Abstract

Small satellites, e.g. cubesats, do not tend to incorporate propulsion subsystems that can compensate for perturbation forces, which causes orbital decay. Cubesats are especially susceptible to the phenomenon of orbital decay, which limits their potential performance, since these effects are more noticeable in Low Earth Orbit (LEO). We postulate that a network of ground-based lasers could extend the operational lifetimes of these satellites by applying a photonic force onto their surfaces. This boosting force would help to counteract the degrading force, which is mainly produced by the drag of the atmosphere. This solution may present an advantage for low cost missions, in that it would enable longer mission durations without the need to incorporate a propulsion system, which comprises a large part of the mass and budget of the power constraints of a satellite.

This poster presents an analysis of the trade space for both the required network of laser ground stations and the satellite orbits. The analysis is based on simulations of the orbital decay of model satellites.

The LightForce concept

LightForce is a novel concept that utilizes an array of ground-based lasers to illuminate objects for orbit correction for various applications. Photon pressure induced by ground-based lasers (fig. 1) results in a force on the order of 1 nN/s on the order of 1 mm/s to 1 cm/s. This can be used as a debris collision avoidance system and to increase the lifetime of small satellites in LEO. 

Features:
- Collision avoidance vs. de-orbit: 1000 times less than gravity
- Refined orbit determination through laser ranging from the same ground stations
- Cost effective: all equipment is ground-based and can support numerous spacecraft

Approach and assumptions

An array of laser ground stations can be used to increase the lifetime of small satellites in LEO:
- 20 kW of power output for each station (tab. 1)
- Station locations selected for high access time
- Simulations assume a 3U satellite
- Circular orbits
- Best case scenario: stations having access to the satellite at every pass

Methodology

- Full simulation of orbital dynamics and laser beam propagation with a custom high precision orbit propagator
- Selection of different ground station location and power output
- Study of a wide range of orbits and satellites with an area to mass ratio of interest
- Goal: Observe the benefits of the applied photonic pressure
- Success criteria: An increment of 30% of the orbital lifetime

Results

Baseline (3 locations)

- LightForce capability to extend the lifetime depends on orbital altitude, laser access and satellite area to mass ratio
- Increasing area to mass ratio increases photonic force but also drag at low altitude
- One hundred baseline stations (33 at each location) can increase the lifetime of a 3U cubesat by 50% for a 450 km circular orbit

Additional locations:

- Increased continuous low thrust improves the performance, if the same number of stations is distributed over multiple locations

Economics and Additional Applications

- Using LightForce for station-keeping alone is economically viable only for high cost satellites
- Maximum satellites engaged with one system (multiple stations) is limited
- Additional applications needed to ensure economic viability, including:
  - Space debris collision avoidance
  - Modulating retro-reflector communications
  - High-precision orbit determination

Conclusion

- LightForce can increase the lifetime of small satellites from Earth with a significant required infrastructure
- Strategically located arrays of laser stations on ground improve the performance
- Benefits of Lightforce for station-keeping include:
  - Savings on power and mass budget for orbit maintenance
  - Increased mission time for constellations
- LightForce can be used at the same time for various additional applications