# Aircraft electrical propulsion: Humanity's Journey towards Net Zero.

**Dr Neil Pickles:**

We're ready. Okay. Good evening, everyone, croeso welcome. So my name is Neil Pickles, Associate Dean for Academic Development at the University. Our Vice Chancellor, Maria is here as well. So I'm slightly nervous doing the introduction in front of Maria,

but it's lovely to see everyone here, particularly to see so many students here as well.

And I'm delighted to introduce Dr Rob Bolam, who has been a wonderful member of academic staff at the university for some time here, a lecturer, senior lecturer now Reader. Got his PhD recently as well, and what he's here to do is talk, as you can see, the title here of Aircraft Electrical Propulsion: Humanity's Journey towards Net Zero.

And Rob has been at the forefront of these developments, looking at his FAST fan project in electrical propulsion, lots of industrial collaboration with this and research. So Rob is very much at the forefront of this.

So I'm sure you will all enjoy this talk very much.

Now, I do have some instructions here, so I'm reminded to talk about crisps, so I'm wondering whether there’s an epidemic of people eating crisps during the during this session.

But I think it's just bear in mind that we want to be able to hear what Rob's talking about.

We want to see the demonstration. So if you want crisps, I believe they'll be available at the end.

Okay, so I'm not going to talk any more. I'll hand it over to Rob and good luck.

**Dr Rob Bolam:**

Thank you very much.

That's great. And if you do have any crisps you’ve got to share them. And yes, thank you. And it's wonderful to see everybody here today. All come to see what research we're doing here at Glyndwr, well Wrexham University, sorry, I'm still in Glyndwr mode.

And yes, and today, going to talk about what we've been doing in the engineering department, we have lots of other departments or areas of study and we've been very busy working, as you can see with these components here, developing equipment and new methods for propulsion, for aircraft, electrical propulsion.

So that's me so you can ignore that.

So net zero aviation, what we've been doing is aiming our research towards a better future really is it's really research about posterity. It's about future generations. And we're trying to develop things here at Glyndwr, Wrexham University. Sorry for that, must get a little pound box, put a pound in the box every time you say Glyndwr and yeah, we're trying to develop our research so it follows what the well what civilisation wants, what people want, what the governments are asking us to do and where the funding is as well actually.

So that's, that's what we're aiming at. And in 2019, to give you an idea about aviation, the impact of aviation was 3.5% of all global greenhouse gases were actually produced by aircraft and in actual fact, if we continue at this rate, it would be about almost 10%, 9.5 I think it says up there, 9.5% of the global greenhouse gases.

And these have impacts, these gases. The impacts are, as you all know, the warming of the climate. And this is a very good little animation of the climate warming since 1880. It's not it doesn't sound like a lot. You know, the climate has warmed about one degree centigrade or just over one degree. And what we're going to do is just show how it's warmed since 1880 from the position. This is a visualisation which has been put together by NASA, but it gives an idea of what the situation is at the moment. So we see the dates, the 1925, 26. And then as we approach the 1960s, the more modern era, notice how it changes.

So this is a kind of a 3-D visualisation of global warming and how the top part from 1980 onwards, how in actual fact we've started to really go more exponential in the global warming and it has impacts it has impacts on our society, impacts some countries existential nature of the actual country that they can actually survive. And some of the impacts are all negative, but some could bring slightly positive impacts.

But all in all, it's perceived that global warming is a threat to the human kind. And the idea being that, uh, that global warming is actually going to take place. It's is warmed up by about one degree centigrade since the 1880s, and it's scheduled to be over 1.5 by 2050.

So what's causing that? And this is this is. This has been defined. It's quite an interesting thing what causes global warming, because I'm, I still have my. I still have my doubts about whether it's just as simply as straightforward as it as it's perceived.

This is the what's called the Keeling curve, and this is one of the underlying curves for predicting what has caused global warming. And it relates CO2 over the years. In actual fact, both this curve and the previous animation were provided to me by a good colleague of mine. He's in the audience called Dr David Sprake, who's he does renewable environmental engineering for us here at the university.

