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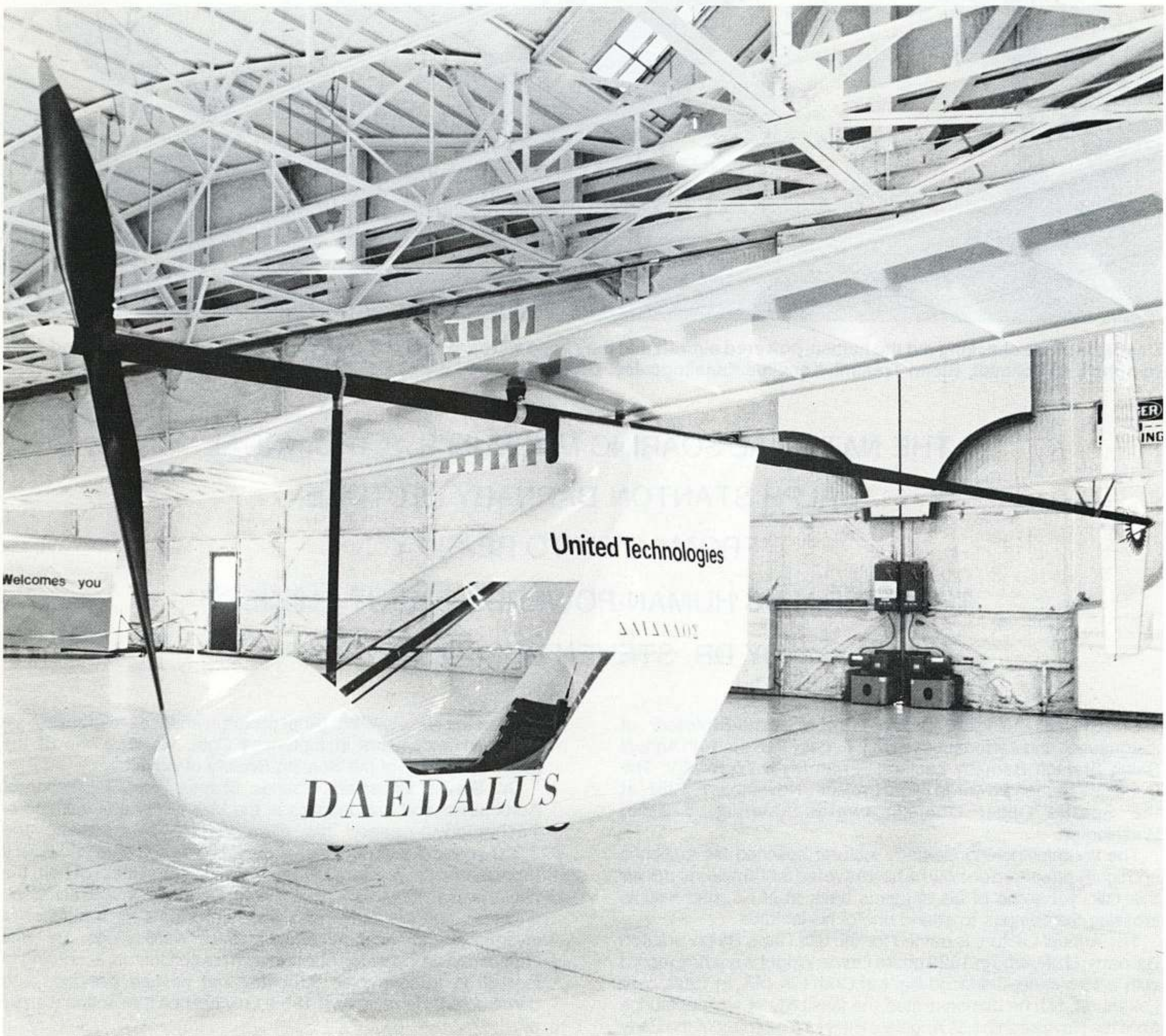

Daedalus pilots checking out the human-powered aircraft that they hope will carry one of them from Crete to Greece this Spring. Left to right: Eric Schmidt, Glenn Tremml, Kanellos Kanellopoulos, Greg Zack and Lois McCallin.

THE NATIONAL SOARING MUSEUM'S 14TH ANNUAL RALPH STANTON BARNABY LECTURE, "FROM MYTH TO REALITY: THE DAEDALUS HUMAN-POWERED FLIGHT PROJECT", BY DR. STEVEN BUSSOLARI.

