SOLAR CHALLENGER

Exclusive first hand report, of Paul MacCready's solar powered aircraft project By Martyn Cowley

A PIONEER of modern aviation, working on a new project, is certain to push forward the frontiers of achievement. Dr. Paul MacCready’s vision was to make the World’s first truly solar powered aircraft, the Solar Challenger. Strong enough, yet light enough to be capable of 100 mile plus flights at altitudes of 5-10,000ft. His consultant for the project, Bob Boucher, has the experience with electric powered flight and use of photovoltaic solar cells to help make the vision become reality. With financial backing provided by the DuPont Company, an enthusiastic and youthful team, guided by project-manager Ray Morgan, worked literally round the clock to build the experimental aeroplane in the unprecedented time of just 4 months. During flight trials late in 1980, the Solar Challenger, piloted by Janice Brown, went on to establish an impressive performance, as a prelude to MacCready’s ultimate goal for 1981 - a solar powered flight from Paris to London!

Paul MacCready, himself a World Soaring Champion in 1957 and a leader of the Hang Gliding movement during the 60s, is internationally famous as the “Father of Human Powered Flight”. His Gossamer Condor won the first Kremer Prize of œ50,000 for competing the 1 mile figure eight course in 1977 and his Gossamer Albatross collected the second Kremer Prize of œ100,000 for crossing the English Channel in 1979, the pilot on both occasions being Bryan Allen.

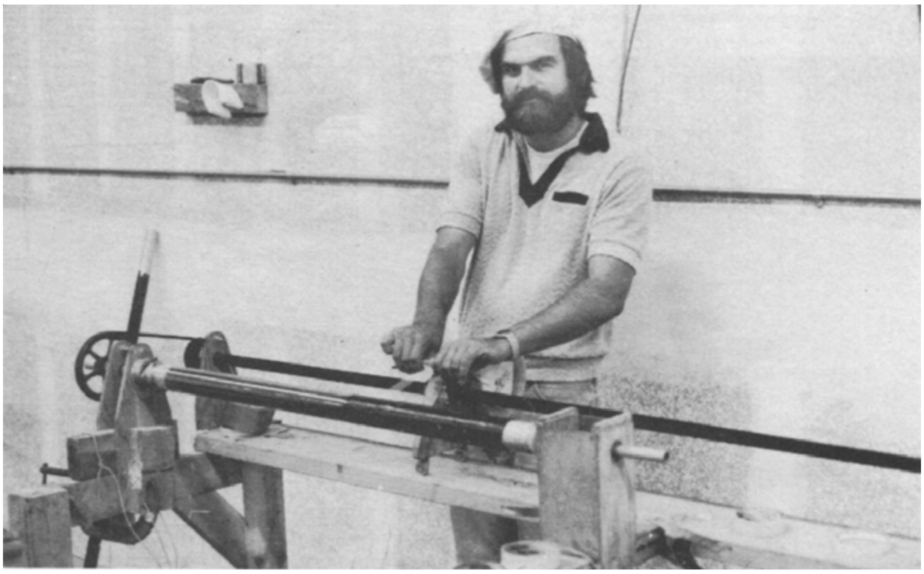
GOSSAMER PENGUIN lifts off for a test flight as the ground crew run alongside. With a solar panel positioned on top to catch the sun's rays, the craft flies at about 15mph at an average altitude of 12ft. The Penguin was designed to achieve the world's first sustained. piloted flight on solar energy without batteries. This goal was achieved August 7, 1980 at Edwards AirForce Base in the Mojave Desert.

Bob Boucher will be better known to model flyers through his company Astro Flight Inc., which has promoted and led the field of electric powered flight since the early 1970s. Bob set World Record flights with electric powered R/C models and holds US patents for electrically powered R/C aircraft. In 1972 he achieved a flight of 19 miles in 29 1/2 minutes at speeds up to 55mph and in 1973 his model carried a 61b payload for a flight of 1 hour.

In 1974, Bob Boucher flew the World’s first Solar Powered RPV (Remotely Piloted Vehicle) the Sunrise l, followed in 1975 by Sunrise 1, which set an altitude record at 17,200ft. Boucher’s concept was perpetual flight - to climb all day on solar power, glide all night, and still be above cloud base at dawn!

