NASA Facts

National Aeronautics and
Space Administration

Dryden Flight Research Center
P.O. Box 273
Edwards, California 93523
AC 661-276-3449
FAX 661-276-3566
pao@dfrc.nasa.gov

FS-1998-10-0054 DFRC

Pathfinder-Plus, which flew to a record altitude of 80,201 feet. NASA photo EC98 44621-247

Solar-Power Research and Dryden

Since 1980 AeroVironment, Inc. (founded in 1971 by the ultra-light airplane innovator—Dr. Paul MacCready) has been experimenting with solar-powered aircraft, often in conjunction with NASA's Dryden Flight Research Center, Edwards, California. Thus far, AeroVironment, now headquartered in Monrovia, Calif., has achieved several altitude records with its Solar Challenger, Pathfinder, and Pathfinder-Plus aircraft. It expects to exceed them with the newer and larger solar-powered Centurion and its successors in NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program, the Helios.

Solar Challenger set an initial altitude record of 14,300 feet. More spectacularly, on July 7, 1981, the solar-powered aircraft flew 163 miles from Corneille-en-Verin Airport north of Paris across the English Channel to Manston Royal Air Force Base south of London, staying aloft 5 hours and 23 minutes.

At the time, AeroVironment was headquartered in Pasadena, Calif. Dr. MacCready, a former gliding champion, whose Gossamer Albatross crossed the English Channel using human power in 1979, saw solar power as a way to "help business and government recognize and meet their environmental and energy objectives." MacCready remains the Chairman of the Board at AeroVironment.

Following the success of Solar Challenger, AeroVironment received funding in 1981 from the U.S. government for a classified program to look into the feasibility of long-duration, solar-electric flight above 65,000 feet. The firm designed an airplane designated HALSOL (High-Altitude Solar Energy), built and test flew three subscale models and a final prototype. The HALSOL proved the aerodynamics and structures for the approach, but subsystem technologies, principally for energy storage, were inadequate for the intended mission. The HALSOL was mothballed for ten years but later evolved into Pathfinder, which first flew at Dryden in 1993 under the auspices of the Ballistic Missile Defense Office for potential use in an anti-ballistic-missile defense role.

When funding for this program ended, Pathfinder became part of NASA's ERAST program to develop remotely piloted, long-duration aircraft for environmental sampling and sensing at altitudes above 60,000 feet. On September 11, 1995, Pathfinder exceeded Solar Challenger's altitude record for solar-powered aircraft by a long margin when it reached 50,500 feet at Dryden.

After moving its flight operations to the U.S. Navy's Pacific Missile Range Facility (PMRF) on Kauai, Hawaii, in April 1997, an upgraded Pathfinder took advantage of the improved angle of sunlight to set a new record of 71,530 feet for solar-powered aircraft on July 7, 1997.

Further modified with longer wings, improved motors, and more efficient solar array, Pathfinder-Plus (as it was now called) flew to still another record of 80,201 feet at the PMRF on August 6, 1998. In the process, it stayed above 70,000 feet for almost three and a half hours while carrying 68 pounds of test instrumentation and other payload.

Background

The first flight of a solar-powered aircraft took place on November 4, 1974, when the remotely controlled Sunrise II, designed by Robert J. Boucher of AstroFlight, Inc., flew following a launch from a catapult.

Following this event, AeroVironment took on a more ambitious project to design a human-piloted, solar-powered aircraft. The firm initially took the human-powered Gossamer Albatross II and scaled it down to three-quarters of its previous size for solar-powered flight with a human pilot controlling it. This was more easily done because in early 1980 the Gossamer Albatross had participated in a flight research program at NASA Dryden in a program conducted jointly by the Langley and Dryden research centers. Some of the flights were conducted using a small electric motor for power.

