Design, Fabrication and Testing of Solar Thermal Thruster for CubeSats During Covid-19

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Motivation

Solar thermal propulsion offers compelling properties in today's space ecosystem. High thrust and efficiency along with inert and refuelable propellants like water make solar thermal propulsion favorable for CubeSats[1].

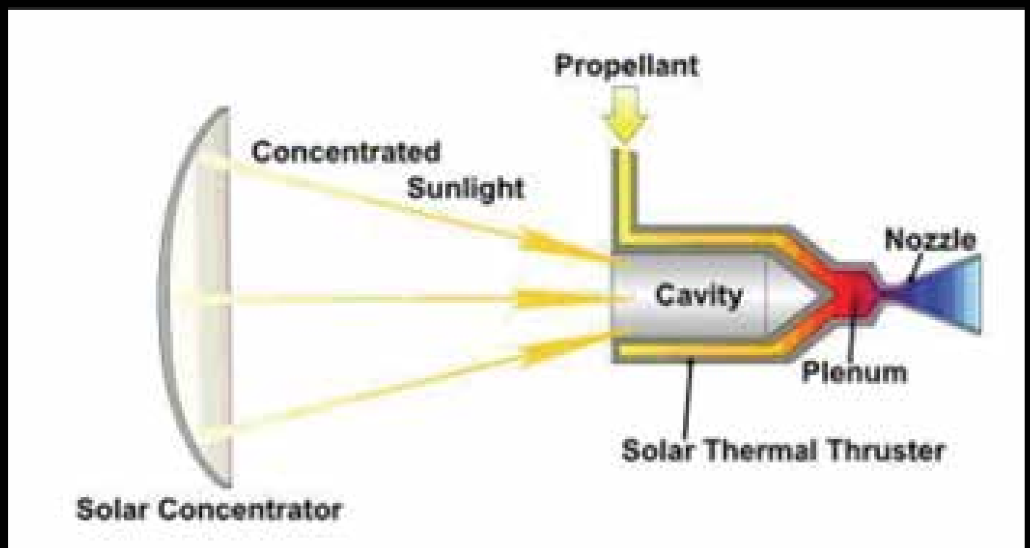


Figure 1: Design for Solar Thermal Thruster [4]

Prior work [2] supports the feasability of solar thermal propulsion at a theoretical level. With recent delopments in optical materials enabling solar thermal propulsion, current research can focus on prototyping solar thermal propulsion.

Project Objective

Design, build and prototype a solar thermal propulsion system to encounter obstacles not identifiable in theoretical research. This aims to help with directing future work done on solar thermal propulsion systems.