Dr. Steven Bussolari, Charles Draper Asst. Professor of Aeronautics and Astronautics at M.I.T., delivered the 14th Annual Ralph Stanton Barnaby Lecture; "From Myth To Reality: The Daedalus Human Powered Flight Project", November 7, 1987, at the Seattle Glider Council Awards Meeting, Seattle, Washington.

The youthful-looking Barnaby lecturer scanned his audience and lightly remarked on how he had travelled 3,000 miles to deliver this talk, yet some of his students back at M.I.T. had trouble crossing the campus to attend one of his lectures.

The Annual Lecture is named for the late Capt. Ralph Stanton Barnaby, USN, who in 1929 broke Orville Wright's soaring record with a 15-minute, 6-second flight at Corn Hill, MA. In 1930, over Lakehurst, NJ, he demonstrated the feasibility of a glider launch from the Navy airship Los Angeles. He was a member of the Early Birds, (American Pilots who flew before 1916). Barnaby also headed the Navy's WWII glider program and was responsible for many advancements in motorless flight. He was one of the founding fathers of the Soaring Society of America.

Dr. Steven Bussolari, Charles Draper, Asst. Professor of Aeronautics and Astronomics at the Massachusetts Institute of Technology, opened his slide lecture by recalling the 3,500-year-old story of Daedalus and his son Icarus and how it represented for Western Civilization, the central myth of both the beginnings and the realization of flight. Daedalus was an architect, engineer, and craftsman and was responsible for a number of inventions, the most famous of which were wings. He was imprisoned on the island of Crete with his son Icarus, according to legend, in a labyrnthian structure that he had designed and constructed. He realized that the only chance for escape was by air.

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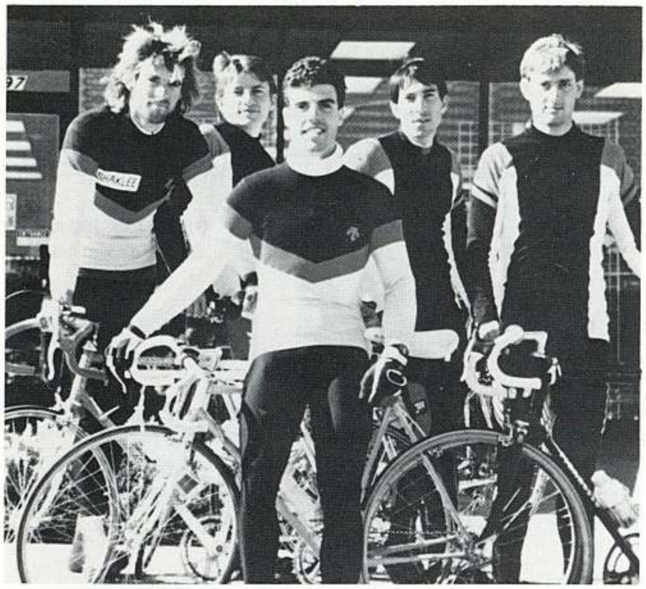

Left to right bicycle racers: Kanellos Kanellopoulos, Frank Scioscia, Glenn Tremml, Erik Schmidt and Greg Zack ride at speeds of 25 miles per hour or more for hours, training for the Crete to Greece try.

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He constructed wings of wax and feathers for himself and Icarus, and with them flew to freedom, using their own muscle power. He warned his son not to fly too high lest the sun melt the wax from his wings. Icarus, full of the joy of new-found flight, disregarded his father's advice and did fly too high. When the sun melted the wax-bonded feathers, Icarus fell to his death.

Dr. Bussolari started flying 11 years ago in France when he was 18. He has 1,000 hours in sailplanes, is a flight instructor, and the director of flight training of the M.I.T. Glider Club. His main interest in aeronautics and astronautics is the human factor and situations where there is an interface with pilot, environment and machine. He holds a Doctorate from M.I.T. and is Engineering Test Pilot for the Daedalus Project.

Bussolari commented on edges of reality to the Daedalus story. There was a palace at Knossos which was thought to have been designed by Daedalus, and the ruins have some labyrinthian storage rooms. The maze-like complexity of these structures probably gave rise to the myth.

Bussolari said, "While trying to think of some way to celebrate the flight of Daedalus with a human-powered flight, the first question to come up was what route did he fly?" After consultation with archaelogists and classicists, he found that there were many versions of the escapees' track. Since Daedalus was Athenian, the most favored course is from Crete to somewhere on the tip of the Peloponnesian Peninsula of the Greek mainland, or alternatively, from the central portion of Crete to the first large island (Thira). Each of these distances is about seventy miles, roughly three times the current straight line distances record for human-powered flight set in 1979 by Dr. Paul MacCready's, Gossamer Albatross, flown over the English Channel by Brian Allen.

