Light Sails for Eco-friendly remitting of payloads into the Cosmos

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Abstract- Light sails (also called Solar sails or photon sails) are a form of spacecraft propulsion using radiation pressure exerted by sunlight on large mirrors. A useful analogy may be a sailing boat; the light exerting a force on the mirrors is akin to a sail being blown by the wind. A concept known as beam sailing is used where high energy laser beams could be used as an alternative light source to exert much greater force than would be possible using sunlight. Solar sail craft offer the possibility of low-cost operations combined with long operating lifetimes. Since they have few moving parts and use no propellant, they can potentially be used numerous times for delivery of payloads.

Solar sails use a phenomenon that has a proven, measured effect on spacecraft. Solar pressure affects all spacecraft, whether in interplanetary space or in orbit around a planet or small body. A typical spacecraft going to Mars, for example, will be displaced thousands of kilometres by solar pressure, so the effects must be accounted for in trajectory planning, which has been done since the time of the earliest interplanetary spacecraft of the 1960s. Solar pressure also affects the orientation (Aircraft attitude) of a craft, a factor that must be included in spacecraft design. Many people believe that spacecraft using solar sails are pushed by the Solar winds just as sailboats and sailing ships are pushed by the winds across the waters on Earth. But Solar radiation exerts a pressure on the sail due to reflection and a small fraction that is absorbed.Solar sails use the sun's energy as a method of propulsion—flight by light. Light is made of packets of energy called photons. While photons have no mass, a photon traveling as a packet of light has energy and momentum. Solar sail spacecraft capture light momentum with large,lightweight mirrored surfaces—sails. As light reflects off a sail, most of its momentum is transferred, pushing on the sail. The resulting acceleration is small, but continuous. Unlike chemical rockets that provide short bursts of thrust, solar sails thrust continuously and can reach higher speeds over time. LightSail is a three-unit CubeSat about the size of a loaf of bread. Once in space, LightSail's solar arrays swing open, revealing the inside of the spacecraft. Three electromagnetic torque rods and a momentum wheel orient LightSail in space. Ground-based lasers will measure the effect of sunlight on the sails. As LightSail breezes around the Earth, its shiny sails will be visible from the ground. In Earth orbit, solar pressure and drag pressure are typically equal at an altitude of about 800 km, *which means that a sail craft would have to operate above that altitude. Sail craft must operate in orbits where their turn rates are compatible with the orbits, which is generally a concern only for spinning disk configurations.*

A sail can be used only where its temperature is kept within its material limits. Generally, a sail can be used rather close to the Sun, around 0.25 AU, or even closer if carefully designed for those conditions. Potential applications for sail craft range throughout the Solar System, from near the Sun to the comet clouds beyond Neptune. The craft can make outbound voyages to deliver loads or to take up station keeping at the destination. They can be used to haul cargo and possibly also used for human travel. For trips within the inner Solar System, they can deliver loads and then return to Earth for subsequent voyages, operating as an interplanetary shuttle. The cost of launching the necessary conventional propellants from Earth are enormous for manned missions. Use of sailing ships could potentially save more than $10 billion in mission costs. Solar sail could be used to modify the orbit of a satellite about the Earth. In the limit, a sail could be used to "hover" a satellite above one pole of the Earth. Spacecraft fitted with solar sails could also be placed in close orbits such that they are stationary with respect to either the Sun or the Earth. By changing the angle of the solar panels relative to the Sun, the amount of solar radiation pressure was varied to adjust the spacecraft trajectory more delicately than possible with thrusters. In May 2015, LightSail 1 spacecraft hitched a ride to space aboard an Atlas V rocket. Since it didn't carry us high enough above the Earth's atmosphere for solar sailing, but it captured a picture of our unfurled sails. In 2017, LightSail 2 will be enclosed within Prox-1, a small satellite developed by the Georgia Institute of Technology (Georgia Tech) to autonomously inspect other spacecraft. Both satellites will be lifted into orbit by the Falcon Heavy, a new heavy-lift rocket built by private spaceflight company SpaceX. Light Sail 2 and Prox-1 will be released into an orbit with an altitude of 720 kilometers (450 miles). Prox-1 will eject LightSail 2 into open space. Later, it will rendezvous with LightSail 2 and inspect it. When LightSail 2 unfurls its solar sails, Prox-1 will be nearby to capture images of the big moment.

