Riders of the Light

BY JONATHAN EBERHART

Solar sails, scudding through space on the press of light, may reach earth-orbit and beyond in the mid-1980s

...For I dipp'd into the future,
far as human eye could see,
Saw the Vision of the world,
and all the wonder that would be;
Saw the heavens fill with commerce,
argosies of magic sails...
Alfred, Lord Tennyson
"Locksley Hall," 1842

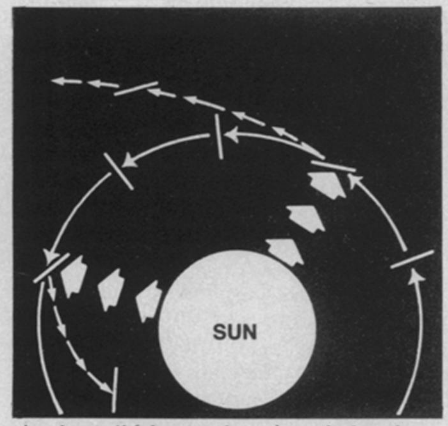
In the argot of many a sailor, engine-powered boats are "stinkpots," reeking of diesel fumes, muttering and roaring, and clanking through the waves totally at odds with the timeless seas. Even the sleekest of nuclear submarines, in such a view, interacts with its surroundings primarily by holding them at bay. Harmony reigns only in the riding of the winds, under sail, taking nature at her best and worst, whatever the terms may be.

A similarly evocative concept is solar sailing — literally soaring before the sun, carried through space on mirrored, gossamer wings propelled by the very light itself. What could be more attuned to the environment between worlds?

Solar sailing uses no rocket engines. It is not even a matter of photovoltaics — converting sunlight to electricity that provides thrust by energizing the contents of a fuel tank. For there is no fuel tank. Photons of light, falling on a vast sheet of some lightweight, shiny material such as an aluminized plastic film, provide the push directly, imparting to the sail an actual momentum. The force would be minuscule — even the rarified, outermost fringes of earth's atmosphere could render it useless — but in interplanetary space, the result could be a tiny acceleration capable of building up to speeds greater than those of today's most powerful chemical rockets.

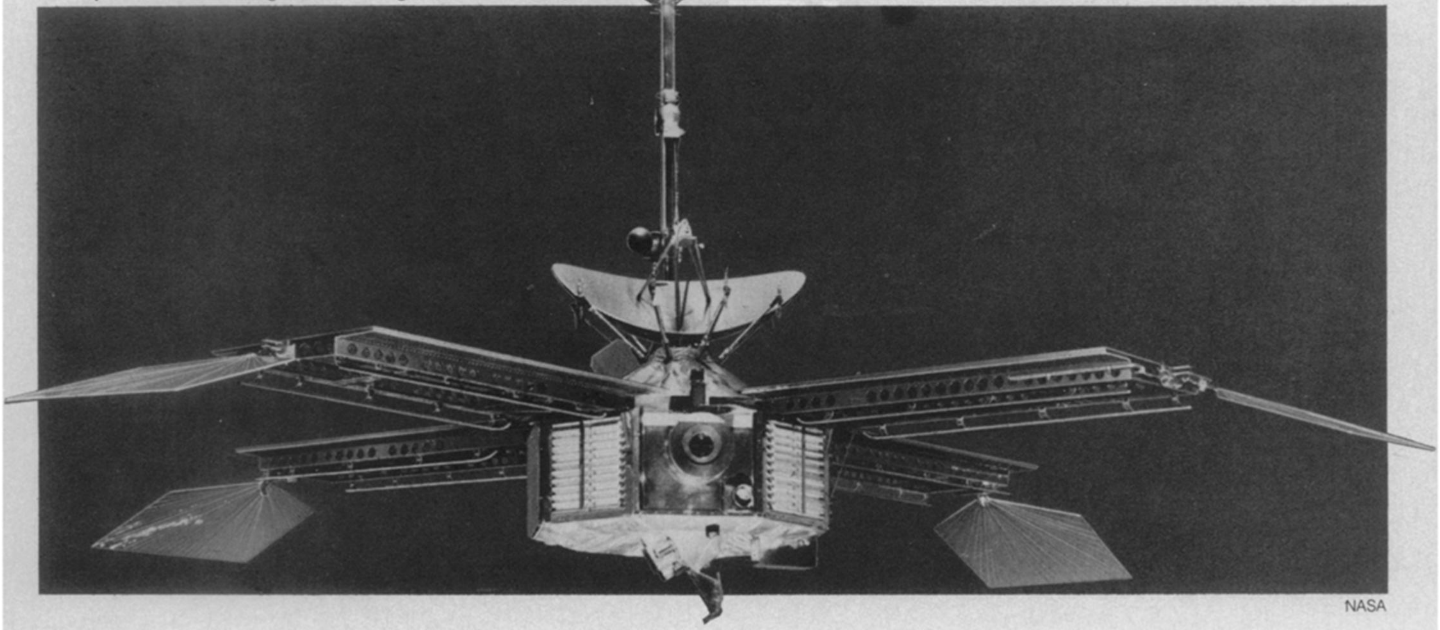
But riding on a sunbeam offers more than just high speeds. The ever-present light can provide its push indefinitely, enabling vast, languid maneuvers that studies suggest would beggar the capabilities of conventional propulsion systems dependent for muscle on whatever propellant they can lug along.

