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Henning Arps
Andreas Hermann
Dr. Wiebke Zimmer
Dr. Walter Krebs
Dr. Stefan Donnerhack
Fritz Kennepohl
Hartmut Kuhfeld

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Authors:

Henning Arps, Darmstadt Office
Andreas Hermann LL.M, Darmstadt Office
Dr. Wiebke Zimmer, Berlin Office

Dr. Walter Krebs (Empa)
Dr. Stefan Donnerhack (MTU Aero Engines)
Fritz Kennepohl (MTU Aero Engines)

In collaboration with
Hartmut Kuhfeld (DIW)

Translated from the German by
Michael Gromm, Berlin (gromm@web.de)

Öko-Institut e.V.
Geschäftsstelle Freiburg
Postfach 50 02 40
D-79028 Freiburg
Tel.: +49-(0)761-452950
Fax: +49-(0)761-475437

Berlin Office
Novalisstraße 10
D-10115 Berlin
Tel.: +49-(0)30 280 486-80
Fax: +49-(0)30 280 486-88

Darmstadt Office
Rheinstraße 95
D-64295 Darmstadt
Tel.: +49-(0)6151) 8191-0
Fax: +49-(0)6151) 8191-33

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16. Abstract
Exposure to aircraft noise at and around airports is a serious environmental problem. This study examines whether the increase of stringency of permitted noise limits for jet aircraft represents an effective instrument of noise abatement. Certification for air transport, as laid down by the ICAO, requires that all new aircraft comply with noise limits contained in *Annex 16*. Scenarios were developed on future noise immissions at various airport categories, based on ICAO regulations on noise-certification, current noise emissions at international airports and an overview of noise reduction technology. More stringent noise limits for jet aircraft are assumed, which take account for progress in noise reduction technology. Evaluation of the scenarios was based on noise computations with Flula2, estimation of likely economic effects and a comprehensive legal examination. On the basis of scenario analyses, general conclusions are drawn and recommendations made concerning noise reduction potentials. Trade-off effects between noise and pollutant emissions are also examined and new engine technologies described, which could pave the way to minimization of such emissions.

17. Keywords
noise protection, noise reduction, noise limit values, jet aircraft, trade-off effects, active noise control, noise certification, limit value tightening, noise reduction technology, noise emission, economic effects, legal basic conditions

18. Price	19.	20.

Contents

Figures

Tables

Abbreviations

Abbreviation	Explanation
%E_A	Percentage share of sound energy, landing
%E_D	Percentage share of sound energy, take-off
°C	Degrees centigrade
ACARE	Advisory Council of Aeronautical Research in Europe
ADP	Advanced ducted propfan
ANTLE	Affordable near-term low emission engine
APU	Auxiliary power unit
Art.	Article
ATFI	Advanced turbofan integrator, PWC demonstration programme fpr GTF
AzB	Instructions on the calculation of noise protection zones (according to the Aircraft Noise Act (FluglärmG)
BAnz	*Bundesanzeiger* – Federal Gazette
BAZL	*Bundesamt für Zivilluftfahrt* – Federal Office of Civil Aviation
BGBl	*Bundesgesetzblatt* – Federal Law Gazette
BImSchV	Federal Immission Control Act
BMVBW	Federal Ministry of Transport, Building and Urban Development
BPR	Bypass ratio
BVerwG	*Bundesverwaltungsgericht* – Federal Administrative Court
BZ	Fuel Cell
C	Tone correction
CAEP	Committee on Aviation Environmental Protection
CLEAN	Component validator for environmental friendly aero-engine
CO_2	Carbon dioxide
CS	Certification specification
D	Time correction
DAC	Double annular combustor
dB	Decibel; unit for measuring the relative loudness of sounds
DES	Data entry system for AzB
DFS	*DFS Deutsche Flugsicherung GmbH* – German Air Traffic Control
DIN	*Deutsches Institut für Normung e.V.*
DLR	*Deutsches Zentrum für Luft- und Raumfahrt* – German Aerospace Center

Abbreviation	Explanation
DOC	Direct operating cost
E_A	Sound energy at landing weighted with the number of flight movements
E_D	Sound energy at take-off weighted with the number of flight movements,
EASA	European Aviation Safety Agency
EC	European Community
ECAC	European Civil Aviation Conference
EMPA	Federal Swiss laboratories for materials testing and research
EPNdB	Effective perceived noise in dB
EPNL	Effective perceived noise level
ESRA	Eurocontrol statistical reference area
ETM	Environmental Technical Manual
EU	European Union
FAA	Federal Aviation Administration
FLULA	Aircraft noise computation programme of the EMPA
FMS	Flight Management System
GC	Generic class
GE	General Electric
GTF	Geared Turbofan
Hz	Hertz
ICAO	International Civil Aviation Organization, Montreal
IFR	Instrument flight rules
INM	Integrated noise model
IRA	Intercooled recuperative aero-engine
ISO	International Organization for Standardization
kPa	Kilo Pascal
L_a	Noise measuring point, approach according to ICAO *Annex 16*
L_{AE}	Single-event sound level
L_{Amax}	Maximum measured sound pressure level L_{AS} according to DIN 45 643
L_{AS}	A-weighted sound pressure level with the time constant "slow" according to DIN 45 643
L_{AZ}	Specific noise level according to DIN 45643-1
LBA	*Luftfahrt-Bundesamt* – Federal Office of Civil Aviation

Abbreviation	Explanation
L_{DEN}	Day-evening-night noise index – according to the Directive on Environmental Noise 2002/49/EC – in decibel as A-weighted equivalent continuous sound level in accordance with ISO 1996-2
L_{EPN}	Effective perceived noise level
L_{eq}	Equivalent continuous sound level
L_f	Noise measurement point, flyover, according to ICAO *Annex 16*
L_s	Lateral noise measurement point according to ICAO *Annex 16*
L_{seat}	Specific sound level for a single seat
LSV	Noise Abatement Ordinance
LTO	Landing and Take-off Cycle, relevant for NOx certification
LuFo	*Luftfahrtforschungsprogramm* – Aviation research programme
LuftGerPO	*Prüfungsordnung für Lugtfahrtgerät* – Aircraft Certification Ordinance
LuftVG	*Luftverkehrsgesetz* – Air Traffic Act – of 1. August 1922
LuftVO	Luftverkehrs-Ordnung
LuftVZO	*Luftverkehrs-Zulassungs.Ordnung* – Air Traffic Licensing Regulations
LVL	*Lärmvorschrift für Luftfahrzeuge* – Noise Regulations for Aircraft
M	Metre
MTOM	Maximum-Take-Off-Mass
MU	Federal Ministry for the Environment, Nature Conservation and Nuclesr Safety
NEWAC	NEW Aero-engine Core configuration (EU)
NfL	*Nachrichten für Luftfahrer* – Information for aeronauts
Ni	Number of movements of type i per year (take-offs and landings)
NOx	Total emissions of nitrogen oxide
N_S	Typical number of seats
OPR	Overall pressure ratio
P 3	Performance value: pressure at compressor outlet
PAX	Passenger
Pkm	Passenger kilometre
PNL	Perceived noise level
PNLTM	Maximum tone-corrected perceived noise level
QC	Quota count
R&D	Research and Development
RC2	Acoustic reference type

Abbreviation	Explanation
RR	Roll Royce
S%E_A	Cumulative total of the percentage sound energy, approach
S%E_D	Cumulative total of the percentage sound energy, departure
s.	Sentence
SARPS	Standards and Recommended Practices
SPL	Sound pressure level
T 3	Performance value: temperature at compressor outlet
T 4	Performance value: temperature at combustor outlet
TALON	PW low-NOx combustor concept
TF	Turbofan
tkm	Tonne kilometre
UBA	*Umweltbundesamt* – Federal Environmental Agency
UHBR	Ultra high BPR engine
U_{tip}	Fan blade – maximum speed
V_{jet}	Jet outlet speed

1 Introduction

Exposure to aircraft noise at and around airports is a serious environmental problem. Although the noise levels measured with the local systems of airport operators and the noise emission of individual aircraft have been decreasing in many cases, the local population is still badly affected. This is due particularly to the fact that the volume of air traffic has grown continually in recent years, and available air traffic forecasts assume an increase in flight movements in the future. Results of a recent survey on noise annoyance, which was conducted by the Federal Environmental Agency (UBA), confirm that aircraft noise is increasingly regarded as disturbing. As a result, the UBA concluded, "a noticeable increase of stringency of noise limits for jet aircraft" is required "at an international level" (UBA 2003). "Aircraft and engine manufacturers should be set ambitious design targets" (UBA 2003).

1.1 Background and issue

Current regulations on the determination of noise levels and noise limits for aircraft subject to certification require "that the technical equipment of an aircraft should be designed in such a way that noise emitted during its operation does not exceed an unavoidable level consistent with the latest developments in technology (LVL 2004). Beyond this, there are currently no regulations regarding noise emission limits. The issue is therefore whether and to what extent these regulations already offer incentives for the purchase and operation of low-noise aircraft, and, beyond that, what opportunities this instrument might have to provide a relevant contribution to noise abatement.

Noise-certification is based on the specifications of the ICAO. From a methodical point of view it has not changed for a long time, comprising noise limits valid in October 1977 and tightened up in January 2006. The regulations on *Chapter 3* aircraft thus existed unchanged for thirty years, and the final phasing out of *Chapter 2* aircraft took place in Europe in April 2002 with a 24-hour take-off and landing ban, 25 years after type-certification for *Chapter 3* jet aircraft came into effect.

Due to the international integration of air transport, it is of particular interest to establish whether an incentive can be proven, which noise reduction effects can be achieved through the setting of noise limits beyond current regulations, and which obstacles exist to stricter interpretation of the regulations. The fact is that a large number of aircraft presently in operation already comply with the new *Chapter* 4 noise regulations.

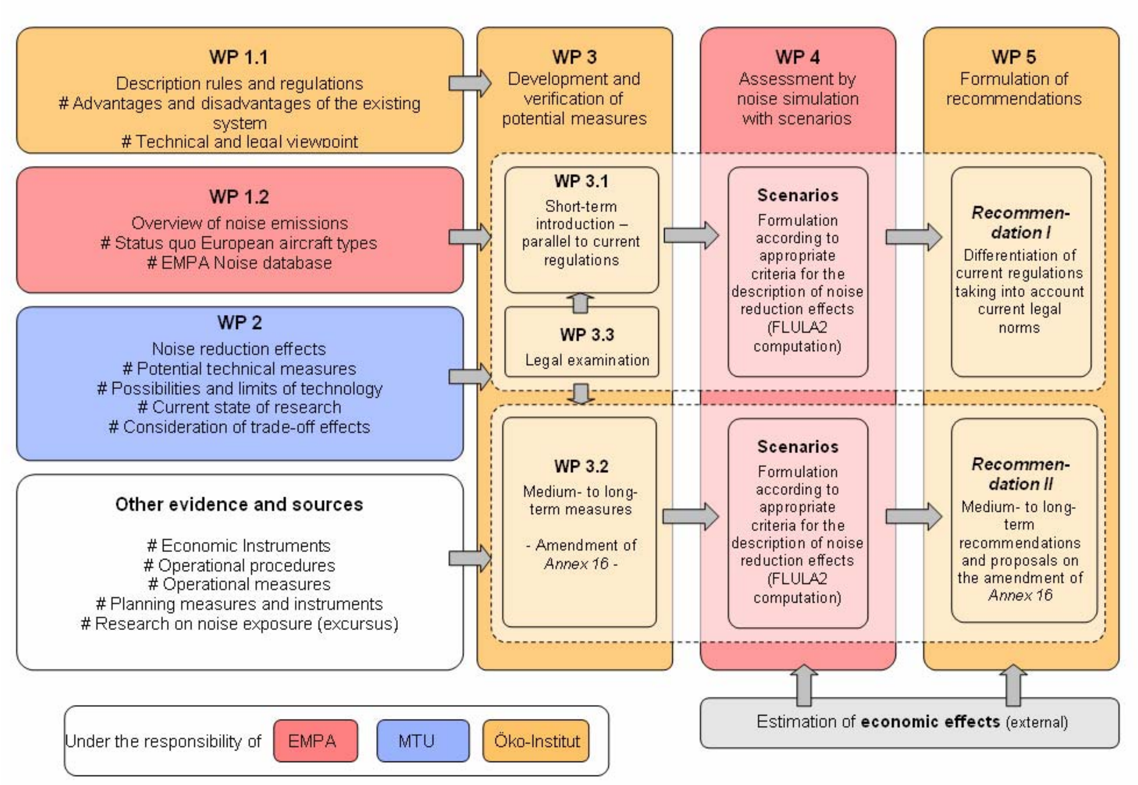
1.2 Terms of reference and objective

The report's main task is the evolvement of proposals for the further development of noise-certification. The extent to which noise-certification can make a contribution to noise control policy should therefore be examined. Substantiated proposals for new noise limits provide a basis for this, and more far-reaching recommendations are derived from the results. The target group comprises, on the one hand, aircraft and engine manufacturers that are responsible for aircraft design, and on the other hand, stakeholders at individual airports that are responsible for the successful implementation of noise control policy. Medium-and long-term extrapolation in the report is based on the assumption that within the framework of further amendment of certification regulations a new "*Chapter 5*" standard is introduced, which is orientated towards expected technical developments in aircraft and engine construction.

The development of the scenarios is based on knowledge of the status quo with regard to current certification, an overall view of noise emissions at European airports, as well as present perspectives for noise reduction technology. The presentation of current regulations comprises a description of evaluation methods and accompanying rules as well as the legal framework of existing regulations in the subject area. The aim of this section is to describe and explain the advantages and disadvantages of existing regulations in *Annex 16*. The review of noise emissions at selected European airports indicates the current state of emissions at various airport categories by identifying the noisiest aircraft types, or by comparing aircraft fleet mix at the respective airports. Status-quo analysis concludes with a review of the current state and future development of noise reduction technology with respect to aircraft as a complete system, and also takes account of the present state of research. Part of this section considers the conflict between competing design objectives in aircraft engine development (trade-off effects). The investigation focuses on conflicting objectives with respect to a reduction in noise and exhaust emissions.

On the basis of these results, a total of six scenarios have been defined and developed, which cover different time horizons (short-term and medium- to long-term) and contain strictly defined specifications. The whole range of possible developments is described and then considered in the subsequent evaluation. The main points of the scenarios were elaborated in a workshop, in which all project partners (including the UBA) participated. Specific examination of the proposals from a legal point of view then took place, in order to check their chances of realization. For the assessment of results, effects are considered by means of aircraft noise simulations and assessed on the basis of aircraft noise contours for varying levels of exposure. This assessment is complemented by consideration of potential costs for airlines and airport operators, so that proposed measures can also be judged from an economic point of view.

Figure 1 Structure of the UBA R&D project on the stringency *of noise limits*



1.3 Structure and procedure

The report is arranged in nine chapters. Analysis of the status quo is in three parts and comprises the following chapters:

- The current position with regard to *Annex 16* as well as its transposition into German and international aviation law is discussed in **Chapter 2**, in which the measuring methods and noise limit values of *Annex 16* are described in detail. In addition, its legal incorporation into international, European and national regulations is described (see Section 2.3).
- A review of noise emissions of aircraft presently operated in Europe is the subject of **Chapter 3**, together with an overview of noise emissions at European airports. In addition, the noise emission situation at selected airports is differentiated and a look taken at the aircraft that use these airports. An extended analysis of noise levels per aircraft seat is also conducted (see Section 3.4). The EMPA noise data base and current flight movement statistics of the airports under consideration were utilized for the purpose of these analyses.

- Short- and long-term perspectives for engine-related noise reduction technology as well as a review of noise reduction potentials for aircraft as a complete system are presented in **Chapter 4**. Current publications are analyzed and summarized, and the expert knowledge of the engine manufacturer *MTU Aero Engine* concerning engine-related topics is presented in detail. In addition, the possible trade-off effect of (decreasing) noise emissions and (increasing) pollutant emissions are assessed (see Section 4.8).

The formulation of the scenarios, which are presented in **Chapter 5**, is based on the analysis of existing sources (for example, air traffic forecasts, methods for determining fleet mix), adaptation to the subject matter of the report through supplementary modification, as well as additional assumptions, that were evolved and agreed upon in the project consortium. The proposed scenarios are also examined with respect to their legal implementability by way of an examination of relevant rules and regulations.

In **Chapter 6,** results are presented and assessed on the basis of aircraft noise simulations created with the EMPA *Aircraft Noise Computation Programme 2*. Further evaluations are also carried using statistical parameters, which flow into a concluding assessment. The work is concluded in **Chapter 7** with the formulation of specific recommendations for the further development of noise-certification and a look at the need for further research.

The report is rounded off with a list of sources and references in **Chapter 8** and an Appendix as **Chapter 9**. This Appendix contains supplementary explanations and analyses with respect to the previous chapters as well as important fundamental information on the assessments made (for example, traffic data at the airports under consideration and statistics on flight route allocation for the scenarios).

2 Description of noise-certification according to *Annex 16*

2.1 Terms of reference

Discussion of the existing body of rules and regulations begins with a description of methodology and prevailing noise limits (Section 2.4). According to ICAO specifications, certification solely concerns type-certification and permission to fly for new aircraft, and does not concern existing aircraft fleets. Moreover, certification should under no circumstances be regarded as a threshold for the reasonableness of aircraft noise. Attention is drawn to the *Lärmvorschrift für Luftfahrzeuge LVL* (noise regulations for aircraft in Germany and to the duties and functions of the Federal Office of Civil Aviation (LBA) as competent authority. Further comments on European and international air transport law round off the legal presentation (Section 0). It is further pointed out that there are now a large number of individual regulations in force at international airports, which make use of classification according to ICAO *Chapter* classes (Section 2.6). The chapter ends with the presentation of conclusions (see Section 2.8).

2.2 Introduction and background

The regulation on noise-certification (ICAO 2005) in *Annex 16* of the ICAO provides the basis, according to German air traffic law, for type-certification and permission to fly for new aircraft. Type-certification confirms, "the technical equipment of the aircraft is designed in such a way that noise arising during its operation does not exceed an unavoidable level consistent with the latest developments in technology" (LVL 2004). This obligation to show compliance arises from an EC Directive (EC 1702/2003) and ICAO environmental regulations in *Annex 16*. Civil jet aircraft are categorized in three classes (*Chapters 2* to *4*) at the time of certification.

This categorization is further applied in the formulation of various instruments of active noise abatement (for example, quota models, night-flight restrictions and noise-related LTO charges). Examples of the existing range of regulations at international airports based on ICAO noise-certification are provided in Section 2.7.

Table 1 *Chapter* classes for jet aircraft according to ICAO *Annex 16*

Noise classification according to ICAO *Annex 16*	Validity of type-certification for jet aircraft	Short description
Chapter 2	Before 6 Oct. 1977	Following the gradual phasing-out of Chapter 2 aircraft a general ban on take-off and landing applies in the EU with effect from 31.03.2002; exceptions are only possible by way of special regulations
Chapter 3	6 Oct. 1977 to 1 Jan. 2006	Noise limits apply, differentiated according to take-off (plus number of engines) and landing (see Table 3) evaluation methods correspond to the specifications in Appendix 2 of *Annex 16*
Chapter 4	From 1 Jan. 2006	Noise limits for *Chapter 3* aircraft apply plus remaining below the limits by a cumulative 10 EPNdB at the three certification measurement points; evaluation methods correspond to *Chapter 3*
Comment: *Chapter 2* aircraft are not further considered in this report		

The obligation to show compliance with *Annex 16* requirements applies solely to jet aircraft for which type-certification[1] and permission to fly ought to be granted. This regulation does not relate to existing aircraft fleets or everyday flight operations; it merely lays down noise emissions that are generally permissible for specific types of aircraft. Noise limits are laid down in *Annex 16* and, under German law, in the LVL, which again refers to *Annex 16* with respect to the compliance procedure and noise limits.[2]

[1] Besides modification of type-certification, modification of type-parts, certification of individual parts and modification of individual parts; cf. LVL 1.3.

[2] Further information on the historic development of noise-certification based on ICAO regulations can be found, for example, in documentation of the ICAO Workshop "Noise-certification" in October 2004 under www.icao.int/icao/en/env/NoiseCertification_04/index.html (for instance, contribution BIP2/1 from A. Depitre); or *Noise Regulation Timeline* from Boeing (see *Airport Noise regulations* under www.boeing.com/commercial/noise/caep5.html).

2.3 Legal framework of existing rules and regulations

In this section, fundamental international, European and German regulations are described, which are important for the noise-certification of aircraft and associated certification procedures (permission to fly, examination of a basic type and type-certification). Regulations are also dealt with, which are linked to noise-certification and are of importance for the operation of aircraft (Section 2.3.5). The framework resulting from these regulations serves as a basis for the later legal assessment of the proposed measures.

2.3.1 The international level (ICAO)

2.3.1.1 Function and legislative power of the ICAO

Regulations on international air transport, which are bound by international law and also regulate aircraft noise, are set, among others, by the ICAO (International Civil Aviation Organisation). The ICAO was founded in Chicago on 7 December 1944 on the basis of the Agreement on International Civil Aviation (Chicago Agreement).[3] This Agreement, a convention under international law,[4] establishes the fundamental legal system governing international air transport.[5] On account of its worldwide validity, the Chicago Agreement sets the regulatory framework for the development of civil aviation.[6] Further sources of air-transport-related statutory regulations at an international level are unilateral regulations and bilateral air-transport agreements between countries, the General Agreement on Trade in Services - GATS)[7] and customary international law.[8] Since, however, these further sources do not concern the essence of the question addressed in this report – the certification of aircraft – they are not further elaborated upon.

The objectives of the ICAO are laid down in Article 44 of the Chicago Agreement, according to which one of the main objectives is to develop the principles and techniques of international aviation and to promote international air transport.[9] Aspects

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3 Giemulla / Schmid, § 31 LuftVG, marginal note 34.

4 Cf. Rosenthal 1989, p. 150.

5 181 states currently belong to the ICAO. Germany became a member of the ICAO in 1956, cf.: Schwenk / Giemulla 2005, p. 89 and 574; Giemulla / Schmid, § 31 LuftVG marginal note 35.

6 Birmanns, S., Internationale Verkehrsflughäfen, p. 82.

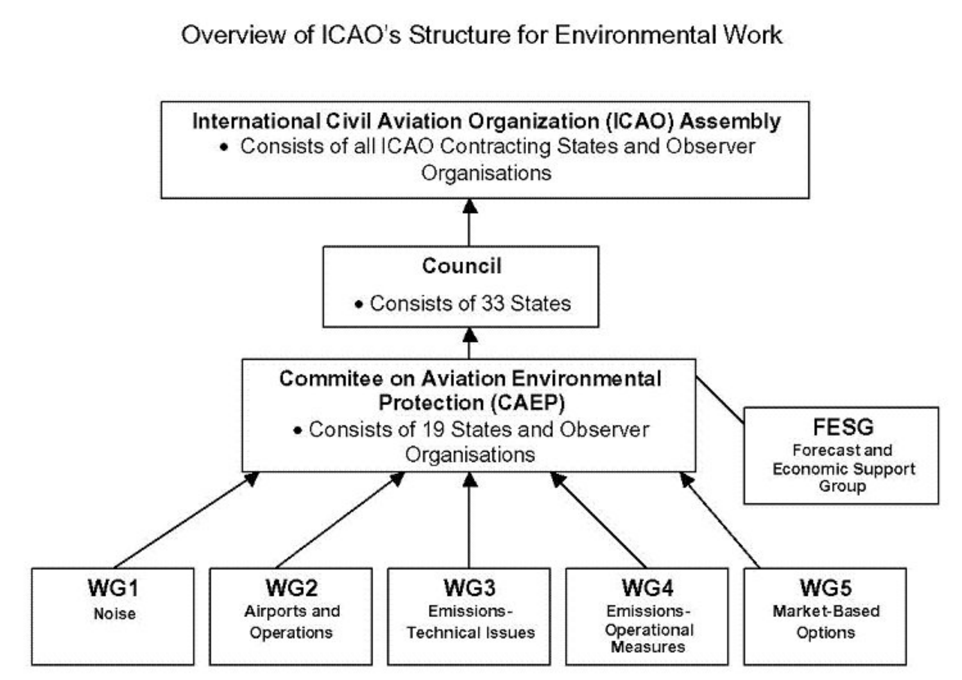
7 BGBl. 1994 II, p. 1473.

8 Apart from the Chicago Agreement, there is also the International Air Service Transit Agreement of 7 December 1944, BGBl. 1956 II, S. 442 and the International Air Transport Agreement of 7 December 1944, ICAO-Doc. 2817, 1944, p. 71 ff.). Neither of these agreements is of direct significance for the subject matter of this report.

9 Schwenk / Giemulla 2005, p. 86.

of environmental protection are not mentioned in Article 44 of the Chicago Agreement. That environmental protection was not among the initial objectives of the Chicago Agreement is confirmed by the fact that it is not mentioned in the preamble to the Agreement.[10] Even if the ICAO does not concern itself explicitly with environmental protection,[11] it does, however, play a role in the standardization of aspects of transport policy, transport-related law and aeronautics[12] (see the following diagram).

Figure 2 ICAO structure for environmental work



Source: Center for Clean Air Policy, Controlling Airport-Related Air Pollution, June 2003

An **obligation** to adopt measures to control noise at source (engine and aircraft design, the laying down of noise limits and state-controlled permission to fly) cannot be inferred from the Chicago Agreement.[13] According to Article 31 Chicago Agreement, every aircraft operating in international aviation requires a certificate of airworthiness. On account of Article 33 Chicago Agreement, were noise characteristics to be included

10 The regulative intentions of an international agreement are always laid down in its preamble. This is why the preamble assumes considerable importance with regard to the interpretation of an agreement. Cf. Birmanns, S., Internationale Verkehrsflughäfen, p. 85.

11 Mengel / Siebel, p. 283.

12 Mengel / Siebel, . 283.

13 With regard to obligations arising from other statutory sources, such as customary international law, see Rosenthal 1989, p. 145 ff.

in the minimum airworthiness specifications of the ICAO, there would be a legal obligation under international law for mutual recognition of these noise criteria. For according to Article 33, contracting states are obliged to recognize certificates of airworthiness issued and rendered valid by other contracting states, when such certificates are equal to or above the minimum standards set by the ICAO. The consequence is that, according to Article 40, an aircraft can only participate in international transport with the permission of states whose airspace or territory it enters. Noise criteria are not included, however, in Annex 8 (airworthiness of aircraft) of the Chicago Agreement, which regulates standards of airworthiness.[14]

Even when an obligation to adopt measures of noise abatement at source does not exist, on the basis of the authority contained in Article 37 s. 2 of the Chicago Agreement, the ICAO does have the **responsibility** to put forward aviation regulations whose uniform application appears to be necessary in terms of international interests.[15]. Article 37 (adoption of international standards and procedures) states:

> *"Each contracting State undertakes to collaborate in securing the highest practicable degree of uniformity in regulations, standards, procedures and organization in relation to aircraft, personnel, airways and auxiliary services in all matters in which such uniformity will facilitate and improve air navigation.*
>
> *To this end the International Civil Aviation Organization shall adopt and amend from time to time, as may be necessary, international standards and recommended practices and procedures dealing with:*
>
> *…*
>
> *(e) Airworthiness of aircraft*
>
> *…"*

The tightening up of noise limits for aircraft by the ICAO – as has occurred in the past – is therefore possible, and in such cases the following requirements have to be adhered to:

The tightening up of noise limits must be consistent with the fundamental aims and objectives of the ICAO, whose primary objective is to develop the principles and techniques of international aviation and to foster the planning and development of international air transport.[16] According to Article 44, further objectives are involved, such as ensuring the safe and orderly growth of international civil aviation as well as safe, regular, efficient and economical air transport and the promotion of flight safety.

The legislative instruments empowering the ICAO to create international aviation standards are:[17]

[14] Rosenthal 1989, p. 145.

[15] Mengel /Siebel, p. 284; Rosenthal 1989, p. 151.

[16] Cf. Article 44 and the preamble to the Chicago Agreement.

[17] With respect to the legislative power of the ICAO cf. Rosenthal 1989, p. 150 with further remarks in Footnote 3.

- international standards,
- recommended practices and
- procedures.

Procedures – which include, for example, take-off and landing procedures – are not the subject of examination in the following section, but rather standards and recommended practices, in short: SARPs.

The adoption of international standards and recommended practices is, according to Article 54 (i), the responsibility of the Council. Among the mandatory functions of the Council are the designation of SARPs as annexes to the Chicago Agreement and informing all contracting states accordingly. Up to now, 18 annexes have been produced, for example on the operation of aircraft (*Annex 6*), on airworthiness (*Annex 8*) and on environmental protection (*Annex 16*).

2.3.1.2 The obligatory nature of SARPs

The extent to which states are obliged to adopt ICAO standards and recommendations in national law is the subject of dispute among lawyers.[18] The Chicago Agreement does not lay down obligatory adoption of annexes in national law. However, the standards and recommendations (SARPs) of the 18 Annexes to the Chicago Agreement only become legally effective in contracting states when they are transposed into national law; in Germany, for example, through act or ordinance (Article 32 (3), s. 1 *LuftVG* (Air Traffic Act).[19]

Development of SARPs in contracting-out procedures

The adoption or amendment of an existing annex (for example, *Annex 16*) requires the vote of two-thirds of the Council (Article 90 in connection with Article 54 (i) Chicago Agreement).[20] A Regulation then becomes effective, as a rule, three months after its submission to the contracting states, unless, in the meantime, a majority of the contracting states register their disapproval with the Council (Article 90 (a) s. 2). On expiry of this period the Council then immediately informs the contracting states of the date of effectiveness of the respective SARP (Article 90 (b)). The date of effectiveness has to be distinguished, however, from the date of applicability, which gives individual contracting states the opportunity to provide for a longer period of time for adoption of the regulation in national law. In the period up to the date of applicability contracting states have to inform the ICAO of any deviations required for adoption of the SARP in national law.

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[18] Rosenthal 1989, S. 151 ff.; the specifications of Annex 16 are not regarded unequivocally as legally binding by Gratjios, p. 37.

[19] Hofmann / Grabherr, Introduction, p. 10.

[20] Ipsen 2005, p. 928.

New or amended standards do not therefore have to be ratified by a particular number of contracting states. On the contrary, an annex to the Chicago Agreement takes effect with a two-thirds vote of the Council combined with the majority of contracting states, whereby the lack of a response is treated as acceptance. This so-called "contracting-out procedure" has the effect that standards become binding under international law without the express agreement of each individual contracting state.

Legal effect of SARPs

The question whether a strict legal obligation is incumbent on all states represented in the ICAO to adopt all regulations deriving from contracting-out procedures in their national legal system, is answered in Articles 37 and 38 of the Chicago Agreement. The wording of Article 37 argues against a strict binding effect:

> *"Each contracting state undertakes to collaborate in securing the highest practicable degree of uniformity in regulations, standards, procedures and organization in relation to aircraft ... in all matters in which uniformity will facilitate and improve air navigation."*

Uniformity is therefore a vigorous demand, but not an obligation.

Article 38, s. 1 also argues against a strict binding effect:

> *"Any contracting state which finds it impracticable to comply in all respects with any such standard or procedure, or to bring its own regulations or practices into full accord with any international standard or procedure ... or which deems it necessary to adopt regulations or practices differing in any particular respect from those established by an international standard, shall give immediate notification to the ICAO of the differences between its own practice and that established by the international standard."*

Article 38, s. 1 thus also recognizes the possibility of states pursuing their own path, and makes high demands neither with regard to the reason for this, nor to the formal procedure. Contracting states have only to maintain that the application of the SARP is impracticable, or, simpler still, that deviation from the SARP appears to be necessary.

In examining the mandatory character of SARPs for contracting states, however, not only has the wording of Articles 37 and 38 to be addressed, but also the regulative purpose of the Chicago Agreement. Since contracting states have undertaken to fulfil the aims and objectives mentioned in Article 44 (see Section 2.3.1.1) of the Chicago Agreement, it cannot be at the sole discretion of contracting states, whether and how they implement SARPs. It has therefore to be assumed that "annexes having become effective, a certain obligation is established to adopt these in the national legal system."[21] Contracting states can act as they see fit, but they are bound by the principles of good faith. This means that ultimately, however, contracting states –

[21] Rosenthal 1989, p. 155.

subject to other regulations, such as obligations at a European level – cannot be compelled to adopt SARPs.

The consequences of a contracting state pursuing its own path in the application of a standard can be concluded from Article 33 of the Chicago Agreement, which governs the recognition of certificates and licenses by the contracting states:

> *"Certificates of airworthiness and certificates of competency and licenses issued or rendered valid by the contracting State in which the aircraft is registered, shall be recognized as valid by the other contracting States, provided that the requirements under which such certificates or licenses were issued or rendered valid are equal to or above the minimum standards which may be established from time to time pursuant to this Convention."*

In the case of deviation by a contracting State, other contracting states are not obliged to recognize licences and certificates – such as the certificate of airworthiness – issued by that state. As a consequence, they can refuse permission to enter their territory to an aircraft whose certificate of airworthiness does not meet minimum standards.[22] By the same token, it has to be concluded from Article 33 that a contracting state cannot deny permission to enter its territory to an aircraft that fulfils ICAO minimum standards.

If a contracting state does not comply with the specifications of the Chicago Agreement, and should disputes arise, that state runs the risk that the ICAO Assembly will suspend its voting power in the Assembly and in the Council (Article 88, Chicago Agreement).

2.3.2 Regulations at the European level

Permission to fly and type-certification are prerequisites for taking up air transport with an aircraft in the European Union. Though certification has previously been within the jurisdiction of EU Member States, with EC Regulation 1592/2002[23] (the so-called basic regulation) the issuing of standards with respect to the design, manufacture, maintenance and operation of aeronautical products, parts and appliances has shifted to the EU level.

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22 Cf. Northeast States for Coordinated Air Use Management and Center for Clean Air Policy, Controlling Airport-Related Air Pollution, June 2003, p. V-3.

23 Regulation (EC) No. 1592/2002 of the European Parliament and of the Council of 15 July 2002 on common rules in the field of civil aviation and establishing a European Aviation Safety Agency Official Journal L 240 of 07.09.2002, p.1; as last amended by Regulation (EC) No. 1701/2003 of the Commission of 24 September 2003 adapting Article 6 of Regulation (EC) No. 1592/2002 of the European Parliament and of the Council on common rules in the field of civil aviation and establishing a European Aviation Safety Agency, Journal L 240 of 07.09.2002, p.5.

2.3.2.1 Regulation EC/1592/2002 and die EASA[24]

In connection with type-certification and the allocation of noise certificates at an EU level, the EC basic regulation on common rules in the field of civil aviation has first to be discussed. The regulation restructured the certification of aircraft in the EU, which was previously carried out by EU Member States (cf. Section 2.3.3 concerning regulations in effect in Germany regarding the certification of aircraft). With this regulation, a European Aviation Safety Agency (EASA) was established[25] and assigned the key role concerning the certification of aircraft and all related matters. The Agency is responsible for issuing airworthiness certificates and environmental certificates with regard to the design, manufacture, maintenance and operation of aeronautical products, parts and appliances (Regulation, Articles 15, 4 and 1 (a)). According to the regulation, "products" cover an aircraft, engine or propeller (Article 3 (b)), and "parts and appliances" include parts of an engine or propeller (Article 3 (d)). According to Article 4 of the regulation, aircraft (including installed products, parts and appliances), which are

a) designed or manufactured by an organization for which the agency or a Member State ensures safety oversight, or

b) registered in a Member State, or

c) registered in a third country und used by an operator for which any Member State ensures oversight of operations,

have to comply with the regulation, unless regulatory safety oversight has been delegated to a third country and they are not used by a Community operator.

National authorities – such as the German Federal Office of Civil Aviation (LBA) – retain only limited scope for independent action in the certification of aircraft.[26] Only those aircraft are subject to national standards – and thus fall within the area of responsibility of the LBA – for which a type-certificate or a certificate of airworthiness has not been issued on the basis of the regulation and its implementing rules, and which belong to one of a number of categories; such as, for example, aircraft with a maximum of two seats and aircraft whose initial design was intended for military purposes only (cf. Article 4 (2) in connection with Annex II of the regulation)[27].

It has to be pointed out, however, that, due to its personnel and organizational structure, the EASA has not yet been able to regularly perform the tasks delegated to it (Article 15, Regulation 1592/2002). It has therefore fallen back on the possibility of

[24] Homepage at: http://www.easa.eu.int/home/.

[25] See Chapter 3 of Regulation (EC) No. 1592/2002.

[26] Schwenk/Giemulla 2005, p. 269.

[27] Schwenk/Giemulla 2005, p. 268.

empowering national aviation authorities.[28] In a contractual agreement between the EASA and the LBA of 30.03.2004, the LBA was empowered to perform the tasks listed in Article 15 of the regulation (issuing certificates of airworthiness and environmental certificates) on behalf of the EASA. The LBA carries out the delegated tasks on the basis of the regulation and rules issued pursuant to it. Should no rules exist, recourse can be made to regulations in effect in Germany. At present, It cannot be said how tasks will actually be performed in future by the EASA and the LBA, but long-term involvement of the national aviation authorities would appear to be likely.

2.3.2.2 The granting of type-certification and noise-certification

The basic regulation lays down the framework for the performance of tasks and procedures assigned to the EASA. These general standards are specified in implementing rules. In connection with type-certification and noise-certification, Regulation (EC) No. 1702/2003[29] on the issuing of airworthiness and environmental certificates needs to be mentioned.

A type-certificate has to be issued for products (aircraft, engine and propellers) (Article 5 (2) a), Basic Regulation). With type-certification, which contains design specifications (certification specifications) that have to be applied for the product, a so-called basic type is approved. In order for an individual aircraft to obtain a certificate of airworthiness it must also correspond with the basic type. Certification specifications (CS) are put into force by the EASA and published on its Website (www.easa.eu.int). They are based on Joint Aviation Requirements (JARs) elaborated by the Joint Aviation Authorities.[30] The JAA, as a working group, have no legislative power, which is why JARs, in which detailed technical specifications are laid down for specific aircraft, are only of a recommendative nature. This applies, however, only when JARs have not been adopted by national legislators or Community bodies in national or EU law (see Section 2.3.2.3 concerning the mandatory nature of certification specifications).[31] JAR-21[32], JAR-25 and JAR-145[33] are significant for the certification of aircraft. Certification specification CS-36 is of particular interest with regard to aircraft noise.

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[28] See the letter of empowerment of 26.09.2003, printed in: Schwenk/Giemulla 2005, p. 282.

[29] Commission Regulation (EC) No. 1702/2003 on the laying down of implementation rules for the airworthiness and environmental certification of aircraft and related products, parts and appliances as well as for the certification of design and production organizations of 24 September 2003, Official Journal L 243 of 27.09.2003, p. 6.

[30] Schwenk/Giemulla 2005, p. 277.

[31] Schwenk/Giemulla 2005, p. 29.

[32] JAR-21: Requirements of the Joint Aviation Authorities' certification procedures for aircraft and related products and parts. Amendment 1 – 1997 of 16.03.1998 as last amended by promulgation of 26.03.1999.

[33] JAR-145: Technical requirements and administrative procedures in civil aviation (94/C 297/10) of 25.10.1994 (Official Journal C 297/12).

The noise-certificate is of significance so far as the design and manufacture of products (aircraft and engines) and parts is concerned, and also with regard to type-certification (Annex 1, Part 21, Regulation (EC) No. 1702/2003). Noise abatement requirements and certification specifications are based on *Annex 16* of the Chicago Agreement; in the case of subsonic jet aircraft these are to be found in Volume I, Part II; Chapters 2, 3 and 4[34].

2.3.2.3 The legally-binding quality of certification specifications

The question of whether certification specifications (CS) are legally binding has not yet been finally resolved. The provisions of Article 249 of the EC Treaty do not provide a precise answer, since this article only relates to regulations, directives, recommendations and statements of the European Commission, the Council and the European Parliament. According to the wording of the basic regulation, however, and also to the explanatory notes that accompany certification specifications, the obligatory nature of certification specifications is to be assumed so far as Member States and affected companies are concerned. The provisions in Articles 13, 14, 43 and 45 of Regulation 1592/2002 on the issue of information, working methods, consultation of Member States, official publication and the possibility of judicial scrutiny of individual decisions, lead to the conclusion that certification specifications have a legally-binding quality.[35]

Until Regulation 1592/2002 came into force, Regulation (EC) 3922/91[36] referred to JAR-25 und JAR-145 with respect to type-certification provisions. This way, both JARs became valid EU law and had therefore also to be adopted in Germany.[37] This no longer applies, since, due to Article 57 (1) of Regulation 1592/2002, Annex II of regulation 3922/91 of 28.09.2003 was abrogated. JAR-25 and JAR-145 thus lost the status of a mandatory EC norm. According to Article 56 (1) of Regulation 1592/2002, the EASA was to take over certification tasks on the same day as the EC norms were repealed (Article 15 of Regulation 1592/2002). Member States could, however, continue to issue certificates and licences during a transition period of 42 months,[38] if this occurred in accordance with the implementation rules of the Commission (Article 56, (2) of Regulation 1592/2002). According to Article 57, (2) in connection with Article

34 See Annex I Part 21A-18 of Regulation (EC) No. 1702/2003; cf. also Article 6 (1) of the Basic Regulation: „Products, parts and appliances shall comply with the environmental protection requirements of Annex 16 of the Chicago Agreement as issued in March 2002 in Volume I and in November 1999 in Volume II, except for its appendices."

35 Schwenk/Giemulla 2005, p. 272 ff.

36 Regulation (EEC) No. 3922/1991 of the Council of 16.12.1991 on the harmonisation of technical requirements and administrative procedures in the field of civil aviation, Official Journal L 373 of 31.12.1991, p. 4; as last amended by Commission Regulation 2871/2000of 28.12.2000, Official Journal L 333 of 29.12.2000, p. 47.

37 JARs, which are still legally valid in the European Community – and thus also in Germany - are listed in Article 3 in connection with Annex II.

38 The transition period ends on 28.03.2007.

8 (2) of Regulation 1592/2002, Member States can apply national standards for the regulation of this area.

The mandatory application of JAR-25 (certification of large aircraft) is enforced in Germany through direct reference to JAR-25 in the second implementation ordinance relating to the regulation on the inspection of aircraft (*LuftGerPO*).[39]

2.3.2.4 Phasing out of *Chapter 2* aircraft

Following the conclusion of the phasing out of *Chapter 2* aircraft in the European Union on 31 March 2002, in accordance with Directive 92/14/EEC,[40] there is now a 24-hour ban on landing and take-off for aircraft of this class. Restrictions or instruments that concern *Chapter 2* aircraft are therefore obsolete and will no longer be considered. Corresponding regulations in German law are to be found in Article 11c *LuftVO* (air traffic regulations – *restrictions on the taking-off and landing of aircraft with jet engines*).

Implementation and the procedure for regulation of the gradual phasing out of *Chapter 2* aircraft in the EU proved to be extremely complicated and protracted. Among other things, the equipment of loud *Chapter* 2 aircraft with so-called *hushkits* – a retrofit muffler, which enabled classification in the more favourable *Chapter 3* class – became a problem. As a result of resistance in the USA, the EU regulation (the so-called *hushkit Regulation*[41]) was suspended and the process delayed and defused until the final ban on refitted aircraft (cf. inter alia Koch 2003). According to Knorr, this regulation was "one of the most contentious environment-policy-related statutory acts of recent years" [Knorr 2003/2004]. The successor to the *Hushkit Regulation*, which was withdrawn in 2002, is the EU Directive on operating restrictions at Community airports, which reflects the *balanced approach* developed by the ICAO (see comments in Section 2.3.5.1).

39 Second Implementation Regulation with respect to the regulation on the inspection of aircraft (airworthiness requirements for aircraft) of 3.02.2000 (BAnz. p. 4897), as last amended by the Regulation of 12.02.2003 (BAnz. p. 3701).

40 Directive 92/14/EEC of the Council of 02.03.1992 on the operating restrictions of aircraft of Part II Chapter 2 Volume 1 of Annex 16 to the Agreement on International Civil Aviation, 2nd Edition (1988), Official Journal L 76 of 23.03.1992, p. 21, as amended by: Directive EEC/20/1998 of the Council of 30.03.1998, Official Journal L 107 of 7.04.1998, p. 4; Directive EC/28/1999 of the Commission of 21.04.1999, Official Journal L 118 of 6.05.1999, p. 53; Regulation (EC) No. 991/2001 of the Commission, Official Journal L 138 of 22.05.2001, p. 12.

41 Regulation (EC) No. 925/99 of the Council on the registration and operation within the Community of certain types of civil subsonic jet aircraft, which have been refitted to comply with the standards laid down in Volume I Part II Chapter 3 of Annex 16, Official Journal L 115 of 04.05.1999, p. 1

2.3.2.5 Role and responsibilities of the European Civil Aviation Conference (ECAC)

The work of the ICAO is further pursued at the European level in the ECAC, an informal alliance of European states. The ECAC was founded in 1955 on the initiative of the European Council, and its membership now comprises 38 European states.[42] In contrast to the ICAO, the ECAC has no legislative power. Resolutions of the ECAC are non-binding recommendations to the Member States (cf. Article 1 (3) ECAC Constitution)[43]. It may not be overlooked, however, that the ECAC is an important institution so far as specialized work on European air transport policy is concerned, in particular through its "Meeting of Directors of National Aviation Authorities". This meeting has the task of preparing the ECAC's working programme, carrying out appropriate investigations and setting up working groups as necessary (Article 7 (2) ECAC Constitution).

2.3.3 National level

Aircraft must be equipped in such a way that the emissions they give rise to in regular operation do not exceed limits for the control of adverse environmental effects (Article 38 (1) s. 1 *BimSchG* – Federal Immission Control Act).[44] Furthermore, aircraft are subject to a minimization order, to the extent that during their operation avoidable emissions have to be prevented and unavoidable emissions reduced to a minimum (Article 38 (1) s. 2 *BImSchG*).[45] This general order of the Federal Immission Control Act is put into concrete terms in Article 2 (1), s. 2 No. 4 *LuftVG* (Air Traffic Act),[46] which lays down that an aircraft is only permitted to fly when its technical equipment is designed in such a way that noise arising during its operation does not exceed an unavoidable level consistent with the latest developments in technology.[47] Permission to fly must be revoked when the prerequisites defined in Article 2 (1) *LuftVG* are no longer fulfilled (Article 2 (4) *LuftVG*).

Type-certification must be carried out and permission to fly granted before an aircraft is licensed to fly (Article 2 (1) s. 2 *LuftVG*).[48] Noise-certification of the aircraft takes place within the scope of type-certification. Following consultations with the aviation industry, noise limits corresponding with the latest developments in technology are published in

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42 http://www.ecac-ceac.org/index.php?content=lstsmember&idMenu=1&idSMenu=10 .

