THE DEVELOPMENT OF THE HUMMINGBIRD COMPOSITE OBSERVATION AIRCRAFT

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Abstract

Hummingbird is a two seater observation aircraft designed to conform to a STOL (Short Take Off and Landing) aircraft requirement and to fit into a standard container in a disassembled state. The aircraft was designed to be constructed of composite materials and to use a Wankel rotary engine for its high power to weight ratio. The downward visibility from the aircraft was required to be excellent.

The aircraft is fitted with a tricycle undercarriage above which is a large two seat cockpit with a large amount of canopy area above and behind which is a wing equipped with Fowler flaps. The engine is mounted above the wing in a pusher configuration with the propeller passing above the single low tailboom. The stabiliser is mounted in a T-tail configuration.

The aircraft was started at the end of 1990 and flew for the first time in May 1993.

After the aircraft was flown once it was disassembled and put on display at the Paris Airshow. As a result of the feedback from the airshow a more powerful engine was fitted and some other small and simplifying modifications were carried out to the airframe some based on the initial flight.

The aircraft is currently undergoing further flight tests.

1. Introduction

The design of Hummingbird started in November 1990 in the form of a requirement for a STOL aircraft with exceptional pilot visibility that could be disassembled to fit into a standard 6m ISO container.

The requirement was very detailed and very tight as detailed in table 1. The aircraft was to be certified to JAR-VLA which set the maximum mass to 750 kg and ruled out the use of a "conventional" certified aircraft engine as according to the initial calculations their weights were prohibitively large.

The original project that set the requirement was later stopped and the decision was made to continue with the development of the aircraft with internal funding pending the outcome of a market survey.

The results of the survey demonstrated that there was a need for an observation aircraft both locally and overseas with a built-in versatility that could cover a wide range of applications such as surveillance, patrol and inspection, search and rescue and local transport.

Aerotek decided it would continue developing the aircraft to meet these requirements.

Although the market survey demonstrated that there was a market for the aircraft, it was apparent from an early stage that what the end user needed or thought he needed varied dramatically from user to user.

It was thus decided to build the aircraft to a specification based loosely on the original requirements with some of the more stringent requirements reduced to more respectable ones. At this point in time the construction was already underway and the overall aircraft geometry did not change significantly at any stage thereafter.

2. Design Philosophy

Looking once again at Table 1. we see that the stall speed requirement is 30 knots as the upper limit with 25 knots being preferable, this is a very tight requirement for any sort of aircraft as is the 80 metre maximum take-off roll.

The design philosophy of the project was to keep the aircraft as light and simple as possible but keeping in mind the need to comply with JAR-VLA requirements. The aircraft also had to be safe to fly at low speeds which is where the majority of its working life would be spent. In particular the stalling characteristics had to be very predictable and safe. There had to be a strong anti-spin tendency.

The cockpit had to be fully enclosed and comfortable to ensure optimum pilot alertness over the length of the mission.

One of the more important requirements initially to comply with JAR-VLA was that the aircraft Maximum All Up Mass had to be kept under 750 kg. This, as mentioned earlier, ruled out the use of the conventional certified aircraft engines due to their weight.

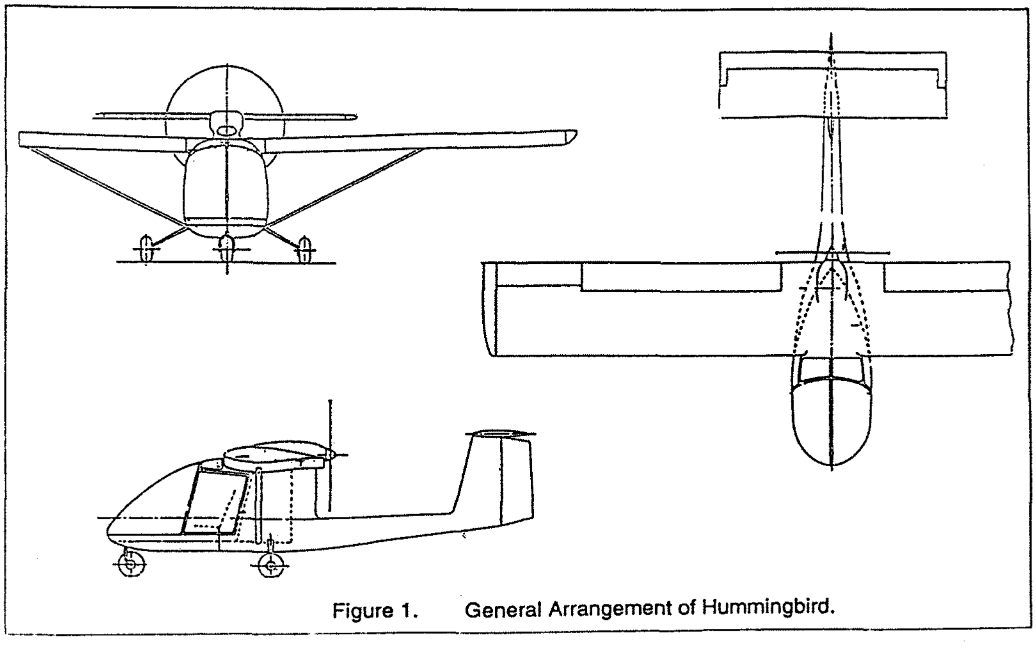


Figure 1. General Arrangement of Hummingbird.