Gossamer Penguin

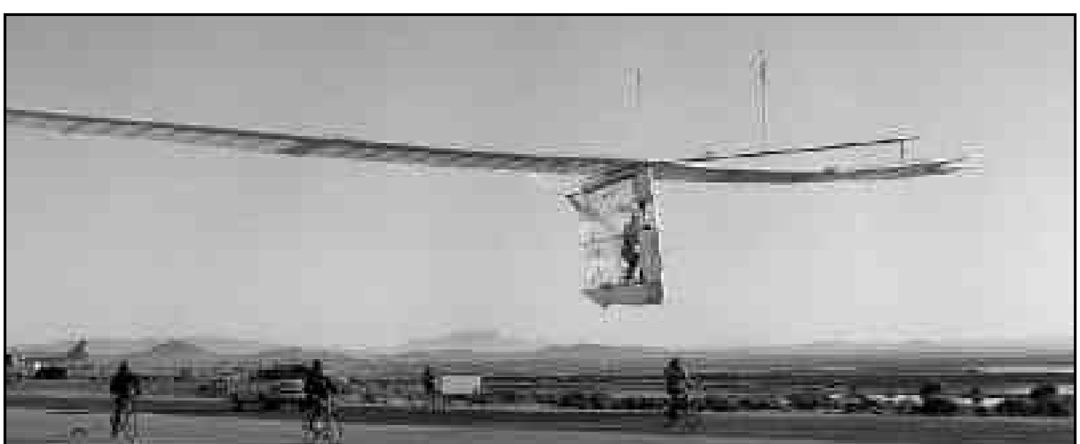
The scaled-down aircraft was designated the Gossamer Penguin. It had a 71-foot wingspan compared with the 96-foot span of the Gossamer Albatross. Weighing only 68 pounds without a pilot, it had a low power requirement and thus was an excellent test bed for solar power.

AstroFlight, Inc., of Venice, Calif., provided the power plant for the Gossamer, Penguin, an Astro-40 electric motor. Robert Boucher, designer of the Sunrise II, served as a key consultant for both this aircraft and the Solar Challenger. The power source for the initial flights of the Gossamer Penguin consisted of 28 nickel-cadmium batteries, replaced for the solar-powered flights by a panel of 3,920 solar cells capable of producing 541 Watts of power.

The battery-powered flights took place at Shafter Airport near Bakersfield, Calif. Dr. MacCready's son Marshall, who was 13 years old and weighed roughly 80 pounds, served as the initial pilot for these flights to determine the power required to fly the airplane, optimize the airframe/propulsion system, and train the pilot. He made the first flights on April 7, 1980, and made a brief solar-powered flight on May 18.

The official project pilot was Janice Brown, a Bakersfield school teacher who weighed in at slightly under 100 pounds and was a charter pilot with commercial, instrument, and glider ratings.She checked out in the plane at Shafter and made about 40 flights under battery and solar power there. Wind direction, turbulence, convection, temperature and radiation at Shafter in mid-summer proved to be less than ideal for Gossamer Penguin because takeoffs required no crosswind and increases in temperature reduced the power output from the solar cells.
Consequently, the project moved to Dryden in late July, although conditions there also were not ideal. Nevertheless, Janice finished the testing, and on August 7, 1980, she flew a public demonstration of the aircraft at Dryden in which it went roughly 1.95 miles in 14 minutes and 21 seconds.

This was significant as the first sustained flight of an aircraft relying solely on direct solar power rather than batteries. It provided the designers with practical experience for developing a more advanced, solar-powered aircraft, since the Gossamer Penguin was fragile and had limited controllability. This necessitated its flying early in the day when there were



During the early part of 1980, in a joint project with NASA's Langley Research Center and AeroVironment, NASA's Dryden Flight Research Center gathered data on a Gossamer Albatross in which the lightweight aircraft flew under three conditions: using human power, using a small electric motor, and in a towed condition with the propeller removed. NASA photo ECN 12558

Gossamer Penguin in flight above Rogers Dry Lakebed at Edwards, Calif., showing the solar panel perpendicular to the wing and facing the sun. NASA photo ECN 13413

minimal wind and turbulence levels, but the angle of the sun was also low, requiring a panel for the solar cells that could be tilted toward the sun.

Solar Challenger

Using the specific conclusions derived from their experience with Gossamer Penguin, the AeroVironment engineers designed Solar Challenger, a piloted, solar-powered aircraft strong enough to handle both long and high flights when encountering normal turbulence. As compared with the Penguin’s 71-foot wingspan, Solar Challenger had only a 46.5-foot wingspan, but it had a huge horizontal stabilizer and a large enough wing area to accommodate 16,128 solar cells.

