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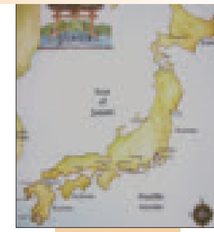


Japan's solar sail heads starward

FORGET THE AMERICA'S CUP YACHTING battle of Valencia in February this year—what's happening in space now may be the sailing event of the century. But we probably will not know the final result for about six months.

On May 21, Japan launched into space a minisatellite with a thinner-than-gossamer sail, to be powered by photons from the Sun. Been there, done that, you say? Agreed, part of the idea may seem old hat—until you take a closer look. This 667-lb, 59-in.-tall, 15-in.-thick cylindrical minisat is to show its paces by heading past Venus and the Sun rather than trying to demonstrate top performance in Earth orbit. No previous satellite has used light pressure as its primary means of propulsion—this is what's new, and it is why this experiment is so important to the future of space exploration.

There is nothing new about the idea of a space sail in itself—Japan deployed one on a suborbital flight to prove the unfurling technology in 2004; the U.S. has tried them in Earth orbit; India and Russia have tried the same. None of the orbital trials succeeded.

The idea has been around in science fiction since 1865, when Jules Verne briefly mentioned the notion of using light pressure to drive a spacecraft. Scientists, engineers, and writers have pursued the idea over a good many years, including, in 1964, scientist and writer Arthur C. Clarke. (The invention of the solar sail is often incorrectly attributed to Clarke, who did conceive the idea of the geostationary communications satellite.)

Interplanetary trial run

Weight and how to get sails to unfurl without tangling or tearing in space have always been problems. But materials science has come a long way since the previous U.S. experiments (of which another is scheduled for later this year by the Planetary Society, a nongovernmental group). So Japan has bitten the bullet and decided to try for an interplanetary trial run, adding the space sail experiment to four other minisats piggybacking aboard its own HII-A F11 rocket, which was already due to launch the Akatsuki (Dawn), a more conventional Venus Climate Orbiter observations satellite.

Weather delays held the launch back by a few days, but then the rocket left from the Tanegashima Space Center in southern Japan with no problems, and rapidly deployed all six of its payload components. The space sail minisat is named Ikaros, which stands for interplanetary kitecraft accelerated by radiation from the Sun. (Never mind that the acronym has unfortunate connotations because of the ancient Greek legend of Icarus: He and his father flew with wings made of feathers held together with wax, but Icarus went too close to the Sun and crashed because the wax melted.) Going for an interplanetary run with a space sail is new, and that is why this technology demonstrator is important to the future of space exploration.

The sail expanded fully on June 9. Pressure exerted by photons—minute "packages" of light energy emitted by the Sun—are now pushing the sail along in much the same way that wind drives maritime sailing craft. The rate of acceleration created by such tiny bundles of energy is very small, but it is constant, and although it takes a while, the sail should accelerate to a reasonable speed, an estimated 100 m/sec, according to Ikaros' creator, JAXA (Japan Aerospace Exploration Agency)—and should be able to reach Venus within about six months.

Slowness and patience

Such a slow speed is hardly useful for manned spaceflight, at least over relatively short distances like those within the solar system, considering the weight of people and stores to be accelerated. But for long-range unmanned probes, it is fine: In theory, at least, a light sail should be able to accelerate up to 10% of the speed of light. If there is a problem with this, it is how to slow down at the end of the trip.

In practice, a great deal of patience will be needed; at the Earth's distance from the Sun, the acceleration of the space sail should be one-sixtieth the force of gravity. Beyond that distance, the inverse square law applies, so the number of photons producing acceleration reduces as the sail gets farther away. Various solutions have been suggested, such as aiming giant laser beams into space to give space sails power, or using a "slingshot" trajectory past the Sun.

In this application of science and engineering, size matters. Ikaros's sail is a technology demonstrator, and is a modest square measuring 46 ft on each side, made up of four triangular petals that unfurled from a drum. To avoid having to provide bracing struts to pull the sail out, JAXA opted for small weights on lines, and centrifugal force from spinning the minisat to throw the weights outward and pull the sail petals off their storage drum. A later version of Ikaros, many times larger, is intended to head for Jupiter in about 2020.

Deployment of the sail occurred over several days. With Ikaros spinning at 25 rpm, the membrane was pulled from its container by guide weights. The four sail petals were released, extending outward as the weights exerted centrifugal force. In the final phase, holders restraining the sail petals' bundled material were ordered released and the petals unfurled. JAXA performed the delicate maneuvers slowly to avoid tearing the fragile membrane. As planned, the sail's expansion slowed the craft's spin rate, just as an ice skater slows a pirouette by extending arms outward. Ikaros should continue to spin at about 1-2 rpm. JAXA confirmed the full expansion of the sail and electric generation with the thin film solar cells at about 7.7 million km from Earth.

