Can technology deliver acceptable levels of aircraft noise?

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ABSTRACT

Meeting community expectations on aircraft noise has always presented a challenge to aircraft and engine manufacturers and to those involved in airport planning and air traffic management. It has been a critical issue for communities living close to airports since the introduction of turbojet and turbofan powered aircraft in civil aviation in the late 1960s and early 1970s. The technical progress which has been made during this period in reducing aircraft noise at source and mitigating its effects by noise reduction technologies is not widely understood or appreciated by the community. These remarkable achievements will be reviewed here, and an assessment presented of current progress towards meeting ambitious new environmental targets for aircraft entering service between now and 2050. While much has been achieved, opportunities still exist to exploit further significant reductions in noise both for current aircraft layouts but also in the longer term for future aircraft and engines which may differ significantly from current configurations. The main sources of aircraft noise will be reviewed and areas identified in which the greatest noise reductions have been achieved. Areas will also be highlighted where future gains are likely. Much of the discussion will revolve around measures of the noise of a single aircraft at takeoff or approach. This forms the basis for noise certification metrics and the focus of industry efforts to reduce aircraft noise. This is only a part of the complex jigsaw of issues however which define the aircraft noise problem. These include the public's perception of what actually constitutes a noise nuisance and also critically the rate at which an expanding commercial fleet transitions to newer quieter aircraft.

Keywords: Aircraft noise, aeroacoustic sources, community noise(I-INCE Classification of Subjects Number(s): 13.1.1, 13.1.5, 21.6, 52.2.1)

1. INTRODUCTION

Aircraft noise has long been a pressing issue for residents near airports. In the case of large airports in developed countries the number of individuals affected by aircraft noise has generally reduced in recent years if objective measures of noise exposure are to be taken at face value. Aggregate figures for the six largest airports in the UK, for example, including Heathrow, show that the number or residents within the critical '$57L_{Aeq}$' contour reduced by almost 40% between 1998 and 2010 while the number of air traffic movements continued to increase (1). This statistic conceals a remarkable but not widely acknowledged technical achievement, that new aircraft entering service today move more people more quietly and with greater fuel efficiency and fewer harmful emissions than ever before. This belies a commonly held view that the adverse environmental impact of aviation is growing rather than diminishing. The real argument however is not whether aircraft are getting quieter and more fuel efficient, but whether the rate at which this is achieved by the introduction of new technology can compensate for future increases in passenger numbers and air traffic movements. To date this has been the case. In this paper the evidence presented recently on whether this trend can be the extrapolated to the future will be reviewed. This raises also the question of what constitutes an appropriate measure of aircraft noise and what is an 'acceptable' level of public annoyance, issues which are currently being aired in the UK in the public debate surrounding potential options to expand London's airport capacity (2)

The environmental impact of aircraft noise is essentially a 'local' problem. It arises at departure and at approach, affects populated areas close to airports but is not generally an issue during flight. A potential exception to this rule is 'en route' noise from aircraft powered by novel Contra-Rotating Open Rotors (CRORs) which generate low frequency, tonal noise at cruise altitude. Concerns have been expressed that this will have an adverse impact at ground level in quiet areas. Recent studies have indicated however that current designs will generate *'.. maximum noise level(s) ... which will be equivalent to that of today's turboprops'* (3). Some

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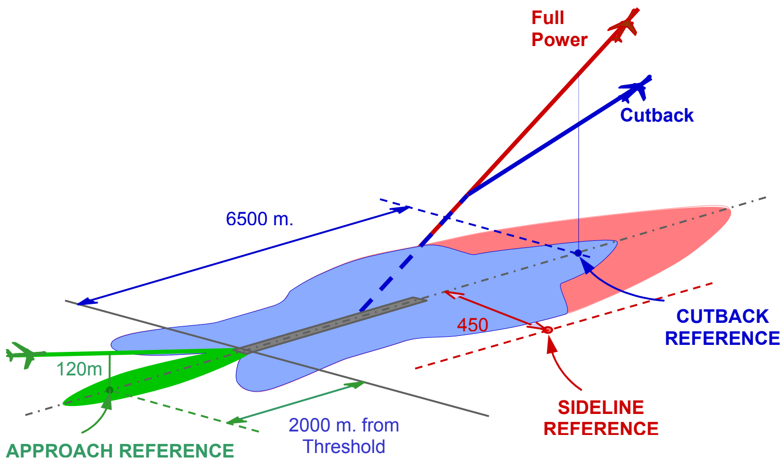


Figure 1 – Noise certification points for ICAO Annex 16 and FAA FAR36.

would argue that en-route turboprop noise is not necessarily acceptable in all situations, and since there may be many more CRORs than turboprops if this technology comes to fruition, this may yet be an issue for further investigation.

In the design of current aircraft, the noise focus of the aircraft industry is therefore on reducing aircraft noise at take-off and approach. This is an essential consideration in the design of all new commercial aircraft. In a broader context, noise is one of three major environmental impacts of aviation - along with air quality and CO_2 emissions. Reductions in all three of these environmental costs, which *at least* offset the effect of the predicted growth in air traffic, projected at around 4.0% *per annum* for the next two decades - less in the west and more in the far east - are regarded as critical to the continued expansion of the aviation sector, and essential if the many benefits that air travel brings to individuals, communities and economies are to be extended to an ever increasing proportion of the world's population.

In this article, the metrics used to characterize and regulate aircraft noise both by industry and by the community will first be reviewed (section 2) and the remarkable successes of airframers and engine manufacturers in reducing noise emissions of individual aircraft since turbojet and turbofan propulsion became widespread in the late 1960s and early 1970s will be detailed. Noise sources on current aircraft and the extent to which they contribute to total aircraft noise will be outlined in section 3. In section 4, an estimate is presented for the noise reductions that will be possible in future aircraft entering service between now and 2030. Noise targets will be reported which have been set as reasonable goals for the aircraft industry during this period. In section 5, the implications for community noise reductions over a somewhat longer time scale will be discussed.