Background

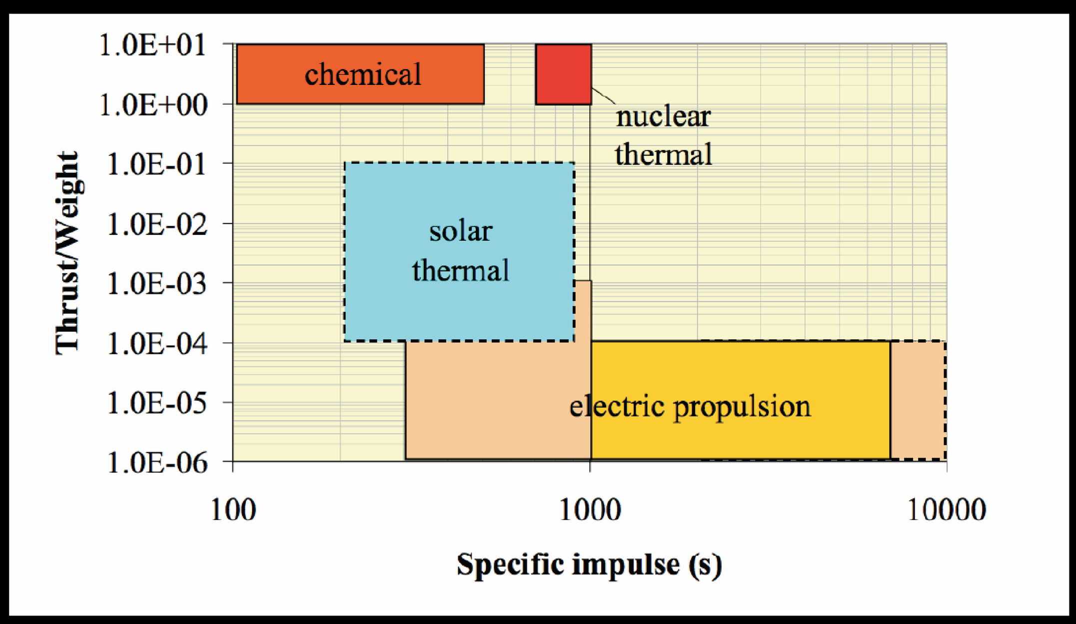
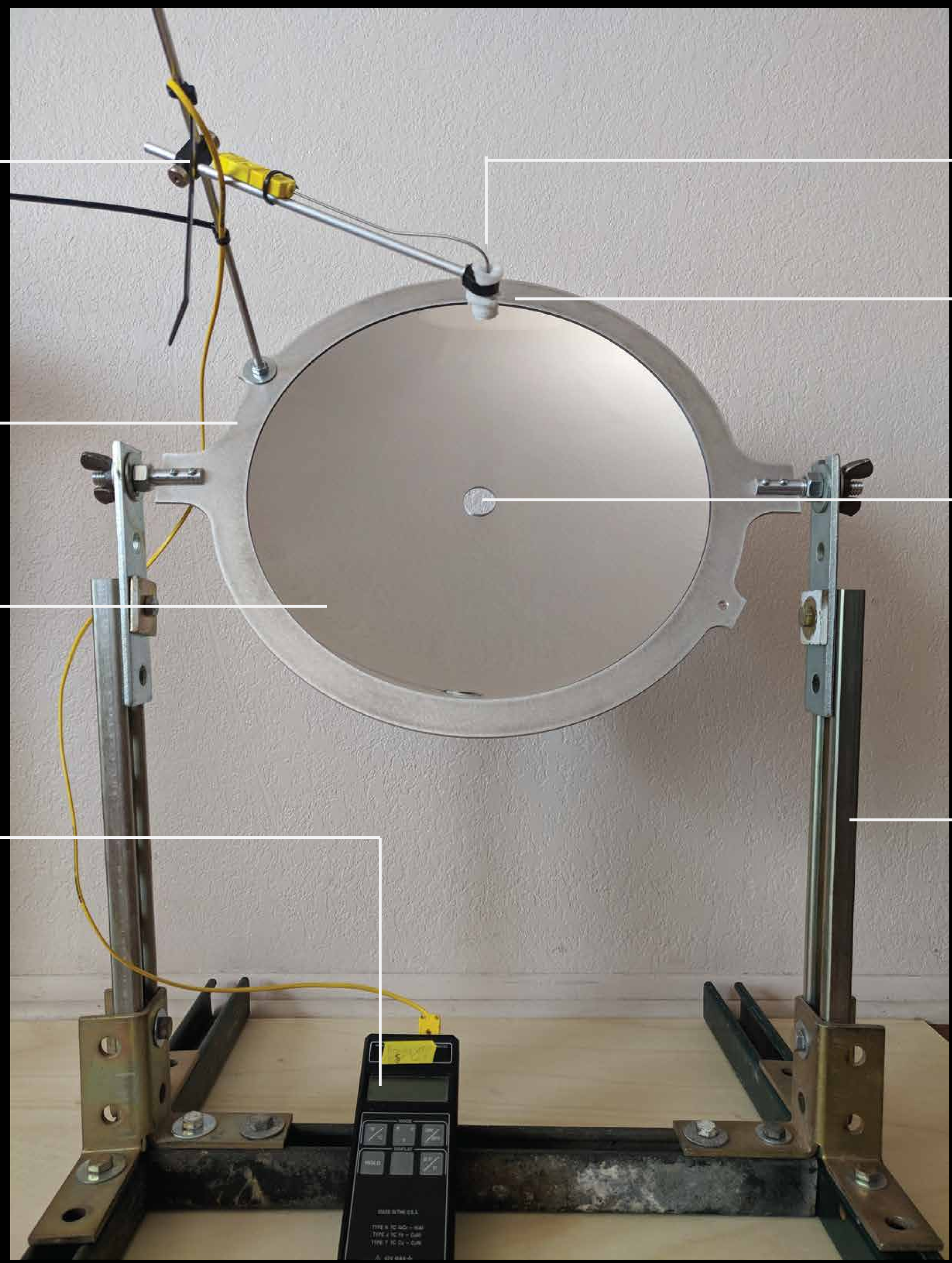


Figure 2: Solar Thermal Comparisons [3]

Precision Requirement

The setup shown in this poster relied on hand adjusting the position of the secondary mirror to redirect and focus incoming sunlight. During testing, it was impossible to properly redirect a focused beam of light by hand. A raytracing simulation was written to diagnose the precision required. It was found that a 0.01 inch change in mirror position would redirect the light enough to miss the engine chamber.

