TOUCAN

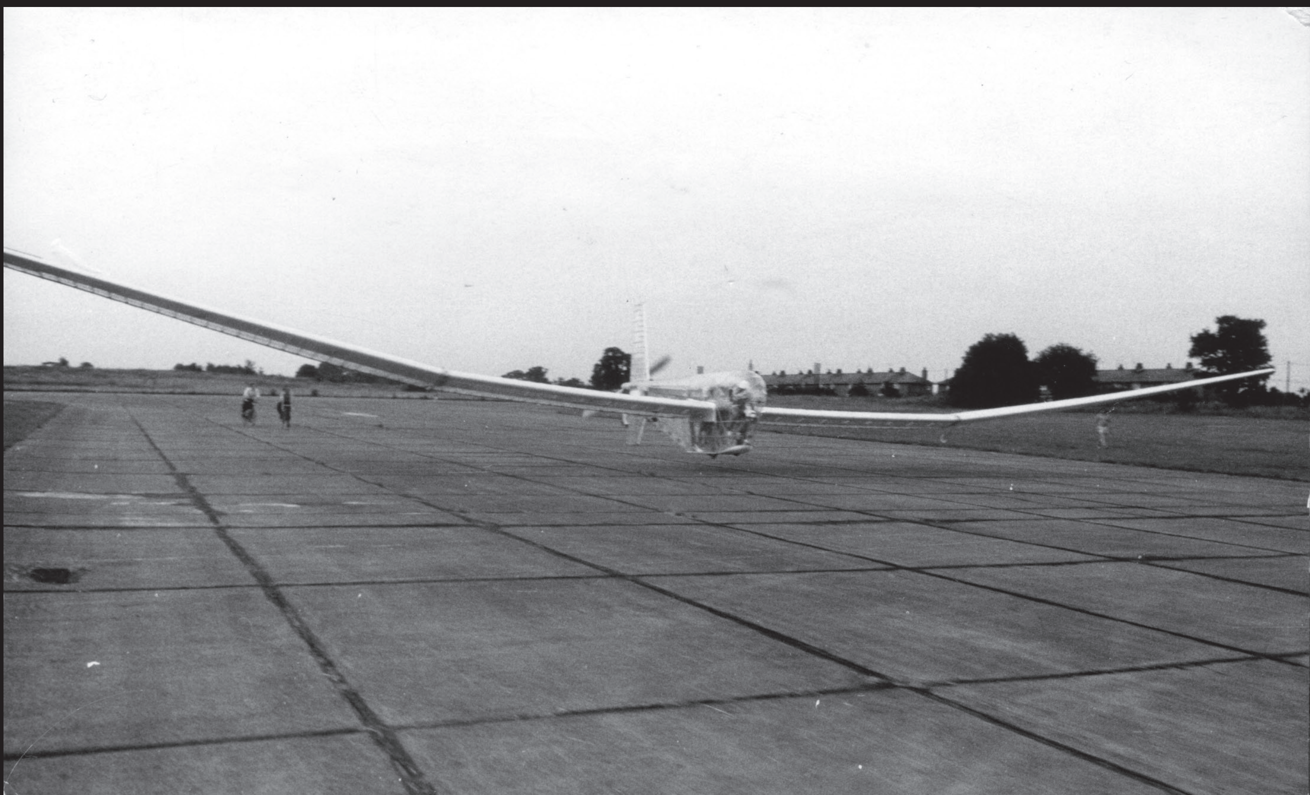


Figure 1. Alan Blundell, fourth from left - front pilot.
Fifty years after this photograph was taken Alan flew Aerocycle.
It was his first flight in an HPA.

TOUCAN

THE DESIGN AND CONSTRUCTION OF THE FIRST TWO-SEAT MAN POWERED AIRCRAFT CAPABLE OF FLIGHT

INDEX

PREFACE

Man has always had a desire to fly like the birds under his own power. In the last decade, this has proved to be a possibility but it still remains a considerable challenge. It is only when all the diverse skills required for such a venture are near the optimum that a man powered aircraft has any chance of leaving the ground. Aerodynamic, control structural, propulsive and human power considerations must be carefully made.

Although technically refined, this area of problem solving is not beyond the scope of craft education in school. Certainly the skills and knowledge gained in such an exercise become an education in themselves.

In this study the author has briefly outlined the history of man powered flight, explained a little of the aerodynamic theory leading to the design of contemporary aircraft and recorded his own experiences with one group in particular.

The work is by no means complete nor is a final conclusion reached but it is hoped that a little insight into an area of mans endeavour which is little known and largely unexplored will be of some interest to the reader

A V Blundell

TRENT PARK COLLEGE
1975

SPECIAL STUDY A. V. BLUNDELL

TOUCAN

The design and construction of the first two-seat man powered aircraft capable of flight.

INTRODUCTION

Man's dream of flight

A lifelong interest in aircraft has left the author of this study with one regret; that he was not there at the start of it all. How he wishes he could have been one of the very first persons to build and fly a heavier than air machine; even to have been amongst the few who were fortunate to witness the early attempts at flying. Alas, this glorious past with its successes and often tragic failures has slipped away and we live in a world where super technology abounds everywhere. Somehow, a modern epic such as men landing on the moon, when watched on another modern wonder, television, is too remote and too perfect to compare with the reality of seeing a man perched aboard a contraption of stick and canvas leaving the ground for the first time.

Fortunately, many of those early aircraft have been preserved either in original or replica form and there are many opportunities in this country to see them flying and to marvel at the painstaking craftsmanship and sheer ingenuity which these early constructors displayed.

There is one aspect of aviation still in its infancy and yet the dream of which is perhaps the oldest and original concept of flying; that of man flying by the power of his own muscles - as a bird.

History of Man Powered Flight

Man powered flight today is a reality. The last decade has seen enormous advances in this field due mainly to the putting up of a considerable amount of money by a wealthy industrialist as the prize for the first person to fly a mile round a figure of eight course. After standing for over ten years the prize has still not been claimed, although the record for straight line flight is 1300 yards by Squadron Leader John Potter in a craft REF 11 called Jupiter. Up to the time of this study there have been about seventy contestants from all parts of the world. Although the problem is immense, it is not insoluble and in this technically sophisticated world here is one area where the ingenuity and efforts of one man can and are competing on equal terms with huge industrial complexes.

The only power sources known to ancient man were either human or animal. It is natural that man should dream of attaching wings to his arms and flying like the birds. Hence the legend of Icarus. He, unfortunate fellow, having achieved flight with the aid of wax wings, flew too near the sun whereupon the wax melted and, having no parachute, he descended rapidly to earth.

Throughout history there have been reports of men trying to fly often with disastrous results. It was not until the nineteenth century that Otto Lilienthal, a REF 15 German, made a shrewd study of bird flight - he observed the storks flying near his village and, with a sound engineering background, constructed a successful man carrying glider. With developments of this he made over two thousand flights before he too was killed in an

* For ref Nos, see bibliography

accident in 1896. From the records of his many experiments into air behaviour has grown the science of aerodynamics today. The exploits of Lilienthal stimulated the Wright brothers in America to develop their biplane gliders and finally to build a suitable engine to power them.
With the advent of powered flight, gliding was largely forgotten.

It was not until after the First World War that, in Germany, gliding became a popular sport, The Germans had been banned from building powered aircraft but they did develop very successful lightweight gliders. From experience of these, the problems of man powered flight were again tackled. Efforts were intensified when, in 1933, a prize was offered, again, in Germany, for the first man powered flight of 1 km around two pylons set 400 metres apart
The prize was never won but two young engineers from the Junkers aircraft factory received the consolation prize with some creditable flights with their " Mufli " machine. The longest of these was 790 yards but was achieved with assisted take off. REF 3

In Italy in 1936 a similar prize was offered and as a result, a flight of 980 yards was achieved by a craft called " Pedaliante " again after an assisted launch, REF 3
Both the " Mufli " and " Pedaliante " were glider like aircraft in which the pilot pedalled with his feet driving, in the first, a single propeller mounted above the wing

and in the second two propellers on the wing. Although both were very light there are no confirmed reports that either of these aircraft actually took off from the ground under their own power. Any further development was abruptly halted by the war and sadly both craft were destroyed during the fighting.

It was not until 1957 that further interest in man REF 1
powered flight was shown and, in the United Kingdom, a committee was formed which joined with the Royal Aeronautical Society and started a fund to finance promising designs. At this point a wealthy industrialist, Henry Kremer, REF 2
offered a prize of £5000 to the first Briton to fly, under his own power, a figure of eight course round two markers, half a mile apart. Ten years later the prize, now doubled, still had not been won although it was now open to all nationalities. In 1973 Mr. Kremer again dipped into his pocket and raised the prize to £50,000. It still stands unclaimed.

Since the first announcement of the Kremer prize in 1959 several promising designs have flown successfully The first of these was designed and built by three post graduate students at Southampton University. It took off and flew entirely by the power of its pilot, Derek Piggott, REF 10
an experienced gliding instructor, in November 1961. The aircraft "SUMPAC" (Southampton University Man Powered Aircraft) was not unlike " Mufli " in general layout although the span at 80 feet was nearly double.

Seven days later, at Hatfield, a second plane aptly named " Puffin " also flew successfully. This was designed by a team of professional aerodynamicists and built at De Havilland Apprentice Training School. It remains as one of the cleanest and structurally most sophisticated designs ever to have flown. An improved and more efficient Puffin II recorded many flights of over half a mile but still did not win the prize. Unfortunately the frail structure did not withstand impact with a runway marker light early in 1969 and was damaged beyond repair. The main components of Puffin II were given to Liverpool University and incorporated into a less sophisticated and, to date, unsuccessful craft called " Liverpuffin ". REF 3

REF 3

It was during 1965 that the author had the privilege of assisting with flight trials of " Puffin I " and the experience was never to be forgotten. Due to the large wing span of 93 feet and the flying weight of 290 pounds including pilot it was only safe to fly in winds of less than 3mph. Thus only calm mornings or more often evenings were suitable for trials. Starting from rest, with the supporting a wing tip, the craft accelerated slowly at first. At little more than walking pace the pilot had lateral control. Then accelerating rapidly with the wing tips straining upwards " Puffin " would take off effortlessly and, climbing to a height of 20 feet, would cruise at 20mph. Apart from a slight swishing from the propeller, flight was silent. The pilot could be clearly seen through the transparent melinex covering material.

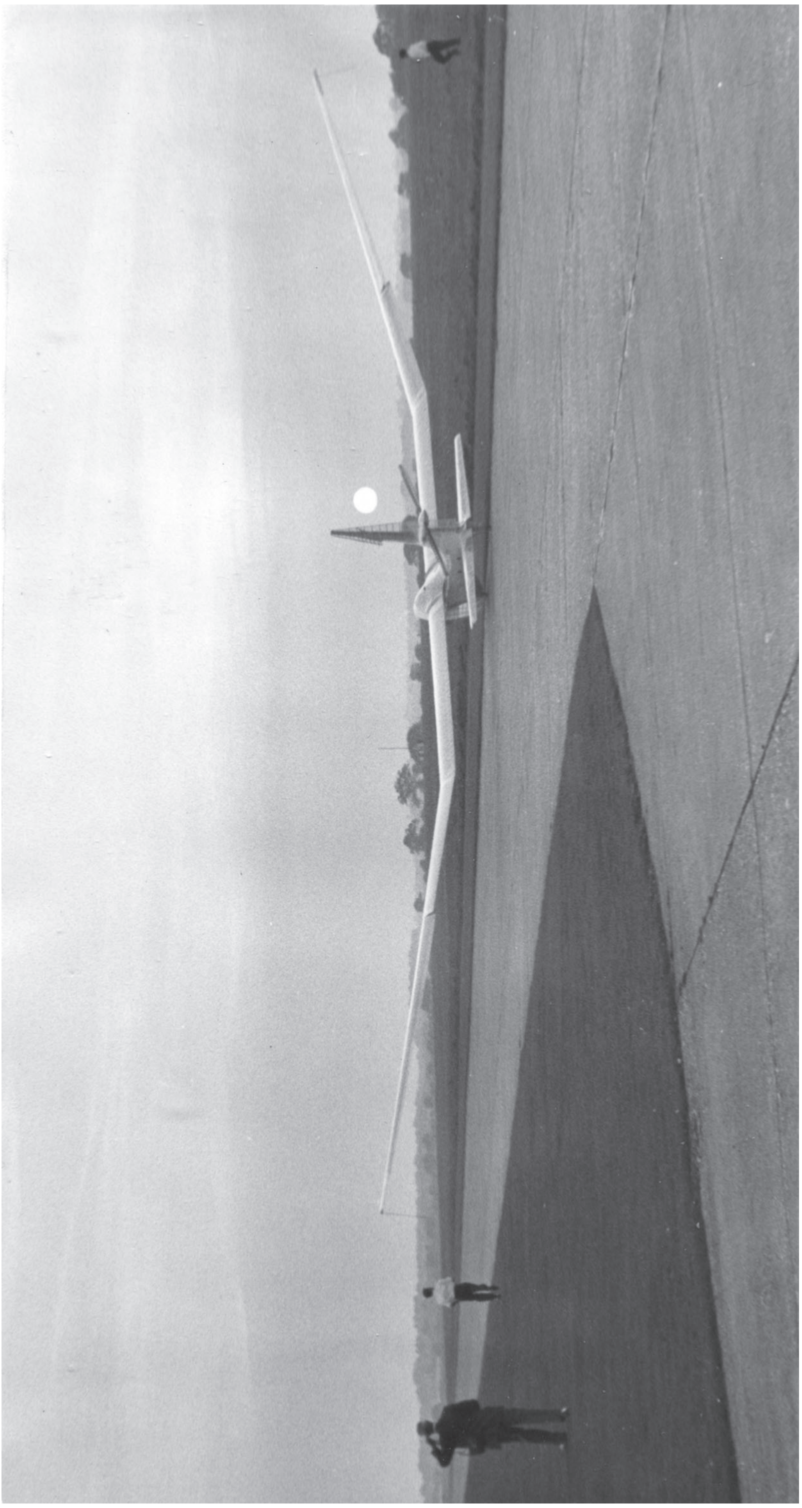


Figure 1. Puffin II, still the cleanest and most sophisticated of all man powered aircraft. Puffins I and II made over 100 flights between them. The furthest was 993 yards.

pedalling steadily against the typical background of a calm sunset. To see such a huge machine taking to the air both silently and apparently effortlessly was a momentous experience technically and historically. This man really was flying as a bird albeit in a straight line.

