LOW COST SOLAR FLIGHT – Stephen Winkworth & David Garlovsky

Stephen Winkworth's publisher friend Peter Usborne came up with the challenge to design a model plane powered by photovoltaic cells early in 2017.

Background

There is nothing new about the concept of a solar-powered drone. When Peter showed Stephen a toy car he had bought at the Science Museum, powered by a single chip of silicon mounted on a mast, and challenged Stephen to make a flying version. Stephen's first thought was of course it could be done, and indeed was done quite a few years ago. His second thought was that it would be very expensive and not very practical.

Some of the more impressive solar powered UAV's or drones were built by the American aerospace company Aerovironment for a NASA low-earth orbital project. The idea was to replace a satellite with a continuously-flying aerial platform, gaining power from the sun to climb to high altitudes during the day, and cruising lower on stored battery energy during the night.

This machine, which was in the form of a large tailless wing with many small motors, and completely covered with high efficiency solar cells, performed impressively for long periods before being destroyed by a storm. Other advanced machines of high aspect ratio and superbly streamlined shape were built or envisioned by the technicians of the American West Coast, covered always with enormous numbers of expensive cells.

But as long ago as the 1970's a Hungarian inventor, Fred Militky, and Graupner, a German manufacturer of model aircraft, combined to build 'Solaris', a hobby-style solar-powered model aircraft. With 96 cells it proved too expensive to be commercial. However, surely forty years later, with the advances in solar cell technology and the modern, lightweight electric equipment popularised by the small drones now available on the market, something much more simple and affordable ought to be possible.

As Stephen lives in the south of France, there was no lack of sunlight. Maybe this could make an attractive retirement project. Now, drones are of two broad types. The ones we see most often, used by photographers, are basically small helicopters, without wings, lift being provided by several vertically facing propellers. The other type resembles an aeroplane with lift being provided by a wing. This latter type is used for longer-range missions, since much less power is required for flight. This would be the type to try, with wing surfaces covered by solar cells.

Solar model aeroplane design process

Before starting to design it, some cells with known characteristics would be needed. An internet search for solar cells turned up thousands of solar rrays, for generating backup electricity, charging cellphones and so on, but no one seemed to offer individual cells, specifying weight, surface area and performance.

Eventually, Stephen came across Solar-active.com, which offers for sale small numbers of light weight flexible high performance cells for school and hobby use and purchased 12 cells. Each unlaminated cell has an open circuit output of 300mA & 2v weighing 8g – 40mm X 180mm X 0.38mm.

Figure 1: flexible solar cell

Before commencing to design a plane, Stephen made up a test board, wiring first five and then six cells into two series, the two then wired in parallel to double the available current. A diode needed on each to prevent reverse charging of cells. The cells would be liable to damage from reverse polarity (with two groups in parallel one is bound to have a slightly higher voltage and will try to charge the other).

The PV cells were intended to replicate a two-element Li-po battery, so that standard hobbyist electronics could be used to control and power the plane. However, while the Li-po, which offers 450 mA at 7.4volts (33Wh), weighs 28g, the 12 solar cells weigh 96g and will probably not supply more than 450mA continuously in actual use taking into account angle of solar incidence, cloud cover and other factors.

It would be important to keep the overall drag of the aircraft as low as possible, while preserving maximum power from the propeller. Airframe weight would also have to be kept to the minimum. Stephen pointed out the Li-po's vital statistics have an 'H' at the end – the little thing can only do its stuff for an hour (before being recharged from some probably solar-derived source of electricity), whereas the solar-active cells are not time-limited: they go on forever (well, they do have to sleep at night, but then, don't we all?)

The rectangular shape of the cells dictated a fore-and-aft alignment, with 6 cells in each wing. This resulted in a comparatively low aspect ratio resulting in higher than ideal induced drag. Against this, with a wing this small, there would be a slight advantage in the broad chord, which would give a higher Reynolds number (the ratio of inertial forces to viscous forces which quantifies the relative importance of these two types of forces for given flow conditions), less prone to the flow problems of very narrow chords.

Wingtips of a shape designed to reduce vortex drag were incorporated, giving a total wingspan of 700mm. The total weight of the plane came to just over 300gm, 60gm lighter than estimated. The standard hobbyist's rule-of-thumb estimate of the minimum power requirements for flight (75 watts per pound weight) works out at 46 watts for 300gm. With only a maximum of 33 watts available, there could be no compromises over the model's efficiency.

A wing section known to work well in lightly loaded models of small chord was chosen from Martyn Pressnell 'Aerofoils for Aeromodellers' (Pitman 1977): Hansen AH60-40-7. Usefully, this section is not too steeply cambered (a steep camber would reduce solar efficiency, the ideal shape being of course a flat surface at 90 degrees to the sun's rays). After building the wing (a conventional balsa wood structure) the rather tricky business of incorporating the cells into the wing was completed.

Figure 2: Under surface of wing takes shape

The tail and wingtips are covered in ultra-light silvered mylar (5gm/m2), The underside of the wing is covered in 10g clear mylar. The cells are bare, but the leading edge of the wing and the metal contact strips are covered in the transparent mylar (the silvered variety is conductive).

Figure 3: The plane completed ready for flight

The motor was arranged in pusher mode, and the choice of a 'V' tail further reduced any interference with the slipstream as well as giving a slight drag reduction by eliminating the need for a fin. The fuselage was made as narrow and shallow as possible, and the pylon mounting of the wing, necessary to place the motor high enough for propeller clearance, was reduced to minimum cross section by making it of four 1.5mm diameter carbon-fibre spars.