Protoyping Setup for Solar Thermal Testing



Light Ray

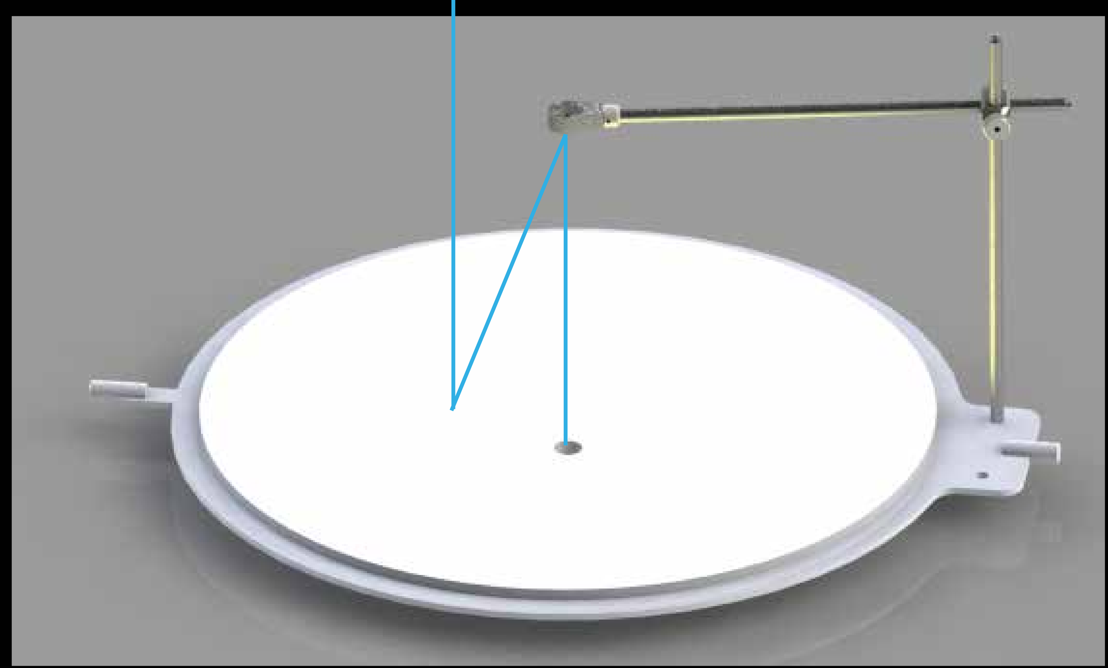


Figure 4: Rays Behavior in Afocal Configuration

Mirror Configuration

To achieve the high temperatures required for efficient thermal propulsion (greater than 1000 C) sunlight has to be concentrated to an area 3000 times smaller than the area of the main mirror. Two mirrors were used to minimize area lost to objects blocking the primary mirror. The engine chamber would be behind the primary mirror.