43 Tietje 2001, p. 458.

44 Act on the prevention of harmful effects on the environment caused by air pollution, noise, vibration and similar phenomena (*Bundes-Immissionsschutzgesetz – BImSchG*) of 26 September 2002 (BGBl. I, p. 3830) as last amended by Article 1 of the Act of 25 Juni 2005 (BGBl I, No. 39, p. 1865)

45 Cf. Feldhaus 2005, § 38 marginal note 1 ff.

46 Luftverkehrsgesetz (LuftVG) of 1 August 1922, RGBl I 1922, p.681; newly formulated through the promulgation of 27. 3.1999, BGBl. I, p. 550; as last emended by Article 2 Act of 19. 4.2005, BGBl I, p. 1070.

47 Cf. also Stoermer 2005, p. 55.

48 Cf., however, the shifting of legislative responsibility to the EU level in: Section 2.3.2.

accordance with Article 3 (2) *LuftVZO* (air traffic licensing regulations)[49] by the Federal Office of Civil Aviation.

The requirements laid down by the *LuftVZO* for the operation of German aircraft include, in particular,

- permission to fly (through the granting of an airworthiness certificate – *LuftVZO*) and
- entry in the aircraft register (Article 14 *LuftVZO*).

The legal systematics of type-certification and permission to fly are discussed below.

2.3.3.1 Permission to fly (Articles 6 to 13 *LuftVZO*)

An aircraft is only entered in the aircraft register when it is in possession of permission to fly. The prerequisites for permission to fly are listed in Article 2 (1) No. 1 to 4 of the *LuftVG*. An important prerequisite is the type-certification of the aircraft (Article 2 (1) No. 1 *LuftVG*; Articles 1 to 5 *LuftVZO*). In addition, it also has to be shown that the technical equipment of the aircraft is designed in such a way that noise arising during its operation does not exceed an unavoidable level consistent with the latest developments in technology (Article 2 (1) No. 4 *LuftVG*). For this purpose, a noise-certificate is issued (Article 10 (4) *LuftVZO*) when compliance with Article 3 *LuftVZO* in connection with noise control requirements for aircraft is confirmed. Proof of compliance is provided by type-certification (see immediately below). Provided that the aircraft, for which permission to fly has been applied for, corresponds with the noise certificate, further proof of compliance with noise limits is not necessary.[50] Foreign noise-certificates are recognized when they correspond with the values laid down in Article 10 (5) and (6) *LuftVZO*.

Permission to fly is confirmation that no doubts or reservations exist concerning the safe use of the aircraft. In granting permission to fly, the state assumes responsibility both at a national and an international level for the airworthiness of the licensed aircraft (cf. Article 33 Chicago Agreement). The inspection concludes with the granting of a certificate of airworthiness (Article 10 (1) *LuftVZO*).

Permission to fly for aircraft from non-member countries

So far as concerns the granting of permission to fly to aircraft that have been manufactured outside the EU, two groups have to be distinguished:

1. New or second-hand aircraft manufactured outside the EU, which have been imported into Germany, where application is then made for permission to fly.

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[49] *Luftverkehrs-Zulassungs-Verordnung (LuftVZO)* in the version of the promulgation of 27 March 1999, BGBl. I, p. 610; as last amended by the regulation of4 April 2005, BGBl. I; p. 992.

[50] *BVerwG*, judgement of 29.01.1991, file no.: 4 C 51.89; *BVerwGE* 87, p. 33 (335).

2. Aircraft licensed outside the EU, which fly into Germany without permission to fly having been granted there.

For aircraft from the first group, which are imported into Germany, the competent authority of the state in which the aircraft was manufactured can issue either a special airworthiness certificate for the export of the aircraft or a normal airworthiness certificate. According to the *Multilateral Agreement on airworthiness certificates of imported aircraft*,[51] contracting states are obliged to mutually recognize the airworthiness of an aircraft for the purpose of import; this, however, only under particular circumstances (for example, in the case of compliance with minimum standards of airworthiness). The same applies to second-hand aircraft that have already been licensed abroad.

For aircraft from the second group, the standards in Article 33 Chicago Agreement apply, namely, that the airworthiness certificate, which is issued or recognized as valid in the contracting state in which the aircraft is registered, has to be recognized as valid by other contracting states. This applies, however, only when the requirements, according to which the certificate is issued or declared valid, are equal to or above the minimum standards of the Chicago Agreement. This means that aircraft licensed abroad, which comply with the noise limits of *Annex 16* of the Chicago Agreement, are generally permitted to fly into German airspace. This permission can be refused, however, on the grounds that the aircraft does not comply with national or European noise regulations that are more stringent than those of the ICAO.

2.3.3.2 Type-certification (Articles 1 to 5 *LuftVZO*)

Aircraft may only be manufactured in Germany on the basis of specific design regulations (airworthiness requirements) (Article 32 (4) No. 1 *LuftVG* together with Article 1 (1) No. 1 and Article 3 *LuftVZO*). Proof of compliance with these regulations is provided by examination of a basic type, at the conclusion of which type-certification is confirmed. The sense and purpose of the regulations are to preclude the serial production of aircraft that are not airworthy.[52] In a legal sense, type-certification amounts to state licensing of an aircraft, with the effect that individual aircraft, which have been constructed on the basis of the certificated type, can be licensed to fly (Article 15 ff. *LuftGerPO*).

Noise-certification takes place within the scope of type-certification. It has to be shown that the technical equipment of the particular type of aircraft is designed in such a way that noise and exhaust gas emissions arising during its operation do not exceed an unavoidable level consistent with the latest developments in technology (Article 3 (2) No. 2, Article 3 (3) *LuftVZO*). "Latest developments in technology" is a legally indefinite term without scope for assessment, which is concretized in practice by the Federal

51 Agreement of 22.04.1960 (BGBl. II 1962, p. 23).

52 Giemulla / Schmid, § 2 *LuftVG*, marginal note 5.

Office of Civil Aviation (*LBA*) (see Section 2.3.3.3 on the *LBA*)[53]. The *LBA* publishes prescribed limits for noise and exhaust emissions, following consultations with the aviation industry, in *Nachrichten für Luftfahrer NFL* (information for aeronauts) (Article 3 (2) No. 2 *LuftVZO*). Currently valid noise regulations for aircraft are laid down in the *Lärmvorschriften für Luftfahrzeuge (LVL)* of 1 August 2004.[54] The *LVL* refers in the case of civil subsonic aircraft to the compliance procedures and noise limits described in *Annex 16* to the Chicago Agreement (see Section 2.4).

Where doubt arises on the part of the responsible body during the licensing process as to whether the level of noise occurring during operation of the aircraft corresponds with that of the type inspected, that body can demand appropriate confirmation from a suitable organization of its choice (Article 8 (2) No. 6 *LuftVZO*).

Type-certification and the granting of permission to fly do not guarantee unrestricted use of airspace, since they are merely the prerequisite for taking up air transport.[55] The same applies for the noise-certificate (Article 11 c *LuftVO*).[56] According to Article 11 c (1) s. 1 *LuftVO*, civil aircraft with jet engines may only take-off and land in Germany when they have a noise-certificate or equivalent document of the state in which they are licensed. The noise-certificate is therefore the prerequisite for taking off and landing in the territory of the Federal Republic of Germany, but that does not imply access to airports at a particular time or the right to exemption from operating restrictions.[57]

2.3.3.3 The Federal Office of Civil Aviation

The Federal Office of Civil Aviation (*LBA*), as superior federal authority, is responsible for all matters concerning civil aviation. It reports to the Federal Minister of Transport, Building and Urban Development. The *LBA's* chief objective is the warding off of danger to aviation safety as well as public safety and order.

The duties of the *LBA* are regulated by statute.[58] The *LBA* undertakes the task of issuing type-certificates and permission to fly in Germany. Noise-certification, like the certification of engine emissions, is part of this task. Further duties are investigations –

[53] Giemulla / Schmid, § 3 *LuftVZO*, Rn 18; Schulte 2003, S. 125.

[54] The preceding regulation was, until July 2003 the „*Lärmschutzanforderungen für Luftfahrzeuge (LSL)*" (noise control standards for aircraft).

[55] Gronefeld 2003, p. 84.

[56] *Luftverkehrs-Ordnung (LuftVO)* in the version of the promulgation of 27 March 1999, BGBl. I p. 580, as last amended by the 8. *Zuständigkeitsanpassungsverordnung* (eighth ordinance on the adjustment of responsibilities) of 25 November 2003, BGBl. I, p. 2304.

[57] Gronefeld 2003, p. 84.

[58] *Gesetz über das Luftfahrtbundesamt* (Act on the Federal Office of Civil Aviation) of 30 November 1954, BGBl. I, p. 354, as last amended by Article 288 of the 8. *Zuständigkeitsanpassungs-Verordnung* (seventh ordinance on the adjustment of responsibilities of 29 October 2001, BGBl. I, p. 2785.

or the monitoring of investigations – to determine the airworthiness of aircraft, type-certification of the aircraft, granting permission to fly, maintaining the aircraft register as well as other relevant registers and the random control of the technical and operational condition of aircraft as a measure of aviation control according to Article 29 *LuftVG* (Air Traffic Act).

2.3.4 Interim conclusion

Regulations for the type-certification of aircraft are to be found at an international, European and national level, whereby noise control standards are based on the specifications of *Annex 16*. Figure 3 provides an overall view of the regulations to be applied for type-certification and noise control standards.

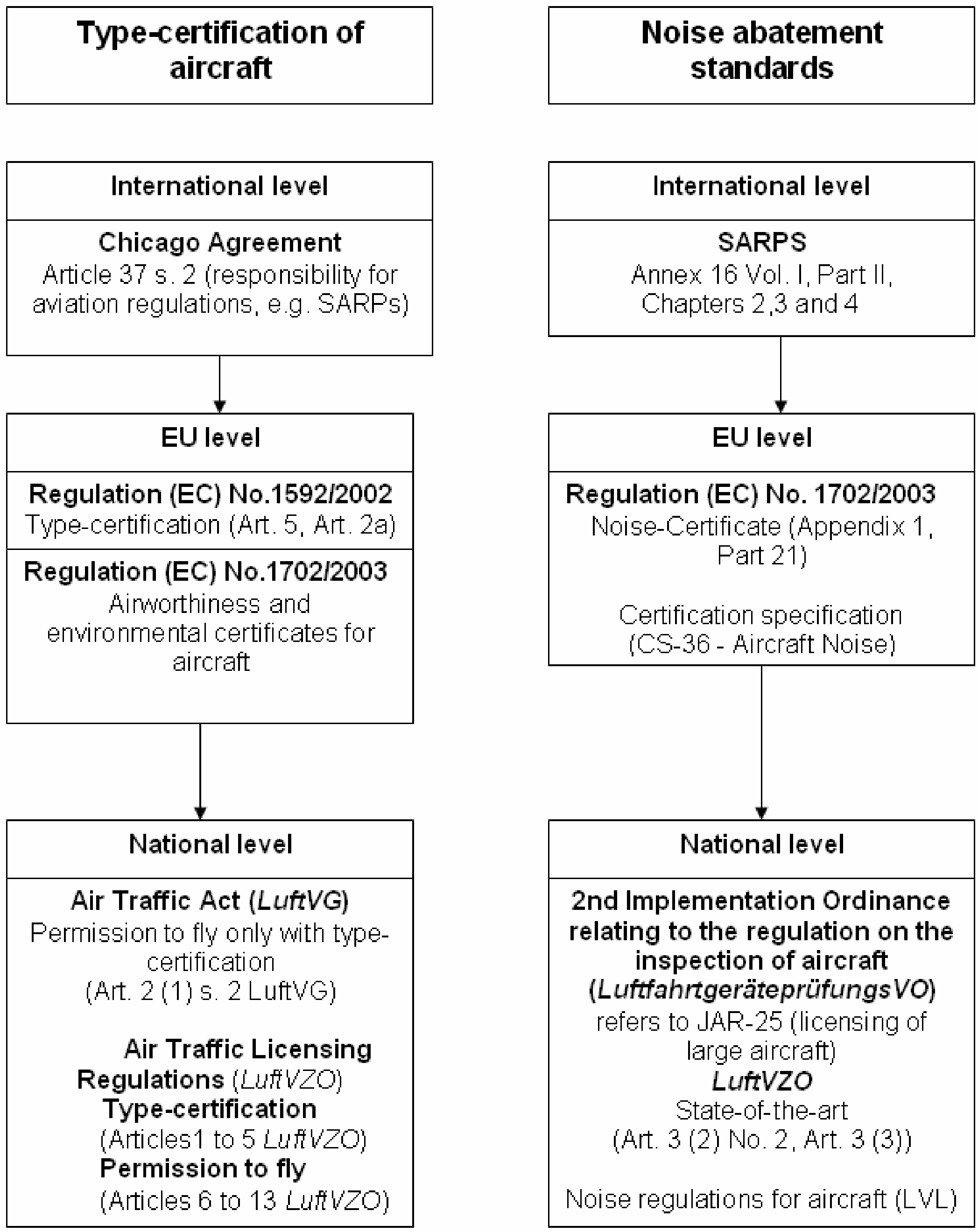
It is legally contentious, to what extent an obligation exists on the part of contracting states – and thus also Germany – to adopt regulations deriving from international standards and recommended practices of the ICAO (including noise-certification according to *Annex 16)*. Within the framework of type-certification, Germany could deviate from ICAO specifications in *Annex 16* and enact stricter noise limits for aircraft licensed in Germany, which would merely have to be notified to the ICAO.

There are two factors, however, which strongly argue against this: ICAO recommendations have such a wide scope that they effectively constitute an internationally valid licensing standard for newly developed aircraft. Due to international air transport integration, a tightening up of noise limits for aircraft licensed in Germany would put German owners at a disadvantage. For Germany is obliged, on account of Article 33 Chicago Agreement as well as bi- and multilateral air transport agreements, to tolerate operation in Germany of aircraft licensed abroad, in particular when these aircraft comply with ICAO standards.[59] Stricter regulations for German owners would have the inconsistent effect that foreign owners could operate in Germany with noisier aircraft of the same type.

It has also to be borne in mind that, with the coming into force of Regulation (EC) 1592/2002, responsibility for setting standards on type-certification and permission to fly passed to the EU. It is questionable to what extent certification specifications enacted on the basis of EC Directive 1702/2003 are binding on Germany. Within the framework of type-certification of aircraft in EU Member States, certification specification CS-36 (aircraft noise) of the EASA has to be observed, which again refers to ICAO specifications in *Annex 16*. Whether EASA certification specifications have a binding effect on Member States has not yet been legally resolved.

59 Schwenk / Giemulla 2005, p. 296.

Figure 3 Rules and regulations to be applied for type-certification and noise control standards



2.3.5 Regulations linked to noise-certification

Noise problems at airports can be lessened not only through the further development of quieter aircraft, but also through operating restrictions and bans on old or particularly loud aircraft. Influence on the development dynamics of quieter aircraft can be exercised at airports not only through restrictions and bans, but also through noise-related landing and take-off (LTO) charges. Both of these instruments are linked to *Annex 16* in so much as they fall back on *Chapter* classes. Directive 2002/30/EC,[60] which provides for operating restrictions including LTO bans at airports with noise problems, as well as its implementation in Germany, is discussed below. Following that, the basic principles of the Chicago Agreement as well as regulations on the determination of LTO charges at a European and national level are discussed.

2.3.5.1 Directive 2002/30/EC on noise-related operating restrictions

Directive 2002/30/EC[61] on noise-related operating restrictions has the aim of creating a uniform framework of regulations and procedures for operating restrictions at the airports of Member States.[62] In future, uniform operating restrictions should apply at airports with comparable noise problems.[63]

The aim of the following analysis is to establish whether the directive allows operating restrictions and, if so, which restrictions and under which circumstances and, in particular, for which noise-certification classes operating restrictions are permissible.

It has first to be established that the directive applies only to certain airports, namely civil airports in Member States with more than 50,000 flight movements[64] of civil subsonic aeroplanes in a calendar year (Article 2 (a) Directive 2002/30/EC) as well as city airports (Article 2 (b)) in connection with Annex 1 Directive 2002/30/EC).[65] The airports currently regarded as city airports are listed in Annex I of the directive,[66] according to which Berlin-Tempelhof is the only German city airport. The list is not exclusive, however, but can be amended in so-called regulating procedures.[67]

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[60] Directive 2002/30/EC of the European Parliament and of the Council of 26 March 2002 on the establishment of rules and procedures with regard to the introduction noise-.related operating restriction at Community airports, Official Journal L 85/40 of 28.03.2002.

[61] Directive 2002/30/EC of the European Parliament and of the Council of 26 March 2002 on the establishment of rules and procedures with regard to the introduction noise-related operating restriction at Community airports, Official Journal L 85/40 of 28.03.2002.

[62] Cf. on this point the aim in Article 1 (a) of Directive 2002/30/EC.

[63] Cf. Recital 7 of Directive 2002/30/EC.

[64] The number of flight movements is to be determined considering the average of the last three years at the airports in question before application of the rules of this directive. Article 2 (c) of Directive 2002/30/EG defines a civil subsonic jet aeroplane as a jet aeroplane with a maximum certificated take-off mass of 34,000 kg or more, or with a certified maximum internal accommodation of more than 19 passenger seats.

[65] City airports are understood by the directive to be "an airport in the centre of a large conurbation, of which no runway has a take-off run available of more than 2,000 metres and which provides only point-to-point services between European states or within European states, where a significant number of people are objectively affected by airport noise, and where any incremental increase in aircraft movements represents a particularly high annoyance."

[66] Among the city airports in Annex 1 are Berlin-Tempelhof, Stockholm Bromma, London City and Belfast City.

[67] Article 13 (3), Directive 2002/30/EC combined with Article 5 of Decision 1999/468/EC.

Type of operating restrictions

The directive allows operating restrictions at the above-mentioned airports taking into account the specifications in Articles 4, 5 and 6 Directive 2002/30/EC. The directive defines an operating restriction as

> *„a noise-related action that limits or reduces access of civil subsonic jet aeroplanes to an airport. It includes operating restrictions aimed at the withdrawal from operations of marginally compliant aircraft at specific airports, as well as operating restrictions of a partial nature, affecting the operations of civil subsonic aeroplanes according to time period" (Article 2 (e) Directive 2002/30EC)*

The term "operating restricting" is to be broadly defined. Every "noise-related action" should be covered, which has the aim of limiting or reducing access to an airport of civil subsonic jet aeroplanes. This broad interpretation is based, on the one hand, on the latitude allowed by the legally indefinite term "noise-related action", and on the other hand, on the word "includes", which indicates that the noise-related action mentioned is not exclusive.

Article 2 (e) of the directive explicitly mentions the following operation restrictions:

- Operating restrictions aimed at the withdrawal from operations of marginally compliant aircraft at specific airports.
- Operating restrictions of a partial nature affecting the operations of civil subsonic aeroplanes according to time period.

Annex II No. 1.4 of Directive 2002/30/EG mentions further operating restrictions, including

- noise limits,
- night limits or curfews,
- preferential runway use and
- noise charges.

Type-certification and noise-certification of aircraft, as defined by Directive 2002/30/EC, no longer count as operating restrictions. These are dealt with in regulations 1592/2002 and 1702/2003, which do not concern specific operating restrictions at airports, but rather a general operating licence for aircraft in Europe (cf. Sections 2.3.2.1 and 2.3.2.2).

Scope of operating restrictions – the *balanced approach*

The scope of possible operating restrictions at an airport has also to be clarified, and in particular the question whether the laying down and extent of operating restrictions is dependent on a specific noise classification.

It has initially to be observed that, according to Directive 2002/30/EC, Member States have to adopt a so-called *balanced approach* in dealing with noise problems at airports

(Article 4 (1) Directive 2002/30/EC). The *balanced approach* is a procedural concept for the abatement of aircraft noise, upon which the contracting states of the ICAO agreed at the 33rd ICAO Assembly in Resolution A33-7.[68] The Directive defines "balanced approach" in Article 2 (g) as

> *"an approach under which Member States shall consider the available measures to address the noise problem at an airport in their territory, namely the foreseeable effect of a reduction of aircraft noise at source, land-use planning and management, noise abatement operational procedures and operating restrictions."*

In the directive on operating restrictions the Commission[69] adopts the ICAO's procedural concept of a *balanced approach* for Community airports.[70] In Community legislation, however, further information on the background to the *balanced approach* and on its application in the EU is not available from documents connected with legislative proceedings concerning the directive on operating restrictions; and in the legislative materials, in particular, there are no specific comments on the "extent" of the *balanced approach*.[71] The European Parliament emphasized in its report for the first reading that the *balanced approach* is an important step towards the reduction of noise, but that stricter technical standards – for instance, stricter noise regulations – and at the same time the withdrawal of loud aircraft, are necessary in order to achieve an effective and permanent reduction of noise.[72] Resolution A 33-7 and explanatory documents are therefore very important for the interpretation of *balanced approach* so far as Community legislation is concerned.[73] Document 9829, "Guidance on the Balanced Approach to Aircraft Noise Management" should be considered.[74]

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68 Cf. concerning the „*balanced approach*": Assembly Resolution A33-7, in particular Annex B and C, at: www.icao.int/icao/en/env/a33-7.htm.

69 Cf. also Recital 10 of Directive 2002/30/EC.

70 Hobe/Stoffel 2002 point out that the definition of balanced approach corresponds fully with that of ICAO Resolution A 33-7 Annex C, and that it could not be adopted in the form of a dynamic reference, since that would violate the rights and duties of European legislative bodies to act autonomously.

71 Cf. The Proposal for a Directive of the European Parliament and of the Council on rules and procedures for noise-related operating restrictions at Community airports COM (2001) 695 final of 28.11.2001; the Report of the Committee on Regional Policy, Transport and Tourism (A5-0053/2002) final of 25.02.2002; the Report of the Committee of the Regions (Official Journal C 192 of 12.8.2002, p. 63); the Report of the Economic and Social Committee (Official Journal C 125 of 27.5.2002, p. 14).

72 Cf. Recital 11 in the Report of the Parliament, Official Journal C 47E of 27.02.2003, p. 392.

73 It is not decisive whether with this reference, as maintained by Hobe/Stoffel 2002 (p.199), the complete content of Resolution A 33-7 is actually part of Community law, or whether the Resolution was merely consulted within the scope of the legislative process.

74 ICAO; Guidance on the Balanced Approach to Aircraft Noise Management, DOC 9829 AN/451, First Edition 2004. The guidelines of the ICAO in Document 9829 are subordinate to SARPs, are not directly binding on ICAO contracting States, and merely serve the purpose of interpreting SARPs (cf. Concerning SARPs: Section 2.3.1.2).

The ICAO *balanced approach* to noise management at airports comprises the identification of a noise problem and the analysis of various available options for action. To achieve the aim of reducing noise as cost-effectively as possible, four elements have to be considered:[75]

- Reduction at source.
- Land-use planning and management.
- Noise abatement operational procedures.
- Operating restrictions.

The ICAO defines "operating restriction"[76] as any noise-related action that limits or reduces access of an aircraft to an airport.[77]

The definition of "operating restriction“ in Article 2 (e) Directive 2002/30/EC is based on that of the ICAO, but the description is more detailed. According to the definition in Article 2 (e), operating restrictions in terms of the directive are only permissible on the grounds of the noise characteristic of an aircraft ("noise-related action"). Operating restrictions for civil subsonic jet aircraft can be such that

- a certain number of (future or possible) flight movements at an airport be not exceeded ("limitation"),
- an existing number of flight movements be reduced ("reduction"),
- aircraft be banned from an airport ("withdrawn from certain airports"), which, however, the directive explicitly lays down only for "marginally compliant aircraft" and
- that access be limited in terms of a time period ("partial operating restrictions")

Investigation of the possible scale of operating restrictions consistent with the *balanced approach* can be regarded as verification of proportionality, a demand that all legal regulations in the EU and in Germany have to satisfy. Verification of proportionality, applied to the procedural concept of a *balanced approach*, implies that the measure taken must be appropriate and necessary to resolve the noise problem. A measure is appropriate when it supports the declared aim – in this case, noise reduction. A measure is necessary when no other equally appropriate but less restrictive measure for resolving the noise problem exists. A measure or a package of measures is defined in Directive 2002/30/EC as appropriate, when it is "not more restrictive than necessary

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[75] Cf. the explanation in the glossary of the ICAO's "Guidance on the Balanced Approach to Aircraft Noise Management”, DOC 9829. Cf. also Statement No. 1.11 of the Economics and Social Committee of the European Parliament, Official Journal C 125 of 27.5.2002, p.14.

[76] These are of particular importance in the context of this report and are therefore further examined.

[77] In accordance with ICAO, “Guidance on the Balanced Approach to Aircraft Noise Management”, No. 7.7.1. DOC 9829. Cf. also the similar explanation in the glossary of the aforementioned ICAO document.

to achieve the environmental objective established for a specific airport" (Article 4 (3), s. 1).

Besides these basic demands on operating restrictions, Directive 2002/30/EC contains special rules for **"marginally compliant aircraft"**. A landing and take-off ban can be imposed on such aircraft at an airport (Article 6 (1) s. 1 Directive 2002/30/EC). "Marginally compliant aircraft" are aircraft that **remain below maximum levels laid down in *Chapter 3* of Annex 16**, **of the ICAO agreement by a cumulative margin of not more than 5 EPNdB** (Article 2 (d) Directive 2002/30/EC). However, complete withdrawal of these aircraft may only be imposed when an assessment – conducted according to Article 5 Directive 2002/30/EC – of all possible measures, including partial restrictions, arrives at the conclusion that noise abatement objectives can be achieved in no other way. The procedure concerning the complete withdrawal of marginally compliant aircraft laid down in Article 6 (1) a) and b) of Directive 2002/30/EC differs from that in Article 9 of Regulation (EEC) 2408/92. Six months after the completion of the assessment and decision on the introduction of an operating restriction, no services over and above those operated in the corresponding period of the previous year may be allowed with marginally compliant aircraft at that airport (Article 6 (1) a) of Directive 2002/30/EC). Not less than six months thereafter, each operator may be required to reduce the number of movements of his marginally compliant aircraft serving that airport at an annual rate of not more than 20% of the initial total number of these movements (Article 6 (1) b Directive 2002/30/EC).

So far as all other *Chapter 3* aircraft are concerned **that are not among those marginally compliant**, an assessment in accordance with Article 5 combined with Annex II Directive 2002/30/EC could also come to the conclusion that only a partial or complete ban on landing and take-off would result in the achievement of noise abatement objectives at the respective airport. In the case of **city airports**, the Directive even allows explicitly for withdrawal of *Chapter 3* aircraft (Article 6 (2) combined with Article 6 (1) Directive 2002/30/EC). Member States can also exclude *Chapter* 3 aircraft from a city airport, subject to a *balanced approach*, by means of a stricter interpretation of the definition of marginally compliant aircraft in Article 2 (d). The definition of marginally compliant aircraft may not, however, be extended to such an extent that *Chapter 4* aircraft are also covered by it (Article 6 (2) Directive 2002/30/EC). Germany has made use of this extended definition of marginally compliant aircraft at city airports to include *Chapter 3* aircraft (see below in Section 2.3.5.2).

Directive 2002/30/EC contains no explicit ban on ***Chapter 4* aircraft**. However, on the basis of the rule in Article 6 (2), which links two different regulative aspects, conclusions are drawn with respect to *Chapter 4* aircraft in publications on air traffic law.

In the opinion of Hobe/Stoffel, it has to be concluded from the rule in Article 6 of Directive 2002/30/EC that uniform noise standards should apply for *Chapter 4* aircraft within the EU. It follows that type-related operating restrictions on *Chapter 4* aircraft –

for instance, in the form of "*Chapter 4* plus bonus list aircraft" – are not permissible.[78] The reason is that with Directive 2002/30/EC the Commission wanted to achieve final harmonization of regulations on the restriction of *Chapter 3* and *Chapter 4* aircraft. Hobe/Stoffel also come to the logical conclusion that the prohibition of stricter noise standards in the directive for *Chapter 4* aircraft at city airports – at which stricter standards are possible[79]– has then, for the purposes of Article 2 (a) Directive 2002/30/EC, to apply at all other airports (*argumentum a minori*).[80] Both these points are dealt with in detail below:

1) Time-related restrictions for *Chapter*-4 aircraft.
2) Tightening up noise standards for *Chapter* 4 aircraft (*Chapter* 4 bonus list)

1) Time-related operating restrictions for *Chapter 4* aircraft

A distinction has to be made between operating restrictions, which are directed at the withdrawal of aircraft at an airport, and partial operating restrictions. According to Directive 2002/30/EC, operating restrictions with the aim of withdrawal of *Chapter* 4 aircraft at an airport are not permissible. As the result of an examination according to Article 5 in connection with Annex II Directive 2002/30/EC, partial operating restrictions are also possible for *Chapter 4* aircraft.[81] This follows from the principle of proportionality recognized in EC law, according to which a measure has to be necessary. A measure is necessary, when no other measure is available that achieves the same purpose but is less restrictive for the party affected. Applied to a partial operating restriction for *Chapter 4* aircraft this means that such a restriction may be necessary when examination of proportionality shows that other less restrictive measures will not result in the successful control of the noise problem at an airport. Where a partial operating restriction is necessary, it must also – in line with the principle of proportionality – be appropriate; that is, the measure may not be completely out of proportion to the set purpose. Appropriateness, just as necessity, can exist in isolated cases at an airport with a noise problem[82]

This interpretation does not conflict with the rule in Article 6, which is more specific and enjoys precedence over the more general provisions of Articles 4 and 5 of Directive 2002/30/EC. Article 6 (1) lays down that with a 24-hour ban on landing and take-off for

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78 Stoffel 2004, p. 65

79 Cf. also Recital 16 of Directive 2002/30/EC.

80 Hobe/Stoffel 2002, p. 201.

81 Cf. also Gronefeld, V., „Die Berücksichtigung der Lärmklassifizierung von Flugzeugen in der Flughafenplanung“, who points out that Directive 2002/30/EC provides no guarantee of restriction-free operation of Chapter 4 aircraft, in: Ziekow, J. (Hrsg.), Speyerer Luftverkehrsrechtstag 2003, p. 83.

82 The legitimacy of operating restrictions in Germany for Chapter 4 aircraft has not yet been judicially resolved. The decision of the Federal Administrative Court (*BVerwG*) on Berlin-Brandenburg International (BBI) Airport of March 2006 could, however, provide further insight the permissibility of operating restrictions for Chapter 4 aircraft in Germany.

marginally compliant aircraft – in departure from procedures according to Article 9 of Regulation 2408/92/EEC – the procedure laid down in Article 6 (1) a) and b) of Directive 2002/30/EC has to be applied. The priority of Article 6 thus relates only to restrictions aimed at the withdrawal of aircraft (see also the heading of Article 6), but not however to partial restrictions.

2) **Tightening up noise standards for *Chapter 4* aircraft and the introduction of a *Chapter* 4 bonus list**:

Article 6 (2) of Directive 2002/30/EC allows Member States, as an exception, to apply a different definition of marginally compliant aircraft at city airports, aimed at the withdrawal of aircraft at such airports. This is a *special rule* for tightening up noise standards for marginally compliant aircraft at *city airports*, and the definition of these aircraft may not go so far that *Chapter 4* aircraft are also covered.

Article 4 (4) of Directive 2002/30/EC stipulates in general terms, however, that the adoption of performance-related operating restrictions has to be based on noise values according to *Annex 16*. It follows from this that Member States may not transfer noise limits within the existing *Chapter* classification in Annex 16 with respect to performance-related operating restrictions. They may not therefore set the noise limit for the start of *Chapter 4* at a high level, or differentiate within a chapter for the purpose of performance-related operating restrictions. Article 2 (a) of Directive 2002/30/EC prohibits Member States from putting into effect a *Chapter 4* bonus list at city or other airports aimed at a differentiated charging system or other restrictions.

The directive on operating restrictions does not, however, prohibit Member States from laying down stricter noise limits for the certification of aircraft than those in *Chapter 4*, since the directive only applies to the operation of aircraft. The tightening up of certification limits in Member States would only then violate European law if the directive had intended to regulate definitively the framework for noise limits. The Commission states in the explanatory memorandum to the proposed directive – under the heading, subsidiarity and proportionality – that the key parameters requiring a harmonized approach are[83]

1. the threshold in decibels, used for the definition of marginally compliant aeroplanes (Article 6) and
2. the assessment method related to noise mitigation (Article 5 and Annex 2).

According to the directive's explanatory memorandum, no further regulation of harmonization is envisaged, particularly not on the question of whether Member States may tighten up noise limits for aircraft certification beyond *Chapter 4*.

[83] COM (2001) 695 final of 28.11.2001, Proposal for a Directive of the European Parliament and of the Council on rules and procedures for noise-related operating restrictions at Community airports, marginal note 25, p. 8.

2.3.5.2 Implementation of Directive 2002/30/EC in Germany

The specifications of Directive 2002/30/EC on operating restrictions were adopted in Germany with the 8th Ordinance on the Amendment of the *Luftverkehrs-Zulassungs-Verordnung – LuftVZO* (air traffic licensing regulations) of 4 April 2005. A special subsection (Article 48 (a) to (f) *LuftVZO*) – "Noise-related operating restrictions on marginally compliant civil subsonic jet at airports" – was added to the *LuftVZO*[84] as well as a new Appendix 5,[85] which largely implemented the specifications of the directive on operating restrictions.

Article 48a *LuftVZO* thus adopts the definition of Article 2 of Directive 2002/30/EG supplemented by the definition of a "developing country". Article 48b *LuftVZO* regulates – in implementation of Article 6 of Directive 2002/30/EC – **operating restrictions** for marginally compliant subsonic jet aircraft. According to Article 48b (1) *LuftVZO*, a landing and take-off ban on marginally compliant aircraft at an airport is at the discretion of the aviation authority. The procedure to be applied in the case of such a ban has been adopted from Article 6 (1) (a) and (b) of Directive 2002/30/EC in Article 48d *LuftVZO*.

With respect to **city airports,** aircraft licensing regulations (*LuftVZO*) make use in Article 48b (2) of the possibility to enforce stricter measures than those contained in Article 6 (2) of Directive 2002/30/EC, which allows Member States to introduce measures that are more stringent, in terms of the definition of marginally compliant aircraft at city airports, provided that these measures do not affect civil subsonic aircraft that comply with the noise standards of *Chapter 4* of *Annex 16*. This means, in effect, that according to Article 6 (2) bans on landing and take-off can be imposed also on *Chapter 3* aircraft at city airports. The rule in Article 48b (2) *LuftVZO* fully exploits the scope of Directive 2002/30/EC, in so much as it places the imposition of bans on landing and take-off at city airports in Germany, also for aircraft that fall below the cumulative maximum value of *Chapter 3* aircraft by up to 10 EPNdB, at the discretion of the aviation authority (cf. also the diagram in Figure 12). This rule will produce no far-reaching effect in Germany, however, since it has up to now only been applicable for the city airport of Berlin-Tempelhof.

With regard to regulatory possibilities for operating restrictions for **aircraft other than marginally compliant aircraft**, the provisions in Articles 48 (a) to (f) *LuftVZO* fall short of the instructions in Articles 4 and 5 of Directive 2002/30/EC. Article 4, for instance, also provides instructions on operating restrictions for aircraft other than marginally compliant aircraft, according to which, in the case of noise problems at airports, Member States may consider, on principle and within the scope of a *balanced approach*, operating restrictions such as noise charges and night limits or curfews.

[84] In the version of the promulgation of 27 March 1999, BGBl. I, p. 610, as last amended by the 9th Ordinance on the Amendment of the *Luftverkehr-Zulassungs-Ordnung LuftVZO* (Air Traffic Licensing Regulations) of 27 July 2005, BGBl. I, p. 2275.

[85] Appendix 5 of the *LuftVZO* corresponds with Annex II of Directive 2002/30/EC.

Implementation in the *LuftVZO* regulates, on the other hand, only operating restrictions for marginally compliant aircraft.

Finally, the exemption of marginally compliant aircraft registered in developing countries, which is regulated in Article 8 of Directive 2002/30/EC, is implemented in Article 48 (f) *LuftVZO*, which, in Article 48 (b), exempts marginally compliant aircraft from developing countries under certain circumstances up to 28 March 2012.

2.3.5.3 Conclusions from the Directive on Operating Restrictions

On account of Directive 2002/30/EC, operation restrictions cannot generally be imposed at Community airports, but rather only after individual assessment in respect of each airport on the basis of a *balanced approach*. The directive allows Member States, on the basis of a *balanced approach* and in compliance with the specifications in Article 6, to impose a 24-hour ban on landing and take-off at an airport as defined in the directive for aircraft that fall below the maximum noise limit laid down in *Chapter 3* by a maximum cumulative margin of 5 EPNdB (marginally compliant aircraft). In Germany, a 24-hour ban on landing and take-off can also be imposed at city airports on aircraft that fall below the maximum cumulative limit of *Chapter 3* aircraft by up to 10 EPNdB (Article 48 (b) LuftVZO).

Member States can also impose partial operating restrictions on *Chapter 4* aircraft in compliance with the procedure laid down in Article 5 in connection with Annex II of Directive 2002/30/EG.

Member States may not differentiate within existing *Chapter* classes of *Annex 16* for the purpose of performance-related operating restrictions. *Chapter* 4 plus bonus list is not permissible. In addition, Member States cannot put into effect regulations on the complete withdrawal of aircraft at an airport, which go beyond noise limits of *Chapter* 3. Regulations, which have the intention of withdrawal of *Chapter* 4 aircraft, are in contravention of European law.

2.3.5.4 Basic legal principles for the levying of charges on landing and take-off

Through the levying of charges on landing and take-off (LTO), influence can be exercised on the types of aircraft that an airline operates at an airport. However, legal specifications at an international, Community and national level have to be observed in the formulation of LTO charges. At the level of international law, these are the "ICAO Policies on Charges for Airports and Air Navigation Services"[86], the "Airport Economics Manual"[87] as well as the procedural concept for operating restrictions at airports – the so-called *balanced approach* – contained in Resolution 33-7, which was agreed upon by contracting states at the 33rd ICAO Assembly. At the EU level, points of reference

[86] Adopted by the Council on 22.06.1992 at the 14th Meeting of the 136th Session, as amended on 8.12.2000 at the 18th Meeting of the 161st Session, Doc 9028/6, 6th Edition, 2001.

[87] Airport Economics Manual, Doc 9562, First Edition, ICAO 1991.

can be found in the withdrawn Proposal COM (2002) 684 final on noise charges[88] as well as in implementation of a *balanced approach* in Article 4 of Directive 2002/30/EC. The formulation of charging regulations in Germany takes place on the basis of an agreement under private law between airline companies and airport operators. In formulating such agreements, standards developed judicially in connection with equitableness have to be borne in mind, as well as the antitrust provisions of the *Gesetz gegen Wettbewerbsbeschränkungen – GWB*[89] (Act against Restraints on Competition). An analysis of international, European and German legislation indicates that the following standards have to be observed in the formulation of noise-related LTO charges in Germany:[90]

- Noise charges should only be imposed at airports with problems of aircraft noise. There are, however, no legal specifications as to the definition of problems of aircraft noise.
- The introduction of noise-related LTO charges has to be appropriate and necessary (*balanced approach*). This means that noise-related LTO charges must be appropriate for resolving the noise problem at an airport. They are necessary when no other instrument is available, which is equally appropriate but has less effect on airport users.
- Noise charges must be **non-discriminatory**. This is the case when the levying of scaled noise charges is on technical grounds; for example, the noise level of each aircraft on landing and at take-off. According to both ICAO recommendations and the Proposal of the EU Commission for a Directive COM (2002) 683, the noise level established in the noise-certification of aircraft on the basis of Annex 16 Volume 1 of the Chicago Agreement is regarded as the appropriate noise level.
- Noise charges must be **transparent**. This requires, in particular, that noise-related LTO charges be separately shown as a component of total charge per aircraft, and that both their calculation and the method of calculation be comprehensible to airport users.
- Noise charges must cover the costs of the prevention and reduction of noise problems (**cost-recovery principle**). Such costs include services, measures and facilities such as noise abatement measures in buildings.

88 The amended Proposal for a Directive COM (2002) 683 final of 29.11.2002 replaces the Proposal for a Directive COM (2001) 74 final of 20.12.2001 on the establishment of a Community framework for noise classification of civil subsonic aeroplanes for the purpose of calculating noise charges.

89 *Gesetz gegen Wettbewerbsbeschränkungen (GWB)*, as promulgated in the new version of 15.7.2005, *BGBl*. I, p. 2114; as last amended by Article 2 (18) of the Act of 12.8.2005; *BGBl*. I, p. 2354.

90 A detailed analysis of legislation on LTO charges at all three levels is to be found in the report Öko-Institut 2004.

- Noise-related LTO charges should have a **neutral effect on revenue**.
- Noise-related charges should be determined on the basis of sound accounting principles and combined with other charges, for example through surcharges and deductions,
- A (noise-related) LTO charge may not be set at such a level that it amounts to a ban.
- An increase in noise charges should be only gradual, to avoid unreasonable problems on the part of airport users. Under certain circumstances another approach may also be employed.
- Before a charging system is introduced at an airport, airport users should be involved at an early stage (**principle of consultation**).

These criteria should be taken into account in the further development of existing LTO charging systems (see also the comments in Section 2.6).

2.3.6 Implications of legal regulations for proposed measures for the control of noise problems

The legal regulations described in Section 2.3 have the following implications for short-term as well as medium- to long-term measures for the control of noise problems at German airports.

2.3.7 Proposed short-term measures

Implementation of proposed short-term measures for the tightening up of noise limits takes place at the level of national law. Short-term action (within one or two years) is generally not possible through amendment of the legal framework, since legislative procedures in Germany and the EU take at least two years. Proposed short-term measures have therefore to be realized within the existing legal framework. The possibilities of partial operating restrictions depending on *Chapter* classifications are also discussed. Due to the thematic connection, operating restrictions aimed at the complete withdrawal of *Chapter 3* aircraft at an airport, or at all airports in Germany are dealt with, even when, in this case, a medium- to long-term measure is involved. The possibility of tightening up charging systems at airports through noise-related LTO charges is also discussed.

2.3.7.1 Operating restrictions and bans on the basis of *Chapter* classes

The term "operating restriction", as defined in Article 2 (e) of the directive on operating restrictions, is to be broadly interpreted. It comprises, among other things

- the laying down of noise limits at an airport,
- the preferential use of runways,
- the levying of noise charges,

- operating restrictions aimed at the withdrawal of marginally compliant aircraft at certain airports and
- partial operating restrictions that limit the operation of civil subsonic aircraft according to time period.

Only the two last-mentioned restrictions are investigated in this report.

Operating restrictions cannot be generally adopted at all airports in Germany (or in other EU countries). Different forms of operating restrictions must be individually determined for each airport on the basis of a *balanced approach*. Where the assessment for a particular airport shows that operating restrictions can be applied in a limited sense as an instrument of noise abatement, they cannot be equally applied to all aircraft *Chapters*:

- 24-hour LTO bans can be adopted for all *Chapter 3* aircraft at German city airports on the basis of a *balanced approach* (Article 48b (2) *LuftVZO*).
- So far as concerns *Chapter 4* aircraft, it has not yet been legally resolved whether partial operating restrictions may be adopted. The authors of this report are of the opinion, however, that according to Directive 2002/30/EC partial operating restrictions are possible at all airports on the basis of a *balanced approach* (see the discussion in Section 2.3.5.1).

Partial operating restrictions on *Chapter 3* aircraft are also possible at airports other than city airports. Operating restrictions for *Chapter 3* aircraft, aimed at the complete withdrawal of such aircraft from German airports, are, according to the directive on operating restrictions, not possible. The binding effect of ICAO Resolution A 33-7 on contracting states is ambiguous. It is therefore a matter of controversy, whether the EU could enact the withdrawal of *Chapter 3* aircraft by way of amendment of the directive on operating restrictions. In Resolution A 33-7, the ICAO rejects operating restrictions for *Chapter 3* aircraft that are aimed at the withdrawal of such aircraft, for the reason that such withdrawal is not justified on cost-benefit grounds.[91] Operating restrictions should only be possible at a local level, and then only on the basis of a *balanced approach*.[92] Were the EU to go it alone, the result would be problems similar to those that arose between the EU and the USA in connection with the phasing-out of *Chapter 2* aircraft and the Hushkit Regulation. All the more so since, to settle the dispute on the phasing-out of *Chapter 2* aircraft, the EU adopted the ICAO's *balanced approach* to the abatement of noise problems in the directive on operating restrictions. And this does not foresee a general ban on certain *Chapter* aircraft, but rather the individual solution of noise problems at particular airports.

[91] Cf. EU Commission Proposal on operating restrictions (COM) 2001 695 final, Section 2.7 of the Explanatory Memorandum.

[92] Comments on the phasing-out of Chapter 3 at the ICAO level ICAO from Dr. Assad Kotaite

2.3.7.2 Tightening up charges in Germany

Within the scope of proposed short-term measures, the noise-related share of LTO charges at German airports could be increased through the introduction of a *Chapter 4* bonus list. In the opinion of the authors of this report, the introduction of a bonus list for *Chapter 4* aircraft, with the aim of differentiation between noisy and less-noise aircraft within this *Chapter*, is impermissible (see the thorough discussion in Section 2.3.5.1). It has not yet been judicially settled, however, whether, following enactment of the directive on operating restriction, such a *Chapter 4* bonus list is permissible.

In general it has to be said that the control effect of noise-related charges on the improvement of the noise situation at airports is not yet verifiable. As the analysis of LTO charging systems in an Öko-Institut report[93] shows, the present structure of noise-related LTO charges contains purposeful elements, which are recommended for further development (see Section 2.6). Basically, however, it was ascertained for the status quo that the financial incentive is insufficient to bring about the intended reactions on the part of airline companies (that is, operation of quieter aircraft and changing the operating times or location of flight movements). That present noise-related LTO charging systems hardly produce a control effect was confirmed by analysis of airline cost structures. Reactions on the part of airlines could only be expected if the noise component of LTO charges were to be increased well beyond status quo limits.

2.3.8 Medium- and long-term measures

Long-term measures basically comprise noise reduction at source (aircraft engine and airframe) as well as planning measures in and around airports. It is not intended to deal in depth with planning measures. In the case of noise reduction at source, however, the tightening up of noise limits through the introduction of a new noise class ("*Chapter 5*") at the ICAO or EU level, or by Germany alone, should be considered. Noise reduction at source should provide the focus of attention of international aviation; for this approach corresponds with the pre-eminence of damage prevention in the field of environmental protection, since the propagation of avoidable aircraft noise would be prevented.[94]

2.3.8.1 Tightening up noise limits for aircraft certification at the ICAO level

As a result of its far-reaching empowerment in Article 37 of the Chicago Agreement, the ICAO has virtually unlimited power to create regulations relating to aviation law.[95] The tightening up of noise limits for civil aircraft by the ICAO (for example, through a

93 Öko-Institut 2004.

94 Rosenthal, p. 144.

95 Cf. on the legislative power of the ICAO: Rosenthal, p. 150.

new "*Chapter 5*) is therefore possible. In making noise limits more stringent the following criteria have to be met:

Tightening up noise limits must be compatible with the fundamental aims of the ICAO. These are to develop the principles and techniques of international aviation as well as to promote the planning and development of international aviation. According to Article 44 Chicago Agreement, further aims are to guarantee the safe and orderly growth of international civil aviation throughout the world, to ensure safe, regular, efficient and economic air transport and to promote aircraft safety.