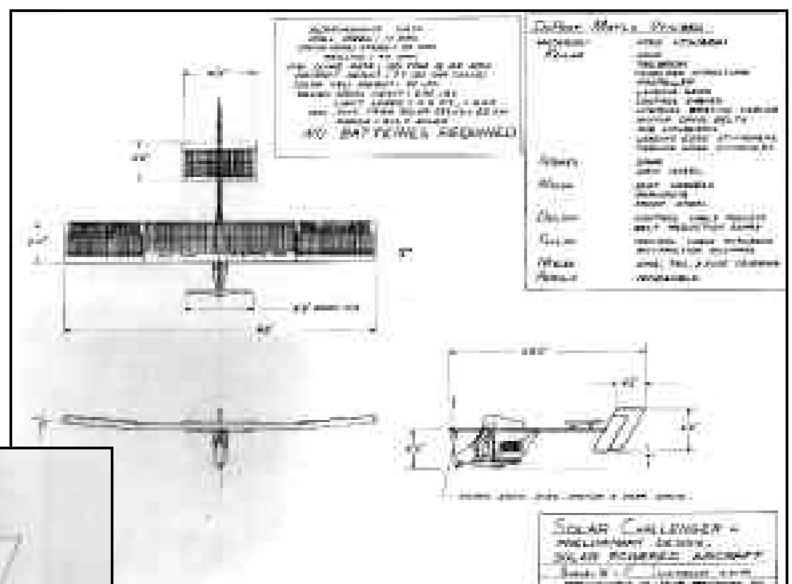
Using in-house computer programs, AeroVironment engineers Peter Lissaman and Bart Hibbs designed the unusual wings and stabilizers, which they made flat on top to hold the solar cells. Hibbs developed the aerodynamic design for the propeller with another in-house computer program. The result was a “smooth and docile” aircraft that dropped in a steady, wing-level attitude when stalled and rapidly regained unstalled flight.

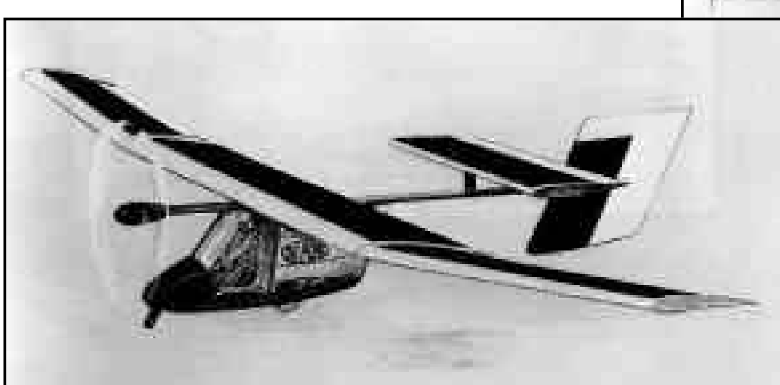
AstroFlight, Inc., again provided the motor, and the DuPont Company, which produced many of the advanced materials for the Gossamer Albatross, Gossamer Penguin, and Solar Challenger, sponsored the project. Janice Brown remained one of the pilots, but she was joined by the slightly heavier Stephen R. Ptacek (almost 150 pounds), who brought to the project over 4,600 hours of flight in a variety of aircraft.

The pilots flew the aircraft, first with batteries and then under solar power, at the Santa Susana, Shafter, and El Mirage airports in California before moving to Marana Airpark northwest of Tucson, Ariz., in late 1980 and early 1981. With some modifications, the Solar Challenger showed itself to be an effective aircraft. This was proved to the world during the cross-Channel flight on July 7, 1981, with Ptacek at the controls.

Pathfinder

Growing out of the post-1983 development of HALSOL, Pathfinder was modified with additional solar arrays and other upgrades. It was then brought back to Dryden for another series of developmental flights in 1995. On Sept. 11, 1995, Pathfinder reached an altitude of 50,500 feet, setting a new altitude record for solar-powered aircraft. The National Aeronautic Association presented the NASA-industry team with an award for one of the “10 Most Memorable Record Flights” of 1995.





Artist’s conception of Solar Challenger (left). Preliminary design of Solar Challenger (above). Photos courtesy of Du Pont Co.

After additional upgrades and one checkout flight at Dryden in late 1996, Pathfinder was transferred to the U.S. Navy's Pacific Missile Range Facility (PMRF) at Barking Sands, Kauai, Hawaii, in April 1997. Kauai was chosen as an optimum location for testing the solar-powered Pathfinder due to the high levels of sunlight, available airspace and radio frequencies and the diversity of terrestrial and coastal ecosystems for validating scientific imaging applications. While in Hawaii, Pathfinder flew seven high-altitude flights from PMRF, one of which reached a world altitude record for propeller-driven as well as solar-powered aircraft of 71,530 feet.