A little history

Others too have made significant contributions over the years. Fred



Left: first lady of solar powered flight. Janice Brown, with designer Paul MacCready.

Project manager Ray Morgan wraps carbon fibre tube with heat shrink polypropylene tape. Rear

Militky developed electrical solar powered Free Flight and R/C models from the mid-60s, and made the World's first man carrying electric flight with a converted HB-3 motor glider in Austria in 1973.

In England Freddie To designed the Solar One, a motor-glider type aircraft powered by electric motor driven by batteries charged before flight by a solar cell array on the wing. Larry Mauro's Solar Riser, a converted biplane hang glider, later used a similar principle to make first man carrying flights in America.

Gossamer Penguin

Paul MacCready's involvement in Solar Powered flight followed a series of tests on low speed flight for NASA which used his Albatross 2, converted to battery powered electric flight to enable accurate computing of in-flight performance. This led to the conversion of the third cross-Channel back-up MPA, the Gossamer Penguin for solar powered flight, using a top mounted solar panel to generate power. The Penguin needed near calm conditions at dawn and utilised a tilting solar panel which could be aligned perpendicular to the rays of the sun low on the horizon, to maximise performance. MacCready s 13-year-old son Marshall piloted the first flight on May 18, 1980 and woman pilot Janice Brown subsequently set official records on August 7th, 1980 of June 1981 1.95 miles during a 14 minute flight.

The solar powered Gossamer Penguin however, had many shortcomings. The added payload of 50sq ft of solar cells made control very difficult, there was insufficient power to take-off without a bicycle tow, and structurally the airframe was barely capable of supporting its own weight during flight, limiting it to a safe height of about 10ft.

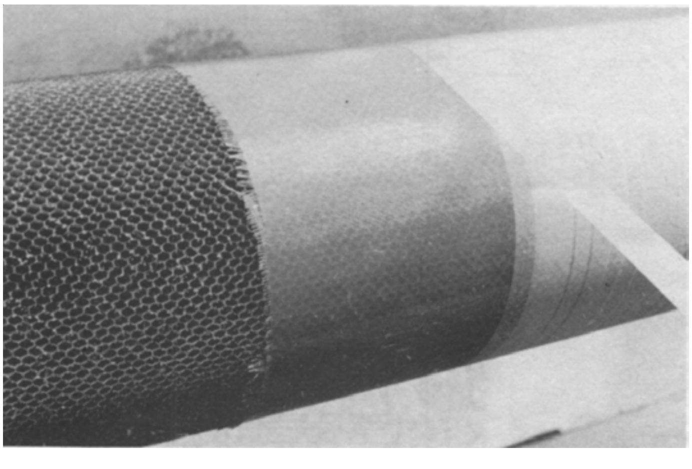
Although the Penguin has no future, it served its purpose as a development prototype, providing essential information and experience in solar powered flight that ensured success for the Challenger.

