

AIR TRAVEL - GREENER BY DESIGN

# ANNUAL REPORT 2018-2019



Greener  
by  
DESIGN



## Greener by Design

### Executive Committee

Prof Peter Bearman  
Jonathon Counsell  
Roger Gardner  
Dr John Green  
Ian Jopson  
Dr Ray Kingcombe  
Geoff Maynard  
Kevin Morris  
Prof Ian Poll  
Robert Whitfield  
Dr Richard Wilson  
Roger Wiltshire

# GREENER BY DESIGN

# ANNUAL REPORT 2018-2019

---

## Contents

Introduction	4
Conference Report	6
Sustainable Alternative Fuels	13
Atmospheric Science	16
Operations Report	22
Technology	27

Front cover: Airbus Bird of Prey concept study.  
*Airbus.*



# Introduction

As the 20th anniversary of the founding of Greener by Design approaches, it is appropriate to reflect on the significant changes that have occurred in the intervening years. Perhaps the most significant of these is the attitude of the public.

20 years ago, few people had heard of global warming, and knew even less about its causes. The turning point in public perception was possibly the Stern report, which spelt out in considerable detail the physical and financial effects of doing nothing. About the same time, global warming and the environmental effects became a part of GCSE Geography examinations, and on a personal note, I started lecturing on aviation and the environment. Each year I have asked my MSc students whether they believe in Global warming. Among those early students barely half did, yet by 2017 all my new students did. Small wonder then that there has been a complete turnaround in attitudes to Global warming by youngsters and indeed many middle aged and older people, no doubt also aided by the recent David Attenborough *Blue Planet* BBC TV programmes.

Recently this change in attitudes has resulted in school children worldwide taking days off school to protest about climate change and 'Extinction Rebellion' protesting in London and other major cities. The protestors want net zero emissions by 2025, implying a massive reduction in CO<sub>2</sub>

emissions, and substantial and very swift growth in renewable energy.

While the 2025 target is widely regarded as unachievable, it illustrates the yawning gap developing between what the public expect governments to do and what can reasonably be done without causing major dislocation of trade and transport. Yet maybe the public is prepared to accept dislocation of services as the price to pay for rapid reduction in CO<sub>2</sub>? There is a real risk of this becoming a 'people versus industry' dispute, which is bound to include Aviation as its percentage of world CO<sub>2</sub> emissions continues to rise (further details are in the Operations report). Is Aviation ready for this challenge? Can more be done faster? These are questions we aim to answer in our next GbD conference to be held on 7 November this year - entitled 'Aviation and the Net Zero emissions challenge'. We hope to see you there.

**Geoff Maynard**  
Chairman  
**Greener by Design**

Right: Airbus Bird of Prey concept study. *Airbus.*







# Greener by Design Conference report

## INTRODUCTION

The 2018 Annual Conference 'Impact of Electric and Hybrid Propulsion in Aviation' was held on 20 November 2018 at the Royal Aeronautical Society's headquarters at No.4 Hamilton Place, London W1J 7BQ. The conference opened with a keynote speech from Adrian Gault, Chief Economist at the UK Government's Committee on Climate Change (CCC). His presentation reminded the conference of the UK Government's legislated emissions target of an 80% reduction by 2050. He pointed to aviation's privileged position in that strategy, assuming UK aviation emissions would be at 2005 levels in 2050.

The CCC is now updating its aviation analysis of 2009 and expects to publish a report in spring 2019, including recommendations to the Department for Transport's review of aviation strategy. The new analysis will take account of the

Paris Agreement which describes a higher level of ambition than formed the basis of the UK's 80% reduction target.

As part of this update they have commissioned a new project to look at technology potential and the aviation report will also take account of the potential from biofuels. Their recent report 'Biomass in a low carbon economy' forecasts some 10% of aviation biofuel produced from biomass with carbon capture technology by 2050.

## SESSION 1: WHAT IS A HYBRID AIRCRAFT

The first speaker in this session was Robert Thompson, Managing Partner in Rowland Berger, who gave an introduction to Electric and Hybrid propulsion. He drew a clear distinction between the More Electric Aircraft (MEA) and an Electric

Propulsion (EP) aircraft. The former has steadily been progressed by aircraft manufacturers, and now thrust reversers control, brake activation, engine start activation, flight controls and wing de-icing are routinely electrically operated. Electric environmental control systems and landing gear activation are being developed now.

Developments in electric propulsion can be grouped into three types: Turbo electric where a turboshaft powers a generator to drive the motor powering the fan; hybrid electric where either battery or turboshaft can be used; and all electric engines where a battery powers a motor which drives the fan. The pace of change is accelerating rapidly with double the number of annual new developments being announced in the last couple of years compared with 2016. The urban air taxi and General aviation sectors comprise the bulk (90%) of current developments. The research is predominately taking place in existing aviation research centres in the US and Europe.

There is broad agreement that hybrid electric engines could enter service in the 2030s. This will be aided by the environmental pressure to reduce CO<sub>2</sub> emissions, otherwise in the face of reducing emissions from other sectors while aviation emissions continue to rise, CO<sub>2</sub> from aviation sources could reach around a quarter of annual CO<sub>2</sub> emissions by 2050.

Progress is being made, but key barriers remain including battery performance, hazard containment, powerful but light electric motors, and installation of charging points at airports. Strong customer and political pressure to move to electric traction will be essential. There will also be potential upheaval to the market, as engine companies, airframe designers and electrical systems companies battle for supremacy in this new market.

David Debney, Rolls-Royce's Chief of Future Aircraft Concepts, spoke on the eVTOL, a radical new concept. Rolls-Royce expect this will grow the market considerably, with the potential to displace light helicopters and large general aviation aircraft, and to increase the market size as the new aircraft will be easier to fly. This will also create new markets, such as urban taxis. Development will be influenced by the extent battery technology improves, which will be key to extending range and therefore winning market share.

It also has the potential to be a game changer for the aviation industry. It will be a radical new aircraft/engine design/architecture, which will provide



Above: The Ampaire Electric EEL is a Cessna 337 Skymaster with an electric rear motor. Ampaire.

Opposite: The E-Fan X hybrid-electric aircraft demonstrator uses a BAe146. Airbus.

massive gains in engine efficiency and a dramatic reduction in emissions. It also opens the door to new entrants to the market and new supply chains.

Issues to consider include whether a mass market should be chased (or high end only), small or large planes be developed, whether to go faster or slower, whether battery only or hybrid, whether autonomous or piloted, and short or long range. This will obviously be influenced by research and development outcomes, and Rolls have already started this project to learn more about the challenges to be overcome before it can become a reality.

Colin Hodges from Airbus addressed this subject with reference to E-Fan X, Airbus's electrification project. First, he drew attention to the massive increase in renewable energy: wind energy production has doubled every five years and solar energy has increased five-fold in the past ten years (albeit from a lower base). Battery cost and specific weight continues to fall, and this has facilitated a big increase in the number of electric cars. Development of a light weight electric aeroplane would increase market size through urban air mobility and air taxis would become practical. Colin also emphasised that sustainable aviation growth requires new technologies to be developed if the internationally agreed targets for aviation CO<sub>2</sub> emissions are to be met. There is also a need to be practical about what can be achieved: a ten-seater all electric aircraft with a range of 100 miles is a potentially achievable target, whereas longer distance larger aircraft would need to be hybrid, perhaps allowing a regional jet seating 100 and with a range of 1,000 miles to be practical.





At this stage Airbus are testing a four-engine aircraft, with one of the engines replaced by a 2.5MW electric engine driving a fan. This gives an opportunity to test the major technologies, to understand the integration challenges, and demonstrate the technology bricks. It is not a product for sale. Using this approach keeps costs down with just a single demonstrator for a single purpose

The key challenges at present are seen as: operating environmental impacts, thermal management, high voltage electrical distribution, the control system, lithium-ion battery integration, operational impacts and regulatory impacts.

### SESSION 2: IMPACTS ON DESIGN, OPERATIONS AND ENVIRONMENT

The second session of the conference examined the environmental and operational aspects of aircraft designed to take advantage of hybrid or full electrification mainly for civil commercial flight. Starting with noise, Professor Rod Self of the University of Southampton identified the types of aircraft that might use electric propulsion and the sources of noise and particularly the new source of electric motors about which relatively little was known. Preliminary analysis for an e-320 (full electric version of an A320neo) had shown that there would be reductions in sideline noise on departure, but that flyover would be likely to increase. Approach noise would also increase on

account of the heavier landing weight though there would be a dependency upon the number of fans that might be included on e-designs. However, there would still be a significant margin against the ICAO Chapter 4 standards: for the Boeing Sugar-Volt concept a margin of 22EPNdB had been estimated.

While it might be easier to estimate noise for electrified versions of conventional designs, more novel designs such as those using boundary-layer ingestion (BLI) require new understanding of source and propagation effects as well as new operational profiles. An additional dimension is that of public perceptions as the nature of noise from electric aircraft would alter with new tones and that raised the question of the continued relevance of metrics that have been applied for decades. This tonal influence would likely become far more pronounced in drones and air taxis and history showed that the most annoying noise is new noise, especially where there is visual intrusion from low altitude flight. While commercial e-aircraft are likely to show noise benefits relative to a gas-turbine powered fleet, the effects of a new urban air mobility fleet would be less easy to predict. This new noise source cannot yet be predicted with confidence so source and operational modelling will be required as well as attitudinal response research with public involvement to achieve trust in this emerging technology.

Turning to the carbon and economic effects of aviation, Professor Andreas Schaefer from University College London (UCL) noted that aviation





Electric flight concept. Rolls-Royce.

generates about 3.5% of gross world GDP and features demand growth of over 5% per annum. Aviation fuel use and CO<sub>2</sub> production are increasing at about 2.2% per annum but fuel use intensity is declining albeit from a level higher than for other forms of transport. For electric aviation the trend in battery specific energy shows increases of about 3% per annum but this suggests long timescales before energy density reaches product viable levels.

