S1 E3 - Designing the Axe EVTOL

An in-depth interview with CTO Dr William Brooks

Foreword from Michael Thompson (CEO):

At Skyfly, we are building a two-seat electric/hybrid Vertical Take Off and Landing (E-VTOL) aircraft.

We are different in that we are focussing on the private market, with the aircraft designed for individual ownership and operation using an existing aircraft certification route, instead of a lengthy and onerous commercial certification process.

We are also efficient in our design, with a strong focus on low weight and a very efficient aerodynamic layout, giving you VTOL capability without the heavy, expensive and failure-prone rotating motor or wing mechanisms found on many other E-VTOL aircraft. Instead, we have fixed rotors which do not rotate, and which are much safer and lighter. We're also different in that we have four wings, giving us increased lift and range, whereas our competitors have no wings, and only rotors to provide lift. Our four wings give low energy consumption in the cruise, half that of a Tesla, giving a much greater range than other E-VTOL aircraft. Importantly, they also add a layer of safety others do not have, delivering glide performance comparable to conventional fixed-wing aircraft like a Cessna or Cirrus, which, of course, are not able to take off and land vertically.

As you will see in this video, the Axe is an aircraft that has been properly designed and thought out by a highly experienced team of aeronautical engineers, rather than being designed as a financial proposition for commercial air taxi companies.

The engineering team is led by Dr William Brooks, our Chief Technical Officer. Bill is an experienced aeronautical engineer who has designed and built numerous aircraft, over 2,000 of which are flying today. He holds a degree in aircraft design and a PhD in composite structures for aircraft. William has already been involved in other ground-breaking new aircraft, such as the Flight Design CT, which revolutionised the world of light aviation; it was among the first made of composite materials, and far outperformed other aircraft of its time. He was also on the design team for Rolls Royce's electric world speed record aircraft before joining Skyfly two years ago.

The team also includes John Wighton, the former head of stress for Swiss aircraft manufacturer Pilatus. You will hear from some of our other engineers, including those leading the flight control design and electrical systems design, in later videos.

In this video, William will explain all aspects of our design, starting with a high-level explanation of our main design choices. Then, we'll go into more depth on specific construction methods and techniques used for the Axe two-seat E-VTOL aircraft.

1. **Why have we chosen a canard layout for the Axe?**

The Axe is very much a fusion between a drone and a fixed-wing aircraft. In order to get the centre of gravity between all four rotors, which is desirable for hovering, that lends itself to an aerodynamic layout with a canard configuration. The centre of gravity is right on the pilot's hips, so it doesn't matter whether you've got one or two pilots, or no pilot at all, it will fly just the same.

In order to create a stable aerodynamic layout, you need the front wing to be working at a higher lift coefficient – doing more work – than the rear wing. With a canard layout, that means that as you approach a high angle of attack, the foreplane stalls first and it loses lift; the nose drops, causing the aircraft to gain speed again, the angle of attack reduces and so the main wing never reaches the point where it can stall.

2. **How have we increased ground clearance to prevent prop strikes?**

The canard is set up with a bit of dihedral, which helps with propeller ground clearance. There's a slight amount of dihedral on the motor pylons as well. That not only increases the ground clearance, but also moves the downwash from the rotors further outboard, which helps to increase the effective span.

It's designed to be quite stable on the ground; the track is about as wide as is practically possible, given an eight foot track limit for ground transport.

3. **How are the wings mounted to the fuselage?**

The wing mounting takes its cues from a well-established glider design. Each wing has a main spar, which takes the bending loads, and on the right hand wing, the spar is further forward than on the left hand side. The spars come together within the fuselage, slightly offset from one another. The bending load is then taken by a pair of pins, which connect the two spars together, but the spars actually float within the fuselage, it doesn't pick up any load into the fuselage. That's done by a pair of pins on the wing root ribs, and these pins take the lift load (sheer) and torsion from the wings, into the fuselage.

4. **How do you maintain rigidity and strength in the wings despite the high loads at the wing tips.**

The span of the aircraft is kept as compact as possible, commensurate with having good aerodynamic performance, because, as is well known, a high aspect ratio, long, thin wing gives you a better glide angle, but it also gets heavier and heavier. The shorter span gives reasonable glide performance (a glide ratio of 9:1), but it keeps the whole structure quite light and rigid. That is the compromise that we have had to take.

The wing spars are tubular carbon spar to mount the motor, and that runs into a carbon fibre uni-directional spar cap top and bottom which runs into the fuselage to the carry-through joint.

5. **How do you retain torsional strength in the fuselage structure?**

There's quite a demanding load case on this kind of aircraft, because it's similar to a drone: you have potentially got the situation where you have got maximum thrust on two diagonally opposite motors, and that would put a large torsional moment into the fuselage. The fuselage, therefore, has frames which transfer the torsional load from the wings into the fuselage shell. The fuselage shell has a central spine or tunnel, and that acts as a large diameter tube, which is very good for resisting torsion.

