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The Physics of Solar Sails and Space Travel

University Physics II: Lab Section 1

Nathan
[Pick the date]

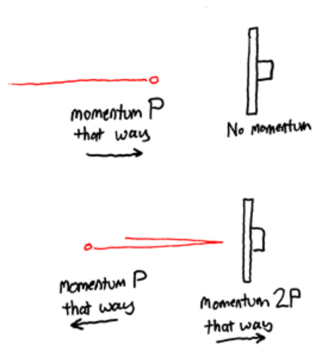
In the 1600's, a European by the name of Johannes Keppler suggested that, with the right boat, humans could sail through the galaxy. He based his statement on the observation of a comet streaking across the sky. From it he hypothesized that a kind of "solar breeze" blew that could be used to sail through the skies (howstuffworks.com).

Though Mr. Keppler's idea for using sails to utilize the "solar breeze" didn't ever come to pass in his lifetime, sails using the light of the sun for propulsion are quickly becoming a reality. Solar sail technology is quickly gaining popularity as an alternative to expensive and heavy chemicals as a means for long distance propulsion in space. The physics of a solar sail are relatively easy to understand, and the physics of deep space flight is very sympathetic to this up and coming technology.

(Artists representation of a spin-stabilized solar sail)

(solar.calfinder.com)

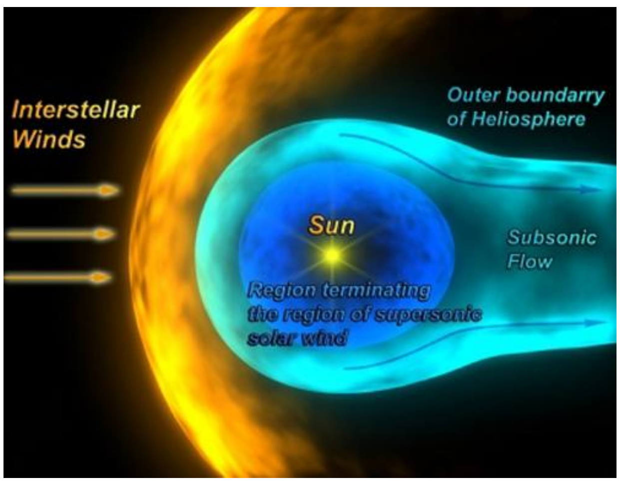
The physics involved in the workings of a solar sail are very easy to understand. Photons, massless particles that make up electromagnetic waves, come from a light source such as a star or a laser and hit the sail. Individually, these photons transfer an extremely small amount of momentum to the sail. While one photon may do next to nothing to affect the sail, trillions upon trillions of little particles continuously hitting the sail and bouncing off of it begin to add up. While this acceleration is not nearly as great as that of a typical chemically powered rocket, the advantage the solar sail has over its chemically powered sibling is in its fuel supply. The typical chemically powered rocket can have an acceleration of around 59 meters per second for as long as its fuel source remains (planetary.org). On the other hand, while a solar sail's magnitude of acceleration is not nearly as great, it can continue to accelerate due to its infinite fuel source. As long as there is light to push the sail, the ship will continue to accelerate.



(Basic illustration of what happens when a photon bounces off of a solar sail. When a photon hits the sail and is reflected, the sail gains twice the momentum.)

(http://blog.xkcd.com/2008/02/15/the-laser-elevator/)

