# *The* ETERNAL AIRPLANE

BY STUART F. BROWN


Men with streaming telltales on long poles monitor breezes while the dawn sky shifts from reddish to pale gold. History is being made, and it sounds like a whirring window fan. Make that a chorus of window fans.

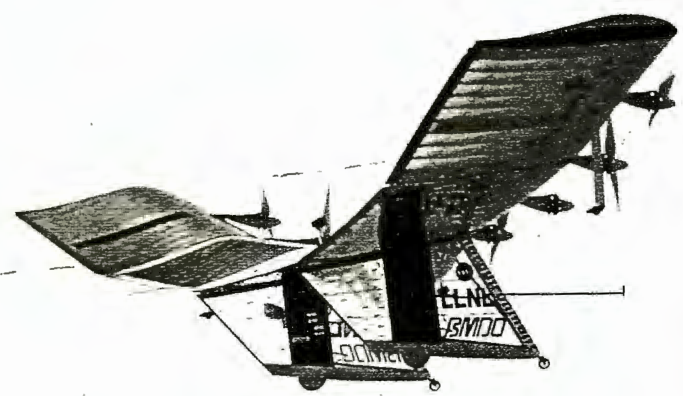
As its eight propellers begin to spin, the drooping tips of an immense, spindly wing rise almost immediately. Rolling on a pair of wheeled pods across the dry lake bed at Edwards Air Force Base, Calif., the wing continues to bow upward. Its eyebrow-like curvature evolves into a Mona Lisa smile, as the solar-electric Pathfinder leaves the ground. The takeoff roll is just 80 feet—less than the craft's own wingspan. It climbs to an altitude of 200 feet, sunlight glinting from the clear-plastic wing skin. Flight speed is a bicyclish 15 mph. Barely a sound can be heard.

This airplane has remarkable potential. If it lives up to expectations, an advanced version could fly around the world in about 20 days at an airspeed averaging 90 mph. On a longer weather reconnaissance mission, it could take off from California in April, traverse Australia, then pass over the Middle East. Sailing eastward, it could follow a hurricane's progress from West Africa to the Caribbean, finally returning to a West Coast airfield for a late June touchdown. It could also perform military missions monitoring troop movements for weeks, while pinpointing Scud-type missiles as they ascend. And fitted with communications equipment, it could work as a mobile relay.

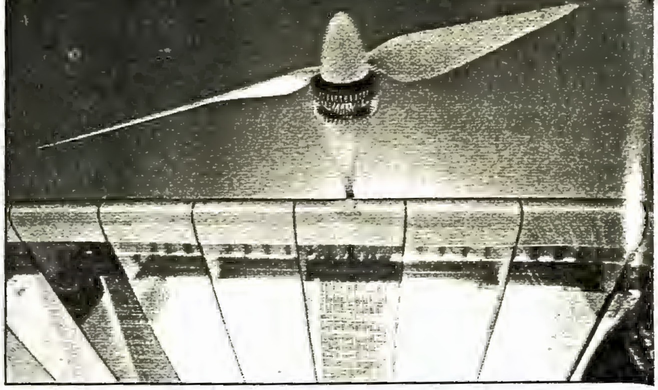
Flying a 2,000-to-3,000-hour mission would require the sun-powered craft to be the most reliable airplane ever built. An incidental reward would be shattering the world endurance record for powered flight.

Viewed from above, the Pathfinder looks like a plank of

PHOTOS BY JAMES CACCAVO




# The liftoff of unmanned solar-electric wing

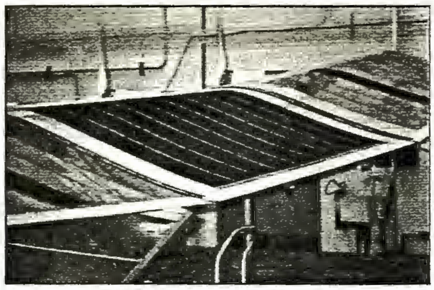


lumber 100 feet long and eight feet wide. There's no taper or sweep. Just eight electric-powered propellers on the leading edge, and a row of 26 individual elevators on the trailing edge to control pitch and dampen turbulence. No rudders, no fins, no tail. Not even a pilot. Where's the rest of this airplane? The upward bowing, or dihedral, of the wing in flight is its only other feature. Turns are made by slowing down or speeding up individual propellers.