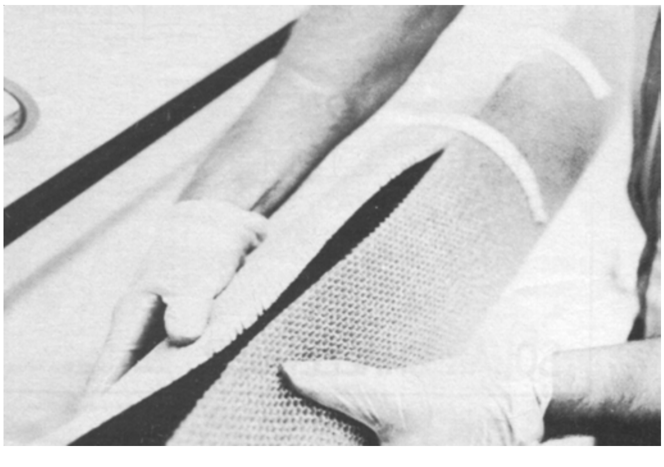
Solar Challenger

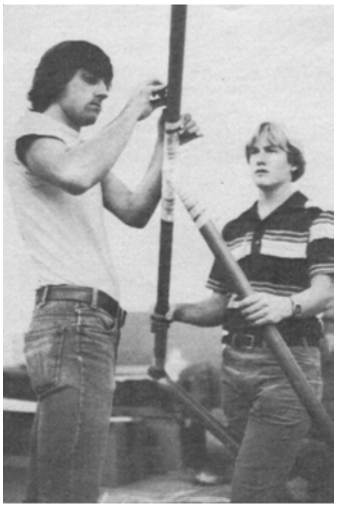
The designers and constructors of the Solar Challenger included two from the previous Gossamer projects, Blaine Rawdon, responsible for much of the structural design, and Ted Ancona. Others on the project owe more to their expertise as hang glider enthusiasts or model builders than to any formal education in aviation. After all, the Challenger is closer to being an outsize model than any regular aircraft. The construction of the Solar Challenger is a masterpiece in fitness for purpose and use of materials, combining as it does, the strongest of man-made materials, Kevlar, and carbon fibers, with probably the weakest, expanded polystyrene. The main skeleton of the airframe is constructed from handmade carbon fibre tubes, using a technique evolved with MacCready's Gossamer aircraft. But

Outer wrap of Kevlar cloth being strapped in place with stretchy Tedler tape while two part epoxy resin cures.

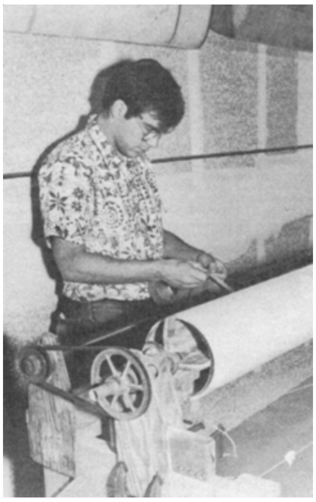
Nomex honeycomb wrapped round fuselage boom and wing spar, to give thin wall carbon fibre tube thickness and rigidity, improving strength.







Left: hang glider flyer Carlos Miralles (left) and model flyer Bobby Curtin. assemble fuselage frame tubes: junctions are well reinforced with extra Kevlar cloth and epoxy. Below: Blaine Rawdon, member of Cross Channel Albatross crew, was responsible for most of the structural design on Solar Challenger, seen here on the tube wrapping machine strapping with Tedlar



because the Solar Challenger has a cantilever wing without the support of wire bracing, it requires stronger tubes of larger diameter. The main wing, spar and fuselage tubes are an ingenious sandwich of materials which result in an immensely strong tube, with the sandwich construction providing inherent shape stability and strength from it's structural wall thickness.

The fabrication technique consists of spiral wrapping two or three layers of preimpregnated unidirectional carbon .005in thick, at 45§ around a waxed aluminum tube mandrel and then adding linear caps, top and bottom, back and front, tapering in strength with diminishing laminations. This hand-assembled tube is then spiral wrapped with 1/4in wide .001 in polypropylene heat shrink tape, and cooked in a long oven (a converted helicopter blade box) at 250?F, which cures the epoxy impregnated carbon under pressure from the expanded aluminum tube and the contracting polypropylene tape.

The next stage, after sanding the carbon to ensure good adhesion, is to wrap the tube in 1/4in. thick Nomex honeycomb, bonded with epoxy and micro balloons and held while curing with stretchy Tedlar tape pulled taut while wrapping. Finally, two layers of 1.7oz/sq yd woven Kevlar cloth, thoroughly impregnated with two part epoxy, form the outer skin, also wrapped while curing with Tedlar tape.

The use of these tubes and other composite epoxy and fibre components for brackets, mounts and fixings, accounts for the incredible strength and lightweight airframe, 1451b without cells.

Another unique feature of the Solar Challenger, certainly to the eyes of model flyers, is the flat-topped aerofoil. This was required in order that all the solar cells attached to the top surface of the wing and tail had the same angular orientation to the sun's rays; not possible with conventional convex upper surfaces. The aerofoil, computer designed by Peter Lissaman and Bart Hibbs at AeroVironment Inc. in Pasadena, has a curved leading edge entry shaped to give a docile stall characteristic, with the rear 80% of the chord perfectly flat! The underside has a convex curve to maintain laminar flow as far back as possible.

