Europe's new aviation vision: is electric the future?

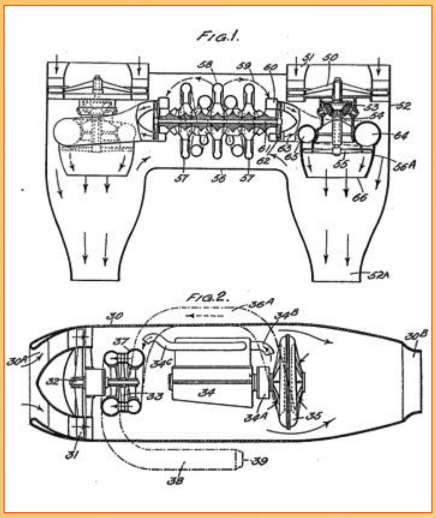
When, not if, we finally exhaust the supply of non-renewable energy sources, how will we continue to travel for work or to see our friends and family across the world? Or maybe more importantly for some, how will we get to the sandy beach we've been sitting at our desks dreaming of?

All fantasies of sandy beaches aside, as the industrial world begins to address this very real and large problem and begins to push towards greener, more environmentally friendly technologies, it is no surprise that there have been success stories in multiple industries. One of many examples, is the rise of electric, hybrid, and fuel cell powered vehicles in the automotive industry. It should not come as a surprise that the aeronautical and aerospace industry is racing to provide greener and more environmentally friendly technologies. A race between rivals in a competitive market to monopolize "green flight" is on but is also being pushed by various regulations and agreements including the European Commission's Flightpath 2050 Vision for Aviation (the Vision) in which the key stakeholders of European aviation have come together to outline the objectives for the future of the aeronautical industry.

Amongst the general goals, the Vision sets out the aims of reducing aviation's impact on citizens and the environment by reducing noise as well as greenhouse gas emissions. In fact, the EU's technical environmental goals are to reduce the emissions of CO2 by 75%, NOX by 90%, and noise by 65%[1].

The aeronautical industry has long been working towards reducing fuel consumption in a bid to save money. Lower fuel consumption equates to a critical saving in weight which can mean less fuel is required or, perhaps more importantly, means more passengers and goods can be carried by the aircraft.

Lower fuel consumptions have so far been achieved by, for example, the use of high-bypass ratio turbofan engines, which were proposed as early as 1936, as evidenced in Frank Whittle's UK patent application no. 471, 368 (below). These high-bypass ratio turbofan engines have been further refined over the years to provide ever increasing fuel efficiency and noise reduction. Other examples for achieving "greener" flight include weight saving on aircraft parts and even in the engines themselves, as well as aerodynamic optimisation.



The reduction targets set out in the Vision are so great that they are unlikely to be achieved by a combination of higher bypass ratio, weight-saving, and aerodynamic optimisation alone. As a result, many companies are looking into the use of bio-fuels. Some in the bio-fuels industry even claim that certain bio-fuels could cut greenhouse emissions by up to 80% compared with traditional jet fuel.

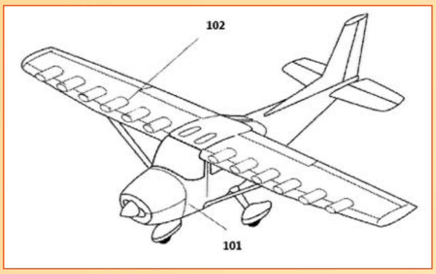
Bio-fuels are, however, associated with several issues:

1. it may take considerable investment to commercialise new technologies to convert biomass, e.g. sugarcane, into bio-fuel;
2. the crops from which the fuel is made would be competing for growing space with crops used to feed the world's population; and
3. the fuel used to power aircraft engines is generally heavier than fuel used to power other vehicles. Hence bio-fuels may not have a cross-industry application, making it difficult to attract investment.

