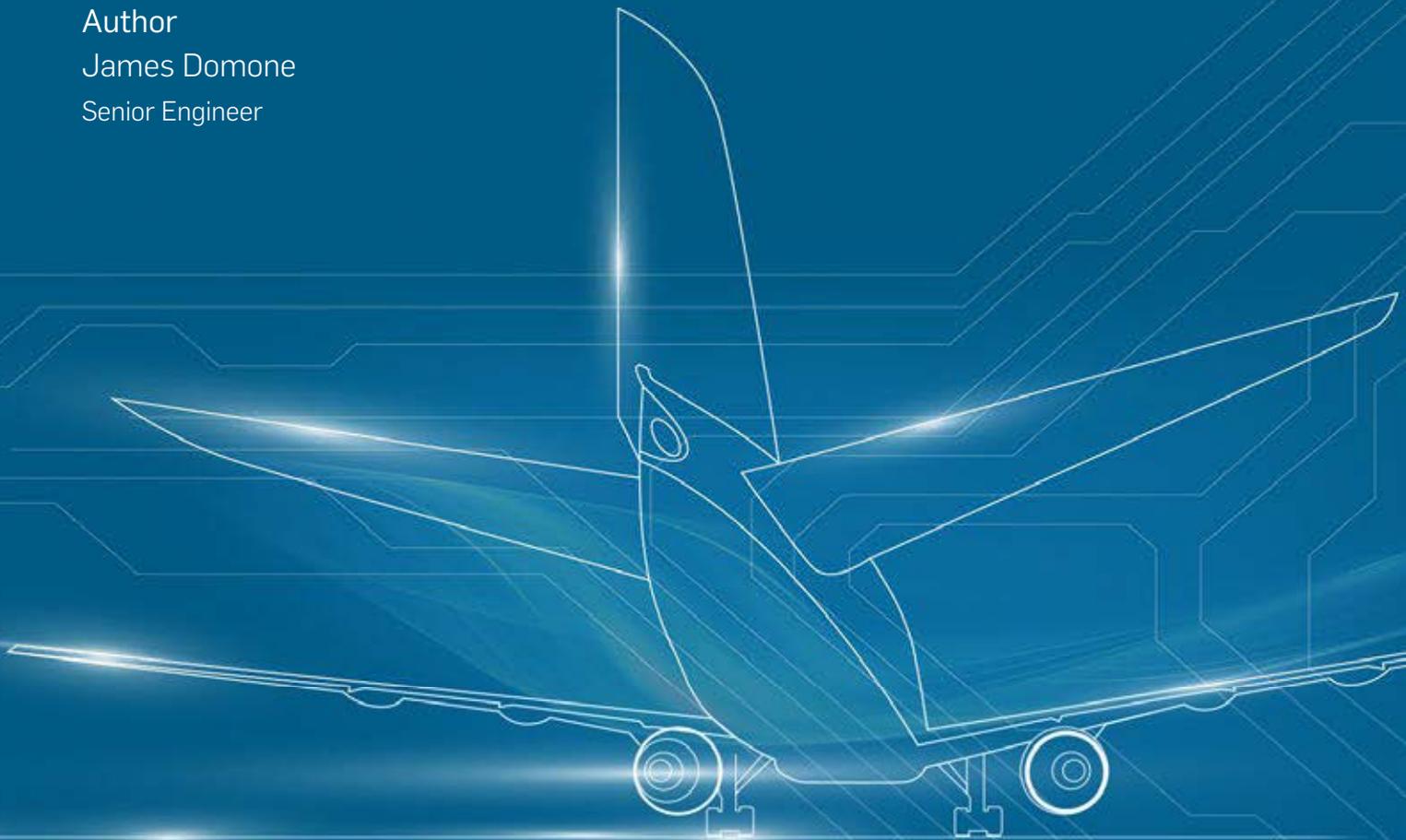


# The challenges and benefits of the electrification of aircraft

No more blue-sky thinking: how and why the aviation sector  
is moving towards cleaner, greener skies

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## About us

SNC-Lavalin's Atkins business is one of the world's most respected design, engineering and project management consultancies. Together, SNC-Lavalin, a global fully integrated professional services and project management company, and Atkins help our clients plan, design and enable major capital projects, and provide expert consultancy that covers the full lifecycle of projects.