Early science fiction tales, for example, would describe hapless space explorers launched from earth only to succumb to an engine malfunction that let them fall into the sun. That would be an improbable accident indeed, since their craft would first have to lose all of its speed *around* the sun — which, because the vehicle was launched from earth, includes earth's own orbital velocity of more than 107,000 kilometers per hour. Some scientists have proposed doing it on purpose, sending an instrumented probe into the sun for some admittedly short-lived research, but today's rockets would require some healthy assistance for such a task. One proposal, for example, begins with a trip all the way out to Jupiter, making up for the rocket's missing energy with a "gravitational slingshot" maneuver around the giant planet.



A solar sail (shown above) angled so that the sunlight's push acts against its orbital motion will slow down and move closer to the sun. Angled to gain momentum, it will move outward.

The first spacecraft deliberately equipped for solar sailing were the twin U.S. Mariner 3 and 4 (shown) probes, launched in 1964. Vanes affixed to each craft's four solar panels were designed to let light-pressure help with attitude-control.



NASA

For a solar sail, however, the feat could be a natural. Once on its own heliocentric course, the sail would simply be angled "back" (see diagram), essentially sailing into the wind, so that the light's push would cause it to slow down and spiral inward. (It is unfortunate from the poetic standpoint of the nautical metaphor that the pushing comes from the light rather than the charged-particle outpourings called the "solar wind," which are 1,000 to 100,000 times weaker as a driving force for sails.) The same sort of maneuver could be used for trips to Venus and Mercury, both inside earth's orbit, while a re-angling of the sail could speed it up and send it out to Mars and beyond.

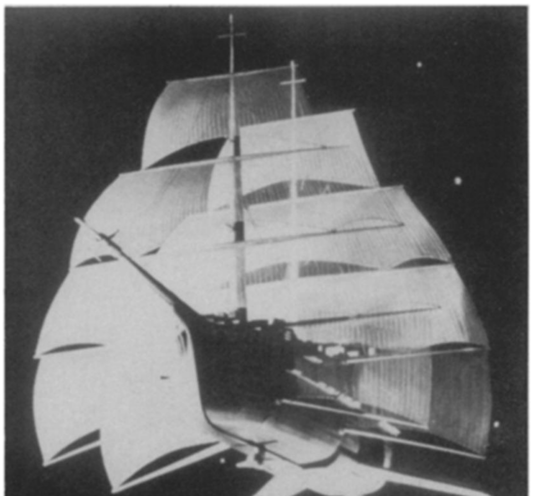
The provocative idea of solar sailing has inspired several works of fiction on its own over the years, as well as a limited number of technical papers. Now a California-based group of engineers and other space enthusiasts hopes to try it for real. In 1979, aeronautical engineer Robert L. Staehle and some friends established the World Space Foundation, a non-profit corporation set up in hopes of giving private citizens a chance to "support and participate in space exploration." Like other groups in the recent grassroots pro-space movement, the WSF is largely dependent on private donations of money, materials, time and expertise, but already taking shape despite such constraints is The Solar Sail Project.

The project's initial goal is to place in earth orbit a relatively small sail, about 30 meters on a side, first to see if it will deploy properly (using an X-shaped array of automatically unrolling spars) and then to evaluate its sailing performance. If that works, the next step would send a larger sail (perhaps 90 meters square or more) on an actual unmanned exploratory mission, such as to one of the asteroids whose orbits carry them near the earth.

