

# MAN'S GREATEST FLIGHT



## Seventy four miles pedalled in 3hr 54min: the epic story of the Daedalus record flight by John McIntyre; plans and detail drawings by Pat Lloyd

MAN'S GREATEST flight, in terms of physical effort, design efficiency and sheer bravado established an incredible record on 23rd April. As an answer to the question 'What's next?' the possibility of recreating the mythical escape of Daedalus from Crete had first been suggested, back in May 1984, by John Langford and Mark Drela shortly after their Monarch HPA had won the £20,000 first prize in the RAeS organized speed competition. Spanning nearly four years the project had bought together experts in the field of aeronautical engineering, meteorology, medicine and even classical literature - all with one, common hobby - AEROMODELLING.

### Achievement

This aeromodelling-based achievement has reached far beyond the flight itself by pushing forward understanding of the limits of human endurance. Ultimately it could enable construction of high-altitude, long-duration aircraft that may even find application in the Planetary Sciences - or be flown in the atmosphere of Mars as airborne 'Martian Rovers'.

Veterans of the MIT Chrysalis and Monarch HPA teams, most of them aeromodellers holding AMA National and FAI International Records, formed the core of this remarkable team. They set their target, survived disaster as well as success and with more than a little skill reproduced a classic myth with a reality that made headlines around the world.

### Prototype success

The Daedalus aircraft, unique amongst HPAs in that the limits of the pilot/engine were established from data collected after endurance tests carried out on a specially constructed ergometer, is the result of over

two years' design and construction work. Only after the success of a prototype, the Michelob Light Eagle, sponsored by Anheuser Busch, did the working group feel ready to build Daedalus. This accumulated many hours' flying time and set a distance record on 22nd January 1987 (when Glen Tremml flew 37.2 miles at Edwards Air Force Base). Nearly three-quarters of a million dollars - actually \$685,000 - was contributed by major sponsors NASA, MIT and United Technologies, while many other companies donated valuable equipment and support.

### Calculation and experiment

But what of the craft itself? Mark Drela, Senior Engineer was responsible for aerodynamic design. A past member of Chrysalis and Monarch HPA teams and Assistant Professor in the MIT Department of Aeronautics at MIT, he devised a computer program accurately to predict the effects of laminar separation bubbles on aerofoil performance in order to design efficient wing, propeller and fairing sections. The extremely high aspect ratio wing, meant to operate at a cruise coefficient of lift (CL) of 1.1 uses three different sections carefully tailored to the conditions of falling Reynolds Number as the plan form tapers from 45in root chord to 15in at the tip.

Everything about Daedalus is the result of careful calculation and experiment. For example, the fairing housing the drive shaft is asymmetric with a section that tapers with propeller diameter so that it can extract thrust from the twisted slipstream, thus increasing overall efficiency.

A flying speed of 15 mph was dictated by the need to fly against a possible light headwind and still make the seventy four mile crossing to Santorini in under seven hours - the longest daylight period for which winds of under three knots could be expected!. Using a single bracing wire to carry some of the lift load from the wing was found optimum for flying speeds between 11 and 18 mph (an aircraft with exten-



Load testing the Michelob Light Eagle wing using bottles filled with water.

sive wire bracing, such as Gossamer Albatross, can achieve greater endurance and range, but not within a weather 'window' that would permit a crossing of the Cretan Sea).

The streamlined fuselage, which provides not only a pilot fairing but vertical area for stability, is suspended from the wing with just two small bolts. A semi-recumbent cycling position reduced frontal area; ergometer tests showed no disadvantage compared to the more usual 'upright' arrangement.