The UCL modelling suite AIM - Aviation Integrated Model - was used in the System Aspects of Electric Commercial Aircraft (SAECA) project to examine all-electric aircraft markets size by distance. This indicated a substantial sub-600 nautical mile opportunity when technology allows though the construct of direct operating costs will be substantially changed with altered capital, maintenance and energy costs. Business models may also need to change to accommodate practicalities such as overnight charging. The global warming intensity for electric aircraft will, of course, vary considerable according to the electricity generating source but it is positive that the cost of renewable power is in steady decline. It was evident that viability of electric aircraft is dependent upon significantly higher specific energy and power batteries and significantly higher specific power aircraft motors and power electronics. Battery costs would also be a prerequisite along with decarbonisation of the electricity grid. An MIT study TASOPTe (Transport Aircraft System OPTimisation - electric) which used a first principle methods to

optimise an aircraft (A320 equivalent) for a given mission noted issues for turnaround and battery management strategies. Retaining a significant level of charge at the end of mission would be critical to achieving cost-effect turnaround times to fit with airline business models. Substantial research challenges remain to be solved before electrification is a practical proposition.

Looking at the design challenges presented by full-electric and hybrid-electric aircraft, Richard Wilson of RAW Aviation Consulting Ltd suggested that the whole design space could be radically opened up. Installed battery energy is an order of magnitude less than kerosene even with improved energy-thrust conversion efficiency. On account of reduced or no weight burn off during the mission, an increase in the total energy required to operate a flight is evident and that argues for new low-weight technologies being brought forward. For full-electric there would be a positive benefit for carbon intensity through battery energy replacing liquid fuel but there would be the negative effect of a mass increase in the electrical power system. For hybrid-electric, there is the penalty for shorter than optimum missions of carrying battery mass without realising its full potential benefits of the battery system. For longer than optimum missions, which depend on 100% kerosene, there would be a penalty of carrying the electrical system mass. Range therefore becomes a critical issue. Additionally, the battery and power management system will increase landing mass with attendant changes to wing sizing and more powerful

## Conference Report



E-Fan X hybrid-electric aircraft demonstrator. Airbus.

high lift systems. Some attention has been given to the possibility of harvesting energy in descent but this may necessitate steeper descent profiles and thus increase cruise distance. These are some of the significant trade-offs that would need to be resolved to come up with practical designs and operational characteristics.

Addressing the issue of airspace management, Brendan Kelly of NATS noted that modernisation of airspace is predicated on the principle that the network and its operation should not be a constraint upon existing and planned runways. The basic structure of the current network developed over 50 years has not fundamentally changed and operational delays for airlines will increase significantly without radical change. Terminal area efficiency is significantly affected by the en route system so changes such as OPERA, a data driven design algorithm for en route airspace, can create routes and an en route network using demand and low-level designs below the en route network.

Through iterative steps, this system optimises the network to minimise interactions and enhance environmental performance. Another initiative relevant to facilitating greater demand including from electrification of aviation is systematised airspace which allows defined routes from the departure airfield to the point of exit from UK airspace. The use of performance-based navigation (PBN) removes the dependency upon point-to-point navigation and systematised airspace also allows optimised descent profiles.

Discussion after the presentations highlighted the potential significance of the tonal characteristics of electric motors and the inadequacy of current prediction tools. In relation to the carbon intensity and cost of electricity to support electric powered aviation, the competition for grid power provisions was seen as a significant factor as other sectors also placed increasing demands on the system. Alongside the drive to electrify, it was stressed that pushing for greater use of alternative fuels to support hybrid-electric aircraft would be necessary to achieve the desired reduction in carbon intensity. There was general lament that relative to some of the international competition, there was insufficient investment to keep the UK up to pace with developments elsewhere. At a practical technical level, it was noted that there were significant hurdles in the electrical power management system such as the risk of arcing effects at altitude.

### SESSION 3: CURRENT PROJECTS

In this first session after lunch three speakers described projects at very different stages of



development. The first was by Simon Gavillet from Safran Landing Systems, who outlined the challenge of taxiing: 6% of fuel is burnt on the ground, with an average of 20 minutes per flight and at JFK even 40 minutes taxiing. The A320 fleet spend more than 15% of their time taxiing.

The Safran solution is a system using power from the APU to drive a motor on the landing gear, with power control from the cockpit and with a total weight of 400kg. The system reduces fuel burn by around 4% per cycle and provides autonomy with no need to wait for a tug.

The second speaker in the session was Adam Newman, Chief Design Engineer, Rolls-Royce Plc who described the E-FAN X Project as one designed to address the challenges of electrification and looking for approaches that might overcome some of those challenges. It seeks to take existing technology today and to push it to its limits.

The project uses a 2.5 megawatt power generating system. The 3,000 volts needed is several orders of magnitude higher than the voltage used on conventional aircraft and has to be managed very careful in terms of separation/isolation. He described an arcing or short-circuiting effect which occurs at altitudes above 3,000ft. Thermal management was also a major consideration.

They are also looking at permanent magnet machines. In contrast to electro magnetic systems, where you can switch the power off in an instant, permanent magnetic systems always generate power when they are running.

The third speaker in the session was Jeffrey Engler, CEO of Wright Electric, who outlined the approach being taken by the Wright Project. His key question was "when will the deadline for zero-emissions be?"

He pointed out that most flights are short, and in this respect he cited two current electric projects, namely a two-seater project built by a partner company, and a nine-seater hybrid-electric project which will be flying next year.

Three quarters of seat-miles and emissions however are from longer-range flights, which pose a greater challenge in respect to carbon free aviation. As possible solutions, he outlined two options for achieving the target. The first was that of hydrogen, demonstrated by NASA-precursor in 1957 and studied by the EU in the 2000s. The second was that of carbon engineering: he pointed out that the direct air technology now exists to convert air to



The EcoPulse demonstrator Airbus Daher Safran Partnership was announced at the 2019 Paris Air Show. EcoPulse is a conversion of the Daher TBM. Airbus.

produce synthetic fuels. He summarised his own organisation's research areas, namely Hydrogen fuel systems, Liquid hydrogen storage, Low-cost hydrogen creation, Water release at high altitudes. But before proceeding much further, he argued, a deadline needs to be set for zero-emissions aviation.

#### SESSION 4: FUTURE DEVELOPMENTS

John Fox from AMTE Power started the final session by giving the perspective of the battery technology company. He started by explaining the history of AMTE which is based in Thurso. The company fills the gap between laboratory and manufacturer in the battery sector. AMTE is the parent company of AGM Batteries. The most popular batteries used in the transport market are based on Lithium Ion technology which was first developed in the UK and then licensed to Sony in the 1990s.

A number of technical constraints limit the adoption of pure electric power in aircraft. These include limitations in Battery Management Systems (BMS), the management of thermal output and the current energy density of batteries. In future metal ion technology would deliver better energy density but this technology requires further development. Sodium Ion batteries reduce the temperature effect but are less energy efficient than Lithium.

The other major constraint is the market for batteries which is driven by the current demand for electric road vehicles. Vehicle manufacturers have placed very large orders for batteries and demand is expected to outstrip supply by 2020. The speed of





NASA's X-57 Maxwell experimental aircraft. NASA.

adoption of electric vehicles could accentuate this problem in the near future.

New technologies are being developed. AMTE has recently acquired a licence to develop QinetiQ battery technology and smart cells could improve BMS. Of the options discussed during the day, John believed that Hybrid Electric is the most likely way forward for aviation.

Dr Simon Weeks, the Chief Technology Officer at the Aerospace Technology Institute (ATI) then presented on the research and development paths for the UK aerospace sector. The objective is to secure UK's position in aerospace technology. ATI is responsible for shaping the research programme which is funded by the Government Department BEIS and delivered by Innovate UK. Some £3.9bn will be invested over

13 years up to 2026 with over a thousand people engaged in the work.

Improvements in fuel efficiency and overall cost are two of the most popular research objectives. About half of the research funding is going into propulsion and about 30% on structures. Approximately £2bn is already committed, covering over 200 projects.

One of the major research projects now under development is the Amy Johnson Challenge. This is aimed at the technologies to enable more electric, highly autonomous aviation that would provide much greater mobility through flight. The benefits would include reduced ground congestion and a whole new range of markets and services. The research is also aimed at identifying reduced environmental impact, from both noise and emissions.

In the final panel session, John Fox and Dr Simon Weeks were joined by David Debney, Colin Hodges and Professor Andreas Schaefer.

On the security of supply for materials used in batteries, John Fox identified cobalt as a critical material and the Congo as its main source. He also acknowledged that how we deal with batteries at the end of their life is currently not satisfactory and further work needs to be done on the design and manufacture of batteries. The audience questioned some of the timescales quoted for all electric commercial flights and also reflected on the challenge of competing for battery supplies with the electric vehicle and electric storage sectors.

The panel was asked their views on the possible use of hydrogen as an aviation fuel. Each of the panel had been involved in considering this option but the outstanding safety issues and the need for new infrastructure were highlighted as major constraints. The session closed with a discussion on how the new electric technology might achieve recognised specifications and certification.





# Sustainable Aviation Fuels

## CLIMATE CHANGE

Globally the challenge of climate change is hardening, but the mission is possible. The Intergovernmental Panel on Climate Change (IPCC)'s Special Report on Global Warming of 1.5 degrees was published in October 2018 setting out the implications of the 1.5 degree aspirational goal set in Paris in 2015. The different sectors and regions of the world have since been reviewing the implications of this report overall. The European Union (EU) is promoting a vision of net carbon zero by 2050, while Sweden has announced 2045 as its net carbon zero target.