"In order to make a flight like this, you really have to push the technologies," Dr. Bussolari said.

Human-powered flight had been around M.I.T. since about 1972, and the Kremer prize for the first human-powered flight across the English Channel added a great impetus to the program. Around 1982, M.I.T.'s "Monarch" won the third Kremer prize for speed around a 1,500 meter triangle. Bussolari continued, "The really fundamental challenge of long duration human-powered flight is the limitation of the power plant."

The aircraft has to be designed to fit the human power plant, "and you can come up with a fairly simple equation to describe the amount of power that's required for straight and level flight," the speaker said.

After about a year's design study, a group of M.I.T. students who have since become faculty members and engineers, came up with the human-powered Daedalus. It has a wingspan of 112 feet, which is a little larger than a DC-9 passenger airliner and an empty weight of 70 pounds (about half the weight of its pilot).

The low weight is achieved through the use of advance composite materials. The entire structure is graphite epoxy and Kevlar, with half a thousandth of an inch thick Mylar covering.

The wing spars were made by a hand lay-up of pre-preg graphite. The fibers are preimpregnated with epoxy and these sheets are wrapped around an aluminum mandrel. The spars were taken for curing to the Sikorsky plant whose autoclaves were used to cure helicopter blades. With a lot of grunt work, the graphite, which is extremely strong and stiff, was pulled off the aluminum mandrel. Five such tubes laid end-to-end were required for the 112-foot wing span.

Strung along the spar are ribs made of polystyrene foam. The quarter-inch thick ribs have a 64th-inch plywood capstrip. Even the Smithsonian Institution National Air and Space Museum's historian who was investigating the history of the myth and its impact on aviation, was put to work assembling ribs on the airplane.

Bussolari said that much of the work was done with computer techniques. An IBM-PC was used to cut a lot of the foam. The foam had to be cut to very precise tolerances since the natural laminar airfoils had to be kept to very tight dimensional tolerances.

A numerically-controlled hot wire foam cutter was used. Two x-y plotters were driven by the IBM-PC. Large blocks of insulation styrofoam were put on a jig for cutting.

Because of Crete's rugged terrain and the possibility of having to launch from a thousand foot cliff (the closest point to the mainland), structural verification was imperative. The Daedalus was designed for 3 "G's" positive load. (Three times the force of gravity). "Pretty good for a 70-pound airplane," Bussolari allowed. "In order to verify that loading we did a static test of the wing. We hung a number of soda bottles, filled with the right amount of water, to give us a good load profile over the span of the wing. The students were kind enough to empty the softdrink bottles before filling them with water. They're not out of their cavity-prone years, so I'm a little worried." The next slide showed the wing undergoing its limit load, Bussolari said, . . . "although there's a good deal of deflection . . . the wing responded quite well and was very stable in its loading configuration."