Furthermore, the recommendations of the CAEP (Committee on Aviation Environmental Protection) must be technically feasible, economically reasonable and beneficial to the environment.[96] There are therefore no criteria related to the timing of adoption of new standards and recommended practices (SARPs).

Regulations on the phasing out of *Chapter 3* are legally possible at the ICAO level, but they would contradict the procedural concept of a *balanced approach*, according to which the noise problems of an airport have to be solved individually and not through the general withdrawal of aircraft. For the general withdrawal of *Chapter 3* aircraft the ICAO would have to exclude these aircraft from a *balanced approach* and develop a "withdrawal plan" for *Chapter 3* aircraft.

2.3.8.1.1 Tightening up noise limits for the certification of aircraft in the EU, or merely in Germany

The introduction of more stringent noise limits for the certification of aircraft in the **EU** is basically possible. Member States transferred responsibility for setting standards on type-certification and permission to fly for jet aircraft to the EU with Regulation EC 1592/2002. Legal opinion varies, however, as to the extent to which contracting states are obliged to adopt regulations contained in the standards and recommended practices of the ICAO, which include noise-certification according to *Annex 16*. The EU could deviate within the framework of type-certification from ICAO specification and adopt more stringent noise limits for aircraft licensed in the EU. This would merely have to be notified to the ICAO.

It is not clear, however, whether Germany could also unilaterally tighten up noise limits for certification. The introduction of stricter noise limits in Germany was possible before Regulation 1592/2002 came into force, although this applied only to aircraft licensed in Germany. On account of Article 33 Chicago Agreement, aircraft licensed in other countries and compliant with the noise-certification specifications of the ICAO cannot be denied landing and take-off rights at German airports. The restriction to aircraft licensed in Germany applies also after the coming into force of EC Regulation 1592/2002. Unresolved, however, is the question whether certification specifications – for example, CS-36 on aircraft noise – issued on the basis of Regulation 1592/2002 are binding on Germany. Type-certification of aircraft in the Member States of the EU has

[96] Cf. the comments in the Clean Air Report, June 2003.

to take account of certification specification CS-36, issued by EASA, which again refers to ICAO specifications in *Annex 16*, Whether these certification specifications have a binding effect upon Member States has not yet been judicially resolved.

Reservations exist, however, concerning the tightening up certification at the EU level and – even more so – at the national level. ICAO recommendations are of such great extent that they virtually constitute internationally valid certification standards for newly developed aircraft.[97] Due to the international integration of air transport, tightening up noise limits for aircraft licensed in Germany would put German owners at a disadvantage, since Germany is obliged under Article 33 of the Chicago Agreement – as well as under bi- and multilateral air transport agreements – to tolerate the operation of aircraft licensed in other countries, in particular when these aircraft comply with ICAO standards[98]. Tightening up certification just for German owners would have the inconsistent outcome that foreign owners would be able to operate in Germany with noisier aircraft of the same type. More stringent certification values could also be considered at the EU level. In contrast to unilateral action, the noise-reduction effect would be greater, since aircraft newly licensed in the EU could operate at all European airports and thereby contribute to an improvement in the noise situation.

2.4 Methodology (evaluation methods)

The method to be applied for noise-certification is described in Appendix 2 *Chapter 3* (Evaluation Method for Noise-certification) of *Annex 16*. The methodical section primarily contains a definition of the noise index to be applied, the scope of noise measurement and the test environment, the applicable calculation as well as documentation.[99] The method for measurement and evaluation of aircraft noise emissions within the framework of noise-certification procedures comprises a series of assumptions and parameters, which are not applied in other noise recording methods. Particular reference has to be made in this connection to the noise index EPNL (effective perceived noise level) that has to be calculated, including tone correction. The selected standardized procedure enables comparison of the results of noise-certification, and it guarantees global classification of noise standards.

Noise index

Within the scope of *Annex 16*, the noise index EPNL is employed for the measurement of noise (in units of EPNdB) during take-off and landing, which is then evaluated

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[97] The uniform application of SARPs is regarded to be necessary in line with international interests, cf. Mengel, Constanze/Siebel, Heiko, *Ziviler Luftverkehr und Klimaschutz*, in: Koch, H.-J., Carpar, J., *Klimaschutz im Recht*, p. 284.

[98] Schwenk / Giemulla 2005, p. 296.

[99] The description of the evaluation method is supplemented by ICAO Doc. 9501, which specifies and standardizes technical procedures in line with *Annex 16*. For further information see below under Framework.

mathematically. This effective perceived noise level, which is applied, in particular, for certification measurements, was introduced by the American FAA and adopted by the ICAO (Piehler 2003). EPNL distinguishes itself as single-event sound level from other noise indices by allowing for special tone and time corrections, which register the special characteristic of aircraft noise.[100] In contrast to other single-event sound levels for the recording of aircraft noise (for example, L_{AZ} and L_{Amax} according to DIN 45 643[101]), it is not A-weighting that is applied, but rather a procedure defined in ISO 3891,[102] so that comparison with other noise levels with A-weighting is not allowed[103] (see also the comparison of certification levels and A-weighted peak levels in Section 2.5). The noise index EPNL is based on measured sound pressure level (SPL), calculation of the perceived noise level for one-third octave bands in the frequency range of 50 to 10,000 Hz, evaluation of the duration of noise during flyover as well as on tone correction. It therefore represents a subjective value, which is intended to describe the exposure of those affected by noise.

Formula: L_{EPN} or $EPNL = 10 * \log_{10} \frac{1}{T_O} \int_{-\infty}^{+\infty} 10^{PNLT/10} dt$ in [dB] or [EPNdB]

with $T_O = 10s$

$$PNLT(k) = PNL(k) + C(k)$$

$$PNL(k) = 40 + \frac{10 * \log_{10} N(k)}{\log_{10} 2}$$ and $C(k) = Tonkorrektur$

$$N(k) = 0.85 \cdot n(k) + 0.15 \sum_i n(i,k)$$

with n(i, k) : perceived noisiness

n(k) : max(n(i,k))

k : time increment index

[100] Perceived noise level (PNL) was developed for the evaluation of noise from jet aircraft (Kryter 1959 a and Kryter 1959 b). The backdrop to these investigations is provided by the generational change from propeller- to jet-based operation. On the basis of interviews on noise annoyance, an alternative evaluation was developed, among others, by Kryter, which shows a better correlation between nuisance and noise index than previous methods.

[101] DIN 45 643, measurement and assessment of aircraft noise; for example Part 2 on aircraft noise monitoring systems according to Article 19a LuftVG.

[102] ISO 3891 *Acoustics - Procedure for describing aircraft noise heard on the ground*, 1st Edition 1978, corrected and reprinted 1981.

[103] The simplified formula EPNdB = dB(A) + 13 can be applied to compare values in EPNdB and dB(A), (ADV 2005).

Framework

The choice of the ideal test environment is determined by weather conditions (temperature, wind, absorption etc.) and the flight path (vertical and lateral position) for standardized conditions. Measurement should be adapted to the particular task. The test environment should ideally be a flat terrain, and significant influence on the sound field should be avoided. All parameters have to be documented and monitored (see Reporting). Should test conditions during measurement not correspond to reference conditions, appropriate corrections have to be made for the comparison of flight tests. This concerns altered flight profiles, atmospheric absorption as well as noise-emissions of engines (with speed and thrust corrections). Besides *Annex 16*, reference should also be made to ICAO Document 9501 (*Environmental Technical Manual, ETM*), which contains detailed information on the standardization of methods.

Re-certification

Re-certification of aircraft types describes a change in the original certification class (from *Chapter 3* to *Chapter 4*) as a result of re-examination, which is not conditional on aircraft modification. This re-examination should take account of changes in the technical details of rules and regulations, and guarantee compliance with current technical standards. This affects *Chapter 3* aircraft that have been certified according to *Annex 16* (Böttcher 2004). The administrative aspect of re-certification is detailed in *Annex 16* (Chapter 4.7) and the technical description in the Environmental Technical Manual (ETM Appendix 8). The necessary procedure is on the same scale as that for new aircraft, and has to be carried out uniformly. Re-certification enables aircraft types, which have been allocated to *Chapter* 3 due to the date of their type-certification, to be later reassigned to a more favourable *Chapter* class. Re-certification is particularly necessary from the viewpoint of airlines and aircraft operators, so that as favourable a classification as possible can be obtained with respect to local noise abatement regulations at airports (for instance, classification in charging systems, regulative measures etc.), which often carry out categorization on the basis of *Chapter* classes.

Evaluation method

The appropriate evaluation method is detailed in *Annex 16* (especially Appendix 2 *Evaluation method for noise-certification*) (ICAO 2005), ICAO Doc. 9501[104] (ICAO 2004 c) as well as in ISO 3891, and it applies uniformly to both *Chapter 3* and *Chapter 4* jet aircraft. The German regulations (LVL) stipulate that noise measurements have to be conducted in accordance with the methods laid down in *Annex 16* (see *LVL* 1.4).

Reference conditions are quoted for the evaluation, namely, temperature 25 °C, pressure 101,325 kPa or 1,013 bar and relative humidity 70 %. Components of the

[104] ICAO Doc. 9501: Environmental Technical Manual on the Use of Procedures in the Noise-certification of Aircraft, 3-Edition – 2004, ICAO 2004 b

evaluation system to be used are also listed (wind screen, microphone system, recording and reproducing unit as well as analytical unit), each of which have to be capable of measuring sound pressure levels in the one-third octave band. The analytical unit should meet the requirements of Class 2, IEC 61260[105]. Calibration according to the accuracy requirements of Class 1L, IEC 60942[106] is likewise a prerequisite. Background noise is measured separately; it should be 20 dB below maximum PNL, and, within the t_{10} period,[107] aircraft noise should also exceed background noise by 3 dB in each measurement.

The sound pressure level over the measuring device is recorded in the one-third octave band for the frequency range of 50 Hz to 10,000 Hz. A slow weighting has to be selected for the measurement. Should the measuring device not allow slow weighting, this can be simulated by means of defined computation subsequent to the test. The measuring device also has to be regularly calibrated.

The test site for the three reference noise measurement points (take-off, flyover and landing) are specified as follows (see also Figure 4):

- **Flyover reference noise measurement point** (take-off): the point on the extended centre line of the runway and at a distance of 6,500 metres from the start of roll.
- **Lateral measurement point** (take-off): the point on a line parallel to and 450 metres from the centre line of the runway, where the noise level during take-off is at a maximum (*lateral full-power reference noise measurement point.*[108]
- **Approach measurement point** (landing): the point on the ground, on the extended centre line of the runway, 2,000 metres from the threshold. On level ground this corresponds to a position 120 metres vertically below the 3° descent path, originating from a point 300 metres beyond the runway threshold (*approach reference noise measurement point*).

A list of institutions licensed to evaluate is published by the *LBA* (Federal Office of Civil Aviation) in the *Nachrichten für Luftfahrer (NfL)*. These institutions possess the required infrastructure and are entitled to conduct noise-certification measurements.

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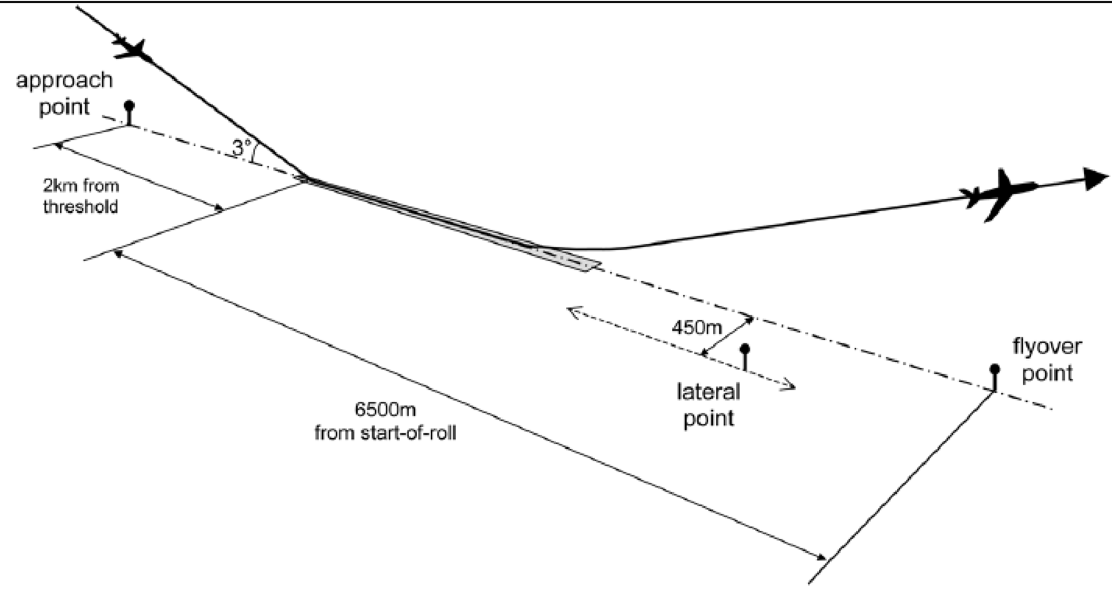
[105] DIN EN 61260, Edition: 2003-03 Electroacoustics - octave-band and fractional octave-band filters (IEC 61260:1995 + A1:2001); German version EN 61260:1995 + A1:2001.

[106] DIN EN 60942, Edition:2004-05 Electroacoustics – Sound calibrators (IEC 60942:2003); German version EN 60942:2003.

[107] The t_{10} period is the time interval within a specific aircraft noise during which the sound pressure level (here PNLT) is not more than 10 dB below the maximum sound pressure level (here PNLTM) of the specific aircraft noise.

[108] The precise site is not laid down and can be varied according to aircraft type, so that several measurements are necessary to ascertain the maximum EPNL.

Figure 4 Measurement points for noise-certification according to ICAO *Annex 16*



Source: CAA 2003 a

Table 2 Calculation steps for determining EPNL according to *Annex 16*

Calculation steps	**Target value**
0. Starting point: measured sound pressure level (SPL) in the one-third octave band	SPL(i,k)
1. Determination of the instantaneous *perceived noise level* (PNL) by means of three intermediate steps (determination of *perceived noisiness* n(i,k), calculation of total perceived noise N(k) as well as conversion of N(k) to PNL(k))	PNL(k)
2. Computation of the tone correction factor C(k) for each spectrum; Calculation in accordance with specifications in Chapter 4.3 and ETM	C(k)
3. Determination of tone corrected perceived noise levels by adding tone correction factor to the perceived noise level PNL, as well as determination of the maximum value of PNL: PNLTM	PNLT(k), PNLTM
4. Computation of the duration correction factor D through the integral of PNLT(k) during the t_{10}-time in accordance with specifications in Chapter 4.5	D
5. Determination of the effective perceived noise level EPNL by adding PNLTM to the duration correction factor D	EPNL
Comment: These five steps as well as the necessary intermediate step to determine EPNL according to *Annex 16* are described in detail in Appendix 2, Chapter 4. Appropriate instructions are contained in the ETM (*Environmental Technical Manual*, ICAO Doc. 9501).	

Calculation (from measured noise data)

The result of the required calculation is described by the noise index EPNL in [EPNdB]. The calculation procedure to deduce EPNL from the measured sound pressure level involves five steps (see Table 2).

Reporting

Annex 16 lays down requirements for competent authorities concerning the necessary documentation of noise-certification, covering the presentation of all relevant and necessary data including corrections and adjustments. This includes, among other things, information on measurement equipment, meteorology and topography. Data is also collected on aircraft configuration (for example, engine configuration and modifications to the aircraft) and flight paths (for example, aircraft speed). In addition, data on statistical significance in the form of 90% confidence intervals is necessary, so that the range is given that covers +/- 1.5 EPNdB.

Results are shown as effective perceived noise levels (EPNL) through corrected arithmetical mean noise values of valid noise-test flights, whereby at least 6 measurements per measurement point are required. The written documentation is generally not made available to the public. On the other hand, so-called noise lists, which comprise a compilation of all aircraft of a particularly country that are certified according to the specifications of *Annex 16*, are presently freely available. The LBA, as competent authority in Germany, is responsible for eight noise lists for different aircraft categories.[109]. Noise list 1 (LBA 2005) contains the certified noise values of all civil jet aircraft licensed in Germany.

Noise limits according to ICAO *Annex 16*

In *Annex 16*, the following noise limits (expressed as EPNL in [EPNdB]) are defined for *Chapter 3* aircraft with jet engines:

The following trade-off regulations apply for *Chapter 3* aircraft when maximum noise levels are exceeded at one or two measurement points (see *Annex 16*, Chapter 3.5):

- The sum of excesses should not be greater than 3 EPNdB.
- Any excess at any single point should not be greater than 2 EPNdB.
- Any excesses should be offset by corresponding reductions at the other points or point.

These rules have been adopted in § 10 *LuftVZO* (Air traffic Licensing Regulations).

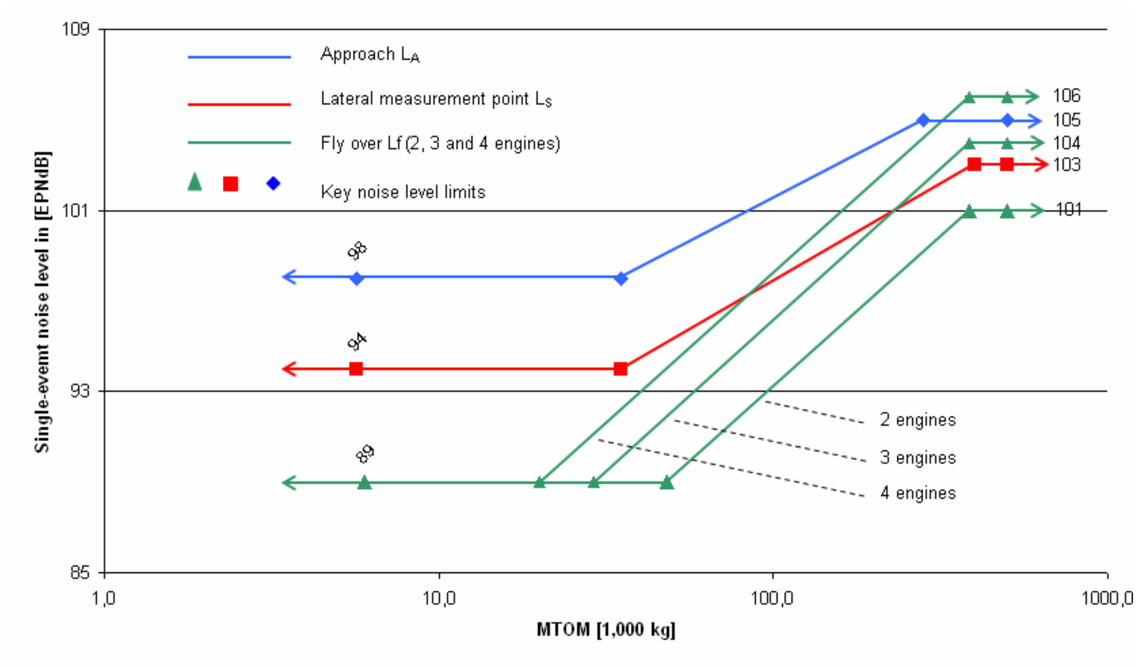
[109] Further freely available noise lists are to be found on the Websites of the *Federal Aviation Administration* (FAA) for die USA and the *Bundesamt für Zivilluftfahrt (BAZL)* for Switzerland.

Table 3 Noise limits of *Chapter* 3 subsonic jet aircraft according to *Annex 16*

Highest permitted maximum take-off mass MTOM [kg]	Noise limit EPNL in [EPNdB]				
	Lateral measure-ment point L_S	Flyover L_f number of engines			Approach L_A
		≤ 2	3	≥ 4	
≥ 400,000	103				
≥ 385,000		101	104	106	
≥ 280,000					105
≤ 48,125		89			
≤ 35,000	94				98
≤ 28,615			89		
≤ 20,234				89	

Explanation: The definition of noise limits in *Annex 16* is weight-related. Above and below the respective data on maximum permitted take-off mass [MTOM], fixed noise limits apply. Within the given ranges noise limits are linear; they can be deduced from effective perceived noise levels [EPNL in EPNdB] on the basis of the logarithmically applied weight [MTOM in kg].

Figure 5 Noise limits for *Chapter 3* aircraft according to ICAO *Annex 16*



Chapter 4 noise standard

CAEP, the environmental committee of the ICAO, reached agreement in September 2001 on a more stringent *Chapter 4* noise standard for civil subsonic jet aircraft and heavy propeller-driven aircraft; a regulation that applies for newly-certificated aircraft from 1 January 2006. These are generally designated as *Chapter 4* aircraft, since they are regulated in Chapter 4 of *Annex 16*. This new regulation does not provide for new noise limits, but rather refers to the existing maximum permitted noise for *Chapter 3* aircraft and lays down additional provisions on the necessity to remain below these limits. *Chapter 4* provides for the following rules for aircraft whose certification occurs after 1 January 2006:

- The maximum permitted noise levels specified in *Chapter 3* should not be exceeded at any of the measurement points.
- The sum of the differences at all three measurement points between the maximum noise levels and the maximum permitted noise levels specified in *Chapter 3* should not be less than 10 EPNdB
- The sum of the differences at any two measurement points should not be less than 2 EPNdB (in comparison to *Chapter 3*).

The introduction of this new standard can be traced back to the initiative of a number of parties that pressed for the tightening up of noise limits (for instance, the German Government[110] and the EU[111]).

2.5 Assessment of rules and regulations in *Annex 16*

The objective of the following assessment is to provide recommendations for the further development of *Annex 16*, based on perceptions of the existing rules and regulations. To begin with, the advantages and disadvantages of the present system are discussed, whereby a distinction is made between

- the character of individual components of existing regulations and
- general advantages and disadvantages that arise due to the methods selected.

Extensive consideration of all existing advantages and disadvantages appears to be important for an assessment of the regulations, in order that permissible noise emissions and the certification procedure can be an effective instrument of noise abatement in the future. Some aspects, which were initially interpreted as

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110 See, for example, the German Government's *Flughafen-Konzept* (airport concept – draft of 30.08.2000).

111 Cf. Communication of the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions on Air Transport and the Environment: Paths towards Sustainable Development of 1 December 1999, COM (1999) 640 final.

advantageous or disadvantageous, did not prove to be so in practice. In this connection, attention should be drawn to the following three aspects:

- typified evaluation conditions versus actual flight operations,
- making use of the rule on compensation between measurements points and
- the laying down of fixed upper and lower limits.

Standardized requirements on the conduct of evaluation, as defined in *Annex 16*, do not correspond with flight operations, so that the conclusion can be drawn that actual noise emissions during flights could lead to more or less exposure, and that certificated values are not appropriate for more far-reaching considerations of immission protection. Whether, and to what extent standardized measurements could lead to less or more exposure to noise, compared to actual flight operations, was investigated by the Civil Aviation Authority's ERCD (CAA 2003 b).

This investigation was conducted against the backdrop of "Quota Count" (QC) classification at the three London airports, Heathrow, Stansted and Gatwick – where classification and evaluation took place solely on the basis of certificated noise levels – to compare QC classification ("cer*tificated noise*“) and actual noise ("*operational noise*") measurements (see also Section 2.6 on the QC system). The noise measurement network was modified for this comparison, so that EPNLs could be measured and sites made available that are as similar as possible to the certification procedure. By means of extensive analysis, which covered the bulk of aircraft operating at night at the three London airports, it could be shown that 95% confidence intervals between measured values and certificated values were not greater than +/-1 EPNdB. During the investigation, only few aircraft could be identified that differed markedly from certificated values or classification in the QC system. As a result of this investigation, fears that considerable differences exist between the results of noise-certification and measurements in operational conditions can be regarded as unfounded. This indicates, at least, that no appreciable advantages or disadvantages arise. The ERCD investigation clearly indicates, however, that the results cannot be simply applied to other airports, and that the particular characteristics of each individual airport have to be taken into account.

Possible trade-offs between points of emission, as envisaged in ICAO regulations (*Annex 16*), could weaken the incentive to remain below noise limits at all measurement points, if compliance at one or two of the three points would suffice. Analysis of the current LBA Noise List 1 shows, however, that measurements in excess of noise limits with respect to *Chapter* 3 aircraft and marginally compliant aircraft arise for only a very small proportion of such aircraft (see Table 4). To a large extent, these excesses concern uncommon and/or old aircraft types, which make no appreciable contribution to emitted noise at the airports under investigation.[112]. And what is the situation in the case of measurements just below noise limits; that is with marginally compliant aircraft? From 3 (0.3 %) at the take-off measurement point to 79 aircraft (6.7 %) at the approach measurement point[113] lie within the range of up to 1 EPNdB below noise limits.

Table 4 Excess noise emissions of *Chapter* 3 jet aircraft, *Noise List 1*

Certification measurement point	Excess noise emissions *Chapter* 3 aircraft	Share of marginally compliant *Chapter* 3 aircraft
	Percentage share of **excesses** per certification measurement point (number)	Percentage share **falling short of** each noise limit by 0 to 1 EPNdB (number)
Flyover	0.2 % (2)	0.3 % (3)
Lateral measurement point	1.9 % (22)	6.4 % (75)
Approach	2.6 % (30)	6.7 % (79)
Accumulated *Chapter 4*	15.7 % (184)	-

Source: *LBA* 2005, own evaluation

Comment: The current *LBA* Noise List 1 shows 1,174 aircraft with Chapter 3 classification (as at 24.06.2005); "accumulated *Chapter 4*" shows the share of aircraft with a 10 EPNdB difference; 10 EPNdB is equivalent to the lowering of noise limits for *Chapter 4* aircraft.

Examination of LBA Noise list 1 (LBA 2005) shows that no general advantages or disadvantages derive from the trade-off option between measurement points, because a maximum of only 7% of certificated aircraft actually exceed noise limits. The positive aspect of this rule can therefore be advanced, namely, that the trade-off possibility between points of emission avoids insignificant excesses having to be remedied at great cost by aircraft and engine manufacturers.

Limit values for the three certification measurement points below and above a defined maximum permitted take-off mass (MTOM) are fixed, so that in such areas there is no mass-related component. It can generally be assumed that the choice of fixed upper and/or lower limits for the determination of noise limits could be inopportune, since there would be no further incentives to remain below noise limits. Analysis of the *LBA's* Noise List 1 shows, however, that the fixed upper limit has no influence, since

[112] For example, take-off measurement point: Beech Jet 400A and DC-9 83 (MD 83); lateral measurement point: A 321-211, B 737-200, Cessna 560, DC-9 83 (MD 83) and DC-9 87 (MD 87); approach measurement point: B 747-230, DC-10 30, A 300, B 737-300/-400/-500 and Fan Jet Falcon.

[113] Examples at the lateral measurement point: A 321, B 747-200, DC-9 and regional jets. Examples at the approach measurement point: A 300, B 737, MD 11.

corresponding heavy civil jet aircraft have not been certificated and licensed to fly.[114] On the other hand, the fixed noise limit would, in fact, be more stringent compared to lighter aircraft.

Assuming that the lower limit would remain linear, individual aircraft would profit from the fact that the weight-related lower limit is fixed (for example, for the lateral measurement point at 94 EPNdB. Under this assumption, various aircraft types – classifiable as business aircraft – would exceed the limit.[115]. The same applies for the other certification measurement points[116]. Due to the fact that the determination of noise limits with fixed MTOM is restricted to a few aircraft types, which make no appreciable contribution to noise emissions, it can be concluded that no relevant difficulties arise from fixed limits.

Existing regulations on noise-certification have further advantages and disadvantages, which arise from the procedural methods. The advantages of the present procedure are as follows:

+ The procedure according to *Annex 16* is an internationally standardized evaluation procedure, which is generally recognized for the classification of every single aircraft type. Noise-certification values are available for every aircraft and are displayed in the noise certificate and in noise lists. The standardized evaluation method guarantees comparability, and compliance with its comprehensive rules and regulations prevents loopholes from arising and being exploited. It is a practicable and frequently applied procedure founded on extensive experience.

+ The noise index EPNL can be regarded as an adequate measurement of noise, which, in contrast to other measurements of noise, takes into account important parameters for the effectual evaluation of aircraft noise exposure. The EPNL comprises, among other things, a tone correction factor dependent on frequency and a duration factor that takes account of the t_{10} period), both of which are intended to provide a better description of exposure to aircraft noise than other noise indices.

+ The setting of noise limits related to weight and number of engines in *Annex 16* takes into account that with an increase in aircraft mass there is greater

[114] At present, the aircraft type A 380 is undergoing certification. Its weight of about 550 tonnes is well above the fixed limit for take-off mass of 400 tonnes, as required in *Annex 16* for the determination of limits within the framework of certification. The inclusion of a fixed upper limit in certification for this aircraft type is therefore disadvantageous. This aspect should be take into account in long-term aircraft concepts for 2020+, which presently have an MTOM > 550 t.

[115] Examples for the lateral measurement point: Learjet 55, Cessna 560 and 650, Beech Jet 400a, Falcon 10.

[116] Examples for the approach measurement point: Fan Jet Falcon, Beech Jet 400, Falcon 10, HS 125. Examples for the take-off measurement point: Leerjet 55, Beech Jet 400A, IAI 1124, HS 125.

potential passenger capacity. With an increase in weight, aircraft can generally transport a greater number of passengers (expressed as pkm – and tkm in the case of freight). This rule appears to be advantageous from the point of view of noise abatement, since noise emissions per passenger (or per tonne of freight) are smaller, so that emitted noise energy, with the same number of transported passengers, is reduced (cf. the comments in Section 3.4.1 with data on noise levels per seat).

The disadvantages of the present procedure are as follows:

- The procedure described (see Section 2.4) comprises a measurement and evaluation procedure for the determination of EPNL, which is very complex and does not match other standards of noise monitoring (for example, there is no A-weighting). The comprehensibility of measurement with respect to certification levels is thus made much more difficult. Due to the complexity of certification measurements only a few institutions are able to carry them out, and re-examination is virtually ruled out.
- Despite extensive documentation, as demanded by the procedure, there is a lack of transparency, since, as a rule, only concluding measurements are published. Even noise lists are published by only some countries and authorized authorities. The situation is made worse by the fact that existing noise lists differ widely in their detail, and comparisons are therefore hardly possible.
- EPNL values cannot be compared with the results of other methods for recording aircraft noise (for example, measurement according to Article 19, *LuftVG* – Air Traffic Act[117]), because other noise indices are used. Although it was specially developed for the evaluation of aircraft noise immissions, EPNL has not gained wide acceptance. No publication is known that deals with investigations – apart from noise-certification itself – on the basis of EPNL. The lack of applicability and comparability to other A-weighted noise levels has had the result that the American FAA, for instance, has published a list with estimated A-weighted peak levels parallel to a noise list (CAA 2002). The list contains maximum measured sound pressure levels (L_{AMAX}) for *take-off* and *approach* measurement points, which are derived for jet aircraft, for instance, from computations with the *Integrated Noise Model (INM)*, or stem from data provided by aircraft manufacturers (see *Table 5*).

[117] Article19a *LuftVG* provides for measurement according to DIN 45 643, Part 2 *Measurement and evaluation of aircraft noise*.

Table 5 Comparison of noise levels in EPNdB and peak levels according to the FAA

Aircraft type	Engine	MTOM [kg]	FAA noise list EPNL in [EPNdB] Take-off	FAA noise list EPNL in [EPNdB] Approach	Estimated L_{Amax} in [dB(A)] Take-off	Estimated L_{Amax} in [dB(A)] Approach
B 747-400	CF6-80C2B1F	396,893	99.8	103.8	87.9	94.2
B 737-300	CFM 56-3B-2	56,472	82.8	99.6	71.5	89.5
B 757-300	RB 211-535E4B	106,989	84.0	95.2	69.0	85.7
A 310-324	PW 4152	150,000	90.6	100.2	76.2	91.6
A 319-131	V 2522A5	71,999	85.3	94.5	73.2	83.5
A 320-231	V 2500.A1	73,500	86.6	96.6	72.9	84.7
Learjet 60	PW 305A	10,478	70.8	87.7	60.9	77.4
MD 80	JT8D-217C	72,575	91.5	93.7	78.3	83.8
Source:			FAA 2001		FAA 2002	
Comment: Exemplary selection of individual aircraft types						

- The tightening up of noise limits with effect from January 2006 has no influence on the present production series of aircraft, which already have appropriate type-certification. These aircraft types can also be manufactured in the future, although they might not comply with the more stringent standards of *Chapter* 4.

Besides the description of advantages and disadvantages, it appears useful to examine the extent to which differences exist between national noise lists, and also whether differences exist between aircraft manufacturers as regards certification measurements. Differences with regard to unequal compliance with existing noise limits would be conceivable; for example, the disregarding of individual noise measurement points.

Excursus: Regulations on limit values in the case of motor cars

Comparison of regulations on the noise-certification of aircraft with exhaust gas limits for otto and diesel engines of motor cars shows that, in accordance with the specifications of EU Directives, regular controls have to be documented not only by manufacturers in the course of production (series inspection) but also on the part of car owners during the life of a vehicle (individual inspection). Appendix 23 of the *StVZO* – Road Traffic Registration Ordinance – requires regular measurement of the exhaust-gas emission of each individual vehicle. Furthermore, limit values have been tightened up within just a few years (from the *Euro I* standard valid from 1992 to the current *Euro IV* standard valid from 2005). In all, with *Euro II to IV* classifications, pollutant emissions of new cars with otto engines have been reduced by 90 to 95% compared to those without catalysts.

Noise limits for motor vehicles, on the other hand, have been laid down by the European Community as standards for new vehicles, and noise emission limits apply solely for initial registration of vehicles. Standards have been tightened up in three stages since 1980, whereby the latest lowering of limits took effect in 1996. Motor vehicles have to be designed in such a way that noise emission does not exceed a minimum level in line with the latest developments in technology (Article 49 StVZO). Because existing limits cover engine noise, additional regulations for roll noise have been laid down for the introduction of low-noise tyres.

Table 6 Comparison of data on certification measurements in noise lists for selected types of jet aircraft

Aircraft type	Engine	MTOM [kg]	Noise list Germany takeoff [EPNdB]	Noise list Germany lateral [EPNdB]	Noise list Germany approach [EPNdB]	Noise list USA takeoff [EPNdB]	Noise list USA lateral [EPNdB]	Noise list USA approach [EPNdB]	Noise list Switzerland takeoff [EPNdB]	Noise list Switzerland lateral [EPNdB]	Noise list Switzerland approach [EPNdB]
B 737-300	CFM 56-3B-1	56,470	84.4	90.4	99.9	84.4	90.4	99.6	-	-	-
B 737-300	CFM 56-3B-1	63,276	87.5	89.9	100.0	87.5	89.9	100.1	-	-	-
B 737-300	CFM 56-3B-2	56,472	-	-	-	82.8	92.2	99.6	82.9	92.2	99.9
B 737-800	CFM 56-7B24	79,002	88.6	92.1	96.5	88.6	92.1	96.5	-	-	-
B 737-800W	CFM 56-7B24	79,002	87.5	92.1	96.3	87.5	92.1	96.3	-	-	-
B 747-400	CF6-80C2B1F	396,900	99.8	98.2	101.7	99.8	98.2	103.8	-	-	-
B 747-400	CF6-80C2B1F N1 Modifier	396,900	99.9	98.2	101.7	99.9	97.9	103.8	-	-	-
A 340-313	CFM56-5C4	275,000	95.4	96.1	97.0	-	-	-	95.6	96.1	96.9
A 319-112	CFM56-5B6/2P	64,000	83.5	93.9	95.0	-	-	-	83.1	94.0	94.8
A 310-325	PW4156A	164,000	91.7	96.8	100.2	-	-	-	91.8	96.8	100.3
DC 10-30	CF6-50C2	251,748	96.8	97.8	105.0	96.8	97.8	105.0	-	-	-
DC 10-15	CF6-50C2-F	206,390	-	-	-	93.8	95.6	103.1	93.8	95.6	103.1
AVRO 146-RJ85	LF-507-1F	43,998	84.3	88.4	97.3	-	-	-	84.3	88.4	97.3
Learjet 60	PW 305 A	10,659	70.8	83.1	87.7	70.8	83.2	87.7	70.8	83.1	87.7
Learjet 60	PW 305 A	10,479	70.8	83.1	87.7	70.8	83.1	87.7	-	-	-
Sources			LBA 2005			FAA 2001			BAZL 2004		

Comment: Nosie level data in [EPNdB] is taken from the specified noise lists; the selection of aircraft types is random

An exemplary comparison of different national noise lists for jet aircraft shows that the ascertained certificated levels for a particular aircraft type are just about identical (see Table 6). Among these randomly selected aircraft types, only certification measurements on *approach* for the B 747-400 varied by a maximum of 2.1 EPNdB. All other certificated values showed virtual concurrence, and deviations were within the bounds of measurement imprecision (maximum of 0.4 EPNdB). A thorough comparison is difficult to carry out, however, since designations in national noise lists are not uniform, with the effect that clear assignment is sometimes not possible.

An additional evaluation of German Noise List 1 with regard to systematic deviations should examine, for example, whether aircraft manufacturers employ different weighting or assess measurement points differently. Comparison of randomly selected common aircraft types shows no discernible systematic shifts to the advantage or disadvantage of a particular measurement point. No trend can be discerned that aircraft of a particular manufacturer remain marginally below the noise limit at one of the certification measurement points, or that in striving to comply with noise limits one measurement point is disregarded in favour of others (see Table 7).

Table 7 Comparison of certification measurement values for selected Boeing and Airbus aircraft

	Aircraft type	Variant	Engine	MTOM [kg]	Certification level take-off	lateral	approach	Limit value take-off	lateral	approach	Difference (Limit val. - Cert.-level) take-off	lateral	approach
					in each case [EPNdB]			in each case [EPNdB]			in each case [EPNdB]		
Airbus	A 300	B4-601	GE CF6-80C2A1	165,000	91.3	97.1	99.1	96.2	99.8	103.3	**4.9**	**2.7**	**4.2**
	A 300	B4-622-R 00 (03)	4158 Phase III, Mod 10925	170,500	90.8	96.7	100.6	96.3	99.9	103.3	**5.5**	**3.2**	**2.7**
	A 319	111 000 (02)	CFM56-5B5	64,000	83.8	92.3	92.8	90.7	96.2	100.0	**6.9**	**3.9**	**7.2**
	A 319	132 000 (01)	IAE V2524-A5	64,000	81.7	92.7	94.2	90.7	96.2	100.0	**9.0**	**3.5**	**5.8**
	A 320	214 011 (02)	CFM56-5B4/P, Mod 30307	75,500	85.0	94.4	95.7	91.6	96.9	100.6	**6.6**	**2.5**	**4.9**
	A 320	232 015	IAE V2527-A5	78,000	85.2	91.6	95.3	91.7	96.9	100.7	**6.5**	**5.3**	**5.4**
	A 321	213 006 (01)	CFM56-5B2, Mod. 31616	83,000	86.6	96.0	95.5	92.2	97.2	100.9	**5.6**	**1.2**	**5.4**
	A 321	232 001(01)	IAE V2530-A5, Mod. 28960	93,000	88.8	94.1	95.6	92.8	97.6	101.3	**4.0**	**3.5**	**5.7**
	A 340	313 000 (01)	CFM56-5C4	253,500	91.9	96.4	96.9	103.6	101.3	104.7	**11.7**	**4.9**	**7.8**
	A 340	642 000 (01)	RR trent 556-61	365,000	93.5	95.5	99.9	105.7	102.7	105.0	**12.2**	**7.2**	**5.1**
Boeing	B 737	300	CFM56-3B-2	62,822	85.5	91.9	99.9	90.5	96.2	100.0	**5.0**	**4.3**	**0.1**
	B 737	375	CFM56-3B-1	61,235	86.5	90.2	99.6	90.4	96.1	99.9	**3.9**	**5.9**	**0.3**
	B 737	800 (20)	CFM56-7B-27 Winglets	78,244	85.7	94.7	96.3	91.8	97.0	100.7	**6.1**	**2.3**	**4.4**
	B 737	800 (04)	CFM56-7B-26	78,244	87.1	93.8	96.5	91.8	97.0	100.7	**4.7**	**3.2**	**4.2**
	B 747-400	(02)	CF6-80C2B1F	394,625	99.7	98.3	103.3	106.0	103.0	105.0	**6.3**	**4.7**	**1.7**
	B 747-400	(03)	CF6-80C2B1F	396,900	99.8	98.2	101.7	106.0	103.0	106.2	**6.2**	**4.8**	**4.5**
	B 757	200 27B	RB211-535E4, Package B	103,872	83.5	93.2	95.0	93.5	98.0	101.7	**10.0**	**4.8**	**6.7**
	B 757	300 (10)	RB211-535E4-B-37 mit 48 Outlet Guide Vanes	116,978	86.2	95.1	95.4	94.1	98.5	102.1	**7.9**	**3.4**	**6.7**
	B 777	200 (IGW) (15)	RB211 Trent 895	297,556	93.4	98.3	99.4	99.5	101.9	105.0	**6.1**	**3.6**	**5.6**
	B 777	200 (04)	GE90-76B	242,671	88.3	93.2	97.6	98.3	101.2	104.5	**10.0**	**8.0**	**6.9**

Source: *Noise List 1* Jet Aircraft LBA 2005

Comment: Aircraft were selected randomly

It can therefore not be ascertained whether a certification measurement point is systematically ignored. Comparison of publications of airline companies and aircraft manufacturers shows (for example, Figure 7), furthermore, that data corresponds with noise lists. It should also be mentioned at this point, however, that the great differentiation in the *LBA's* Noise List 1, which contains more than 100 different types and variants of the A 320, could not be reflected in such publications. The results of noise-certification of the huge number of aircraft types differ only slightly (see also Section 3.4.2.2).

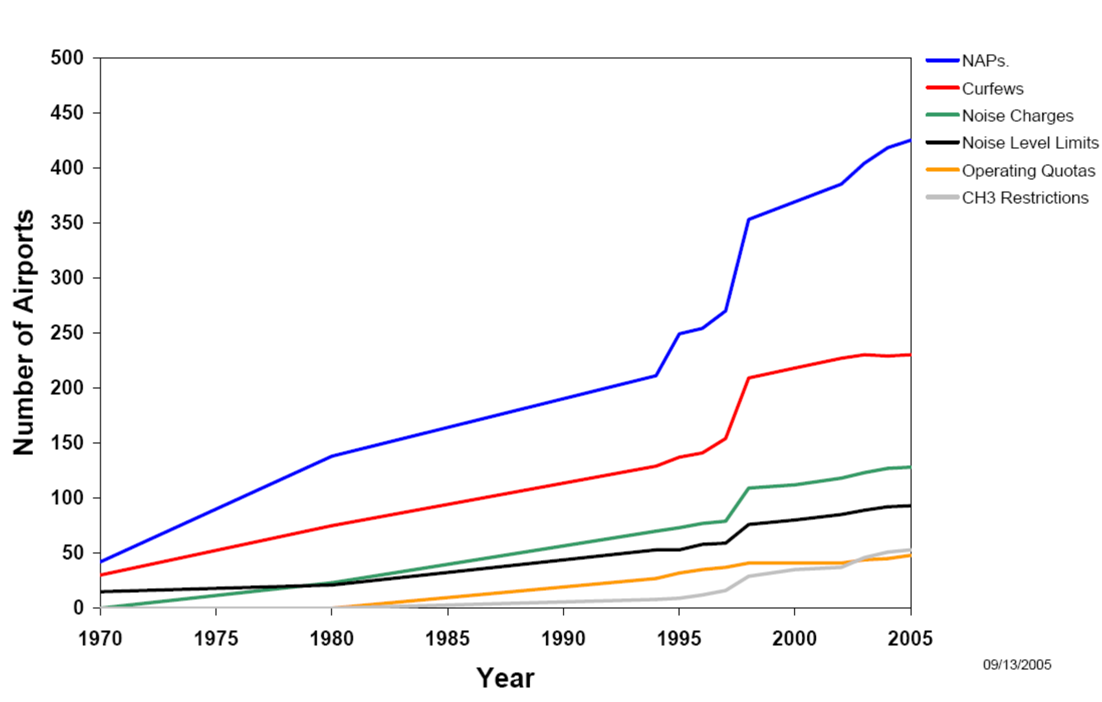
2.6 Noise control regulations at international airports

The necessity for noise control at airports is generally accepted, and is reflected in air traffic regulations. Due to growing air transport, noise control regulations are regarded as making an important contribution to protection from noise nuisance and damage to health as well as to increasing acceptance among those exposed to noise, in particular in the area immediately surrounding airports. The number of noise control regulations at airports has increased greatly in recent years (see Figure 6). A huge number and variety of regulations and instruments now exist, which – partly making use of noise-certification according to *Annex 16* and its *Chapter* classes – have neither uniform formulation nor application, and are generally drawn up locally for specific airports.

Instruments such as LTO charging systems contain a variety of individual regulations on bases for assessment or the classification of aircraft types (see, for example, Öko-Institut 2004). This variety leads to a lack of clarity and uniformity, with the effect that practically no comparability or transparency can be guaranteed.[118] In the following discussion of types of regulation, the intention is to show that positive effects on noise abatement can be achieved through appropriate design and formulation (for instance, the quota-count system in force at London airports). On the other hand, the example of charging systems shows that an effect on active noise abatement or a corresponding incentive effect has up to now not been substantiated (Öko-Institut 2004). It has to be pointed out that only local noise control regulations allow consideration of local exposure to noise, and that these local specifications are important for appropriate active noise abatement (see also the excursus on noise exposure research in Appendix I). Such regulations can be rated as advantageous from a systematic point of view when a common structure (for example, uniform bases for assessment) is applied to guarantee comparability.

[118] A review of existing regulations is to be found in the *Boeing Airport Noise Regulations* database, which provides up-dated and comprehensive information on existing instruments and measures for noise abatement at all international airports (www.boeing.com/commercial/noise).

Figure 6 Noise regulations in force at international airports since 1970



Source: Boeing 2005

London quota-count system

The existing regulation at London Heathrow Airport is described as a combined noise and flight movement quota (Öko-Institut 2003). At night, from 23:30 to 6:00 (local time), restrictions apply to the number of flight movements in the form of maximum noise points, which are intended to encourage the operation of low-noise aircraft.[119]. Other measures of active noise control are also employed, such as a night curfew for aircraft of the highest quota-count categories, or limitations on flight movements determined by assigned maximum sound energy (Marohn 2003). The quota regulation exists since the introduction of *Night Noise Categories* in 1993 (CAA 2005) as the precursor of the current quota-count system, introduced in 1995, which applies to the three London airports Heathrow, Gatwick and Stansted (British Airways 2005). At each of the three airports, "noise quotas" are laid down for the summer and winter season during the night period from 23:30 to 6:00.