Another problem that had to be overcome was how to design an all composite aircraft with a large wing area while keeping the weight low.

It was also decided that due to the tight budget and time scales, no wind tunnel tests would be done. All the design methods would be conservative and as the aircraft appeared to be reasonably conventional it was felt that it would not be essential.

The General Arrangement of the aircraft is shown in Figure 1.

3. Aerodynamics

3.1 Geometric Limitations

The overall limitations as mentioned before were that the aircraft had to fit (once disassembled) into a standard ISO container of 6 metres in length as shown in Figure 2. The span was also limited to 10.9 m by the original specification the idea being that the aircraft could be landed on a road if required.

This limited the length of the aircraft to a little less than 6 metres which was achieved by placing the rudder hinge line at the limit of the longitudinal dimension and allowing the removal of the rudder for storage.

3.2 Wings

With the performance requirements leaning heavily in the direction of a very low wing loading aircraft with a reasonably sized powerplant, the wing chord was the first item to be looked at. The span was initially limited to 10.9 m by the original requirement so that it could operate from the bush and small strips. It was built that way but tip fairings were added later to increase the span of the aircraft by another 600 mm. As a relatively large wing area would be needed in order to fill the STOL requirements but with a limited span the only remaining variables were the size of the wing chord and the wing layout. A constant chord of 1.5 metres was chosen.

In order to obtain a safe stalling characteristic, it was decided to use a constant chord wing which although not the most efficient aerodynamically produced a very safe stalling flow separation pattern. Although possibly more lift could have been obtained through the use of a more optimised wing with some taper, the aerodynamic advantages were offset by the possibly greater complexity of the flap tracks and operating system. The low Reynold's number characteristics of the aerofoil at Hummingbird's stalling speeds were not documented and in order to err on the conservative side it was decided not to taper the wing as the small tip could have resulted in tip stalling problems.

As the aircraft would spend a great deal of its time flying at low speeds not too far from the stalling angle of attack, an additional one degree of washout was added for additional safety. It was assumed that the angle of twist was too small over the length of the flaps to affect their operation by any measurable amount.

The choice of wing location was based on the higher efficiency of a high wing at low speeds over that of a low wing which has a tendency to "float" in ground effect more than a high wing, reducing the STOL performance by lengthening the landing distance. On the more practical side a high wing would clear many obstacles that could damage a low wing. This is especially true for large flap deflections. A high wing allows the use of a lift strut reducing the structural mass and complexity of the root fitting and simplifies the ground handling on a removeable wing.

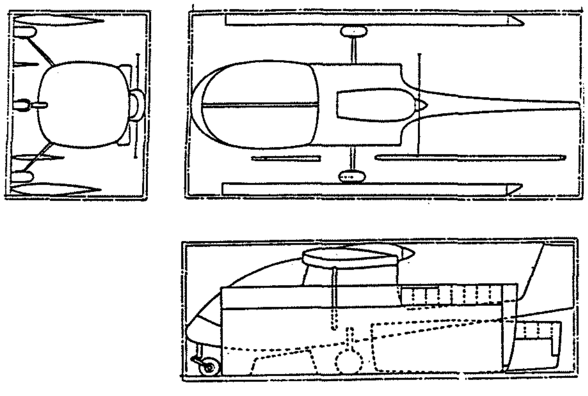


Figure 2. Containerisation of Hummingbird.

3.3 Flaps

Considering the area of wing required to meet the stall speed and the fact that the wing would be of all composite construction, the chord was kept as small as possible to reduce the wing mass.

In chosing the wing chord the maximum lift generated by the wing with flaps was the basic starting point. A single element Fowler flap system for the GAW-1 aerofoil developed by NASA was chosen. The section lift coefficient obtained reached 4.0 with the use of vortex generators. Unfortunately the stall speed of Hummingbird would be so low that the Reynolds number at the stall was slightly below that at which the wind tunnel tests on this aerofoil/flap system were carried out. Due to a lack of any known further options of simple single element flap systems available that could potentially produce the same kind of lift coefficient, the Fowler flapped GAW-1 was chosen. See Fig 3.

3.4 Ailerons

The span of the flaps was maximised in order to obtain the lift required to meet the stalling speed requirement resulting in the span of the ailerons being rather smaller than what would normally have been selected. The resulting roll rate due to the small ailerons was still predicted to be a little better than that of a sailplane. At full deflection the ailerons are able to almost give the 0.07 helix angle (in radians) that is the guideline roll requirement for most types of aircraft.

The ailerons are set up for a two to one differential in order to reduce adverse yaw.

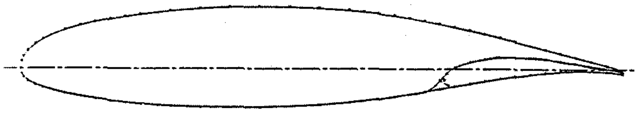


Figure 3. GAW-1 aerofoil with a 30 % Fowler flap.