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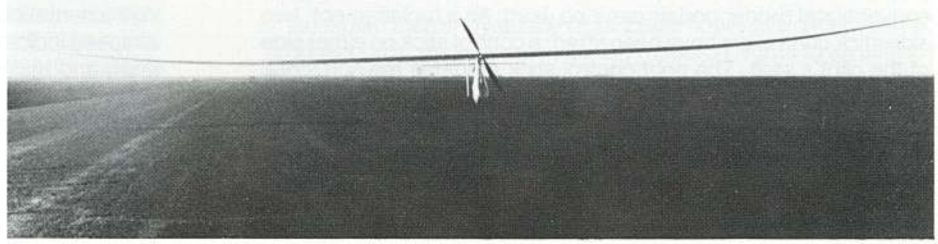
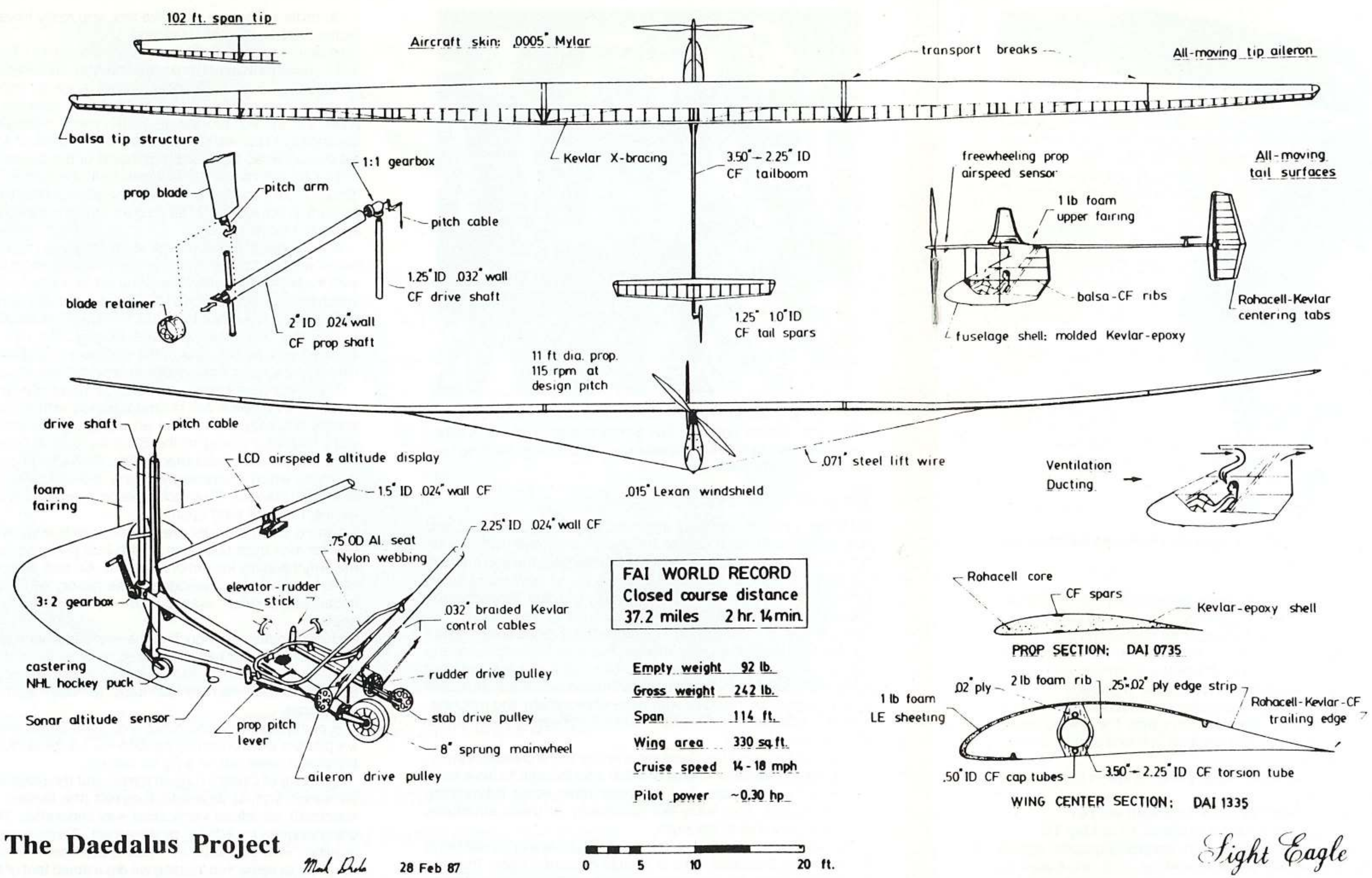
THE LIGHT EAGLE human-powered aircraft in low flight.





The Daedalus Project

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The 11-foot propeller was made of short blocks of styrofoam, glued together in a twisted fashion, then bonded to a thin strip of graphite epoxy that acts as the main spar. After sanding and shaping the entire blade was covered with a sheet of Kevlar epoxy. It has a controllable pitch that can be manipulated by the pilot. The 1.7 pound blade can absorb about one horsepower of mechanical power.

The pilot sits in a lounge-chair position, putting his or her feet in bicycle shoes clipped to the pedals. The pedals are connected to a gearbox, which has a carbon fiber driveshaft, going up into the fuselage boom where another right-angle gearbox drives the propeller. Because the pilot's feet are otherwise occupied, conventional rudder pedals can't be used. As a replacement, two side stick controllers have been fitted: a control stick on either side of the pilot's seat. The right control stick actuates the horizontal stabilizer and rudder. Both of these surfaces are all-flying. The stick on the pilot's left controls the ailerons. These ailerons, the outboard 10 feet of each wingtip, rotate about the spar. "This aircraft flies at wing Reynolds numbers of somewhere between 100 and 200,000," which are extremely low even compared to sailplane standards," according to Bussolari. (The Reynolds number is a - dimensionless ratio used in predicting change in flow character of fluid, e.g. air, - from the Aerospace dictionary by Frank Gaynor.) The lecturer said that human powered aircraft are notoriously difficult to fly because they have a good deal of adverse yaw. (Yaw is the movement of an aircraft about its vertical axis.) They are very slow responding and have very flexible structures. Yaw is controlled with aelerons and roll with the rudder in the Daedalus machine.