[119] Noise quotas have been similarly adopted at Frankfurt Airport as a result of the notification of 26 April 2001 and 24 September 2001 of the Ministry of Transport of the State of Hessia (HMWVL), within the scope of realization of the operating license according to Article 6 *LuftVG*.

Table 8 Categorization of the quota-count system with example aircraft types

EPNdB	Quota Count	Aircraft types
< 90.0	**0.5**	Landing: A 320, B 737-800 Take-off: ATR 42, BAe 146
90.0 – 92.9	**1**	Landing: B 737-500, A 340-600 Take-off: A 320-200,
93.0 – 95.9	**2**	Landing: B 747-400, MD 11 Take-off: A 300, B 767-300
96.0 – 98.9	**4**	Landing: B 747-200, TU 154 Take-off: DC 10, B 747-400
99.0 – 101.9	**8**	Landing: B 747-100, Take-off: B 747-SP, B 747-200F
> 101.9	**16**	Landing: Concorde Take-off: DC 8, IL 86

Comment: According to CAA information, categorization in the quota-count system is carried out separately for take-off and landing, and is based on certificated values according to *Annex 16* for each individual aircraft type (including engine). It applies for jet aircraft with an MTOM in excess of 11,600 kg MTOM.

Calculation method *Chapter 3*: *take-off* = (*take-off* + lateral) 2;

Chapter 2: [(*take-off* + lateral) / 2] + 1.75

Chapter 2 and *3*: *Approach* = *Approach* -9

Source: CAA 2005 and Boeing 2005

Aircraft are allocated noise quotas per take-off and landing, based on their certificated EPNL, which are added in the course of the flight plan season for all flight movements at night, a maximum number having been determined within the framework of flight-plan co-ordination. When an aircraft exceeds or remains below this maximum number, rules take effect that are then applied in the following season[120]. This quota-count system at the three London airports had an influence on the design of the new A 380, during the development of which Airbus formulated a new design target, aimed at meeting the criteria at Heathrow Airport for QC/2 (CAA 2005). This target had primarily to do with the fact that a take-off and landing ban for QC/4 aircraft is planned.[121] It had been forecast that with its original design the A 380 would be allocated to noise

[120] Unused quotas can be transferred to the following season so long as they amount to less than 10% of total quotas. On the other hand, where allocated noise quotas are exceeded, the quota for the following season is reduced; whereby an excess is only allowed up to 20%, and where it is greater than 10%, double the amount is deducted in the following flight plan.

[121] Up to now, co-ordinated take-offs and landings of aircraft of categories QC/8 and QC/a6 at the airport in question are completely banned at night; but there are certain exceptions for take-offs, so that, for instance, delays can be handled (CAA 2005).

category QC/4 (SNECMA 2002). The new target was realized through additional modification on the part of Airbus, who succeeded in keeping forecast noise emissions of the A 380 below QC/4 categorization; while, for example, even the smaller and lighter B 747 (*Jumbo*) is at present allocated to QC/4 (Airbus 2004 b).

Re-examination of the QC system, which was carried out by the CAA, showed that the selected method based on certificated values is appropriate, since no available alternative, similarly straightforward method would better describe measuring and calculation procedures (CAA 2002). It was finally shown hat only isolated differences occur between certificated noise measurements and actual operational measurements, which are primarily to be explained by different flight procedures (see also Section 2.5).

Charging systems

An investigation by Öko-Institut showed that a large number of regulations existed at the airports under consideration, which in each case had been developed as local charging systems (Öko-Institut 2004). Within the scope of a systematic and extensive status-quo analysis, noise-related LTO charging systems in force in 2002 at European and German airports were analysed with respect to their structure (for example, the level and spread of charges and their time-related differentiation) and financial incentives for the introduction of quieter aircraft.

Chapter allocation according to *Annex 16* is frequently used within the scope of existing LTO charging systems to differentiate the level of special LTO charges. Only in restructured charging models is orientation towards locally measured single-event sound levels (for instance, Frankfurt/Main and Hamburg) to be found. Differentiation of *Chapter 3* aircraft is partly realized through supplementation of the so-called bonus list (for example, Düsseldorf and Berlin-Tegel). The bonus list is complied by the Federal Ministry of Transport and differentiates within the *Chapter 3* class, in as much as low-noise aircraft are separately shown. The bonus list is published in *"Nachrichten für Luftfahrer, Teil I"*, whereby this is partly modified and supplemented by airports.

Analysis of LTO charging systems indicates target-related elements concerning the structure of noise-related LTO charges, which are recommended for further development of systems. These include elements such as transparency of charging systems through clear separation of an MTOM-related[122] charge and a noise component, orientation towards the polluter-pays-principle through the separate treatment of take-off and landing, high prices at night and at other sensitive times of day as well as consideration of the local noise immission situation.

For the status quo, it was basically established that the financial incentive is insufficient to bring about intended reactions on the part of airline companies, namely the operation of quieter aircraft and the changing of operating times or location of light

[122] MTOM: maximum (permitted) take-off mass.

movements. An orientating analysis of airline cost structures confirms that present noise-related LTO charging systems hardly produce a steering effect. Reaction could only be expected on the part of airlines, if the noise component of LTO charges were to be increased well beyond usual status-quo levels. It has to be said, however, that this steering effect cannot be seriously predicted on the basis of the present state of knowledge.

2.7 Conclusions

The presentation and description of methods of noise-certification based on *Annex 16* has shown that, in comparison to other (aircraft) noise evaluation methods, a costly and complex procedure is involved. The sole target, according to the ICAO, is noise-certification, and no far-reaching operative regulations or noise abatement measures are intended on the basis of *Chapter* classification. This restriction relates likewise to the introduction of more stringent certification for *Chapter 4* aircraft (ICAO 2001 b). This conflicts with the usual practice of using *Chapter* classification within the framework of existing noise control regulations.

A glance at aircraft currently in operation in international air transport shows that a large proportion of aircraft already meet the stricter criteria of the *Chapter 4* standard. According to an analysis carried out by the Federal Environmental Agency, three-quarters of all aircraft presently licensed in Germany meet the stricter criteria in force from 2006. It is pointed out, however, that this *Annex 16* approach appears to be both sensible and necessary for more far-reaching proposals concerning noise limits[123]. Examination of a selection of Airbus aircraft types also shows that they all currently remain well below the new noise limits (see Figure 7).

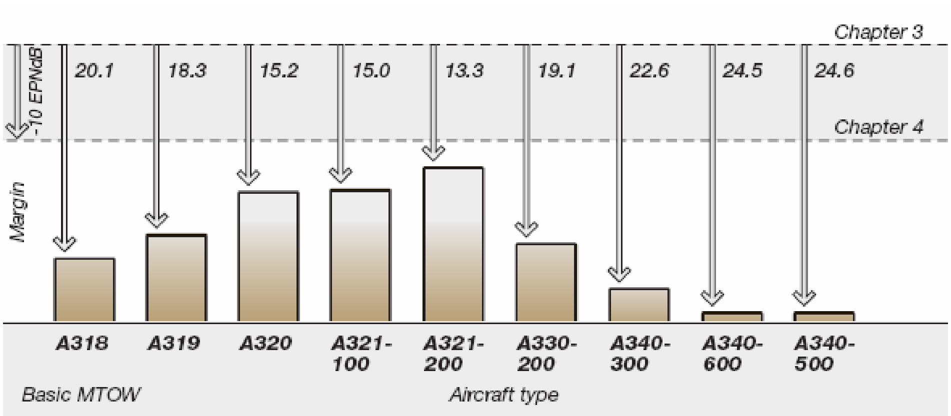
Furthermore, all Lufthansa aircraft fall below current noise limits: In 2004, 88% of the fleet met the new ICAO noise limits (Lufthansa 2004 b), and in 2005 this applied to more than 90%[124] (Lufthansa 2005 b). 90% of the IBERIA fleet today also meets the strictest noise standards for *Chapter 4* aircraft (IBERIA 2005). In the case of British Airways, 83.4 % of the aircraft fleet in 2003/2004 were equipped in accordance with *Chapter 4* (British Airways 2004). Comparable figures are also published by other airlines, such as Singapore Airlines for example, whose whole fleet already meets *Chapter 4* standards (Singapore Airlines 2004); or the integrator UPS, where 92% of its present fleet of cargo aircraft comply with the new certification class (UPS 2005). It is therefore clear that with the introduction of the new *Chapter 4* class the status quo for modern passenger aircraft fleets is merely confirmed. There is therefore an incentive

[123] The Federal Environmental Agency (UBA) analyzed the noise values of aircraft types and series licensed in Germany. 78 % of jet aircraft certificated according to Chapter 3 ICAO *Annex 16* met Chapter 4 noise limits (*UBA* 2003).

[124] This applies also to the Lufthansa-Cargo fleet, which, following fleet renewal, comprises solely MD 11 aircraft and entirely complies with the noise limits of Chapter 4 (Lufthansa 2004 c).

for neither further developments nor improvement in noise emissions, if the new standards are already met. This conclusion is likewise confirmed by further investigations carried out within the scope of this report (see Section 3.4.2.1).

Figure 7 Cumulative noise-certification values for the *Airbus family* in EPNdB



Source: Airbus 2004

On account of the problems described, the suitability and effectiveness of noise-certification in its present form for more far-reaching noise abatement measures has to be judged critically. "Certificated noise limits [are] suitable only to a limited extent as an instrument for the promotion of technical progress" (Fichert 1999). Fichert therefore favours the use of other instruments. Certificated limits in the form described would be unsuccessful in promoting technical progress in noise mitigation in the areas of design and construction. According to Fichert, only more restrictive measures, such as a ban on the production of older licensed aircraft types, following the coming into force of new noise limits, would present more far-reaching incentives for the development and operation of quieter engines and aircraft (Fichert 1999).

The current statutory framework shows that deviation from ICAO regulations is fundamentally possible, but that important misgivings exist and issues have not yet been legally resolved (see Section 0). The effect is that the retention of certification rules and regulations appears to be necessary. International integration in air transport is a particular problem, as are unresolved questions in connection with the founding of EASA and new regulations in force throughout the EU with the concomitant division of responsibilities.

3 Overall view of noise emissions

3.1 Terms of reference

The present state of noise emissions of aircraft operating at European airports should be described. For this purpose, the sound emissions of aircraft taking off and landing at different airports is measured and weighted with the respective flight movements. The evaluation is carried out at several airports to take account of the varied composition of aircraft fleets at individual airports; and not only large airports are investigated, but also small and medium-sized airports. Acoustic reference values are provided by the source data of the EMPA noise data bank that is measured in real air traffic conditions. For the purposes of comparison, the acoustic parameters of EMPA source data are matched with those of certification data published by aviation authorities. In a further investigation, certification data for individual aircraft types is compared with current ICAO noise limits.

3.2 Procedure

3.2.1 General information

To calculate the share of sound energy of an aircraft in total sound energy, the sound emission of each aircraft type is weighted with the respective number of flight movements and set in relation to total sound energy. The acoustic parameters of aircraft types contained in the EMPA noise data bank are used for evaluation purposes, and the single event sound level L_{AE}, standardized for reference conditions,[125] is used as a characteristic acoustical parameter. Flight movement figures are taken from operational data published by individual airports. The analysis carried out is merely of a general nature and is related to total sound volume. The time-related and spatial distribution of sound energy is not considered. To take account of the widely varying sound volume of aircraft at take-off and landing, evaluation of these flight phases is carried out separately.

3.2.2 Choice of airports

In order to obtain representative information on the current state of noise emissions at European airports, the investigation was carried out at several airports that differed both in terms of traffic volume and type of operations. In selecting airports the following criteria were considered:

[125] Cf. Section 3.2.5.

- Airport size (number of flight movements per year).
- Type of operations (share of intercontinental traffic, short and medium haul, cargo transport).
- Availability of up-to-date operational data.

Based on these criteria, the following five airports were selected (see Appendix A for further traffic figures for the selected airports):

Table 9 Airports

Airport (data source)	Year	Flight movements (take-off and landing)	Operational characteristics
Frankfurt/Main (Fraport 2005)	2004	458,800	Large intercontinental airport
Zürich (ZRH 2004)	2004	266,600	Medium-sized intercontinental airport
Geneva (GVA 2003)	2003	161,600	Medium-sized airport
Cologne (Köln 2004)	2004	152,600	Large proportion of cargo aircraft
Hamburg (Ham 2003)	2003	149,700	Medium-sized airport

3.2.3 Distinguishable aircraft types

For a meaningful comparison of flight movements at different airports, the types of aircraft should be the same at all locations. Since the designation of aircraft types at the airports under investigation vary, however, these designations have to be partly changed or supplemented. Based on the designations applied in the EMPA data bank, a new type designation – RC2 – has been adopted. This designation distinguishes aircraft with respect to manufacturer, type and construction series; while on the other hand, the number of different aircraft types should remain manageable. Allocation of individual aircraft types to the reference type RC" is described in Appendix B.

3.2.4 Flight movement data

The total annual number of flight movements per RC2 type is applied. Flight movement data of the airports under investigation is available in the form of synoptic charts with a varied degree of detail. Additional information was requested from airport authorities, when required for allocation to the standardized type designation RC2. Flight movement data for the two Swiss airports is available, however, in the form of detailed lists of movements with precise information on aircraft type, flight route and take-off and landing time. Allocation to RC2 types is carried out with database tools.

Only a general evaluation is made of total flight movements per type and year. Differences with respect to season or time of day as well as distribution among individual approach and departure routes are not considered. An overview of type-specific flight movement data is to be found in the Appendix.

3.2.5 Parameters

The single event sound level L_{AE}, standardized for reference conditions, is used as a characteristic acoustical parameter in conformity with the EMPA noise data bank. This parameter defines the single-event sound level of an aircraft flying over in a straight line at a distance (D_{ref}) of 305 metres and a speed (V_{ref}) of 160 kt in the flight configuration for take-off or landing. L_{AE} thus represents a unit of measurement for sound energy emitted by an individual aircraft.[126] Effective distance and speed is not considered, however, in this investigation. Since the noise emission of aircraft on take-off and landing varies greatly, evaluations of take-off and landing are carried out separately.

Sound energies *E_D* and *E_A* are determined for each aircraft type through the weighting of the type-specific, single-event sound level L_{AE} with the annual number of flight movements. These parameters characterize the total sound energy emitted by a particular aircraft on take-off and landing, taking account of the annual number of flight movements. This sound energy, determined for each type of aircraft, is subsequently presented as a percentage of the total emitted sound energy of all aircraft operating at the respective airport (*%E_D* and *%E_A respectively*).

The additional parameters *S%E_D* and *S%E_A* are used for special investigations. These represent the cumulative total of energy shares *%E_D* und *%E_A* set according to different criteria. Among other things, the contribution of a certain number of the most sound intensive aircraft types to total sound energy can be determined. Precise definitions of the applied parameters are shown below.

[126] For heavy jet aircraft, two different source values are available in each case in the EMPA database for heavy and middle take-off weight. In this evaluation account is taken of each of these values to the extent of 50%.

Single event sound level:

$$L_{AE} = 10 \lg\left(\frac{1}{T_0}\int 10^{\frac{L_i(t)}{10}}\,dt\right) \qquad \text{Equation 1}$$

Sound energy per aircraft type:

$$E\_D_i = N_i \cdot 10^{\frac{LAE\_D_i}{10}} \text{ and } E\_A_i = N_i \cdot 10^{\frac{LAE\_A_i}{10}} \qquad \text{Equation 2}$$

Percentage share of sound energy:

$$\%E\_D_i = \frac{E\_D_i}{\sum_{j=1}^{n} E\_D_j} \text{ and } \%E\_A_i = \frac{E\_A_i}{\sum_{j=1}^{n} E\_A_j} \qquad \text{Equation 3}$$

Cumulative total of percentage sound energy:

$$S\%E\_D_k = \sum_{j=1}^{k} \%E\_D_j \text{ and } S\%E\_A_k = \sum_{j=1}^{k} \%E\_A_j \qquad \text{Equation 4}$$

with:

$L_i(t)$ = Momentary sound pressure level of type i on flyover under reference conditions.[127]

T_0 = Reference time = 1 s

$L_{AE}\_D_i$ Single event sound level under reference conditions on take-off of type i (analogous designation for landing)

N_i = Number of flight movements (take-off or landing) of type i per year.

3.3 Findings

3.3.1 Sound share per aircraft type

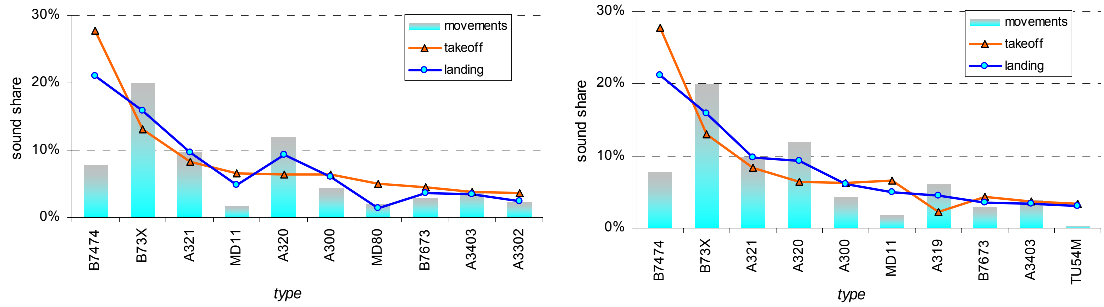
The percentage sound energy of the 10 most sound-intensive aircraft (RC2 types) on take-off and landing are shown below for each airport. For the purpose of comparison, percentage flight movement data is also displayed in the diagrams for the respective aircraft. Further data and diagrams are to be found in the Appendix.

[127] Aircraft flying over in a straight line at a distance D_{ref} of 305 metres and a speed v_{ref} of 160 kt in a standard atmosphere (15°C, 70 % relative humidity).

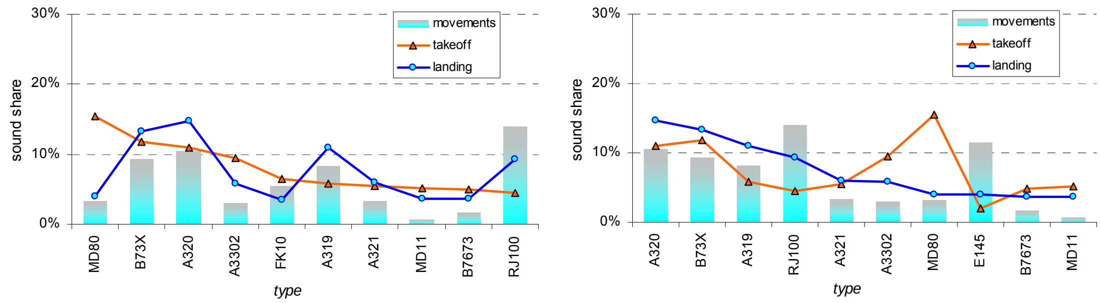
Figure 8 Percentage of sound energy of the 10 most sound-intensive aircraft types, plotted according to deceasing sound share on take-off and landing, together with percentage flight movement data.

Take-off Landing

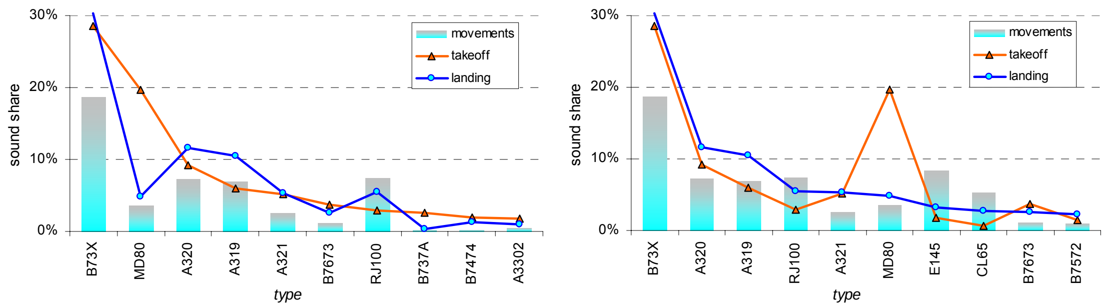
Frankfurt (2004)



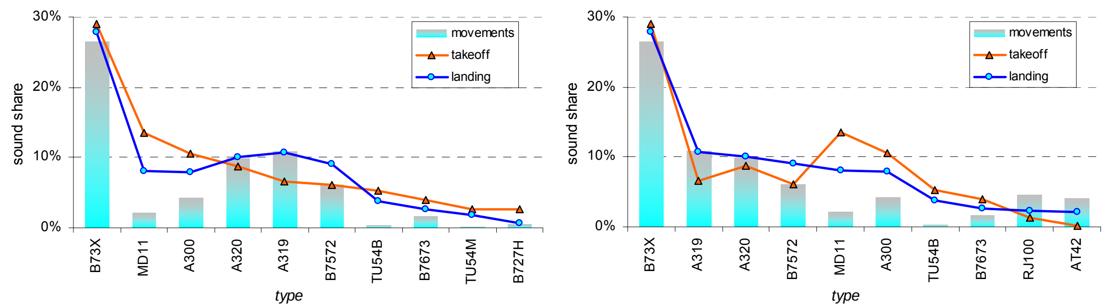
Zürich (2004)



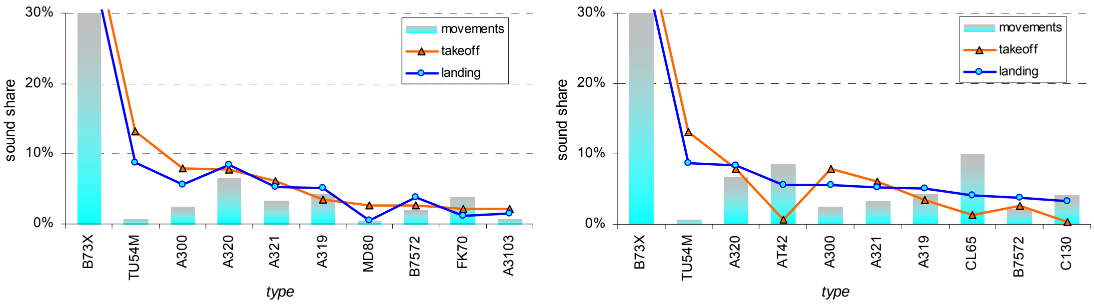
Geneva (2003)



Cologne/Bonn (2004)



Hamburg (2003)



The share of individual types of aircraft in total sound energy differs not only between the two flight phases of take-off and landing, but also from airport to airport. While at Frankfurt the Jumbo B747-400 is the most sound-intensive aircraft both on take-off and landing, total sound energy at the remaining airports is dominated, above all, by medium-sized aircraft of the series Boeing B737 (later series from the B737-300) and Airbus A320; and at Zürich and Geneva airports, the MD 80 is a major contributor. At Cologne/Bonn and Hamburg airports the less-frequent flight movements of the Tupolev 154 make a considerable contribution to total sound energy.

While the share of total sound energy of more recent types of aircraft, such as the Airbus A320, Boeing B737 and B747, are about the same on take-off and landing, flight movements of the MD80 and MD11 make a much greater contribution to total sound energy on take-off than on landing; in other words, these aircraft are loud on take-off, but relatively less noisy on landing.

3.3.2 Comparison of shares of total sound energy

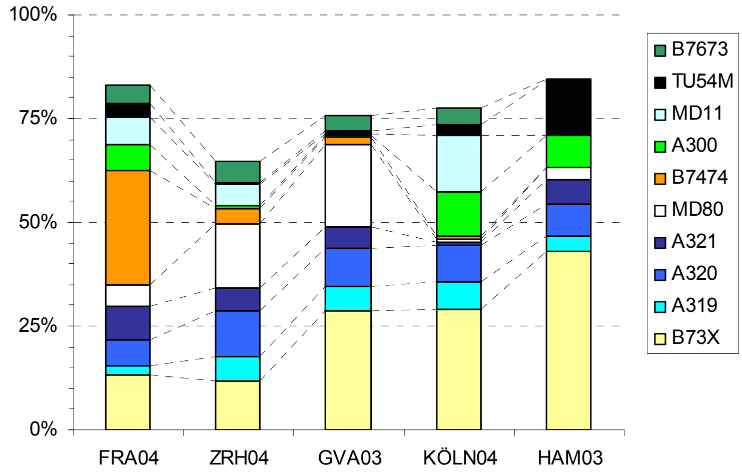
An analysis was also made of the share of those aircraft that contribute most to total sound energy across all airports under consideration. In this case, only the 10 most sound-intensive aircraft types were investigated. The calculated sound share %E_D on take-off of each of the select aircraft types at the five airports is averaged, and the ten aircraft types with the highest share of total sound energy are selected. Dependent on the airport, the share of the selected aircraft in total sound energy is 65 to 84 per cent.

It can be seen from Figure 9 that flight movements of Boeing aircraft of the B737 series and the Airbus A320 family (A318 to A321) dominate sound emission. At Cologne/Bonn, Hamburg and Geneva airports these aircraft contribute around 50% of total sound energy. In the case of landings, the share is even higher. These aircraft are somewhat less predominant at Frankfurt and Zürich airports, where they make up about one-third of total sound energy on take-off. The contribution of the remaining aircraft types varies considerably. At Frankfurt, the Boeing B747-400 contributes considerably to total sound emissions, while at the other airports it plays only a minor role. At Zürich and Geneva airports, sound emissions of the MD 80 on take-off are significant. Since, however, the Boeing B747-400 and MD 80 are relatively quite on landing, they contribute little during this flight phase to total sound emissions. At

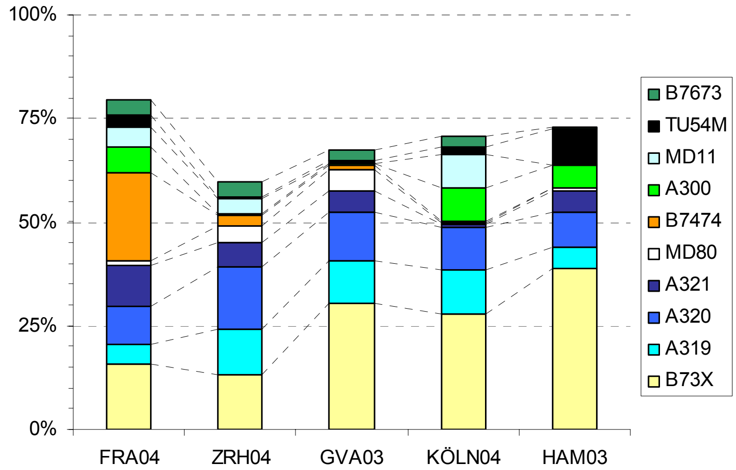
Cologne/Bonn, the wide-bodied MD11 and Airbus A300 jets have to be mentioned, which account for just less than 25 % of emitted sound energy on take-off and more than 15 % on landing. Finally, the Tupolev 154M contributes appreciable to total sound emissions only at Hamburg Airport.

Detailed information on the shares of total sound emissions of individual aircraft types is to be found, together with further diagrams, in Appendices C and D.

Figure 9 Comparison of the shares in total sound energy of the 10 most sound-intensive aircraft types at different airports on take-off (a) and landing (b).



a)



b)

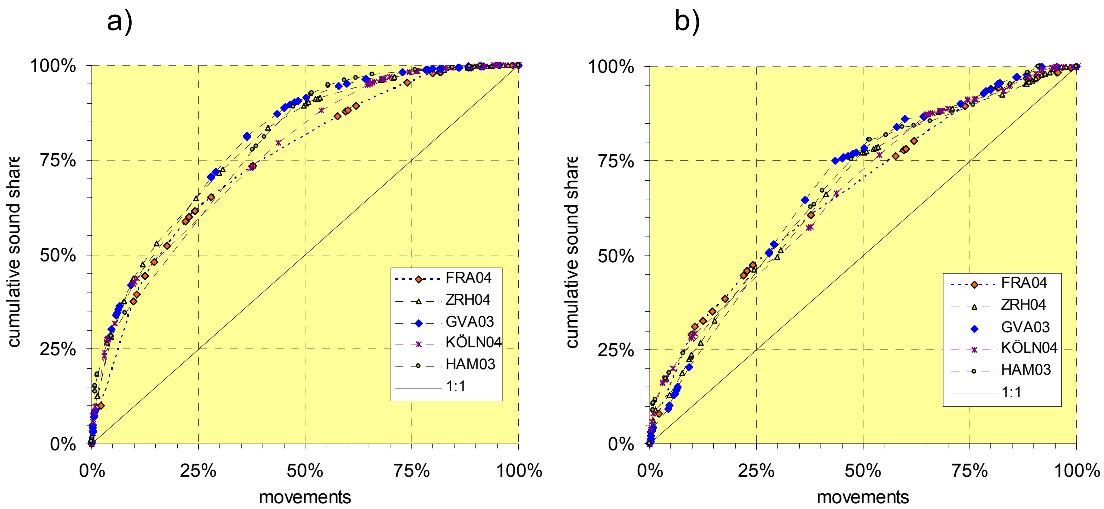
3.3.3 The share of loud aircraft in total sound emissions

In this investigation, the contribution of very loud aircraft to total sound emissions is analyzed. For this purpose, the cumulative shares of total sound $S\%E\_D_k$ and $S\%E\_A_k$ (cf. Equation 4) – sorted according to diminishing single-event sound level – are determined for aircraft operating at individual airports and then compared.

These cumulative shares of sound emissions at different airports, dependent on respective flight movements, are displayed in Figure 10. It can be seen that on take-off a few very loud aircraft make a greatly disproportionate contribution to total emissions. Merely 5% of flight movements of the loudest aircraft account for 25% of total sound emissions. 50 % of sound energy is brought about by 15 to 20 per cent of take-offs as a whole. In the case of landings, the share of very loud aircraft is somewhat smaller: 25 % of landings of the loudest aircraft give rise to just under 50% of total sound energy.

Despite the widely varying composition of aircraft fleets, the connection between sound emission and flight movements is very similar at all airports. This means that the share of sound emissions of very loud aircraft is more or less the same at all airports under investigation.

Figure 10 Cumulative share of sound emissions of flight movements of aircraft at various airports, plotted versus sound volume on take-off (a) and landing (b)



3.4 Broader analyses

3.4.1 Sound level per seat

In order to further assess the sound intensity of different types of aircraft, sound emission per seat L_{seat} is determined by dividing sound energy (corresponding to single-event sound level L_{AE}) by the number of seats, the result again being again described as sound level.

$$Lseat = 10\lg\left(\frac{1}{N_s}10^{LAE/10}\right) = L_{AE} - 10\lg(N_S) \qquad \text{Equation 5}$$

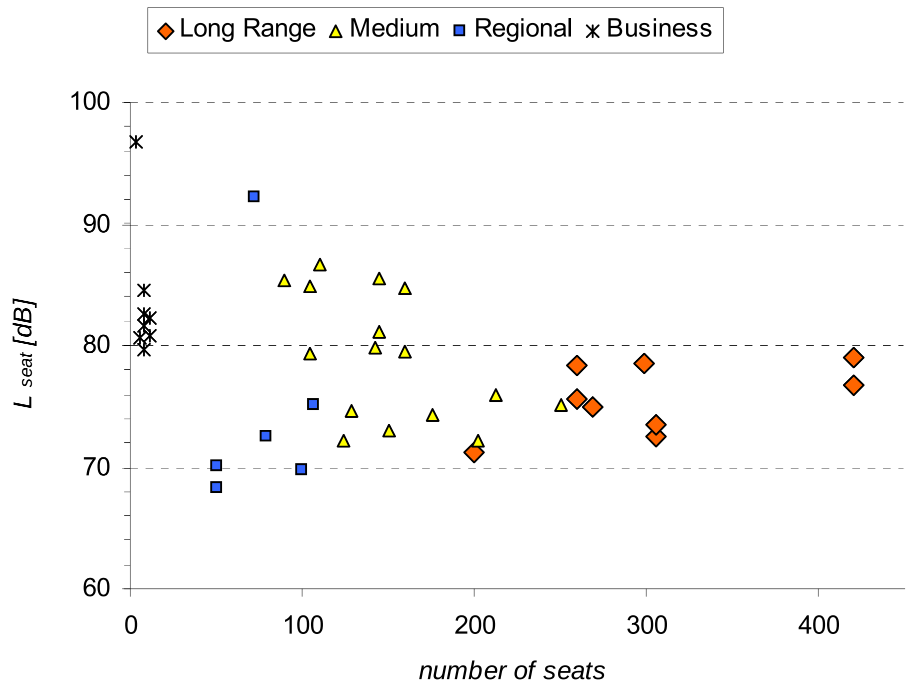
with L_{AE} = single-event sound level under reference conditions
N_S = typical number of seats

The evaluation of take-off and landing is conducted separately, and the number of seats is based on figures accessed on the Internet for a typical seating arrangement.[128] In the case of long-haul jets, the number of seats reflects a typical three-class seating arrangement; with short- und medium-haul jets that of a two-class seating arrangement. The number of seats thus determined can vary according to arrangement; but since this figure is merely a logarithmic element of the calculation, the applied method of estimating seat-related sound emission is quite sufficient. A possible difference of 20% between the assumed number of seats and the actual number, for instance, would result in a deviation of just 0.8 dB; and such a difference can therefore be disregarded within the scope of the above estimation.

Because of their varied type of operation, it is not expedient to compare regionally operating aircraft with long-haul aircraft. For the purpose of this investigation, aircraft are assigned to the following four categories and separately evaluated:

- Long Range: heavy long-haul aircraft
- Medium: medium-haul aircraft
- Regional: regionally-operating aircraft
- Business: business jets

Figure 11 Sound level L_{seat} according to Equation 5 on take-off for different categories of aircraft



[128] For example: www.airliners.net/info/

Further diagrams are to be found in Appendix G.

Figure 11 shows that, with the exception of relatively loud business jets, sound energy per seat increases slightly with an increase in the number of seats. This means that the sound emission of large and heavy aircraft increases disproportionate to the number of seats. The least sound emission per seat – about 70 dB – is generated by regional aircraft. Modern medium-haul aircraft produce around 75 dB per seat, while heavy, long-haul jets account for about 75 to 80 dB per seat. Business jets are among the loudest aircraft under investigation. Due to their very low number of seats, sound emission per seat is for the most part in excess of 80 dB. Medium-haul aircraft of earlier construction series, such as the B 727, B 737-200 or TU 154, are among the loudest aircraft, with sound emissions similar to those of business jets.

As already mentioned, different categories of aircraft cannot be directly compared on account of their varied types of operation. Long-haul jets basically have a worse payload to total weight ratio due to the quantity of fuel required. It is therefore no surprise that these aircraft are generally louder than short- and medium-haul jets, which are designed for shorter distances. Rather unexpected, however, is the discovery that within comparable aircraft categories sound emissions per seat tend to increase with an increase in the number of seats. Relatively small regional jets, such as the CL 65 and E 145, which have only 50 seats, are thus among the quietest aircraft. Seat-related sound emissions also increase with an increase in the number of seats in the case of medium- and long-haul jets, so long as extremely loud older types are not taken into account. The increase is only very low and of little significance, however, bearing in mind uncertainties resulting from simplifications and generalizations in the present investigation. On the other hand, the investigation shows that the replacement of large aircraft by a correspondingly greater number of smaller aircraft with the same overall seating capacity, need not necessarily lead to an increase in noise emissions during their operation.

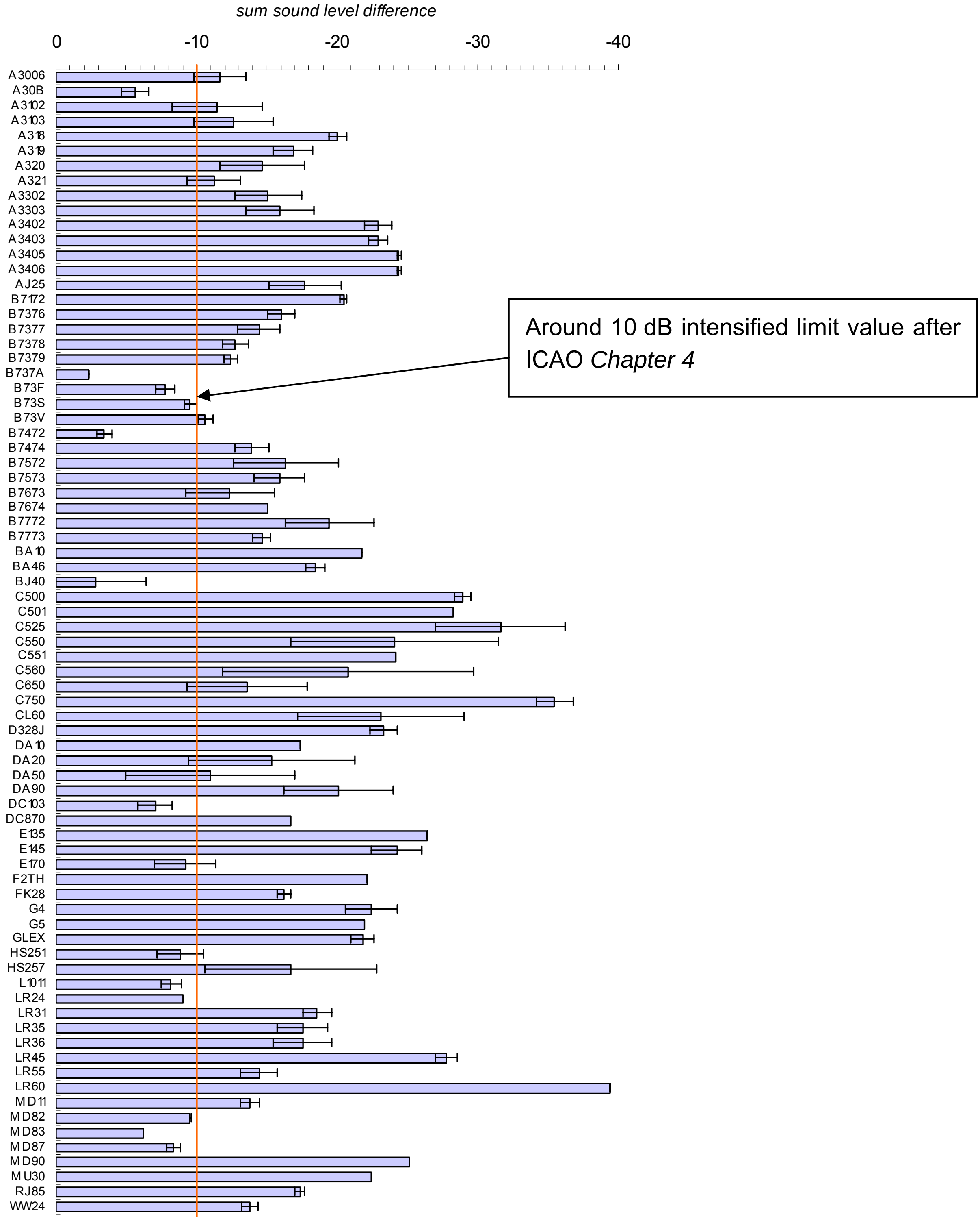
3.4.2 Certification data

3.4.2.1 Comparison with ICAO noise limits

Certification now provided for in ICAO *Chapter* 4 lays down a cumulative 10 dB reduction of noise limits compared to those previously required under *Chapter* 3. Many aircraft, which are certificated in accordance with *Chapter 3*, already comply with these more stringent noise limits. This is shown by the following analysis, which was carried out with the aid of certification data published by the Federal Office of Civil Aviation (*LBA*).[129] Figure 12 displays the cumulative differences arising at the three measurement points – take-off, lateral and approach – between noise-certification limits for individual aircraft types and noise limits according to ICAO *Chapter* 3 (see also Section 2.8. Since several certificated limits already exist for the majority of aircraft

[129] www.lba.de/deutsch/technik/laermlisten/laermlisten.htm

Figure 12 Sum total of differences at the three certification measurement points between noise-certification limits and ICAO *Chapter 3* noise limits.



types distinguished in this analysis – due to varied take-off mass (MTOM), engine configuration and other modifications – the diagram displays the respective mean value of resulting differences in noise levels. Error bars indicate differences deviating from the standard to show the spread of certificated values applicable to individual aircraft types.

The diagram shows that it is only older types of aircraft, such as the Airbus A 300B2, Boeing B 737A and B 747-200 as well as the DC 10-30 and MD 80 – 87 series, that do not meet the more stringent requirements of ICAO *Chapter* 4. Aircraft of the current generation, however, surpass the required noise values, in some cases by a clear margin. Airbus aircraft of the A 330 series, for instance, are around 15 dB and those of the A 340 series more than 20dB below *Chapter* 3 noise limits. The Boeing B 757 und B 777 series likewise remain more than 15 dB under noise limits. Regional jets of more recent design also fall considerably short of noise limits. Embraer E 135/145 and CL 60 aircraft, for instance, better the limits by more than 20 dB. Some modern business jets (Cessna C525 and C 750) have noise values more than 30 dB under the respective limit, and the Learjet LR 60 achieves the best result of all with a cumulative difference in noise values of just less than 40 dB.

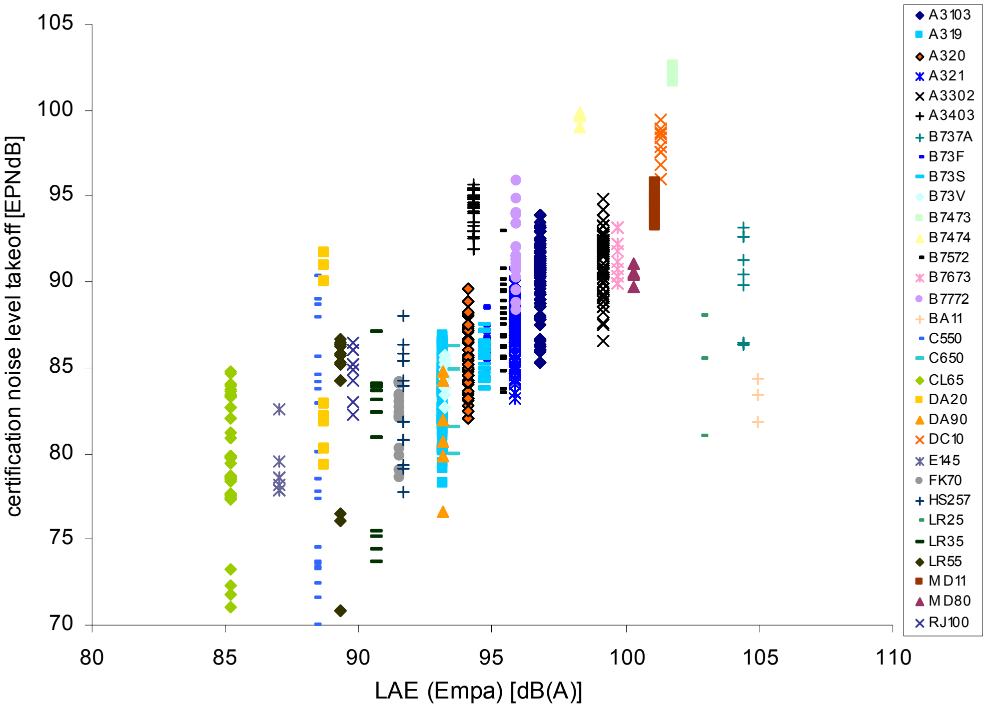
3.4.2.2 Comparison with EMPA data

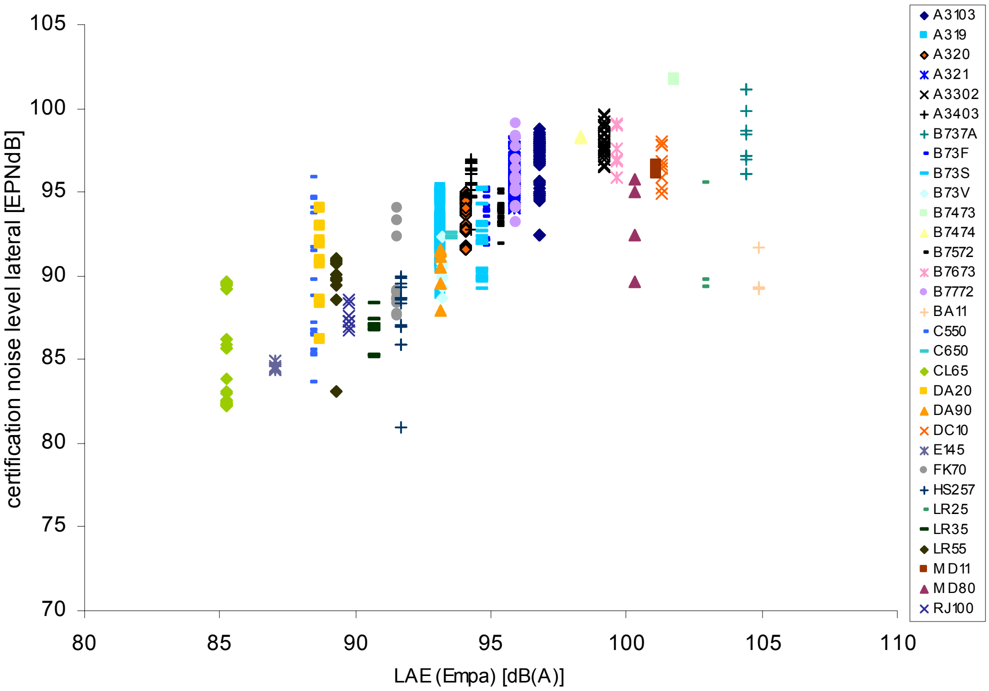
For permission to fly, each type of aircraft is required to possess a noise-certificate. The relevant certification procedure is laid down in detail by the ICAO; and the prescribed operating conditions for certification can differ from those prevailing in normal flight operations. Moreover, certificated levels are measured as effective perceived noise level (EPNL), an acoustic unit of measurement that specifically weights the magnitude of pure tones of the sound source. To evaluate noise exposure resulting from air traffic at and around airports, however, the A-weighted sound pressure level (SPL) is generally applied, which can differ considerably from EPNL (see further comments in Section 2.4).

That is why a direct comparison of noise-certification data with other noise data, such as levels measured at monitoring points or with simulated sound levels, is not all that easy. In order to estimate resulting deviations, certification data published by the *LBA* is compared with EMPA acoustic source data. For this purpose, existing certification data, with its highly detailed aircraft-type differentiation, must be assigned to acoustic parameters from EMPA source data records. Such assignment is undertaken manually on the basis of type and engine designations.

Figure 13 displays a comparison between certificated values for take-off and lateral measurement points, expressed in EPNdB, and A-weighted single-event sound levels (L_{AE}) for the corresponding reference types in the EMPA noise data bank. In doing so, differentiation for varied take-off mass in certification data cannot be considered. EMPA data used in this case applies to average take-off mass and describes a mean value derived from measurements for different aircraft subtypes and flight configurations.

