



The sustainability of UK Aviation:

Trends in the mitigation of
noise and emissions

Peter Hind and RDC Aviation Ltd
March 2016



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March 2016



Foreword from the ITC Chairman

The ITC has demonstrated through several research reports the importance of good international aviation connectivity for Britain, and the particular benefits of hosting a top, globally-connected, hub airport. We have therefore encouraged the Government to act swiftly and implement the Airports Commission's recommendations to allow the delivery of new aviation infrastructure.

That the Government has not yet done so is due to concerns about the environmental impacts of aviation, particularly in three areas: noise, carbon emissions, and local air quality. The Government announced in December 2015 that it would be conducting further work on noise and local air quality, as well as addressing sustainability concerns that have arisen over airport expansion, before it takes a decision on airport expansion. The ITC agrees that these are crucial issues. We have commissioned this report to explore the trajectory of improvements in aviation sustainability and to reach an assessment on whether these will continue.

This report, by aviation sustainability experts at RDC Aviation, has examined a wide range of sources relating to the noise, carbon emissions and pollutants that arise from aviation operations in the UK. The report indicates that technological and other improvements are available to mitigate any increases in noise, CO₂ and oxides of Nitrogen (NOx) emissions arising from airport expansion. Progress in these areas has been rapid over the past 30 years and the evidence suggests that improvements are likely to continue.

The researchers analysed NOx emissions and concluded that the contribution of these pollutants to poor air quality, even in the vicinity of airports, is caused principally by surface transport. The issue clearly needs to be tackled irrespective of airport expansion, and the report suggests tools exist to enable this to happen.

Aircraft noise is the other major local sustainability issue. The report points to the very significant progress in reducing noise impacts over the past 30 years and evidence that progress will continue. While clearly the measured noise impact is greater in areas of denser population, it is difficult for us to evaluate that impact when aircraft and significant other ambient noise exists. Noise could be reduced if the airport approach paths were managed with that objective, rather than, as for the rest of the flight, fuel economy.

Carbon emissions, meanwhile, are also likely to continue to reduce through progress in aircraft efficiency and operations. This is a global issue where unilateral action alone is insufficient. Significantly, the research suggests that, as well as its economic benefits, the 'hub' operational model produces up to 24% less carbon per passenger than the same connectivity provided through point-to-point services.

Finally, the report recognises that technology alone is not enough. It flags the need to build public confidence and trust, for example through a regulator with independence and powers to monitor and control sensitive issues such as noise.

The report concludes that although these environmental challenges are important and difficult, they are not insuperable. If tackled vigorously and transparently, it is possible for the UK to drive down the environmental costs of aviation while realising the great connectivity benefits that an expanded hub can provide. The challenge now is to move forward and actually deliver!

Dr Stephen Hickey
Chairman of the Aviation working group
Independent Transport Commission





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Executive Summary

This study forms part of a series of papers that the ITC is commissioning on UK aviation strategy and how to meet our international connectivity needs. It has been produced following the studies undertaken by the Airports Commission into Airport capacity and the subsequent decision by the Government to undertake more research into the environmental effects before deciding on where to build the new capacity.

The aviation industry has come a long way in efficiency and sustainability through improvements in operations and technology since jet engines first soared over UK skies. However, as the industry continues to grow it will face a number of key challenges if it is to do so without adverse impacts on the environment and local communities. We see three core areas in which the industry must continue to improve: noise, local air quality and CO₂ emissions. Our analysis suggests that, over the coming decades, it is foreseeable that a range of solutions will enable forecasts of future growth to be delivered within acceptable environmental boundaries, even without step-changes in technology.

At a global level, we consider the most important of these to be the reduction in emissions of the greenhouse gases that contribute to climate change, but this is also the most difficult to reconcile since it will require global standards and international cooperation to achieve a workable solution without market distortion. Still, with progress being made by the United Nation's International Civil Aviation Organisation (ICAO), this is not an impossible problem to solve, and we suggest that even without mass-uptake in biofuels there are opportunities to mitigate and reduce the contribution of CO₂ from air transport. Market-based mechanisms such as carbon trading coupled with continued advances in airframe technology and operating procedure improvements can all contribute to reducing fuel burn and CO₂ emissions. Our work suggests that the hub-and-spoke model is the more efficient method of transporting passengers and freight across a wide range of routes – through the use of larger, more efficient aircraft – when it comes to CO₂, although the model concentrates noise at the hub location.

At a local level, the more apparent issues are those of noise and local air quality. Our research shows that whilst these pose significant challenges within the UK, neither are insurmountable. Aircraft noise has been falling year-by-year with new technology improvements and is substantially lower than 30 years ago, while improvements in the technology behind aircraft navigation will offer much improved opportunities for noise respite. Our findings show a 'technology implementation gap' from the late-1980s to very recent times, with almost no completely new airframe development, other than the Boeing 777 in 1995, until the Airbus A380 in 2005. Consequently much of today's fleet, particularly in the long-haul segment, is operating legacy equipment with airframes and engines designed in the 1980s and 90s. The very recent introduction of aircraft built on new technology, the Boeing 787 (commercial launch, 2012) and Airbus A350 (2015), will deliver quantifiable improvements in noise and are expected to quickly proliferate the global fleet, replacing the old equipment. Short-term fixes such as sharing standard operating procedures between airlines can play a part in ensuring avoidable noise, such as that caused by the drag from landing gear, can be minimised across all operators using a particular airport.

Local air quality remains an important issue, particularly in the communities immediately around any airport. Whilst the Airports Commission was unable to confirm that some of the expansion proposals would not breach EU limits, the most significant observation here is that Oxides of Nitrogen (NO_x) output is a product of the whole transport spectrum and not primarily aviation. Road transport accounts for just under one third of NO_x emissions in the UK¹, with the proportion increasing in areas of intense vehicle concentration such as the M25 and M4 road network around Heathrow, which carries over 300,000 vehicle journeys per day². Road travel has seen significant reductions in NO_x and other harmful gases in recent years, and unlike aviation it has the opportunity to embrace green propulsion within the next decade or two, meaning that in the long term, even with growth in aircraft movements, there is opportunity to improve air quality around our airports. That is not to dismiss the need to reduce airport-based NO_x emissions, which are mostly generated by aircraft taxiing and running the Auxiliary Power Unit (APU) while stationary. Moving to biofuel powered Ground Power Units (GPUs) or clean Fixed Electrical Ground Power (FEGP) with single-engine taxi, provide immediate alternatives to current procedures and will reduce NO_x output.

For these local issues it is especially important to engage with the communities, so that they can understand and influence the way the airports operate and what is being done to reduce the impact on noise and emissions. These include consultation on and full disclosure of long-term proposals for flight paths and periods of respite; legally binding targets; and the creation of tools to aid in monitoring aircraft, such as the WebTrak tool in use at Helsinki airport.

Policy at a UK and international level can also provide a focus on bringing forward solutions. Government mandates to use alternative fuels can bring forward investment in such technology; the ICAO noise chapters provide a mechanism for airports to penalise noisy aircraft and for governments to ban them from airspace. We note that there is sometimes a trade-off between environmental objectives where, for example, a more noise efficient route may be less CO₂ efficient. Development of a flight-level environmental scoring metric which balances noise around airports with CO₂ for other phases of flight, similar to the NATS 3Di measure, could be used to highlight which airlines operate with environmental sensitivity rather than just in the most fuel efficient way. Mandated use of some flight paths could be considered to offset the flexibility airlines have in their daily flight planning, coupled with a coherent strategy on noise from government, mandating how to use flight paths to limit the impact on communities. We support the creation of an independent noise authority with powers to research and recommend best practise, monitor performance and fine operators for breaching agreed targets. Likewise, existing and planned market-based mechanisms should be adapted to recognise that different objectives apply for flight phases close to airports.

By UK standards the London airports have high levels of access by public transport, but these remain behind the global leaders. In order for any new capacity to be delivered sustainably, it needs to be developed in the context of the wider transport network and not as a standalone project. This means, as far as possible, closer integration with the rail network to provide easy dispersion of traffic not just to London but the rest of the South East, Midlands and West.

1 https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/486085/Emissions_of_air_pollutants_statistical_release_2015_-_Final__2_.pdf

2 Department for Transport – Annual road traffic census counts



I. Introduction

- 1.1** This paper has been commissioned by the Independent Transport Commission (ITC), Britain's leading research charity focused on transport, land-use and planning issues, and written by the independent consultancy firm RDC Aviation Ltd. (RDC).
- 1.2** Previous studies by the ITC have concluded that the hub model is the optimal choice for improving the UK's long-haul connectivity and therefore the prospects for the UK as an international economy. In order to meet future demand projections, it has been identified that a hub with a minimum of three runways would be required.
- 1.3** The ITC analysis has been published following the recommendations of the government-appointed Airports Commission and the UK government's subsequent response. The Commission investigated the options available to the South East UK's airport capacity problem, concluding that a hub model must be pursued and that the optimal location for additional capacity is at London's Heathrow Airport. The UK government has requested more work be undertaken to understand the environmental costs of the proposals. The aim of this ITC paper is not to compare the proposals, but to investigate the overall sustainability of UK aviation in this context.

Airports Commission Findings and Government Response

- 1.4** The conclusions of the Airports Commission highlighted that although additional capacity is urgently needed, it must be delivered using a "balanced approach" that ensures the long-term sustainability of the project.
- 1.5** This report builds on and supplements the previous publications of both the ITC and the Airports Commission by assessing the capability of UK aviation to develop sustainably in the medium to long-term future. In this report, sustainability is viewed as meeting the demand for air travel whilst not increasing, and where possible decreasing, the social and environmental impacts of its operation, both in terms of local impacts (air quality and noise) and global impacts (specifically climate change).
- 1.6** The Airports Commission concluded that sustainability is highly important for the delivery of much needed capacity to London's airports but that it is also achievable. Of the schemes that were considered, the Commission concluded that a second runway at Gatwick would have the least impact in terms of noise, air quality and CO₂. We also note that the sustainability of a scheme is a factor of the type of setting/locality that each occupies, and that decision makers will need to look at the core areas of noise, air quality and carbon, alongside the broader environmental, social and economic sustainability aspects of a major infrastructure scheme such as airport capacity expansion. However, it was also concluded that the impacts were not significant enough to outweigh the economic argument in favour of Heathrow, and therefore overall the Commission recommended a third runway to be built at Heathrow.
- 1.7** There are challenges in unravelling the incremental noise attributable to aircraft flying over West London and there is scope for substantial additional research in this area. Present policy is based around concentrating noise, which produces greater periods

of exposure for fewer people. Understanding whether this approach is preferable to dispersing noise around a wider population base but for shorter periods should be a core aim. Both Heathrow runway proposals offer different solutions in this respect, with Heathrow Hub giving potential to move the whole noise envelope approximately two-miles west when capacity allows, whilst the Heathrow scheme offers options for more respite periods. Both schemes enable alternation of the runways being used for landing and take-off to some extent, and thereby provide scope for extended periods of respite for residents. The Commission believe that this, along with improving technology and the use of displaced thresholds, will significantly reduce the noise impact on the community after the construction of a new runway.

- 1.8** In terms of emissions, the Airports Commission could not be certain that some EU limits on air quality would not be breached with expansion of Heathrow, but requested more work be undertaken before setting concrete conclusions on this and acknowledged that the mitigation measures put forward were credible. The forecasts suggested all expansion schemes are likely to increase CO₂ emissions by varying extents, although this could be mitigated to an extent by carbon trading and/or carbon capping.
- 1.9** The UK government's response to this, published in December 2015, declares that while it is agreed that more capacity is needed, more research into the environmental effects of the proposals needs to be undertaken to ensure that the decision creates a sustainable future for UK aviation. The Secretary of State for Transport, The Rt Hon Patrick McLoughlin said: *"The case for aviation expansion is clear – but it's vitally important we get the decision right so that it will benefit generations to come. We will undertake more work on environmental impacts, including air quality, noise and carbon."*

UK's Commitments on Climate Change

- 1.10** The UK has been one of the leaders worldwide in addressing the climate change problem. It was a signatory on the Kyoto Protocol, which committed the UK to reducing greenhouse gas emissions to 12.5% below 1990 levels by 2012 – a task which was successfully accomplished, with emissions actually falling to 27% below 1990 levels in 2011 (Committee on Climate Change). However, the UK remains committed to reducing emissions further, and the 2008 climate change act has set the target of reducing greenhouse gas emissions to 80% below 1990 levels by 2050. Furthermore, as a part of the European Union the UK has agreed to several more specific measures for tackling climate change, these include the emissions trading scheme and a commitment for the transport sector to use 15% renewable fuels by 2020.
- 1.11** There have been a number of practical difficulties in placing aviation within these targets in the past, as the multi-national nature of the industry makes it difficult to assign responsibility for emissions. Indeed at the latest meeting of the United Nations Framework Convention on Climate Change (COP21) aviation, along with maritime, was not specifically covered by the milestone agreement. However, it is clearly important aviation is included in these targets as soon as possible and rightly held accountable for its environmental impacts.



2. Sustainability and Air Transport – A Background

2.1 Air transport's impact on climate change through CO₂ emissions has been well documented in the mainstream media. It is the industry's largest pollutant and has been shown to have a direct effect on climate change. It is formed by the combustion of fuel in aircraft engines and therefore is a direct linear function of fuel burn, which means that airlines have a significant incentive to reduce their CO₂ emissions indirectly by reducing their fuel costs, which can account for up to 40% of operating cost on some routes. Therefore whilst CO₂ emissions remain a long-term challenge for the industry, it is an issue that can be tackled through technological developments and market forces.

Industry Position

- 2.2** The aviation industry has been developing its environmental agenda for many years and although growth in air transport has meant an increase in total emissions and frequency of noise at many airports, at an individual flight level aircraft are now more fuel efficient and quieter than ever before. Efforts were focused more on noise reduction in the early years of the jet engine, while the last two-decades have seen fuel burn and emissions output become of equal importance. Sustainability is now recognised as being critical to future expansion rather than simply an aspiration.
- 2.3** The International Air Transport Association's (IATA) goal for aviation emissions over the next 35 years is for the industry to reduce its carbon footprint to half that of a baseline year (2005). It has developed a four-pillar strategy to achieve this, focusing on technology, operations, infrastructure and carbon trading as the key levers of improvement. The core ambition is for airlines to increase fuel efficiency at a rate of 1.5% per annum to 2020; carbon neutral growth after 2020; and by 2050 to have achieved a reduction of 50% in CO₂ emissions against the 2005 baseline. For this to be achievable at a global level, within the backdrop of growing demand for air travel, each of the four-pillars will need to deliver potential savings unless there is a step-change in technology.
- 2.4** Our analysis shows that long-term fuel efficiency of 1.6% should be achieved simply through the proliferation of new aircraft replacing old and that a range of other measures can deliver additional fuel savings at a flight-level. The industry is already participating in various market-based mechanisms (MBMs) – intra-European flights have been included in the Europe's Emissions Trading Scheme since 2012, meaning emissions are monitored, reported and accounted for along with the other industries within the scheme.

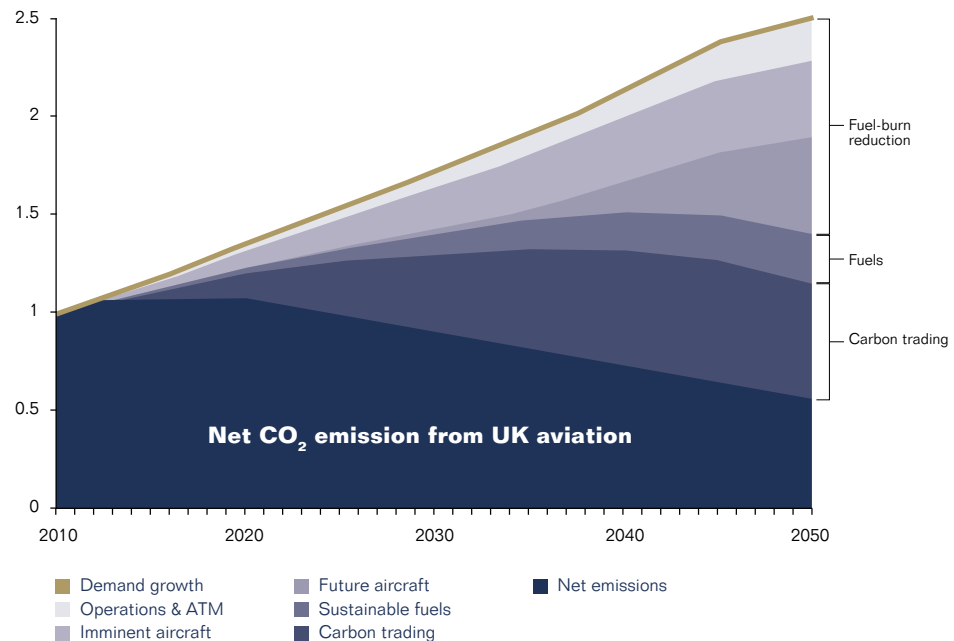
2.5 Although the recent UNFCCC COP21 meeting concluded with the adoption of the Paris Agreement, it lacked any specific reference to international aviation. The UN agency responsible for aviation, ICAO, has committed to the implementation of a MBM solution covering international aviation from 2020 and will be discussing high level resolution text in May 2016, ahead of presenting recommendations at its 39th Assembly later in the year.

2.6 Alongside IATA and ICAO sit a number of other groups looking into the long term sustainability options for air transport, notably Sustainable Aviation; Air Transport Action Group (ATAG); and the US-led Commercial Aviation Alternative Fuels Initiative (CAAFI). What is unusual about these groups, compared to other industries, is they pull together the spectrum of industry participants rather than acting as a lobby group representing the views of one side of the industry. Sustainable Aviation, for example, counts airlines, airports, airframe and engine manufacturers and air navigation service providers amongst its members. This collaborative approach ensures expert input and common understanding can be used to develop workable solutions.