In the UK the Committee on Climate Change (CCC) will be reporting to Government in May on the UK's carbon targets, in the light of the IPCC report. The CCC Chief Executive Chris Stark has provided an indication of the nature of the advice to be given<sup>1</sup>. Any idea of a sequential transition, moving from sector to sector, needs to be abandoned. It will be necessary to move quickly to decarbonise every sector in unison and policy reforms will need to start soon. Prices will be key, but so too will speed and as a result Stark sees the need for the strongest leadership in the heart of government.

## AVIATION AND SAF

Sustainable Aviation Fuels (SAF) have come a long way in the past ten years. From the first Virgin Atlantic biofuel flight in 2008, to the 100,000 biofuel flights in 2018, the industry has risen to the technical challenge of identifying suitable feedstock, designing suitable pathways to producing drop in fuels that can be certified, certifying a series of different pathways - and finally building the production facilities to get the SAF industry going.

Off-take agreements are key to the construction of SAF production facilities and such agreements have been secured by World Energy Paramount, Fulcrum Bioenergy, Red Rock Biofuels, Total and Amyris, SG Preston and Gevo<sup>2</sup> in addition to numerous demonstration programs. These off-takes/efforts represent more than 250 million gallons per year and provide the demand for the initial set of commercialisation efforts. This is in addition to other recent announcements by Velocys, Neste, Agrisoma, SkyNRG, DG Energy, Preem and Lanzatech.

More ambitious commitments include United Airlines' pledge to reduce its own emissions by 50% by 2050 (vs 2005) following on from

## Sustainable Aviation Fuels

FedEx's commitment to obtain 30% of its jet fuel from alternative sources by 2030. World Energy Paramount is progressing its \$350m expansion to enable 306 million gal/year, including infrastructure for jet capacity of 150 million gals/year.

In the UK, the SAF projects of both British Airways and Virgin Atlantic have made progress. Funding has been secured for the next development phase of the waste-to sustainable jet fuel project that Velocys is pursuing with Shell and British Airways. Meanwhile, Virgin Atlantic and Lanzatech achieved some publicity this year for a first flight using SAF from Lanzatech's waste carbon gas recovery system. But Virgin are looking for government action on incentives and investor commitment, to move towards building the world's first full size plant producing jet fuel from waste carbon gases.

A key question however is whether those production facilities are being built at a fast enough rate to achieve the required rate of decarbonisation of air transport. Are the airlines prepared to pay the necessary price to get the projects off the ground and drive down the learning curve? Will the cost come down to the point where they are cost competitive with fossil fuels? Will aviation have to compete with other sources of demand in a low carbon world? What more should governments be doing to support the decarbonisation of aviation?

### THE WAY FORWARD

The Energy Transition Commission (ETC), in its report Mission Possible<sup>3</sup>, reviewed the challenges presented by the 'harder to abate' sectors of the economy, namely cement, steel, plastics, heavy road transport, shipping and aviation. They concluded that reaching net-zero CO<sub>2</sub> emissions from these harder-to-abate sectors by 2050 is both technically and economically feasible.

Specifically, for aviation, ETC estimates the maximum CO<sub>2</sub> reduction potential from demand management and energy efficiency by 2050 to be 15% and 30/45% respectively. The balance they see coming from decarbonisation technologies including biofuels already available, synfuels in the late 20s and hydrogen and electric batteries (for short distance) from 2040. They see the key actions to accelerate the transition to be:

- Innovation: Driving down the cost of sustainable biofuels and synfuels
- Policy: Creating a 'greenfuel' mandate imposing an increasing percentage of zero-carbon fuels reaching 100% by 2050.

- Policy: Creating fuel taxes of about US\$100 per tonne of CO<sub>2</sub>, applied at full rate to domestic flights and reduced rates to international flights.
- Policy: Tightening sustainability standards on biofuels, based on life-cycle carbon analyses and assessment of other environmental impacts
- International Air Transport Association (IATA): Increase ambitions of IATA roadmap to aim for zero emission by mid century
- Airports and airlines: create a coalition to secure a large-scale supply of cost competitive sustainable biofuels
- Airlines: develop a 'green flight' offer at a premium price in co-ordination with major travel agencies/corporate consumers of air travel.

In recent years many Governments in Europe, including the UK, took a false path, incentivising biofuels for road transport, which will be transitioning to electricity (whether powered by batteries or hydrogen) while not incentivising biofuels for aviation (which has no realistic alternative apart from very short range). Governments have come to realise this and have now been taking steps to make amends, through the REDII within Europe – and in the UK, through the RTFO. Norway's government has introduced a 0.5% blending mandate for advanced aviation biofuels from 2020, but there is a delicate issue of wanting to maximise biofuel use while needing to ensure that it is from a genuinely low carbon pathway and avoiding pulling biofuels from unsustainable sources into the market. The airline industry does not support national biofuels mandates as they are seen to create competitive distortion in a similar way to national carbon policies. One of the potential options to create more investor certainty is to have a global target, which could work with the appropriate target and time line. The one currently being discussed is 2% by 2025, which is ambitious but potentially achievable.

The CCC take a different view to the ETC however regarding the levels of SAF that one can expect by 2050. The ETC and the International Energy Agency (IEA) estimate the total bioenergy resource to be about 100 and 140 EJ respectively. This compares with around 26 EJ (600 million gallons of jet fuel) that ICAO estimates to be the level of demand from aviation in 2050. ETC conclude that in principle, all aviation demand could be met by sustainable biofuels production. The CCC however takes a broader look at the how sustainably sourced biomass can best be used and they conclude that up to 10% of aviation fuel could be biofuel production with Carbon Capture and Storage<sup>4</sup>. Indeed, in a letter on 13 February 2019 to the Secretary of State for Transport, Lord Deben, the Chair of the CCC



advised, as an input to the Department's upcoming Aviation strategy, that "the Government should not plan for high levels of biofuel use in aviation."

A key reason that the CCC take a more cautious view of the level of aviation biofuels is that their analysis<sup>5</sup> indicates that the tonnes of CO<sub>2</sub> equivalent savings per tonne of biomass when used in aviation (using Fischer Tropsch) biofuels with Carbon Capture and Storage (CCS) is very comparable to at least four other uses of biomass with BECCS (Bioenergy with Carbon Capture and Storage), namely

- Industrial uses with CCS (displacing gas with CCS)
- Industrial uses with CCS (displacing coke / coal with CCS)
- Hydrogen with CCS (displacing gas reforming with CCS)
- Electricity with CCS (displacing low-carbon generation)

The CCC have for some years been flagging up that as CCS becomes commercially available, some

applications could become more carbon competitive than use in aviation and that the best use of that biomass is the prime requirement as far as addressing climate change is concerned.

To conclude, Sustainable Aviation Fuels offer a major opportunity to significantly reduce the carbon emissions of aviation. This opportunity is being seized by industry and an effective combination of government policy and industry engagement will be required to drive this transition through. Net zero carbon for aviation is possible. Do we collectively have the will to make it happen?

### References

1. <https://www.theccc.org.uk/2019/03/19/chris-stark-towards-net-zero/>
2. CAAFI Offtake-News October 2018
3. 2018 <http://www.energy-transitions.org/mission-possible>
4. 2018 Committee on Climate Change Biomass in a Low Carbon Economy
5. *ibid*



# Atmospheric Science

## NON-CO<sub>2</sub> EFFECTS

Of the main contributors to climate change from aviation, it is the non-CO<sub>2</sub> effects that we believe should now be the primary target for research. It remains the case that, because of its long lifetime, CO<sub>2</sub> is still the main long-term threat to the Earth's climate and, for aviation, reducing CO<sub>2</sub> emissions must be the most important long-term objective. This requires advances in aircraft and engine design, in operations, in sustainable alternative fuels but not in understanding the role of CO<sub>2</sub> in climate change. The scientific understanding of the latter is high and the rate at which aviation contributes to the increase in CO<sub>2</sub> concentration in the atmosphere is accurately known. True, there may be some uncertainty in accurately quantifying the processes by which CO<sub>2</sub> is removed from the atmosphere, and hence in projecting future CO<sub>2</sub> concentrations. That is not, however, a question specific to aviation, however. It is relevant to future policy to reduce the net emission of CO<sub>2</sub> by aviation but it is not currently a significant question for aviation.

In contrast, the non-CO<sub>2</sub> impacts of aviation are substantial and are peculiar to aviation. Because

they are believed currently to account for more than half of the radiative forcing from aviation, they deserve our serious attention. These impacts were the theme of the section on Atmospheric Science in last year's Annual Report and what was reported under three of the four headings in that section – NO<sub>x</sub>, REACT4C and WeCare, and Aerosols remains a fair statement of our understanding today. The uncertainties are largely unchanged and the need for continued research is no less than a year ago.

During the year, the DfT commissioned a report<sup>(1)</sup> by Lee of Manchester Metropolitan University of current understanding of the non-CO<sub>2</sub> effects of aviation on climate. It covers some of the same ground as last year's Annual Report but in addition discusses two areas of uncertainty not mentioned in the GBD report that we believe should be in the list of research priorities. These are (1) the choice of metric for comparing the relative climate impacts of short-lived climate forcers with long-lived greenhouse gases, and (2) the 'efficacy' of radiative forcing – ie the variation between different forcers in the increase they cause in surface temperature per unit radiative forcing. Both these are needed to assess the climate benefit of any measure taken to



mitigate the climate impact of the non-CO<sub>2</sub> effects. And since any mitigation measures are likely to require some form of regulatory enforcement, there will need to be consensus about them before any regulation can be agreed.

