Solar One – A Proposal for The First Manned Interstellar Spaceship

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Abstract

In this paper it is presented the concept and design of a beam-powered propulsion system that could become the first manned interstellar spaceship. Light-sail spacecrafts such as the so-called Starships from the Starshot project have already been designed, but this type of spaceship might not be the best option to explore exoplanets in detail. Solar one would be a manned spaceship that would integrate three existing or near-term technologies, namely: the US Navy CFR fusion reactor, a larger version of NASA's Sunjammer light sail, and a continuous-wave version of the Teramobile laser system. With a mile-long light sail, Solar One could accelerate at almost 0.1 g and reach 30% the speed of light, arriving at the Alpha Centauri system in slightly more than 15 years.

1. INTRODUCTION

Several light-sail spacecrafts have already been tested. Some examples are LightSail 1 and LightSail 2, from the Planetary Society. However, these light-sails are propelled by sun light, and the solar radiation pressure is very small (just 6.7 Newtons per gigawatt, which equals to 9 Newtons/km2 or 1,400 watts/m2 at 1 AU). Lasers can provide radiation pressures much higher than the Sun. The laser system presented in this paper would have a power density of at least 10 million watts/m2.

Previous experiments with directed-energy weapons have proved successful. The Boeing YAL-1, a spacecraft equipped with a Kilowatt-laser, was able to deliver a power density over 100 watts/cm2 at a distance of 1 km (US Air Power, 2008).

In 2016, scientists announced the first design for a beam-powered spacecraft that could reach speeds of 0.2c. The project, called StarShot, entailed the idea of sending 1,000 nanocrafts with light sails attached that would be powered by a 100 GW laser array. As of today, the concept is still considered to be the best option for unmanned interstellar travel. Potentially habitable exoplanets such as Proxima b could be reached in only 20 years.

However, the idea is to send the Starshot nanocrafts 1 AU away from Proxima b. This distance would be enough to photograph the exoplanet, but perhaps not sufficient to notice the presence of a possible intelligent civilization less advanced than humanity. For this reason, and to better study the exoplanet, a manned interstellar spaceship becomes necessary.

The proposal more similar to Solar One was presented by Robert Forward in 1984. Forward proposed a 64-ton payload sail surrounded by a 644-ton decelerator sail and launched by a 7.2-Terawatt laser system to reach 21% the speed of light. However, his concept did not include the laser system on board. In theory, an on board laser system would not significantly counteract the momentum of the spacecraft. Photons have a small thrust to power ratio: 3.34 x 10^{-9} Newtons per watt (Young Bae, 2012).

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2. CONCEPT

Solar One is the first design for a manned spaceship that would be powered by beam propulsion. The name ‘Solar One’ has been chosen to better represent our civilization: the term ‘Solar’ refers to the solar system and the term ‘One’ refers to the first design of a possible fleet of future spaceships. Three are the technologies that would be used: the US Navy CFR nuclear fusion reactor, a slightly larger version of the NASA’s Sunjammer light sail, and a Terawatt-mobile laser called Teramobile.

Firstly, the US Navy CFR (Compact Fusion Reactor) is a mobile unit that can provide one Terawatt of power (Forbes, 2019). The weight of similar CFR units has been estimated to be around 200 tons, but Solar One would need 25 Terawatt-reactors of around 2 tons each. To minimize weight, the use of a Petawatt reactor would be ideal.

Antimatter would be a better source of energy for the laser. Only 10 milligrams of antimatter could yield power densities in the Terawatt order. To produce the antimatter needed, a rocket such as the VARIES Mk 1 could generate Schwinger antiparticle pairs directly from the vacuum (Next Big Future, 2012).

Secondly, the Sunjammer light sail is a proposed NASA sail with a size of 38 x 38 m (1,444 m²) (NASA, 2017). Solar One would need a 1.6 km by 1.6 km light-sail.

Finally, Teramobile is a 10-ton portable 5-Terawatt laser currently funded by the French National Research Agency (Wille, 2002). Solar One would need 5 Terawatt lasers to achieve 10 MW/m2, although a Petawatt laser would be ideal. It is important to bear in mind that current high-energy lasers are usually designed to emit short pulses. A continuous-wave laser would be necessary for Solar One.

If a 50-mm laser is placed at 1 km from the light sail, and with a divergence of around 100º, an irradiance of 10 MW/m2 is theoretically achievable.

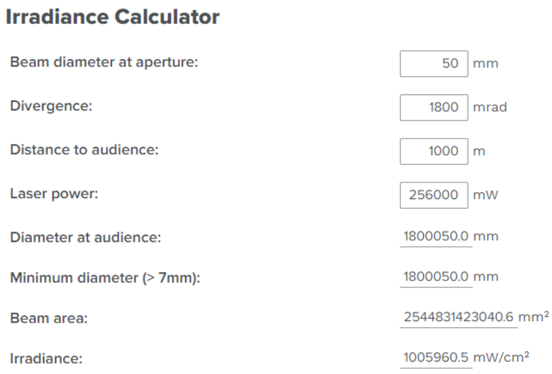

Figure 1 – Power density
Source: Kvant Lasers

The idea behind Solar One is to combine the three projects. A 2-crew spaceship with a total mass of around 100 tons (50 tons from the reactors, 50 tons from the laser system, and 5 tons from the structure, equipment and crew) could be powered by a 1,600 meters-long light sail and achieve the speed of 0.3c with a constant acceleration and deceleration during approximately the first and last one year and a half of the trip.[2]

$$F^* = 2\,(P \times A) / c$$

$$F = 2\,(10{,}000{,}000 \times 2{,}560{,}000) / 300{,}000{,}000$$

$$F = 170{,}667 \text{ newtons}$$

F* = force (newtons)
P*= power (watts / m2)
A*= surface area of light sail (m2)
c* = speed of light
10 MW* = duration of 2.4 years

Considering that photons have a thrust to power ratio of 3.34×10^{-9} newtons per watt, the laser system would provide the following opposite force:

(Manned Spacecraft Design Principles, Pasquale M Sforza).

