Space Debris Mitigation Utilizing Laser Ablation

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UC SANTA BARBARA SUMMER SESSIONS Research Mentorship Program

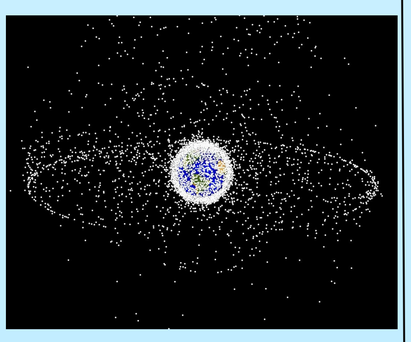
Abstract

Space debris poses an increasingly serious threat to satellites and spacecraft. Our project will aim to mitigate this problem using an array of kilowatt-class lasers, powered by photovoltaics. An experiment was implemented to study this using a directed energy system to completely vaporize or propel space debris out of Earth's orbit. Common materials found in space debris were tested using a 60MW/m^2 laser to simulate mission level flux. We vaporized samples in a low thermal conductive sample holder inside a vacuum chamber. The difference in the reflection of a measurement laser aimed at a mirror on the torsion balance correlated with success of vaporization/ablation. Applications of this system include diminishing or propelling space debris, which can result in reduced risk of collision.

Space Debris

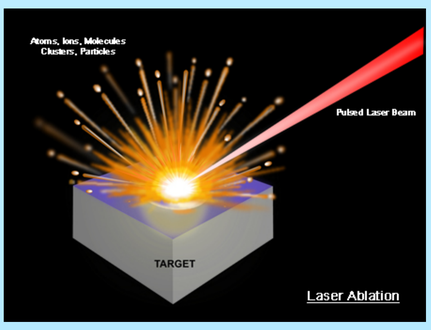
The Problem

- Space debris accumulating
- Kessler syndrome: Debris will continuously build up causing collisions
- 2007 - China destroys their spacecraft creating debris
- 2009 - Debris from Russian satellite destroys American satellite
- 2015 - American satellite explodes because of faulty battery



https://en.wikipedia.org/wiki/Kessler_syndrome

The Solution



http://www.appliedspectra.com/technology/LIBS.html

DE-STAR

- Array of powerful lasers
- Orbits Earth
- Powered using solar panels
- Use ablation to push debris out of orbit or completely vaporize

Goals

- Use laser ablation to decrease amount of debris
- Observe how the laser reacts with materials of low thermal conductivity
- Determine how powerful the laser will need to be
- Measure the thrust produced

Acknowledgements

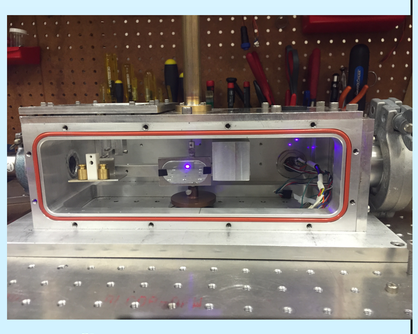
Special thanks to NASA for their NASA California Space Grant, my mentor, Travis Brashears, Lina Kim, Ross Melczer, and the Deep Space Laboratory: Philip Lubin, Travis Brashears, Payton Batliner, Jonathon Madajian, Aidan Gilkes, Jana Georgieva, Olivia Sturman, Kenyon Prater

The Setup

Laser

- Frequency: 808nm
- Attached to thermoelectric coolers
- Fed through fiber optic cable to lens

Torsion Balance



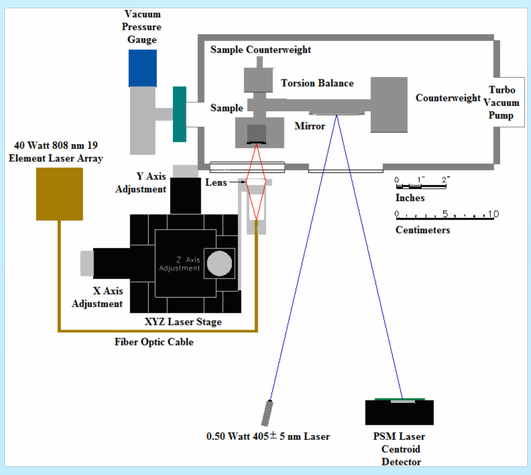
- Measures thrust produced by sample of space debris
- Sample holder on left
- Counterweights
- Mirror in center
  - Measurement laser - reflects off mirror onto detector which measures movement

