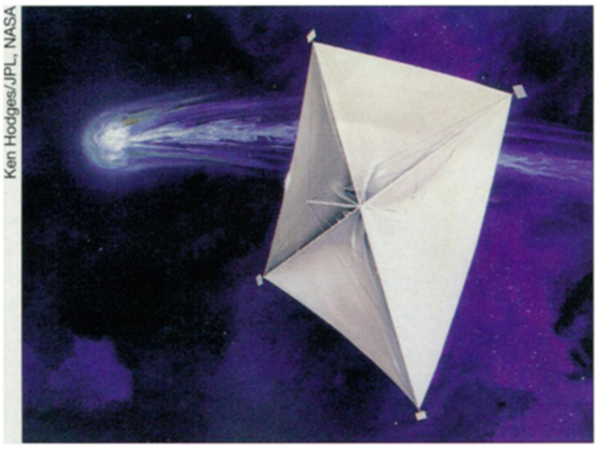
Travelin' Light

Sailing through the solar system . . . and beyond

By RON COWEN

"Just one of those fabulous flights,
A trip to the moon on gossamer wings . . ."
—"Just One of Those Things," Cole Porter

Thirty years ago last month, three astronauts roared into space on a historic journey to the lunar surface. Their trip to the moon, however, was hardly on gossamer wings. The Saturn V rocket that launched Apollo 11 crewmembers Buzz Aldrin, Neil Armstrong, and Michael Collins weighed 15 times as much as the Statue of Liberty, stood 20 meters taller, and carried 2,500 tons of fuel.


Ken Hodges/JPL, NASA

Depiction of a solar sailcraft rendezvous with a comet.

Now, imagine another craft cruising through space. This lightweight vehicle has neither rocket nor fuel to weigh it down. Unfurling a shiny aluminized sail less than 100 atoms thick, the craft gets a continuous push from a limitless supply of energy—sunlight.

Like a sailboat on the ocean, such a spacecraft could adjust the tilt of its sail to steer itself in any direction (SN: 11/21/81, p. 328). It could move out of the plane in which the planets revolve or drift closer to the sun. Moreover, sunlight could push the craft to the very fringes of the solar system and into interstellar space. Augmented by an extraordinarily powerful laser beam shining light into space from Earth's orbit, a sailcraft might travel even farther, to the nearest star, completing its journey in just 40 years.

If that sounds like science fiction, in some ways it still is. A sail thin enough and large enough to propel a craft to the solar system's edge has yet to be built. Two decades ago, NASA turned its back on solar sails, concluding that the technology was just too far-out.

In the past few years, however, solar sails have gotten a second wind. Revolutions in microelectronics and materials science have shrunk the size of spacecraft and made possible lighter-weight construction. "We can do a lot more in a small package," says John L. West of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif.

The space agency's oft-proclaimed quest for faster, better, and cheaper missions also has refocused attention on sails. NASA scientists now say that the first sailcraft to venture to the solar system's edge could be launched a decade from now.

This novel means of transport may soon get a major push forward. The National Oceanic and Atmospheric Administration (NOAA) and the Air Force have proposed a mission called Geostorms, which would closely monitor upheavals on the sun and become the first craft to navigate by sail. Although NASA this week decided not to contribute funds to the project, it has set aside money in its fiscal year 2000 budget for development of solar cells and related technologies.

"There's definitely been renewed interest in sails," says Les Johnson of NASA's Marshall Space Flight Center in Huntsville, Ala. "We want to develop propulsion systems to let us get out of the solar system. And when you look at the options that are available . . . the one that looks doable in the next 10 years is the solar sail."

You don't have to be a rocket scientist to understand the physics underlying solar sails. More than a century ago, Scottish physicist James Clerk Maxwell realized that light must exert a pressure. Physicists now think of light in terms of photons, particles that have no mass but carry momentum. Like ping-pong balls bouncing off a wall, photons striking a perfectly reflecting surface exactly reverse their direction of motion, imparting twice their momentum to the surface in the process.

The nudge delivered by a single photon is minuscule, so a solar sail must be large in order to intercept as much light as possible. Indeed, at Earth's distance from the sun, the force applied by light on a square meter of sail is only 9 micronewtons, less than the weight of an ant. To maximize the acceleration from sunlight, the sail must be wrinklefree. The sail must also be lightweight, with a density less than that of this printed page.

