

Draft CAP 725 Part B

**AIRSPACE CHANGE PROPOSAL –
ENVIRONMENTAL ASSESSMENT OF AN AIRSPACE CHANGE**

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Glossary of Terms

$\mu\text{g.m}^{-3}$	microgrammes per cubic metre – a measure of pollutant concentration
ADMS	Atmospheric Dispersion Modelling System – commercial local air quality model
agl	above ground level
ask	available seat-kilometre
atm	air transport movement
AIE	Average individual exposure
amsl	above mean sea level
ANCON	Aircraft Noise Contour Model
ANIS	Aircraft Noise Index Study
ANSP	Air Navigation Service Provider
AONB	Area of Outstanding Natural Beauty
AQMA	Air Quality Management Area
ask	available seat-kilometre
ATC	Air Traffic Control
atm	air transport movement
BADA	Base of Aircraft Data
CAA	Civil Aviation Authority
CO₂	carbon Dioxide
DAP	Directorate of Airspace Policy
dB	Decibel units describing relative changes of sound level.
dBA	Decibel units describing the absolute level of noise measured on an A-weighted decibel scale.
DfT	Department for Transport
CAEP	Committee on Aviation Environmental Protection
CDA	Continuous Descent Approach
COMEAP	Committee on the Medical Effects of Air Pollutants
DAP	Directorate of Airspace Policy
DEFRA	Department for the Environment, Food and Rural Affairs
DfT	Department for Transport, previously known as the Department of the Environment, Transport and the Regions (DETR) , the Department of Transport, Local Government and the Regions (DTLR) or the Department of Transport (DoT)
DoT	Department of Transport, since renamed Department for Transport
EDMS	Emissions and Dispersion Modelling system (US FAA Air Quality Model)
ERCD	Environmental Research and Consultancy Department
FAA	Federal Aviation Administration (US)
ft	feet

H₂O	Water
Hz	Hertz
kg	kilogramme
IAIA	International Association for Impact Assessment
ICAO	International Civil Aviation Organization
INM	Integrated Noise Model (US FAA Aircraft Noise Model)
L_{eq}	Equivalent continuous sound level
L_{DEN}	Day-evening-night sound level
L_{max}	Maximum sound level
L_{Night}	Night sound level
LPLD	Low Power/Low Drag
LTO	Landing and take-off
mb	Unit of pressure, one thousandth of a bar equivalent to 100 pascals
NO	Nitric oxide
NO₂	Nitrogen dioxide
NO_x	Term used to describe the sum of nitric oxide (NO), nitrogen dioxide (NO ₂), and other oxides of nitrogen
NPV	Net Present Value
N70	Noise contour describing the number of events above 70 dBA L _{max} . Typically, contours ranging from 10 events to 500 events over 70 dBA L _{max} are plotted.
N80	Noise contour that describes the number of noise events above 80 dBA L _{max} . Typically, contours ranging from 10 events to 500 events over 80 dBA L _{max} are plotted.
Newton	Unit of force, equal to the force that would give a mass of one kilogramme an acceleration of one metre per second per second
NNI	Noise and Number Index
O₂	Oxygen
OS	Ordnance Survey
Pascal	Unit of pressure equivalent to 1 Newton per square metre
NPR	Noise Preferential Route
PEI	Person-Event Index
POST	Parliamentary Office of Science and Technology
P-RNAV	Precision Area Navigation
RCEP	Royal Commission on Environmental Pollution
RFI	Radiative Forcing Index
rsk	revenue seat-kilometre
RNAV	Area navigation
SEL	Sound Exposure Level
SES	Single European Sky
SID	Standard instrument departure

STAR	Standard arrival route
tonne	1,000 kilogrammes
WGS 84	World Geodetic System 1984 – an earth fixed global reference system
W.m⁻²	Watts per square metre – the unit of measurement for sound intensity or radiative forcing

1 INTRODUCTION

- 1.1 The Civil Aviation Authority (Air Navigation) Directions 2001 (HMG, 2001) requires the CAA to take into account 'the need to reduce, control and mitigate as far as possible the environmental impacts of civil aircraft operations, and in particular the annoyance and disturbance caused to the general public arising from aircraft noise and vibration, and emissions from aircraft engines'. In order to achieve this, DAP requires airspace change sponsors to provide an environmental assessment. Every airspace change will be different and the extent of environmental assessment will vary from case to case. It is the function of this document to assist those preparing airspace change proposals in providing sufficient environmental information for public consultation and to inform the decision-making process.
- 1.2 This document gives a broad outline of relevant methodologies for use in environmental assessment. It is not a complete instruction manual on all aspects of the topic. Readers **should** consult the further reading section or seek expert assistance where relevant. The purpose of this document is to provide clarification of the requirements for environmental information in the submission of an airspace change proposal. It does not place additional obligations on airspace change sponsors over that contained in current legislation and guidance issued by the Department for Transport (DfT) and other Government departments.
- 1.3 Guidance to DAP from DfT (DTLR, 2002 - paragraph 36) specifies that changes to airspace arrangements (which includes procedures for the use of controlled airspace in addition to its design) '**should be made after consultation, only where it is clear that an overall environmental benefit will accrue or where airspace management considerations and the overriding need for safety allow for no practical alternative.**'
- 1.4 The environmental impact of an airspace change **must** be considered from the outset. The airspace change sponsor **should** discuss their general intentions for environmental assessment with the DAP case officer and, if necessary, with ERCD staff who will provide independent expert advice. These discussions **should** take place before any form of external consultation. Each airspace change is specific and raises different issues, while the guidance in this document is, of necessity, quite general.
- 1.5 Environmental science is continually evolving and this document describes assessment methods applicable at the date of publication. New methodologies based on sound principles may well be developed. This document will therefore be subject to review and updating in order to ensure that it reflects 'best practice'.
- 1.6 Airspace changes are increasingly the subject of public debate and it is important that environmental assessment and associated public consultation are carried out thoroughly. Incomplete consideration of environmental issues will cause delays to the handling of airspace change proposals.
- 1.7 It is extremely important for change sponsors to discuss the general nature of the airspace change with the DAP case officer. This can prevent wasted effort. For example, it may be that the change sponsor can demonstrate by approximate calculations, that some effects of an option are relatively small. In such an instance, the case officer could well indicate that there would be little point in further refinements to the calculation. The message is that analysis should be proportionate to the utility of the information gained from it.

- 1.8 The following terms are used here to indicate the degree of compliance expected from airspace change sponsor in following this guidance:
- **must** – change sponsors are to meet the requirements in full when this term is used;
 - **should** – change sponsors are to meet these requirements unless there is sufficient reason which must be agreed in writing with the DAP case officer and the circumstances recorded in the formal airspace change documentation; and
 - **may** – change sponsors decide whether this guidance is appropriate to the circumstances of the airspace change.

Where these three words are used in relation to actions by change sponsors, the words have been emboldened in the following text.

- 1.9 The following text is divided into eight sections:

Principles of Environmental Assessment

Inputs to Environmental Assessment

Noise: Standard Techniques

Noise: Supplementary Methods

Climate Change

Tranquillity and Visual Intrusion

Local Air Quality

Economic Valuation of Environmental Impact

2 PRINCIPLES OF ENVIRONMENTAL ASSESSMENT

- 2.1 There are many definitions of environmental assessment. For the purposes of this document the UK definition (DOE, 1989) will be used: 'A technique and a process by which information about the environmental effects of a project is collected, both by the developer and from other sources, and taken into account by the planning authority in forming their judgements on whether the development should go ahead'. The developer here is understood to be the sponsor of an airspace change, the development is the airspace change and the planning authority is the Director of Airspace Policy or, in exceptional circumstances, the Secretary of State for Transport.
- 2.2 Environmental assessment within the scope of this document excludes the provision of projects falling within the Town and Country Planning Regulations or those that are subject to a public planning inquiry. The scope of this document includes all environmental impacts that the CAA has an obligation placed on it by Government to consider both by the Directions (HMG, 2001) and the Guidance (DLTR, 2002). It excludes impacts on animals, livestock or biodiversity. If appropriate, the issue of bird strikes in relation to the proposal should be addressed as a safety issue. Safety aspects should be considered separately from environmental issues.
- Purposes of environmental assessment**

2.3 The function of environmental assessment is to ensure that environmental considerations are explicitly addressed and incorporated within the planning and decision making process for airspace change. This takes into account the statutory obligations on the CAA and guidance on environmental objectives promulgated by the then DTLR, now DfT (DTLR, 2002). Environmental assessment **should** set out the base case or current situation so that changes can be clearly identified.

