Interest Group on Traffic Noise Abatement

European Network of the Heads of Environment Protection Agencies (EPA Network)

Progress report on aircraft noise abatement in Europe v3

Berlin, Maastricht | July 2015

Colophon

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Title	Progress report on aircraft noise abatement in Europe v3
Report No.	M+P.BAFU.14.01.1
Revision	2
Date	July 2015
Pages	66
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Executive Summary

This report describes the present situation and future developments with regard to aircraft noise in the European region. Although the exposure of the population is far below that of road traffic noise, the impact on society cannot be neglected. First since the effect of a certain level of aircraft noise on society in terms of annoyance and health related problems is much larger than the effect of the some level of road traffic noise. Second, since the exposure concentrates in certain areas around airports that more and more become regions of economic development.

The International Civil Aviation Organization (ICAO) formulated an method to noise control of aircraft, *the balanced approach*, consisting of the following steps:

- reduction at source (quieter aircraft),
- land-use planning and management, including market based instruments (noise charges)
- noise abatement operational procedures and
- operating restrictions.

This report shows the big achievements in noise reduction of the source that are accomplished by aircraft manufacturers. Modern aircraft are, cumulated over three measurement positions, more than 20 EPNdB quieter than aircraft certified in the seventies (EPNdB differs from dB(A) in the added effect of tonal components). The certification levels are gradually tightened with chapter 3 in 1977, chapter 4 in 2006 and a scheduled tightening on base of chapter 14 in 2018. The defined limit values however must be rated technology-following and do not anticipate on new noise reducing developments.

The slow refreshment of aircraft results in a slow reduction of the noise emission of the existing aircraft fleet. By taking measures such as extra charging of noisy aircraft or applying restrictions to the usage of noisy aircraft, industry is stimulated to use more silent aircraft in European airports. However before such restricting measured can be taken, other measures as are defined in the balanced approach have to be applied. This procedure has received a legal base in the regulation 598/2014 of the European Union. This report describes the components of this procedure and how this regulation relates to the former 2002/30 directive.

The balanced approach implies a cost and benefit analysis of measures. This report presents a few examples of such analysis and concludes that no harmonized method is available at the moment.

In the last chapters interesting information is compiled on aircraft noise reducing technology, on a noise classification system, developed by the airport industries and an overview from Boeing aircraft company on noise restrictions, regulations, curfew and noise charges of European airports.

Finally a series of five recommendations are formulated that the IGNA group may bring forward:

1 The development of a harmonized noise classification system that can be used in the noise based landing/take-off charges by airports.
2 The definition of technology forcing limit values for the next phase of tightening of certification levels.
3 The development of a harmonized method for the determination of the costs and the benefits of noise mitigation measures.
4 The amending of the 598/2014 regulation to strengthen the position of the environment relative to the position of the industry.
5 The extension of noise mapping of aircraft noise within the framework of the European Noise Directive (EC/2002/49) to a lower limit of 50 dB Lden and 40 dB Lnight to improve representativity of the reported data for annoyance and health effects.

Contents

1 Introduction

1.1 Background

The EPA Network is an informal grouping bringing together the directors of environment protection agencies and similar bodies across Europe. The network exchanges views and experiences on issues of common interest to organizations involved in the practical day-to-day implementation of environmental policy.
In the September 2010 EPA-Network meeting in Krakow an Interest Group on Traffic Noise Abatement (IGNA) was created. The IGNA will be forum to exchange information on current and future developments, an opportunity to learn from each other, particularly in relation to the development of the regulatory framework and scientific issues. The outcome shall be reports on the activities of the group, containing concrete and helpful recommendations to successfully protect the population from traffic noise.
The Swiss Federal Office for the Environment has contracted M+P -Consulting engineers in Netherlands to support the IGNA with relevant input for the work of the IGNA, with the preparation and reporting of the IGNA workshops, with summarizing the discussions within the workshops and with the composition of a final report.
M+P Consulting engineers is member of the international Müller-BBM group with offices in several countries throughout Europe. M+P is very active in the field of international standardization and regulation on noise properties of sources of transportation noise, such as road, rail and air transport.

1.2 Objectives of this study

This study has the following objectives:

- to produce a concise insight in the technical and policy aspects of sources of air traffic noise,
- to relate the state of noise abatement to the effect on the society
- to relate potential improvements with performances in the area of safety and sustainability
- to evaluate the costs of the measures with the benefits for society.

The study is performed on a European level, meaning that specific national rules and systems are taken into account less detailed. The air transport enterprises operate on a global scale meaning that developments in other parts of the world have to be taken into account. This is specific the case for NOX and CO2 emission which are global issues. At the other hand the noise pollution, local air quality and safety issues concentrate in the vicinity of airports and one can observe individual solutions for individual airports that may even differ within a country.

The study is directed to policy makers and will therefore not be too extensive in technical details, although the general technical scheme, essential to understand the relevance of sources, technical measures and operating procedures, is given. We will refer to background documents for necessary technical detailing.

The context of the report implies that most of the information presented in this report originates from existing studies. Only limited new work is presented.

The study focusses on the main topics that are on the table at the moment and are relevant for the IGNA group to be informed about and possibly be addressed by them on a European scale.

1.3 Noise exposure of air traffic in Europe

In 2002 ANOTEC investigated the noise exposure at 53 airports in Europe accounting for 8.7 million aircraft movements [2]. Results of their estimation are given in table I.

table I *Estimation by [2] about noise exposure to aircraft noise in Europe (number of affected persons in millions).*

Noise level/year	2002
> 55 Lden	2,2
> 45 Lnight	2,7

In the explanatory memorandum in the proposal for an updated Directive EC/2002/30 the following data and forecasts are presented by the commission on base of the 53 airports in [2] .

table II *Data from the Commission regarding the number of people affected by noise (in millions) in Europe [18] on base of the 53 airports in [2]. Prediction based on 2002/30 policy.*

Noise level/year	2002	2006	2010	2015
> 55 Lden	2,2	2,2	2,4	2,7
> 45 Lnight	2,7	3,0	3,2	3,2

In STAPES (ref [14]) the noise immission around 27 major airports which cover around 90% of the European population exposed to significant aircraft noise levels in Europe is detailed modelled using the ECAC DOC29 methodology and the EEA/JRC population data base. It leads to the following results:

table III *More detailed data from the STAPES model [14] regarding the number of people affected by noise (in millions) in Europe.*

Noise level/year	2006	2016	2026	2036
> 55 Lden	2,625	3,196	3,432	3,811

The European Environmental Agency (EEA) in Copenhagen reports for the EU27 the following graphs for exposure to transportation noise (see figure 1). The distinction between “agglomerations” and “major airports” originates from the European Noise Directive (2002/49) in which the obligation is defined to map noise exposure in the vicinity of the major transport axes and in urban agglomerations over 250.000 inhabitants. It is not clear to what extend double counting happens when the effect of major airports is also taken into account in the agglomeration data. On the other hand, the effect in smaller agglomerations around smaller airports is not taken into account.

The green bars are based on the reporting of the member states up to end August 2013. It is however noted that only about 50% of the to be reported data is actually received. The green bars thus underestimate the actual situation. An effort is done by the European Topic Centre on Air Pollution and Climate Mitigation (ETC-ACM) to extrapolate the data to the full agglomeration and major infrastructure set. The outcome of the “gap-filling” is presented by the grey bars (ref. [3]).

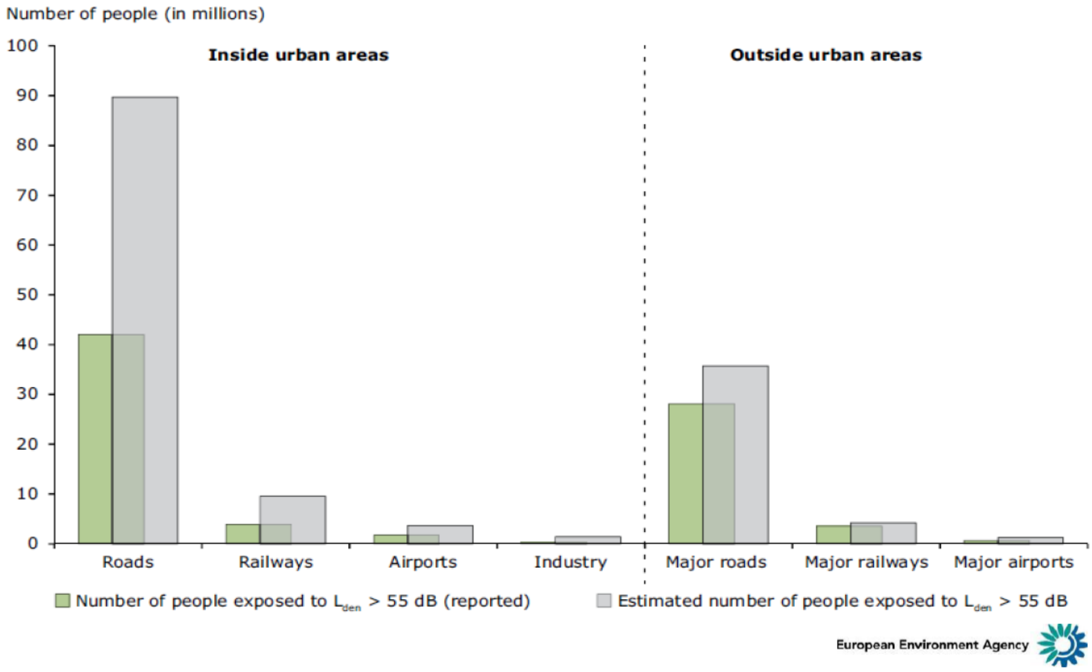


figure 1 *Exposure of EU27 population to transportation noise ref. 2014. Green bars present reported data up to August 2013 covering about 60% of the agglomerations and infrastructure. Grey bars: result of extrapolating to 100% coverage (source EEA [3]).*

The table below (see table IV) presents the exposure data in 5 dB classes and total numbers.

table IV *Results of exposure to air traffic noise in EU27 (ref. 2012) in 5 dB classes and total (n.b. based on about 50% of the to be reported data)*

Exposure class [dB L_{den}]	Number exposed (*1000)		
	Agglomeration	Major airport	total
55-59	944	690	1.634
60-64	313	146	459
65-69	98	18	116
70-74	13	1	14
≥ 55	1.368	855	2.223

Differences can be noticed between the presented exposure data. For a part they can be explained by the variation in number of airports taken into account. The EU27 data do cover only the agglomerations larger than 250.000 and major airports (and when not “gap-filled a coverage of about 50% is presented) while the other inventories include also smaller airports. The main cause might be the incomparability of the noise calculation methods. Although Doc 29 [31] is indicated as preferred method, national schemes may be used.

An additional source of scatter is the year-to-year variability in noise contours caused by meteorological variations between years. The END presents the situation for a specific year that might not be a representative situation. Finally, the exposure calculations rely on housing and population density around airports. To have them up-to-date can be a challenge.

The introduction of DOC 29 as mandatory calculation method in the 2022 noise mapping round, will at least solve the variation in calculation methods.

1.4 Effect of aircraft noise on society

The data presented may indicate that air traffic noise is a minor problem, however, according to the established dose-effect relations, the effect of aircraft noise on annoyance is roughly 50% higher than road traffic noise and more than 100% higher than rail traffic noise (see figure 2). Air traffic is considered second in environmental noise relevance. Another reason air traffic must be considered when investigating environmental noise is that air traffic noise is not evenly spread over the total area of Europe but is concentrated in the vicinity of airports. Locally it can cause fierce reactions (see for instance Frankfurt and Heathrow airports).

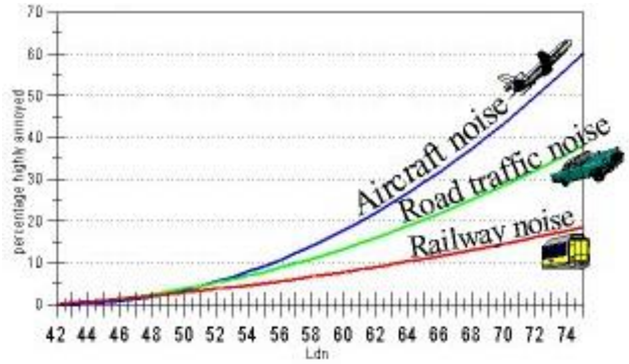


figure 2 *Fraction of people that are highly annoyed by road, rail and air traffic noise as a function of the Ldn level.*

The impact of aircraft noise is wider than the annoyance data suggest. A CAEP study on the impact of air traffic [12] presented as series of annoyance, sleep and health issues that are connected to the exposure to aircraft noise (see table V).

Also the European Environment agency reported the negative effect of aircraft noise on the wellbeing, learning abilities and health of people living in the vicinity of airports (ref. [4]).

The population that is severely annoyed and severe sleep disturbed is estimated in a study by the RIVM. They distinguished the reported data set (august 2013), the gap filled data set and the full distribution, including exposure below the END threshold of Lnight 50 and Lden 55 dB.

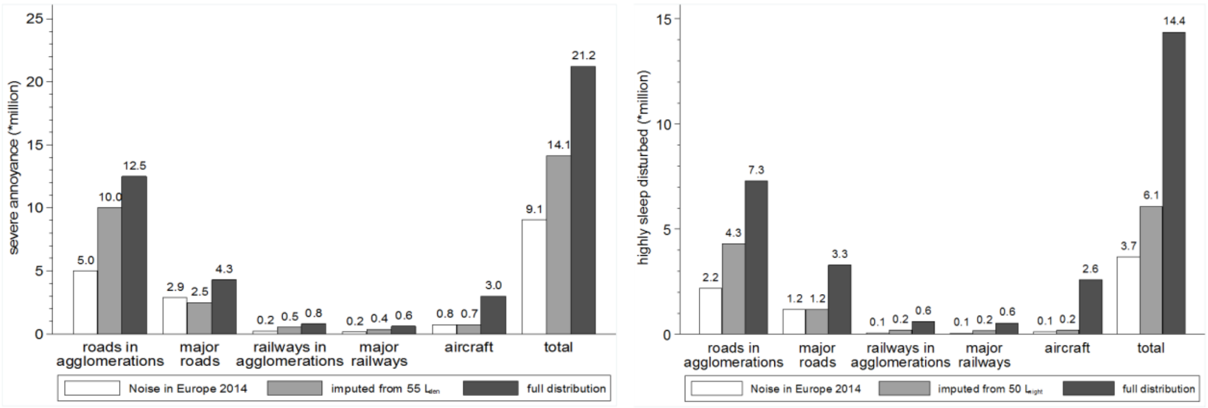
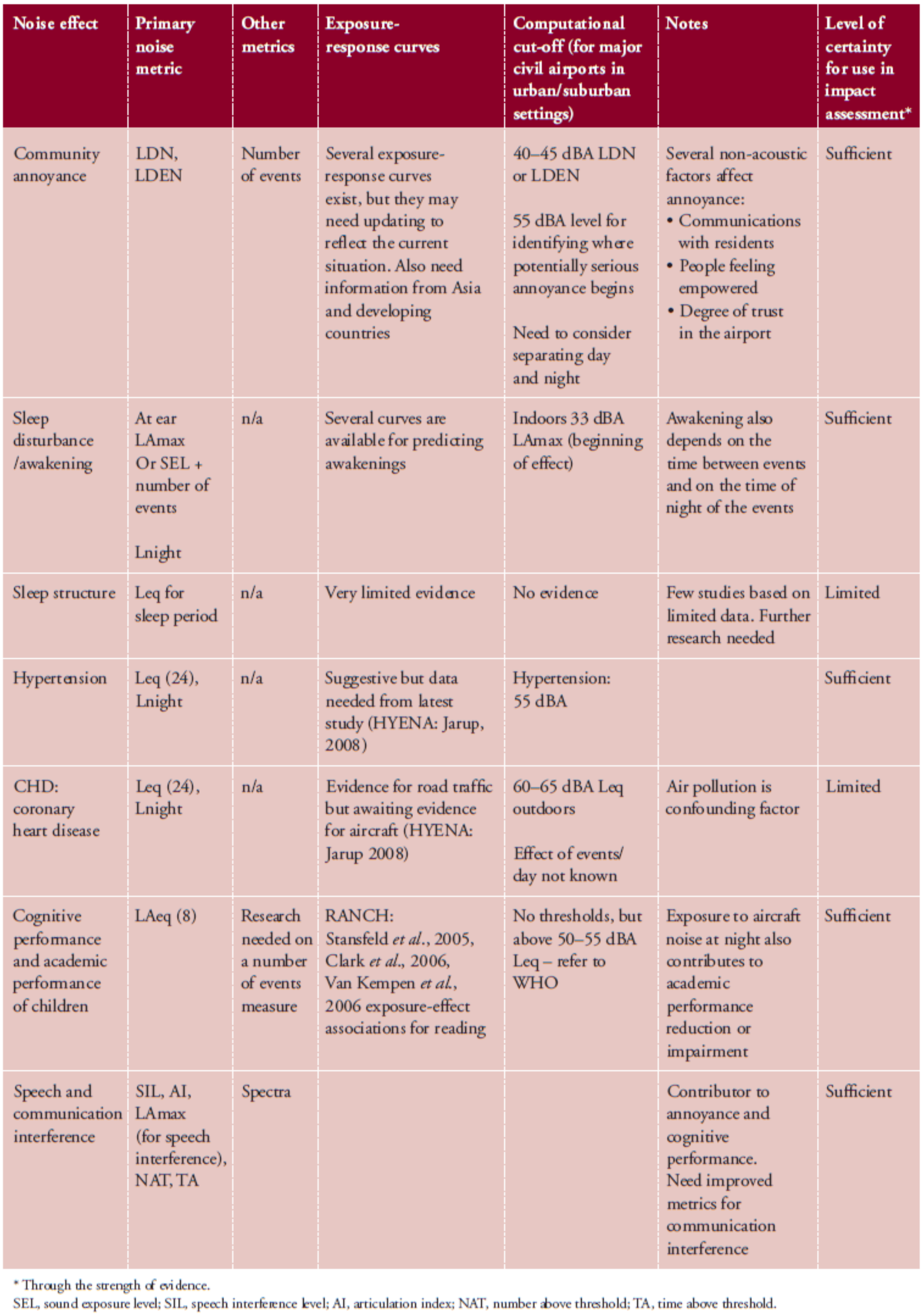


figure 3 *Severe annoyance calculated for the member states in the EU based on the outcome of noise mapping. “noise in Europe 2014” data present reported data up to August 2013, “imputed from 55 / 50 Lden/Lnight” the extrapolated data set to cover the not yet reported data, “full distribution” includes also levels below 55/50 dB.*

It is interesting to notice that including data from below the lower noise mapping limit of Lden 55 dB or Lnight 50 dB results in a significant increase in the affected population. In case of Severe annoyance the figure goes from 0,7 million to 3,0 million and for sleep disturbance from 0,2 to 2,6 million. The relative shifts are lower for road and rail transport.

table V *Assessment of metrics and dose-effect relations available for aircraft noise impact, copy from [12]*



Noise effect	Primary noise metric	Other metrics	Exposure-response curves	Computational cut-off (for major civil airports in urban/suburban settings)	Notes	Level of certainty for use in impact assessment*
Community annoyance	LDN, LDEN	Number of events	Several exposure-response curves exist, but they may need updating to reflect the current situation. Also need information from Asia and developing countries	40–45 dBA LDN or LDEN 55 dBA level for identifying where potentially serious annoyance begins Need to consider separating day and night	Several non-acoustic factors affect annoyance: • Communications with residents • People feeling empowered • Degree of trust in the airport	Sufficient
Sleep disturbance /awakening	At ear LAmax Or SEL + number of events Lnight	n/a	Several curves are available for predicting awakenings	Indoors 33 dBA LAmax (beginning of effect)	Awakening also depends on the time between events and on the time of night of the events	Sufficient
Sleep structure	Leq for sleep period	n/a	Very limited evidence	No evidence	Few studies based on limited data. Further research needed	Limited
Hypertension	Leq (24), Lnight	n/a	Suggestive but data needed from latest study (HYENA: Jarup, 2008)	Hypertension: 55 dBA		Sufficient
CHD: coronary heart disease	Leq (24), Lnight	n/a	Evidence for road traffic but awaiting evidence for aircraft (HYENA: Jarup 2008)	60–65 dBA Leq outdoors Effect of events/ day not known	Air pollution is confounding factor	Limited
Cognitive performance and academic performance of children	LAeq (8)	Research needed on a number of events measure	RANCH: Stansfeld *et al.*, 2005, Clark *et al.*, 2006, Van Kempen *et al.*, 2006 exposure-effect associations for reading	No thresholds, but above 50–55 dBA Leq – refer to WHO	Exposure to aircraft noise at night also contributes to academic performance reduction or impairment	Sufficient
Speech and communication interference	SIL, AI, LAmax (for speech interference), NAT, TA	Spectra			Contributor to annoyance and cognitive performance. Need improved metrics for communication interference	Sufficient

* Through the strength of evidence.
SEL, sound exposure level; SIL, speech interference level; AI, articulation index; NAT, number above threshold; TA, time above threshold.

1.5 International organizations relevant for aircraft noise

EUROPEAN COMMISSION DG-ENV
DG Environment is responsible for the European Noise Directive and works on developing a common method for evaluating environmental noise levels in Europe. The European environmental Agency in Copenhagen gathers all results from the noise mapping of large agglomerations, roads, railway lines and airports each 5 year and makes them available to the public. The EU does not impose noise limits in individual countries (such as is the case with air quality). Relevant doc: 2002/49 (END) [30].

EUROPEAN COMMISSION DG-MOVE
DG Move regards air transport as an important sector that makes a vital contribution to the EU's overall economy and employment. In order to fully exploit the economic potential of the sector, the European Commission constantly works on several important aspects for our skies:

- To create a single European market, free of restrictions that limit growth and prevent cross-border investments.
- To develop a more coordinated EU external aviation policy.
- To create a Single European Sky to decrease congestion at airports and to allow further growth.
- To investigate air traffic management technology required for the future single sky (SESAR)

Relevant doc: 598/2014 [17].

EASA
The European Aviation Safety Agency is the centrepiece of the European Union's aviation safety system comprised of the Agency, the European Commission and the National Aviation Authorities (NAAs).
The main tasks of the Agency currently include:

- Drafting aviation safety legislation and providing technical advice to the European Commission and to the Member States;
- Inspections and training to ensure uniform implementation of European aviation safety legislation in all Member States;
- Airworthiness and environmental type-certification of aeronautical products, parts and appliances;
- Approval of aircraft design organisations world-wide and of production and maintenance organisations outside the EU;
- Coordination of the European Community SAFA (Safety Assessment of Foreign Aircraft) programme;
- Coordination of safety programmes, data collection, analysis and research to improve aviation safety.