2. CHARACTERIZING AND REGULATING AIRCRAFT NOISE

Two types of metric are used to characterize aircraft noise. In the first, the noise of a single aircraft operation is measured under carefully controlled conditions. In the second, the noise experienced by an observer on the ground (and usually near an airport) is measured over a fixed interval for multiple departures and arrivals of different types of aircraft. The noise of a single aircraft operation is characterized by the Effective Perceived Noise Level (EPNL) measured in EPNdB. A number of different metrics are used to measure community noise from multiple aircraft operations.

2.1 EPNL and aircraft noise certification

Characterizing the the 'noisiness' of a specific type of aircraft became necessary for regulatory purposes in the late 1960s as the use of turbojet and turbofan propulsion became widespread in the United states and subsequently throughout the world. In 1969 the US Federal Aviation Administration issued a noise certification regulation, Federal Air Regulation, part 36 commonly known as FAR36. Two years later, ICAO issued an annex (Annex 16) to the Convention on International Civil Aviation which contained similar provisions. Annex 16 and FAR36 have been revised three times in the years since, always to make the requirements more stringent. They became identical at the second revision (stage 3 of FAR36 and Chapter 3 of Annex 16). The current version of Annex 16 (Chapter 4) applies to aircraft entering service after February 2006 and a further reduction (Chapter 14) will be implemented for new aircraft entering service after December 2017 subject to formal

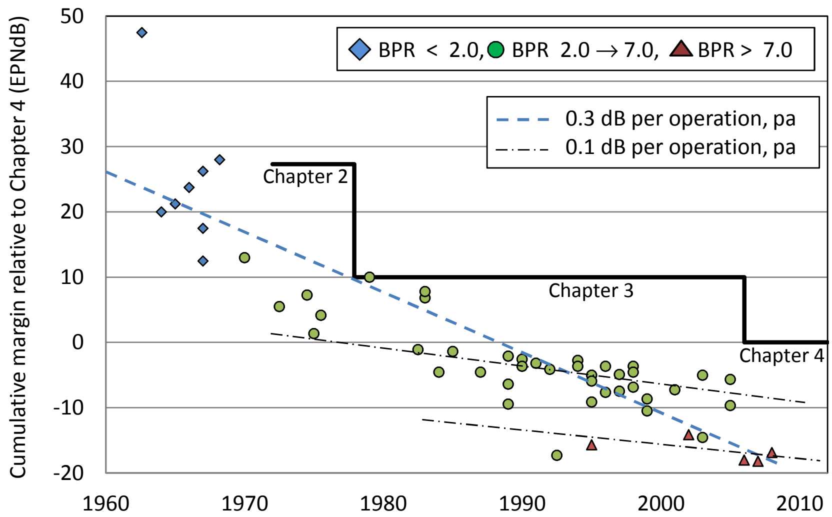


Figure 2 – Historical trends in aircraft noise reduction as measured by cumulative noise levels per operation (EPNdB) for aircraft entering service 1960-2010 (modified from Figure 21 of (1)

ratification of the member states and implementation into their legal frameworks. Certification levels are based on EPNL measured at three certification points. EPNL is a noy weighted, tone adjusted, integrated measure of the acoustic power as the aircraft passes a measurement point on the ground. A step-by-step guide to calculating EPNL for certification purposes is given by Smith (4). The three certification points are precisely located in relation to the flight path, as shown in figure 1. The *sideline* or *lateral* point is located to the side of the runway as the aircraft takes off and climbs steeply at full power. The *cutback* or *flyover*, point is located below the flight path as the aircraft cuts back to a slower rate of climb at a lower power setting (typically around 80% of maximum power). The *approach* certification point lies below the flight path as the aircraft comes in to land at a steady 3 degree glide angle.

A value of EPNdB is recorded at each of these points to give a measure of the noisiness of each operation. These form the basis for the certification of new aircraft entering service. Maximum certification limits are defined for each certification condition. These increase with aircraft weight and depend (at departure) on the number of engines. The certification limits do not however increase or decrease indefinitely with aircraft weight but level off to constant values for large aircraft.

A cumulative value of EPNdB for a particular aircraft and engine combination is obtained by summing together the three individual measurements of EPNL. When this total is subtracted from the cumulative, weight-adjusted, certification limit, a single number (in EPNdB) is obtained. This defines a cumulative noise margin by which a particular aircraft lies below its certification limit. This can also be divided by three to gives an average margin *per aircraft operation.*

Data for the cumulative margins against chapter 4 for a representative selection of aircraft entering service between 1960 and 2010 are plotted in figure 2. Each point represents a rated certification measurement of cumulative EPNL for a specific aircraft/engine combination. The points are separated into three categories based on the Engine ByPass Ratio (BPR). Three generations of aircraft are defined in this way. These correspond to aircraft with BPRs in the range; (i) less than 2.0, (ii) between 2.0 to 7.0, and (iii) greater than 7.0. It will be useful later to refer to aircraft in category (ii) i.e with BPRs in the range 2.0-7.0, though predominantly in the upper half of that range, as ‘Chapter 3’ aircraft.

An overall trend line corresponding to a noise reduction of approximately 0.3dB per operation per year can be drawn through the complete set of points from 1960 to the present. Much of the reduction stems directly or indirectly from changes in the BPR (referred to also as changes in ‘engine cycle’) but within each generation of aircraft a weaker but significant trend can be seen which is characterised by a slope of approximately 0.1 dB per operation per year. This relates to evolutionary improvements in noise reduction technology distinct from BPR changes. The extrapolation of these trends to future designs will be discussed later in this paper.