And what this curve has shown us, this is showing is that the CO2 rise in the atmosphere over the past 2000 years there, in actual fact, the part which is the curve starts is after about 1750, which coincides with the start of what we call the Industrial revolution. It curves and it goes up not long after 1960 ,that point at which we could see the exponential growth, it is really picked up and it's going very, very, very high. The CO2 emissions. Now, I'd like you to bear that in mind, whether it's related directly to the CO2 emissions. And I'd like you to think while I'm giving this presentation at the end of ask you if everybody can think, is that what's causing it? Or is there something else that could also be an underlying reason why that's happening?

Just a question to you and I'll hopefully when we get to the end of it, maybe you can have some thoughts on that.

So what's the effect on us? Well, it affects the climate. It puts more energy into the climate. And if there's more energy into the climate, the climate's warmer. The climate, unsurprisingly, becomes more and more active. So you have stronger winds, bigger oceans, more waves in the oceans. With storms, you have hotter climates. And here in Wales, we've already seen that with the Aberystwyth storm January 2014, very, very powerful storm. In actual fact, I know there are people in this audience at the moment who witnessed that firsthand, who were staying… Jack’s nodding there…

And also, other people have studied Aberystwyth University and lots of students live on the front there, and they would have witnessed that storm first hand. And also in the warmer countries like Greece and in Spain, Spain in particular, there's an increase in wildfires. And this causes an awful lot of environmental damage to society and to the countries.

So it's not surprising that governments have got behind this. And the UN, which is 196 countries, have got together and they've made a legally binding pact in the Paris Agreement to keep the global warming below 1.5 degrees centigrade increase by 2050, there are also other legal movements which have happened in laws which have been passed. The UK climate change legislation, which actually came before the Paris Agreement of 2016 2015 and the UK Climate Change Agreement and founded with the UK country and also the devolved governments to keeping to aiming for net zero by 2050. So what that means is that Scotland, Northern Ireland and Wales also have to meet this and England that they all have to meet this legislation. So the Welsh governments have a net zero strategic plan. And partly that's kind of where we fit in and where our research has been drawn on because we're aiming to meet the net zero plan.

So, what do aircraft emits, the gases which they emit, which are the harmful aviation gases. Our main one is CO2. There's also methane and also nitrous oxide and surprisingly as well, some people probably don't always realise that vapour trails, that's another greenhouse gas. So by far the largest one of these contributor is CO2 and aircraft in general, aviation contributes about 2.5% of the overall CO2 emissions in the globally for the world.

It doesn't sound like a lot, but a single corporation such as Airbus, could be responsible for 1% of the global CO2 emissions. So that's just one company. Now, I've kind of pointed out Airbus and Boeing the same, they're the two largest commercial aircraft companies. But the reason for that is that I was at a conference last week and one of the directors of Airbus was there, and he pointed this out as well. So I'm not trying to single them out. And he did that because he wanted to show that Airbus tried to take accountability for what they do in regard to that. You know, I thought maybe that's a lot of accountability to take. But in actual fact, it's not just the aircraft manufacturer, it's the aircraft operators to do that. And so it's important that that's realised. But they're making a start by doing that and they they're making good headway into overcoming their emissions.

So this is a visualisation of the actual global emissions where most of them are coming from and the darker blue areas show shown here show America and also the United States and also China as being main contributors to CO2 gases, the lighter blue areas are lesser. And in Africa, there's hardly any CO2 emissions. And of course, this graph or this chart shows the shows the CO2 emissions from internal flights as well as external flights.

So, technologies which are currently being explored to reduce aircraft emissions are efficiency savings. This is a big one. And most aircraft, if you can make them more efficient, they will burn less fuel and you will get a better performance. And if they burn less fuel, you'll get less emissions. So a lot of work is being done to try and make what we existing have, try to improve that so that we can reduce that.