With a strong, proven heritage in aerospace design and consultancy services, we have worked on some of the industry's biggest projects. Including: Airbus' A380, A400M and Single Aisle aircraft, and with Marshall Aerospace and Defence Group, Bombardier, BAE Systems, Rolls-Royce and the Royal Air Force.



# Introduction

The earth's climate is changing and our behaviour must also change. That means moving towards cleaner, more efficient, forms of transport.

As road and rail travel shift towards electric, is now the time for aviation to join them?

Each day we see the electric car industry growing apace. In the UK, hybrid and electric cars are becoming a more common sight on our roads, as are electric charging points in car parks. Their price is falling, too. Railway electrification is on the renewal agenda across the UK, because it offers better performance and protection of the environment than diesel trains, as well as reducing noise pollution for people living along busy train lines. So, when will other forms of transport, like shipping, and air travel, join them?

There's no doubt that aircraft emissions cause pollution. The European Union says direct emissions from aviation account for about three per cent of the EU's total greenhouse gas emissions, and more than two per cent of global emissions. Figures suggest that if current technology isn't advanced, then CO<sub>2</sub> output from aircraft will likely increase by two and a half times. This is due mostly to the growing middle classes of China, India, and African and South American countries, who increasingly want to fly. Even when offset by countries seeking to reduce CO<sub>2</sub> output, that still means an overall global rise of CO<sub>2</sub> emissions from aircraft of somewhere in the region of five per cent.

But that's only part of the story. Increased aircraft operations activity in or around where an airport is located also produces emissions that degrade the air quality. The risk comes from the production of nitrous oxides, NO<sub>x</sub>, fine

particulate matter, PM<sub>2.5</sub>, and ozone, O<sub>3</sub>. This is documented widely by scientific evidence; and as a serious risk to public health it must be tackled. The other complaint from residents near airports is noise. More recent aircraft designs have reduced noise levels, but there are still improvements needed.

Anyone taking a return trip from London to New York today will generate roughly the same level of emissions as it takes to heat the average European household for a whole year. By introducing electric battery powered aircraft, the potential exists for charging the batteries using power generated via more sustainable means – such as nuclear, wind, hydro, solar and tidal generation. However, if non-sustainable means of power generation for battery charging are used, then at least potentially harmful emissions are released away from areas with denser populations and the upper atmosphere.

There's also the economic argument. Reducing the quantity of fuel needed reduces the costs of operating an aircraft. This will become more apparent over time if the predicted reduced availability of oil materialises and drives costs ever higher.

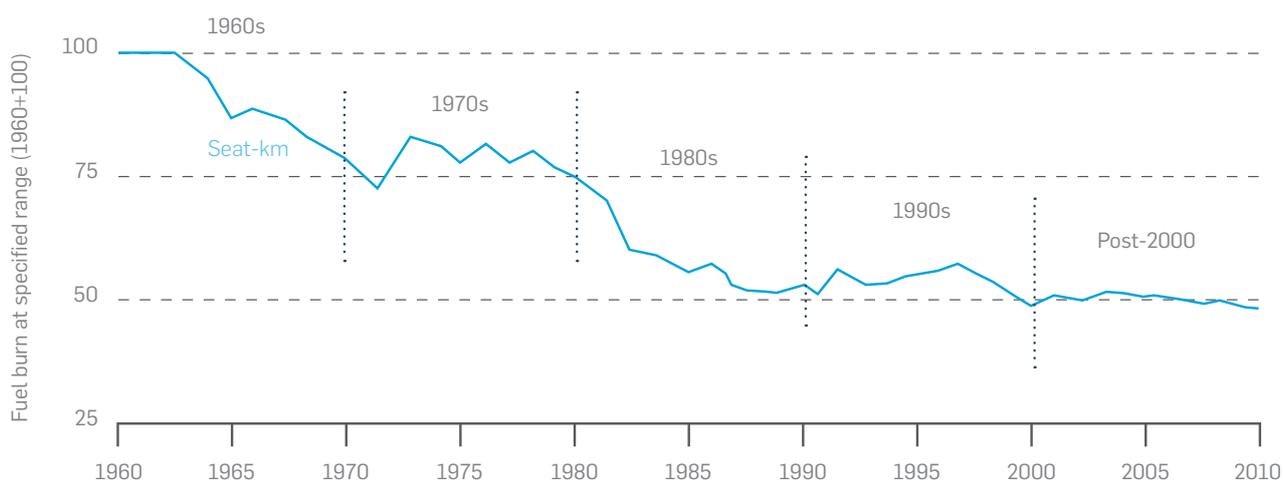
So, there's the target for cleaner air travel: the reduction of CO<sub>2</sub>, NO<sub>x</sub>, PM<sub>2.5</sub> and O<sub>3</sub> emissions, noise and fuel costs. But how can we achieve this when faced with so many technological challenges?