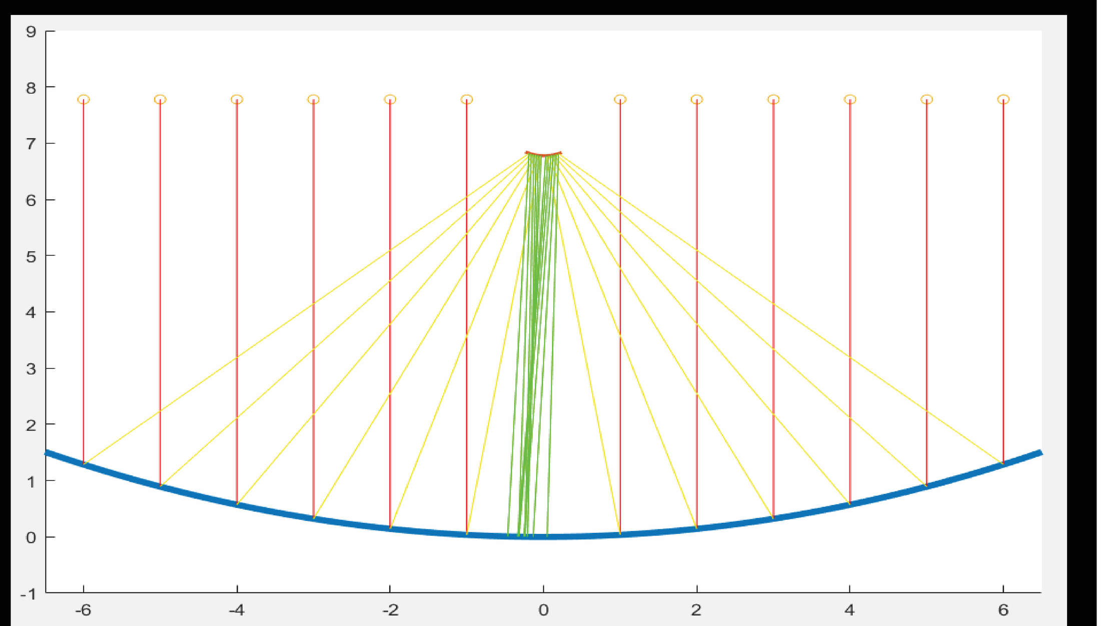


Figure 6: Collimated Light with Off-Adjustments

Optical Accuracy

When testing mirror placement,f ocal length of the primary mirror was significantly different from what was listed. For high Requirements on accuracy, imaging grade optics are required.