Basic principles

2.4 Environmental assessment [adapted in part from international guidelines produced by the International Association of Impact Assessment (IAIA, 1999)] **should** be:

- purposive – informing decision making;
- rigorous – applying best available scientific knowledge, including methodologies and techniques relevant to the problem under investigation;
- practical – resulting in information and outputs that assist with problem solving and are acceptable to, and capable of implementation by change sponsors;
- relevant – providing sufficient, reliable and usable information for planning and decision-making;
- cost-effective – achieving objectives within the limits of available information, time, resources and methodology;
- focused – concentrating on significant environmental effects and key issues;
- adaptive – adjusting to the realities, issues and circumstances of proposals under review without compromising the integrity of the process and be iterative, incorporating lessons learned throughout the proposal's life cycle;
- participative – providing appropriate opportunities to inform and involve interested and affected individuals and groups, ensuring that their inputs and concerns should be considered in decision making;
- interdisciplinary – ensuring that appropriate techniques and experts in the relevant technical disciplines are involved;
- credible – implemented with professionalism, rigour, fairness, objectivity, impartiality and balance;
- integrated – addressing the interrelationships between social, economic and environmental aspects;
- transparent – having clear, easily understood requirements; ensuring public access to information; identifying the factors that are to be taken into account in decision making and recognising limitations and difficulties; and
- systematic – resulting in full consideration of all relevant information on the affected environment, of proposed alternatives and their impacts and of measures necessary to monitor and investigate residual effects.

2.5 DfT environmental objectives (DTLR, 2002 - paragraph 10) give guidance on how DAP should contribute to the aims of sustainable development by seeking to optimise the benefits and minimise harm to the environment. This guidance requires DAP to proceed in a manner that is:

- comprehensive – by utilising the most up-to-date and comprehensive information available, including on engineering, navigational and demographic factors;

- rigorous – by identifying and reviewing all significant environmental effects of proposed changes, assessing their environmental impact, technical feasibility, any health and safety implications, cost-effectiveness, and carrying out a thorough examination of the options for minimising and reducing aircraft noise and emissions;
- forward looking – by taking account of likely future as well as current planned operations, with a view to delivering stability in airspace arrangements as far as practicable;
- transparent – by utilising clear assessment methodologies and making relevant information accessible through consultation or otherwise in accordance with open Government principles; and which is
- aimed at seeking improvements – by not confining policy and activity to measures which prevent a worsening of the environmental impacts of aviation, but also seeking ways of reducing those impacts and improving the environment where possible.

Environmental Assessment Users

- 2.6 Environmental assessment is required to satisfy two different audiences – the public and the decision-maker. Moreover, it must cater for the technical expert and those affected by the changes, who can only be assumed to have a general knowledge of aviation or environmental matters. The public will certainly expect a description of the airspace change written in readily understood, non-technical language. However, some people may wish to read the full technical detail or to provide it to technical experts employed for that purpose. It is important that the level of detail is appropriate to these audiences.
- 2.7 A technical document containing complete details of the airspace change and environmental impact will be required and **must** be produced for all airspace changes. This is the document that will be used as a primary source in decision making. Airspace change sponsors **must** also consider production of a separate description of the environmental impact of the proposal in an easy-to-read format for public dissemination during the consultation. It is important that both documents are made available to the public and that they are wholly consistent. This will enable members of the public without technical expertise in either aviation or environmental science to understand the impact while providing sufficient technical information to enable a sound decision to be made based on accurate and detailed information.

3 INPUTS TO THE ENVIRONMENTAL ASSESSMENT

3.1 The inputs to the environmental assessment process are derived from two sources:

- airspace design: and
- traffic forecasts.

These are examined in turn.

Airspace design

3.2 The environmental assessment **must** include a high quality paper diagram of the airspace change in its entirety as well as supplementary diagrams illustrating different parts of the change. This diagram **must** show the extent of the airspace change in relation to known geographical features and centres of population.

3.3 The proposal **must** consider and assess several options and demonstrate why the selected option is best in environmental terms or, if not, why it is being proposed (DTLR, 2002 paragraph 57).

3.4 The change sponsor **must** provide DAP with a complete set of coordinates describing the proposed change in electronic format using World Geodetic System 1984 (WGS 84). In addition, the change sponsor **must** supply these locations in the form of Ordnance Survey (OS) national grid coordinates. This electronic description **must** provide a full description of the horizontal and vertical extent of the zones and areas contained within the airspace change. It **must** also include coordinates in both WGS 84 and OS grid that define the centre lines of routes including airways, standard instrument departures (SID), standard arrival routes (STAR), noise preferential routes (NPR) or any other arrangement that has the effect of concentrating traffic over a particular geographical area. Coordinates for current airspace and airport arrangements can be found in the UK Air Pilot (NATS, 2006) and associated web site. Details of WGS 84 Latitude/Longitude and the OS national grid coordinate system can be found on the Ordnance Survey web site (Ordnance Survey, 2006) – this contains software that will facilitate conversion between Latitude/Longitude and OS national grid.

3.5 Change sponsors **should** provide indications of the likely lateral dispersion of traffic about the centre line of each route. This **should** take the form of a statistical measure of variation such as the standard deviation of lateral distance from the centre line for given distances along track in circumstances where the dispersion is variable. Change sponsors **may** supply the outputs from simulation to demonstrate the lateral dispersion of traffic within the proposed airspace change or bring forward evidence based on actual performance on a similar kind of route. It may be appropriate for change sponsors to explain different aspects of dispersion e.g. dispersion within NPRs when following a departure routeing and when vectoring – where the aircraft will go and likely frequency.

3.6 Change sponsors **must** provide a description of the vertical distribution of traffic in airways, SIDs, STARs, NPRs and other arrangements that have the effect of concentrating traffic over a particular geographical area. For departing traffic, change sponsors **should** produce profiles of the most frequent type(s) of aircraft operating within the airspace. They **should** show vertical profiles for the maximum, typical and minimum climb rates achievable by those aircraft. A vertical profile for the slowest climbing aircraft likely to use the airspace **should** also be produced. All profiles **should** be shown graphically and the underlying data provided in an Excel

spreadsheet with all planning assumptions clearly documented.

- 3.7 The DfT guidance (DTLR, 2002 - paragraph 49) requires DAP to 'ensure that consideration is given to how the use of Continuous Descent Approaches (CDA) and Low Power/Low Drag (LPLD) procedures can be promoted in the course of developing new procedures and when considering proposals for changes to existing airspace arrangements'. A description of CDA and LPLD is provided in Appendix D. Change sponsors **should** explain how such consideration is taken into account within their proposals.