***Keywords:* Photonic Pressure, Light Sails, Attitude Controlled Unit, Electromagnetic Radiations , Photons**

I. INTRODUCTION

Jaunting on the light from the sun ,Solar Sails are gigantic , elegant weapons that can deliver pay loads to unique locations in our solar systems .Just as the sailing ships of past centuries opened up new frontiers for affordable transport and exploration ,Solar Sail can offer revolutionary capabilities for in-space propulsion ,transport and exploration of the earth ,the sun ,the planets and even for an interstellar travel . Also termed as Light Sail or Photon sail , they use radiation pressure for propulsion , the pressure excreted by electromagnetic radiation. Having minimum moving parts they can be used many times. The total force excreted is around 1 Newton, making low trust space craft .Thus, Solar Sails prove to be a more efficient, economical, eco- friendly source for space monitoring.

II. PROBLEM DEFINITION

Existing Rocket propulsion systems used in spacecrafts , space shuttles to launch satellites and other payloads into the cosmos causes pollution and depletion of non-renewable fuels . So to combat this snag, eco - friendly, efficient structure called Solar Sails could be used, since it works on the principle of Solar Radiation pressure from the radiations of the cosmos

III. MATERIAL DESCRIPTION

Generally, there are three major components to a solar sail-powered spacecraft:

1.Continuous force exerted by sunlight

2. A large, ultra thin mirror

3. A separate launch vehicle

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For an Earth-launched near-term sail craft, one approach is to create the sail using a sandwich of three materials. A metallic, highly reflective (front) layer faces the Sun, followed by a layer of flexible, temperature-resistant plastic. The back layer is composed of a highly emissive material such as chromium

The function of the layer facing the Sun is to reflect as much of the sunlight as possible (up to about 90%). The plastic layer's function is to improve sail flexibility during the sail unfurling process. Sunlight absorbed by the front layer is re-emitted as infrared electromagnetic radiation from the back emissive layer. The sail thickness is typically in the order of a few microns.

Additional sail strength is achieved by including strips of metallic ribbing within the sail structure. These might reduce the effects of micrometeoroid impacts. There is a possibility of using plastics that would rapidly degrade when exposed to solar ultraviolet radiation. In a sail constructed of this material, the "sandwich" layers would be reflective, emissive, and finally UV-sensitive plastic. This approach could greatly reduce sail area mass thickness such a sail could be less than 1 gram per square meter. A sail craft constructed using this material could operate well within 0.1
AU

Figure 1: Outer Appearance ofSolar Sail

1) PHYSICAL PRINCIPLES

Momentum of the photon is given by Einstein's equation P=E/c where p is momentum ,E is photon ,c is speed of light. Perfect sail→ perfect absorbance F=4.54μN/m²,perfect reflectance F=9.08μN/m² and 100% specular reflectance Due to wrinkles ,absorbance ,curvature, normal sail will have efficiency of 90% Force on a sail is given by $F=F_0\cos^2\Theta/R^2$(ideal sail) Θ→angle between sail force vector and radial from sun. R→distance from sun in AU. But for an actual sail ,force is

$F=F_0(0.349+0.662 \cos 2\Theta-0.011 \cos 4\Theta)/R^2$ Force and acceleration approach zero as Θ nears 60^0