Relevant doc: CS-36 (adopting ICAO Annex 16)

ICAO
(International Civil Aviation Organization) is a specialized agency of the United Nations. It codifies the principles and techniques of international air navigation and fosters the planning and development of international air transport to ensure safe and orderly growth. The ICAO Council adopts standards and recommended practices concerning air navigation, its infrastructure, flight inspection, prevention of unlawful interference, and facilitation of border-crossing procedures for international civil aviation. ICAO defines the protocols for air accident investigation followed by transport safety authorities in countries signatory to the Convention on International Civil Aviation (Chicago Convention). Relevant doc: ICAO Annex 16 Vol.1 and “Balanced Approach”

CAEP
(Committee on Aviation Environmental Protection) Committee under ICAO. This committee effectively develops new environmental regulations for both noise and emissions, and provides recommendations to the ICAO Council.

ECAC
The European Civil Aviation Conference is an intergovernmental organization which was established by the International Civil Aviation Organization (ICAO) and the Council of Europe. ECAC now totals 44 members, including all 28 EU, 30 of the 31 European Aviation Safety Agency and all 39 EUROCONTROL Member States. ECAC "promotes the continued development of a safe, efficient and sustainable European air transport system. In doing so, it seeks to harmonise civil aviation policies and practices amongst its Member States and promote understanding on policy matters between its Member States and other parts of the world". Its strategic priorities are safety, security and the environment. Relevant doc: ECAC Doc29 (airport noise modelling methodology)[31].

ACI
(Airports Council International) is a global trade representative of the world’s airports. Established in 1991, ACI represents airports’ interests with governments and international organizations, develops standards, policies and recommended practices for airports, and provides information and training opportunities to raise standards around the world. It aims to provide the public with a safe, secure, efficient and environmentally responsible air transport system. Relevant doc: ACI noise index

EUROCONTROL
is an international organisation founded in 1960 and composed of Member States from the European Region, including the European Community which became a member in 2002. They are involved in almost every aspect of air traffic management, in close cooperation with their stakeholders. One of their tasks is to support the European Commission, EASA and National Supervisory Authorities in their regulatory activities. Relevant: STAPES harmonized noise calculation input data.

ARC
(Airport Regions Conference) is an association of regional and local authorities across Europe with an international airport situated within or near its territory. The ARC brings together a wide range of expertise at the interface of air transport and local and regional policies. A common concern is to balance the economic benefits generated by the airports against their environmental impact, notably the effect on the quality of life of local residents. ARC works with the European Commissioner for Transport and his Cabinet and the EC Directorates for Transport, for the Environment, and for the Regions.

1.6 Relevant topics at the international level

At this moment there are five relevant topics on the international “table”:

- Definition of “chapter 14” as new noise standard for new aircraft
- Tightening of the definition of “marginally compliant aircraft”
- Implementation of the “Balanced Approach” in EU regulation (through replacing 2002/30 with 598/2014 [17])
- Development and standardization of noise abatement procedures
- Revision of noise annoyance curves.

These five topics have separated discussion areas, but are closely connected in the following way.

New planes introduced in the market are significantly less noisy than existing planes. The current type approval levels as are in force from 2006 do not reflect the state-of-technology today. There is room for tightening the acoustic requirements of new aircraft types in terms of an improved “chapter 14” set of levels. More background information is found in part 2.4 of this report.
Due to the long service life of aircraft types (typically 25 years) renewal of the fleet develops slowly. Older types attributes significantly to noise levels around airports. Improvement can be found when the operations of these older types can be reduced. Older types are identified by the term “marginally compliant with chapter 3 levels” . The scope of marginally compliant originally was set at a cumulative margin of 5 EPNdB to the chapter 3 limit values. In the present regulation 598/2014 that replaces 2002/30 a value of 8 EPNdB is defined that after a transition period of six years ending on 14th of June 2020, will increase to 10 EPNdB. This will be detailed in Chapter 7

The implementation of the balanced approach in EU regulation implies the balancing of several aspects when deciding on operating restrictions for older “marginally compliant” aircrafts
In the “balanced approach” it is recommended that before restrictions for older aircraft are implemented, the possibilities for noise abatement operational procedures shall be investigated (read more in the appendix, chapter 13).

The emphasis on noise abatement procedures reveals the large variation in such procedures at different airports (see table XXIII in which each “nap” contains a link to the procedures for that airport).

Research is currently be conducted to provide a better understanding is required of how annoyance is generated and what can be done to reduce annoyance by both acoustical and non-acoustical measures. Most likely this will lead to updated noise annoyance curves.

1.7 Noise measure EPNdB

The exposure levels L_p in dB(A) of aircraft noise are determined in the same way as those for road or rail traffic noise. The sound signal is frequency weighted with an A-filter that represents the sensitivity of the human ear at a moderate noise level. Especially lower frequencies are suppressed by this filter. No specific penalty or weighting is applied to penalize for specific tones or impulses. In general the equivalent level over a longer period (12h in the day period, 4h in evening and 8 h in night period) is determined when calculating Lnight or Lden.

The standards for evaluating and regulating aircraft noise do not use the dB(A) but a more complex measure, the Effective Perceived Noise Level (EPNL) expressed in EPNdB’s. Not only the overall level is taken into account, but also the duration of the sound (duration defined as the period during which the noise is within 10 dB from the maximum level of the passing aircraft) and the occurrence of pure tones in the signal. The procedure is described in [21].

It starts with the determination of the overall Noy value N, from the Noy values of individual 1/3rd octave bands on base of the iso-loudness contours with their Noy value that are given in figure 4:

$$N = 0{,}85 \cdot n_{max} + 0{,}15 \cdot \sum n$$

With n_{max} is the value of the 1/3rd octave band with the greatest Noy value
$\sum n$ the sum of the Noy values in all bands.

The perceived noise level PNL is calculated from the overall Noy level as follows:

$$L_{PN} = 40 + log_2(N)$$

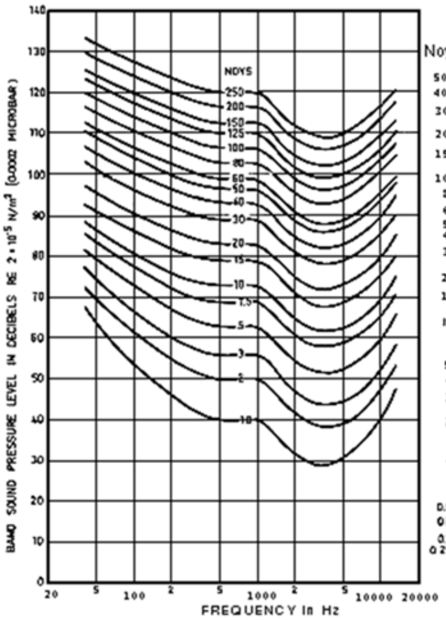


figure 4 *Graphs of equal loudness contours and their Noy value. Noy is used for calculating the EPNdB level of a sound signal.*

The extra disturbance due to tonal components is taken care of by a correction factor C leading to a Tonal Perceived Noise Level (TPNL):

$$TPNL = PNL + C$$

C can be up to 1,5 to 3 PNdB.

The Effective Perceived Noise Level (EPNL) is calculated by integrating the tonal perceived noise level over the length of the total fly-over event and normalizing it to 10 s:

$$L_{EPN} = 10 \cdot log\left[\frac{1}{T_{10}}\int_0^T 10^{L_{TPN}(t)/10}.dt\right] \text{ in } EPNdB$$

With T_{10} : the reference time of 10 s

$L_{TPN}(t)$: instantaneous Tone corrected Perceived Noise Level

All certification levels and results of type approval testing are expressed in EPNdB's. There is no simple conversion from EPNdB to dB(A) since the specific weighting of spectral irregularities, implemented in the EPNdB calculation procedure does not have a comparable weighting in the dB(A) procedure. Neither is it easy to interpret a reduction in EPNdB's to a reduction in the dB(A) level, since for instance the removal of pure tones directly affects the EPNdB value, but is less relevant for the dB(A) value.

1.8 Balanced approach

In 2001 the ICAO general assembly adopted the concept of Balanced Approach in 2001. It consists of identifying the noise problem at an airport and then analysing the various measures available to reduce noise through the exploration of four principal elements, namely:

- reduction at source (quieter aircraft),
- land-use planning and management, including market based instruments (noise charges)
- noise abatement operational procedures and
- operating restrictions,

with the goal of addressing the noise problem in the most cost-effective manner. ICAO has developed policies on each of these elements. The recommended practices for balanced approach are contained in Doc 9829 – Guidance on the balanced approach to aircraft noise management-. The Balanced Approach is explained in more detail in chapter 13. It serves also as an essential part of the EU regulation on airport noise management 598/2014 [17] (see chapter 7).

The graph below gives an overview of current (2008) measures by airports to control environemntal noise. An overview of measures for individual european airports is given in table XXIII.

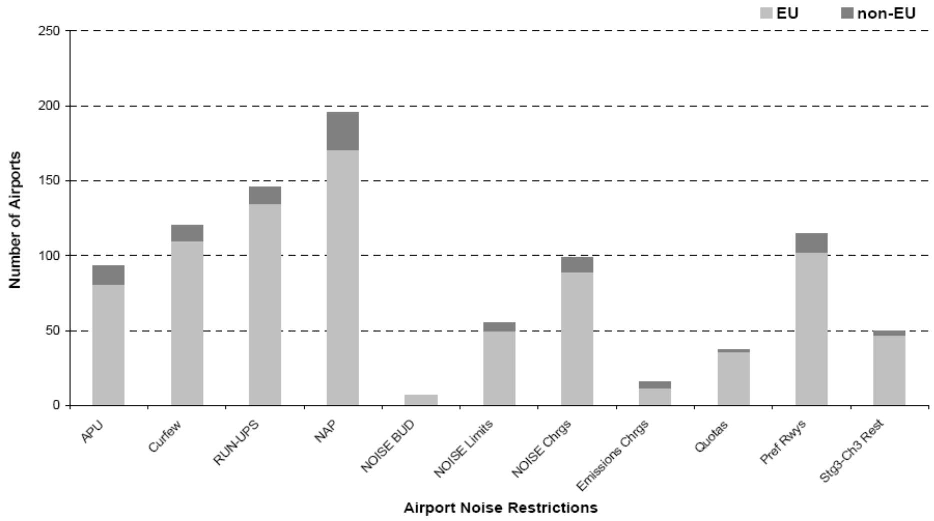


figure 5 *Overview of European (EU and non-EU) airport noise related restrictions [18]. APU: regulated use of auxiliary power units, NAP: Noise Abatement Procedures.*

2 Reduction at the source

2.1 Sources of noise

The picture below gives an indication of the major noise sources of an aircraft. The actual noise levels generated and their mutual contribution to the overall noise depends on the type of aircraft, the type of operation and of course on the level of noise reducing technology applied. In chapter 14 a more detailed review of possible reduction techniques is presented.

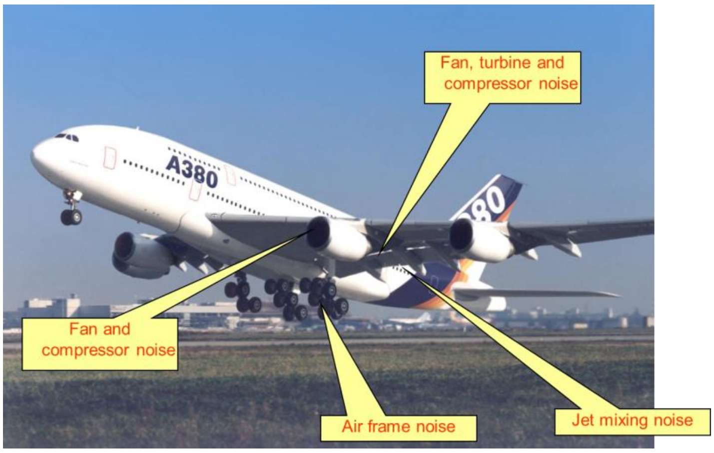


figure 6 *Overview of the noise sources of a modern jet aircraft (see Chapter 14 for more information).*

2.2 Noise certification of an aircraft

The determination of the noise production is part of the certification process of an aircraft. All new aircraft types introduced in the market have to comply with requirements concerning the noise produced by the aircraft during take-off and landing. The noisiness is evaluated according to the procedures laid down in Volume 1, Annex 16 to the convention on International Civil Aviation.

The European certification of aircraft with respect to noise are based on the limit values and procedures that are defined in Annex 16, Vol. I. The regulation distinguishes between helicopters, small propeller driven aircraft and subsonic jets. We refer to the category of subsonic jets. The noise tests refer to three test positions and two types of aircraft operations.

- The noise level produced during landing is referred to as “approach”. It is determined at a position directly under the flight path of the approaching aircraft at a distance of 2 000 m from the beginning of the runway (see figure 7).
- The noise levels produced during take-off are determined at two locations (see figure 8):
  - 6 500 m from the beginning of the runway directly under the flight path of the climbing aircraft referred to as “fly-over”.
  - At a distance from 450 m aside from the ground track of the starting and climbing aircraft at the point where the noise is maximum, referred to as “side line”.

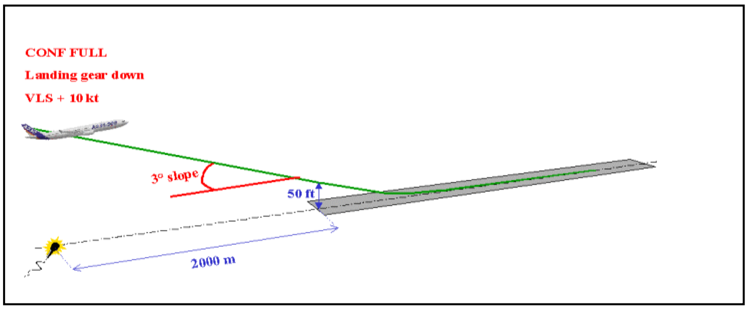


figure 7 *Measurement position and aircraft operations during the determination of "approach"-level.*

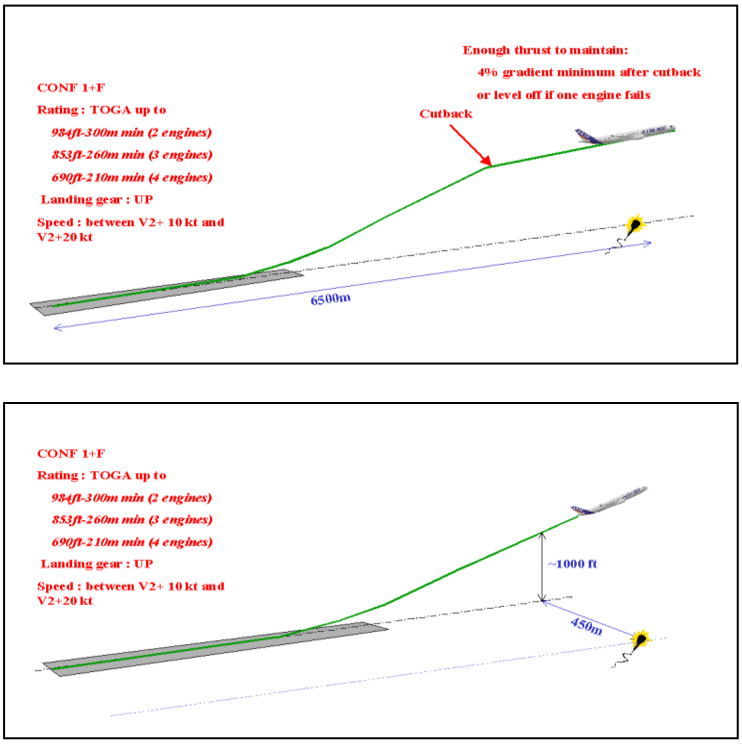


figure 8 *Measurement positions and aircraft operations during the determination of "fly-over"-level (top graph) and "side line" level (bottom graph).*

2.3 Limit values

In order to get a certificate, the noise levels at each of the positions have to meet maximum levels. Up to 2006 those levels were based on Chapter 3 requirements. For general commercial jet types, the graphs below depict the maximum allowed levels at the take-off and the approach position. The levels are depending on the take-off weight and also on the number of engines. Some trade-offs are allowed, where any exceedance at one point shall be compensated by a margin at the other points.

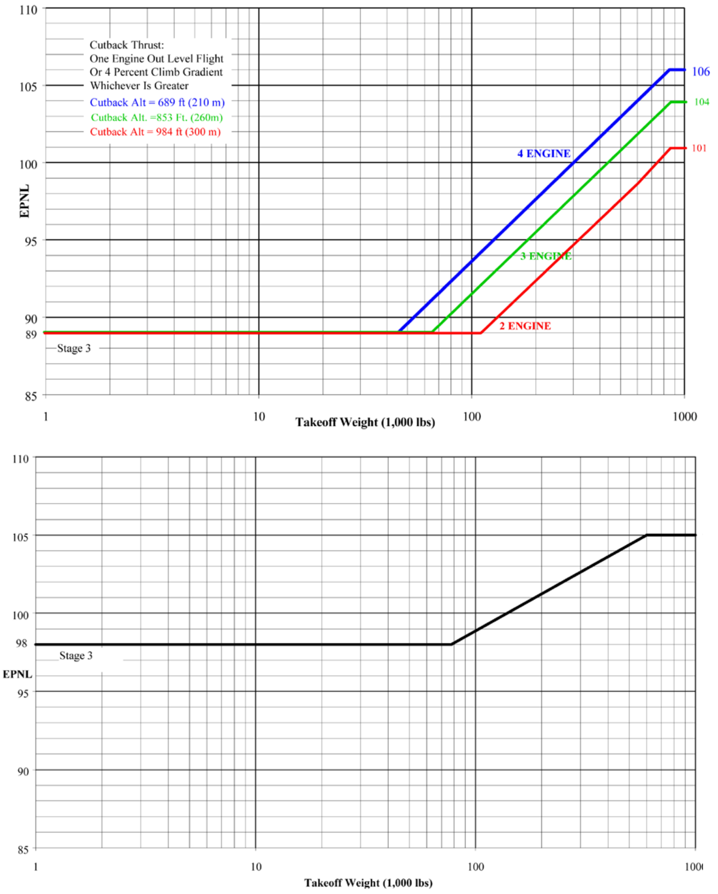


figure 9 *Maximum noise levels (in EPNdB) according to chapter 3 (or stage 3) requirements. Top: at take-off position, bottom: at approach position. Side line limits are 94 EPNdB TOW< 80.000 lbs, increasing to 103 EPNdB for TOW>600.000 lbs.*

The chapter 3 requirements date from1972 and were at that time considered to represent state-of-the art. The continuous development of less noisy and more efficient engines has resulted in a significant reduction of the noise production of aircraft since 1970 as can be seen in figure 10.

In 2001 an updated limit was defined in the following way:

1 The cumulative margin over all three measurement positions relative to the chapter 3 requirement shall be 10 dB or more
2 At every two of the three positions the cumulative margin relative to chapter 3 shall be 2 dB or more.
3 At no measurement shall the noise level exceed Chapter 3 limits.

This requirement, referred to as chapter 4, came into force from 2006. All new aircraft from that date shall comply with these more stringent limit values. The modest severity of the new requirement is demonstrated in the graphs below. In figure 11 the certification results of a sample of common types is presented relative to the chapter 4 requirements. It is clearly shown that already a significant number of types do comply with chapter 4 with a large margin.

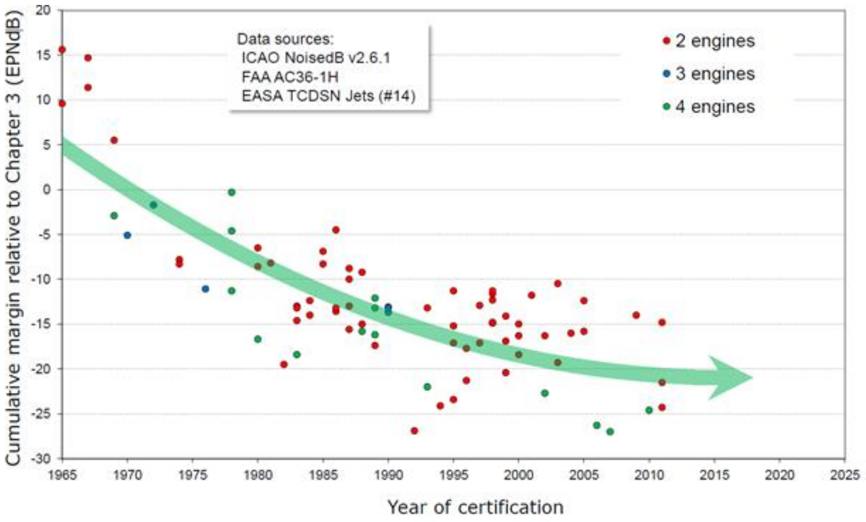


figure 10 *Development of noise emission from 2, 3 and 4 engines aircraft between 1965 and 2010 (source EASA). The value at the y-axis represents the sum of the margins to the limit values at each measurement point (approach, fly-over and side-line).*

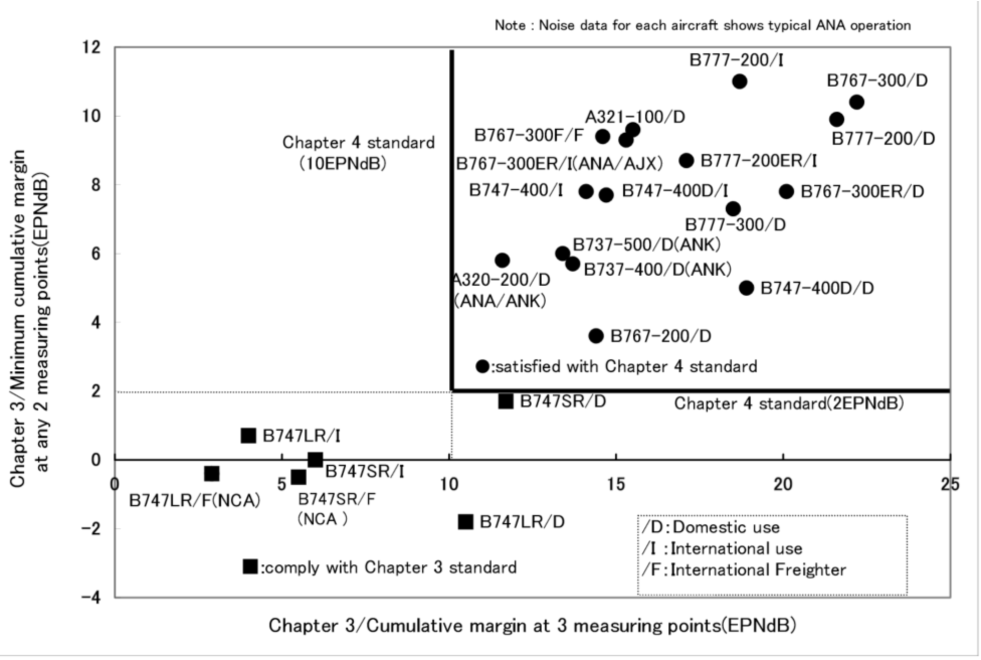


figure 11 *Noise levels of a sample of aircraft relative to the Chapter 3 and chapter 4 requirements (source ANA).*

2.4 CAEP/8 and CAEP/9 targets for noise reduction

Based on the success of the independent expert process to set medium and long term NOx reduction goals, a similar process was launched for noise reduction technologies. This independent expert review was completed in 2008 and the panel presented its final report to CAEP/8 meeting in February 2010. The goals for four classes or categories of aircraft were as follows (see table VI).

