Feasibility Analysis of Small-Size Space Debris Removal in Low-Earth Orbit by Space-Based Laser Ablation

E. Bögel[1,3], H. Buurmeijer[2,3], **L. Veithen**[3], F. Meijering[3], G. Alves Teixeira[3], D. Rehling[3], J. Bas Fernández[3], P. van Wolfswinkel[3], N. Zandvliet[3], J. Struziński[3]

[1] Delft Institute of Applied Mathematics, Delft University of Technology, Delft, The Netherlands
[2] Aeronautics & Astronautics, Stanford University, Stanford, United States of America
[3] Faculty of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands

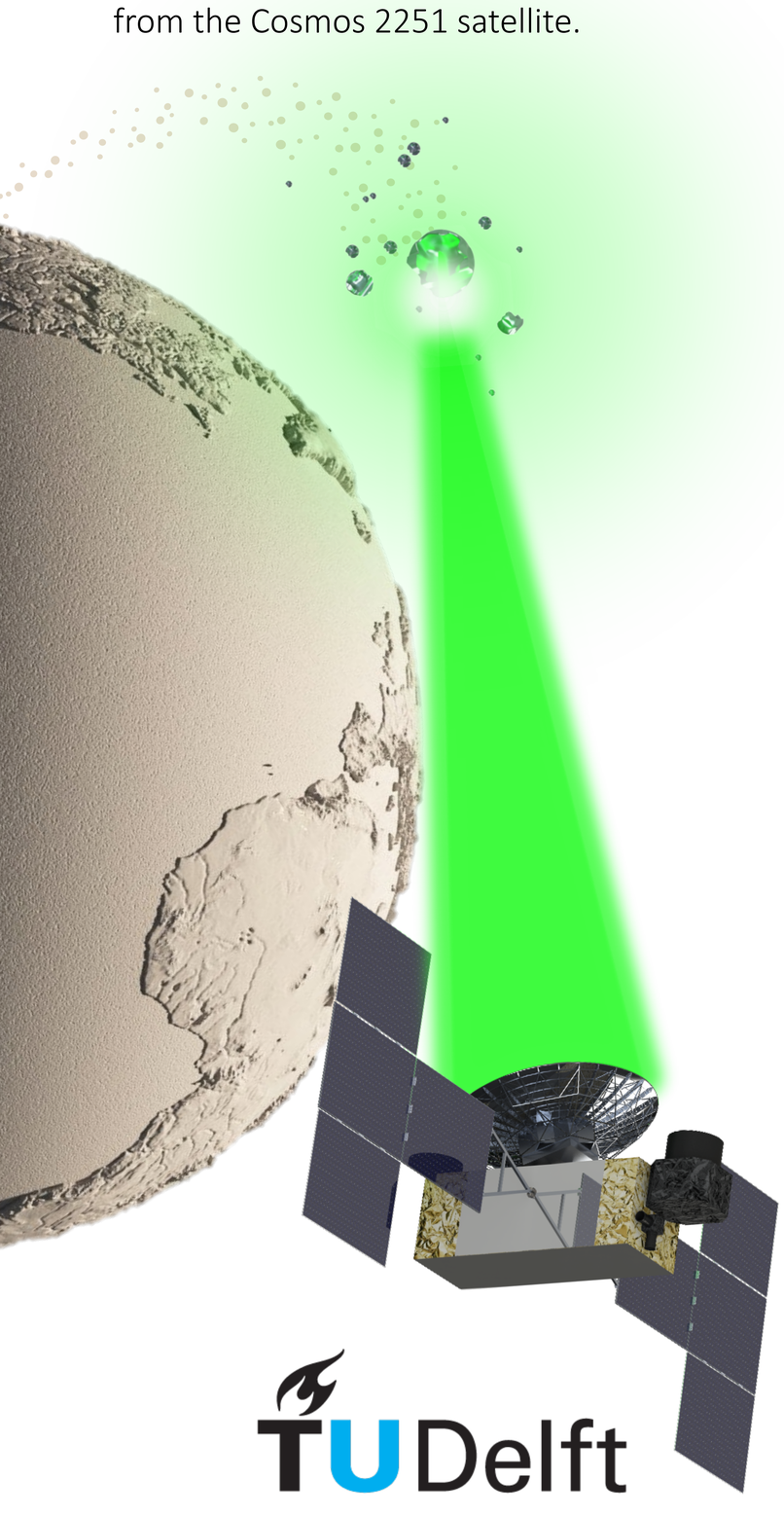
Keywords: small space debris removal, laser station, orbital collision

Take home message: A space-based laser mission aiming to de-orbit 50% of the 1-10 cm debris resulting from an on-orbit catastrophic event is conceptually, technically, and financially feasible with technology within reach in the next 5-10 years.