Power is transmitted to the propeller via carbon fibre drive shafts and special gearboxes built by Bob Parks, the Senior Engineer responsible for mechanical design. His uncompromising craftsmanship served as an inspiration to the team. The variable pitch propeller, geared to rotate at 1.1/2 times pedal revolutions, is controlled through Bowden cable R/C model type 'snakes' from a small lever so the pilot/engine can match output to his pedalling rate. In truth, Daedalus is an REM model - that's Rudder/ Elevator/Motor! There are no ailerons. Rudder alone provides more than adequate maneuverability during the long, slow flights. The all-flying fin and tailplane are connected to a side-stick at the pilot's right hand by closed-loop braided Kevlar cables. A foam servo tab, which runs the whole length of the fin trailing edge, generates a powerful cantering force to allow 'hands-off' flight - a most important consideration, for at the end of a multi-hour flight the pilot, who will be fatigued, may not be thinking clearly at

#### **Tubular secrets**

The carbon-fibre epoxy tubes which form the craft's load-bearing structure are all hand-made by structural engineers Hal Youngren, Juan Cruz and Claudia Ranniger using uni-directional CF pre-pregs. This material is supplied uncured, sandwiched between waxed paper backing sheets. It is cut to size and wrapped around Teflon release-film-coated aluminum mandrels. Great care is taken to ensure that the spirally wound carbon fibre plies butt exactly, leaving no gaps. The number of layers, and their angle of application is determined by the load to be sustained. For example, in

the main spar (which carries not only the main wing bending loads but some compression and torsion too) the carbon fibre is applied at plus and minus forty degrees to the tube's longitudinal axis. On the other hand, the equivalent angle at the rear spar, which carries only tension and compression is  $\approx 12$  degrees.

#### **'The entire fuselage tips the scales at 51b 14ozs...'**

Tapered caps are then added to form flanges at the top and bottom of the spar. The tube is wrapped with 'peel ply' to leave a rough surface which will aid subsequent bonding. Finally the whole sandwich is tightly bound with heat-shrink tape on a purpose built machine.

When enough tubes had been made they were taken 200 miles to the Sikorsky helicopter plant where they were oven-cured at 175 $\circ$ . At this temperature the aluminum mandrel expands and the heat shrink tape contracts, thus compacting the carbon fibre. Tubes over one-inch diameter are pulled off their mandrels - an operation not always without difficulties, as modellers or builders of composite HPAs will be aware! After several unsuccessful attempts to free one sixteen-foot tailboom, involving winches and two university rugby teams, the trio of tube builders stayed up till 2am to ensure no witnesses before fixing one end of the mandrel to a concrete bollard and lashing the tailboom itself to the back end of a truck, which was then slowly driven away... Smaller tubes are etched out with hydrochloric acid, as usually employed for cleaning swimming pools.

To prevent catastrophic buckling of such thin walled, large diameter tubes, balsa/ Rohacell sandwich bulkheads are fitted at 10in intervals. Tubes are butted at joints, reinforced with carbon fibre cloth and finally lashed with Kevlar or carbon fibre. The five piece, 112ft mainspar, stressed to 2G, weighs only nineteen pounds - and the entire fuselage structure, which is 26ft long and 6ft high, tips the scales at just 51b.14oz!

#### **Ribs and wrapping**

In common with other HPA projects, wing ribs are from 1/4in thick, 1lb density styrofoam beadboard. Cap strips of 1/32in basswood are bonded with aliphatic resin; holes around the spars are locally reinforced with 1/16in balsa sheet.

Remarkably, the leading edge sheeting is hot wire cut - not wrapped - from 1.1/4lb density pink foam sold in the States under the trade name Foamular'. Steven Finberg, Senior Engineer in charge of electronic design, built a numerically controlled cutter expressly for this purpose. This resembled two upended 'X-Y' plotters bolted to a ply base and connected by nichrome wire. IBM donated a PC which can be programmed to cut the complex, tapered wing sheet panels. Result: a most accurate profile which means the lowest drag and required power yet achieved in any HPA.