Figure 13 Comparison of certificated values for take-off and lateral measurement points in EPNdB with the A-weighted single-event sound levels (L_{AE}) – at a standard distance of 305 metres – from EMPA source data





It can be seen from the diagram that certificated values for individual aircraft types are widely spread. A greater spread is generally observed at the take-off measurement point than at the lateral and approach measurement points. This is attributable, among other things, to the fact that besides an aircraft's sound volume the take-off value also directly reflects its climbing performance. Large spreads are observed, above all, with business jets. In the case of the Cessna C 550 Citation, for instance, the difference between the highest and the lowest certificated value at the take-off measurement point amounts to 17 dB. This obviously has to do with the fact that certain certificated values apply for take-off procedures with thrust cutback, while others do not. But also in the case of larger passenger aircraft, which generally make use of take-off procedures with thrust cutback, the spread between maximum and minimum certificated values can amount to several decibels (A 330-200: 8.2 dB, A 320: 7.6 dB, B 757-300: 6.8 dB). These certifications differ with respect to engine type, maximum take-off mass (MTOM) and appropriate flap/slat deflection settings.

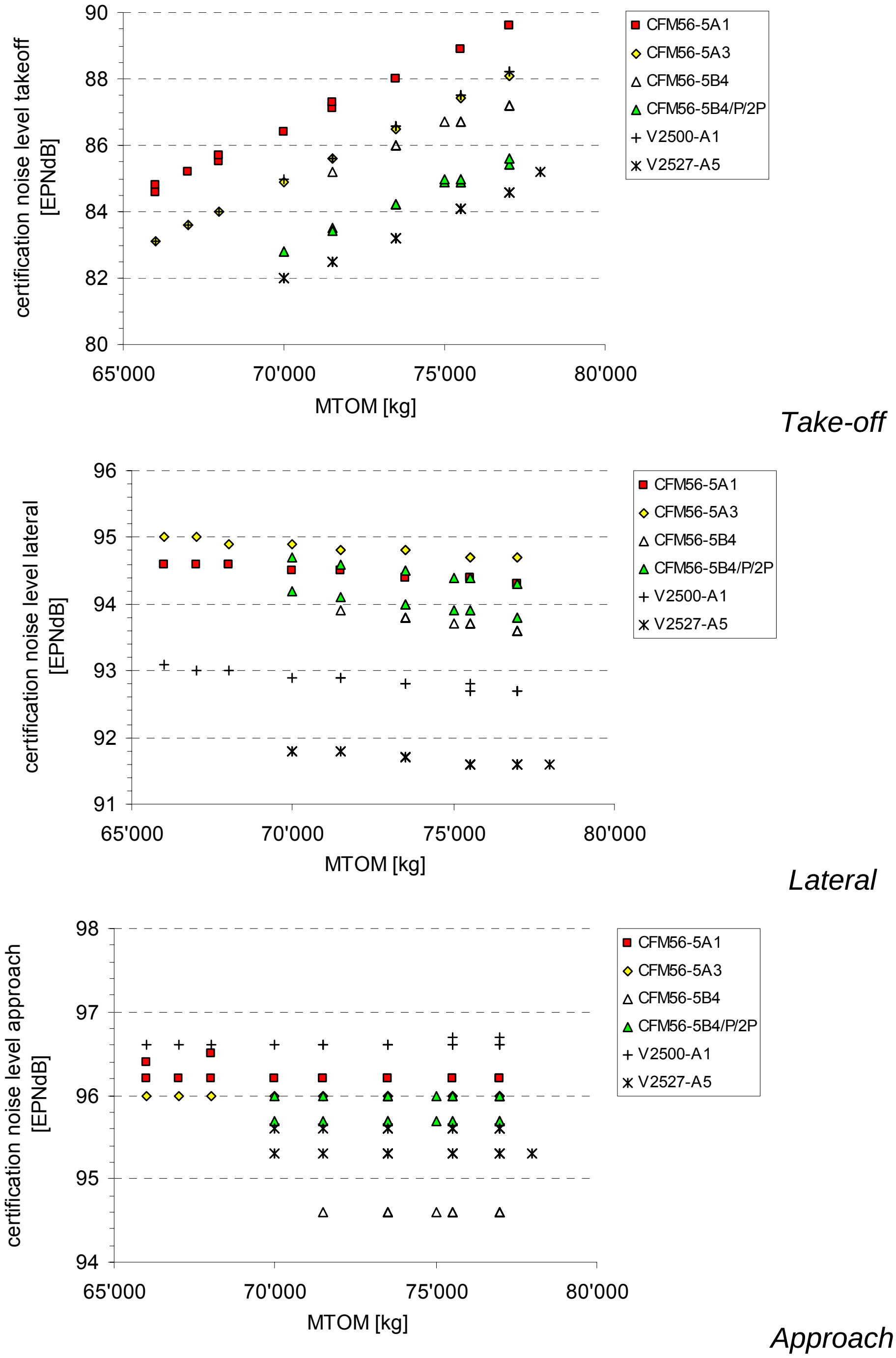
3.4.2.3 Influencing factors

For a detailed analysis of factors influencing certification, certificated noise levels for different engine configurations of individual aircraft types are shown as a function of take-off mass. Exemplary evaluation is carried out of the Airbus A 320, A 321 and A 330 as well as of the Boeing B 777. The resulting certificated values for various aircraft configurations at the take-off, lateral and approach measurement points, dependent on maximum take-off mass, are displayed for the Airbus A 320 in Figure 14. Corresponding presentations for other aircraft types can be found in Appendix H.

It can be seen in these diagrams that certificated levels depend not only on certificated take-off mass, but also on the type of engine. The effects of take-off mass and engine type are not the same, however, at all measurement points. With the Airbus A 320, for instance, the highest levels are recorded at the take-off measurement point for aircraft equipped with a CFM56-5A1 engine. These levels lie for the full range of take-off mass around 1.5 dB above the certificated value for the CFM56-5A3 engine. At the lateral measurement point, on the other hand, the aircraft equipped with a CFM56-5A3 engine reaches the highest level, which is about 0.5 dB above the corresponding value for aircraft equipped with engine type CFM 56-5A1. And quite different circumstances on landing are recorded at the approach measurement point, where engine types V 2500-A1 – that on take-off are much quieter than CFM 56 engines – are the loudest.

The dependence of certificated levels on take-off mass is also noticeably different at individual certification points. While at the take-off measurement point, levels of all aircraft under examination increase virtually linear with take-off mass, at the lateral and approach measurement points only a very limited dependence of certificated values on take-off mass can be ascertained. With the A 320 and A 321, recorded levels at the lateral measurement point actually decrease with increasing take-off mass.

Figure 14 Certificated levels for the Airbus A320 with various engine configurations, dependent on take-off mass, at the take-off, lateral and approach measurement points



Noise levels measured at certification points are pure exposure levels, which depend not only on the sound source, but also on other influencing factors. Noise levels measured at the take-off measurement point, for instance, are very much dependent on flyover altitude and thus on the climbing performance of the aircraft. At the lateral measurement point, on the other hand, ground interference plays a major role, since the sound source is measured at a low angle of incidence. Certificated values thus characterize not so much the sound volume of the source, but rather sound exposure under very special circumstances at specific points of exposure. That is why sound levels measured at certification points allow no direct conclusions concerning the effective sound volume of the respective aircraft.

3.5 Assessment

Considering airports as a whole, noise emission is mainly caused by the operation of relatively quiet medium-haul jets of more recent series of the Boeing B 737 (from series 300) and the Airbus A 319/320/321. The comparatively low sound volume of these types of aircraft is more than offset, however, by the proportionately higher number of flight movements. Averaged over all the airports under investigation, these aircraft contribute around 50% of overall sound energy; and they dominate sound volume not only on take-off but also on landing, whereby the share of sound is somewhat higher on landing than on take-off.

A detailed analysis shows that considerable differences exist among the airports under investigation with regard to the shares of total sound of individual types of aircraft. While aircraft of the B 737 series make up by far the most noise-intensive aircraft group at the medium-sized airports of Cologne/Bonn, Hamburg and Geneva, with a 20 to 40 per cent share of sound, at Zürich Airport it is flight movements with the somewhat older MD 80 to MD 87 series that contribute most to total sound volume, with a good 15% share. At Frankfurt Airport, which is primarily involved in intercontinental transport, the Jumbo B 747, with just less than 30% of total sound volume, is the most sound-intensive aircraft group. The share of the heavy long-haul jets B 747, MD 11, DC 10, A 340 and B 777 amounts in Frankfurt to around 40 %. At Zürich and Cologne airports, their share is around 15%, while at the remaining airports it is less than 5%. At Frankfurt, Zürich and Geneva airports, the share of total sound of very loud jets of older series is of practically no importance, while the less frequent flight movements of aircraft types B 727, B 737A and DC 9 as well as of the TU 154B/M and YK 42 are nevertheless responsible for a good 10% of total sound volume at Cologne/Bonn and Hamburg airports.

An analysis of seat-related sound emission shows that, with the exception of relatively loud business jets, sound energy per seat depends only insignificantly on the number of seats. Due to varied flight operations, not all aircraft can be directly compared. The analysis shows however, that also in the case of aircraft with a comparable operational spectrum, seat-related sound energy is dependent on the number of seats to only a negligible extent. At the same time, there are signs that emitted sound volume per seat increases with an increase in the number of seats.

In a further analysis, certification data was compared with ICAO noise limits. This comparison showed that only older aircraft series, such as the Airbus A 300B2, Boeing B 737A and B 747-200 as well as the DC 10-30 and the MD 80 to 87, do not meet the more stringent standards of *Chapter 4*. Aircraft of the latest generation already clearly surpass *Chapter 4* noise limits.

4 Present state and future development of noise-reduction technology and assessment of possible trade-off effects

4.1 Terms of reference

The noise characteristics of an aircraft can only be considered in terms of the combined effect of all noise sources of the complete system, that is, airframe and engines together. The reason for this is the highly complex interaction of individual sources in the noise emission of the aircraft system. Since an aircraft manufacturer was not involved in the present report, in addition from the presentation of engine-related matters MTU also took over the additional task of dealing with noise-relevant interrelations and situations of the entire aircraft system, the airframe as well as corresponding interaction. For the most part, use was made of published material. An integral examination is also essential, since the assessment of trade-offs, which is called for within the framework of this report, can basically only be conducted convincingly in terms of their effects on the entire aircraft system.

In the following sections, the main noise sources in the airframe (Section 4.2) and engine (Section 4.3) are identified, and comments made on the contribution of overall configuration and engine installation (Section 4.4).

4.2 Main noise sources of the airframe

The main noise sources of the airframe are displayed in Figure 15. A number of general comments can also be made. The noise characteristics of flaps, slats and undercarriage are very much dependent on the mechanical design of these modules. Noise induced by the outer surface of the airframe and wings depends on aerodynamic quality, on the one hand, and naturally also on the dimensions of all surfaces, and thus on the overall size of the aircraft. Further sources of noise could be small irregularities, such as recessed cover plates and external airframe edges. These isolated noise sources can make a significant contribution to total noise when tonal shares in sound are generated in audible frequency ranges.

Figure 15 Main airframe noise sources

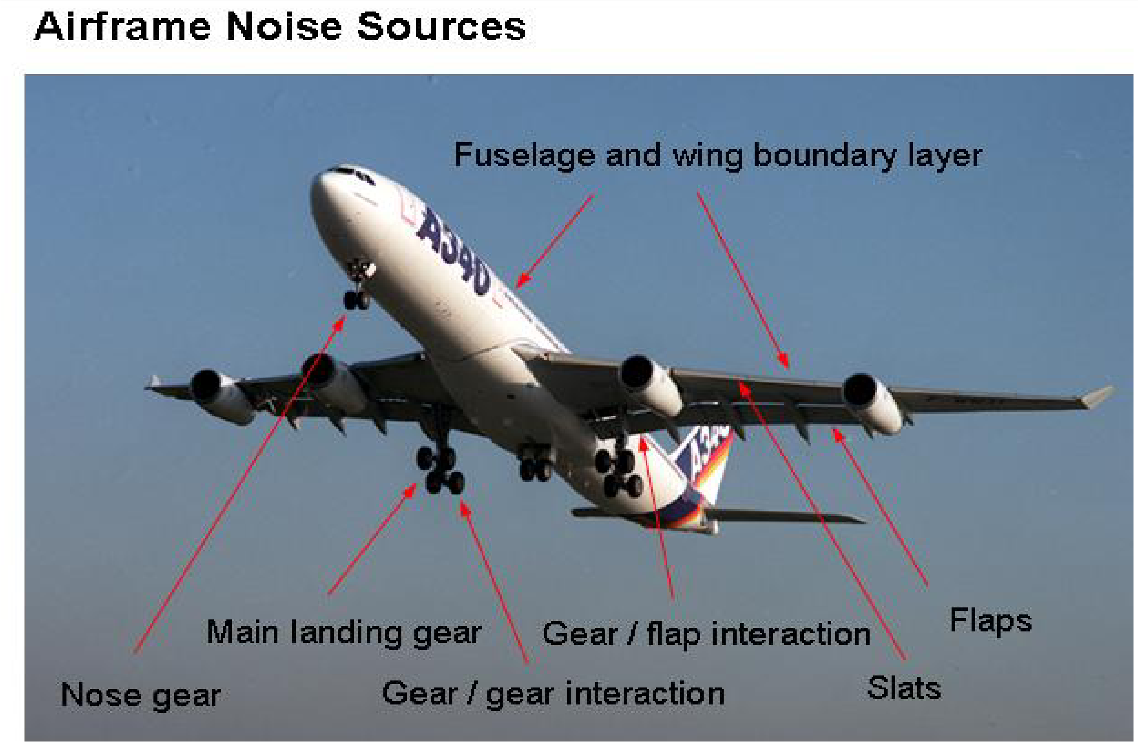
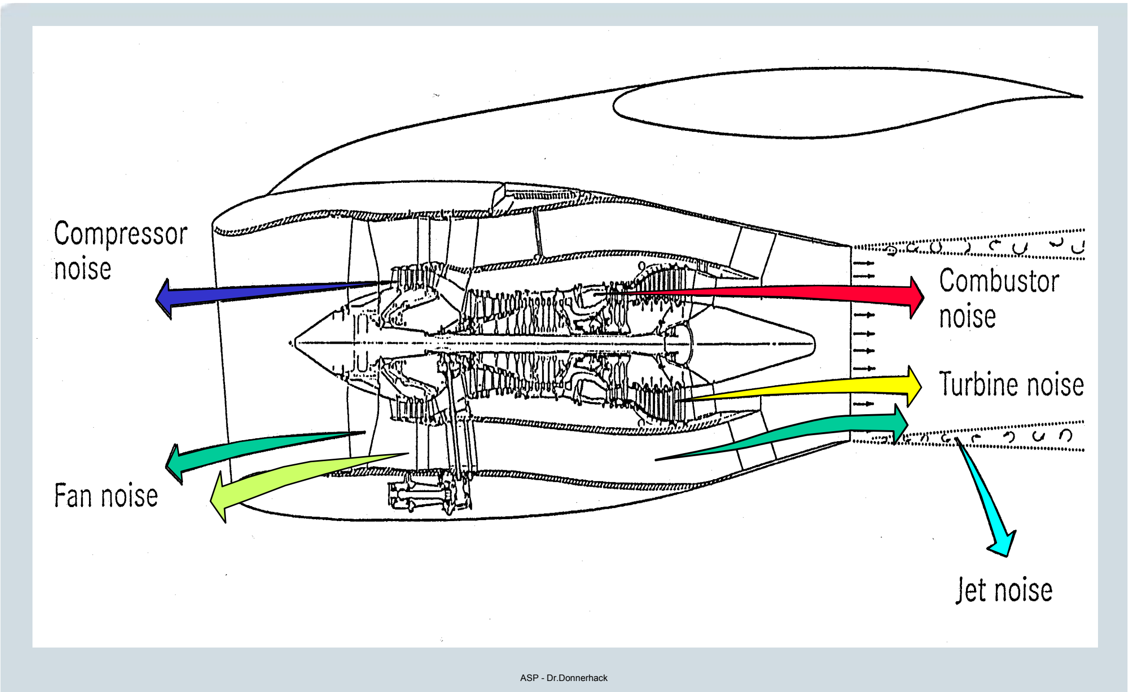


Figure 16 Engine component noise sources



4.3 Main sources of engine noise

The main sources of engine noise are identified in Figure 16. Here, too, a few additional general comments can be made. Jet and combustor noise involve broadband shares, whereas noise from the fan, compressor and turbine has large tonal spectra. In the case of fan noise, the importance of aerodynamic interaction of rotor and stator flows is indicated in Figure 16. Jet noise depends highly on the jet velocity of the engine, and can therefore be clearly influenced by the parameter of specific thrust and, thus, by the bypass ratio (BPR).

4.4 Influence of the nacelle and engine installation

Apart from single noise sources, described in Sections 4.2 and 4.3, the interaction of airframe and engine also has a decisive influence on total noise. This interaction is determined by overall configuration and also by the type of engine installation on the aircraft. While the currently most common under-wing engine installation offers only limited noise insulation through the fuselage and wings in a lateral direction and downwards, tail or over-wing installation offers advantages.

4.5 Status description of aircraft and engine noise

In the following status review the main focus is on engine noise. Figure 17 displays the noise contributions, in absolute terms, of the above-mentioned single sound sources in a typical state-of-the-art application: medium-range aircraft with engines with a bypass ratio of 5. In the diagram, the noise contributions of the fan, compressor and turbine as well as jet noise, combustor noise and integral airframe noise are displayed for two of the three certification measurement points (take-off/lateral and approach). Total system noise is displayed in each case on the bottom line. This analytical data is expressed in the usual noise level unit of EPNdB.

Differing noise contributions at the two measurement points can be discerned: Jet and fan noise are predominant on take-off; remaining contributions can be more or less ignored. On approach, besides the fan the airframe and (low-pressure) turbine also make a substantial contribution. In comparing the two measurement points it should be borne in mind that, due to different measuring distances and the frequency-related atmospheric attenuation characteristic, values in absolute terms can vary widely.

It can be deduced from this description that the design of widely differing engine modules has to be optimized with respect to noise characteristics, taking account of very different noise sources in an individual engine. It is also important to mention that measures involving isolated modules are only practical up to the point where the level of other noise sources is reached. A disproportionate noise reduction of isolated noise sources without consideration of the total system is therefore neither practical nor recommendable.

Figure 17 Contributions of engine noise sources

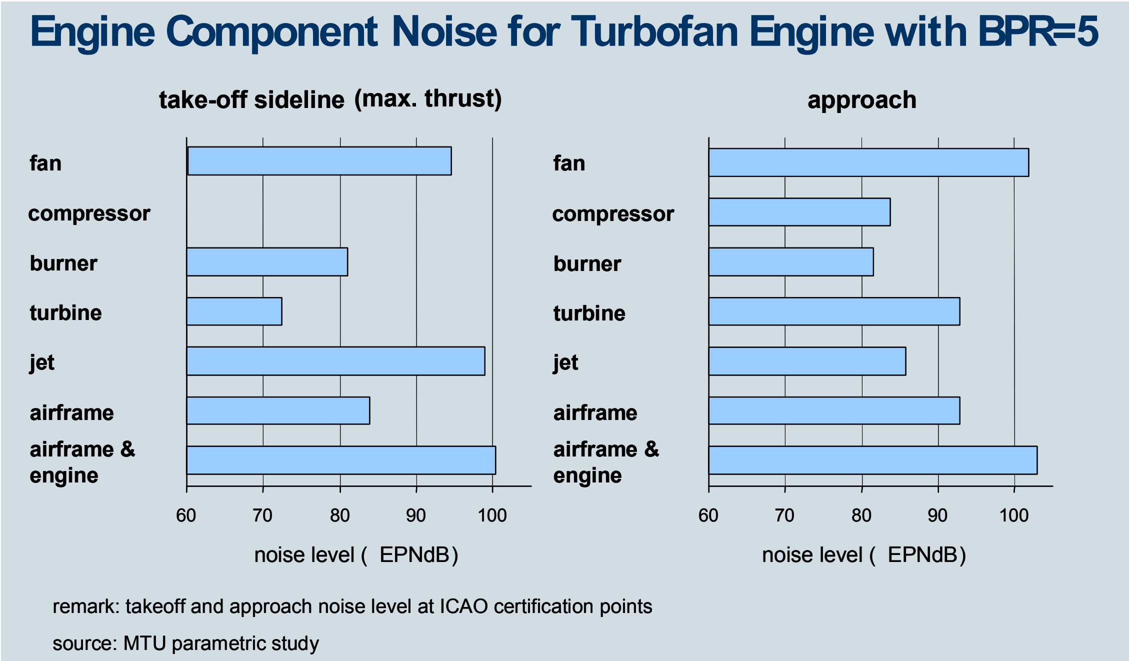
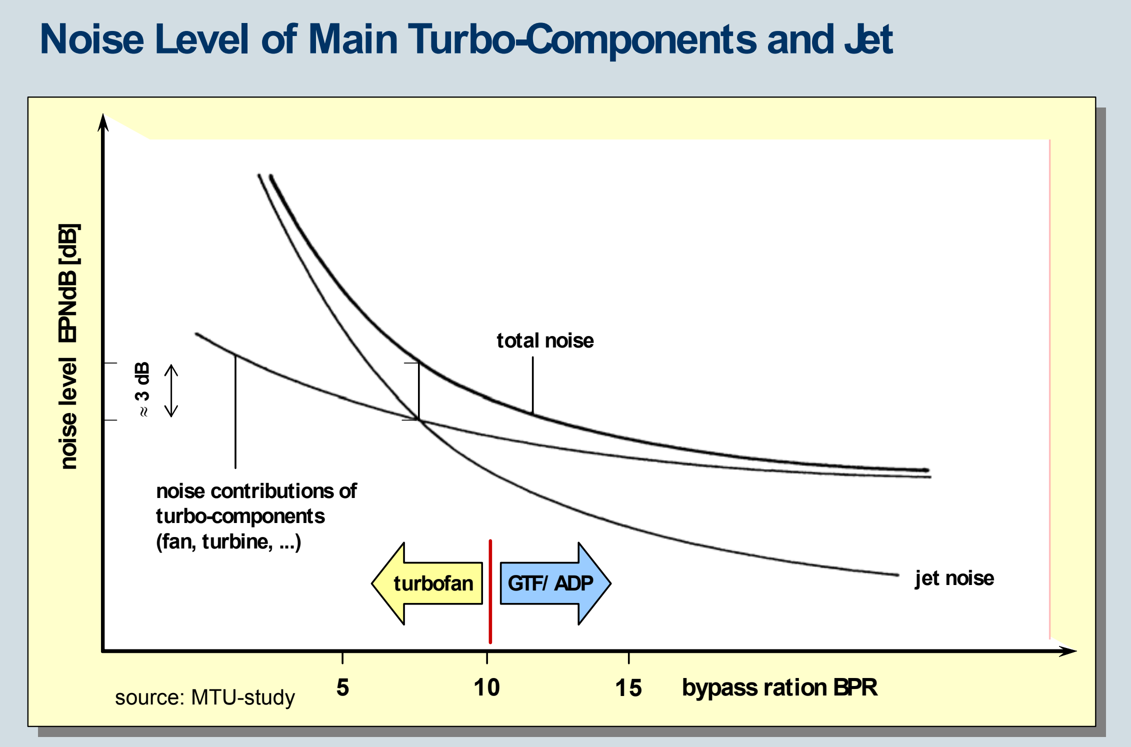


Figure 18 shows how the fundamental interrelation of the two main engine sources, jet noise and noise from turbo components, as well as total noise depend on the bypass-ratio (BPR) parameter, in this case for the take-off configuration. A regime separation is also indicated in Figure 18 with respect to the conventional turbofan (BPR < 10) and the so-called geared turbofan (GTF for BPR > 10).

While with engines without bypass, first-generation "turbojet' engines and "turbofan" engines with modest bypass (BPR < 5) jet noise clearly dominates all other noise sources, with turbofan engines with higher bypass ratios – that is 6 < BPR < 9 – turbo components, and in particular the fan, also make an appreciable contribution to total noise at a reduced total noise level. With BPR > 9, turbo components, and in particular the fan, predominate at a further reduced total noise level. See also Figure 19, which displays noise characteristics (*lateral*) over all engine generations and data on the BPR of exemplary engines.

Figure 18 Engine noise level depending on bypass ratio at takeoff

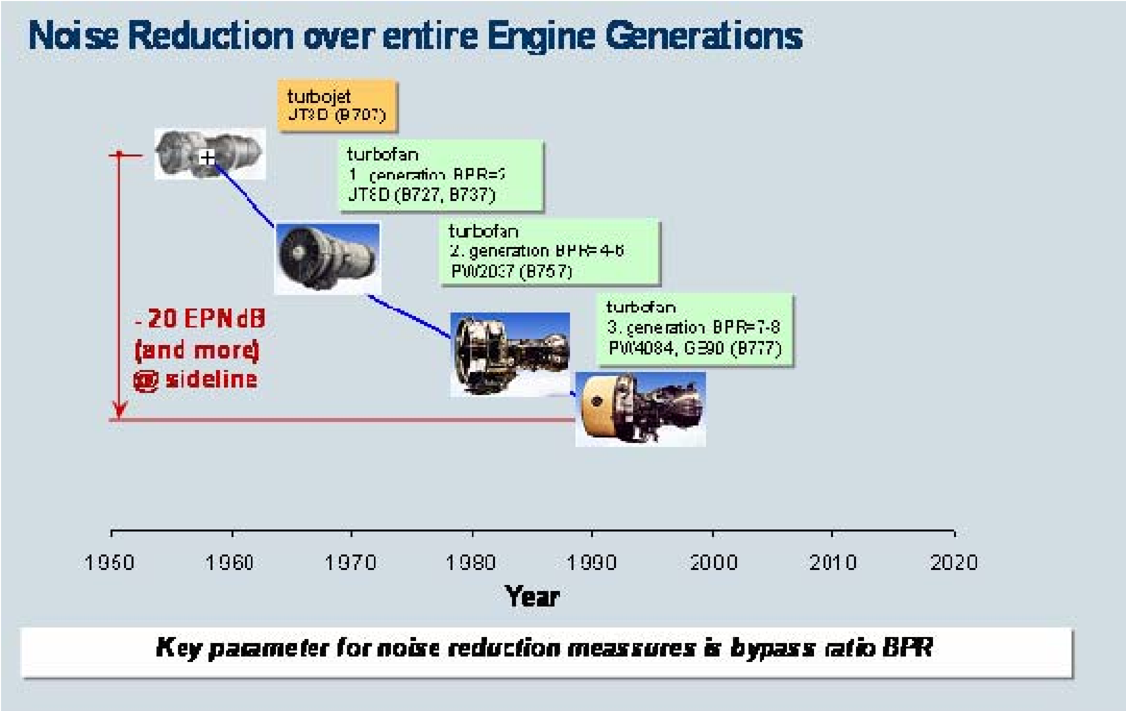


4.6 Objectives of "ACARE Vision 2020"

In the past, improvements in engine noise went practically hand-in-hand with constant efforts to improve propulsion efficiency and thus with improvements in economic efficiency (specific fuel consumption). This way, engine noise was reduced over a number of generations by more than 20 EPNdB (single point; for example, take-off/*lateral*), which roughly corresponds with a 75% cut in noise exposure. Figure 19 displays this connection on the example of selected engines during the period in question.

Through the combination of constantly growing air transport and the resulting great increase in noise exposure, on the one hand, and steadily increasing sensitization of the population worldwide on the other hand, the issue of aircraft noise has become highly important for the aviation industry. The consequence is that demand for low-noise aircraft and engines is steadily growing, and the purchasing decisions of airline companies are also increasingly influenced by the issue of noise.

Figure 19 High effort with engine noise reductions achieved in the past

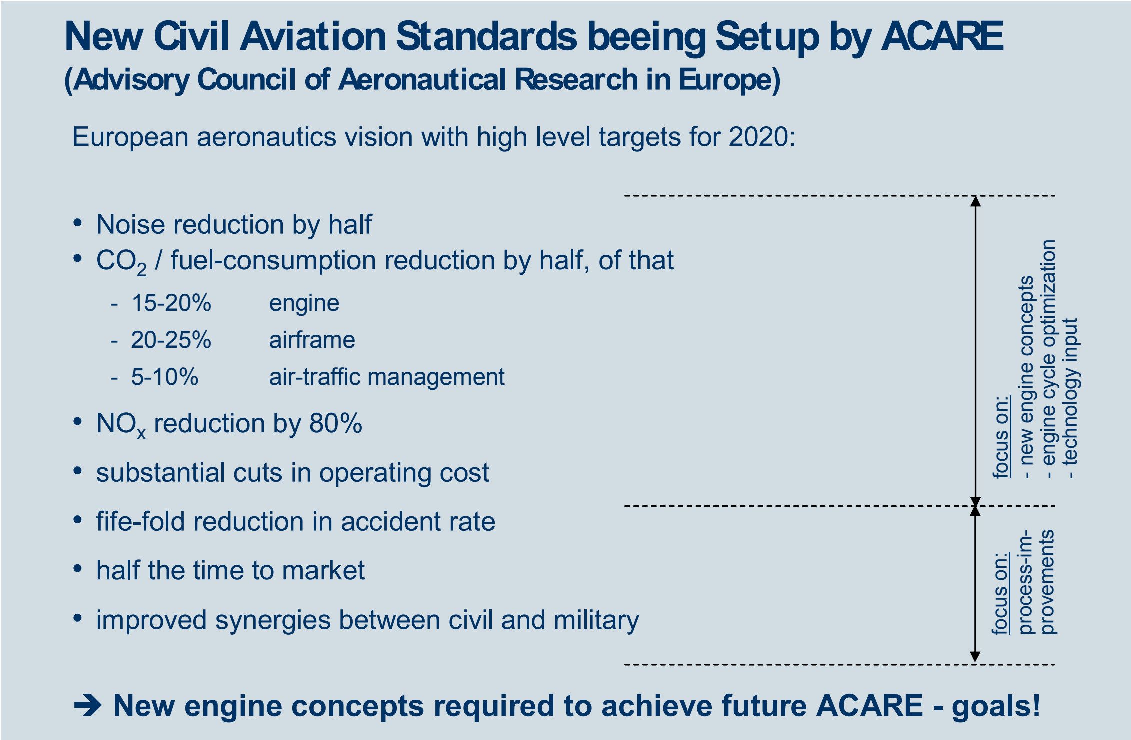


The European aeronautics industry entered into a commitment, entitled "ACARE Vision 2020", according to which further expected growth in air traffic volume should not be at the expense of the environment. ACARE Vision 2020 defines highly ambitious targets, which are summarized in Figure 20. Within the given period, a further halving of perceived aircraft noise is laid down. Besides noise reduction further targets are defined:

- NOx: Reduction by 80%
- CO_2: Reduction by 50%
- A five-fold reduction in accident rates
- Halving the "time to market" for new products
- Reduction of operating costs

Following on from ACARE Vision 2020, a number of technology programmes focussed on noise have been concluded or are in progress or planned at a European and national level, with the aim of producing a roadmap for product maturity up to 2020.

Figure 20 Summary of ACARE Vision 2020 goals



4.7 Description of important noise technology programmes and configuration studies

In this section, the targets and results of the most important programmes in the area of aircraft noise are surveyed, divided into the following five subsections:

- Studies on low-noise aircraft configurations (Section 4.7.1)
- Studies on aircraft-related noise technology (Section 4.7.2)
- Studies on low-noise engine configurations and technology (Section 4.7.3)
- Studies on engine- and nacelle-related noise technology (Section 4.7.4)
- General studies (Section 4.7.5)

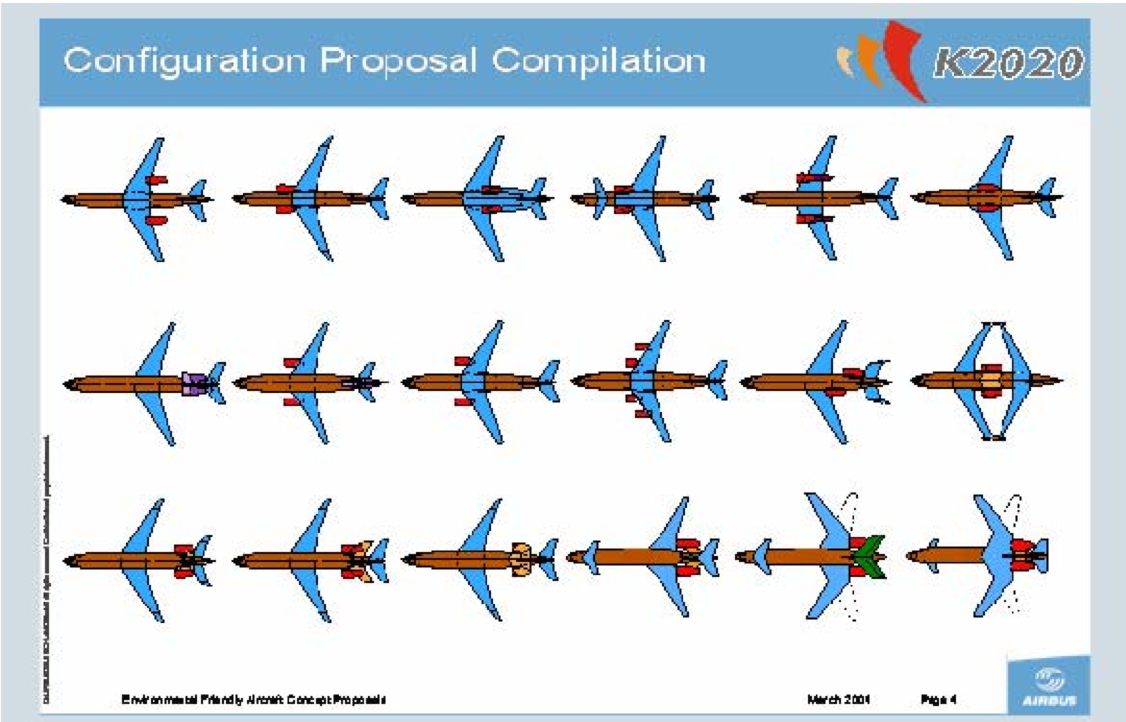
4.7.1 Studies on low-noise aircraft configurations

<u>A. Konfig2020</u>

Different concepts with varied objectives are examined in the national programme, *"LuFo III: Konfigurationen 2020*", for which Airbus Germany is responsible. *"ProGreen-umweltfreundliches Flugzeug"* focuses primarily on environmental topics such as noise and emissions, but also looks at manufacturing processes and the recycling of materials. Numerous concepts related to engine integration and the screening of engine noise are investigated in this programme with respect to their suitability for aircraft design. Figure 21 displays the full range of integration variants presented at the commencement of the study.

The aim of these investigations is to establish to what extent the aircraft configuration itself can contribute to engine noise reduction by shielding of the wings, airframe, empennage, by engines themselves or by additional engine shieldings, while avoiding a negative effect on engines through excessive engine related noise measures. A major topic in these examinations is the "trade off" of weight-related influences of configuration measures. Besides additional weight, the majority of proposed configurations have an adverse effect on all aspects of maintenance. MTU participates in "Konfig2020" through the provision of engine data.

Figure 21 LuFoIV-K2020: Pre-studies of different variants for the “ProGreen” aircraft



B. NACRE

In the 6th EU Framework Programme, an integrated programme entitled "NACRE-New Aircraft Concepts Research in Europe" was launched on 1 April 2005 under the responsibility of Airbus France. In this programme, too, various aircraft concepts with varied principle objectives are investigated, including *"ProGreen"*. Supplementing studies of Konfig2020 Phase I, design solutions for selected engine configurations are evolved in NACRE. MTU also participates in NACRE through the provision of engine data.

The aims of both major Airbus configuration programmes reflect the global goals of ACARE Vision 2020.

C. NASA Quiet Green Transport

The "NASA Quiet Green Transport" programme in the USA is comparable to NACRE. According to the NACRE consortium, the USA is ahead in time in this area, with respect not only to numerical techniques but also to hardware tests.

4.7.2 Studies on aircraft-related noise technology

A. Quiet traffic and Quiet Air Traffic II

This category includes work in the industry-wide national project, "Quiet traffic / Quiet air traffic II". In this integrated project, which is under the direction of the German Aerospace Center (DLR) and also covers rail and road traffic as well as research on noise exposure, a number of selected, aircraft-related noise reduction measures are carried out and evaluated on flyover. DLR's partners in this project are Lufthansa, Airbus and SNECMA. The following topics are being dealt with:

- Aircraft measure: aerodynamic vortex generation.
- Chevron nozzle: in this case, the core engine nozzle.
- Landing and take-off procedures.

Individual measures were identified and quantified on flyover using array measurements ("acoustic camera").

The choice of subject matter was predetermined by the possibilities of simple adaptation and attachment of noise reducing equipment, cladding etc. to the aircraft and engine. The project is therefore mainly concerned with demonstrations; and a number of demonstrated measures (core engine Chevron nozzle and flap/slat settings on approach) already have a high degree of product or procedural suitability.

B. "FREQUENZ" Project

Deutsche Lufthansa (co-ordinator), Airbus Germany, Rolls-Royce Germany, Dornier, EADS F&T and three universities are involved in the *LuFo III "FREQUENZ"* project, which comprises numerical studies (CFD/CAA) and wind tunnel tests with regard to flap and slat noise.

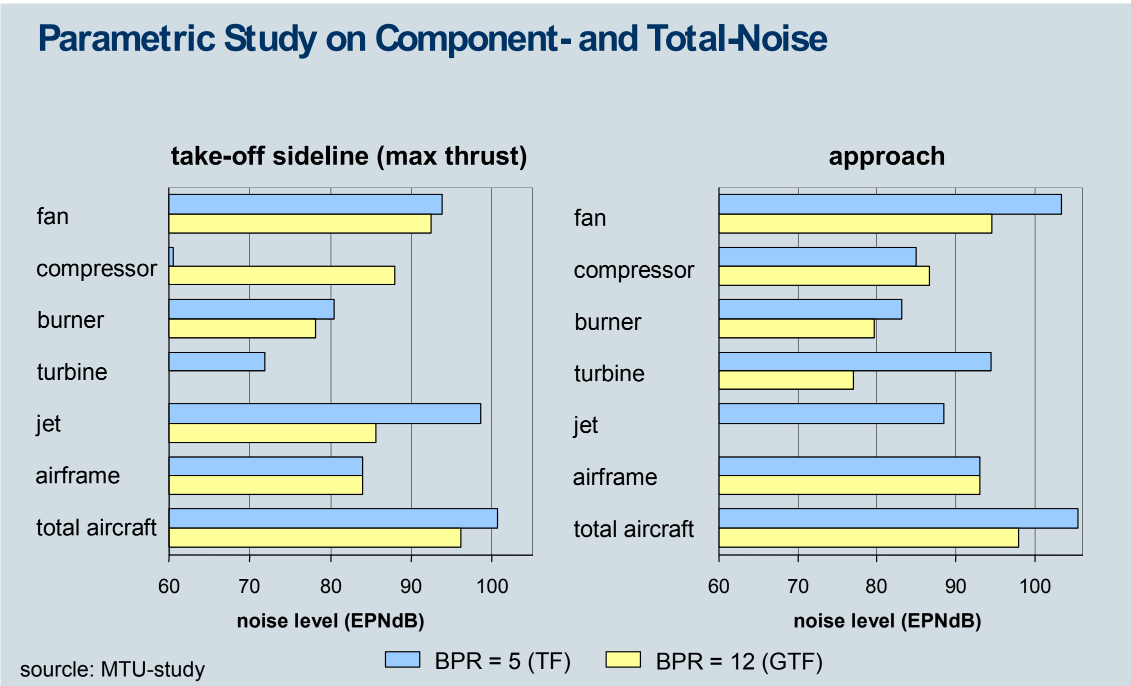
4.7.3 Studies on low-noise engine configurations and technology

A. EEFA-E with ANTLE and CLEAN

EEFA-E (Efficient and Environmentally Friendly Aero-Engine), ANTLE (affordable near-term low emission engine) and CLEAN (component validator for environmental friendly aero-engine) are all part of the 5th EU Framework Programme. The task of the ANTLE and CLEAN technology projects was the validation of varied component technology in engine tests. In the meantime, the tests have been concluded and relevant reports will shortly be presented to the EC (European Commission). CLEAN, which has validated not only a low-NOx combustor but also a so-called "high-speed low-pressure turbine" for the geared turbofan, is closely associated with this report. The particular influence of the bypass ratio (BPR) on engine noise was dealt with in Section 4.5 ("status description"), and in Figure 18 the geared turbofan regime was defined for BPR > 10. The design of the geared turbofan is distinguished from that of the conventional turbofan by transmission gearing between low-pressure turbine and fan. This enables the fan and low-pressure turbine to attain their respective optimum rotational speed independent of each other. This initially presents the option of a fan speed with a more positive effect on noise. In addition, higher BPR can be achieved with the geared turbofan, so that jet noise can also be reduced. A key component of the geared turbofan is the high speed low-pressure turbine, whose operation is much more efficient than die conventional, low-speed low-pressure turbine. Due to the different characteristics of noise radiation, the high-speed low-pressure turbine also contributes less noise on approach than the corresponding conventional low-pressure turbine of a TF engine. Module-side noise contributions of a turbofan with a BPR of 12 are displayed in Figure 22. The comments in Section 4.5 also apply here.

Figure 22 shows that, as a result of its design, the geared turbofan achieves a noise bonus at the total system level of around 5 to 6 dB at each noise measurement point.

Figure 22 Comparison of conventional TF (BPR=5) with geared turbofan (BPR=12)



B. Status of the geared turbofan in the USA

"Geared turbofan will shortly be on the market"

The driving force behind the geared turbofan is the American manufacturer Pratt & Whitney (P&W), which since the mid-1990s has conducted a range of technologyl programmes and even sales campaigns, among them:

- ADP demonstrator (advanced ducted propfan; with MTU participation)
- PW 8000 (1998/1999 campaign, with MTU participation)
- ATFI (flight-demo for regional and business applications; directed by P&W Canada with MTU participation)
- PW 800 (campaign for regional and business applications; directed by P&W Canada with MTU participation)

Participating manufacturers regard the geared turbofan design as an appropriate solution to the dilemma of fan speed and thus fan noise on the one side, and efficiency demands on the low-pressure turbine on the other. A further advantage is improved operational distribution between turbo-modules, with the possibility to reduce the number of components. Furthermore, GTF opens up the possibility of higher BPR and, as a result, greater propulsive efficiency.

The disadvantages of GTF are

- the greater complexity of the gear unit,
- the thermal regime of the gear unit,
- greater weight (additional gear unit and heavy low-pressure turbine) and
- a flight-test demonstration has not yet been carried out.

In the US, Pratt & Whitney, with the support of MTU, is making every effort – including further work on technology and flight-demonstrations – to establish the GTF as economic and low-noise approach for the coming engine generation.

C. VITAL

VITAL, which was launched on 1 January 2005, is the major integrated technology project in the 6th EU Framework Programme in the field of low-pressure systems; that is, fan, low-pressure compressor, turbine and shaft as well as installation. Through the combination of module technology and engine configuration, VITAL aims at achieving an improvement in propulsive efficiency of around 7% and a cumulative reduction in noise of about 18 dB compared to the current state-of-the-art, with a neutral effect on weight. Targeted technology maturity is not the same for the modules and technologies under consideration. VITAL's global objective is orientated towards the targets of

ACARE 2020. All European engine manufacturers as well as the aircraft manufacturer Airbus and further R&D partners are actively involved in VITAL.

VITAL defines three engine concepts, against which VITAL objectives have to be measured:

- a direct-drive fan, follow-on of RR's "ANTLE" concept,
- a geared fan, follow-on of MTU's "CLEAN" GTF concept and
- a counter-rotating fan; a concept proposed by SNECMA and favoured by GE.

Key VITAL tasks will be to deal with technology risks and shortcomings as well as to indicate ways of closing the remaining gap to fulfilment of noise targets in the 7th EU Framework Programme.

4.7.4 Studies on engine- and nacelle-related noise technology

A. RESOUND

The EU project RESOUND, which ran from 1998 to 2001, investigated design measures and new types of technology for the abatement of predominant engine-noise sources. Two types of fan and a turbine outlet disk were designed with low noise emissions, using computer fluid dynamics (CFD), and then tested. In addition, new passive and active noise reduction concepts were investigated at the sound source.

B. RANNTAC

The EU project RANNTAC, which has also been concluded, was concerned with passive and active noise reduction in the engine nacelle. New concepts were developed for sound absorbers and then evaluated in the laboratory and in operational conditions. In addition, active sound reduction was modelled computationally with loudspeakers mounted to the inner wall of the nacelle and tested in a fan. Work also focussed on the development of suitable loudspeakers.

C. RAIN

Parallel to the projects described under A and B, which concerned noise propagation in engines and its reduction in the nacelle, the EU research project RAIN investigated airframe noise. In this case, the two main noise sources are auxiliary lift-off power on wings – that is, flaps and slats – and landing gear.

On the example of a long-range aircraft with four engines with a BPR of 8, it was established that aircraft noise could be reduced by 4.4 dB (accumulated over the three certification measurement points) through the joint application of the most successful technologies developed in the RESOUND, RANNTAC and RAIN projects.

D. TurboNoiseCFD

The aim of this project was application of existing CFD computation methods in calculating the sound generation of turbo-generators. For this purpose, computations generated with different methods were benchmarked with results produced analytically and experimentally. In addition, methods were developed for combining the results of CFD computations with methods for calculating sound radiation. Finally, studies were conducted on the reduction of turbo-machinery noise by means of design applications.

E. NASGeT

The NASGeT project on "New types of active / passive systems for the reduction of noise in engines" is part of the German research network "*Leiser Verkehr*" (quiet traffic), initiated by the German Aerospace Center (DLR), in which Dornier, DLR, EADS F&T and MTU are also involved. Its aim is the practical application of technical means of active and passive noise abatement in engines.

To this end, tests are carried out on a fan with new types of actuators, active / passive systems (active absorber array) are developed and tested, and numerical studies are conducted on different concepts for active noise reduction in compressors.

A further investigation within the scope of NASGeT aims at the active control of jet noise, with tests planned with actuators on nozzles.

The passive measures dealt with in NASGeT can be generally regarded as appropriate in the "mid term"; while the technical feasibility of the majority of active measures has still to be proven, which are therefore more a "long-term" option.

F. LEXMOS

The LEXMOS project, for which Rolls Royce Germany is responsible, and in which Dornier and DLR also participate, investigates the effect mechanisms of jet noise. Sound sources are located experimentally, and it is planned to test measures for reducing jet noise through the design and sound absorbing lining of the nozzle's trailing edge.

F. ALIDE

In this EU project, for which AerMacchi is responsible, sound absorbers for cold and hot flow ducts are modelled mathematically.

G. Fuel cell study

Under the designation APAWAGS (*Advanced Power and Water Generation System*), the possibility is investigated of generating water and electricity on board aircraft by means of a fuel-cell system run on kerosene. The study is conducted by Airbus Germany with the co-operation of MTU and the support of the Federal Ministry of

Economics. Preliminary studies showed that, on the grounds of weight, fuel cells are not a suitable substitute for the auxiliary power units (APU) in aircraft. If the task of water supply on board is also taken on, a useful auxiliary energy system could possibly be configured in the form of a hybrid power unit, with a gas turbine for charging as well as application of a kerosene reformer. The APAWAGS study is not primarily concerned with problems of noise, but hybrid energy supply based on fuel cells could operate much more efficiently and with less noise than a conventional auxiliary gas turbine (APU).