Traffic forecasts

- 3.8 The amount of air traffic is an important consideration in the assessment of airspace changes and their environmental impact. Change sponsors will have made a comprehensive assessment of traffic forecasts before reaching the conclusion that a change to airspace changes should be considered. In planning changes to airspace arrangements, change sponsors **may** have conducted real and/or fast time simulations of air traffic for a number of options. Such simulations will help to establish whether options will provide the required airspace capacity.
- 3.9 Change sponsors **must** include traffic forecasts in their environmental assessment. Information on air traffic **must** include the current level of traffic using the present airspace arrangement and a forecast. The forecast will need to indicate the traffic growth on the different routes contained within the airspace change volume. The sources used for the forecast **must** be documented.
- 3.10 Typically, forecasts **should** be for five years from the planned implementation date of the airspace change. There **may** be good reasons for varying this – for example, to use data that has already been made available to the general public at planning inquiries, in airport master plans or other business plans. It **may** also be appropriate to provide forecasts further into the future than five years: examples are extensive airspace changes or where traffic is forecast to grow slowly in the five-year period but faster thereafter.
- 3.11 There are considerable uncertainties in forecasting growth in air traffic. Traffic forecasts will be affected by consumer demand, industry confidence and a range of social, technological and environmental considerations. It **may** be appropriate for change sponsors to outline the key factors and their likely impact. In these circumstances, change sponsors **should** consider generating a range of forecasts based on several scenarios that reflect those uncertainties – this would help prevent iterations in the assessment process.
- 3.12 Traffic forecasts **should** contain not only numbers but also types of aircraft. Change sponsors **should** provide this information by runway (for arrivals/departures) and/or by route with information on vertical distribution by height/altitude/flight level as appropriate. Types of aircraft **may** be given by aircraft type/engine fit using ICAO type designators. If this is not a straightforward exercise, then designation by the UK Aircraft Noise Contour Model (ANCON) types (shown in Table 1) or by seat size categories (as shown in Table 2) would be acceptable.

Table 1: Current ANCON database aircraft type listing

ANCON Type	Type Description	Engine Description
B717	Boeing 717-200	BR715
B727C3	Boeing 727-100/200 with hush kit	PW JT8D-15/17
B732C3	Boeing 737-200 with hush kit	PW JT8D-15A/17A
B733	Boeing 737-300/400/500	CFM56-3
B736	Boeing 737-600/700	CFM56-7
B738	Boeing 737-800/900	CFM56-7
B741C3	Boeing 747-100 Chapter 3	PW JT9D-7A/F
B742C3	Boeing 747-200 Chapter 3	GE CF6/PW JT9D-7Q/RR RB211-524
B747SP	Boeing 747SP	GE CF6/PW JT9D-7Q/RR RB211-524
B744G	Boeing 747-400	GE CF6-80
B744P	Boeing 747-400	PW4000
B744R	Boeing 747-400	RR RB211-524G/H
B752C	Boeing 757-200	RR RB211-535C/PW2037/2040
B752E	Boeing 757-200	RR RB211-535E4/E4B
B753	Boeing 757-300	RR RB211-535E4B
B762	Boeing 767-200/ER	GE CF6/PW4000/RR RB211
B763G	Boeing 767-300/ER	GE CF6-80
B763P	Boeing 767-300/ER	PW4000
B763R	Boeing 767-300/ER	RR RB211-524G/H
B764	Boeing 767-400	GE CF6/PW4000
B772G	Boeing 777-200/ER/LR	GE GE90
B772P	Boeing 777-200/ER/LR	PW4000
B772R	Boeing 777-200/ER/LR	RR Trent 800
B773G	Boeing 777-300ER	GE GE90
B773R	Boeing 777-300	RR Trent 800
B787	Boeing 787-300/800	GE GENX/RR Trent 1000
BA46	AVRO 146-RJ	LF507-1F
CRJ	Canadair Regional Jet	GE CF34-3A1
CRJ700	Canadair Regional Jet 700	GE CF34-8C
CRJ900	Canadair Regional Jet 900	GE CF34-10C
DC87	Boeing (McDonnell Douglas) DC8-70	CFM56-2C
DC9C3	Boeing (McDonnell Douglas) DC9-10/20/30/40 with hush kit	PW JT8D-9/11/17

ANCON Type	Type Description	Engine Description
DC10	Boeing (McDonnell Douglas) DC10-10/30/40	GE CF6/PW JT9D
EA30	Airbus A300-B4/600/R	GE CF6/PW4000
EA31	Airbus A310-200/300	GE CF6/PW4000
EA318	Airbus A318	CFM56-5
EA319C	Airbus A319	CFM56-5
EA319V	Airbus A319	IAE V2500
EA320C	Airbus A320	CFM56-5
EA320V	Airbus A320	IAE V2500
EA321C	Airbus A321	CFM56-5
EA321V	Airbus A321	IAE V2500
EA33	Airbus A330-200/300	GE CF6/PW4000/RR Trent 700
EA34	Airbus A340-200/300	CFM56-5C
EA346	Airbus A340-500/600	RR Trent 556
EA350	Airbus A350-800/900	GE GENX/RR Trent
EA380	Airbus A380-800	GP700/RR Trent 900
EMB145	Embraer EMB 135/145	RR AE3007A
E170	Embraer EMB 170	GE CF34-8E
E190	Embraer EMB 190	GE CF34-10E
EXE2	Chapter 2 Executive Jet	-
EXE3	Chapter 3 Executive Jet	-
FK10	Fokker 70/100	RR Tay 650
L4P	Large 4-propeller	-
LTT	Large twin turboprop	-
L101	Lockheed L1011 TriStar all series	RR RB211-524
IL62	Ilyushin IL62M/MK	D-30KU
MD11	Boeing (McDonnell Douglas) MD11	GE CF6/PW4000
MD80	Boeing (McDonnell Douglas) MD80) all series	PW JT8D-200
MD90	Boeing (McDonnell Douglas) MD90	IAE V2525/8
SP	Single piston-propeller	-
STP	Small twin piston-propeller	-
STT	Small twin turboprop	-
TU54	Tupolev TU154M	D-30KU-154

Table 2: Passenger and freighter aircraft classes by seat size and freight load

Passenger aircraft classes		Freighter aircraft classes	
Class 1	<70 seats	Class A small	<30 tonnes
Class 2	71-150 seats	Class B medium narrow	31-50 tonnes
Class 3	151-250 seats	Class C medium wide	51-65 tonnes
Class 4	251-350 seats	Class D large	66-100 tonnes
Class 5	351-500 seats	Class E very large	> 100 tonnes
Class 6	>500 seats		

4 NOISE: STANDARD TECHNIQUES

4.1 Noise is a complex phenomenon. Background information on the subject can be found in the Appendices. The Appendices are:

- A. Noise Measurement
- B. Noise Modelling
- C. Effects of Noise
- D. Continuous Descent Approaches and Low Power/Low Drag Procedures

The references also include a selected bibliography covering important noise documents.

L_{eq} contours

4.2 The most commonly used method of portraying aircraft noise impact in the UK is the L_{eq} noise exposure contour. Noise exposure contours show a set of closed curves on a map. Each contour shows places where people get the same amounts of noise energy – L_{eq} – from aircraft (the 'eq' subscript is an abbreviation of the word equivalent i.e. L_{eq} is the equivalent continuous sound level). They are analogous to the contours on an ordinary map showing places at the same height. Noise exposure is generally used to indicate the noise environment averaged over some time interval.

4.3 Research has indicated that L_{eq} is a good predictor of a community's disturbance from aircraft noise. L_{eq} is measured in a unit called dBA, where dB means 'decibel' and the A suffix means A-weighted (which matches the frequency response of the human ear).

4.4 Conventional noise exposure contours, which are produced regularly for major airports, are calculated for an average summer day over the period from 16 June to 15 September inclusive, for traffic in the busiest 16 hours of the day, between 0700 and 2300 local time. These are known as $L_{eq, 16 \text{ hours}}$ contours. This calculation produces a cautious estimate (i.e. tends to over-estimate) noise exposure. This is mainly because airports are generally busier during the summer and a higher number of movements is likely to produce higher L_{eq} values. Aircraft tend to climb

less well in higher temperatures, so because they are closer to the ground, L_{eq} values will tend to be higher than in generally cold weather.