And the good example of this is Rolls-Royce are designing an ultra fan which is incredibly large found that goes on a jet engine. It's the largest fan in the world for the jet engine over 14 foot diameter. And it's it rotates very, very slowly for a jet engine. And this is a quite a novel concept, is run by gearbox and it will give efficiency savings of about 20% on current aircraft jet engines. But if you get physical problems arriving then because the aircraft that it goes on has to be able to have the ground clearance the actual fans to be able to be installed. So all these things have little knock on effects. Lightweight constructors is another one. And just down the road here, Airbus are working on the wing of the future. And one of the big things of this wing is it's also going to be light in weight through the production methods of making it out of composites. So they're investigating new production methods and lightweighting in the structures. If an Aircraft is lighter in weight, it needs less fuel to push it through the air.

And another area here is sustainable aviation fuels. And this is seen very favourably by airlines. In actual fact, Virgin Atlantic last week flew across it did the first 100% sustainable aviation fuel flight from London Heathrow over to County airport. And they managed to do this complete flight with 100% sustainable aviation for.

Another area that's been looked at explored is hydrogen. And with hydrogen, that's either can be burnt in the jet engines, just like a fuel would be. You have to change the you can ignite and combust as an injectors. Or you can use it and use it in a fuel cell, which is much more efficient way to use hydrogen. And in that way, it can give you an electrical current and you can drive electrical propulsion from that method.

So hydrogen. Another area is hybrid electric with internal combustion engines or batteries and pure electric with batteries. Now, those three areas are the three areas here at Wrexham that we mainly look at with regard to how we can propel used electrical propulsion for aircraft, because these allow you to generate electrical currents to drive electrical propulsion.

So really that's what we've been working on and that's set the scene for why we've been working on electrical propulsion and electrical propulsion goes quite a long way back, but you might be quite surprised that it's over 140 years since the first aircraft was propelled electrically and that aircraft was in actual fact an airship, it is called an aerostat. And it was French the Tissandier brothers. And they flew this dirigible, dirigible balloon around Paris in that area as part of an experiment. One of the interesting things to note about this was that they used a production electric motor for it that was made by Siemens Motors, Electric motors, and this is back in the 1880s. So that was the very, very first recorded electric flight of an aircraft.

It was a long time till the next flight of an electrical aircraft. But the most memorable flight was one which somebody actually flew in an electric aircraft. They got in it and flew it. And this took place in Austria in 1973. And this aircraft here, the Militky is a very nice looking aircraft, was designed by a glider designer. It was a type of glider aircraft, and it flew for a very short duration, but it was the first manned aircraft flight.

There have been other notable electrical aircraft. This one, particularly, which is an unmanned aircraft, which is designed to fly extremely high altitudes of 100,000 feet and work like a satellite system. The local satellite system. This is the Helios aircraft. This was flew from photoelectric cells. So along the wing, the wing was larger than any commercial aircraft or military aircraft in existence at the time. This this aircraft had photoelectric cells across the whole wing. And as you can see, the wing bent a lot during flight. But it was made of composites and it was a great design.

And more recently, Rolls-Royce have been involved in a project called the Spirit Aircraft or the Spirit of Innovation. And this was an aircraft which became the world's fastest aircraft, and it recently flew in 2021 and got a top speed of 345 miles per hour. So at the moment, electrically, that's the fastest an aircraft has ever flown. And one of the areas we're looking at when we did our research was how can we make an aircraft fly fast using electrical propulsion? And that's really what this is about. When I say fast, twice that speed is what we're trying to think about.

So. The main categories of aircraft and electrical propulsion, I know from speaking just earlier, there are quite a few members here in the in the audience who have already worked in this area and have some experience in this these type of aircraft. So the main categories, the electrical propulsion, are applicable to uncrewed aircraft. And you see those mainly like small drones and quadcopters, uh, fixed wing uncrewed aircraft. Model aircraft. And then we have electric powered light aircraft. So aircraft, which typically fire for about 40 minutes or an hour. And they can be used to train people in flying around. So they have flight training. Very useful way to use an aircraft. The Pipistrel Velis is an aircraft of that type. And then some more exciting aircraft, really. The Lilium Jet, which is a German aircraft, has a whole series of small electric jets like fans along the leading edge of the wings, the tail planes that generate lift using it. Now, when you have lots and lots of fans arranged like that, that's called distributed thrust. And if they're ranged at the trailing edge of a wing, they can ingest all the turbulent air and it makes the wing very, very efficient. So this is a very interesting aircraft to look at and also is a very efficient aircraft considering it can do vertical take-off.

