, T., Formation keeping control for simultaneous deorbit using laser ablation,73 rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022.

$$\Delta\boldsymbol{\alpha}_{\mathrm{des}} = \delta\boldsymbol{\alpha}_{\mathrm{des}} - \boldsymbol{\Phi}(t_m, t_{\mathrm{ini}})\delta\boldsymbol{\alpha}_{\mathrm{ini}}$$

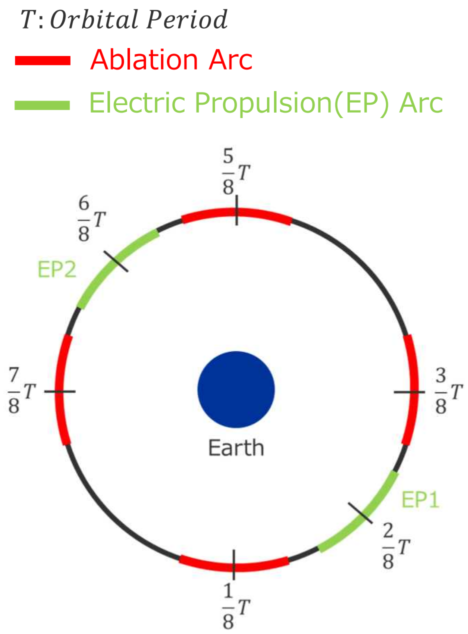
$$\Delta\boldsymbol{\alpha}_{\mathrm{des}} = \sum_{j=1}^{N} \boldsymbol{\Phi}(t_m, t_{j,f})\boldsymbol{\Psi}_d(t_{j,f}, t_{j,0})\boldsymbol{F}_{\mathrm{ab}} + \sum_{j=1}^{N} \boldsymbol{\Phi}(t_m, t_{j+1,0})\boldsymbol{\Psi}_c(t_{j+1,0}, t_{j,f})\boldsymbol{F}_{\mathrm{el}}$$

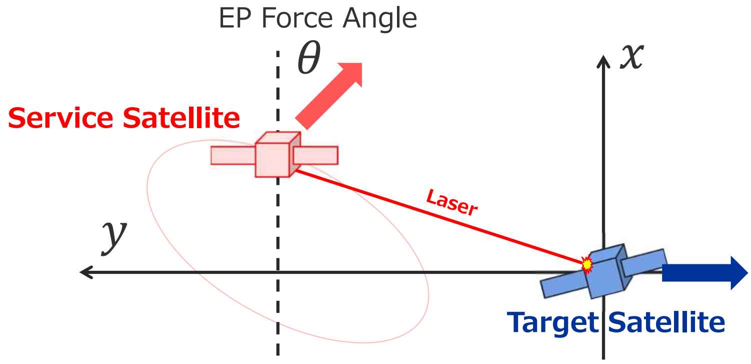
$\delta\boldsymbol{\alpha}_{des}$: *Desired ROEs*
$\delta\boldsymbol{\alpha}_{ini}$: *Initial ROEs*
$\boldsymbol{F}_{el}$: *Electric Propultion Force*
$\boldsymbol{F}_{ab}$: *Ablation Force*

Details & Analysis of Equation

- Gaussian Equation is combined with ROEs representations
- Ablation Force is assumed to always act in In-Track direction
- 4 Non-Linear Equations are obtained (= 4 parameters can be designed)
- According to the analysis, uncertainty of ablation direction and orbital perturbation (geopotential) can be compensated.

