SOLAR SAILS – THE FUTURE OF EXPLORATION OF THE SPACE

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Abstract: *The research and curiosity about outer space had been always constant in the mankind. Looking for others planets, ways, civilizations wherever the exploration of the space will be a thing which the human desire. The challenge here for several years was the obtaining energy sufficient for the application of the missions. So, currently the major objective in the missions is offer more autonomy to the spacecrafts and consequently to lower the cost of the missions. Solar Sails have long been envisaged as an enabling technology because is a promising low-cost option for space exploration for it uses for propulsion an abundant resource in space: solar radiation. In this paper a mission catalogue is presented of an extensive range of solar sail applications, allowing the knowledge of the key features of missions which use solar sail propulsion.*

Keywords: *Solar Sails, Space Exploration, Mission Applications.*

1 Introduction

The perception of solar sailing can be found back to the 17^{th} century afterward, solar sailing was articulated as an engineering principle in the early 20^{th} century by several authors. And into the 21^{st} century a significant amount of both theoretical and practical work has been performed, considering the astrodynamics, mission applications and technology requirements of solar sailing (Macdonald and McInnes, 2010).

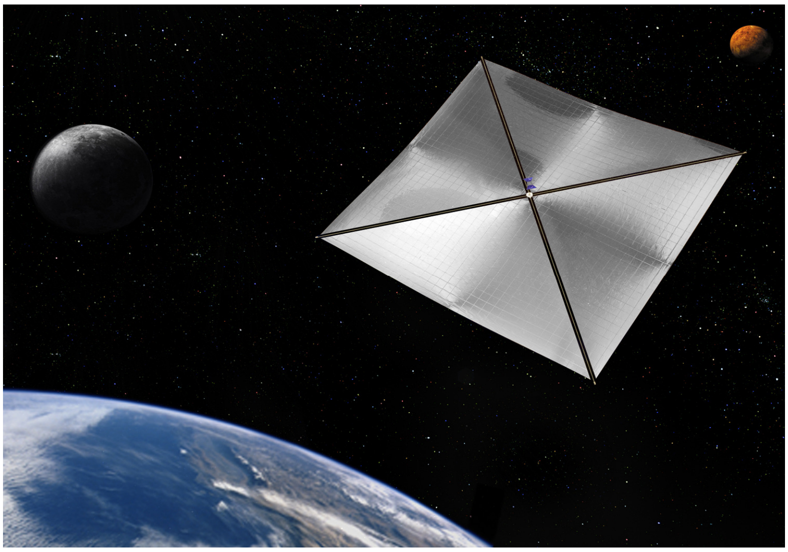

Figure 1. Solar Sail

Sailing vessels on Earth navigate with wind sails, which divert a little portion of the massive momentum flux present in moving bodies of air. In space, a spacecraft called a solar sail can realize the similar by diverting a small portion of the massive flux of electromagnetic energy put out by the sun as light by the use of large and lightweight mirrored sails. Sunlight has long been known to carry momentum (Herbeck et all., 2002).

Over several years, solar sailing has been studied as an original propulsion system for space missions. Solar sail technology appears as a gifted form of advanced spacecraft propulsion which can make possible exciting new space-science mission concepts such as solar system exploration and deep space observation (Simo and McInnes, 2010). The advantage is obvious: solar sails do not need to carry an active main propulsion system nor any propellant for it. For that reason, extended missions in our solar system and beyond seem possible (Leipold, 1999). Even though solar sailing has been considered as a practical means of spacecraft propulsion only relatively recently, the fundamental ideas are found in McInnes (1999).

Certainly, solar sails must also obey Newton's third law. On the other hand, solar sails gain momentum from an ambient source, namely photons, the quantum packets of energy of which sunlight is composed. It may be startling that photons with zero rest mass can push matter; but, relativity states that a zero-rest-mass particle with energy E, will also transport momentum p = E/c, where c is the speed of light (McInnes, 2003).

To access inaccessible orbits and permit longer missions lifetime with low cost, the solar sails in the last days have shown great potential for both application and research (Wie, 2007). So the advance of new technologies are grown up, in lightweight deployable booms, ultralightweight sail films, and small satellite, technologies advancement complexity of low technology readiness level research is typically underestimated due to a lack of recognition of the development degree of difficulty scale. These recent progresses are spurring a renewed curiosity in solar sailing and the missions it enables (Wie and Murphy, 2007).

The traditional solar sailing concepts, along with their high advancement degree of difficulty and a lack of near-term applications a new vision for solar sailing is presented which increases the technology readiness level and reduces the advancement degree of difficulty of solar sailing.