So the question currently being asked is whether the future of aerial transportation is electric powered aircraft? Possibly. Paul Eremenko, Chief Technology Officer of Airbus, clearly thinks so[2]. Airbus, Rolls Royce, and Siemens think that they can solve the problem of reducing CO2, NOX, and noise emissions by replacing a turbofan engine with an electric motor and, in doing so, follow the automotive industry down the route of electric, or at least hybrid, powered vehicles[2]. The name that has been given to this revolutionary project is "The E-Fan X", in which the goal is to replace one of the turbofan engines of a 100-seat BAe146 aircraft with a 2 MW electric motor and Rolls-Royce AE2100 gas turbine to power a 2 MW generator (below).

Electric power is already part of the history of the aeronautical industry. Batteries and electric motors have previously been used to power recreational remote control aircraft and are now even used to operate larger unmanned aerial vehicles for surveillance or search and rescue. There has even been a circumnavigation of the Earth by a fixed-wing aircraft, the Solar Impulse 2, which used solely solar power[3] (below).

Airbus has already designed, built, and flown a 2 seater electric powered aircraft, the E-Fan[4], which was demonstrated at the Farnborough Airshow in 2014. In this technology demonstrator the motors were powered by a series of batteries located in the inboard section of the wing. The batteries were lithium-ion type 18650 with an energy density per battery of 207 Wh/kg and provided total energy of 29 kWh whilst weighing in at 167 kg. This provided up to an hour of flying for an aircraft with a maximum take-off weight of 600 kg. Airbus has also been working on concepts such as the Distributed Electric Ducted Fan Wing (US2017190436) which incorporates ducted fans on the lifting surfaces to enhance aerodynamics and performance (below).



Siemens were also working on solutions for providing electric powered flight before this joint venture was announced. In Siemens' case, the focus was on an electric motor. Back in 2016, an electric powered 2 seater aircraft, an Extra 330LE aerobatic plane, demonstrated Siemens' SPD260D motor (above right). The figures for the new motor were certainly impressive with Siemens reporting that the motor, which weighs only 50 kg, has an output 260 kW at as little as 2,500 rpm[5]. This is 5 times more power than comparable drive systems[6]. The power to weight ratio of over 5 kW/kg is partially due to the finite element analysis conducted to design a new lattice-like structure which was implemented in the end shield of the motor, instead of using the usual aluminium slab, to reduce its weight by half. This is to be reduced by half again using a carbon fibre-reinforced polymer.

Other potential modifications included cobalt-iron alloy stators for high magnetisability, rotor permanent magnets in a Halbach array to direct flux using the minimum amount of material, and conductor cooling provided by electrically non-conductive liquids. The result is a motor that could propel a 4 seater aircraft with a take-off weight of up to 2 tons[6] and that is not far off the 500 kW to 2MW that some estimate would be needed to fly small aircraft regionally.

> **"it is clear that ... electric powered aviation is already well and truly established and is likely to stay"**

From the achievements by the aeronautical industry already, it is clear that, although not common, electric powered aviation is already well and truly established and is likely to stay. So, can the aeronautical industry make the technology work when it is scaled up to power large passenger aircraft and how long will it take? At the time of writing, Airbus, Rolls Royce, and Siemens obviously feel that it is possible. Siemens expects to see aircraft with 100 passengers and a range of 1,000 km by 2030[5] in just over 10 years! More ambitiously, the group is aiming for the E-Fan X project to fly in 2020 with at least one, if not two, of the gas turbine engines replaced by 2 MW electric motors.

The workload for this project is being split between the three companies, each having responsibility for different aspects of the design. Airbus is responsible for the overall integration, as well as control architecture of the hybrid-electric propulsion system and batteries, and its integration with the flight controls. Siemens is responsible for delivery of the 2 MW electric motors and their control unit as well as the power distribution system. Rolls Royce is responsible for the turbo-shaft engine, the 2 MW generator and power electronics, and will also help Airbus with the fan adaptation to the nacelle and the Siemens motor.

This means that rather than the purely electric flight as achieved on the E-Fan and Extra 330LE, the E-Fan X will be hybrid powered. The Rolls Royce AE 2100 Gas Turbine will be housed in the fuselage of the aircraft and will combust fuel, much like the remaining turbofan engines. The energy output of the combusted fuel will then be used to spin the rotor

of the 2MW generator which will generate the electricity used to power the motor. The motor will rotate the fan which will ultimately provide the thrust of the experimental engine.