Then there's regional air mobility. And regional aircraft are generally aircraft, which can take 12 20 people, passengers enroute locally. Now, a company that's working on that based one of the most successful companies is working on regional areas called Zeroavia. And they're based in down by Bedford, and they are working on designing small regional aircraft. They've had some success and have flown some aircraft and their aircraft are good. They're working well and they're based basically on different types of fuel types, like hydrogen and using hydrogen fuel cells.

And then there are future aircraft which none are flying at the moment. Which of the plans of of aircraft manufacturers like Airbus and Boeing, which are large commercial passenger aircraft, blended wing body concepts, blended wing bodies, when the fuselage on the wings are blended together to gain less drag and more lift. And in that way, you can achieve 30 to 40% savings to what you call a traditional tube and wing aircraft. And if you can do that, you can you can fly further and you can also incorporate distributed thrust in those aircraft. So they are very good type of concept.

So what I like to do now is discuss, having set that scene, what we've been doing for the last couple of years, three years actually now at Wrexham University with regard to electrical propulsion, and you may have seen and as you came in, you saw some of the components there. We have been working on a thing called the Fast Fan Project. It's a project which really happened throughout the COVID period. It was mostly done as Neil was a he was our Associate Dean at the time when this happened. And it was, if anything, it's been designed by Teams meetings this has. So it's it was quite an undertaking at the time.

Yes. Well, what we did is we come up with some concepts for how can we make an electrical aircraft fly quickly, because really, and when it comes to a form of transport, aircraft are really only beneficial because they're a very quick form of transport. And to fly quickly in an aircraft, and I know there are some real experts and, uh, who would probably like to pitch in a bit later in the question time. And one of our visiting professors is a pilot will be, his ears will prick up now, I think. So to fly quickly as an aircraft, it's very important to fly high. If you fly high, the density of the air is less and the drag is less and you can fly more quickly. And this was you know, this isn't the concept I've come up with. This is the concept which formed the jet engine, that the jet engine was based on that. And when I say fly high, we're talking about flying the top of the troposphere, which is about 30, 35000 feet, or even above there into the stratosphere which is typically above 36000 feet and that's why when you go flying on an aircraft, a jet aircraft, you'll be flying somewhere between 33 and 42,000 feet for the most of the time, depending on the aircraft and what stage you're flying at.

So we wanted to look at that. We knew that it's important to have an open intake with no structure here, with bearings on it. We also knew that it had to be light in weight and be able to put a lot of power into the air because jet engines put an awful lot of power into the air. But they do this by pouring fuel in, pressurising air to a high density and then burning the fuel and expanding the fuel through a turbine and out of a nozzle.

So what we needed to do was design an energiser unit that could do this. And the best way we thought of doing that was to have rim driven. And this here you can see is a suction through this actual motor here where we drive the rim of the fan, we drive this rim. And this what is seen here is white gubbins, really, that's the electrical circuitry of the motor which drives the rim. And there's a gap between the two, called the air gap and typically an electric motor, that's the very, very thin air gap, one millimetre or less. And we knew this would be a very difficult thing to achieve for something which would be loaded and it's likely to try and structurally flex. And what I mean by that is the fan blades. Fan blades typically want to move. They want to stretch. They want to extend them under centrifugal forces, under the aerodynamic forces of thrust they want to bend. And they also under the inertial forces, they want to sheer. So they've got everything going on there. And if you have a firm which is driven at the hub. All those loads are on the fan at the root. They're all carried at the root at the hub of the of the fan. And we thought ,well, you know, the best way to do this is to drive it from the rim. Because driving it from the rim would help us to alleviate loads and also make more air go through a smaller frontal area.