The wing ribs are made from 1/4in low density expanded polystyrene sheet, capped with 1/4in .0151n thick carbon, retained by l in strips of 0.6oz/ydz glass cloth. Patches of Kevlar cloth reinforce the sides of the ribs at the leading edge and around the spar location, and 1/4in ply blocks are set in the trailing edge to accommodate control surface hinges. The upper surfaces are sheeted with 1/4in expanded polystyrene just in order to give support to the solar cells and prevent damage from flexure. The leading edge sheeting is also 1/4in thick pre shaped by hot wire cutting. All the sheeting fits between the ribs to enable the .005in clear Mylar heat shrink covering to adhere directly to the carbon rib caps for better transmission of loads.

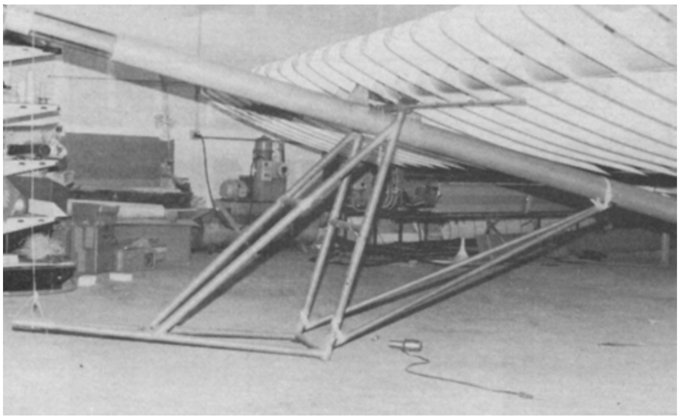
The 5in diameter tip spars plug into the 7in centre panel main spar to give a dihedral angle of 3§. The tips are retained by a bolt through flange to allow disassembly for transportation.

The tailplane is built with two carbon tube spars at leading and trailing edges and is attached to the fuselage boom with two pin-jointed hinging brackets. The brackets can move fore and aft on a parallelogram principle to increase or decrease tail incidence for in-flight trimming without the need for elevator deflection, thereby reducing drag during cruise on long flights. In practice this system has yet to be connected to the pilot's controls and it remains to be seen if this will even prove necessary.

Elsewhere, anything that is not contributing directly to structural integrity or pilot safety is made according to the Gossamer principle - make it as light and weak as possible and replace it only if it ever fails.

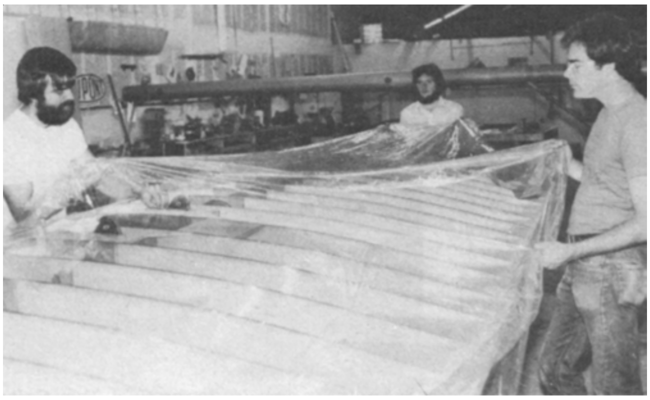
The 1 1 x 9 ft propeller blades designed in accordance with the theories of Professor Eugene Larabee of MIT, were constructed by R/C Sailplane and "San Fernando Valley Flyer" Mike Bame. As with previous Gossamer propellers, the core is hot wire cut from 21b/cu ft blue Styrofoam in short segments, each incorporating the appropriate blade twist for each station. The assembled blade, which incorporates carbon tube hub spar and carbon caps, tapering from 21 to 3 laminations of .005in material 1/4in wide, is then covered with woven carbon fibre cloth before final surface finishing.

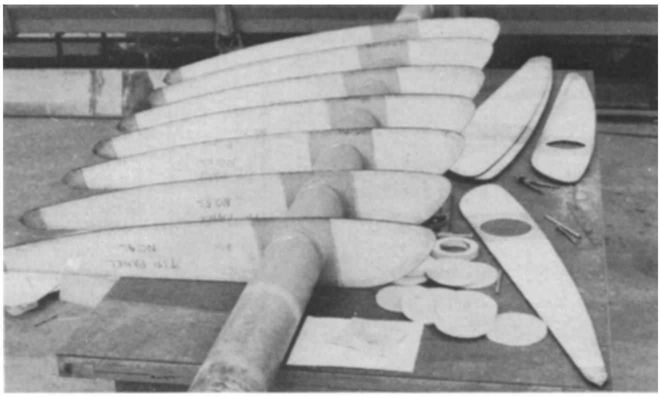
assembly of flying surfaces and fuselage fairing from the biggest kit of parts you can imagine. Martyn with wing centre panel (inverted).



