Ablative collision avoidance for space debris in the Low Earth Orbit by a single multi-kJ pulse from a ground-based laser

Stefan Scharring, Gerd Wagner, Jürgen Kästel, Wolfgang Riede, Jochen Speiser
German Aerospace Center (DLR), Institute of Technical Physics

Abstract

We analyze the conceptual idea whether already a single high-energy laser pulse, emitted from a laser station on ground, might cause material ablation at the surface of a debris object generating recoil for a sufficiently high velocity change to allow for space debris collision avoidance. The simulation results on laser imparted momentum are discussed in terms of irradiation elevation angle, displacement on the orbital trajectory, momentum transfer uncertainty, success probability, debris material and limitations due to debris size, mass, and the required minimum fluence for the initiation of a laser ablation process.

Simulation method

- Computation of turbulence compensation for laser power beamng using adaptive optics
- Numerical simulations based on RTIDL debris targets
- Simplified geometries using SIA DSS/CO data on shape, mass, dimensions and cross-sectional area
- Ray-tracing based simulation code EXPO2D for the computation of recoil from laser-induced surface ablation
- Simulation of laser-material interaction based on experimental data for Al, Cu, and stainless steel as generic sample materials
- Consideration of random orientation and beam-pointing jitter by Monte Carlo sampling

Results

Laser-ablative momentum generation is limited for lower fluences by the ablation threshold and small momentum coupling in the vaporization regime, resp. Herein, laser beam quality constraints demand for moderate distances between ground station and debris, which makes laser-ablative momentum transfer more effective for LEO objects at smaller altitudes. Low beam pointing elevations are beneficial to yield high in-track deacceleration, but detrimental in terms of laser fluence.

Debris in-track displacement

Depending on target material, size and mass, velocity changes in the order of 1.0 mm/s for a single multi-kJ pulse from a ground-based laser can be expected, which corresponds to a displacement of ~2.5 m to ~250 m one day after the laser engagement.

Momentum transfer on smaller debris objects can be less efficient due to sticking losses within a comparably large laser spot.

Beam pointing jitter and sparse information on target orientation yield large scatter in the prediction of momentum. Related success probabilities for collision avoidance have been derived from statistics over a multitude of Monte Carlo samples.

Summary

A single multi-kJ laser station might constitute an attractive stand-alone alternative to a network of high-power CW laser stations. Alternatively, it might serve as a useful supplementary device in a hybrid (CW + pulsed) framework for collision avoidance. Responsible use and consumable misuse should be addressed by global governance regulations.