A pilot's eye view of the cockpit.  
Photo Steve Finberg



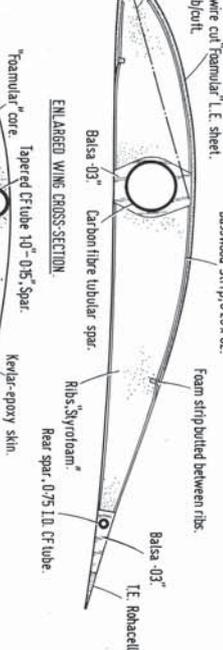
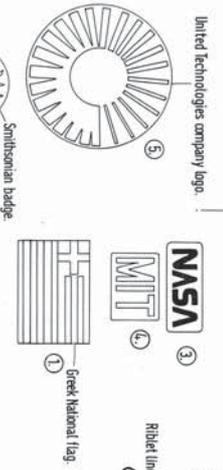
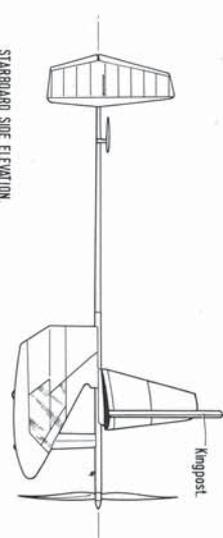
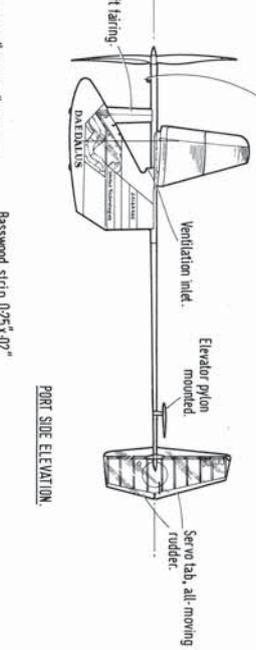
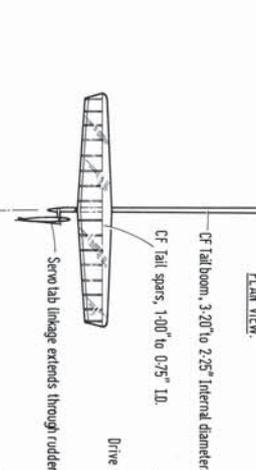
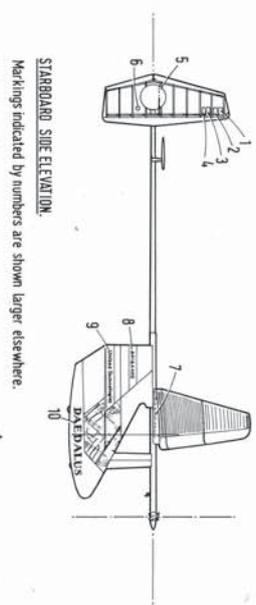
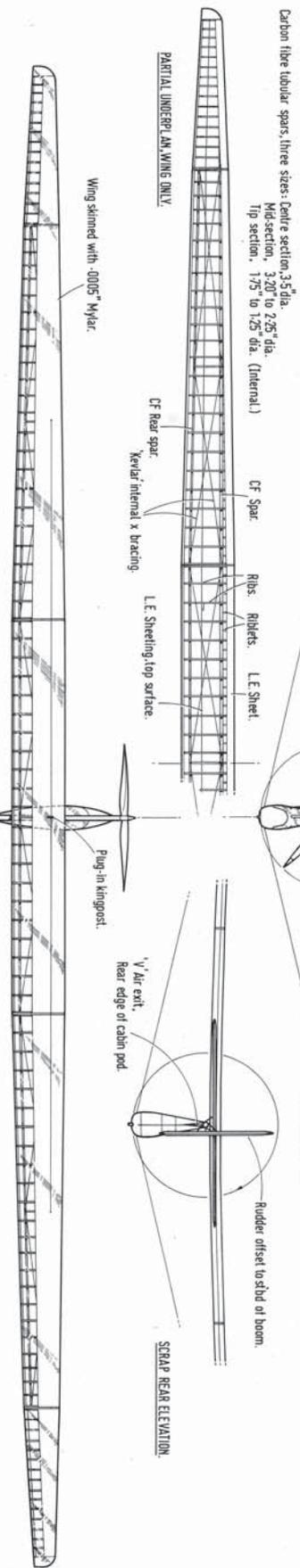
Ryan recumbent cycle paces Daedalus 'A' over the vast flats of Edwards air force base in California. Significantly, with experienced cyclists the aerodynamic efficiency of the human powered aircraft enables aircrew drive to match the effort required for the wheeled bicycle. Photo Steve Finberg