Optimized for low-speed, high-altitude flight, this machine is a flying wing in the purest sense of the term. Even though its span is slightly greater than a Boeing 737 airliner's, it weighs a mere 400 pounds. The Pathfinder has to be this light to do its job, which is proving the feasibility of long-duration flight using sunlight as the sole energy source. A decade ago, it couldn't be done, but a series of ten low-altitude test flights conducted late last year shows that the goal is now within reach.

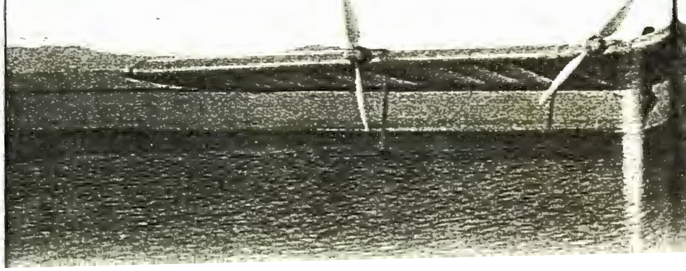
Pathfinder was developed and built by a small team at AeroVironment Inc. in Simi Valley, Calif., the engineering firm headed by Dr. Paul MacCready, noted builder of human-powered aircraft and other ultra-high-efficiency vehicles. The plane, he admits, "is a technological stretch."

AeroVironment possesses a unique fund of knowledge about solar-electric flight gained by constructing the fledgling Gossamer Penguin in 1980, and the 47-foot span Solar Challenger, which in 1981 flew from Paris to England at 11,000 feet at an average speed of 40 mph. The company's engineers, many of them longtime model-glider fliers, are ex-



MIKE GASPAR


**Each propulsion unit (top) weighs just 13 pounds and consists of a fixed-pitch propeller, motor with internal power electronics, nacelle, cooling fins, and mounting strut. The solid-state, 1.5-horsepower motors are derived from the AeroVironment design developed for the General Motors Impact electric-car prototype. At the remote-control pilot's station on a chilly morning (second from top), designer Ray Morgan prepares for takeoff. Segmented solar arrays (above left) follow the contours of the 100-foot wing's upper surface, which is only partly "populated" with silicon photovoltaic cells in this photo. In flight (far right), the airplane flexes into the upward-bowed dihedral angle that gives it roll stability. Space shuttle Mission 58 (above) was undergoing postflight processing when Pathfinder flew by last October. On the ground (bottom right), pylons under the outboard tips prevent overstretching of the transparent Mylar wing skin.**



pert in selecting optimal lightweight materials for the thousands of structural parts that add up to an airplane. Pathfinder's contents include carbon, aramid, glass-fiber composites, Mylar, Styrofoam, balsa, and even some spruce.

Theoretical calculations convinced Ray Morgan, Pathfinder's designer, that a solar-electric airplane should be able to stay aloft continuously if it carries an energy-storage system, or battery, capturing about one-half the solar array's output to power its motors through the night. The required array would need to occupy twice the area of the Solar Challenger—yet weigh no more.

He considered stretching the Solar Challenger, which has a conventional cruciform design with wings-and-tail assembly attached at right angles to a longitudinal spar. But as the cantilevered wings grew, so would the amount of internal structure needed to support the motors and aerodynamic loads. The idea became too heavy to work.