[2] Based on the calculation that a 4-crew spacecraft is expected to have a mass of 10 tons

$F = 25{,}6 \times 10^{-12}$ watts $\times\ 3.34 \times 10^{-9} = 85{,}504$ N

Thus, the thrust of Solar One would be the as follows:

$$170{,}667 - 85{,}504 = 85{,}163 \text{ N}$$

The acceleration obtained would around 0.1 g:

$$a = F/M$$

$$a = 85{,}163 / 100{,}000$$

$$a = 0.85 \text{ m/s2} \approx 0.1 \text{ g}$$

a* = acceleration (m/s2)
M = mass (kg)

And it would take around 3.3 years to reach 0.3 c:

$$t = v / a$$

$$t = 89{,}994{,}000^* / 0.85$$

$$t = 105{,}875{,}294 \text{ sec} = 3.3 \text{ years}$$

89 million m/s* = 0.3 c

At the speed of 0.3 c, the crew would arrive to the Alpha Centauri system in 17 years. All the necessary measures would be taken in order to enable the crew to withstand the lack of gravity during such a long trip.

$$\text{Average speed} = 0.25^* \cdot 0.15^* + 0.6^* \cdot 0.3^* + 0.25 \cdot 0.15 = 0.255 \text{ c}$$

0.1* = approx. % trip time during acceleration
0.15* = average speed during acceleration and deceleration
0.8* = approx. % trip time with constant speed
0.3* = maximum speed

$$\text{Duration of the trip to Alpha Cen} = \text{Distance / Average speed} = 4.37 / 0.255 = 17 \text{ years}$$

3. DESIGN

The spaceship would be composed of the following main elements: a laser system equipped with a beam expander, a light sail, a nuclear micro-reactor, a descend module and a cockpit protected from space radiation. An extra amount of light sail would be ideal in case of damage caused by micro-meteorites. To reduce damage and drag, the light sail would be rolled when the spaceship is neither accelerating nor decelerating, that is, 80% of the time.

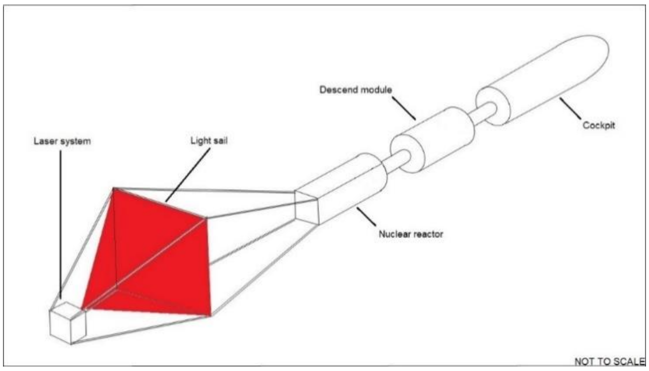

Figure 2 – Solar One

For the deceleration, the hydraulic structure would re-orientate the laser system 180º. Once the destination is reached, the crew could orbit the exoplanet, take images and send a robot to the surface. If the air turns out to be breathable, the crew could choose to land in order to personally explore the exoplanet. However, if the crew decides to do so, they would probably have to wait for the next expedition to leave the exoplanet.

4. CHALLENGES

Engineers would likely face several challenges while building Solar One. One of them would be to make a laser able to produce a high-energy continuous wave with the smallest possible energy loss. Forward’s proposal (1984) implied an energy loss of 11%. The ideal would be to reduce it to a value closer to zero. Another obstacle would be to reduce the weight of the small nuclear reactors to that of a car.

Other challenges would be to protect the reactor module and the light sail from micro-asteroid impacts. Potential nuclear failures include neutron radiation damage and tritium release. The module containing the nuclear micro-reactor would have a protective coating thicker than the rest of the spaceship. The cockpit could also be equipped with an emergency propulsion system such as an ion thruster in case there is a nuclear failure and the crew has to separate from the spaceship. However, this additional system would probably increase the budget and there is also a low chance of survival if the failure occurs outside the solar system.

5. CONCLUSIONS

In this paper it has been analysed the possibility of building a manned interstellar spaceship propelled by a laser system, which would receive the necessary electricity from a small nuclear fusion reactor. Small modular reactors such as the US Navy CFR already exist, large light sails such as Sunjammer have already been built, and portable Terawatt-class lasers such as Teramobile have proved successful. Nuclear fusion is the most near-term technology that could be used to power the laser system of Solar One. However, research on antimatter propulsion is advancing at a rapid rate. If scientists are able to produce more antimatter than the energy used to generate it, this would be the best way to power the laser system of Solar One.

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