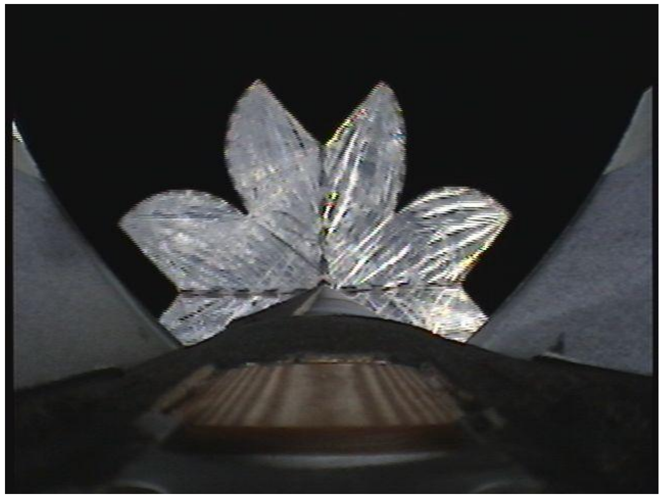
In the case of our sun, the point at which a solar sail ceases to accelerate is at the edge of the heliosphere, the giant bubble surrounding the solar system that contains all the area affected by the Sun's magnetic field and solar wind (nasa.gov). However, the velocity of a craft at the point it reaches the heliosphere would be immense. According to Kevin Bonsor of howstuffworks.com, "Eventually […], the continuous force of the sunlight on a solar sail could propel a spacecraft to speeds five times faster than traditional rockets."As this technology improves and matures, solar sails will be capable of reaching speeds unthinkable for chemically driven craft. Ten times the speed of a conventional rocket could become normal among ships with this kind of propulsion. At this kind of velocity, it would take only take a ship eight years to catch the farthest manmade object from Earth, Voyager I, which has been traveling through space for over 20 years. Even then, NASA scientists have claimed that by aiming a laser or magnetic beam at the sail, speeds of 18,600 miles per second could be reached. That is one tenth the speed of light. This technology promises not only to increase the speed of the vessel with the solar sail, but it also gives the ship the ability to operate outside of the heliosphere. At such speeds, humankind's long dreamt of voyages between the stars could become a very real possibility (howstuffworks.com).



(www.newscientist.com)

(Here is a diagram of the Sun's heliosphere. Outside of this, solar sails unassisted by lasers or magnetic rays would not be pushed by the Sun's light)

Has humanity found an answer to interstellar travel? Though the solar sail has many things that make it a tempting choice for such kinds of missions, there are many things to take into consideration before making widespread use of this technology. Solar sail technology takes exceptional patience in order to make any use of it. Unlike a chemically driven force that gives instant gratification when you tell it to what to do, a solar sail will do the same task over a much slower interval. That is, whereas a chemically driven thruster can change the direction of a spacecraft with the firing of a thruster, a change of direction in the ship with the solar sail would have to be planned hours or days ahead and would go almost unnoticed by the crew. This means no evasive maneuvers in the case of an emergency with a craft powered only by light. Another concern one could have with this technology is that, if a ship is going one tenth the speed of light, how exactly will it stop when it gets to its destination without another kind of propulsion system? One answer to these concerns is being developed by the Japanese, a solar sail and ion propulsion hybrid (planetary.com). In adding a system that allows for easier control in interplanetary travel, many of the inherent difficulties of steering a ship with solar sails diminish or disappear completely.



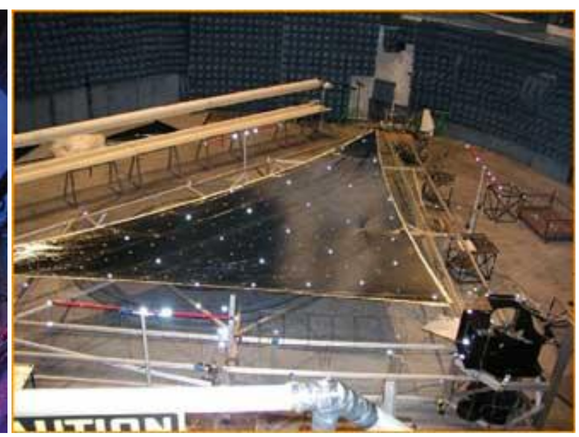
(http://images.spaceref.com/news/2004/08.10.04.camera03.jpg)

(Japanese test opening experimental solar sail in space)

Another one of the problems faced by solar sails is the size and material of the sail that is required in order to gain a sufficient amount of light. Since the amount of force exerted by a photon is extremely small, it is necessary to have a large sail in order to ensure that a large amount of photons are allowed to strike it. Since this is the case, strong artificial substances like Mylar are used to minimize the chance of tearing in large sheets. But strength is not the only thing sought in a solar sail. However, the sail has to be extremely light or else the photons will not be able to fill the sail. Without an extremely reflective surface, the amount of pressure that the light exerts on the sail would be cut in half, greatly diminishing its ability to accelerate in open space. When a surface reflects a photon, that particular photon gives the sail twice as much momentum as a photon that is absorbed. As such, these large sheets of Mylar are covered in an extremely thin layer of a shiny metal such as aluminum. This allows the sail to reflect as much of the light shown on it as possible, thus maximizing the pressure that light puts on the sail and allows it to reach such incredible speeds. However, with sail sizes for proposed missions reaching a size of 800 meters by 800 meters, weight is guaranteed to be an issue. Thus, in order to ensure that the sail is as light as possible, it needs to be made as thin as possible. In response to such a demand, some solar sails have been developed to be 100 times as thin as a piece of paper.