4.5 Change sponsors **must** produce $L_{eq, 16 \text{ hrs}}$ noise exposure contours for airports where the airspace change **entails changes to departure and arrival routes for traffic below 4,000 feet agl**. Under these circumstances, at least three sets of contours **must** be produced:

- i. current situation – these may already be available as part of the airport's regular environmental reporting or as part of the airport master plan;
- ii. situation immediately following the airspace change; and
- iii. situation after traffic has increased under the new arrangements (typically five years after implementation although this **should** be discussed with the DAP case officer).

The height of 4,000 feet agl was selected as the criteria for L_{eq} contours because aircraft operating above this altitude are unlikely to affect the size or shape of L_{eq} contours.

4.6 The contours **should** be produced using either the UK Aircraft Noise Contour Model (ANCON) or the US Integrated Noise Model (INM) but ANCON **must** be used when it is currently in use at the airport for other purposes (DTLR, 2002 - footnote 23).

4.7 Terrain adjustments **should** be included in the calculation process (i.e. the height of the air routes relative to the ground are accounted for). These corrections are limited to geometrical corrections for aircraft-receiver distances and elevation angles. It is not necessary to include consideration of other more complex effects, such as lateral attenuation from uneven ground surfaces and noise screening or reflections from topographical features or buildings.

4.8 Contours **must** be portrayed from 57 dBA $L_{eq, 16 \text{ hours}}$ at 3 dB intervals. DfT policy is that 57 dBA $L_{eq, 16 \text{ hours}}$ represents the onset of significant community annoyance. Change sponsors **may** include the 54 dBA $L_{eq, 16 \text{ hours}}$ contour as a sensitivity analysis but this level has no particular relevance in policy making. Contours **should not** be produced at levels below 54 dBA $L_{eq, 16 \text{ hours}}$ because this corresponds to generally low disturbance to most people, and indeed aircraft noise modelling at such levels is unlikely to generate accurate and reliable results.

4.9 A table **should** be produced showing the following data for each contour 3 dB contour interval:

- i. area (km^2); and
- ii. population (thousands) – rounded to the nearest hundred.

It is sometimes useful to include the number of households within each contour, especially if issues of mitigation and compensation are relevant:

- i. This table **should** show cumulative totals for areas/populations/households. For example, the population for 57 dBA will include residents living in all higher contours.
- ii. The source and date of population data used **should** be noted adjacent to the table. Population data **should** be based on the 2001 census as a minimum but more recent updated population data is preferred.
- iii. The areas calculated **should** be cumulative and specify total area within each contour including that within the airport perimeter.

- iv. Where change sponsors wish to exclude parts of the area within contours, for example, excluding the portion of a contour falling over sea – this **may** be shown additionally and separately from the main table of data.
- v. Change sponsors **may** include a count of the number of schools, hospitals and other special buildings within the noise exposure contours.

4.10 Contours for assessment **should** be provided to DAP in the following formats:

- i. Electronic files in the form of a comma delimited ASCII text file containing three fields as an ordered set (i.e. coordinates should be in the order that describes the closed curve) defining the contours in Ordnance Survey National Grid in metres;

Field	Field Name	Units
1	Level	dB
2	Easting	six figure easting OS national grid reference (metres)
3	Northing	six figure northing OS national grid reference (metres)

- ii. paper version overlaid on a good quality 1:50 000 Ordnance Survey map. However, it **may** be more appropriate to present contours on 1:25 000 or 1:10:000 Ordnance Survey maps.

Contours for a general audience **may** be provided overlaid on a more convenient map (e.g. an ordinary road map with a more suitable scale for publication in documents). The underlying map and contours **should** be sufficiently clear for an affected resident to be able to identify the extent of the contours in relation to their home and other geographical features. Hence, the underlying map **must** show key geographical features, e.g. street, rail lines and rivers.

Sound Exposure Level (SEL) Footprints

- 4.11 SEL footprints show the extent of noise energy generated from a single aircraft event, for example, an aircraft either taking off or landing (in contrast to the summing of events in noise exposure). This footprint shows a contour of equal SEL values. Thus, a 90 dBA SEL footprint shows the area in which SEL values are greater than 90 dBA. These footprints are useful in evaluating options by identifying the relative contribution of different aircraft types, routes and operating procedures on the total noise impact.
- 4.12 Footprints are particularly useful in portraying the impact of aircraft movements at night on sleep disturbance. Research has shown that residents tend to be awoken by the noise levels in a single noise event, as measured by SEL, rather than by an aggregation of noise events, as measured by L_{eq} (DoT, 1992). One of the key findings of this research is that outdoor aircraft noise events below 90 dBA SEL, the average person's sleep disturbance is unlikely to be disturbed. At higher levels, between 90 and 100 dBA SEL, the chance of an average person being awoken by that aircraft noise event was found to be about 1 in 75. Thus, it is possible to calculate the approximate number of awakenings by combining knowledge of the population count within 90 dBA SEL footprints, the number of movements of different aircraft types and the probability of being awoken.
- 4.13 SEL footprints **must** be used when the proposed airspace includes changes to the number and/or distribution of flights at night below 7,000 feet agl **and** within 25 km of a runway. Night is defined here as the period between 2300 and 0700 local time. If the noisiest and most frequent night operations are different, then footprints **should**

be calculated for both of them. A separate footprint for each of these types **should** be calculated for each arrival and departure route. SEL footprints **may** be used when the airspace change is relevant to daytime only operations. If SEL footprints are provided, they **should** be calculated at both 90 dBA SEL and 80 dBA SEL.

4.14 Footprints for assessment **should** be provided to DAP in the following formats: Contours for assessment **should** be provided to DAP in the following formats:

- i. Electronic files in the form of a comma delimited ASCII text file containing three fields as an ordered set (i.e. coordinates should be in the order that describes the closed curve) defining the footprints in Ordnance Survey National Grid in metres;

Field	Field Name	Units
1	Level	dB
2	Easting	six figure easting OS national grid reference (metres)
3	Northing	six figure northing OS national grid reference (metres)

- ii. paper version overlaid on a good quality 1:50 000 Ordnance Survey map. However, it **may** be more appropriate to present footprints on 1:25 000 or 1:10:000 Ordnance Survey maps.

As with contours, footprints for a general audience **may** be provided overlaid on a more convenient map (e.g. an ordinary road map with a more suitable scale for publication in documents). The underlying map and footprints **should** be sufficiently clear for an affected resident to identify the extent of the footprints in relation to their home or other geographical features. Hence, this underlying map **must** show key geographical features, e.g. streets, rail lines and rivers. Calculations **should** include terrain adjustments as described in the section on L_{eq} contours.

4.15 It should be noted that a footprint is employed in assessing a single noise event: a contour is for noise exposure from many noise events.

Number of ‘Highly Annoyed’ People

4.16 It is possible to calculate the numbers of people who would be ‘highly annoyed’ by particular levels of aircraft noise exposure by using L_{eq} contours and a well established response relationship known as the Schultz curve (Schultz, 1978). The Schultz curve is S-shaped in form and shows aircraft noise level on the horizontal axis and the percentage of highly annoyed people as described by social survey on the vertical axis. It shows that the incidence of highly annoyed people is low at low levels of aircraft noise and the curve is relatively flat at these levels. At progressively higher noise levels, the proportion of highly annoyed grows steadily, so the slope of the curve increases. At higher levels of aircraft noise the curve begins to flatten, until at very high levels of aircraft noise the curve is nearly flat at 100% i.e. at these levels, everyone is said to be highly annoyed by aircraft noise.

4.17 The Schultz curve is well supported by scientific research (Fidell, 2003). A suitable equation to calculate the proportion described as highly annoyed people is:

$$\% \text{ Highly Annoyed} = \frac{100}{1 + e^{(13.2 - 0.19L_{eq,16hours})}}$$

This expression provides an estimate of the percentage of highly annoyed people as a function of aircraft noise measured in dBA $L_{eq, 16 \text{ hours}}$. For the mid points of 3dB intervals from 54 dBA $L_{eq, 16 \text{ hours}}$ to 75 dBA $L_{eq, 16 \text{ hours}}$ the results from the expression are shown in Table 3.