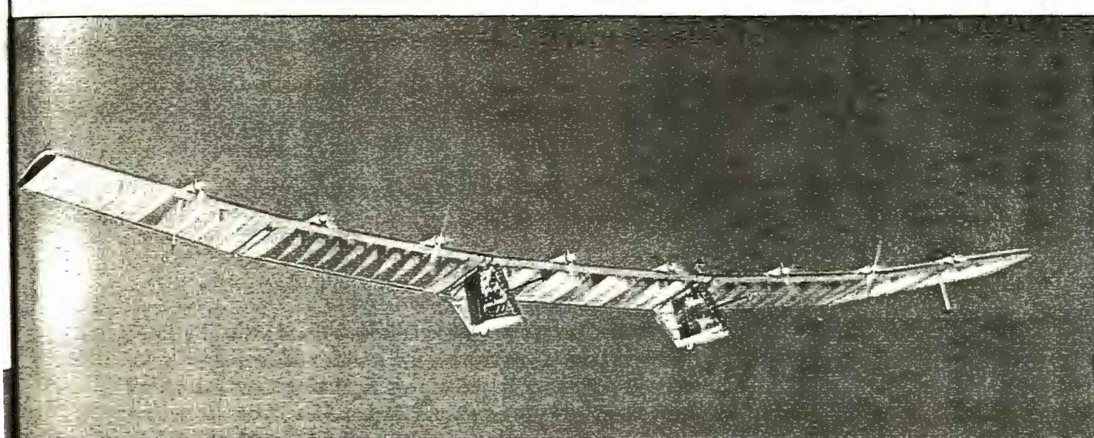
Morgan realized the only way to get a large wing area for the solar array, while keeping weight under control, was to distribute the plane's mass throughout its structure. "We did it by making what's really a series of very small airplanes that just happen to be connected together," he explains. "This is called a span-loader. It's a flying wing with small, lightweight spars that make it very flexible. Each piece flies stably, so the wing doesn't need a lot of torsional, or twisting, strength. I could cut this airplane in pieces, and each one would fly by itself."