Emissions Roadmap

2.7 Looking at how the UK can meet its emissions objectives, the roadmap developed by Sustainable Aviation shows the effect of various improvements in fuel burn on UK emissions to 2050. By carefully considering the relative potential of improvements from operations, new aircraft, sustainable fuels and carbon trading, Sustainable Aviation predicts that with contributions from all these areas, UK aviation can accommodate significant growth to 2050 without substantially increasing its contribution to CO₂ levels.

Figure 1: Sustainable Aviation Carbon Roadmap

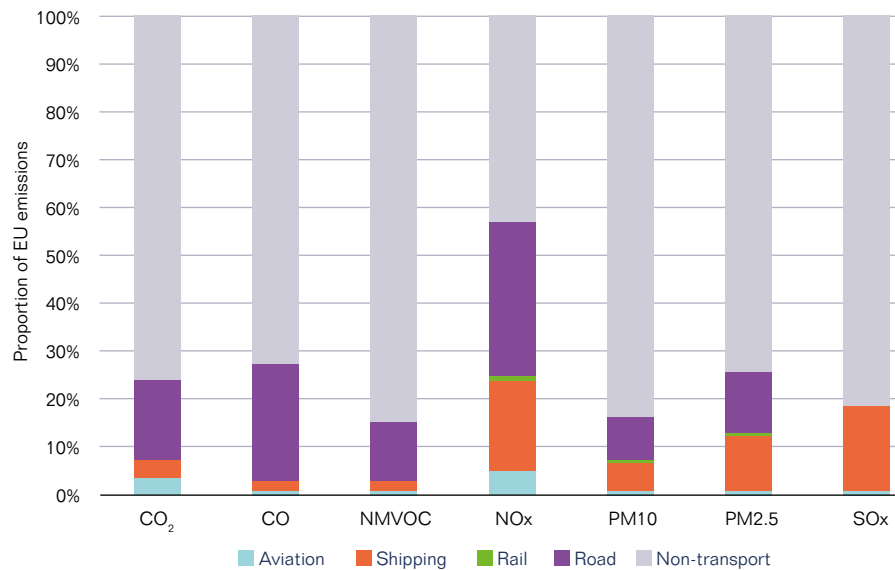


Source: Sustainable Aviation CO₂ Roadmap

Local Air Quality

2.8 Whilst CO₂ is the greatest contributor towards the global climate change problem, at a local level several emissions are known to be contributors to local air quality problems, which recently have been highlighted in a number of challenges against expanding London's airport capacity. In urban areas road traffic is the dominant source of pollutants affecting local air quality. Figure 2 shows how aviation's contribution to these harmful emissions compares with both other transport modes and the EU as a whole.

Figure 2: EU Emissions by Transport Mode



Key to Abbreviations: CO₂ = Carbon Dioxide; CO = Carbon Monoxide; NMVOC = Non-methane volatile organic compounds; NO_x = nitrogen oxides; PM10 = Particulate matter 10 microns or lower; PM2.5 = Particulate matter 2.5 microns or lower; SO_x = sulphur oxides.

Source: European Environment Agency (EEA)

2.9 Although various emissions are created in flight, aviation only generates a significant contribution to overall emissions in the cases of CO₂ and NO_x. Unlike CO₂, the production of NO_x is not directly linked to fuel burn, and therefore there has been a strong push from industry to regulate and minimise NO_x production, particularly in new aircraft. Above about 200m aircraft do not make a significant contribution to local air quality.³ The largest source of NO_x at airports is usually not the aircraft but the surface access routes; however road travel in particular is also making strong progress in reducing NO_x emissions (see chapter 6) and therefore the impact of NO_x at airports is expected to decrease over time.

3 Rogers, H.L., Lee, D.S., Raper, D.W., de, F., Forster, P.M., Wilson, C.W., Newton, P.J., 2002. The impacts of aviation on the atmosphere. The Aeronautical Journal. 106, 521–546. Copy available at http://uk-air.defra.gov.uk/assets/documents/ozone-uv/aviation_impacts.pdf

Noise

- 2.10** Noise from aviation and its supporting operations is a key issue at airports across the world. It is frequently perceived as a nuisance and detriment to quality of life, and can be a significant barrier to the growth of an airport and its related aviation facilities. This problem is greatest in the evening, night and early morning when people are more likely to be at home and it can have a serious impact on sleep patterns and the quality of life of local residents. This is a problem that airlines and airports are actively engaged in rectifying, as limits on night flying (“curfews”) can harm an airline’s profitability for overnight freight and long flights that must arrive/depart at inconvenient times in order to comply with curfews. However, as discussed in the ITC’s previous work, we do not believe a UK hub needs 24 hour operations to be effective.
- 2.11** The most direct cause of noise from aircraft is from the combustion of fuel in engines. This is typically louder on take-off but is also significant on approach when aircraft are in line with the runway for several miles before touchdown. It generally peaks on touch-down as reverse thrusters are deployed to bring the aircraft to a safe and swift stop.
- 2.12** Noise improvements from technology have typically come from engines, but as these have become significantly quieter, other aspects of the aircraft are increasingly being studied for their own noise improvements. This particularly considers the frame of the aircraft itself, and the noises that are created as high-speed air rushes across it. Noise can also be made by the turbulence created by hot air from the engines mixing with cold surrounding air – a particular solution to this problem can be seen on the serrated edges of the nacelles on the Rolls Royce Trent 1000 and General Electric GEnx engines that power the Boeing 787 Dreamliner (below).

Figure 3: Rolls Royce Trent 1000

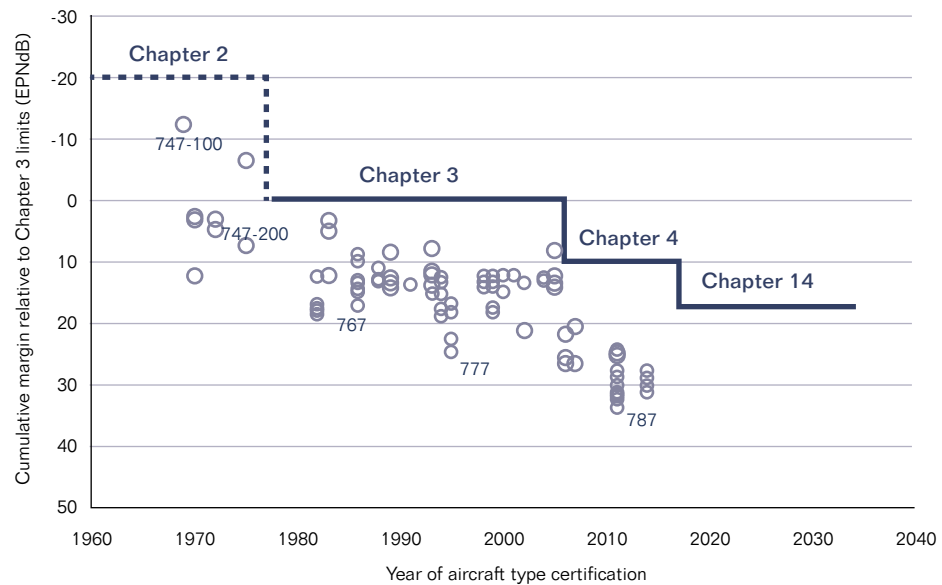


Source: [Wikimedia Commons](#)

2.13 Noise problems from aviation are not limited to aircraft operations. Airports, as the focal point for transport interchanges, generate additional noise from airport-based vehicle operations as well as surface access traffic using the local road and rail infrastructure.

2.14 Noise can be regulated in a number of ways. On an industry-wide scale, the International Civil Aviation Organisation (ICAO) provides a pre-emptive regulation measure through the categorisation of aircraft into noise “chapters”. Airports and authorities can then place limits on noise by chapter of aircraft, either through a total ban, time restrictions or quota limits. There is therefore an incentive for manufacturers to reduce noise output from their aircraft in order to fit into the more flexible of these noise chapters. Chapter 2 aircraft have been completely banned from flying in European airspace since 2002, and chapter 3 will be expected to follow in due course. This measure effectively performs as a ‘one way valve’, as aircraft are only allowed to become quieter and never noisier. This also leads to improved technology, both for new aircraft and for the retrofitting of older aircraft with quieter or cleaner equipment such as hush-kits. The noise chapters have been displayed in figure 4 with wide-body aircraft plotted, showing the progression of chapter 4 and beyond compared to a baseline of chapter 3.

Figure 4 - ICAO noise chapter performance of wide-body aircraft since 1960

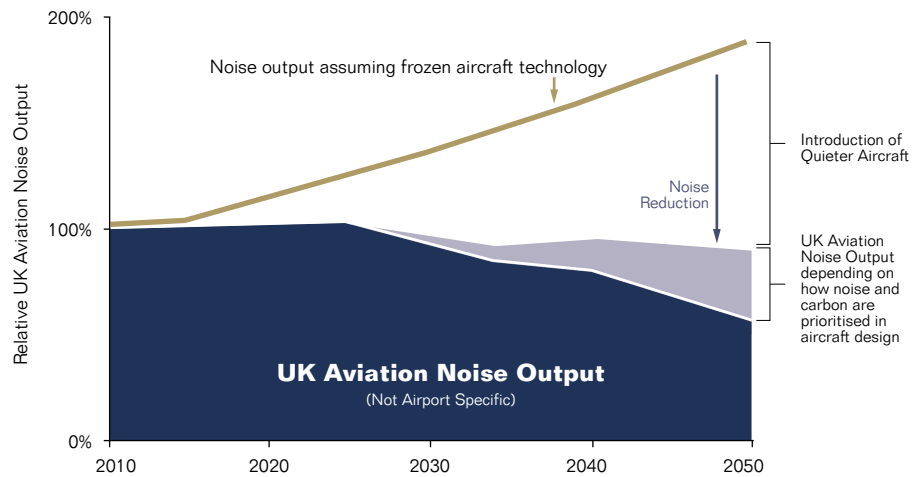


Source: EASA European Aviation Environmental Report

2.15

The noise roadmap compiled by Sustainable Aviation produced the diagram below as a sign of how the industry is expected to develop to 2050 assuming a strong level of growth. The most significant reductions are seen to come from improvements in technology and the implementation of the best technology that is available today, keeping overall noise output below 2010 levels even with significant traffic growth. This roadmap does not include other potential reductions in noise such as from operational and behavioural changes that are described later in this paper.

Figure 5: Sustainable Aviation Noise Roadmap



Source: Sustainable Aviation Noise Roadmap

2.16

Unfortunately, the solutions to the aviation industry’s problems of noise and emissions are not always mutually compatible. Some solutions to one problem may come at the cost of another. This is highlighted by Sustainable Aviation as a potential area for noise improvement depending on where priorities are placed. Perhaps the clearest trade-off is in the design of airport flight-paths – for many local communities, re-routed flightpaths may be desired to avoid densely populated areas; however by flying indirectly more fuel will be burnt and therefore the impact from CO₂ and other gases on the global climate change problem will be greater. Other examples of these trade-offs exist in aircraft technology, where a noise reducing design on the fuselage may be aerodynamically less efficient, and a more fuel (and therefore carbon) efficient engine design, such as open rotor, may prove to be noisier than the jet engines they replace. Sustainability can only be achieved where these various demands are carefully evaluated and balanced alongside economic impacts to develop the optimal approach.

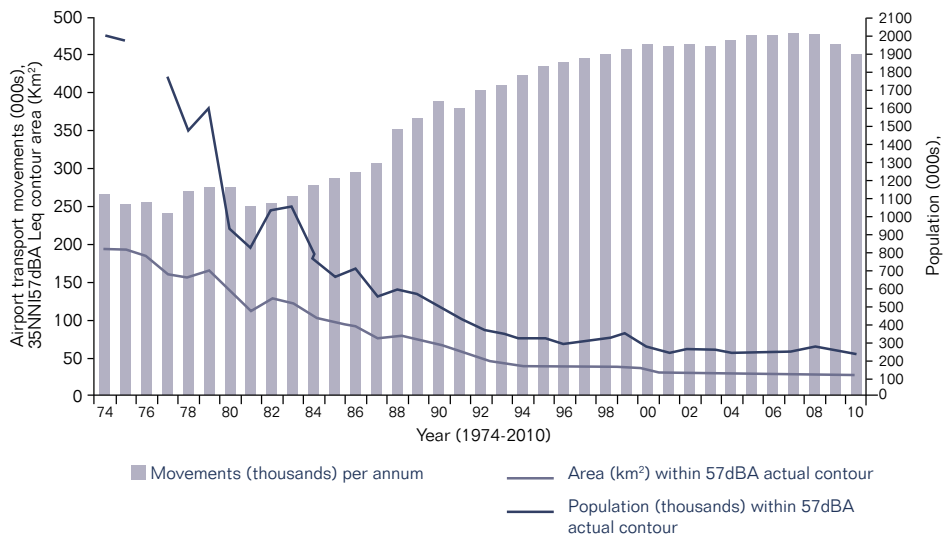


Noise Progress

2.17 Noise measurement and reporting is a complex area and whilst we know that aircraft are becoming quieter, and will continue to do so, understanding the impact on communities is challenging. The tolerance of resident groups affected by noise will differ based on a range of individual factors, as will the willingness of others to consider changes to flight-paths that might bring new areas into the noise envelope. One solution is to provide a long-term noise roadmap for the UK's major airports that considers how growth forecasts would be accommodated in a re-optimised UK airspace using next-generation navigation methods and working with communities to implement a binding agreement. An independent noise authority along the lines of that recommended by the Airports Commission should be a priority in ensuring any targets are implemented and adhered to.

2.18 The noise improvements that have been made in the last half decade have been recorded by some airports and show progress has been made through the continued reduction in aircraft noise. The diagram below shows how the population within the 57dBA noise contour around Heathrow has decreased at a greater rate than the increase in movements from air transport.

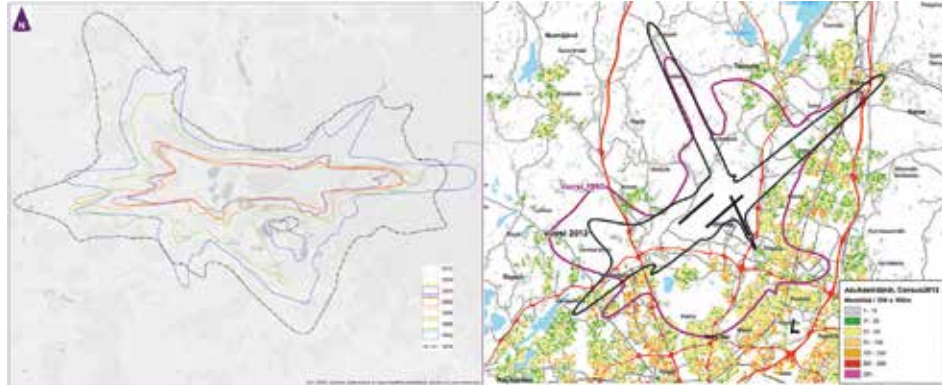
Figure 6: Land Area and Population Within the 57dBA Noise Contour



Source: Heathrow Airport Ltd.

2.19 The impact of quieter aircraft can be illustrated from the noise maps of Heathrow and Helsinki airports, which are shown in Figure 7. Both charts show the size of the noise envelope over time and suggest that a combination of engine/airframe improvements and changes to navigation patterns can dramatically alter the shape of noise nuisance.

Figure 7: Shrinking Airport Noise Contours: Heathrow, 1974-2012 (left) and Helsinki, 1990-2013 (right)



Source: Heathrow Airport Ltd, Helsinki Airport⁴.

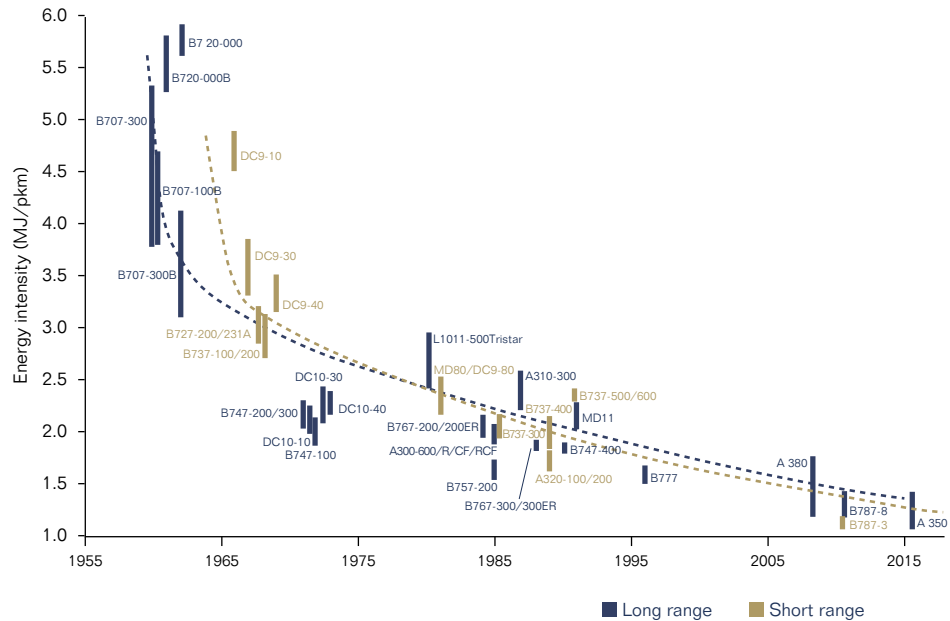
2.20 There is, of course, a limit to the progress that can be made in aircraft noise and ultimately the area beneath the final flight path, in which the aircraft is configured for landing and in line with the runway, will inevitably be the most affected by noise. That said, there remain ways to mitigate this by use of displaced thresholds or, in the case of the Heathrow Hub proposal, using the western runway for landing, in which case the noise contour could move 3km west at certain times of the day. Many of the Airports Commission proposals also promote the use of runway alternation, where runways used for arrivals or departures are changed predictably across the day to offer periods of respite. This is something that can only be offered when spare capacity is available.