Table 3 – Percentage Highly Annoyed People as a function of $L_{eq, 16 \text{ hours}}$

Mid points of L_{eq} 3 dB intervals	% Highly Annoyed
55.5	6.6
58.5	11.1
61.5	18.0
64.5	28.0
67.5	40.7
70.5	54.9
73.2	68.2

The calculation of the total number people said to be highly annoyed is achieved by multiplying the number of people within each 3 dB contour band and the appropriate percentage in Table 3 then summing the totals over all contour bands.

- 4.18 An advantage of this methodology is that it is possible to take into account areas outside the standard 57 dBA L_{eq} contour but also in the 54 - 57 dBA $L_{eq, 16 \text{ hrs}}$ where the percentage of highly annoyed people will be small but the number of those people might be significant. But note that this method considers all highly annoyed individuals as equivalent, even when they may be getting very different levels of noise exposure. Thus, it equates an 'average' person at high L_{eq} value with a 'sensitive' person at a low L_{eq} value.
- 4.19 Change sponsors **may** use the percentage highly annoyed measure in the assessment of options in terminal airspace to supplement L_{eq} . If they choose to use this method, then the guidance on population data for noise exposure contours set out above **should** be followed. Change sponsors **should** use the above expression and associated results in Table 3 in calculating the number of those highly annoyed. If they wish to use a variant method, then this would need to be supported by appropriate research references.

L_{DEN} contours

- 4.20 European Directive 2002/49/EC relating to the assessment and management of environmental noise requires the production of noise maps for airports and other transport and industrial sources at five yearly intervals beginning in 2006. This Directive requires the use of the L_{DEN} metric which measures noise on an L_{eq} basis over an annual average 24-hour period, but which applies weightings for the evening and night periods. It essentially does this by calculating L_{eq} for evening and night operations as if those noise events were 5 dB and 10 dB noisier than actually measured.
- 4.21 Change sponsors **may** use the L_{DEN} metric but, if they choose to do so, they **must** still produce the standard $L_{eq, 16 \text{ hrs}}$ contours as previously described. L_{DEN} contours will generally be larger than the standard $L_{eq, 16 \text{ hrs}}$ contours, and hence contain a higher population/household count. There are two main reasons for this. First, the evening and night weightings will cause higher modelled noise levels than actually observed. Second, the outer contours are set at 55 dBA L_{DEN} rather than 57 dBA L_{eq} .

- 4.22 As people become familiar with the application of L_{DEN} contours following publication of the 2006 contours in June 2007, it is possible that change sponsors will be expected to produce L_{DEN} contours in circumstances where it is appropriate to produce L_{eq} contours. However, it **should** be noted that L_{DEN} is supplementary to $L_{eq, 16 \text{ hours}}$ and not a replacement for it.
- 4.23 If change sponsors wish to use the L_{DEN} metric they **must** do so in a way that is compliant with the technical aspects of the Directive and any supplementary instructions issued by DEFRA. Change sponsors **should** note the requirement for noise levels to be calculated as received at 4 metres above ground level. In particular, the guidance on how contours are to be portrayed, as described in the section dealing with L_{eq} contours applies. Calculations **should** include terrain adjustments as described in the section on L_{eq} contours.
- 4.24 An exception regarding L_{DEN} contours is the production of a table showing numerical data on area, population and households which **should** be presented by band (e.g. 55 dBA to 60 dBA) rather than cumulatively as for UK L_{eq} contours (e.g. >55 dBA). This is a Directive requirement. It means that, for example if the total number of people exposed to a given level of noise or higher is required then the reader has to add the data for that band to all higher bands to form a cumulative total. There is potential for confusion between the application of long standing current practice with L_{eq} contours and implementation of the Directive requirements. Change sponsors **should** make it clear where areas/counts are by band or cumulative.
- 4.25 The CAA conducted a study into the production of L_{DEN} contours for DEFRA. Change sponsors considering the application of L_{DEN} contours are advised to consult the study report (CAA, 2004).
 L_{Night}
- 4.26 European Directive 2002/49/EC also requires the production of L_{Night} contours. The principles outlined for the production of L_{DEN} contours are applicable to the production of L_{Night} contours. Although the European Commission intends that L_{Night} contours are to be used for the assessment of sleep disturbance, there is little scientific evidence on the relationship between the amount of noise exposure, as measured by L_{Night} , and the degree of sleep disturbance. The CAA and DfT, therefore, place more reliance on the use of SEL footprints, which are an indicator of awakenings from sleep.
- 4.27 Change sponsors **may** use the L_{Night} metric within their environmental assessment and consultation. If they do so, SEL footprints **must** also be produced. Calculations **should** include terrain adjustments as described in the section on L_{eq} contours.

Difference contours

- 4.28 Indicators such as those described so far are important in measuring and portraying the total noise impact, but can be complemented by showing how an airspace change redistributes noise burdens. In effect, other indicators can be used to show the changes in noise exposure over an area.
- 4.29 One way of portraying changes in noise exposure is the difference contour. These contours show the relative increase or decrease in noise exposure, typically in L_{eq} , on a base scenario, which is normally chosen to be the current situation. The increases/decreases are shown in bands:

- Increase/decrease (\pm) of 1 - 2 dB;
- \pm 2 - 3 dB;
- \pm 3 - 6 dB;
- \pm 6 - 9 dB; and
- \pm > 9dB.

Because the contours show increases and decreases, some form of colour shading is required to show whether a particular area will experience an increase or decrease in noise exposure. It is recommended that red is used for increases in noise exposure and blue is used for decreases in noise exposure.

- 4.30 Population/household counts can be used to compare the numbers of people that may experience increased noise exposure with those who will gain from the proposal.
- 4.31 Difference contours are particularly applicable where the redistribution of noise impact is significant, e.g. revising arrival and departure routes or in adapting the mode of runway operation. Change sponsors **may** use difference contours if it is considered that redistribution of noise impact is a potentially important issue. One caveat is that where aircraft noise is relatively low, aircraft noise may well not be the dominant noise source. As such, the benefits and disbenefits shown by difference contours may or may not be realised in practice.

5 NOISE: SUPPLEMENTARY METHODS

N70 Contours

- 5.1 A common objection to L_{eq} type metrics is that they are not easy for a non-technical audience to interpret. For this reason, the Australian Department of Transport devised a set of metrics that might be more easily understood by the Australian public (Australian Department of Transport and Regional Services, 2000). Note, however, that the report describing the metrics stresses that the proposed metrics do not replace the Australian ANEF system (their version of L_{eq}). The ANEF system, like L_{eq} , was based on social survey and noise measurement work and remains the metric for use in Australian policy making. Hence, the Australian position is that these are supplementary methods. This is also the CAA's position.
- 5.2 N70 contours show the locations where the number of events exceeds 70dBA L_{max} . The level of 70 dBA L_{max} was selected because it was considered to represent the level indoors that would be likely to interfere with conversation or listening to the radio or television (approximately 60 dBA L_{max}). This allows for about 10 dB attenuation (i.e. noise reduction) through the fabric of a house with its windows open. In this instance, attenuation of 10 dB is based on typical Australian housing, much of which is pre-fabricated and pre-dominantly wooden construction. The corresponding attenuation is likely to be somewhat higher for typical UK housing. Rationale for the selection of 70 dBA is subjective in its assumptions about interference with communication and the sound insulation properties of dwellings. Typically, contours ranging from 10 events to 500 events over 70 dBA L_{max} are plotted. N80 or any other level can be selected for plotting but the level selected is largely arbitrary.
- 5.3 By showing the distribution of noise events under different circumstances, N70 contours may be used to address the common criticism that L_{eq} contours only show the impact on an average day. N70 contours could be used to demonstrate different

methods of runway usage or show how movements vary at different times of day. Unfortunately, with so much data being presented, the public may be faced with an indigestible plethora of information. Nevertheless, N70 contours are an attractive aid to the public because if the number of movements doubles, then the N70 doubles, all other things being equal. L_{eq} type metrics are logarithmic in nature, which translates to an increase by 3 dB for a doubling of traffic: less dramatic, but it does have the advantage of being representative of people's actual responses to increased traffic.