## Going beyond the plateau

Through years of refining and optimising aircraft design, many feel that we've reached a plateau in terms of aircraft performance when it comes to fuel efficiency and aiming for lower emissions. If we look to battery power, like the car industry has, how can we square the circle, and reconcile the fact that batteries are heavy, and planes need to fly? The role of engineering is about finding solutions and solving problems, and to find new and better ways of doing things. To that end, new technologies are emerging, and their prototypes are starting to be tested.

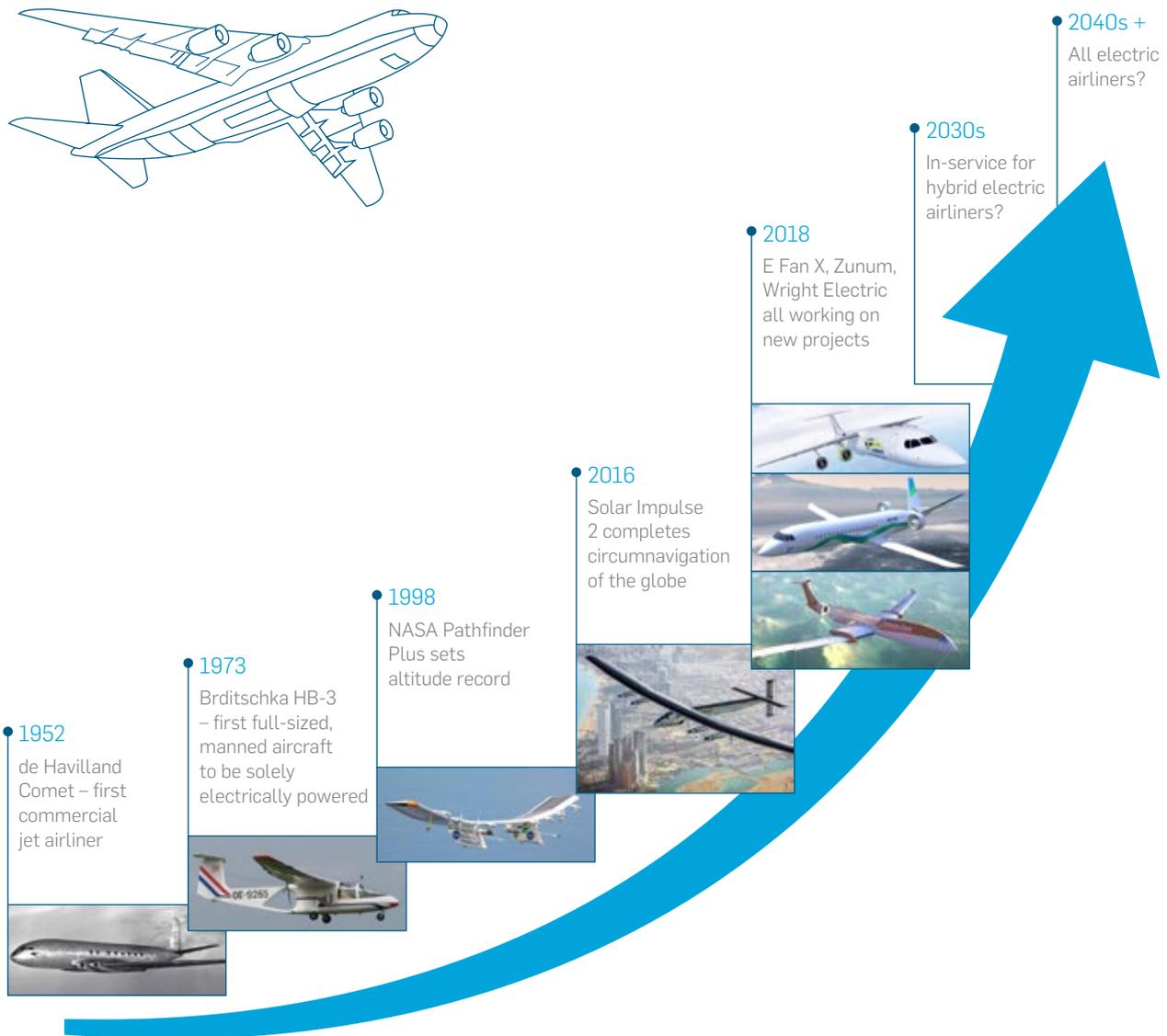
So, what does that mean for those of us in the industry? It means making sure, if you're a company involved with the maintenance, repair and overhaul of aircraft, or you manufacture equipment, or operate an airline or airport, that you must prepare for disruption – but also position yourself to exploit the opportunities that cleaner, greener air travel will bring to the industry.