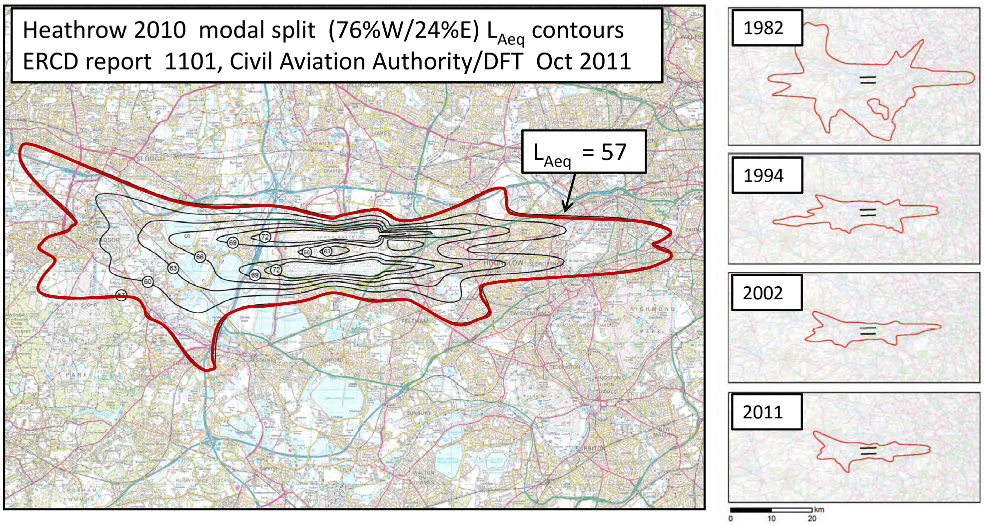


Figure 3 – Left: Contours of $L_{Aeq,16hrs}$ for Heathrow airport (2010) redrafted from (5). Right: Comparable contours for 1982, 1994, 2002 and 2011 (2)

2.2 Community noise metrics

The very significant noise reductions which have been achieved for individual aircraft at take-off and landing are evident in the cumulative data of figure 2. Broadly speaking, it is equivalent to a reduction of 10 EPNdB or more per operation since the 1970s, and much more if we include the early turbojets which entered service in the 1960s. The noise footprints of today's aircraft are orders of magnitude smaller than those of their equivalents in the 1970s and 1980s. This is a remarkable technical achievement far outstripping progress in fuel efficiency over the same period (2). Such figures appear to be at odds with widely held views that aviation noise is a rapidly growing problem.

The mismatch between engineering achievement and public perception is in part a result of the growth in passenger numbers and aircraft operations. EPNL is a measure of the noise of a *single* aircraft movement. Public annoyance depends not only on the noise level of a single event but also on the number of events and the frequency with which they occur. Global passenger numbers have grown at around 4 % per annum since the early 1970s. Broadly speaking the number of aircraft doubles every 20 years and along with it the number of aircraft operations. This growth rate is projected to continue with minor variations until 2050. While the noise of each aircraft operation has decreased significantly with time, the number of operations has increased. The community noise impact depends upon both factors, and indeed on the mix of aircraft of different ages and noise levels which land and take off at a particular airport. For this reason community noise must be assessed by using noise metrics which have a cumulative element and take into account the number of aircraft operations as well as the noisiness of each event. The most important of these are; the equivalent continuous sound level (L_{Aeq}), the Day-Night Average (L_{DN}), the Day Evening Night Level (L_{DEN}) and (historically in the UK) the Noise and Number Index (L_{NNI}). These measures all take into account not only of the maximum level and duration of each noise event, but also the number of events which occur within a given period. L_{Aeq} and L_{DEN} are the unit of EU legislation. In the UK (L_{Aeq}) is the most widely used. This accumulates the level and duration of each noise event into a single decibel measure. If *two* events which involve equal acoustic power occur within the specified period, the resulting value of L_{Aeq} will be 3dB higher than if a single event had occurred. If four events occur in the same interval, the value of L_{Aeq} will increase by a further 3 dB, and so on.

An L_{Aeq} value defined for the 16 hour period 0700-2300 ($L_{Aeq,16hr}$) has been used to assess the community impact of aviation noise at London Airports since 1990. On the basis of the UK Airport Noise Index Study (ANIS) undertaken in 1982 (6), 57 dB is taken as a threshold for 'the onset of significant annoyance', a finding which remains the subject of debate.

The 57dB contour of L_{Aeq} is used extensively to monitor the extent of noise exposure around UK airports. Contours of L_{Aeq} around Heathrow airport are shown in figure 3 for the year 2010. They are presented for the dominant modal split of runway usage (5). Comparable contours for the years 1982, 1994, 2002 and 2011 (2) are shown as insets to the main figure. The large reductions of noise achieved for single aircraft operations already noted in figure 2 over the same 30 year period have clearly fed through to a significant contraction of the contours, although moderated by a large increase in the number of aircraft operations. By any measure however there has been a significant decrease in terms of the number of residents affected by noise, and in particular those within the 57dBA zone, particularly at the start of this period but continuing to the present. This is supported by figures derived from historic noise contour data for the six largest airports in the UK, which indicate that the aggregate population within the 57dBA contour around major UK airports has reduced by about 40% since the late 1990s (from 470,000 in 1998 to less than 300,000 today (1)). This does not mean that the problem of aviation noise has been solved for those who remain, but merely that the trend is in the right direction. This begs the question of whether the 57dBA level is a valid measure of annoyance and we will return to this later.

