C18

レーザアブレーションを用いたマルチデオービットの相対軌道設計
Formation Flying Design for Multi-deorbit Using Laser Ablation

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能動的デブリ除去の一つに，レーザ照射により表面から放出する物質の反作用を利用する手法がある．このレーザアブレーションを用いたデブリ除去ミッションでは，デブリに非接触であるため安全性が高い．さらに取付デバイスや燃料を必要としないため，単一のターゲットを軌道離脱するだけでなく，複数のターゲットを同時に軌道離脱するマルチデオービットへの拡張が見込まれる．本発表では，ターゲットの近傍軌道へランデブー後の軌道離脱フェーズにおける，サービス衛星と複数ターゲットのフォーメーションを提案する．レーザ照射時間，衝突回避性能を評価指標とし，レーザシステムの制約を満たす２つのフォーメーションを設計する．またサービス衛星の姿勢変更を伴うフォーメーションを含む２つの案について検討を行う．

To remediate the orbital environment, active debris removal (ADR) from low Earth orbit is required. Laser ablation is a vital technology for contactless active debris removal, where a service satellite irradiates laser pulses to a target satellite to generate the ablation force for deorbiting. Since the ADR method using a laser requires no deorbiting device to attach, the ADR by laser enables simultaneously deorbiting multi-targets, which is a promising ADR technology. As a preliminary study of multi-deorbit, this paper designs the formation with respect to multi targets to maximize the laser duration or minimize collision probability. Furthermore, the laser system has significant constraints such as laser focal length, laser irradiating angle, and camera angle. Thus, the designed formations must satisfy the constraints of the laser system. To this end, two formations that require attitude control or no attitude control are proposed. Their performances are compared in terms of safety and deorbit efficiency.

Nov. 30, 2022

C18. Formation Flying Design For Multi-Deorbit Using Laser Ablation

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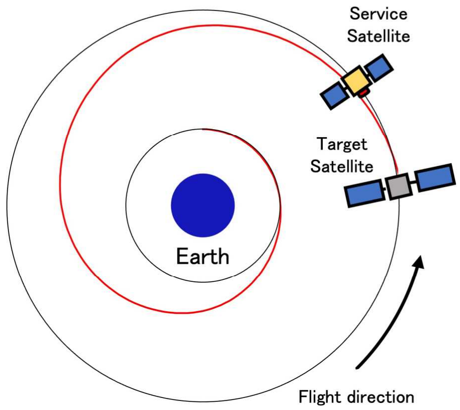
Wednesday, November 30th, 2022
10th Space Debris Workshop

スカパーJSAT 九州大学

Deorbit service using laser ablation



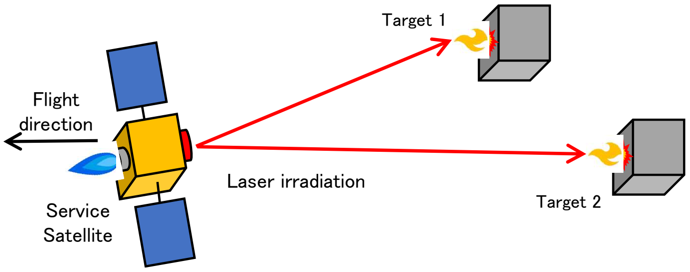
Mission Scenario

Descent altitude using force generated by laser ablation

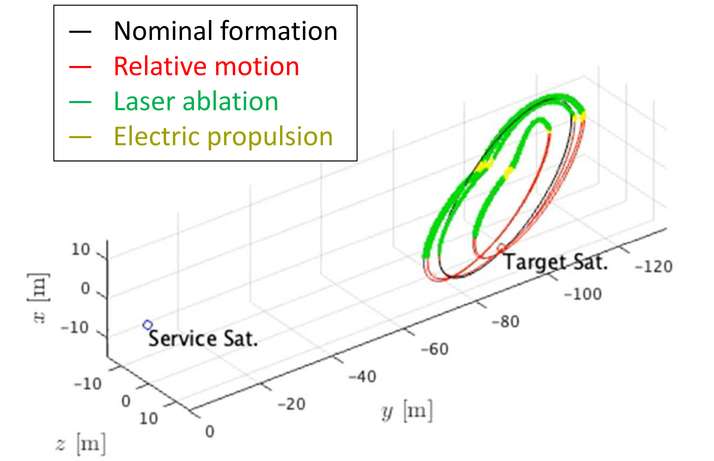
Advantages [1,2]