In his report for the DfT, Lee notes that any measures to reduce the climate impact of eg NO<sub>x</sub> emissions, contrails and contrail cirrus will have the likely consequence of a small increase in fuel usage, which will increase CO<sub>2</sub> emissions. He concludes his report: "However, the clear message is that mitigation of non-CO<sub>2</sub> impacts tends to raise complex questions regarding both scientific uncertainty and trade-off (with CO<sub>2</sub>) consequences, whereas reducing CO<sub>2</sub> emissions has clear and long-term benefits and does not suffer from the same levels of scientific uncertainty." This is a familiar line of argument that Lee used at the Royal Aeronautical Society conference on "Contrail-cirrus, other non-CO<sub>2</sub> effects and smart flying" in October 2015. At the end of the round table discussion at the conference, however, the consensus among the scientists was more positive. It was thought that current scientific understanding and forecasting ability did indeed justify moving forward to a demonstration of the practicability of smart flying to reduce the climate impact of contrails and contrail-cirrus, now termed aircraft-induced cloudiness (AIC).

### CONTRAILS AND CONTRAIL-CIRRUS

There were two main drivers for the smart flying conference. They were (1) the fact that AIC is believed to account for more than half the Radiative Forcing (RF) from aviation and (2) that using air traffic management (ATM) to avoid the ice supersaturated regions (ISSRs) in which persistent contrails form, and in which the cirrus cloud into which they develop is sustained, could be introduced relatively quickly, and affect the entire world fleet, in a way that new technology to reduce fuel burn could not.

### AIC CONTRIBUTION TO AVIATION RF

In May 2018 Kärcher of DLR published a comprehensive review<sup>(2)</sup> of the formation and radiative forcing of contrail cirrus, a substantial paper with 147 references. It deals with all aspects of the contrail life cycle from formation immediately downstream of the aircraft through to evolution into cirrus cloud, eventually ending in sedimentation and sublimation as the ice crystals grow with age and fall into warmer or drier air. In the present context, the

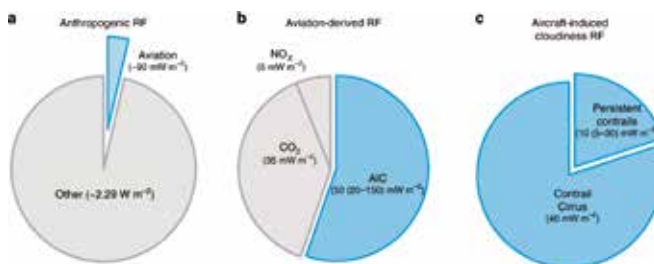


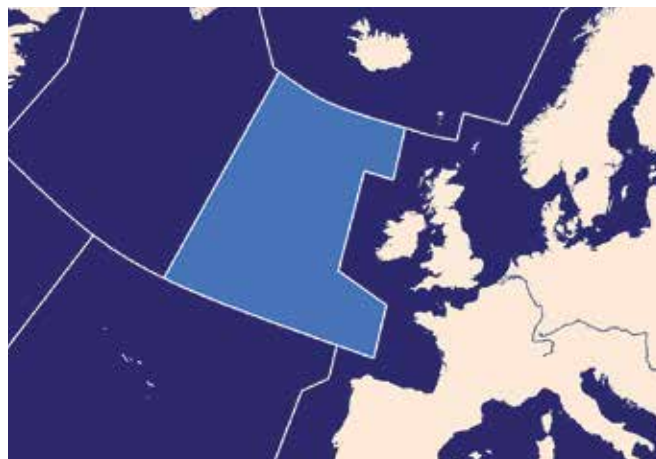
Figure 1. Aviation radiative forcing components in the year 2011, from Kärcher<sup>(2)</sup>.

set of pie charts in Fig 1 is the key figure, showing aviation in 2011 contributing about 4% (chart a) of anthropogenic RF and AIC accounting for about 55% of the aviation contribution (chart b), with CO<sub>2</sub> providing about 40% and NO<sub>x</sub> about 5%. Chart c shows persistent contrails providing some 20% of the AIC RF, with the contrail cirrus that develops from them providing the other 80%.

The review by Kärcher supports earlier estimates of the magnitude of the AIC RF cited at the smart flying conference. In the round table discussion, Gierens of DLR tellingly argued that the great bulk of the AIC RF was caused by a very small proportion of the total air traffic. That undoubtedly contributed to the consensus that emerged from the round table discussion to work towards some kind of practical demonstration.

At the close of the conference, Greener by Design accepted the task of moving events forward towards the kind of practical demonstration that had been discussed. An ad hoc group was set up, organised and chaired by Greener by Design, the core of the group being eight participants in the conference, five as speakers and three as chairmen. They came

Figure 2. The Shanwick Oceanic Control Area.



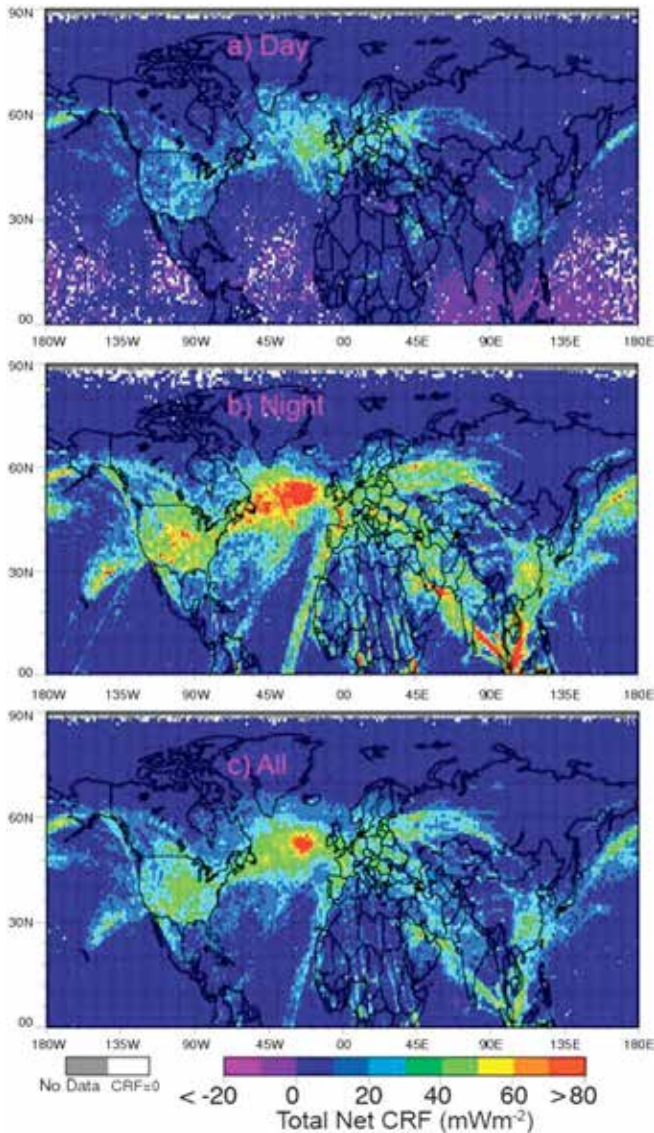


Figure 3. Mean 2006 net-contrail RF from Aqua MODIS data: (a) daytime, (b) nighttime, and (c) all data (NASA Langley) - from Brasseur et al: FAA's ACCRI Phase II.

initially from DLR, NATS, Reading University and Greener by Design, with Imperial College joining in place of Reading University in 2018. The group has met three times, in April 2016, April 2017 and October 2018 and has stimulated work that has strengthened our understanding of some of the key issues.

The participation of NATS in the group is predicated on the Shanwick Oceanic Area Control Centre being a suitable base for the management of a physical trial to demonstrate AIC control by ATM measures. The Shanwick OACC, shown in Fig 2, controls air traffic through a sector in the Eastern half of the North Atlantic through which pass about 80% of oceanic flights (1,500 per day).

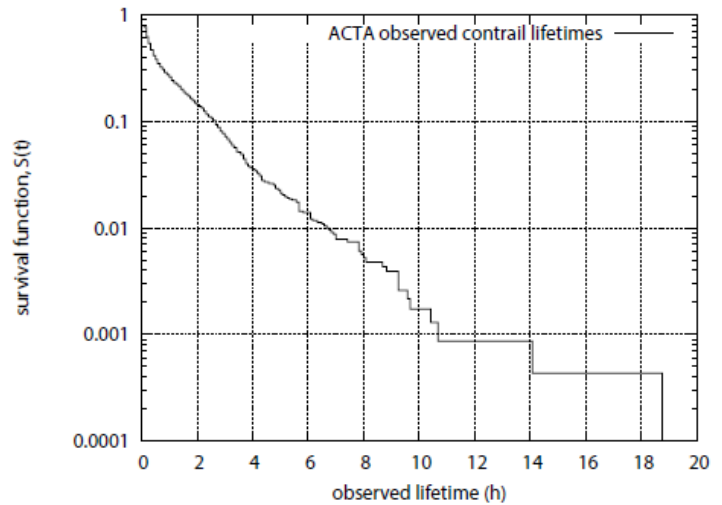


Figure 4. The distribution of contrail observed lifetimes in the ACTA data base plotted as a survival function.

Its suitability as an area to demonstrate contrail control by ATM is illustrated in Fig 3, which is a global map of the net radiative forcing in 2006 by linear contrails over the northern hemisphere, which contains 93% of air traffic. The results are from the NASA Aqua MODIS (Moderate Resolution Imaging Spectroradiometer) satellite. The image screening algorithms selected linear contrails only, excluding cirrus clouds. The figure shows the greatest net RF occurs at night (Fig 3b), because long-wave (warming) and short wave (cooling) forcing partly cancel each other during the day (Fig 3a). The contrail RF hotspot appears to be in the Shanwick OACC.