Material breakthrough

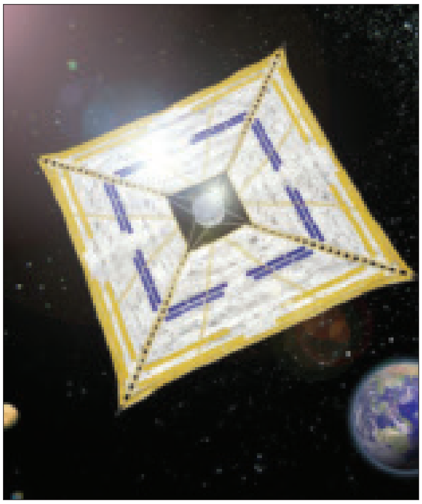
The sail itself is a masterpiece of design and technology, comprising several different elements. The basic sail is an aluminized polyimide film only 7.5 µm thick. Ikaros project leader Osamu Mori describes the material: "This film has to be made from a material that's not just lightweight but can withstand extreme radiation and heat in space. The material that meets these conditions is polyimide resin, which is used as a foam insulation for satellites. Once such a high-quality material became available, the development of a solar sail came much closer to reality.

"Today, Japan has the largest market share in the world for polyimide resin. We are currently leading the race to develop applications for this technology, and it would mean a great deal to us to be the first in the world to build a working solar sail. Polyimide resin allows us to create a much lighter sail. As well as being extremely strong, it doesn't need glue, because it can be joined using heat sealing.

"Polyimide resin is originally yellow, but one side of Ikaros's sail is silver. This is because aluminum is vapor-deposited on one side of the film, in order to reflect sunlight more efficiently. In addition, the film is reinforced in such a way as to prevent it from splitting all the way if it is ripped. If the solar sail is torn, its performance will decline slightly, but it can still continue its space travels."

The sail is also providing electrical power. About halfway up each sail petal are thin-film solar array strips; collectively all four sets of strips occupy about 5% of the sail's area and produce about 500 W of power. Assuming it works as planned, this will take care of Ikaros's "housekeeping" reports and computing needs. Sail shape is fixed; changing course is a matter of using the steering device in each petal—two reaction control device strips near each edge contain liquid crystal cells whose reflectivity can be changed.

Says Mori, "It works just like frosted glass. Normally, the entire area of the sail will reflect sunlight, but by 'frosting' part of the film, we can reduce the reflectivity of that area." This, in turn, cuts the force exerted by the photons on that part of the sail, and so can change the direction of flight.



It has not been an easy trip to the launch pad. The sail's deployment was a particular headache, said Mori before takeoff. "The sail film doesn't have a supporting frame," he said, and for storage at launch it was folded and wrapped around the main body of the spacecraft. Because the spacecraft continues to spin following the deployment of the sail, it will maintain centrifugal force and thus keep the sail open. "This eliminates the need for a supporting frame for the sail film, so the spacecraft can be very light."

Goals and outlook

Looking ahead to future missions, Mori continued: "Using the centrifugal-force method, a bigger sail is easier to unfurl. Ikaros's sail is small for a solar sail, but I think sails with a diameter of 50-100 m will be developed in the near future."

The Ikaros Venus/solar mission has four main objectives:

•Demonstrating deployment of a large membrane sail in space by mechanical means—this is described as an "enabling technology."

•Generating power through the solar cells on the sail.

•Demonstrating photon propulsion or "light power" and measuring and analyzing the results.

•Demonstrating guidance and attitude control by the sail's reaction control devices to show that a particular flight path can be achieved and maintained.

The first two are regarded as minimum objectives and have now been achieved, according to JAXA.

Assuming all goes well, showing the solar power system to be capable has implications for the Jupiter mission in the next decade. Says Mori, "The plan is to equip the probe with an ion engine, as well as a solar sail approximately 50 m in diameter. The larger the sail, the larger the solar cell area, so the probe will be very efficient, with no need to carry fuel.

"But it is very difficult to use only solar power for acceleration and at the same time control the probe's attitude, so we are planning to use a fuel-efficient ion engine along with the solar sail. However, the weakness of an ion engine is that it consumes a lot of electricity, so how do we give it a power source without carrying fuel? Jupiter is five times farther from the Sun than Earth is. At that distance, solar cells will be only 4% as efficient in generating power.

"For that reason, other countries' missions that ventured past Jupiter have all used isotope batteries. But we are determined to go to Jupiter using solar cells, so we invented a way to generate electricity using the thin-film solar cell on the sail. We would like to use Ikaros to evaluate it, and share the technology with the next near-Jupiter exploration mission."

Japan has a history of setting up very reasonably priced scientific efforts. JAXA previously announced plans to set up an unmanned lunar base by 2020 with a wheeled robotic lunar rover to explore the surface and report its findings back to Earth. Achieving that is expected to cost around $2 billion. Against that, the cost of the Ikaros experiment was a bargain at $16 million (yes,$16 million)—a small price for a potentially huge scientific and engineering reward.

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