Pathfinder silhouetted by the morning sun on Rogers Dry Lakebed, Edwards, Calif. NASA photo EC96 43817-2

Pathfinder "Plus"

During 1998, the Pathfinder was modified into the longer-winged Pathfinder-Plus configuration. On Aug. 6, 1998, the modified aircraft was flown to a record altitude for propeller-driven aircraft of 80,201 feet on the third of a series of developmental test flights from PMRF on Kauai. The goal of the flights was to validate new solar, aerodynamic, propulsion and systems technology developed for the Pathfinder's successor, the Centurion, which is designed to reach and sustain altitudes in the 100,000-foot range.

Essentially a transitional vehicle between the Pathfinder and the follow-on Centurion, the Pathfinder-Plus is a hybrid of the technology that was employed on Pathfinder and developed for Centurion.

The most noticeable change is the installation of a new 44-foot-long center wing section that incorporates a high-altitude airfoil designed for Centurion. The new section is twice as long as the original Pathfinder center section and increases the overall wingspan of the craft from 98.4 feet to 121 feet. The new center section is topped by more-efficient silicon solar cells developed by SunPower Corp., Sunnyvale, Calif.; they can convert 19 percent of the solar energy they receive to useful electrical energy to power the craft's motors, avionics and communication systems. That compares with about 14 percent efficiency for the older solar arrays that cover most of the surface of the middle and outer wing panels from the original Pathfinder. Maximum potential power was boosted from about 7,500 Watts on Pathfinder to about 12,500 Watts on Pathfinder-Plus.

In addition, the Pathfinder-Plus was powered by eight electric motors, two more than had powered the previous version of Pathfinder. Designed for Centurion, the motors are slightly more efficient than the original Pathfinder motors.

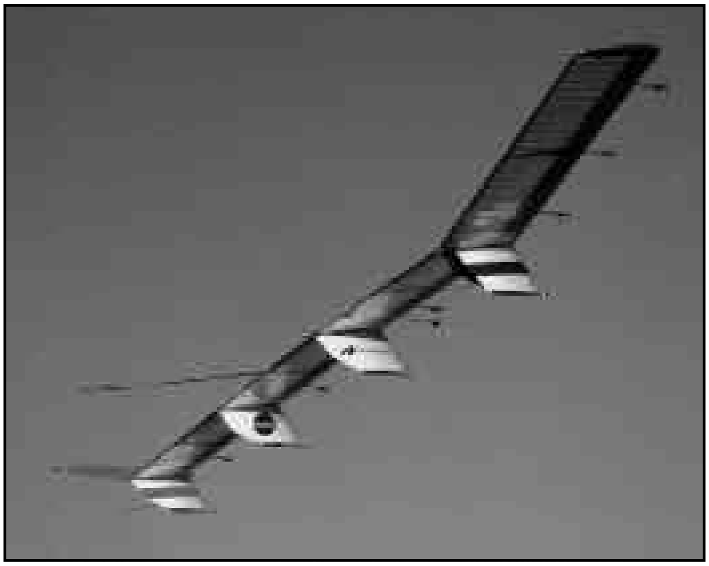
Centurion

Centurion, like its immediate predecessors Pathfinder and Pathfinder-Plus, is a lightweight, solar-powered, remotely piloted flying wing aircraft that is demonstrating the technology of applying solar power for long-duration, high-altitude flight. It is considered to be a prototype technology demonstrator for a future fleet of solar-powered aircraft that could stay airborne for weeks or months on scientific sampling and imaging missions or while serving as telecommunications relay platforms.

Although it shares much of the design concepts of the Pathfinder, the Centurion has a wingspan of 206 feet, more than twice the 98-foot span of the original Pathfinder and 70 percent longer than the Pathfinder-Plus' 121-foot span. At the same time, it maintains the eight-foot chord (front to rear distance) of the Pathfinder wing, giving the Centurion wing an aspect ratio (length-to-chord) of 26 to 1.