The lecturer showed a slide of the graphite epoxy structure that makes up the fuselage and the Kevlar epoxy fairing that goes around the pilot.

"One of the problems in human-powered flight is in the instrumentation," Bussolari said. "It's very difficult to build an airspeed indicator that reads 15 knots to plus or minus a tenth of a knot, and that's the kind of precision that you need. We used a carved basswood propeller with a Hall-Effect sensor on it which would count the speed of the propeller; and that was fed into the cockpit."

The altimeter was a Polaroid camera range finder that looks out the bottom of the fuselage and bounces a sonar signal off the ground, giving a very accurate indication of altitude.

Bussolari said cooling the cockpit and the pilot was the biggest physiological challenge that the project group faced. When exercising, the body is only about 20% efficient. If the body generates about 200 watts of mechanical power, which is about a quarter horsepower and the amount required to fly this aircraft, then 800 watts of heat are generated. Bussolari described the cockpit as the equivalent of being inside a baggie, with a hair dryer turned on.

The human body dissipates this heat by sweating, so some kind of airflow is needed to carry away this evaporated sweat.

Unfortunately, in any kind of aircraft, a ventilation system causes drag, which puts an additional load on the pilot.

Flying this aircraft for the 4 to 6 hours that it would take to cover 70 miles will be roughly like, "running two sub-three hour marathons back-to-back." The speaker described it as a formidable athletic challenge and requires national or world class athletes.

A type of auto-pilot system is being investigated to relieve the pilot of the work load associated with flying the aircraft. It is a fiber-optic cable that runs along the fuselage to servo-tabs on the tail surfaces. The idea is to drive these servos automatically. The project received support from a number of public and private organizations, including the Smithsonian's National Air and Space Museum, Sikorsky and a number of other aircraft companies.

A considerable amount of direct financial support was needed to pay the salaries of the professional people on the project and this cost was underwritten by the Anheuser-Busch Company. At their request, the ship was named, "Michelob Light Eagle".

"When the Light Eagle was rolled out for testing," Bussolari said, "there were a number of goals that we wanted to achieve . . . the first of which was education and research. We were very interested in low-speed aerodynamics, structures and the physiology associated with this project. Our flight test program was intended to validate some of the design predictions that we made. In addition, we wanted to do a convincing demonstration that this aircraft was capable of very long duration human-powered flight."

To get a background in glider training, Lois McCallin, one of the human-powered pilots, went to the Schweizer Soaring School in Elmira, N.Y. Then she was given flight instruction in Bussolari's 1946 Piper Cub, "which is also an underpowered and sometimes cantankerous aircraft," according to the speaker.

In addition, a flight simulator was developed for the human powered aircraft pilots to practice in, before the Light Eagle was built. It even had graphic displays similar to the view out of the front end of the cockpit.

This type of aircraft has one or two landing gear wheels along the fuselage center-line but it cannot afford to have a wing tip drop and scrape on take-off or landing, so a group of wing runners must be positioned not only for take-off, but to catch the aircraft on landing. A landing aircraft is led with a truck, while the ship keeps the wings level with aerodynamic controls until the runners can get underneath the tips.

Bussolari and another engineer test pilot, Hal Youngren, made the first shakedown test flights of the Light Eagle. Then in the Fall of 1986, two of the project's athlete pilots, Glenn Tremml and Lois McCallin, made between 30 and 40 flights at Hanscom Field (near Cambridge, MA). That runway was only about a mile long and it took about 2½ minutes to go from one end to the other. It was apparent that more room was needed.

The group received permission from the Air Force and the NASA Dryden Flight Research Facility to use Rogers Dry Lake, CA, the largest of its kind in the world, 11 miles long and 5 miles wide.

The biggest problem at Edwards was ice collecting on the wing surfaces prior to flight. The January clear air and cool-air temperatures caused condensation and ice formation on the upper wing surfaces, which destroyed the laminar flow.

After many unsuccessful attempts, a generator was brought out to the lake bed and heat guns were used to dry and shrink the Mylar covering smooth just before each takeoff. Once into the flight, the ice would dissipate as fast as it would form.

Among the efficiencies that were designed into the airplane was an extremely small access door. The pilot had to pretzel himself into the cockpit. Then a sheet of Mylar was taped over the door, shrunk tight and sealed with an air gun.

While at Dryden, Tremml and McCallin set 4 world records for human-powered flight in January, 1987.