- Contactless debris removal
- Adaptability to Tumbling Objects
- No need to carry deorbit fuel

➡ Extending to multi-target deorbit by a single service satellite



Deorbit Phase



Relative motion respect to the service satellite

Nominal formation

- The relative motion periodically returns to the nominal formation.
- Forming the nominal formation when not irradiating the laser.

Outcome of this research

Nominal formation design and evaluation for multi-deorbit using laser ablation

Relative motion [3,4]

Relative Orbital Elements (ROE)

$$\begin{bmatrix} \delta a \\ \delta \lambda \\ \delta e_x \\ \delta e_y \\ \delta i_x \\ \delta i_y \end{bmatrix} = \begin{bmatrix} (a_d - a)/a \\ (u_d - u) + (\Omega_d - \Omega)\cos i \\ e_{xd} - e_x \\ e_{yd} - e_y \\ i_d - i \\ (\Omega_d - \Omega)\sin i \end{bmatrix}$$

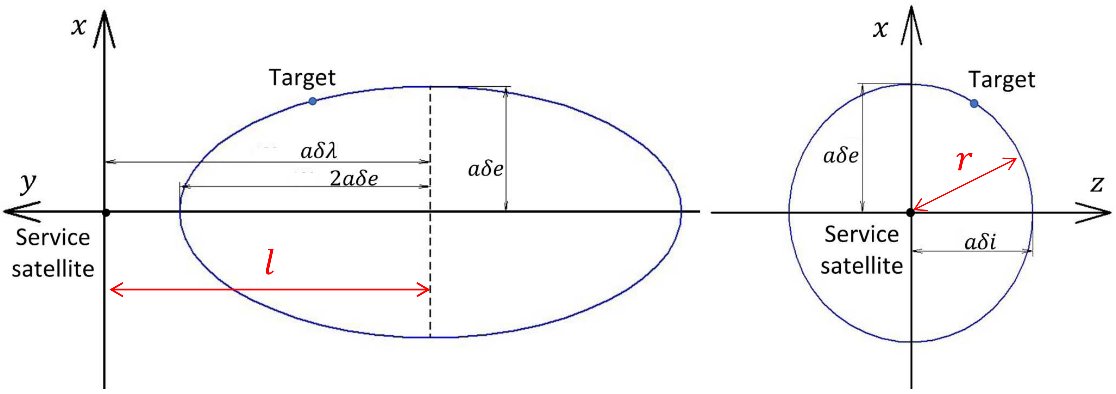
Safety Ellipses

- Bounded in-plane motion
- Target doesn't intersect the tangential axis.