Unquestionably, there is a united sense of purpose across the European aviation sector to move towards greener solutions that will have proven efficiency and performance and become less reliant on fossil fuels. One example is ACARE, the Advisory Council for Aeronautics Research in Europe, which launched in 2001 and has set itself some challenging environmental goals through its Flightpath 2050 initiative which it is seeking to achieve through joint research projects, by the year 2050. ACARE's members include industry giants Airbus and Rolls-Royce, and its goals range from achieving a seventy-five per cent reduction in CO<sub>2</sub> emissions per passenger to ensuring all aircraft are designed and manufactured to be recyclable.



Average fuel burn for new jet aircraft, 1960-2010.\* Large reductions in fuel burn are seen from 1960 up to the 1990s; however, since then any decrease has been modest, despite the development costs of new aircraft continuing to rise.

\*[www.theicct.org/blogs/staff/overturning-conventional-wisdom-aircraft-efficiency-trends](http://www.theicct.org/blogs/staff/overturning-conventional-wisdom-aircraft-efficiency-trends)



History of electric innovation in aerospace

While it's still early days, key research and development in this area is preparing for take-off, as major players in the aviation sector start to roll-out prototypes and test concepts. Finding an alternative to kerosene, and identifying a sustainable power source, suggests electric power is the first answer. As such, aircraft programmes such as the Airbus A350 and Boeing 787 have increasingly used batteries to power on-board systems.

The 787 also exhibits greater use of electric power from engine installed generators. This approach is described as the 'more-electric aircraft'. Future progression to electric propulsion is increasingly being proposed; first, by considering a hybrid option with energy still provided by hydrocarbon fuel but powering electric propulsion – then, progressing to a fully electric system with batteries providing the energy. In which case, we would start to see reductions in emissions even at the earliest, hybrid, stage, with further gains from a move to full electric systems.



## 'UK-built hybrid electric plane flying by 2020'

In 2017, The Guardian reported that Rolls-Royce has joined the race to develop 'electric passenger jets' and how Rolls-Royce claims its collaboration with Airbus and Siemens on their E-Fan X project could result in a partly UK-built hybrid electric plane flying by 2020.

**"Manufacturers will convert a short-haul passenger jet, paving the way to making commercial air travel running partly on electricity a reality."**

Also, the report says, "engineers involved in the E-Fan X project said the technology could mean cleaner, quieter and cheaper journeys. They also raised the prospect of radically changing aircraft and airport design, allowing air travel to supplant rail for many more intercity journeys."