Follow-up Maneuver during Detumbling & Deorbiting

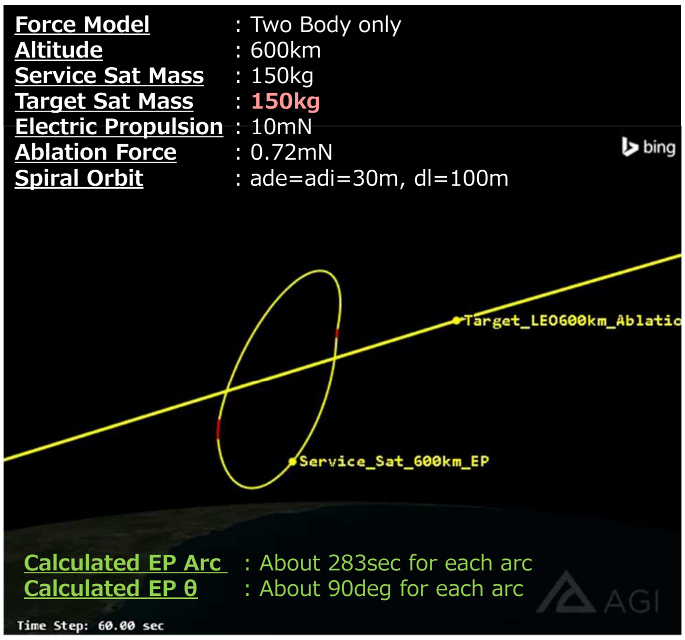


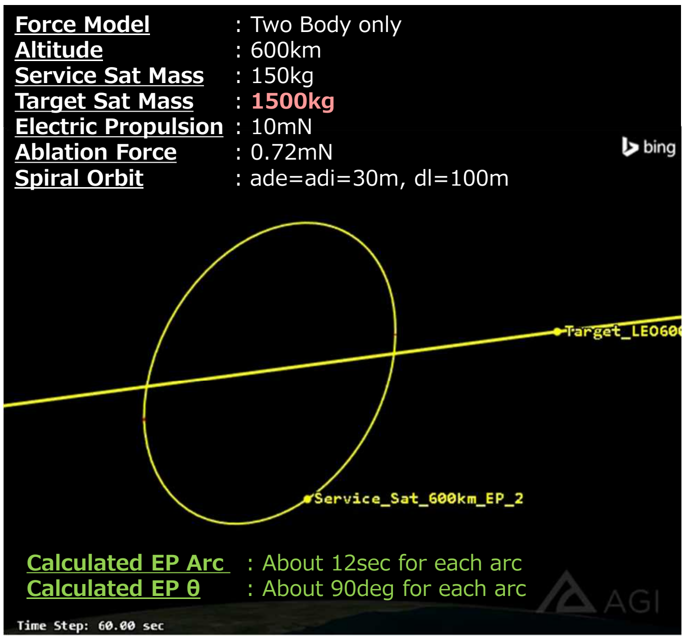


Constraints
- Total Ablation Arc = 0.6T
- Ablation Force Direction = In-Track
- Arc Centers are fixed

Parameters
- EP1 Duration
- EP2 Duration
- EP1 Angle
- EP2 Angle

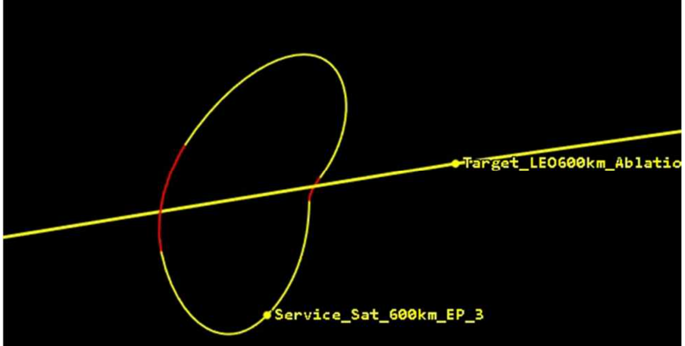
Examples of Orbit Design





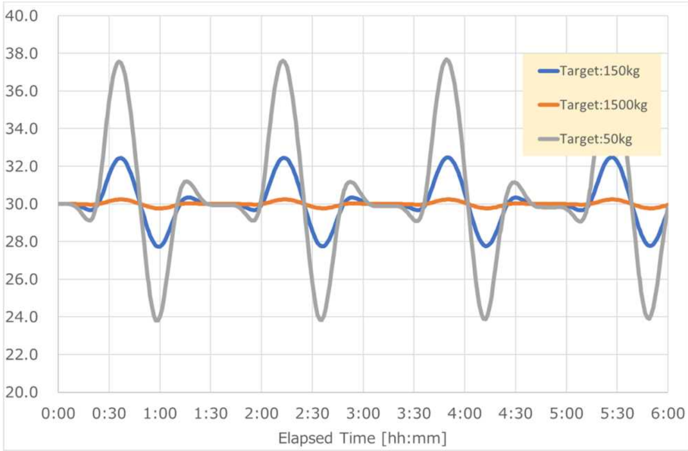
Examples of Orbit Design

Force Model : Two Body only
Altitude : 600km
Service Sat Mass : 150kg
Target Sat Mass : 50kg
Electric Propulsion : 10mN
Ablation Force : 0.72mN
Spiral Orbit : ade=adi=30m, dl=100m