Although several science fiction writers at the turn of the century penned stories about spaceships propelled by mirrors, it wasn't until 1924 that Russian aeronautics pioneer Konstantin Tsiolkovsky and his colleague Fridrickh Tsander wrote of "using tremendous mirrors of very thin sheets" and "using the pressure of sunlight to attain cosmic velocities." It was Tsander who first proposed the solar-sail design still in use today—an ultrathin layer of reflective metal coating a rigid plastic backing.

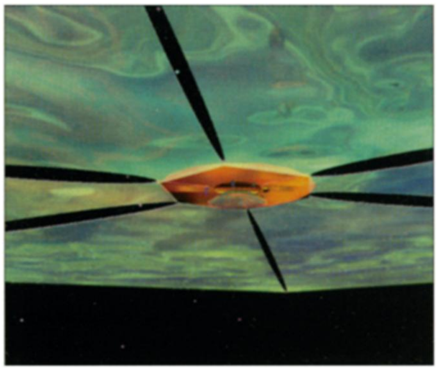
Space scientists were slow to follow up on his ideas. In the early 1950s, engineer Carl Wiley became the first U.S. scientist to discuss the design of sails, orbits for sailcraft, and the advantages of solar sailing for travel between the planets. He even envisioned that a sail could be tilted to steer or track a craft.

Wiley was so worried about what his peers would think that he published his work under a pseudonym, Russell Sanders. Perhaps that was just as well, considering that his May 1951 article appeared in the journal ASTOUNDING SCIENCE FICTION.

Columbia University engineer Richard Garwin first coined the term solar sailing in the late 1950s. However, it took science fiction writer Arthur C. Clarke, who wrote about a solar-sail race in his 1963 short story "The Wind from the Sun," to capture public attention.

In 1976, JPL scientists proposed a solar-sail mission on a grand scale. They suggested building a sailcraft that would rendezvous with Comet Halley during its 1986 return to the inner solar system. An early design called for a mammoth sail, 800 m on a side, to transport an 850-kg payload. Not long after, NASA deemed the plans too risky and abruptly terminated all solar-sail research. A few private groups tried to keep the idea alive through the 1980s, raising funds for a solar-sail race to the moon, but the race never happened.

A Russian experiment eventually rekindled interest. In 1993, the resupply vehicle Progress, which services the Russian space station, successfully used an onboard motor to unfurl a 20-m, disk-shaped sail. Designed as a prototype of a mirror that could illuminate northern Russian cities during the dark winter months, the experiment proved a success, demonstrating that a sail could be deployed in space.


JPL/NASA

Drawing of the Interstellar Probe, a sailcraft that would venture to the edge of the solar system.

In 1996, NASA's space shuttle deployed a large inflatable radio antenna, using a technology that gave solar sails another boost (SN: 1/13/96, p. 24). All along, engineers had been uncertain how to unfurl a large, tightly rolled sail without creasing it. The shuttle experiment, by demonstrating that a large structure could inflate in space, suggested a way to solve the problem. The sail could be pushed out of its storage container by an inflatable boom, similar to the way a party blower would push out any material that had been rolled up along with it. Inflatable booms or struts could keep a sail under tension—wrinklefree—after it opened.

Around the same time, scientists came to realize that solar sails need not be several times the size of a football field. A modest sail, too small for a trip to the outer solar system, can allow a craft in Earth's neighborhood to maneuver in novel ways.

Geostorms is a prime example of such a mission. It would travel by conventional rocket from Earth directly toward the sun, coming to rest 1.5 million km from Earth. At that position, the sun's gravity balances that of Earth.

Soon after it arrives there, Geostorms would unfurl a relatively small 70-m sail. Set at a carefully chosen angle, the sail would provide the energy required to send the craft an additional 1.5 million km closer to the sun yet keep in sync with Earth's motion. From that vantage point, Geostorms would closely monitor the sun for magnetic storms that could disturb satellites and knock out power grids on Earth, providing warning of solar storms 2 hours before they strike our planet (SN: 3/13/99, p. 164). That's nearly double the warning time currently available.