Other visible changes from its predecessor include a modified wing airfoil designed for flight at extreme altitude and four underwing pods to support its landing gear and electronic systems, compared with two such pods on the Pathfinder. The flexible wing is primarily fabricated from carbon fiber and graphite epoxy composites and kevlar. It is built in five sections, a 44-foot-long center section and middle and outer sections just over 40 feet long. All five sections have an identical thickness that is 12 percent of the chord, or about 11.5 inches, with no taper or sweep.

Solar arrays that will cover most of the upper wing surface will provide up to 31 kilowatts of power at high noon on a



One quarter-scale model of AeroVironment's Centurion ultra-high-altitude flying wing, flown as a low-cost, low-risk proof-of-concept vehicle before going ahead with the full-scale prototype. NASA photo EC97 43965-4

summer day to power the aircraft's 14 electric motors, avionics, communications and other electronic systems. Centurion also has a backup lithium battery system that can provide power for between two and five hours to allow limited-duration flight after dark. Initial low-altitude test flights at Dryden in 1998 are being conducted on battery power alone, prior to installation of the solar cell arrays.

Centurion flies at an airspeed of only 17 to 21 mph, or about 15 to 18 knots. Although pitch control is maintained by the use of a full-span 60-segment elevator on the trailing edge of the wing, turns and yaw control are accomplished by applying differential power—slowing down or speeding up the motors—on the outboard sections of the wing.

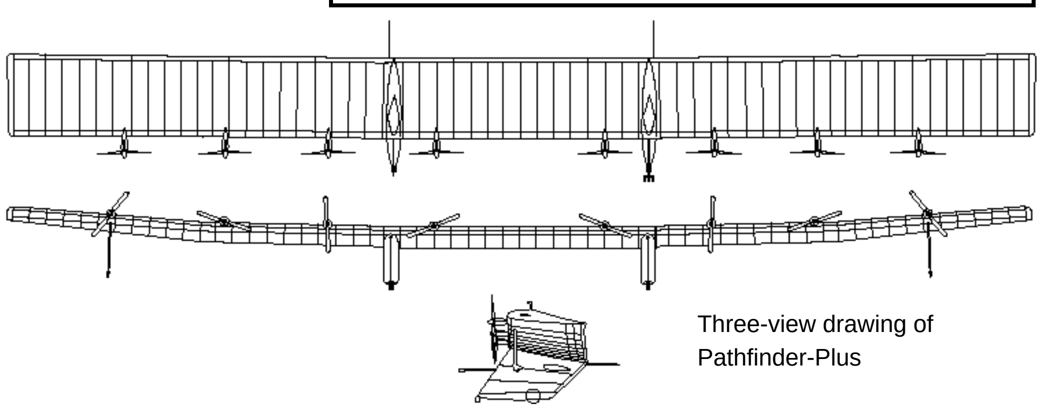
Helios

AeroVironment envisions Helios as the ultimate solar aircraft that can offer virtually eternal flights in the stratosphere. It will build upon the technologies developed by Pathfinder and Centurion but will add an energy storage system for nighttime flying. From 25 to 50 percent larger than Centurion, the Helios will store up to two-thirds of the energy received by its solar array during the day and will use this stored energy to maintain its altitude overnight. Because it will renew its energy every day from the sun, the Helios will have flight endurance limited only by the reliability of its systems, meaning a practical limit of perhaps six months on station.