In this paper, the focus is a comparison of the technological and objectives development of the two mentioned projects. All information is taken directly out of papers available to the public or Internet pages. The two solar sail projects are:

1. Gossamer (1, 2, 3) by DLR (Deutschen Zentrum für Luft-und Raumfarht)/ ESA (European Space Agency).
2. IKAROS was launched on May 21st, 2010. JAXA (Japan Aerospace Exploration Agency).

2 Historical Background

Even if solar sailing has been considered as a practical means of spacecraft propulsion only reasonably freshly, the basic ideas are by no means new (McInnes, 2003). The concept of solar sailing was first envisioned in science fiction in 1865 by Jules Verne. Tsiolkovsky proposed in 1924 that large spacecraft could be propelled through space using photon pressure, and in the same year Tsander (1924) proposed the lightweight solar sail design. The modern concept of solar sailing was reinvented much later by Richard Garwin, 1958.

In 1960, Arthur C. Clarke wrote a short story, "The Wind from the Sun", racing: Solar sail power interstellar vehicle. In the same year, Echo-1 felt these solar pressure effects loudly and clearly. Photon pressure played orbital soccer with the Echo-1 thin-film balloon in orbit (Echo-1, 1960). NASA had a more positive experience with solar sailing in 1973 when the Mariner 10 spacecraft ran low on attitude control gas. They angled Mariner's solar arrays into the sun and used solar radiation pressure for attitude control. Halley's Comet was to make its closest approach to Earth in 1986, and NASA conceived the exciting idea of propelling a probe via solar sail to rendezvous with the comet.

The Russian Space Agency in 1993 launched a 20-meter diameter, spinning mirror called Znamya 2, hoping to beam solar power back to the ground. In 1999, the ESA and the DLR co-funded the fabrication of a 20mx20m solar sail which was successfully ground-tested, showed in Figure 2. Following this successful ground test, the agency funded a series of mission studies at the University of Glasgow to investigate the potential of the technology for future space-science-mission applications (McInnes, 2003). In 2004, the Japanese deployed solar sail materials sub-orbitally from a sounding rocket. And the Planetary Society demonstrated the technology with its Cosmos 1 (NanoSail-D) mission in 2005; nevertheless the launch vehicle failed and destroyed the spacecraft.