3. Aircraft Design

3.1 Improvement in the efficiency of technology is frequently cited as the main source of improvements in sustainability for the industry. The Committee for Climate Change (CCC) 2008 report into aviation and climate change predicted a 0.8% increase in fuel efficiency per annum as a result of these improvements, increasing to 1.5% with funding support for these new developments. This figure sits below our estimate of 1.6% before new developments.

3.2 The improvements in technology can be easily demonstrated by the diagram below, produced by the International Energy Agency (IEA). Whilst it is immediately apparent that the greatest increases in efficiency were made in the early years of the jet age, the industry is continuing on a steep path of improvement. There was also a significant gap in the development of new technology between 1998 and 2008, other than the Boeing 777. Most of the aircraft in operation today are still of the pre-1998 generation but this is likely to rapidly swing towards the newer generation over the next few years, bringing with it substantial improvements in emissions and noise.

Figure 8: Aircraft Efficiency Gains since 1955



Source: IEA, 2009

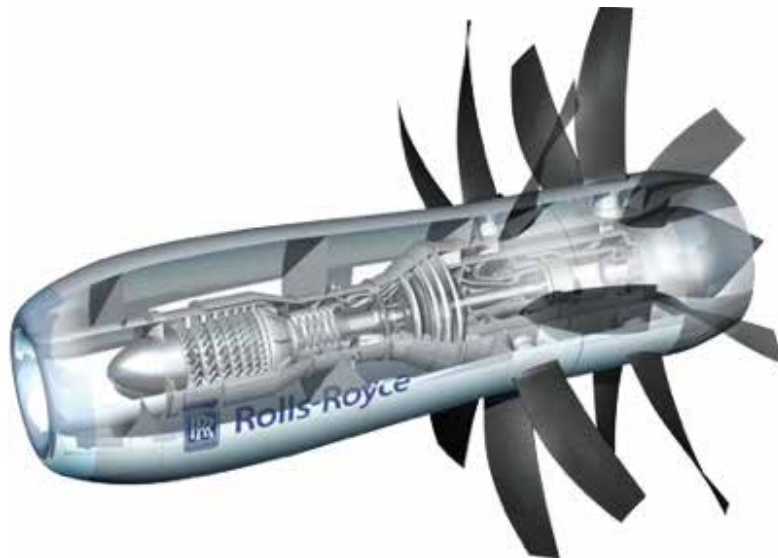
3.3 Engines have understandably been the focus of most of the technological improvements for aviation in recent years, as they are responsible for both the greatest noise output and the vast majority of emissions outputs. The technology has taken great leaps since the beginning of the “jet age” in the 1950s. The most visual difference is the switch from turbojet engines (known for their “cigar” shape) to the more modern and efficient turbofans.

- 3.4** Turbofans have been incrementally improved by increases in the bypass ratio – that is, the ratio of the amount of air that passes through the fan but not the engine core to the amount of air that passes through the core itself. In practice this leads to larger, stubbier engines and increased fuel efficiency.
- 3.5** Further improvements in turbofan performance are expected to arrive in the next generation of aircraft. One variety of improvement is known as a “geared” turbofan, which uses a series of gears to operate various compressor stages at different speeds. This is more efficient, providing greater thrust per unit of energy burned, and the reduction of the fan-tip speed below the speed of sound creates considerably less noise. Pratt and Whitney claim that their PW1000G geared turbofan engine will burn 16% less fuel than the current equivalent engines and reduce noise footprints by up to 75%.
- 3.6** A turboprop is an alternative engine that is often preferred by regional and some low cost airlines. These engines provide a fuel efficiency benefit over turbofans that leads to lower emissions and lower operating costs. However, as well as being significantly noisier than turbojets, most turboprops lack the speed to be able to compete over longer distances.
- 3.7** A study by Aviation Economics and Loughborough University⁵ found that the narrow-body category of aircraft (formed mainly of variants of the Boeing 737 and Airbus A320 families) has become very efficient, able to offer a fuel burn of around 200g per seat per minute in the approach phase of flight, and there is a vast gap between these aircraft and the smaller wide-body aircraft in terms of efficiency.
- 3.8** At the opposite end of the spectrum, “jumbo” sized aircraft are also becoming significantly more efficient. These were highlighted by the older 747-400 (530g of CO₂ per seat per minute) and its cutting-edge replacement Airbus A380 (320g of CO₂ per seat per minute), showing the vast improvements that have been made in technology in the 29 years between the aircraft developments.
- 3.9** Whilst engine technology has improved substantially over previous decades, there remain a large number of opportunities for further improvement. In the short-term, increases of the propulsive efficiency through higher bypass engines may still yield the greatest improvements, however more radical engine designs may be needed in the mid to long term.

Open Rotor

- 3.10** Open rotor engines are one particular design that the aviation industry has highlighted for future potential. These utilise many of the fuel efficiency gains of a turboprop engine whilst still maintaining the long distance speed that can be achieved with a turbofan. By increasing the fuel efficiency, emissions will be kept to a minimum. General Electric estimates that the first generation of open rotor aircraft could burn 15% less fuel than the current series of 737 aircraft. One potential issue with the open rotor design that will need to be resolved is that it would be expected to be noisier than an equivalent turbofan engine. Passengers have also been found to be sceptical to the use of propeller-based engines (viewed as old and less safe) and so the issue of passenger acceptance must also be addressed.

Figure 9: Open Rotor Engine



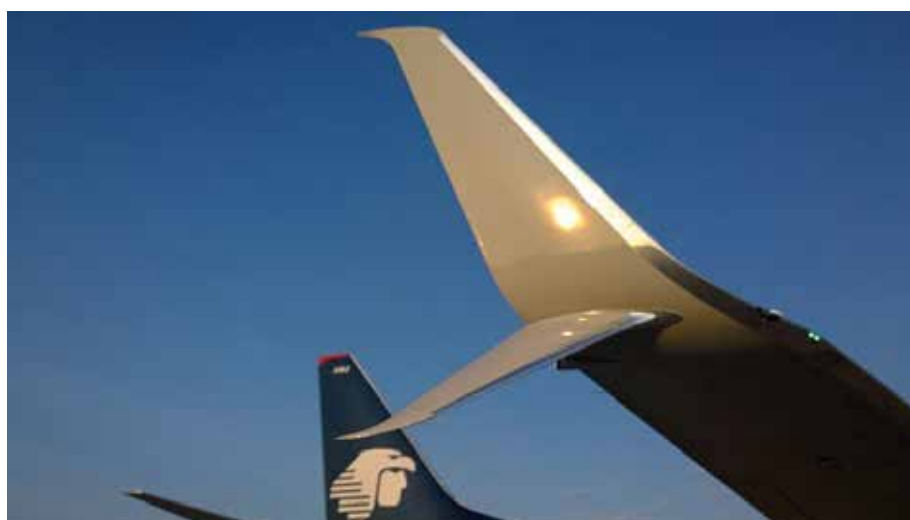
Source: Rolls Royce

- 3.11** In the very long-term, the aviation industry must look to switch to a green propulsion option. The technology is currently not advanced enough to power a large airliner, however a number of milestones have been made with much smaller aircraft which demonstrate the feasibility of the technology. More information on these can be found in Chapter 7.

Wing

- 3.12** The wing of an aircraft is one of the most critical aspects in determining the efficiency of the airframe and how much noise it may generate in flight. An interesting case study in the improvements made in wing technology can be seen from Boeing's 737 family of aircraft. These aircraft have been manufactured since the 1960s and have undergone several significant redesigns in that time. From the 737 'Classic' series to the 737 'Next Generation' series (introduced in 1998), the wing span was increased significantly (by around 20%) to increase fuel efficiency and general performance. Blended winglets offer a 3.5% saving on fuel for an average length trip by the aircraft, while the newer split-scimitar winglets offer a further 1.6% fuel saving.

Figure 10: Split Scimitar Winglets



Source: [Wikimedia Commons](#)

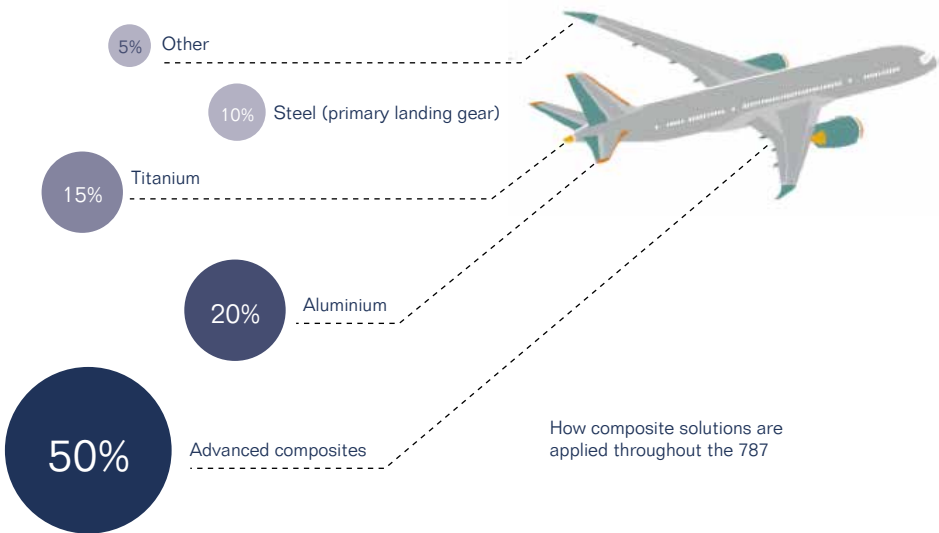
- 3.13** The Airbus A320 is one of the most popular airliners flying today but has gained a reputation among residents under the flightpaths of some airports for its distinctive "whining" sound. This is caused by air rushing over circular openings on the underside of the wing, creating an effect similar to that of blowing over the top of a bottle. Airlines and airports have identified this and a solution has been created, reducing the noise impact by around 6dB. New aircraft now come with this update fitted and older aircraft are in the process of being retrofitted.
- 3.14** In the long-term, efficiency of wing designs is likely to be improved by the use of laminar flow control – this means controlling the air flowing over the top of the wing and avoiding it becoming "turbulent" until as far back along the wing as possible. Estimates suggest this could save 4-5% in fuel burn (Airbus).



Airframe

3.15 The latest generation of new aircraft, the Airbus A350 and Boeing 787, are the first aircraft to be developed primarily with composite materials rather than aluminium or other metals. There are currently 375 of these types flying, representing just 24% of the total order-book to date. Both aircraft feature over 50% composite materials. For the Boeing 787 this represents a 20% weight reduction over a conventional aluminium design. The effect of this is that less thrust is required to propel the aircraft, and therefore not only is fuel efficiency dramatically increased but noise from the aircraft is lower.

Figure 11: Airframe Composition – Boeing 787

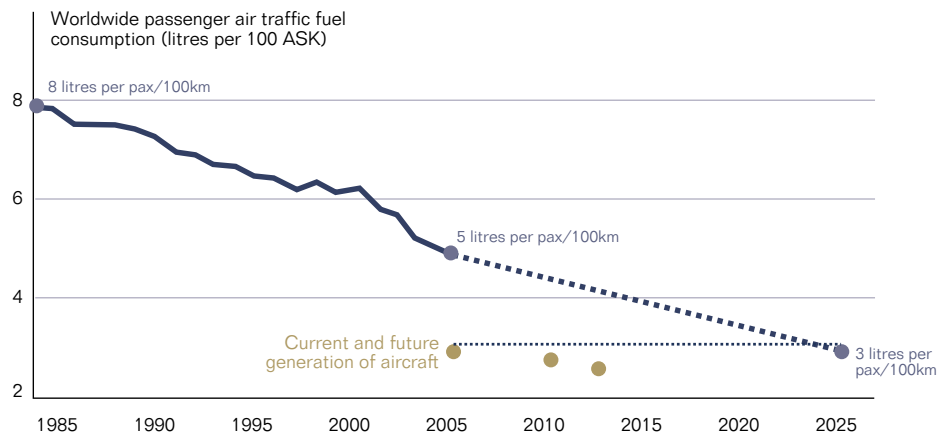


Source: Boeing

Fuel Efficiency over Time

3.16 Fuel efficiency of aviation has developed continually since the 1960s. Studies undertaken by the International Council on Clean Transportation (ICCT)⁶ found that the gains were particularly large in the 60s and 70s, and though efficiency gains have slowed since 1990, they are estimated to be less than 50% of 1960 levels. A further study has been made by the International Coordinating Council of Aerospace Industries Associations (ICCAIA) using a metric of fuel burn per person per 100km. This interpretation suggests that fuel efficiency gains have continued since 2000, perhaps driven by a greater focus on improving load factors, which would not be accounted for in the ICCT model.

Figure 12: Fuel Efficiency and Forecast v Today



Source: ICAO and ICCAIA

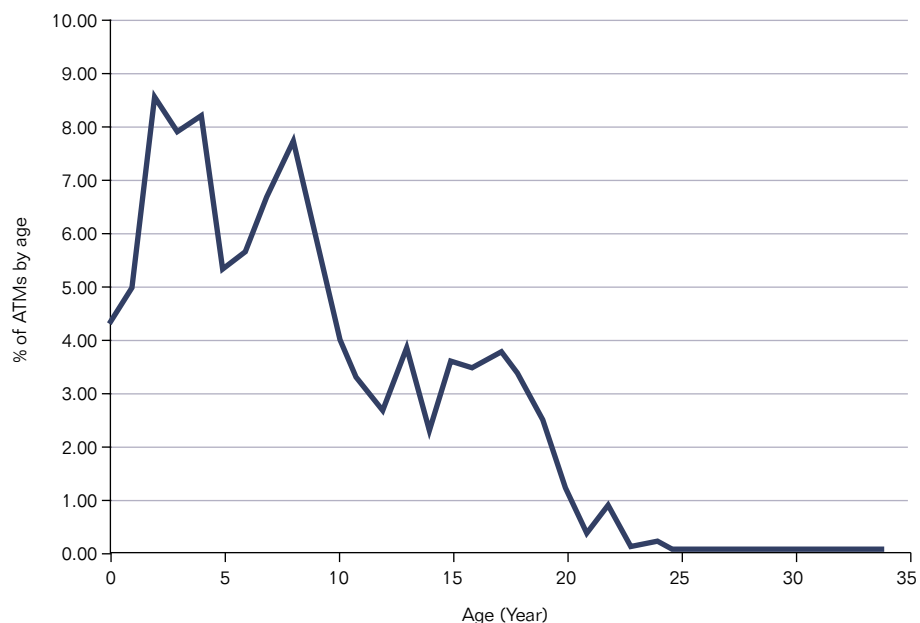
3.17 This diagram also displays the current fuel efficiency of the latest cutting edge aircraft (shown in gold). These aircraft currently burn around 60% of the overall industry average fuel consumption. The forecast here then makes the reasonable assumption that the industry average will reach this level by around 2025.

Speed of Technology Implementation/Aircraft Life Cycles

3.18 It stands to reason that the improvements in aircraft technology are limited in their impact by the speed at which they are taken up by the airlines. For all airlines, aircraft are a substantial investment leased or depreciated over long periods, and the economics of retiring old aircraft early to move to more efficient new airframes does not add up – the additional cost to change outweighs the savings. The balance sheet life of aircraft, and the cost element factored into airfares, is generally based on the life-cycle cost over 10 to 20 years. Furthermore, as the returns on operating new aircraft are long-term, a smaller or newer airline may look to purchase second-hand aircraft rather than the latest model (low cost airlines are the exception to this – see chapter 3). This means that it can take a very long time for a new and more efficient aircraft to completely replace the older, less efficient fleet.

3.19 Shown below is a diagram from a study undertaken by consultants Ecometrics Research and Consulting (EMRC) and the AEA Technology (AEA) for the Department for Transport (DfT) on the sustainability opportunities in aviation. It showed the age of the UK fleet in 2007, demonstrating that the vast majority of the fleet at that stage was young (under 10 years old). However, there are several important aspects that this does not show. Firstly, by operating on a “per ATM” basis, the greatest emphasis is wrongly placed on short-haul flights, when research has shown the majority of emissions are burned on long-haul. Secondly, the study focuses only on UK airlines, ignoring the fact that foreign airlines flying to the UK are equally responsible for UK emissions. Finally, it is important to look at the age of the technology, rather than the age of the airframe itself, as this is a far bigger factor in emissions and noise output.

Figure 13: UK Fleet, Average Age

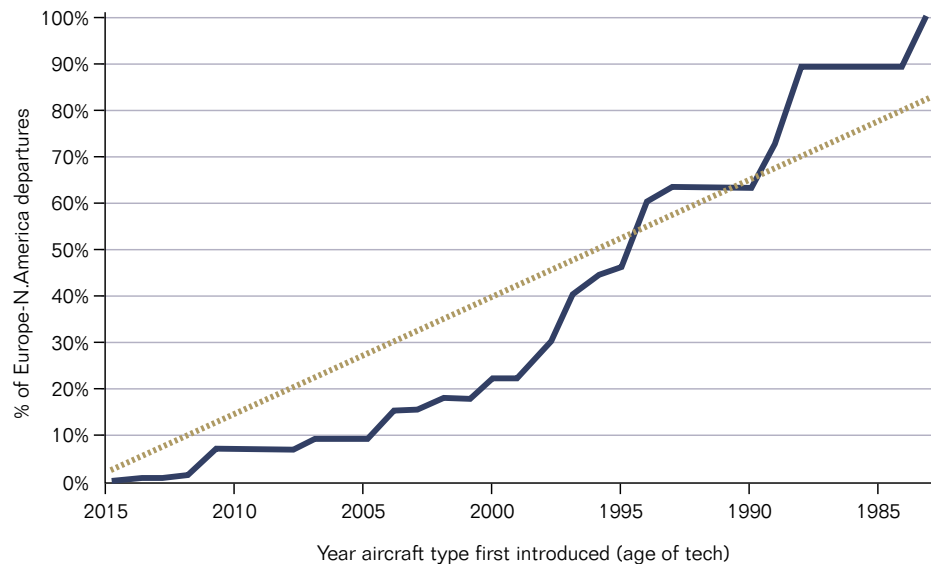


Source: EMRC/AEA (for DfT)

Case Study – Trans Atlantic Market

3.20 The figure below shows the technology age of aircraft operating in the transatlantic market (age based on date of first commercial flight for type). The transatlantic market has been chosen as it mostly negates the issue of varying distances affecting the “per ATM” metric and the North Atlantic crossing is operated by a reasonable selection of common aircraft with clearly defined aircraft models – the short-haul market view is clouded by dozens of smaller improvements over time to a small number of very popular models. The chart is slightly skewed by the presence of the 747-400, which was exceptionally popular in the 1990s/early 2000s and is soon approaching its retirement age, however the clear trend can be seen. The rate of technology uptake is around 2.5% per year, such that over 50% of the technology in operation is under 20 years old; however, the trend from the last 10 years has seen a very poor uptake of new technology, partly due to the lack of new technology to acquire.