After the fateful crash in 1969 when the task of rebuilding Puffin II was too great even for the dedicated Hatfield group it is not surprising that the author and few others should show more than a little interest in a project progressing steadily at nearby Radlett. In 1972 an invitation to help at the first outdoor trial assembly was gladly accepted and from that time the author rapidly became an enthusiastic member of the group.

As each huge section of wing and fuselage were carefully extracted through the doorway the groups hut it soon became apparent what an immense project this was. When the three sections of the main wing had been bolted together (3 hollow 3/8 inch diameter titanium bolts per joint) the span stood at an incredible 123 feet. Thus equal in span to a Boeing 707 this craft was to be powered by two men. The seats, or rather saddles were in tandem, the pilot being at the rear. A 10 feet diameter pusher propeller to supply the thrust was mounted behind the fin in a similar manner to Puffins. The aeroplane had been optimistically named " Toucan ". Martin Pressnell, the groups chairman and a lecturer in aeronautical engineering explained the basic reasoning behind the project and a little of its history.

History of Hertfordshires pedal aeronauts and their “Toucan”

Between 1959, when the Kremer prize was first announced, and 1965 several man powered aircraft had flown successfully, nor only in the United Kingdom but also in America, Japan, Austria and France. All were single seaters and had wing spans between sixty and one hundred feet. While flights of to half a mile had been recorded no craft seemed capable of completing the Kremer course.

In September 1965 Martyn Pressnell, who had already had experience building an unsuccessful man powered aircraft, together with three colleagues, all employees of the Handley Page Aircraft Company, formed a group called the Hertfordshire Pedal Aeronauts. Their object was to investigate the problems of man powered flight and to obtain the support of the Royal Aeronautical Society and the Company to enable the group to build a second generation man powered aircraft.

Early evaluation soon showed that it would be extremely difficult to design-and build a single seat aircraft that would show a significant improvement on Puffins performance The point was that although theoretically one man could just about provide enough power to fly the course, in practice he must also devote energy to controlling the aircraft. Control required a mental thought process as well as physical effort and the more tired he became the less effective was the thought process. Accidents had already happened to both Puffin and SUMPAC due to their exhausted pilots making an error of judgement and losing control of the aircraft. To some extent training and familiarity with the machine could reduce this problem but not entirely.

If, however, a two seater craft were built where one man could devote all his energies into pedalling while the other was not required to pedal so hard, and thus be capable of safely controlling the aircraft, then some significant benefits might result - provided, of course, that the two seater was less than twice the weight of single seater.

The group set to work designing and testing a great variety of structures. The strength to weight ratios of many varying materials were analysed. Here was an exercise involving designing the strongest structure with the lightest possible weight. Even more important than pure strength, the structure had to be stiff enough to maintain the essential aerodynamic shape necessary for optimum performance even when subjected to maximum flying loads. This remains a problem for all types of aircraft - low and high speed.

With the successful testing of a dummy wing section as well as various panels and struts, the group was able to estimate that a total structure weight of 145 pounds might be possible. This compared very favourably with Puffin’s 118 pounds and SUMPAC’s 128 pounds but was, in the event, extremely optimistic.

However, being suitably encouraged, a draft technical summary of proposals was prepared and, in December 1966,

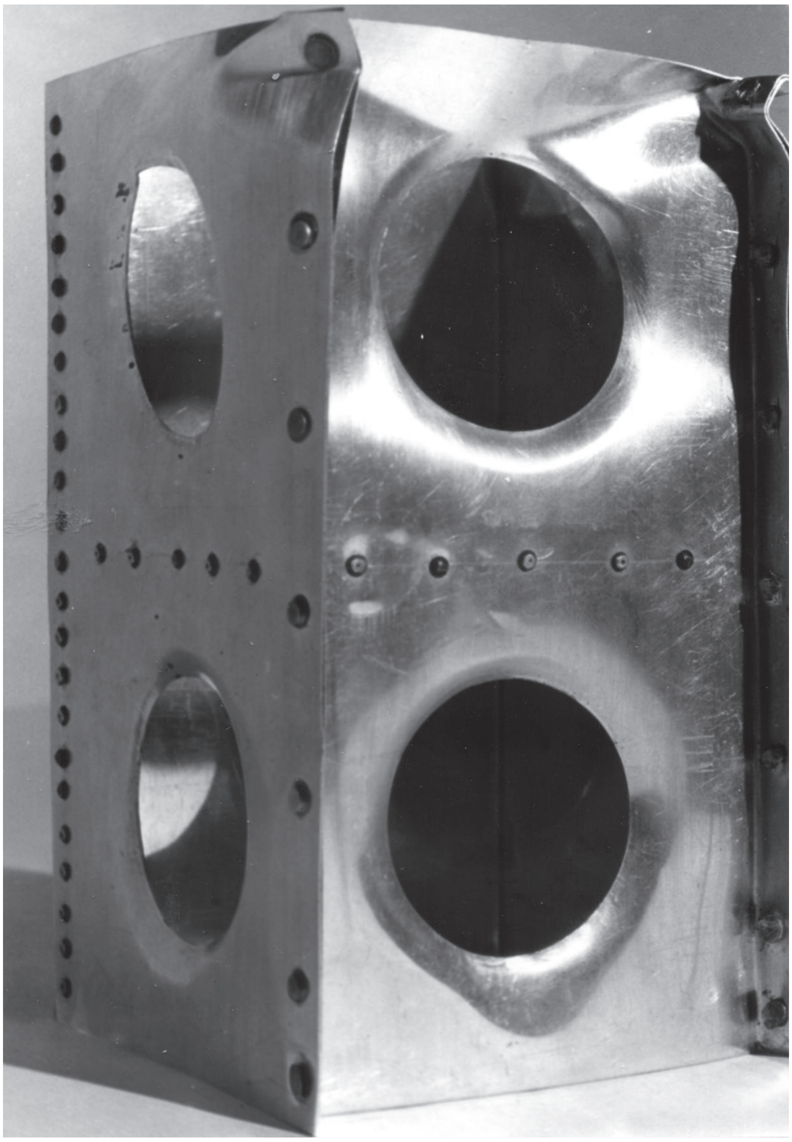


Figure 2. Test specimen for crew support structure.
The 3 inch square tube in 30 SWG (0.0124″) aluminium alloy was subjected to a compression test. It failed at a load of 740 lbf. Note use of different diameter rivets and different pitches. Buckling occurred at 1/8″ dia rivets with one inch pitch.

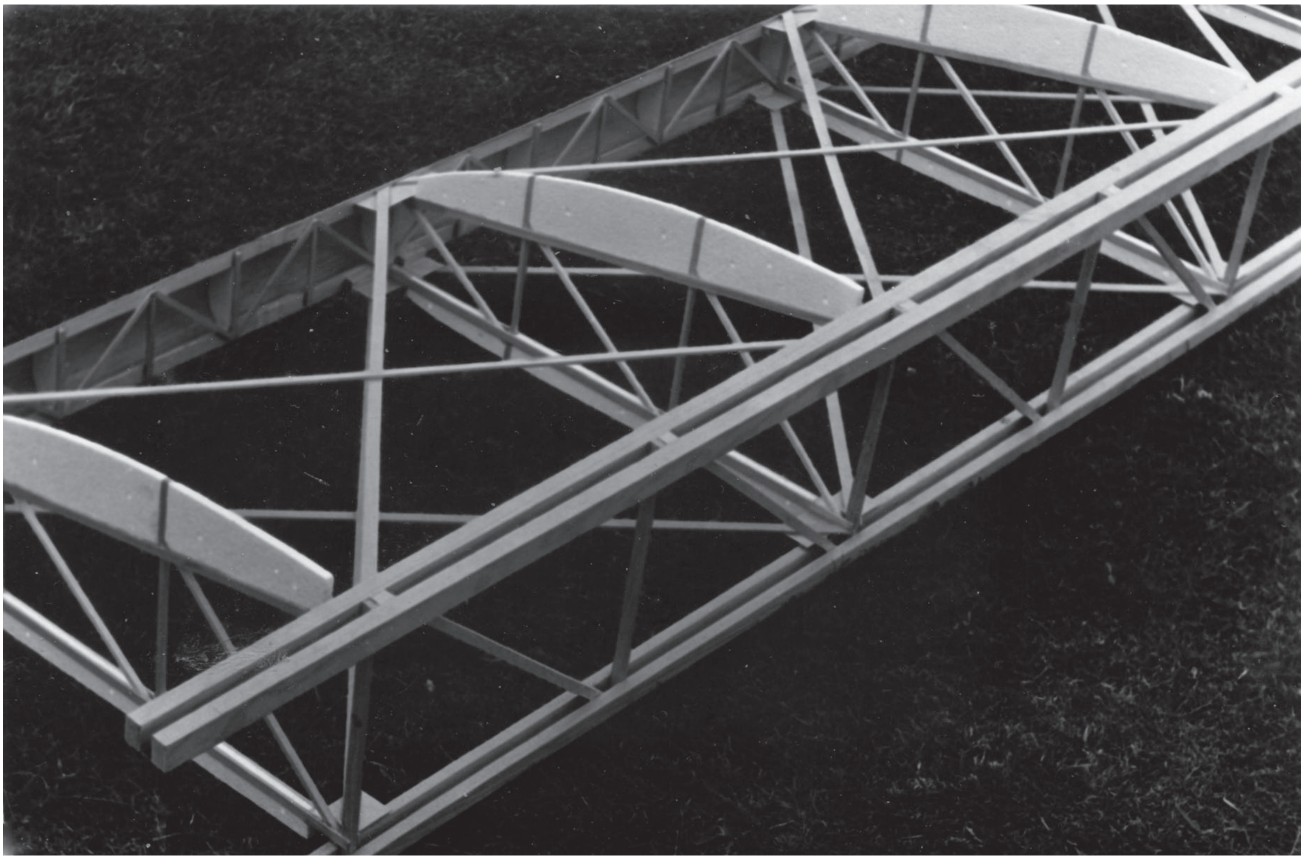


Figure 3. Test section for wing torsion box.
The structure comprises: the main spar (spruce) with double booms top and bottom; nose ribs (balsa); leading edge spar (balsa); top and bottom bracing struts (spruce).
Note the sectional area of the top boom (compression) is twice that of the bottom boom (tension).
The spar web girder construction was replaced by 0.5mm ply web with vertical balsa stiffness. See fig. 11. Polystyrene rib cappings support a 0.25 inch thick wing skin also in polystyrene. See fig.4 The overall wing torsional stiffness was found to be substantially increased by the melinex covering.

Figure 4. Wing test section mounted on vehicle.
The section was tested at speeds up to 30mph in order to check the effects of airloads on the rear structure. An observer was able to stand behind the wing and observe any distortion of the covering skin.

submitted to the Royal Aeronautical Society. It was received enthusiastically and financial assistance was assured.

With the group having now grown to twenty members, all of whom were paying regular subscriptions, construction was able to begin. Working in a private garage the hundreds of detail parts were made and built into small assemblies. Larger assemblies such as the fin and tailplane followed until it became essential to find a larger work space.

In 1969 most of the group therefore devoted all their energies into rebuilding two old post war bungalows that originally had housed families in the Birmingham area.

This task alone was considerable and initially required an area 66 feet by 21 feet to be cleared, levelled and concreted. To provide power, a trench 250 yards long had to be dug, much of it through concrete. Permission had been granted to build the hut in a disused corner of the Handley Page airfield. Ironically the Company went into liquidation a year later and thanks to the Receiver the club hut now remains as the only site of aircraft construction on the airfield. With the collapse of Handley Page, the Toucan project itself was in jeopardy as many members were forced to move away from the area in search of new employment. Happily some only moved as far as Hawker Siddeley at Hatfield (formerly De Havilland’s) and it was not long before new recruits had been gained, some them ex “ Puffin “ helpers.