When compared to a baseline of today's aircraft, the goals show more promise of noise reduction for larger aircraft because of a broader scope of technologies that can be applied to such aircraft.

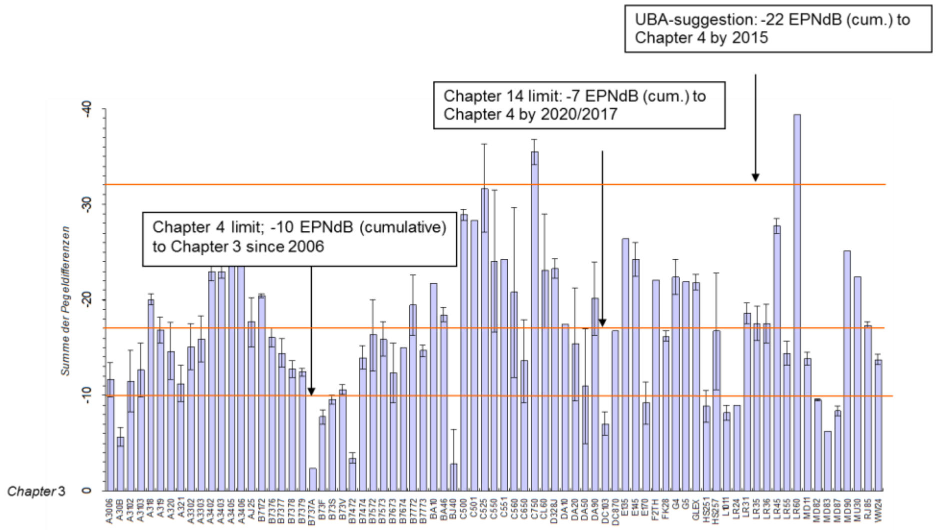
table VI *Targets for future aircraft noise thresholds. Proposal from expert panel to CAEP/8 [15].*

Aircraft Category	***Margin to Chapter 4 (EPNdB)***	
	Mid-Term (2018)	***Long-Term (2028)***
Regional Jet	*13.0±4.6*	*20.0±5.5*
Small-Med. Range Twin	*21.0±4.6*	*23.5±5.5*
Long-Range Twin	*20.5±4.6*	*23.0±5.5*
Long-Range Quad	*20.0±4*	*23.5±5.5*

The CAEP/ 9 meeting in February 2013 recommended that ICAO should adopt a new, more stringent aircraft noise certification for new aircraft designs

1 The new standard would reduce the noise from new aircraft types by 7 EPNdB relative to the Chapter 4/Stage 4 standard that was adopted in 2001.
2 The new noise standard would go into effect in 2017 for large aircraft and in 2020 for smaller aircraft.

The figure below illustrates the stringency of the future Chapt 4 – 7 EPNdB limit that is advised by CAEP/9 relative to the Chapt 4 - 22 EPNdB limit that is proposed by CAEP/8.



Source: Increased stringency of noise limits for civil jet aircraft with emphasis on the trade-off between noise and pollutant emissions of jet engines, Öko-Institut 2006, PW, own editing

figure 12 *Cumulative margin relative to Chapter 3 requirements for a number of aircraft, together with the existing Chapt 4 limit level and the proposed by CAEP/8 and advised by CAEP/9 future limit level. Source: UBA.*

2.5 Development of limit values over time

The graph below presents the development of limit values (defined as cumulative margin at three measurement positions relative to Chapter 2) over the period 1970-2020. In total stringencies were tightened with about 35 EPNdB relative to Chapter 2. The effective reduction observed in the vehicle fleet is in the same order of magnitude as can be derived from figure 10 but here Chapter 2 values are used as reference.

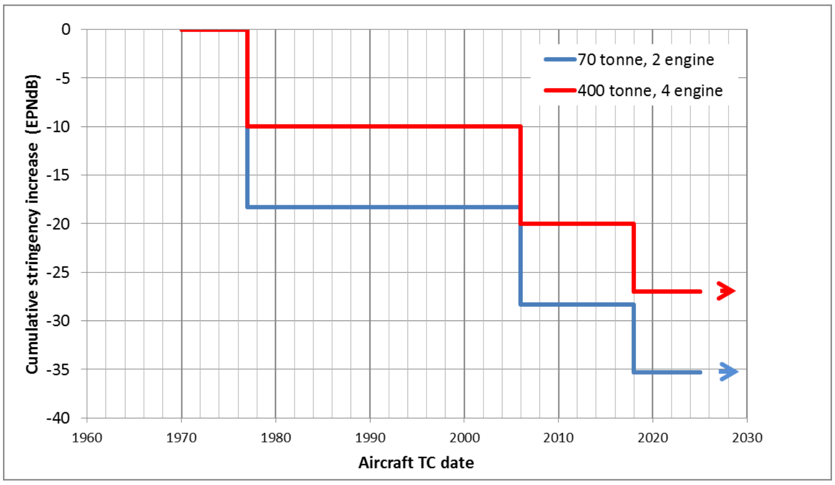


figure 13 *Development of noise standards for commercial jet aircraft (source EASA). The y-axis represents the cumulative value over all three measurement positions relative to the values for Chapter 2 aircraft.*

2.6 ACI Noise rating Index

The Airport Council International (ACI) considered the Chapter 4 standard, approved in 2001 and entering into force in 2006, as too less stringent to bring any noise relief for airports. Not only was the in total 10 dB margin seen as modest, the minimal margin of 2 dB at any two of the three measurement points, made it possible that at one point no reduction was observed at all.
Most of the aircraft in the modern fleet do already meet this requirement and thus the actual impact of classification based on a chapter 4 requirement will not result in any differentiation between regular and classes of less noisy aircraft.
In 2002 the Environment Standing Committee of ACI has developed a noise rating index based on the margin relative to chapter 3 but with more ambitious reductions of up to 20 dB cumulative margin and with a noticeable minimum reduction at each measurement point. The certification of new aircraft with cumulative margins better than 25 dB enabled the extension of the index to even higher reductions. In 2010 a rating index was modified to incorporate margins of 30 dB and more. The categories according to this rating R1 to R8 are given in table VII(ref. [19]).

For a series of common aircraft types the noise rating is given in the table below (see table VIII). It can be seen that several common types perform much better than chapter 4 noise reduction targets. Interesting is also that the type/engine combination defines the noise category of the aircraft/engine combination.: The light grey rows at the bottom show that depending on the engine type, a B-767 can be rated as R2 or R6.

table VII *The Modified ACI Noise Rating Index 2010 ([19]).*

Criteria to be met concurrently	**ACI noise rating index categories**							
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**
Cumulative EPNdB reduction from ICAO Chapter 3 standard of at least:	<0	0	5	10	15	20	25	30
Individual EPNdB reduction from ICAO Chapter 3 Standard at each noise measurement point of at least:	n.a.	0	1	2	3	4	5	6

table VIII *Categorization of common aircraft types according to ACI noise rating index 2010 ([19]).*

type	version	ACI rating	MTOM (tons)	engine	Margin level			
					FO	SL	AP	Cum
B-737	700	R4	70.1	CFM56-7B24	5.4	3.6	4.5	13.5
B-737	800	R4	79.0	CFM56-7B24	3.3	5.0	4.3	12.6
B-747	400	R4	396.9	PW4056 H3(FB2C)NR	8.6	4.9	2.9	16.4
B-747	400	R3	396.9	RB211-524G	6.8	5.0	1.2	13.0
A-340	600	R6	368.0	TRENT556	12.0	7.2	5.1	24.3
A-320	200	R2	60.0	CFM56-5B4/P	11.5	0.8	4.3	16.6
A-321	200	R4	93.0	V2533A5	4.6	2.4	5.5	12.5
A-330	200	R5	230.0	TRENT772	7.7	3.6	7.6	18.9
B-767	300	R6	131.0	CF6-80C2B2	11.7	4.6	5.9	22.2
B-767	300	R2	136.1	JT9D-7R4D(B)	4.0	3.4	0.3	7.7

In Annex 12 the noise ratings of a more extensive sample of aircraft are presented. In table IX below a sample is presented of lowest noise aircraft with a noise rating index of R7, indicating a 25 dB or more margin relative to Chapter 3 and at least 5 dB margin at an individual measurement position.

table IX *Category R7 aircraft according to ACI noise rating index 2010 ([19]).*

Manufacturer	Type	Version	MTOM (tons)	Engine	Margin level rel to chapter 3			
					FO	SL	AP	Cum
AIRBUS	A380	841	569	TRENT 970	11.2	8.1	7	26.3
AIRBUS	A380	842	569	TRENT 972	11.7	7.7	7	26.4
AIRBUS	A340	541	305	TRENT 553EP	16.2	5.9	5.9	28
BOEING	777	200	229	GE60-76B	11.3	7.7	6.7	25.7
BOMBARDIER	CRJ	200	240	CF-34-3B1	10.3	11.6	5.9	27.8
SAAB	2000		23	AE2100A	9.9	7.1	10.1	27.1

2.7 Discussion and conclusion

The displayed information corroborates the significant improvement of engine and aircraft technology that has resulted in a large reduction of the emitted noise of the averaged fleet. With an 8 EPNdB improvement when averaged over measurement positions (based on 25 EPNdB cumulative effect over three positions) it surpasses road transport and equals rail transport after the total ban on C.I. block brakes.
The largest improvements are found at the fly-over position where due to the increased by-pass ratio the typical jet noise is suppressed. At approach it is found however that the fan becomes the dominant source and the trend towards even higher by-pass ratios interferes with further reduction. In addition distributed sources at the air frame become more and more relevant (see chapter 14 of this report).

The development of limit values for certification of aircraft lag behind the development. While -25 EPNdB (rel. to chapt. 3) aircraft are on the market today, a moderate tightening to -17 dB is scheduled between 2017 and 2020.

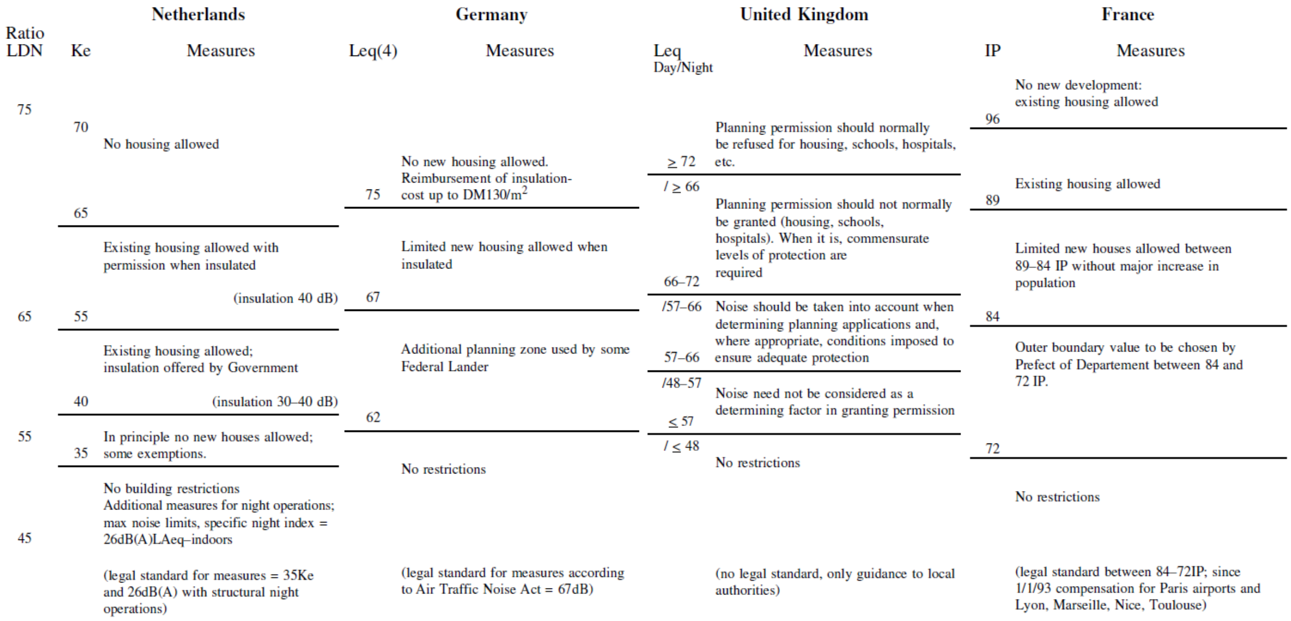
3 Land use planning and management

Large airports with frequent international connections attract economic activities and through that will lead to a migration of people into the direction of the airport. In this process the negative effects seem to be neglected, causing problems on the long term. For the population because of the annoyance and health risks related to the noise exposure close to the airports, for the air traffic business because of the limitations in growth and development caused by the surrounding urbanization. A key component in the balanced approach is to prevent the coming into existence of such problems. This not only refers to noise but also to air quality and safety issues. The latter defined in the Netherlands as the risk of an inhabitant on the ground of becoming a victim of an aircraft crash. A typical maximum value for new housing is 10^{-6}, i.e. a yearly chance of 1 in a million. The evaluation of such risks is based on modelling.

The general term “land use planning” has a broader scope than exposure of the population. It includes the restriction of building heights under landing and take-off paths, the management and rules of growing crops in agricultural areas (to not attract birds that may cause safety issues for aircraft), etc. The report focuses on the noise exposure and related environmental issues.

Most countries in Europe do have some zoning system around airports that based on the preferred and allowed noise values do regulate residential building activities in some way. The table below (table X) give examples for four countries in Europe [8].

table X *Copy from ICAO doc 9184 on relationship between noise indices and housing permits illustrating the ways different countries address the issue of controlling urbanization and living quality close to airports [8] .*



	Netherlands		Germany		United Kingdom		France	
Ratio LDN	Ke	Measures	Leq(4)	Measures	Leq Day/Night	Measures	IP	Measures
75	70	No housing allowed			≥ 72	Planning permission should normally be refused for housing, schools, hospitals, etc.	96	No new development: existing housing allowed
	65		75	No new housing allowed. Reimbursement of insulation-cost up to DM130/m^2	/ ≥ 66 66–72	Planning permission should not normally be granted (housing, schools, hospitals). When it is, commensurate levels of protection are required	89	Existing housing allowed
65	55	Existing housing allowed with permission when insulated (insulation 40 dB)	67	Limited new housing allowed when insulated	/57–66 57–66	Noise should be taken into account when determining planning applications and, where appropriate, conditions imposed to ensure adequate protection	84	Limited new houses allowed between 89–84 IP without major increase in population
	40	Existing housing allowed; insulation offered by Government (insulation 30–40 dB)	62	Additional planning zone used by some Federal Lander	/48–57 ≤ 57	Noise need not be considered as a determining factor in granting permission	72	Outer boundary value to be chosen by Prefect of Departement between 84 and 72 IP.
55	35	In principle no new houses allowed; some exemptions.		No restrictions	/ ≤ 48	No restrictions		No restrictions
45		No building restrictions Additional measures for night operations; max noise limits, specific night index = 26dB(A)LAeq–indoors						
		(legal standard for measures = 35Ke and 26dB(A) with structural night operations)		(legal standard for measures according to Air Traffic Noise Act = 67dB)		(no legal standard, only guidance to local authorities)		(legal standard between 84–72IP; since 1/1/93 compensation for Paris airports and Lyon, Marseille, Nice, Toulouse)

The comparison is based on the results of several studies: by ECAC/ANCAT3-WP/9, dated 4 October 1975; by NATO/CCMS — *Pilot Study on Aircraft Noise in a Modern Society*, dated November 1989; by Peutz & Associates BV., *Noise Exposure Calculations for Schiphol Airport*, dated November 1990; by EC/DG-VII — *A Study on Measures to Protect the Environment In and Around Airports Against Aircraft Noise*, dated August 1993; and by the Noise Exposure, Land Use and Insulation Subgroup (NLISG) in the framework of ICAO/CAEP/3 (1993 to 1995), *A Study on the Development of the Noise Exposure in LDN Around a Number of Airports.* The comparison is only valid for positions on the extended runway centre lines.

In several countries a transition from national noise indicators to the European harmonized Lden system is initiated. A rough cross section of national zoning instruments based on the Lden would look like this (see table XI).

table XI *Cross section of European noise zoning system around airports. Existing systems averaged and normalized to the harmonized Lden noise rating. From [24].*

Lden value [dB(A)]	restrictions
< 55	▪ No restrictions for housing developments ▪ incidental insulations for night time noise
55 < Lden < 65	▪ No development of new housing areas. Restrictions for building of individual houses ▪ Insulation required for maintaining healthy indoor level
> 65	▪ No new houses permitted ▪ Heavy insulation for existing houses required
>70	▪ No housing allowed. Existing houses have to be removed.

4 Market based instruments

4.1 General

Airports are in general responsible for the noise exposure of airports operations in the vicinity of that airport. Therefore they generally have an interest in improving the noise performance of aircrafts that use the airport and to make movements in the noise sensitive evening and night period less attractive. For these objectives about half of the European airports use noise differentiated landing/take-off charges [1]. To make the noise-sensitive night period less attractive also about half of the airports differentiate between day and night period in the airport charge [1]. Some airport have total bans on night flights or forbid marginally compliant aircraft to use the airport during the night.

As an alternative or in addition to a market based instrument several airports have a quota system installed. Such system maximizes the total amount of noise produced by an airport taking into account the period of the day.

The following paragraphs present examples of systems used in a some airports or countries in Europe.

4.2 French system

For all French airports a harmonized system for taxation of noise pollution is active. The tax on noise pollution is to be paid for every take-off with a Maximum Take-Off Weight (MTOW) ≥ 2 tons and the charge is calculated according to the following formula:

$$T = t \,.\, c \,.\, \log(M)$$

- t : tax rate depending on the airport (ranges from € 6 for f.i. Lyon to € 47 for Paris Orly)
- c : multiplication term depending on noise category of aircraft and take-off time.
- M : MTOW

The term c includes a malus for evening and night time take-off and a bonus/malus for aircraft category in one of the six acoustic groups. The ratio between the most silent and most noisy category is about 24. The ratio between the day time period and the noise sensitive night time varies between 6 and 10. The values for each period and each noise category are given in table XIII.

As an example the take-off charges are calculated in case of a B747-400 with PW4056 engine, belonging to acoustic group 2 and an A320-200 with CFM56-5A2 engines belonging to acoustic group 4 at the noise sensitive airport Paris-Orly.

table XII Example of noise related take-off charges for a B747-400 and a A320-200 in case of Paris-Orly. All values in €.

aircraft type	**period of the day**		
	06-18	**18-22**	**22-06**
B747-400	47*12*log(395)=1.464,-	47*36*log(395)=4.393,-	47*120*log(395)=14.645,-
A320-200	47*2*log(74)=176,-	47*6*log(74)=527,-	47*12*log(74)=1.054,-

In case of Paris-CdG the value of t is € 19,- instead of € 47,- as is the case for Paris-Orly. This factor reflects the relative lower population density and thus lower exposure of the population around Paris-CdG compared to the density and exposure around Orly (see graphs in figure 14).