Also quoted in the article was Carolyn McCall, EasyJet's former chief executive, who said it was

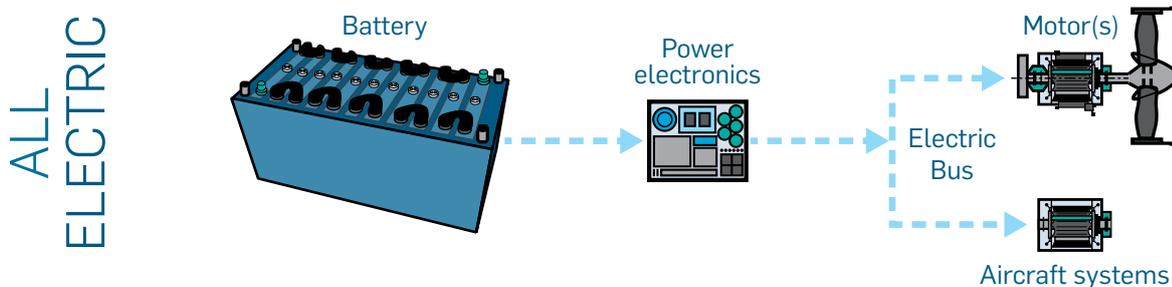
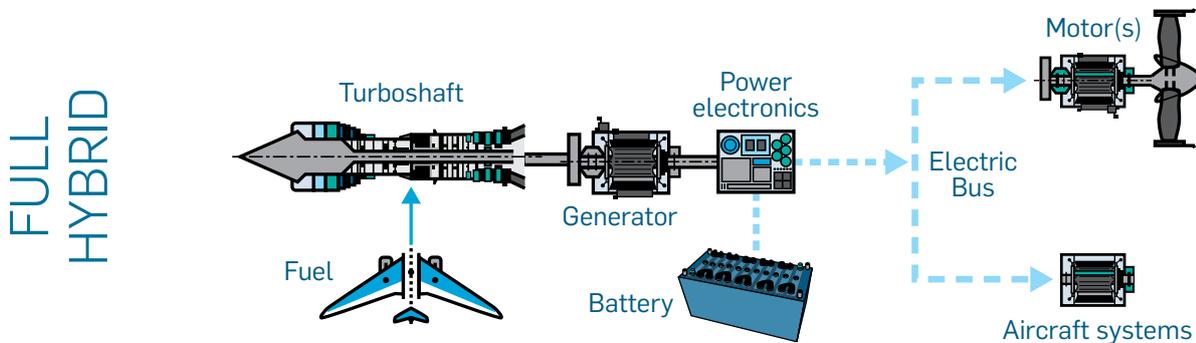
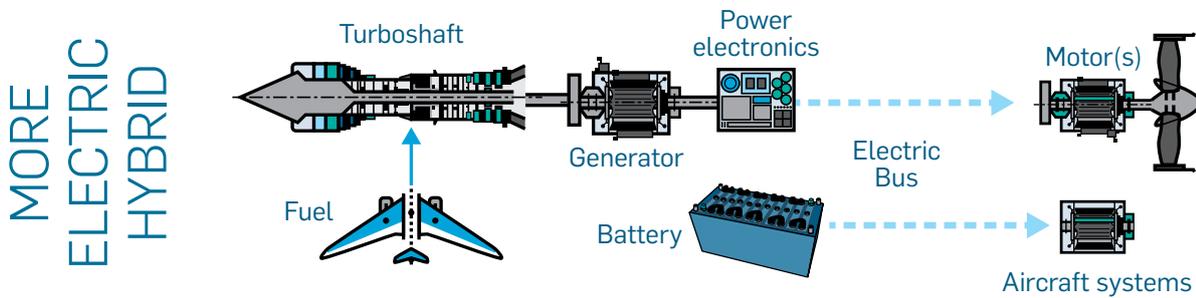
**"a matter of when, not if, a short-haul electric plane will fly."**

And later, in April 2018, Siemens announced: "The world's first flying serial-hybrid aircraft landed its maiden flight at Matkópuszta airfield in Hungary, powered by a Siemens propulsion system. This hybrid Magnus eFusion is equipped with a Siemens SP55D electric motor and a FlyEco diesel engine to allow for silent take-off and landing with an extended range. The complete propulsion system including a new generator, inverters and control systems has been developed by Siemens eAircraft and is expected to provide meaningful insights into the application of hybrid-electric systems for aircraft during future operation."