With the new light and airy workshop and group membership now twenty four, construction progressed rapidly. By June 1972 Toucan was ready for the first roll out, to achieve this stage of completion it was estimated that the total construction time amounted to more than twenty thousand man hours. REF 7

Figure 5. The first complete assembly of Toucan.

The Problem

Before going into the detail design of Toucan it is first necessary to explain how the fundamental design of any man powered aircraft is arrived at.

There are certain known facts concerning flight: -

1. During flight the entire weight of man and machine. will be supported by the air.
2. A man can produce about 1/2 HP for a relatively short time. REF 3
3. The man’s weight will be around 150 pounds.
4. We know the weights and strengths of structural materials.
5. We know the physical properties of air such as its density and viscosity. REF 4
6. We know the laws governing the movement of a given shape of body through the air. REF 4

Since we cannot change the weight or power of a man significantly (apart from ensuring that he is fit) our main variables will be:

1. The structure weight
2. The size and shape of the aircraft.
3. The aircraft’s speed

The weight will depend on the size and shape of the aircraft and the choice of materials. The size of the aircraft will however depend on its weight and speed.

Speed will depend on power available as well as weight, size and shape. Thus all the variables are interlinked and must be carefully calculated to achieve the best compromise.

Aerodynamic Considerations

Lift and Drag

When we move a flat plate through the air without tilting it, very little pressure acts on it. If we tilt up the front slightly a resultant pressure will both try to lift the plate and slow it down. If we observe a kite flying this resultant force will be equal to the tension on the string and opposite in direction. As kites rarely fly with the string at more than 45 degrees to the ground they are quite inefficient as aircraft. In fact the slowing down force or DRAG will be almost equal to the LIFT.

As a mans weight acts downwards, the force to support him, when flying, will be the LIFT acting upwards, The DRAG force can be overcome by his own power assuming he is in level flight. If he flies downhill as in a glider, the DRAG force will be balanced by gravity.

Power is the rate of doing work.

i.e. Power = force x velocity.

Now if we only have a limited amount of power available and we want to produce as much force as possible to overcome DRAG the velocity must be small. i.e. we must fly slowly.

The LIFT on an inclined plate travelling through the air will depend on its velocity v REF 4

will depend on its velocity	v	REF 4
its plan area	S	
the air density	ρ	
its inclination	α	
and its shape		

Experiments have shown that in fact LIFT and DRAG are proportional to the square of the velocity. In aerodynamic terms:-

LIFT = $0.5\ \rho V^2 S\ C_L$ REF 4

C_L is non dimensional coefficient being a function of inclination and shape. It is called the LIFT COEFFICIENT.

Nature can give us a very good idea of how to generate as much LIFT with as little DRAG as possible. If we imagine a longitudinal section cut through a birds wing we get a streamlined shape similar to a fish or a dolphin.

By experimenting with wing sections in a Mind Tunnel it is possible to measure the LIFT and DRAG for varying angles of incidence or inclination. In order to compare one wing section with another it is convenient to use non dimensional coefficients. Thus we can directly compare shapes without needing to specify sizes.

As with the equation $L = 0.5\ \rho V^2 S\ C_L$

or $C_L = L/0.5\ \rho V^2 S$

there is a similar one for Drag.

$D = 0.5\ \rho V^2 S\ C_d$

or $Cd = D/0.5\ \rho V^2 S$

The values for C_L, and C_d, can be plotted against incidence. See Figure 6.

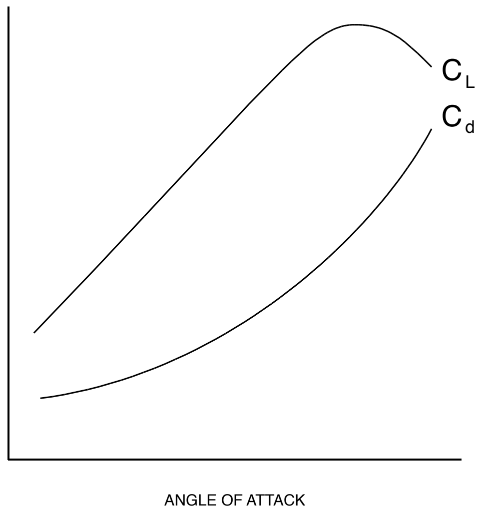


Figure 6

The C_L curve increases almost linearly until a peak is reached and it then drops rapidly. In practice, just after maximum lift is developed, the air ceases to flow smoothly over the wing and it is said to STALL. The drag rises rapidly near the stall point. Flying an aircraft too near the stall is both dangerous and requires extra power to overcome the sharp increase in drag.

In fact the most efficient angle of incidence to fly at involves most LIFT for least DRAG.

i.e. $\frac{\text{LIFT}}{\text{DRAG}}$ maximum

or $\frac{C_L}{C_d} = \text{maximum} = L/D = C_L/C_d$

It is possible to plot a curve of C_L against C_d
This is called the LIFT - DRAG CURVE.
See Figure 7.

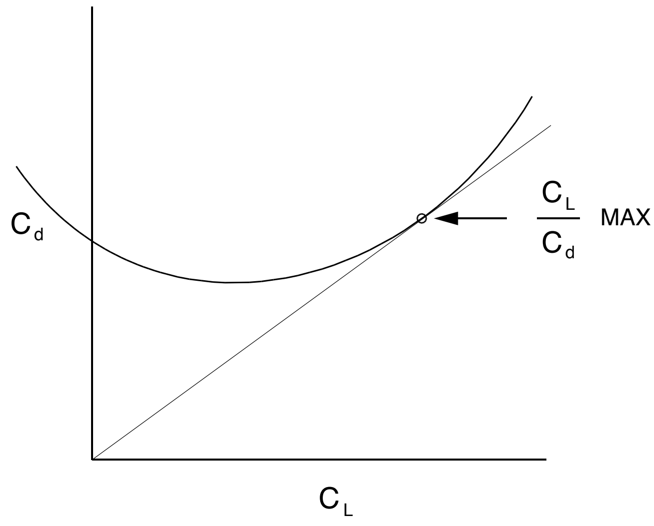


Figure 7

Where the dotted line from the origin 'O' touches the curve will give C_L/C_d max.

Standard reference books such as Abbott and Doenhoff's "Theory of Wing Sections" give the C_L/C_d curves of great number of different wing sections. One simply has to go through them and pick out the one with the most favourable characteristics. If we select a thin section we may run into trouble making the wing strong enough.

On the other hand a thick section which would be ideal structurally may incur a heavy drag penalty and give poor performance.

This work is not intended as a substitute for a Text Book on Aerodynamics but merely to give an idea of the design background required before building an aeroplane

Toucan in particular. Much aerodynamic theory is not just based on pure mathematics but relies on empirical formulae derived from experiments on models and also from previous successful aircraft. The adage " If it looks right it will probably fly right " is possibly partly true. What we think looks right is probably related to something similar we hare seen in Nature. Certainly Nature can give reliable pointers to many aspects of design. For insane the most efficient birds are probably those which can remain airborne simply by using natural air currents.

They can fly for many hours without flapping. These soaring birds such as seagulls, albatrosses and condors have one important thing in common - long slender wings It is not an accident that high performance gliders and also man powered aircraft also require long slender wings.

Scale Effect

One aspect of design already mentioned is the relating models or even birds to full size aircraft. We simply cannot relate their performances pro rata, After all, molecules remain the same whatever flies through them.

Hence, again from nature small insects have very fast wing beats, large birds flap slowly. By relating the size and speed of an aircraft to air density and viscosity we can arrive at a comparative figure known as the Reynolds REF 4
Number. Using this we could arrive at reliable performance estimations for a full size aircraft by using experimental

model data provided that me keep the Reynolds Number constant. Unfortunately it is here that we come across a large snag as far as man powered aircraft are concerned.

Available aerofoil data is always related to ordinary aircraft flying at speeds in excess of 100mph. Now a man on a bicycle rarely travels at more than 20mph. It is surely unreasonable to expect him to pedal an aircraft weighing probably 100 pounds more than the bicycle at a much higher speed than this. Neither can we argue that as birds go faster than 20mph our man might also, once he became airborne. Birds are designed for flying, man is definitely not.

Thus with the shortage of reliable test data on low speed aerofoils, we again have proof of the infancy of man powered flight. It is interesting to note however that with the advent of vertical take off aircraft capable hovering or flying very slowly, some research is now being done in this field. Of course ideas used in man powered aircraft might even be useful for vertical take off ones. REF 3&5

Special Wing Sections

It is fortunate perhaps for all designers of man powered aircraft that the Hatfield Puffin group managed to enlist the services of a Dr. Wortmann in Germany who was a specialist in designing efficient aerofoil sections

for high performance gliders. At his institute of aerodynamics Dr. Wortmann developed a special section to operate at a Reynolds number suitable for slow speed aircraft. Used in Puffin II this new section the FX 63-137 REF 3
was an improvement on earlier types. Its higher lift-drag ratio allowed the pilot to fly with less effort. Unfortunately this new wing section came too late for the designers of Toucan who were already committed to one developed in America by the National Advisory Committee for Aeronautics REF 5
(NACA). This section was not unlike the Wortmann one although it had not been specifically designed for low speed. It is a fact of aerodynamics however that subtle differences in profile can lead to large differences in performance. It is another hard fact that good theoretical performance of an aircraft can easily be lost due to a poor finish or bad workmanship. It is no mean feat to design and build a wing of the size me are considering, 100-140 foot span, so that it is aerodynamically clean throughout.

Aerodynamic Calculations

It is the writer's intention to show by facts and not too complicated figures basically how the size of a man powered aircraft is arrived at.

Having outlined some and by no means all of the basic issues let us take another look at the basic aerodynamic formula.

LIFT is proportional to air density, velocity, wing area, and the LIFT COEFFICIENT.

or $L = 0.5\ \rho V^2 S\ C_L$ REF 4

It is beyond the scope of this study to discuss the units used in such a formula save to mention that obviously they must all be compatible.

In aerodynamics we use pounds for units of force
slugs for units of mass
feet for units of length
seconds for units of time

Returning to our formula, what do we know for a single seat aircraft?

1. The LIFT must be equal to the total weight of the aircraft. As a first approximation say 100 pounds the structure and 150 pounds for the pilot. Therefore L = 250 pounds.

2. The air density at sea level is $2/29^2$ or .00238 slugs per cu, feet REF 4

3. C_L the lift coefficient would be about 1 for a high lift aerofoil at L/D max. REF 5

Thus we are left with V, velocity and S, wing area. As previously mentioned it would be unreasonable to expect a man to pedal at more than 20mph. with a 100 pound weight fixed to him, therefore a take off speed of 15mph, might be realistic - this converts to 22 feet per second.

Transposing our equation for Wing Area S :-

$$S = L / 0.5 \rho V^2 C_L$$

$$= 250 / 0.5 \times 2/29^2 \times 22^2 \times 1$$

$$= 250 \times 29^2/22^2$$

= 430 square feet.

We have previously noted that efficient birds and aircraft need long slender wings. By relating the span of a wing to its mean chord or average width we arrive at a figure known as the ASPECT RATIO, A.R.

A.R. = SPAN/CHORD = SPAN x SPAN/CHORD x SPAN = $SPAN^2$/AREA REF 4

High performance gliders often have ASPECT RATIOS between 15 and 20. REF 5

Thus for A.R. = 15 SPAN = $\sqrt{(AREA \times A.R.)}$

SPAN = $\sqrt{(430 \times 15)}$ = 80 feet for A.R. = 20

SPAN = $\sqrt{(430 \times 20)}$ = 93 feet

Thus we see the magnitude of the problem, and this for only a single seater.

Now add another man and estimate a further 50 pounds for additional structure.

LIFT now becomes 150 + 150 + 150 = 450 pounds

AIR DENSITY is the same at $2/29^2$ slugs / cu feet.

Velocity we will assume is still 22 feet / sec.

The LIFT COEFFICIENT is still 1.0

Thus WING AREA = $L / 0.5\ \rho V^2 C_L$

$= 450 / 0.5 \times 2/29^2 \times 22^2 \times 1$

$= 450 \times 29^2 / 22^2$

= 780 square feet

At A.R. = 20

SPAN = $\sqrt{(A.R. \times S)}$

= 125 feet.

The CHORD will be AREA/SPAN = 6.2 feet

Thus it has been shown that for two men to fly at 15mph they would need to be supported by a wing 125 feet long and six feet wide. This is just a first approximation - a first stab in the dark, There now requires a long process involving refinement and compromise. Obviously the smaller one can make an aircraft the lighter and stronger it can be. It will take less time to make, be easier to handle and store. On the other hand it will fly less efficiently and require more power to fly. Thus the efficient design of a man powered aircraft - any aircraft, becomes the job of a large team of specialists and requires the services of a computer.

