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No more blue-sky thinking

The role that electrification plays as the aerospace sector moves towards cleaner, greener skies.

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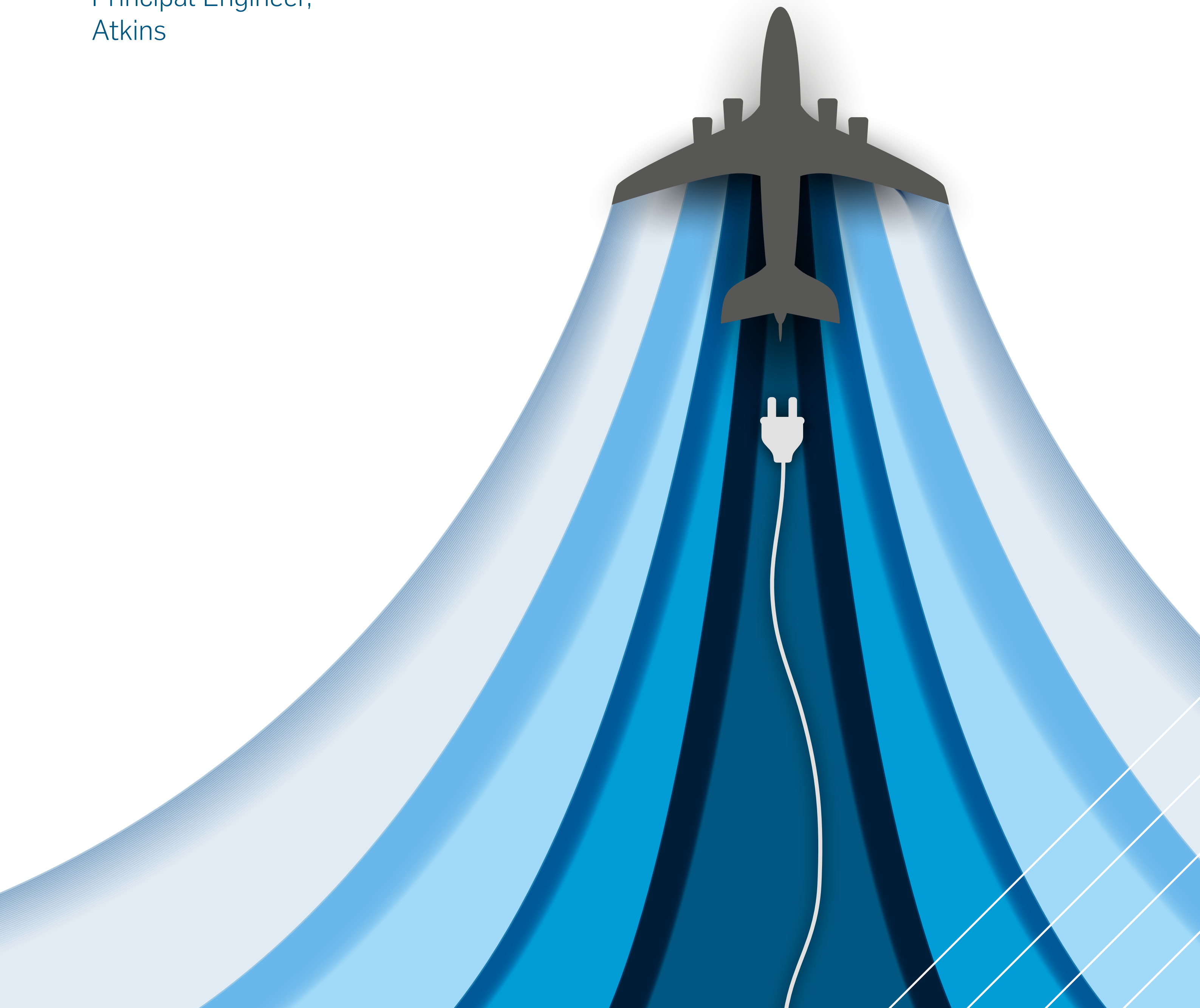

About us

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.

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Introduction

The earth's climate is changing, and so our behaviour must also change. That means moving towards cleaner, and more efficient, forms of transport. As road, rail, and maritime travel shift towards electrification, isn't now the time for aerospace to join them?