Figure 14: Europe to North America Proportion of Flights in 2015 by Technology Age

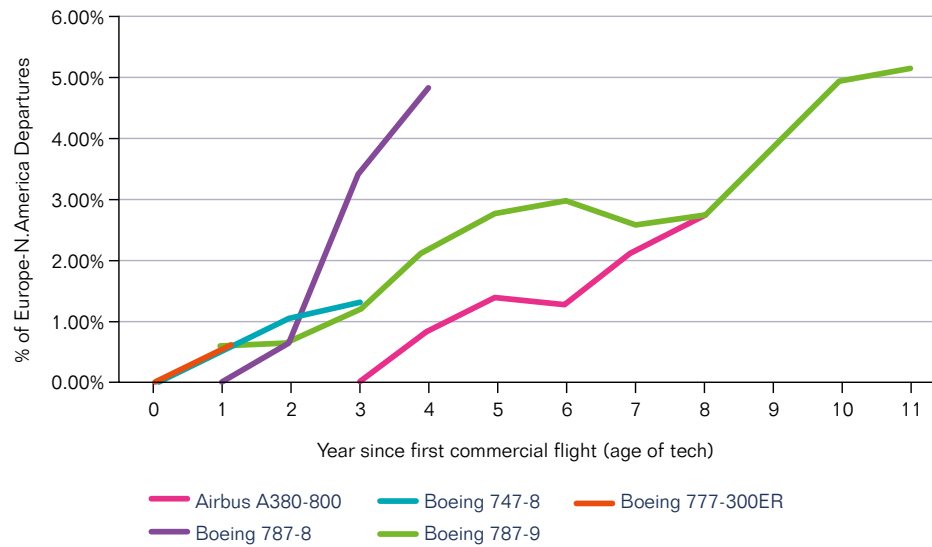


Source: Capstats.com

3.21 To understand this situation further, the trend for five of the most popular recent aircraft models has been plotted on Figure 15 opposite. The oldest model of the chart, the 777-300ER is essentially an update of a slightly earlier model with improved range and performance. The steady rate of growth for this aircraft is therefore as would be expected. It is the last of the previous generation of wide-body aircraft, and the remaining four represent the latest generation. The Airbus A380 has been slow to enter the North Atlantic, not appearing in schedules until 2012, but has since developed strongly as British Airways, Air France and Lufthansa have taken more deliveries of the type. The newer aircraft types entering service since 2011 display a greater promise for the uptake of new technology. The 787-8 in particular has already

reached levels comparable with the 777-300ER despite being in commercial service for only four years. This therefore suggests that the apparent slowdown in technology uptake observed in the previous chart is more representative of a brief gap in technology generations and that the latest technology should be invested in coming years at least at the rate of 2.5% per year.

Figure 15: Uptake of New Technology, Trans-Atlantic Market



Source: Capstats.com

3.22 The rate of technology uptake is critical to the sustainability of the aviation industry. Although to a certain extent the industry is able to address this itself thanks to the cost savings made from operating new aircraft, the prohibitive cost of these new airframes remains a significant problem, especially when older models are available for a mere fraction of the price, and the benefits of retiring an old airframe (i.e. scrap value) are also low. Furthermore, in times of low fuel prices, the incentive to fly more efficient equipment is reduced. Changes to the regulations regarding the operating lives of aircraft could provide a benefit to sustainability, however it is important that any national or EU-wide regulations encourage new aircraft investment, rather than simply punish operators of older aircraft, and that regulation is universal to avoid harming British or European airlines at the extent of international competitors.

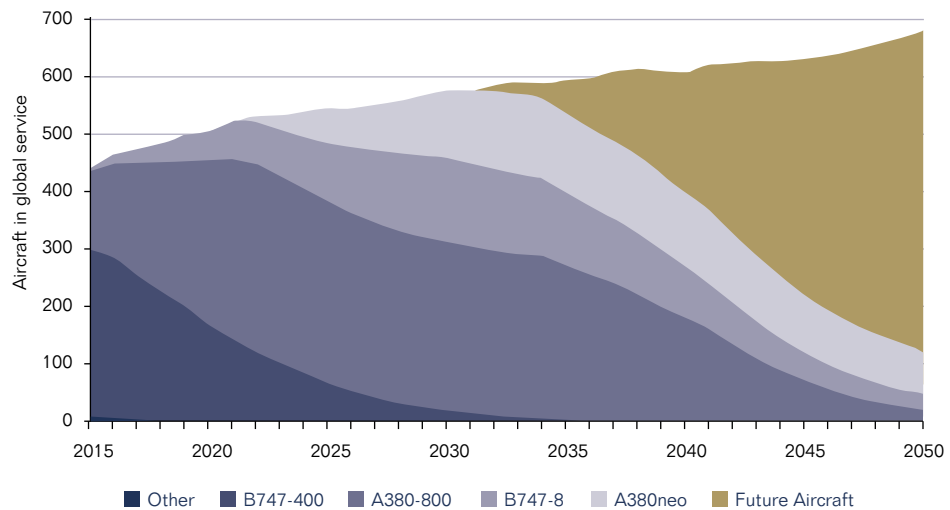
3.23 We have produced an estimate of the global fleet to 2050 using known production rates of new aircraft and estimated retirement rates of current aircraft based on their age. Airbus and Boeing both publish forecasts against which we compared our own, although the manufacturer’s forecasts both stop at 2034, which is when many analysts expect the next generation of aircraft to begin operations. In the forecasts presented here, an assumed “future aircraft” of unknown technology and manufacturer is presented to show how great of an impact this will have by 2050.

3.24 “Jumbo” sized aircraft (definition here being an aircraft featuring multiple floors and with four engines) is a small and unpredictable market, a characteristic well represented by the varying opinions of the two manufacturers, with Airbus forecasting significant demand for new aircraft in the next 20 years and Boeing forecasting a modest decrease in overall number of aircraft over the same period. Whilst it is too early to confirm which of these forecasts will be correct, orders for the two types in this category, the A380 and 747-8 have been infrequent as airlines are showing a preference for the slightly smaller, twin-engine aircraft such as the 777 and A350.

3.25 The Boeing 747-400 is still the dominant workhorse, comprising 66% of the global jumbo fleet; however it is in the process of retirement, with the second largest UK operator of the type, Virgin Atlantic, having made its final 747 flight in early 2016. The two replacements, Boeing’s 747-8 and Airbus’ A380-800 are selling modestly and production looks set to continue only until around 2022. Other than Dubai-based Emirates, which has 77, only 102 A380s are in operation to date. Airbus has suggested an upgraded A380neo design which could take over the production line for potentially around 10 years, but would be unlikely to out-sell its predecessor unless substantial efficiency gains are made.

3.26 This means that between 2030 and 2040 the industry will be looking for a new aircraft to fill this size market. Radical technologies such as blended wing bodies could give this market a renaissance if the efficiency gains are there, but if they are not the industry would likely shift its focus back to smaller aircraft. Therefore this particular area of the aviation market has to be viewed with great uncertainty beyond 2040, and consequently our forecast for this sector of the market is relatively conservative.

Figure 16: Future Shape of Jumbo Fleet



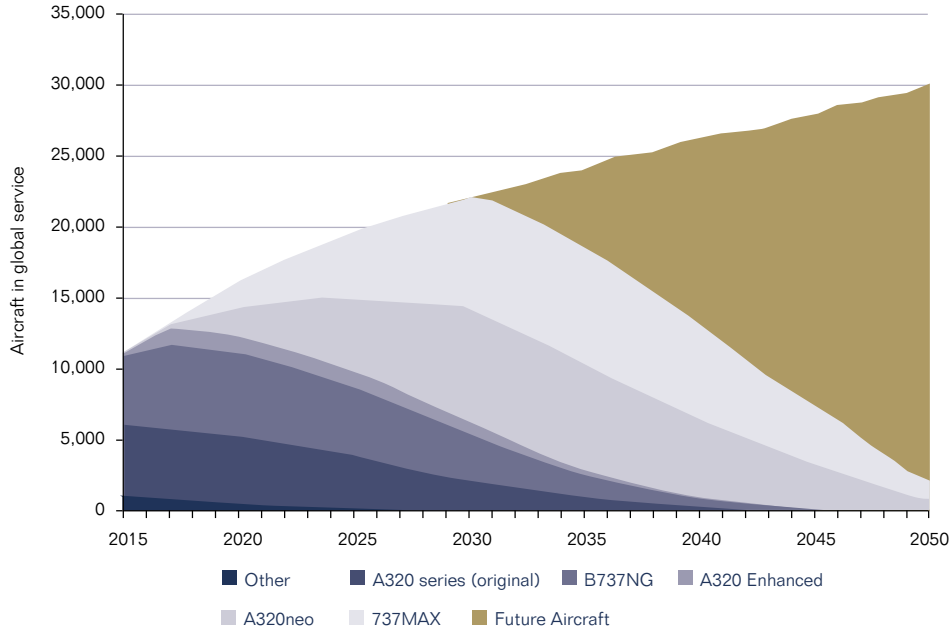
Source: RDC analysis



3.27

The narrow-body sector has seen the highest growth rates over previous decades, and all forecasts suggest that will continue. Currently Airbus's A320 and Boeing's 737 types dominate the market, with roughly 50% each. Both programmes have recently reached the end of their production cycle and will be replaced with the A320neo and 737MAX respectively – accounting for 50% of airframes by around 2026. It is expected that these two product lines will carry on the dominant position of their predecessors and potentially outsell them. Based on previous product cycles it seems likely that a replacement for, or the next upgrade of these would enter the market in the early 2030s, and account for 50% of the fleet by around 2040. In both instances the speed of aircraft turnover in the narrow-body market means the new generation reaches this 50% point within 10 years of entering service.

Figure 17: Future Shape of Narrow-body Fleet

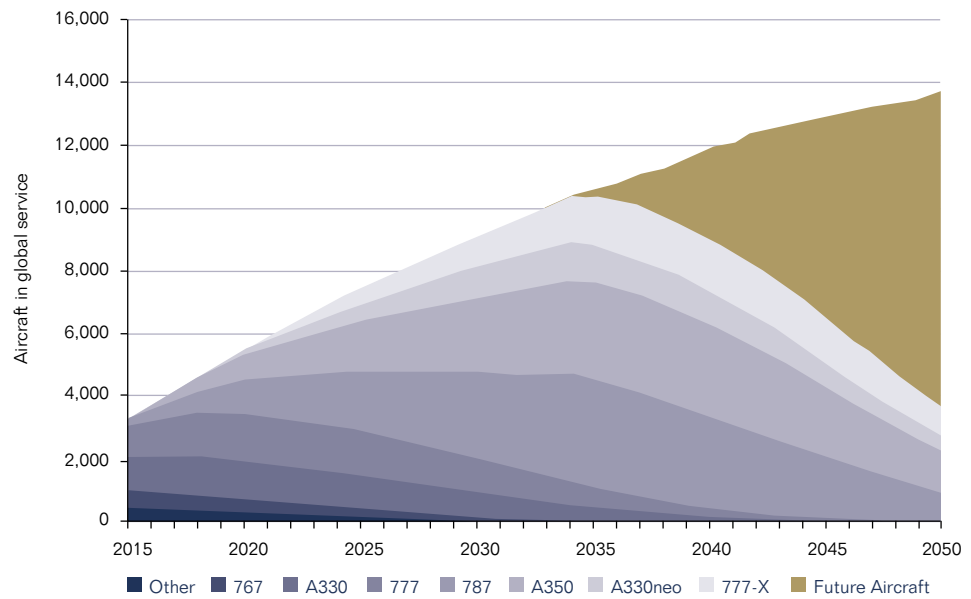


Source: RDC analysis

3.28

In the widebody market, the situation is a little more complex. A number of different aircraft models exist from each of the two major manufacturers, filling a variety of roles and needs, primarily on the long-haul market. The most popular aircraft from each manufacturer in 2015 are the A330 and 777, together accounting for around 61% of the total wide-body fleet. Both models are being substantially upgraded, to the A330neo and 777x respectively, which should see at least a decade of successful production. The greater change in this sector will be from the entirely new-build 787 and A350.

Figure 18: Future Shape of Widebody Fleet



Source: RDC analysis

3.29

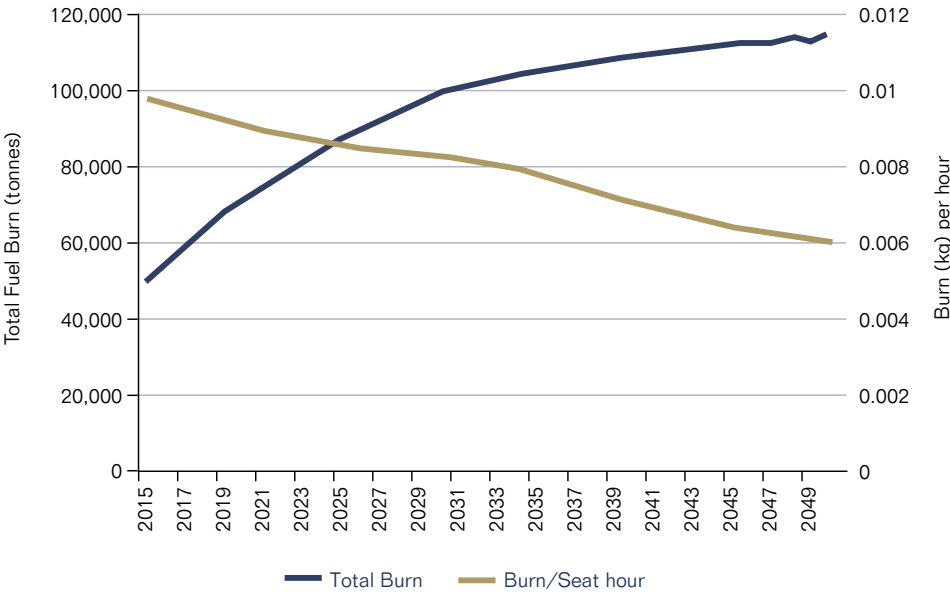
These technology cycle forecasts have been compiled together with RDC data on fuel consumption to provide a forecast of fuel consumption up to 2050. It must be stressed that while the near-term forecasts are very stable, beyond 2030 (when as-yet-unplanned aircraft enter service) it is difficult to predict with absolute certainty how the industry will perform. This forecast is deliberately conservative due to the magnitude of these unknowns, however the opportunity for large-scale reductions with the introduction of new technology is vast and should not be understated. In all segments, we expect the majority of aircraft flying in 2045 to be types that are not currently on the drawing board.



3.30

The forecast suggests that the rate of fuel burn improvements by implementation of technology should be fairly constant at around 1.6% per year, meaning that 45% less fuel would be burnt per seat hour by 2050. Whilst this is a substantial rate of consistent improvement, when put in the context of rising demand for aviation, particularly from developing countries, the total fuel burn from global aviation would still be expected to increase at a rate of around 2.5% per year. However, this model does not consider the effects from other changes and improvements, such as operational efficiencies and alternative fuels. These matters will be addressed in the following sections.

Figure 19: Global Industry Fuel Burn Forecast (tech improvements only)

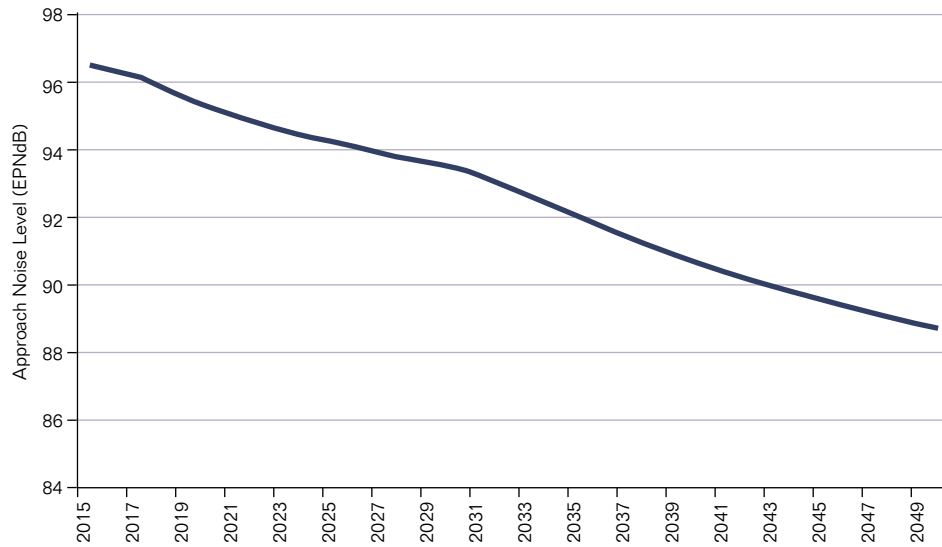


Source: RDC analysis

3.31

A similar forecast can be made for noise, which is shown in figure 20 below. This has been calculated using noise data from EASA (European Aviation Safety Agency) for current aircraft, supplemented by industry predictions for new aircraft types and extrapolating trends for aircraft as-yet unplanned. This forecast shows that the current generation of aircraft will reduce the average approach noise by around 5dB by 2035. The technology that will come on line after that could take the reduction as far as 8dB below current levels by 2050.