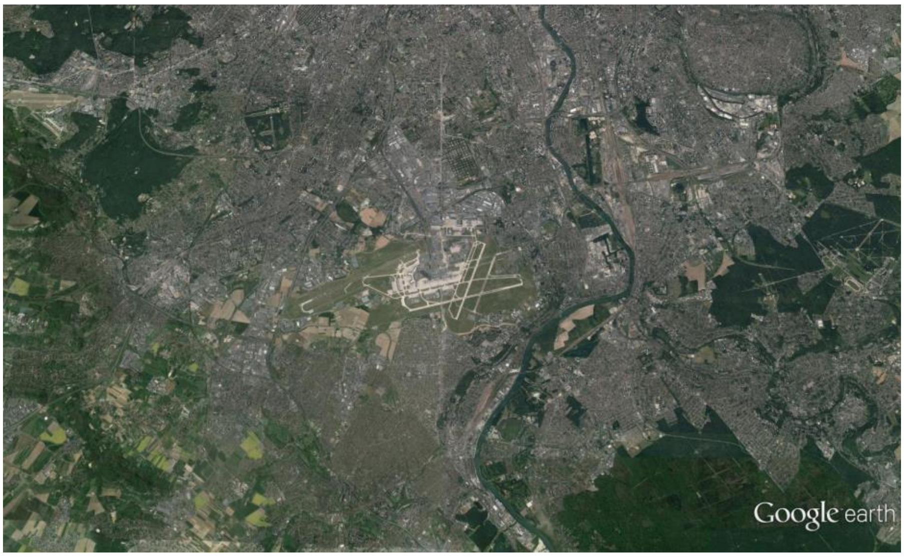


figure 14 *Maps of Paris-CdG (top) and Orly (bottom). They show the less densely populated area around CdG compared to Orly (source Google-Earth).*

table XIII *Multiplication term based on acoustic group and on day/evening/night period*

Acoustic group	06-18	18-22	22-06
1	12	36	120
2	12	36	120
3	6	18	50
4	2	6	12
5a	1	3	6
5b	0,5	1,5	5

table XIV *Acoustic group type of aircraft included in each category*

group	criterion
1	Aircraft not included in the acoustic groups 2, 3, 4 or 5.
2	Chapter 3 or 5 noise certificated aircraft with a corrected* cumulative margin less than 5 EPNdB.
3	Chapter 3 or 5 noise certificated aircraft with a corrected* cumulative margin greater than or equal to 5 EPNdB and less than 8 EPNdB.
4	Chapter 3 or 5 noise certificated aircraft with a corrected* cumulative margin greater than or equal to 8 EPNdB and less than 13 EPNdB
5a	Chapter 3 or 5 noise certificated aircraft with a corrected* cumulative margin greater than 13 EPNdB.
5b	Chapter 6, 8, 10 or 11 noise certificated aircraft

*correction on cumulative margin: 4 engines: 5 dB, 3 engines : 3 dB, 2 engines : 0 dB

4.3 Zurich airport

This airport defines a classification of aircrafts types in 5 noise classes. Classification is based on actual measurements done in the vicinity of the airport. These classes deviate from the chapter 2, chapter 3, marginal chapter 3 and chapter 4 classification because it does not take into account the MTOW relation with the threshold value. A relative silent aircraft such as the A 380 falls within class III because of its high MTOW. A few examples of classification are given in table XV.

table XV *Classification of aircrafts in noise charge categories. A relative silent aircraft as the 380-800 falls in a noisy category due to its high MTOW.*

Classes	I	II	III	IV	V
Aircraft types	B707,B727, DC10, MD8x, B777-300, MD80, A340-2/3/4/5/600, …….	A300, A310, A340, A380-800, B767, MD87, B777-300ER, …….	A321, B737-3/4/8/900, B757-3/300, B777-200, ……….	A318, A319, A320-1/200, B737-5/6/700, MD90, F70, F100, …….	BA-146-1/2/300, EMB135, EMB145ER, DO328, ….

table XVI *Noise charges (in CHF) in place for Zurich airport in the day and night period. For the evening and early morning charges in between day and night period are applied.*

Classes	I	II	III	IV	V
Starts in the Day (07.00-21.00)	2.000,-	400,-	40,-	10,-	
Starts in the night (00.01-06.00)	18.000,-	9.000,-	4.500,-	2.500,-	1.500,-

4.4 Amsterdam Schiphol airport

In case of Amsterdam Schiphol airport four noise categories are distinguished based on their cumulative margin to the chapter 3 requirements:

- noise category MCC3: 0 ≥ ΔEPNdB > -5 (marginally Compliant Chapter 3)
- noise category A: -5 ≥ ΔEPNdB > -9 (relatively noisy aircraft);
- noise category B: -9 ≥ ΔEPNdB > -18 (average noise producing aircraft);
- noise category C: ΔEPNdB ≤ -18 (relatively-low-noise aircraft).

Based on these four categories a take-off and a landing charge is defined for the day (06-23 h) and the night (23-06 h) period. Actual charges are given in table XVII

table XVII *Noise related charges for Schiphol in case of Point-to-point flight figures charges in €/1.000 kg. Example for "connected handling". Day: 06-23 h, night: 23-06 h. For cargo a tariff of about half of these values is charged.*

MCC3			Cat. A			Cat. B			Cat. C		
day	night		day	night		day	night		day	night	
landing / take-off	landing	Take-off	landing / take-off	landing	Take-off	landing / take-off	landing	Take-off	landing / take-off	landing	Take-off
€ 7,62	€ 14,51	€ 17,41	€6,66	€ 8,46	€ 10,00	€ 4,76	€ 6,05	€ 7,14	€ 3,81	€ 4,84	€ 5,71

As of 1 April 2002 a total ban on Chapter 2 operations is in force at Schiphol Airport. This ban is based on European legislation. If, in spite of the above ban, Chapter 2 aircraft land at Schiphol Airport an additional surcharge on the landing charges will apply. The basis for calculating the surcharge is as follows:

- up to 100 tonnes MTOW : € 1,837.80 per landing
- from 100 tonnes MTOW : € 2,756.70 per landing

4.5 Discussion

Market based instruments are mainly differentiation in the landing and/or take-off charge based on the noise emission of the aircraft and/or the period of the day. The table XXIII in the appendix (Ch.15) displays an overview of nearly all European airports (250 in total). In 40% of the cases a noise related landing or take-off charge is applied. The ns that indicates that a noise surcharge is applied to that airport contain a link to the specific regulation for that airport.

As already illustrated by the examples above and in table XXIII, the categorization and day period definitions differ strongly. Some of them are based on margins relative to chapter 3. Others such as Swiss and German systems, use a system based on actual measurements.

One can imagine that the non-uniformity in the definition of low noise aircraft in these regulations hampers the influx of present low noise aircraft in the existing fleet and the creation of a market for future low noise technology. A more uniform definition of noise categories is advisable. The system proposed by the Airport Council International, the ACI Noise Rating Index (see part 2.6) could serve as such a system. The more since it is endorsed by the worlds representative airports.

5 Noise abatement operational procedures

5.1 Introduction

Noise abatement operational procedures can be categorized in three groups (ref. [4]):

1. Noise abatement flight procedures, such as
    - Continuous Descent Arrival (CDA)
    - Noise Abatement Departure Procedures (NADP)
    - Modified approach angles, staggered, or displaced landing thresholds
    - Low power/low drag approach profiles
    - Minimum use of reverse thrust after landing
2. Spatial management
    - Noise preferred arrival and departure routes
    - Flight track dispersion or concentration
    - Noise preferred runways
3. Ground management
    - Hush houses and engine run up management (location/aircraft orientation, time of day, maximum thrust level)
    - APU management
    - Taxi and queue management
    - Towing and Taxi power control (Taxi with less than all engines operating)

In [7] results are presented from an overview of such procedures and the expected effects.

The Boeing company has made an inventory of the noise related restrictions for all relevant airports in the world. In the appendix (Chapter 15, table XXIII) an overview for the EU27+ airports is given. In nearly all displayed airports some type of noise abatement procedure is implemented.

5.2 Noise abatement flight procedures

The general arrival procedures consist of an approach path with a series of consecutive level segment, the final usually at 2000 ft. followed by a final slope of 3°. The noise relevance of such procedures lies in the relative close distance of 2000 ft. to the ground and the thrust required to maintain a constant height. Therefore some define the final level segment at 3000 ft during night time in order to increase the distance effect. In the ultimate case when the aircraft is allowed to approach following a continuous descent, it will “glide” down, using idle thrust and a clean configuration, maintaining on average a larger distance to the ground.

An example of the resulting peak levels of the descending aircraft are given in the graph below. The effect of increasing the approach height to 3.000 ft. is apparent up to 12 km from the runway. With CDA an additional reduction of up to 10 dB is observed at larger distances from the runway (see figure 15)

In several cases the noise abatement procedures include recommendations or rules for low drag/low thrust settings during landing. By reducing the amount of high lift devices (flaps/slats) the drag can be lowered so a lower thrust level can be used. Also the not optimal aerodynamics of these devices are responsible for considerable amount of flow noise.

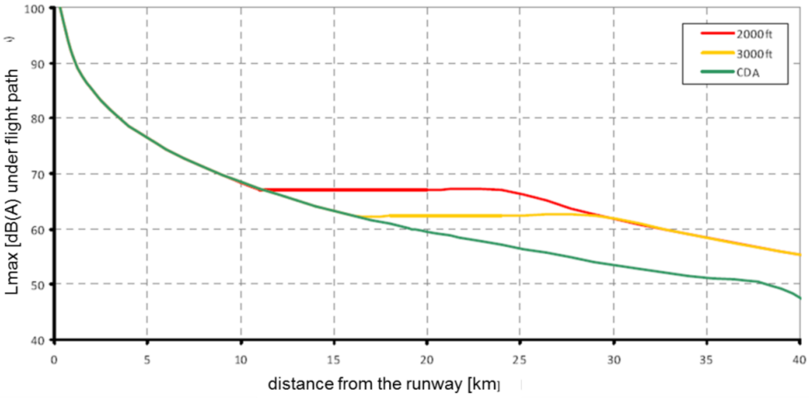


figure 15 *Effect of 3.000 ft approach and of continuous descent approach on peak nose levels under flight path.*

The effect of noise abatement departure procedures (NADP) is usually less impressive. Since a certain amount of thrust is needed to gain the required speed and required height, the noise management can only decide if reduction is wished on close or on large distance from the runway. With a high thrust departure, the noise situation will only improve far away from the runway, where the aircraft has substantial height from the ground and thrust can be reduced. A low thrust departure will improve the noise situation close by, since lower thrust means lower noise, but due to the aircrafts lower height farther away, noise levels there will be relatively high. Recently more investigation is done into the use of Continuous Climb Operations.

5.3 Spatial management

By choosing runways and steering the flying routes to be further away from the urbanized areas the exposure of the people living nearby can be reduced significantly. The freedom to optimize routes and runway choice is limited by safety constraints. The usage of the noise optimal runway is limited by cross and tailwind constraints. Also, with more than one runway in operation, approaching and departing aircraft may not interfere with each other.

Modern flight instruments allow the specification of narrower and curved departure routes. The picture (see figure 16) below shows the noise optimized departure route (green) versus the original route (black). This also allows for the use of so-called respite schemes, where alternate use of well-defined routes is planned, giving scheduled respite to part of the community.

figure 16 *Noise optimized departure route (green) versus original route (black). Source AMS airport.*

It should be noticed that a route optimized for noise might imply an increase in fuel consumption and hence CO2 production. Usually a trade-off has to be made between both environmental effects. However, some procedures (like CDA) are beneficial for both noise and emissions.

Safety and capacity conditions require that in busy times, approaching aircraft shall be lined up with a minimum allowable separation, preventing such procedures as CDA or curved ground paths.

When optimizing routes one should take care the calculated reduction in exposed population does not always reflect the improvement in wellbeing of that population. A study at the airport Heathrow showed that concentrating flight paths in order to reduce population exposure was in general experienced less positive than the original situation where flight pats were distributed over a wider area. Surprising was that not only the more exposed part responded negative, but also negative ratings came from the area where exposure decreased. The general opinion in that area was that sharing the burden with a larger group of people is favoured over concentrating it to small group [6].

5.4 Ground management

Extra care is taken by several airports to control the noise production by the taxing, testing, handling and parking on and around the platform. For that, specific rules are issued that define the way the aircraft is operating once it is on the ground.

For instance, engine testing end engine run up is limited to certain areas, often on locations where there is some kind of shielding to the neighbouring houses. Also these activities have to take the meteo-condition into account. Several types cannot be tested with tail wind. Also the large structures needed for the shielding may not cause unwanted turbulences in their wake.

The usage of the APU can be reduced by installing power facilities on the platform. Rules for usage of the engines during taxiing and cueing control the noise production between platform and runway.

The noise emitted during these operations is often not taken into account in the noise exposure calculations around airports.

5.5 Discussion

There are several opportunities to control the noise situation around airports by optimizing approach and take off procedures, by routing aircraft away from build-up areas, and to give attention to the noise production of aircraft once they are on the ground.

Not all measures are effective, some lead to shifting the disturbance form one area to another. Effectiveness is also reduced by the safety constraints and capacity requirements imposed on the procedures and routing. Nevertheless, it is found worthwhile to introduce such measures. The positive attitude towards the control of the nuisance in the environment is appreciated by the environment and, although in terms of dB(A) level, only marginal improvement is gained, the experienced annoyance is found to be dropped considerably. Even a measure that presents scheduled on and off periods for runways (as is used in Heathrow) do have positive effects although the yearly averaged noise level is not affected.

6 Operation restrictions at national or local level

The freedom to introduce operation restriction at a national or local level are restricted. It is considered very undesirable that local or national administrations impose specific restrictions on the operation of aircraft. Mainly because it directly affects air transport in a negative sense. The activity of international operating companies will be severely tightened when they have to take too many and sometimes contradictory requirements into account. The situation with diverging noise categories in the noise charging systems of nations and airports is already not preferable.

It is therefore that the EU has introduced supra-national regulations for the restriction of aircraft (see chapt. 7). Operation restrictions at national and local level are possible in the form of exploitation restrictions. In several airports in Europe there exists some type of ceiling for the noise produced by their operations, either in the form of noise quota's, as not to exceed contours or levels in the vicinity of the airport or combinations of it.

6.1 Noise restrictions

Nearly all airports in Europe have restrictions for the aircraft operations on or around the airports that might lead to noise annoyance and sleep disturbance in the vicinity.

- In many airports APU usage is restricted and fixed power connections are available at the apron.
- Application of reverse thrust in the final phase of the landing is restricted or instructed to use it only when safety requires.
- Starts/landings during the night are forbidden or restricted to less noisy aircraft.
- Engine run-up is regulated and restricted in day period

A total overview for about 250 European airports is given in table XXIII.

Besides these general rules airports have boundaries on the total yearly (or part from it) number of operations and the resulting noise production in the form of noise quota. A few examples are described in part 6.2 and part 6.3.

6.2 Quota systems

In great Britain a quota system is in operation that puts a maximum to the total noise production of an airport based on the sum of the noise quotas of individual aircraft. These are calculated based on the certification levels as follows (see table XVIII).

table XVIII *Certification noise levels (EPNLs) are used for determining the British QC category. Take-off = (Take-off+Sideline)/2 for Chapter 3 or ((Takeoff+Sideline)/2)+1.75 for Chapter 2. Approach = Approach – 9.*

Certificated Noise Level (EPNdB)	Quota Count
> 101.9	16
99-101.9	8
96-98.9	4
93-95.9	2
90-92.9	1
87-89.9	0.5
84-86.9	0.25

Similar quota systems based on certification levels are in force in other airports such as Brussels.

A very basic quota system is one based on number of flights, irrespective of the noise category. Düsseldorf airport has a maximum of 131.000 flights for the six busiest months per year, Schiphol has a maximum of 510.000 flights per year and 32.000 night flights. In almost all cases such maxima on the number of flights are accompanied by specific boundaries for the noise production since limiting a number of operations without stating acoustic requirements will not be an effective control of noise exposure in the environment.

6.3 Noise production maxima and noise contours

In many cases these two enforcement systems are used in combination. The geographical noise boundaries in the form of not-to-exceed contours maximize the yearly averaged noise levels at a certain location in the vicinity of the airport. However, some freedom in the choice of routes and runways is needed to cope with varying weather situations. Safety issues impose restrictions on the amount of tail or cross wind and thus the usage of a specific runway.

Since the weather situation cannot be predicted, the maximum contours have to allow such variations in flight paths. This means contours larger then is strictly needed to allow for the actual traffic. The “filling up” of these extended contours is then prevented by also defining a maximum to the total amount of noise produced by the aircraft. In Copenhagen airport this maximum is formulated as the Total DENL, which is the Lden value times the log of the area (147 is 67 dB Lden over a 10 x 10 km area). In Schiphol airports this is defined similar as the average over a series of immission levels at positions close to the landing or starting aircraft.

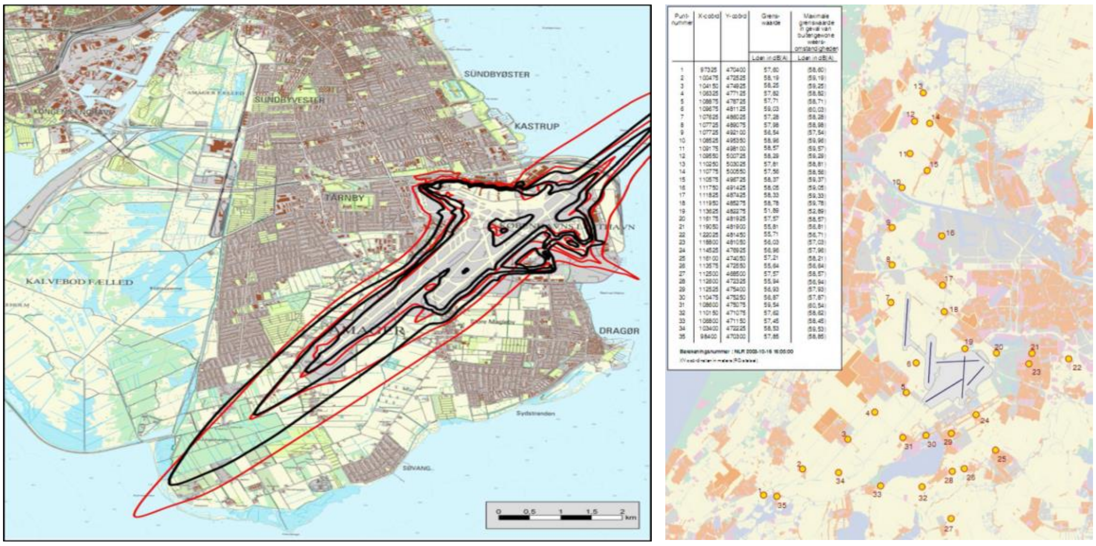


figure 17 *Examples of maximum noise contours. Left: Copenhagen airport. The red are the not-to-exceed contours, in black the recently realised ones (year unknown). Right: Amsterdam airport. The yellow circles indicate enforcement positions and the list defines the not-to-exceed Lden levels.*

7 Operating restrictions at EU level

7.1 Phase-out of Chapter 2 aircraft by directives 92/14 and 2006/93.

The directive 92/14/EEC limited the operation of the very noisy Chapter 2 aircraft in the community airports, culminating in a ban on Chapter 2 aircraft as of 1 April 2002. This is further effectuated in the EU directive 2006/93 (Regulation Of The Operation Of Chapter 3 Aircraft). Member states must ensure that all aircraft operating from airports in their territory comply with standards specified in chapter 3. Only very few exemptions may be granted. This directive applies to aircraft with a maximum take-off mass of 34.000 kg or more and a capacity for more than nineteen passengers, excluding the crew.

7.2 EU directive 2002/30 “rules and procedures with regard to the introduction of noise-related operating restrictions”

Phasing out marginally compliant aircraft

In order to be able to take a next step in phasing out noisy aircraft, rules were established in 2002 to restrict the use of aircraft that are marginally compliant with chapter 3 requirements. The directive introduction of noise-related operating restrictions at Community airports” regulates the way operational restrictions of noisy aircraft at airports in the European community shall be applied.
In this directive the term marginally refers to a cumulative margin over all three measurement positions of not more than 5 EPNdB.

Such restrictions may be implemented under the condition that the procedure specified in the “balanced Approach” (see chapter 13) is adopted. That means that Land use planning, economic incentives and noise abatement procedures shall also be taken into account when dealing with noise problems. The optimal choice of measures shall be based on a cost and benefit evaluation of the various measures.

When the procedure is followed, airports may decide on operation restriction of marginally compliant aircraft based on the 5 EPNdB margin. In case of city airports more stringent requirements may be applied, but the margin must be limited to the chapter 4 limit margin of 10 EPNdB.

Effect of restrictions by directive 2002/30 on airport noise management

Through airport interviews with 52 of the 70 airports an assessment was made on the impact of the 2002/30 directive on airport noise management. Two airports introduced bans on -5 EPNdB aircraft and three have introduced restrictions. 10 airports expected introduction of restrictions on -5 EPNdB aircraft or had already decided on it.

In many cases alternative restriction systems are in use. On German airports a restriction system, based on the Bonus lists was used that partially affected -5EPNdB aircraft. This list was not based on the certification levels, but on actual measurements. In the UK airports use the QC (Quota Count system) based on actual certification levels of approach and take-off measurement positions. Large UK airports have restrictions on night time landing or starts based on the QC category of the aircraft and the operation.

7.3 Review of 2002/30 in 2007

Effect of phasing out -5dB aircraft

Evaluation of the effect of 2002/30 was investigated in 2007 by *MPD Group Limited* in association with *ERM* and *CE Delft* [1]. The study contains an inventory of the mitigation measures for noise including the restrictions for marginally compliant (-5 EPNdB) aircraft, the effect of noise mitigation since the introduction of 2002/30 and to identify possible improvements in future legislation, including more stringent phase out options.

Results were reported in [1]. The study included the EU27 and Switzerland, in total covering 70 airports and 10 million aircraft movements in 2003 and about 11 million in 2006. When comparing the situation in 2002 before implementation of 2002/30 and the situation in 2006, when 2002/30 has become into force, they found the following shifts in vehicle fleet and usage.

Effect of phasing out more stringent aircraft

The effect of phasing out marginally compliant aircraft by 2002/30 was studied by comparing the usage of aircraft not meeting the -5 EPNdB margin, aircraft meeting the margin (5-10 dB) and aircraft meeting Chapter 4 margins (>10 dB) in 2002 and in 2006.

It was found that:
- Marginally compliant aircraft usage dropped between 2002 and 2006 by 80 %, but that usage was already very low (2,5% in 2002 was reduced to 0.5% in 2006).
- Movements with aircraft meeting the 5-10 dB Chapter 3 margin, but not meeting Chapter 4 limits dropped with 20% from 10% to 8% of the aircraft movements . It represented in 2006 18% of the total usage.
- The fraction of Chapter 4 compliant aircraft increased from 75% in 2003 (7.4 million movements) to 83% in 2006 (9.1 million movements).

One could conclude that the directive 2002/30 was very successful in phasing out -5 dB aircraft, but one notices that also a significant reduction in movements occurred in the -5 to -10 dB category. Chapter 4 thus has to be regarded as a type of minimum standard with only 17% of the movements still in the Chapter 3 category in 2006.

The effect of banning marginally compliant aircraft was assessed by studying four scenarios:
1. Ban only aircraft not compliant with chapter 3 (base scenario)
2. Ban of aircraft with a cumulative margin of <5 dB
3. Ban of aircraft with a cumulative margin <8 dB
4. Ban of aircraft not compliant with chapter 4 (cumulative margin <10 dB)

The effect of each of the scenarios were predicted for 2010 and 2015 for the EU population with an exposure of Lden >55 dB and Lnight >45 dB (see table II).

table XIX *Prediction of effect of scenarios of phasing out Chapter 2 aircraft (base) and phasing out all aircraft not complying with chapter 4 (scenario 3) [1].*

Scenario/year	**Population [in million]**		**Comment**
	> Lden 55	**> Lnight 45**	
2006 base	2,2	3,0	From 2002 to 2006 Lden 55dB population increases by less than 0.1million
2010 base	2,4	3,2	From 2006 to 2010 Lden 55dB population increases by 10%
2010 scenario 3	2,3	3,1	Lden 6% reduction over the base case Lnight 4 % reduction over base case
2015 base	2,7	3,2	From 2010 to 2015 Lden 55dB population increases by 9%
2015 scenario 3	2,5	3,1	Lden 5% reduction over the base case Lnight 3 % reduction over base case

The data show the marginal effect of restrictions of non-chapter 4 aircraft which of course can be explained by the already large fraction of 83% of movements of chapter 4 compliant aircraft in 2006. This corroborates again the finding that already in 2006, chapter 4 reflected the daily practice instead of a state-of-art requirement.