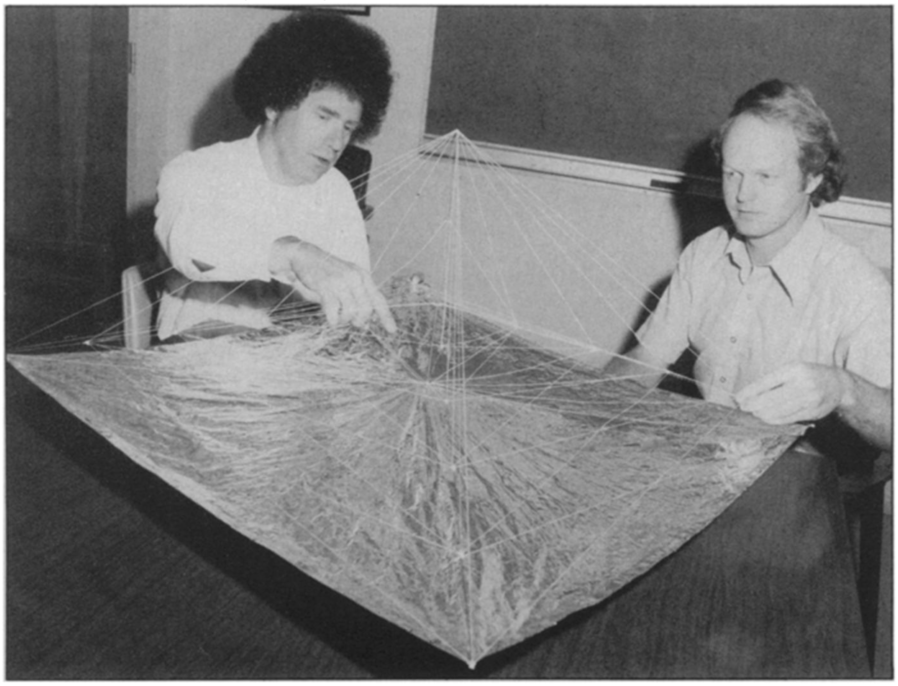
Considerable funding (probably including a free launching, for which negotiations are now in progress) and development are still needed for the first flight, envisioned for 1985 or 1986, but WSF's solar sailors have already successfully deployed a 14-meter sail in a ground test. The test, conducted Aug. 25 in an exhibit hall at the Planetary Society's Planetfest in Pasadena, Calif., was only a preliminary step, but it may be the most significant step yet toward reality for a notion whose roots go back to the earliest days of astronomy.

Solar sailing's central principle — that light pushes — has been an object of speculation for centuries. As long ago as the early 1600s, Johannes Kepler wondered about whether light pressure might play a role in the behavior of comet tails and even the motions of the planets. A quarter-millennium later, Maxwell's theory of electromagnetism indeed yielded the prediction that, if light were a form of electromagnetic radiation, it should produce a pressure on any matter from which it was reflected. Experimental

Sailing between worlds has inspired many fantasies, such as this vessel from the Japanese science-fiction film Message from Space.

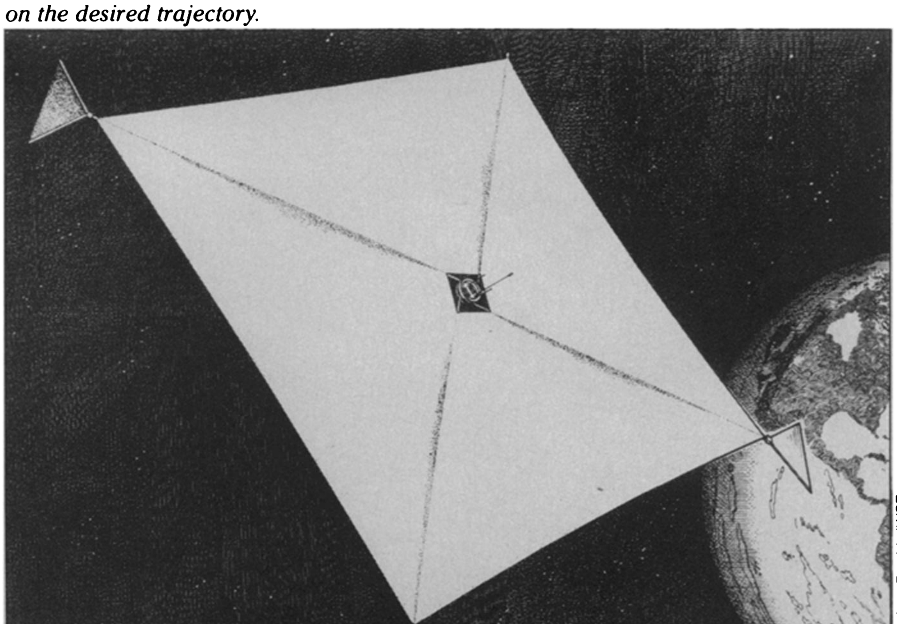


Model of a fully rigged solar sail was part of a study at Jet Propulsion Laboratory, discussed here in 1976 by development manager Louis Friedman (left, now executive director of the Planetary Society) and team leader Jerome Wright.



JPL

Solar sail (below) planned by the World Space Foundation is to be steered by two triangular corner vanes, which can rotate along the axes of the spars to which they are mounted. Shifting the vanes' angles to the sun will vary the light-pressure against them, causing the sail itself to roll to an orientation at which the light-pressure will move the sail on the desired trajectory.



Jean-Luc Beghin/WSF

Prototype solar sail of about 200 square meters was hand-built by World Space Foundation volunteers for a ground test in August to see if the planned system of extendible spars would produce a smooth, wrinkle-free result. The sail was constructed by unrolling a strip of aluminized Mylar plastic film from onto a long table and fastening one pair of their common edges together with tape (below); a third strip was unrolled on top of the second and joined to the second strip's free edge. The process was repeated several times, building up a multi-layered, accordion-folded "sandwich" of Mylar, which was then rolled around another drum-shaped assembly, representing what would be the instrumentation module of an actual solar-sail spacecraft.