(control.ae.gatech.edu)

(example of solar sail scale)



(science.howstuffworks.com)

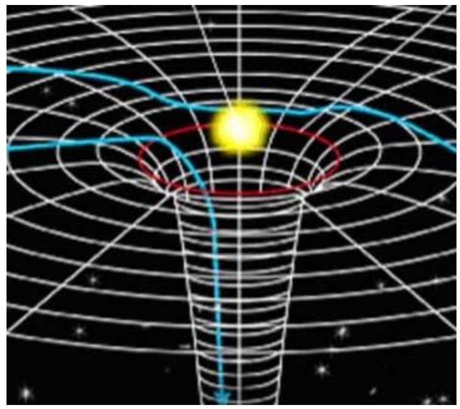
(Solar sail piece stretched out)

Were it not for the climate and physics of space, solar sails would not be a viable way of transportation. Space is just that, empty space. It is a vast expanse of nothingness with little bits of rock, gas, and light scattered throughout. Space has a more complete vacuum than any lab on Earth has yet to create. Another thing that deep space has is a lack of overwhelming gravitational force. Both these aspects of space are what allow solar sails to do their job.

If not for the vacuum of deep space, moving at speeds one tenth the speed of light would not be possible for an object the size of a spaceship. Were it even possible for a solar sail to work in an atmosphere without being torn apart or tossed around wildly, friction from particles of air would instantly rip any ship to shreds that was going anywhere close to 18,600 miles per second. The lack of an atmosphere also assures that the sail is getting the maximum amount of reflection. If there was air, some photons would inevitably be reflected by these air particles and not allowed to touch the solar sail. This would reduce the force acting on the sail. Vacuum is an essential piece to the puzzle. Were it not for a lack of particles in space, solar sails would be an impossible fantasy.

The other aspect of deep space that is absolutely essential to solar sailing is the lack of overpowering gravitational fields. Of the four primary forces in the universe; Strong force, weak force, electromagnetic force, and gravitational force, gravity is the weakest. However, though it is a comparatively weak force, in the presence of a massive amount of mass gravity becomes a force to be reckoned with. Gravity is the reason why everything on Earth is not slung off at a speed of 1000 miles per hour and how the planets are kept in their elliptical paths around the Sun. When not in close proximity to a large collection of mass gravity, while still present, is not nearly as strong. This is due to gravitational force decreasing with an increase in distance. The low gravity of space allows a ship powered by light to work because if gravity were to affect the ship more, the low rate of acceleration given by the photons could easily be overpowered by the gravitational force. If such a thing were to happen, the ship would lose all control and would be helplessly dragged to the center of mass of the body from which the gravitational force emanates.

A limitation that space does put on a vehicle is the universal speed limit of 3x10^8 meters per second, the speed of light in a vacuum. When a mass is accelerated, it takes more and more energy to get it to move faster. According to Einstein’s theory of relativity, no object or information can move faster than the speed of light. As matter approaches 90% of the speed of light, it becomes more massive. If a spaceship were to attempt to accelerate to the speed of light, it would eventually become infinitely massive and would take infinitely more energy in order to accelerate it. As there is a limited amount of energy in the universe, it is impossible for a craft to reach that lofty speed.



(Einstien's theory of general relativity changed the way the universe is viewed.)

(x-journals.com)

In humanity's reach for the stars, many new ideas for propulsion have been suggested as a substitute to chemical propellants. Among these, solar sails stand out as a prominent candidate. Working on the basic principles of reflection and capitalizing on the harsh environment of space, solar sails offer a way to utilize the natural sunlight nature has provided. While several challenges still remain to be solved with this system, a solid international initiative to improve this progressive technology is currently underway. With such speeds, a bright future for interplanetary and interstellar travel looms on the horizon.

Works Cited

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