The minimum weight aircraft

It is perhaps useful as a means of getting our aircraft into perspective to consider what size it would need to be if it was made of a new super material that weighed nothing. In other words the size of wing to lift the weight of a man given that it can only be powered by him, Using the previously mentioned formulae we would arrive at a wingspan of about 40 feet - still a considerable sized machine. REF 8

The Human Engine

Although men are often capable of remarkable feats of strength and endurance, as a means of producing power efficiently they are pretty feeble. The writer, when riding his bicycle, is constantly reminded of this fact when faced with a headwind or a slight gradient or when being overtaken by a 25cc moped. Most animals can outpace a man. Almost any fish can outswim him, and even insects, when compared on a size to strength ratio, are vastly superior. We won't even consider where he stands relative to the endurance of tiny migrating birds.
Nevertheless if we do set ourselves up with the task of becoming an aeroplane engine it is as well to know just what we are capable of. " Not much," we can say straight away. Tests on Puffin II showed that half the power to fly could be provided by a 10 cc model aero engine. REF 8

With the intention of finding out a little more about ourselves, the writer, together with a few other enthusiasts from the Hertfordshire Pedal Aeronauts, went to University College, London, to perform some experiments under the guidance of Professor Wilkie. This learned gentleman has made an exhaustive study of the capabilities of the human body. Starting first with data obtained from German sources he has related this to his own tests on champion athletes. Various methods of producing power have been tested but the most useful from an aero engine point of view have proved to be cycling and rowing. Improved outputs have been obtained by both pedalling and hand cranking simultaneously but this might lead to serious problems controlling the aircraft.

At University College we were introduced to Professor Wilkie and invited to try a new cycling test rig he had recently constructed. Resembling a keep fit type static bicycle this machine had eddy current braking on the rear wheel. Instruments on the handlebars showed speed of pedalling, torque reaction and power output. These were also coupled to a continuous print out recording machine. One simply pedalled at a comfortable speed and then adjusted the torque control until a respectable amount of power was being produced. Then all that was necessary was to keep this up for five minutes, this being a reasonable time to fly the Kremer course. The result was quite devastating.

The writer's attempt at maintaining 0.375 HP ended after 2.6 minutes and it seemed like hours. On staggering off the bicycle it was difficult to even stand up. In our group were the pilot and crewman of Toucan who had already completed a successful half mile flight. Brian Bowen, the pilot, regularly cycles forty miles each day. He achieved .5 HP for 3.2 minutes and on a later run .4 HP for four minutes. Derek May, the crewman, a well built fellow with lots of stamina recorded 0.45 HP for 3.5 minutes. Later, by lowering his output to 0.35 HP he went on for 5.5 minutes

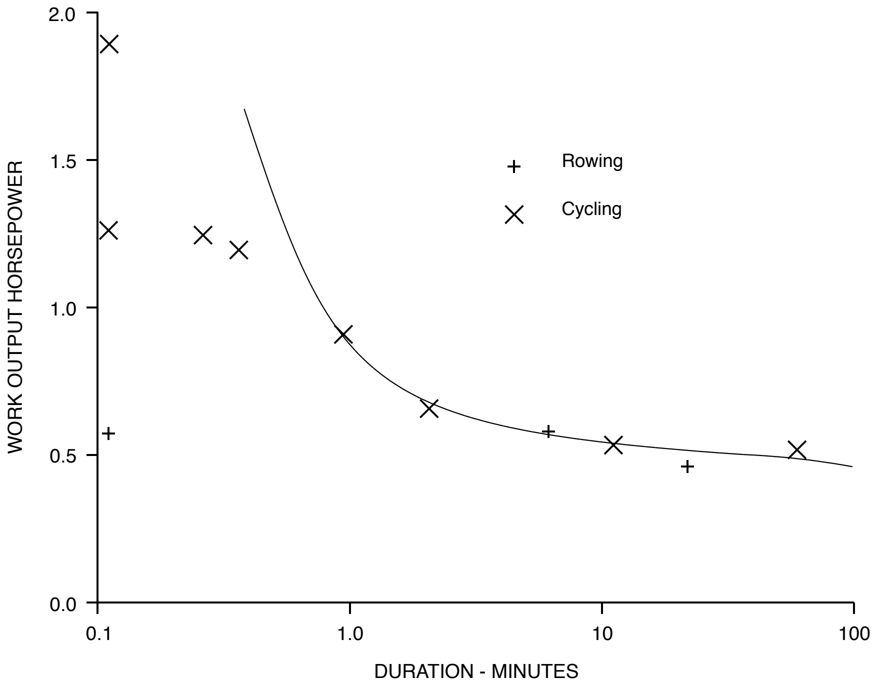


Figure 8. Maximum power output by champion athletes plotted against total duration of the exercise.
From Man as an Aero Engine. D. R. Wilkie. REF 3

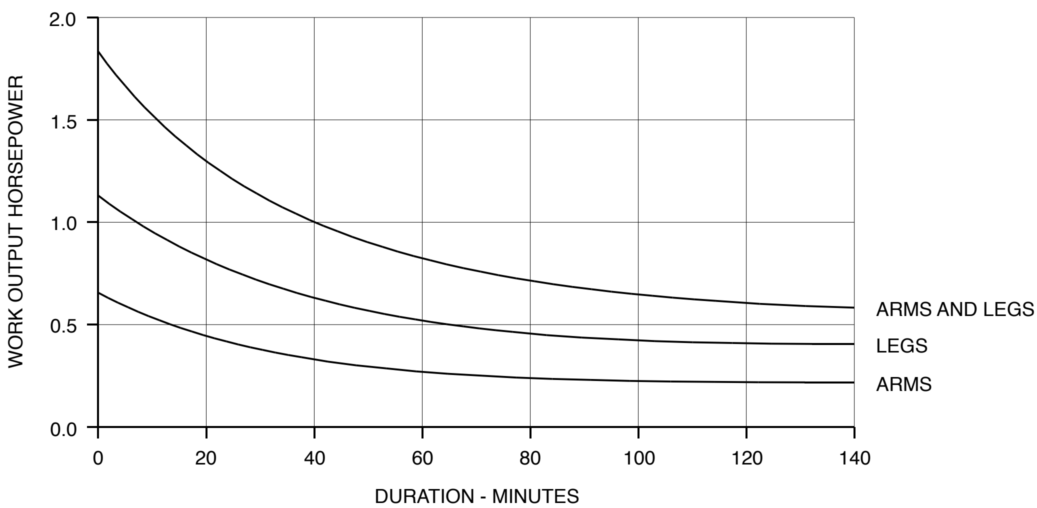


Figure 9. Power output available by pedalling and hand cranking from Ursinus. The advantage of using both arms and legs is shown to last for only a short time. REF 3

It was found that although 1/4 HP could be maintained indefinitely, the higher figures were only achieved for very short periods. Professor Wilkie explained that energy can be stored in the bodies muscles. At high outputs this is quickly used up and then the power is obtained by using oxygen from the lungs. The rate at which this can be converted into energy depends very much on fitness and training. Hand cranking coupled with pedalling, he were told, could give extra benefit only from the energy stored in the arm muscles. When this was used up, as it would be within two minutes, there was little to be gained. Rowing on the other hand, although efficiently utilising all the body muscles, could only be done at a relatively slow pace otherwise power would be wasted in overcoming the body’s inertia, controlling the aircraft would of course present a problem with this method.

The actual power output of a man must obviously be related to his weight. Thus Professor Wilkie’s final power assessments for each person he tested were recorded in the unlikely units of Watt mins / kg. Using this rating, Brian and Derek came out on top of the group tested. For any record attempts the group may make however it is planned for the crewman to be a champion cyclist from a local club.

Toucan's structure

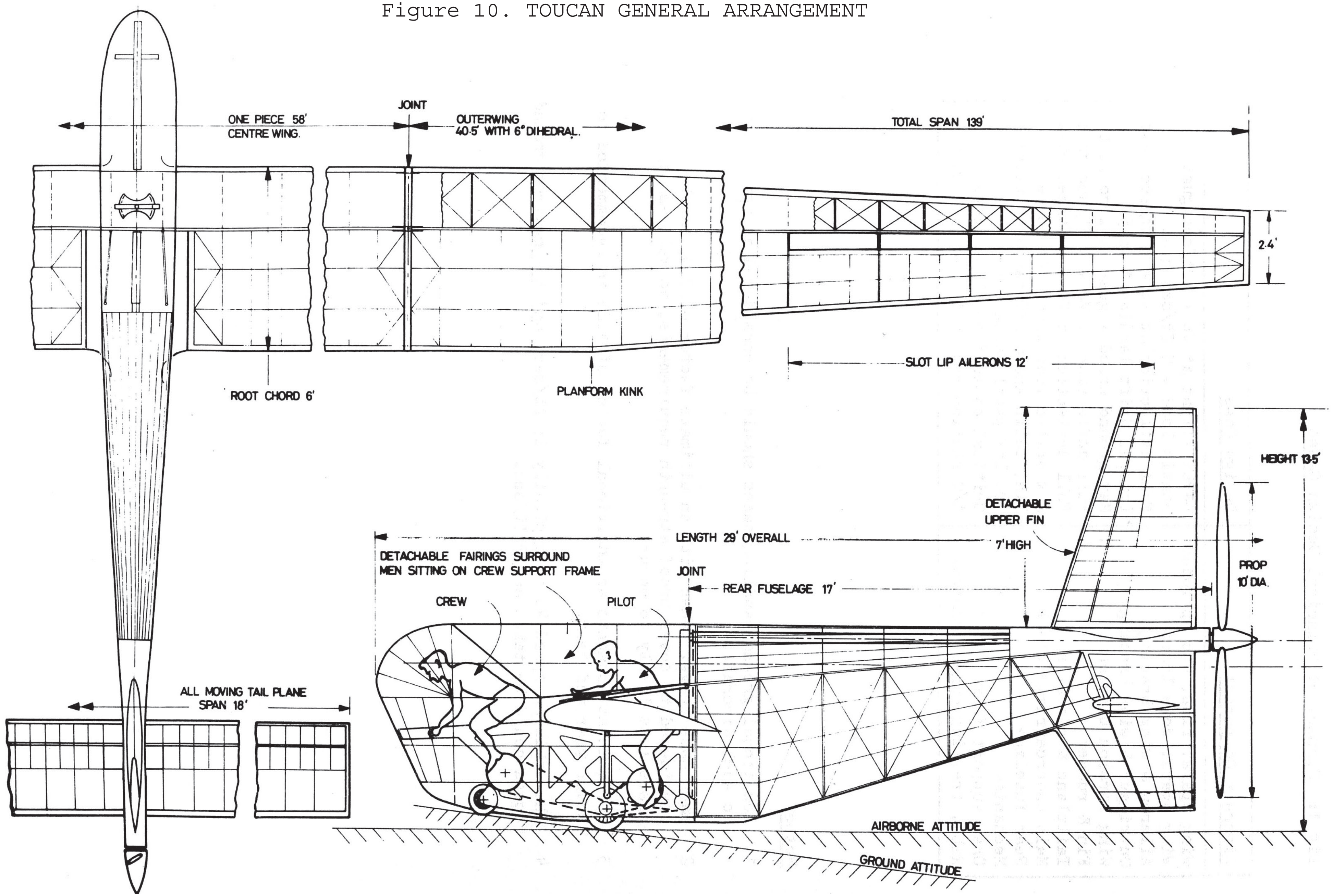
Wing

Apart from the local structure round the pilot, supporting his weight and allowing his power to be transmitted to some form of propulsion unit, (usually the propeller), the most critical part of a man powered aircraft is the main wing. We have already seen that colossal span is necessary for flight although the structure must be both strong and stiff while still being as light as possible.

At a recent symposium on man powered flight at the Royal Aeronautical Society in London, John Wimpenny, the REF 8 designer and very successful pilot of Puffin explained the problem in simple terms. "The airframe weight typical of man powered aircraft leads to actual spans in the region of 80 feet for a single man design. The prime structural design problem is then to support a man weighing say 150 pounds on a beam of total span around 80 feet for the minimum possible weight and to clothe this beam with the lightest possible aerofoil surfaces shaped to achieve a high LIFT over DRAG ratio." The designers of Toucan believe they have done just that except that their beam started at 123 feet.

The basic bending strength of Toucan's wing is provided by twin top and bottom spar-booms that taper in section from the fuselage to the wing tip. The material is aircraft quality spruce and has ultimate strength

Figure 10. TOUCAN GENERAL ARRANGEMENT



ratings of 10,000 lb per sq. in. tension and 5,000 lb per sq. in. compression. Thus the top boom which is in compression under flying loads is twice the cross section of the bottom. The shear web between the booms and running full span is 1 mm 3 ply birch. See Figure 11.

This spar assembly is also the vertical rear wall of a triangular torsion box assembly. The front member of the triangle is a channel section front spar in balsa.