2.3 local noise regulations

It is clear from the data shown in figure 2 that current aircraft designs with BPRs greater than 7.0 give cumulative margins against Chapter 4 of up to 20dB cumulative. This substantial margin will be eroded by new limits (Chapter 14) and also by growth versions of successful aircraft, and one cannot therefore conclude that the aircraft industry will necessarily continue to satisfying mandatory noise requirements in future aircraft by using current noise reduction technology. New limits have also been imposed by local noise regulations at major airports. These local restrictions are generally more demanding than than ICAO certification requirements, particularly for larger aircraft. The Quota Count (QC) system introduced by the UK government in 1995 is perhaps the most influential of such local regulations in Europe. It was introduced to manage the noise generated by aircraft movements at the three London Airports. The QC bands for the approach condition are shown in figure 4. Also shown are the Chapter 3 ICAO requirements (Chapter 4 requires a 10 EPNdB cumulative margin below chapter 3 and is difficult for this reason to define precisely for each certification point). Superimposed on the figure are points which correspond to a selection of aircraft of various sizes and weights. They are located on the vertical axis according to their rated noise certification level for the approach condition, and plotted horizontally according to takeoff weight. For a given aircraft type the noise levels are dependent on a number of factors including aircraft weight, thrust rating and design configuration. For a given aircraft type the noise levels are dependent on a number of factors including aircraft weight, engine type and thrust rating and design configuration; the data points given here should therefore be regarded as samples to illustrate general trends. All aircraft using London airports fall within a given QC band. These are used for various purposes. For example, a fixed quota of noise tokens is allocated for aircraft landing or taking off at critical times preceding and following the night curfew, according to their ‘QC‘ status. An aircraft with a QC2 rating requires twice as many tokens as an aircraft with a QC1 rating and four times as many as an aircraft with a QC0.5 rating. This system of rationing by QC band offers an incentive for airlines to re-equip with up-to-date aircraft which have lower EPNL levels, since this will allow them more aircraft movements within a given quota allowance. The QC bands are separated by increments of 3dB and this has the effect of aligning the aircraft EPNL system with community noise metrics such as L_{Aeq} since these also equate a three dB increase with a doubling of the radiated acoustic power. The commercial impact of such rules for airlines has been significant and leads to strong pressure and competition among aircraft manufacturers as customers demand low noise aircraft. While the ICAO Annex 16 requirements remain the essential noise certification standards for engine and airframe manufacturers, achieving a satisfactory QC rating, is something that none can ignore.

3. THE SOURCES OF AIRCRAFT NOISE

The major sources of aircraft noise are illustrated in figure 5. The engine generates fan and compressor noise from the intake; fan, turbine and combustion (‘core’) noise from the bypass and hot exhaust ducts, and jet noise which is generated by turbulent mixing downstream of the exhaust nozzle. Noise is also generated by the airframe as a result of unsteady flow over the landing gears and high lift devices (flaps and slats) which are deployed at takeoff and approach. All of these sources have their own strengths and directivities and contribute to the noise signature of the aircraft as a whole for a given set of flight conditions. The relative magnitudes and directivities of the engine sources are indicated in figure 5 for a typical ‘chapter 3’ aircraft of the late 1990’s with a BPR towards the top end of the 2.0 - 7.0 range (see figure 2). The balance between the engine and airframe sources depends upon the flight conditions and power setting of the engine. A prediction for the relative power of the contributions to EPNL from engine and airframe sources is shown in Figure 6. The data is shown for the three noise certification conditions and has been estimated for a 1990s, large four-engined ‘quad’ aircraft (9). Such data is not readily available for current aircraft, but the relative breakdown of source contributions would not be dissimilar, although absolute values would be reduced and the fan noise contribution would be proportionally more important.

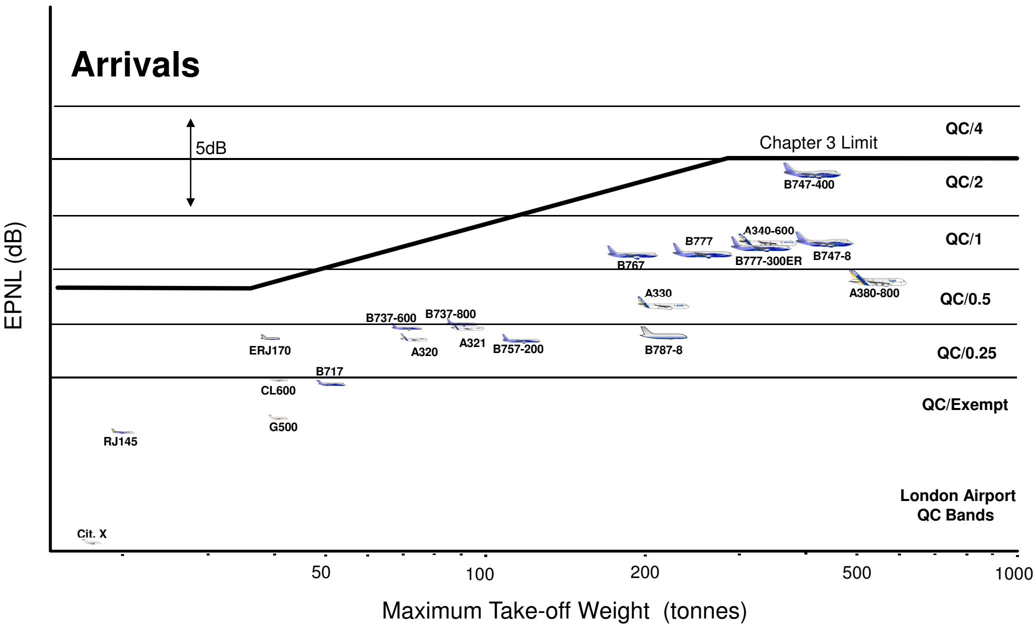


Figure 4 – ICAO certification limits at approach (Chapter 3) showing London Airports Quota Count (QC) bands and EPNL ratings for selected aircraft (reproduced with permission,Rolls-Royce plc)

It is clear from Figure 6 that at approach, the dominant contributors to EPNL are fan noise and airframe noise. At sideline and cutback however, fan noise and jet noise are more important with airframe noise playing a secondary role. The nature of the dB scale is such that if *all* of the engine noise sources could be eliminated at approach, the total radiated acoustic power noise would only reduce by around 3dB. Similarly if jet noise were completely absent at the cutback condition, the total noise would only decrease by a few dB. In order to achieve a significant reduction in aircraft noise as a whole, all sources must be reduced together in a balanced way, with emphasis on the three dominant contributors; fan, jet and airframe noise. A detailed discussion of the physical mechanisms involved in the noise generated by each of these sources or of the various techniques which have been developed to predict and mitigate their impact lies beyond the scope of the current article. The reader is referred to (10) for a comprehensive review of these topics.