This drawing depicts 'DAEDALUS', Massachusetts Institute of Technology's Man-powered distance record holder at the time of its 73 mile flight from Heraklion, Crete, to the island of Santorini, on April 23rd 1988. Grateful thanks and acknowledgements to Mark O'Lea of MIT, John McInyre and Andrew Cranfield for sketches, photographs, drawings and enthusiasm!



\* All flights prior to April 23rd were made with the kingpost and bracing wires in position to protect the wingtips from damage, on the day of the attempt the post was removed and wing walkers supported the tips.

Empty weight: 70 lbs.  
 All up weight: 229 lbs.  
 Span: 112 ft.  
 Length: 28 ft 3 ins.  
 Prop diam: 113 ft.  
 Wing area: 332 sq ft.  
 Design speed: 14 - 17 mph.  
 Power: 0.27 hp.  
 Prop RPM: 108.



# DAEDALUS

HUMAN-POWERED DISTANCE RECORD BREAKING AIRCRAFT.

United Technologies  
 ENLARGED MARKINGS: See starboard side elevation for positions.  
 Drawn by: A.P. LLOYD



Covering of 0.0005in tensilised Mylar, donated by Paul MacCready of Gossamer project fame (who kept in close touch with the Daedalus team throughout) is fixed to the wing structure with two sides tape and contact adhesive. 'Incredible' is the only way to describe the empty weight of 69.1/21bs; carefully calculated construction of carbon epoxy being solely responsible for this.

### **Pedal power**

The major difficulty facing HPA builders has always been finding athletes who are also qualified pilots. In a complete reversal for the Daedalus project, five world class cyclists were recruited and taught to fly, first in high performance gliders and then in a flight simulator built by Steven Finberg. Training programs were staggered so that one flier would always be at readiness. Who were the chosen ones?

Kanellos Kanellopoulos is a fourteen-time Greek cycling champion, a graduate of the University of Athens and a member of the Greek Olympic Cycling team. Erik Schmidt and Frank Scioscia are full-time amateur cyclists from Colorado and Pennsylvania respectively; Frank being a member of the US National Cycling team. Co-ordinator and senior member of the Daedalus pilot team was Glen Tremml from Connecticut, an amateur triathlete and licensed sailplane and light aircraft pilot. Fourth member of the pilot/engine team was Greg Zack, whose

## **'To keep Daedalus flying nearly one kilowatt of waste heat is produced...'**

credentials include two years' participation in national level cycling races in the States.

What problems are faced in translating human power for flight? Working as an aero engine, the pilot reaches only about 20% efficiency, which means that in generating the 200 watts needed to keep the aircraft flying nearly one kilowatt of waste heat is produced - as much as a one-bar electric fire! Preventing overheating and dehydration thus assume major importance. Most of the fuselage facing is covered in reflective, silver Mylar to minimise solar heating, and a large, carefully designed air scoop beneath the wing collects the oh-so-important cooling air.

To compensate for fluid loss, five litres of a cocktail of a carefully balanced mixture of salts, water and glucose, formulated by project physiologist Dr. Etham Nadel in association with the Shaklee Corporation who specialise in the manufacture of sports foods, was carried in six plastic 'lemonade' bottles. Consumption was regulated at one litre/hour!

### **First wings**

First flight of Daedalus A was on 2nd December 1987. By the second week in January '88 twenty-four hours of

air time had been accumulated, including four flights of over 25 miles each (thus breaking Bryan Allen's record of 22 miles, set in 1979) during a three-day period by Greg Zack, Erik Schmidt and Kanellos Kanellopoulos.