3.5 Stabiliser

It was at this point that the decision not to carry out any wind-tunnel testing was rued. Due to the short tail boom, the change in downwash angle at the tail with changes in airspeed and flap angle was marked. To make matters worse, the downwash would not be constant across the span of the tail. The position of the propeller was such that the flaps inboard edge had to stop at the edge of the propeller disc to avoid fouling the propeller disk due to its Fowler action. This left a large gap in the centre of the trailing edge with the flaps deflected.

The resulting downwash behind the wing could thus vary from a positive angle of attack at the tail in the centre to a very large downward angle at the tail behind the flaps at full deflection. It was felt that the downwash pattern on the stabiliser was too complex to attempt to carry out an accurate prediction of the tail's performance. The simplifying assumption that the areas immersed directly downstream in the propwash would behave according to their own local conditions and the areas outside the propwash would be affected by the flap system were made. No attempt was made to allow for the contraction of the propwash (or expansion if windmilling) over the area of the stabiliser.

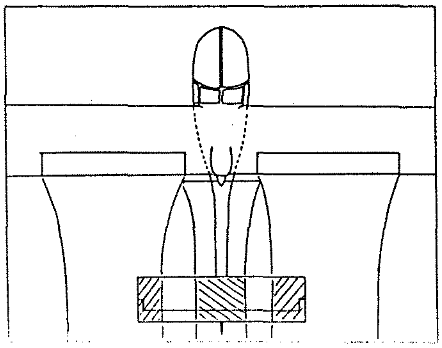


Figure 4. Flap downwash and propwash impingement on the horizontal stabiliser.

The decision was made to utilise a T-tail for a number of reasons, the most practical being that the high horizontal stabilizer minimizes possible damage when landing in rough areas.This is a very real problem in Southern Africa due to the possible use of small rough dirt strips.

Another advantage of the T-tail configuration is that the horizontal stabiliser is also less influenced by ground effect and thus requires less elevator movement for rotation; or conversely, for a given elevator power, the airframe can be rotated earlier. This has the added advantage that a nose wheel can be lifted off the ground sooner during take off, reducing the ground roll, or held off longer during landing, reducing the chance of it being damaged in a rough field.

The horizontal stabiliser was placed almost directly in line with the propwash ensuring increased effectiveness especially at low speeds and high throttle settings such as during take-off when increased elevator power is required at the same time providing an increased down force which would tend to offset the pitch down effect of the high thrust line.

Being in the downwash of the wing at low speeds and especially with flaps, the stabiliser would also reduce the nose-down tendency due to an increase in flap angle.

The tailplane and elevator can both be manufactured in one piece reducing the weight, complexity and cost of manufacture.

The tailplane was designed to be easily and quickly rigged and derigged by one man, with the whole tailplane attaching to the fin with two pins at the rear and one locking pin in the front.

The flaps were electrically operated due to the long travel required followed by the application of a large force to rotate the flap to its final angle.

All that remained then was to choose either an all moving stabilator or a stabiliser and elevator. It appeared from the calculations of downwash angles at various flap angles and aircraft speeds that the latter was the better choice as it required less trim changes with flap angle changes.

3.6 Directional Stability

The directional stability of a pusher configuration aircraft usually cause problems and Hummingbird is no exception. Due to the relatively large cockpit area forward of the wing where it creates a destabilising influence, the area of the fin had to be made sufficiently large in order to ensure a positive directional stability especially with the engine inoperative.

In the case of the engine running, the propwash would increase the dynamic pressure over the tail increasing the effectiveness of the tail surfaces. The directional stability is thus greatly increased and feels satisfactory to the pilot.

With the engine windmilling and the aircraft flying at high speed the flow over the tail is greatly disturbed by the passage of the windmilling propeller. The dynamic pressure of the flow that passes over the tail surfaces is greatly reduced. This results in a reduction in the directional stability of the aircraft. There was unfortunately insufficient funding and time to carry out any accurate predictions in that area. As the aircraft appeared to be safe at lower speeds it was decided to investigate the amounts of directional stability available at various throttle settings during the flight tests.

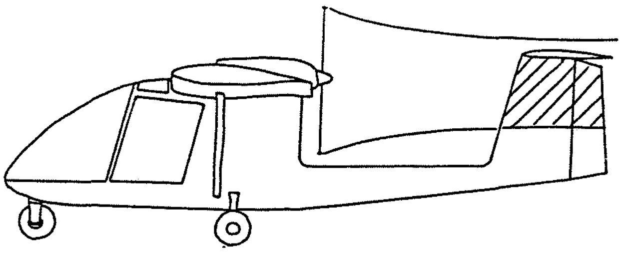


Figure 5. Propwash impingement on the vertical fin and rudder.

3.7 Powerplant

The Norton NR 642-GF-90 Wankel rotary engine was selected as Hummingbird's powerplant for its excellent power to weight ratio and high power output as well as its small frontal area. See Fig. 6.The engine also sports an integral reduction gearbox with torsional damper allowing efficient and quiet propeller speeds. The damper reduces the level of vibration which is an important aspect for both structural and crew fatigue. It is expected that it would also be advantageous from an acoustic nuisance point of view.