Figure 20: Future Noise Forecast for Aircraft > 100 seats



Situation	Sound Pressure Level (LpA) dB(A)
Threshold of pain	130
Threshold of discomfort	120
Chainsaw at 1 m	110
Disco, 1m from speaker	100
Diesel truck pass-by, 10m	90
Kerbside of busy road, 5m	80
Vacuum cleaner, 1m	70
Conversational speech, 1m	60
Quiet office	50
Room in a quiet, suburban area	40
Quiet library	30
Background in TV studio	20
Rustling leaves in the distance	0
Hearing threshold	0

Source: EASAS, Airports Commission



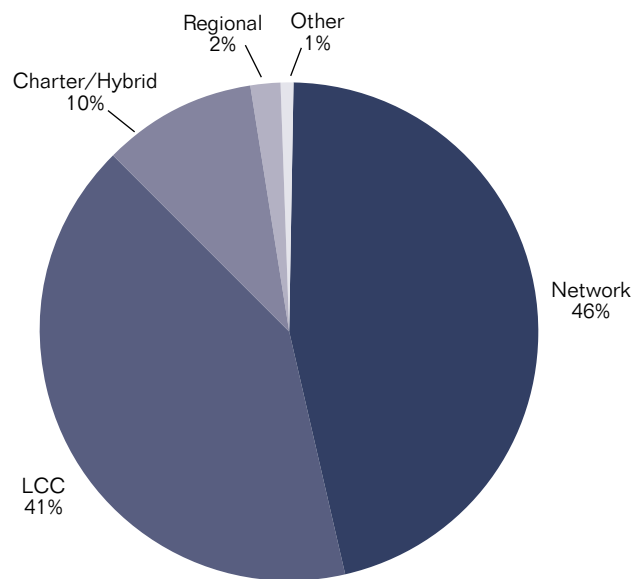
3.32 The Effective Perceived Noise (EPNdB) metric is used in aviation to measure the “annoyance” of aircraft noise on local residents. It takes a weighted average of the aircraft noise on both approach and departure, to provide a comparable figure of annoyance. Aircraft currently in operation average around 96.5EPNdB (a scale based on taking averages of several readings of both arrival and departure), which is above the noise of a diesel truck at 10m, on the Airports Commission scale.

3.33 These forecasts for fuel-burn and noise are able to provide an indication of the type and performance of aircraft that may be operating at around the time that new capacity is built at either Heathrow or Gatwick airports. Our analysis shows the average aircraft will burn 15% less fuel (and therefore CO₂) by 2030 and be around 4dB quieter, with trends set to continue long after this date. These improvements could potentially be fast-tracked and increased with the use of policy measures to incentivise the renewal of UK and European fleets.

4. Airline Business Models – Environmental or Economic Sustainability

4.1 The shape of the airline industry has changed substantially over the last two decades. From the widespread implementation of low cost business models in Europe and Asia to the rapid rise of “super-hubs” in the Middle East, all of these changes are having an effect on the industry’s sustainability in one form or another, and this is the subject that will be addressed in this chapter.

Figure 21: Composition of Current UK Market



Source: Capstats.com

Low Cost Carriers

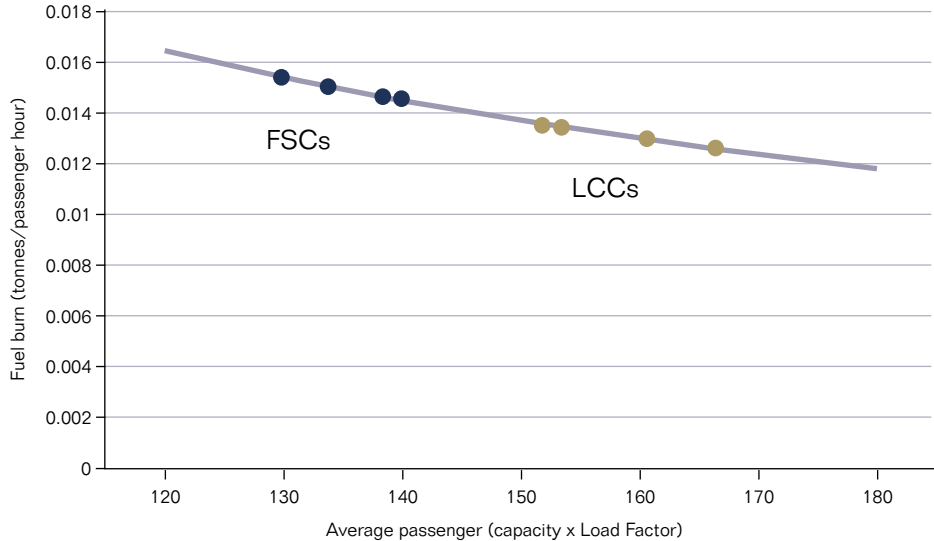
4.2 Perhaps the biggest change the airline industry has seen in recent years (especially in Europe) has been the rise of the low cost carriers (LCCs). These airlines established themselves in the late 90s and early 2000’s thanks mainly to widespread liberalisation of the laws surrounding international air traffic and therefore the removal of considerable barriers to entry, creating the possibility for new airlines to challenge longstanding monopolies and oligopolies.

4.3 One of the key aspects of these business models is a highly efficient system of yield management, ensuring almost all the seats on board the aircraft are sold. This, combined with operating higher density seat configurations, means that LCCs will fly many more passengers than a traditional carrier using the same type of aircraft. Therefore this makes them more fuel efficient on a per passenger basis.

4.4 The effect of this can be seen in the figure 22 opposite. The fuel burn per passenger hour has been calculated for a Boeing 737-800 with various levels of passengers on board and a selection of LCCs and network carriers have been plotted according to their seat capacity and average load factor. This shows that the LCCs are burning around 2kg less fuel for every passenger hour, equivalent to a saving of around 13% in CO₂ per passenger.



Figure 22: Average Fuel Burn by Airline Type

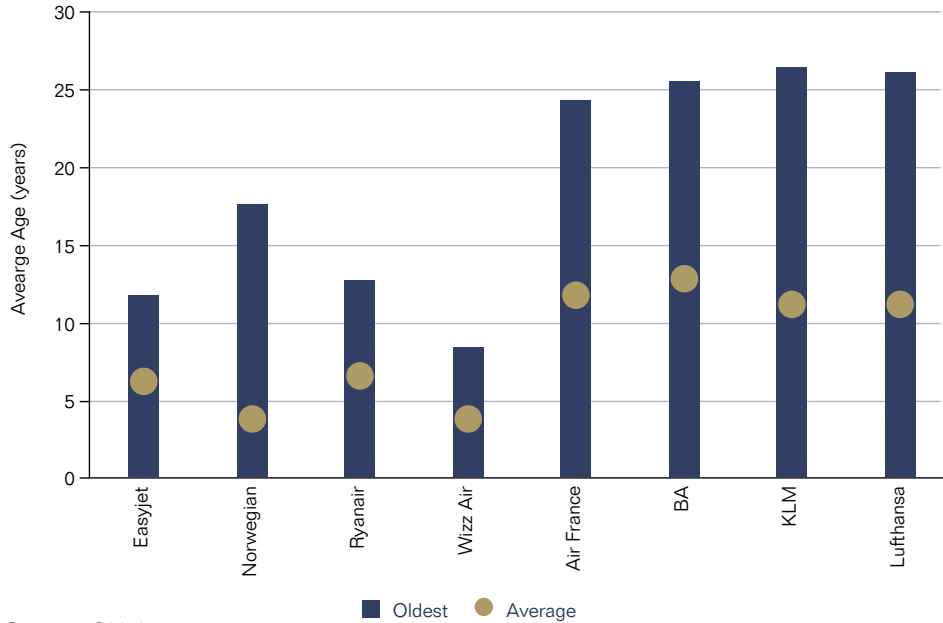


Source: RDC Apex. Airlines: Ryanair, Norwegian, Pegasus, Transavia, KLM, Qantas, Turkish and SAS.

4.5

A further consideration that can be made in favour of LCCs is that they generally operate a much younger fleet than their competitors. This is not a universal rule, as the "original" LCC, Texas' Southwest Airlines operates several aircraft that are over 25 years old; however for more modern LCCs in Europe and Asia, a constant stream of new aircraft deliveries and the phasing out of aircraft after just six or seven years is commonplace.

Figure 23: Average Fleet Ages for LCCs and Network Carriers



Source: CH-Aviation

- 4.6** The Figure 23 on the previous page shows a visualisation of this phenomenon, with four of the largest LCCs in Europe compared with four of the largest traditional network carriers. As well as being on average five to six years older, the aircraft life cycle in a network carrier appears to be over twenty years, while for an LCC it is no more than twelve. This means in practice an LCC is more likely to implement the latest environmentally sustainable aircraft sooner (see chapter 2), and dispose of outdated equipment earlier by shortening its life cycle through more intensive utilisation. However, these aircraft will probably be sold on to another airline, rather than scrapped, so that they could theoretically still be operating for many more years, although their high utilisation rates under LCC usage may make them less economical to operate and maintain at that age.
- 4.7** While LCCs can be more efficient on a per passenger basis than more traditional business models, when looking at the wider environmental context, the situation is more complex. There is a case to suggest that the entrance of an LCC into a market stimulates new demand rather than simply replace the demand served by less efficient airlines and whilst high asset utilisation shortens the aircraft life-cycle, it is simply producing a life-time of emissions over a shorter period of time. In the wider context it could be suggested that LCCs have created a net increase in emissions over what would otherwise have been generated by the more expensive business models.

Network Carriers

- 4.8** Despite the rise in LCCs, the majority of the world's air traffic is still carried by network carriers. Traditionally these airlines were supported by and/or represented their national governments and identity, but are increasingly becoming more independent, privatised and international. Ultimately, complete relaxation of foreign ownership restrictions is one way the industry can cut out 'vanity capacity' and exercise true free-market discipline.
- 4.9** A key differentiator is that a network carrier aims to provide a level of service for its passengers that goes above and beyond simply "flying from A to B", consequently they often have several classes of carriage, with varying levels of service and associated cost. In broad terms, network carriers can be seen as the opposite of LCCs. They operate longer flights using larger aircraft (with the exception of regional hub feed) and often at a lower density seat configuration. As demonstrated in the LCC section, their fleets tend to be older, although this may be just as much to do with long-term fleet investment (and therefore not "asset-squeezing" their aircraft) as it is to do with greater focus on cost efficiency by LCCs
- 4.10** One particular aspect of network operations that is important in sustainability terms is the use of hubs. These hubs allow fast and smooth connections to be made between flights, vastly increasing the number of possible city pairs that the airline can offer. This in turn makes the flights more profitable and therefore a greater number of cities can be successfully linked to the hub. This is an ideal situation for the city in which the hub is based, since it opens up more connections around the world, however it does also have some sustainability impacts.



- 4.11** Compared to a simple point-to-point model of airline operations (either from network carriers or LCCs), a hub can be expected to increase the number of flights – and connectivity – in the region which means at a local level may lead to greater noise and emissions. Extreme examples can be seen around the world in places such as Amsterdam and Dubai, where the level of aeronautical activity is exceedingly high compared to the demand for travel to and from the city itself. Hubs are most sustainable where there is strong local demand in place, such as New York, Shanghai or London. This is because the extra demand created is less likely to require new flights, and more likely to require a transition to larger (more efficient) aircraft on existing flights.
- 4.12** The beneficial effect on sustainability of operating a hub can be demonstrated with a simple model. Using London as a central hub, 10 popular short-haul cities and 10 popular North American cities have been modelled for operation with and without the hub.
- 4.13** In the *without hub scenario*, it is assumed that a point-to-point network serves all combinations of airports with the smallest modern wide-body aircraft available (in this instance, the state of the art Boeing 787-8) at a 75% load factor on a single daily frequency. In a real life situation, some routes (such as Paris-New York) could be operated at a good level of service without the need for an intermediary hub; and the reverse is also true that there will be some city pairs that cannot justify a long-haul service at all, but the combined demand would be enough to justify a link with a hub.

Figure 24: Network Map - Direct Services



RDC analysis

- 4.14** The hub scenario then assumes that all passengers re-route via the London hub. The passenger numbers are divided by the capacity of a sensible aircraft for the route to give a 5x daily 777-300ER service on the North American sectors and a 10x daily Airbus A320 service on the European sectors. The short-haul frequency may appear excessive, but in reality these flights would be spread among more regional airports within the catchment, rather than 10x daily at one central hub.



Figure 25: Network Map - Hub Services



RDC analysis

4.15 The net effect has been to reduce the number of daily long haul flights from 100 to 50. Economies of scale are gained by the use of larger aircraft and therefore the emissions on the long haul flights are considerably lower. The short haul flights are performed on efficient aircraft designed to move large numbers of people at minimal cost/maximum efficiency. By offering a greater daily frequency, the hub service can safely compete with the point-to-point services while offering considerably improved connectivity for its home market.

Table 1: Simplified Hub Model Outcome

	City Pairs	Short-haul Flights	Long-haul Flights	Short-haul Seats	Long-haul Seats	kT of CO ₂	CO ₂ /Seat (Tonnes)
Point-to-Point	100	0	100	0	21,400	12.84	0.60
Hub	100	100	50	17,200	23,450	11.36	0.48

RDC analysis

4.16 This example has been built to show only the effect of carrying the same number of passengers between the same cities using two different airline models. Extrapolated over a wider air transport system, such as that to and from Europe, the environmental efficiency benefits are magnified whilst delivering a substantial connectivity improvement to the country hosting the hub.

4.17 Using fuel burn data from RDCApex.com, the overall reduction in CO₂ produced is 12%, based on a very efficient aircraft on the without hub model and a moderately efficient aircraft flying the with hub model. This is without considering that the hub services could accommodate additional local traffic or use a more efficient large aircraft. For a city such as London, the non-hub traffic could account for as much as 50%, further increasing the economies of scale and reducing the overall CO₂ produced compared with a pure point-to-point model – potentially by as much as 24%. This analysis suggests that a hub model produces less CO₂ on both a per-passenger and overall CO₂ burn basis, while increasing connectivity for the hub airport.



- 4.18** The downside of this approach is that the hub airport becomes the focal point for all flights and therefore accrues the noise and local air quality issues surrounding a larger airport. It also means the host-country counts all carbon emissions on its national inventory.

Charter

- 4.19** This business model has been popular with many independent carriers (i.e. not state owned or influenced) since the 1960s. Its core market is leisure, and particularly the transportation of passengers to and from holiday destinations. As such, the model is designed for maximum flexibility – the route network changes and adapts through the season and capacity is leased in and out as required. As most of the passengers are low yielding, a lot of the principles of the low cost airlines such as high-density seat configurations were first used and advanced by these charter airlines. However, low cost airlines have found that their own models are just as efficient at serving these markets, and the influence of their competition has driven the charter market down to an exceedingly small scale. These days the main charter carriers (in the UK: Monarch, Thomson, Thomas Cook and Jet2) operate hybrid models that have more in common with LCCs. Though they and some of the smaller airlines may still operate ad-hoc charter work, the proportion of traffic of which this accounts for is now very slim.

Regional Services

- 4.20** The regional sector of aviation consumes a lot less fuel, and therefore is much less of an issue for emissions, as the aircraft are significantly smaller and the distances travelled are relatively short. They are also quieter, being smaller and requiring less thrust. The 1990s and early 2000s saw the rise in popularity of regional jets, at the expense of turboprops. Overall this would have a negative impact for the sustainability of air transport as these regional jets are comparatively inefficient on a per-passenger basis. However the most recent capacity data suggests that this trend has flat-lined as fuel prices have become more volatile and turboprops more economically viable. The trend was also less applicable to the UK market, where rail travel is a viable substitute on many short distance routes, and other routes to Europe have a large enough demand to support larger aircraft.

Freight

- 4.21** The transportation of freight is a part of the industry that has always been considered integral to its function. However recently this side of business is becoming increasingly polarised. LCCs, in an effort to reduce turnaround times and reliance on external suppliers, rarely accept freight on their flights, and with their fast increasing share of the market, this means the choices for transporting freight by scheduled air services are becoming few and far between.
- 4.22** At the other end of the spectrum, the industry has seen a large rise in the use of freight forwarding conglomerates, such as DHL, UPS and FedEx. These companies have globe-spanning networks with dozens of local bases and regional subsidiaries.

They provide a seamless service from pick-up to delivery which is highly attractive to their customers. The air network forms the link between major hubs of these freight forwarders, sometimes using other airlines' aircraft (such as Aerologic for DHL) or increasingly using their own fleet of aircraft – most importantly these aircraft are dedicated freighters, which do not and cannot carry revenue passengers on the same flight.

- 4.23** Traditionally, freight has been carried in the bellies of large passenger aircraft, particularly those operating in and out of hub airports (as these offer opportunities for onward connections and therefore economies of scale). This is a highly efficient means of transporting freight, as it is on-board flights that are already carrying revenue passengers and therefore the marginal cost of transporting the freight is extremely low. The use of dedicated freighters is not necessarily inefficient in itself if the loads are high for both the outbound and return legs (demand for freight can often be mono-directional), however these aircraft are usually either conversions of older passenger aircraft or the last aircraft from a given aircraft production line. This means that the rates of technology implementation for dedicated freighter airlines are among the lowest in the industry. Popular aircraft types for these airlines continue to include the McDonnell Douglas DC-10 (first flight 1970) and Airbus A300 (1974). Furthermore, dedicated freighter aircraft frequently operate at unsociable hours, due to the desire to guarantee overnight deliveries and the availability of cheap slots – this can be a primary cause of noise complaints for local residents, especially at airports without night curfews.
- 4.24** Sustainability for air freight is most likely to be achieved through the use of existing passenger airline hub networks supplemented by large-scale freight aggregators with dedicated aircraft fleets linking logistics hubs. This will minimise the need for extra flights, ensure economies of scale from larger aircraft, and utilise the most modern and efficient technologies available.