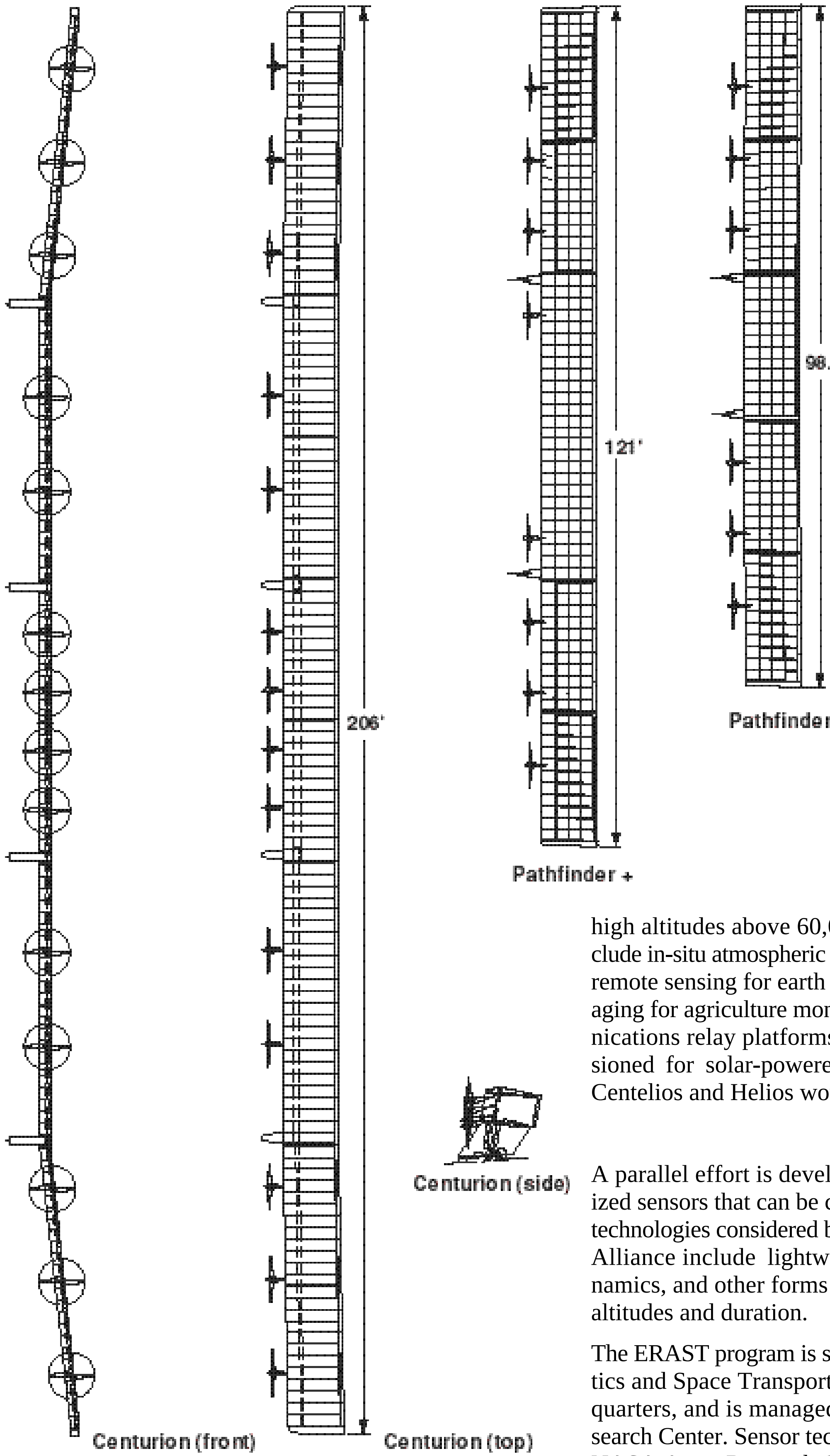
Because of this long duration of flight, the Helios will be extremely economic in operation. However, it will have to be perhaps the most reliable aircraft ever built, with each flight lasting longer than the time between overhaul for a typical, general aviation aircraft. As a consequence, much of the Helios design will involve a minimum of moving parts, high redun-

Aircraft Specifications

- **Wingspan:** Solar Challenger, 46.5 feet (14.8 meters); Pathfinder, 98.4 feet (29.5 meters); Pathfinder-Plus, 121 feet (36.3 meters) Centurion, 206 feet (61.8 meters)
- **Length:** Solar Challenger, 30.3 feet (9.22 meters); Pathfinder, Pathfinder-Plus, and Centurion, 12 feet (3.6 meters)
- **Wing chord:** Solar Challenger, 5.8 feet (1.78 meters); Pathfinder, Pathfinder-Plus, and Centurion, 8 feet (2.4 meters)
- **Gross weight:** Solar Challenger, about 336 pounds (152.8 kg); Pathfinder, about 560 pounds (252 kg.); Pathfinder-Plus, about 700 pounds (315 kg.) Centurion, varies depending on power availability and mission profile; approximately 1,900 pounds for a mission to 80,000 feet altitude.
- **Payload:** Solar Challenger, weight of pilot, up to 150 pounds Pathfinder, up to 100 pounds (45 kg.); Pathfinder-Plus, up to 150 pounds (67.5 kg.) Centurion, varies depending on altitude; about 100 pounds. to 100,000 ft., 600 pounds. to 80,000 feet.
- **Airspeed:** Solar Challenger, approx. 25-34 mph cruise Pathfinder, Pathfinder -Plus. approx. 17-20 mph cruise Centurion, approx. 17-21 mph cruise
- **Power:** Arrays of solar cells, max. output: Solar Challenger, 2,700 Watts Pathfinder, about 7,500 Watts; Pathfinder-Plus, about 12,500 Watts Centurion, 31,000 Watts
- **Motors:** Solar Challenger, one electric motor, 2.7 kW Pathfinder, six electric motors, 1.25 kW each Pathfinder-Plus, eight electric motors, 1.5 kW maximum each Centurion, 14 electric motors, 2.2 kW each
- **Manufacturer:** AeroVironment, Inc.
- **Primary materials:** Composites, plastic, foam.