The electric car industry continues to grow apace, with hybrid and electric cars, and charging points, becoming a more common sight on our roads. Their price has fallen too. Railway electrification is being rolled out across the UK, offering better performance and greater protection of the environment than diesel trains, and reducing noise pollution for people living along busy train lines. When will air travel, join them?

There's no doubt that aircraft emissions cause significant 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_2 output from aircraft will likely increase by two and a half times by 2050. 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_2 output, that still means an overall global rise of CO_2 emissions from aircraft of somewhere in the region of five per cent per year.

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_x, fine particulate matter, $PM_{2.5}$, and ozone, O_3. This is documented widely by scientific evidence. As a serious risk to public health, it must be tackled. The other complaint from residents living near airports is noise. More recent aircraft designs have reduced noise levels, but still improvements are needed.

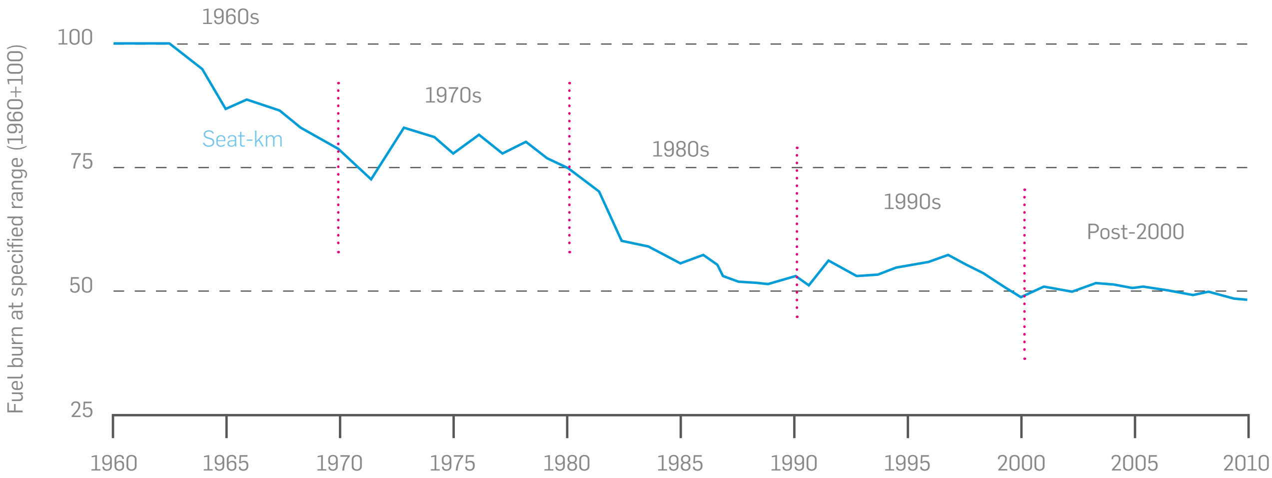
Anyone taking a return trip from London to New York today will generate roughly the same level of emissions as it takes to heat the average European household for a whole year. By introducing electric battery-powered aircraft, the potential exists for charging the batteries using power generated via 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.

So, there's the target for cleaner air travel: the reduction of CO_2, NO_x, $PM_{2.5}$ and O_3 emissions and noise. 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 experts in the industry think we may have reached a plateau in terms of aircraft performance, when it comes to fuel efficiency and aiming for lower emissions. As a result, alternative, low carbon, energy sources are being explored to support commercial aircraft operations. These typically fall into broad categories of drop-in sustainable fuels, hydrogen, and batteries.