Conclusions and Future Direction

- 4.25** Overall it is clear that the way in which the aviation industry develops with respect to the various business models will have a significant impact on its sustainability. The rise of low cost airlines can be seen as a net benefit in this respect, transforming short-haul travel into an efficient and fuel-lean means of connecting across relatively short distances and making flying more affordable. However, the long-haul market will continue to be orientated towards service levels as well as cost, requires the aggregation of freight alongside passengers, and therefore is unlikely to be as successful for low cost airlines in the future. With this in mind the industry needs to focus on finding an efficient means of connecting thousands of possible city-pairs across the world with the smallest amount of infrastructure, and the solutions to this are hubs. Hubs provide the economies of scale from a wide selection of possible routes, combined with the movement of high volume freight through belly-hold space, which can reduce emissions of CO₂ and other harmful gases by at least 12% even in a simplified 20-city model.



5. Operations

- 5.1** The air transport system is already relatively efficient (in terms of fuel burn and therefore emissions as well as noise) as it exists in a situation where mostly-private companies are motivated to operate at maximum efficiency to minimise costs, particularly with regards to fuel burn as this is frequently the airline's most significant cost. However there are some bottle-necks in the system caused by regulation or congestion which may provide opportunities or further improvements in the coming years.

Taxiing and Ground Delays

- 5.2** With a finite amount of runway capacity, peak times can cause a build-up of delays at many airports. The effect that this has on the local environment in terms of noise and emissions is almost totally dependent on how the airport and airline choose to handle the situation.
- 5.3** The Aircraft on Ground Reduction (AGR) Programme developed by Sustainable Aviation found that at Heathrow airport, emissions from ground aircraft accounted for 30% of CO₂ emissions (not including emissions created in the "en-route" phase of flight), and is therefore an identifiable area for future improvement.
- 5.4** Taxiing is a relatively inefficient process, as it uses the aircraft's engines, designed to propel the aircraft to over 600mph, at speeds closer to 20-30mph. There are a number of initiatives both proposed and in use around the world that aim to reduce the fuel burn during taxiing, thereby reducing noise and emissions on the ground. The simplest of these initiatives is single-engine taxiing, where one engine is not started until as late as possible (around 2-5 minutes before departure). A study by Deonadan and Balakrishnan of MIT⁷ found that at busy US airports such as New York JFK, NO_x emissions from taxiing could be reduced by as much as 40% by employing this method.
- 5.5** Alternatively, aircraft can be towed to the runway by a tug or similar vehicle, and the same study found that this could reduce the CO₂ emissions from taxiing by around 70%. However it also noted that the use of these vehicles could also increase NO_x by around 60% depending on the age and type used. There is potential in the future for aircraft tugs to be electrically powered, and therefore effectively eliminate emissions; however, these are not widely used and the appetite for universal uptake is dependent on the airport handling agents.
- 5.6** A perfectly managed situation would see an aircraft never leave the gate until it was able to taxi to an available runway without delay. This way the aircraft would not have to start up its engines or APU (a small engine usually located in the tail of the aircraft that powers the aircraft while on the ground) and instead could rely on the GPU or FEGP⁸ until the exact moment it is required. The GPU is both quieter and less pollutant than the aircraft's on-board power systems. However this procedure requires a high level of coordination between the airport and airlines, and for airports

7 Deonadan and Balakrishnan (2010) "Evaluation of Strategies for Reducing Taxi-out Emissions at Airports"

8 Ground Power Unit and Fixed Electrical Ground Power

such as Heathrow and Gatwick, could be a very inefficient way to make the most of its scarce gate and runway capacity. Deonadan and Balakrishnan found that using this system of “advanced queue management” taxi emissions could be reduced by around 50%. However, this system would not be practical in a situation of very limited runway capacity, as the act of maximising the limited available capacity would require aircraft to queue at the entrance to the runway.

- 5.7** Sustainable Aviation estimate that around 50% of the emissions from APUs can be cut through increased use of GPUs and other systems, and a 0.6% reduction in UK aviation’s overall CO₂ emissions. A study at Zurich airport found that the NOx reduction from use of GPUs would be around 4.3% per flight.

Delays from Airborne Holding

- 5.8** While delays on the ground may be costly, aircraft naturally burn more fuel in the air, and so delays that occur to aircraft awaiting a slot to land can be far more devastating to both the airline and the local environment. A study by researchers from Aviation Economics and Loughborough University (2015) found that an aircraft in a holding pattern burns around 1 kg of CO₂ per seat per minute (varying greatly depending on the aircraft used).
- 5.9** The researchers also discovered that the particular situation at London Heathrow leads to a 0.6% increase in the overall fuel and CO₂ burn of all flights arriving at the airport. There may also be an added impact of noise, since each arrival spends an average of 4-5 minutes extra holding at a height of between 8,000 and 12,000ft over mostly built-up areas. However, the noise impact of aircraft at this altitude has not been quantified.
- 5.10** The paper finds that these delay impacts are all directly the result of poor access to runway capacity, since an airport system with appropriate runway capacity would not have the need for holding patterns or long ground waiting times. It concludes that expansion of capacity should not always be viewed as a net cost to the surrounding environment, as it has benefits from reducing delays.

Single European Skies and Global Navigation

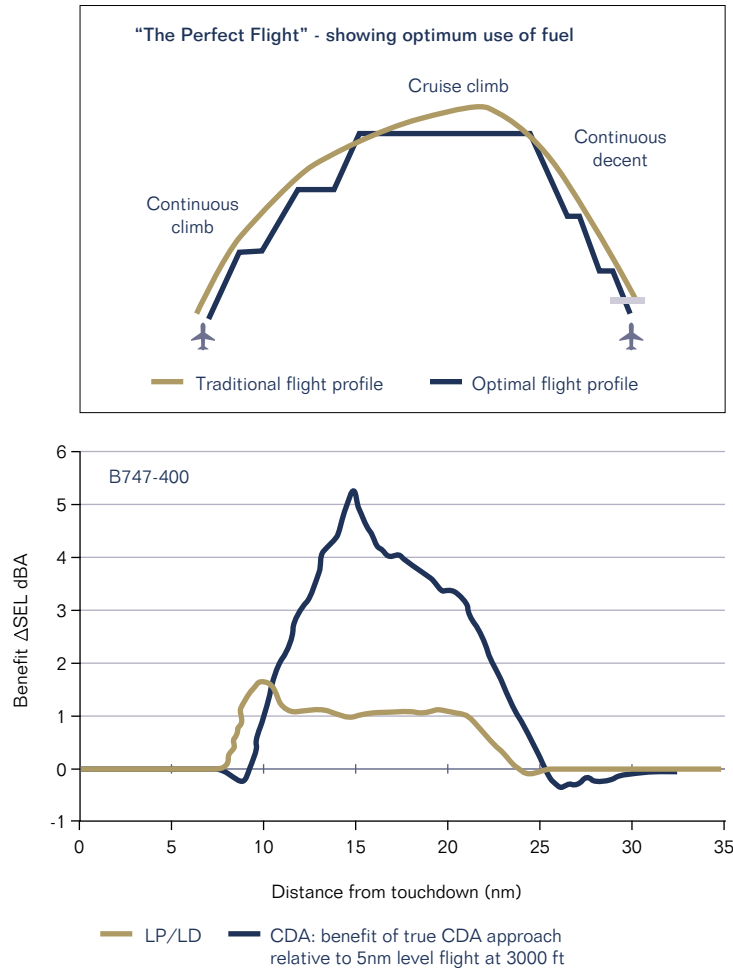
- 5.11** The “invisible infrastructure” that makes up the airways crossing our skies has remained largely unchanged for several decades. This means that many flights are directed on paths that are not as direct as they could be, leading to unnecessary fuel burn and emissions. The industry is working on a solution known as Performance Based Navigation (PBN) that would allow flights to travel on more direct flightpaths without the risk of collision. This system requires the cooperation of nations controlling the airspace, so is likely to be gradually implemented rather than a sudden ‘big bang’. PBN is expected to be operating in Europe in the early 2020s.
- 5.12** NATS, the UK’s primary air traffic service provider, monitors every flight that travels through UK airspace and gives it a *3D inefficiency* (3Di) score. This considers the difference between the track travelled by the aircraft and the optimal track to reduce fuel burn and emissions. NATS has several targets written into its UK license to improve the average 3Di score of aircraft under its control.



- 5.13** One critical issue to consider in the choice of flightpaths is that it is often not possible to reconcile both reducing emissions and reducing noise impacts at the same time. For example under a PBN system, all departures to the Middle East and Asia (usually large aircraft heavily laden with passengers, freight and fuel) would fly an almost identical departure track – concentrating the impacts on particular communities and not offering respite. However, fanning or splitting departures to offer respite causes longer routings which burn more fuel and emissions. Handling these separate issues is one of the challenges that needs the combined effort of regulators, airlines, airports, navigation service providers and local communities to resolve.
- 5.14** One of the largest sources of noise complaints from aviation is on the approach phase of flight. Although quieter than the departure phase, the approach offers less flexibility in planning because aircraft have to be approaching in line with the runway from around 10 miles out, whereas on departure can be vectored out to different departure paths comparatively quickly. This is a particular problem for Heathrow where the runways are East-West aligned such that aircraft approach over West and Central London when the wind is in the prevailing Westerly direction. This accounts for about 70% of Heathrow's flights.
- 5.15** There are a number of potential ways in which the operation of airport approaches can be optimised to reduce the impact on local residents. One of the most beneficial and simple to operate is referred to as “low power, low drag”, or LP/LD approaches. This means reducing thrust to a low level early in the approach and maintaining this until landing, whilst also operating in a “clean” configuration with minimal application of flaps and no landing gear deployed for as long as safely possible. Pilots that are familiar with the airport are likely to fly in a style similar to this, however unfamiliar pilots may be anxious to complete their pre-landing checklists and establish the landing configuration as soon as possible. Establishing an airport-wide practice for LP/LD would provide benefits in these instances of around 1-2dB for most of the approach (see figure 26). Indeed, simply sharing best practice from each airlines' standard operating procedures at an airport can bring substantial benefits in noise above local communities.
- 5.16** Greater gains can be made with the use of continuous descent approaches (CDA). These are performed by aircraft flying a single constant descent from its cruising altitude, as opposed to the more common stepped approach. This means the aircraft can stay at a lower, quieter thrust level for longer on the approach, without the short bursts of increased thrust seen on stepped approaches. The difficulties in implementation of this system are that it often requires airspace to be redesigned, high levels of coordination to ensure aircraft begin their descent at the correct distance from the airport and sufficient capacity to not delay aircraft in holding stacks. However when this is correctly performed the expected benefits can be as high as a 5dB reduction in noise for residents under the approach path, as well as associated emissions benefits from reduced thrust.

5.17 The figure below from the DFT’s code of practice for arrivals shows the relative benefits of the two systems. Continuous descent approaches provide the greatest benefit, but this can be complimented with LP/LD operations for optimal noise reduction.

Figure 26: NATS Optimal Flight Profile and Continuous Descent Profile



Source: NATS

Comparative Benefits of LP/LD and CDA Approaches

5.18 Continuous Descent Approaches fit into NATS’ “perfect flight” initiative (shown above). Sustainable Aviation forecasts that improvements from this and other navigational techniques can lead to a 6.5% decrease in CO₂ emissions, while analysis by IEA indicated that a CDA could save between 5% and 11% of fuel on the final 300km of a flight.

5.19 For some aircraft operations, the impact of aircraft noise can be further mitigated through the use of displaced thresholds. These change the position of touchdown for aircraft to further down the runway, thereby increasing the relative height at which the aircraft pass overhead local communities, and limiting the lowest part of the approach to within the airport perimeter. In order to perform these operations, the



aircraft must have a sufficient length of runway to land with no safety implications. A 1 nautical mile displaced threshold can mean aircraft are 300ft higher when flying over local communities. In Heathrow Airport’s submission to the Airports Commission, it claimed that it could operate one or more runways like this with a three-runway configuration, alternating usage to give residents periods of respite – an activity which Heathrow has calculated to provide a net benefit in terms of reduced sleep disturbance and annoyance over the current operations at a two-runway Heathrow. A study by Jacobs UK Ltd. on behalf of the Airports Commission found that the use of displaced thresholds on Heathrow’s runways would reduce the population within the 90dB SEL noise contour by around 78% (although it must be noted that not all flights could perform this operation). Some of the schemes analysed by the Airports Commission promoted the use of displaced thresholds. Of particular note is the Heathrow Hub scheme, which involved extending the Northern runway out to the West. This would mean that at off-peak times (such as the first arrivals of the morning) aircraft could land further down the runway and that the last 2 nautical miles of flight would be over the airport site itself.

Table 2: Summary of Potential Improvements

	CO ₂ benefit (global)	NO _x benefit (local)	Flightpath noise benefit	Notes
APU reduction	0.6%	4.3%	-	
Single-engine taxi	0.5%	10%	-	Using SA estimate of 30% CO ₂ emissions from ground
Advanced Queue Management	2.0%	20%	-	
No Holding	0.6%	2.5%	-	Some noise benefit under holding patterns
Performance Based Navigation	1.7%	-	-	
LP/LD Approach	0.3%	-	1 db	
Continuous Descent Approach	0.5%	-	4db	
Displaced Thresholds	-	-	4db	300ft higher but not for all aircraft
Estimated Total*	6.20%	36.8%	6-9db	

Using various sources supplemented with RDC data and assumptions.

*Assumes that all measures are independent and not currently being employed.

5.20 The table above shows a summary of the methods described in this chapter and the gains that could hypothetically be made with all measures in place. It should be noted that some of these measures may already be partially in place or not fully realisable in combination with other measures, but that with the use of as many of these measures as is realistically possible, the impacts from aviation could still be reduced substantially. The opportunities for the greatest environmental benefits from operational changes are for local air quality and noise. CO₂ remains a global issue that needs to be dealt with in all phases of flight.

6. Policy and Implementation Options

Surface Access

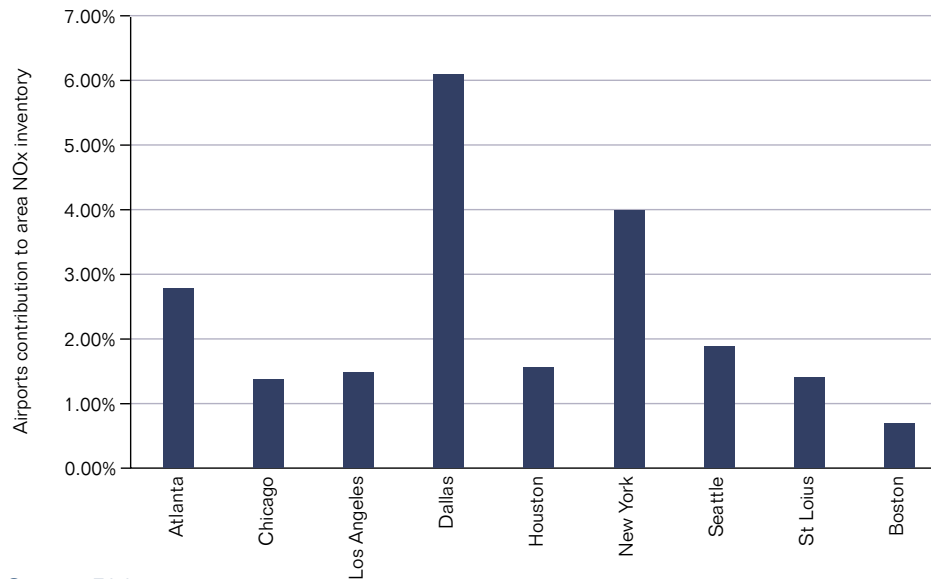
- 6.1** When considering the sustainability of aviation, it is important consider it as part of a wider transport network, creating demand for traffic on modes such as road and rail, and it exists in a system in which much of the traffic bypasses the airport as if it were not there.
- 6.2** A Heathrow Airport study of its surrounding area found that NO_x emissions from aviation were only 13%, while other airport impacts including surface access accounted for a further 10% (19% and 28% respectively on the airport site itself). Measurements taken at nearby Hillingdon and Hayes were found to be higher than at the airport or its immediate surroundings and in excess of legal limits despite the airport and its associated impacts only accounting for 6% of these emissions at Hayes. The road network around Heathrow includes the UK's busiest stretch of motorway – the M25 between J13 and 14, which combined with the M4 carries over 350,000 vehicles per day⁹, while the airport handles around 1,300 flights per day, forecast to peak at 2,000 with a new runway.
- 6.3** An academic study by Farias and ApSimon¹⁰ reinforces this assertion, as they found that the impact from traffic on local emissions was found to be significantly larger than that from aircraft. This evidence shows that while aviation can have an impact on local air quality, it is often polluting indirectly through other modes – and in some cases the other modes are far greater sources of emissions, regardless of airport traffic. Therefore it is important to consider both the effect of an airport on other modes and also its impacts in context with these other modes.
- 6.4** Similar analysis by the USA's FAA can be seen in the Figure 27 opposite. This study features 9 cities with at least one airport in the top 20 in the country. The airports' contribution to the area NO_x inventories vary from 0.7% to 6.1%, with the greatest contributor being Dallas which has two very large urban-located airports and is obviously an extreme case.