The Kessler syndrome predicts the denial of protected space regions through space debris build-up resulting from a cascading collision process. While laser ablation methods have been proposed for the removal of 1-10 cm debris objects resulting from such collision, no mission-level feasibility analysis has been performed so far. Here, we show the technical and financial feasibility of a a space-based laser mission aiming to de-orbit 50% of the debris generated by an on-orbit catastrophic event in LEO. We developed an agent-based model simulating the mission performance on the Cosmos-Iridium dataset.

Case Study

- The Cosmos-Iridium collision occurred on the 10th of February 2009 at an altitude of 789 km.
- The NASA Standard Satellite Breakup Model is used to generate 23091 1-10 cm debris objects from the Cosmos 2251 satellite.



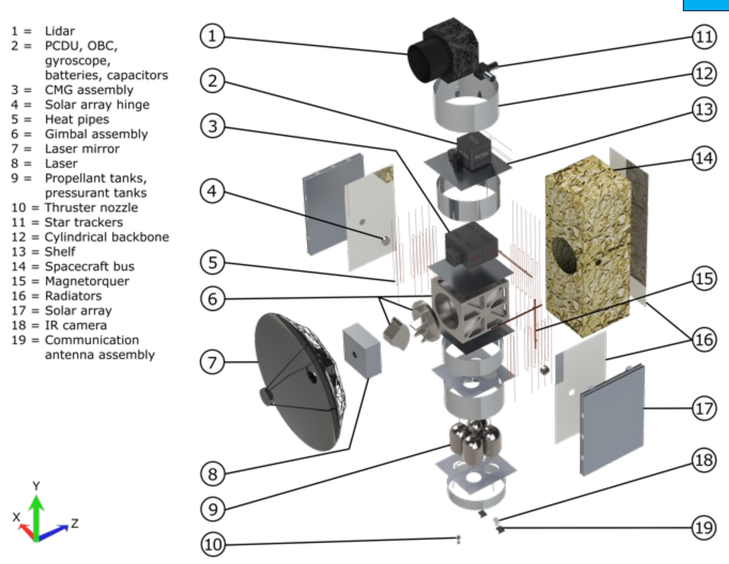


Figure 1: Spacecraft Design
A complete preliminary design of the space-based laser spacecraft was developed to support this study. Only the lidar and ablation laser systems require further R&D.

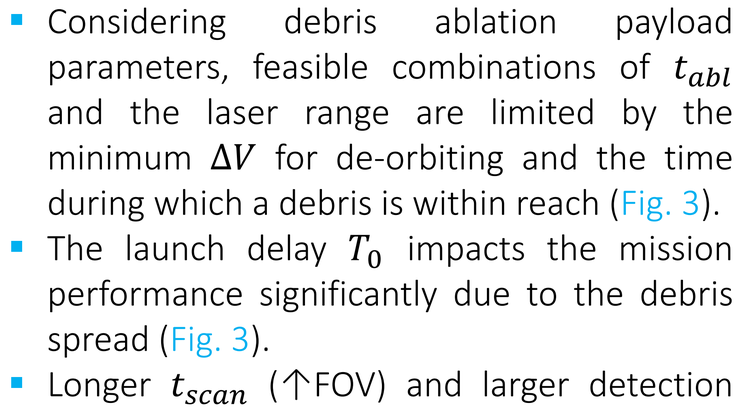


Figure 2: Cost Estimate
The spacecraft design was used to obtain a most likely cost estimate of 550 M€ per system (FY2022). However, this cost can be lowered through small series production.