Cosponsored by NOAA and the Air Force, Geostorms could be the first of a series of solar-sail missions that venture ever closer to the sun, says Patricia Mulligan of NOAA's satellite office in Suitland, Md.

"Solar sails have been around theoretically for years and years," says West. "The thing that is different with the Geostorms concept is that for the first time, there is actually a practical application that users are willing to pay for."

Sail by design

"Their ship was a kind of sphere with a shell—the sail—made of amazingly thin material, and it would move through space, just pushed by the pressure of light beams."
—*The Planet of the Apes*, by Pierre Boulle (1963, Vanguard)

Essentially a giant mirror in space, a solar sail needs to be as thin and lightweight as possible. On the ground, researchers have tested sails made of Mylar, a clear plastic, coated with aluminum. Though inexpensive and readily available in sections as thin as half a micrometer (μm)—a few hundred atoms thick—Mylar has one key drawback, notes Charles E. Garner of NASA's Jet Propulsion Laboratory (JPL) in Pasadena, Calif. Mylar is easily degraded by the sun's ultraviolet radiation.

That's a critical problem because sail missions will typically venture closer to the sun than Mercury's orbit in order to maximize the acceleration they receive from sunlight. At their closest approach, one-quarter of the distance between the sun and Earth, solar radiation is 16 times as intense as on Earth.

Another type of backing, Kapton, can withstand ultraviolet radiation but isn't available in layers much thinner than 8 μm. A solar sail made of Kapton would have a density of 12 grams per square meter, acceptable for the Geostorms mission but too heavy for a sail mission to the solar system's edge.

Scientists at JPL and private companies are experimenting with a backing made from a meshwork of interlocking carbon fibers. This porous structure would provide a stiff but extremely lightweight support for the sail coating. In addition, carbon is relatively impervious to solar-radiation damage.

To deploy a sail, a ship must have a mast and a way to support the mast—typically, a boom. In some models, the booms are made of material that becomes rigid as it inflates. Even after removing the inflating gas, the material maintains its support.

Another type of sail doesn't need a boom to maintain its shape. Instead of having a rigid support, the sail is set spinning, and centrifugal force keeps it taut. A spinning sail is highly stable, but it's difficult to change its tilt. It's best for missions such as the Interstellar Probe, which requires little steering as it makes a beeline for the edge of the solar system.

A team led by Red Whittaker of Carnegie Mellon University in Pittsburgh is designing a variation on the spinning sail. Their whirling sail, known as a heliogyro, resembles the four blades of a helicopter and can be easily steered.

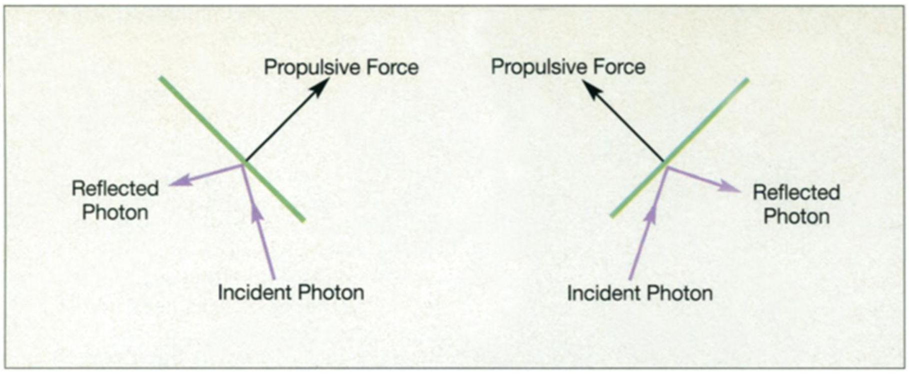
In the earliest designs of sailcraft, notes Peter B. Ulrich, NASA's director of the advanced technology and mission studies division in Washington, D.C., the sail was merely a propulsion element, separate from the rest of the spacecraft and its science instruments. With recent advances in microelectronics and microcomputing, the sail can become a complete package. "The view of the spacecraft of the future isn't necessarily something like the Starship Enterprise. It's a structure in which the sail itself and its rigidized membrane contain the microcomputers [and other miniaturized instruments] necessary for the mission." —*R.C.*

Geostorms may be just the first of several solar-sail missions that could be launched by 2005, says Charles E. Garner of JPL. These include commercial satellites that would orbit Earth at high latitudes, improving broadcast communication to residents of Alaska. At present, conventional satellites can remain in such orbits only with great difficulty.

