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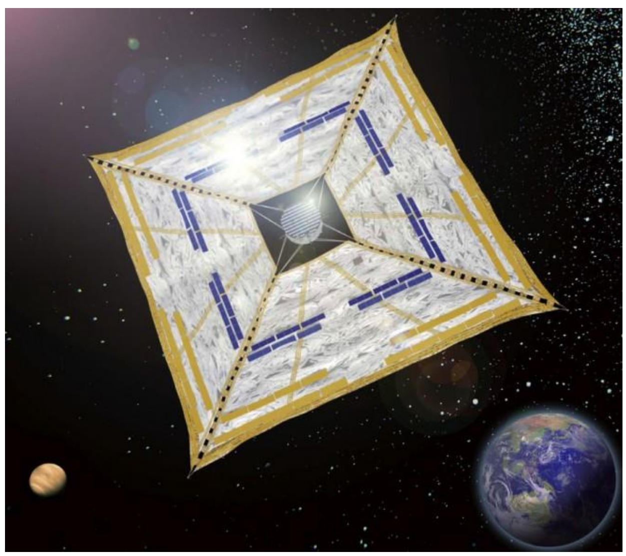
Light sail
(Solar sail)



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Intro

By the beginning of 20^{th} century; many things have changed and many theories has achieved.

In addition to that scientist try every day to make travelling in the space available to people by inventing new methods and ways to carry them out.

In one experiment of that scientists tried to make solar spacecrafts which need solar radiation to move into the space.

So we will take a look about these spacecrafts and how they were made? what techniques do they use? For which mission do they work? And what's the future of these spacecrafts.

I hope that you get interested in this research.

The problematic nature

My problematic nature is inspired from several solar ships were launched in last six years. So can we replace our traditional spacecrafts with solar ships. And what is the benefit from these different solar ships.

A brief history

Pyotr Lebedev was first to successfully demonstrate light pressure, which he did in 1899 with a torsional balance;[1] Ernest Nichols and Gordon Hull conducted a similar independent experiment in 1901 using a Nichols radiometer.[2]

James Clerk Maxwell, in 1861–64, published his theory of electromagnetic fields and radiation, which shows that light has momentum and thus can exert pressure on objects. Maxwell's equations provide the theoretical foundation for sailing with light pressure. So by 1864, the physics community and beyond knew sunlight carried momentum that would exert a pressure on objects.

What is solar sail?

Solar sails (also called light 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. High-energy laser beams could be used as an alternative light source to exert much greater force than would be possible using sunlight, a concept known as beam sailing.

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 by thousands of kilometers 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.[3]

Physical principle

But Solar radiation exerts a pressure on the sail due to reflection and a small fraction that is absorbed.

The momentum of a photon or an entire flux is given by Einstein's relation:[4]

$p = E/c$

where p is the momentum, E is the energy (of the photon or flux), and c is the speed of light. Solar radiation pressure can be related to the irradiance (solar constant) value of 1361 W/m^2 at 1 AU (Earth-Sun distance), as revised in 2011:[16]

- perfect absorbance: F = 4.54 μN per square metre (4.54 μPa) in the direction of the incident beam (an inelastic collision)
- perfect reflectance: F = 9.08 μN per square metre (9.08 μPa) in the direction normal to surface (an elastic collision)

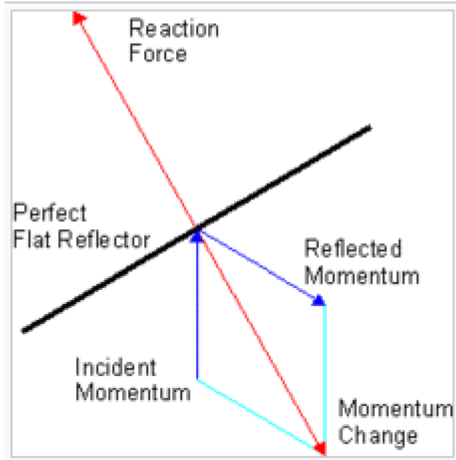
The force on a sail and the actual acceleration of the craft vary by the inverse square of distance from the Sun (unless extremely close to the Sun [5]), and by the square of the cosine of the angle between the sail force vector and the radial from the Sun, so

$F = F_0 \cos^2 \theta / R^2$ (ideal sail)

where R is distance from the Sun in AU. An actual square sail can be modeled as:

$F = F_0 (0.349 + 0.662 \cos 2\theta - 0.011 \cos 4\theta) / R^2$

Note that the force and acceleration approach zero generally around θ = 60° rather than 90° as one might expect with an ideal sail.



Force on a sail results from reflecting the photon flux

If some of the energy is absorbed, the absorbed energy will heat the sail, which re-radiates that energy from the front and rear surfaces, depending on the emissivity of those two surfaces.

Solar wind, the flux of charged particles blown out from the Sun, exerts a nominal dynamic pressure of about 3 to 4 nPa, three orders of magnitude less than solar radiation pressure on a reflective sail.[6]

Sail parameters

Sail loading (areal density) is an important parameter, which is the total mass divided by the sail area, expressed in g/m^2. It is represented by the Greek letter σ.