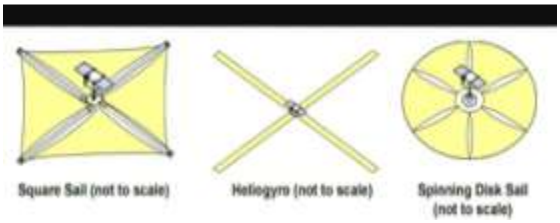

Figure 2: configuration types of solar sails

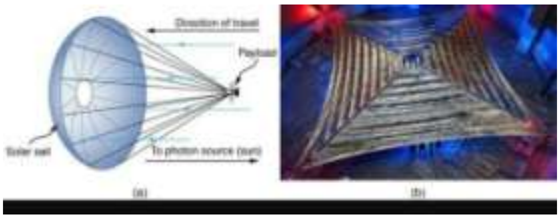

Figure 3: Radiation Convergence

2) ATTITUDE CONTROL

Attitude→behavior of craft towards various force acting on it. It is maintained by ATTITUDE CONTROL UNIT(ACS).Control is by changing crafts centre of pressure and centre of mass. →achieved with control vanes,moments of individual sail etc.Along trajectory:total force and torque changes.

Sail temperature also changes with solar distance.ACS must be able support these changes.

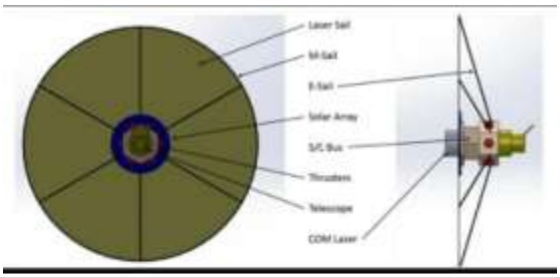

Figure 4: Internal Structure

IV. WORKING METHODOLOGY

A solar sail-powered spacecraft wouldn't need traditional propellant for power, because its propellant would be sunlight and the sun would be its engine.

If the perforations are substantially smaller than the wavelength of incident light, low mass and high reflectance might combine to greatly increase sail performance.

If one places a spacecraft in orbit around the sun, it moves on a trajectory that is defined by the sum of all the forces acting on it. The dominant force acting on an orbiting space craft is the centripetal force due to the gravitational pull of the sun as described in figure and table below. This force is balanced by the outward centrifugal force, mv2/r, of the spacecraft's motion.

Maneuvering a solar-sail spacecraft requires balancing two factors: the direction of the solar sail relative to the sun and the orbital speed of the spacecraft. By changing the angle of the sail with respect to the sun, you change the direction of the force exerted by sunlight.

When the spacecraft is in orbit around the Earth or sun, it is traveling in a circular or elliptical path at a given speed and distance. To go to a higher orbit (travel farther away from the object), you angle the solar sail with respect to the sun so that the pressure generated by sunlight is in the direction of your orbital motion. The force accelerates the spacecraft, increases the speed of its orbit and the spacecraft moves into a higher orbit. In contrast, if you want to go to a lower orbit (closer to the object), you angle the sail with respect to the sun so that the pressure generated by the sunlight is opposite the direction of your orbital motion. The force then decelerates the spacecraft, decreases the speed of its orbit and the spacecraft drops into a lower orbit.

The pressure of sunlight decreases with the square of the distance from the sun. Therefore, sunlight exerts greater pressure closer to the sun than farther away. Future solar-sail spacecraft may take advantage of this fact by first dropping to an orbit close to the sun -- a solar fly-by -- and using the greater sunlight pressure to get a bigger boost of acceleration at the start of the mission. This is called a powered perihelion maneuver.

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A) SAIL CONFIGURATION

Many sail configuration have been propsed like →parachutes;failed as it tends to collapse due to absence of rigid structure.

- square type
- disk sail.

In most cases angular momentum is used to stiffen the structures →thereby eliminating the need for struts. In all cases,a large amount of tensile stress is needed. →weaker sails would ripple and cause structural damage. Latest developments include the use of electric and magnetic fields for propulsion .

Electric solar wind sail →electric solar wind sail uses an electric field generated by electrically charged wires to deflect solar electrons in light rays. →electric field is generated by straightened conducting wires placed around the craft.