Daedalus flew well from the start, its power requirement of only 2.9 watts per kilogram of pilot mass at 15mph being significantly lower than the equivalent figure of 3.5 w/kg for Gossamer Albatross for a speed only two-thirds as much. The specific power requirement (watts/kg) is the governing requirement for successful human powered flight. As a further comparison, Gunther Rochelt's Musculair I needs 220 watts for a pilot weight of 54kg, meaning an endurance-limiting 4.2 w/kg requirement.

Daedalus A was badly damaged in a crash on 7th February 1988, caused by a combination of a thermal under one wing and a stretched rudder cable. Repairs were not completed until the middle of March. In order to minimise the risk of a further similar crash the dihedral was slightly increased. By February 1988 Daedalus B was ready. After testing, both craft (and the Michelob Light Eagle) were taken to McGuire where they were loaded into a Greek Air Force C-130 and flown, via Athens, to Heraklion on Crete itself.

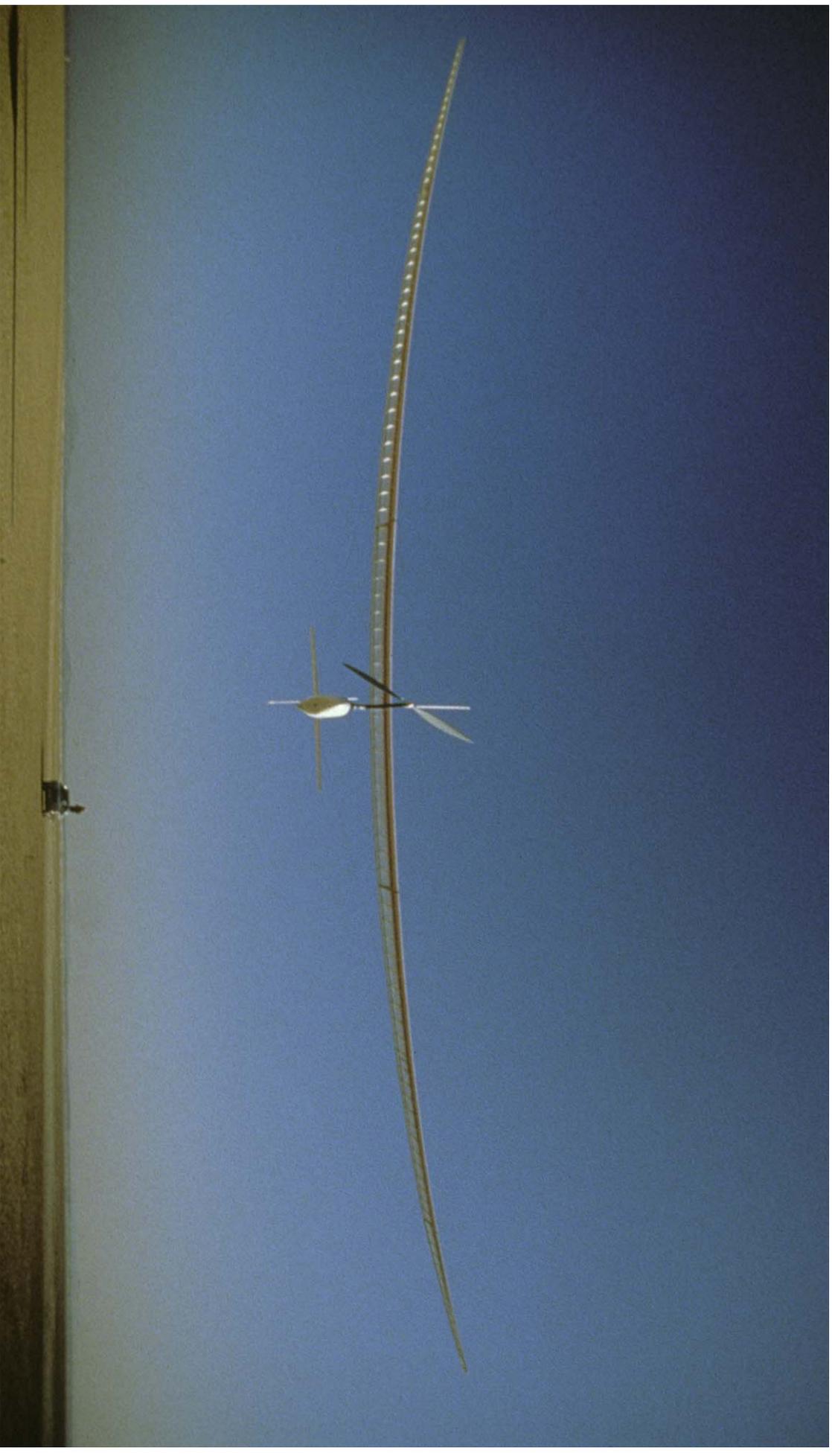
There had been no idleness in the preceding weeks. A hangar had to be shipped to Crete and erected for the craft's arrival - a process which took rather longer than expected as the crew were at first unable to reconcile the high level of craftsmanship needed for HPA assembly with the rather more basic standards usually applied to hangar building!