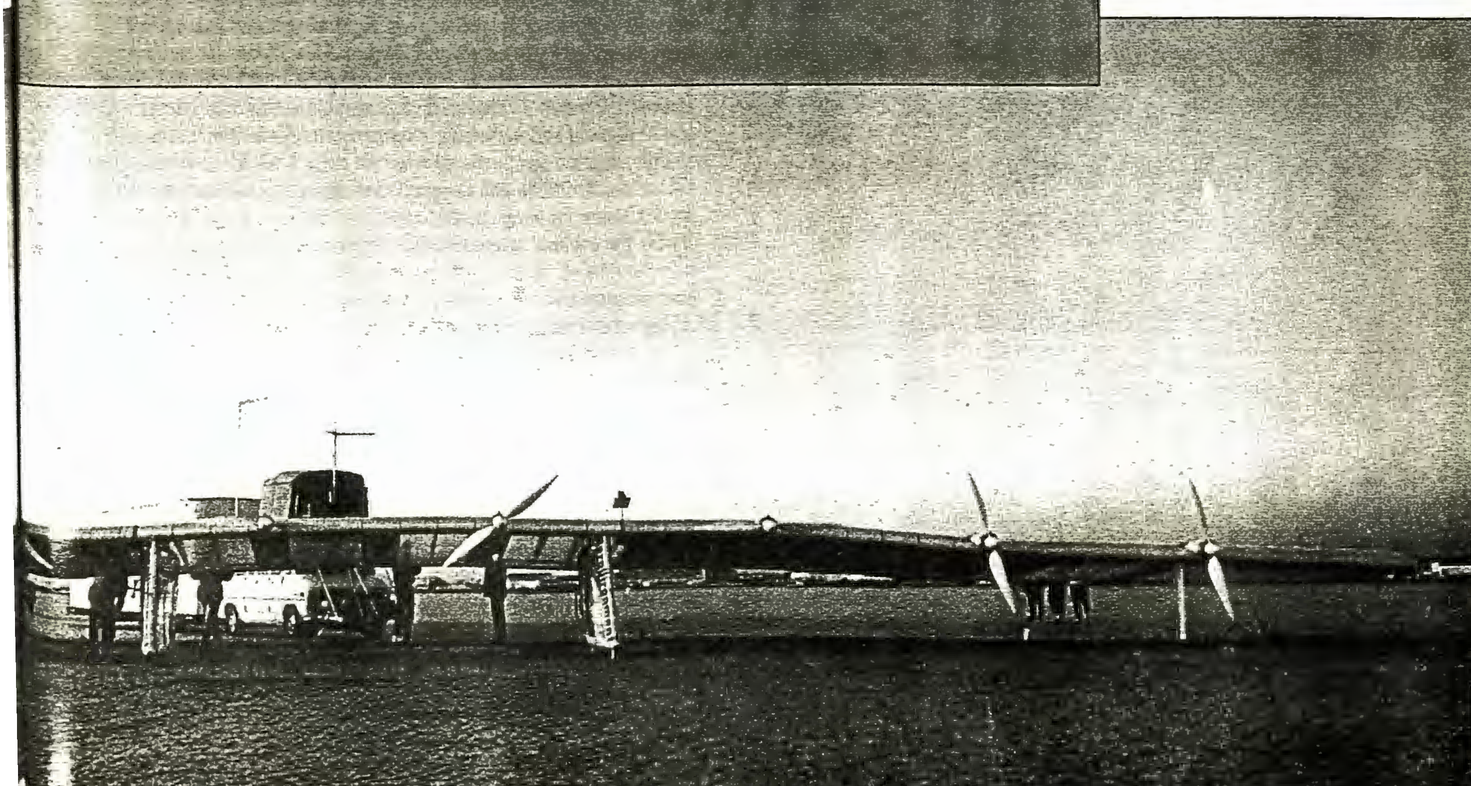
Dividing Pathfinder's 800-square-foot wing by its 400-pound weight reveals its exceptionally light wing loading: one-half pound per square foot, or roughly the same weight-to-area as foam-core art board for mounting photographs. By comparison, high-performance birds of prey such as eagles have wing loadings of four to six pounds; light aircraft ten to 15 pounds; and jumbo airliners 150 to 200 pounds. Low wing loading permits the use of minimal structure. It's the secret to making a large airplane ultralight.