The rotary engine generally has a low maintenance requirement, an overhaul requiring generally only bearings and seals to be replaced.

The exhaust was placed under the engine in a fairing that exhausts rearwards into the propeller disc, thus keeping the noxious gasses away from the cockpit. The fairing completely shrouds the engine and has two scoops that duct cold air into the engine/exhaust cowling.

The propeller is a Hoffman two-position prop. This was chosen to get the best possible aircraft performance at various speeds. The propeller pitch is changed to coarse by pulling on a lever once the speed reaches above 1800 RPM and reduced again once the RPM drops below 1200 RPM and the lever is pulled.

3.8 The fuel system

A 40 litre integral fuel tank is mounted in the leading edge of each wing. Each tank feeds its own electric fuel pump through a fuel filter. Both fuel lines combine, pass through a cut-off valve and pass on to the engine (mechanical) fuel pump.

The advantage of the fuel being outside the cockpit area is that it will tend not to penetrate the cockpit in the event of a crash.

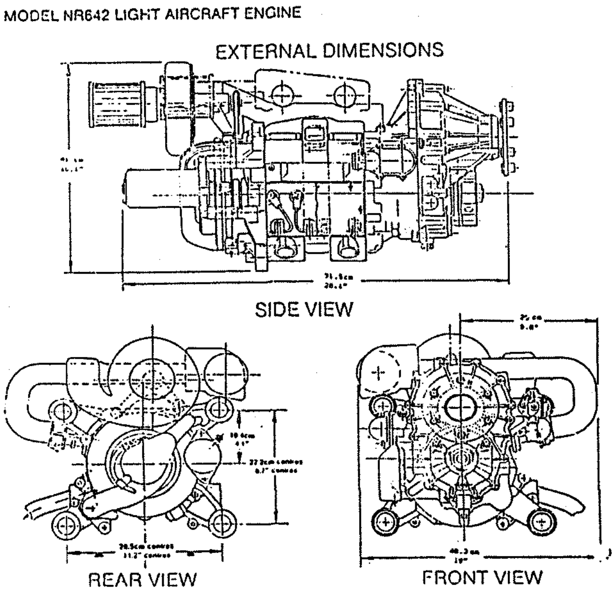


Figure 6. Norton Wankel Engine of 90 hp.

4. STRUCTURES

4.1 Materials and Tooling

The experience gained at Aerotek in composite aircraft structures showed that a simple and very low maintenance airframe could be achieved.

Several methods of construction were considered. It was decided that jigs and tooling required for a metal airframe were prohibitively expensive, especially to achieve the shapes required. The lack of availability of aircraft grade woods their cost and the requirement to withstand harsh bush conditions eliminated it as a material. Fabric as a covering materiels was considered to be a very high maintenance item.

It was felt that composites offer very definite advantages in the South African industry that does not have access to a large trained manpower resources. The materials would allow the quick and cost effective manufacture that can be carried out with a small team of experienced personnel.

Although the personnel may have to be experienced it does not mean that they have to be specialised artisans. Operationally a composites allow the construction of a simple, low maintenance airframe that is easy to inspect with a low parts count and low cost complex shapes.

There were two options available to manufacture the airframe, either wet layup or resin pre-impregnated fibre-glass or carbon cloths (pre-pregs). It was felt that the wet layup method may have caused serious quality control problems with the use of unskilled labour. Although the wet layup systems would be cheaper, it is easier to reduce material usage more efficiently with pre-pregs. The the number of persons required to layup a very large item is also reduced as you are not restricted by the pot life of a resin. Since it was decided to use Nomex Honeycomb as a core due to its superior compression strength and lower density, the quality of the bond to the laminate was easier to ensure with the pre-preg process. A further advantage of the pre-preg system was the health and cleanliness aspects which are today becoming more important issues.

The Ciba Geigy 913 120°C curing pre-preg was chosen based on its price, self adhesion to Nomex, reasonable environmental properties and relatively high Glass Transition Temperature (TG). The 913 resin system has the added advantage that it could be vacuum bagged and oven cured. Most of the parts used on the aircraft were eventually cured in the autoclave using 2.5 bar pressure. The systems chosen was required to have a TG in the region of 110°C, giving at least a 20°C margin above the maximum possible temperature seen by the structure if painted in a dark colour. It should be noted that this is particularly important in the sunny, hot South African conditions.

Similarly an adhesive was chosen with the same characteristics. A further requirement was that the adhesive had to cure initially at room temperature. The reason being that Aerotek did not have the facilities for hot bonding such large structures. A further consideration was that in production the assembly jigs would be fixed in one place for accuracy. It would also be very costly to have to provide a hot bonding capability.

The adhesive chosen was the Hysol EA 9394 system. Due to the cost of the system an investigation was made into using a laminating resin system with cotton flox that can be post cured to the required TG.

The pre-preg route was also followed in investigating the technology required to manufacture high temperature tooling of this size. The plugs were manufactured using three different methods.