### LIFETIMES OF PERSISTENT CONTRAILS

One step towards understanding the RF patterns evident in Fig 3 is to gain an insight into the lifetimes of persistent contrails. Gierens and Vázquez-Navarro<sup>(3)</sup> have analysed the statistics of linear contrail images from the Rapid Scan Service of the geostationary Meteosat Second Generation satellite which enables individual contrails to be identified and tracked at five-minute intervals. The dataset, derived using the ACTA contrail tracking algorithm, covers a full year of observations over the heavily flown areas of the North Atlantic and Europe, tracking 2,305 individual contrails. The raw data are presented in Fig 4 as a semi-logarithmic plot of survival function against the contrail lifetime as observed by the satellite. The survival function  $S(t)$  is the number of contrails still observed after a time  $t$  as a proportion of the total number of contrails observed. Although the average observed lifetime

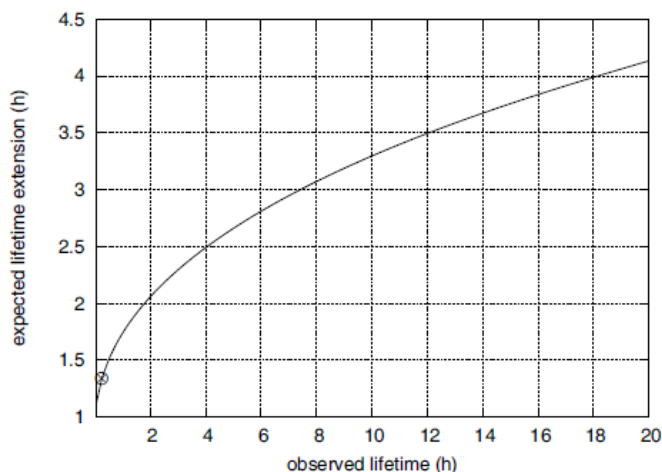


Figure 5. Expected lifetime extension of contrails in hours versus duration of observation.

is less than 2h, the greatest observed lifetime is greater than 18h. The authors find that the statistics evident in Fig 4 are best fitted by a Weibull distribution in which the chances of the contrail remaining visible over the next five-minute interval increases with the contrail's age. This tendency to survive longer the older they are is a noteworthy property, explained by the fact that old persistent contrails are located in ice-supersaturated regions in mostly uplifting air.

The satellite observation gives only part of the contrail life. The limited spatial resolution of the image means that an individual contrail is not identified until some time after formation – on average  $1.5 \pm 0.4$ h – when the average width of the contrail is  $7.7 \pm 2.2$ km. Also, analysis shows that the satellite ‘goes missing’ at the end of its observed life, because it can no longer be distinguished from its background. Gierens and Vázquez-Navarro estimate the initial, unobserved lifetime from the contrail width when initially identified and the empirical observation, attributed to the late Hermann Mannstein, that contrails spread at the pedestrian rate of 5km/h. The authors present an analysis of probable residual life after observability is lost, estimated from the Weibull distribution, as an increasing function of the observed life as shown in Fig 5. A contrail that has been observed for two hours can be expected to exist for another two hours but a contrail that has been observed for 18 hours can be expected to exist for another four hours.

Combining their estimates of the pre-observable life, the observed life and the estimated life extension, the authors propose Fig 6 as a depiction (the red line) of the cumulative distribution of persistent contrail lifetimes in the area covered by their data.

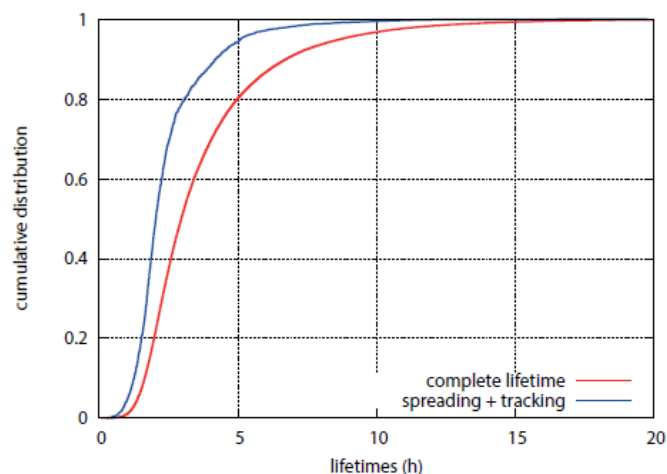


Figure 6. Cumulative distribution (red) of the complete lifetime, including initial spreading, tracking and extended life periods. The blue curve, shown for comparison, is the cumulative distribution of the first two of the three periods.

In all, the total lifetimes are substantially greater than the lifetimes observed by satellite, often by a factor of three or more. The mean value and standard deviation of the total lifetime is  $3.7 \pm 2.8$ h. 80% of all persistent contrails have lifetimes up to 5h and only 5% have lifetimes exceeding 10h.

## BIG HITS

In working towards a practical demonstration of contrail control by ATM, Gierens has made a statistical study<sup>(4)</sup> of how situations with strong warming contrails can be characterised and whether and how reliably it is possible to predict them. The study, reported at the meeting of the GBD contrail group in October 2018, should be regarded as work in progress, but already a strong and important message – the concept of ‘Big Hits’ – has emerged.

The study used ECMWF data from the ERA Interim Reanalysis for the period 1-30 April 2006, taken at three-hour intervals. It covered an area of the North Atlantic from 40°W to 20°E and 30° to 60°N, using data at 1°x1° spatial resolution obtained at three pressure levels, 300, 250 and 200hPa (ie altitudes of approximately 30,500, 34,300 and 38,900ft). Starting from these 1,361,520 points, temperature and relative humidity were checked to confirm that contrails were possible (the Schmidt-Appelman criterion) and then if this was an ISSR (ice supersaturated region) in which persistent contrails could form. This reduced the number of potential contrail cases in the study set to 186,329 – ie about 13.7% of the original field. For each of these cases, the radiative forcing (positive and negative) from AIC was calculated taking account of all the relevant meteorological parameters (pressure, temperature,



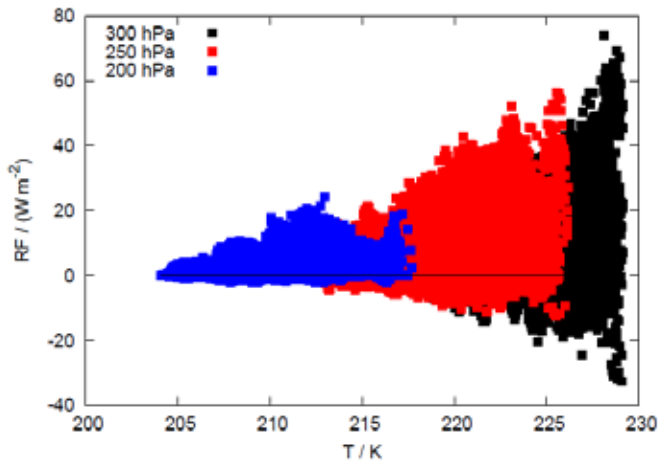


Figure 7. Radiative Forcing versus temperature - all 186,329 data points.

relative humidity, background cirrus, solar zenith angle) and the statistics of the influence of each of these on the radiative forcing was explored.

Figure 7 presents a typical result. The three colours represent the three altitudes, with the highest values of both positive (warming) and negative (cooling) RF occurring at the lowest altitude. This is to be expected. The air is denser at the lower altitudes and carries a larger mass of water vapour to form into contrails. Note that the largest RF values are greater than  $60\text{W/m}^2$ , which may be compared with the  $50\text{mW/m}^2$  shown in Fig 1 as the global net warming from AIC. The instantaneous RF from these Big Hits is three orders of magnitude greater and, indeed, is 25 times the global average for all anthropogenic RF.

Figure 8 shows the cumulative warming first order effect for positive values of RF, that is, for warming cases only. The colour coding of altitude is the same as in Fig 7. In considering the question of developing a method for predicting Big Hits, Gierens chose to define Big Hits as AIC with an RF of  $10\text{W/m}^2$  or greater. The great majority of these occur at the two lower altitudes and account for 8.1% of the potential contrail cases or 1.1% of the cases in the original data set. Even so, as Fig 8 shows, they contribute quite substantially to the first-order impact.

Gierens investigated the dependency of the occurrence of Big Hits on all the variables in the study. For the lowest altitude he was able, applying a Bayesian analysis, to show that the probability of a Big Hit at night time, with temperature  $T \geq 225\text{K}$  and a degree of supersaturation  $\text{RHi} \geq 120\%$ , was 1. In his data set there were 17 cases which met these criteria and all were Big Hits.

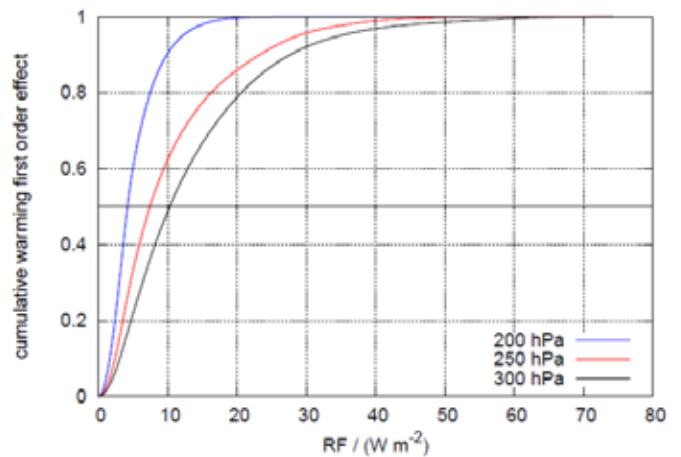


Figure 8. Cumulative distribution of potential RF at three different altitudes: Big Hits taken as  $\text{RF} > 10\text{W/m}^2$ .

