Laser Photonic Propulsion Force for Station-Keeping Applications

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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 budget and 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 laser stations to illuminate objects in orbit for various applications. Photon pressure induced by ground-based lasers (fig.1) results in Δv 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 Δv required
- 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

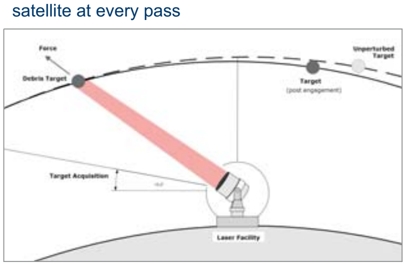

Figure 1: Schematic of laser system for orbital debris collision avoidance

Methodology

- Full simulation of orbital dynamics and laser beam propagation with a custom high precission 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

Table 1:Scenario input parameters for a baseline laser ground station

Laser	IPG YLS-10000-SM
Power	20kW (continuous)
Wavelength	1070 nm
Beam quality	$M^2 = 1.3$
Telescope Diameter	1.5 m
Atmosphere	US Standard (1976)
Aerosol content	MODTRAN rural (VIS=23)
Turbulence	Hufnagel/Valley 5/7

Table 2: Location of the sites chosen for the ground stations arrays during the simulation.

Ground based station locations		
Location	**Country**	**Altitude**
MAUI	USA	3067 m
KILIMANJARO	Tanzania	3881 m
PICO DA NEBLINA	Brazil	2636 m

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 stations (33 at each location) can increase the lifetime of a 3U cubesat by 50% for a 450 km circular orbit

Table 3: Number of baseline stations required for station keeping and 50% / 30% increment of lifetime. Stations distributed at the three locations listed in tab. 2

Orbit Altitude	Station Keeping	50% Increased orbital lifetime	30% Increased orbital lifetime
400 km	300 stations	225 stations	150 stations
450 km	210 stations	100 stations	60 stations

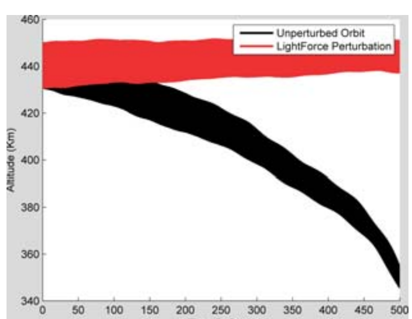

Figure 2: Station keeping for a 450 km equatorial circular orbit with the three station locations listed above.

Additional locations:

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

Table 4: Results with a set of five locations all placed in equatorial latitudes.

Altitude	Station Keeping	50% Increased orbital lifetime	30% Increased orbital lifetime
400 km	250 stations	125 stations	75 stations
450 km	125 stations	75 stations	40 stations

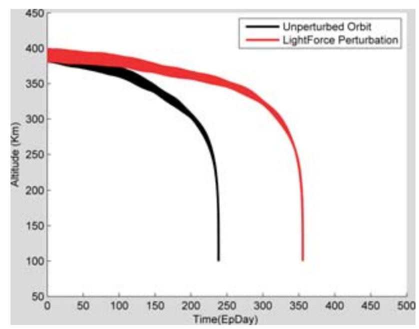

Figure 2: Lightforce perturbation for a 3U satellite in a 400 km and equatorial circular orbit with 5 arrays of stations distributed at 0 degrees of latitude along the equator. Lifetime increment of 50%.

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

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