The fuselage plug was manufactured using plywood formers with hard foam bonded in between. This was then shaped to templates and covered with a layer of fibreglass to provide vacuum integrity. The plug was then finished with a polyester spray filler and spot putty.

The horizontal tail has a constant chord, symmetrical section and no twist. This allowed each half to be splined on a flat surface with a single template. This was done by constructing a wood "filler pad" which was covered with gypsum. The final spline was done with a gelcoat. This was sprayed with spray fill and finished.

The wing plugs were manufactured by assembling plywood ribs around a wooden beam. The ribs were then covered with sheets of 3mm plywood. The plug was then filled and finished.

All three methods proved reasonablysuccessful. It was felt though that adjustments had to be made to the methods to improve accuracy and reduce finishing time.

The glass fibre moulds were manufactured using Ciba Geigy high temperature tooling resin. The resin would cure on the plug at room temperature. Once cured a welded tubular steel backing would be attached to the mould. The tool would then be de-moulded and post cured while free standing. It was decided to use a steel truss type backing structure to reduce cost. Since the coefficient of expansion between the glass fibre and steel was very small it was felt this would have very little effect. The backing frames were designed to fit into the autoclave.

Significant experience was gained in the development of such large tools which has been used since then on other similarly sized projects.

4.2 The structure of Hummingbird

In general the aircraft uses a sandwich panel construction of glass fibre skins and Nomex honeycomb core. In areas such as the spar caps and the tail boom carbon fibre unidirectional material was used for stiffness. In particular in the case of the wings to reduce deflection over the large flap span. This was also assisted with the use of the lift strut. In the case of the tail boom the carbon prevented excessive deflections under manoeuvering loads that would affect the stability or controllability of the aircraft.

The fuselage is a semi-monocoque construction. The wing loads were introduced into the fuselage by two frames and the lower lift strut attachment. The underfloor area has four longitudinal webs for attachment to controls and cockpit equipment, while providing energy absorbing members for the crash case. The floor was designed as a beam to which the whole cockpit is attached. All the control are mounted on top of the floor for ease of maintenance. The only items under the floor are the cable and hydraulic pipe runs that are accessible were needed giving a largely unbroken floor structure.

The wings have a single spar with four ribs in positions required to transfer loads. The wing is attached to the fuselage with the lift strut and two pins at each root.

The tailplane and elevator are both be manufactured as single items reducing weight, complexity and cost.

4.3 Ground Vibration Testing

After the construction was complete the aircraft was subjected to ground vibrations tests in order to ascertain the predicted flutter modes and the speeds at which they were expected to occur. The aircraft was cleared to 160 kts once the rudder was mass balanced with the first mode predicted being a fin bending mode.

5. ERGONOMICS

5.1 The Fuselage Layout and Ergonomics

The overall fuselage shape was determined by a combination of the best possible cockpit ergonomics, the best possible all round vision and the best faired shape to accommodate the above and provide an efficient aerodynamic shape.

Of the normal two options for a pusher configuration aircraft, a low boom configuration was chosen as it would allow the complete fuselage and fin to be manufactured in two halves simplifying the mould. This greatly reduces the component count with less complex control runs compared with the twin boom arrangement.

The canopy was designed for the largest possible uninterrupted view of the pilot in command between the 7 o'clock and 10 o'clock positions especially when looking obliquely downwards. It was felt that this was the direction in which most of the observation work would be done. It was decided that windows beneath the feet would not be required as this area fell outside the target area defined above. The vision in this area would also be of little use due to the rudder pedals being in the way. The canopy curves in at the floor level to effectively provide a downward view as close to vertical as possible.

The results of the design can be seen in Fig. 7 which is an AITOFF plot of the view from the pilot's position. Fig.8 and 9 are an interesting presentation of the unsighted foot print of the pilot while flying at 1000 feet. Both plots were drawn based on an older cockpit layout. The final layout of the cockpit had the canopy lower edge at the cockpit floor level and the visible range of the aircraft has been found to be better than initially predicted.

The instrument panel was kept as small as possible and positioned as low as possible for better pilot visibility on the opposite side of the aircraft. The final size and position ensured that essentially only floor interface restricted the crew's view.

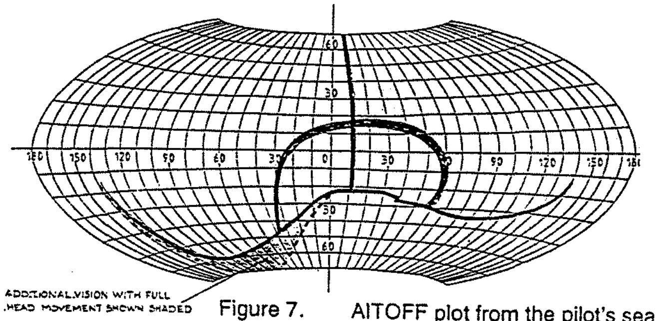


Figure 7. AITOFF plot from the pilot's seat showing visibility.

The cockpit has been laid out according to Mil 33574. The 1250 mm width provides side by side accommodation for two 97.5 percentile crew members. It also meant that since control sticks were used limiting any movement of the seats, the rudder pedals had to be adjustable fore and aft through a total of nine inches.