Approach

1. Laser ablation propulsion principles are used to derive the ΔV imparted on a debris:

$$\Delta v_{opt} = C_{m,opt}\phi_{opt}\left(\frac{A}{m}\right)_{\text{object}} f t_{\text{abl}}$$

2. An agent-based model is setup with the Cosmos-Iridium collision as representative dataset. Debris are passive agents but the spacecraft can detect debris through its FOV and de-orbit them through laser ablation.
3. Payload performance parameters are varied to study the mission feasibility.

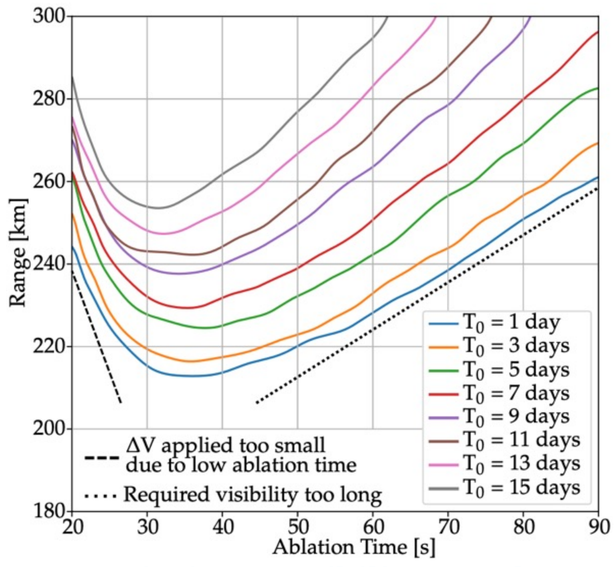


Figure 3: Mission Feasibility Enveloppe
Feasibility envelope on ablation range and ablation time as a function of the launch delay. Combinations above the line yield removal times within 1 year.

Results

- Considering debris ablation payload parameters, feasible combinations of t_{abl} and the laser range are limited by the minimum ΔV for de-orbiting and the time during which a debris is within reach (Fig. 3).
- The launch delay T_0 impacts the mission performance significantly due to the debris spread (Fig. 3).
- Longer t_{scan} (↑FOV) and larger detection ranges yield a better mission performance, but all detection ranges are similarly efficient for a scanning time around 10 s (Fig. 4).

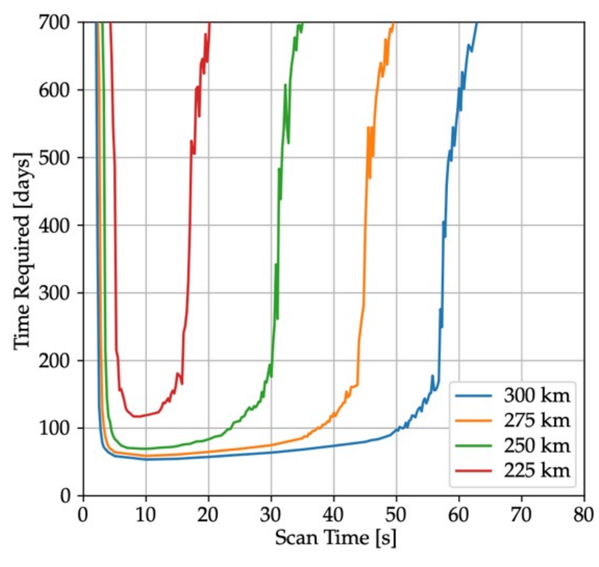


Figure 4: 50% Removal Time Dependence
50% removal time as a function of the scanning time for different ablation ranges. All ranges have feasible configurations around 10 s scanning time.

Discussion

1. A small space debris removal mission using a space-based laser is conceptually feasible. Particularly, for an ablation range of 250 km, 50 s of ablation and a scan time of 5 s, 50% of the debris are removed in 132.78 days despite a 5 day launch delay.
2. The spacraft bus design is feasible with state-of-the-art COTS components, but laser and lidar need further R&D.
3. The mission cost is reasonable compared to the cost of losing access to LEO.

Conclusion

A small space debris removal mission using a space-based laser is both technically and financially feasible. The system is capable of de-orbiting 50% of the fragments of a collision similar to the Cosmos-Iridium event. The spacecraft design results in a total mass of 2794 kg, peak power of 27.7 kW during 50 s and can be launched using an Ariane 62. The mission is projected to cost 550 M€ (FY2022).