Daedalus B was given a shakedown flight at Heraklion Airport. It seemed as though the whole town had turned out to watch, for the terminal building balcony was packed as the craft was carried out and rigged with the sea and the barren island of Dia, about three miles offshore, as a backdrop. After a short roll the wheels lifted from the tarmac and Daedalus slowly flew the length of the runway - a milestone in itself; its first flight in Crete.

In the event it was to be nearly a month before the weather, hotter than expected and dominated by persistent headwinds, allowed a chance for the Santorini flight. Three attempts had to be abandoned in the first week alone. This frustrating period was spent in making detailed improvements to the aeroplanes, and, of course, pilot training continued so that one was always on stand-by. Various unsuccessful attempts were made to cycle up Mount Ida in the centre of the island! Defeat - and buckled wheels - were the result. Nevertheless, besides sightseeing, time was taken up with a useful series of seminars covering project-associated topics such as Aerofoil Design and Documentary Film Making.

### **Readiness...**

Towards the middle of the third week in April '88 the evening weather forecasts began to look more hopeful. Northerly winds dropped and the sea became a mill-pond. During Friday the 22nd, Steven Bussolari, Project



The sheer grace of Daedalus 'A' in flight at Edwards is captured in Mike Smith's photo where the azure Californian sky emphasises the elegant ultralight form. From the first tests over the desert, the team of aeromodelling engineers had every confidence of making the target flight over the Aegean sea.



Daedalus pilots, left to right: Greg Zack, Frank Scioscia, Glenn Tremml, Erik Schmidt and Kanellos Kanellopoulos (Steve Finberg photo.)



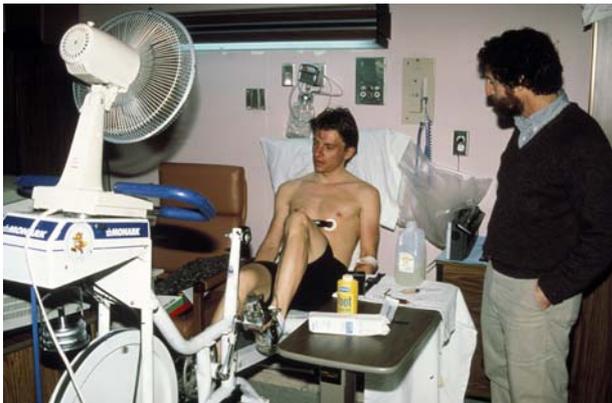
How did it go? - Post flight checks by the flight directors and engineers logged every detail. At this stage the drive shaft aerodynamic fairing is not fitted. Who played with the Daedalus name stickers we wonder. (Mike Smith photo.)



Kanellos Kanellopoulos learning to fly before piloting Daedalus. (Mike Smith photo.)



Mark Drela encourages Lois McCallin at the start of a test flight on Crete. Louis McCallin holds the Woman's duration and distance records, flying 15.44 km in 37 minutes and 38 seconds over Rodgers dry lake. (Steve Finberg photo.)