The top and bottom sides of the triangle are formed by cross braced struts of spruce. These are very light and designed only to take tension. Built up balsa ribs are fitted fore and aft of the spar at 18 in. pitch along the whole span. The forward ribs being basically triangular are built up above and below with light polystyrene sheet cappings, Laying on these and wrapping right round the wing forward of the spar are continuous sheets of polystyrene. The trailing edge of the wing is formed by a hollow balsa triangular section. See Figures 12, 13, 14 & 15.

A real boon to all modern man powered constructors has been the introduction of Melinex. This is an extremely lightweight transparent film of terylene half a thousandth of an inch thick. It can be attached easily with Evostick and then made drum tight by the simple process of waving a hot iron close to its surface. The entire covering of Toucan weighs 4 pounds! Not only is this material extremely light, it also has good strength and

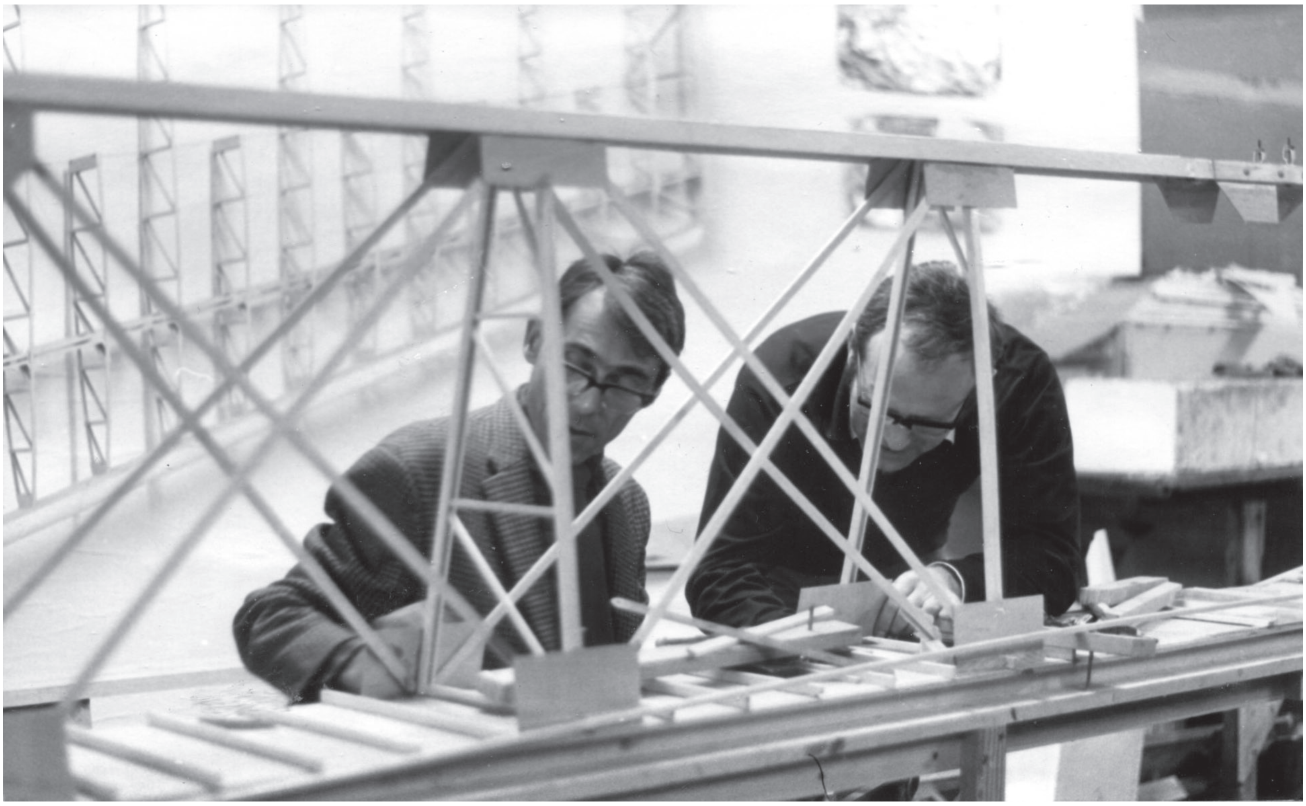


Figure 11. Figure 11. Actual wing torsion box showing the revised spar web.

Figure 12. Outer wing torsion box.
Before construction could begin the 50 ft. table had first to be levelled and firmly secured to the concrete floor.
Due to the wing taper, every rib is different.

Figure 13. Centre-section wing.
The main spar and front spar are continuous through the centre-section box (where the glue bottle is standing). After the first series of flights, another 14 feet was grafted into the centre-section wing making this section alone 57 feet long. With the hut being 60 feet there is just room to get the door open.

Figure 14. Centre section wing (inverted).
The pronounced undercamber of the wing section can be seen in this picture and is typical of modern high lift sections. A problem with the undercamber concerned the attachment of the melinex covering. When this was tightened by ironing (see figure 13) there was a tendency for it to lift off the ribs. To avoid recovering, more Evostik, the adhesive normally used, had to be injected through the film with hypodermic syringes.

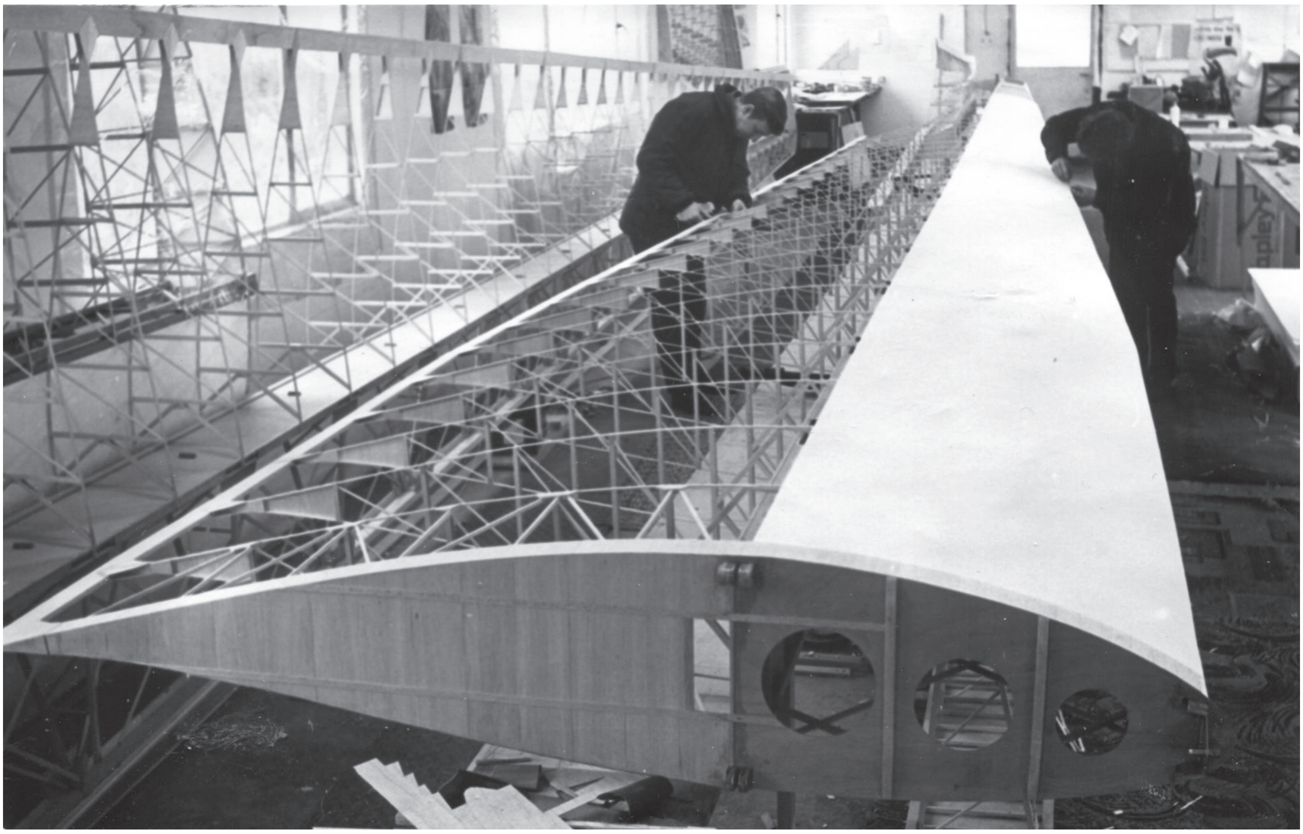


Figure 15. Outer wing nearing completion.

The important part of a wing from the point of view of reducing drag and providing maximum lift is from the leading edge to a third of the way back. It can be seen that this area has been sheathed in polystyrene sheet to provide an extremely smooth profile.

Note the minimal fixing points for attachment to the centre-section - one pin at the front spar and one top and bottom of the main spar.

One problem encountered on the wings concerned the aft ribs, seen clearly in this picture. Flight loads produce an up load at the trailing edge. This is reacted by compressive forces in the rib top booms. As can be seen these are curved and of 1/4″ by 1/8″ section in balsa. The combined effect of suction loads-on the top skin with compressive forces along the curved boom did lead to many instances of buckling failures during early tests. The problem was overcome by doubling the boom thickness at at the first three bays.

Also worthy of note is the girder box construction of the first two ribs. This is to react any end loads encountered in the trailing edge member.

presents a very smooth surface to the airflow thus reducing skin friction to a minimum. See Figure 16.

For the purposes of storage and transport the wing is broken into three sections. The centre section chord is parallel while the outer sections taper down to the tips. The joining of the spruce spars at these joints presented the group with quite a problem. Spruce reacts high loads satisfactorily if joints have large glue areas. Any holes drilled in it seriously reduce the strength, While light alloy plates were suitable at the joint so that reamed holes could accommodate shear pins, these plates had to somehow be bonded to the spruce. Araldite between metal and wood was found to be unsatisfactory. Although Aerolite 306 was suitable for all scarf joints in the spar it was also unsuitable for joining metal. Thus with this problem in mind the Group contacted CIBA, the manufacturers of Aerolite. It was arranged that the alloy plates be sent to this firm where a thin wood veneer could be Redux bonded at high temperature to the metal. Then the wood surfaces could be glued as normal to the spar.

On receiving the duly processed joint plates the Toucan members were dismayed to find that they had curled round to an alarming degree. Investigation finally revealed that at the high bonding temperatures used, the moisture content of the veneer had been much reduced. On returning to a normal atmosphere during postage the wood had again absorbed moisture. This had expanded the fibres and the

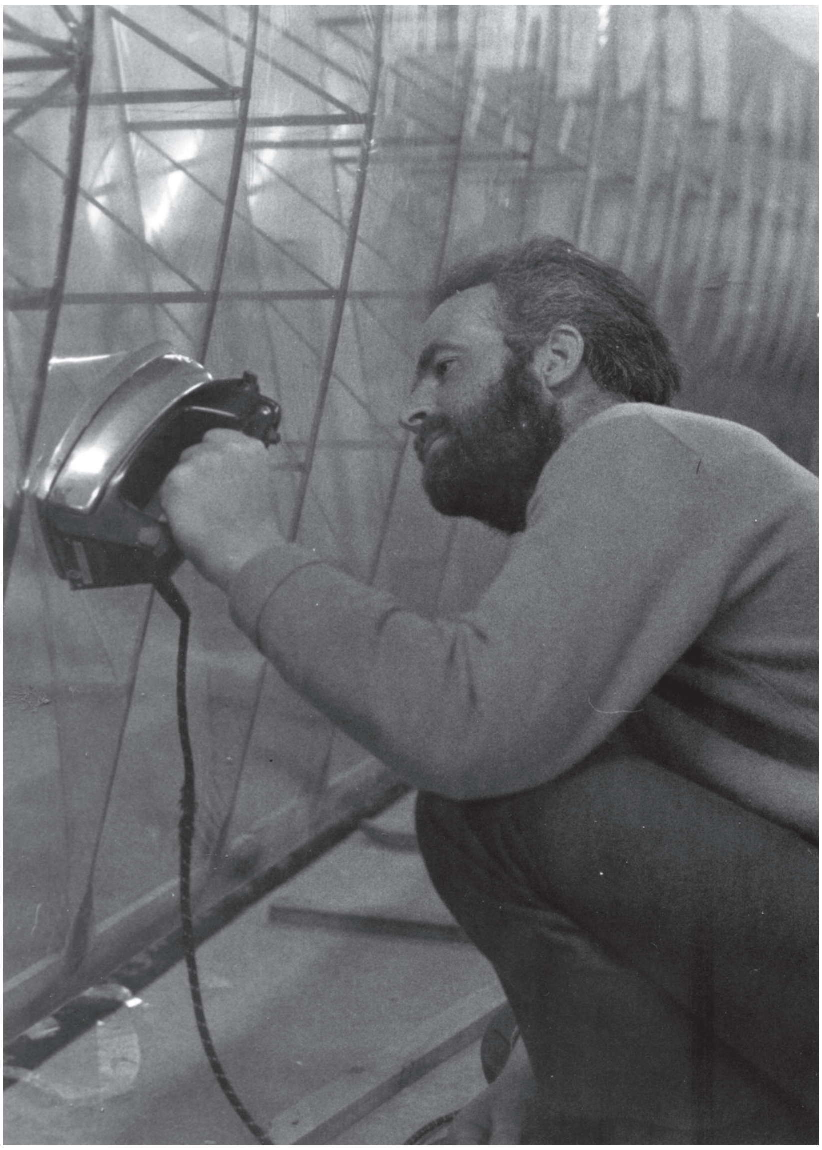


Figure 16. Ironing the melinex.
Most wrinkles in the skin miraculously disappeared with this method although great care had to be taken in getting the right heat too much and large holes appeared. Areas where the melinex covered polystyrene sheet called for careful control. Setting the iron heat control to “Silk” produced satisfactory results.

resultant strain had curled the alloy. The satisfactory answer proved to be the use of a thinner wood veneer.