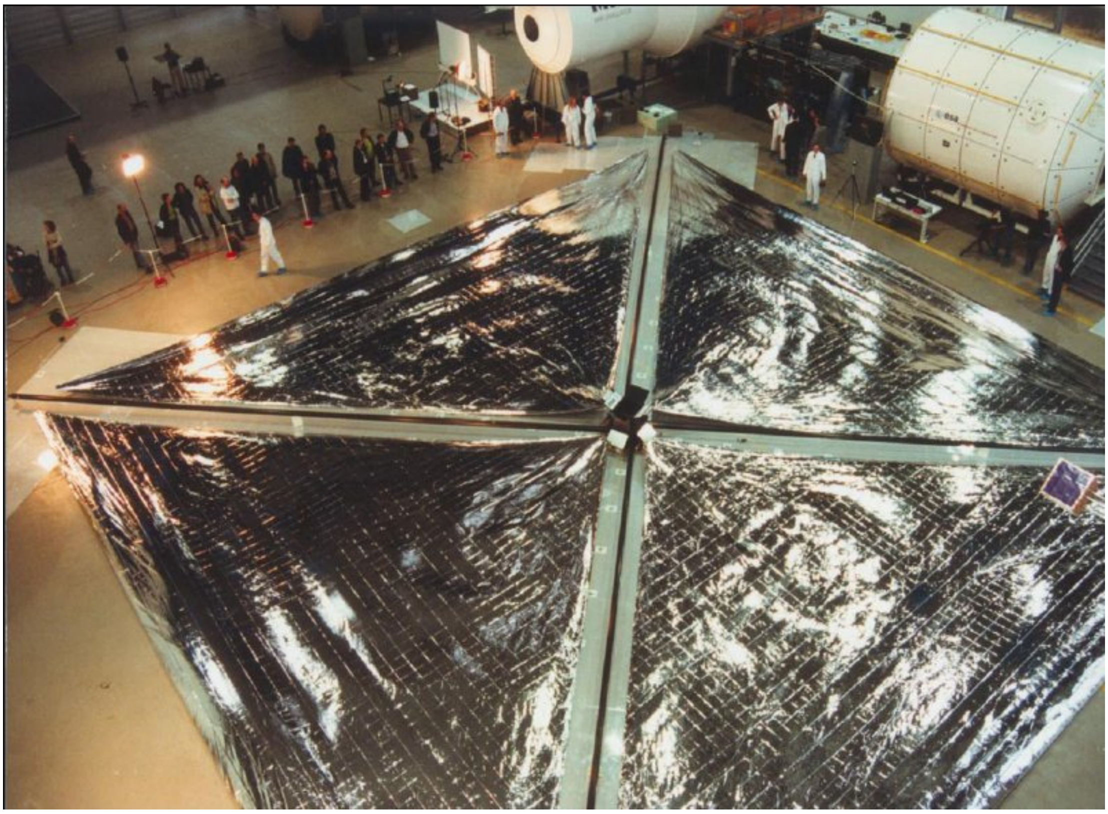

Figure 2. Solar-Sail deployment test – DLR/ESA

But, one question is necessary to make, why so important? Solar sails could expand our reach as far as our dreams. For the reason that there's no friction in space, once a solar sail starts moving, it can go on forever. Indeed, long after a rocket would run out of gas and begin to coast, a solar sail could still be accelerating, achieving speeds much faster and covering distances far greater than any rocket. Carl Sagan's words "the shore of the cosmic ocean," leading us closer to sailing among the stars.

3 Solar Sail Projects

In this chapter you will find a description of two different Solar Sail projects.

3.1. Gossamer

After at worked together in project Solar-Sail, Fig. 2, ESA and DLR decided to start the Gossamer project, Figure 3. The cooperative effort between DLR, ESA and the industry has been tremendously successful in defining and prototyping an sophisticated technology concept, in test proofing its feasibility and defining roadmaps for its further development and application. At what time all three steps of the Gossamer roadmap have successfully been completed, the solar sail propulsion will be declared operational and can be used in space mission.

Also supporting the Gossamer project is a Light Pressure Measurement Facility (LPMF) set up by the DLR Institute for Space Systems in Bremen and Berlin. The first step of the Gossamer project is the deployment of a 5-by-5 meters solar sail in Earth orbit, to demonstrate the capabilities of manufacturing, packaging and successfully deploy in space a fully scalable system (Romagnoli and Theil, 2011).

Figure 3. Gossamer Project

To guarantee that Gossamer will not fail, ESA and DLR focus on a pure technological demonstrator mission with growing complexity and level of difficulty in the three steps. Furthermore, any scientific payload will be discarded. It shall also be secured, that all Gossamer technologies are scalable. To avoid a failure in material or technologies, only those are used which have previously been proved and tested in numerous studies and projects. Lastly, the Gossamer project and its technological success shall be perfectly documented and communicated to potential users.

The projected roadmap of DLR-ESA Gossamer contains three stages:

Gossamer-1: A 5-meter square solar sail launched as a deployment demonstrator to a 320 kilometer Earth orbit. Documentation of the deployment is to be handled by two onboard cameras. This demonstrator mission would be launched in 2013.

Gossamer-2: A 20-meter square sail launched to a 500 kilometer Earth orbit. Here the idea is to test orbit and attitude control of a sail built out of thinner materials than the 7.5 µm Kapton used in Gossamer-1. Launch in 2014.

Gossamer-3: A 50m x 50m solar sail launched to a 10,000 kilometer Earth orbit, with testing of orbit and attitude control and, as with the earlier missions, documentation by onboard cameras. An acceleration > 0.1 mm/s2 is sufficient for the sailcraft to leave the Earth's gravitational field after a period of about 100 days. It is planned to perform a lunar swing-by after about 600 days.

The possibility of testing in space complex and sensible mechanisms, such as the deployment system, is of crucial importance in order to achieve the required reliability for more complex scenarios. Gossamer program allow early risks to be spread over a number of low cost missions.

3.2. IKAROS (Interplanetary Kite-craft Accelerated by Radiation of the Sun)

The Solar Sail most recent in operation was launched on May 21st, 2010. JAXA is studying two missions to evaluate the performance of the solar power sails, how showed in Figure 4. It deployed the membrane successfully and generated solar power by means of thin film solar cells (minimum success level) within several weeks. Two separation cameras took images of the deployed solar sail of IKAROS. Acceleration and navigation using the solar sail will then be demonstrated (full success level) within half a year.