It was found that the probability of a Big Hit increased steeply with increase in the normalised geopotential height. Although this was not included in the Bayesian analysis, the combination of high geopotential height and high temperature is characteristic of anticyclonic weather with light winds - both stable and more predictable.

Gierens regards this as work in progress, with questions about the robustness of his statistical results which require a much larger data base in order to eliminate questions about noise and autocorrelation. Work is also needed to move from determining the instantaneous RF to determining its full lifetime history. The DLR CoCiP (Contrail-Cirrus Prediction) tool is suitable for this but it will be a substantial computational task. Funding to carry this work forward is currently being sought.

Meanwhile, at the meeting of the GBD contrail group in October 2018, Marc Stettler and colleagues from Imperial College, in co-operation with Ulrich Schumann of DLR, reported a study of the effect of soot number uncertainties in the prediction of contrail characteristics. This too is work in progress, requiring further work before publication. Although its first focus was on soot, the study also drew on the CARATS open database of aircraft activity over Japan, combined with data from ECMWF on ambient atmospheric conditions, to investigate AIC from air traffic over Japan. The study used the DLR CoCiP code to estimate the AIC Energy Forcing (RF integrated over time). It found that, depending on meteorological conditions, between 3.2% and 15.1% of the flights studied formed contrails. For the particular week of 9-15 July 2012 it found that between 0.83% and 1.21% (95% confidence interval) of all flights contributed 80% of the total



(positive) AIC energy forcing. This is consistent with the Gierens conclusion.

The important take-home message from these two pieces of ongoing work is that only about 1% of air traffic needs to be diverted by ATM to achieve a substantial reduction in the RF from the Aircraft Induced Cloudiness that accounts for more than half of the total RF from aviation. The inconvenience and cost to airlines should be minimal.

### CONSEQUENTIAL EFFECT OF CONTRAIL AVOIDANCE ON FUEL BURN

One objection to smart flying – diverting from the planned flight path to avoid the supersaturated air in ISSRs in which persistent contrails can form – is that it will usually entail an increase in fuel burn. This will increase airline fuel costs and CO<sub>2</sub> emission and meet resistance from the airlines and possibly some policymakers and atmospheric scientists.

To address this question, Poll<sup>(5)</sup> has developed a new analysis of fuel burn in cruise that is aimed particularly at identifying the most fuel-efficient flight condition and quantifying the fuel burn penalty of departing from this. His analysis has novel, simplifying features from which a near exact solution is derived in which the aircraft-related input data are reduced to just three parameters; these are quantities that are either available from open information sources or can be estimated using established analytic methods. At the meeting of the GBD contrail group in October 2018 he reported on work with Schumann of DLR aimed at making the method available to and easily used by the atmospheric science community; the purpose is to provide quick and accurate answers to questions about fuel burn and CO<sub>2</sub> trade-offs arising from flight path deviations to avoid ISSRs.

In reference (5) Poll estimates that, on a Transatlantic flight in still air that for 20% of the flight time will be diverted to a higher or (preferably) lower altitude to avoid an ISSR, the increase in trip fuel requirement will be 0.5%. As he points out, this is small compared to the fuel penalties resulting from other operational inefficiencies. Further, this might happen on only one flight in 20, with an impact on the annual fuel costs to the airline of perhaps only 0.025%.

### VIRTUAL AND REAL-LIFE TRIALS

Following the Smart Flying conference in 2015,

the ad hoc group set up by GBD has been working towards a virtual and then a real-life trial of the proposition developed at the conference. The purpose is to test the feasibility, climate benefit and cost of using ATM to divert aircraft under, over or around ISSRs to avoid contrail formation. The proposed area for the trial is the Shanwick OACC.

The working party set up to address this question, which includes atmospheric scientists and representation of the ATM and airline communities, is focussed on two questions. What must the real-life trial demonstrate to convince the international community to take up the concept, develop it further and eventually roll it out, where appropriate, across the world? And before that, what evidence is needed from a virtual trial, based on historic atmospheric and air traffic data, to make a convincing case for committing resources to the real-life trial?

It is clear that a substantial amount of analytical work will be needed to make a case that will convince the ATM and airline communities to support a real life trial. Nevertheless, the evidence developed already, cited above, is that substantial reductions in AIC RF should be achievable with far less cost and disruption of airline operations than some have suggested. Given the challenge of the 1.5°C limit we now face, and the particular difficulty of reducing CO<sub>2</sub> emission from civil aircraft, GBD believes this exploration of the potential for reducing the non-CO<sub>2</sub> impact of aviation should be pursued to its conclusion.

### References

1. David S Lee, The current state of scientific understanding of the non-CO<sub>2</sub> effects of aviation on climate, report for UK Department for Transport, 2018.
2. Bernd Kärcher, Formation and radiative forcing of contrail cirrus, nature communications, (2018) 9:1824.
3. Klaus Gierens and Margarita Vázquez-Navarro, Statistical analysis of contrail lifetimes from a satellite perspective, *Meteorologische Zeitschrift*, Vol 27, No 3, 183-193 (DOI 10.1127/metz/2018/0888).
4. Klaus Gierens, Statistics of potential radiative forcing of persistent contrails, private communication, 2018.
5. D I A Poll, On the relationship between non-operations and fuel requirement for large civil transport aircraft, with reference to environmental impact and contrail avoidance strategy, *Aeronautical J*, 2018, doi:10/1017/aer.2018.121.



# Operations Report

## NOISE AND ENVIRONMENTAL CHARGES

For several years London Heathrow airport has charged aircraft based on their environmental performance. These charges in 2017 made up some 29% of the overall charging regime, with departing passenger charges making up the bulk (67%) with the balance (4%) from aircraft parking charges. Around 80% of the environmental charge comes from noise charges, with the rest from NO<sub>x</sub> charges. The aim is to incentivise operators to use their quieter and more environmentally friendly aircraft on Heathrow routes.

Following a further increase in these charges (1) from 1 January this year, Chapter 3 aircraft (the noisiest classification permitted to operate in Europe) are now charged £10,604 per landing, compared with Chapter 4 aircraft, which only pay £2,727 (Base category) and £3,030 (high category). For aircraft meeting the new Chapter

14 category (introduced on 1 January 2017), even lower charges apply - only £909 for the Chapter 14 low category. All charges are surcharged by 150% during the night quota period (23.30 - 04.30).

These differential charges are having a significant effect, with virtually no Chapter 3 aircraft flying into Heathrow last year. They are being replaced rapidly by newer types, in many cases the new Boeing 787 Dreamliner. Heathrow Airport anticipates no Chapter 3 aircraft will operate into the airport after 2020, and this target looks as though it will be met early, all contributing to a quieter environment around the airport.

Heathrow also levies an emissions charge per kg of ascertained NO<sub>x</sub> emission: this charge is currently £16.38 per kg of NO<sub>x</sub>.

The airport has also been 'naming and shaming' airlines with poor environmental performance under

its 'Fly Quiet and Green' programme (2). This is produced quarterly, and measures each airline on seven criteria: Noise quota count per seat, Noise certification chapter, NO<sub>x</sub> emissions per seat, Engine emissions, Continuous descent approach violations, Track keeping violations (ability to keep to the agreed noise preferential routes (NPRs)), and Early/late movements between 23.30 and 04.30. In the latest report (Q4 2018) Oman Air took top spot, with Middle East Airlines taking bottom place. A year ago, Turkish Airlines took bottom place, but this year they have moved up to near the middle of the chart. So the programme is having a significant impact on environmental performance.

The cumulative effect of these measures has been to impress on all airlines, irrespective of their local environmental issues at home, of the paramount need for minimising noise at Heathrow. This is allowing the airport to handle more passengers – 80.1m in 2018 – while shrinking its noise footprint.

### EFFECT OF CLIMATE CHANGE ON AIRCRAFT OPERATIONS

Rising temperature is already affecting some airports. More intense rainfall from tropical storms is increasing the flooding risk, as dramatically demonstrated by Tropical storm Sandy flooding New York's La Guardia airport in 2012. Changes in the permafrost levels at Svalbard airport have caused settlement damaging the runway. Many runways are

close to the sea, and improved protection against storms and rising sea levels are now required.

The effects of rising temperature are also being felt by airline operators, especially those operating in warmer parts of the world. In June 2017 at Phoenix, Arizona, temperatures reached 120°F (49°C), causing American Airlines to cancel several flights. This was because smaller regional aircraft are only certified for operation up to 118°F, and as the density of air reduces with rising temperature, aircraft wings generate less lift. As the air gets hotter at some point the aircraft will either be unable to go fast enough to take off or it will run out of runway.

The short-term solution is to reduce the weight of the aircraft by leaving some seats empty or reducing the amount of hold cargo, but both these have negative consequences for the airline – and maybe customers if they have been pre-booked. In the longer term, aircraft will need to be redesigned to cope with warmer conditions.

Runway length will also be an issue, especially at smaller airports where many aircraft use the full length of the runway. Lengthening these shorter runways may be necessary in the future. Many larger airports will, however, be unaffected as they already have runways substantially in excess of the length required today, even for the biggest aircraft.

A study by the University of Columbia (3) found that since 1980 the average temperature has gone up





by around 1°C, and temperatures are likely to rise by up to a further 3°C by the turn of the century. The study found that airports with shorter runways, higher elevations and those in hotter parts of the world could suffer considerable disruption in the years to come, unless changes are made.

Depending on the actual temperature rise, it could be necessary to reduce take off weights by 0.5% to 4%, resulting in a Boeing 737-800 being able to carry some 3 to 13 less passengers. Larger aircraft such as 777-300 and 777-8 are forecast to experience the biggest effects, with potentially 30-40% of flights experiencing some disruption. For smaller A320s and 737-800 the effect is less, with perhaps 5-10% of flights affected. It should be noted that these are maximum effects, as the researchers have based the reduction on maximum take-off weights (MTOW), and many flights (often because of short flight lengths) do not operate at MTOW. The researchers also found the A380 was little affected, because as it needs a code F (the widest) runway, it is only operated at larger airports which already have very long runways.