M.S. Knuckles

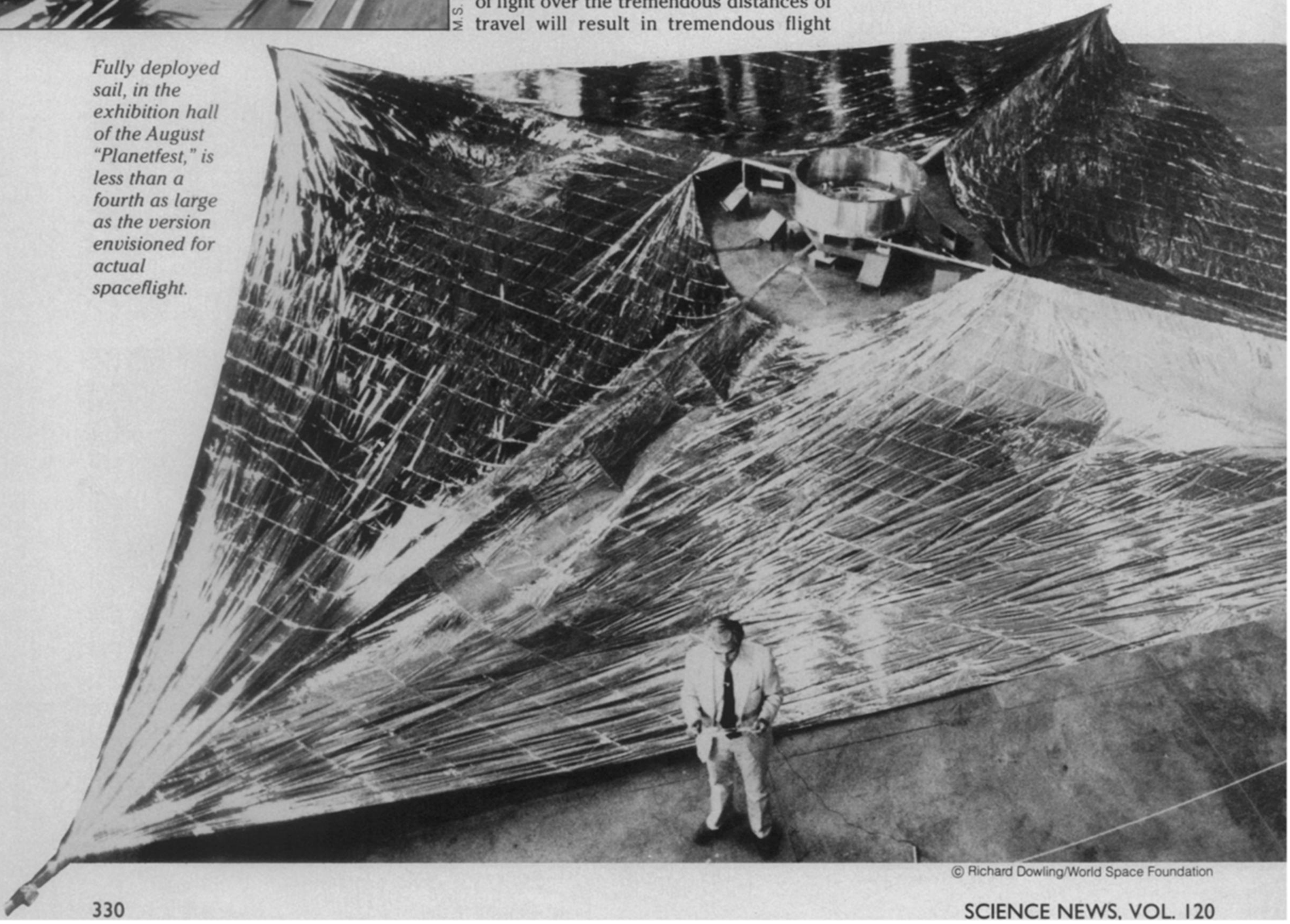
proof of radiation pressure was finally obtained by various researchers at about the beginning of this century.

The actual concept of a solar sailing, according to Chauncey Uphoff of Jet Propulsion Laboratory, appears to have been first discussed in the early 1920s by one of two Russian researchers, the famed Konstantin Tsiolkovskiy or Fridrikh Tsander. Incomplete and imprecisely dated records make it difficult to assign final credit, Uphoff says, but in 1924, Tsiolkovskiy wrote that "the pressure of sunlight ... may ... be applied in the ether [space] to vehicles that have already conquered the gravitation of the earth and only require further propulsion in outer space." In the same article he envisioned propelling a one-ton vehicle by means of a mirrored surface of at least 16 million square meters, although, he noted, "this is obviously not feasible, particularly at the present time." Also in 1924, Tsander raised the possibility of reflecting sunlight from earth-orbiting stations to interplanetary spacecraft. "The interplanetary ships ...," he wrote, "should be equipped with large mirrors almost one square kilometer in area; the ... stations should also have mirrors, but even larger. The light is collected by these mirrors and sent to the mirror of the ... spaceship in flight. The low pressure of light over the tremendous distances of travel will result in tremendous flight speeds, thereby shortening flight durations."