More advanced missions, which would require larger sails with lower densities, might be ready for launch between 2005 and 2010, Garner says. These include a mission to Mercury. With a sail 100 m on a side and having a density no higher than 10 grams per square meter (g/m^2), "we could go to Mercury and get there quicker than by [rocket]," he predicts.

Launched into a solar orbit at Earth's distance from the sun, the sail would be angled to slow its speed, allowing the

Garner/JPL



By tilting its solar sail, a sailcraft could move in different directions.

sun's gravity to draw the craft into Mercury's orbit. On arrival, the craft could tilt its sails to begin orbiting the poles of the planet, as well as its equator.

A sail mission venturing outward, to Saturn's methane-shrouded moon Titan, would have similar design requirements, notes Garner. It would take significantly less travel time than the rocket-propelled Cassini mission, which is expected to arrive at Saturn in 2004, after a 7-year journey.

If engineers can develop a 200-m sail with a density of 1 to 5 g/m², it would make possible a slew of far-flung missions. Achieving a density of 1.5 g/m² "is the holy grail for solar sails," says Garner, because the photon pressure falling on such a sail balances the pull of the sun's gravity.

In the inner solar system, vehicles could sit permanently above the sun's poles, watching the writhings of the sun from a vantage point no craft has so far attained. By combining images of the sun from a fleet of craft at various latitudes, stereo views of the sun would be possible.

Similarly, a sailcraft could hover above Earth's poles, watching the weather evolve over the Arctic and Antarctic regions.

The typical long-distance sail mission would build up its solar-powered acceleration by first spiraling to well within Mercury's orbit. "In the same way that [conventional spacecraft] swing by Jupiter to get a big gravitational kick, a solar sail will swing by the sun and use radiation pressure to give it a big kick," notes David Alexander of the Lockheed Martin Solar and Astrophysics Laboratory in Palo Alto, Calif.

Jettisoning the sail near Jupiter's orbit, where solar radiation becomes too feeble to provide significant acceleration, the spacecraft's momentum would speed it through the outer solar system. Relying on small amounts of chemical propellant, these vehicles might land on such intriguing sites as Europa, the Jovian moon suspected of harboring an ocean, or a comet in the Kuiper belt, Garner suggests.

For missions that aim to linger in the outer solar system, however, West argues that a nuclear-powered engine would maneuver more easily than a solar sail.

Another proposed sail mission, the Interstellar Probe, would be the first to leave the solar system. It would travel beyond the Kuiper belt to a region about 200 astronomical units (AU) from the sun. (One AU is the distance between Earth and the sun.)

If it travels farther into interstellar space, a sailcraft would pass by a special zone. According to Einstein's theory of gravitation, every massive body can act as a gravitational lens, bending or distorting light emitted by an object lying directly behind it. This includes the sun. At distances of 550 AU or more, the sun's gravity can bring light from distant objects to a focus, enlarging and brightening them. A sail-powered telescope parked at this distance would view remote objects, such as the stars swirling around the center of our galaxy, with unprecedented clarity.

Then comes the final frontier. Garner and other researchers envision a day when a sailcraft will travel to another star. That will require a sail 1 km on a side having a density of 0.1 g/m². Even so, an artificial source of radiation—a powerful laser or a source of microwaves—will need to assist.

In one scenario suggested a decade ago by Robert L. Forward of Forward Unlimited in Clinton, Wash., the craft would rely on a light source that has yet to be built—an Earth-orbiting laser as powerful as six suns—and a focusing lens the size of Texas positioned between the orbits of Saturn and Neptune. The craft could fly through space at one-tenth the speed of light. At that rate, it would reach Alpha Centauri, the nearest star, in a few decades, notes Garner.

"For us, making the laser is hard, making the lens is hard, but that doesn't mean that in 25, 20, 40, or 50 years in the future it will be hard," he says. "I really have come to the conclusion that people are just incredibly smart and that it is just impossible to predict what can or cannot be done."

Upon arrival at Alpha Centauri, the sailcraft would continue its flight. This time, however, the light propelling the spacecraft would come from a star other than our own. □