Distance in closed circuit	36.6 mi (58.7 km)	Glenn Tremml
Distance in closed circuit, female pilot	9.6 mi (15.4 km)	Lois McCallin
Straight distance, female pilot	4.2 mi (6.8 km)	Lois McCallin
Duration, female pilot	37.6 mi	Lois McCallin

Bussolari then showed the Light Eagle flown as a glider, with no propeller on it. He was doing gliding research flights to an altitude of about 100 feet using ground tow. A compilation of data after about 35 tows showed an L over D of about 34 to 1, which he said was fairly good for this low a Reynolds number and for a low speed aircraft with an aspect ratio of 40. It is the biggest open class glider in the world.

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Dr. Stephen R. Bussolari, Director of Flight Operations, (left) and Juan R. Cruz, Senior Engineer for composite structures examine the Daedalus prop.

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The airfoils were designed to have a laminar flow back to about 70% of their cord.

The pilots' heart rates and oxygen uptakes were minutely measured to check their efficiency.

After all these data were compiled, Bussolari's group began making the necessary changes to the design and construction of the next generation of aircraft.

In the meantime, the National Air and Space Museum displayed the aircraft for six months, and then it was returned for more flight testing.

Bussolari chuckled, "I believe that this is the only case of an aircraft hanging in the N.A.S.M. and then subsequently flying."

Another big question faced by the group was the logistics of a 70-mile flight over the Aegean Sea under unknown weather conditions. For over a year, weather sensors were placed along the route of the proposed flight to determine the best time of the year to make the flight. Additionally, there was the problem of trailoring and assembling the aircraft. It has five 28-foot sections.

To test their capabilities, the project group went down to the Rhode Island coast of Block Island Sound and did trial runs from an abandoned naval air station.

The Light Eagle wound up weighing 88 pounds. The Daedalus weighs 68 pounds, a 20-pound saving.

Three world class cyclists were added to the pilot team, Erik Schmidt and Greg Zack, both Category 1 Cyclists from the United States; and Kanellos Kanellopoulos, who is and has been National Champion of Greece, 13 times.

From November, 1987 through January of 1988, research flights of up to three hours are scheduled at Edwards.

From data now available, the 70-mile flight from Crete is scheduled for sometime between March 15th and May 15th.

At this point, the speaker showed a video tape of the aircraft in flight off Rhode Island last August. He explained the tremendous support requirements involved in such a project.

A minimum crew is 15. When the aircraft takes off, it leaves the crew behind on a hard surface runway and then picks up boats. Radio communications are extremely important.

Commenting on the slow 80 revolutions per minute of the prop, Bussolari said that there is about a 1½ to 1 gear ratio between the pilot's feet and a prop speed of about 80 revolutions per minute. Even after one half-hour flight, the cockpit was completely steamed up. At the flight's end, Tremml was shown with steam rising off him even though it was 60 degree weather.

Answering questions from the audience, Bussolari said that the turning radius is between 200 and 400 yards, the sinking speed without the prop is 6 inches per second. Speed is about 15 knots or 17 miles per hour.

Another question was how much power is lost in the gearing? Answer: about 2%.

Q. When do you contemplate your final flight will be?

A. Our weather window is between March 15 to May 15.

On the question of automatic flight control, Bussolari replied that the system that they are now working on is one based on measuring the earth's atmospheric electrical potential. "It turns out that the earth has a vertical electrical field. At the surface it is about 200 volts per meter, so if you measure the electrical potential at each wing tip and there is a difference, then you know that the wings are banked; they are at different altitudes."

To a question on the use of servos, the lecturer answered that they are powered by a battery-driven electric motor. This is within the rules for human-powered flight, since they don't provide propulsion.

When asked about the mythological significance of this flight, the speaker answered that he felt it represented humankind's desire to fly, to be free. Daedalus symbolized technology. Bussolari pointed out that, at that time, there was no status in being skilled in technology and crafts; the aristocratic class would find that demeaning. The myth represents a hero who, without intervention of the gods and by using his own ingenuity, realizes his dreams, unusual in Greek mythology. Further, for Western civilization it represented the birth of aero-engineering as well as the birth of flight.

One questioner asked why a conventional design was used instead of a canard and pusher prop. Bussolari answered that for a given level of stability, a conventional tail is more efficient. The

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Daedalus was designed so that the tail is not loaded in level flight and is flying at zero lift co-efficient, so it does not have any induced drag. A computer simulation can be done to determine the efficiency of any configuration and if that is done with a canard design, the readout indicates that a canard should be about ten times as big as the wing, which is what a conventional aircraft design is. The aircraft flies 30% faster than the Gossamer Albatross with the same power.