Three-view drawing of Pathfinder-Plus



Three-view drawing of Centurion with top views of Pathfinder and Pathfinder-Plus for comparison.

dancy, low temperatures, and solid-state control systems. The Helios will also be able to diagnose degradation of its control systems and reconfigure the autopilot while in flight. As a result, AeroVironment expects the Helios to perform as a non-polluting, re-configurable "atmospheric satellite" in the new millenium.

The ERAST Program

Centurion is and Helios will be one of a number of remotely piloted aircraft being evaluated under NASA's Environmental Research Aircraft and Sensor Technology (ERAST) program. The ERAST program is one of NASA's initiatives designed to develop the new technologies needed to continue America's leadership in the highly competitive aerospace industry.

The primary focus of ERAST is on the development of slow-flying, remotely-operated aircraft that can perform long-duration science missions at very high altitudes above 60,000 feet. These missions could include in-situ atmospheric sampling, tracking of severe storms, remote sensing for earth sciences studies, hyperspectral imaging for agriculture monitoring, and serving as telecommunications relay platforms. The most extreme mission envisioned for solar-powered aircraft such as the Centurion, Centelios and Helios would reach altitudes of 100,000 feet.

A parallel effort is developing lightweight, microminiaturized sensors that can be carried by these aircraft. Additional technologies considered by the joint NASA-industry ERAST Alliance include lightweight materials, avionics, aerodynamics, and other forms of propulsion suitable for extreme altitudes and duration.

The ERAST program is sponsored by the Office of Aeronautics and Space Transportation Technology at NASA Headquarters, and is managed by the NASA Dryden Flight Research Center. Sensor technology development is headed by NASA Ames Research Center, Moffett Field, Calif.

Sources

AeroVironment Web site, URL: http://www.aerovironment.com/overview/history/history.html and linked sites;

Benedek, Ladislao, *Solar Energy and the Aeronautics Industry*, translation of “Energía Solar y la Industria Aeronautica,” thesis, Olivos, Argentina, Oct. 9, 1985 (Washington, DC: NASA TM-77957, 1985): 24-33;

Cowley, Martyn, “Wings in the Sun: the evolution of Solar Challenger,” *Flight International* (Jun. 13, 1981): 1865-1868;

Documents relating to Solar Challenger, Dryden Historical Reference Collection, including 3-view photograph and various background papers and fact sheets;

Dornheim, Michael A., “Pathfinder Plus Exceeds 80,000 Ft.; Centurion Assembled,” *Aviation Week & Space Technology* (Aug. 17, 1998): 33;

Fact Sheets on Pathfinder and Centurion, NASA Dryden Flight Research Center, prepared by Alan Brown, Sept. 1998, and coordinated with ERAST and AeroVironment personnel;

Flittie, K., and Curtin, B., “Pathfinder Solar-Powered Aircraft Flight Performance,” paper delivered at AIAA Atmospheric Flight Mechanics Conference & Exhibit, Aug. 10-12, Boston, Mass. (AIAA 98-4446);

“Gossamer Penguin Makes First Sustained Flight,” *X-Press*, vol. 23, Issue 6 (Aug. 22, 1980): 2;

MacCready, Paul B., et al., “Sun Powered Aircraft Design,” paper delivered at the AIAA 1981 Annual Meeting and Technical Display, Long Beach, Calif. (AIAA-81-0916);

Penner, Hellmut, *Sun Worshiper [sic]. McCready’s [sic] Solar Challenger Flies Over the English Channel*, translation of “Sonnenanbeter. McCreadys Solar Challenger flog über den Armelkanal,” *Flug Revue* (No. 9, Sept. 1981): 67-69 (Washington, DC: NASA TM-77327, 1983).