Above: bare bones of fuselage. test fitted to tail boom and wing, early during construction.All carbon fibre tubes around pilot were encased in

Above Paul MacCready attempts to break the wing Once flat wing deflected 18ins at tips to





Each blade is a work of art, weighing just 11/2lb, and is mounted on a ball race stub shaft, free to rotate in pitch. A perpendicular carbon bracket restrains movement, attached by a short yoke to a push-pull rod controlled by the pilot.

Just testing

Pre-flight tests were performed on the structure in order to check calculations and construction of the finished components. Sand bag static load testing was used to check the deflection and load carrying capacity of all flying surfaces for 613 positive and 3G negative forces. A similar practical test could prove most illuminating for aeromodellers for measuring the strength and rigidity of their designs. During the test, the wings were progressively loaded up with sand bags until they supported almost half a ton - equivalent to +6G which gave a deflection of 18in at each tip.

Further tests were performed by bolting the flying surfaces to the roof of a van which was then driven at high speed to test for deflection and flutter from air loads. The Solar Challenger was designed to fly at a maximum speed of about 35mph, but the wings, tail and fin reached 65mph in test with no ill effects. Finally the FAA inspected the airframe and certified it as an experimental aircraft. No prizes for guessing the significance of the registration - N 181 SC.

First battery flights

To eliminate its dependence on midday sun during initial test flights, rechargeable NiCads were installed, which could provide up to 20 minutes of power from a 1 hour charge. Taxi tests and first flight hops were performed by experienced test pilot Steve Ptacek, who has over 4,600 hours of flying logged.

Bob Boucher. consultant for solar cells and electric motor, fits Astro Flight motor. Lower rubber belt cog drives bicycle chain and spocket to give 23–1 reduction to the propeller.

The first real test flights were performed at Shafter Airport near Bakersfield - site of the Condor’s Kremer prizewinning flight back in 1977. The C.G position was varied during these tests by adding lead weights to nose or tail. Moving the C.G. affected rotation at take-off, climb rate and control response. So the Solar Challenger was flight trimmed just like any Free Flight model aircraft!

After two days of taxi trials and brief flight hops, Steve Ptacek lifted off soon after sunset on the evening of November 8th for a 5:30 flight during which he completed one lap of the perimeter track, about 2 miles.

With the docile handling of the Solar Challenger confirmed, Janice Brown took over as official pilot for the project, and within a couple of days was achieving 20 minute flights, the limit imposed by the charge capacity of the 120 ‘D’ size NiCads. The best of these early flights came on the morning of November 13th, when thanks to some thermal assistance, Janice was able to extend the flight time to 92 minutes during a flight that reached 1600ft above the airfield - believed to be a World Record for Electric Battery powered flight.

Those solar cells

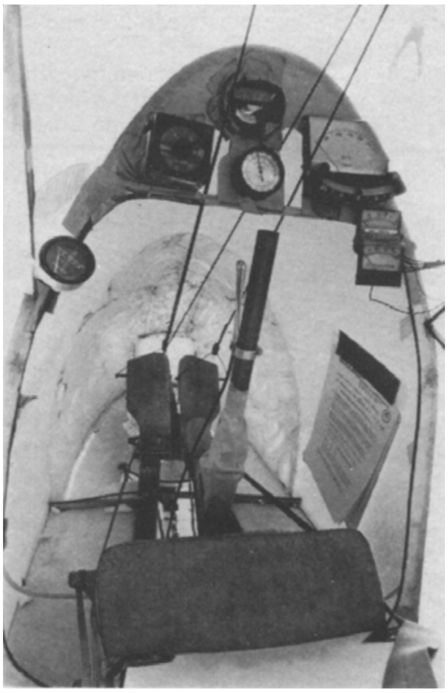
The Solar Challenger then returned to

the workshop in Simi Valley just north of Los Angeles, where the battery pack was removed and replaced with the photovoltaic solar cells fixed to wing and tail in pre-assembled strings, using double sided transfer adhesive tape.