4. NOISE REDUCTIONS IN FUTURE AIRCRAFT.

In 2007, the ICAO Committee on Aviation Environmental Protection (CAEP) appointed an Independent Experts Panel (IEP1) to recommend technology and operational goals for aircraft noise with a 10 year and a 20 year horizon. This exercise focussed essentially on current and imminent technology, assessing the *status quo* and projecting it forward. Novel concepts were not considered. In 2011, CAEP established a second Independent Experts Panel (IEP2) with a wider brief to look at the potential impact of new technology (novel aircraft and engine concepts). Once again they were asked to look forward 10 years and 20 years respectively from the review date to assess technologies that would be available at appropriate Technology Readiness Levels (TRLs) in 2020 and 2030. They were asked to set operational noise goals for 2020 and 2030 on the basis of these estimates, updating those proposed by IEP1 where necessary.

The report of the IEP2 panel was delivered in February 2013 (11, 12). It provides an up-to-date estimate of probable reductions in EPNL ratings for aircraft of different classes entering service - or about to enter service - up until 2030. It gives invaluable data for informed prediction of the community noise impact of aviation over the next 3 or 4 decades, bearing in mind that aircraft entering service towards the end of the CAEP period, in 2030 say, will contribute to the noise output of the commercial fleet for several decades following that date. The general findings of the IEP2 report is reviewed below and reference will also be made to a parallel European goal-setting exercise which resulted in the ‘Vision 2020’ and ‘Flightpath 2050’ environmental targets for the European aircraft industry.

The IEP2 report subdivides the period 2010-2030 into a ‘Mid Term’ from 2010 to 2020, leading to noise goals for aircraft entering service around 2020, and a ‘Long Term’ leading to goals for aircraft entering service around 2030. The panel concluded in both cases that the enabling technologies which are required for radical changes in aircraft architectures - such as the introduction of blended wing or hybrid body designs -

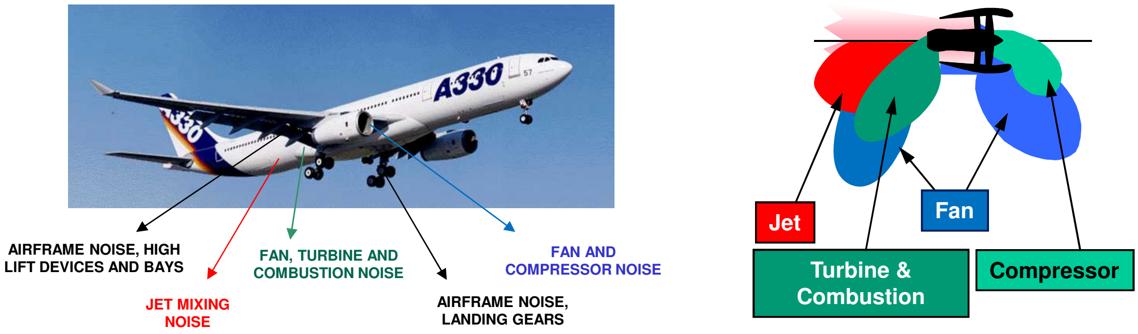
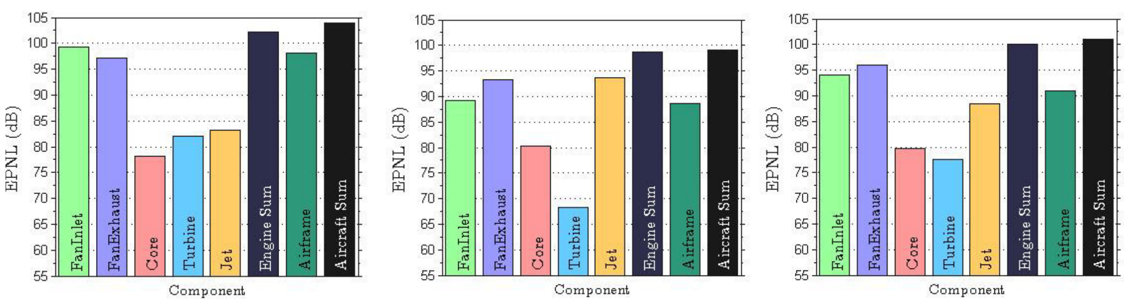


Figure 5 – Left: Aircraft noise sources. Right: Relative magnitudes and directivities of engine sources for a typical 1990s turbofan engine (redrafted from (8)).

will not reach a sufficiently high Technology Readiness Level (TRL) to make these designs feasible within the 2010-2030 timeframe. It is assumed therefore that aircraft entering service up until 2030 will retain the traditional ‘wing and tube’ design, with minor variants such as engine noise shielding by canards or wings. It seems inevitable also that larger aircraft will continue to be powered by turbofan engines, albeit of increased bypass ratio with larger slower fans and geared designs. In the case of short-medium range aircraft however there is a finite probability that fuel efficient, Contra Rotating Open Rotor (CROR) propulsion systems may become feasible and these could enter service towards the end of the second period. The noise implications of a short-haul CROR aircraft are therefore considered in the IEP2 study, and will be reviewed here under a separate heading.

4.1 Noise reduction technologies. CAEP short and medium term goals (2010-2020)

The principal sources of aircraft noise in the short term will continue to be those identified in Figure 6, *viz:* Rear and forward arc fan noise, jet noise, and airframe noise (particularly at approach). Reductions in core and combustion noise may also be significant as other sources reduce. Historically the reduction of aircraft noise has correlated well with increasing BPR, as indicated in Figure 2, and this is expected to continue. Indeed a significant portion of the benefit can attributed *directly* to the increase in BPR rather than to any associated noise reduction technology. Fan noise, for example, scales aggressively with fan tip speed which tends to decrease with increasing BPR. Jet mixing noise scales with a high power of jet velocity which also decreases with BPR. In the data which is presented in the IEP2 report the total predicted noise reduction for each class of aircraft is divided into two contributions; the reduction due to BPR alone and that due to other Noise Reduction Technologies (NRT). The value of these quantities varies with aircraft type (size and range) but is generally in the ratio of about 2:1.



APPROACH SIDELINE (LATERAL) CUTBACK (FLYOVER)

Figure 6 – Breakdown of EPNL contributions from engine and airframe sources for a large four-engined ‘chapter 3’ 1990’s aircraft (9).