The Gossamer Penguin's wing loading was also 0.5 pounds, but the craft was fragile, barely stable, and only capable of safe flight during early morning calm conditions. Solar Challenger's wings supported one pound per square foot. Calculations predicted that Pathfinder would be able to stay at a 50,000 foot altitude with a wing loading of less than 0.8 pounds. By achieving the half-pound loading, the engineers gave the plane a much higher cruising altitude. It should be able to fly above 70,000 feet continuously.

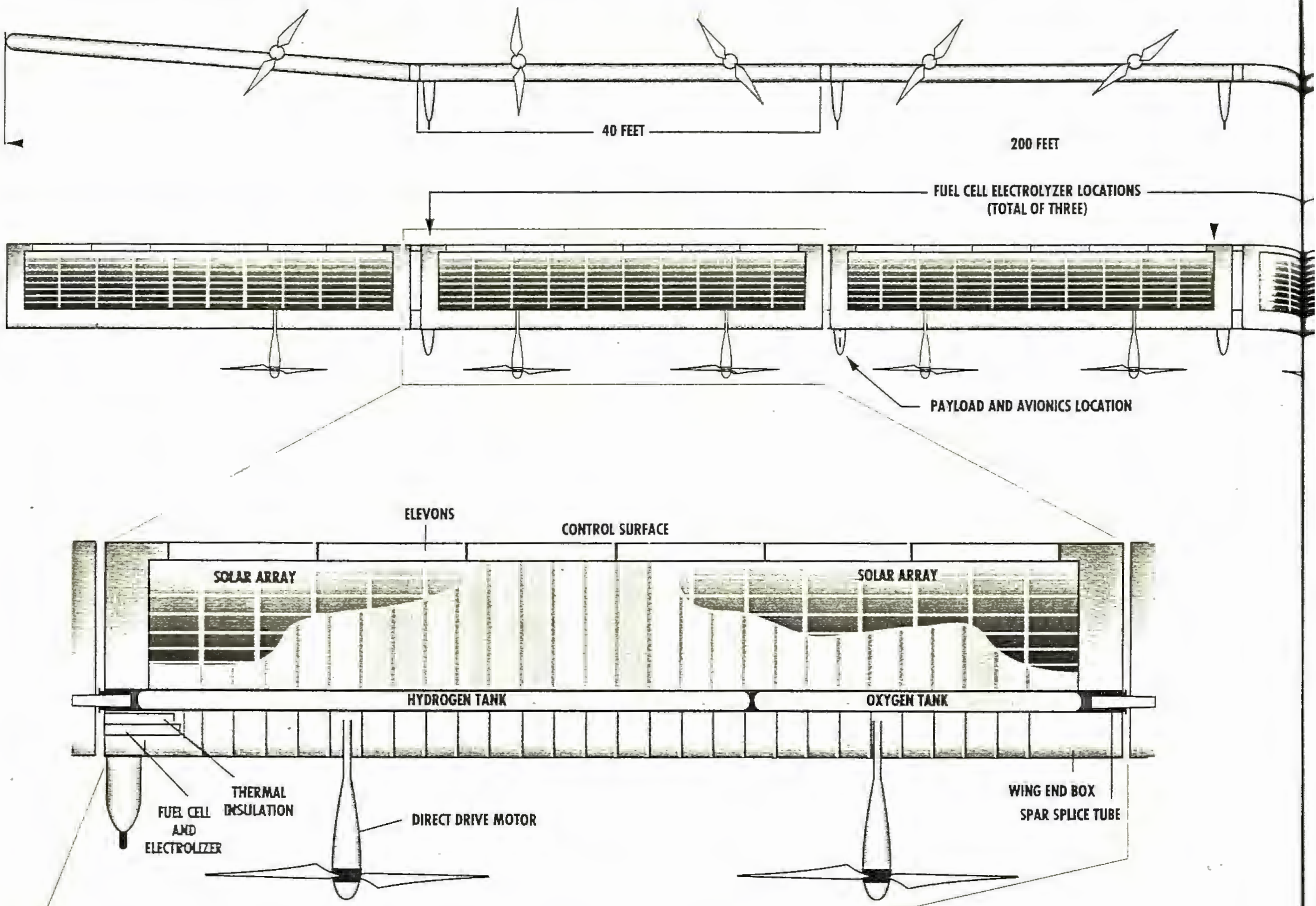
Last year's flights showed that Pathfinder has a lift-to-drag, or glide, ratio of 22 or better. Thus, with its motors shut off, the craft will glide at least 22 feet forward for each foot of descent. Yet even at this seemingly gentle descent rate, it would glide all the way to earth during the night without some sort of electrical energy-storage system on board.

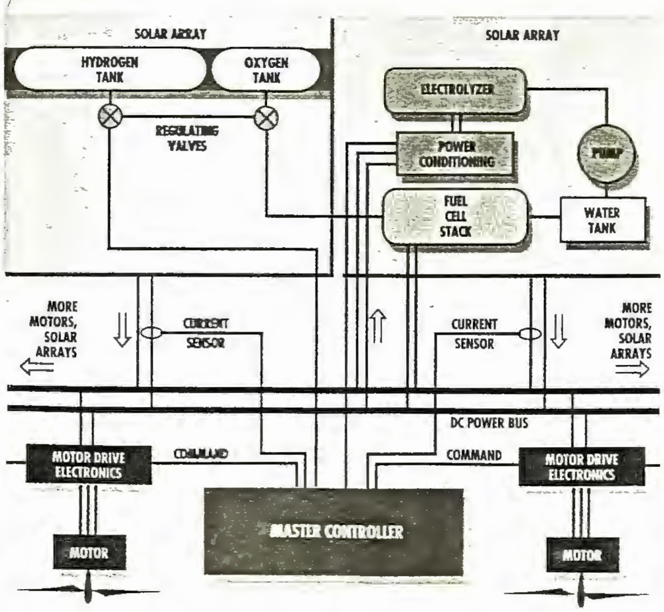
Lawrence Livermore National Laboratory in Lawrence, Calif., which administers the Pathfinder project, launched an exhaustive study to identify storage devices that provide the highest energy density at the lowest weight for the Pathfinder's planned successor, the 200-foot span Helios (see "The Next Solar Electric Wing"). Flywheels, supercapacitors,