# Powerful, yet lightweight

The key phrase here is 'complete propulsion system'. In technical terms, the challenge that E-Fan X and other projects of its kind that are also in the pipeline – such as the Magnus eFusion, Zunum Aero and Wright Electric – are faced with the question of power to weight ratios; a fully electric system requires batteries with greater energy densities than those currently available that are fully reliable and have a long life.

Predictions of when appropriate batteries might be available for all-electric larger aircraft, and even the specific technologies that will be used, vary widely – and historical judgement, combined with the current understanding of aircraft development cycles, suggest such batteries won't be available until at least the late 2030s. Full-integration with an aircraft and potential in-service dates would likely stretch further into the 2040s.



Three potential system architectures are shown with a progression from the 'More Electric – Hybrid' to 'Full Hybrid' to 'All Electric'. There are varying development needs for each system component and a large integration challenge for the complete systems. While other proposals for hybrid systems exist, those presented here are considered the most feasible at present.

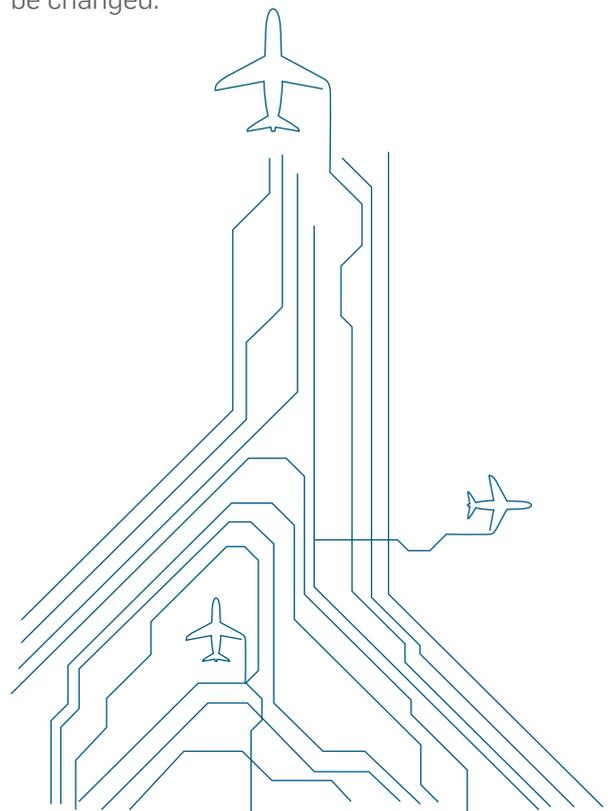
A hybrid-powered solution is much more likely to be available sooner. This could deliver real benefit through reduced emissions. It would also allow for the development of electric propulsion motors and power electronics so that these would be ready for the switch to full electric operation. Let's look at the system level integration of a hybrid-powered solution within an aircraft.

The gas turbine and the electrical generator, which are existing and understood solutions, are put together. Jet fuel – kerosene, which could include biofuels for further environmental benefit – powers the gas turbine, which drives the electrical generator. A new power electronics system is likely to be required to then transfer this electrical energy to new electric motors to provide thrust. A 'More Electric-Hybrid' system could extend the use of batteries to power all remaining systems on the aircraft. A 'Full Hybrid' solution would combine the power available from the generator and batteries to power all aircraft systems, with each means of energy supply augmenting the other in different ratios during different flight phases. Both architectures can collectively be described as hybrid solutions, with a high likelihood that prototype testing will enable the jump straight to the Full Hybrid solution with electrical energy being combined from both sources to power all systems. So, where does the emission reduction come from if kerosene is still providing the energy?

In this case, when we consider how the aircraft's flight will be affected by a variety of different thrust requirements that are needed for take-off, climb and cruise, as well as different air flows coming onto the aircraft, changes in altitude, and varying aircraft design – the current generation of gas turbine engines are designed to operate in all these conditions, but do not function with optimal efficiency in all cases. In a hybrid solution, the gas turbine could be kept relatively isolated from those shifting conditions, so that its only job is to power a generator and it can run at an optimised, single speed. Then, in turn, it would

power an electrical generator that drives the conversion systems needed to give electrical energy.