Magnetic sail →magnetic sail use magnetic field to deflect electrically charged particles in both sails,maneuvering is achieved by changing the size and shape of their respective fields

B) MAKING OF SAILS:

Sails have been developed from many materials.Drexler developed a solar sail with thin aluminum film of 0.1 mm thickness.The most common material used is aluminized 2µm kapton film. Solar sails made from alumina , carbon fibre , are found to be superior to aluminum or kapton films New carbon fibre material is over 200 times thicker than conventional solar sail but has the same mass. Lithium can also be used for sail making. In all cases,sail should be manufactured in space to avoid tearing during folding and deployment and to reduce weight. Sails are mostly fabricated using vapor deposition and molecular manufacturing techniques Magnesium and beryllium can also be used for sail making. Reflection of light is preferred over absorption. →absorption exerts a force directed straight from the sun which is not useful for high performance sails →absorption raises the equilibrium temperature in proportion to the fourth rot of its absorptivity.

V. CONCEPTUAL DESIGN OF SOLAR SAILS

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If the perforations are substantially smaller than the wavelength of incident light, low mass and high reflectance might combine to greatly increase sail performance.

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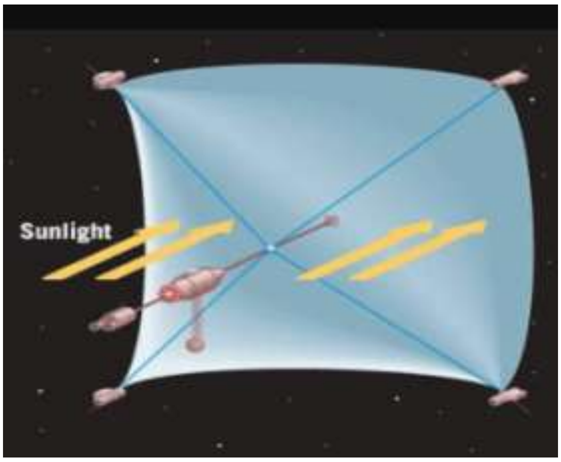