9 Department for Transport – Annual road traffic census counts

10 Farias and ApSimon (2004), "Relative contributions from traffic and aircraft NO_x emissions to exposure in West London", Environmental Modelling Software 21



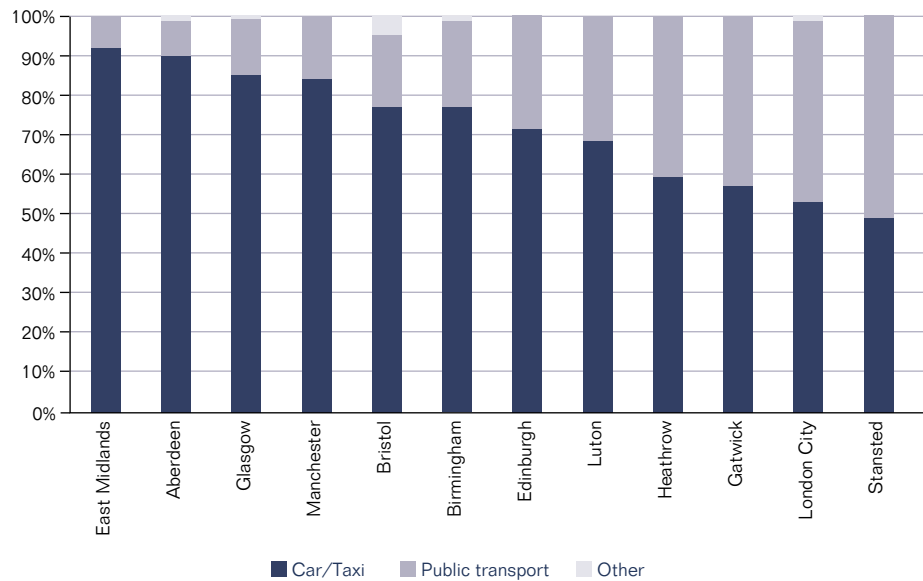
Figure 27: Airport Contribution to Local NOx at Selected US Airports



Source: FAA

- 6.5** Road vehicles have seen substantial improvements in emissions such as NOx and PM10 since the introduction of catalytic converters in the 1990s, however their overall emissions represent the greatest challenge to the wider transport network and were still recording year-on-year increases until the economic recession of 2008 caused reductions in road traffic.
- 6.6** The automotive sector already has a mandated quota of biodiesel in circulation, and is able to embrace electric and electric-hybrid powered vehicles in a way that aviation cannot until battery technology vastly improves. The Department for Transport have taken this improvement in automotive technology into account in their road emissions forecasts, estimating that NOx will fall by 62% and CO₂ by 15% from 2015 to 2040.
- 6.7** As aviation is a part of this collective system, improvements in emissions from road vehicles and a continuing shift away from private cars use for staff and passengers will see benefits flow through to the areas around our airports, resulting in lower levels of particulate and NOx emissions within those areas.
- 6.8** Surface access to UK airports is currently made predominantly by road, though it varies greatly depending on the airport (e.g. public transport share at London City is 46% but at East Midlands is 7%). However the UK government is supporting the creation and improvement of alternative modes, such as Crossrail to Heathrow and improving capacity on the line to Gatwick Airport. The diagram 28 overleaf shows the public transport mode share of the top 12 UK airports. As a general rule, larger airports can support greater infrastructure investments and therefore have a larger share of public transport usage. The two notable exceptions to this are London City, which is small but has a high public transport share, and Manchester, which is large but with a much lower public transport share.

Figure 28: UK Airport Modal Split

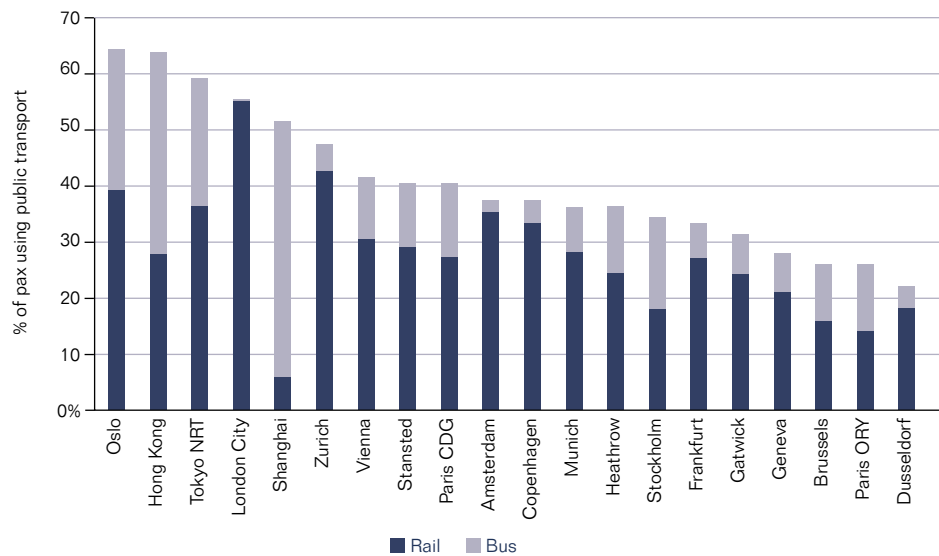


Source: CAA (2011)

6.9

The chart below shows how four of London's airports perform among a worldwide selection in terms of public transport usage. The data shows that the London airports have a reasonable share of public transport (approx 30-40%) but there remains room for improvement compared to leading-class airports such as Oslo and some of the largest Asian airports.

Figure 29: Modal Splits at a Selection of Large Airports

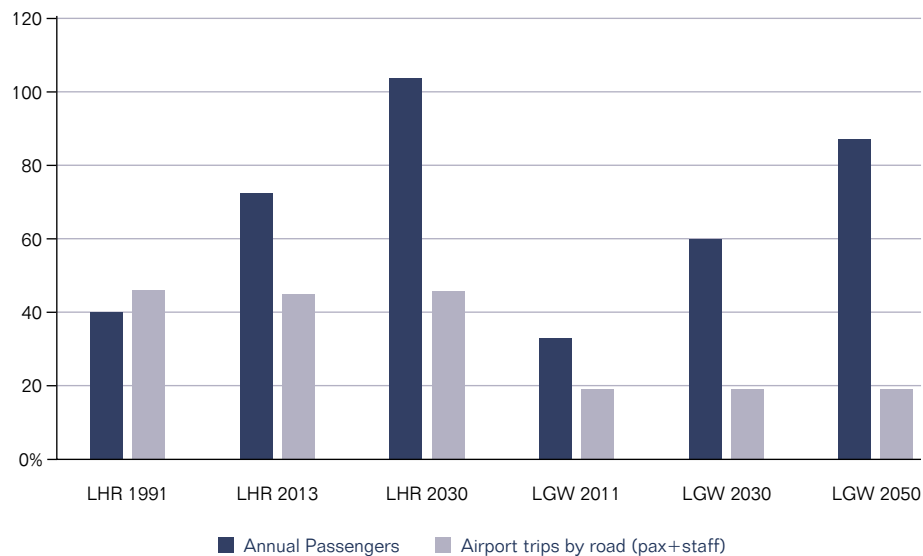


Source: FAA NB. The FAA definition of public transport (bus and rail only) is slightly less comprehensive than that used by the CAA in Figure 28 above.

6.10 Emissions from surface access are primarily from road travel and can be reduced through increased use of public transport and other less-pollutant means. In order to ensure that this happens, new airport capacity should be delivered as part of a wider integrated intermodal transport plan. The relative geographic and temporal proximities of any Heathrow expansion and High Speed 2 plans have made them obvious candidates for being integrated together (and it is disappointing that they have not been) but the approach should be wider than that and consider modes of transport from all directions. The proposals for Southern and Western rail access to Heathrow are steps in the right direction.¹¹

6.11 The assumption is often made that airports increasing in size will increase the amount of road traffic, however where investment in infrastructure is made to meet the demand, then this effect can actually be reversed. Heathrow Airport presents a key case study of this phenomenon, with road trips not increasing between 1991 and 2013, despite an increase in passengers of 80% over the same period. This has been due to investment in public transport such as the Heathrow Express alongside improvements to the Piccadilly line as well as Heathrow’s comprehensive commuter programme to reduce travel to work by car.

Figure 30: Surface Transport Mix – Heathrow and Gatwick Forecasts from Airports Commission Submissions



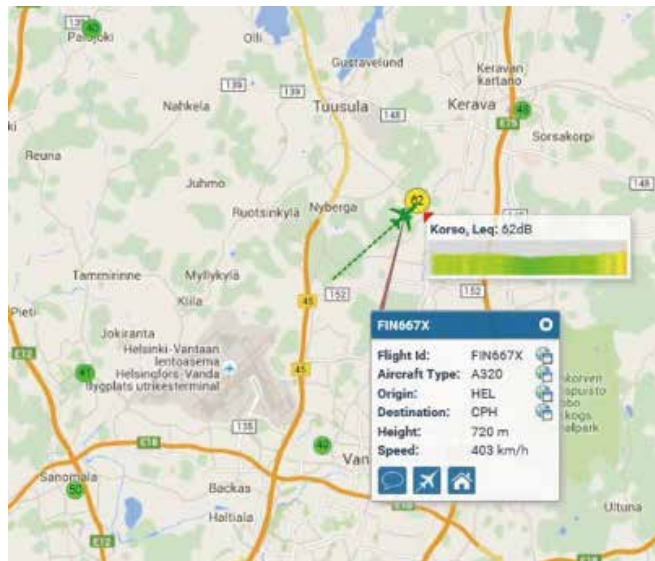
Source: Heathrow Airport and Gatwick Airport

6.12 Gatwick Airport’s own forecast of surface access usage paints a very similar picture of substantial growth not leading to an increase in car usage, and its position on the London to Brighton rail line is core to this.

Community Engagement

- 6.13** Emissions and noise impacts go far beyond simple numbers and charts in their effect on local residents. Commercial airports in the UK are already engaging with their local community to ensure that information is available on noise, how it might affect them and what is being done about it to improve the situation for the future. Many airports currently offer grants for additional noise insulation to local communities, understanding that it is important that they engage in this way to improve the understanding of the airport and wider aviation industry.
- 6.14** The UK's national air traffic service provider, NATS, engages with the communities whenever changes are made to airspace or flightpaths. It has found that proposed changes are often met with a cautious response. For instance the aim of a flightpath change might be to provide periods of respite to those most overflown, but if it brings new households under the flightpaths then there will be a negative reaction from these residents, even though as a whole the community might be better off. However, through this process of engagement, it has been able to conclude that predictable periods of respite are critical to enable those affected to plan their activities around known 'quiet' periods.

Figure 31: Helsinki Airport WebTrak



Helsinki Airport WebTrak

- 6.15** Finland is a global leader in dealing with the environmental impact of Vantaa airport in Helsinki, which handles around 80% of the country's flights and 99% of long-haul services. Through a range of local and national environmental policies, Vantaa Airport is able to meet the objectives of providing greater connectivity for Finland within its goal to minimise impact on the environment.



- 6.16** The air transport landscape in Finland is more joined-up than other parts of Europe with one entity, Finavia, operating the airports and navigation services for the country. This provides the opportunity for a joined-up national policy and implementation framework. As part of its noise commitment around Vantaa, the airport publishes flight tracking and noise monitoring in real time, enabling communities to monitor the performance of particular airlines, aircraft and routings at a number of points around the airport. Heathrow uses a similar system but with less transparency. Until recently, data were delayed by 24 hours before being shown, and the system currently has no real time noise monitoring, but is being enhanced with new noise monitoring terminals being added that will bring the ability to conduct self-service analysis.
- 6.17** We believe the industry in the UK can go further, however there is an important trade-off to be made. Systems employed by NATS and other organisations in the past have looked to optimise flight paths to reduce fuel burn and CO₂ production, but this can be vastly different from the optimal flightpath for reducing noise impacts. RDC proposes that a system similar to NATS “3Di” (see section 5) could be introduced in the UK, whereby airlines are monitored and scored for their fuel and CO₂ efficiency during the cruise phase (above a height of around 10,000ft) but on approach and landing at UK airports they are monitored and scored by their noise impact. The noise impact would be a combination of the intensity of the sound measured from ground stations and the population size that is affected by it. Airlines would then be incentivised to fly noise-friendlier approach paths and controllers incentivised to facilitate them. The key to making this system work would be making it publicly available and usable, similar to the WebTrak system at Helsinki Airport, allowing residents to see how current flights are performing as well as being able to access historical data showing which flights consistently perform poorly.

Policy Measures

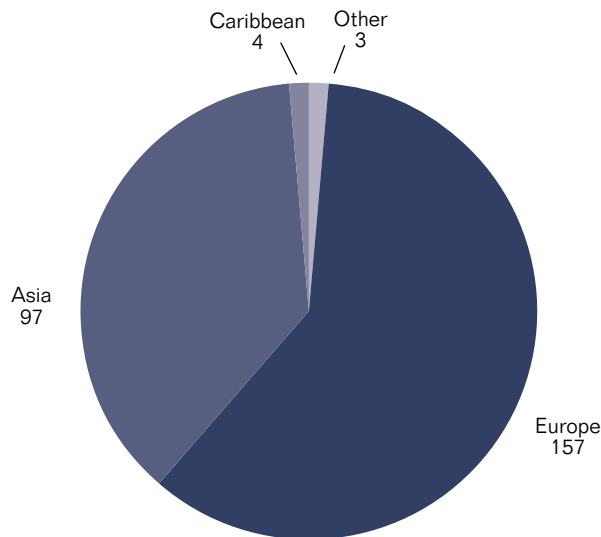
- 6.18** There are a number of ways an airport can look to reduce emissions from the operation of its own facilities and by encouraging users to reduce their own. Airports Council International (ACI) in Europe has produced a carbon accreditation scheme which offers a roadmap for airports to become carbon neutral from their own operations. So called “kiss and fly” visits, where a person is dropped off or picked up by a relative (creating double the necessary car trips), are particularly undesirable and airports can introduce charges for drop-offs to limit these and encourage passengers to use alternative modes of transport. A large number of trips to airports are made by staff, so most major airports have schemes in place to reduce these, including staff shuttle buses and incentive schemes to use public transport.
- 6.19** At a government policy level, the UK Air Passenger Duty (APD) is charged to departing passengers at UK airports. Depending on the distance and the class of travel, this is charged at between £13 and £142 per passenger, and is one of the most expensive taxes of its type worldwide. It has in the past been referred to as an environmental or “green” tax, however it has no clear direct link to reducing emissions other than discouraging low-income travel and potentially has the effect of shifting inbound tourism to neighbouring countries such as France, Germany and Ireland where air passenger taxes are either significantly lower or non-existent.



Ireland, Netherlands and Belgium are examples of countries that have successfully abolished their tax and benefited as a result. Any economic policy measure to reduce emissions must be significantly more direct (i.e. charged on a per emission or fuel burn basis) and applied as universally as possible to avoid harmful market distortion. Revenues gained through such measures or, indeed, incremental revenues from APD, could be hypothecated for use in supporting communities around the airport or wider environmental measures.

6.20 Around the world, Europe is leading the way in terms of establishing noise and environment-related charges on airlines. 60% of all airports with such charging structures are in Europe, whereas there are none in North America. At an airport level, industry has taken to incentivising quieter and less polluting travel through the use of differentiated charging structures, with the number of airports using these systems increasing over recent years. These charges typically take the form of either a noise charge or a NOx charge, as these are the impacts that are most relevant to the airport and its local community.

Figure 32: Airports with Environmental Charge Elements Split by Continent



Source: Airportcharges.com

6.21 Within Europe, the UK is one of the front-runners in implementing environmental charges. The nine largest airports all have noise charges, and three of those also charge for NOx.

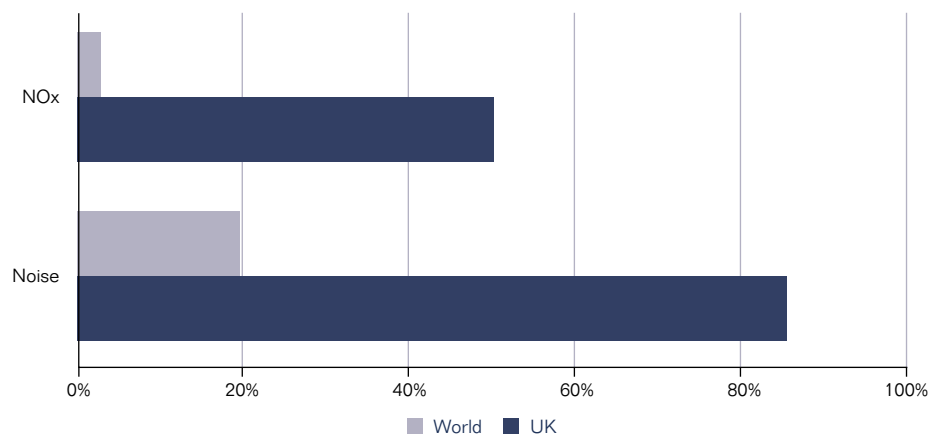
Table 3: UK Airports with Environmental Charging Elements

Airport	Noise charges	Nox charges
London - Heathrow Airport	Yes	Yes
London - Gatwick Airport	Yes	Yes
Manchester International Airport	Yes	
London - Stansted Airport	Yes	
London - Luton Airport	Yes	Yes
Edinburgh Airport	Yes	
Birmingham International Airport	Yes	
Glasgow International Airport	Yes	
Bristol Airport	Yes	
London City Airport		
Newcastle Airport		
Liverpool John Lennon Airport		
Belfast International Airport		
East Midlands Airport	Yes	
Aberdeen Airport	Yes	
Leeds/Bradford Airport		
Belfast City Airport		
Southampton Airport	Yes	
Jersey Airport		
Guernsey Airport		

Source: airportcharges.com and RDC analysis. Note that London City and Belfast City airports have local planning agreements that restrict movements

6.22 Although there remain a number of airports in the UK without environmental charges, the high coverage of the largest airports means that 86% of the UK departing seats are covered by noise charges and 51% by NOx charges.