The bypass ratio for all aircraft types entering service between now and 2020 is set to increase from the reference values used by the panel, in the range 5-6, to values in the range 7.0-10.0, or higher. This in itself will provide a significant 'BPR' noise benefit. In the area of **fan noise**, additional noise reduction technologies will also play an important role. These include the introduction of the Geared Turbo Fan (GTF), improved design methods for swept and leaned blades and stators, and greater integration of blade and liner design. The introduction of zero-splice liners (already in service on the A380 and B787) and other new nacelle technologies such as scarfed intakes, nacelle lip liners and aft cowl liners will also bring noise benefits.

In the general area of **jet noise**, fixed geometry jet chevrons have already been implemented (on the B787) and variable geometry nozzles have been developed to TRL6. Advanced long-duct forced mixers have also been identified as offering potential noise benefits.

Airframe noise noise reductions are expected from new slat track/wing leading edge treatments, the use of porous material for slat trailing edges and flap edges, and the extension of the droop nose device (in service on the A380) to other types of aircraft. The exploitation of landing gear fairings and caps which have already been demonstrated to be effective to TRL6 may also contribute.

Opportunities exist to reduce **core noise** through improved hot-stream liners and bleed valve silencers. Estimates of the magnitudes of the potential noise benefits listed above were converted by the CAEP expert panel into noise goals for the short to mid term. These represent an expectation of what could be achieved for aircraft entering service in 2020 if noise reduction were prioritized. The goals are presented in table1 for five notional aircraft configurations. Also shown are the reference values of EPNdB for similar aircraft in service at the beginning of the original (IEP1) study. Cumulative margins over Chapter 4 are proposed for each aircraft type and the noise reductions needed to achieve this are broken down into 'BPR' and 'NRT' contributions as noted above. The figures given are based on technologies which will have been demonstrated by 2020 to TRL6. It is assumed that there would be some attrition in converting these into the harsh aircraft environment, and equivalent TRL8 values, not shown here, can be obtained by discounting these figures by 10%.

4.2 Noise reduction technologies. CAEP Longer term goals (2020-2030)

Beyond 2020, bypass ratios will continue to increase, to levels in the vicinity of 12-14 by 2030. Noise reduction technologies currently at somewhat lower readiness levels may then be applicable. In the case of **fan noise** these would probably include; variable area nozzles with major benefits for performance *and* noise, 'Soft' vanes, active stators, active blade tone control and the 'zero hub fan'. Scope exists also for further refinement of passive and active liners. New technologies which may reach appropriate TRLs for **jet noise** include a range of flow control techniques (fluidic injection, microjets, plasma actuators..). Flow control is also expected to contribute to reductions in airframe noise, particularly for landing gear although such methods are currently at very low TRL. No specific long term technologies were identified for **core noise** beyond those already noted in the previous section. Fewer options exist for significant noise reduction technologies in this longer term, above and beyond those associated directly with increases in BPR. This is reflected in the figures for the long term goals also given in table 1. Here the rate of incremental improvement for has clearly slowed when compared to the previous figures. Error bands have been inserted to reflect increased uncertainties in the technical predictions on which the goals are based.

Table 1 – CAEP IEP2 Aircraft Noise Goals for short-medium (2020) and long (2030) term.

Aircraft type	Reference		Mid Term Goal (2020) TRL6			Long term goal (2030) TRL6		
	cumulative margin (EPNdB) v chapter 4	Bypass ratio	cumulative margin (EPNdB) v chapter 4	reduction EPNdB: Total (BPR,NRT)	Bypass ratio	cumulative margin (EPNdB) v chapter 4	reduction EPNdB: Total (BPR,NRT)	Bypass ratio
Regional jet	4	5.0	14	10.0 (6.0 ,4.0)	7 ± 1	21.5±4.0	17.5 (12.0, 5.5)	9 ± 1
Small-medium range (turbofan)	5	5.0	22.5	17.5(12.0, 5.5)	9 ± 1	30.0 ±4.0	25.0(18.0 , 7.0)	13 ± 1
Small-medium range (CROR)	5	–	–	–	–	7.5 → 15.5	8.5	–
Long range twin (Turbofan)	6	6.0	22	16.0 (10.5, 5.5)	10 ± 1	28.0 ±4.0	22.0 (15.0, 7.0)	13 ± 1
Long range quad (Turbofan)	5	5.0	22.5	17.5 (12.0, 5.5)	9 ± 1	27.0 ±4.0	22.0 (15.0, 7.0)	11 ± 1

4.3 Contra-Rotating Open Rotors; a special case.

Data is given in the third row of table 1 for a small to medium range aircraft powered by a contra-rotating open rotor (CROR). This will become viable from a technology point of view by 2030. There is no reference value for this type of aircraft. A goal for its noise margin over chapter 4 has been estimated at 7.5-15.0 EPNdB cumulative. This represents a relatively small noise improvement over the reference turbofan aircraft of similar size and range, and compares poorly with the anticipated noise improvements over the same period for this option. These figures for a CROR propelled aircraft are obtained for a rear-mounted, pusher configuration. An equivalent wing-mounted 'tractor' configuration would give less noise benefit , reducing the cumulative margin over chapter 4 by 6.0 EPNdb. The rationale for including the CROR option relates entirely to fuel efficiency. Estimates vary, but a NASA study cited in (11) shows that the fuel burn for the CROR option will be 36% lower than an equivalent 'chapter 3' aircraft (such as the A320 or Boeing 737) whereas the Ultra High Bypass Ratio (UHBR) turbofan option is predicetd to give a 27% lower fuel burn. This presents a stark tradeoff between noise and fuel burn. A low noise strategy would certainly opt for the CROR option, which would represent a noise benefit of around 15 EPNdB cumulative. A low carbon strategy would opt for the UHBR with a fuel saving of around 10%.