A mock-up of the entire cockpit was built to carefully considered all ergonomic aspects. As a result test flights have proven that very comfortable accommodation with excellent visibility has been achieved to ensure that the crew can operate efficiently for long periods of time.

5.2 Seats

A great deal of research was done into getting an optimum seat in which the pilot could spend a great deal of time. The seat was designed using a pre-manufactured sandwich panel using a cut and fold method to reduce manufacturing time. Tufnol, a reinforced phenolic board, inserts were bonded into the base of the seat to which metal brackets were bolted to attach it to the floor. Inserts were also provided on the sides for the lap belts attachments. Specially designed cushions, that were covered in leather and an absorbant material down the centre, were held in place with Velcro allowing the pilot to adjust the cushions as required. The seats are attached to the floor with mushroom type fittings and two pins. Once the pins are remove the seat can be slid back and lifted out of the aircraft. This gives access to the payload bay.

5.3 Engine location.

To ensure an unobstructed view from the cockpit the engine had been mounted as a pusher. For maximum flexibility the engine bay was designed as a pod added to the aircraft. This allowed for a wide selection of engines to be fitted by merely designing a new engine mount and cowl.

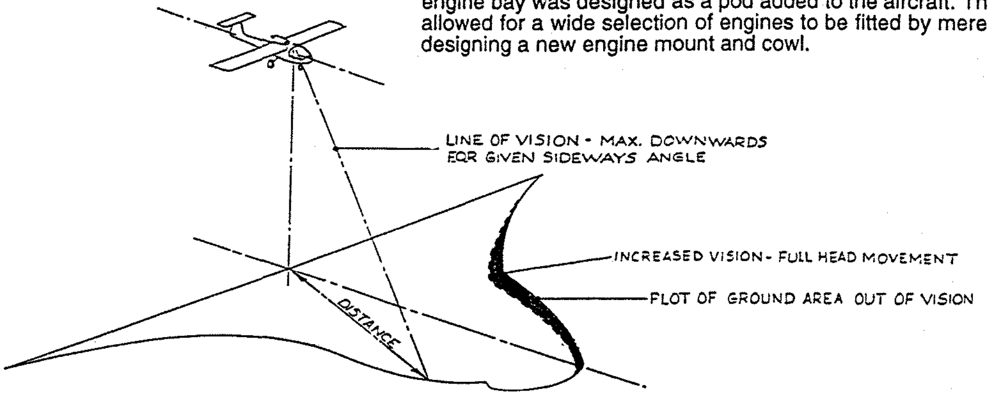
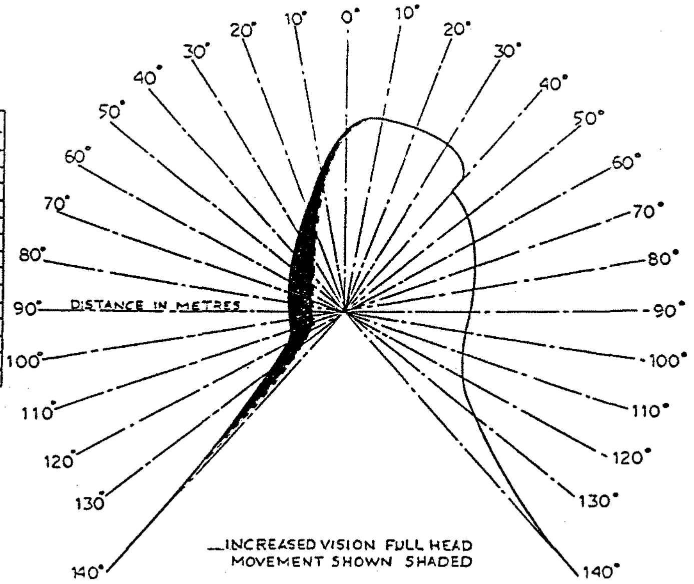


Figure 8. Unsighted footprint of the aircraft.

L.H. SIDE

DISTANCE	ANGLE
325	0
263	10
199	20
161	30
135	40
117	50
109	60
101	70
94	80
92	90
90	100
90	110
97	120
179	130
652	140



R.H. SIDE

ANGLE	DISTANCE
0	325
10	350
20	360
30	371
40	337
50	282
60	265
70	240
80	231
90	222
100	222
110	231
120	255
130	322
140	652

Figure 9. Actual footprint of the aircraft from 300 m above ground level.

5.4 Payload Bay

The payload bay is directly behind the crew seats and due to the layout of the aircraft it is usefully large. Access to this area is gained through a hatch on the side of the fuselage or through the large cockpit doors and removing the seats as described above.

The large payload bay is conveniently situated directly below the aircraft's centre of gravity. This minimises the effects of different payload weights on the stability of the aircraft.

A further advantage of the payload bay in the future development of the aircraft, is that it can accommodate a bench seat to grow the airframe into a four seater. See Figure 10.

5.5 Undercarriage layout

The tricycle layout of the undercarriage was chosen. This was to ensure that the greatest cross section of pilots could fly the aircraft without specialised training. The undercarriage was so shaped as to enable it to be manufactured in one piece. The shape would still allow it to pass through the two holes on either side of the fuselage above the floor line and be pinned in place at the rear of the payload bay. This allowed for a lighter and simpler under carriage member.