6. How does the ballistic parachute work?

The ballistic parachute system is intended to recover the entire airframe and its occupants. The parachute will deploy from a hatch behind the cockpit, fired straight upwards by a rocket, and it will reach the full extent of its parachute bridle. The motors will be cut off as part of the deployment sequence, and the aircraft and passengers will descend under the parachute.

7. Why have we opted for a tricycle undercarriage layout?

One of the most important things about a tricycle layout is that the main wheels are behind the centre of gravity, and if the nosewheel is allowed to castor, that makes the undercarriage dynamically stable as it travels along a runway; the aircraft will tend to keep straight. That is as opposed to a taildragger like on a Spitfire, which is unstable.

Secondly, we need this undercarriage to work both for conventional take offs and landings at a normal attitude, but also when the aircraft takes off vertically, during which it tips up onto its tail and rises vertically. The tricycle undercarriage does a very good job of keeping it stable when it is moving forward over the ground, and also having a tip-up feature to facilitate vertical take offs and landings.

8. Where are the batteries and hybrid generator located?

The Axe has two battery compartments: one in the nose and one just behind the pilots. They are maximum size, 24kWh each. It is possible to substitute the rear battery packs with a hybrid generator, which would run on fuel carried in a tank under the seats, which is on the aircraft's centre of gravity – so that doesn't change the balance of the aircraft.

9. How easy is it to remove the wings on the Axe?

The Axe is designed to be road-transportable, and to that end, the wings are designed to be easily removable. There are two spar pins as I have previously explained, joining the spar together. When those pins are removed, each wing can be extracted from the fuselage.

10. How is the Axe fuselage built?

The fuselage has got a lot of compound shaping in it, and that really lends itself to composite construction – especially as we need to drive the weight right down. These compound curves are quite good for stabilising the structure against buckling, but we will have sandwich panels where necessary in order to stabilise it further. We also have made integral bulkhead frames at the front and back of the fuselage, which carry the compression load from the root pins.

The fuselage will be made up in two halves, but will be joined together in the mould, and cured in one shot using the resin infusion technique. Resin is good because there is no time constraint on putting the laminate together until you inject the resin under vacuum, and it produces lightweight structures with very low void content. It also saves some cost, compared with pre-???? construction, and I have previous experience of using this construction technique.

11. How are the wings made?

Wing construction utilises sandwich-stabilised skins – you need a nice aerodynamic surface. The basic wing structure is a box-type spar, which will have uni-directional carbon top and bottom caps and a sheer web of plus or minus 45 degrees to take the sheer forces, and that will be laid up into a top and bottom skin moulding, which will be sandwich-stabilised. This is, again, very similar to composite glider construction.

12. How have we ensured crashworthiness of the Axe?

As far as impact protection goes, this layout is good because the pilots are right in the middle of the structure, surrounded by impact-absorbing wings and undercarriage, which creates some quite large crumple zones. We're using a hybrid of aramid and carbon in the cockpit construction, which is good for absorbing impacts, and also prevents the possibility of a lot of carbon shards coming into the cockpit area.

There are standard emergency landing conditions that have to be fulfilled, and one of them is a 9G forward impact case; the pilots have to be restrained inside the structure under a force of 9G forwards, and any large item of mass which is behind the pilots, such as the batteries or hybrid generator, has to resist 15G forwards. That is to ensure that these big masses aren't thrown forwards into the cockpit area.

13. How is the canopy of the aircraft made?

The canopy is a one-piece acrylic moulding. There are two flush panels which project from the front corners of the canopy, with a hinge above the wing root – the whole canopy will then hinge upwards, enabling the pilots to get in and out. It is a large canopy, giving the pilot an excellent field of view.

14. What is powering the Axe?

The Axe is equipped with four duplex motors – meaning there are two independent motors driving each shaft. Each of these independent motors is run by a separate speed controller and battery system. While they all operate independently, if one should fail, the flight control system would detect an excursion in roll and pitch, would automatically increase the power to the remaining good motor, and would reduce the power to the motors diagonally opposite, in order to keep the aircraft stable.

Each motor is 50kW maximum continuous power. The aircraft will take about 110 to 120kW in order to hover.

We're keeping to one rotor on each wingtip – they will be three-bladed to reduce vibration.

15. Why are the rotors wingtip-mounted?

One of the interesting things about the Axe design is the fixed 45-degree rotor angle and the positioning of the rotors at the wingtips. Normally on a wing, you've got high pressure underneath and low pressure on the top, but with leakage around the wingtip – and that generates a wingtip vortex, which consumes energy. However, with this design, there's a component of the rotor wash that is acting downwards, so whereas the airflow at the wingtip would normally curve upwards, the rotor downwash prevents it from doing so. This pushes the tip vortex outboard, so having the motor in this location increases the effective wingspan, giving us a span that is more like from rotor axis to rotor axis rather than just from wingtip to wingtip.

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