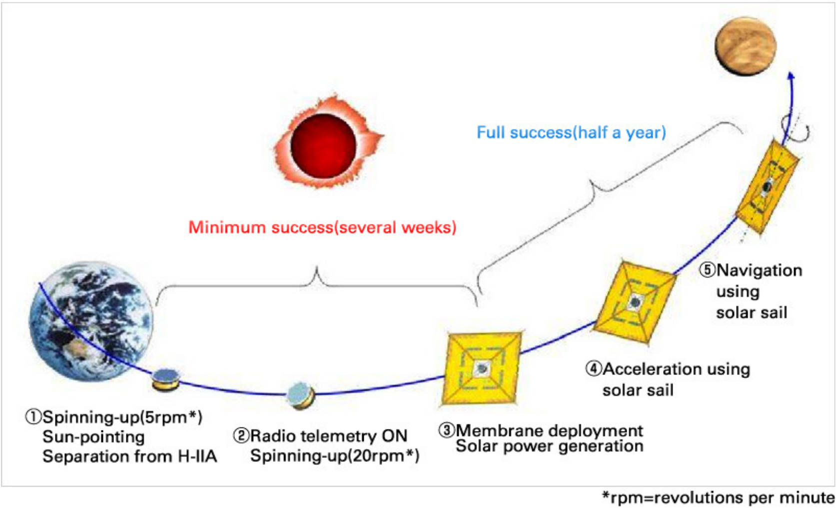

Figure 4. Summary Mission IKAROS

A 20-meter sail made of polyimide resin just 0.0075 mm thick was unfurled in space. The craft rotated 25 times per minute, and extended four "arms" of material folded origami like, which unraveled and started generating power, see Figure 5.

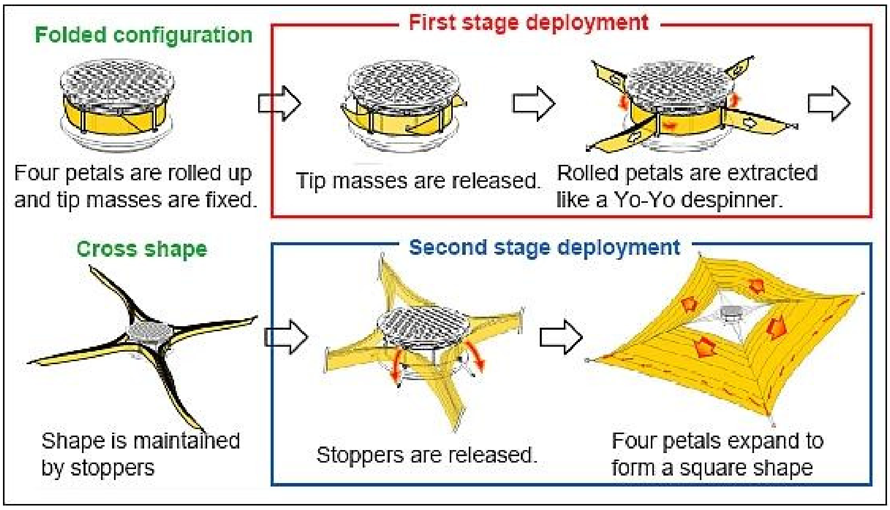

Figure 5. Ilustration of the sail deployment concept

The success criteria of the IKAROS mission are summarized as follows (Osamu, 2010):

a) Deployment of a large membrane sail in space using a analogous mechanical device and events to those in a Solar Power Sailcraft. Required is organization data that verify the expansion status of the membrane. The successful deployment of a solar sail in space represents an enabling technology.

b) Generation of electricity from the thin-film layer of solar cells on the membrane. This must be verified by housekeeping data.

c) Demonstration of the photon propulsion technique. This includes verification data of the reflectance parameters to determine the diffuse and specular properties of the radiation impinging on the sail. Also measurement of the overall sail reflectance, the temperature, and the condition of the sail surface under the influence of debris impacts.

d) Demonstration of GN&C (Guidance, Navigation and Control) techniques in support of solar sail propulsion. This involves navigation and orbit determination under the conditions of continuous but tiny acceleration. There must be means to control the acceleration direction and to maintain the attitude of the spacecraft.

The last news from IKAROS was very good. It has completed its regular operations. The demonstrator will be in the post operational phase, which leads to the development of a successor while acquiring basic knowledge of solar power sail technology including a navigation guidance technique.

4 Conclusions

Solar sailing is an elegant concept. Once developed, solar sails open up the opportunity to realize challenging deep space charges. The future utilizations of solar sailing for operational science missions will likely exploit the ability of this exceptional form of propulsion to deliver continuous thrust to enable high-energy and/or long duration missions. The projects presented in this paper demonstrate successfully the use of solar sail in space exploration. Especially the candle IKAROS already launched and operating with excellence. The Gossamer project is excellent and we desire the end launch and operation in space with successful. The agencies DLR / ESA already has years of experience in the subject and must surely will reap the good fruits of this partnership. Finally, the use of solar sails once more is the way of time for space exploration and a huge field for research and development. Besides being an ecological way of navigating through our space.

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