Credit for actually launching the first — and so far only — solar sails, however, appears to belong to the United States. On November 5 and 28, 1964, the National Aeronautics and Space Administration launched Mariner 3 and 4, the first U.S. spacecraft bound for Mars. Each craft carried four solar panels in an X-shaped array, and affixed to each panel's outer end was a "vane," shaped somewhat like a shovel blade. The vanes were provided in hopes that judicious use of the sun's light-pressure would reduce the amount of steering gas needed to control the orientation of each probe in space. Unfortunately, Mariner 3 suffered a launch malfunction that kept it locked behind an all-concealing shroud, and Mariner 4's vanes could not be properly adjusted once they had deployed. Solar panels and attitude-control systems have both improved since that time, and solar vanes have not been included on subsequent U.S. probes.

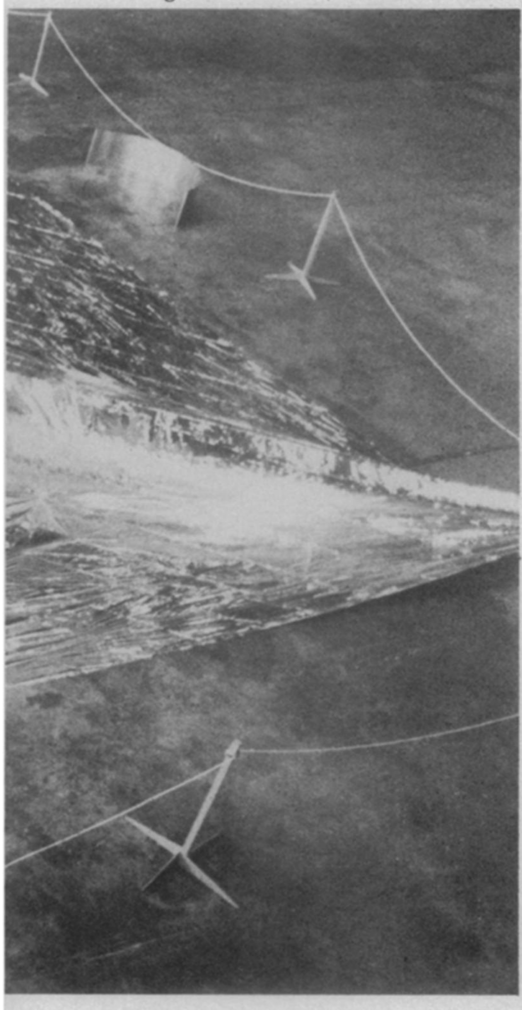
Solar sailing has made at least one major, positive contribution on a U.S. interplanetary flight, however. In 1974, the Mariner 10 spacecraft had passed by Venus and was heading for the first of three planned encounters with Mercury, when it developed a problem in the roll axis of its

Fully deployed sail, in the exhibition hall of the August "Planetfest," is less than a fourth as large as the version envisioned for actual spaceflight.



© Richard Dowling/World Space Foundation attitude-control system, which threatened to use up the probe's limited supply of steering gas. Without gas, the spacecraft would have been uncontrollable, bringing its mission to a disheartening and expensive end. After months of study, says JPL's Bill Purdy, engineers hit upon the solution of deactivating the roll-axis control completely, stabilizing the craft instead by aligning its two solar panels to take advantage of the differential light-pressure against them. Without the "solar-sailing mode," Mariner 10 might never have completed its latter Mercury flybys — the last of which revealed, among other findings, that the planet's magnetic field (surprising enough when it was discovered during the first flyby a year before) was intrinsic to Mercury, rather than induced by the solar wind.