# 200-FOOT HELIOS: THE NEXT SOLAR ELECTRIC WING



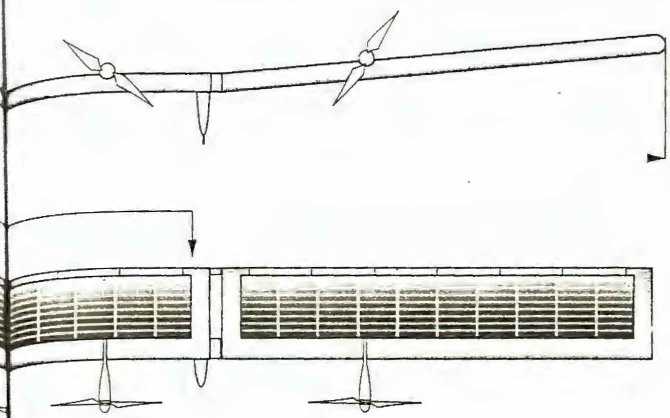



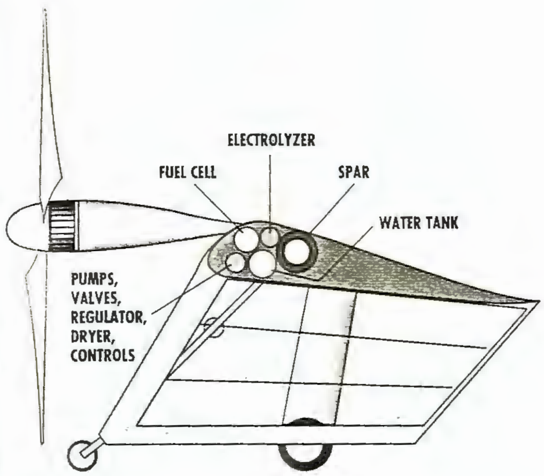

**The planned successor to the Pathfinder is called Helios. Its 200-foot span (top) is comprised of five modular, 40-foot sections, supported by a quartet of landing pods. Eight electric motor-propeller units similar to Pathfinder's provide propulsion. A tubular carbon- and aramid-fiber wing spar running across the span is the main structural element. Proton-exchange membrane fuel cells located above three of the landing pods serve as storage batteries. During sunlight hours, surplus current from the solar array electrolyzes water into hydrogen and oxygen gases, which are compressed and stored inside the wing spar. At night, the fuel cells provide electricity for the engines by recombining the gases. The sole by-product—water—is stored, and the closed-loop cycle repeats daily (see diagram at left). The Helios will carry its avionics system and 150-pound payload above one of the inboard landing pods.**

several types of chemical batteries, and hydrogen-oxygen regenerative fuel cells were compared.

The fuel cells are clear winners, according to Dr. Nicholas Colella, program manager at Livermore. They have an energy density of 300 watt-hours per kilogram, which is about ten times that of lead-acid batteries and more than twice the energy density of advanced zinc-air batteries.

"We found out that the essence of the fuel cell, which in our case is a proton-exchange membrane electrolyzer, exists and is used in underwater vehicles, so we don't have to invent it," Colella says. "The same membrane performs both the electrolysis and the combining of the gases to make water. We






need to package it into a lightweight system, which will take about two years of engineering. But no fundamental breakthrough is needed in the chemistry or the materials."

The airframe now called Pathfinder has a mysterious past. It first flew in 1983 under the name HALSOL (high-altitude solar energy) as part of a classified program sponsored by an unnamed agency to explore the feasibility of long-duration, solar-electric flight in the calm air at altitudes above 65,000 feet. HALSOL flew nine times in two months, eventually reaching an altitude of 2,000 feet powered by rechargeable silver-zinc batteries.

Sources outside the program have revealed that testing took place at the unacknowledged air base at Groom Lake, Nevada. Organizations known to have studied sun-powered aircraft include the Air Force, the Naval Research Laboratory, the Central Intelligence Agency, the National Reconnaissance Office, and NASA. Which one was the customer? That's a secret.

The craft proved airworthy but would clearly have become too heavy to carry a useful payload if equipped with the solar arrays and power-control equipment then available. HALSOL embodied ideas that were ahead of the state of technology in 1980, and it was parked in long-term storage.