7.4 Revision of 2002/30

Between 2007 and 2010 the EU organized an extensive stakeholder consultation on the topic of noise issues around airports [16]. From this, it became clear that a revision of the 2002/30 directive was required on the following parts;

- The Balanced Approach was generally supported by all consulted parties
- A strong support to widen the definition of marginally compliant to have real impact, view supported by the local community groups, presented by the Aviation Environment Federation (AEF), the ACI and the French Independent noise Council ACNUSA . The AEF stressed the need to regulate a noise protection threshold and to acknowledge the key-role of operation restriction to improve noise nuisance situations.
- Fine tuning of the relation between 2002/30 and 2002/49 (see part 4.4)
- Proposals from specific parties were formulated on the following topics:
  - Operators advised the full application of ICAO’s balanced approach cost-effectiveness as guideline for the application of measures. Land use planning should be integrated in the decisions on operating restrictions.
  - For instance ACNUSA (French independent noise council) argued a widening of the marginally compliant aircraft definition (supported by ACI), use of parameters that reflect the experienced nuisance of the population, improved modelling and more systematic use of low-noise procedures such as CDA.
  - Local community groups, represented by the Aviation Environment Federation, stressed the need to regulate immission levels based on actual threshold’s and also advocated widening of marginally compliance.
  - Aircraft industry advices to consider the interdependence between possibly conflicting objectives, like noise and CO2.

7.5 New regulation 598/2014 (repealing Directive 2002/30/EC)

At 13 June 2016 the directive 2002/30 will be replaced by a new one: *Regulation (EU) no 598/2014 of the European Parliament and of the council, on the establishment of rules and procedures with regard to the introduction of noise-related operating restrictions at union airports within a balanced approach and repealing directive 2002/30/EC of April 16, 2014* [17].

It presents a development of the 2002/30 directive on the following topics:

1 A more consistent implementation of the principle of “balanced approach” as is adopted by the ICAO in 2001 (see more in chapter 8).
2 Extending the margin of “marginally compliant” from the present 5 EPNdB to 8 EPNdB and by 14 June 2020 to 10 EPNdB. (in a proposal from the EP in 2011 the 8 EPNdB transition period was not included)
3 More consistent link with Directive 2002/49.
4 Mandatory application of the ECAC report Doc 29 noise modelling procedure to establish cost/benefit ratio’s of the noise-related operation restrictions.

It is noted that this Regulation is applicable to airports with more than 50.000 civil aircraft movements per year (based on the average of the last 3 years)

The regulatory impact is increased since the former ruling was a directive (meaning there is some freedom in the implementation in national rules and legislation) whilst the present one is a regulation that supersedes national legislation (and thus has no possibility to be implemented in a slightly relaxed way in national schemes).

7.6 Evaluation of protecting performance of 598/2014 vs. 2002/30

The regulation 598/2014 can be regarded as a revision of the 2002/30 directive. The question evolves to what extent can this revision be regarded as an improvement for the environment. It is not considered feasible to present an overall rating, since its effect would depend a lot on the actual situation around a certain airport. However it is possible to make an assessment on the level of individual aspects (see table XX).

table XX *Comparison of directive 2002/30 and its replacing regulation 598/2014 in view of the protection of the environment. In the last column an assessment of possible improvement of 598/2014 in comparison with 2002/30 is given.*

Subject	Comment	Improvement
Sustainable development in 2002/30 used to be only noise nuisance but in 598/2014 it includes also compatibility between aviation activities and residential areas.	Interest of industry is increased.	no
In 2002/30 the balanced approach was acknowledged but not introduced as a basis of the regulation. In 598 it serves as the basis (in 2002/30 only #10, now #3 on the “whereas” listing).	Balanced approach emphasis the interest of the industry.	no
In 2002/30 it was acknowledged that the balanced approach is an important step forwards, but more stringent noise standards and actions to take noisy aircraft out of service will also be necessary.	The extra actions are softened or removed in 598/2014.	no
In 2002/30 more stringent rules for city airports were possible. In 598/2014 this is not mentioned any more.		no

Marginally compliant in 2002/30 was <5 EPNdB, in 598 <8 and in 2020 <10 EPNdB.	Restrictions applies to larger noisy fleet.	yes
Consultation process is less strict in 2002/30 compared to 598. In the latter, the parties to be consulted are more strictly described and only one of the six/seven parties defined are the local residents.	The industry has a larger say in the consultation. It is an improvement in cases where residents were not heard	Yes/no
Operating restrictions are more widely defined in 598/2014. It now includes night flying restrictions and runway usage.	Measures that could be implied freely by authorities are now subject to the regulation.	no
Heath effects are now taken into account.	“Annoyance” is replaced by the more specific theme of “health”.	yes

One notices a majority of aspects where the revised restriction regulation presents to the opinion of the IGNA working group members a worsening for the effectivity of authorities to control environmental noise. Only the extended margin represents a clear improvement. One may conclude that the repealing of directive 2002/30 and its replacement with the regulation 598/2014 presents a shift in focus from environment to industry.

7.7 EU directive 2002/49/EC (Environmental Noise directive or END)

The END [30] aims to “define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to the exposure to environmental noise”. Its objective is to reduce the exposure of the EU population to harmful the harmful effects of environmental noise. The relevance for the topic of aircraft noise lies in the availability of strategic noise maps and action plans that are to be made available to the public and the procedures to evaluate the environmental noise exposure in the vicinity of airports.

At the moment the development of the common approach is taken a step further with the definition of the harmonized method for determination of the immission levels. For aircraft noise, ECAC.CEAC Doc. 29 ‘Report on Standard Method of Computing Noise Contours around Civil Airports’, 1997 is to be used. Of the different approaches to the modelling of flight paths, the segmentation technique referred to in section 7.5 of ECAC.CEAC Doc. 29 will be used [31].

It is important to note, however, that the present Directive does not set binding limit values, nor does it prescribe the measures to be included in the action plans thus leaving those issues at the discretion of the competent authorities.

8 Cost benefit analysis

8.1 Introduction

It is generally acknowledged that measures whose benefits are small in relation to its costs shall be regarded critically. Therefore the balancing of the costs of a measure by its effects is an important part in the design and application of mitigation measures. It is observed that there exists no general accepted approach to the performing of C/B analysis, nor is it clear how costs and how benefits shall be defined. In this chapter we will list topics in the estimation of costs and benefits and present some examples of C/B studies.

8.2 Costs of noise measures

The cost of noise mitigation measures are related to the costs involved in technical and operational measures:

1 Hush kitting of existing aircraft or replacement by noise optimized types.
2 Extra flying distances caused by following noise optimized routes for landing and take–off paths.
3 Extra runways when runway capacity is reduced by noise abatement procedures.

Hush kitting and replacement

The costs of hush-kitting (adding silencing systems to the engine such as chevrons and liners) are estimated in a study given in [28] where for the OHARE airport near Chicago costs are estimated to reduce the emission of chapter 2 aircraft to marginally compliant chapter 3. It was found that over a 10 yr. period the costs of the installation and the extra costs due to lower fuel efficiency was estimated on an average 2,7 M$ per plane. Taking into account the number of operations on the airport of each plane, a cost of $ 700,- per operation was concluded.

Partial or full replacement of the aircraft presents a cost factor due to the faster depreciation of the older aircraft, but also it presents a profit since newer aircraft save fuel and therefore costs. Taking into account the slope in aircraft noise levels versus manufacturing year presented in figure 10 of about 0,2 dB/yr per type of operation (0,6 dB/yr cumulative over three operations) and assuming a service life of 25 years before its asset value is zero, it can be concluded that each 1 dB reduction (3 dB cumulative)presents retiring the old plane 5 years earlier related to a depreciation of 20% of the costs of the plane.

The fuel efficiency associated with newer engines at the other hand will present a saving. Retiring a plane of 20 years of age (instead of 25 years) and replacing it with a new one presents an improvement in fuel efficiency of about 20%. The effect of this can be estimated as follows.

1 The average fuel consumption of a modern 200 seat plane is about 50 g/pax/km
2 The average distance travelled by an aircraft per year is about 1,5 M km.
3 The 2014 fuel price is 3$/gallon which is about € 0,80/kg.
4 A 200 seater thus uses 15 M kg jet fuel per year equals about 12 M€/ year as fuel costs.

A saving of 20% represents a saving of 2,4 M € per year which over the 5 year earlier retirement period presents a sum of 12,5 M €. This figure almost covers the costs of a 5 year earlier retirement of a 65 M € aircraft.
In basic economic terms early retirement carries no costs but represents an improvement for society because of the 1 dB lower noise level per operation. Also will the improved NOX emission (CAEP stringency reduction of -50% over the last 20 years) presents a profit for society. It is the estimation of CAEP study group [13] on the C/B ratio of NOX stringency that the benefit of this

effect supersedes the effect of noise considerably. However, in modern engines there exists a trade-off between CO2 and NOX emission. Further modernization of an already modern fleet might lead to further fuel saving and less noise but the NOX emission might get worse.

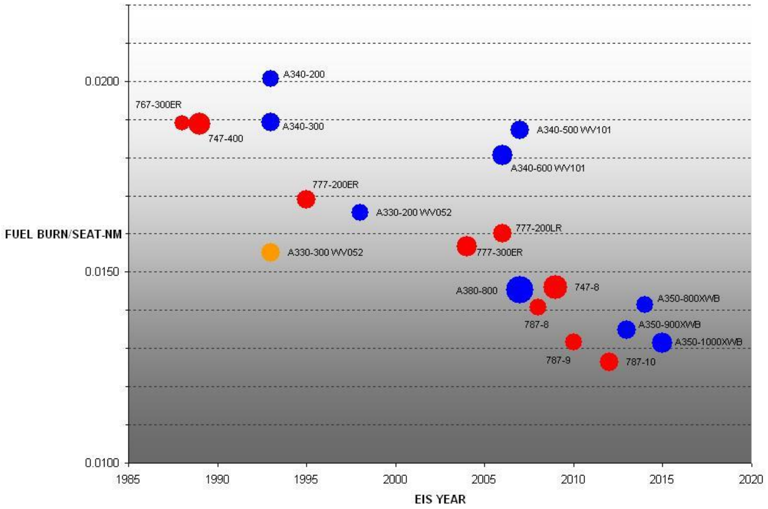


figure 18 *Development of fuel efficiency over the period 1985 -2015. Source: www.airliners.net*

Costs of extra distance and time loss

It is our estimation that this is a minor effect since it affects only the local routing and not the paths between the exit and entrance points at origin and destination airport. The latter represents the largest fraction of the travelled route.

Costs of extra infrastructure

This might be a significant effect when NAP’s are enforced in busy periods of the airport. At the moment, safety considerations prevent such NAP’s in the busy periods. There are costs involved in building extra infrastructure to enable noise optimized routes. For instance, in Amsterdam Schiphol an extra runway was built to enable take-off and landing over a less populated area. The magnitude of such costs however is very hard to determine.

8.3 Benefits of noise measures

Benefits of mitigation measures lies in the improvement of health and the value that people attribute to a less noisy environment. The latter is referred to as the “willingness-to-pay” (WTP).

Willingness-to-pay for reduction of aircraft noise

The WTP for lower aircraft noise is generally based on two types of sources:
1 The relation between house prices and environmental noise levels.
2 Inventory of the statements of inhabitants about their valuation of a less noisy environment.

CAEP , 8th meeting, has issued a report on the cost-benefit analysis NOx stringency of air traffic. Since some strategies for NOx reduction in engines compromises the noise emission, also the costs of noise are taken into account. In this report an income related value for WTP is used, based on the work in [13].

The data presented in figure 19 distinguishes between USA and non-USA situations. The WTP refers to an improvement that brings the value from above the significance level of 65 dB(A) Lden (or DNL) to a background level of about 55 dB(A).

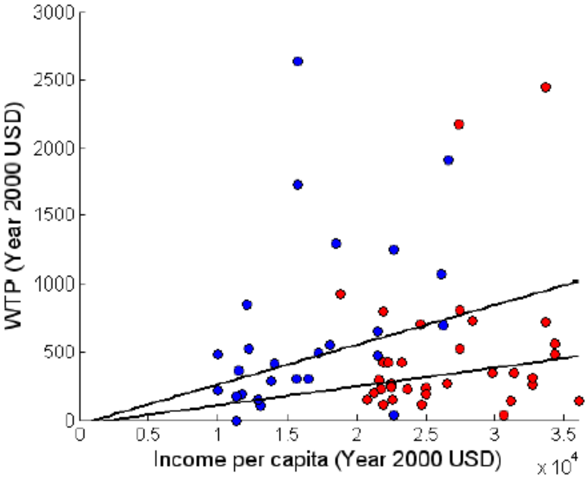


figure 19 *Yearly willingness to pay for aircraft noise reduction as a function of income per capita based on 60 hedonic studies of housing price depreciation. The blue symbols are studies of non-US airports; the red symbols are studies of US-airports [25].*

Through the (widely) scattering data a regression line is drawn for USA and non-USA data. The result for USA are:

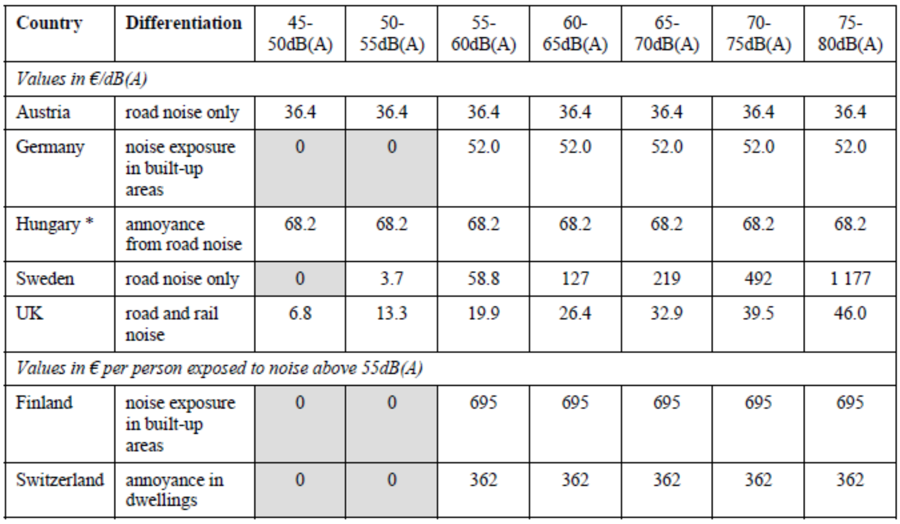
*Yearly WTP = 0.014*Income – 30 [$]*

The result for non-USA are:

*Yearly WTP = 0.029*Income – 30 [$]*

There are several studies done in European countries but they nearly all refer to road or road/rail traffic noise (see table XXI). One may expect that since the annoyance of air traffic noise at the same dB(A) level is higher and the slope of annoyance versus noise level is steeper, also the WTP for reduced aircraft noise will be higher.

table XXI *Yearly willingness-to-pay inventory for European countries (source road traffic noise). Values in €/dB(A) –upper part- and values in € -lower part- [23].*



Country	**Differentiation**	45-50dB(A)	50-55dB(A)	55-60dB(A)	60-65dB(A)	65-70dB(A)	70-75dB(A)	75-80dB(A)
Values in €/dB(A)								
Austria	road noise only	36.4	36.4	36.4	36.4	36.4	36.4	36.4
Germany	noise exposure in built-up areas	0	0	52.0	52.0	52.0	52.0	52.0
Hungary *	annoyance from road noise	68.2	68.2	68.2	68.2	68.2	68.2	68.2
Sweden	road noise only	0	3.7	58.8	127	219	492	1 177
UK	road and rail noise	6.8	13.3	19.9	26.4	32.9	39.5	46.0
Values in € per person exposed to noise above 55dB(A)								
Finland	noise exposure in built-up areas	0	0	695	695	695	695	695
Switzerland	annoyance in dwellings	0	0	362	362	362	362	362

A general WTP value for noise, used in the EU27 studies per household is € 26 dB(A)/year. No distinction is made between sources of noise.

A Dutch study [27] specific for aircraft noise in the agglomeration around Amsterdam Airport resulted in a total benefit per household (based on depreciation of house prices) of a 1 dB reduction of € 1500,- which is reported to be equivalent to a marginal benefit of € 75,- /dB/Yr. These values are, as expected, higher than the data found for road and rail presented in table XXI.

The graphs below distinguish between the Noise Depreciation Index (based on the loss in property value per dB) and the Willingness To Pay. Presented are results of an inventory over European, North American, Japanese and Australian studies of aircraft noise. APMT indicates the value used in the Aviation Environmental Portfolio management Tool (source Kish 2008). A wide range of values is found. But their average is around what is presented before.

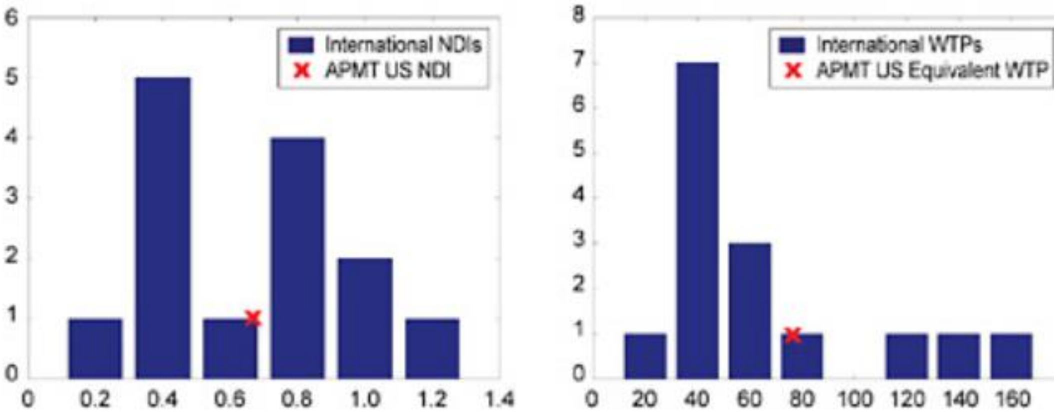
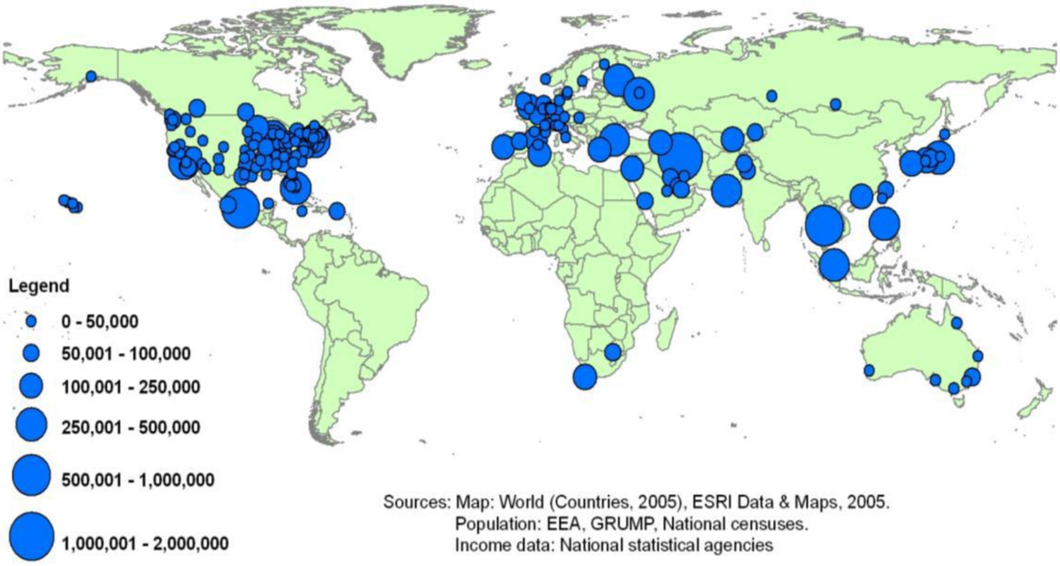


figure 20 *Left: house price depreciation and right: yearly willingness-to-pay data from a study of a number of North American, European, Japanese and Australian investigations. Source Kish 2008.*

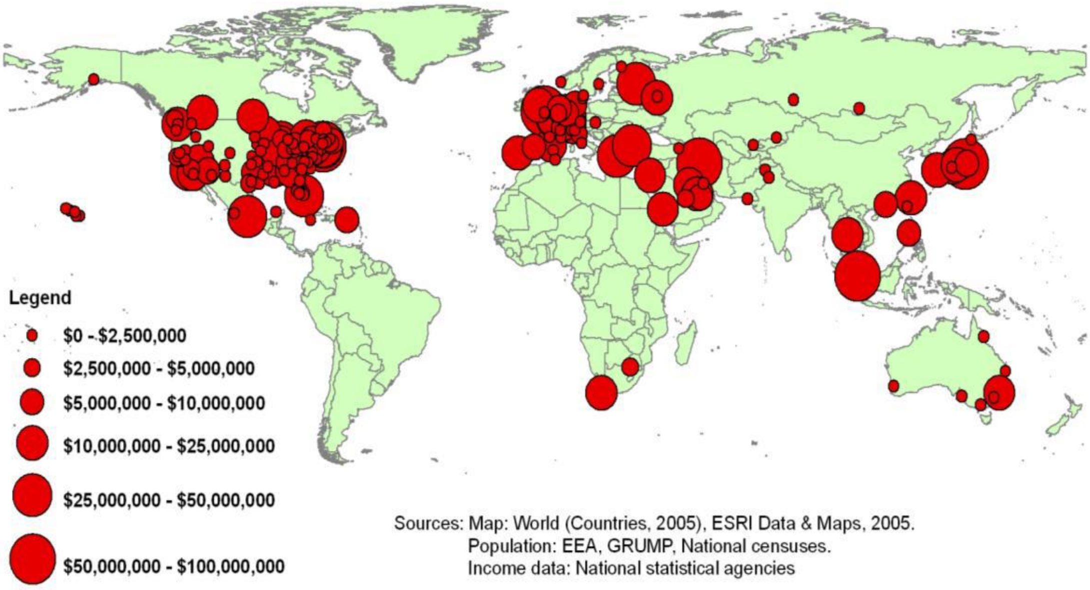
Applying the WTP figures on the noise exposure data around airports worldwide is done in [13].

In 2005 it is estimated that approximately 14 million people were exposed to noise levels greater than 55 dB day-night noise level for 178 commercial service airports worldwide (see figure 21).