A risk to this approach would be the reliance on unproven power distribution systems and high power electric motors – but this is one of the issues being addressed through prototype development, such as with the Airbus E-Fan X, which does so initially by switching one, of four, engines to be powered in this way. This system could then be developed by changing the energy source from a kerosene powered gas turbine and generator to the use of batteries in an 'All Electric' system. If suitable battery technology does not emerge, the system also presents the option of switching the kerosene for hydrogen. This is not without its own challenges, including the supporting infrastructure, but moves towards the same goal of (harmful) emission free flight, with water vapour as the by-product. With an 'All Electric' system, the initial conversion electronics may then need to be adjusted from the hybrid solutions, but the propulsive element of the system wouldn't have to be changed.



## A 50kg electric motor

Siemens has already developed a new type of electric motor that, with a weight of just fifty kilograms, delivers a continuous output of about two hundred and sixty kilowatts – five times more than comparable weight systems – using a hybrid-electric propulsion system. While this is pushing at boundaries, it's important to remain realistic: two hundred and sixty kilowatts is a small amount compared to what's needed to power a commercial aircraft – anything from two to fifty megawatts. But the company says it is determined to establish hybrid-electric propulsion systems for aircraft as a future area of business, in its ongoing drive to get the weight down – so this without doubt marks a significant step forward.

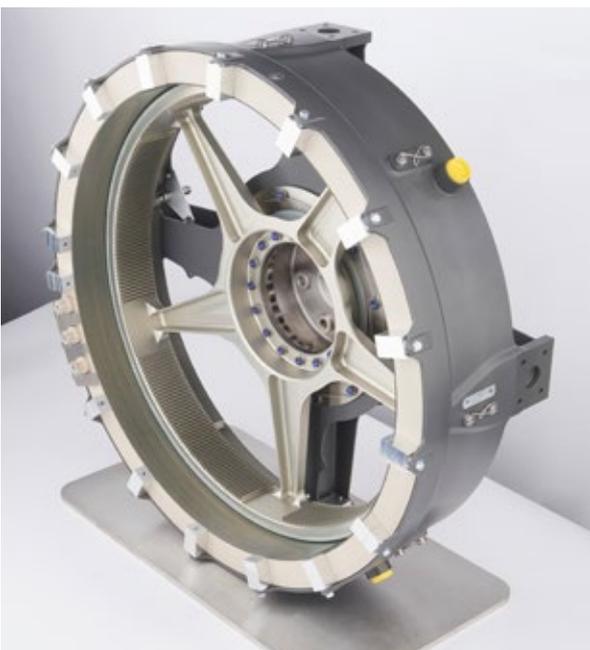
But can enough power be generated through improved technology, bearing in mind the size of existing jet engines, to power planes to fly at acceptable speeds, and at an acceptable overall weight? And what about safety considerations with electrical systems, such as wiring routes, redundancy considerations, electrical interference – or faults – and the thermal environment from heat generated by batteries.



## Longer, thinner wings

One key aspect of design here is in the distribution of the energy supply system. Aeroplane wings are tuned to withstand aerodynamic and mass loads – today, they carry distributed jet fuel – but what could be the effects on wings if they have to carry batteries, instead of fuel? One possible answer could result in a very positive side-effect. Currently, jet fuel in the wings depletes as the flight continues, and the structure of the wing accounts for that. Batteries could help in a future wing because they'd be a fixed mass throughout the flight; and adding their mass into the wing could help with aeroelastic tailoring. That means there's a possibility of tuning the wings to make them more aerodynamically efficient by allowing them to become longer and thinner.

While, historically, this type of shift in design would have made a jet-fuelled aircraft more prone to 'flutter' – a physical phenomenon whereby a build-up of wing oscillations can break them away from the main structure – with the strategically-placed, immovable, batteries on thinner wings, a more efficient, aerodynamic shape could emerge that won't succumb to flutter and improves aerodynamics. The change to an electrical system could also enable distributed propulsion allowing radically different aircraft configurations.