So, although traditional fuel will still be being burnt, there is likely to be a significant fuel saving during cruise due to the higher efficiency of a gas turbine driven electric motor. When additional power is required, such as during take-off or landing, the additional power is to be provided by the batteries allowing further fuel saving during each flight. Plus, emissions and noise are reduced. In fact, the Head of Flight Demonstrators at Airbus envisages that fuel savings could be in the "double digits" [7]. The savings may be even higher if eventually all the turbofan engines are replaced by the experimental arrangement.

If this project is a success it will be a huge leap forward in electrifying possibly the most complicated form of commercial transport. The project does, however, have some rather large hurdles that must be overcome before it can be deemed a success. Even if it does jump those hurdles, some may still ask why the project is focussed on hybrid power systems and not solely electric powered aircraft? Perhaps the largest hurdle, and reason the project is not focussed on purely electric power, is the batteries.

Simply put, current battery technology does not have a high enough energy density; and the power-to-weight ratio is not high enough. For example, combustible fuels like kerosene have an energy density of roughly 40 MJ/kg, about 12,000 Wh/kg. If you compare the energy density of the lithium-ion batteries which powered the first E-Fan, it is about 60 times less. In other words the specific energy of batteries is roughly 2% that of liquid fuel. Remember, the 167 kg of batteries on the 600 kg E-fan was enough for roughly an hour flying at low speed. In comparison, the operational empty weight of a standard Bae146 is roughly 24,000 kg.

The numbers seem to suggest that the battery weight for an electric aircraft would be 60 times that of the fuel weight for a current aircraft for the same flight. However, this does not take into account the efficiency of electrical motor compared to internal combustion. By some estimates this would reduce the energy densities required by batteries down by between half to three-quarters, before taking into account that an electric motor weighs a lot less than a turbojet engine.

Add to this the fact that there is a slow but consistent increase in battery energy density of 2-3% a year, a battery providing 1,000 Wh/kg, or somewhere between 16-33% the density of kerosene, may be achievable this century. This may be enough to fly up to 100 passengers on short flights.

When this is finally achieved, the way we fly will be changed forever. Airlines using aircraft that make significantly less noise may be able to take-off and land during the night, resulting in more flexible travel. The air quality surrounding airports will also be significantly increased. Even the shape of the aircraft we travel in may be dramatically different as focus would shift towards better optimising aerodynamics and design around the new engines.

A final problem facing electric powered aircraft is whether the industry can be convinced to adopt the technology straight away. The manufacturers appear to want to do so, but whether the airlines do is another story. The uptake of the electric aircraft engine may have many parallels with the treatment of Frank Whittle's jet engine in the 1950s, which was largely ignored at first, as explained in our Spring/Summer 2014 edition.

Either way, the aeronautical industry as a whole appears to be set on making electric powered aircraft a reality. The collaboration of Airbus, Rolls Royce, and Siemens is not unusual. Companies such as EasyJet and Wright Electric or Horizon X and Zumun Aero are also looking to work together towards the common goal of aircraft electrification. Unquestionably, the engineers taking up this challenge will produce innovative solutions to the problem facing the industry and move us towards greener flight. However, unless a significant breakthrough is made in the development of the battery, whether it be new materials, such as magnesium, lithium-metal, or graphene batteries, improved electrolytes, or new architecture which provide vastly improved energy densities; the age of all electric wide-bodied long-haul aircraft still seems to be beyond the horizon.

Whilst this is the case, those same engineers will continue to simultaneously reduce the impact of our liquid fuel engines until we are ready to make the switch to the all-electric variety. It is likely that the innovations from this sector will continue to be directed towards slight improvements on the current aircraft, with those directed towards hybrid and electric technologies constantly increasing. What will be interesting is whether aeronautical companies will decide to patent their future electric technologies or keep them secret until the battery technology is sufficiently advanced for the other innovations to be implemented efficiently. All we can do is wait and see, preferably on that sandy beach...

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