Dr. Etham Nadel tests a pilot on the ergometer. (Steve Finberg photo.)



At the point of no return - midway on the 73 mile flight, Kanellos Kanellopoulos advises the command boat that he's coasting and confident. (John McIntyre photo.)

Approaching the beach at Santorini. (Steve Finberg photo.)



Meteorologist, was frequently cross examined, and there was speculation about what might happen at one Athens newspaper which had run an article stating that the team had given up and gone home!

At the 7pm press conference MIT student Tim Townsend surprised many by passing round a half-inch length of carbon fibre tube, announcing that he had saved two grams and a little drag by sawing off a redundant bit of the fin. Steven Bussolari, with aid of a weather map that had taken all afternoon to prepare, forecast light, southerly tailwinds on Saturday and Sunday. A definite attempt had to be made on the morrow, with Sunday as reserve date, if flight operation had to be cancelled. John Langford, program Manager, who had initiated the Daedalus project four years previously after leading development of Chrysalis and Monarch craft, explained the rigging of Daedalus so that no one would walk into a bracing wire in the pre-dawn darkness. The team's Director of Engineering, Hal Youngren, dealt with the ditching and recovery procedure (the plan was to dismantle the craft and load it onto one of the coastguard boats). A quiet supper and early bed was next for the team after the press had melted away.

By 3am the weather boat, out at sea beyond Dia, had reported a one-knot southerly wind. Just what was wanted. At five o'clock we walked down to the harbour. Equipment was stowed and someone went in search of ice cubes for the champagne.

Confidence! Radios on, and crews on boat and at the field could now communicate. As Daedalus was rigged under arc lamps it was time for crowded thoughts. Would this be just a practice? Would the flight be called off, allowing everyone to return to the Xenia Hotel for breakfast and Juan Cruz's seminar on Daedalus' structural design? Or might there be a ditching? Pilot fatigue? Supposing the flight was achieved - what would happen at Santorini? The aimed-for beach at Perissa is small with soft sand and trees beyond. At a fast, downwind landing might the aircraft bog down, crumpling the wings forward and precipitating the pilot through the windscreen?

The boats drifted half-a-mile offshore in the cold dawn land breeze. Radio interrupted - and we heard that fourteen-times Greek cyclist champ Kanellos was taped into the cockpit and spinning the prop to warm up. Out at Santorini the weather station reported a three-knot southerly. It was up to Steven Bussolari. His was the responsibility to ahead or cancel. Came the OK - the flight was on!

### ...and away!

Daedalus was supported, gently, at the wingtips. A smoke flare's horizontal trail meant a momentary wait for a lull - then at 7.06 Kanellos was rolling. Sun flashed on the propeller as daylight appeared under the wheels - an easy take-off despite the pilot's concern about the strong tailwind.

To the offshore observers Daedalus grew steadily larger as it seemed to drift out to sea, chased by

inflatables. Sunlight glanced from those elegant wings as it swept by, fifty feet up. The flotilla raced out past Dia, throttles wide to keep pace with Daedalus which was now making 20 knots over the water thanks to the healthy tailwind. Kanellos made sure he kept above the turbulent layer next to the surface - doubly sensible, for the extra height would give the leading inflatable a few valuable seconds in which to pick up the line if there were problems. In this way a water landing could be avoided and Daedalus could be towed to safety for a further attempt.

In company with Louis Toth from MIT I tried unsuccessfully to count Kanellos' pedalling rate, or cadence, to get a figure for prop RPM. In fact, the pilot put in an almost constant 80 revs at the pedals to give 120 at the airscrew. Kanellos radioed his pulse rate and airspeed every fifteen minutes, allowing careful monitoring of his fluid consumption to avoid dehydration and exhaustion.