The photovoltaic cells, as used on space projects, are made from thin slivers of silicon crystal, grown in a cylindrical core, accounting for the circular shape of some low grade cells. Higher efficiency is obtained by trimming to square or rectangular shape, allowing denser mounting, thinner cells also being lighter but more fragile. One side of the cell is positive, the other negative, and when excited by solar radiation, a minute current flows. Each cell has a fine pattern of silver filaments on the upper surface to collect the charge to one electrode, the undersurface coated in solder being the other.

Coupling sufficient cells together in series parallel produces a usable power source. The Solar Challenger uses 16,128 cells, each approximately 3/4 x 2 1/2in to produce an estimated 3,800 watts power on a typical June day in California with the sun nearly overhead at noon. As the cells heat up under the sun however, they lose efficiency - but fly them high enough and the temperature drops, regaining power. Optimum operating altitude may be around 3,000ft. The cells used on the Challenger valued at one quarter of a million dollars, are on loan from the USAF and convert the sun's energy into electricity with an efficiency of just 13% -which is quite high for photovoltaic

Left: Heath Robinson take note – Paul checks out the controls during the 'first test hop' even before aircraft was complete at Santa Susana. Streamlined fuselage fairing added later. allowing lull access to all controls during this phase.
Below: Janice–eye–view of cockpit layout. showing rudder, pedals and joystick, with instruments held in place temporarily with adhesive tape during early flights.



cells. Each had to be individually tested and wired in circuit, because a faulty, cracked or dirty cell can degrade the power of a whole string. Shading the solar cell arrays during flight was also a prime design consideration, partly accounting for the configuration of flying surfaces in relation to fin and propeller arc shade.

Unlike most vehicles, the solar powered aircraft has no throttle. Mother Nature decides how much energy is delivered as a product of haze, cloud cover, sun intensity and precise orientation. An early lesson of interest to aeromodellers was the need to exactly match the pitch of the propeller to the available power. On the Penguin this was achieved using a simple test dolly with pitch optimised following test ground runs, the propeller being clamped in place with pitch adjusted. For the Solar Challenger the ingenious variable pitch propeller mechanism allows the pilot to continuously tune the propeller thrust approximately plus or minus 2ft pitch, and consequently alter the load on the motor to match the available in-coming power, monitored on a watt meter. Adjustments by pilot to keep the meter needle pointing to the optimum setting is all that is required.

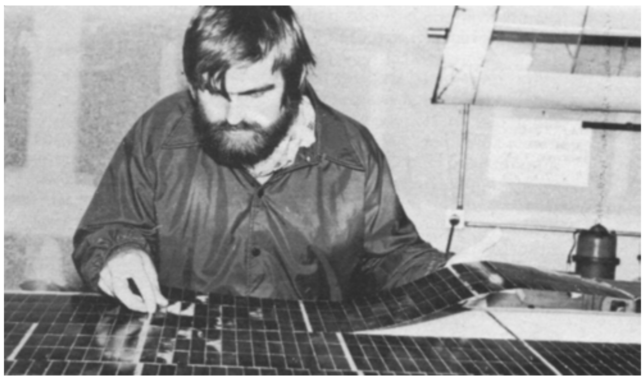
The electric motor used was a 2.75hp unit developed specially by Astro Flight Inc., operating up to 70 volts 40amps and 7,500rpm. A Kevlar reinforced belt and bicycle chain sprocket produce 23:1 two stage gear reduction to turn the propeller at an average of 300rpm.

First solar flights

The high desert area of El Mirage Soaring Centre was chosen for solar test flights because of better weather prospects. However the first day, November 20th, started windy and cold, with ice on the ground from the previous night, and plenty of thin cloud high overhead impeding the sun's rays.