So that's what we were really after. So we decided to call that a rim-driven fan, the name, you'll hear from fans spoken a lot of these days. The actual term name, rim-driven fan came from Wrexham University, we’re the first to call anything a rim-driven fan.

So. This is the rim-driven fan technology and it's the range that we drive from the rim. And I'll go into a little bit more detail about how that's done. But typically this is what we were looking at. If you look at an ancient water where the force is at the rim, you need less force because of the leverage at the rim of a fan or of a device than what you do if you're trying to turn it from the centre. So if you've got a heavy wheel and you try to turn from the centre, it feels like put a lot of force. What you're actually doing is you are putting a lot of force but you're trying to generate a torque, and the torque is that force time to distance from where it's rotating and if you're doing it right, where it rotates, the pivot way rotates, you have to apply a lot of force to get the same torque.

Or the alternative is apply a little force at the rim when you've got a big lever arm. But you'd have to do it very, very quickly. That's the difference. You have to apply that force many times, very, very quickly, all around the rim in the water wheel, it's doing it slowly and it's just doing it at one place on the rim. But you can imagine every bucket receiving a force. That's essentially what an electric motor like the rim driven fan’s doing. It's being pushed all the way round all the time. So that's how we've looked at the water wheel.

Now, this is good for driving a motor, but it's not a good way to generate electricity. So a motor running the other way around is an electrical generator. So a good electrical generator is what we have now, wind turbines. So they drive the turbines, drive them out in the motors in the centre. That's good because the leverage is working in the right direction then.

Another aspect we looked at was we thought, well, in order to get the fan and this the right forces maximum force, we could get in this gap. And remember, that gaps big for electric motor. It's really well quite a magnitude bigger than what you would get on an electric motor, that gap. But we wanted to make sure that gap had enough flux in it to make the most effective. But we also wanted to make sure that the motors weren’t too powerful. That's really, really important. And it took us a while to realise that that if the motor is too powerful, it's going to be too heavy. We're going to be taking too much current. We have to make it just powerful enough to do exactly what we wanted it to do. And that took a while to work out the equations and to come up with a formula to be able to achieve that.

So what we needed to do is make sure we got a lot of magnetism into that gap. So we looked around and we noticed that in particle accelerators, such as the lenses that they use in particle accelerators, just like in the Cornell electron storage ring or in CERN, they use a pattern called the Halbach array of magnets. And we decided to put a Halbach array of magnets, which essentially is an arrangement of the north and south poles of a magnet and such an arrangement that they throw the magnetism out one side of the rotor. In our case, the rotor has the magnets on it and not the other side. Now, the benefit of that is that traditionally the way that that's achieved is by putting a lot of steel in, in a rotor. And the rotor that steel acts like a mirror reflects the magnetism in the direction of the gap. And what we did was we decided to take the steel out to make it lighter and just put the magnets in and put some really powerful magnets and which are rare earth magnets, neodymium iron, cobalt magnets, and manufacture them, put them onto the rim of the rotor. Here's the rim of a rotor here. Put them onto the rim of a rotor all the way round in a Halbach array pattern. And totally uninterrupted. And that way we would get a sinusoidal magnetic pattern all the way around the rim. And that was an excellent way of getting the magnetism there. And when we put that into our final element models for designing the motors, we found that we could achieve that maximum torque we wanted to achieve and not exceed it and make the rotors very, very light indeed. So that's what we did.

One other thing which enables the electrical propulsion to happen is the great advances happened to lithium ion batteries, and that has come down through the use of mobile telephones and the commercial opportunities there to develop lithium ion batteries, that’s enabled the electrical propulsion or pure electric propulsion to actually be possible. So it's important to note that, you know, if we were trying to do this with alkaline batteries or like other batteries, it’d be impossible to make an aircraft fly. But now it is possible. And the thing that they have batteries on, really important plot that we've looked at throughout and for electrical propulsion, it's a thing called a Ragone plot. A Reagan plot is basically plots the power density of any device against energy density and gives you an idea of how much power a device can give and how much energy can give. Now, that may not sound very important, but plotting one against the other. It does give you an idea of the performance. Electrical performance of these devices and batteries are typically energy density strong, but not power density strong and capacitors of the opposite way round. So we tend to want to make our systems for our lack of electrical propulsion for unmanned aircraft, a combination of these two things capacitors and batteries, so that we can get to where the ultimate goal is to be, where in the top right hand corner of such a chart where typically internal combustion engines are.