There were some balance issues, owing to the rearward position of the motor and the weight of the solar cells. It was realised (and first glide tests confirmed this) that the balance point could not be at the usual 'safe' 30% of the wing chord. Such a CG position would have meant adding a prohibitively large weight to the nose of the model, raising its wing loading to a level where the available power would be insufficient.

The glide tests also showed immediately that there was a need to ensure some means of continued power to the radio (which was at first fully dependent on the solar input), when the model is in shadow or away from the sun. With the usual 'safe' CG position, the wing's positive pitching moment is countered by the weight of the aircraft acting in front of the aerodynamic centre, pulling the nose down. The horizontal tail then acts in either direction to raise or lower the nose as required.

Another balanced situation can be achieved if, instead of the weight of the aircraft acting to counter the pitching moment, the tail-plane is used in lifting mode. A fairly large tail plane area and a suitable lifting section are needed for this to work, but it will always be a less stable configuration. Accordingly, the tail plane was modified for this mode of flight. A side benefit is that the total lifting area is increased, so the wing loading is correspondingly decreased.

Figure 4: Evening flight under lipo power

Powered tests then ensued. In place of a lead weight needed to correct the centre of gravity position a small lipo battery was used for the powered flight test.

On a calm evening on June 8th the model flew in a reasonably stable manner. There was a marked effect of power on the trim, which was very nose-down as power was increased, though the model seemed able to sustain flight on very little power.

Minor adjustments to the thrust line were made by moving the motor forward half an inch and altering the thrust line to give more useful power and save a little weight. Owing to the marginal stability of the model, quite small adjustments to the thrust line would have major effects – on one occasion causing a 'nose-high' mush (deep stall) into the ground, giving the impression of inadequate power for flight.

An unusual problem for the solar tests was that at mid-day with cloudless conditions a high wind usually prevailed – too strong for the model's slow flight and limited stability. However, on July 19th there was a light southerly, with only slightly veiled covering of cirrus cloud. The model flew for several minutes under solar power, the cells being backed up with a small lipo battery in parallel to enable the radio to continue operating during intervals of lower solar flux (e.g. while turning away from the sun). The ancillary battery is of small capacity (250 mA) and is further hampered by a 1.5 ohm resistor in series, so that it is not able on its own to provide enough power to fly the model, but is still able to operate the servos.

This would have been a triumphant demonstration, but at one point the sun got in Stephen's eyes, and he temporarily lost sight of the model, regaining control too late to prevent a sharp dive into the ground with extensive damage: tail ripped off, wing mount broken (though not the carbon-fibre supports). Luckily the wing and the cells remained undamaged.

Figure 5: In flight. Picture courtesy of Jennifer Winkworth

Figure 5 shows the solar plane aloft on auxiliary battery. The flight consisted of three or four wide circuits of the field, slowly gaining height to a maximum of around 60ft. For the following two months, though the model was soon repaired, tests had to be abandoned owing to a series of violent wind events with high fire risks causing local sites to be closed to the public.

Finally, after some more battery-powered tests to confirm the effectiveness of the repairs and improve fine trimming, on October 16th 2017 there was a day of almost unclouded sun, very high atmospheric pressure and no wind. Another fully successful solar flight was made, with several circuits of the field and an excellent landing.

NEXT STEP

Stephen had the idea of using the top of a flat fuselage for the solar cells. It was the configuration employed by Militky in his pioneering 1976 model 'Solaris'.

Stephen is thinking of building an alternative model using this idea. The main reason against it would be the weight of the structure to support the cells. However, if the portion of the fuselage carrying the tail-plane were made independent of the rear cells, for instance, perhaps a looser and lighter structure could be used for the cells themselves. Or maybe a very open girder-like structure of carbon fibre might replace the rear portion of the fuselage.

In any case, the resulting model, with a fuselage length of 42 inches (I am imagining placing two strings of six cells each side by side), would be a lot less compact than my present machine. This might not matter, because although it would be difficult to build it down to the same weight, the increased efficiency and lower drag might, as you say, be decisive. This would be an interesting challenge.

At present a model is being tested a model of an early (or in all probability THE FIRST) man-carrying solar plane: Larry Mauro's Solar Riser of 1979.

Figure 1: Larry Mauro's historic Solar Riser of 1979

The interest of this machine is rather as a historic symbol of the possibilities of solar flight than as a technological breakthrough. Aerodynamically, it belongs to the category of ‘blind alley’ or ‘throwback’ so excoriated by Charles Gibbs-Smith in his book ‘Aviation: An historical Survey’ (Science Museum 1985).

Stephen relished the novelty of the constructional techniques and its quaint, perky appearance. The solar power delivered by its cells, which covered only two-thirds of the upper wing, was used to charge the flight batteries, after which it could remain airborne under power for a matter of five minutes or less.

The hope was to take off near some source of lift such as a cliff with a breeze blowing towards it, and then soar as a ‘hang-glider’ while recharging the batteries. It was not a commercial success, but it was the first time anyone had thought of using solar power for this purpose.

An even more convincing achievement would be to eliminate the ancillary lipo battery altogether, substituting a 4.8v rechargeable battery of say 150 mA capacity. Stephen was not sure how that would interact with the electronic controller for the solar cells. If the controller lost power from the sun, would it try to milk the 4.8v rechargeable battery, or conversely in full sun would it try to charge it?