What did Dr. Bussolari think that this project's contribution to aviation would be?

He responded ". . . the codes that were developed to design the airfoils of Daedalus are currently being used to design airfoils for the more conventional aircraft."

"The structures? The design of lightweight materials? Stiff structures? Using advanced composite materials and technology? The human factor? Understanding the limits of exercise? These are questions that we are asking now. What happens to the human body after exercise periods of 4 to 6 hours? These questions have not been answered," Bussolari said.

"The entire aircraft as a system has a number of applications, one of which is high altitude, long endurance research aircraft that might fly under solar power with batteries for periods of up to a month, or longer, unmanned. Another is what you might call a poor man's satellite used for ground mapping or communications. Also, a little more far-fetched design like this would be perfect for exploring the Martian atmosphere . . . same Reynolds number, different problem. It could be used as a low-powered, long-endurance aircraft for mapping the Martian surface," he said, and with a chuckle added, "besides being fun and educational. That's why we're really in it."

After several other queries from an obviously fascinated audience, the human-powered flight engineer closed.

In a very short time, he brought his listeners from the myth-shrouded dawn of human-powered flight, through today's dazzling aerodynamic and human-endurance successes, to beyond, with a proposal for tomorrow's Martian explorations.

ON THE COVER:

Top picture standing from the left: Dr. Paul Gray, President of M.I.T., Lois McCallin, Prof. Jack Kerrebrock, principal investigator of the project, His Excellency George Papoulias, Greek Ambassador to the United States, and Ben Koes, United Technologies Sponsor. Front row: Kanellos Kanellopoulos, Glenn Tremml, Greg Zack, Erik Schmidt, and Dr. John Langford, Project Manager.

ΔΑΙΔΑΛΟΣ

Daedalus, the human-powered aircraft that will push the limits of technology and human endurance in a planned flight from Crete to Greece.

1988 CALENDAR OF EVENTS

Date	Event	Location
Date to Come	Dedication of the Soaring Capital of America Monument	Rt. 17
May 18	International Museum Day	NSM
May 27, 28, 29	1988 Exhibit Opening — "Youth and Soaring" "Motorgliders" & "U.S. Sailplane Designers and Builders - Richard Schreder." United States Soaring Hall of Fame NSM Trustees Annual Meeting	NSM
May 28, 29, 30	Vintage Sailplane Regatta VSA Annual Meeting	Harris Hill/NSM
June 6 - 12	National Soaring Week	NSM
Aug. 11	Twin Tier Hangarfest, Pilots Outing	Harris Hill Park
Sept. 3, 4, 5	Labor Day Weekend - Informal Sailplane Regatta.	Harris Hill
Oct. 1, 2, 8, 9	Fall Foliage Weekends	Harris Hill/NSM
Oct. 8	The National Soaring Museum's 3rd Annual "Kitecitement" Kite Fly	Harris Hill/NSM
Dates to be announced	15th Annual Ralph S. Barnaby Lecture	To be announced
Nov. 25, 26	45th Annual Snowbird Regatta	Harris Hill/NSM
Dec. 9	Community Soaring Committee Luncheon	NSM

FROM THE EDITOR:

Winter seems to be the time when we find ourselves scurrying around meeting deadlines for NSM displays and posters for libraries, other museums and conventions. NSM volunteers Ann Briggs, Barbara Fitzpatrick and Ralph Gernert turn piles of correspondence and press lettering into attractive invitations to visit the National Soaring Museum to see the largest exhibit of classic and contemporary sailplanes in the world.

Plans are going ahead for the 1988 Exhibit Focus, which will include "Youth and Soaring", with emphasis on U.S. Youth Soaring Awards; a photo display of motorgliders and power sailplanes and "U.S. Sailplane Designers and Builders - Dick Schreder".

The inclusion of the last category represents a continuing National Soaring Museum program to recognize American sailplane designers and builders with special exhibits of their work.

Attention, motorglider and power sailplane manufacturers and distributors . . . You can be considered for a part of the 1988 NSM Exhibit Focus. If you have not already done so, send us copies of your brochures, (two each) graphics and especially large color pictures of motorgliders, power sailplanes and related equipment. Information on motorglider assembly, specifications, history and personnel will be welcomed.

The Museum's National Landmark Program is generating a lot of interest in the motorless flight community. For our NSM members who didn't see the article in the February, 1988 Soaring magazine, the National Soaring Museum's National Landmark Program identifies and memorializes sites, individuals or historic events relating to the history of motorless flight. The Museum is interested in obtaining information and suggestions for landmark consideration. The program, developed by the NSM's Board of Trustees in 1981, has established three such landmark sites to date.