So what are the advantages of having a rim driven fan? Typically an increase in thrust per frontal area. And that's what we're going for. We get more thrust per frontal area we can fly faster than other aircraft, because there'll be less drag on the aircraft and less momentum drag in the engine. A shorter overall length compared to actual motored engines , our fans are much, much shorter in length. So we have reduced motor forces and that comes from having the force is at the rim of the motor. Improved fan aerodynamics, and that comes from having closed ends to the blades for the most part. So, for instance, if you look here, the blades, there's no cap at the blades, but it turns inside the shroud. And because of that, it's much, much more efficient. The closed blades increased the pressure, decrease the leakages.

Also because the winder’s arranged around the outside of the motor, the motors run very, very cool and the air cooled. They run cool because they need less force, they have less current introduced into the wires because less force is required and it's the current that heats the wires up. And it's easy to install two contra rotating rim driven fans in tandem.

But as the big disadvantage or a possible disadvantage would be their weight, if you don't optimise them, they're not optimised correctly for the amount of torque that you want to be able to produce. And this is a cutaway view of the fan that we designed and we've worked on, this fan here is of this design. And the cutaway view shows two rim-driven motors driving fans in tandem and in between a piece of stationary structure called the Stator. And the stator is designed with air force for a special angle to enable the air coming from the first fan to impinge on the second fan at the right angle to make it as efficient as possible. And the calculation of that is done through a what we call a 2D method of 2D pitch calculation method for the air force and defining the weight. And then once we is done that and made it, we then model that using CFD to check that it would work okay. And then finally we went to testing it.

So right at the centre of the fan is the energised section that I was discussing before and this is really, really important is energise the section that's the heart of the fan and as much torque as we can, we try to deliver as much torque as possible into the volume, into an entrained volume, which is slowly decreasing. You can see this is conical in shape. And what that does is it decreases the swept volume of the fan. That's very, very important for getting high speed. Once you decrease that swept volume, the torque, which is for the engineering students, engineers here, the units of which is Newton metres, if you divide that by the volume metres cubed, you'll get pressure, Newtons per metre squared. And that's what we were designing for. So we designed that central conical part. Just to the right dimensions so that the volume decreased enough for us to increase the pressure to get to the speeds we want. And you don't have to increase the pressure very, very much to get to a high speed when you're flying in the jet engine in your aircraft, for instance, going say, on holiday in an A320, the actual fan pressure rise is only 1.65 across the fan. So that means it's 1.65, the pressure of what comes into the fan.

If you were to look at the compressor inside the jet engine, that's completely different. That pressurised can be about 40 to 1. So the compressor is just compressing air so that you can burn it. In our case, we don't compressed air to burn it. We just compress the air as much as you need to make the aircraft fly fast.

In other areas in the entrained duct gradually decreases in volume. Closed fan tips minimise the pressure leakages, the control rotation of the fans, the fact that one fan's going in one direction, the others rotate in the other direction actually straightens the air out because the first fans spins air like a corkscrew and the fan behind it unspins the air and straightens out because we actually want the vector of the thrust coming directly out the back like a laser beam comes out the back. And in the case of this fan, you see it running later. You can actually see that we've achieved that quite remarkably, I think.

The relative rotor speeds can be independently modulated to control fan performance. That's another area that we can drive these motors independent of each other in a jet engine, typically, they're all in the same shafts or the rotors have to rotate at the same speed or you have to introduce another rotor usually with inside that rotor. Concentrically, but in this case, the shafts don't rotate. And that's a real big advantage. Having stationary shafts prevent them from wobbling and prevent vibration. And so if we can contra rotate them and if we can independently change speeds, then what that means is that we can change those speeds and not have to change the Central stator guide vane angles. As you go through a different range of speeds, as you fly, you can actually adjust the speeds and change the vector triangles rather than change the central guidance.