The rebirth of HALSOL as the Pathfinder is a dramatic confirmation of the rapid leaps in miniaturization and performance presently taking place in the electronics world. The airplane that couldn't achieve pure solar-powered

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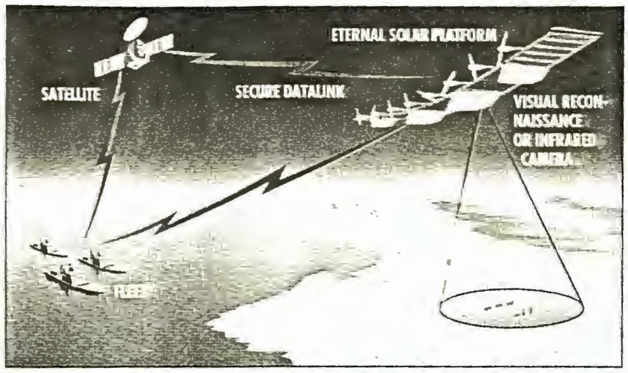
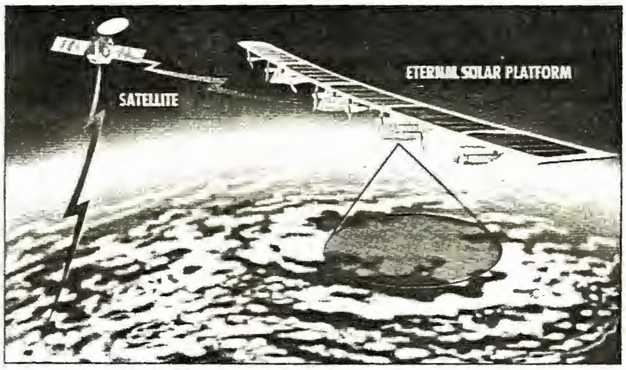
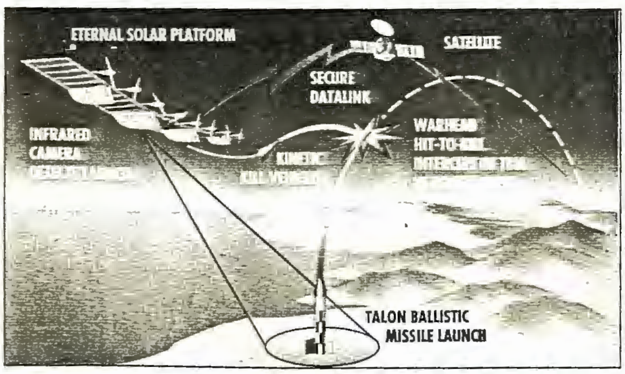
# JOBS FOR LONG-DURATION HIGH FLYERS




An eternal airplane could function as an atmospheric "pseudo-satellite" providing a relocatable, over-the-horizon communications relay, or a persistent platform for reconnaissance sensors. In military use, the craft would fly a racetrack-shaped pattern above friendly territory and peer into areas of conflict. Civil roles might include border patrol and disaster management during forest fires or earthquakes, when local telecommunications are interrupted.




Severe-storm tracking at altitudes of 60,000 to 80,000 feet is a likely role for an eternal airplane. Flying above a hurricane's fury, the drone could monitor the storm's evolution and course, warning of an impending landfall. Because it is electrically powered and breathes no air, the plane could safely fly atmospheric-sampling missions through abrasive volcanic ash or the radiation released in a nuclear powerplant accident.




ILLUSTRATIONS BY IAN WORPOLE

The Ballistic Missile Defense Organization is exploring solar drones as platforms for detecting launches of Scud-type ballistic missiles, then attacking them during the boost phase of their flight, when the missile's exhaust plume is easily detectable by infrared sensors. A 50-pound kinetic-kill rocket called Talon would be launched from the drone's landing pod, destroying the missile in a mid-course collision.

## The eternal airplane

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flight a decade ago can do it today.