Sources: Map: World (Countries, 2005), ESRI Data & Maps, 2005.
Population: EEA, GRUMP, National censuses.
Income data: National statistical agencies

figure 21 *Population impacted by aircraft noise greater than 55dB day-night noise level in 2005 [13].*



Sources: Map: World (Countries, 2005), ESRI Data & Maps, 2005.
Population: EEA, GRUMP, National censuses.
Income data: National statistical agencies

figure 22 *Mean annual noise damages in 2005 calculated with the exposure given in figure 21 and the income and continent related WTP date shown in figure 19 [13].*

The mean annual noise damages are shown in figure 22 . These are computed to be: $1.4 B globally (178 airports), and $0.56 B for the U.S. (95 airports). The results take account of both the population exposure and also the income levels. Thus, relative to the population exposure results in figure 21, the regions with higher income are accentuated compared to those with lower income.

8.4 Case for O’Hare airport

In 2004 an extensive study was performed to the costs and benefits of reducing the noise level in the urban areas around the airport of O’Hare in Chicago to below 65 dB Ldn (ref. [28]). It this study the benefits were calculated on base of hedonic pricing and in base of the improvements in health and learning abilities. The costs were calculated on base of the retrofit of hush kits on rather old fashioned aircraft such as DC 8, B727 and so on. This already illustrate the non-representativity of this example for the present situation in Europe were such planes cannot fly anymore and even the hush kitted versions are phased out by the 2002/30 directive. At the other hand it is an example of a study taking into account several aspects.

Benefits from reduced noise level

Benefits from reduced annoyance

A survey in the urban areas in the vicinity of The population within the 65 dB Ldn contour is 169.000 equal to about 50.000 households. The found required compensation for annoyance per household is $12.000/yr based on statements of the inhabitants. The yearly compensation is

50.000 x $ 12.000 = **$ 600.000.000**

Applying a yearly discount of 3% over a period of 10 yrs. results in:

5.3 Billion $

Benefits from improved health

Reducing the noise exposure of the population will lead to lower impacts and consequently a better situation for the population on the topics mentioned in table V. The evaluation of the beneficial effects from each of the impact components extends the scope of this report. However an example of such a calculation is found in literature fir the Chicago airport O’Hare [28]. In this example the positive effects of reduced noise exposure are estimated over a period of 10 years , for two impact types:

- Hypertension and the resulting cardiac diseases
- Affected learning abilities.

table XXII *The data in the boxes represent a total 10 year benefit in health for reducing the noise pollution around O’Hare of close to 400 million dollar and an effect on learning abilities of children around 750 million dollar.*

Health Effects (Benefits)		
O'Hare Community Population	*200,000*	
Normal Population with Hypertension	*0.10*	
Effects of Noise Creating Hypertension	*0.06*	
O'Hare Pop. Hypertension Due to Noise		*12,000.00*
Costs of Screening (assume all screened)		*24,200,000.00*
Treatment of Hypertension - O'Hare due to Noise		*7,200,000.00*
Heart Disease Caused by Noise		*0.02*
Cost of Heart Disease Treatment Due to Noise (O'Hare)		*12,240,000.00*
Total Annual Benefits	***43,640,000.00***	
Ten Year Benefits Discounted at 3%	***383,425,793.35***	

Learning Effects (Benefits)	
Number of Affected Children in Area	*50,000.00*
Percentage of Affected Children Severely Damaged Unknown,	*say 25%*
Value of Damages to Learning Abilities (Annual)	***87,500,000.00***
Ten Year Benefits Discounted at 3%	***768,784,530.66***

Costs of measures

Hush kitting of noisy aircraft

Costs of hush kitting are estimated as follows. The average cost of hush kits per plane over the ten years spanning the Stage 3 compliance is assumed to be around $1.000.000. The costs per year (using the 3% discount rate) is $115.000. The average number of operations for each aircraft per day at O'Hare is 0,5 (that is, on average, the same aircraft flies in or out of O'Hare once every two days). Dividing $115.000 by (365 x 0,5) therefore gives us the cost of the hush kit per airplane operation of $6.300.
With yearly around 900,000 operations (1999), the total yearly costs is found to be 0,5 Billion $. Over a 10 year period this is 4,35 Billion $.

Sound insulation for nearby houses.

The costs of insulating windows and doors is estimated to be 25.000 $/household over a 10 yr. period. With 50.000 households , the total costs for insulation is found to be 1,250 Billion $

Cost/benefit ratio

The total costs of the measures for the aircraft and the households: TC is:

TC = 1,25 + 4,35 Billion $ = 5,60 Billion $

The total benefits based on the hedonic pricing, the saving on health costs and the improved learning abilities TB is:

TB = 5,3 + 0,38 + 0,77 = 6,45 Billion $

For this case it is calculated that TB > TC. One must notice however that the presented situation is not representative for the European case and that the outcome is heavily based on assumed and estimated figures.

The B/C ratio will increase of course when the effect of the hush kitted aircraft at other locations is taken into account. With an average number of operations per day of 4, the costs per operation will be one eighths and the B/C ratio for O'Hare will be 3,0 instead of 1,1.

8.5 Example of GB practice

In Great Britain the cost/benefit analysis has a firm position in the assessment of the environmental impact of large projects. The DEFRA has developed a series of evaluation tools that can be used to integrate the costs and benefits of decisions that have consequences for the environmental noise quality around road and railways and airports (see https://www.gov.uk/noise-pollution-economic-analysis). These tools incorporate a standard valuation of the effect of changes of noise levels per household. Such valuations are made for road, rail and aircraft noise separately andalso distinguish between Lden and Lnight (the latter more related to sleep disturbance). The graphs below (see figure 23) present the marginal costs in £/household/dB as a function of the exposure level. An improvement in Lden from 72 to 71 dB is valued at £ 100 while a shift from 50 to 49 is valued at £ 24.

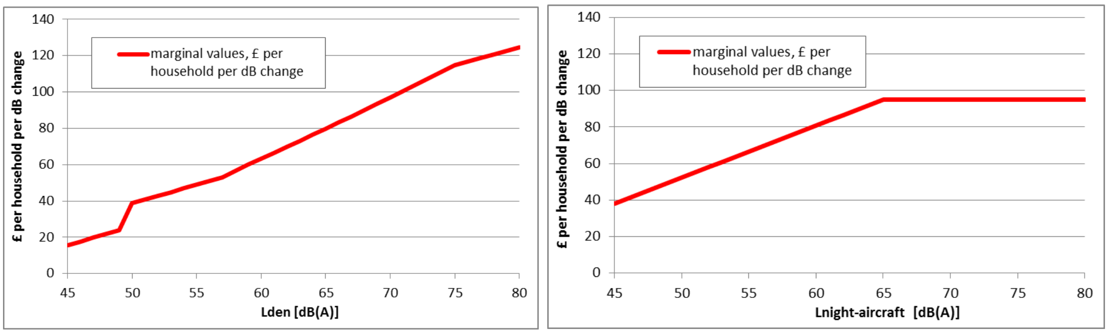


figure 23 *Marginal values in £ /household/dB change for aircraft noise, left: Lden, right: Lnight. 2014 prices.*

8.6 Conclusions

The EC regulation 598/2014 defines cost/benefit as a mandatory procedure in the evaluation of restrictive measures. The performing of C/B analysis on a regular scale however is inhibited because generally accepted procedures are not available and reliable ways to value effects are lacking. The input data needed to actually do the calculation of the costs of the measures and the determination of the profits of noise reduction for society are not clear and often exhibit a big spread in values over different countries.

The implementation of the 598/2014 and the bringing into practice of the “balanced approach” would certainly benefit from a the availability of a clear procedure and unambiguous input data for the performance of a cost-benefit analysis.

9 Discussion, conclusions and recommendations

This progress report has illustrated the present status of technical noise reduction and regulations for the control of environmental noise in the vicinity of airports.

The overflight condition at cruising altitude is not taken into account since its levels are extremely low compared to other sources such as road and railway. Also not taken into account is the effect of military aircraft and the effect of general aviation. Although these operations do generate annoyance, their control can be organized on a local or national level. A third source of environmental annoyance are the operations on the airport itself. The taxiing from the landing position and to the starting position is neglected. The stationary noise emission coming from APU's and from engine testing or engine run-up is also not taken into consideration. Again, because the effect is very local and can be addressed by local regulations, guidelines and in case of APU's by local electric energy facilities. The links to airport rules given in the overview in chapter 15 presents the various ways local authorities address these issues.

The report has focussed on issues that have a global impact or that, through the working of international regulations and guidelines, have to be addressed in a certain way and a certain order of importance.

The most relevant development is the continuous improvement of the noise control of aircraft over the last 40 years. Over the 3 measurement positions a cumulative effect of 25 dB is achieved, which is about 10 dB per position. The relative easy measures are taken now and further increase of bypass ratio will probably not result in lower noise, since the larger fan becomes the major noise source. In addition the number of contributing sources increase like airframe noise with its several small sources like gears, flaps, etc. Also for a long time the low noise development was stimulated by the fuel saving, but at the moment that is not so much the case anymore and issues like NOX emission become relevant.

The usage of low noise aircraft is made attractive by diversifying landing charges based on noise class and the implementation of quota systems for airports that cap the total amount of noise. One observes however a very diversified field where each airport or nation uses its own classification, that may even be contradictory since based on different data sources. Stricter restrictions in the usage of noisy aircraft are limited because of the regulation 598/2014 that formulates specific constraints in the implementation of such rules.

The airport is more and more becoming a centre of economic activity and consequently attracts people to live close by. Although new airports are planned in rural areas, after a decade, one observes a high degree of urbanisation. Land management is essential to prevent new cases of annoyance and health issues by aircraft noise, though economic forces will work in the opposite direction.

The possibilities to improve the exposure of the population by optimizing routes and flight procedures are limited. The region around airports do in general not exhibit deserted areas over which flights can be planned. Furthermore meteorological conditions and elevated areas do not allow free choice of routing. Noise Abatement Procedures (NAP's) do shift noisiness from close by to farther away, or can only be applied in the less busy night period such as is the case with CDA's.

More and more cost of measures have to be balanced with the benefits to society. It is a mandatory part in the procedures described in 598/2014. It was found quite hard to define a method of how to do this. The values attributed to the benefits of lower noise levels vary considerably over studies. Some measures on the aircraft have positive effects on more airports and neglecting them in the C/B analysis of a single airport would underrate the benefit part in the C/B ratio. The assessment of costs of measures exhibits similar unclearness. In a global perspective the issue of noise has to be related with CO2 emission and NOX emission.

We see the following topics that can be of interest to be put forward by the IGNA group:

1 The development of a harmonized noise classification system that can be used in the noise based landing/take-off charges by airports.
2 The definition of technology forcing limit values for the next phase of tightening of certification levels.
3 The development of a harmonized method for the determination of the costs and the benefits of noise mitigation measures.
4 The amending of the 598/2014 regulation to strengthen the position of the environment relative to the position of the industry
5 The extension of the lower limit for noise mapping within the framework of the European noise directive (EU 2002/49) to come to a representative coverage of the severe annoyed and the severe sleep disturbed population.

10 Acknowledgements

The author gratefully acknowledge the valuable information and critical support supplied by Mr. Jos Dolderman and Mr. Dick Bergmans of the Dutch National Aerospace Laboratory (NLR), Mr.Kornel Köstli from the Swiss BAFU and Mr. Nico van Oosten of Anotec Engineering (Spain).

11 References

[1] MPD group ltd, ERM and CE Delft, “Study of aircraft noise exposure at and around community airports: evaluation of the effects of measures to reduce noise”, TenderNo TREN/F3/15-2006, October 2007

[2] ANOTEC consulting S.L. Study on current and future aircraft noise exposure at and around Community airports, 2003/4

[3] European Environment Agency, “Noise in Europe 2014”, EEA report nr. 10 /2014, December 2014

[4] European Environment Agency, “Good practice guide on noise exposure and potential health effects”, EEA Technical report nr. 11/2010 , October 2010.

[5] REPORT ON THE LEGAL REQUIREMENTS FOR THE PROTECTION OF THE POPULATION AGAINST NOISE AT SELECTED AIRPORTS, Reference 11-129, Lausanne, 16 October 2012.

[6] I.Flindell, presentation at Euronoise2015, Maastricht June 1-3, 2015.

[7] ICAO, “Review of noise abatement procedures research and developments and implementation of results, discussion of survey results”, 2007

[8] ICAO-Doc 9184, “Airport planning manual, part 2: Land use and Environmental control”, 3rd edition 2002.

[9] European commission working group on health and socio-economic aspects, “Position paper on dose response relationships between transportation noise and annoyance”, ISBN 92-894-3894-0 2002 ,

[10] European commission working group on health and socio-economic aspects, “Position paper on dose-effect relationships for night time noise”, November 11th, 2004.

[11] National Institute for Public Health and the environment, D. Houthuijs et al, “Towards a complete health impact assessment for noise in Europe, Expected consequences of the limitations of the available noise exposure data”, Euronoise2015 proceedings.

[12] “Assessing Current Scientific Knowledge, Uncertainties and Gaps in Quantifying Climate Change, Noise and Air Quality Aviation Impacts”, Final Report of the International Civil Aviation Organization (ICAO) Committee on Aviation and Environmental Protection (CAEP) Workshop, 29 October – 2 November 2007, Montreal, Canada, Edited by L. Q. Maurice and D. S. Lee

[13] “CAEP/8 NOX stringency cost-benefit analysis demonstration using APMT-impacts”, Review of technical proposals relating to aircraft engine emissions, Montreal, 1-12 February, 2010.

[14] EASA, “STAPES , System for AirPort noise Exposure Studies, Final Report”, 28/12/2007, TREN/05/ST/F2/36-2/2007-3/S07.77778. [Brussels, 1.12.2011

[15] ICAO site: http://www.icao.int/environmental-protection/Pages/technology-standards.aspx

[16] COM(2011) 828 final, “Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on the establishment of rules and procedures with regard to the introduction of

noise related operating restrictions at Union airports within a Balanced Approach and repealing Directive 2002/30/EC of the European Parliament and of the Council, 2011/0398 (COD).

[17] REGULATION (EU) No 598/2014, OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 16 April 2014.. on the establishment of rules and procedures with regard to the introduction of noise - related operating restrictions at Union airports within a Balanced Approach and repealing Directive 2002/30/EC.

[18] Brussels, 15.2.2008, COM(2008) 66 final, REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT Noise Operation Restrictions at EU Airports (Report on the application of Directive 2002/30/EC)

[19] Airport Council International, ACI Environment Standing Committee, “Aircraft Noise Rating Index”, March, 9 2005.

[20] Paul Traub, “Noise Aspects of Future Jet Engines”, MTU Aero Engines AT 35 000-03, d.d. 19.03.2012

[21] Federal Aviation Regulations, “Calculation Of The Effective Perceived Noise Level From Measured Data”, FARS-Part 36, Appendix 2A- Section 36.4

[22] Japan Institute of Aeronautical Technology (JAXA), FQUROH: Flight Demonstration of Quiet Technology to Reduce Noise from High-lift Configurations) project: http://www.aero.jaxa.jp/eng/research/ecat/fquroh/

[23] P.Bickel et al., HEATCO Deliverable 2 ‘State-of-the-art in project assessment’. IER, University of Stuttgart. 2006.

[24] “Ruimtelijke ordening en geluidbeheer rond Europese luchthavens”, Departement van leefmilieu, natuur en energie van Vlaamse Administratie (in Dutch), December 2007

[25] He, Q., C. Wollersheim, M. Locke, and I. Waitz, "Estimation of the Global Impact of Aviation-Related Noise Using an Income-Based Approach," Transport Policy (in review)

[26] C.Kish, “An Estimate of the Global Impact of Commercial Aviation Noise," S.M. Thesis, Department of Aeronautics and Astronautics, Massachusetts Institute of Technology, Cambridge, MA, June, 2008.

[27] J.Dekkers and W v.d.Straaten, “Monetary valuation of aircraft noise”, Tinbergen institute, report nr. TI2008-064/3 d.d. May 2008.

[28] Justin Brown, Jesse Seidman, Neil Solanki, David Neinstein, Steven Factor, „O’Hare International Airport Noise Pollution: A Cost-Benefit Analysis”, Economics 370, Winter Quarter 2004

[29] UK Department for Environment, Food & Rural Affairs, “Guidance, Noise pollution: economic analysis”, 19 December 2014 , https://www.gov.uk/noise-pollution-economic-analysis.

[30] DIRECTIVE 2002/49/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 25 June 2002 relating to the assessment and management of environmental noise.

[31] ECAC.CEAC Doc 29, 3rd Edition, “Report on Standard Method of Computing Noise Contours around Civil Airports”, December 2005.

12 ACI Noise ratings of a sample of aircraft

A-300	B4	R2	165.0	CF6-50-C2	2.1	2.8	0.8	5.7
A-300	600R	R3	174.8	CF6-80C2A5F	5.0	1.5	3.4	9.9
A-300	600R	R3	174.6	PW-4158	3.4	2.1	1.5	7.0
A-310	200	R4	138.6	JT9D-7R4D1	4.6	4.3	2.0	10.9
A-310	300	R4	160.0	CF6-80C2A2	3.1	3.6	4.3	11.0
A-310	300	R3	150.0	PW-4152	5.0	2.2	2.7	9.9
A-319	100	R4	74.0	CFM56-5A5	4.7	2.6	5.7	13.0
A-320	200	R4	68.0	CFM56-5A1	5.7	2.1	3.8	11.6
A-320	200	R2	60.0	CFM56-5B4/P	11.5	0.8	4.3	16.6
A-321	200	R4	93.0	V2533A5	4.6	2.4	5.5	12.5
A-330	200	R5	230.0	TRENT772	7.7	3.6	7.6	18.9
A-330	200	R4	230.0	PW4168A	5.6	2.0	6.3	13.9
A-330	300	R4	230.0	CF6-80E1A2	3.8	3.8	5.6	13.2
A-330	300	R4	230.0	PW4168	3.7	2.7	6.3	12.7
A-330	300	R5	217.0	TRENT768	8.0	4.3	7.3	19.6
A-330	300	R5	217.0	TRENT772	8.6	3.2	7.3	19.1
A-330	300	R5	233.0	TRENT772B	7.4	3.6	7.6	18.6
A-340	200	R6	270.0	CFM56-5C3	7.9	6.2	7.7	21.8
A-340	300	R6	270.0	CFM56-5C3	7.8	6.3	7.7	21.8
A-340	600	R6	368.0	TRENT556	12.0	7.2	5.1	24.3
AN-124	100	R2	392.0	D-18T	0.0	0.2	0.4	0.6
B-737	300	R1	63.3	CFM56-3B-2	5.0	4.3	-0.1	9.2
B-737	300	R3	63.3	CFM56-3-w/HWFAP	6.8	5.3	1.4	13.5
B-737	500	R2	52.4	CFM56-3-B1	6.9	4.7	0.0	11.6
B-737	600	R5	65.1	CFM56-7B22	6.4	4.1	4.6	15.1
B-737	700	R4	70.1	CFM56-7B24	5.4	3.6	4.5	13.5
B-737	800	R4	79.0	CFM56-7B24	3.3	5.0	4.3	12.6
B-747	100	R1	332.9	JT9D-7A	0.9	-0.3	-0.5	0.1
B-747	200	R1	377.8	CF6-50E2	3.3	1.1	-1.5	2.9
B-747	200	R1	332.9	JT9D-7A	1.7	1.1	-1.9	0.9
B-747	200	R1	340.2	JT9D-7F	1.8	0.4	-1.9	0.3
B-747	200	R1	349.3	JT9D-7J	1.9	-0.5	-1.0	0.4
B-747	200	R1	377.8	JT9D-7Q	2.7	-0.7	-1.6	0.4
B-747	200	R2	377.8	RB211-524D4	2.0	3.1	0.1	5.2
B-747	300	R1	377.8	CF6-80C2B1	6.9	4.6	-0.2	11.3
B-747	300	R1	377.8	JT9D-7R4G2	3.5	1.5	-1.6	3.4
B-747	SP	R1	299.4	JT9D-7F	5.9	-0.3	1.2	6.8
B-747	SP	R3	315.7	RB211-524B2	5.4	2.3	1.8	9.5
B-747	400	R3	396.9	CF6-80C2B1F	6.2	4.8	1.2	12.2
B-747	400	R2	396.9	PW4056	4.4	3.3	0.3	8.0
B-747	400	R3	396.9	PW4056 PH3(FB2B)	6.3	4.4	1.4	12.1

B-747	400	R4	396.9	PW4056 H3(FB2C)NR	8.6	4.9	2.9	16.4
B-747	400	R3	396.9	RB211-524G	6.8	5.0	1.2	13.0
B-747	400	R3	394.6	RB211-524H	8.2	4.2	1.2	13.6
B-757	200	R5	115.9	RB211-535-E4	8.4	4.3	6.8	19.5
B-767	200	R2	127.9	JT9D-7R4E	7.2	2.0	0.5	9.7
B-767	200ER	R2	163.3	JT9D-7R4E	0.7	3.5	0.6	4.8
B-767	200ER	R3	159.2	PW4052	5.0	4.7	4.9	14.6
B-767	300	R6	131.0	CF6-80C2B2	11.7	4.6	5.9	22.2
B-767	300	R2	136.1	JT9D-7R4D(B)	4.0	3.4	0.3	7.7
B-767	300	R4	172.4	PW4056	4.4	3.9	4.6	12.9
B-767	300ER	R4	133.8	PW4060PH3(FB2C)NR	13.4	2.4	5.9	21.7
B-767	300ER	R3	156.5	PW4062PH3(FB2C)NR	11.2	1.6	6.4	19.2
B-767	300ER	R5	184.6	CF6-80C2B6F	5.9	4.2	5.1	15.2
B-767	400ER	R5	204.1	CF6-80C2B8F	6.2	3.7	5.2	15.1
B-777	200	R6	229.5	GE90-76B	11.3	7.7	6.7	25.7
B-777	200	R6	201.9	PW4077	12.4	4.3	5.0	21.7
B-777	200	R5	207.8	RR TRENT875	10.4	4.5	4.8	19.7
B-777	200	R5	207.8	RR TRENT877	10.8	4.1	4.8	19.7
B-777	200ER	R6	297.6	GE90-90B	8.2	6.9	7.2	22.3
B-777	200ER	R6	297.6	GE90-94B (BLK IV)	8.4	5.5	6.7	20.6
B-777	200ER	R5	297.6	PW4090	5.6	3.7	5.8	15.1
B-777	200ER	R5	286.9	RR TRENT884	5.0	4.9	5.5	15.4
B-777	200ER	R5	297.6	RR TRENT892	5.5	4.2	5.5	15.2
B-777	200ER	R5	297.6	RR TRENT895	6.1	3.6	5.5	15.2
B-777	300	R4	299.4	PW4090	5.2	4.7	5.1	15.0
B-777	300	R4	299.4	PW4098	6.5	3.5	3.9	13.9
B-777	300	R4	299.4	RR TRENT884	3.4	6.1	4.6	14.1
B-777	300	R5	299.4	RR TRENT892	5.4	5.1	4.6	15.1
DC-10	30	R1	267.6	CF6-50C2	2.9	3.8	-1.6	5.1
DC-10	40	R1	251.7	JT9D-59A	0.2	3.3	-1.8	1.7
MD-11		R3	273.3	CF6-80C2D1F	9.2	5.3	1.3	15.8
MD-11		R2	286.0	PW4460	6.5	5.7	0.6	12.8
CRJ	100	R6	24.0	CF-34-3A1	9.2	11.8	5.9	26.9
CRJ	200	R6	24.0	CF-34-3B1	10.3	11.6	5.9	27.8

13 Balanced approach

ICAO advocates the “balanced approach” to control the noise issues from air transport. The text below explains the concept of “balanced approach” around airports. This text is cited from the ICAO website. The understanding of the concept is relevant since the EC Regulation 598/2014 is based on the principles of this balanced approach.