And in common with turbo jet engines, the FAST Fan design should benefit from what we call ram effect. And ram effect goes back to what I was saying about flying high altitude. When you fly at high speeds of the jet aircraft, the air starts to increase the pressure at the front of the engine if you increase the pressure in front of the engine, you'll increase the pressure on the back of the engine because essentially the engine is a pressure multiplier. It's an amplifier of air pressure. So the faster you go, the better it gets. That doesn't go on forever. It reaches a point when the thrust equals the drag and then you're stuck at that speed.

And cooling air enters vents on the outer surfaces here and runs past the windings and comes out. The cooling air comes out in the Efflux of the jet because the cooling would be slightly warmer. You introduce more energy into Jet efflux and there's a slight increase in efficiency because of it. So those are the main benefits of the FAST Fan that we've been working on, and that's what we aimed at getting. We knew those benefits before we tried designing it, but it's I guess at this point it's important to note that at the time we were doing that, there's never been a rim driven fan, driven like this. There have been some rim driven propellers, but not a fan for propulsion for an aircraft. So there was a fundamental thing. We didn't know whether it was going to work and lots and lots of advice and people would tell you why it wouldn't work and you can look at it and say, Yeah, that makes sense. Vibration, not enough magnetism in the in the gaps and the centrifugal load to be too high. There are lots and lots of reasons given why it could fail, potentially, the whole thing would be too heavy. The copper windings would be too heavy.

But when you go through a period of development, you have to mitigate each of those and think about them. And what we did is we change from using, say, copper windings to using aluminium windings. We took away iron where we didn't need it, and motor designers couldn't believe we would take an iron out of a motor because it's against their instincts to do that. But if you take it with a fresh pair of eyes from an aerospace perspective rather than a motor design perspective, that helps because you know your main priorities, light weight, make it as light as possible and as much effort as you can into just making it do exactly what it's got to do.

So these are the previous slide shows, the analytical methods that we used and the research assistant on this project who did a lot of this CFD work and the finite element worker is sitting here in the audience, Paolo Roque, and you'll see his picture a bit later. So full credit is great.

So we verified what we were doing. We were very happy. We had a lot of these kind of high five moments when these things happened. It's hard to explain now, but it was really good to see, to see it work and then coming together. And we used CFD and all the latest computer programs to design this fan. And then we went into our little workshop at the end here at the end of this block, which is soon to be demolished actually, and started making parts and assembling parts and using things on the lathe and on the millers and giant machines and putting them together. We had collaborating partners, helping them working as well with us. A lot of what we did is 3D printed about at least 80% of this film has been 3D printed, which made it an undertaking for a university that could be done; normally to make the essentially a jet engine would only be something done by a large corporation. But universities can do that now. We can you know, that's one of the wonderful things about the modern techniques which are available.

Here is some more of the equipment that we made. We had to make special tooling. Some of these tooling, we've got IP patents for, the companies that we work we work for we worked with and asked to do them, the magnets, for instance, on the rims. This is one of the rims. They've never done one before. They've never done a rotor that didn't have a middle. And so we designed a middle and made this here in our workshops. And this is a special centrepiece that you can actually put the magnets on wind it with carbon fibre crushed, within the elastic limits of crust, the rim about point three of a millimetre. And then if you notice, this is tapered so you can release it and then get the rim off. And when we were doing that, there was a lot of a lot of people thought the whole thing would just collapse. And luckily it didn't, down to the calculations. It all worked out really well and that was another high five moment is really good.