## The challenge of reducing airframe mass

Next, what about weight? Let's say we reach the hybrid system. The full propulsion and electrical system, combining all the technical operation equipment inside the aircraft, would almost certainly become heavier than the current systems it replaces. Also, the aircraft will land at a higher proportion of the take-off weight compared to today's aircraft, due to the batteries. Some estimates suggest that to compensate for these effects we'd need to reduce the airframe mass by around twenty per cent. The potential reductions required for a full electric system are greater still.

This would be a huge challenge. Structurally, today's aeroplanes have reached a plateau: a large effort is required for minimal mass reductions. That means the next step must be in advancing materials science and asking how much the physical properties of structural materials might be pushed. We must look at the full capabilities of future metallic alloys and fibre reinforced plastics.



## Funding future flight

A further important point to consider is funding, and the importance of co-ordinated effort to ensure a collaborative, knowledge-sharing approach that leads to conformity in standards and the emergence of the best solutions. The good news is, as a major player in aerospace Research & Development, the UK is engaged in extensive research networks and partnerships, and bids into numerous funding bodies – from university grant funding to industry-level consortia – working on developing the future technologies of air travel.

Such bodies include the Engineering and Physical Sciences Research Council (EPSRC) and the Aerospace Technology Institute (ATI), which was established as a collaboration between government and industry to create the UK's aerospace technology strategy through £3.9 billion of investment. Another is the Air Transportation Systems Lab\*, which collaborates on research projects with universities in the UK and overseas.

Further, Airbus' BLADE and Safran's Contra-Rotating Open Rotor engine are just two examples of very many projects backed by the EU's €4 billion Clean Sky initiative, a 'research powerhouse for greener aircraft' which is the largest European research programme developing innovative, cutting-edge technology aimed at reducing aeroplane gas emissions and noise levels.

\*[www.atslab.org](http://www.atslab.org)

## The view from the ground

The sheer size and breadth of these funding pools certainly suggests a financial confidence in developing future cleaner air travel, but that's just one part of the overall story. Maintenance, repair and overhaul companies should also be alive to the potential opportunities in, and far-reaching consequences of, the new world of air travel from another position: services on the ground. What kind of physical infrastructure will we need to support this game-changing technology? From supporting spare battery capacity to locating recharging points? How long between flights will it take for batteries to be changed, or charged? Will flight times be dramatically affected? What happens when flights are diverted?

Could greener air travel lead to an expansion of essential support locations across the world? And, could quieter planes in our skies mean more runways are built to connect-up our major cities? And what about the important issues of safety, and instilling confidence in flying passengers about the new technology, where combustible fuel is taken out of the equation, but new technology is put in? And what kind of air travel will take priority? Large civil aircraft, on-demand air taxis, or commuter traffic?



## Fasten your seatbelts, there may be turbulence

The challenge of integration is, arguably, the biggest challenge of all. How will all the new technology integrate with legacy systems, design, and infrastructure? When engineers and designers have the new technologies refined and ready for flight, how does the industry then support in-service operation? And, as an aviation company, what will your business model need to look like over the next five, ten or twenty years, when that time comes? When is the optimal time to start thinking about how to integrate your business model strategically with this major shift in aircraft architecture and supply chain?

Because, alongside understanding the technological barriers and breakthroughs – while it may be fifteen or twenty years away, change of this nature will be, without doubt, disruptive right across our industry, and that isn't a lot of time when you consider how long new aircraft developments can take. But disruption also brings opportunity: and forward-looking companies will need to take the time to understand and map-out what's on the horizon, and pinpoint where activity can connect.

As that green-sky future moves closer, forward-looking companies will also need to seek professional support in terms of traditional aviation engineering knowledge and integration capability, as well as support from business consulting and change management experts. Atkins is in a great position to help with the transition to green aviation, and across many different aspects. We are involved in developing cutting-edge vehicle engineering as well as aircraft design and systems analysis. There is going to be both turbulence and enormous opportunities ahead as the electrification of aircraft slowly becomes a reality, so it's important to be prepared, to ensure a smooth flight.

## About the author



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James Domone is a senior engineer in aerospace design, security and technology for Atkins, a member of the SNC-Lavalin Group that is working to transform aerospace engineering for faster design, reduced downtime, and lower costs.

Transforming aerospace engineering, for faster design, reduced downtime and lower costs.

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