A sail craft has a characteristic acceleration, a_c, which it would experience at 1 AU when facing the Sun. Using the value from above of 9.08 μN per square metre of radiation pressure at 1 AU, a_c is related to areal density by:

$$a_c = 9.08(\text{efficiency}) / \sigma \text{ mm/s}^2$$

Assuming 90% efficiency, $a_c = 8.17 / \sigma$ mm/s^2

The lightness number, λ, is the dimensionless ratio of maximum vehicle acceleration divided by the Sun's local gravity. Using the values at 1 AU:

$$\lambda = a_c / 5.93$$

The lightness number is also independent of distance from the Sun because both gravity and light pressure fall off as the inverse square of the distance from the Sun. Therefore, this number defines the types of orbit maneuvers that are possible for a given vessel.

The table presents some example values. Payloads are not included. The first two are from the detailed design effort at JPL in the 1970s. The third, the lattice sailer, might represent about the best possible performance level.[7] The dimensions for square and lattice sails are edges.

Attitude control

An active attitude control system (ACS) is essential for a sail craft to achieve and maintain a desired orientation. The required sail orientation changes slowly (often less than 1 degree per day) in interplanetary space, but much more rapidly in a planetary orbit. The ACS must be capable of meeting these orientation requirements. Attitude control is achieved by a relative shift between the craft's center of pressure and its center of mass. This can be achieved with control vanes, movement of individual sails, movement of a control mass, or altering reflectivity.

Holding a constant attitude requires that the ACS maintain a net torque of zero on the craft. The total force and torque on a sail, or set of sails, is not constant along a trajectory. The force changes with solar distance and sail angle, which changes the billow in the sail and deflects some elements of the supporting structure, resulting in changes in the sail force and torque.

Sail temperature also changes with solar distance and sail angle, which changes sail dimensions. The radiant heat from the sail changes the temperature of the supporting structure. Both factors affect total force and torque.

To hold the desired attitude the ACS must compensate for all of these changes.[8]

Applications

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.[7]

Inner planets

For trips within the inner Solar System, they can deliver loads and then return to Earth for subsequent voyages, operating as an interplanetary shuttle. For Mars in particular, the craft could provide economical means of routinely supplying operations on the planet according to Jerome Wright, "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.[7]

Outer planets

Minimum transfer times to the outer planets benefit from using an indirect transfer (solar swing-by). However, this method results in high arrival speeds. Slower transfers have lower arrival speeds.

The minimum transfer time to Jupiter for a_c of 1 mm/s^2 with no departure velocity relative to Earth is 2 years when using an indirect transfer (solar swing-by). The arrival speed (V_∞) is close to 17 km/s. For Saturn, the minimum trip time is 3.3 years, with an arrival speed of nearly 19 km/s.[7]

	Jupiter	Saturn	Uranus	Neptune
Time, yr	2.0	3.3	5.8	8.5
Speed, km/s	17	19	20	20

Trajectory corrections

The MESSENGER probe orbiting Mercury used light pressure on its solar panels to perform fine trajectory corrections on the way to Mercury.[24] 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. Minor errors are greatly amplified by gravity assist maneuvers, so using radiation pressure to make very small corrections saved large amounts of propellant.

Sail making

Materials

The most common material in current designs is a thin layer of aluminum coating on a polymer (plastic) sheet, such as aluminized 2 µm Kapton film. The polymer provides mechanical support as well as flexibility, while the thin metal layer provides the reflectivity. Such material resists the heat of a pass close to the Sun and still remains reasonably strong. The aluminum reflecting film is on the Sun side.

The least dense metal is lithium, about 5 times less dense than aluminium. Fresh, unoxidized surfaces are reflective. At a thickness of 20 nm, lithium has an area density of 0.011 g/m^2. A high-performance sail could be made of lithium alone at 20 nm (no emission layer). It would have to be fabricated in space and not used to approach the Sun. In the limit, a sail craft might be constructed with a total areal density of around 0.02 g/m^2, giving it a lightness number of 67 and a_c of about 400 mm/s^2. Magnesium and beryllium are also potential materials for high-performance sails. These 3 metals can be alloyed with each other and with aluminium. **[7]**

Reflection and emissivity layers

Aluminium is the common choice for the reflection layer. It typically has a thickness of at least 20 nm, with a reflectivity of 0.88 to 0.90. Chromium is a good choice for the emission layer on the face away from the Sun. It can readily provide emissivity values of 0.63 to 0.73 for thicknesses from 5 to 20 nm on plastic film. Usable emissivity values are empirical because thin-film effects dominate; bulk emissivity values do not hold up in these cases because material thickness is much thinner than the emitted wavelengths.[8]

Fabrication

Sails are fabricated on Earth on long tables where ribbons are unrolled and joined to create the sails. Sail material needed to have as little weight as possible because it would require the use of the shuttle to carry the craft into orbit. Thus, these sails are packed, launched, and unfurled in space.

Projects

- IKAROS 2010
- NanoSail-D 2010
- LightSail-A
- Light sail 2 is a project to build a solar sail spacecraft, scheduled for launch in March 2017 and developed by The Planetary Society, a global non-profit organization devoted to space exploration.[9]The kite-shaped spacecraft, which was announced in 2009, will have a total sail area of 32 square meters (340 sq ft), and will be fitted with guidance and diagnostic electronics.

Conclusion

As we saw that solar sail ship is developing quickly and it has many benefits like low cost and high speed so I propose to enlarge the possibilities of using these ships instead of traditional ones and it has so many activities that can do it better than the other ships.

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