New motors, power-control electronics, flight-control actuators, autopilots, and lightweight, high-performance silicon solar arrays make the difference. Now, when electrical losses and mechanical friction in the propulsion system are considered, seven percent of the solar energy collected is converted into propulsive thrust powering the airplane, Colella says. The best system that could be built in 1980 was only four percent efficient. The new motors need no gearboxes, and fixed-pitch propellers replace the complex variable-pitch props previously used, eliminating almost 100 parts from each motor pod.

A lot of things happen to a solar-electric airplane as it gradually climbs from a runway in the dense air near sea level to the cold, thin air at very high altitudes. On takeoff, Pathfinder's props spin at about 300 rpm to reach a lazy 15 mph. As the craft ascends through the thinning air, motor speed must increase to maintain the propellers' thrust, and airspeed must increase to maintain the wing's lift.

At 70,000 feet, the motors need to spin at 1,700 rpm to reach an airspeed of about 90 mph. Cruising in the middle stratosphere requires about six times the power and speed needed at sea level. Fortunately, the solar cells increase their output somewhat during the climb, due to better cooling and escaping the atmospheric haze present at lower altitudes.

Ascending through the powerful and unpredictable winds of the jetstreams will be the airplane's most formidable trial. Consequently, it's built to withstand five-g loads during flight. The effects of strong gusts are minimized by distributing the wind's force throughout the featherweight airframe.

Though Pathfinder lacks the fuel cell energy-storage system slated to appear in its successor, the Helios, the craft actually could fly for weeks on end—as long as it's in the vicinity of the North or South Pole. If funding permits, the airplane may be launched from Allen Army Airfield near Fairbanks, Alaska, during the summer months when continuous daylight above the Arctic circle would provide 24-hour solar electricity. New bi-facial solar cells to be installed on the transparent wingskins will make the most of the low sun angles encountered in polar regions by capturing some of the energy of the earth's albedo, or light reflected upward from the clouds and atmosphere below.

Before departing on such an exotic mission, Pathfinder must first pass high-altitude flight trials. This spring, the craft is slated to climb to 60,000 feet or higher. Taking off at seven a.m., the solar flyer should be able to reach a 60,000-foot altitude by about 2 p.m. Many miles from the radio-control van that follows the plane at takeoff, the drone needs to switch over to an autopilot system that will control its flight.

The autopilot's basic software was developed during last year's series of flights up to a maximum altitude of about 200 feet. Ray Morgan sat in his command chair atop the chase van, calling off endless lists of flight-control settings that pushed the Pathfinder to the edges of its safe flight envelope—and a little beyond.

During a right turn, for example, the outboard-most propeller at the left wingtip was run at a high-power setting, while its counterpart at the right wingtip slowed to a standstill. Stall speeds and instabilities were noted, and the best combinations of motor speed and elevator positions determined. The results are encapsulated in a software program that makes the plane capable of autonomous flight using small computers, compact gyroscopes, and four-antenna global positioning satellite (GPS) equipment that senses the craft's pitch and yaw and roll angles, as well as its location.

Pathfinder is funded by the Pentagon's Ballistic Missile Defense Organization (BMDO) under the code name Raptor Talon, which symbolizes a bird of prey with fearsome claws. The Talon part of the program involves developing a small, high-velocity rocket that could be stored in pairs aboard Pathfinder derivatives, giving them the ability to attack hostile missiles in flight.

BMDO wants to be able to destroy high-explosive, chemical, or biological clustered-submunitions in flight, before they can separate from a missile's warhead and inflict damage on the ground. "I look at these Raptors as very visible targets flying border patrol over the enemy, keeping him on his toes 24 hours a day," says program manager Lt. Col. Dale Tietz. "We're going to try to have the Talon be so precise that it knows what target it's after, where the warhead compartment is, where to hit it—and from what angle—to really wipe out the weapons."

Experience gained from Pathfinder and the proposed 200-foot-span Helios could lead to the development of commercially available solar-electric drones. Program officials estimate they would cost $2 million to $3 million apiece, assuming a minimum production run of 20 aircraft. Sometimes supply can create demand. Who knows what unforeseen uses may be found for eternal airplanes? PS