The Challenger was set up in readiness but midday passed without any chance of a flight due to cloud cover. Finally at 1.10 p.m. a small patch of blue sky permitted an attempt to be made, and into an 8mph head wind, Janice rolled forward in the Solar Challenger for take-off. The world's first exclusively solar powered lift off preceded a first flight of 2min 50sec which traveled the length of the main runway at heights up to 60ft. Paul MacCready is a super optimist, but even he admitted his delight and surprise that the Solar Challenger performed so apparently effortlessly under these extreme conditions. Other flights made later that afternoon, confirmed that the Challenger has a potential flight time of 5-6 hours, even on a mid-November day with the sun's path between 20? and 35? above the horizon.

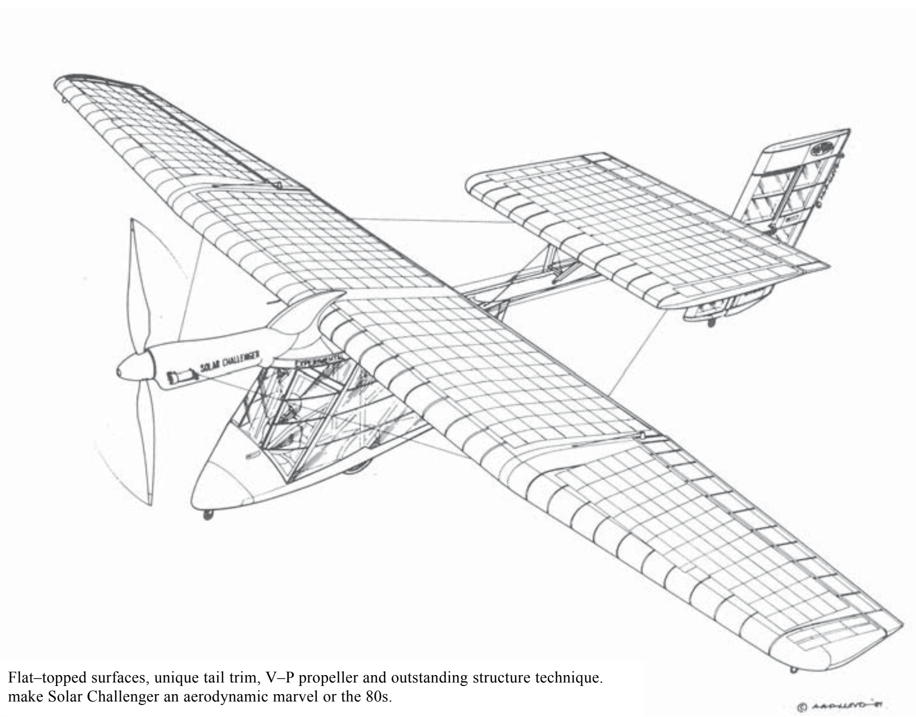
Ray Morgan adds another string of photovoltaic cells. A total of 16, 128 cells covered flat top surfaces of wing and tail.



High winds and bad direction in relation to the sun for take-offs limited the flights at El Mirage and resulted in some off-field landings in the nearby dry lake bed. The problem was how to get the machine back to the hangar 2 miles away! The answer was to walk it back through a maze of narrow sandy tracks between desert scrub and the occasional Joshua tree - an epic journey in its own right.

Long distance attempt Arizona, home of cactus and cowboys, was chosen as the location for the final phase of the project for 1980. Considering the time of year and low sun angle, Arizona offered better prospects for sun and fair weather. A route was chosen between Marana Air Park near Tucson, and Stellar Air Park, one of several landing sites near Phoenix, a distance of 63 miles with few obstacles in between except for the small Picacho mountain range and the 30ft high saguaro cactii. Any following tail wind would of course help the flight North, but needing to take-off away from the sun would then require a down-wind take-off!

One of the main problems facing the Solar Challenger so late in the year was that the extremely low sun angle not only reduced energy but also inhibited the direction of flight. The solar cells, being mounted on the sloping surfaces of wing and tail, are inclined 15§ to the rear during flight - adding to the sun angle when flying North away from the sun, but reducing it when flying South. This meant in effect that the Challenger would be unable to fly circuits due to the requirement to only fly away from the sun. This would present no problem for the ideal straight line flight North under clear blue skies. But in order to gain sufficient height over the Air Park to guarantee safety over flying nearby ground obstacles or to navigate around cloud formations, the ability to fly circuits would be required.



Flat–topped surfaces, unique tail trim, V–P propeller and outstanding structure technique. make Solar Challenger an aerodynamic marvel or the 80s.