Vacuum Chamber

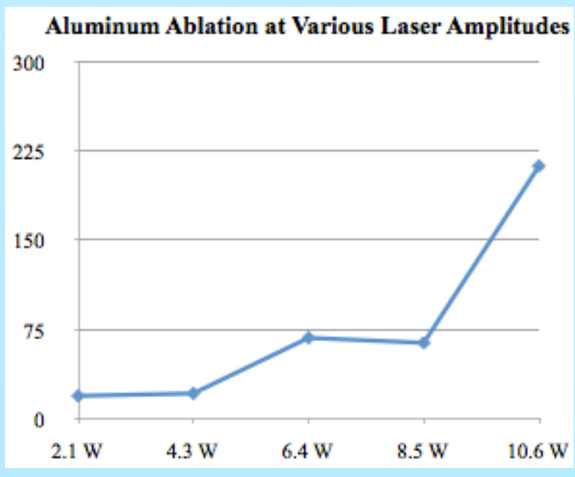
- Simulate space - low pressure
- Roughing pump and turbo molecular pump used
- Two quartz windows
  - One for ablation laser
  - One for measurement laser

Samples

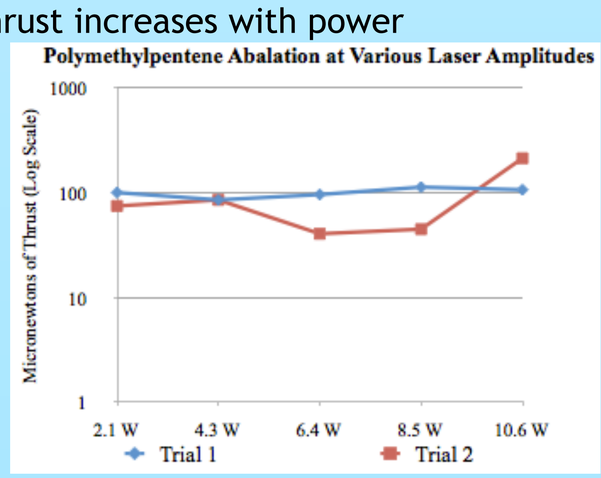
- Aluminum, titanium, carbon fiber, stainless steel, ceramic paint
- Placed in a low thermally conductive holder



Thrust Produced

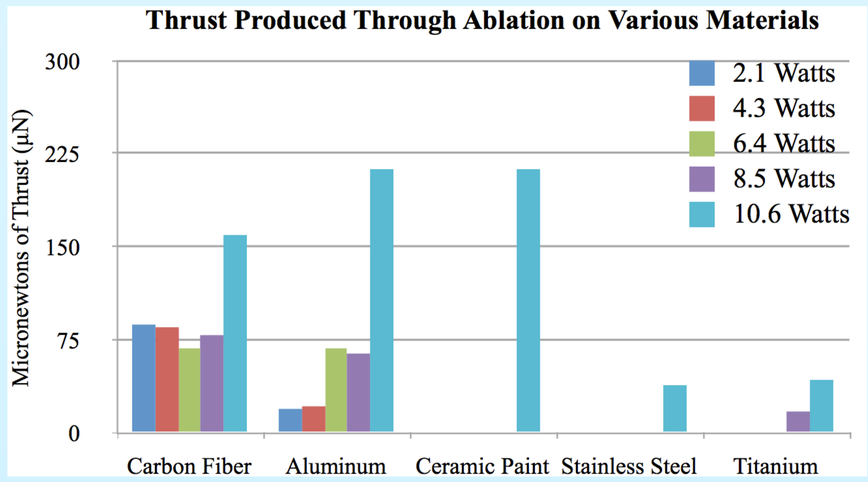


- Aluminum - most thrust at 10.6 W
- Thrust increases with power



- Carbon fiber - could not be ablated
- Polymethylpentene - polymer in carbon fiber - completely vaporized
- Similar values for microns of movement

Thrust of Multiple Samples



- Different materials ablated 5 power levels
- Carbon Fiber - most easily ablated
- Stainless steel and titanium very little thrust

Discussion and Conclusion

Tests

- Carbon requires 715 kJ/mol to vaporize - unable to be delivered by laser
- Polymethylpentene - holds fibers together - can be ablated
  - Ablation not maximized since ablated too easily
- Same amount of thrust at each power level
  - All of the polymer is vaporized
  - Coupling Coefficient - 19.2 μN/W
- Aluminum
  - Coupling Coefficient - 10.4 μN/W
  - High thermal conductivity - 237 W/mK
  - Low heat of vaporization - 293 kJ/mol
- Ceramic Paint - Able to be ablated easily
- Stainless Steel
  - Low thermal conductivity - 15 W/mK
- Titanium
  - Low thermal conductivity - 180 W/mK
  - High heat of vaporization - 425 kJ/mol
- Both stainless steel and titanium - high luster - reflect laser

Problems and Future Work

- Macor Holder - Gave incorrect results
- Bumped into cable - Use automatic focusing
- Not a complete vacuum - Diffusion pump
- More tests and more materials
- CubeSat - Tests in space

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