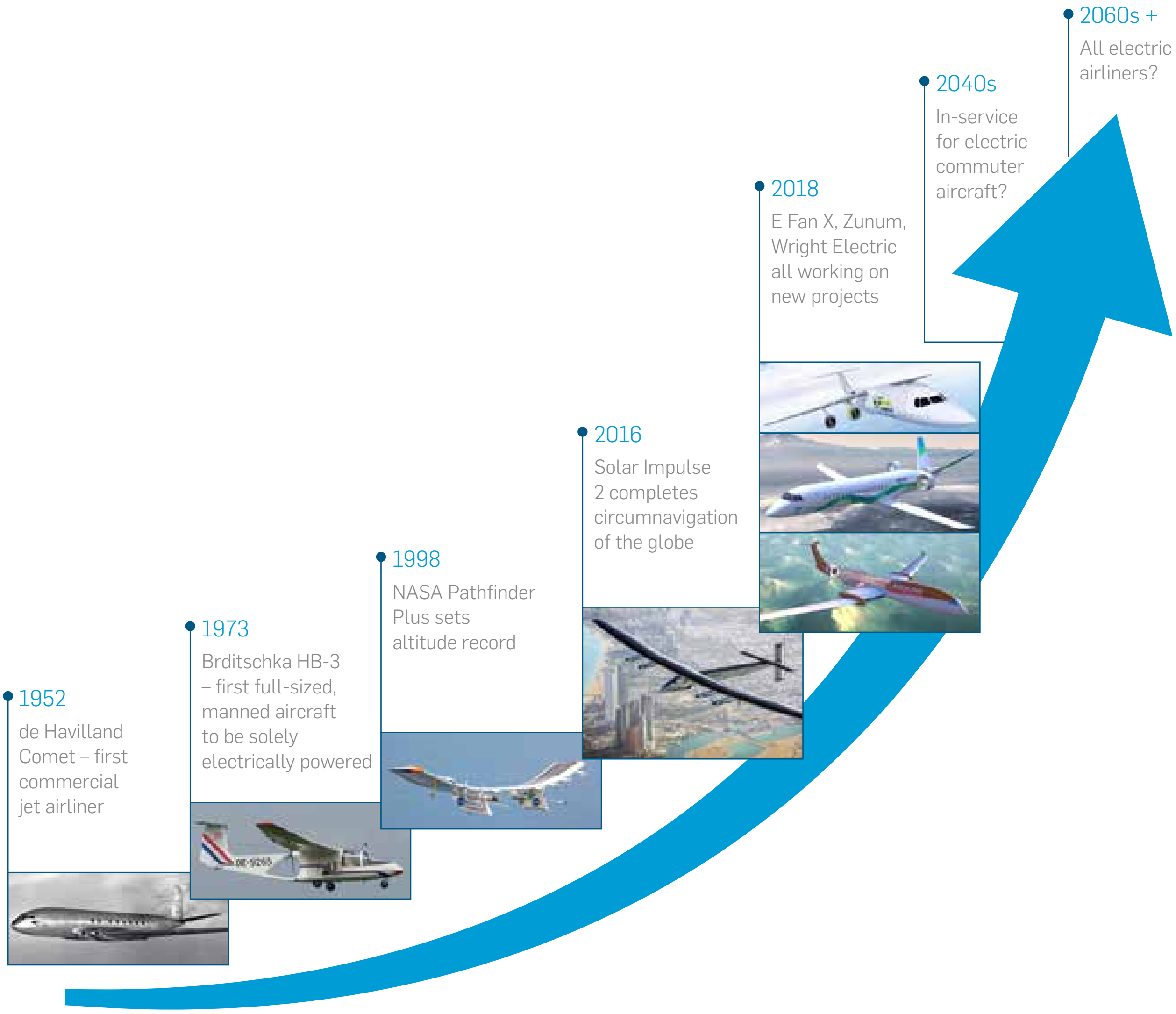
There are benefits and challenges across the aerospace value chain associated with each option, but batteries are the only solution that results in completely zero emissions, even of contrail forming water vapour, during operation. If we look to battery power, like the car industry has, how can we square 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.



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.

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 if 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 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. More recently, in the wake of COP26, we can see the formation of the International Aviation Climate Ambition Coalition, IACAC, and the International Air Transport Association, IATA, publishing its net zero roadmap.



History of electric innovation in aerospace

R&D prepares for take-off

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. Recent large 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 could follow a phased approach; 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.