4.4 Vision for 2020 and Flightpath 2050. A European perspective.

The noise goals defined by the CAEP expert panel align closely with more broad reaching environmental targets set by the Advisory Council for Aviation Research (and innovation) in Europe (ACARE). ACARE promotes a broad approach which incudes reductions of emissions and noise and improved air quality. Integrated targets in these three areas were set in 2001 in the 'Vision for 2020' (13). This proposed that the European aviation sector should work to reduce the noise of aircraft entering service in 2020 by '50%' starting from a 2000 reference level. This has been interpreted by industry as a reduction of 10EPNdB *p*er operation, and it is recognised that some of this will be achieved by improvements to air traffic management and operational procedures. 'Vision for 2020' does not specify in detail how this target should be applied to different types of aircraft. The overall objective is however compatible with the Mid Term goals of the IEP2 recommendations. Progress towards the ACARE 2020 noise goal during the first ten years (up to 2010) has been promising with a trend line that has broadly achieved half of the goals for 2020 (5.0 EPNdB).

In 2011 the directorate-general for research and innovation of the European Commission in association with ACARE, issued a new vision for aviation in Europe, 'FLIGHTPATH2050' (14). This confirms the 'vision for 2020' goals and extends them to 2050. It is again based on the 'balanced approach' in which integrated goals are set for air quality, carbon emissions and noise. The noise target for 2050 is set at a '65% reduction over reference 2000 levels'. This has been interpreted within the aviation sector as a reduction of 15.0 EPNdB per operation over reference 2000 levels, or a cumulative reduction of 45.0 EPNdB for all three certification levels. This exceeds the 2030 goals of table 1 by a margin of perhaps 10-15 EPNdB cumulative. It is acknowledged that this will be difficult to achieve for traditional aircraft layouts even if new noise reduction technologies are supplemented by additional noise benefits from Noise Abatement Procedures (NAPs). It may however be possible if radical new aircraft designs are considered, such as the Hybrid Wing Body (HWB). Indeed a noise reduction of 45 EPNdB cumulative below chapter 4 has been defined as a reasonable goal for recent HWB designs. Indeed, some evidence to support this has recently been obtained from large-scale wind tunnel tests with realistic scaled fan and jet sources as part of NASA's Environmentally Responsible Aviation (ERA) programme (15). The proposed sequence leading to the achievement of these targets, including the ambitious 2050 objective, is illustrated in figure 7

5. PREDICTING THE IMPACT ON AIRPORT NOISE 2010-2050

Current and future reductions in the noise generated by individual aircraft at takeoff and landing, as suggested in figure 7, indicate that conventional 'wing and tube' designs could achieve margins of around 20 EPNdB below chapter 4 by the end of this decade, around 30 EPNdb by the mid 2030s, and 40 EPNdB or more by 2050 if radically new aircraft configurations were developed. These figures correspond to margins of around 7, 10 and 13 EPNdB per operation. In the context of current London airports restrictions, they would move aircraft entering service in the 2030s and 2040s close to the 'QC exempt' band, and would bring us close also to a situation in which aircraft noise would not significantly exceed background levels outside airport boundaries. We cannot however infer from such estimates that the community noise problem near airports will be solved by 2050. As noted previously, potential reductions in EPNdB do not give a complete picture of the community impact of aircraft noise.Important factors which are not accounted for include;

1. The rate of growth of passenger numbers and aircraft movements.
2. The rate at which the airline fleet is renewed and at which noisier aircraft are replaced.

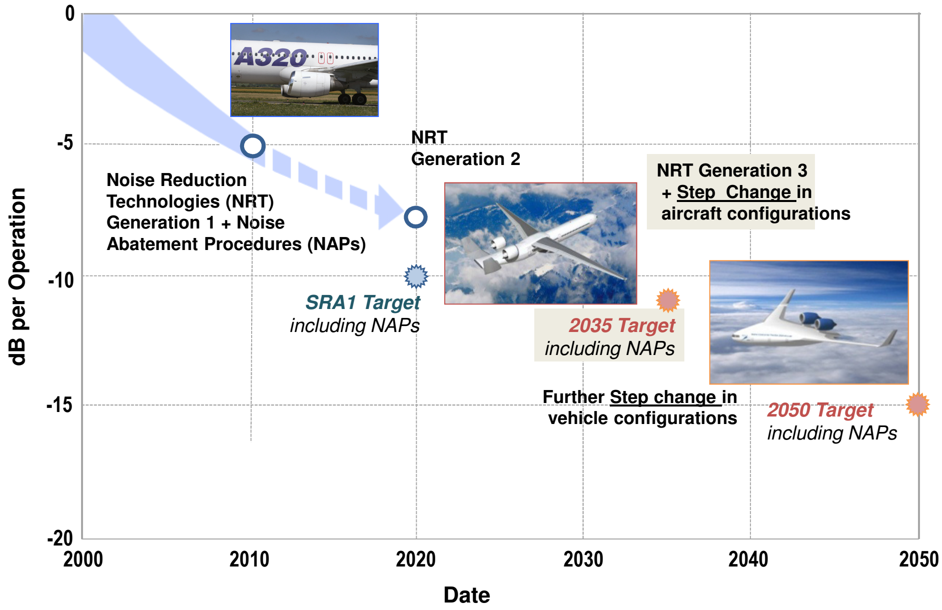


Figure 7 – ACARE 'Vision for 2020' and EC 'Flightpath2050' targets for reductions in aviation noise 2000-2050 (reproduced with permission, X-noise EV)

3. The priority which is placed on noise reduction over other environmental and economic imperatives in the design of new aircraft.
4. The changing perception in the community of what constitutes an annoyance.

ICAO predicts that the global passenger fleet will continue to grow at between 4% and 5% per year globally (16). The number of passenger aircraft, which is estimated to reach 29,000 in 2020, will increase to 58,000 in 2040. Freight traffic will grow at an even faster rate. The UK Department for Transport (DfT) predicts that the annual growth of aircraft operations within the UK will be of the order of 1-2% from 2010 and 2020. The rate at which the fleet will transition from the current fleet, to 'imminent aircraft' and to 'future aircraft', will depend upon the economic and commercial environment. An industry best estimate of fleet transition until 2050, based on growth data from DfT, is shown in Figure 8.