Fuselage

Like all other parts of Toucan, the fuselage is designed to be stored in the 60’ x 20’ club hut and be extracted through the one 6’6” by 2’6” door. The forward section comprises a fabricated structure in 30 SWG light alloy. It is basically a tandem bicycle frame but is of unique (and extremely complex) design. See Figures 17&19 Termed the “ crew support structure “ it also mounts both the landing wheels as well as the drive mechanism. Being a complete mobile unit although unsteerable, the crew support structure was initially attached to a dummy wing centre-section with outrigger stabilisers for first tests down the runway. When fitted to the aeroplane, the structure and crew are covered by detachable transparent fairings of balsa and melinex. See Figure 23.

The rear fuselage section carries the fin, tailplane and propeller. In section it is an inverted triangle with a semi-circular fairing on top. See Figure 18. The two upper corners of the triangle comprise spruce longerons while the lower corner is itself a hollow triangular longeron in balsa and spruce. The whole structure is cross braced with lightweight three strand control-line wires. Tensioning of these is by miniature turnbuckles of

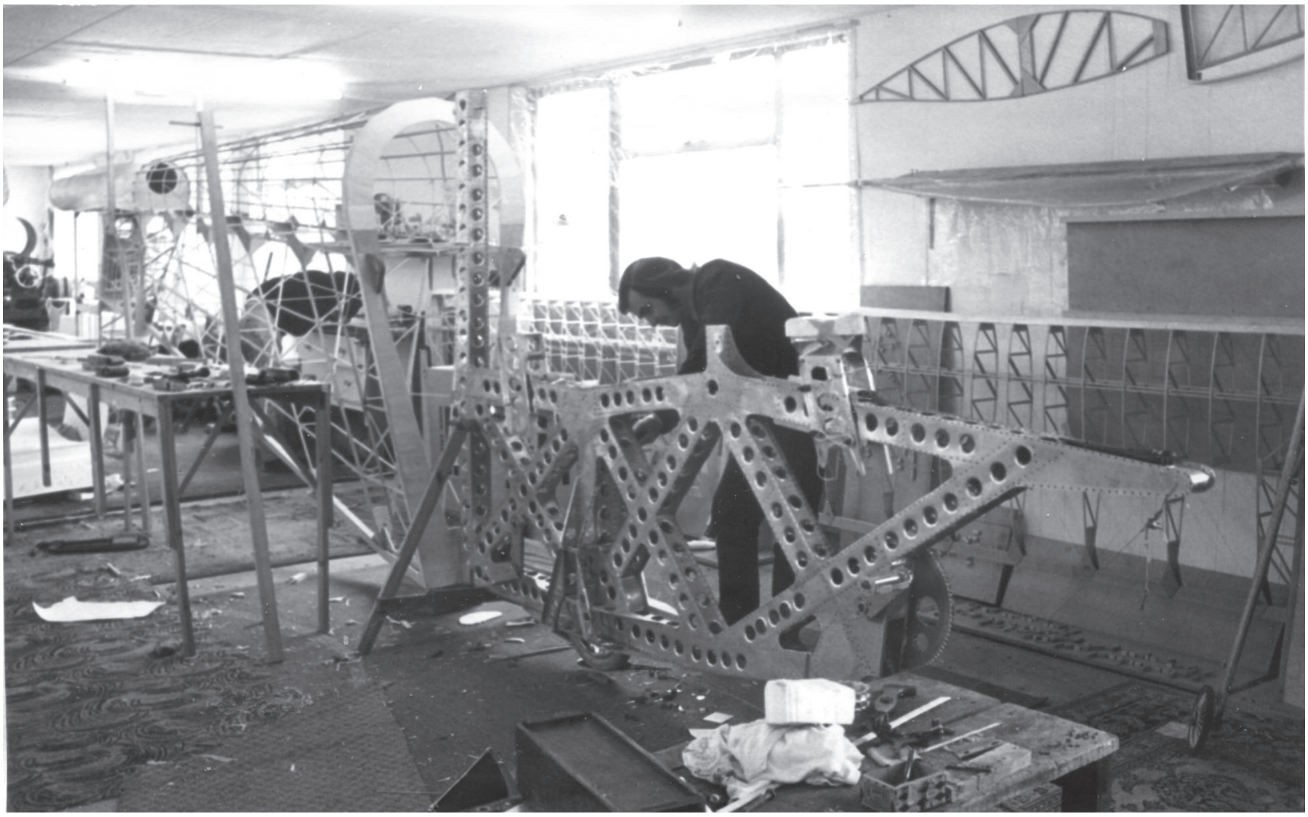


Figure 17. Crew support structure mounted to rear fuselage.
Note wing test rib and tailplane structure in background.

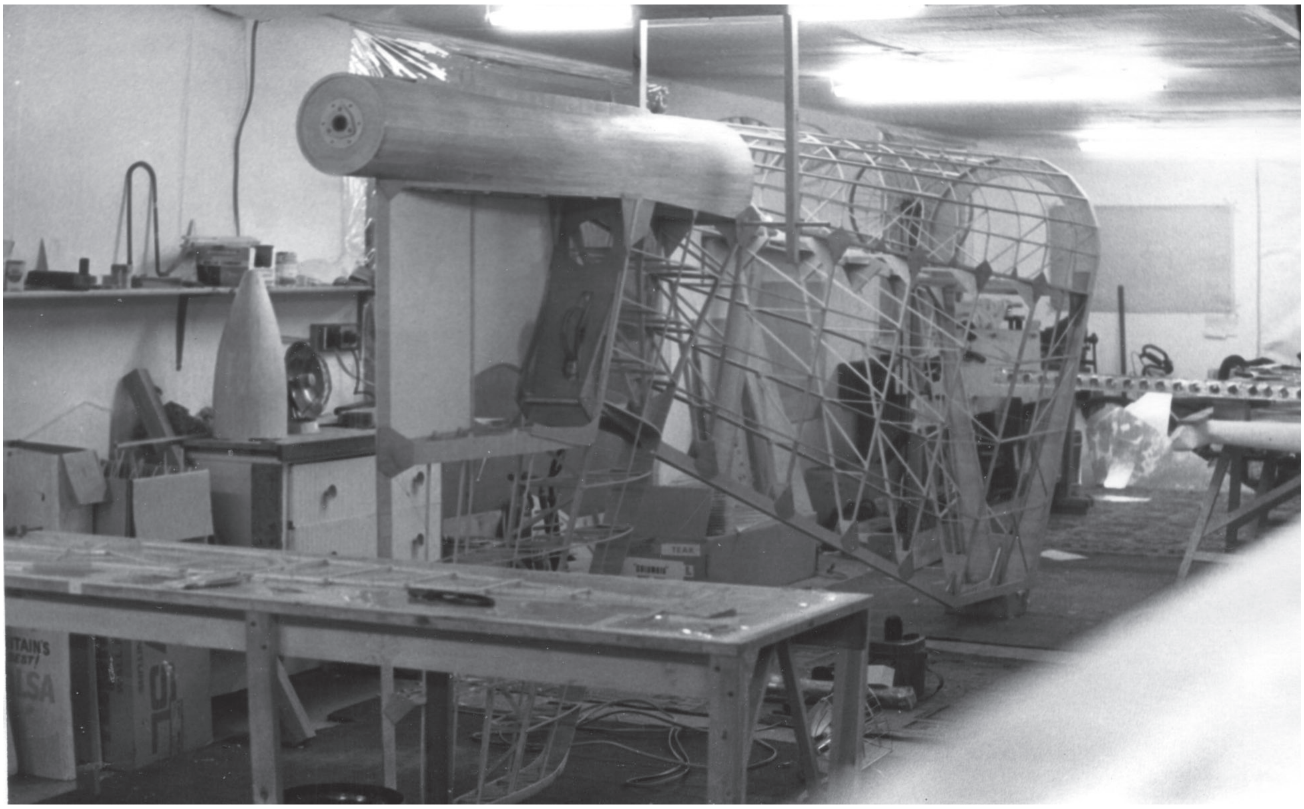


Figure 18. Rear fuselage with integral underfin.
The propeller shaft rear bearing can be seen top left behind is the propeller hub fairing.

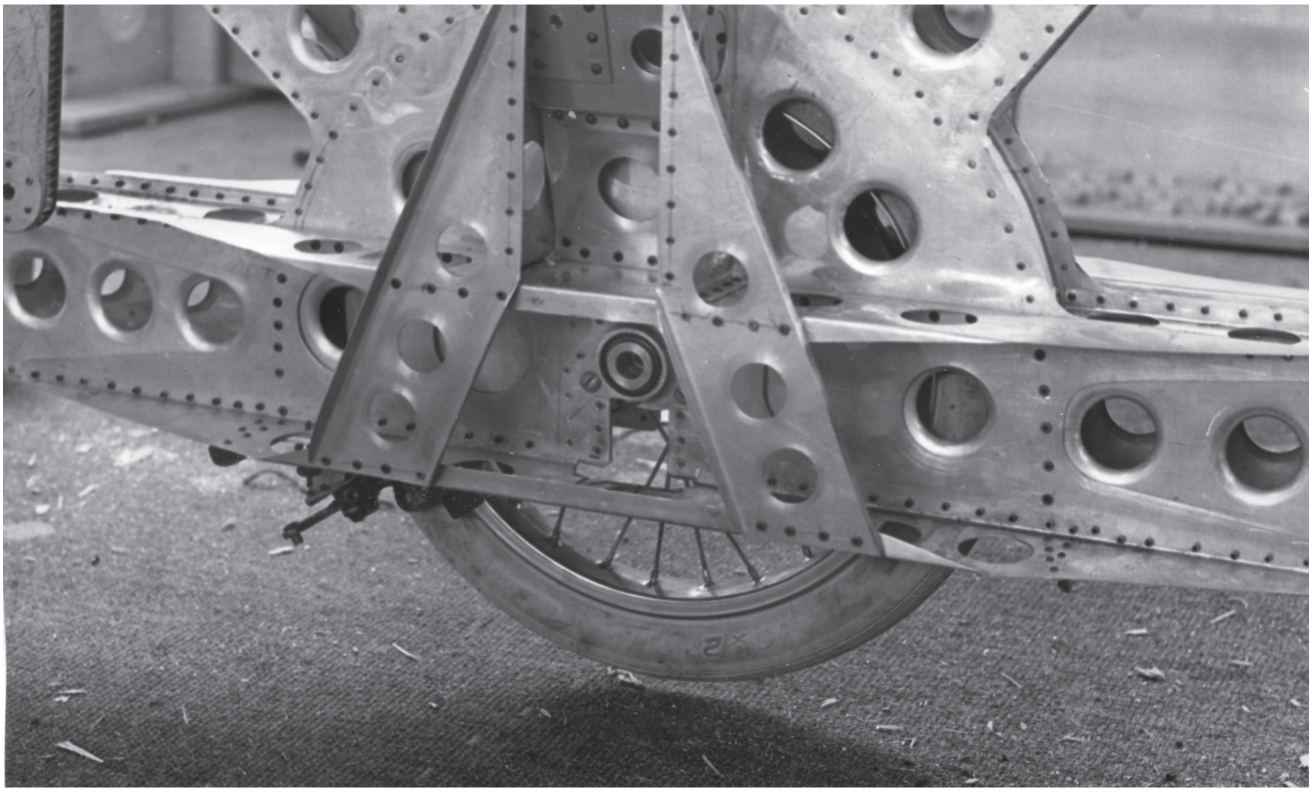


Figure 19. Main wheel support structure.
All in 30 SWG aluminium alloy, the main wheel support is the focal point of the crew support structure since all landing loads are absorbed at this point.

A triple sprocket on the wheel spindle transmits chain loads from both crewmen a third chain-running aft and then upwards to drive the propeller shaft.