The wind began to veer west, slowing Daedalus and forcing Kanellos to crab in order to stay on course. Calm conversations passed between the boats and the group on Santorini. John Langford in the command vessel announced the records as they were set; first came straight-line distance after 37.2 miles, followed by 2 hours, 49 minutes duration at 9.51am. Somehow Steven Finberg had managed to get on board an escorting coastguard helicopter. He raced past at wave top height, filming from the open door. Louis and I shared an impromptu picnic with our crew on LS 34, during which they were presented with Daedalus sweat shirts to mark the occasion.

Then came drama. Just after loam a container ship was spotted on a collision course with the flotilla. At first contact was unavailing; then the skipper thought



Heraklion to Santorini - seventy four miles across the sea of Crete. A UK equivalent would be from London to Peterborough!

he was the victim of a hoax. Once convinced, he made a spectacular about-turn to divert from trouble.

Santorini ahead! On the beach the wind was gusting at five knots, parallel to the shore. As we powered ahead to be on site for the landing, Daedalus shimmered over the sea, now far astern and to starboard. Thanks to the local radio station, which had broadcast progress reports every half-hour, about 400 spectators were ready to welcome Kanellos.

### **The record!**

Ashore - and how hot was the black sand after the cool sea wind as we ran to the landing area, already marked with flares. Then Daedalus curved in as Kanellos tried to head into wind - and the starboard wing folded as the fin went hard over, tumbling the craft ten yards offshore. Kanellos broke through the Mylar door and swam to the beach where congratulations and champagne were on hand to commemorate a record smashing seventy-four mile crossing in 3hr. 54min, giving an average speed 18.5mph.

As Daedalus was pulled ashore the scene was a mixture of crash, conference and beach party. There was no escape for Hal Youngren, the project's Chief Engineer, who was interviewed for TV while he was still in the water, grasping one end of the shredded wing he was helping to rescue. He told them; 'This is easily the coolest airplane crash I've ever seen!'

## **'Celebrations continued late into the night... surely more aeromodellers share their vision...'**

The wreckage was loaded into the waiting trailer, parked at the beach for over a month in readiness. Then it was time for the Press as John Langford stood atop a beached boat, first with the pilots, then with the rest of the team, to spread the words of achievement.

Suddenly the team found themselves alone on the beach. Hal went to phone Bob Parks, the Senior Engineer responsible for mechanical design, with the news. No matter that over in California it was three in the morning! Juan Cruz, composite structures mastermind, summed up feelings by his comment that without the crash, which underlined the craft's fragility, it would all have seemed too easy. Project Engineer Jean Joseph Cote added, 'That wasn't a crash - that was a happening!'

Much to her credit, the owner of the Elfersina Hotel (where the weather station crew were based) wasn't in the least ruffled by the sudden invasion of almost the entire Daedalus team, disheveled, sunburned, some clutching pieces of aeroplane, and for the most part without a Drachma apiece. And imagine everyone's delight to find, on the verandah writing postcards, Peter Ernst, a Swiss leading builder of human-powered vehicles. He had spent a month at Santorini waiting to

see Daedalus. Never had he any doubt that it would be successful.

Celebrations continued late into the night. It was after 2am before the remains of Daedalus were finally collected from the beach and allowed to slumber outside the hotel...

### **What next?**

The story does not end there. The Michelob Light Eagle is to return to the USA for more flight tests and Daedalus is assured of display in the Smithsonian Institute. Then what? Henry Kremer is to sponsor two more prizes for human-powered flight, as announced in Hangar Doors in this issue. The success of a small group of dedicated enthusiasts shows what imagination and ingenuity can achieve - surely there are more aeromodellers and engineers who share their vision?

But perhaps the final words should rest with Juan Cruz. After the press had departed, seemingly bemused by an aeroplane crash where everyone was happy, he said: 'That's it, folks. You've been working for three years; you've been famous for fifteen minutes - and I bet we miss the news!'

Miss the news? Man's greatest flight? Not a chance...

Aeromodellers every where will appreciate the extreme serenity of successful man-powered flight, perfectly illustrated by this evocative shot of Daedalus during trials...

J. McIntyre, drawings by Pat Lloyd  
Aeromodeller August 1988

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