Person-Event Index (PEI)

- 5.4 A further supplementary method developed by the Australian Department of Transport and Regional Services is the Person-Event Index. The particular problem it addresses is that comparing options by counting the population within standard L_{eq} type contours to evaluate options gives little indication of the number of aircraft noise events that might be expected. The Person-Event index (PEI) combines information on single event levels with the number of aircraft movements.
- 5.5 The PEI is based upon the N70 (or similar) metric and so suffers from all the limitations of this method previously described above. The PEI attempts to measure the total noise load generated by an airport to be computed by multiplying the number of people exposed by the number of events to which they are exposed. PEI can be expressed by the mathematical expression:

$$PEI(x) = \sum_{N=N_{min}}^{N_{max}} P_N N$$

where x = the single event threshold noise level expressed in dBA L_{max} ;

P_N = the number of persons exposed to N events $> x$ dBA L_{max} ;

N_{min} = the lowest number of noise events $> x$ dBA L_{max} (a defined cut-off level); and

N_{max} = the highest number of noise events $> x$ dBA L_{max} (a defined cut-off maximum).

Change sponsors **may** use PEI as a supplementary assessment metric.

Average Individual Exposure (AIE)

- 5.6 The PEI does not indicate the extent to which aircraft noise is distributed across the exposed population. A given PEI could indicate that a small number of people are exposed to high numbers of aircraft noise events but could equally well result from a high number of people being exposed to a low number of events. The average individual exposure is an indicator of the mean number of aircraft noise events experienced over a given time period. AIE is described by the following expression:

$$AIE = \frac{PEI(x)}{\text{Total Exposed Population}}$$

where $PEI(x)$ = the person-event index for events $> x$ dBA L_{max} .

Change sponsors **may** use the AIE metric as a supplementary assessment metric. If the Change sponsor uses PEI as a supplementary metric then AIE **should** also be calculated as both metrics are complementary.

Operations Diagrams

5.7 Operations diagrams portray a representation of how the airspace is to be used. A feature of operations diagrams is that they do not use or contain any information about noise levels. This can be advantageous when it is difficult or impossible to measure aircraft noise accurately and reliably, for example, when aircraft noise levels are relatively low. It is a disadvantage when aircraft noise levels can be accurately determined. In such cases, the omission of noise information might result in a misleading presentation. For each route, a box with information about the distribution of air traffic is shown on a diagram of the airspace overlaid on a map showing recognisable geographical features. Each box includes the following information:

- average number of daily movements;
- percentage of all aircraft movements at the airport using that route;
- daily range of movements – minimum and maximum; and
- percentage of days with no movements.

Operations diagrams are typically used to show daily traffic movements but can be used to portray other time periods where air traffic varies considerably over time.

5.8 Change sponsors **should** always bear in mind that the production of a large number of operations diagrams covering every eventuality in great detail has the potential for confusion. The challenge is to present information on aircraft noise in ways that are clear and accurate, without omitting essential detail, but which can be readily understood by a non-technical audience. N70 contours, PEI, AIE and operations diagrams **should** be considered as communication tools with limited applicability in the assessment process. There is a professional balance to be struck between the amount of data produced and the degree to which this information actually helps the audience to understand the key issues. Thus, N70 contours, PEI, AIE and operations diagrams **should** be considered as supplementary communication tools.

Population count methodology

5.9 One method of portraying noise impact, which has been employed in recent airspace changes, is a simple count of the population residing or residential area beneath the proposed affected airspace. The attraction for both airspace change sponsors and residents alike is that this concept is easy to understand. The inherent problem is in the term 'affected'.

5.10 The methodological limitations of population counts and the calculation of residential areas overflowed are:

- i. The areas considered for population counts or built area calculations are largely arbitrary.
 - a. Some change sponsors define the swathe for departure routes as extending 1.5 km either side of the departure track. This arbitrary definition has been used for many years at a number of UK airports as a threshold for compliance with noise preferential routes (NPR) prior to ATC being able to vector aircraft for safety or to follow a more expeditious route. This enables airports to measure and monitor track adherence. The width of the swathe is a function of the aircraft's ability to navigate accurately along the NPR track and does not necessarily have any relationship with noise impact experienced on the ground.
 - b. For arrivals, change sponsors sometimes show broad swathes that encompass the areas likely to be over-flown by arriving aircraft. These

broad swathes necessarily include a wider area than departure swathes. This is because ATC vector aircraft to organise a stream of arrivals at the required separation distances along the final approach path to the runway. The probability of being over-flown within an arrival swathe is therefore less than that within a departure swathe because the arrival swathe will be larger.

- ii. Not all individuals within the swathe are affected to the same extent. For example, a resident living 15 nm along track from the airport with aircraft operating at 5,000 feet will experience less impact than a resident at 5 nm from the runway threshold with aircraft at 1,500 feet. However, the population count method considers both residents to be somehow equivalent.
 - iii. The population count method takes no account of the usage patterns of particular routes. Because of the prevailing wind conditions, westerly arrivals and departures at most UK airports are more prevalent. Thus, swathes for westerly operations will occur more frequently than those for easterly operations.
 - iv. Since any definition of a built up area is largely arbitrary, the identification of such areas can be inconsistent. The same considerations outlined in the previous three paragraphs would apply to the calculation of built-up areas.
- 5.11 A possible way of addressing some, but not all of these problems, is to divide the arrival/departure track into 1 km segments and then to count the population for each segment separately. This then allows some account to be taken of the varying impact on the populations affected.
- 5.12 Nevertheless, even given all these limitations the population count and built up area methods do provide an indication of the population and areas over flown. They enable an assessment of whether a proposed route structure accords with the Government policy that 'departures should be concentrated on the least practical number of routes which were designed specifically to minimise the number of people over flown' (DTLR, 2002 - paragraph 31). The warning from the above is that these are coarse tools, and so caution **should** be applied in their interpretation for environmental assessment.

6 Climate Change

- 6.1 Thousands of research papers and policy documents have been published about climate change. The main problem is that burning fossil fuels cause the surface temperature of the earth to heat up – global warming. Aviation mainly contributes to global warming because of the fuel burned by aircraft in flight. A set of important documents on the topic is: DfT (2003a, 2003b, 2003c), ICAO (2001), POST (2003) and RCEP (2001, 2002). DfT (2004) appears to be the most recent UK Government technical statement specifically concerned with aviation and global warming.
- 6.2 The problems arise because 'greenhouse' gases, including water vapour, carbon dioxide (CO₂) and methane (CH₄), absorb infrared radiation and thus trap heat near to the earth's surface. The impact of aviation on climate change is increased over that of CO₂ alone by the range of secondary emissions released and their specific effects at altitude, plus other effects e.g. contrail formation and associated cirrus clouds. The impact is measured using a concept called radiative forcing. The radiative forcing index (RFI) measures to magnitude of a potential climate change mechanism. It expresses the change in the energy balance of the earth-atmosphere system measured in watts per square metre (W.m⁻²). Positive values of radiative forcing imply warming, and negative values imply cooling. The RCEP and other

credible authorities state that the total radiative forcing due to aviation is probably some 3 times that due to aviation's carbon dioxide emissions alone. It should be noted that there is uncertainty about some of the emissions from aviation, particularly contrails and associated cirrus clouds.