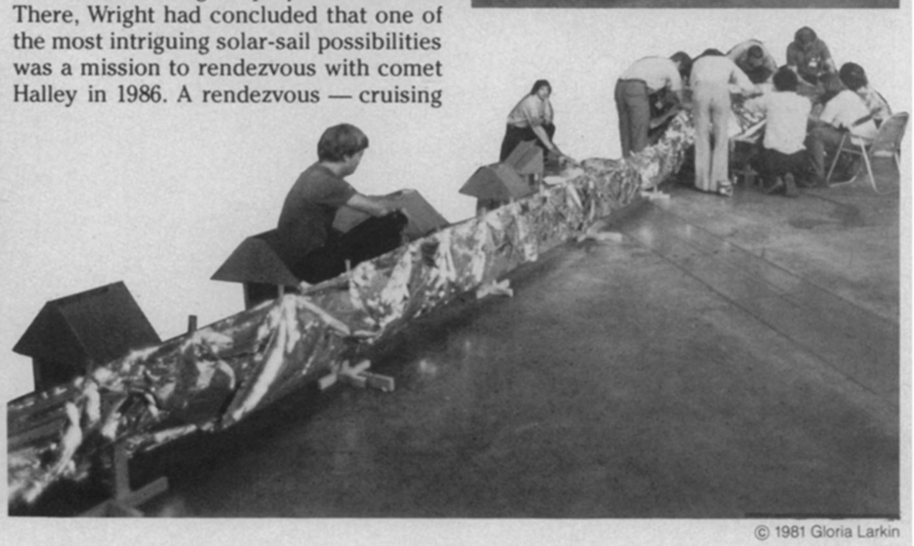
Even without such specific need, the sunlight's push has been taken into account in planning the trajectories of just about every U.S. interplanetary flight. Over the vast distances between worlds, the tiny but continuous nudge can add up to a substantial error. For example, the two 1975-76 Viking flights to Mars, says Charles Kohlhase of JPL, would have missed the planet by as much as 15,000 km if light-pressure had somehow been omitted from the calculations. (Before Viking's biology experiments had lowered expectations of finding Martian life, Kohlhase notes, light-pressure was even considered in the question of whether the red planet might somehow become contaminated by earthly microorganisms. Though only a remote possibility, it was considered barely conceivable that particles clinging to spacecraft surfaces might come off in space and be transported to Mars by light-pressure, where they might enter the atmosphere at speeds too low to burn them up. Playing it safe, Kohlhase and others conducted studies to confirm that particles released from spacecraft while in the lightpath from the sun to Mars would take long enough reaching the planet that they would be sterilized by solar ultraviolet radiation.)



The possibilities of using solar sails for propulsion, rather than just course-corrections and stabilization, had begun to get the space agency's attention at about the time of Mariner 10's launching in late 1973. A NASA-funded study was conducted at Battelle Memorial Institute in Columbus, Ohio, and led to a further analysis at JPL, where various kinds of planetary missions were evaluated for possible advantages of the solar-sail approach. One graphic example was an idea for collecting a sample of Mercury, a difficult task for conventional rocket propulsion because of the energy required to get a heavy, sample-collecting spacecraft so close to the sun. Getting a 30-kilogram sample back to low earth orbit with conventional propulsion, says Phillip H. Roberts of JPL, would require starting from earth-orbit with a spacecraft and fuel supply having a typical mass of a million kilograms. The use of multiple gravitational "slingshots" at Venus in both directions could cut the amount to a "mere" 75,000 kg, still about two and a half times the payload capacity of the space shuttle. With a solar sail, Roberts says, the total mass drops to about 2,500 kg, some 92 percent of which can be devoted to the Mercury surface-lander and the ascent vehicle that will deliver the sample to the waiting sail.

One of the people working on the sail study at JPL was Jerome Wright, who had conducted the original project at Battelle. There, Wright had concluded that one of the most intriguing solar-sail possibilities was a mission to rendezvous with comet Halley in 1986. A rendezvous — cruising

During deployment of the WSF-designed sail, two spars first unroll the wrapped sail into its multi-layered strip form, after which a second pair pulls the pleats open into a flat sheet. The WSF originally considered using spars that had already been developed for other purposes by a major aerospace company, but the likelihood of a $300,000 bill prompted the group to seek a cheaper method. For each spar, two flat ribbons of 0.5-mil stainless steel were formed into long, arc-section channels and welded at their edges. The resulting tubes could then be flattened again, attached to the sail and rolled onto the central drum. As the now-flat spars next unrolled from the drum, they would reform into rigid structures (a similar design was used for the soil-sampling arms of the two Viking landers on Mars), carrying the sail with them and holding it in shape. For the recent test, only the first pair of spars were built to deploy automatically; the others were hand-operated "dummies."



side-by-side with the comet for months rather than just flashing by — would be virtually impossible for conventional propulsion, he knew, because Halley would be circling the sun in the opposite direction from the earth and other planets. The proposed sail mission would have involved going close to the sun and circling it repeatedly, each time at a slightly higher inclination, until the sail's orbit carried it over the top of the sun so that it would be traveling in the same direction as the comet. Of the various sail designs considered at JPL, the best for the job was deemed to be the "heliogyro," an array of 12 radial "blades" each 8 meters wide and 6.25 *kilometers* long, providing some 600,000 square meters of sail area. With the device set slowly spinning, the designers felt, centrifugal force would serve to deploy the blades as well as eliminate the need for a weight-wasting stiffening structure.