As the atmosphere (and seas) warm up, they contain more energy and therefore higher wind speeds are likely. This can also lead to more severe weather events, such as hurricanes and typhoons. These cause the suspension of all flights within and near the hurricane's track, leading to widespread dislocation of schedules. However, the disruption will not stop there, because the great majority of major airports have all their runways parallel, and therefore it is frequently necessary to land with a crosswind.

However, ICAO (International Civil Aviation Organization) rules lay down limits on the maximum speed of the crosswind for landing different sizes of plane. If higher wind speeds become more prevalent, more airports, particularly those handling smaller planes, are going to have to suspend landings. The airports most likely to be affected are those which have a runway direction not optimally aligned to the most prevalent wind direction, for example Birmingham (UK). If wind speeds do increase significantly, perhaps more likely in coastal locations, then more widespread disruption to schedules can be expected. In extreme cases it may be necessary to consider providing an additional runway at right angles to the existing runway(s).

Another less obvious effect of climate change is the increasing incidence of clear air turbulence (CAT). This is caused by stronger high-altitude wind instabilities in the jet stream, which can generate areas of CAT of increased size and strength. In May 2017, 27 passengers on board a Boeing 777 flight from Moscow to Bangkok were injured when CAT was encountered.

Researchers at the Universities of Reading and East Anglia (4) have shown that since 1958 the incidence of CAT over the North Atlantic has grown by 40-90%, with forecasts of a doubling by 2050, accompanied by a 10-40% increase in strength. Their new study also included the southern hemisphere and showed that increases can be expected here too.

This research adds urgency to the work being carried out by Boeing and the Japan Aerospace Exploration Agency to devise an advanced warning system for CAT, using light detection and ranging technology mounted on board the aircraft to give about a minute's warning of CAT. While this is too late for the aircraft to take avoiding action, it would give time for passengers to fasten their seatbelts and minimise injuries.

### FUEL EFFICIENCY

Last year this report focused on fuel efficiency, following on from a lot of research on emissions per passenger km. It included a resume of Ryanair's environmental report (5), and the many steps the company was taking to bring down emissions per passenger km. These included introducing the new 737 MAX - 200, winglets, lower weight seats, single engine taxiing and increased use of ground power.



Boeing





However, against this background of increasing fuel efficiency, Ryanair is also growing very fast (last year passenger numbers grew by 9% (6)), considerably faster than its improvements in fuel efficiency. So, its total CO<sub>2</sub> emissions have continued to rise – by 6.9%. Although this is not unexpected it has produced a timely reminder that as other sectors, especially those outside the transport sector, steadily reduce their CO<sub>2</sub> emissions, airline emissions are growing. It has been calculated that airline emissions covered by the EU Emissions Trading System (ETS) have risen by 49% in the past five years, whereas emissions from coal fired power stations have fallen significantly.

Each year the EU produces a list of the ten largest (site) producers of CO<sub>2</sub> in Europe. Up to last year this was the exclusive preserve of large (brown) coal fired power stations in Germany and Eastern Europe. However, as the shift to renewable energy gathers pace, these power stations are producing less electricity (and less CO<sub>2</sub>), and Ryanair has now overtaken one of them to make it into tenth place in the list. A harbinger of what is to come, as successful airlines are unable to reduce their absolute total CO<sub>2</sub> in the face of rapidly rising passenger km, whereas all the other occupants of top ten will be consigned to history in the next 15 years in the face of toughening European rules. Without some dramatic changes, by 2038 (the deadline set by the German government for phasing out all coal fired power stations) the top ten EU CO<sub>2</sub> producers will be Europe's largest airlines, not the biggest power stations. This emphasises the even greater importance and relevance of the Greener by Design ethos in aviation.

## ICAO'S MITIGATION MEASURES FOR CO<sub>2</sub>

Mitigating the effects of CO<sub>2</sub> (or perhaps more correctly reducing net CO<sub>2</sub> production) from aviation has been a concern of the International Civil Aviation Organization (ICAO) for many years. In that period, it has developed a so called 'basket of measures' to mitigate the effects of aviation CO<sub>2</sub>. There are currently seven strands to this initiative:

1. Aircraft related technology developments (meaning less fuel is used for the same weight of aircraft)
2. Sustainable Aviation Fuels (notably biofuels and electricity, both covered in the Sustainable Aviation fuels section of this report)
3. Improved Air Traffic Management (less delays and more direct routes reduces fuel consumption)
4. More efficient operation (higher load factors, lighter seats etc)
5. Market Based Measures (MBM) (see below)
6. Regulatory Measures (such as the recent CO<sub>2</sub> standard for new aircraft designs)
7. Airport improvements – such as reducing delays so eliminating the need for holding stacks.

All the above are designed to improve efficiency and so minimise CO<sub>2</sub> emissions. However, because worldwide aviation is expanding faster than the above measures can reduce it by, more needs to be done. ICAO recognised this and Market based measures (MBM) have been developed over the last few years to help plug this gap. This has culminated in agreement among all the nations to introduce CORSIA (Carbon Offsetting and Reduction Scheme for International Aviation). The principles of the scheme are straightforward – all airlines have to record and report their emissions to ICAO. The baseline is 2019/20, and all emissions in excess of the 2019/20 baseline must be offset by purchasing CO<sub>2</sub> credits from accredited schemes to reduce CO<sub>2</sub> emissions. Currently ICAO is working out the final details of the scheme, including the criteria for the offset schemes. Airlines are at this moment recording their CO<sub>2</sub> to determine the baseline, because in future years they will need to offset all the extra CO<sub>2</sub> over the baseline: in other words, finance a scheme which will reduce CO<sub>2</sub> emissions by the amount airlines have exceeded the baseline. This will mean there will be no net increase in CO<sub>2</sub> produced by the industry after 2021 (except from the few countries that have not joined, but the scheme is compulsory from 2027).

The scheme has also been criticised for not being ambitious enough. This is because the scheme does not reduce emissions (only offset the excess),



and also because it is not compulsory until 2027 (although most airlines have signed up to start in 2021).

However, with the proviso that a mechanism for reducing net emissions in the future needs to be included, it is a major step in the right direction. So far as the UK is concerned, a particularly significant aspect relates to the third runway at Heathrow. This is not scheduled to be open until 2026/7 by which time **all** additional emissions must be offset under CORSIA. There will therefore be **no** net increase in CO<sub>2</sub> emissions from its expansion. Nevertheless, the industry cannot afford to be complacent: younger people in particular are frustrated at the slow rate of progress. More must be done by the industry to reduce its overall net emissions, and more quickly. Public opinion will not countenance delay and prevarication until 2050. Effective action needs to be delivered much quicker.

### References

1. Heathrow Airport charges: Schedule 5
2. Fly Quiet and Green, The League Table, Quarter 4 2018, Heathrow Airport Ltd
3. The impacts of rising temperatures on aircraft take-off performance, Coffel, E D, Thompson, T R, and Horton, R M, *Journal of Climate Change* (2017), pp 144-381
4. Global response of clear-air turbulence to climate change, Luke N Storer, Paul D Williams, Manoj M Joshi; *Geophysical Research Letters*, Vol 44, Issue 19 pp 9976-9984
5. Ryanair Annual Report 2018
6. Environmental Policy Document, Ryanair 2018



Airbus' Project Vahana all-electric aircraft. Airbus.

# Technology

During the past 12 months, the level of aerospace innovation has at times seemed 'electric', quite literally. Almost every week, there have been news releases from established and start-up airframe companies, propulsion and systems suppliers, research organisations, certification authorities and universities concerning air vehicles with some degree of electrical storage and/or distribution of their propulsive energy.

These announcements and news releases have covered vehicles ranging from fully electric and hybrid electric propulsion architectures applied to small package delivery drones, personal air vehicles, urban air mobility vehicles, long endurance pseudo

satellites, regional aircraft, Hybrid Air Vehicles and single aisle aircraft.

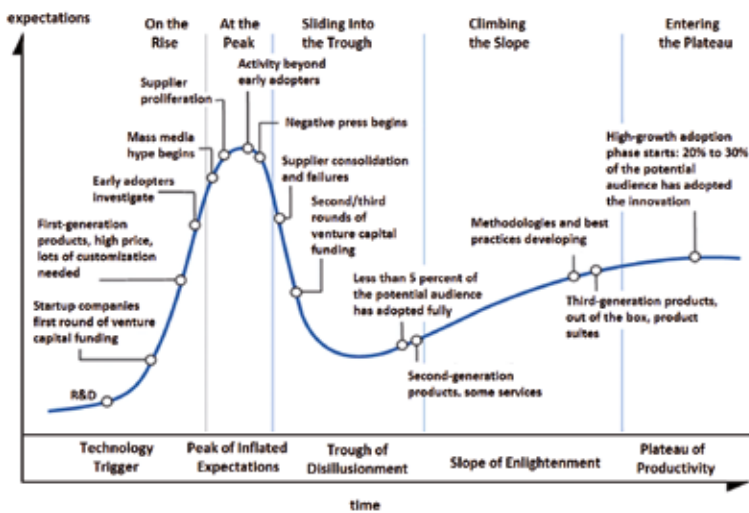
Last year's Greener by Design 'Technology' section concluded with a question on where electric propulsion technology sits on the Gartner Hype Cycle and the possible extent of the 'peak of inflated expectations' and the 'trough of disillusionment'. Much of the last year's activity aligns with the description of being 'At the Peak.'

## FARNBOROUGH AIR SHOW 2018

After the usual aircraft order announcements at



## Technology



General hype cycle for technology.

