GeoShade

Large Scale Sun Shade

1. Summary

GeoShade is developing a large scale sun shade to help buy time against global warming. The idea is not new, but the GeoShade's patent pending design breaks ground in terms of scale and cost, without requiring exotic new technology. The target design is a 1km radius sail craft, positioned near the Sun-Earth Lagrange 1 equilibrium point. One sun shade reduces enough solar insolation to cancel out the radiative forcing of 1.7M metric tons of CO_2 emissions.

2. Introduction

There is long history behind using sunlight for propulsion in space. Johnson et. al. (1) describes progress that had been made to date (2006) through NASA's In-Space Propulsion Technology Program, and working on demonstration programs with ATK Systems and L'Garde. These programs targeted bringing effective solar sail subsystems to TRL6 ground demonstration. An area of their focus was for the Heliostorm mission, which positions a coronal mass ejection (CME) detector farther sunward than is otherwise possible without the constant force from a solar sail. Currently, CME detectors must be positioned at the Sun Earth Lagrange 1 (L1) equilibrium point, about 1.5M km from Earth. Using a solar sail, the equilibrium location (sub-L1) moves sunward to about 2.4M km from Earth, roughly doubling the early warning from 30 minutes to an hour.

In 2019, the Planetary Society launched Lightsail 2, which is the first spacecraft in Earth orbit propelled solely by sunlight (2), demonstrating a significant milestone in technology readiness level of solar sail craft. Next year, the Near Earth Asteroid (NEA) Scout is slated to launch and attempt a rendezvous with an asteroid.

Solar sails can be enlisted in the fight against climate change. As one of many solar radiation management (SRM) techniques, solar sails can reduce the amount of solar flux reaching Earth. This application requires a dramatic increase in scale to make a useful contribution to the climate change problem. Roger Angel (3) proposes using an electromagnetic rail gun to launch billions of lightweight disks at 12.8 km/s to reach sub-L1. GeoShade has re-visited the problem of launching sun shades to L1, and developed a proposal that can accomplish the task using existing technology.

Fig 1. figure shows a range of solar sailing projects. The progression up and to the right has increasing sail area, and higher characteristic acceleration. Two versions of the GeoShade design are annotated towards the right side of the graph.

In addition to helping address the global issue of climate change, GeoShade can provide a platform for future NASA missions. Our experience with assembly of large structures in space will contribute towards the commercialization of space.

3. Climate Change and Radiative Forcing

Solar irradiation at Earth is 1367 W/m^2. Subtracting 30% that is reflected directly back to space, and averaging over the surface area of the Earth, rather than the cross-sectional area, this becomes 239

W/m². When the amount of incoming and outgoing radiation are balanced, the global Earth temperature remains stable. Anthropomorphic greenhouse gas emissions have changed this balance. Greenhouse gasses tend to transmit the wide range of incoming wavelengths of sunlight, but they block transmission of infrared radiation out from Earth. Currently, the incoming sunlight energy exceeds outgoing energy by about 3W/m². This imbalance (~1.2% today) is called radiative forcing (RF).

The 2018 International Panel on Climate Change (IPCC) report (4) states that radiative forcing is increasing at a rate of 270mW/m²/decade. Based on current global emissions of about 40G metric tons s of CO_2 equivalent greenhouse gasses, we can compute how much radiative forcing increases for each metric ton of CO_2 emissions.

Next, we can compute what fraction of the sun's radiation needs to be blocked to cancel out that 1 metric ton of CO_2 RF. That can be used to determine how large a sun shade needs to be at sub-L1 to cancel out the RF. The result is approximately 1.6 m² per metric ton of CO_2.

Andrew Lockley (5) explored the concept of having an authorized market for SRM offsets, similar to today's carbon credit offsets. Carbon credit offsets currently sell in the retail market for about $10/metric ton. In the commercial market, the price has a large variation, with an average price of about $3/metric ton. These prices are expected to rise as the size of the markets grow.

4. GeoShade Design

The GeoShade goal is to produce RF offsets on a very large scale using existing technology, with a heavy emphasis on minimizing cost. We start by targeting a sail size many orders of magnitude larger than existing solar sail programs. For example, a disk with a 1km radius.

The cost of deploying a sun shade to sub-L1 will be dominated by two items: the cost of the reflective film, and the cost of the launch. The launch cost is a function of the total mass, and the destination altitude.

Square rigger sails require rigid beams to hold the sail film in position. When considering dimensions in the km range, it became apparent that rigid beams come with a high cost. Their total mass would be greater than the mass of the sail film itself, driving up launch costs. In-space assembly of such long beams would also be a challenge. So it became clear that a spinning disk design is preferable at this scale. Centrifugal forces can be used to keep the sail extended, and the rigid beams can be replaced by much lighter cables.