6.3 DfT (2003a) states that:

'For 2000, estimates show that UK civil passenger aviation produced 30 million tonnes of CO₂, which corresponds to 18% of all UK transport CO₂ emissions and 5% of UK CO₂ emissions from all sectors.

[In] 2020 aviation might produce ... about 10 – 12 % of total UK CO₂ emissions from all sectors. For the reasons given in the section on radiative forcing ... aviation's share of total climate effects is higher than its share of CO₂ alone.'

Thus, even over 20 years, aviation is projected to increase its global warming effects markedly.

6.4 DfT state that climate change considerations most relevant to DAP involve improvements to air traffic management and associated operating procedures (DTLR, 2002 - paragraph 24). The Intergovernmental Panel on Climate Change has estimated that these measures have the potential to reduce fuel burn by 6% and 12% over the next 20 years (IPCC, 1999). More recently, the European Commissioner for Transport claimed that the Single European Sky (SES) initiative would enable reductions of emissions from aircraft by 4-6% per flight through the use of more efficient trajectories (Flight International, 22 November 2005). This aim is repeated in the EC communication proposing a regulation for the establishment of the SESAR project (European Commission, 2005).

6.5 Airspace change sponsors **must** demonstrate how the design and operation of airspace will impact on emissions. The kinds of questions that need to be answered by the change sponsor are:

- i. Are there options which reduce fuel burn in the vertical dimension, particularly when fuel burn is high e.g. initial climb?
- ii. Are there options that produce more direct routing of aircraft, so that fuel burn is minimised?
- iii. Are there arrangements that ensure that aircraft in cruise operate at their most fuel-efficient altitude, possibly with step-climbs or cruise climbs?

6.6 It **must** of course be recognised that airspace design and operation is only one element in determining the quantity of aircraft emissions. The design of aircraft and engines, growth of air traffic, capacity and load factors of aircraft, airline operating procedures and other factors will all have an influence on aircraft emissions although these factors are outside the scope of the airspace change process.

6.7 For the purposes of the assessment of airspace change proposals, it is deemed sufficient to estimate the mass of carbon dioxide emitted for different options considered. This can be calculated by multiplying the mass of kerosene burned during flight by a factor of 3.18. Determining the quantities of other emissions is considered to be too complex and scientific understanding of the impact too poor for inclusion in environmental assessment of airspace change proposals. This guidance will be reviewed as understanding of the measurement of emissions and their impact improves.

- 6.8 The mass of fuel burned and, therefore, carbon dioxide emitted can be derived from a range of aircraft performance models and simulators. An example is the EUROCONTROL Base of Aircraft Data (BADA) model (EUROCONTROL, 2004).
- 6.8 Change sponsors **should** estimate the total annual fuel burn/mass of carbon dioxide in metric tonnes emitted for the current situation, the situation immediately following the airspace change and the situation after traffic has increased under the new arrangements – typically five years after implementation. This set of scenarios needs to be discussed with the DAP case officer. Change sponsors **should** produce estimates for each airspace option considered.
- 6.9 In order to remove consideration of traffic growth *per se* from the assessment, change sponsors **should** use a metric to demonstrate the environmental efficiency of their proposal. The simplest method would be to calculate the fuel burn/carbon dioxide emissions per air transport movement (atm) through the airspace. However, this metric suffers from the limitation that every flight is considered to be the same. Better metrics are the fuel burn/carbon dioxide emissions per revenue passenger-kilometre (rpk) or available seat-kilometre (ask). Of these two, ‘emissions per available set-kilometre’ is a simpler measure as it is not dependent on forecasting the load factors of different aircraft. Freight **should** be assessed on the basis that 100 kg of freight is equivalent to 1 passenger.
- 6.10 Change sponsors **should** provide the input data for their calculations including any modelling assumptions made. They **should** state details of the aircraft performance model used including the version numbers of software employed.

7 Local Air Quality

- 7.1 Air is mainly nitrogen and oxygen, with smaller proportions of inert gases and carbon dioxide. Human activity has added other components to the atmosphere, which are less benign to people’s health and result in ‘air pollution’ or degraded ‘air quality’. This has mainly occurred through industrial processes and the burning of fossil fuels in vehicles and power plants. Aviation in combination with road traffic contributes to the total emissions of air pollutants near to airports. The most important emissions for aviation are of nitrogen dioxide (NO₂) and particulates or small particles (PM₁₀).
- 7.2 Damage to human health from air pollution can potentially be of many kinds (COMEAP, 2000):
- death within a short time to normally healthy people (highly unlikely as a consequence of aviation alone);
 - death within a short time to susceptible people (highly unlikely as a consequence of aviation alone);
 - reduced life span through cumulative pollution effects;
 - statistically reduced life span through possibility of carcinogenic effects; and
 - reduced quality of life e.g. asthma symptoms.
- 7.3 ICAO deals with the environmental effects of aviation through its Committee on Aviation Environmental Protection (CAEP). Its resolution A33-7 addresses *inter alia* the problem of limiting exhaust pollution from aircraft. ICAO has set engine certification standards in the convention on International Aviation (Annex 16 Volume

- 2). These limit the emissions of unburned hydrocarbons, NO₂, CO and smoke during the landing and take-off (LTO) cycle up to an altitude of 3,000 feet agl. The LTO cycle includes idle, taxi, take-off, climb out, descent and approach. Local air quality at ground level remains largely unaffected by aircraft emissions that take place above 3,000 feet agl because dispersion reduces concentration levels for these emissions. In 1999, ICAO mandated a further reduction of 16% in NO₂ for all aircraft jet engines certificated after December 2003 (ICAO, 2005).
- 7.4 The European Union strategy is set out in Directive 96/62/EC on ambient air quality (EC, 1996 and 2003). It defines several thresholds – limit values that should not be exceeded, target goals that will avoid impact on human health and alert thresholds where a breach of the threshold requires some action. This strategy subsequently generated further Directives which specified the levels appropriate for different pollutants. The first ‘daughter’ Directive (Directive 99/30/EC), which specifies values for NO₂ and PM₁₀, among others, is the most relevant to aviation. It is unlikely that these limit values will be approached or breached for all but the largest UK airports. The recent EC ‘thematic strategy’ (EC, 2005) does not significantly affect these criteria.
- 7.5 Since 1997, local government is required to review and assess air quality in its geographical area. The aim of such reviews is to ensure that the national air quality objectives, which are based on European legislation, will be achieved. If a local authority finds any places where the objectives are not likely to be achieved, it **must** declare an Air Quality Management Area (AQMA). The extent of declared AQMA can be ascertained from local authorities, which are obliged to publish this information. Government policy on air quality AQMAs is set out in substantial documents (DEFRA, 2000 and 2003).
- 7.6 There are two models in widespread use for local air quality modelling – the US FAA Emissions and Dispersion Modelling system (EDMS) (FAA, 2000) and the Atmospheric Dispersion Modelling System (ADMS) produced by Cambridge Environmental Research Consultants Ltd.
- 7.7 Change sponsors **must** produce information on local air quality only where the airspace change affects traffic below 3,000 ft agl and the airspace is above an AQMA. In these cases, change sponsors **should** produce concentration contours for nitrogen dioxide or particulates as appropriate. Concentrations **should** be portrayed in microgrammes per cubic metre (µg.m⁻³). They **should** include concentrations from all sources whether related to aviation and the airport or not. Three sets of concentration contours **should** be produced:
- i. current situation – these may already be available as part of the airport’s regular environmental reporting or as part of the airport master plan.
 - ii. situation immediately following the airspace change.
 - iii. situation after traffic has increased under the new arrangements – typically five years after implementation although this **should** be discussed with the DAP case officer.
- 7.8 Contours for assessment **should** be provided to DAP in similar formats to those used for noise exposure contours. Where change sponsors are required to produce concentration contours they **should** also produce a table showing the following data for concentrations at 10 µ.m⁻³ intervals:
- area (km²); and
 - population (thousands) – rounded to the nearest hundred.