The nose wheel was selected as large as possible for the best rough field capability. The nose wheel is steerable and the radius of turn was selected so that the aircraft would rotate about its wing tip. It was decided that independent braking would also be provided on the prototype to enable the operational evaluation of both systems.

6. Flight

The first flight of the Hummingbird aircraft took place early in May 1993 after extensive engine cowling modifications and lengthy tuning problems on the rotary engine. The aircraft was instrumented with a 36 channel telemetry system althought the flight of approximately 45 minutes was essentially a shakedown flight with only a few test points being flown. As the purpose of the flight was a general evaluation of the aircraft the first flight was completely successful.

Unfortunately after the initial flight the flight testing had to be halted and the aircraft was returned to the CSIR where it was crated and flown to France to be exhibited at the 1993 Paris Airshow.

Although the flight was a success the feedback obtained from interested parties at the Paris Airshow brought up some new and realistic requirements that had not come out of the original market study. The most important one being that although the aircraft had been designed to a very low stall speed, a 40 to 50 knots stall speed was quite adequate for the type of flying that was commercially required, at least in Europe. Even more importantly the cruise speed of approximately 90 knots was far too low to be competitive in the business of observation flying because of the longer transit time and therefore greater costs travelling to the place at which the observation role was required.

It was obvious from this feedback that the powerplant would have to be upgraded in order to increase the cruise speed of the aircraft. The new engine modification would of necessity result in a number of new modifications taking place. Some due to the increased mass of the aircraft, some improvements brought about from the results of the first flight.

7. Modifications

Following the funds being made available in January, a number of new modifications to the aircraft were carried out in the first three months of this year once again under a tight budget.

7.1 Engine

The most obvious modification to the aircraft was the installation of the Lycoming O-360-A3A engine in place of the Norton rotary engine. The two main reasons were the increased cruise performance and the availability of dealers and service agents as well as the availability of spares throughout the world for the Lycoming engines. The Norton engine obviously does not have this sort of back up world wide. Using the Lycoming engine makes marketing the aircraft easier.

The new engine meant a mass increase of approximately 60 kg i.e. double the mass of the original engine. Although this would affect the stall speed performance of the aircraft, the take off length and climb rate would be improved. It was felt that this was a step in the right direction.

Some time was spent evaluating the merits of various locations for the new engine such that its affect on the centre of gravity was minimised but without raising the thrust line too high to avoid unnecessary trim changes with various power settings.

A new engine frame was manufacture to fit onto the existing engine mounts and one additional bracket which was attached to a hard point which had been inserted in the skin above the cockpit. The resultant placing of the engine results in a very full rear engine bay with the exhausts, carb heat box, flap levers as well as the air inlet manifold all occupying the same space.

One of the compromises made was that in order to carry out an oil change the engine would have to be removed from its frame. It was felt that although certainly not acceptable from a production aircraft point of view this could be accepted on the prototype.

7.2 Propeller

The two position Hoffman propeller used on the first flight was changed for a fixed pitch wooden prop of 1.7 metre diameter for the Lycoming engine which although sufficient for the first set of flights, will most probably be changed for a finer pitch propeller to improve the low speed and climb performance.