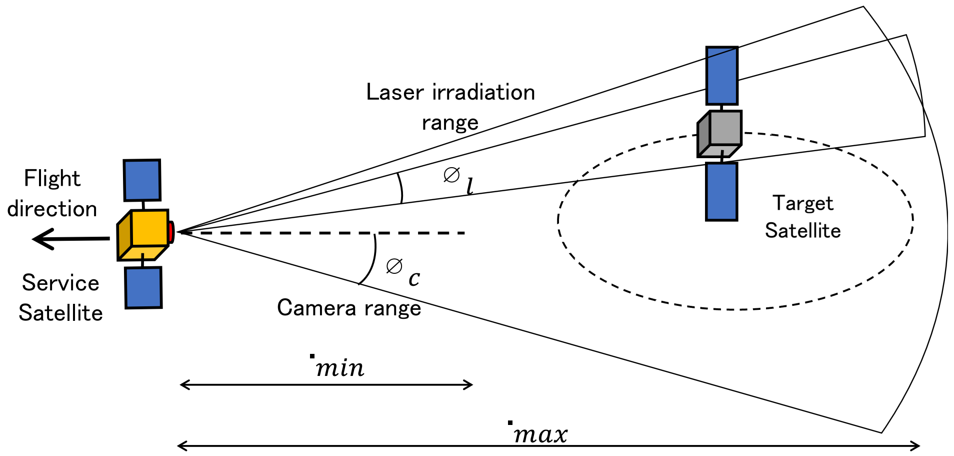
In this research

$$a\delta a = 0 \quad \delta \boldsymbol{e} \parallel \delta \boldsymbol{i} \quad a\delta\lambda = l \quad a\delta e = a\delta i = r$$

Formation parameters = l , r



Constraint



Laser system
$\emptyset_l$=5 [deg]
l_{max} = 200 [m]
$\emptyset_c$=10 [deg]
l_{min} = 50 [m]

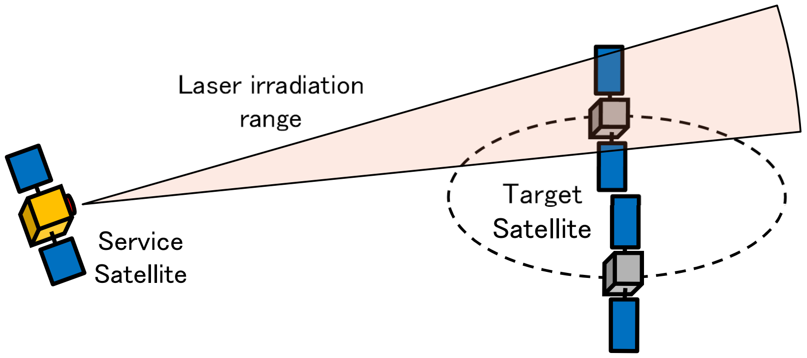
- Always capturing the targets by the camera
- Limited laser and camera range

Evaluate the closest distance and laser irradiation time

Design Policy

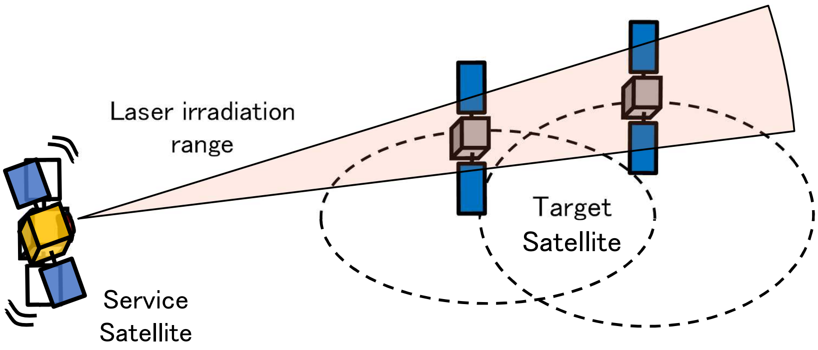
Formation 1

- Same relative orbit
- One by one irradiating laser
- No attitude control



Formation 2

- Different relative orbit
- Always irradiating laser
- Need attitude control



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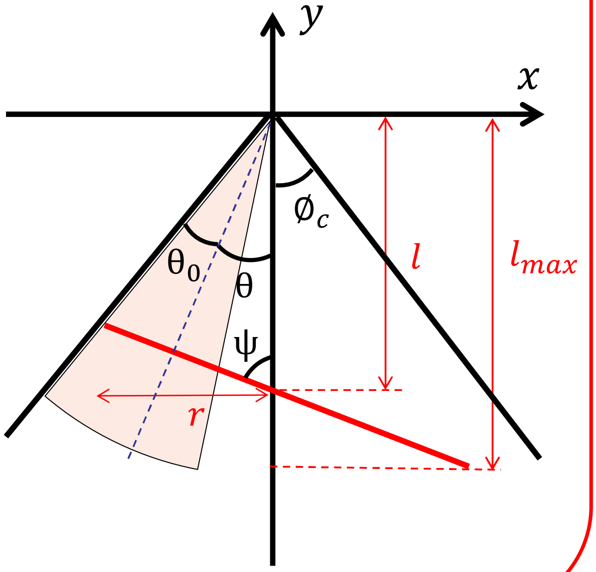
Formation flying design for multi-deorbit using laser ablation