4.7.5 Comprehensive studies

A. SILENCE(R)

Almost all European aircraft and engine manufacturers and aviation research establishments as well as a number of universities – altogether 51 partners from 14 countries (see Figure 23) – are involved in the SILENCE(R) research project, whose total budget exceeds 110 million euros, 50 % of which is funded by the European Commission, and which runs from 1 April 2001 to 30 June 2006.

The objective is the development of noise reduction technologies and their validation with the aid of tests on models, aircraft and engine components as well as complete engines on test stands and in wind tunnels, but also with flight tests on Airbus A320 and A340 aircraft. The technologies under investigation will be evaluated not only with regard to their contribution to airport noise reduction, but also with respect to their effects on flight performance, costs, weight etc. (Figure 24). The noise-related objective is a reduction in aircraft noise of 3 dB by 2006 and 6 dB by 2008.

A broad spectrum of noise technologies for engines, engine nacelles and aircraft components have been investigated (see also Figure 25):

- Low-noise blade and vane design of fans, turbines and compressors (CFD design, swept blades etc.).
- Engines with high bypass ratios (UHBR engines).
- Negative scarfed intake to redirect noise-radiation upwards.
- New types of materials for sound absorbers for fans and turbines (for instance, titan-aluminide materials for hot environments).
- Zero splice liners.
- Additional sound absorbing liners on the nacelle intake lip (in conjunction with anti-icing devices)
- Sound-absorbing splitters in the bypass duct.
- Sound-absorbing plugs in core nozzles.
- Active / passive and adaptive sound absorbers.
- Corrugated nozzles (Chevron nozzles)

- Aerodynamically more favourable landing gear (retrofittable and new design)
- Low-noise high lift devices (flaps and slats on wings) with brushes to seal gaps and cavities lined with porous materials.
- Active sound reduction with actuators in the nacelle.
- Active sound reduction with Piezo actuators on blades.

During the course of the project, individual technologies are subject to a standardized process of assessment and selection, which ensures useful employment of available funds. The assessment of technologies is based on a series of generic aircraft and engine configurations: short- and long-range aircraft as well as engines with varying bypass ratios.

SILENCE(R) pursues the intention of cutting back the lead of programmes in the USA, such as "NASA Quiet Green Transport" (previously mentioned in connection with NACRE).

B. SEFA

The EU project known as SEFA (sound engineering for aircraft), which is co-ordinated by Dornier, concerns itself with the quality of noise perceived by those affected by aircraft flying over, and attempts to establish criteria for the generation of "acceptable" noise, analogous to now common "sound design" in the interiors of motor cars. Twenty companies from different industry sectors are involved in the project.

Figure 23 EU - platform SILENCE(R)

Figure 24 SILENCE(R) evaluation of noise reduction technologies

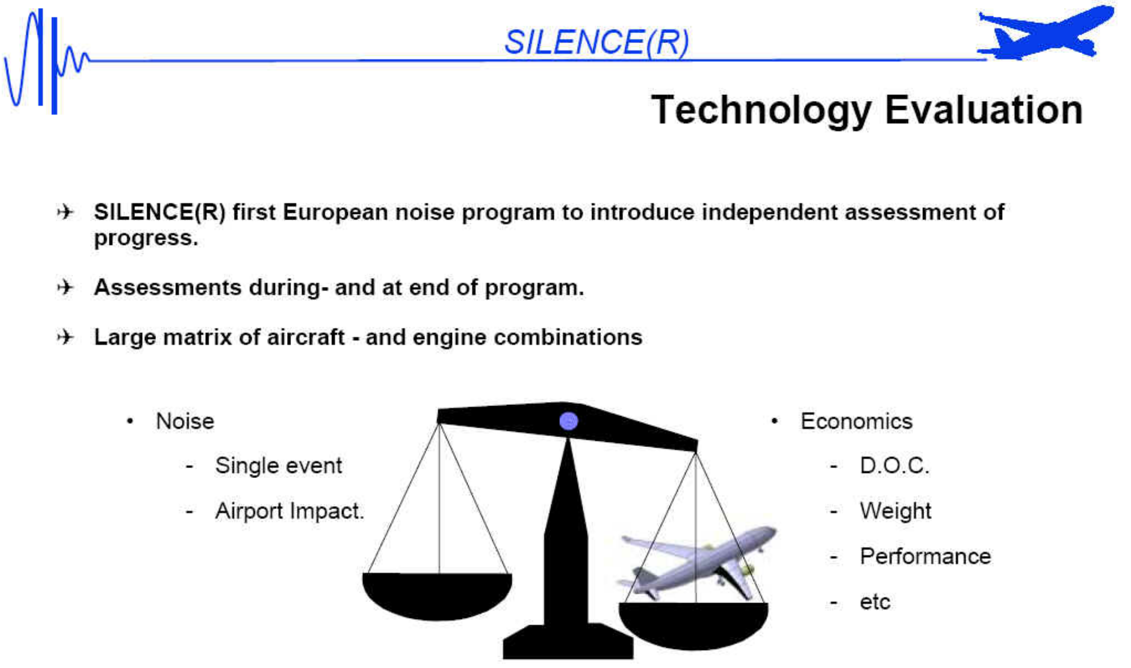
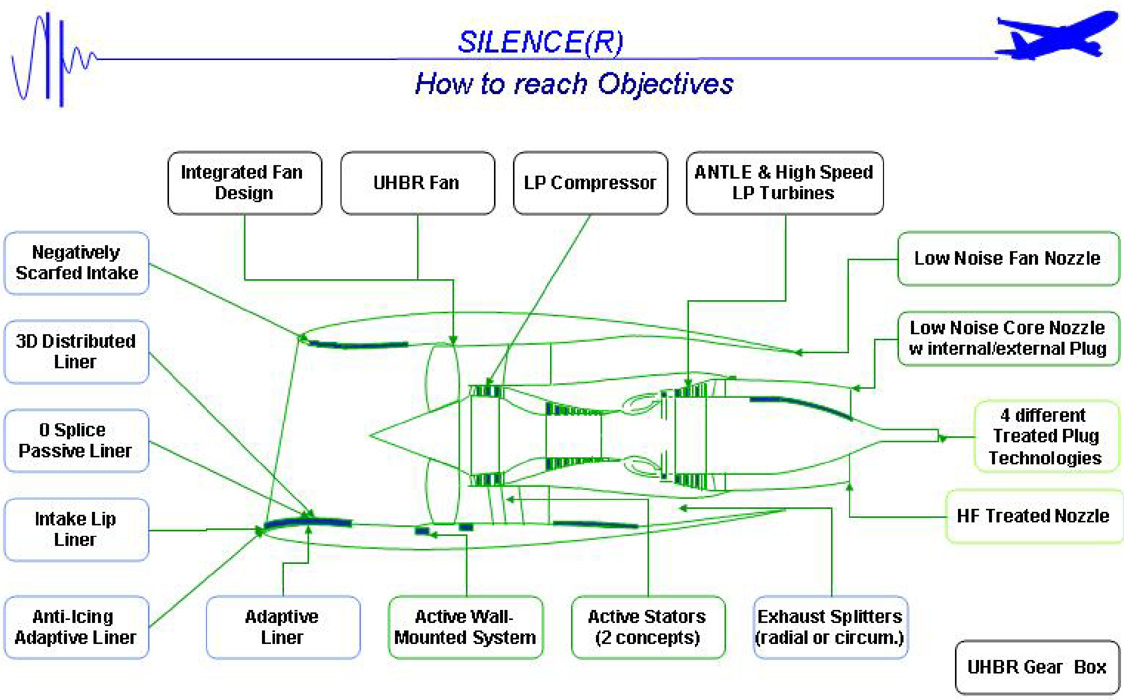


Figure 25 SILENCE(R) noise reduction technologies for engine and nacelle



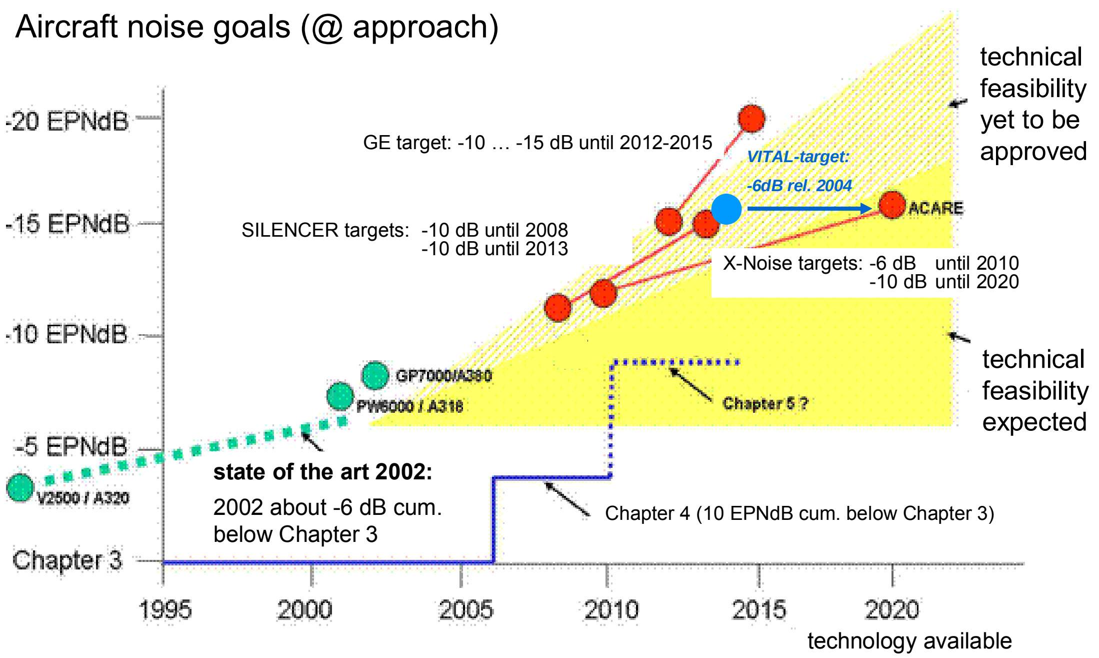
4.7.6 Roadmap for aircraft noise objectives

If earlier noise reduction activities were often of an isolated nature, since the 5th EU Framework Programme the aviation industry, in particular in Europe, has pursued a highly comprehensive approach with SILENCER and CLEAN as well as the voluntary commitments of ACARE Vision 2020. Larger projects at a national and European level must now prove their significance and contribution to the achievement of ACARE targets. Each project must set out

- targeted improvement in relation to current status and point of departure,
- targeted technology maturity (with a "roadmap" for product maturity) and
- potential interaction with other measures

The description of aircraft noise reduction targets is summarized in a roadmap (or diagram of target values) for the period up to 2020. Figure 26 displays such a roadmap compiled on an exemplary basis for the approach measurement point. This measurement point is particularly significant, since it is on approach – to a greater extent than at other noise measurement points – that airframe noise makes a substantial contribution to total aircraft noise (see Figure 17). The plotted points apply to total aircraft noise and therefore represent target values or technology potential for engine and airframe (for example, SILENCER). Besides defining current status, the roadmap also indicates important milestones of different programmes and projects. From a present-day perspective, engine- and airframe-related noise-reduction targets can be attained with product maturity by 2020, while at the same time avoiding solutions at the cost of other ACARE targets. The roadmap also contains further areas of potential, whose technical feasibility has not yet been substantiated.

Figure 26 Roadmap for engine and airframe contributions to a reduction in aircraft noise in the period to 2020



4.8 Trade-off effects between noise and pollutant emissions

The description of trade-offs between the different and, in particular, competing aims of aero- engine design is not insignificant. In defining new products, trade-offs – based on consideration of economic effects on aircraft as a complete system on a defined mission – have been established as a weighting factor.

The application of trade-offs in the assessment of technological measures is critical, since

- no standardized engine product is definable for the abundance of technological measures dealt with in Section 4.7,
- no standardized aircraft product is definable,
- no standardized flight mission is definable, and
- frequently no standardized technological reference is definable.

There is also a lack of established methods for the quantitative assessment of the economic implications of adverse environmental effects resulting from air transport. An additional problem is that, on account of the challenging ACARE targets, a combination of evolutionary and revolutionary measures concerning

- noise-reduction technology,
- emission-reduction technology,
- module technology,
- engine concepts and
- aircraft concepts

has to be assessed. For such new combinations there are often no consistent analytical or empirical correlations from which trade-offs could be deduced. This applies, in particular, to the treatment of interaction between noise and exhaust emissions. It will be shown, on the example of two new engine configurations (geared turbofan and inter-cooled recuperative aero engines), how the apparently competing design aims of noise reduction and exhaust emission reduction can both be achieved, within the scope of certain design limits, through more favourable design of thermodynamic engine cycle associated with appropriate engine architecture and advanced engine modules. It is therefore proposed that the treatment of trade-off effects between noise and pollutant emissions be discussed on the basis of respective weight-effects, since a very large proportion of measures for improving specific performance characteristics with respect to the three environmental goals of

- CO_2 reduction,
- NOx reduction and
- noise reduction

involve clear and generally unfavourable weight-effects. These weight-effects can be consistently applied at all system levels (flight mission, aircraft, engine, integration, engine modules, specific noise technology and low-emission technology). The advantage lies in the following points:

- Application to consideration of the economic efficiency of aircraft as a complete system is basically possible in accordance with the original use of trade-offs.
- The "weight" variable directly addresses the accompanying technology demand and relevant technology requirements (“aims“).
- The "weight" variable also allows an indication of costs.

4.8.1 Survey of aims with regard to pollutant and noise emissions

In the following survey, the technological "aims" of improvements at different system levels (transport task / passenger kilometres, aircraft, engine and engine modules) are broken down according to the environmental goals defined above. This way, common and complementary, but also opposing and exclusive targets can be deduced. In the "Aims" column, the term "weight" is used as an abbreviation for "construction and design solution for low weight".

A. CO_2 target

System	Target	Aims
Transport task:	total fuel consumption	flight mission
Aircraft:	required thrust (per seat-mile)	aero quality, weight***
Engine:	low specific thrust, small Vjet	high BPR, weight***
	low specific fuel consumption	conventional, high-efficient thermodyn. cycles with high P3 and T3, T4
Engine modules:	high efficiency	aero quality, weight***
	low losses	

B. NOx target (LTO & cruise NOx)

System	Target	Aims
Transport task:	total fuel consumption	flight mission
Aircraft:	required thrust (per seat-mile)	aero quality, weight***
Engine:	lower specific fuel consumption	new, high efficient thermodynamic cycles with low P3, e.g. IRA*
Engine modules:	high efficiency	aero quality, weight***
	low losses	
	low-NOx combustion chamber	weight***

C. Noise target

System	Target	Aims
Transport task:	take-off and landing procedures	adjustment of regulations
Aircraft:	thrust on take-off and landing	aero quality & weight***
	low-noise aircraft design	aero quality
	engine installation & shielding	weight***
Engine:	low specific thrust, small Vjet	high BPR, weight***
	low-noise configuration, e.g. GTF**	weight***
	nacelle & nozzle configurations	weight***
Engine modules:	low-noise design	aero quality
	Insulation measures	weight***
	passive and active measures	weight***

* IRA: intercooled recuperative aero-engine with heat exchanger and inter cooler

** GTF: geared turbofan

*** Weight: equivalent to "construction and design solution for low weight"

The main compromise between different environmental goals arises to a large extent from the utilization of conventional engine design with the aim of the highest possible T-3 and P-3 thermodynamic cycle data (temperature and pressure at the compressor outlet or combustor inlet). This is required to optimize fuel consumption and to enable higher bypass ratios, at the cost, however, of a further increase in NOx emissions during combustion using comparable combustor technologies. This well-known characteristic of thermal NOx formation ("an increase in temperature at an already high temperature and pressure level with sufficient time in the reaction zone leads to an exponential increase in NOx formation") can be considerably reduced by means of different measures.

Through the application of new combustor technology, such as

- double-ring combustors with fuel-staging as with the GE-DAC (in service),
- air-staged combustors based on the rich-lean-concept, as in the PW-TALON (in service in 2006 with PW 6000) and
- lean direct fuel injection based on the RR concept,

the NOx level of the respective thermodynamic cycle can be significantly reduced. The above-mentioned combustor technologies can be integrated, in principle, into conventional engines. They are generally characterized by greater weight (double the number of injection nozzles, more sophisticated fuel injection modules etc.). Further details on the operating principles and potentials of low-NOx combustor technologies can be gleaned from the MTU presentation, "Contributions of aircraft engines to pollutant reduction in air traffic", at the Germany Federal Environmental Agency's workshop "Air traffic and Air Quality" (Berlin, June 2005), as well as from the RAND Europe study, "Development of a proposal for the reduction of currently valid international limit values for nitrogen oxide emissions …" (Berlin, November 2002) with additional references to the fundamentals and design rules of engine thermodynamic cycles and interaction with exhaust emissions.

Through the application of new types of unconventional engine configurations, such as recuperative engines with intercooling, the above-mentioned design compromise can be considerably reduced. Through the use of intercoolers, an IRA engine can achieve high thermodynamic efficiency at very low overall pressure ratios (see the following section). This form of engine design can therefore make a decisive contribution to low NOx emissions in absolute terms. The main disadvantage of IRA is the appreciable additional weight resulting from the use of intercoolers and exhaust heat exchangers.

4.8.2 Assessment of trade-offs on the examples of GTF and IRA

Target values for fuel consumption, noise and NOx emissions as well as for weights are discussed below with regard to two exemplary engine configurations, which represent a synthesis – based on actual engine configurations, relating in each case to a design solution for the medium term (GTF) and the longer term (IRA for 2020+) – of

- the description of important noise-technology programmes and configuration studies (Section 4.7),
- the roadmap for aircraft noise targets (Section 4.7.6) and
- the survey of aims with regard to pollutant and noise emissions (Section 4.8.1)

In connection with this synthesis it should again be mentioned that exploitation of these great potentials for engine improvements only makes sense concomitant with complementary improvements to the airframe (required thrust, weight and aerodynamics). Figure 22 is called to mind, which showed that for engine at BPR > 12 the (conventional) airframe is among the greatest contributors of sound at a certain measurement point.

A. GTF

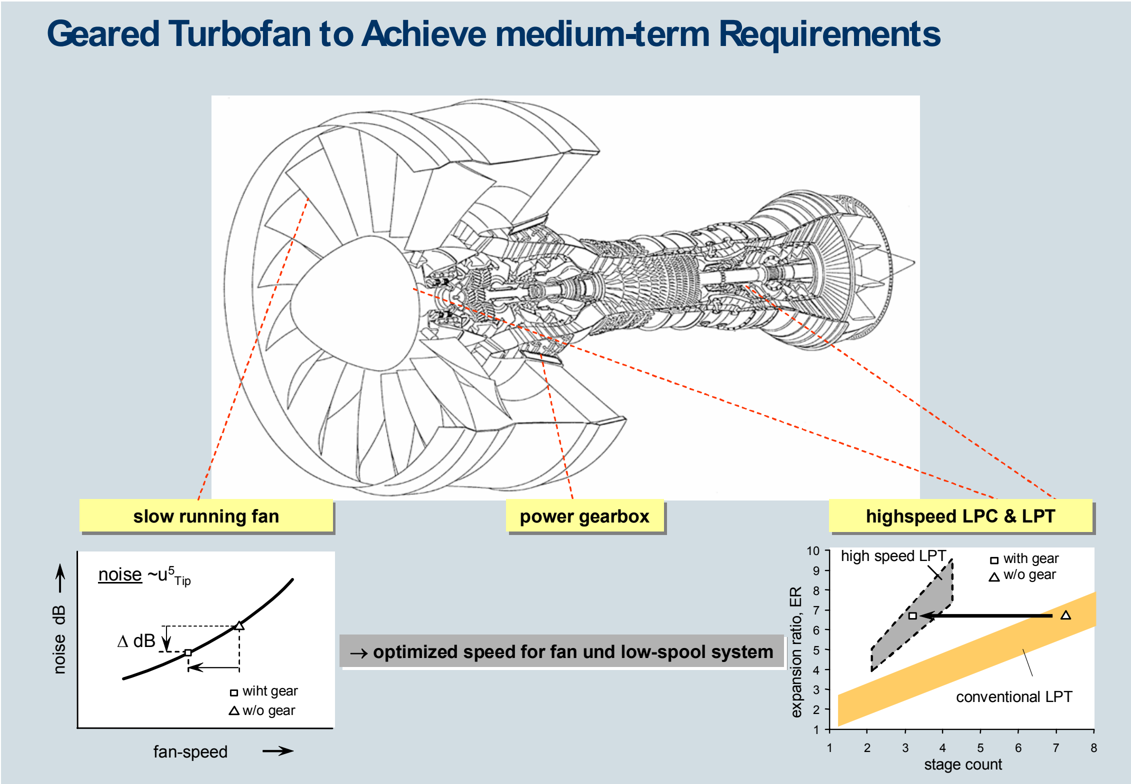
Geared turbofan, see also:

Section 4.7.3	CLEAN
	Studies in the USA
	VITAL
Section 4.7.5	SILENCER
Section 4.8.1,	

Figure 22, Figure 25 und Figure 27

The GTF is designed to enable higher bypass ratios and higher propulsive efficiency, with the possibility to adjust the rotational speed of the fan for low-noise operation by way of the gear transmission ratio (Figure 27). The low-pressure turbine of a GTF is "high speed" and, apart from a marked increase in efficiency, can therefore contribute additionally to noise reduction on *approach*. The GTF has already been featured in sales campaigns carried out by P & W. It is defined within the framework of this report as "mid-term", that is, suitable for the next generation of turbines.

Figure 27 Outline of geared turbofan configuration (GTF)



GTF characteristics:

- SFC: -6 to -10 % (specific fuel consumption)
- Noise: -15 to -20 EPNdB (cumulative), in connection with „mid-term "SILENCER technology
- NOx: suitable for DAC, TALON, lean-direct
- Weight: +8 to +10%
  "neutral" with VITAL technology

B. IRA

Intercooled recuperative aero engine, see also:

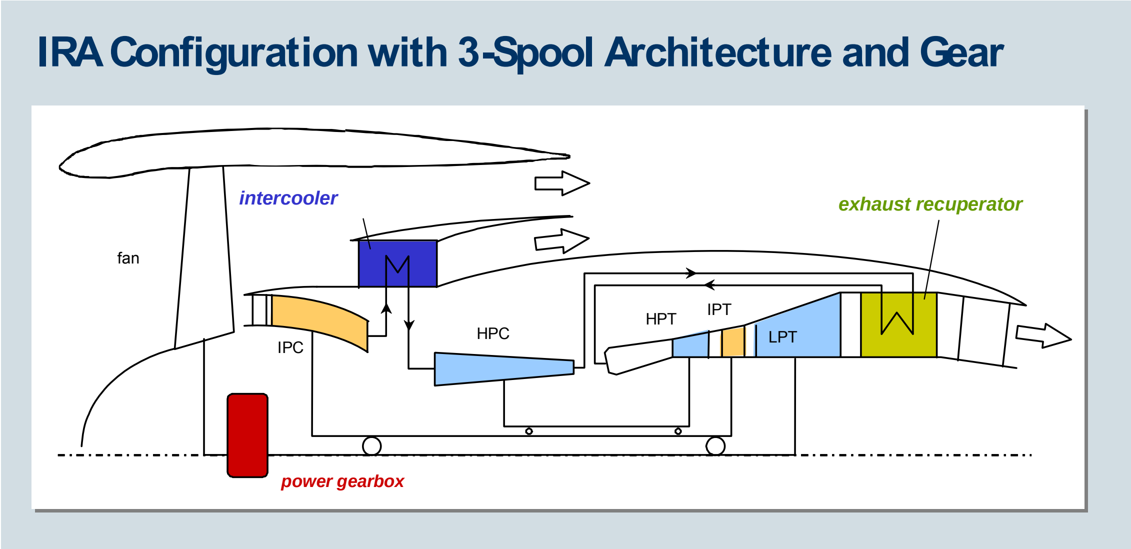
Section 4.7.3 CLEAN

Section 4.8.1

Figure 18 and Figure 28

The MTU presentation, "Contributions of aircraft engines to pollutant reduction in air traffic" at the Federal Environmental Agency's workshop on "Air traffic and Air Quality" on 14 June 2005.

Figure 28 Outline of intercooled recuperative aero-engine configuration (IRA)



The IRA is the engine design preferred by MTU for the realization of ACARE Vision 2020 targets for typical long-range applications. The IRA combines the characteristics of the GTF for increasing thrust efficiency with the advantages of intercooling and exhaust heat recuperation. Very high propulsive efficiency can be achieved with the IRA at high bypass ratios (BPR > 20), as well as very high thermodynamic efficiency at overall pressure ratios (OPR < 30). The IRA is therefore appropriate for both low noise emissions and low exhaust emissions and is defined as "long-term 2020". First IRA modules were already tested in CLEAN (high-speed low-pressure turbine and exhaust heat exchanger), and further IRA activities are planned in IP-NEWAC (NEW Aero-engine Core configuration) in the period 2006-2010.

IRA characteristics:

- SFC: -16 to -20 % (specific fuel consumption)
- Noise: -18 to -22 EPNdB (cumulative), in connection with SILENCER technology
- NOx: -80 % (application-related and absolute: better than -80 %)
- Weight: +18 to +24 %
  +5 to +10 % with VITAL technology

4.9 Conclusions

The subject of noise emissions is of steadily growing importance in the field of civil aviation, touching upon all aspects from technology development and availability to product design and the purchasing decisions of airline companies. The marked reductions in noise that have been achieved up to now – compared to earlier aircraft generations – are regarded as insufficient. Through the ambitious voluntary commitment of the European aviation industry in ACARE Vision 2020, it is intended that aircraft noise be halved in the period from 2000 to 2020. This target is reflected in an abundance of isolated and integrated projects concerning noise reduction, which cover, on the one hand, the aircraft system as a whole (from low-noise landing and take-off procedures to low-noise aircraft and engine configurations as well as numerous isolated technologies, and, on the other hand, the whole spectrum of ideas and principles right up to approaching product maturity.

With the roadmap discussed in Section 4.7.6 the attempt is made to deduce a noise target from national, European and American programmes. This noise target function is subject to the indispensable requirement that it does not fall back on solutions at the cost of other ACARE goals. The achievement of the ACARE target for the year 2020 therefore appears to be technologically feasible. This roadmap shows also that beyond ACARE targets further noise-reduction technologies are under development, and that further potential, particularly in the case of engines, appears to be exploitable. Their technical feasibility cannot be conclusively assessed at present, however, and their application could possibly be at the cost of other aircraft and engine design targets.

The deduction and application of universally applicable "trade-off effects" between noise and exhaust emissions cannot be carried through unreservedly, and is therefore not to be recommended. It has been shown, based on the examples of GTF and IRA engines, that with favourable thermodynamic engine cycles combined with appropriate engine architecture and advanced engine modules, design targets for the minimization of both noise and exhaust emissions are attainable within the scope of certain design limits. The issue of weight is common to a large number of measures; it also addresses the most important aim for technological development.

5 Development of scenarios

As far as possible, reference points have been considered in the development of scenarios that emerge from the status quo analysis in chapters 2 to 4. They include expected technological progress in noise reduction in aircraft and knowledge of existing noise control regulations at international airports. The attempt is also made to address the varied interests of affected stakeholders – for instance, through consideration of adequate planning security for aircraft manufacturers and airlines on account of long and costly development periods and the life-cycles of aircraft – in order to achieve the best possible acceptance of the assumptions. At the same time, maximum noise alleviation should be realized within as short a period as possible. Aircraft noise exposure at and around airports is frequently already very high and urgent improvements are required.

The specific formulation of scenarios is based on general requirements in the specifications for tenders in respect of the project that is the subject of this report, and in the proposal of the bidder consortium. In an initial approach, time horizons were defined, on the one hand, in terms of short-term measures that are put into effect parallel to current rules and regulations for jet aircraft and, on the other hand, of medium- to long-term measures that allow for amendment of *Annex 16* in the year 2015. In each case, three to four typified airports were to be examined, which represent different kinds of significant and critical noise problems that are assignable to particular airport categories (for example, international hub airports). Potential noise alleviation was also to be differentiated within a given range. Here, one had in mind the selection of an optimistic scenario, which adopts proposed measures more or less completely, so that maximum noise reduction potentials arise. Furthermore, a conservative scenario ought also to be considered, covering measures with modest noise reduction effects as reference case. This approach should ensure that the potential spread in the development of emissions is indicated.

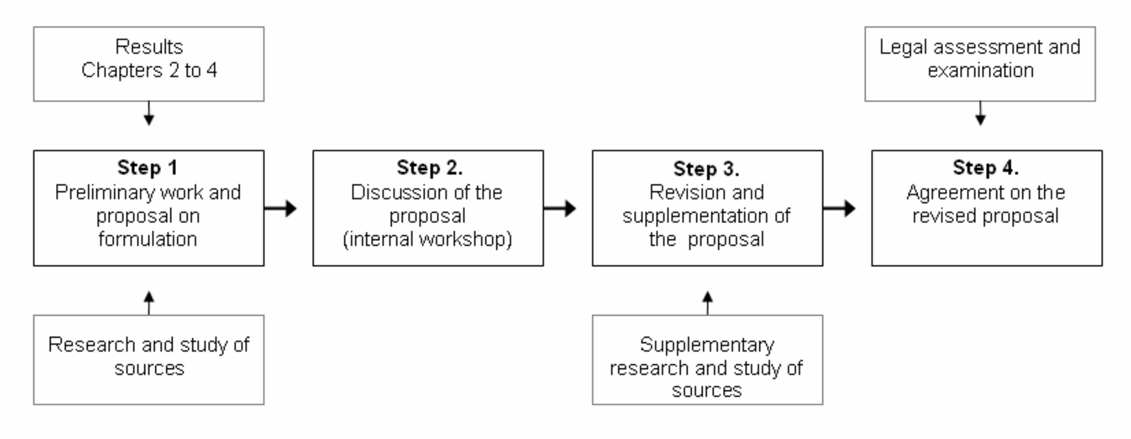
5.1 Procedure

The following four-step procedure was selected for the development of scenarios:

1. As a basis for discussion, an initial rough draft was prepared based on the consortium's tender, results described in chapters 2 to 4 as well as further available sources. This internal draft served, together with proposals for fundamental aspects of the package of measures, as preparation for subsequent discussion in the project team.
2. The discussion on the draft formulation of the scenarios took place during an internal project workshop, where the proposed concept was intensively discussed, supplemented and, in part, modified. Agreement was reached on the basic approach and procedure. Numerous unresolved points were identified for further examination and settlement.

3. Following appropriate revision and supplementation of the draft, a full proposal for the development of scenarios was prepared, which included definition of individual scenarios as well as the specific application of assumptions at airports of types A, B and C in the form of route assignment, which served as input data for subsequent computations of noise.
4. In conclusion, the complete draft on scenario formulation was agreed upon internally and final modifications and supplementation carried out. A legal assessment of the package of measures was then conducted, in order to check their conformity with existing legal standards.

Figure 29 Procedure for the development of scenarios



5.2 Basic assumptions on the typified airports

Basic assumptions are understood to be basic data on the types of airports (for example, number of runways), basic traffic forecasts (number of flight movements), future fleet mix[130] as well as approach and departure routes at the typified airports. These basic assumptions have been formulated as simply as possible, so that the results of the procedural steps can be readily understood. On the other hand, it is regarded as important that the conditions considered are as realistic as possible, and the assumptions are therefore orientated towards existing international airports in Germany.

[130] Fleet mix (or aircraft mix) is understood to mean the subdivision of types of aircraft operating at an airport. .

5.2.1 Basic data

Basic data of airport types includes fundamental definitions based on airports already examined and discussed in the project team. The main focus of the investigation is on large airports, at and around which noise exposure exists. Three typified representatives of different airport categories are examined. Besides one large intercontinental airport, two medium-sized airports with different types of operation are considered: on the one hand, an airport with a large proportion of cargo aircraft and a large share of night flights, and on the other hand, an airport whose emphasis is on passenger transport with a minor amount of night traffic. Traffic figures cover total traffic, which also includes non-commercial air traffic. Changes in runway systems are not assumed within the scenario framework.[131]

Table 10 Basic data on airport types A, B and C

Airport	Type A	Type B	Type C
Status	International hub airport	Medium-sized airport with a large PAX share	Medium-sized airport with a high cargo share
Number of runways	4	2	2
Status quo Flight movements p.a.	500,000	150,000	150,000
Status quo Passengers p.a.	50,000,000	10,000,000	8,500,000
Night movements (22:00-06:00) p.a.	50,000 (about 10%)	6,000 (about 4%)	35,000 (about 23 %)
Fleet mix	Frankfurt/Main	Hamburg	Cologne/Bonn

5.2.2 Traffic forecast

Assumptions on the future development of flight movement figures, which are an indispensable element for the development of scenarios, are derived from [ANOTEC 2003] and local traffic forecasts. For the [ANOTEC 2003] study, which was conducted on behalf of the EU (DG-TREN[132]), forecast flight movements in the European area are adopted or deduced from various publications. Besides forecasts of aircraft manufacturers (Boeing and Airbus) use is also made of Eurocontrol forecasts. In addition, further sources are called upon in order to check or complete figures for future flight movements. These sources relate, for instance, to the local situation at individual

[131] Expansion of aviation-side capacities – for example, of taxiway and apron systems – are not considered here, since such adjustments have no direct relevance for the calculation of noise.

[132] DG-TREN: Directorate-General for Energy and Transport.

airports (for example, Intraplan 2004), to the German traffic sector as a whole (for example, traffic route planning by the federal government, Intraplan 2001), or they come from an engine manufacturer (Rolls-Royce 2005).

One difficulty in the consideration of available forecasts relates to the presentation of results, which generally take the form of the future development of traffic or transport services (for example, as passenger kilometres). These reference values are applicable neither to questions of flight movement figures for individual airports nor to developments in fleet mix, on which the scenarios are based. Other analyses relate, for instance, to future sales of aviation fuel, so that these forecasts can also not be directly applied. All forecasts have in common, however, that they assume further growth in the aviation market. And all results indicate that forecast figures are of a similar order of magnitude, so that extensive arguments are available to support forecast figures. At the same time, however, local, material and time-related considerations have to be differentiated (for instance, between passenger and cargo transport, or with regard to regional points of view or the development of hub and point-to-point traffic).

Forecasts cover traffic figures up to the year 2025 at the latest. Two different time horizons (short- and medium- to long-term) were to be considered in the scenarios of this project. The project team agreed on the two forecast years of 2012 and 2020. The year 2012 was selected because sufficient time will remain following the planned publication of this report to enable implementation of recommendations. On the other hand, bearing in mind the life cycles of modern aircraft, the six years that lie between completion of the report and the forecast horizon are a short period of time, and successful implementation of the recommendations will require corresponding efforts. It has further to be borne in mind that the fleet mix up to 2012 will solely comprise aircraft already in operation and, to a lesser extent, new types of aircraft that have already been ordered. Forecasts of fleet mix up to 2012 can therefore be regarded as relatively reliable.

The choice of 2020 as the medium- to long-term forecast year can be explained, in particular, by the fact that traffic forecasts for this horizon are considered to be relatively stable. Forecasts beyond the year 2020 are available, but their uncertainties grow with the extended horizon. Bearing in mind necessary technical development cycles in aircraft and engine construction, corresponding lead time has to be allowed for to enable application of new technology on the part of aviation companies. The choice of the year 2020 as a medium- to long-term time horizon is therefore regarded as a useful compromise.

With a conservative approach to the development of flight movement figures, the attempt is made to pursue assumptions that take account of the uncertainties of medium- to long-term forecasts. Developments in recent years have shown that unpredictable events have repeatedly had an important influence on developments in the aviation industry. For this reason, the choice of what can be described as a conservative approach is appropriate.[133] Furthermore, bearing in mind the objective of this report, it is of particular importance that the difference between the scenarios resulting from varied developments in noise reduction be considered. This "delta analysis" indicates the noise reduction potentials that could be possible with the further development of *Annex 16*. It therefore becomes clear that, due to different assumptions on flight movement figures in this report, consideration of developments is not of primary importance. Moreover, in contrast to [ANOTEC 2003], an EU-wide harmonized approach applicable to as many airports as possible is not necessary for this study, but rather an approach directed solely at the selected three typified airports. Moreover, use of conservative forecast figures is justified by the fact that data on growth, which is differentiated according to country in [ANOTEC 2003] and is based on a Eurocontrol publication, only applies for the period up to 2010. More recent investigations by Eurocontrol (Eurocontrol 2004) also show that increases in the number of IFR flights in Germany of between 2.1 and 3.1 per cent per year (according to scenario and compared to base year 2003) are assumed up to the year 2025.[134] Under these circumstances, the selected growth rates appear to be plausible. Deduced from this, the following assumptions on flight movement figures were made for the three selected types of airport:

Table 11	Number of flight movements at airport types A, B and C

Time horizon		Type A	Type B	Type C
Status quo	2005	500,000	150,000	150,000
Short term	2010	600,000	170,000	197,000
	2012	**625,000**	**176,000**	**207,000**
Medium to long term	2015	660,000	187,000	222,000
	2020	**726,000**	**205,000**	**247,000**
Source		Intraplan 2004, ANOTEC 2003	ANOTEC 2003	MWMEV 2000 ANOTEC 2003
Comments		2010-2015: +2,1 % p. a. From 2015: +2,0 % p. a.	From 2005: +2,5 % p. a.	From 2010: +2,5 % p. a.
Note: Assumptions from [ANOTEC 2003] correspond with the study's conservative scenario and are extrapolated linear for 2015+. Constant annual growth is assumed.				

[133] Besides the conservative scenario, further assumptions are made in [ANOTEC 2003] for the differentiation of scenarios with regard to expected traffic growth. These include the so-called "probable" scenario (3.6% traffic growth) and the "differentiated" Scenario (for example, 2.44 to 3.86 % traffic growth for Germany) (see Assumption 11, *Forecast for growth in number of movements until 2015*).

[134] Average annual growth of between 2.3 and 3.35 per cent is assumed for the period 2004 to 2025 for the whole Eurocontrol statistical reference area (ESRA) under consideration.

5.2.3 Future fleet mix

The procedure for consideration of developments in fleet mix pursued in [ANOTEC 2003] will be adopted for and adjusted to the modified requirements of this report.[135] In the study commissioned by the DG-TREN, the future fleet mix was established empirically for forecasts of aircraft noise and aircraft noise exposure for the years 2007 and 2015. Assumptions are based on the analysis of existing traffic forecasts as well as on forecast developments in the European aircraft fleet. In [ANOTEC 2003], categorization is undertaken according to *generic class* (GC), which distinguishes seven classes with a varied number of seats and comprises assumptions on future developments in the number of aircraft types. An *aircraft evolution matrix* is drawn up, which shows the development of 73 types of aircraft assigned to GC classes for the years 2007 and 2015. An alternative method for establishing the future fleet mix could not be found despite intensive research.

5.2.3.1 Methods applied in ANOTEC 2003

The most important procedural steps are explained below, and accompanying assumptions for the ascertainment of fleet mix on the basis of forecast flight movements and the status quo (traffic figures and fleet mix) are described. At the same time, general trends (for example, the predominance of aircraft with two jet engines, dominance of a single type of aircraft in each weight class as well as concentration on the two large aircraft manufacturers Airbus and Boeing) are identified and taken into account. Account is also taken of the fact that aircraft, which are no longer manufactured (for instance, the MD-80 and MD-11), are more rapidly withdrawn from service than aircraft still in production.

- Reference point (representative day)

The representative day is selected as the basis for forecasts and the determination of future fleet mix, and consists of two parts: on the one hand, the number of flight movements for each generic class (GC), which is defined as the total number of flight movements within each class per year, divided by 365, and on the other hand, the fleet mix for each class, equivalent to the total number of flight movements within each class per year and per aircraft type, divided by 365 (see Assumption 15, *Definition of representative day* in [ANOTEC 2003]).

- Changes in airport infrastructure

It is assumed in [ANOTEC 2003] that no changes in airport infrastructure are considered (see Assumption 3, *Future changes in the airport configuration* in [ANOTEC 2003]). This assumption has been adopted for this investigation, whereby –

[135] For further information on the procedure and methodology see Section 4.*3 Current and future fleet composition* in [ANOTEC 2003].

corresponding to their definition in Section 5.2.1 *Basic data,* no capacity restrictions or limitations are to be expected at any of the airports under consideration.[136] Further adjustments to air- and land-side airport infrastructure (for example, operational facilities or terminal capacity) or optimization of the runway system or aprons are possible, but are not considered here (see also Footnote 131).

- Structural changes in the route network

Changes in future route structures at individual airports are only considered with regard to the number of flight movements; they are not dealt with qualitatively (see Assumption 5, *Changes in routes served by the airport* in [ANOTEC 2003])[137].

- Consideration of aircraft from developing countries and the effects of re-certification

Since the potential effects of re-certification are difficult to determine, they are not considered (see Assumption 21, *Marginally compliant aircraft and re-certification* in [ANOTEC 2003]). The possible effects of aircraft from developing countries, which experience shows can be relatively loud, can likewise be ignored, since due to their very low number no appreciable effects are expected (see Assumption 20, *Effect of noisy airplanes from developing countries* in [ANOTEC 2003]). This assumption has been adopted, although current developments point to the fact that, due to commencing deregulation of air transport in development countries, there is boom in the founding of low-cost carriers, which largely use modern low-noise aircraft and which could lead to a redistribution of passenger shares (for example, in India and China)

- Shifting the operating hours of flight movements

A shift in flight movements (for instance, as a result of regulative measures) from and to particular operating hours is not assumed, since a generally applicable harmonized

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[136] Airports with capacity restrictions are distinguished in [ANOTEC 2003] from airports not subject to restrictions. Should an airport's capacity be exhausted, flight movement figures are kept constant and flight movements are shifted to the next higher GC class (see Assumption 12, *Increase in aircraft size due to airport capacity constraints* in [ANOTEC 2003]). For intercontinental hub airports it is assumed that each year 1% of flight movements are shifted from GC 4 to GC 5 and from C 5 to GC 6. With regard to the three types of airport under investigation, 120 co-ordinated flight movements per hour are assumed for type A, 48 for type B and 52 for type C, so that the assumptions on forecast flight movements can theoretically be realized (see *Initiative Luftverkehr 2004*).

[137] Qualitative changes are conceivable, for example in the form of increased traffic volume from and to Eastern Europe and resulting changes in fleet mix, or changes arising from liberalization of the trans-Atlantic air transport market.

approach is unlikely (see Assumption 13, *Shift in operating hours* in [ANOTEC 2003])[138].

- Consideration of changes with respect to secondary airports

Shifts or changes in the number of flight movements in favour of secondary airports or alternative airports (for instance, within the scope of an airport system according to Regulation EEC/2408/92) are not considered, due to the limited number of movements involved, compared to the total number of movements at the primary airport; and the effects on noise emissions are regarded to be insignificant (see Assumption 14 *Shift of operations towards secondary airports* in [ANOTEC 2003]).

- Consideration of the development of jet and propeller-driven aircraft ≤ 80 PAX (GC 1)

The evolution matrix according to [ANOTEC 2003] considers aircraft with less than 80 seats (corresponding to categorization in GC 1) by means of constant factors applicable to all such aircraft types. These factors have been deduced from the development of the *Embraer 135/145* and the *Canadair Regional Jet*. The following factors are taken into account in the evolution matrix[139]:

Jet aircraft (GC 1): 2007 **2.00** and 2015 **3.00**

Propeller-driven aircraft (GC 1): 2007 **0.85** and 2015 **0.95**

5.2.3.2 Further development of methods for the determination of future fleet mix

The method for the determination of future fleet mix in [ANOTEC 2003] comprises different aspects, which have to be adapted to the terms of reference of this report, namely:

- Choice of airports

In contrast to the assumption in [ANOTEC 2003], in this report an EU-wide harmonized approach for all large airports is not pursued. Future fleet mix is determined for three typified airports (see Section 5.2.1) (see Assumption 1 *Airports selected for Phase 2* in [ANOTEC 2003]).

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138 In connection with the decision not to consider a shift of flight movements from sensitive times of day, it should be mentioned that such a shift can be useful from a medical point of view (see Section 2.7 *Excursus on noise-exposure research* in the first interim report).

139 These evolution matrix factors are not contained in the publication [ANOTEC 2003], but can be obtained from the authors on request.

- Reference point

The basis and departure point for the procedure in [ANOTEC 2003] is current flight movement figures and the number of aircraft in operation as status quo for the past twelve months (09/2002 to 08/2003) and the calendar year 2002 respectively. In line with the above comments, this report deviates from this procedure (see Section 5.2.2 *Traffic forecast)*, in order to represent the latest circumstances at specific airports.

- Adaptation of forecast years for the development of scenarios

In [ANOTEC 2003], the years 2007 und 2015 are looked at as forecast horizons. With respect to the questions raised this report it was agreed that two time horizons should also be looked at, but in this case two different forecast years were selected, namely 2012 and 2020. Different forecast years were selected to take account of the time remaining following the planned presentation of this report in 2006. The two forecast years are shown with the help of the linear developed evolution matrix. In Scenarios 1 and 4, assumptions apply from the year 2007, so that for the period from 2005 to 2007 the evolution matrix is applied to provide time for implementation of the recommended measures.

- Technical developments with regard to noise emissions

Further technical developments with regard to the noise emissions of the aircraft and engines under consideration are not directly assumed in [ANOTEC 2003], with the effect that constant specific emission data is adopted. Technical developments are reflected solely with respect to fleet renewal (see Assumption 9, *Evolution of noise and performance of existing aircraft* in [ANOTEC 2003]). The present report deviates from this assumption with respect to medium- to long-term scenarios, where it is assumed that technical progress will be reflected in the operation of new, quieter aircraft, and varied assumptions are made for different cases (see Section 5.3.2 *Medium- to long-term time horizon*).

- Introduction and operation of new types of aircraft

In [ANOTEC 2003], new (foreseeable) types of aircraft (for example, A 380 and B 787) are not separately considered, but rather introduced into the evolution matrix by equal redistribution of the number of new aircraft envisaged among the existing aircraft in the same generic class (see Assumption 10 *Introduction of new aircraft* in [ANOTEC 2003]). This is explained, in particular, by referral to currently unknown emission data, which would be necessary for consideration of new aircraft, so that a conservative approach is pursued.[140]

[140] According to [ANOTEC 2003], as soon as appropriate emissions data is available, conversion factors, which also take account of improvements in performance, should, if necessary, be employed within the scope of noise computations.

The Airbus A 380 is separately considered as an *ultra high capacity aircraft* (UHCA) in [ANOTEC 2003], since its operation lies in the immediate future and the certification procedure has already taken place. However, specific emission data for the Airbus A 380 is not yet known (see Assumption 19 *Effect of the introduction of Ultra High Capacity Aircraft* in [ANOTEC 2003]. On account of available knowledge concerning *noise targets* for the two new aircraft A 380 und B 787, these aircraft are defined as additional new aircraft for the purpose of this study and flow into noise computations. With this, two particularly important types of aircraft are covered by forecasts, whereby it is assumed that the A 380 will come into service in 2007 and the B 787 in 2010. Further new aircraft, which are expected to come into service within the period under consideration, are not covered, however, since only insufficient information is available.