While the sail mission was under study, however, an alternative propulsion system for a Halley rendezvous was being considered by a different team at JPL. Called the solar-electric propulsion system, or "ion drive," it would use electricity from huge solar panels to ionize a propellant, providing, like a solar sail, low thrust over a long period of time. The two study teams were fierce competitors to gain NASA's interest in further developing one of the ideas, and the agency's selection process in the summer of 1977 was subsequently dubbed "The August Shootout." The sail lost, primarily because NASA had had at least some small-scale experience with ion thrusters. But although the ion drive, too, was ultimately deferred until the time to prepare a Halley rendezvous had passed, the solar-sail seed had been sown.

Working at JPL that summer was Gary Flandro of the University of Utah, who returned to his professorial duties with the idea of developing a solar sail as a student project. The resulting design was for a triangular sail, about 20 meters on a side, that would be launched as one of the space shuttle's low-cost "Getaway Specials" into a low earth orbit that would merely test the reliability of its deployment, to be accomplished by automatically extendable spars. A space reservation was even purchased for the sail by the American Institute of Aeronautics and Astronautics, but the project faded when NASA said that it would not qualify as a Getaway Special, apparently because the specials could not be used to deploy structures outside the shuttle.

By that time, however, the Utah group was in contact with the World Space Foundation, which has since taken on the project and is now pursuing the possibility of obtaining a launch aboard the European Ariane rocket. Free launches have been made available in the past (when uncommitted payload weight has been available) for such devices as the OSCAR amateur-radio satellites. The OSCARS, too, were built on a shoestring, with much donated help, and some OSCAR veterans, according to WSF president Staehle, are assisting with the electronics for the small spacecraft that will be carried by the solar sail. Staehle expects the whole project to cost about $1 million, assuming that the launch and several other elements are free, along with the many hours of time that are already being volunteered.

The one WSF sail built so far — the one used for last August's deployment test — was made of Mylar, a thin plastic film, aluminized to a mirror finish. The resulting material has the look of household aluminum foil, but more the feel and weight of something like Saran Wrap. For an actual mission, says Wright, the sail might be made of another film called Kapton, which is both more thermally stable

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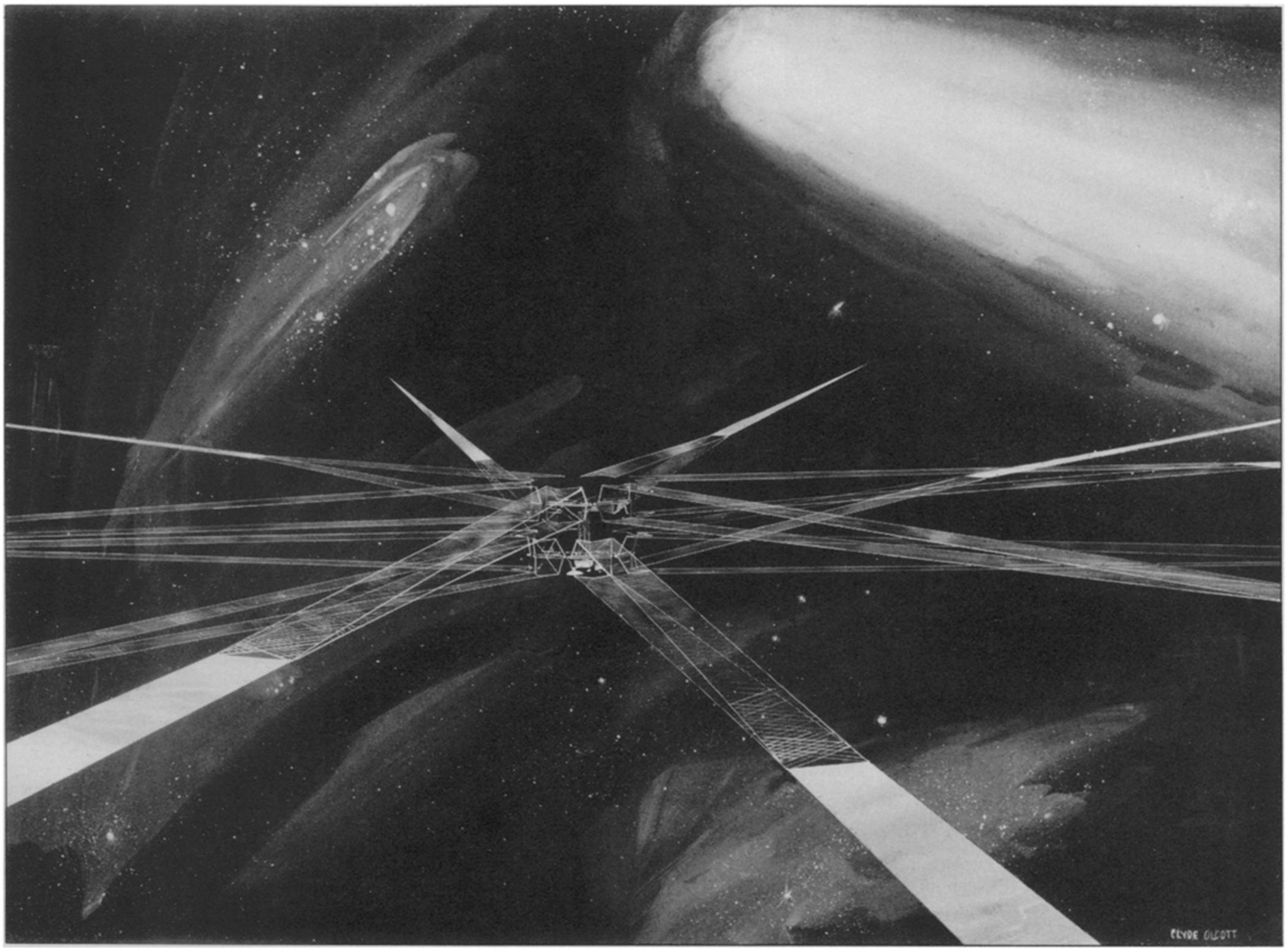
Artist's concept of the rotating "heliogyro" solar sail, with 12 blades each 6.25 kilometers long, studied at JPL for a possible mission to rendezvous with comet Halley.