1. Background 2. Preliminaries **3. Design** 4. Evaluation and Conclusion

Formation 1

Input

$\emptyset_l, \emptyset_c, l_{max}, r$



output

l, θ

$$r_{max} = \frac{\tan\phi_c}{1+4\tan\phi_c} l_{max} \qquad l = l_{max} - 2r$$

$$\theta = \begin{matrix} -\operatorname{atan}\left(\frac{l\sqrt{-l^2\tan(\theta_0)^2+4r^2\tan(\theta_0)^2+r^2}+2r^2}{l^2-4r^2}\right) \\ \operatorname{atan}\left(\frac{l\sqrt{-l^2\tan(\theta_0)^2+4r^2\tan(\theta_0)^2+r^2}-2r^2}{l^2-4r^2}\right) \end{matrix} \qquad \theta_0 = \frac{\phi_l}{2}$$

Result

r [m]	12.0
l [m]	176.0
θ [deg]	2.53
laser irradiation time [%]	27.2
closest distance [m] (in RN plane)	24.0 (24.0)

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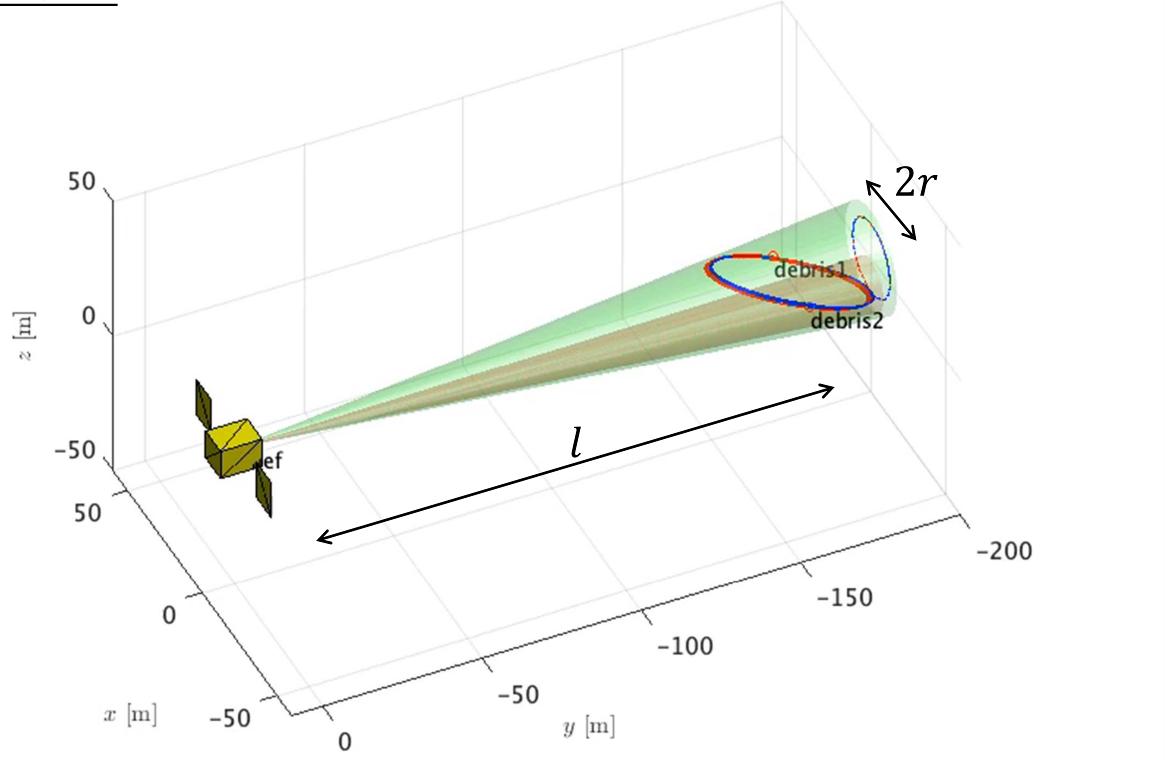
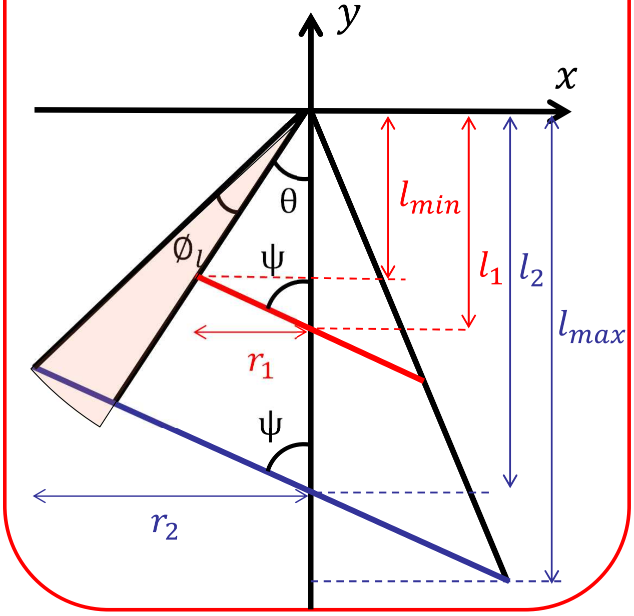
Formation 1