The UK media first reported in 2017 that Rolls-Royce had joined the race to develop 'electric passenger jets'. Fast forward four years, and in November 2021 the BBC reported an all-electric aircraft built by Rolls-Royce had broken two world speed records. In November 2021, The Spirit of Innovation hit an average of 555.9 km/h (345.4 mph) over 3 km, and 532.1km/h (330 mph) over 15 km[1]. And, following the statement by former easyJet CEO Carolyn McCall in 2017 that it was

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

the airline's partner Wright Electric began its engine development programme for 186-seat electric aircraft in January 2020, which it hailed as

> "a crucial step on the path to electric commercial aircraft." [2]

Powerful, yet lightweight

The biggest challenge all-electric aircraft are faced with is the question of power to weight ratios: a fully electric propulsion 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 for perhaps another 15 to 20 years; with full integration with aircraft and potential in-service dates going beyond that and completely dependent on an aircraft's size and range.

A hybrid-powered solution is likely to be available sooner if this is determined to be a worthwhile step towards a full electric solution. 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. However, the E-Fan X programme by Airbus and Rolls-Royce was reported to have been cancelled on the grounds that a hybrid electric, or even full-electric solution for larger aircraft wouldn't be viable. Arguably, it could still become a long-term solution, but most likely to a timeframe beyond 2050. Let's look at the system-level integration of a hybrid-powered solution within an aircraft.

[1] BBC News report: https://www.bbc.co.uk/news/uk-england-derbyshire-60068786#:~:text=An%20all%2Delectric%20aircraft%20built,330%20mph)%20over%2015%20km

[2] easyJet media centre: https://mediacentre.easyjet.com/story/13660/easyjet-s-partner-wright-electric-begins-engine-development-program-for-186-seat-electric-aircraft

Hybrid-electric solutions

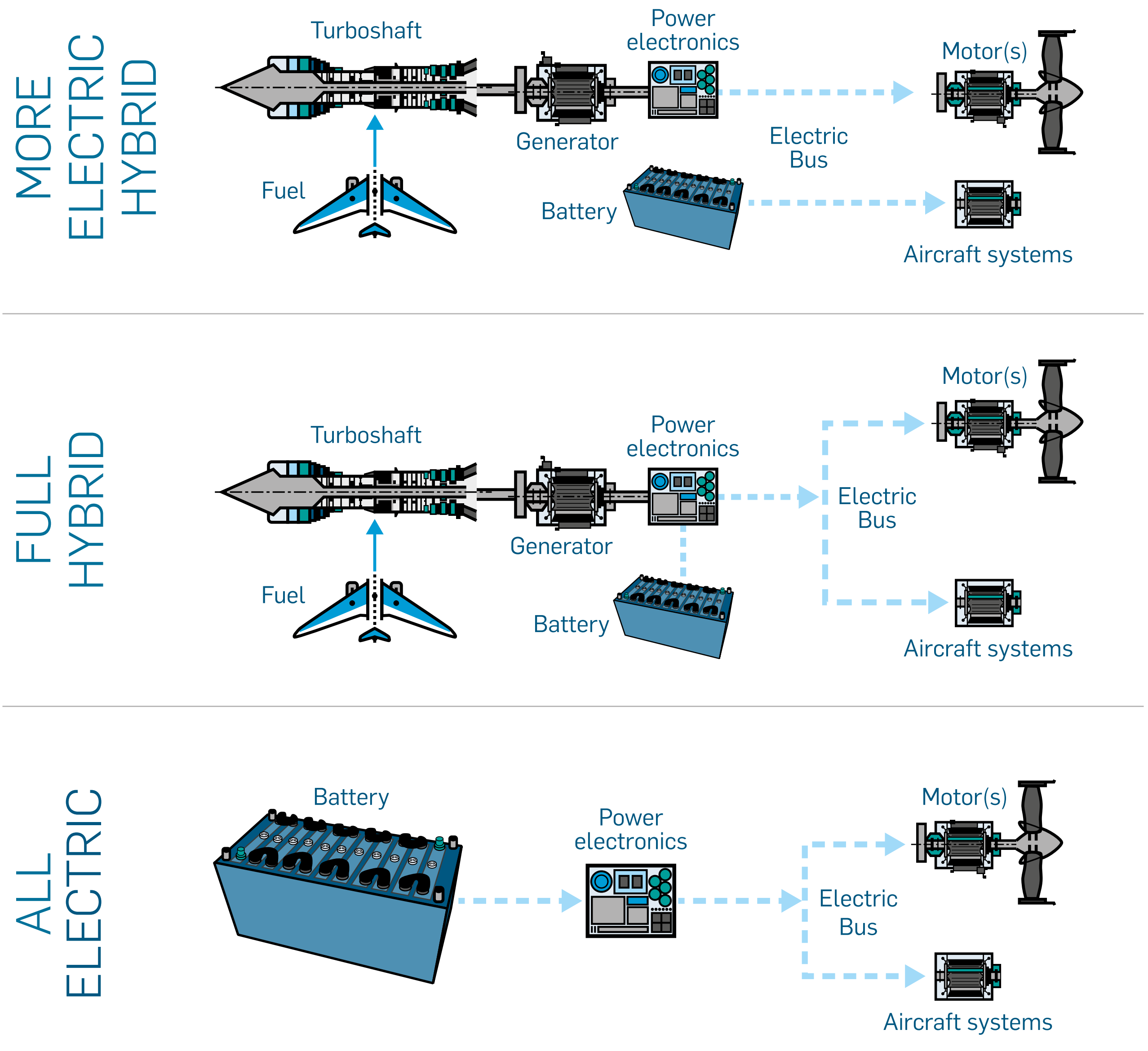
The gas turbine and the electrical generator, which are existing and understood solutions, are put together. Jet fuel – kerosene or sustainable aviation fuel – powers the gas turbine, which drives the electrical generator. A new power electronics system is likely to be required to then transfer this 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 Eviation Alice aircraft and eVTOL (electrical Vertical Take-Off and Landing) aircraft. This system could then be developed by changing the energy source from a liquid fuel-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 hydrocarbon-based fuel (kerosene or sustainable aviation fuel) for hydrogen. This is not without its own challenges, including the supporting infrastructure, but moves towards the same goal of emission-free flight, with water vapour as the by-product.