Consideration of forecast flight movements is similar to that in [ANOTEC 2003]. The assumption is made that the A 380 will operate at large hub airports (here, type A) and that 5% of flight movements will be shifted from GC 6 to GC 7. In the case of the B 787 it is assumed that this aircraft is assignable to GC 4, and that it will account for approximately 2.5 % (2012) and 7.5 % (2020) of flight movements within this class. Corresponding factors in the evolution matrix have been supplemented to take account of both new aircraft (see Appendix M). Such assumptions for the B 787 have been deduced from forecast sales figures and advance orders.

Further new aircraft are taken into account in medium- to long-term scenarios through the creation of a new aircraft type for each defined class, which complies with new more stringent noise limits (see Section 5.3.2). No specific aircraft can be associated with these aircraft, which merely represent a typified aircraft that corresponds with forecast noise emissions.

- Categorization in *generic classes* (GCs)

For the purpose of simplification, *one* standard configuration supplied by aircraft manufacturers is applied for categorization in generic classes, whereas in [ANOTEC 2003] individual types of aircraft are assigned to several GCs.[141] In this study, *one* typical two-class seating arrangement is assumed for short- and medium-haul aircraft and *one* typical three-class seating arrangement for long-haul aircraft. This simplification is regarded as expedient, since experience shows that consideration of one typical seating arrangement is sufficient (see, for example, Öko-Institut 2004). This also applies to aircraft that are in operation both as passenger and cargo aircraft. Categorization as a passenger aircraft is prioritized. Where an aircraft is operated purely for the transport of cargo (for example, the RC2 types B 7272 and DC 870), the

[141] In [ANOTEC 2003], because seating is variedly selected according to each airline and service, an aircraft is assigned to several GCs. To take account of this circumstance, in [ANOTEC 2003] a percentage distribution to the relevant GC is applied for the affected aircraft (for example, "735" in GC 2 and GC 3 or "744" in GC 5 and GC 6).

corresponding factors in the matrix for cargo aircraft are applied to determine future flight movement figures.

- Separate consideration of cargo aircraft

Since no explicit distinction is made between passenger and cargo aircraft in flight movement lists available to the authors of this report, no separate analysis is made. In available type lists, however, typical cargo aircraft such as the RC2 types B 7473 and MD 11 are represented, which will be taken into account in determining future fleet mix. This ensures that reliable results are also achieved, for example, for the selected airport of type C, which has a large proportion of cargo aircraft. In [ANOTEC 2003] a distinction is made on the basis of detailed flight movement lists, so that the development of cargo aircraft is separately presented. For this purpose, it is assumed, among other things, that cargo aircraft have a longer service life (35 years compared to 25 years for passenger aircraft). Average high annual rates of growth in cargo transport, which are reflected in current transport forecasts, are considered in the form of average growth rates.

- Adjustment of aircraft types covered

Within the scope of this report, aircraft are considered not in accordance with the *Aircraft Evolution Matrix*, but rather in a modified form, which reflects the results of Chapter 3. RC2 aircraft are considered, which have already been adopted as standardized EMPA designations in Section 3.2 and are used for noise simulations in the form of the respective directivity patterns. This emissions data from the EMPA noise data bank is used instead of data from the Integrated Noise Model[142] (in contrast to Assumption *8 Use of noise and performance data of existing aircraft* in [ANOTEC 2003]). Comparison of both type lists shows a large degree of concurrence (see Appendix K).[143]

- Consideration of other flight movements and aircraft types

The description and analysis in this report takes account of flight movement lists that were accessible or made available. Where individual types of aircraft are not separately listed, they cannot be covered. Under certain circumstance, this could affect flight movements of aircraft that are of particular relevance from the point of view of noise abatement. This share ("others") covers, however, a maximum of 1.9 % of flight movements and can therefore be ignored.

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[142] Integrated Noise Model (INM): Aircraft noise computation programme developed by the FAA in Washington.

[143] In defining lists of aircraft types (RC2 aircraft according to EMPA and the *Aircraft Evolution Matrix* [Anotec 2003]), typical types of aircraft are selected from detailed flight movement lists that are representative of the local feet mix.

5.2.4 Procedure for determination of future fleet mix

Future fleet mix at the three airport types A, B and C has been determined taking into account the above assumptions and the methods described in [ANOTEC 2003]. The main procedural steps can be described as follows:

- Modified **evolution matrix for 2012 and 2020**

Revision of the matrix from [ANOTEC 2003] comprises, in particular, adjustment to the aircraft applied (RC2 types) and extension to the two forecast years 2012 and 2020 (see Appendix M). All necessary assumptions have been discussed in Sections 5.2.3.1 and 5.2.3.2. The modified evolution matrix contains multiplication factors for all types of aircraft (RC2 types) covered by this study, which lead finally to calculation of forecast flight movement figures (see Appendix N).

- Determination of forecast **flight movements for each airport type**

To begin with, the number of flight movements within individual generic classes and their shares in total annual flight movements for 2012 and 2020 have been determined on the basis of the modified matrix and available flight movement lists of the selected airport types (see Table 12 up to Table 14).

Table 12 Distribution of flight movements (landings only) for each GC at airport type A

Type A	**2005**		**2012**	**2020**
	Number	% Share	Number	Number
GC1	34,513	13.8	43,142	50,113
GC2	119,470	47.8	149,337	173,470
GC3	30,806	12.3	38,508	44,730
GC4	32,030	12.8	40,038	46,508
GC5	13,350	5.3	16,687	19,384
GC6	19,818	7.9	23,557	27,364
GC7	0	0.0	1,215	1,411
Cargo	5	0.0	6	7
Total	**249,992**	**100**	**312,490**	**362,989**

Table 13 Distribution of flight movements (landings only) for each GC at airport type B

Type B	**2005**		**2012**	**2020**
	Number	% Share	Number	Number
GC1	31,700	42.3	37,195	43,323
GC2	34,300	45.7	40,245	46,877
GC3	4,480	6.0	5,257	6,123
GC4	2,440	3.3	2,863	3,335
GC5	50	0.1	59	68
GC6	70	0.1	82	96
GC7	0	0.0	0	0
Cargo	5	0.0	6	7
Others	1,955	2.6	2,294	2,672
Total	**75,000**	**100**	**88,000**	**102,500**

Table 14 Distribution of flight movements (landings only) for each GC at airport type C

Type C	**2005**		**2012**	**2020**
	Number	% Share	Number	Number
GC1	21,299	28.4	29,392	35,072
GC2	39,651	52.9	54,719	65,293
GC3	5,581	7.4	7,702	9,190
GC4	6,304	8.4	8,700	10,381
GC5	0	0.0	0	0
GC6	206	0.3	284	339
GC7	0	0.0	0	0
Cargo	365	0.5	504	601
Others	1,594	2.1	2,199	2,624
Total	**75,000**	**100**	**103,500**	**123,500**

In the following step, the number and share of flight movements of each aircraft type is determined on the basis of the evolution matrix and the number of flight movements of each GC. This computational step is carried out for the three airport types for both 2012 and 2020 (for *Type A* see *Table 15* or *Type B* and *Type C* see Appendix N). Here, special cases have also been considered (see for instance, the assumptions concerning the Airbus A 380 and the Boeing B 787).

Table 15 Distribution of flight movements (landings only) of each RC2 aircraft at airport *type A*

No.	RC2	Number 2005	2012	2020
1	A300	11,026	7,083	0
2	A3103	2,138	2,970	3,786
3	A319	15,588	39,407	62,900
4	A320	30,318	47,956	58,305
5	A321	24,791	35,286	42,531
6	A3302	5,543	13,666	23,313
7	A3403	9,926	12,192	13,912
8	AT42	7,775	4,326	4,160
9	B737A	7	0	0
10	B73X	50,845	50,265	47,144
11	B7474	19,818	23,557	27,364
12	B7572	5,004	2,807	2,026
13	B7673	7,426	9,025	8,876
14	B7772	3,423	4,495	5,472
15	C550	895	1,432	1,714
16	CL65	11,327	18,130	21,698
17	DC10	1,499	468	0
18	DC930	5	6	7
19	DH8	3,391	1,887	1,815
20	E145	5,745	9,196	11,005
21	FK10	900	953	1,035
22	FK50	423	235	226
23	FK70	3,832	6,134	7,341
24	LR35	1,125	1,801	2,155
25	MD11	4,398	5,917	7,155
26	MD80	5,206	3,014	1,520
27	RJ100	16,613	7,743	2,567
28	TU54M	1,011	415	173
29	A380	0	1,215	1,411
30	B787	0	921	3,395
Total		**250,000**	**312,502**	**363,005**

Comment: Diagram does not take into consideration scenario assumptions, which partially lead to shifts in flight movements (see Section 5.3).

5.2.5 Flight tracks (approach and departure routes)

The choice of flight tracks for the typified airports, which are used for the computation of noise, resemble as far as possible realistic flight routes. In addition, the flight regime at real airports was analyzed and adapted to the questions raised in this report. While several alternative routes and main departure courses are assumed for each departure route, two approach courses are considered for each runway. In each case, a number of ideal flight routes are constructed, which ensure a quick overview and minimize the effort involved in processing noise computations, but nevertheless represent realistic conditions (see Figure 30 and Table 16 16 to Table 19 19). A diagrammatical and tabulated presentation of flight tracks for airport types B and C can be found in Appendix U. Allocation to defined approach and departure routes is also carried out on the basis of assumptions that are as realistic as possible and easy to describe (see Section 5.3.3 *Flight movements of typified airports*).

Figure 30 Ideal approach and departure tracks at airport type A with the main departure courses

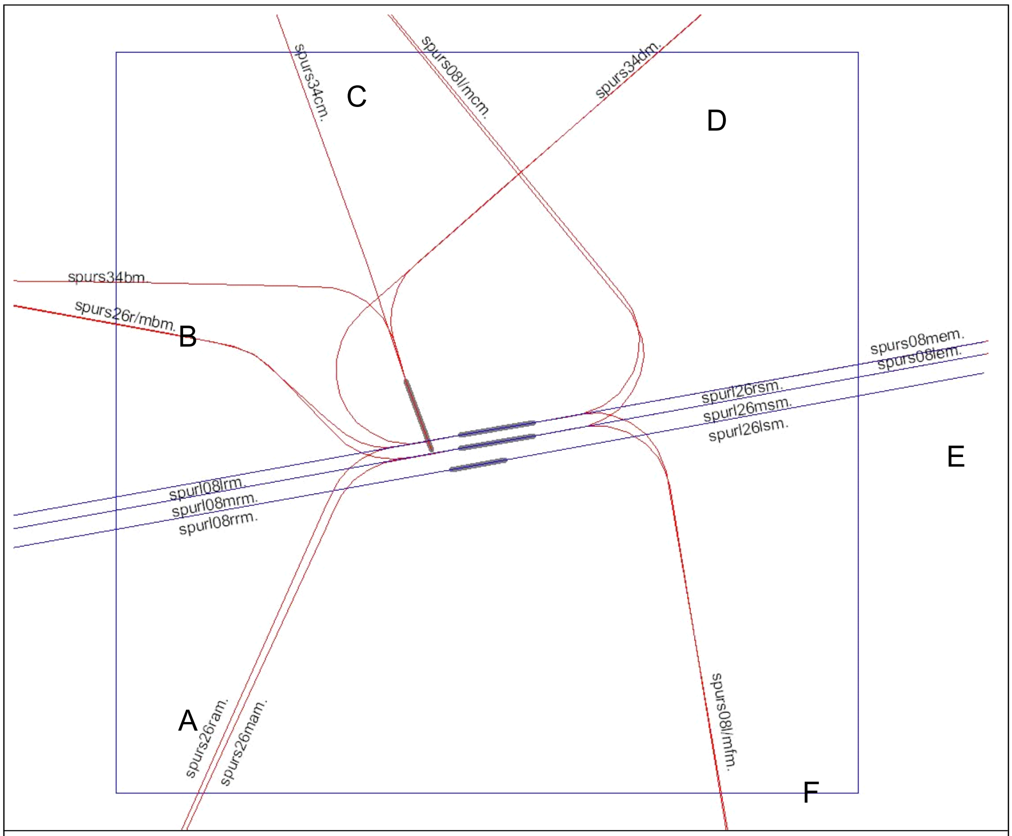

Diagram prepared by EMPA

Table 16 Runway allocation at airport type A (scenarios)

Time	Runway	Flight course distribution West : East	Runway use C 08 08 L/C LTO	C 08 08 R LTO	C 08 34 LTO	C 26 26 R/C LTO	C 26 26 L LTO	C 26 34 LTO
Scenarios	4	75 : 25	49 % / 49 %	- / 51 %	51 % / -	51 % / 48 %	- / 52 %	49 % / -

Comments: Flight course distribution corresponds to the longstanding average at Frankfurt/Main; Assumption on runway use correspond to data in the report: Angaben in Gutachten Flugbetriebliche Gesamtfunktionalität *Prognosenullfall* und *Planungsfall 2015* in ATSC 2004; Course 08 or 26 comprises a dependent parallel runway system; assumption on runway use 08L/C or 26R/C is equivalent to 50:50 distribution.
Abbreviations: LTO = landing & take-off, C = course, L = left, R = right, C = centre.

Table 17 Flight tracks at airport *type A*

Runway	Departure course A	B	C	D	E	F	Approach course R	S
08 L	-	-	**08LC**	-	**08LE**	**08LF**	**08LR**	-
08 C	-	-	**08CC**	-	**08CE**	**08CF**	**08CR**	-
08 R	-	-	-	-	-	-	**08RR**	-
26 L	-	-	-	-	-	-	-	**26LS**
26 C	**26CA**	**26CB**	-	-	-	-	-	**26CS**
26 R	**26RA**	**26RB**	-	**26RD**	-	-	-	**26RS**
34	-	**34B**	**34C**	**34D**	-	-	-	-
Total	2	3	3	2	2	2	3	3

Table 18 Runway allocation at airport *type B* (scenarios)

Time	Runway	Runway use 24 LTO	06 LTO	14 LTO	32 LTO
Status quo and scenarios	2	6 % / 53 %	29 % / 17 %	64 % / 28 %	1 % / 2 %

Comment: Assumptions correspond to Airport HAM (2004)
Abbreviation: LTO = Landing/Take-off;
Source: www.fluglaerm-hh.de (accessed 11. 10. 2005)

Table 19 Runway allocation at airport *type C* (scenarios)

Time	Runway	Runway use			
		21 LTO	03 LTO	28 LTO	10 LTO
Status quo and scenarios	2	4 % / 1 %	4 % / 21 %	59 % / 45 %	33 % / 33 %
Comment: Assumptions correspond to Airport CGN (2004) Abbreviation: LTO = Landing/Take-off.					
Source: www.koeln-bonn-airport.de (accessed 11. 10. 2005)					

5.3 Formulation of the scenarios

A distinction is made between short-term measures, which can be realized parallel to regulations for *Chapter 4* aircraft in *Annex 16*, which are in force since January 2006, and medium- to long-term measures.

Table 20 Formulation of scenarios

Time horizon	Noise reduction potential		
	Reference	Minimum	Maximum
Short term (2012)	*Reference scenario 1*	*Scenario 1*	*Threshold Scenario 2*
Medium to long term (2020)	*Reference scenario 2*	*Scenario 3*	*Scenario 4*

Three situations representing different noise reduction potentials are examined in respect of both time horizons. Subsequent assessment of the scenarios is in each case conducted separately for the short-term and medium- to long-term time horizon within the three selected cases, with different noise reduction potentials compared to the reference case. Scenarios 2 and 4 as well as both reference scenarios demonstrate the scope of possible developments and changes. At the same time, the theoretical borderline case in Scenario 2 (*Threshold Scenario*) is orientated to a target that already takes account of unexpected changes. This choice, which from the point of view of possible realization can be regarded as unrealistic, was consciously made to demonstrate theoretical opportunities for maximum noise reduction taking account of aircraft types currently in operation. The assumptions for Scenario 4 are based on realistic targets from a technical point of view. Furthermore, in the reference scenarios the prevailing status quo is re-enacted and continued. In addition, a gradual fleet switch to quieter aircraft is assumed. As a third situation, in *Scenarios 1* and *3* assumptions are examined with regard to minimum noise reduction potential, which, on current assessment, is realizable (see Table 20).

As agreed within the project consortium and with the project sponsor, further noise reduction measures[144], which cannot be deduced from more stringent noise limits (for example, low-noise flight procedures and far-reaching regulatory measures), will not be considered. Their consideration is not possible within the scope of the intended assessment. Methodical modifications to *Annex 16* are considered later in the report.

Determination of future fleet mix according to the modified [ANOTEC 2003] method (see above) is further changed through consideration of the classification of RC2 aircraft included in the EMPA noise data bank, which aids the formulation of scenarios with varied noise reduction potentials (see Table 21), while the reference scenarios are based solely on the evolution matrix. Classification is differentiated according to the average range of an aircraft (short, medium and long haul) and the size of an aircraft (number of passengers). The quietest and an averagely loud aircraft type of each class is identified and defined for *Scenarios 1* to *4*.[145]

The six cases under consideration differ regarding aircraft renewal as follows:

- Reference Scenario 1 and 2 as well as *Scenario 3*: Consideration of the modified evolution matrix. From 2015, a tightening up of noise limits for all new aircraft types is considered in *Scenario 3*.
- *Scenario 1* and *4*: The new aircraft in the fleet mix correspond to the best of a class, that is, the quietest aircraft type of each class. From 2015, a tightening up of noise limits for all new aircraft types is carried out in *Scenario 4*.
- *Threshold Scenario 2*: All aircraft of the fleet mix correspond to the quietest types of each class.

5.3.1 Short-term time horizon

Scenarios for the short-term time horizon comprise the following assumptions and measures:

- Description of the perspective in the year 2012. For this, the adjusted evolution matrix is applied (Appendix M). Replacements within existing aircraft fleets (as at 2003 and 2004) are assumed on the basis of existing technology.
- *Reference Scenario 1*: Continuation of the status quo, with assessment of fleet renewal and replacement rate solely in accordance with the evolution matrix.
- *Scenario 1*: From 2007, new aircraft are equivalent to the best, that is the quietest aircraft of each class (see Table 21).

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144 See further explanations in Appendix AB.

145 The quietest and an averagely loud aircraft type are identified on take-off and landing by means of the cumulative single-event sound level L_{AE} of the EMPA noise data bank, and are defined for medium- to long-term scenarios on the basis of new noise limit specifications in "Chapter 5" by means of the newly-defined directivity characteristics of typical representatives of the classes.

- *Threshold Scenario 2*: All aircraft correspond to the quietest aircraft type of each class (see Table 21).

Table 21 Assignment of RC2 types (jet aircraft) to Classes1 to 6

Distance	Aircraft size			
	small		medium	large
	PAX < 50	PAX 50 to < 150	PAX 150 to < 300	PAX > 300
Short haul	**C 550** **C 650** DA 20 DA 90 G 4 1 G 2 HS 257 LR 25 LR 35	**CL 65** E 145 **FK 10** 2 FK 70 RJ 100 TU 34A	-	-
Medium haul	-	**A 319** B 7272 [C] **B 727H** [C] B 737A B 73X 3 BA 11 DC 930 MD 80 YK 42	A 300 [C] **A 3103** **A 320** A 321 4 B 707F [C] B 7572 TU 54B TU 54M	-
Long haul	-	-	A 3302 **B 7673** DC 10 [C] 5 **DC 870** [C] MD 11 [C]	**A 3403** B 7473 [C] **B 7474** [C] B 7772 6
Explanation: Aircraft printed in red represent the quietest aircraft of each class; aircraft printed in blue represent an averagely-loud aircraft of each class (in each case cumulative single-event sound level L_{AE} from the EMPA noise database on take-.off and landing; as at April 2005); abbreviation [C] designates aircraft with a cargo variant.				

5.3.2 Medium- to long-term time horizon

These scenarios comprise assumptions for the medium- to long-term time horizon of 2020. Long-term noise reduction potential is estimated cumulatively, on the basis of existing knowledge, at approximately 28 to 32 EPNdB for the entire aircraft.[146] Consideration of this noise reduction potential is differentiated for variedly formulated cases and subsequently reproduced in the form of noise computations (see Chapter 6). For this purpose, more stringent noise limits and a corresponding noise reduction are assumed. The difference to consideration of the short-term time horizon is that reduction potential from 2015 is directly considered by means of changed source data. In addition, the source data of RC2 types is/are reduced for an averagely loud representative of the defined class (aircraft types marked in blue in Table 21), which is thus quieter. Noise computations for the medium- to long-term time horizon therefore simulate potential future noise situations, which allow for a certain number of new aircraft that fulfil newly defined noise limits (a tightening up of 32 EPNdB).

[146] This noise reduction potential relates to comparison of a typical medium- to long-haul aircraft with *Chapter 3* noise limits.

Formulation has been specifically defined as follows:

- Description of the perspective in the year 2020, making use of the evolution matrix for 2020 (see Appendix M). Up to the year 2015, regular fleet renewal corresponding to the matrix is assumed; from 2015, further specific assumptions are partially made (see below). The year 2015 was selected for the definition of new noise limits on the assumption that the implied lead period takes sufficient account of the product cycles of aircraft manufacturers.
- *Reference Scenario 2*: Continuation of the status quo, taking account of fleet renewal and replacement rates corresponding to the evolution matrix up to 2020.
- *Scenario 3*: Fleet renewal and replacement rates corresponding to the evolution matrix up to 2015.
- *Scenario 4*: All new aircraft (2007 to 2015) correspond to the quietest type of each defined class.
- *Scenarios 3* and *4* from 2015: A tightening up of noise limits and a reduction in noise in new types of aircraft is assumed; this implies that aircraft are available or in operation that meet the new standard. The new "*Chapter 5*" standard is 32 EPNdB more stringent than *Chapter 3* and 22 EPNdB more stringent than *Chapter 4*). For this purpose, a new aircraft type is defined for each class, which serves a representative function in the evolution matrix and is considered in aircraft noise computations (the basis of which is an aircraft of average noise of each class). This tightening up of noise limits is adopted in the emission data of noise computation through adjustment of source data. Conversion of cumulative data on noise reduction potential takes place as an assumption with the value of 11 dB as single-event sound level L_{AE}.

Assumptions on new noise limits for noise-certification in *Annex 16* have been adopted within the framework of scenarios for the medium- to long-term time horizon, which are orientated to the *roadmap for noise reduction* of *ACARE 2020*. This roadmap was drawn up, and is borne jointly, by the European aviation industry as a voluntary commitment (see detailed comments in Section 4.7.6). With Vision *ACARE 2020*, for the first time an improvement on the status quo was laid down in the form of a defined target, which concerns the provision of appropriate technology and foresees the halving of noise exposure and the halving of noise volume in the period up to 2020.[147] Current noise technology programmes and configuration studies (Section 4.7) provide the backdrop to the defined target.

[147] The halving of noise exposure and the halving of noise volume is equivalent, as a rule, to a reduction of 10 dB. The doubling of the sound energy of a noise and the addition of two similarly loud sound sources is equivalent to an increase of 3 dB in noise level.

Table 22 Summarized formulation of scenarios for 2012 and 2020

Forecast horizon *2012*	*2015*	Forecast horizon *2020*
-	-	**Reference scenario 2:** Development corresponds to the evolution matrix and is defined **unchanged** up to 2020
Reference scenario 1: Development corresponds to the evolution matrix and is defined **unchanged**	Grenzwertverschärfung („*Chapter 5*")	**Scenario 3:** Development corresponds to the evolution matrix and is defined **unchanged** up to 2015 plus **more stringent noise limits** and noise reduction of **32 EPNdB** for all new aircraft types 2015 - 2020
Scenario 1: **All new** aircraft (2007 - 2012) correspond to the quietest type of each class (2005 - 2007 according to the evolution matrix)		**Scenario 4:** **All new** aircraft (2007 - 2015) correspond to the quietest type of each class plus **more stringent noise limits** and noise reduction of **32 EPNdB** for all new aircraft types 2015 - 2020 (2005 - 2007 according to the evolution matrix)
***Threshold* Scenario 2:** **All** aircraft correspond to the quietest of each class	-	-
Comments: *Chapter 3* provides the reference point for more stringent noise limits; data on emission reduction as a cumulative value of the three certification measurement points is considered in the EMPA database as single-event sound level L_{AE}; for this, an averagely-loud aircraft type is newly defined for each class (32 EPNdB is equivalent to an 11 dB reduction in single-event sound level L_{AE}).		

5.3.3 Flight movements of typified airports

The description of input data for aircraft noise simulation is necessary in the form of cross tabulation, which, differentiated according to approach and departure, comprises the number of aircraft types for each approach and departure route. For this purpose, use is made of assumptions on basic data as well as of the scenarios of the airport types under consideration, and future allocation to the defined aircraft types is carried out according to the method used in [ANOTEC 2003], taking account of the modifications described above. To simplify data preparation, the allocation of aircraft types to individual flight routes is carried out evenly and consistently for the respective time horizons. The allocation of flight movements to individual aircraft types (type allocation irrespective of scenario assumptions) for the three airport types is listed in Table 15 and Appendix N.

For flight operation scenarios, changes in flight course are further adopted, corresponding to the description in Section 5.2.5. As an assumption for the distribution of flight movements over the course of a day (0:00 to 24:00), consistent distribution is applied for day and night according to [ANOTEC 2003] (see Assumption 13 *Shift in operating hours* in [ANOTEC 2003]); also because appropriately differentiated data is not available. Assessment is carried out by means of the energy-equivalent continuous sound level Leq(3) for 24 hours. Further factors (for instance, topography) are not taken into account. These simplifications – as well as doing without further specifications - are regarded as sensible, since determination of the difference between variedly formulated scenarios is decisive for the assessment of results. The following table shows specific route allocations determined for the three airport types A, B and C for consideration of the defined scenarios. The accompanying tables are to be found in Appendices O to T).

Allocation of individual flight movements to different approach and departure routes is carried out consistently in all scenarios under consideration. Actual operational experiences at selected airports provide the basis for route allocation at the typified airports. Because information on the allocation of specific aircraft types to approach and departure routes is not available, corresponding differentiation within the scenarios was not possible. Due to the specifications on standard departure routes in the *Luftfahrthandbuch* (Aviation Manual) (DFS 2006 a), in actual airport operations type-specific allocation to departure routes varies.

Table 23 Overview of Appendices with respect to route allocation at the three airport types A, B and C

Differentiation Scenarios				Airports				Appendix
No.	Time	Scenario	Approach/ Departure	Type A 08	Type A 26	Type B	Type C	
1	2012	Reference 1	A	A R1 A 08	A R1 A 26	B R1 A	C R1 A	O.
2	2012	Reference 1	D	A R1 D 08	A R1 D 26	B R1 D	C R1 D	1-8
3	2012	1	A	A S1 A 08	A S1 A 26	B S1 A	C S1 A	P.
4	2012	1	D	A S1 D 08	A S1 D 26	B S1 D	C S1 D	1-8
5	2012	2	A	A S2 A 08	A S2 A 26	B S2 A	C S2 A	Q.
6	2012	2	D	A S2 D 08	A S2 D 26	B S2 D	C S2 D	1-8
7	2020	Reference 2	A	A R2 A 08	A R2 A 26	B R2 A	C R2 A	R.
8	2020	Reference 2	D	A R2 D 08	A R2 D 26	B R2 D	C R2 D	1-8
9	2020	3	A	A S3 A 08	A S3 A 26	B S3 A	C S3 A	S.
10	2020	3	D	A S3 D 08	A S3 D 26	B S3 D	C S3 D	1-8
11	2020	4	A	A S4 A 08	A S4 A 26	B S4 A	C S4 A	T.
12	2020	4	D	A S4 D 08	A S4 D 26	B S4 D	C S4 D	1-8
Remark: description of Type A considers flight courses 08 and 26 separately; Abbreviations: A = Arrival, D = Departure								

The flight geometry of approach and departure procedures applied in computations results from the course of typified flight tracks and EMPA altitude and speed profiles for individual aircraft types. These flight profiles are determined through the evaluation of radar images of flight movements at Zürich Airport, where the angle of approach is 3°. The ICAO-A procedure is recommended as take-off procedure.

5.4 Legal examination and assessment

The realizability of the preceding scenarios is subjected below to legal examination on the basis of comments in Section 2.3. Here, the tightening up of noise limits for aircraft certification has to be examined, which is a crucial measure in Scenarios 3 and 4.

5.4.1 Tightening up noise limits for aircraft certification at the ICAO level

In the light of the extensive empowerment of the ICAO in Article 37 sentence 2 of the Chicago Agreement on the creation of aviation regulations, the introduction of a new "Chapter 5" is possible.[148] The ICAO has the power to tighten up noise limits for aircraft, as has happened in past decades, whereby the following requirements have to be fulfilled:

The tightening up of noise limits has to be consistent with the fundamental objectives of the ICAO, which are to develop the principles and techniques of international aviation and to promote the planning and development of international transport. Further objectives evolve from these basic objectives (Article 44 of the Chicago Agreement), including ensuring the safe and orderly growth of international civil aviation throughout the world, ensuring safe, regular, efficient and economic air transport and promoting flight safety.

Furthermore, the recommendations of the CAEP must be technically feasible, economically reasonable and environmentally beneficial.[149] There are therefore no time-related requirements concerning the laying down of new SARPs (standards and recommended practices), other than in connection with technical feasibility. The technical feasibility of the developments described in the scenarios is proven, and economic reasonability and beneficial effects for the environment can be substantiated (cf. for example, the comments in Chapter 6).

The latest introduction of more stringent noise limits took place with the introduction of *Chapter 4* aircraft, upon which the CAEP had decided at its 5th Assembly in Montreal in the spring of 2001. The ICAO Council gave its consent in June 2001, and the Council's resolution was adopted at the 33rd ICAO Assembly in October 2001. The new noise limits came into force on 1 January 2006.

[148] Cf. Rosenthal, p. 150.

[149] Cf. the comments in the Clean Air Report, June 2003.

5.4.2 Tightening up noise limits for the certification of aircraft in the EU or in Germany

The introduction of more stringent noise limits for the certification of aircraft is also possible, in principle, in the EU. Responsibility for setting standards for type-certification and permission to fly was transferred to the EU by Member States in Regulation EC/1592/2002. It is a matter of legal dispute, however, to what extent Member States are obliged to adopt regulations incorporated in international standards and practices, which include noise-certification according to *Annex 16*. The EU could therefore deviate from ICAO specifications in *Annex 16* and enact more stringent noise limits for aircraft licensed in the EU. These would merely have to be notified to the ICAO.

Besides the introduction of a new "*Chapter 5*" through the EU, the phasing out of *Chapter 3* aircraft would also be conceivable. This would very likely lead to political difficulties, however, as occurred with the phasing out of *Chapter 2* aircraft in the past. The phasing out of *Chapter 3* aircraft by the EU would be particularly problematical, since this would contravene the recently passed regulation on the so-called *balanced approach*, according to which noise problems at airports of Member States have to be resolved by means of an individual solution for each airport.

It is uncertain whether German could go it alone and tighten up noise limits at a national level. Before Regulation EC/1592/2002 came into force, the introduction of more stringent noise limits in Germany was possible. This applied, however, only to aircraft that were licensed in Germany. Aircraft, which are licensed in other countries and meet the noise-certification specifications of the ICAO, cannot be denied landing and take-off rights at German airports on account of Article 33, Chicago Agreement. Following the shifting of responsibility for the certification of wide-bodied jets, it is unresolved whether certification specification CS-36 on aircraft noise, enacted on the basis of Regulation EC/1702/2003, is binding also for Germany.

Doubts exist concerning the tightening up of noise-certification limits not only at the EU level, but even more so at a national level. ICAO recommendations have such a wide effect that they virtually represent an internationally valid certification standard for newly developed aircraft.[150] Due to the international integration of air transport, a tightening up of noise limits for aircraft licensed in Germany would place German owners at a considerable disadvantage, since Germany is obliged by Article 33 of the Chicago Agreement and bi- and multilateral air transport agreements to tolerate the operation in Germany of aircraft licensed in other countries, in particular when such aircraft comply with ICAO standards[151]. More stringent noise limits imposed solely on German owners would have the inconsistent result that foreign owners could operate in

[150] In the light of international interests, the uniform application of SARPs is regarded as necessary. Cf. Mengel, Constanze/Siebel, Heiko, Ziviler Luftverkehr und Klimaschutz, in: Koch, H.-J., Carpar, J., Klimaschutz im Recht, p. 284.

[151] Schwenk / Giemulla 2005, p. 296.

Germany with louder aircraft of the same type. Similar considerations could also be applied for stricter noise-certification limits at the EU level. Compared to unilateral action on the part of Germany, however, the noise reduction effect would in this case be greater, since aircraft newly certificated in the EU could operate at all European airports and thus make a contribution to an improvement in the noise situation.

6 Description and assessment of results of scenario analyses

6.1 Computation method

6.1.1 General information

Aircraft noise simulations are conducted with the Flula2 simulation programme[152] for the quantification and comparison of immissions arising in the different scenarios. For this purpose, a runway system with two to four runways and accompanying approach and departure tracks is modelled for each of the three defined airports. Aircraft noise computations are carried out on the basis of Flula2 acoustic source data for this flight geometry and for flight movements determined for individual scenarios. New source data for aircraft not presently in operation is deduced from existing aircraft types.

6.1.2 Definition of flight paths

A runway system based on actual airports is defined for each of the typified airports. In drawing up a realistic airport runway system, 5 to 6 departure courses, spreading out in all directions, are laid down for each of these airports. For each take-off runway, 2 to 3 flight tracks are defined in the direction of specified departure courses. For landings, only the final approach in the direction of the respective runway axis is considered, which is relevant for noise exposure. Approach in the opposite direction or possible holding areas are not simulated. Where available, approaches are spread over several parallel runways. This results for every airport in a total of 9 to 14 individual flight tracks for aircraft taking off and 4 to 6 flight tracks for aircraft that are landing. An overview of the defined runways and flight tracks can be found in Appendix U.

For the modelling of three-dimensional flight paths, flight tracks are combined with aircraft-type-specific altitude and speed profiles, which are based on radar data at Zürich Airport. With these profiles, the type-specific speeds and climbing performance of individual aircraft are accounted for. ILS approaches on route S14 are applied. The angel of descent of these approaches is 3 degrees.

In the case of individual types of aircraft that seldom operate at Zürich as well as future aircraft types that are not yet in operation, similar aircraft were substituted (cf. Appendix V). An overall view of all applied profile data can be found in Appendix W.

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[152] Flula2 is the aircraft noise simulation programme developed by EMPA. Flula2 is employed in Switzerland as the standard programme for determining aircraft noise exposure at and around large airports.

6.1.3 Acoustic source data

Acoustic source data is used for the computation of exposure. In order to consider decreased engine power in the case of take-off with reduced weight, there are two different data sets in the database for each large aircraft with respect to high actual take-off mass (ATOM > 85 % MTOM) and low actual take-off mass (ATOM ≤ 85 % MTOM). Since no reliable statement on the effective take-off mass of individual types of aircraft can be made in the investigated scenarios, no differentiation of take-off mass is made and all computations are conducted in respect of high take-off mass. The reduction in noise level as a result of a drop in engine power from take-off to climbing performance is compensated by the addition of a type-specific noise level.

New source data is drawn up for new types of aircraft that are not yet in operation, which is based on the emissions data of similar aircraft types and is adjusted by a standard level correction dL for take-off and landing.[153]

An overview of acoustic source data with different parameters is to be found in Appendix X.

Table 24 Deduced source data for new types of aircraft

Type	**Reference type**	**DL**	
	Type	Take-off	Landing
A380	B7474	0 dB	0 dB
B787	A3302	0 dB	0 dB
NT1	C650	-11 dB	-11 dB
NT2	FK10	-11 dB	-11 dB
NT3	MD83	-11 dB	-11 dB
NT4	A3103	-11 dB	-11 dB
NT5	B7673	-11 dB	-11 dB
NT6	B7474	-11 dB	-11 dB

[153] Acoustic target values were defined by the manufacturers of the aircraft types A380 and B787, which will go into operation in the foreseeable future, so that these aircraft should better *Chapter 3* noise limits by around (cumulative) 25 EPNdB. Since this target is ambitious, and because no reliable information exists on effective emission values, in the current computation the acoustic emissions of these new aircraft were put on a level with those of the comparable aircraft B747-400 and A330-200, which bettered noise limits by around 15 EPNdB. With this conservative approach, the new types A380 and B787 are simulated around 3 dB louder than the acoustic values lead to expect.

6.1.4 Computations with Flula2

For immission computations with Flula2 a rectangular computation sector is defined for each reference airport, whose extent is determined in such a way that the expected contour lines of 55 dB exposure lie within this area. In the case of airport type A, a correspondingly larger area was defined due to its considerably greater number of flight movements. Within this computation sector the single-event sound level L_{AE} resulting from for every single flight movement is computed on a regular grid at intervals of 250 metres. The total exposure assigned to individual scenarios is then computed through the energetic addition of this grid data, weighted with the appropriate flight movements. This way, 6 different examples of total exposure are determined for each airport, which are then shown as continuous sound pressure level (Leq) over the whole day (24 hours).

Table 25 Summary of computations with Flula2

	Runways	Number of flight tracks		Computation grid			Computed scenarios
Type	Number	Take-off	Landing	Extent	Grid interval	Number of grid points	
A	4	14	6	54 x 40 km^2	250 m	34,937	6
B	2	9	4	40 x 40 km^2	250 m	25,921	6
C	2	9	4	40 x 40 km^2	250 m	25,921	6

6.2 Evaluation

6.2.1 Method

With the Flula2 simulation programme, the levels of exposure resulting for different scenarios are determined for each of the airport types A, B and C. The following methods are applied for the assessment and comparison of different computations of exposure:

- Graphic description of noise contours appropriate to different levels of noise.
- Determination and description of the differences in noise level of individual scenarios and accompanying reference scenarios.
- Determination of the areas enclosed by individual contour lines.
- Determination of statistical parameters for the differences in noise level of individual scenarios and accompanying reference scenarios.

The graphic presentation of noise contours and differences in noise levels, as well as the quantification of areas enclosed by individual noise contours, is carried out with NMPlot[154]. Statistical parameters of differences in noise level determined at individual grid points for individual scenarios are computed with the help of Excel statistical functions.

The different steps of evaluation are explained below. The most important results of this evaluation are described in Section 6.6.2. A detailed description of all results can be found in Appendix Y, Z and AA.

6.2.1.1 Noise contours for different levels of exposure

The resulting noise contours for three different levels of exposure are shown for all computed scenarios:

- Leq (24 h) = 55 dB
- Leq (24 h) = 60 dB
- Leq (24 h) = 65 dB

The exposure curves of the three levels of exposure are described for each scenario on an exposure map. The 55 dB curves for

- Reference Scenario 1, Scenario 1, Scenario 2
- Reference Scenario 2, Scenario 3, Scenario 4

are compared on two additional maps for each airport.

6.2.1.2 Differences in noise level of different scenarios

For each airport, differences in noise level resulting for comparable scenarios at individual grid points are described in an additional grid file with coloured gradation together with the 55 dB curve of the appropriate Reference Scenario. For each of the airports under investigation the following differences in noise level were established and described on a separate map:

- Difference Scenario 1 minus Reference 1
- Difference Scenario 2 minus Reference 1
- Difference Scenario 3 minus Reference 2
- Difference Scenario 4 minus Reference 2

6.2.1.3 Determination of areas enclosed by individual noise contours

The areas enclosed by individual noise contours are determined and compared for each of the 18 investigated examples of total exposure. The areas of noise contours

[154] NMPlot is a freely accessible graphics and evaluation programme for the description of space-related data, which has been developed by Wasmer Consulting (http://wasmerconsulting.com).

relating to 55 dB, 60 dB and 65 dB levels of exposure are computed with NMPlot for each example of total exposure.

6.2.1.4 Statistical parameters for differences in the level of noise

The following statistical parameters are computed from the differences in noise level computed at individual grid points for different scenarios:

Mean value:	arithmetic mean value of differences in noise level at all grid points.
Standard deviation:	Standard deviation of differences in noise level at all grid points.
Maximum:	Maximum difference in noise level at all grid points.
Minimum:	Minimum difference in noise level at all grid points.

6.2.2 Results

6.2.2.1 Noise contours for different scenarios

The contour lines – determined for individual scenarios – of the continuous sound pressure level over the whole day (Leq/24 h) are described on the example of airport type A. A comprehensive description of all exposure maps and differences in noise level for all airports under investigation is provided in Appendix Y, Z and AA.

Figure 31 55 dB contour line Leq (24 h), airport type A, Reference Scenario1 (black), Scenario 1 (blue) and Scenario 2 (red).

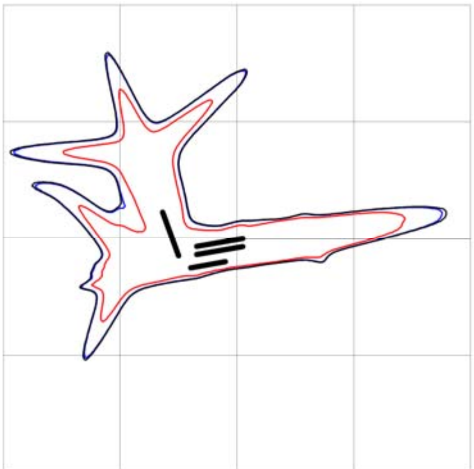
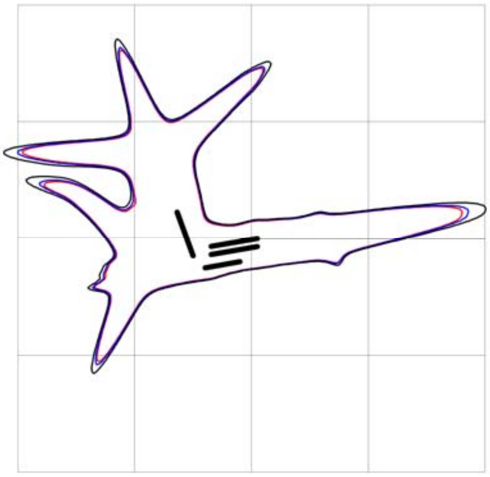


Figure 32 55 dB contour line Leq(24 h), airport type A, Reference Scenario 2 (black), Scenario 3 (blue) and Scenario 4 (red).



6.2.2.2 Differences in noise level of different scenarios

Figure 33 Airport type A, difference in noise level dLeq (24 h) Scenario 1 minus Reference 1

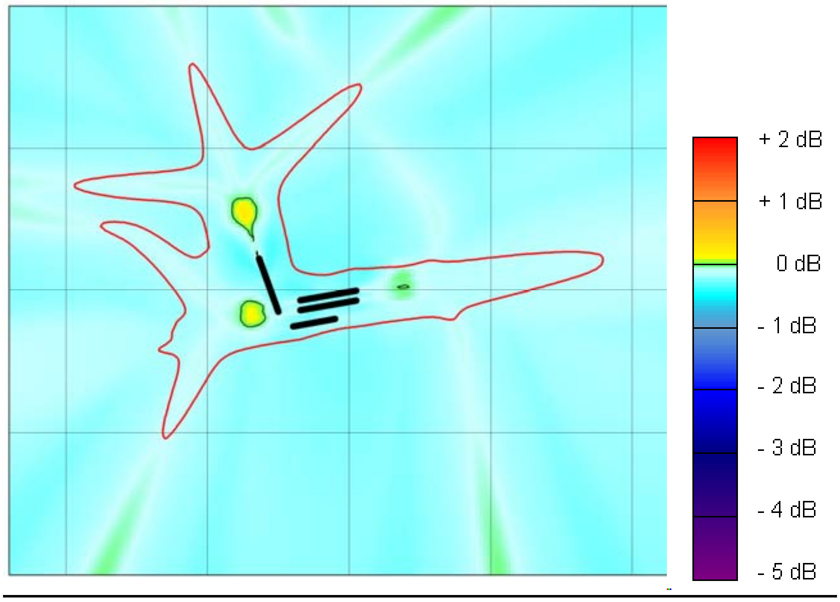
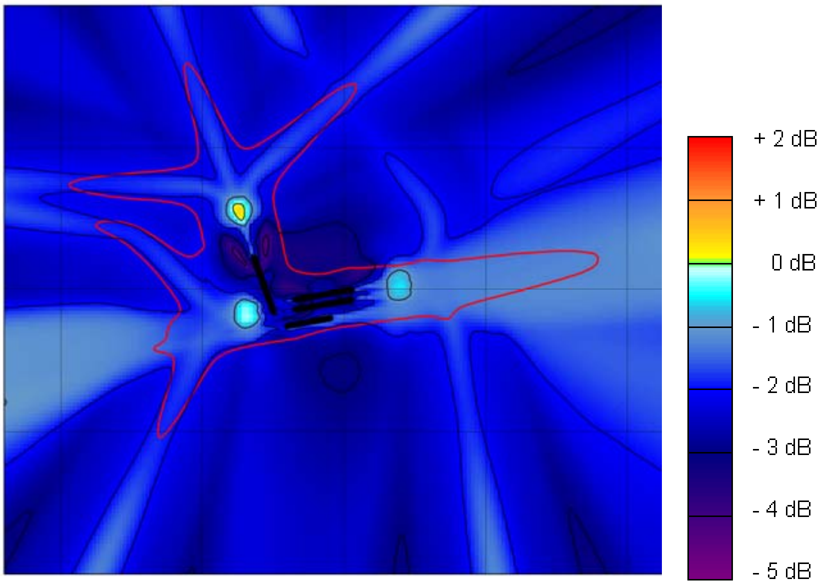


Figure 34 Airport type A, difference in noise level dLeq (24 h) Scenario 2 minus Reference 1



6.2.2.3 Enclosed areas

The areas lying within individual contour lines are determined and compared for each scenario.