Formation 2

Input

$\emptyset_l, \emptyset_c, l_{max}, l_{min}, r_1$



output

r_2, l_1, l_2

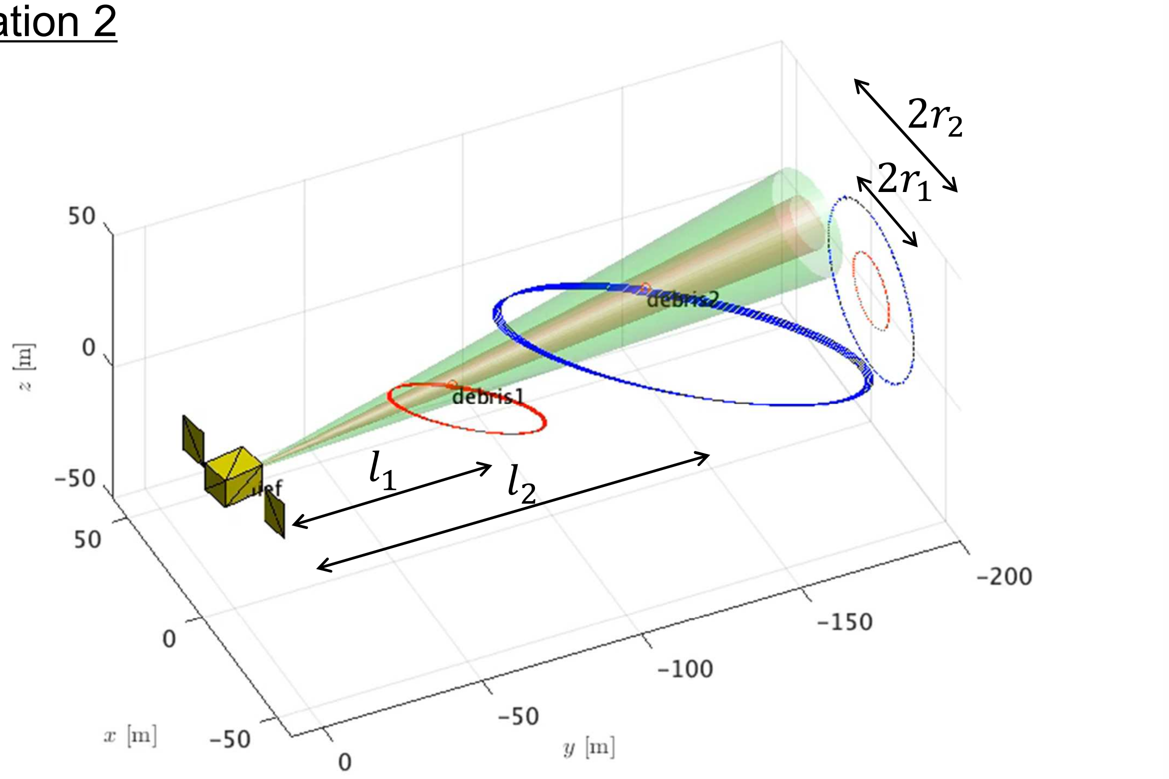
$$r_2 = \frac{\frac{l_{max}}{l_{min}+2r_1}(1+W)}{1+\frac{2r_1}{l_{min}+2r_1}(1+W)} r_1 \begin{cases} W = \frac{\sin\phi_l \sin\psi}{\sin\theta \sin(\phi_l+\theta+\psi)} \\ \theta = arctan\frac{r_1}{l_{min}} \\ \psi = arctan\frac{1}{2} \end{cases}$$