www.theguardian.com/business/2017/dec/28/electric-passenger-jet-revolution-looms-e-fan-x-air-taxis-hybrid-planes



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.

All-electric systems

With an 'all-electric' system, the initial conversion electronics may need to be adjusted from the hybrid solutions, but the propulsive element of the system wouldn't have to be changed. 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?

It is encouraging to see recent developments in this space, with magniX and Brazilian aeronautical company DESAER announcing their partnership to develop a hybrid electric aircraft in February 2022, which is "expected to save between 25 to 40 percent of fuel depending on the range of the operation."[3] In addition, in December 2021 aviation engineering giant Rolls-Royce announced it had "delivered more than a megawatt of power from a hybrid-electric propulsion system after going on test for the first time."[4]

[3] magniX and DESAER announcement: https://www.prnewswire.com/news-releases/magnix-and-desaer-announce-partnership-to-develop-hybrid-electric-aircraft-301477071.html

[4] Rolls-Royce announcement: https://www.rolls-royce.com/media/press-releases/2021/07-12-2021-rr-hybrid-electric-propulsion-system-sets-megawatt-milestone.aspx

Longer, thinner wings

One key aspect of design 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 liquid-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 R&D, 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. For aircraft electrification the biggest technological challenge is the power density (expressed as power-to-weight ratio) of the batteries. As the time horizon for development of suitable batteries for large aircraft is long, funding should be focused on providing support to early-stage research into new battery chemistries.

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. This funding route is concentrated on taking relatively mature technologies and industrialising them and could support the power systems and electric motor development which are likely to have applications in hydrogen fuel cell aircraft ahead of battery availability.

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 ten, 20 or 50 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 twenty to fifty 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 and airport infrastructure 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.

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James Domone is a Principal Engineer and Account Lead at Atkins, a member of the SNC-Lavalin Group, working within the Aerospace and Defence market. He has supported numerous aerospace clients through his career, including Airbus and Rolls-Royce, on both commercial and military platforms, working on structural and propulsion systems. James has played a leading role at Atkins in developing knowledge and capabilities around improving the sustainability or aircraft with objective of achieving net zero operations.

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