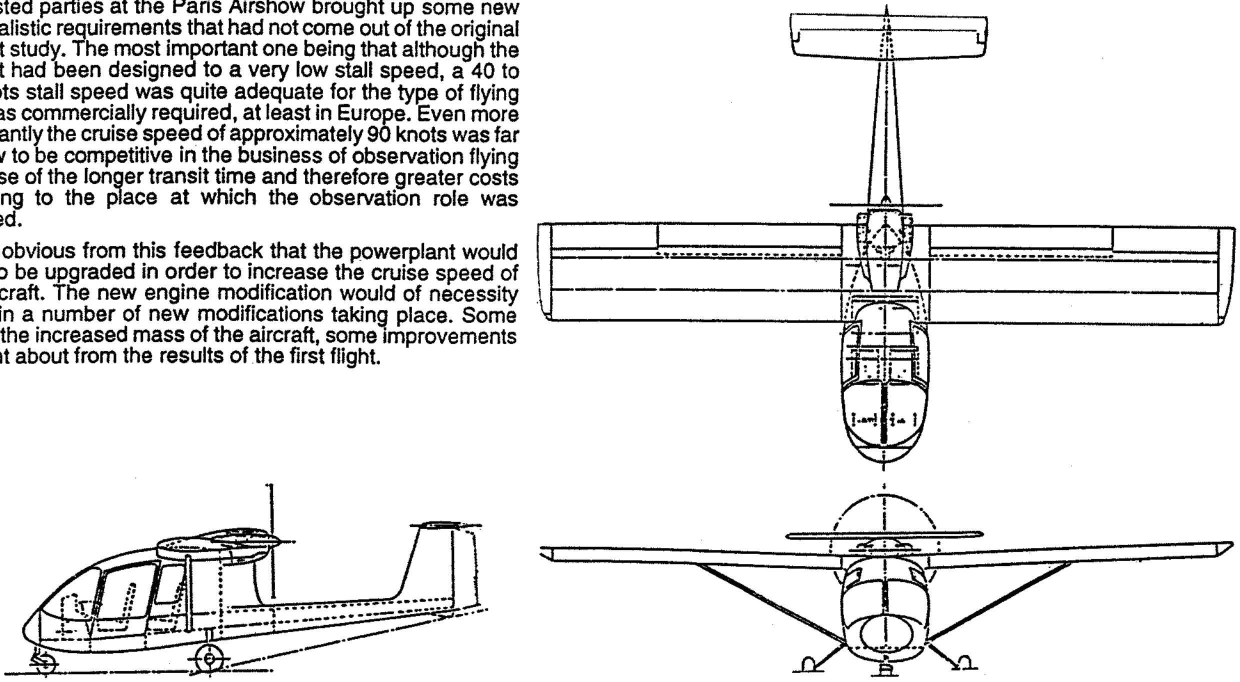


Figure 10. Conceptual drawing of the four seater version of Hummingbird.

7.3 Structural modifications

The maximum permissible take off mass was increased to 1100 kg in order to allow for the larger engine, full fuel load, two crew, and the weight of the telemetry equipment.

The strength of the wing spars was also increased to allow for the higher allowable mass of the aircraft. This was carried out by removing the layer of filler, primer and paint from the area over the wing's carbon spar caps and laying up a number of layers of carbon unidirectional rovings over the original spar caps. The end result after fairing and painting was a negligible change to the aerofoil profile.

The wing was then placed in a wiffle tree and structurally tested to limit load for the new aircraft mass.

7.4 Flaps

Due to the apparent lack of interest in the very low stall speeds, the complex and expensive Fowler flap systems were removed and, once modified, the flaps were converted into split flaps. Part of the reasoning behind this decision was the original requirement of a large tail volume and hence large stabiliser area brought about by the large pitching moment of the Fowler flaps at full deployment on the original wing. Through the use of split flaps the stabiliser size and hence mass could be reduced in an effort to reduce on the amount of nose weight required in order to obtain the correct centre of gravity. The additional weight requirement was caused by the placement of the larger engine behind the centre of gravity.

7.5 Stabiliser

The original stabiliser was replaced with one of approximately 85 % of the area. The rigging angle was also modified to - 3 degrees in order to give the aircraft sufficient elevator power to rotate the aircraft in ground effect at the stall. An added advantage of the new angle was that the effect on pitch of a power transient was almost zero.

7.6 Fin/Rudder

It was also apparent from the first flight that although the directional stability power-on was sufficient it was felt that power-off it may be too low especially at higher aircraft speeds. Part of this apparent low directional stability was due to the friction in the rudder/steering control runs reducing the rudder's ability to centre itself upon removal of the control force. The effect of this was an apparent tendency to appear like rudder lock.

Nevertheless it was felt that it would be sensible to increase the fin and rudder area. Interestingly due to the low directional stability, the apparently too small rudder area was more than sufficient for directional control achieving almost as much sideslip angle as rudder displacement angle.

The tailplane was thus extensively modified to increase the vertical fin and rudder area. In particular the fin and rudder were increased in height the effect being to increase the effective aspect ratio of the vertical surface although this was partially negated by the increase in the chord of the rudder.

7.7 Undercarriage

The undercarriage legs were also strengthened to accommodate the higher mass and faster landings. Provision was also made for the installation of wheel spats to protect the propeller from foreign objects thrown up by the wheels. As an added advantage the spats would also produce less of a downward pitching moment due to their drag reducing the load on the stabiliser at the higher speeds.

8. Flights

On completion of the modifications to the airframe, the aircraft was once again fitted with telemetry and transported by truck to the airport.

The flight tests that followed were carried out at a density altitude of approximately 5000 feet. The initial flights were flutter clearance flights with the excitation on the tail being supplied by the propwash. The aircraft was cleared initially to 110 knots so that low speed flight testing could be started.

At this point in time the aircraft has flown a total of over twenty hours with the Lycoming engine.

9. Conclusions

Although flight tests are continuing at this point in time, the Hummingbird has demonstrated most of the expected performances and the visibility that was the original goal of the project.

The aircraft is the second all composite aircraft to be built in the last few years by Aerotek using the technologies developed with the production of the all carbon military trainer, now called ACE.

There still remains a great deal of work ahead if the aircraft is to be certified.

Performance at 1200 m altitude	Required Lower Limit	Required Upper Limit
Max. Level Speed	115 kts	115 kts
Max Cruising Speed @ 75%	80 kts	100 kts
Stalling Speed: flaps up	41 kts	41 kts
flaps down	30 kts	25 kts
Loiter Speed	45 kts	40 kts
Max. Climb Rate:flaps up	250 m / min.	300 m / min.
T-O Run	80 m	50 m
T-O Run to 15 m	150 m	100 m
Landing Run	50 m	20 m
Landing Run over 15 m	150 m	75 m
Endurance	4 hours	5 hours
Glide Ratio	8:1	12:1

Table 1. Original performance specifications to which Hummingbird was designed.