Launch costs increase exponentially as the deltaV, or altitude, increases. Cost can be reduced by a factor of 5X to 10X if the sail can be launched to low Earth orbit (LEO), and sailed to sub-L1. Lightsail 2 is currently demonstrating the ability to sail in LEO. It uses a momentum wheel to alter the sail orientation twice per orbit. Changing the orientation of a very large spinning disk becomes problematic. A momentum wheel would need a very large mass to overcome the rotational momentum of the sail craft. Not only would the mass of a momentum wheel be unacceptably large, but without rigid beams in the structure, torques at the center of the disk would be ineffective at turning the disk.

GeoShade solves the problem by changing the orientation of many smaller sail panels rather than changing the orientation of the entire spinning disk. Fig. 2 shows a GeoShade sail craft, with a radius of 1km, and 528 individual sail panels. The sail panels are 50m x 100m (about the size of a football field), totaling 2.6M m² of sail area. Each sail panel is attached along 9 rings of a cable-based spider web-like framework. Each sail panel has its own actuator that can rotate the panel along its radial centerline. With this design optimization, the moment of inertia to reorient the sail panels is reduced by more than 3 orders of magnitude. The sail panels are sized such that a lightweight motor is sufficient to rotate a panel by 90 degrees twice per orbit, as required for orbit raising. Each 90 degree rotation occurs in less than 15 minutes.

Sail panels can be manufactured terrestrially, and folded compactly and securely for stowage into the launch payload volume. Fig. 3 shows how the 528 sail panel assemblies can be packed with its hub, collapsible rim, and robot arm and potentially small thrusters to provide initial rotational speed. The rim has a 15 meter radius, and is used as the base for staging and releasing the cable structure and sail panel assemblies. The robot arm can reach throughout this rim area. The hub position within the rim is adjustable with cables to give the opportunity to adjust the center of mass relative to the center of solar pressure. The robot arm un-stows and attaches each sail panel assembly to the cable structure starting from the outermost ring. After each ring of sail panels is readied, radial cables are extended to allow that ring to extend away from the rim. The process is repeated for each ring. Once the cable mesh has been fully extended from the rim, with sail panel assemblies attached, each sail panel is unfurled using simple rotational motions by its actuator. So the in-space assembly and deployment only relies on robot operation around the central hub and rim area. If needed, the robotic operations can be performed through manual remote control and feedback from cameras on the robot arm.

GeoShade intends to leverage as much material, components, and subsystems as possible from previous programs that have already achieved TRL9. New structural components should be realized without new technology, using straightforward mechanical engineering design. However, until the design work and validation is complete, these new components are starting around TRL3.

The GeoShade design can be easily scaled. A much smaller prototype can be built using just 3 of the 50m x 100m sail panels. This “small” prototype would be 50 to 150 times larger than NEA Scout and Lightsail 2.

5. Benefits and Business Model

Using a space-based sun shade to cancel out radiative forcing will benefit us all by buying time for our transition to renewable energy sources. There is an on-going effort to define protocols related to geoengineering radiative forcing reductions. The value can be compared to the value of carbon credits that are sold for carbon offset projects. The cost of deploying a GeoShade sun shade is about $60/metric ton equivalent. There are future paths to drive that cost down by at least a factor of 2.

The full scale GeoShade sun shade deployment will follow a much smaller prototype to advance the technology readiness level in sensible steps. It would ideally be launched within 2 years of funding. Launch of a full scale sun shade will likely be limited by the revenue model, but without that limit, could follow by about 1 ½ years (after the prototype arrives successfully at sub-L1). We are looking for grants to help fund the launch of the prototype.

6. References

(1) Status of Solar Sail Propulsion: Moving Toward an Interstellar Probe. Les Johnson et al. , 2006, https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20070037462.pdf

(2) https://www.planetary.org/explore/projects/lightsail-solar-sailing/

(3) Feasibility of cooling the Earth with a cloud of small spacecraft near the inner Lagrange point (L1), Roger Angel, 2006, http://www.pnas.org/content/pnas/103/46/17184.full.pdf

(4) https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf , p. 661

(5) Licence to chill: Building a legitimate authorisation process for commercial SRM operations, Andrew Lockley, 2016, https://journals.sagepub.com/doi/10.1177/1461452916630082