Farnborough air show, many of the headlines in the wider press centred around electric propulsion announcements. These included several aircraft concepts including the Aston Martin Volante Vision, the Rolls-Royce eVTOL concept vehicles, the SAMAD Aerospace Startling VTOL aircraft (electric options are planned) and an electric racing aircraft.

UK government research funding totalling £343 million was announced at Farnborough by the Aerospace Technology Institute (ATI) and UK Research & Innovation (UKRI) to support 18 projects that will promote UK involvement in electric and hybrid flight. This supports the UK government's 'Clean Growth Strategy'. The Airbus, Rolls-Royce, Siemens E-Fan X flight demonstrator was a major beneficiary from this funding and will use a BAe146 aircraft to explore the attributes of electric propulsion architectures.

United Technologies Corporation also made a Farnborough announcement that it was also planning a hybrid electric demonstrator aircraft programme. The details of this were released in April 2019: 'Project 804' will modify a DHC-8 Q100 with a parallel hybrid system, ie the propeller power is supplied directly by a gas turbine but with the option for an electrical motor to provide additional energy to the propeller drive during take-off and climb. No details were provided on programme timings.

### EU CLEAN SKY ELECTRICAL DEVELOPMENTS

The Clean Sky 2 NOVAIR reported mixed results for studies on Hybrid Electric propulsion systems on an A320 sized aircraft. Up to 10% block fuel benefits relative to a conventional baseline were



Rolls-Royce EVTOL concept. Rolls-Royce.

reported for a parallel hybrid system (HS1) – a turbofan fan was powered by both a gas turbine and an electrical motor in take-off and climb. However, two serial Hybrid Electric propulsion systems (HS2 and HS3) with kerosene powered engines powering distributed electrically powered propulsors (one with propellers, the other ducted fans) showed 30-50% more energy usage relative to the baseline due to very large increases in propulsion mass – this was with aggressive battery assumptions.

### NASA ELECTRIC PROPULSION DEVELOPMENTS

Development of the NASA X-57 all electric distributed propulsion demonstrator continues with first flight planned for mid-2019 (as of September 2018). The development process has been described as more difficult than expected with a year 'lost' due to a redesign of the battery system. However, NASA aims to provide this experience back into industry – the electric Sun Flyer 2 pilot training aircraft battery design is quoted as already benefited from this experience. NASA has also approved the next four X-57 phases conditional on lessons learned being available to industry (presumably US Industry).

NASA have also launched a programme to help understand the transition flight phase for VTOL aircraft, again with an intent to share the findings with industry

### ELECTRIC RACING AIRCRAFT

The world of air racing has announced a first 'Air Race E' event for electric aircraft with Airbus



ACCEL, the world's fastest electric-powered aircraft.  
Rolls-Royce.

signed up as the 'Official Founding Partner'. The format will be close to the 'Air Race 1' events with aircraft negotiating a tight circuit at high speeds against the clock. Clearly, high power is a priority over endurance although lower battery weight and volume improves speed. An aircraft concept for this was presented at Farnborough 2018.

## PROGRESS TOWARD ELECTRIC FLIGHT

The following are very brief descriptions of other electric aviation related announcements and programmes but does not cover them all:

- i) DHC-2 Beaver seaplane aircraft with electric engines replacing the current engine. Harbor Air (a small British Columbian airline) have stated an intention to become the world's first all-electric airline.
- ii) Norway has stated a desire for all short-haul flights to be electric by 2040.
- iii) The Eviation Alice nine-passenger aircraft has received many headlines in the past year,
  - a. \$200m reported to have been secured for development to certification.
  - b. Construction through 2018 and 2019 with an initial target of approval for a first flight certification ahead of the 2019 Paris air show has now moved towards the year end with certification in 2021-2022.
- iv) Airlander are considering electric propulsion for their production Hybrid Air Vehicle.
- v) Many other small electric projects (some eVTOL) are working towards flight from established and start-up airframe companies. These include: Airbus Vahana, Boeing Aurora PAV, Embraer DreamMaker, Vertical Aerospace, Faradair BEHA, Pipistrel plus many others.

## CERTIFICATION OF SMALL VTOL (MAINLY ELECTRIC) AIRCRAFT

Certification is an obvious, critical and challenging hurdle for electric propulsion systems. While existing certification rules and conditions will provide much of the general requirements, electric propulsion will also introduce new challenges not covered by the existing rules. VTOL operation using many smaller rotors (proposed in many eVTOL concepts) have much reduced auto-rotation capability relative to helicopters with just one or two large rotors - this reduced energy in the rotors is one of the attractions of the eVTOL concept.

Given the high levels of current activity in the urban air vehicles, often electric and/or VTOL, and the highly probable increase in those companies wishing to engage with the certification authorities, EASA published its first guidelines in a 'Proposed Special Conditions small VTOL aircraft' (<2t Maximum Take-Off Weight and five or less seats) for public comment in October 2018. The headline from the original document requires that any operation over 'congested' (ie urban) areas must be capable of sustained safe flight to a designated safe landing site.

## EU CLEAN SKY ACTIVITIES

The two Clean Sky 2 rotorcraft demonstrators continue development with the Airbus RACER compound helicopter first flight planned for 2020 and the Leonardo Next Generation Tilt-Rotor planned to fly in 2021-2022. Both programmes are targeting high speed, rotary wing flight over 200 knots.

Airbus RACER compound helicopter. Airbus.





The Lockheed Martin X-59 QueSST (Quiet Supersonic Transport) is an experimental supersonic aircraft being developed for NASA's Low-Boom Flight Demonstrator programme. *Lockheed Martin.*

Other major milestones currently being worked towards during late 2019 and the first half of 2020 include a Laminar Nacelle Virtual Demonstrator (for business jet applications) and a regional aircraft Flying Test Bed programme to explore a semi-morphing wing and multi-functional high-lift surfaces.

The Clean Sky 3 programme will target an 80% CO<sub>2</sub> reduction for air vehicles entering service in 2035. This phase of work is expected to start in 2021 and run through to demonstration in 2027 (required for 2035 entry into service) although budget details will only be set and finalised once the EU budget for 2021-2027 is approved in late 2019-2020.

### US SUPERSONIC

Research into supersonic flight continues mainly in the US through NASA, Boom Technologies and Aerion Supersonic (partnered by Boeing). The most imminent milestone is for Boom, the first flight of a manned one third subscale development, the 'XB-1 Baby Boom', is planned for late 2019 (as of early 2019).

Lockheed Martin was reported to have started production on the X-59 QueSST low boom supersonic demonstrator in November 2018 with a first flight planned for 2021.

### BOEING TECHNOLOGY DEMONSTRATION

Boeing completed its 777 Freighter 2018 eco-demonstrator and has announced plans for some 787 tests in 2021 to explore automated take-off and taxiing.

### NEW LARGE AIRCRAFT

The A330-800 made its maiden flight and the first A330-900 entered service in November 2018. The Boeing 777-9 was 'rolled out' in March 2019 with first flight planned for later in the year.

It will be interesting to see where Airbus and Boeing will next choose to develop their product lines given the high level of renewal in recent years, particularly with them absorbing the Bombardier C-Series and Embraer EJet programmes.

Boeing are clearly considering the NMA (New Midsize Airplane) with a launch decision required to proceed in the coming year if a 2025 entry into service is to be achieved. For Airbus, the ending of A380 production leaves the question of whether they need an aircraft larger than the A350-1000 and, if they do, whether this is a new airframe or a stretch on the A350-1000.

### SUMMARY

The past year has seen plentiful innovation across the aerospace world as interest in electrical propulsion for aircraft has intensified. Some of the challenges associated with developing and certifying this technology are coming more into focus as many of these projects move closer to flight test and certification, and this will ultimately determine the shape of the 'Hype' Cycle for this technology.

A hugely influential element in determining the ultimate success of electric propulsion will be the specific energy density (energy per unit mass) of energy storage and the associated components when installed on a certificated aircraft.

For supersonic projects, the technical challenges need to address the critical issue of achieving environmental attributes (emissions and noise) that are acceptable to society.



---

## The Greener by Design Group

Greener by Design was formed in 1999 by the Royal Aeronautical Society and bodies representing airports, UK airlines and the aerospace industry, bringing together experts from every part of the aviation industry with Government bodies and research institutions. The initiative is supported by the Department for Business, Energy and Industrial Strategy and other bodies in the aviation sector but it is non-aligned, researching and advising independently of any interest.

### Greener by Design

Researches, assesses and advises Government and industry on operational, technological, economic and regulatory options for limiting aviation's environmental impact.

Promotes best practice across the aviation and aerospace sectors.

Promotes a balanced understanding of aviation's true environmental impact and its environmental programmes, in liaison with other groups with similar objectives.

Issues an annual report and holds an annual conference and workshops on sustainable aviation.

The next annual Greener by Design Conference, Aviation and the Net Zero Emissions Challenge, is scheduled to be held on 7 November 2019 at the Royal Aeronautical Society, No.4 Hamilton Place, London W1J.



ROYAL  
AERONAUTICAL  
SOCIETY

Greener  
by  
DESIGN



Department for  
Business, Energy  
& Industrial Strategy

We are grateful for the support provided to Greener by Design by the Department for Business, Energy & Industrial Strategy.

Air Travel - Greener by Design draws on the expertise of industry and academia.

Any views expressed in this report are those of Greener by Design and do not necessarily represent the view of the Royal Aeronautical Society as a whole.

For further information or comments on this paper

**Air Travel - Greener by Design**  
**ROYAL AERONAUTICAL SOCIETY**

No.4 Hamilton Place  
London W1J 7BQ, UK

+44 (0)20 7670 4300

[www.aerosociety.com/get-involved/specialist-groups/air-transport/greener-by-design/](http://www.aerosociety.com/get-involved/specialist-groups/air-transport/greener-by-design/)