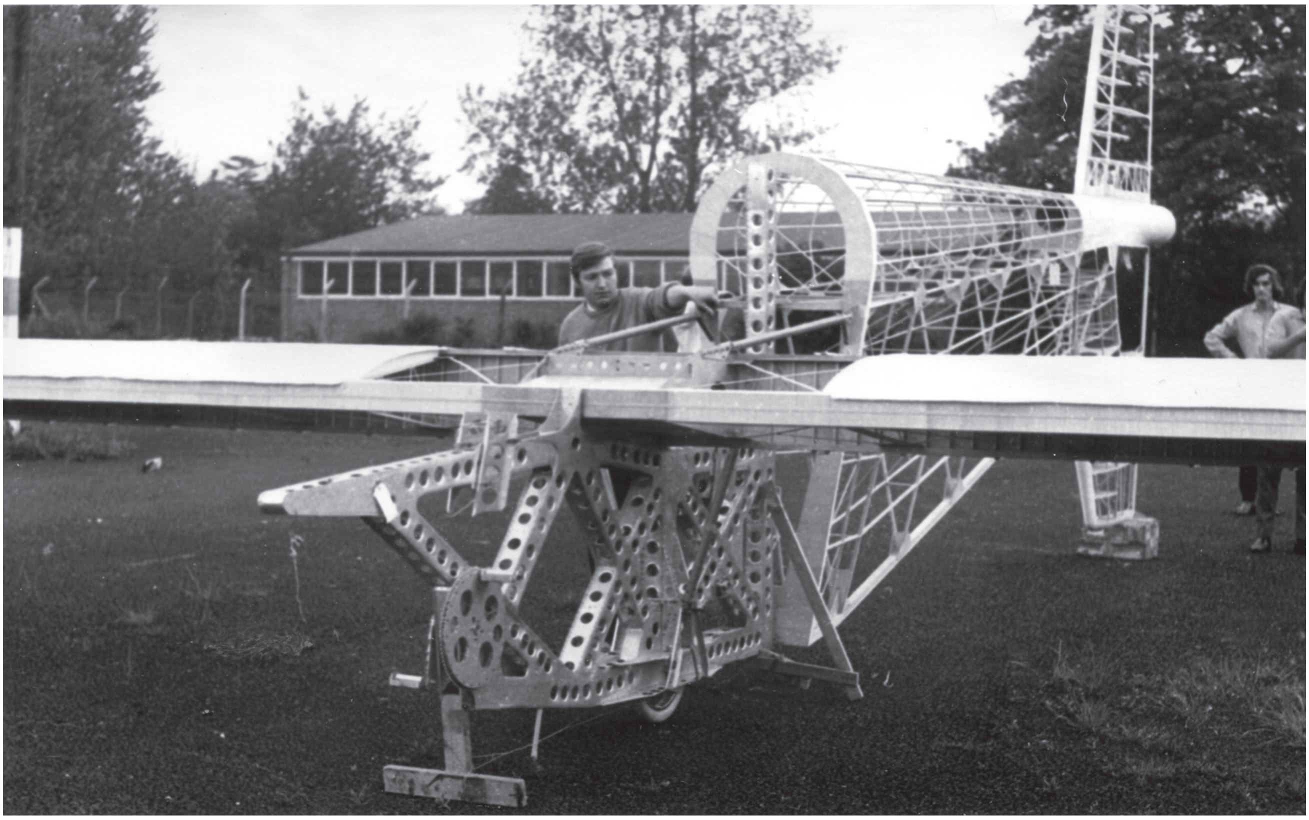


Figure 20. Wing to fuselage mounting.
The wing is mounted to the crew support via a single spigot on the front spar and two ‘V’ struts from the main spar to the main-wheel structure. A single vertical spigot under the main spar transmits drag loads to the crew support.

The rear fuselage is mounted by pins at top and bottom of vertical alloy box section and parallel struts from main-spar to spruce fuselage longerons.

The chainwheel and crank are constructed from light alloy honeycomb.

the group’s own design. Indeed, apart from the wheels and one or two aluminium bolts everything on this aeroplane has been entirely designed and constructed by the group.

Fin

The under fin is integral with the rear fuselage. The over fin is symmetrical in section and is of balsa construction. The melinex covering film supplies sufficient torsional stiffness.

Tailplane

The tailplane is of similar construction to the fin and again torsional stiffness is supplied only by the melinex. The tailplane is of the “ all moving “ type i.e. there is no separate elevator. It is mounted on two pilots attached to the rear fuselage. Up and down movement is provided by a slotted cam.

The aerodynamic centre of pressure of a symmetrical aerofoil section is at 25% of the chord from the leading edge. As this roughly corresponds to the maximum thickness of the section it is convenient to position the main spar at this point in order to reduce torsional flexibility to a minimum. The spars of both tailplane and fin have therefore been positioned at 25% chord for this reason.

The Control System

In order to achieve simplicity, the control system was made as basic as possible. Normal aircraft have rudders ailerons, elevators and flaps operated by the pilot’s hands and feet. This is obviously not possible when the pilot is pedalling. Model aircraft can be designed to be inherently stable and it was hoped that Toucan would fly in a similar manner. Unnecessary controls not only mean a more complicated structure, they also produce unwanted drag during operation. It was this thinking that prompted the Toucan designers to dispense with the rudder control While conventional ailerons were considered initially, it was decided to try a little known but potentially superior lateral control known as slot-lip ailerons. See Figure 21.

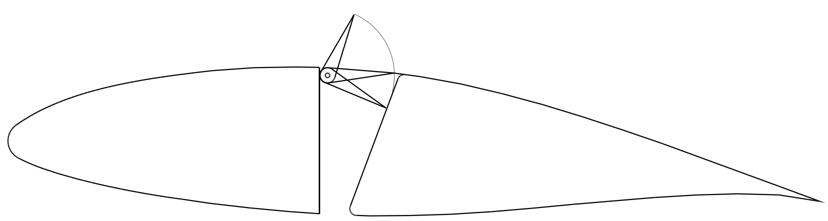


Figure 21. Section of Slot Lip Aileron

The advantages of this system Were:-

they were simpler to construct,
they were lighter,
the resultant structure would be far stronger,
both lateral and directional control would be possible with this system.

Basically the outer wings were provided with a 10 foot long slot right through at about 50% chord. Partially sealing this slot was a small flap, hinged at its leading edge and flush with the top surface. Moving the flap down closed the slot and tended to slightly increase lift while moving it up both reduced lift and provided an airbrake effect. The flaps were connected differential so that while one was up the other was down. They were operated by light stranded wire from the pilot’s handlebars.

Apart from the obvious power control the only other control system is for the tailplane. Being of the all moving type i.e. there is no separate elevator, this is both simple and effective. Originally, only two positions were envisaged. The first was to hold the aircraft nose down, allowing maximum acceleration on the take-off run, The second was the flying position. Up and down movement of the aircraft was then to be controlled by varying the rate of pedalling. In practice a more comprehensive control was required and the tailplane was connected to a twistgrip control on the pilot’s right handlebar.
See Figure 22.

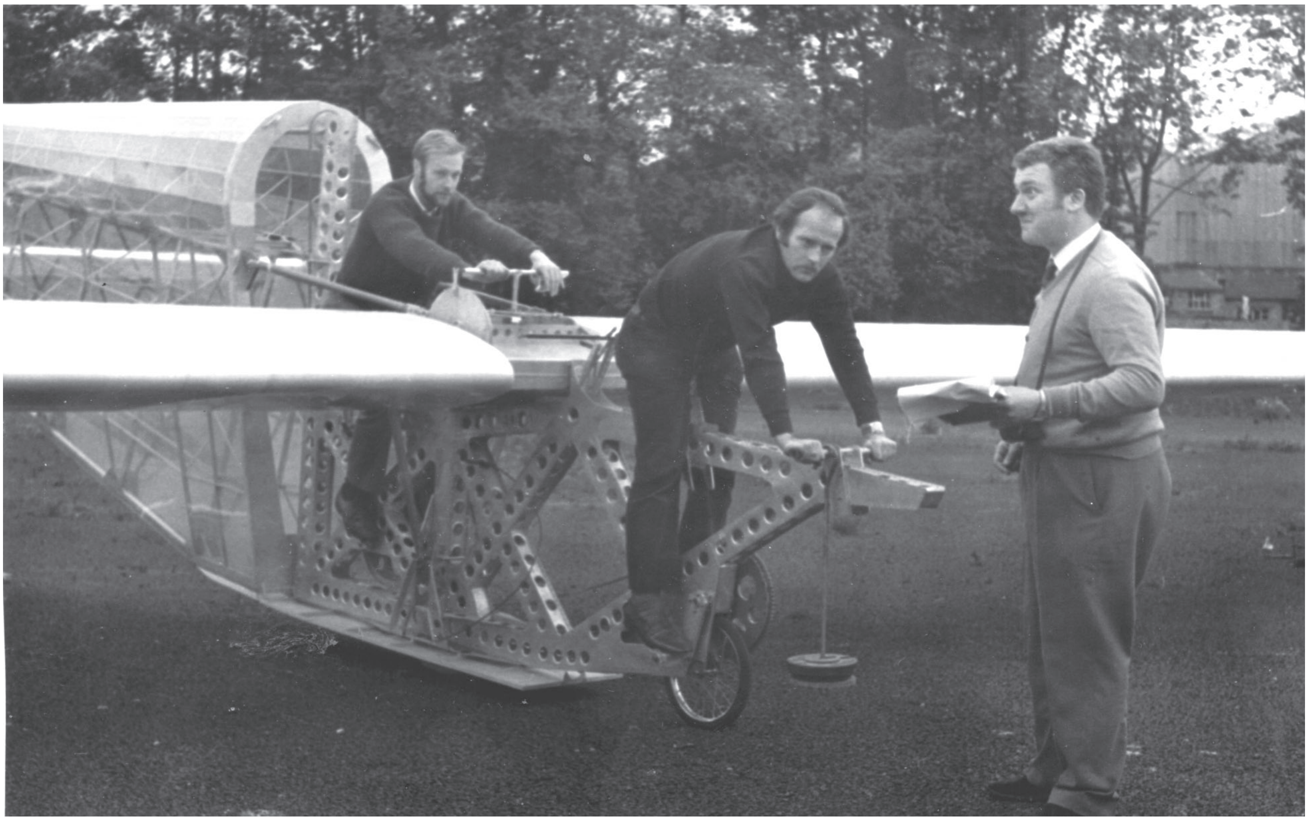


Figure 22. Pilot and crew positions.
The pilot at rear holds handlebars which control yaw and roll via slot lip ailerons at wing tips. Up and down longitudinal control is trimmed via a quadrant (near his right hand) connected to the tailplane. The control was later replaced by a twistgrip mounted on the right handlebar.
The weight on the nose is required to balance the aeroplane when the crewman is not in position. The centre of gravity of the whole aircraft is roughly on the main-spar i.e. above and just forward of the main-wheel.

The Transmission System

Unfortunately no man powered aircraft has yet been devised where the axis of pedalling is parallel to the axis of the propeller. They always end up at right angles, Thus there is a problem in getting a light, simple and reliable transmission system for these aircraft. The most sophisticated system yet used was a bevel gear drive incorporating the pedal crank spindle concentric with the road wheel with a shaft drive to the rear mounted propeller. This was fitted on Puffin and made by a specialist company. Such REF 8 manufacturing facilities were not available to the Toucan designers who began by testing their own drive system This consisted of small drums swaged onto an endless cable REF 6 which ran round toothed pulleys. Although this was the right approach theoretically, it did not work well in practice - due to fraying of the cable strands at the swage positions. A bicycle was specially converted for the test.

It was after the unsuccessful tests with the cable drive that the group discovered the existence of light alloy bicycle chain. This is made by Reynold for use in food processing machines where oil or rust could not be tolerated. Having a breaking strain of 600 pounds it is ideally suited to the type of drive system used on Toucan where the chain is required to twist through 90° between the chainwheel and propeller shaft sprocket. When used with a suitable tensioning system this chain has been entirely successful.

While power for flight must be transmitted to the propeller it is also necessary to drive the road wheel in order to accelerate the aircraft up to take-off speed. Thus chains from both crew drive to a triple sprocket on the road wheel spindle where a third chain runs aft and then round a special pulley where it goes upwards to the high propeller shaft sprocket. On the vertical run the chain twists through 90°. See Figure 10. The propeller shaft is 1 1/8″ dia 18 SWG light alloy and supported only by bearings at each end of its 10 foot length. (Risky, but it works.)

The Propeller

Having a claimed efficiency in excess of 85%, the propeller is 10 ft. diameter and runs at an optimum 200rpm. A free wheel system allows the propeller to windmill if the crew stop pedalling. It is entirely of balsa construction having ribs, spar and a full covering of 1/16″ sheet. A clamping device in the hub allows for adjustment of pitch. Although weighing less than 4 pounds the group however have not been entirely happy with its performance and a new propeller awiats testing. This is of simpler construction being series of ply ribs set around a light alloy tube and filled between with polystyrene. At 3 pounds it is hoped that this propeller will also be more efficient.

Jointing Methods

For maximum strength with minimum weight all joints in the wooden structure rely entirely on glue. One problem with this method of construction on such a complex structure is the weight of the glue itself, particularly if absorption into the wood is not controlled. Thus glues Were required to be compatible with the materials involved. REF 11

The main adhesives used were:-

Balsa to balsa	Balsa cement.
Balsa to spruce or ply	Araldite.
Spruce to spruce or ply	Araldite.
Spruce to light alloy	Redux for high strength.
	Araldite for low strength
Polystyrene to anything	P.V.A.
Melinex to balsa	Evostick.