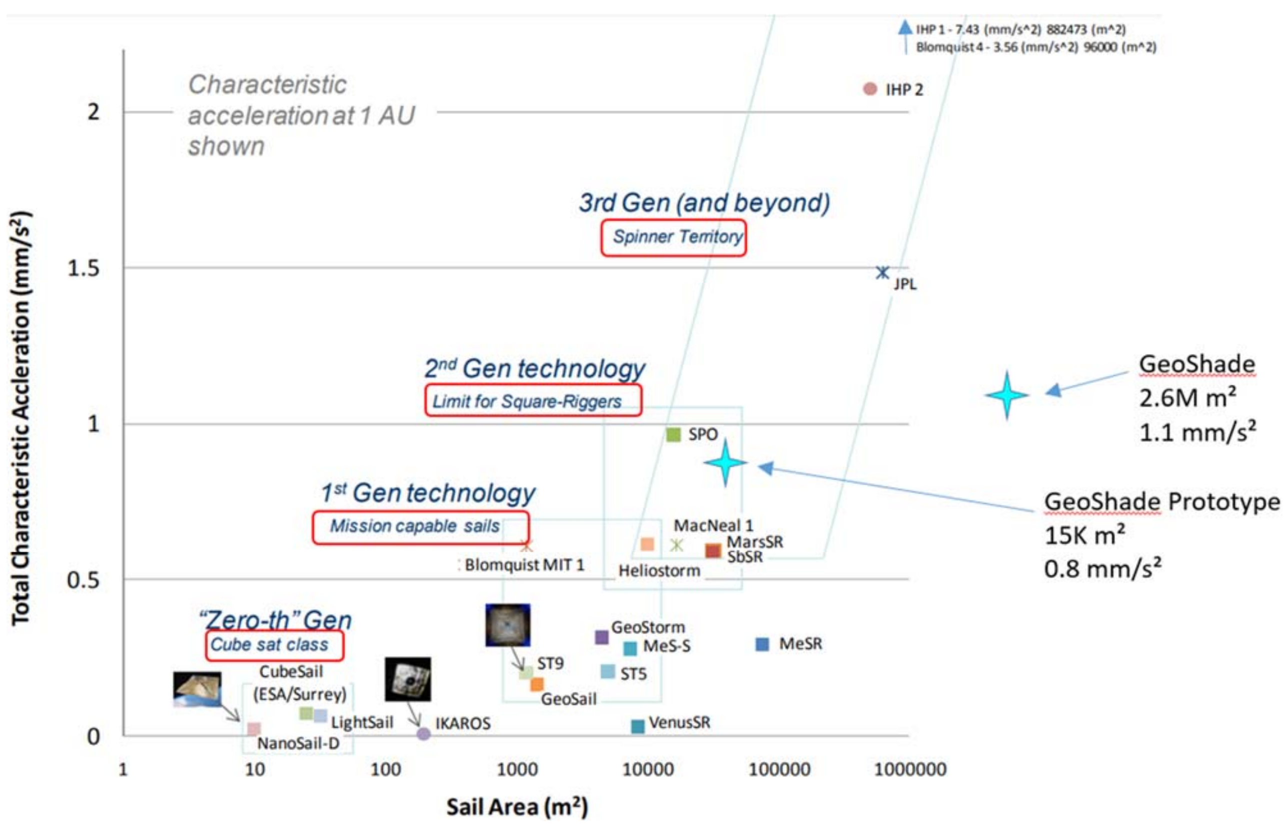

Fig. 1. Comparison to other solar sail projects.
(https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20110023680.pdf)

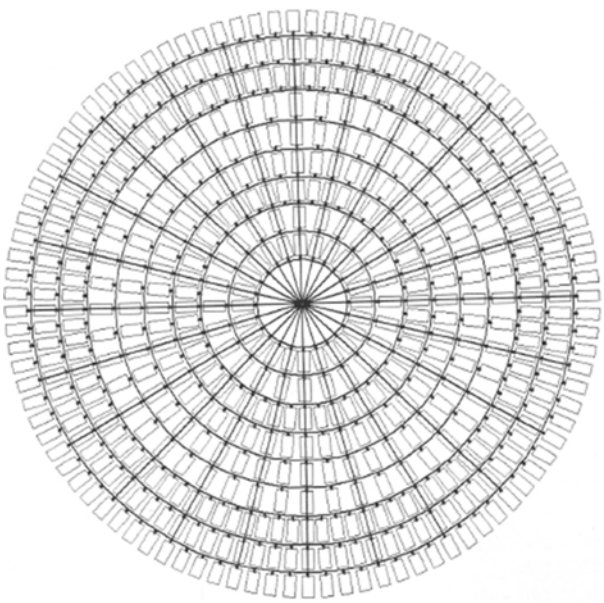

Fig. 2 1km radius sail craft with 528 sail panels.

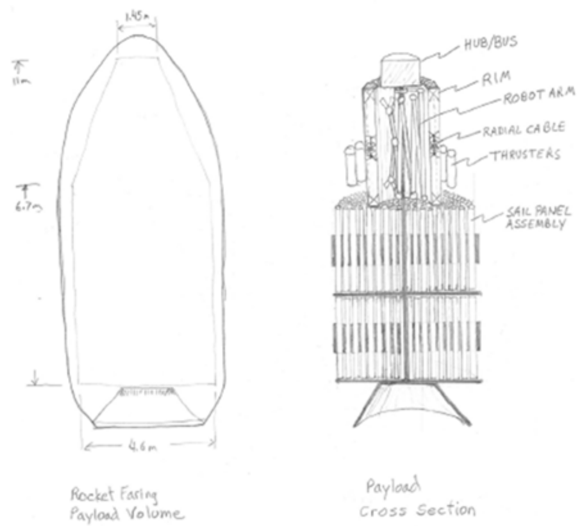

Fig. 3 Payload volume, and stowed configuration.