And what that meant was that that rim would never move when it was being driven at really high speeds. It wouldn't move. It would stay the same geometrically, the same something which is one of the other problems we needed to mitigate because a lot of people thought there'd be a lot of movement in the in the rotors when they are operating under a lot of high speed. So we made rigs and jigs and balanced the wheels and wound the wheels of carbon fibre to maintain the magnet. So the motors are lightweight and incorporate minimal iron stators there. They’re multi slotted. That means they've got lots of slots, a bit like a comb, they’re multi slotted and that gives you very, very smooth and that gives you very, very smooth wave, magnetic wave. They operate from a higher supply voltage by operating from a high supply voltage, they have a very low current is required to get the same power and the resulting compact concept demonstrated this one at the end here, the concept demonstrator, is actually a 30 kilowatt engine, so it's about the same power as you might have in a small car, which is gives a lot of power for a small such a small engine.

And here's a video of it operating. I don't think it's that noisy. But if you if you are particular to noises, high pitched noises, you can cover your ears. If you're sensitive to that, but see what you think.

\*plays fan video\*

Okay, that's a short demonstration done on the motor. During that run, the motor went up to 10,000 R.P.M. That's 167 revs per second and had two motors doing that. It's although it looks powerful that it's well within its capabilities, it's only operating at 10,000 R.P.M when it’s designed for 15,000 R.P.M. and the thrust was about one third of what it will achieve at 15,000 R.P.M. The air speed coming out the back of just it running essentially was partly a tick over for it was 165 miles an hour. In actual fact, we need to get a new metre because it wouldn’t register any faster than that.

And that's the first time ever in the world that a rim driven fan has ever achieved 10,000 RPM.

And we actually have students working on this. And this is the design of the Quest aircraft, which is being designed to be an unmanned aircraft, which would enable that fan to fly. And some of the students in the audience at the moment, if you want to just give us a wave.

So. Yeah. So that's being built at the moment here. The fan can be made larger and it can be increased. And if you increase diameter about two foot, and run it at the highest speeds that that will give you, then a fan of about two foot intake diameter, 600mm, would give you close to one tonne of thrust. And if you want that in perspective, say a dozen of those fans which are relatively small on the trailing edge of a blended win body aircraft could make it quite a large aircraft fly and take passengers so it could be used for regional and commercial aviation.

So. We built this and have shared all the papers that we've done with this. And the thing with climate change is that climate change has come about as we initially started, because the devices have been engineered. So engineering has really been taking a lot of responsibility for making climate change happen through the Industrial Revolution. But it's also most likely to be sorted out by engineering as well. So we've got to start applying ourselves to that. And this is what we've been doing at Wrexham University. And we've made all the research that we've done with regard to this and the calculations freely available. And I know it's been taken up worldwide. I'm and contacted on a regular basis with people wanting to know how to access papers and I send them to the repository. And they can use that and do use the calculations and then do further publications.

So the whole project was with grateful acknowledgement to the Welsh Government, who with their net zero ambitions, have funded this and made sure that it worked well for us. I also need to thank other people as well. I need to thank our collaborating partners. We had six collaborating industrial partners have Ad-Manum UAS Technologies, Invertek Drives Ltd.(of Welshpool), Motor Design Ltd., just across the way here in Wrexham. We also had Drone Flight up in Cumbria and we also did work on the project Geola Technology Ltd, Geola down in Surrey, yeah..

So that's great. Yeah. But also I'd like to thank the staff here at the university because the staff here at the university supported this with regard to running the project, getting the project underway and also doing the finances through the project as we went through it. And there were lots of ups and downs. So how does this work with you guys. So where do you fit in? Research opportunities. There are lots of research opportunities in aircraft, electrical propulsion, in electrical engineering, in mechanical engineering and computing, business, chemistry, biology, physics and philosophy. And that last one there, the physics and philosophy is the question which I wanted to ask you before we get to that , well no, we’ll go to the questions now. First, the question for me, did anybody get to think of what else might be causing global warming other than C02 gases?

\*audience member answers\*

Yeah, I would say it most definitely is cyclical to a certain extent, but I think the underlying trend seems to be upwards at the moment. But it will still be cyclical, I'm sure.

\*audience member speaks\*

One other thank you I’d forgotten to say is to the research department for setting this up. That's really good. Thank you for all your hard work and for Neil for introducing this. And I think you're going to introduce the questions as well. Okay.

\*applause\*