Care had to be taken to keep balsa cement and particularly Evostick away from polystyrene. Fumes from Evostick were found to be affecting it even after six months in structures where no ventilation was provided.

During tests on wood joints glued with Aerolite the Puffin group encountered some specimens well below design strength Investigations showed this to be due to the inclusion of air bubbles formed when the glue powder was mixed with water

The spruce main spar booms were joined with scarf joints sloping at about 1 in 14.

Flying Toucan

It is one thing to construct a man powered aircraft, and quite another to fly it. The relatively poor performance of these machines precludes their use on anything but the calmest of days. Although some flights have been made in a 10mph wind it can be a risky operation. The effects of wind shear (the slowing down of the wind near the ground) can present a considerable problem if the aircrafts flying speed is little more than the wind speed Thus flying days have to be chosen when the wind is preferably below 3mph and likely to remain so. The period around sunset can often produce calm conditions but of course failing light can seriously restrict the flying time.

Due to the large numbers of people required to be present in order to do any flying, an elaborate call-out system had to be devised so that once the decision to fly had been made, the rest of the group were contacted as soon as possible. The chances of everyone being free to attend a call-out was remote and of course if the pilot was not available then all ideas had to be abandoned.

For early tests, the aircraft was operated directly from the group hut. All parts had to be carefully extracted through the one narrow door and then carried 100 yards over rough ground to the nearest corner of the runway. The whole

Figure 23. The transparent crew fairing and side panels are being positioned in this picture. The polystyrene trailing edge root fairings are standing on the left.

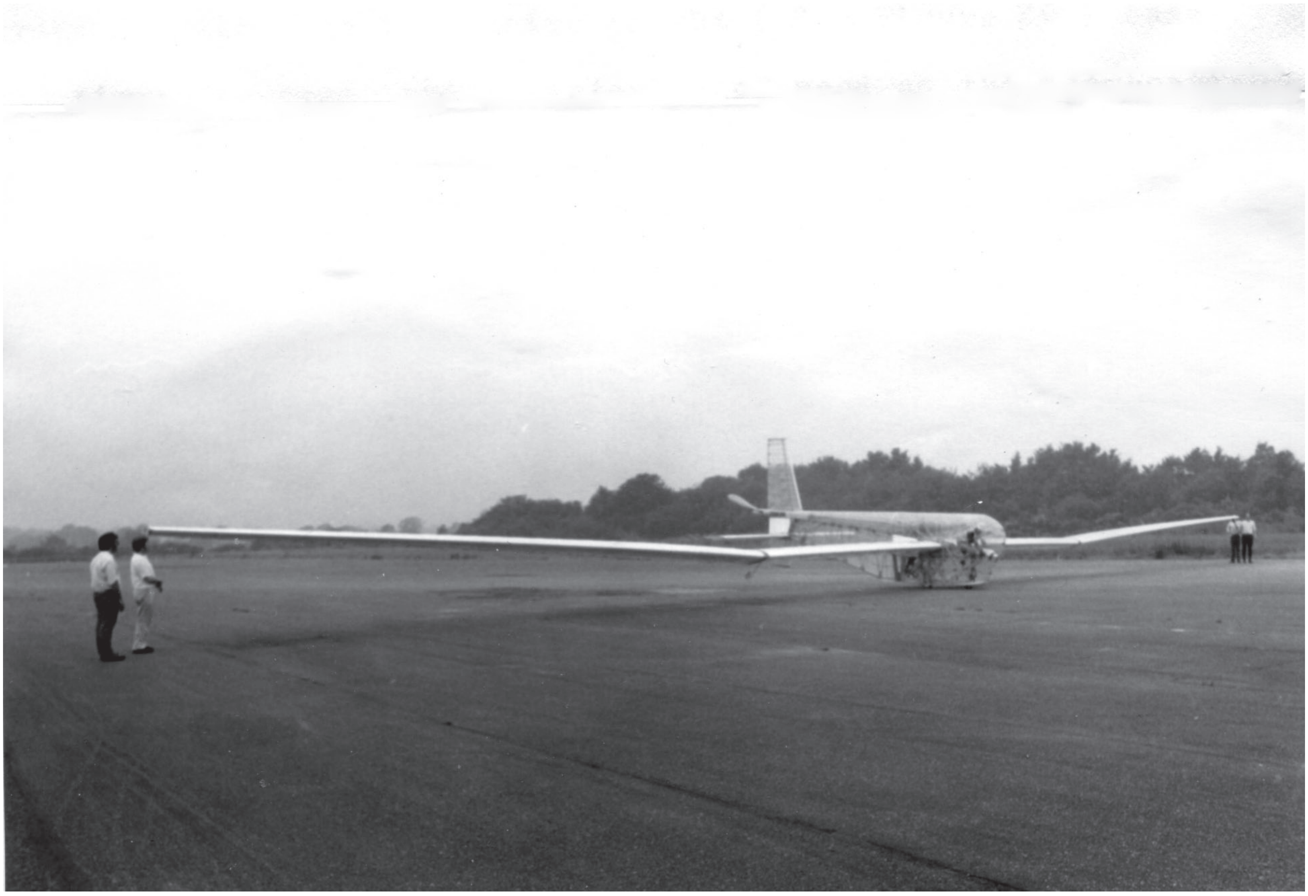


Figure 24. Toucan is lined up at the end of the runway for the start of a test flight.

assembLy sequence often took 1 1/2 hours and never less than an hour. With the dismantling operation taking at least half an hour there was very little flying time left during a normal evening session. Many of the early sessions ended abruptly after perhaps only one taxi run due to the failure of some small component. As mechanical reliability improved and confidence was gained sufficiently to enable flights to be made, so were sessions liable to end equally as abruptly due to the failure of larger components such as the main spar. The first of these major failures occurred in July 1973 shortly after the longest flight Toucan has made to date - 700 yards. Following the jubilation of the group by this most impressive flight, (see Figure 26), came the sickening crack and splintering of wood as the starboard wing wrenched itself off the aircraft, leaving a trail of litter down the runway. Fortunately the plane was not quite airborne at the time.

During the eighteen month rebuilding phase following this accident, the opportunity was taken to graft a further sixteen feet of wing into the centre-section, bringing the total span up to a staggering 139 feet.

In November 1974 Toucan was again ready for flight trials. Permission had been granted to store the fully assembled aircraft in the old Handley Page flight hangar This would have obvious advantages in reducing flight preparation time. In the face of deteriorating weather

Figure 25. Banking while close to the ground can produce a heart stopping moment. Small outrigger wheels at the wing transport joints are provided to keep the outer wings off the ground in such an event.

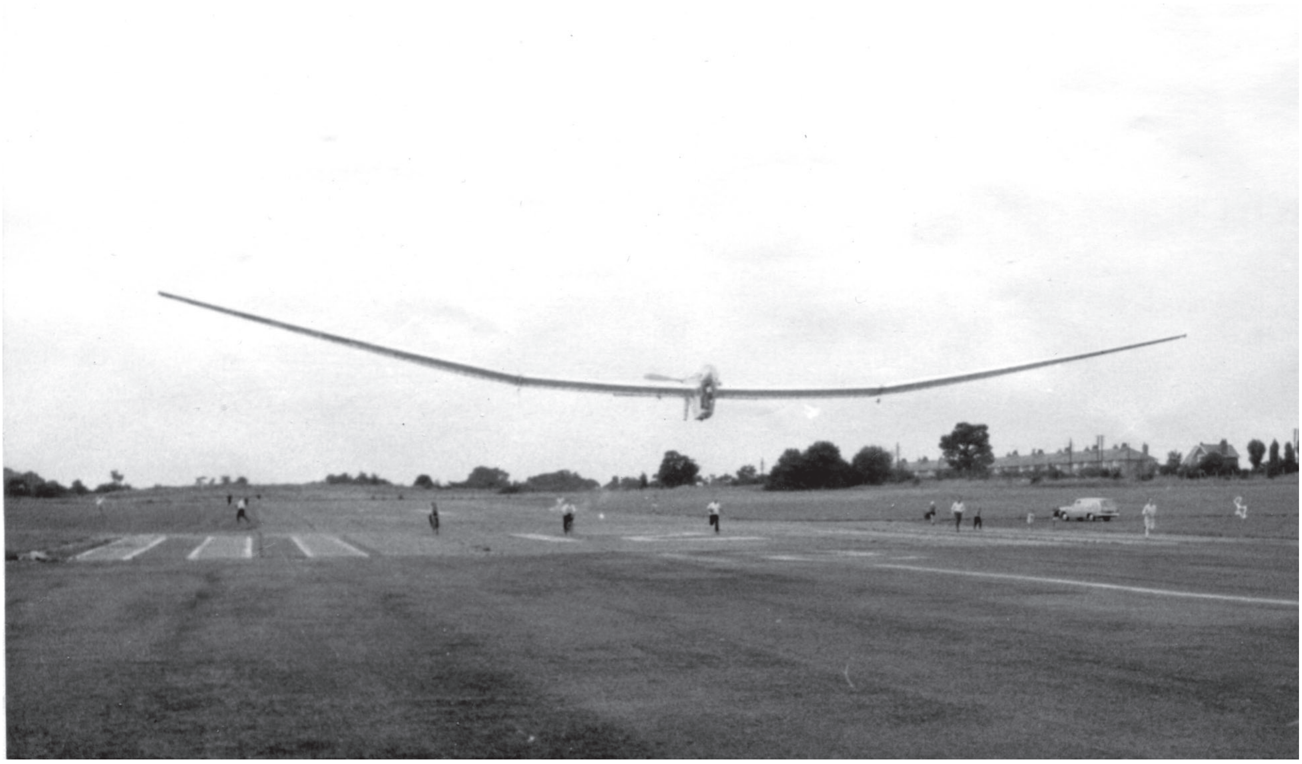


Figure 26. Toucan flying high during the half mile flight. On a bicycle one could comfortably keep up with the aircraft. Running, however, required considerable effort.

conditions, Toucan was hurriedly assembled with the intention of taxiing the complete machine the mile or so from the hut to the flight hangar. It never arrived. During an exuberant piece of taxiing when the pilot decided to try a short hop, too much airspeed was gained while the nose of the aircraft was held down on the runway. The result was that the wings developed negative lift and literally flew into the ground The starboard lower spar did not withstand the extreme down loading and buckled causing extreme damage to much of the outer end of the starboard centre wing.

Almost a year later at the end of October 1975 Toucan was once again ready. On Sunday 26 October three flights were made, the longest of these being 285 yards. Spirits Were again raised and talk centred around attempting the world record for man powered flight, (held by the RAF REF 11
operated Jupiter craft at 1200 yards.)

On Sunday 23 November 1975, a 7am callout was made and official observers from the Royal Aeronautical Society were asked to be present. After taxiing to the far end of the runway, Toucan was turned into wind and a short flight was performed. By then a considerable breeze had built up at a slight angle to the runway. The aircraft was backed up to the far edge of the tarmac so that a diagonal tale off run could be made. Toucan accelerated rapidly under the combined efforts of the pilot Brian Bowen and crewman Derek May. The nose was held down to increase the take off speed, then disaster, the starboard wing again flew into the ground and was ripped right off.

In theory this accident should not have happened. With the nose of the aircraft fully down, the wings were supposed to generate neutral lift. In practice the extra 16 feet of wing span may have been responsible, due to the extra bending and torsional flexibility unavoidably built in.

It is a fact of aerodynamics that if a wing is developing negative lift near to the ground it will in fact be sucked closer due to the venturi effect. The opposite is also true, that a lifting wing close to the ground in fact rides on its own down-wash and generates more lift than one well away from the ground.

Thus this study must end on a rather dismal note where the builders of Toucan are again faced with a year of dedicated work rebuilding their aircraft. Morale at this moment is extremely low. Indeed, the future of the Radlett aerodrome is now in jeopardy due to building development schemes being discussed at the present time. One thing is certain, that the striving for success in the realm of man powered flight will continue. News is coming in of a promising project progressing well in Scotland and others in France and Belgium.

Man has always taken up the challenges of the unknown, and flying under his own power with an aircraft of his own mating is still very much one of those challenges.

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POST SCRIPT

Since the completion of this study two important events have taken place.

Firstly, at a meeting of all the Hertfordshire Pedal Aeronauts a film was shown which had been made by the BBC shoving the last accident to Toucan. A careful study of this film showed conclusively that a structural failure had taken place before the starboard wing came into contact with the ground, It is thought that one of the diagonal bracing struts in the wing leading-edge torsion box failed, allowing the wing to twist downwards slightly and thus develop negative lift. The effect of this could be clearly seen on the film.

The second development was the announcement of the shelving of plans to develop Radlett aerodrome as a residential and sports complex.

At the meeting of Toucan members it was agreed to continue with the project with the hope of commencing flying by May 1976.

Publishers note.
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A shack 49 publicastion
John McIntyre
July 15th 2026