$$l_1 = l_{min} + 2r_1 \qquad l_2 = l_{max} - 2r_2$$

Result

r_1 [m]	12.0
l_1 [m]	74.0
r_2 [m]	28.6
l_2 [m]	142.8
laser irradiation time[%]	100.0
closest distance [m] (in RN plane)	39.2 (16.6)

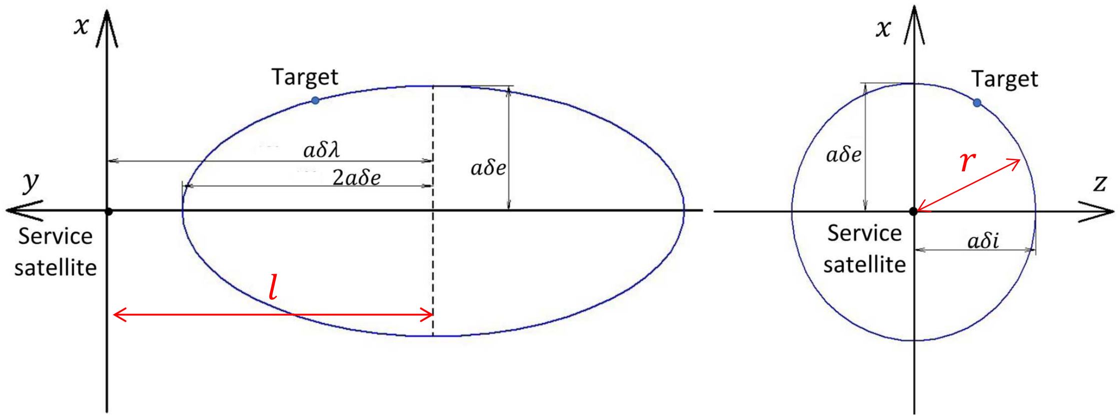
Formation 2



Evaluation

Result

	Formation 1	Formation 2
r_1 [m]	9.0 – 12.9	5.0 – 21.0
laser irradiation time [%]	40.5 – 25.0	100
closest distance [m] (in RN plane)	18.0 – 26.0 (18.0 – 25.8)	70.0 – 19.3 (16.5 – 12.9)



Conclusion

- As the first step of multi-deorbit, this research designed two nominal formations.
  Formation 1 → No attitude control
  Formation 2 → Need attitude control
- Formation 2 has longer laser irradiation time and better collision avoidance performance.
- The user should select the formation based on whether or not attitude control.

Future works

- Orbit Control for configuration of the formation
- Analysis of safety between non-cooperating objects

References

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