The dilemma was easily solved by the innovative MacCready, who simply dispatched a van into the desert to drive round and round in circles. The result? Rising columns of desert dust lifted into the air, passing thermals on which the Solar Challenger could centre and maintain altitude in circuits. The all-letter registration of the van in zany Californian tradition was GCONDOR!

The hurried nature of the project, literally chasing the sun as it sank lower each day of the year, finally brought the Challenger to the moment of truth on Wednesday, December 3rd. Under clear blue skies, Janice Brown contemplated take-off for a flight to Phoenix, some 20 times longer than any previous solar flight she had ever made!

After five take-offs and landings due to insufficient height, Janice finally climbed out along the main runway gaining sufficient height to complete a circuit and maintain altitude in a rising dust cloud over the end of the runway. Several circuits later she was steadily gaining height, as the ground crew raced to their vehicles to follow the flight by road. Soon the Challenger was the highest it had ever flown under solar power as it headed North towards its destination. The long distance attempt was on, and soon Janice had broken her previous solar flight record of 14 minutes achieved in the Penguin. Regrettably, that was not all that was broken during the flight. A short one inch diameter pitch control pushrod buckled, and without full power, Janice was forced to land in the desert near Red Rock, some 5 miles and 22 minutes away from Marana.

Nevertheless, this first attempt had produced the best ever solar powered flight, with the advantage that they could try it all over again the next day ... and the next day ... So it was, during more test flying on Friday, 5th December, the Solar Challenger

Left. provisional fuselage design – no, actually more high speed tests for 47ft. span wing, taken to almost twice the speed Solar Challenger will ever reach in flight. Janice Brown, strapped into Challenger, helmet is made from Kevlar for improved strength and less weight. Note also two way radio taped to Myler covering.

established another new record of 92 minutes at altitudes up to 3,500ft over Marana Air Park, flown under remarkable conditions of almost total cloud over at times. Even so the sun continued to produce some power, perhaps a third at times, which still enabled the flight to continue much to everyone's surprise.

With this latest success, the Solar Challenger was again prepared for a flight to Phoenix the next day. But this time it was the weather that played a major role. An hour after take-off, Janice found herself being surrounded by approaching rain clouds and losing height fast as she tried to circumnavigate them and stay in the sunshine. The accompanying party of light aircraft were soon radioing advice to the solar pilot, of cloud and thermal conditions to enable Janice to pick the best route. As rain started falling on the solar plane, the chances looked hopeless. Janice flew the Challenger towards the Picacho mountains in search of slope lift that might enable her to sneak through a pass towards the sunnier conditions further North. But she could find little assistance, and after 1 hour 55 minutes Janice finally conceded, to land near Picacho Peak, about 12 miles out from Marana. Her actual flight distance including dodging between the clouds, was nearer to 50 miles.

With bad weather forecasts and some doubts about mechanical reliability, Paul MacCready finally decided to settle at that, and pack up for the winter.

Goal for 1981

Solar power will never become a reality for everyday flight - at least that is the opinion of Paul MacCready. Even if Solar cells were developed that were 100% efficient, there still wouldn't be sufficient energy available per square foot of solar wing area to make it really feasible. Where development of solar cells will bring benefits is not necessarily with improved efficiency, but in reduced cost per watt. The future of solar power is one of plentiful and cheap power for the more mundane earthbound uses. Paul MacCready's purpose with the Solar Challenger flight programme is to draw attention to the application of solar power and lightweight energy efficient design to highlight other potential uses for the future.

Under summer sun, the Solar Challenger will be able to take-off and fly, without need for thermals, in any direction, irrespective of wind or sun direction. Flights could last up to 11 hours producing a range of 400 miles. The fact remains that even so late in the year, the Challenger was easily capable of flying from Tucson to Phoenix, a feat it will no doubt achieve early this year as a build up to the proposed Paris to London flight in the Summer. In June there will be more solar radiation at 9.0 a.m. in Paris than there was in Arizona in December at midday!

Martyn Cowley, drawings by Pat Lloyd.
Aeromodeller, June 1981.

Paul MacCready sits on top of van during 65mph trials to check structural integrity and flutter. Working elevator and rudder operated during tests.