Calculated EP Arc : About 375sec for each arc
Calculated EP θ : About 90deg for each arc
Time Step: 60.00 sec

$\sqrt{y^2+z^2}$ [m] (Distance from In-Track axis(=x axis))



As EP duration becomes longer,
the spiral orbit becomes more distorted.

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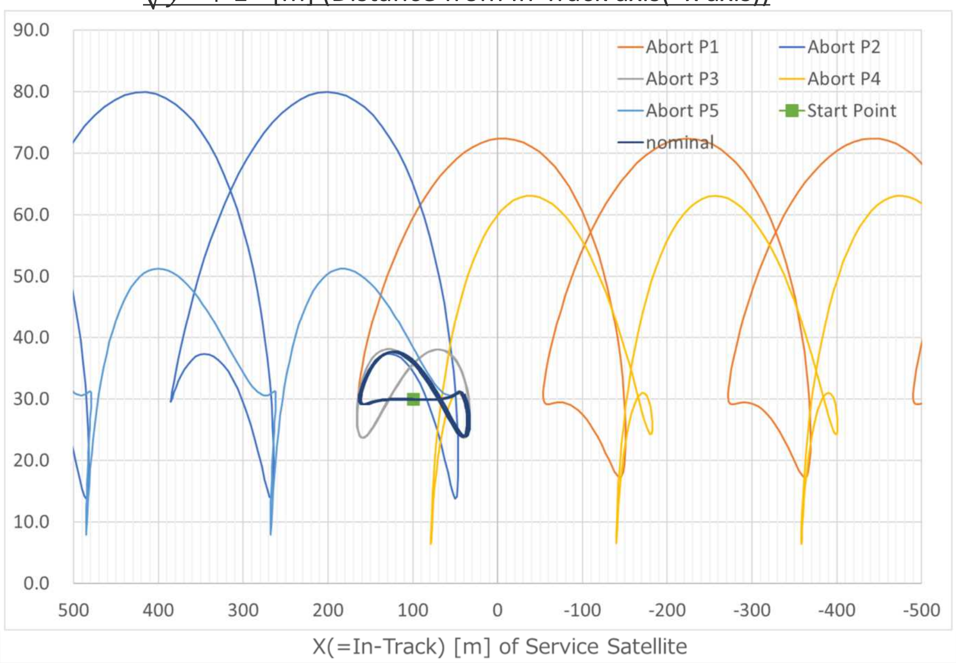
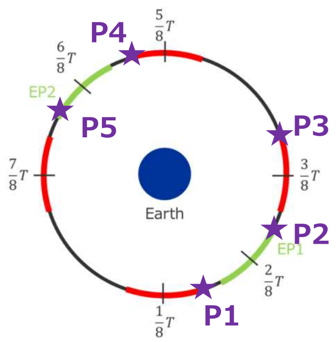
Orbital Safety after Abort

$\sqrt{y^2+z^2}$ [m] (Distance from In-Track axis(=x axis))



Abort Point Definition



In some case, spike-like approach to x-axis is observed

To ensure orbital safety, design should be done not to cause the spike around Target (=coordinate origin)

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Summary & Future Works

Summary

- The research shows the examples of orbit design for Laser ADR mission.
- Relative elliptic orbit can be maintained by following the maneuver plan provided by a specific equation, but sometimes the ellipse partially collapses depending on the initial conditions.
- The degree of collapse and abort timing determine the safety of the orbit (possibility for colliding target satellite).

Future Works

- Further evaluation of Abort Safety (Analytical & Numerical)
- Mission safety evaluation by taking into account the orbit determination error.

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