Figure 5: Complete view from space

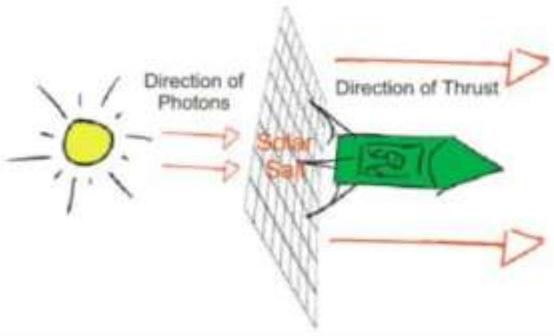

Figure 6: Conversion of Energy into thrust

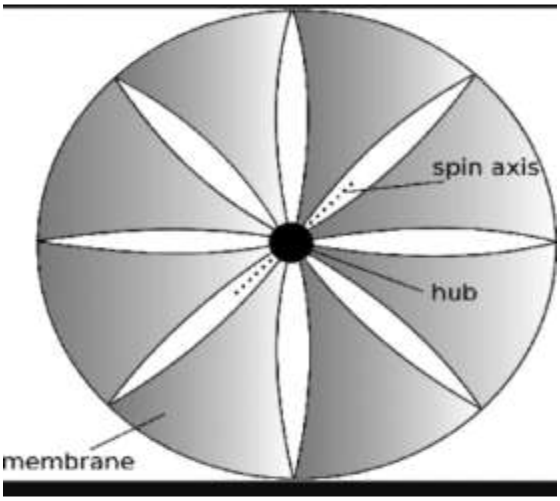

Figure 7: Axis

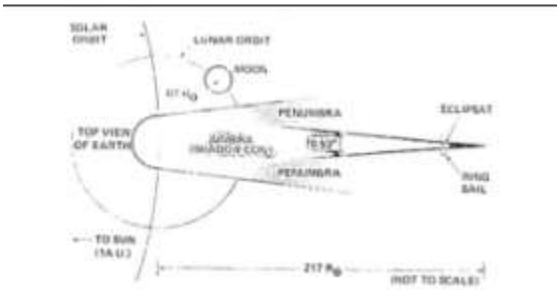

Figure 8: Layout of structure

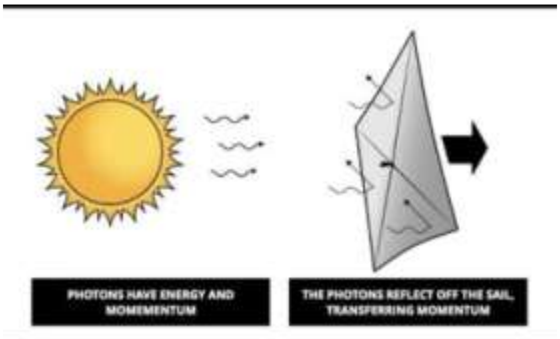

Figure 9: Photonic Pressure

VI. CALCULATIONS

Light is composed of electromagnetic radiation that exerts force on objects it comes in contact with researchers have found that at 1 astronomical unit (AU),which is the distance from the sun to Earth, equal to 93 million miles (150 million km), sunlight can produce about 1.4 kilowatts (kw) of power. If you take 1.4 kW and divide it by the speed of light, you would find that the force exerted by the sun is about 9 Newton (N)/square mile (i.e., 2 lb/km2 or .78 lb/mi2).

In comparison, a space shuttle main engine can produce 1.67 million N of force during liftoff and 2.1 million N of thrust in a vacuum. Eventually, however, the continuous force of the sunlight on a solar sail could propel a spacecraft to speeds five times faster than traditional rockets.Using the following equations and values, you can calculate the force of sunlight on solar sail and acceleration of the spacecraft:

- Force (F) = 2(P x A)/c
- Acceleration (a) = F/M

At 1 astronomical unit, the power of sunlight is about 1,400 watts/meter2.

Our spacecraft weighs 2.2-lb (1-kg) and has a sail area of 1 km2 or 1-million m2,
So:

* P (power) = 1,400 watts/m2

* A (area) = 1-million m2

* c (speed of light) = 3x108 m/s

* M (mass) = 1 kg

This works out to a force (F) of about 2 lb or 9 Newton’s (N).

This force leads to an acceleration (a) of about 29 ft/s 2 (9 m/s2), slightly less than the acceleration due to Earth's gravity.

In comparison, a space-shuttle main engine can produce 367,000 lb (1.67-million N) of force during liftoff and 462,000 lb (2.1-million N) of thrust in a vacuum

VII. APPLICATIONS

1. Eco-Friendly and reliable.
2. Easy fabrication.
3. Cost efficient.
4. Increased pressure and thrust generation.
5. Continuous generation of pressure is possible.
6. Reduces pollution.

VIII. FUTURE WORK

This paper is initiated to create an impact on solar sails in aerospace. The future vision and mission of this concept are

1. Testing solar sails as launch vehicles in aircrafts experimentally..
2. To increase the efficiency of solar sails with the help of Nanotechnology.
3. To increase the pressure output of Solar Sails as replacement for normal propulsion systems

IX. CONCLUSION

Although the force on a solar-sail spacecraft is less than conventional chemical rockets, such as the space shuttle, the solar-sail spacecraft constantly accelerates over time and achieves a greater velocity.

It's like comparing the effects of a gust of wind versus a steady, gentle breeze on a dandelion seed floating in the air. Although the gust of wind (rocket engine) initially pushes the seed with greater force, it dies quickly and the seed coasts only so far. In contrast, the breeze weakly pushes the seed during a longer period of time, and the seed travels farther. Solar sails enable spacecraft to move within the solar system and between stars without bulky rocket engines and enormous amounts of fuel.

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