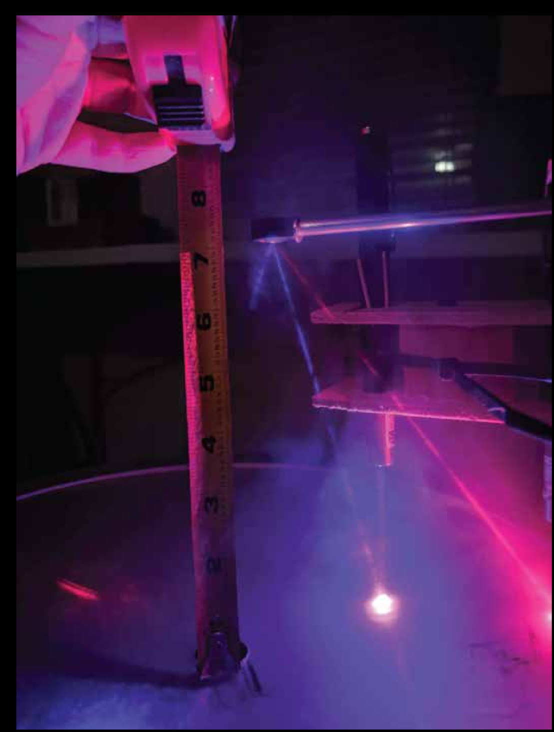


Figure 5: Laser Focal Finding

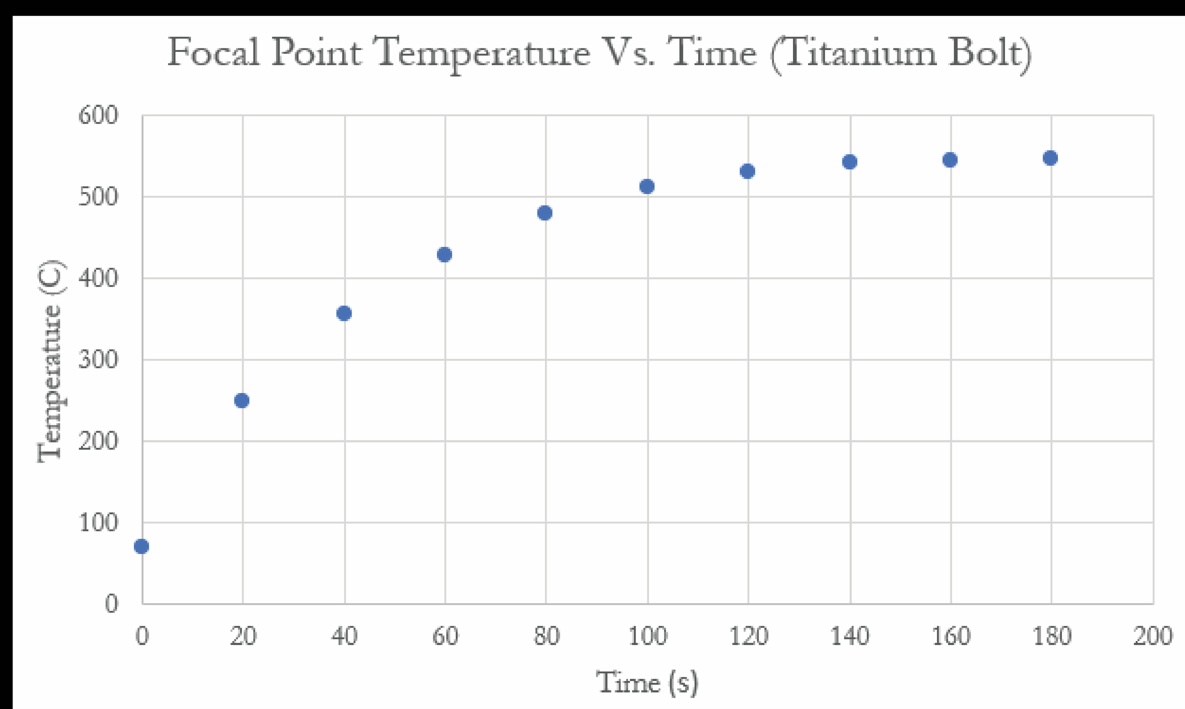


Figure 3: Prototype Thermal Performance

Specifications

Main Mirror Area: 0.085 m^2
Concentration ratio: 3400
Power Collected: 77 W

Main Mirror: 13" Parabolic Acrylic from Green Power Science

Secondary Mirror: 12.5mm Spherical
F: 6.1 mm from Edmund Optics

Propellent Max Temperature: 1000 C
Max Flow Rate: 12.8 mg/s
Flow Length Required: 10 cm

Discussion

Low budget optical components are not suitable for solar thermal propulsion. There is a higher cost associated with custom optics as well as high quality reflectors. Not taking into account the cost of high precision mounting and engine chamber design and fabrication, the high efficiency benefits of solar thermal could beoffset by more expensive but higher collection area photovoltaics.

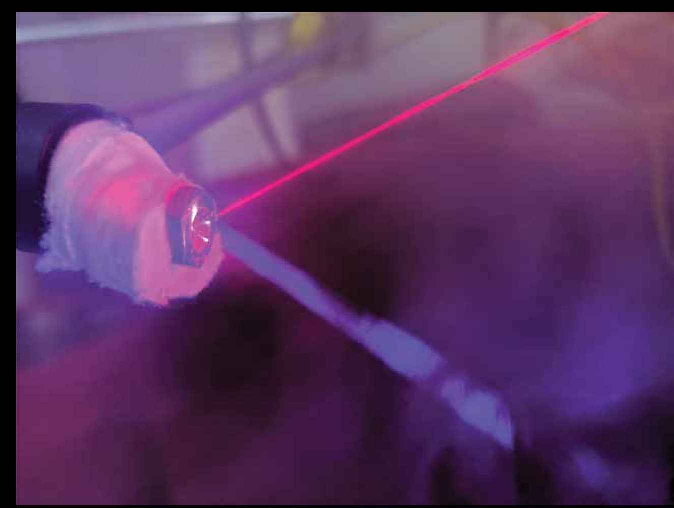


Figure 6: Bolt Alignment for Testing

Conclusion

The design and build process of a solar thermal propulsion system was followed to discover possible setbacks. It was found that concentrating sunlight with parabolic mirrors would require high quality optical components comparable to those used in imaging telescopes. Simulations also showed that mounting precision on the scale of 0.001" is required to focus light at the cocentration ratios required for solar thermal propulsion.

References

[1] Salil Rabade, Nathan Barba, Gavin Liu, Laurence A.J. Garvie, Jekanthan Thangavelautham. "The Case for Solar Thermal Propulsion System for Interplanetary Travel: Enableing Simplified ISRU Utilizing NEOs and Small Bodies." IAC-16 (34659) Sept. 2016

[2] Jorge Martinez, Jekan Thangavelautham. "Propelling Interplanetary Spacecraft Utilizing Water-Steam." AAS 19-084. (n.d.)

[3] F. G. Kennedy and P. L. Palmer, Aiaa 2002-3928, 1 (2002).

[4] Laboratory of Space Systems, Hoikado University, Japan