Figure 33: Proportion of UK Airport seats Covered by Environment Charges



Source: Airportcharges.com

Noise Management

- 6.23** Before construction of any new capacity at either Heathrow or Gatwick, the government should introduce new noise abatement policies, limits or quotas to ensure that the capacity is delivered whilst limiting the impact on local residents. It could also mandate the use of certain routing pathways to ensure airline flight plans are optimised for the needs of communities rather than to simply reduce fuel burn. However on their own, bilateral actions by government or the airport operators may be treated with extreme scepticism by those living under flight paths. Building the trust of communities is a vital part of the planning and delivery process, with community participation essential to delivering effective noise management. The chances of meaningful engagement with community groups will be greatly improved if there are independent redress and control measures that oversee all short and long term agreements, with direct powers of intervention for breach of agreed limits.
- 6.24** For this reason we support the creation of an independent regulator responsible for highly sensitive issues such as noise. Ideally this body would have a wider ranging remit than simply flight-path noise and would objectively consider how best to manage noise from aircraft and other forms of transport around the airport in conjunction with those most affected. An authority independent from government and the other aviation regulatory bodies would be able to advise on a range of critical issues, from the location of monitoring stations to consulting on proposed solutions and advising government on best practise.
- 6.25** With the Airports Commission having published a revised set of long-term growth projections for the UK, a noise authority should look to create a long-term noise road-map that links current and future flight paths to demand projections, showing how noise is expected to develop in terms of intensity and frequency. It would be in a position to work with local stakeholders and NATS on developing a range of environmentally optimised approach and departure paths that balance reducing fuel burn with carbon emissions and minimising local noise.
- 6.26** Planning permission, or even the airport operating licence, should include new regulatory limits or noise quotas, backed up with ongoing publication of results by airline, aircraft type and route across a range of monitoring stations. Add to this real-time noise monitoring and a noise authority with the power to approve, suspend or fine operators for failure to use agreed flight paths or hit targets for aircraft operations, it should be possible to gain the trust of local communities.

**6.27**

It is increasingly common for such restrictions to be included in the planning permission at major airports across Europe, and there are a number of key examples to learn from:

- Frankfurt – In 2011 the airport opened its fourth runway, which came with a ban on night flights – a total ban for 6 hours during the night, and a tight restriction on the number of flights in the borderline times.
- Berlin Brandenburg – Marketed as a new airport but essentially a major expansion of the current Schönefeld Airport, including the construction of a second runway. Flights will be banned between midnight and 5am, with “strict quota limitations” from 10pm and between 5-6am.
- Amsterdam Schiphol – Constructed sixth runway in 2003. Night operating procedures were tightened to include shoulder periods of one runway used for arrivals and one runway for departures.

7. Radical Technologies

7.1 So far we have looked at the efficiencies that should be achievable within the aviation sector through the implementation of 'known' or relatively low-risk technologies. These tend to be improvements in equipment, techniques or procedures that are either in use today or that are very likely to be introduced before 2030.

7.2 Looking beyond the 2030 time period, which is the point beyond which we expect the current and planned global fleet starting to be replaced by aircraft that are yet-to-be developed, there are likely to be further enhancements across the environmental spectrum that could have a material impact on CO₂ emissions, NO_x and noise. However the levels of uncertainty are such that they should be considered as 'unknown' in the context of a study such as this. Nonetheless, there is scope for radical future technologies to make a step-change in emissions and/or noise from aircraft.

Biofuels

7.3 At present biofuels (also known as Sustainable Aviation Fuels) are seen as an important part of the long-term sustainability solution for aviation. Depending on the projections, anywhere between 5% and 20% of future emission savings could come about from use of biofuels as a replacement for the jet kerosene that is currently used to power the global fleet.

7.4 For production, distribution and logistical reasons, biofuels must be compatible with conventional jet fuel so that aircraft can be flown safely irrespective of the type of fuel available at an airport, which means any alternative fuel must have 'drop-in' properties whereby it can be mixed with regular fuel and behave in the same way. Unlike road transport, for which there are relatively few risks in achieving a stable mix of bio- and regular fuels, replicating the properties of jet kerosene comes with significant challenges. Any 'drop-in' fuel must share similar properties to that with which it is being mixed, including having the same freeze- and flash-points; density and energy content; and being able to share the same on-site infrastructure in order to propel an aircraft safely through the extreme range of operational conditions, be that at high altitude over the Polar Regions or taking-off at sea level in the desert.

7.5 Given the potential value of achieving a breakthrough in developing sustainable biofuels it is no surprise that there are a considerable number of processes, techniques and fuel sources under investigation. In the US alone, an estimated 2,700 biofuel patents have been issued since 2002 and there are now several alternative fuels that have been certified for use and tested in real-life flight conditions. In its 2014 report into alternative fuels, IATA details 3 already-approved pathways to producing biofuels and highlights 21 agreements between airlines and producers to develop and test these alternative fuels. Over the last decade, in excess of 1,500 flights have been undertaken using a blend of regular and biofuel and the world's

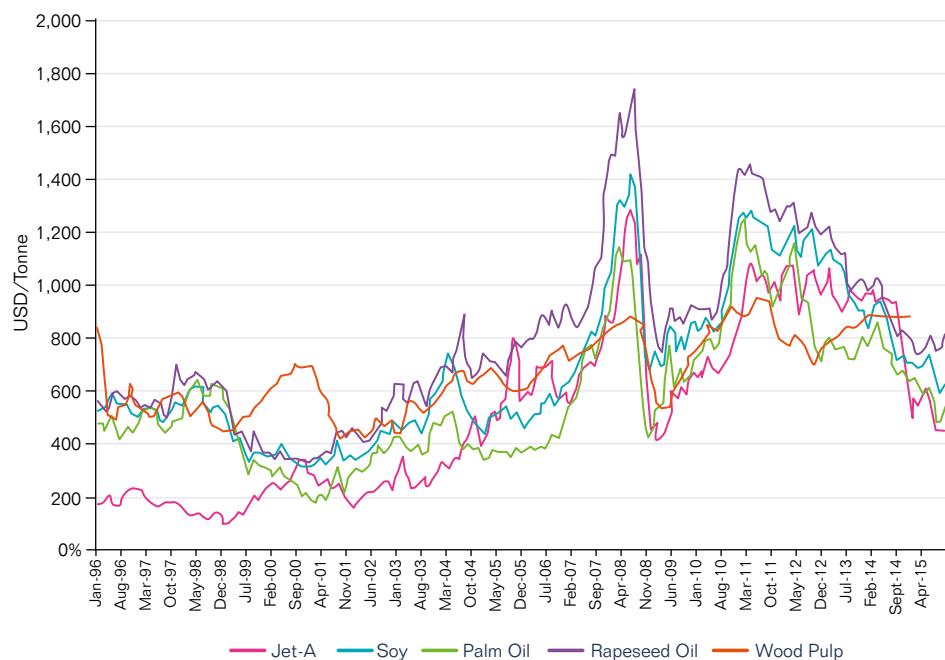


largest airlines – who are also the heaviest consumers of jet fuel – have conducted test flights using mixes of up to 50% biofuel developed using various techniques and fuel sources. To date, there have been a range of raw materials used to synthesise aviation fuel, including agricultural waste, used cooking oil, various plant and switchgrass sources such as jatropha and camelina, and fermented hydro-processed sugar.

7.6 However, although it is now proven that aircraft can be safely powered by various mixes and types of biofuel there is yet to be clarity over how to achieve future large-scale production at commercially viable prices. There are a number of reasons behind this. Firstly, crop-based biofuels must come from sustainable sources, meaning they cannot be derived from food-crops, nor can they compete with land or other resources, such as water, that could be used to grow such crops. Second, fuel sources must be able to generate a predictable and stable yield, which is not the case with some of the plants used to date. Finally, production and retail costs must be similar to the cost of the fuel they are replacing, or at least the cost of the fuel plus any environmental mitigation costs such as associated carbon trading or emissions charges.

7.7 Looking at the cost of a sample of raw materials that could be used to produce bio-jet, including soy and palm oil or wood-pulp, we can see that the commodity cost-per-tonne tracks a similar line to that of jet fuel over a 20-year period. In this example, the chart compares the cost of raw materials for the crop-based commodities versus refined jet fuel. In the case of rapeseed oil, about 2.5 tonnes is required to produce one tonne of biofuel¹², making the rapeseed around three-times more expensive per tonne than jet fuel – before production costs are factored.

Figure 34: Cost per Tonne of Jet Fuel and Selected Biomass Raw Materials



Source: US EIA, Index Mundi, RDC

- 7.8** The second major challenge for crop-based biofuels is the land-mass required for large scale production. Using a simplistic illustration, UK airlines consume an estimated 8m tonnes of fuel per year. A mid-yield biofuel crop such as rapeseed has a yield of around 1,000 litres of fuel per hectare, which equates to over 9m hectares of land required to generate enough fuel to power the UK airline fleet for a year – an equivalent land mass to Portugal.
- 7.9** Other resources such as municipal or agricultural waste, or used cooking oil, offer ‘win-win’ potential as source materials for biofuel but are difficult to aggregate and transfer to production sites in large volumes without adding carbon.
- 7.10** In a recent MIT study into the use of advanced biofuels in aviation¹³, Winchester et al conclude that there are significant challenges to scaling-up production of biofuels for commercial use in aviation, which include *“high production costs and lack of integration of aviation biofuels into regulatory frameworks, limits in scale-up due to feedstock availability, environmental and socio-economic consequences of large-scale land-use change and competition with food and feed needs, water consumption associated with biomass cultivation and time required for scaling up biomass cultivation and conversion facilities.”*
- 7.11** Biofuels have a role in the mitigation of carbon emissions and are part of a range of measures that we believe can help the wider transportation industry reduce its environmental impacts. However, given the challenges currently facing large-scale production, they are unlikely to produce a step-change in emission levels for any mode of transport, and in terms of air transport it is safer to assume that for the next two-decades there will be a slow and steady introduction of such fuels in modest quantities rather than a radical shift.

Other Alternative Power Sources

- 7.12** As with road, rail and other transport, the long-term future for the propulsion of air transport is likely to be with electrical power. Unfortunately for an aircraft the technology required to make this feasible needs to be considerably more advanced than other modes, as the power output is high and the distances between possible opportunities for charging are huge.
- 7.13** Airbus is one of several manufacturers to carry out research into this field. In 2015 they successfully flew the Airbus “e-fan” for the first time – a twin seat electrically powered aircraft aimed at the flight training market.
- 7.14** Airbus has also developed a concept, known as the “e-thrust”, which would essentially be a hybrid-powered aircraft for commercial use. One jet turbofan engine would charge a battery, which provides the power to six large fans. This would increase the effective bypass ratio and significantly increase the efficiency of the aircraft. However the technology required is currently well beyond that of the e-fan, as each of the e-thrust’s engines are required to deliver 670kW of power, while the entire e-fan aircraft runs off just 60kW of power.

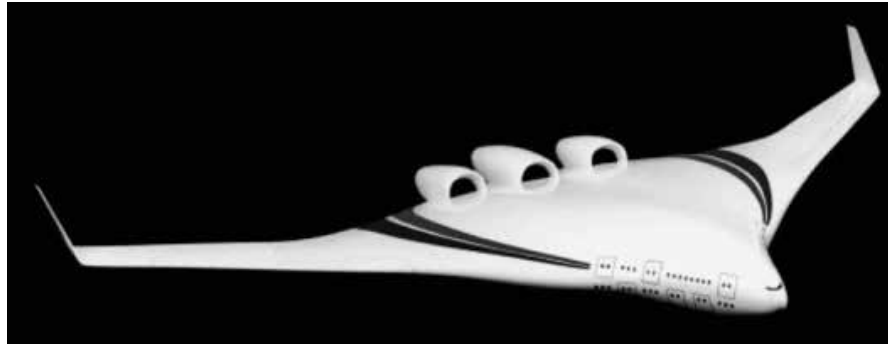
13 Niven Winchester et al, The Impact of Advanced Biofuels on Aviation Emissions and Operations in the US, Feb 2015



Non-powerplant Changes

- 7.15** A number of opportunities exist for commercial aircraft design to develop away from what has become “the norm” in aircraft design. One idea that has been discussed on a number of occasions – albeit often as too radical – is known as the blended wing body, and an even more radical change is known as the flying wing.

Figure 35: Concept of a Blended Wing Body Airliner



Source: Wikimedia Commons

- 7.16** Both designs are significantly more fuel efficient and quieter than traditional commercial aircraft designs, although estimates vary greatly. The greatest challenges in their implementation will be a redesign of existing infrastructure (as the designs require long wingspans/shorter fuselages) and acceptance from passengers of the new configurations, such as less windows.

Summary

- 7.17** With some of these technology options, key challenges including financial viability of research and development may not be resolved from the private sector alone. As we have seen very recently, projects that appeared commercially attractive with oil at \$150/barrel no longer appear viable when it falls below \$50/barrel. Low oil prices in the short term affects the development of long-term market-based environmental solutions, including the UN’s Clean Development Mechanism which underpins global carbon trading, that are currently struggling to attract investment while oil remains cheap. Governments have a role to play here in supporting R&D or requiring its own departments to use or develop clean technologies that will filter through into the commercial world over time.
- 7.18** The military plays a part here, particularly in terms of aviation. The US Department of Defence has mandated itself to reduce reliance on fossil fuels, targeting 50% from renewable sources by 2020. The US Air Force alone uses an estimated 2.4 billion gallons of jet fuel annually, and its investment in support of the US biofuel industry to generate over 1bn gallons of biofuel for its consumption can only bring forward production solutions. The same goes for airframe technology, where radical designs may be tested and developed for military use many years before entering commercial service.

7.19

We conclude that the aircraft of the future is likely to be very different to that of today, but is unlikely to be taking to the skies any time before the mid-2030s at the earliest, and more likely post-2040. Until then, working on incremental efficiency gains and a combination of policy intervention, development of international standards and research pathways coupled with market forces, will drive change at a sufficient rate to ensure radical technologies are not essential to enable short-term growth.



8

Conclusions

- 8.1** The UK aviation industry clearly has to show responsibility for its environmental and social impacts. For many years the wider industry has avoided CO₂ targets, and this is something that must be rectified swiftly in order to bring the global industry into line and make it as answerable as other sectors. However, in the UK this process is already underway, and EU regulations have made possible the stringent measurement of NO_x and other gases which can harm air quality around the airport perimeter. The outcomes of the UK's Airports Commission have shown that there is an urgent need to build more airport capacity, but this cannot come at the detriment of sustainability.
- 8.2** Local air quality is a problem that is rightly high on the public agenda but it is difficult to unravel the full impact of aircraft from NO_x emissions from the wider transport network, of which London is the worst performing capital city in Europe¹⁴. Firstly, the impact is limited to the immediate surroundings of the airport itself, as emissions from altitude are sufficiently dispersed so as not to be a problem for residents on the ground. The impacts from aircraft themselves are relatively modest, with research suggesting airport vehicles and surface access add an equivalent amount. Surface access is difficult to split out from with non-airport traffic – for instance at the air quality monitoring stations around Heathrow, the highest NO_x emissions are seen at areas where less than 5% of the NO_x comes from airport traffic. Where emissions such as NO_x are a problem, there are a number of opportunities for reducing these impacts with more efficient airport operations – and new technology will have an impact as well. With surface access forming a substantial portion of these emissions, the continuous improvement in automotive technology should significantly reduce the impact from the airport, for instance the DfT forecast a 62% reduction in NO_x from road vehicles by 2040.
- 8.3** From a noise perspective the industry has been driving gains since the height of the jet-age in the 1960s and 70s, however it is apparent that residents local to airports are still affected by noise nuisance. We consider the means to address this are three-fold. Firstly, continued technology improvement through new aircraft and retro-fitting upgrades to older aircraft – we forecast that the average aircraft will be at least 9dB quieter by 2050, without any radical new technology. Secondly, the tweaking of airport operations to minimise noise to local communities, such as the use of continuous descent approaches and displaced runway thresholds, could save up to 9dB. Use of PBN in conjunction with a legally binding flight paths with guaranteed periods respite can offset the impact of continual and concentrated noise. Airports need to continue and further develop engagement with their local communities in order to disseminate information and increase awareness of the airports operation, providing the knowledge and prior warning of flightpath usage that should make living under a flightpath a less stressful experience, with guaranteed periods of respite wherever possible. This should be enhanced by giving communities access to an independent arbiter in the form of a noise authority with powers to monitor and report on performance against agreed limits and penalise where necessary.

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Clean Air in London - <http://cleanair.london/sources/guide-to-sources-london-has-the-highest-levels-of-nitrogen-dioxide-of-any-capital-city-in-europe/>

8.4

CO₂ is a global issue that must be tackled with global measures. The fuel efficiency of new technology will see the industry becoming more fuel efficient by around 1.6% per year, however this will almost certainly be outstripped by increasing demand from developing economies. Carbon trading and greater multinational coordination are the potential long-term solutions to this, along with a continued drive to deliver improving technology. In the meantime, the UK should avoid attempting to address its own problem with unilateral action. By stifling the country's air transport industry, the UK would only succeed in pushing its portion of emissions to other countries, in what is undoubtedly a global problem, whilst allowing delays and severe inefficiencies to become commonplace. Furthermore, the evidence laid out in this report suggests that the hub model is a more efficient means of transporting passengers over long distances than the point-to-point alternative, and therefore capping airport growth as an environmental measure is likely to be flawed if it inhibits a hub model from functioning effectively.

8.5

Sustainability is undoubtedly one of the greatest challenges facing the aviation industry in the 21st Century, and we have explored various impacts and mitigation measures available. Aviation can meet almost all of its targets for sustainability by following the current trend, helped by pragmatic engagement with communities and some regulatory intervention. Noise and local air quality impacts have been improving greatly as new technology becomes greener and more efficient. CO₂ is also falling on a per passenger basis, however high rates of growth in developing regions of the world are likely to lead to an overall increase in CO₂ without further action. The aviation industry requires greater coordination on a global scale in order to contain this problem, including encouraging greater streamlining through the use of hubs and a global approach to carbon trading and other measures.

Notes

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Author Profile

Peter Hind is Managing Director of RDC Aviation and has over 20 years' experience in the aviation sector, including senior roles in the strategy and network planning team at bmi. He has also authored the ITC's reports on 'The Optimal Size of a UK Hub Airport' and 'Delivering improved airport capacity' which were submitted to the Airports Commission. Peter also teaches Sustainable aviation on the Air Transport Management MSc at City University.

The Brief

This Report was commissioned by the Independent Transport Commission (ITC) to review and assess advancements in the sustainability of air travel over recent decades, as well as to determine whether or not progress can be expected to continue. The report is intended to give an independent assessment of how technology and operations have contributed towards improving the sustainability of air travel, particularly in the areas of emissions and noise, and seeks to determine the scale of progress made so far and whether or not this is likely to continue over the next 30-50 years.

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