Table 26 Areas enclosed by noise contours of 55 dB, 60 dB and 65 dB exposure levels for different scenarios (data in square kilometres)

Airport	Type A					
Scenario	AR1	AS1	AS2	AR2	AS3	AS4
>55 dB	229.3	222.0	149.3	263.5	240.5	230.5
>60 dB	82.0	80.1	61.1	90.8	84.9	82.1
>65 dB	34.9	34.3	25.0	38.7	36.2	35.3

Airport	Type B					
Scenario	BR1	BS1	BS2	BR2	BS3	BS4
>55 dB	32.9	32.2	26.4	37.4	33.7	32.5
>60 dB	11.3	11.0	8.7	12.8	11.4	10.8
>65 dB	4.2	4.1	3.4	4.7	4.3	4.0

Airport	Type C					
Scenario	CR1	CS1	CS2	CR2	CS3	CS4
>55 dB	53.7	50.7	39.3	64.4	56.1	51.2
>60 dB	18.9	17.7	13.5	23.3	19.8	18.0
>65 dB	6.8	6.3	4.6	8.2	7.1	6.3

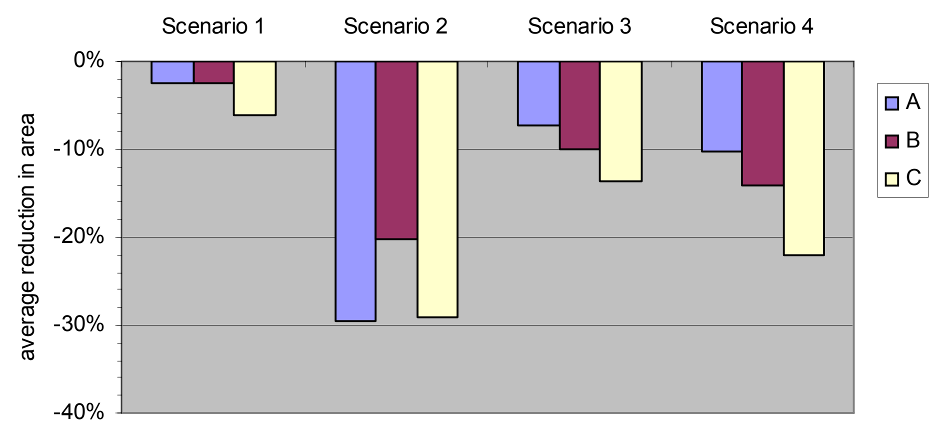
Table 27 Difference between areas of individual scenarios at different levels of exposure

Airport	Type A			
Scenario	AS1-AR1	AS2-AR1	AS3-AR2	AS4-AR2
>55 dB	-3 %	-35 %	-9 %	-13 %
>60 dB	-2 %	-25 %	-6 %	-10 %
>65 dB	-2 %	-28 %	-6 %	-9 %
Average	-2 %	-30 %	-7 %	-10 %

Airport	Type B			
Scenario	BS1-BR1	BS2-BR1	BS3-BR2	BS4-BR2
>55 dB	-2 %	-20 %	-10 %	-13 %
>60 dB	-3 %	-23 %	-11 %	-15 %
>65 dB	-2 %	-18 %	-10 %	-14 %
Average	-2 %	-20 %	-10 %	-14%

Airport	Type C			
Scenario	CS1-CR1	CS2-CR1	CS3-CR2	CS4-CR2
>55 dB	-6 %	-27 %	-13 %	-20 %
>60 dB	-6 %	-29 %	-15 %	-23 %
>65 dB	-7 %	-32 %	-13 %	-23 %
Average	-6 %	-29 %	-14 %	-22 %

Figure 35 Average reduction of areas exposed to aircraft noise of airport types A, B and C



Comment: The diagram displays the average reduction in area resulting at levels of exposure of 55, 60 and 65 dB for scenarios 1 to 4, compared to the respective reference scenario.

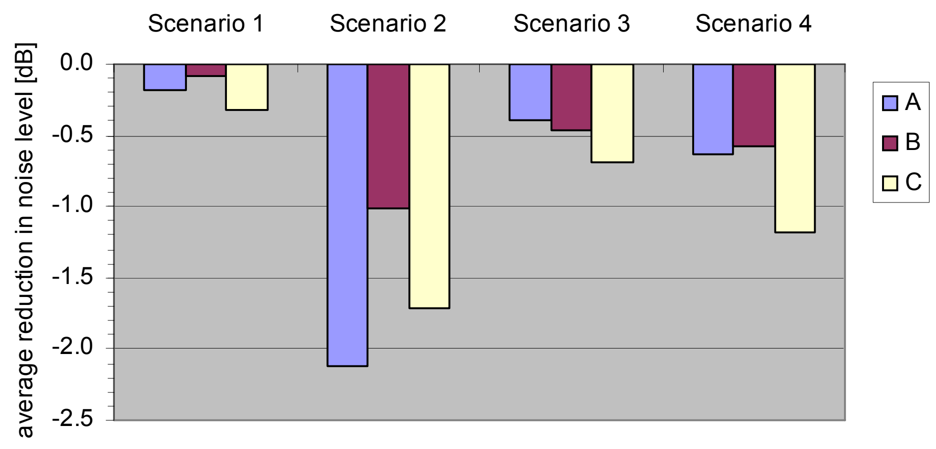
6.2.2.4 Statistical parameters

Statistical parameters are computed from differences in noise level determined at individual grid points for different scenarios.

Table 28 Statistical parameters of differences in noise level determined at individual grid points of different scenarios

Reference Scenario	Reference 1		Reference 2	
Comparison Scenario	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Airport Type A				
Average	-0.18	-2.12	-0.39	-0.63
Standard deviation	0.05	0.53	0.03	0.07
Minimum	-0.49	-6.99	-0.47	-1.21
Maximum	0.23	0.75	-0.29	0.02
Airport Type B				
Average	-0.09	-1.01	-0.46	-0.58
Standard deviation	0.03	0.46	0.04	0.06
Minimum	-0.24	-2.17	-0.74	-1.26
Maximum	-0.02	0.80	-0.24	-0.45
Airport Type C				
Average	-0.32	-1.71	-0.69	-1.19
Standard deviation	0.06	0.36	0.08	0.13
Minimum	-0.55	-2.91	-0.97	-1.73
Maximum	0.07	0.04	-0.49	-0.60

Figure 36 Average level reduction at the investigated airports A, B and C.



Comment: The diagram displays the average noise level measured at individual grid points for Scenarios 1 to 4, compared to the respective reference scenario.

6.2.3 Assessment

6.2.3.1 General information

In the scenarios, the effects on resulting noise exposure are analyzed when, on fleet renewal, quieter aircraft are operated to a varying extent. The effects are analyzed in respect of different time horizons. For a short-term time horizon of about five years, noise reduction potential is analyzed for the case that quieter aircraft, which according to current regulations and existing technology are already available, are operated during the course of fleet renewal. The longer-term effects of more stringent noise limits in *Annex 16* are investigated for a time horizon of around 15 years, through consideration of fleet renewal in which much quieter aircraft types are operated, equivalent to the current best of each class. For both time horizons, and on the assumption of a varying degree of realization of noise reduction measures, the effects are shown with an unchanged number of flight movements and compared with the respective reference scenario.

The following assessment is based, on the one hand, on the quantification of areas enclosed by contour lines and, on the other hand, on average differences in noise level of individual scenarios.

6.2.3.2 Spatial effect

The analysis of the spatial extent of differences in noise level shows that noise reduction is distributed homogeneously over the whole computation sector (cf. Figure 34 and Appendix Y to AA). Areas exposed primarily to aircraft noise on take-off and landing benefit to approximately the same extent from noise reduction. Only in the immediate area of airports are there in some cases very small areas, in which differences in noise level differ considerably from those determined elsewhere. These limited areas are located about 3 to 4 kilometres after the end of the runway directly under departure tracks. The difference is caused by the fact that in this area thrust reduction from take-off to climbing performance takes place. The required altitude of 450 metres is reached somewhat earlier, or later, depending on the type of aircraft. Since, in simulation, reduction in noise level brought about by the thrust reduction of each type of aircraft always occurs at the prescribed altitude, and thus at the same place, this place can shift through the replacement of one type of aircraft by another type with different climbing performance. Since climbing performance in actual flight operations varies greatly, however, this effect is averaged. Local level deviations shown in differential plotting are therefore to be regarded as an artefact of this assessment.

Great differences between the scenarios are observed for the short-term time horizon. Fleet renewal in Scenario 1, for instance, in which only replacement aircraft correspond to the best of the respective class, results merely in a reduction of 2 to 6 per cent in the area subject to noise exposure. Reduction of the area of exposure is much greater, however, when in Scenario 2 all aircraft are replaced by aircraft corresponding to the best of each class. Here, the extent of areas enclosed by noise contours is reduced by 20 to 30 per cent compared to the Reference Scenario, with the greatest reduction occurring at intercontinental airports of type A (cf. Table 27 and Figure 35).

In the investigations in Scenarios 3 and 4 for the long-term time horizon, the area affected by aircraft noise is reduced, depending on the level of exposure and the airport, by 6 to 23 per cent, whereby noise reductions determined for these scenarios at individual airports differ only slightly. The most striking reduction in areas exposed to aircraft noise is always observed at airport type C (-14 % in Scenario 3, - 22 % in Scenario 4), while for airport type A the resulting reduction is -7 % (Scenario 3) and -10 % (Scenario 4).

6.2.3.3 Differences in noise level

The statistical assessment of differences in noise level at individual exposure points provides a very similar picture in a comparison of scenarios (cf. Figure 36 and Table 28. In this case, too, the greatest differences of up to -2 dB are determined in Scenario 2 for airport type A; while differences in noise level are low for Scenario 1, namely -0.1 to -0.3 dB, compared to the Reference Scenario. Similar to the spatial extent of noise exposure, average differences in noise level of Scenarios 3 and 4 differ only slightly, amounting to around 0.5 dB. On the other hand, noise reduction is greatest in the case of airport type A. For Scenario 4 the average reduction in noise level, compared to the Reference Scenario, is -1,2 dB.

In considering differences in noise level at different airports, it is noticeable that the greatest reductions for Scenarios 1, 3 and 4 always result in the case of exposure at airport type C, which has a large share of cargo aircraft, and where intended fleet renewal obviously results in a greater reduction in noise exposure than at the other airports under investigation. Only in the theoretical borderline case of Scenario 2, where all aircraft are replaced by aircraft equivalent to the quietest aircraft of the respective class, is there a somewhat larger noise reduction at airport type A than at type C (2.1 dB compared to 1.7 dB).

Comparison of average reduction in noise level with corresponding reductions in the areas enclosed by contour lines confirms the general rule, familiar from various investigations, that a reduction in noise level of 1 dB results in a reduction of around 20% in the area enclosed by noise contour lines.

6.2.3.4 Uncertainty of computations

Estimated uncertainty in the determination of noise exposure has also to be taken into account in the assessment of noise reductions indicated in this study for individual scenarios. Since these computations are based on very many assumptions and simplifications, it is difficult to quantify computational uncertainties. It is known from empirical analyses and various investigations that the computational uncertainty grows with increasing distance from an airport and thus with decreasing total noise exposure.

In a study carried out in respect of Frankfurt Airport, the authors came to the conclusion that computational uncertainty amounts to around 1 dB at a noise level of 65 dB. With decreasing noise level, uncertainty increases and amounts to around 2 dB at 55 dB.

Since in this study different examples of exposure are compared, which were largely determined with the same methods, total computational uncertainty is not decisive for the assessment of results. Various factors influencing comparative computations are identical, and therefore cancel each other out in direct comparison (for example, uncertainties in computing sound dispersion in the atmosphere, flight geometry or the engine power of particular aircraft). As a result, uncertainty decreases considerably. On the other hand, account has to be taken of additional elements of uncertainty arising from assumptions on flight movements for individual scenarios, which, however, are very difficult to quantify.

On the basis of empirical figures and the influencing factors described above, and because of the observed spread of differences in noise levels for particular scenarios, applicable computational uncertainty is estimated for the comparison of scenarios – without mathematical deduction – at 0.5 dB.

6.3 Conclusion

It can be said in summary that the measures on which individual scenarios are based result in a slight reduction in total exposure to noise in decibels. The measures in Scenario 2, with which not only aircraft recently put into service but rather all aircraft correspond to the quietest aircraft type of each class, result in a reduction in noise exposure, depending on fleet mix, of between 1 dB and 2 dB. With all other scenarios, the reduction in noise exposure, compared to corresponding reference scenarios, amounts with one exception to much less than 1 dB.

While reductions in noise levels expressed in decibels tend to be low, these result nevertheless in a not insignificant reduction in the area affected by noise. An average reduction of 0.5 dB has the effect of reducing the area affected by noise by around 10 per cent, which at the level of the 55 dB contour for an intercontinental airport of type A corresponds to an area of around 30 square kilometres.

In evaluating differences in noise levels, however, computational uncertainty has also to be considered, which, with regard to the comparison of computations of the same kind, was estimated at 0.5 dB. The difference noise level determined for Scenario 1 must therefore be regarded as negligible, and that for airports A and B for Scenarios 3 and 4 as only marginally significant. Nevertheless, the present results enable the size of reductions in noise exposure expected in particular scenarios to be roughly estimated.

6.4 Excursus: Estimation of economic effects

In this research project, more stringent noise limits are examined, which are orientated towards what is technically feasible in aircraft (Section 5.3). The effect results from the operation of less noisy aircraft.

In assessing the consequences of the measures foreseen in the four scenarios, a distinction has to be made between different stakeholders, as well as between short-term and long-term effects and possible reactions. The consequences are considered for

- airline companies and
- airport operators.

Were possible costs relating to the proposed measures to be passed on by aviation stakeholders to customers, negative consequences could also occur in other sectors. The following section therefore looks at the economic importance of aviation as a whole.

6.4.1 Economic importance of aviation

The economic benefits of aviation have been examined with respect to several airport locations (for example, Cologne and Frankfurt/Main).[155] In order to quantify the economic effects of the development of an airport, a distinction is made between the following effects, whose categorization can also be applied to the aviation sector as a whole:

- Direct effects on an airport. Here, the production, employment and earnings of companies are considered, which are located at an airport.
- Indirect effects. Here, changes in the production, employment and earnings of suppliers are covered, whose goods and services are demanded by companies at an airport.
- Induced effects. Here, the increase in the demand for goods and services is considered, which arises through the expenditure of earnings resulting from direct and indirect effects.
- Locational effects ("catalytic effects"). These arise for industry and the population from high-quality air transport accessibility. This manifests itself in increases in productivity, reductions in costs, settlement effects, an increase in competitiveness and the furtherance of structural change.

The first three of these effects are likely to be of only regional importance. For Germany as a whole, the direct and indirect employment effects of airline companies and airport operators are modest in comparison to other sectors of the economy. On the other hand, the overall economic importance of aviation is considerable at both a regional and a national level. Imports and exports are of vital importance for the

[155] So, for example, Baum et al. (1998).

German economy as a whole, and flight connections are a necessity for many sectors dependent on foreign trade, whether with respect to specialized personnel (for example, maintenance staff), production (for example, special replacement parts) or quick accessibility for foreign customers. Air transport enables quick business trips and the speedy transport of goods, and is thus a prerequisite for globalization, increasing international integration and the division of labour. On the other hand, industrial sectors, which are directly dependent on import and export, also have close links to almost all other sectors, and the strategic "catalytic effect" of air transport thus reaches well beyond sectors directly involved in foreign trade that make use of air transport.

In contrast to the strategic importance of air transport for Germany as an industrial location, the direct, indirect and induced effects of air transport activities are rather modest. According to information from the Federal Statistics Office, 32,000 people are employed by airport operators and 56,000 by airline companies.[156] These figures have remained constant, or even fallen, during the past decade. Since the number of air passengers and the volume of cargo transported are increasing, this can only be explained by the shifting of work into sectors indirectly dependent on air transport, where an increase in employment can be assumed. Specific figures are available only at a regional level (for Frankfurt/Main for instance). Quantification is difficult, since it is hard to separate the work segment directly linked to flight operations (for example, the loading and unloading of aircraft) from induced further effects, which include restaurants and businesses in the area around airports, where airport-related and "normal" customers mix.

These secondary employment effects emanating from air transport can therefore not be clearly demarcated and quantified. It has to be further considered to what extent additional jobs are actually created, and to what extent there is merely a shifting of jobs into the region around an airport. It is said that one job in aviation generates 1.8 additional jobs. In this project, with its global view of Germany, a more specific quantification is not necessary, since every other economic activity also has indirect effects, in part of a similar order of magnitude. Furthermore, induced effects have to be assessed in terms of their background. From a national point of view they are only relevant as a balance; for instance, of purchases of foreign visitors in duty-free shops at German airports on the one hand, and of purchases abroad of the resident population on the other hand.

6.4.2 Consequences for airline companies

Costs of airline companies can be increased by the noise reduction measures assumed in the scenarios for two reasons:

[156] By comparison, the *Deutsche Bahn* (German Railway) had around 222,000 employees in reference year 2003.

1. In Threshold Scenario 2, a re-equipment of engines in existing aircraft fleets or a switch to new aircraft is required, which, without a change in noise limits, would not yet be necessary from an economic point of view. Additional capital investment is therefore necessary.
2. Fuel consumption, and thus operating costs, can increase as a result of noise-optimized engines (among other things, heavier weight is possible; cf. Sections 4.7 and 4.8).

For both areas, detailed estimates of costs were not possible; an estimate of their possible magnitude, however, is made below. Capital expenditure and potential losses on the part of airline companies as a result of a possible drop in the value of existing fleets depend on the manner in which noise limits are lowered, and whether this occurs worldwide (as ICAO Chapter 5) or as an EU standard or as a result of Germany going it alone.[157]. The worldwide introduction of new noise limits by the ICA would, in accordance with its principles, be over an "economically reasonable" period, so that economic consequences for airline companies could be ignored. But even if more stringent noise limits were not introduced worldwide in one move, a major fall in the value of existing aircraft fleets would not occur, even in Scenario 2, since with further long-term growth in air transport affected aircraft could be operated in other regions. German and other European carriers would be disproportionately affected, but also these airlines would be able to cope with the gradual introduction of lower noise limits, not only in Threshold Scenario 2, but also in other scenarios.

Neither can precise quantification occur in respect of a possible increase in operating costs. Since the tightening up of noise limits would affect all carriers that fly to corresponding airports, it is very likely that at least a proportion of increased costs would be passed on to customers. Even the maximum possible increases in ticket and cargo prices are unlikely to bring about either a drop in demand or negative effects on the economy as a whole, since for this the level of fuel costs in air transport is not high enough.[158]

6.4.3 Economic consequences for airport operators

Changes in the level of charges for landing and take-off are not foreseen in the scenarios. Realization of the scenarios therefore involves no direct consequences for the costs and earnings of airport operators. Receipts from noise-related charges could decrease, but on the other hand, airports with a low required level of passive noise protection measures (for example, grants for noise-proof windows) would benefit from a reduction in costs.

A change in the competitive situation of airports is more difficult to assess. Besides changes in noise-related charges, abatement of noise-related operating restrictions

[157] Cf. Section 5.4 on realizability from a legal point of view.

[158] Cf. UBA 2001 b. Here, considerable increases in the price of aviation fuel were assumed and assessed.

(such as night curfews, limitations on the number of flight movements and restrictions on the use of individual runways) could occur, which could improve the level of costs as well as the competitive situation of individual airports. Statements would only be possible on the basis of detailed analysis of specific locations. It has also to be pointed out that the general conditions of airport operation are not always set on a rational economic basis, but rather on political grounds that include the viewpoint of regional promotion. Subsidization as a measure of regional development cannot be excluded.

6.4.4 Macroeconomic effects

It follows from the comments in the preceding section that buyers of air transport services, whether passengers or the dispatchers or recipients of air cargo, need expect if any, then only very low price increases as a result of the measures considered in this report. A price-related change for the worse on the supply side (for example, less flexibility and lower flight frequency) is also not to be expected, since, with the exception of Threshold Scenario 2, more stringent noise limits are adapted to fleet renewal, which will take place in any case. Negative macroeconomic effects are therefore not to be expected.

Positive effects are to be expected, on the other hand, for manufacturers of engines and aircraft, since new noise-reduced engines cost more to manufacture and will thus be more expensive. In relation to the cost of turbines and, in particular, aircraft, the additional cost is, however, relatively low, so that this positive effect is likely to be similarly low. This aspect was considered with respect to airline companies as purchasers and operators of aircraft in Section 6.8.2.

6.4.5 Conclusion

Negative consequences for air transport are not to be expected from the measures defined in this report. Only in Threshold Scenario 2 could increases in costs arise, which, however, in relation to increases in the price of kerosene in recent years, can be ignored. The noise-reducing effects (cf. Chapter 6) of these measures therefore involve no, or in Scenario 2 only insignificant negative economic consequences.

It has to be pointed out, that in this report only three typified airports have been considered. Regional disparities cannot be ruled out In actual realization of the measures, which – locally and regionally restricted – could well bring advantages for airports previously restricted through aircraft noise, with corresponding negative economic effects for other airports. More far-reaching statements in this respect require individual analyses, which are not the subject of this research project. Negative macroeconomic consequences for Germany as a whole, or for the EU, can be ruled out.

7 Summary and recommendations

This project on the *tightening up of noise limits for civil jet aircraft* has the objective, based on the insights of a status-quo analysis, of preparing proposals for updating *Annex 16* and of undertaking an assessment of proposals for new (more stringent) noise limits, bearing in mind aspects of environmental protection as well as from a technical, legal and economic point of view. Recommendations on the methodical and technical modification of existing rules and regulations as well as on the appropriate scale of further more stringent noise limits are seen as a further development of noise-certification. Knowledge derived from Chapters 2 to 6 of this report provides the basis for this.

In addition, the connection between noise and pollutant emissions has been examined. This so-called trade-off effect has been defined and, in part, quantified within the scope of various analyses. Such analysis is based on the premise that proposals for new noise limits ought not to have the result that other adverse effects of air transport (in this case, pollutant emissions) worsen.

A summary of insights gained together with resultant recommendations for the updating of *Annex 16* are detailed below. These relate not only to short-term but also to medium- to long-term measures. This chapter is divided into three parts. It begins with general conclusions, which are followed by a description of trade-off effects and, finally, a discussion of the consequences of scenario examination.

7.1 General conclusions

The certification procedure described in detail in the ICAO's *Annex 16* provides important specifications for German and European certification procedures, in so much as reference is generally made to existing ICAO regulations on the specification of compliance procedures. Analysis has shown that different aspects of the compliance procedure need to be improved (see Section 2.5). Furthermore, topics have also been examined, which have repeatedly been the subject of criticism by third parties, but which have not been confirmed in analyses conducted by them (for example, exploitation of the trade-off between noise measurement points as well as typified evaluation conditions as opposed to actual flight operations). General conclusions are drawn below with respect to both points of view (own analysis and the verification of assumptions of third-parties), and, as far as possible, proposals made for their consideration or adaptation.

As a result of knowledge gained from investigations, it appears to be useful to add the aspect of environmental protection to the **definition of the objective of the compliance procedure**. In addition, so-called "*latest developments in technology*" should be described in more detail and a specific connection established to noise abatement. Up to now, "*it should be shown that the technical equipment of the aircraft is designed in such a way that noise arising during its operation does not exceed an* *unavoidable level according to latest developments in technology* (LVL 2004). Greater specification in this passage – for instance through the definition of specific noise targets – could contribute to long-term planning security for the aviation industry and, above all, help to ensure that greater weight is attached in the certification procedure to noise abatement. Consideration of specific targets in the form of dB values should take place within the scope of routine updating (see below) with expected technological advances in mind.

The present system of prescribed noise limits provides for upper and lower limits with respect to maximum permitted take-off mass (MTOM) From an environmental point of view, fixed upper and lower limits are undesirable, since in certain cases no further incentives are created for emission reduction. For this reason, an **adjustment of the basis for assessment** is considered to be important. With the coming into scheduled service of the wide-bodied jet A 380, an aircraft with about 560 tonnes MTOM (and 590 tonnes MTOM in the cargo version) is certificated whose weight lies above the previous maximum weight for a civil aircraft (Airbus 2006). The present form of noise limits, with its fixed level above a certain maximum take-off mass, represents a more stringent regulation of those aircraft that, from the point of view of noise abatement, should be assessed preferentially. As it is, aircraft of varied maximum take-off mass are assessed identically. The lower limit has already been identified as a weak point, since comparatively light jet aircraft (such as the Leerjet 55 and the Cessna 560) are favoured at the lower end of the weight scale, in so much as noise limits are at a fixed level below a certain take-off mass (see Section 2.5). The favouring or disadvantaging of particular aircraft does not make sense, even when these aircraft are seldom in operation and make only a modest contribution to total noise emissions. There is no justification for the application of fixed noise limits from the point of view of those exposed to noise, since there exists neither a generally accepted *de minimis* limit nor a defined upper limit of reasonable noise emissions. Assessment on a continuous scale is generally preferred. An alternative approach to an appropriate assessment value – seen from the exposure side – could be consideration of noise emission per aircraft seat. The evaluation in Section 3.4.1 showed that corresponding analysis is possible, taking into account differentiation according to aircraft type.

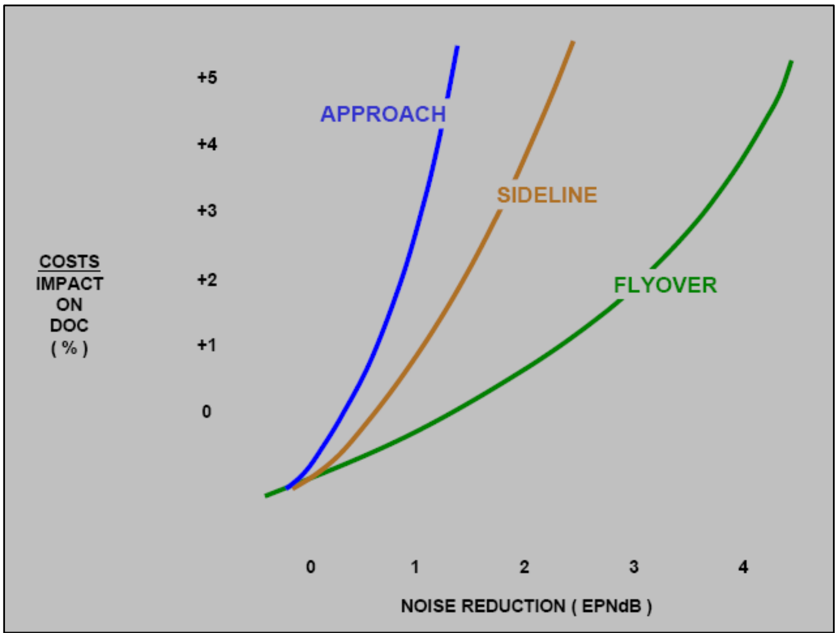
As far as concerns the evaluation method, **reconsideration of the applicable noise index** appears to be sensible, since the effective perceived noise level EPNL, which has been applied up to now, is not undisputed. This noise index, which was specially developed for certification to take account of the particular acoustic characteristics of aircraft noise, has proven its worth over many years. It also addressed varied criticism of established noise measurements on the basis of dB(A), in order to better record the situation of those exposed to aircraft noise through consideration of additional assessment factors (for example, tone correction) (see also Section 2.5). EPNL has up to now not found acceptance with regard to other applications, and is neither compatible nor comparable with other noise indices. In all known studies in the field of research on the effects of (aircraft) noise (see Appendix I) it is not EPNL that is employed, but rather continuous sound pressure level or single-event sound level in units of dB(A). On account of these advantages and disadvantages of the application of the effective perceived noise level EPNL, a critical assessment should be carried out.

Present **certification documentation**, so far as its presentation to interested members of the public is concerned, is incapable of improvement, despite the fact that extensive documentation of the certification procedure, as well as of its results in the form of a database, are already available to experts. An important element of transparent and comprehensible presentation for different target groups would be proper disclosure of the compliance procedure as well as the processing of evaluation results. **Standardization** should be striven for on the part of competent authorities (at present, in Germany, the Federal Office for Civil Aviation) – for example, in the publication of noise lists – and based on existing specifications in *Annex 16*. Comparison of variedly accessible noise lists has shown that the designation of certificated aircraft types is not on a uniform basis, with the effect that the matching of different national publications is difficult.

It also appears sensible to examine whether standardized flight configurations for certification measurement can be abandoned in future and, in their place, the specific conditions on approach and departure selected, corresponding to **actual flight operations** at an airport. This way, public acceptance of certification measurements would be substantially improved. Alternatively, it should be examined whether the positive results obtained in the study on the three London airports could be generally applied to the validation of actual noise measurements and certification values (see Section 2.5).

Differentiated **weighting of the three certification measurement points** can also not be recommended from the perspective of those exposed to aircraft noise. Noise exposure exists at and around an airport, and a decision in favour of a particular measurement point cannot be made. Evaluations in Section 2.5 have also shown that a systematic trend in favour of or against a particular measurement point cannot be substantiated with respect to individual types of aircraft, aircraft series or aircraft manufacturers. Inasmuch as differing evaluations arise at the certification measurement points, due to considerations of costs and benefits (see Figure 37), these can be weighed up in the course of realization. Consideration of a lowering of noise limits by a cumulative margin, as occurred with the introduction of the *Chapter 4* standard, can accordingly also be regarded as sensible. Furthermore, existing **differentiation according to the number of engines** in the fly-over noise limit on take-off can also not be followed. From the viewpoint of noise abatement, only noise emissions that arise are important, irrespective of the number of noise sources. This differentiation should therefore be done away with in future, so that jet aircraft are then classified according to total noise emissions. Broader conclusions on the definition of isolated noise limits and the course of accompanying curves were not the subject of the present investigation, could not be determined on the basis of available results and should therefore be the subject of more far-reaching analyses.

Figure 37 Relation between noise reduction and the impact on costs



Source: Kors 2004

Finally, noise-certification limits should be **regularly updated,** bearing in mind product cycles in the aviation industry and taking account of continuing technological advances. Technological advances have lead to the expectation that, with respect to aircraft as a complete system, a halving of aircraft noise can be attained in the period up to 2020 (see ACARE Vision 2020 in Section 4.9). This perspective is, however, not even considered in the present determination of limits for noise-certification, which is directed solely at the existing state-of-the-art. With the introduction of *Chapter 4* in January 2006 account is taken of technology that already exists. A large proportion of aircraft types now in operation already meet this new standard (see Section 2.8). In the light of previous experience concerning the revision of noise-certification limits, it is not to be expected that technological advances will be speedily reflected in ICAO standards. No incentive whatsoever is therefore directly created by noise-certification for optimization of existing emission values. The instrument of certification should be employed, however, to lessen noise exposure. Through the formulation of the scenarios in Chapter 5 and aircraft noise computations in Chapter 6 it has been shown that through the further development of existing regulations on noise-certification, noise-reduction effects and a reduction in the areas exposed to aircraft noise are possible at and around airports.

7.2 Conclusions on the trade-off effect

Trade-off effects are compensative factors of different competing or opposing design targets for aircraft, including engines (for further details see Section 4.8). Reference is made to this problem in the IPCC report on *Aviation and the Global Atmosphere* (IPCC 2001) in connection with aircraft performance, which suggests consideration of alternative design approaches. The particular interactions between the noise and exhaust emissions of an engine are extremely difficult to record and equally difficult to assess. These difficulties are to be explained by the fact that, due to the current huge number of technological developments, no homogeneous engine or aircraft product can be defined, for which an appropriate reference basis could be laid down. It is recommended that *weight*, which is the most important aspect of aircraft design, play an important role in further technological development, so that both design targets of minimizing noise and exhaust emissions can be attained concurrently within certain limits. The design target *weight* appears to be particularly appropriate, since all measures for influencing relevant environmental objectives (CO_2, NO_x and noise reduction) have – in part, pronounced – effects on weight, with possible application to considerations of the economic efficiency of the overall aircraft system. This approach is considered, for example, in the IRA engine, which enables low noise and exhaust emissions but is much heavier than a conventionally engine.

Based on an analysis of the technological objectives for different system elements (aircraft, engine, engine modules), and taking into account the three environmental goals mentioned above, a common conclusion can be drawn: The use of a conventionally-designed engine, with the highest pressure and temperature possible at the compressor outlet and combustor inlet, favours optimization of fuel consumption and high bypass ratios. This, however, involves increased NO_x emissions, which, on the other hand, can be significantly decreased through modified engine modules (for example, double-ring combustors and air-regulated combustors) that can be integrated into conventional engines. The geared turbofan (GTF) is a fan drive gear system, which can be employed in the next generation of engines. The intercooled recuperative aero-engine (IRA)[159] represents an engine concept with which the objectives of *ACARE Vision 2020* can be achieved. This IRA engine is realizable in the long term (> 2020). These examples show that the two design targets of minimizing noise and exhaust emission are already being achieved within the scope of planned and, in part, existing engine configurations, and that their concurrent realization could be possible in the future.

[159] Recuperation is the heating of air in combustors with hot exhaust gases.

7.3 Consequences of scenario analysis

The **results of scenario analysis** are available for assessment in the form of aircraft noise computations (see Chapter 6). The results indicate smaller noise reduction effects than the formulation of the scenarios led to expect. Assumptions have been made that can all be assessed as technically feasible, but which, in part, also require extensive action and efforts. The assumptions allow for a noticeable tightening up of noise limits. Demanding quality standards with regard to noise emissions of the most modern aircraft are considered and operationalized in the scenarios.

Two scenario packages were investigated for the time horizons 2012 and 2020. In each case, reference scenarios were extrapolated and, in addition, two scenarios developed, in which accompanying measures and more stringent noise limits were implemented. The short-term scenarios considered measures based on the best current developments in technology with respect to noise minimization. In one scenario, from 2007 all newly certificated aircraft comply with the latest developments in technology), and in the second scenario, a so-called threshold scenario, all aircraft movements are conducted with this latest technology. A scenario was developed for the medium- to long-term time horizon, in which noise limits are lowered in the year 2015 by 32 EPNdB. The second scenario for 2020 additionally assumes that from 2007 only such aircraft go into service that are equipped with optimum noise reduction technology. Noise computations showed that the average reduction in noise level in Threshold Scenario 2 amounted to up to 2.1 dB(A). In the other scenarios, average noise level reductions of up to 1,2 dB(A) were achieved (see Table 32 and further details in Section 6.6).

Table 29 Summary of the results of scenario analysis for the three airport types

Airport Type			Scenario 1	Threshold Scenario 2	Scenario 3	Scenario 4
			Reference 1		Reference 2	
Type A	Area difference	% share	-2 %	-25 %	-6 %	-10 %
	Noise difference	dB(A)	-0.18	-2.12	-0.39	-0.63
Type B	Area difference	% share	-3 %	-23 %	-11 %	-15 %
	Noise difference	dB(A)	-0.09	-1.01	-0.46	-0.58
Type C	Area difference	% share	-6 %	-29 %	-15 %	-23 %
	Noise difference	dB(A)	-0.32	-1.71	-0.69	-1.19
Comment: All results concern the determined **difference compared to the reference case**. Data on area difference relates to an exposure level >60 dB (see details Table 27). Data on noise difference corresponds to the average from statistical evaluation (see details in Table.						

The trend within noise computations is similar for all the typified airports. The question arises as to why noise reductions were not greater. This can be explained by the predominance of isolated loud aircraft types and the greater number of relatively quiet – and at the same time relatively new – medium-haul aircraft, for which short-term replacement is not to be expected. These conclusions arise as a result of the following analysis of future fleet mix, as developed in the scenarios (see Section 5.3).

7.3.1 Analysis of future fleet mix

The average **service life of an aircraft** can be estimated at about 30 years, which is made possible by both intensive and extensive maintenance. The average age of the Lufthansa fleet is about 8.1 years (as at the end of 2004, Lufthansa 2005 b). A glance at the worldwide – IATA – fleet indicates an average age of about 10.8 years (as at the end of 2003, Lufthansa 2005 b). Additional age-related differentiation arises, for example, between a long-haul fleet and a cargo aircraft fleet. One can also assume that the fleet planning of individual airlines involves long lead time, so that short-term changes or reactions to changed conditions are generally not possible. Service life and lead time in the acquisition of new aircraft are decisive reasons why, in the scenarios up to 2020, reductions in noise levels due to a tightening up of noise limits in 2015 are initially very low; that is, they cannot be described for the period up to 2020.

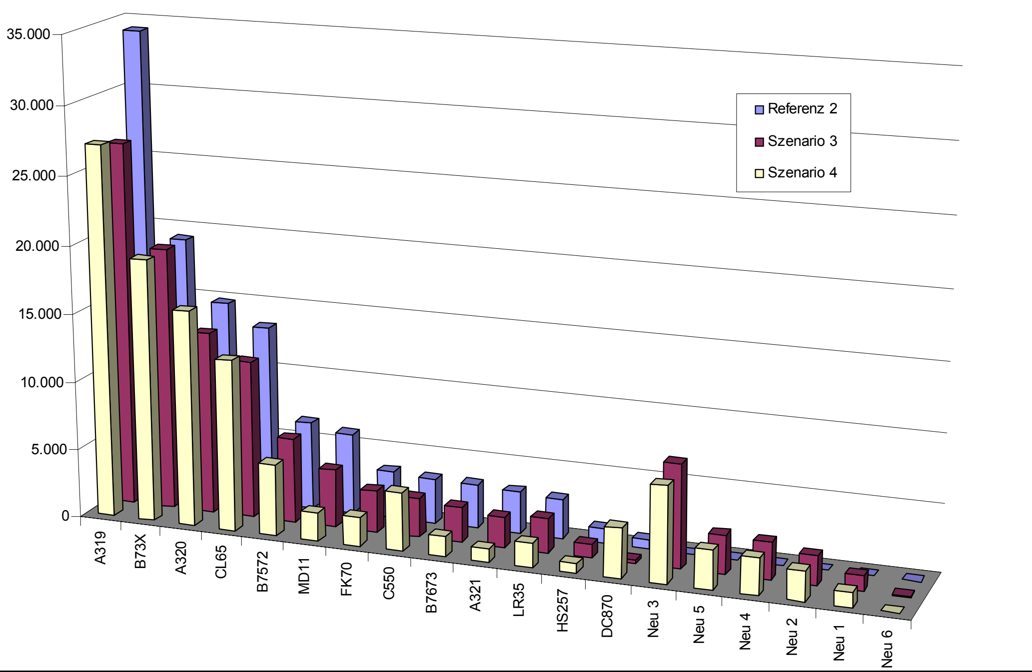
Assumptions have been made within the scope of long-term scenarios **on additional new types of aircraft** that are technically orientated to the objectives of ACARE Vision 2020. For this, a new fictive *Chapter 5* standard has been defined, in which the emission parameters of an averagely-loud aircraft are lowered and these new values then applied to all new aircraft going into service in the period from 2015 to 2020. In all scenarios, these newly defined types of aircraft make merely an insignificant contribution to sound energy, since their share of total sound energy – despite a share of up to 20% in flight movements – is only between 1 and 3 per cent (and amounting to a cumulative maximum of 5% for all six newly defined aircraft) (see Table 30). Even were the share of these aircraft to be appreciably increased, total sound energy would not be substantially influenced, so that only negligible changes in noise emissions would arise. The same conclusion could also be drawn for the case that greater noise reduction potentials could be exploited through technical improvements to aircraft.

These results are also confirmed in a further analysis, differentiated according to individual types of aircraft. On account of assumptions on the development of fleet mix, relatively constant developments in flight movements emerge for individual aircraft types (see Figure 38, on the example of airport type C).

Table 30 Number and share of flight movements with "*Chapter 5*" aircraft

	Airport Type A				
	Flight movements				Share of noise
	≤ Chapter 4		"*Chapter 5*"		"*Chapter 5*"
Reference 2	363,005	100 %	0	0 %	0
Scenario 3	292,976	81 %	70,029	19 %	1 %
Scenario 4	292,976	81 %	70,029	19 %	1 %
	Airport Type B				
Reference 2	123,501	100 %	0	0 %	0
Scenario 3	107,064	87 %	16,437	13 %	5 %
Scenario 4	99,172	80 %	24,329	20 %	5 %
	Airport Type C				
Reference 2	102,501	100 %	0	0 %	0
Scenario 3	91,161	89 %	11,340	11 %	3 %
Scenario 4	86,257	84 %	16,243	16 %	4 %
Comment: The share of noise of "*Chapter 5*" aircraft reflects their share of sound energy (intensity multiplied by the number of flight movements).					

Figure 38 Number of flight movements per aircraft type for long-term scenarios for airport type C



Comment: Number of flight movements of jet aircraft with >1.000 flight movements

Additional **sensitivity analysis**, in the form of an evaluation of shares of individual aircraft in total sound energy,[160] shows that at all airports under investigation, as well as over all analyzed scenarios, just a few types of aircraft are predominant (see Table). The evaluation also showed that in the medium- to long-term scenarios the shares of sound energy of the **noisiest types of aircraft** differ only insignificantly, and that therefore no large differences in noise exposure are to be expected (see Table 34). Predominant aircraft types are typically *Chapter 3* aircraft, such as the A320, A321, MD 11 and B747-400[161], which account for up to 90% of total sound energy at the typified airports under consideration (for details see Appendix AC). A comparable picture emerges on examination of the shares of total energy, in absolute terms, of the noisiest aircraft, since the share of flight movements of individual aircraft types remains more or less constant in the scenarios analyzed.

Table 31 Shares of total sound energy of the five noisiest aircraft types at airport type A

	Reference Scenario 1		Scenario 1		Threshold Scenario 2		Reference Scenario 2		Scenario 3		Scenario 4	
Type	E-%	B-%	E-%	B-%	E-%	B-%	E-%	B-%	E-%	B-%	E-%	B-%
B 7474	34	8	33	7	0	0	35	8	35	7	32	6
A 320	8	15	9	18	30	31	8	16	8	14	10	17
A 321	9	11	8	9	0	0	10	12	10	10	8	8
A 3403	4	4	6	5	29	13	4	4	4	4	7	5
MD 11	8	2	6	1	0	0	8	2	8	2	6	1
∑	63	40	62	40	59	44	65	42	65	37	63	37
Comment: E-% corresponds to the share in total energy (intensity multiplied by the number of flight movements); B-% corresponds to the share in flight movements under consideration.												

7.3.2 Final recommendations and outlook

The updating of noise-certification is itself not enough to achieve the desired positive effects on noise exposure at and around airports. For an appreciable relief of those exposed to noise and for an audible reduction in noise, a combination of further noise abatement measures is necessary, taking account of local circumstances. The

160 To determine the energy shares of individual types of aircraft, the specific intensity of aircraft from the EMPA data bank (resulting single-event sound level for standardized flyover) was multiplied by the number of flight movements.

161 The contribution to total sound energy of the five noisiest aircraft at each of the three airport types is as follows: Airport type A (B7474, A320, A321, A3403 and MD11) between 59 und 65 per cent; airport type B (B737, A320, A319, A321 and A3103) between 69 und 88 per cent; and airport type C (MD11, A319, A320, B737 and B7673) between 61 und 75 per cent.

updating of noise-certification must therefore be viewed as an important element of a successful noise abatement concept. The assessment of scenario results shows that on the assumption of various additional measures (for example, the preferential treatment of low-noise aircraft and the penalizing of loud aircraft), noticeable noise reduction can be achieved through the tightening up of noise limits. Under no circumstances can efforts in the area of improved technology for noise reduction be reduced or neglected. *Threshold Scenario 2* demonstrates noticeable noise reduction effects. This type of scenario was selected to indicate a maximum noise reduction effect on the basis of latest developments in technology. The formulation of this scenario is of a theoretical nature, since the short-term renewal of a complete aircraft fleet (corresponding to the assumptions made) is not to be expected. With the assumptions made in this scenario the maximum possible noise reduction was described.

The long-term scenarios assume **more stringent noise limits** with effect from 2015. An estimated cumulative noise reduction of up to 32 EPNdB for the entire aircraft from 2015 – compared to *Chapter 3* (up to 22 EPNdB compared to *Chapter 4*) – is regarded as technically feasible, taking account of past knowledge and experience of technical potential. Suitable technologies of appropriate maturity are already available, whose technical feasibility is accepted (see section 5.3.2). The assumed tightening up of noise limits is orientated to the roadmap in *ACARE 2020,* a voluntary commitment on the part of the European aeronautics industry. *ACARE 2020* aims, among other things, at a halving of perceived aircraft noise and the establishment of new environmental standards in civil aviation in the period up to 2020 (see section 4.6).

A successful strategy requires a co-ordinated and balanced approach, such as that already developed in the ICAO's "b*alanced approach*", which takes account of the special local situation. This approach foresees an assessment and solution for specific airports instead of a global solution. In a balanced approach, besides noise reduction at source, important supplementary elements are land-use planning, noise-reducing flight procedures and further operating restrictions (see Section 2.3.5.1). Essential features of a balanced approach are procedural transparency, consultation with stakeholders and consideration of costs. The initiative for corresponding measures must come from responsible politicians, and legislators must provide the initial impulse. It is essential that legislators set a clear political framework regarding both time frame and objective (in particular of future certification values), and thus provide the aviation industry with planning security in respect of standards to be met. All those responsible for the operation of an airport have to involved in the realization of such measures, including, above all, the airport operator, air traffic control (DFS), licensing authorities, the aviation control authority and the airline companies. A further important condition for a balanced approach according to ICAO specifications is consideration of necessary planning horizons of the aviation industry (for the introduction of new technology, the preparation of airport co-ordination, changes in approach and departure routes etc.). The long-term time horizon of 2020 selected for this investigation is in effect too early, so that the protracted process of fleet renewal itself indicates hardly any success in noise abatement (see above). The selected time horizon was determined, however, by the availability of air transport forecasts.

More far-reaching measures to exploit noise reduction potential can, however, be taken by responsible parties at airports. Appropriate legal steps have been examined in this report and found to be realizable (see Section 5.4). Further measures of active noise abatement are available and can be put into practice (see Appendix AB). It would be useful, if greater importance was attached by the ICAO to the topic of noise abatement; for instance, through its inclusion in the general definition of objectives in the *ICAO Memorandum*. Up to now, the ICAO has at no point attributed particular importance to noise abatement, but rather treated it within the general context of environmental protection.

A possible positive measure on the part of the ICAO would be early preparation for the **phasing out of *Chapter 3* aircraft**, based on experience with regard to *Chapter 2* aircraft. Such action would be at variance with current ICAO standards defined in the *balanced approach*, but would appears to be useful. From a legal point of view, a corresponding regulation is basically possible, and the phasing out of *Chapter 3* aircraft can be regarded as promising. This way, the few particularly loud aircraft, which in certain circumstances dominate noise emission, could be covered. At a European level, such a solution would also be legally possible but difficult to realize, due to international integration in air transport and the partially restrictive criteria of the ICAO with regard to a *balanced approach* (see Section 5.4.1).

Besides loud aircraft, a further important point concerns the types of aircraft that operate frequently at an airport and are of particular significance for airport operators. Flight movements at all the airports under investigation are dominated by modern medium-haul aircraft, which are difficult to cover with noise reduction measures since they already rank among the quietest aircraft, but which, due to their number, also make an major contribution to noise exposure. Further differentiation of these types of aircraft with regard to noise immissions is possible through **appropriate charging** of medium-haul aircraft (for example, within the scope of noise-related LTO charges). This way, a shift in the operating times and / or location of flight movements could be effected as a further measure of active noise abatement; but this would appear to be unlikely, however, through the updating of noise certification, as investigated in this report.

The final recommendations see the updating of noise certification as an important element in an integrated noise reduction concept, which has to be developed at individual airports, taking account of local circumstances. Further important elements are measures of active and passive noise abatement, such as noise-reducing approach and departure procedures and operating restrictions. This approach can be brought into line with the demands of a balanced approach, which, however, currently imposes limits. Due to the results of scenario analysis on the updating of noise certification, a promising solution with appreciable noise reduction appears to be quite realistic in the medium to long term.

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9 Appendix

(Appendix page references apply to the German edition of this report)