The impact of predictions for traffic growth on community noise levels near specific airports - such as Heathrow - then depends upon important local factors; the mix of aircraft landing and taking off, building regulations and planning in the vicinity of the airport, the implementation of Noise Abatement Procedures *et cetera*. It also depends upon the priority that is placed on noise reduction compared to other criteria (carbon emissions for example) when future aircraft are designed. Gross calculations have however been performed for UK airports taken as a whole. These are not airport specific and use three scenarios to estimate the 'relative aviation noise output' for all scheduled flights arriving or departing. The 'noise output' of a particular aircraft operation is assumed to be proportional to the certification level of the aircraft. The levels for imminent and future aircraft are estimated for two extreme scenarios; an ultra-low-carbon scenario in which aircraft are designed overwhelmingly for low carbon emissions, and an ultra-low-noise scenario, where low noise is the first priority. The variation of the predicted Noise Output from 2010 to 2050 is shown in Figure 9. Also shown is the noise output if it is assumed that noise technology is frozen at 2010 levels. We see that future improvements in noise technology have a huge effect on the outcome. Instead of a doubling of noise output as passenger numbers and aircraft movements increase, we see that even with the baseline or ultra-low-carbon scenarios there is a real reduction in absolute levels, and that if the ultra-low-noise scenario is adopted there is a 45% decrease from current levels. The above estimates are based on a conservative estimate that does not take account of noise abatement procedures and operational changes, which would reduce this figure further.

Finally, the application of predictions of this type to specific airports is predicated on the notion that the 'onset of significant annoyance' is a known and unchanging quantity. In the UK, it has been assumed to be equivalent to a level of 57dBA for L_{Aeq} , mainly on the strength of the ANIS report of 1982. Thirty years later, in 2005/6, the UK government commissioned a new study 'Attitudes to Noise from Aviation Sources in England ' (ANASE) (17). This indicated that for various reasons the $57dBA$ criterion was not necessarily a robust measure of community annoyance to aircraft noise. Data collected in the ANASE project indicated that if this metric is applied today we must conclude that the public is significantly *less* tolerant of aircraft noise

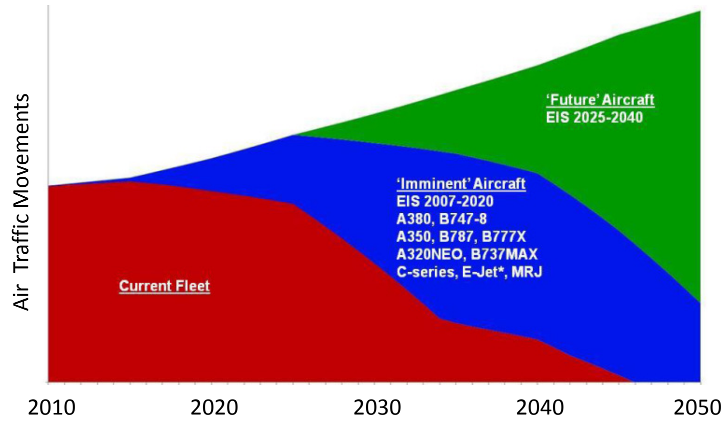


Figure 8 – Predictions of Fleet transition from current aircraft to imminent and future aircraft 2010-2050 (1)

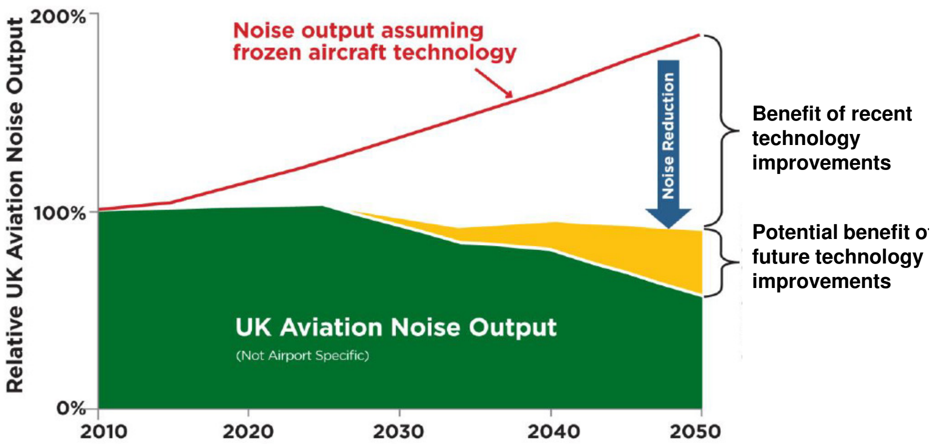


Figure 9 – Predicted changes in UK aviation noise output between 2010 and 2050, (1)

than it was in 1982. This adds a new dimension to the debate on what 'acceptable' means in the title of this paper. It warrants a debate of its own, but not here.

6. CONCLUSIONS

The technical achievements of aircraft and engine manufacturers in reducing the noise generated by aircraft at takeoff and landing have been phenomenally successful over the last 50 years. This has been a collaborative effort with both parties working with governments and international regulatory agencies to achieve common goals. It has resulted in a reduction of more than 20EPNdB per aircraft operation since noise certification was introduced. A single first generation turbojet or low bypass ratio turbofan aircraft, such as a 1960s Boeing 707 had a noise footprint at takeoff or landing equivalent to 30 or more current aircraft taking off simultaneously. This is a remarkable technical achievement. It has ensured that in spite of a doubling of the number of aircraft movements every twenty years, the net community noise impact of aircraft has been tracking downwards since the late 1970s and should continue to do so. The predictions presented here indicate that further noise reductions due to new engine cycles (further increases in bypass ratios) and noise reduction technologies over the next two decades, followed by the development and introduction of new low-carbon *and* low-noise aircraft concepts towards the middle of the century, are sufficient to ensure that this can continue. This assumes that there is an economic and commercial framework which provides adequate incentives to the aircraft industry to develop and implement the necessary new technologies and that the benefits of reduced noise at source are complemented by enlightened airport planning and the introduction of appropriate noise abatement procedures.

The answer to the question posed by the title of this paper is therefore a qualified 'yes'. It may well be possible to deliver acceptable levels of aircraft noise provided that there is the political will, economic incentive and public support to drive technology and operational changes forward over the next three decades.

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