The first was erected in 1981, at Corn Hill Beach, Cape Cod, MA to honor Ralph Stanton Barnaby's 1929 flight, in which he became the first American to win an international soaring certificate and to break Orville Wright's 1911 record 9-minute 45-second soaring flight.

The second was dedicated in 1982, at the brow of Harris Hill, Elmira, NY, to note 50 years of soaring support from the local community and to recognize the late J. Thomas Rhodes and his family for helping early gliding and soaring enthusiasts in the days before Harris Hill.

The most recent 1985 landmark was to recognize the citizens of Akron, OH, for their pioneering spirit and their support of significant advances in motorless flight from 1929 to 1936.

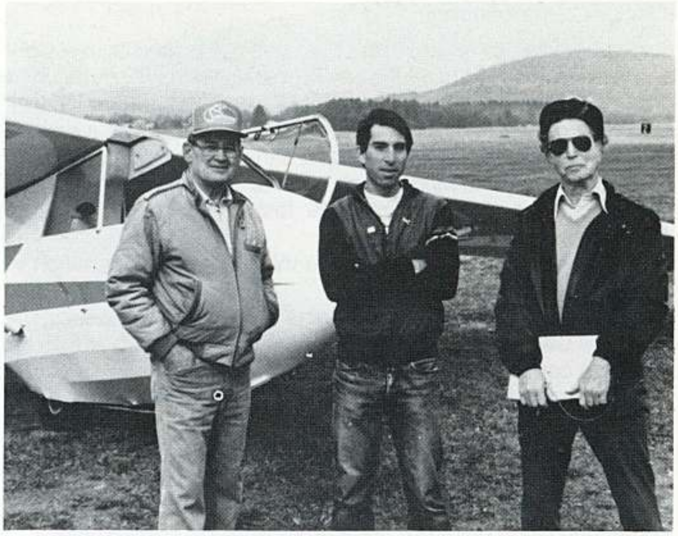
If you, or your soaring group, have a recommendation for National Landmark consideration, please contact Jennifer Hayworth Trimber, National Soaring Museum, Harris Hill RD #3, Elmira, NY, 14903; (607) 734-3128 and she will explain how the program works and the steps necessary for authorization and implementation.

More on the Daedalus Project: Three of the five Daedalus pilots visited the National Soaring Museum during their sailplane instruction at the Schweizer Soaring School.

Lois McCallin, who stopped here in 1986, later participated in many of the tests on which the design of the Daedalus is based. She is from Belmont, MA and is on leave from her job as a Senior Programmer/Analyst. An amateur triathlete, she was the first person to successfully complete the four-hour duration test given to all pilot candidates.

Last Fall, Erik Schmidt, Boulder, CO, and Greg Zack, Lexington, KY, stopped by and toured the Museum. Schmidt is a fulltime amateur cyclist and has trained at the Olympic Training Center in Colorado Springs, CO. A Cultural Anthropology graduate of the University of California at San Diego, he placed 30th in the 1983 Ironman Triathlon.

Greg Zack has participated in national level cycling races for the past two years. He holds a B.A. in Business and minored in Music at the University of Kentucky and also has trained at the U.S. Olympic Center.



At the Schweizer Soaring School, Elmira, N.Y., left to right: John McCabe, Erik Schmidt, and Dale Gustin, instructor.

Dale Gustin, their instructor while at the Schweizer Soaring School, received letters from Zack and Schmidt and a note from Kanellos Kanellopoulus, the Greek pilot/athlete, describing their soaring progress.

Since October, 1987, Zack has worked his way through a Grob-103, an ASK-21, a Caproni, an LS-3 to a Nimbus III. Stablemate, Schmidt did much the same, except for the LS-3 and the Nimbus III. He holds the pilot/athlete altitude record so far, at 31,750 feet. Commenting on that flight in his letter to Gustin, Schmidt said, "It was both exciting and scary". . . . Just a reminder: buy a National Soaring Museum Expansion brick and you or your club can be a part of an enduring reminder of your commitment to soaring history. Your brick will be laser-engraved with your name and be placed in the permanent wall display of the newly-expanded NSM. For detailed information, write or call The National Soaring Museum.

You can help in preserving our soaring heritage.

If you have historic memorabilia and excess or duplicate publications, send them to the National Soaring Museum for cataloging and archiving.

Share your collection of soaring artifacts and reminiscences with people who would not otherwise have an opportunity to appreciate them.

Address: Shirley Sliwa, Director
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