Clyde Olcott for JPL

Riders of the Light *(continued from p. 332)* (long exposure to the heat of even the distant sun might produce a gradual sagging) and more resistant to the weakening effects of solar ultraviolet radiation, which could break down some of the molecular bonds in the plastic. A Kapton sail of 1,000 square meters, according to Wright, could weigh a mere 100 kilograms.

Next summer, the WSF plans to conduct a similar ground test using a 30-meter-square sail. After that, Staehle hopes to build a sail of Kapton, to be followed by a twin that will actually make the maiden trip into earth-orbit. The first flight, in addition to testing the deployment process in space, would determine how much energy could actually be gained by carefully controlling the sail's angle to the sun — the first true demonstratrion that a solar-sail propulsion system *works*.

The second flight, on the WSF's present calendar, would be deep-space-bound. But escape from the earth could be a long time coming. The sail would repeatedly circle the earth, a little faster and higher each time, but so tiny is the sunlight's push that it could take a year and a half for the WSF-designed sail to reach escape velocity. A more costly alternative would be to kick the still-furled sail out of earth-orbit using an auxiliary rocket motor.

The mission possibilities are numerous. An asteroid rendezvous is the leading candidate, but comet visits, into-the-sun probes and Mercury sample-gatherings are only a few of the other options. One idea considered during JPL's solar-sail study was called the "milk run," in which a sail would carry a payload such as a landing craft to Venus, drop it off, return to earth orbit where it would be provided with another payload, deliver that one to, say, Mars, and then return again to earth orbit to await its next assignment. Another idea is a multi-asteroid rendezvous, in which a sail-equipped vehicle would travel to one asteroid, match speeds with it and travel along side by side for a month or so, then move on to another and repeat the exercise, etc. Solar sails have even been considered for manned missions, for which the necessarily more massive spacecraft prompt visions of vast sails measuring kilometers on a side.

Although thundering rockets may always be needed to ferry payloads into orbit from the earth's surface, even groundlings — who could actually see a fully deployed, orbiting solar sail glinting in the sun — may someday have a chance to view the silent but spectacular comings and goings of the riders of the light. □

"A SOLAR PRIVATEER"

I wrote the song on the cover in 1976, long before there was such a thing as the World Space Foundation but at a time when JPL's solar-sail study was suggesting that reality might be catching up with a concept that had fascinated me for years. The song began with my realization of the months it might take for even a large sail, dependent on the light alone, to reach escape velocity from earth orbit.

A commercial interplanetary shipping line using manned solar sails (why not?) could eliminate that delay by firing a rocket to kick the sail out of orbit, still furled, and then deploying it en route. A low-budget private operator, however, with no such auxiliary hardware, would simply have to endure the wait— the "Deadman's Year" might be the jargon of the time. Yet he might also relish the experience, sharing the wind-sailor's sense of freedom from the technological fussiness of an engine. A solar privateer, in fact, might view the sailor of the seas as a mere "water-lubber," confined forever to the surface of his world.

The song contains some technical terms, but only such as the lightriders themselves might use, and certainly no more than one encounters on a water-borne sailboat. "Hotbox" is my solar sailor's derogatory term for a conventional rocket engine. "Vee-sub-ee," actually written V_e, is technical notation for escape velocity, and to the privateer depending on it for a livelihood it would be just as common a term as, say, "carburetor" is today. LOX is liquid oxygen, used with some chemical rocket propellants, and Mylar is, at least for the present, the stuff of the solar sail itself.

The tune is in the style of the forecastle ballads and forebitters common on British sailing ships in the nineteenth century. A guitar suits it fine; a concertina would be wonderful, bringing the sound of tradition to an idea which, though still untried, may yet have its day in the sun.

—Jonathan Eberhart