13.1 Introduction

In 2001, the ICAO Assembly endorsed the concept of a "balanced approach" to aircraft noise management (Appendix C of Assembly Resolution A35-5 (pdf)). The Assembly in 2007, reaffirmed the "balanced approach" principle and called upon States to recognize ICAO’s role in dealing with the problems of aircraft noise (Appendix C of Assembly Resolution A36-22 (pdf)). This consists of identifying the noise problem at an airport and then analysing the various measures available to reduce noise through the exploration of four principal elements, namely reduction at source (quieter aircraft), land-use planning and management, noise abatement operational procedures and operating restrictions, with the goal of addressing the noise problem in the most cost-effective manner. ICAO has developed policies on each of these elements, as well as on noise charges. The recommended practices for balanced approach are contained in Doc 9829 – Guidance on the balanced approach to aircraft noise management.

13.2 Reduction of Noise at Source

Much of ICAO's effort to address aircraft noise over the past 40 years has been aimed at reducing noise at source. Aeroplanes and helicopters built today are required to meet the noise certification standards adopted by the Council of ICAO. These are contained in Annex 16 — Environmental Protection, Volume I — Aircraft Noise to the Convention on International Civil Aviation, while practical guidance to certificating authorities on implementation of the technical procedures of Annex 16 is contained in the Environmental Technical Manual on the use of Procedures in the Noise Certification of Aircraft (Doc 9501).

The first generation of jet-powered aeroplanes was not covered by Annex 16 and these are consequently referred to as non-noise certificated (NNC) aeroplanes (e.g. Boeing 707 and Douglas DC-8). The initial standards for jet-powered aircraft designed before 1977 were included in Chapter 2 of Annex 16. The Boeing 727 and the Douglas DC-9 are examples of aircraft covered by Chapter 2. Subsequently, newer aircraft were required to meet the stricter standards contained in Chapter 3 of the Annex. The Boeing 737-300/400, Boeing 767 and Airbus A319 are examples of "Chapter 3" aircraft types. In June 2001, on the basis of recommendations made by the fifth meeting of the Committee on Aviation Environmental Protection (CAEP/5), the Council adopted a new Chapter 4 noise standard, more stringent than that contained in Chapter 3. Starting 1 January 2006, the new standard became applicable to newly certificated aeroplanes and to Chapter 3 aeroplanes for which re-certification to Chapter 4 is requested. Most recently, CAEP/8 in February 2010 requested the noise technical group to review and analyze certification noise levels for subsonic jet and heavy propeller driven-driven aeroplanes and, based on the analysis, develop a range of increased stringency options. This analysis will be considered at the CAEP/9 meeting in 2013[1].

A Noise database NoisedB was developed in 2006 by the French DGCA under the aegis of the International Civil Aviation Organization (ICAO). The database is intended to be a general source of

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[1] At CAEP/9 new noise limits have been proposed as Chapter 14 of ICAO Annex 16. See section 2.5

information to the public on certification noise levels for each aircraft type as provided by certification authorities[2].

13.3 Land-use Planning and Management

Land-use planning and management is an effective means to ensure that the activities nearby airports are compatible with aviation. Its main goal is to minimize the population affected by aircraft noise by introducing land-use zoning around airports. Compatible land-use planning and management is also a vital instrument in ensuring that the gains achieved by the reduced noise of the latest generation of aircraft are not offset by further residential development around airports. ICAO guidance on this subject is contained in Annex 16, Volume I, Part IV and in the Airport Planning Manual, Part 2 — Land Use and Environmental Control (Doc 9184). The manual provides guidance on the use of various tools for the minimization, control or prevention of the impact of aircraft noise in the vicinity of airports and describes the practices adopted for land-use planning and management by some States. In addition, with a view to promoting a uniform method of assessing noise around airports, ICAO recommends the use of the methodology contained in Recommended Method for Computing Noise Contours around Airports (Circular 205[3]).

13.4 Noise Abatement Operational Procedures

Noise abatement procedures enable reduction of noise during aircraft operations to be achieved at comparatively low cost. There are several methods, including preferential runways and routes, as well as noise abatement procedures for take-off, approach and landing. The appropriateness of any of these measures depends on the physical lay-out of the airport and its surroundings, but in all cases the procedure must give priority to safety considerations. ICAO's noise abatement procedures are contained in Annex 16, Volume I, Part V and Procedures for Air Navigation Services — Aircraft Operations (PANS-OPS, Doc 8168), Volume I — Flight Procedures, Part V. On the basis of recommendations made by CAEP/5, new noise abatement take-off procedures became applicable in November 2001. Doc 9888 – Review of noise abatement research and development and implementation projects contains a summary of two surveys of key aviation stakeholders conducted in 2006 and 2009.

13.5 Operating Restrictions

Noise concerns have led some States, mostly developed countries, to consider banning the operation of certain noisy aircraft at noise-sensitive airports. In the 1980’s, the focus was on NNC aircraft; in the 1990s, it moved to Chapter 2 aircraft; today, it has moved to the noisiest Chapter 3 aircraft. However, operating restrictions of this kind can have significant economic implications for the airlines concerned, both those based in the States taking action and those based in other States (particularly developing countries) that operate to and from the affected airports. On each occasion, the ICAO Assembly succeeded in reaching an agreement – contained in an Assembly resolution – that represented a careful balance between the interests of developing and developed States and took into account the concerns of the airline industry, airports and environmental interests.

In the case of Chapter 2 aircraft, the ICAO Assembly in 1990 urged States not to restrict aircraft operations without considering other possibilities first. It then provided a basis on which States wishing to restrict operations of Chapter 2 aircraft may do so. States could start phasing out operations of Chapter 2 aircraft from 1 April 1995 and have all of them withdrawn from service by

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[2] More recently this task has been taken over by EASA with its TCDSN database (type-certificate data sheet for noise), available on the EASA website

[3] Now ICAO Doc9911

31 March 2002. However, prior to the latter date, Chapter 2 aircraft were guaranteed 25 years of service after the issue of their first certificate of airworthiness. Thus Chapter 2 aircraft which had completed less than 25 years of service on 1 April 1995 were not immediately affected by this requirement. Similarly, widebody Chapter 2 aircraft and those fitted with quieter (high by-pass ratio) engines were not immediately affected after 1 April 1995. Many developed countries including Australia, Canada, the United States and many in Europe, have since taken action on the withdrawal of operations of Chapter 2 aircraft at their airports, taking due account of the Assembly's resolution. This has had a substantial impact in reducing noise levels at many airports. However, the benefits of removing Chapter 2 aircraft have now been largely achieved.

In the case of Chapter 3 aircraft, the ICAO Assembly in 2001 urged States not to introduce any operating restrictions at any airport on Chapter 3 aircraft before fully assessing available measures to address the noise problem at the airport concerned in accordance with the balanced approach. The Assembly also listed a number of safeguards that would need to be met if restrictions are imposed on Chapter 3 aircraft. For example, restrictions should be based on the noise performance of the aircraft and should be tailored to the noise problem of the airport concerned, and the special circumstances of operators from developing countries should be taken into account (Appendix E of Assembly Resolution A35-5 (PDF)).

13.6 Noise Charges

ICAO's policy with regard to noise charges was first developed in 1981 and is contained in ICAO's Policies on Charges for Airports and Air Navigation Services (Doc 9082/6). The Council recognizes that, although reductions are being achieved in aircraft noise at source, many airports need to apply noise alleviation or prevention measures. The Council considers that the costs incurred may, at the discretion of States, be attributed to airports and recovered from the users. In the event that noise-related charges are levied, the Council recommends that they should be levied only at airports experiencing noise problems and should be designed to recover no more than the costs applied to their alleviation or prevention; and that they should be non-discriminatory between users and not be established at such levels as to be prohibitively high for the operation of certain aircraft.

Practical advice on determining the cost basis for noise-related charges and their collection is provided in the ICAO Airport Economics Manual (Doc 9562), and information on noise-related charges actually levied is provided in the ICAO Manual of Airport and Air Navigation Facility Tariffs (Doc 7100).

14 Sources of aircraft noise and control measures

14.1 Sources of engine noise

Aircraft turbofan engines nowadays are more complex machines than the straightforward turbojet engines in the old days. This is reflected in the amount of noise sources. It used to be just the mixing noise caused by the high speed gradient in the boundary between the high velocity jet and the stationary air around it that led to strong turbulences.
The introduction of fans with ever increasing by-pass ratio’s resulted in significant reduction of the jet noise component due to the more gradual speed gradient between the jet and the outer air. The fan itself however caused noise of its own. An overview of the relevant sources is given in the graph below.

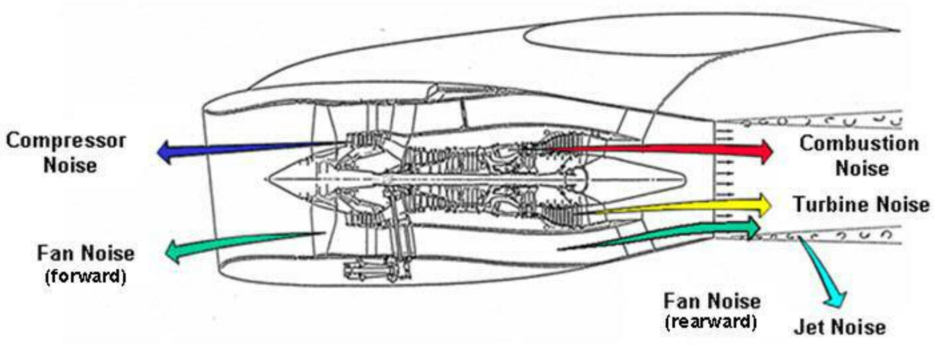

figure 24 Sources of noise in a modern high-by-pass ratio jet engine. The relative contribution from each source to the total produced sound depends on the thrust (see figure 30).

14.2 Noise control measures

Next to fuel efficiency, noise is an important aspect in the engineering of a modern jet engine. Big improvements on both aspects have been achieved by the introduction of high by-pass ratio engines. The thrust of the engine is produced much more efficient by the fan than through the straight jet and the intermediate layer of air accelerated by the fan greatly reduced speed gradients in the mixing zone behind the engine, suppressing the creation of turbulences, hence jet noise.

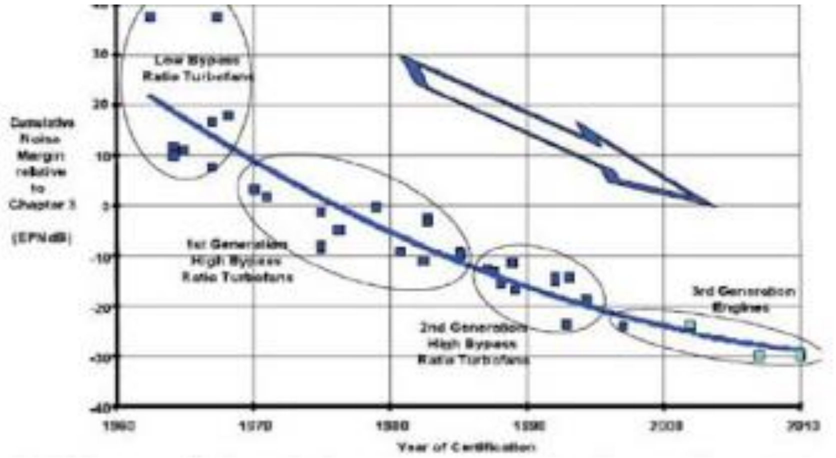

figure 25 The trend towards lower noise aircraft closely follows the increasing by-pass ratios.

The ever increasing fan size however caused an additional noise source, specifically relevant under landing condition. At take-off a new source known as buzz-saw noise is created by the shock waves that are generated due to the supersonic tip speed.   By applying carefully designed acoustic liner in the nacelle the propagation of fan and turbine related noise is suppressed (see figure 26). Control of fan noise when further increasing by-pass ratios may be obtained by application of a geared fan (technology implemented in the A 320 neo and B-737 max). In figure 27 it can be seen how with chevrons turbulences at the engine exhaust are suppressed.
Removal of tonal components will, due to the specific weighting of these components in the EPNdB, result in lower EPNL values and annoyance, even when the total A-weighted level remains more or less the same. In figure 28 an example of such measure is given.

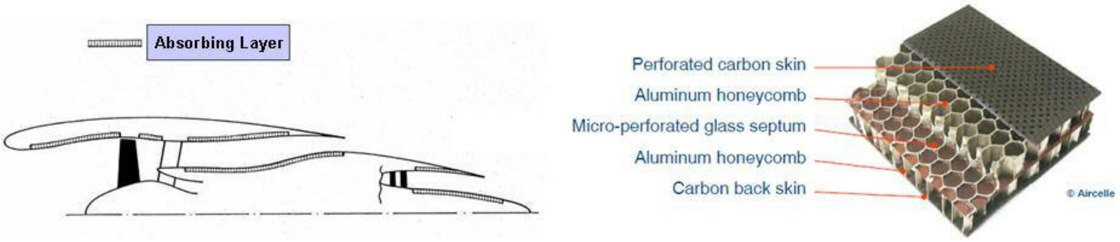

figure 26 *Application of acoustic absorbing liner at the inside area of the nacelle, to reduce fan noise and turbine/combustion noise.*

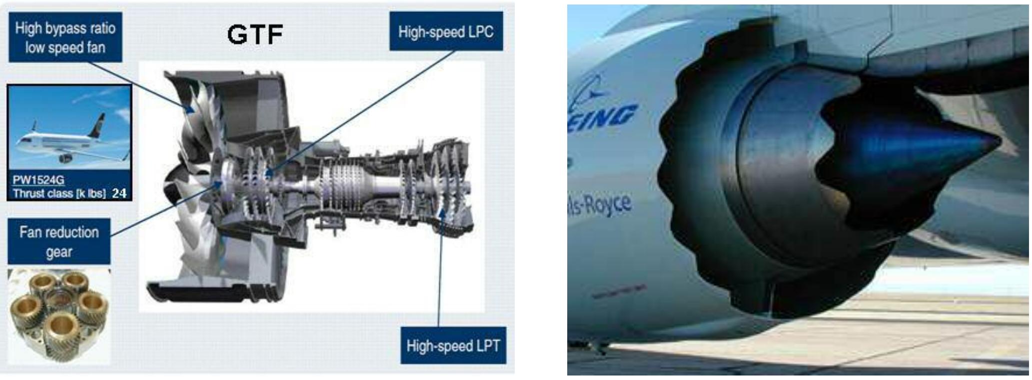

figure 27 *Two examples of noise measures that are applied in modern jet engines. Left: gearing of the fan to reduce fan speed (and thus fan noise), Right: chevrons to reduce turbulences on the rear edge of the engine parts.*

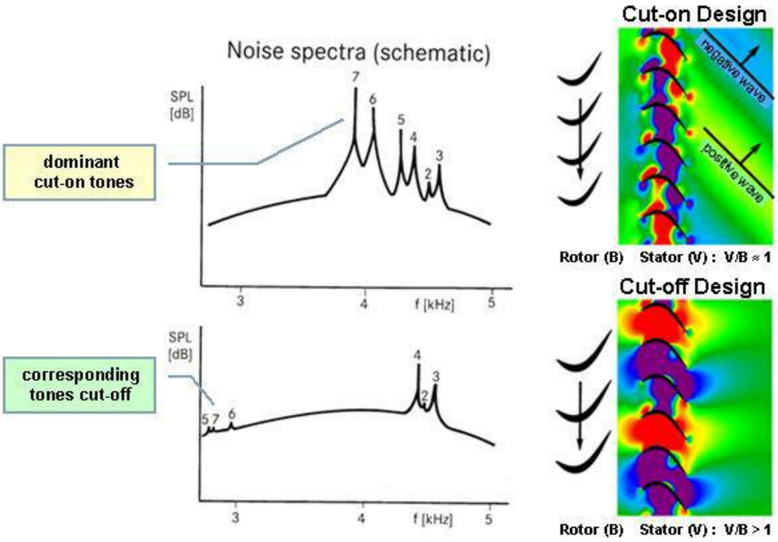

figure 28 *A specific example of suppression of tonal components by optimization of the rotor-stator design in the fan, such that the relevant frequencies (5, 6 and 7 in the graph) are becoming non-radiating.*

14.3 Airframe noise

The engine is the most relevant source of noise in an aircraft. When noise control of engines becomes more effective, secondary sources like the aerodynamic noise from the air frame become relevant, but mainly under landing conditions where flaps, slats and landing gear cause disturbances of the air flow around wings and body. The picture below (figure 29) shows a mapping of the sources of the underside of a landing aircraft obtained with an acoustic camera.

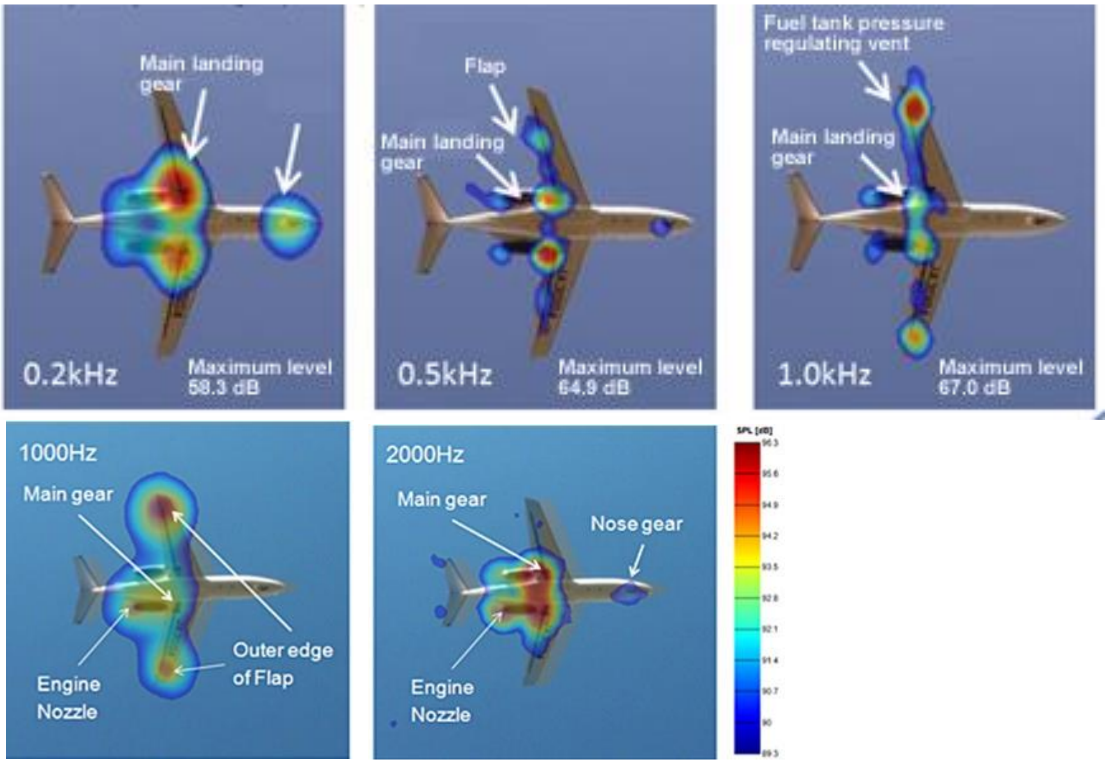

figure 29 *Spectral composition of sources of noise sources of a landing aircraft (engine : 40% thrust, level flight at 60 m at a speed of 120 kt). The possible sources of noise are identified [22].*

14.4 Contribution of noise sources

The relative contribution of the different sources of engine noise and of airframe noise depends on the flying conditions. When taking-off, thrust will be high, leading to a strong component of jet noise. With gear and flaps/slats (partly) retracted airframe noise is relatively low.
Under approach conditions, thrust will be modest resulting in low contribution from the jet, the spinning fan will continue to produce noise and will become relevant, the more since in the EPNdB evaluation the tonal components may add another 3 to 5 EPNdB's.
With flaps/slats and gear exposed to the air flow airframe noise will also become a relevant factor. The graphs below depict the contribution of sources to the overall noise level.

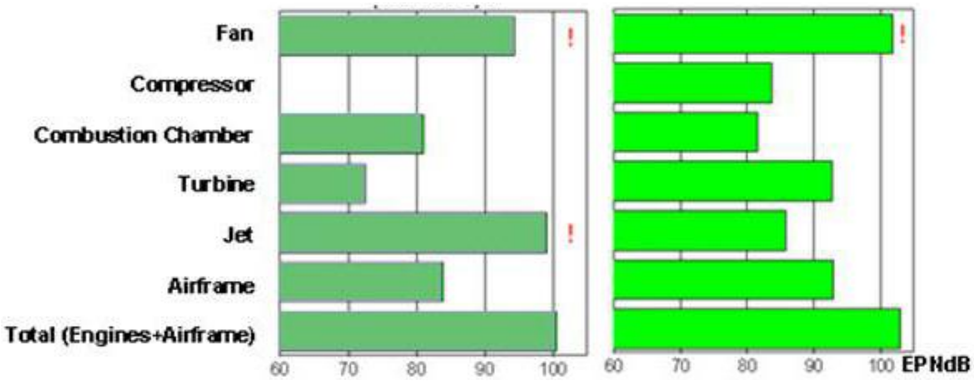

figure 30 *Contribution of the different sources of engine noise and of airframe noise to the overall noise level. Left: take-off, Right: approach (**!** Indicates a dominant contribution).*

14.5 Trade-offs between noise control and fuel efficiency or emission

Up to now noise control and fuel efficiency were clearly co-variant. Improvements in efficiency through higher by-pass ratios were also beneficial for noise. One might expect that in modern engines some efficiency is sacrificed for noise control by increasing acoustic liners and applying lobbed jet exhausts, mainly due to the additional weight. On the other hand, the introduction of stringencies on emissions like NOx and the related changes to the engine design may negatively affect noise.

A possible next step in engine design to improve fuel efficiency is the application of unducted fans, consisting of two counter rotating propellers without the shielding or acoustic absorption of a nacelle. These engines were first tested in the 1980's and appeared too noisy to be viable. However, due to the significant improvements in noise reduction technology and materials, such engines nowadays are expected to be sufficiently quiet to be feasible. Due to their specific sound, with a markedly tonal nature at low frequencies, also the noise at cruising altitude may be audible and is thus being investigated.

figure 31 Picture of a concept high efficiency engine design with counter rotating propellers.

15 Airport Noise restrictions in EU-27+

table XXIII *Overview of noise related restrictions imposed on European airports APU: APU (Auxiliary Power Unit) operating restrictions, CUR: Airport curfew, RUN: Engine run-up restrictions, NAP: Noise Abatement Procedures, NB: Noise budget restrictions, NL: Noise level limits, NS: Noise Surcharge, ES: Emission Surcharge, OQ: Operating quota, PR: Preferential runways, S3R: Stage 3 / Chapter 3 restrictions. Source: http://www.boeing.com/commercial/noise).*

	CODE	COUNTRY	City	APU	CURFEW	RUN-UPS	NAP	NOISE BUDGET	NOISE Limits	NOISE CHARGES	EMISSION CHARGES	Quota	Pref Rwys	Stg3-Ch3 Rest
Aalborg Airport	AAL	Denmark	Aalborg	apu		run	nap					oq		
Aarhus Airport	AAR	Denmark	Aarhus	apu		run	nap					oq		
Aberdeen Airport	ABZ	Scotland	Aberdeen	apu	cur	run	nap			ns		oq	pr	s3r
Agen-La Garenne Airport	AGF	France	Le Passage		cur								pr	
Ajaccio Airport	AJA	France	Ajaccio				nap			ns				
Albacete Airport	ABC	Spain	Albacete			run	nap							
Albany International	ALB	US	Albany			run	nap						pr	
Alghero Fertilia Airport	AHO	Italy	Alghero	apu	cur	run			nl				pr	
Alicante	ALC	Spain	Alicante			run				ns				
Allgau Airport	FMM	Germany	Memmingen		cur	run								
Ancona Airport	AOI	Italy	Ancona	apu		run	nap							
Antwerp Airport	ANR	Belgium	Antwerpen			run	nap		nl				pr	
Athens International	ATH	Greece	Athens	apu		run	nap						pr	
Augsburg Airport	AGB	Germany	Augsburg			run				ns				
Bacau	BCM	Romania	Bacau				nap							
Balaton	SOB	Hungary	Budapest				nap							
Barajas-Madrid Airport	MAD	Spain	Madrid	apu	cur	run	nap			ns			pr	s3r
Barcelona	BCN	Spain	Barcelona	apu			nap		nl	ns			pr	s3r
Bari - Palese	BRI	Italy	Bari	apu		run	nap							
Bastia Poretta	BIA	France	Bastia							ns				
Beauvais Airport	BVA	France	Beauvais	apu	cur		nap						pr	s3r
Belfast City Airport	BHD	UK	Belfast	apu	cur	run	nap		nl			oq	pr	s3r
Belfast International	BFS	UK	Belfast			run	nap							
Benbecula Airport	BEB	UK	Benbecula										pr	
Bergamo Orio al Serio	BGU	Italy	Orio al Serio	apu		run	nap						pr	
Bergen	BGO	Norway	Bergen			run	nap							
Bern-Belp	BRN	Switzerland	Bern	apu	cur		nap		nl	ns	es		pr	
Biarritz Bayonne Anglet	BIQ	France	Biarrit	apu	cur		nap			ns			pr	
Biggin Hill Airport	BQH	UK	London	apu	cur	run	nap		nl			oq		s3r
Bilbao	BIO	Spain	Bilbao	apu	cur	run	nap							
Billund Airport	BLL	Denmark	Billund	apu		run	nap		nl					
Birmingham International	BHX	UK	Birmingham	apu	cur	run	nap		nl	ns		oq	pr	s3r
Blackpool Airport	BLK	UK	Blackpool	apu		run	nap						pr	
Bodo	BOO	Norway	Bodo				nap						pr	
Bologna G Marconi Airport	BLQ	Italy	Bologna	apu	cur	run	nap		nl				pr	
Bordeaux Airport	BOD	France	Merignac		cur	run	nap		nl	ns			pr	
Bournemouth Intl. Airport	BOH	UK	Christchurch	apu	cur	run	nap						pr	
Bratislava M.R. Stefanik	BTS	Slovakia	Bratislava	apu		run	nap						pr	
Bremen-Neueland	BRE	Germany	Bremen		cur	run	nap			ns				s3r
Brindisi-Casale	BDS	Itlay	Brindisi			run	nap						pr	
Bristol International	BRS	UK	Bristol	apu	cur		nap		nl	ns		oq	pr	s3r
Bromma	BMA	Sweden	Stockholm	apu	cur	run	nap		nl	ns	es	oq		s3r
Brussels Airport	BRU	Belgium	Brussels	apu	cur	run	nap	nb	nl	ns		oq	pr	s3r
Bucharest Baneasa	BBU	Romania	Bucharest	apu	cur	run	nap			ns			pr	
Bucharest Henri Coanda Intl	OTP	Romania	Bucharest	apu		run	nap		nl				pr	
Budapest	BUD	Hungary	Budapest	apu	cur	run	nap			ns			pr	
Burgas Airport	BOJ	Bulgaria	Burgas	apu		run	nap						pr	
Cagliari Airport	CAG	Italy	Cagliari				nap							
Cambridge Airport (UK)	CBG	UK	Cambridge	apu	cur	run	nap						pr	
Cannes	CEQ	France	Mandelieu	apu	cur		nap						pr	
Cardiff International	CWL	UK	Cardiff			run	nap							

Charleroi	CRL	Belgium	Brussels		cur	run	nap	nb		ns		oq	pr	s3r
Charles de Gaulle	CDG	France	Paris-Roissy		cur	run	nap		nl	ns				s3r
Ciampino Airport	CIA	Italy	Rome	apu	cur	run	nap						pr	
Clermont-Ferrand/Auvergne	CFE	France	Clermont-Ferr.			run	nap			ns			pr	
Cluj-Napoca	CLJ	Romania	Cluj-Napoca				nap							
Copenhagen	CPH	Denmark	Kastrup	apu	cur	run	nap	nb	nl		es		pr	s3r
Roskilde	RKE	Denmark	Roskilde			run	nap		nl			oq	pr	s3r
Cork	ORK	Ireland	Cork				nap							
Cote D'Azur	NCE	France	Nice	apu	cur	run				ns			pr	s3r
Coventry Airport	CVT	UK	Coventry		cur		nap		nl			oq		s3r
Cuneo Airport	CUF	Italy	Levaldigi – C.		cur								pr	
Dijon Bourgogne Airport	DIJ	France	Dijon	apu	cur								pr	
Dinard-Pleurtuit	DNR	France	St. Malo				nap							
Dortmund Airport	DTM	Germany	Dortmund		cur	run	nap			ns				
Dresden	DRS	Germany	Dresden		cur	run	nap			ns				
Dublin	DUB	Ireland	Dublin			run	nap						pr	
Dubrovnik Airport	DBV	Croatia	Dubrovnik		cur	run	nap						pr	
Durham Tees Valley	MME	UK	Darlington			run	nap							
Dusseldorf	DUS	Germany	Dusseldorf		cur	run				ns	es	oq		s3r
Monchengladbach	MGL	Germany	M.gladbach	apu	cur	run	nap			ns			pr	
Dusseldorf Niederrhein	NRN	Germany	Weeze		cur	run	nap							
East Midlands	EMA	UK	Castle	apu	cur	run	nap		nl	ns			pr	
Edinburgh	EDI	Scotland,	Edinburgh		cur	run	nap			ns				
Egelsbach Airport	QEF	Germany	Egelsbach		cur		nap			ns			pr	
Eindhoven Airport	EIN	Netherlands	Eindhoven				nap			ns				
Eldorado International	BOG	Colombia	Bogota				nap							
Erfurt	ERF	Germany	Erfurt		cur	run			nl	ns			pr	
Esbjerg Airport	EBJ	Denmark	Esbjerg				nap							
Exeter Airport	EXT	UK	Exeter	apu	cur	run	nap							
Faleolo International	APW	Samoa	Faleolo										pr	
Farnborough Airport	FAB	UK	Hampshire	apu	cur	run	nap					oq		
Faro Airport	FAO	Portugal	Faro	apu	cur	run	nap							
Fiumicino	FCO	Italy	Rome	apu	cur		nap						pr	
Forli International	FRL	Italy	Forli				nap							
Francisco Sá Carneiro-Porto	OPO	Portugal	Porto	apu	cur	run	nap		nl					s3r
Frankfurt	FRA	Germany	Frankfurt		cur	run	nap		nl	ns	es	oq	pr	s3r
Friedrichshafen Airport	FDH	Germany	Friedrichshafen	apu	cur	run	nap	nb		ns			pr	
Fuerteventura Airport	FUE	Spain	Rosario		cur	run	nap						pr	
Gatwick Airport Limited	LGW	UK	London	apu	cur	run	nap		nl	ns	es	oq		s3r
Geneva-Cointrin	GVA	Switzerland	Geneva	apu	cur	run	nap		nl	ns	es			
Genova Airport	GOA	Italy	Genova	apu		run	nap						pr	
Gibraltar Airport	GIB	Gibraltar			cur									
Girona-Costa Brava	GRO	Spain	Girona				nap							
Glasgow	GLA	UK	Glasgow		cur	run	nap		nl	ns		oq		
Goteborg City Airport	GSE	Sweden	Gothenburg	apu	cur		nap		nl				pr	
Gran Canaria Airport	LPA	Spain	Telde			run	nap			ns				
Hahn Airport	HHN	Germany	Lautzenhausen		cur	run	nap			ns			pr	
Hamburg	HAM	Germany	Hamburg	apu	cur	run	nap			ns	es		pr	s3r
Hannover-Langenhagen	HAJ	Germany	Hannover		cur	run	nap			ns			pr	s3r
Heathrow	LHR	UK	London	apu	cur	run	nap		nl	ns	es	oq	pr	s3r
Helsinki-Vantaa	HEL	Finland	Helsinki	apu		run	nap		nl	ns			pr	
Humberside International	HUY	UK	Kirmington,			run								
Ibiza Airport	IBZ	Spain	Ibiza			run	nap						pr	
Innsbruck Airport	INN	Austria	Innsbruck	apu	cur	run	nap			ns			pr	
Isle of Mann Airport	IOM	Isle of Man	Ballasalla				nap							
Jerez Airport	XRY	Spain	Jerez de al F.			run								
Jersey Airport	JER	UK	St. Helier		cur	run	nap		nl					
Jonkoping	JKG	Sweden	Jonkoping	apu			nap			ns	es		pr	
Kalmar Airport	KLR	Sweden	Kalmar				nap		nl	ns	es		pr	
Karlsruhe-Baden	FKB	Germany	Baden-Baden		cur									
Karlstad	KSD	Sweden	Karlstad	apu		run	nap			ns	es	oq		
Kaunas Intl.	KUN	Lithuania	Kaunas						nl					
Keflavik	KEF	Iceland	Keflavik	apu		run	nap						pr	
Kent International Airport	MSE	UK	N. Caterbury		cur	run	nap			ns		oq	pr	s3r
Kerry Airport	KIR	Ireland	Killarney		cur									
Kiel Holtenau Airport	KEL	Germany	Kiel		cur	run	nap			ns				
Kiruna Airport	KRN	Sweden	Kiruna		cur					ns	es		pr	
Kittilä Airport	KTT	Finland	Kittilä				nap							
Klagenfurt	KLU	Austria	Klagenfurt				nap						pr	
Koln-Bonn/	CGN	Germany	Koln		cur	run	nap		nl	ns				s3r
Kristiandand	KRS	Norway	Kjevik				nap							
Kuala Lumpur Intl.	KUL	Malaysia	Kuala Lumpur			run								
Lampedusa Airport	LMP	Italy	Lampedusa		cur		nap							

Landvetter	GOT	Sweden	Goteborg	apu	cur	run	nap			ns	es		pr	
Lappeenranta Airport	LPP	Finland	Lappeenranta				nap		nl				pr	s3r
Le Bourget	LBG	France	Paris		cur	run	nap			ns			pr	
Leeds-Bradford Intl.	LBA	UK	Leeds	apu	cur	run	nap		nl	ns		oq	pr	
Leipzig Halle Airport	LEJ	Germany	Leipzig		cur	run	nap			ns				
Liege Airport	LGG	Belgium	Grâce-Hollogne			run	nap		nl	ns		oq	pr	s3r
Lille Airport	LIL	France	Lille			run	nap			ns				
Linate Airport	LIN	Italy	Milan	apu		run	nap		nl				pr	
Linz Blue Danube Airport	LNZ	Austria	Linz	apu	cur	run	nap						pr	
Lisbon International	LIS	Portugal	Lisbon	apu	cur	run	nap		nl			oq	pr	s3r
Liverpool John Lennon	LPL	UK	Liverpool		cur	run	nap					oq	pr	
Ljubljana JP	LJU	Slovenia	Brnik				nap						pr	
London City Airport	LCY	UK	London		cur	run	nap		nl			oq		s3r
Londonderry	LDY	UK	Londonderry				nap							
London Southend Airport	SEN	UK	Southend			run	nap							
Lourdes-Pyrenees	LDE	France	Trabes							ns				
Luebeck Airport	LBC	Germany	Luebeck			run				ns				
Lugano Airport	LUG	Switzerland	Lugano	apu	cur		nap		nl	ns	es			
Luleå - Kallax	LLA	Sweden	Luleå				nap			ns	es			
Luton	LTN	UK	Luton		cur	run	nap		nl	ns	es			
Luxembourg International	LUX	Luxembourg	Luxembourg	apu	cur	run	nap			ns				s3r
Lyon Saint Exupery	LYS	France	Satolas		cur	run	nap			ns		oq	pr	s3r
Maastricht Aachen	MST	Netherlands	Maastricht		cur	run				ns				
Madeira Airport	FNC	Portugal	Santa Cruz	apu	cur	run	nap		nl			oq	pr	s3r
Malaga Airport	AGP	Spain	Malaga			run	nap		nl	ns				s3r
Malmo Airport	MMX	Sweden	Malmo	apu		run				ns	es			
Malpensa Airport	MXP	Italy	Milan	apu	cur	run	nap		nl				pr	
Malta International	MLA	Malta	Luqa			run	nap						pr	
Manchester	MAN	UK	Manchester	apu	cur	run	nap	nb	nl	ns		oq	pr	s3r
Marculesti Airport	YV4	Moldova	Lunga				nap							
Marseille-Provence Intl	MRS	France	Marignane	apu	cur	run	nap			ns			pr	s3r
Menorca Airport	MAH	Spain	Menorca			run	nap							
Metz-Nancy-Lorraine	ETZ	France	Goin										pr	
Molde Airport	MOL	Norway	Molde				nap							
Monastir-Habib Bourguiba	MIR	Tunisia	Monastir		cur		nap						pr	
Montpellier Airport	MPL	France	Montpellier		cur		nap			ns			pr	
Moron Airport	OZP	Spain	Moron				nap							
Munich	MUC	Germany	Munich		cur	run	nap			ns	es	oq	pr	s3r
Munster	FMO	Germany	Munster		cur	run				ns				
Nantes Atlantique Airport	NTE	France	Nantes	apu	cur	run	nap			ns		oq		s3r
Naples International	NAP	Italy	Naples	apu	cur	run	nap							
Neubranden- burg Airport	FNB	Germany	N.brandenburg										pr	
Newcastle Airport	NCL	UK	Newcastle	apu		run	nap							
Norrkoping	NRK	Sweden	Norrkoping		cur		nap		nl				pr	
Norwich International	NWI	UK	Norwich		cur	run	nap			ns			pr	
Nurnberg	NUE	Germany	Nurnberg		cur	run	nap			ns			pr	s3r
Odense Airport	ODE	Denmark	Odense	apu	cur		nap		nl				pr	s3r
Frederic Chopin	WAW	Poland	Warsaw		cur	run	nap			ns			pr	
Olbia-Costa Smeralda	OLB	Italy	Olbia Sassari	apu		run	nap							
Orly	ORY	France	Paris		cur	run	nap		nl	ns		oq	pr	
O.R. Tambo Intl	JNB	South Africa	Johannesburg		cur		nap							
Oslo Gardermoen Airport	OSL	Norway	Oslo	apu	cur	run	nap		nl				pr	s3r
Ostend International	OST	Belgium	Ostend	apu	cur	run	nap					oq		s3r
Ostrava International	OSR	Czech R.	Ostrava											
Ottawa International	YOW	Canada	Ottawa		cur	run	nap						pr	
Oulu Airport	OUL	Finland	Oulundsalo				nap							
Paderborn-Lippstadt	PAD	Germany	Paderborn		cur	run				ns				s3r
Pafos International	PFO	Cyprus	Pafos				nap			ns				
Palanga International	PLQ	Luthuania	Palanga											
Palma de Mallorca	PMI	Spain	Palma de M.	apu		run	nap			ns			pr	
Pardubice Airport	PED	Czech R.	Pardubice		cur	run							pr	
Pescara - Abruzzo	PSR	Italy	Pescara	apu		run	nap							
Pontoise	POX	France	Paris				nap			ns				
Prague Ruzyne	PRG	Czech Republic	Prague	apu	cur	run	nap		nl	ns		oq	pr	s3r
Prestwick International	PIK	UK	Prestwick			run	nap							
Reykjavik Airport	REK	Iceland	Reykjavik	apu	cur	run	nap						pr	
Riga International	RIX	Latvia	Riga			run	nap							
Rimini - Federico Fellini	RIM	Italy	Rimini				nap							
Robin Hood	DSA	UK	Doncaster	apu	cur	run	nap					oq	pr	s3r
Rodez Marcillac Airport	RDZ	France	Rodez	apu		run							pr	
Rotterdam	RTM	Netherlands	Rotterdam		cur	run	nap			ns		oq		
Rovaniemi	RVN	Finland	Rovaniemi				nap							

Saarbruecken-Ensheim	SCN	Germany	Saarbrucken		cur	run				ns				
Salzburg Airport WA Mozart	SZG	Austria	Salzburg	apu	cur	run	nap		nl					s3r
Samedan Airport	SMV	Switzerland	Samedan	apu		run	nap			ns			pr	s3r
San Sebastian	EAS	Spain	San Sebastian				nap							
Santander Airport	SDR	Spain	Santander			run								
Schiphol	AMS	Netherlands	Amsterdam	apu	cur	run	nap	nb	nl	ns			pr	s3r
Schonefeld	SXF	Germany	Berlin		cur		nap			ns				
Shannon	SNN	Ireland	County Clare				nap							
Sion Airport	SIO	Switzerland	Sion	apu	cur		nap			ns			pr	
Sofia Airport	SOF	Bulgaria	Sofia		cur		nap		nl				pr	
Southampton Intl.	SOU	UK	Southampton	apu	cur	run	nap			ns		oq		s3r
Split Airport	SPU	Croatia	Split/Kastela				nap			ns				
Stansted Airport Limited	STN	UK	London	apu	cur	run	nap		nl	ns		oq		s3r
Stavanger Airport	SVG	Norway	Stavanger	apu		run	nap							
Stockholm-Arlanda	ARN	Sweden	Stockholm	apu		run	nap	nb	nl	ns	es		pr	
Stockholm Skavsta	NYO	Sweden	Stockholm				nap							
Stockholm Vasteras	VST	Sweden	Vasteras				nap							
Strasbourg Airport	SXB	France	Strasbourg	apu	cur	run				ns				s3r
Stuttgart Airport	STR	Germany	Stuttgart		cur	run	nap			ns				
Sundsvall-Härnösand	SDL	Sweden	Sundsvall-H.				nap			ns	es			
Sydney Kingsford Smith	SYD	Australia	Sydney		cur		nap					oq	pr	s3r
Tampere-Pirkkala	TMP	Finland	Pirkkala		cur		nap						pr	
Tegel	TXL	Germany	Berlin		cur	run	nap			ns				s3r
Tenerife Sur-Reina Sofia	TFS	Spain	Tenerife			run	nap			ns				
TF Green Airport	PVD	US	Providence	apu	cur	run	nap							
The Eastern Iowa Airport	CID	US	Cedar Rapids			run	nap							
Timisoara International	TSR	Romania	Timisoara	apu			nap						pr	
Torino Caselle Airport	TRN	Italy	Caselle	apu	cur	run	nap							
Torp Airport	TRF	Norway	Sandefjord	apu	cur		nap							
Toulouse-Blagnac	TLS	France	Blagnac		cur	run	nap			ns				
Treviso Airport	TSF	Italy	Treviso	apu		run	nap							
Tunis Carthage Intl.	TUN	Tunisia	Tunis				nap						pr	
Umea Airport	UME	Sweden	Umea	apu	cur		nap			ns	es		pr	
Vassa Airport	VAA	Finland	Vaasa				nap						pr	
Valencia Airport	VLC	Spain	Valencia				nap			ns				
Växjö Smaland	VXO	Sweden	Växjö	apu			nap							
Venice Marco Polo	VCE	Italy	Tessera-Ven.	apu		run	nap		nl				pr	
Verona - Valerio Catullo	VRN	Italy	Verona				nap							
Visby Airport	VBY	Sweden	Visby				nap			ns	es			
Vitoria Airport	VIT	Spain	Vitoria			run								
Wroclaw - Strachowice	WRO	Poland	Wroclaw				nap						pr	
Zurich Airport	ZRH	Switzerland	Zurich	apu	cur	run	nap			ns	es		pr	