The source and date of population data used **should** be noted adjacent to the table. Population data **should** be based on the 2001 census as a minimum but more recent updated population data is preferred.

8 Tranquillity and Visual Intrusion

- 8.1 Tranquillity can be defined as 'a state of calm or quietude'. Guidance to the CAA (DTLR, 2002 - paragraph 46) the Government requires DAP to 'pursue policies that will help to preserve the tranquillity where this does not increase significantly the environmental burdens on congested areas'. This guidance takes into account the relevant parts of the Rural White Paper (DETR, 2000) which states that the countryside has a unique character which includes less tangible features such as tranquillity and lack of noise. The white paper goes on to state that protecting the countryside from further intrusion of noise is not a luxury.
- 8.2 It should also be noted that Areas of Outstanding Natural Beauty (AONB) and national parks are afforded certain statutory protection. However, this does not extend to precluding overflight by aircraft.
- 8.3 The measurement of tranquillity is not well developed. There is no universally accepted metric by which tranquillity can be measured, although several interesting ideas have been suggested. For example, a recently published study has produced a tranquillity map of a national park (CPRE, 2005). However, it is not obvious how such a methodology could be reliably adapted for aircraft noise. There is very little published material on the subject of visual intrusion with respect to aircraft. There is some literature on the subject of visual intrusion related to wind farms but there is not an obvious way of applying this method to aircraft.
- 8.4 DAP will maintain a careful watch on research and ideas about the definition and measurement of tranquillity and visual intrusion. No formal guidance can be issued at present. Change sponsors **may** use the techniques described under operations diagrams to communicate to consultees how the airspace will be used. Assessment by DAP of these aspects will be on a case-by-case basis until methodologies are well established.

9 Economic valuation of environmental impact

- 9.1 Change sponsors **may** wish to conduct an economic appraisal of the environmental impact of the airspace change, assessing the economic benefits generated by the change. This **should** be conducted following the guidance from HM Treasury in the Green Book (HM Treasury, 2003). The Green Book contains specific guidance on the subject of the valuation of environmental impact including climate change, noise and local air quality. It discusses a number of techniques used in financial appraisal.

Calculation of Net Present Value (NPV)

- 9.2 Net Present Value (NPV) is well established technique used in financial appraisal, which focuses on the positive and negative cash flows generated by a change. Projects would normally be accepted as worthwhile if the NPV is positive. In the present context the benefits would be economic gains and the costs might include estimates of some environmental costs, to the extent that estimation of these is possible. The technique is the subject of a number of technical and philosophical criticisms when used for environmental assessment. Business and economics textbooks cover NPV in detail (e.g. Brealey and Myers, 2003). There are several reviews of environmental assessment in relation to aviation (e.g. Dings et al, 2002).
- 9.3 If change sponsors include a calculation of NPV then they **must** show financial discount rates, cash flows and their timings and any other assumptions employed. The discount rate **must** include that recommended in the Green Book currently set at 3.5%. Additionally, other discount rates **may** be used in a sensitivity analysis or because they are representative of realistic commercial considerations. The reader is referred to a standard textbook on this subject for further details (Brealey and Myers, 2003).
- 9.4 The benefits and costs of environmental impact are typically difficult to value because there is no overt market for such things and, therefore, costs cannot be readily ascertained. Two categories of techniques are available – revealed and stated preference. Both techniques have limitations.
- 9.5 *Revealed preference techniques* are used to observe real world financial transactions and from these deduce the underlying value of environmental impact. A typical revealed preference technique relevant to the valuation of aircraft noise is the use of property values and characteristics to estimate a value for noise. This technique is known as hedonic pricing and is comparatively well established with many studies providing estimates for the value of aircraft noise (e.g. Nelson, 2004).
- 9.6 *Stated preference techniques* involve asking respondents for their preferences in order to extract a value for environmental impact from their responses (Schipper, 2004). These techniques have the advantage of collecting data that is not available in the real world. For example, attributes and costs of an option that does not currently exist **may** be presented to a respondent and the environmental costs of the postulated option can be derived from their responses.
- 9.7 If change sponsors wish to use either of these techniques, they **should** seek specialist advice from environmental economists with expertise in assessing aircraft noise.

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APPENDIX A – NOISE MEASUREMENT

Sound

- A.1 Sound is energy propagating through the air by the mechanism of the wave motion of its particles. It causes small fluctuations in air pressure, which are detected by the ear or other receiving instrument such as a noise monitor. The audible quality and quantity of the sound depends upon the amplitude and frequency of these fluctuations. Most sounds consist of a mix of different frequencies. Frequency refers to the number of vibrations per second of the wave motion and is measured in Hertz (Hz). ‘Noise’ is generally used to denote unwanted sound.

Sound power and intensity

- A.2 The strength of a noise source is usually quantified in decibels – abbreviated as dB. Sound quantities described in decibels are referred to as sound levels. Decibels are used because sound powers and intensities cover a wide range of values. Using the decibel, which is a logarithmic unit, avoids the problems caused by having to manipulate numbers with many digits. Decibels relate one quantity to another. In effect, they are ratio measures. In sound measurement, the reference level is taken to be the threshold of human audibility – this is 20 μPa (micro Pascals) or 2×10^{-5} Pascals (where one Pascal equals 1 Newton per square metre). Decibels are subject to the usual rules applying to the manipulation of logarithms. This means that increasing the sound energy by a factor of k , i.e. k times as much, increases the dB value by $10 \log_{10} k$. Thus, doubling the sound energy results in an increase of 3 dB. Similarly, halving the sound energy results in a decrease of 3 dB.

Loudness and Intensity

- A.3 The extent of the unacceptability of sound depends at least on three physical characteristics:
- intensity;
 - duration; and
 - frequency.
- A.4 Intensity is the rate of flow of sound energy through a unit area normal to the direction of propagation. It is a physical quantity measured in Watts per square metre. (W.m^{-2}). Loudness is the perceived or subjective magnitude of sound. Other things being equal, the approximate relationship between intensity and loudness is that a tenfold change in intensity produces a twofold change in loudness. It must be stressed that this is an approximate relationship; it varies between individuals and with the characteristics of the sound. It is not the same as the relationship between sound energy and sound level. Loudness is a subjective measure, which is not easy to measure.

Noise measurement scales

- A.4 Noise is inherently complex. A number of different noise measurement scales have been devised. Each of them captures some, but not all, of the different aspects of this complexity.

A-weighted sound level - L_A

- A.5 Frequency affects how sound is perceived. The normal human ear responds to sound over a wide range of frequencies but with different sensitivities. A variety of frequency weightings have been developed to match these response characteristics – the most common being A-weighting. This broadly matches the frequency response of the human ear. It is widely used for the measurement of noise from all modes of transport. Decibel levels measured on this scale, abbreviated as L_A , are written as dB(A) or dBA. References to sound levels within this document imply the use of A-weighting unless stated otherwise.

Maximum sound level – L_{max}

- A.6 The simplest measure of a noise event such as the over-flight of an aircraft is L_{max} , the maximum sound level recorded. It is usual to measure L_{max} using the sound level meter's slow response, which damps down the very rapid, largely random fluctuations of level.

Sound Exposure Level – SEL

- A.7 The sound exposure level (SEL) of an aircraft noise event is the sound level, in dBA, of a one second burst of steady noise that contains the same total A-weighted sound energy as the whole event. In other words, it is the dBA value that would be measured if the entire event energy were compressed into a constant sound level for one second. Mathematically, SEL is defined as:

$$SEL = 10 \log_{10} \left[\frac{1}{T_{Ref}} \int_0^T 10^{\frac{L(t)}{10}} dt \right]$$

where $T_{Ref} = 1$ second (the 'reference period');

$L(t)$ = the instantaneous sound level L at time t ; and

T = duration of the sound event in seconds.

- A.8 Most of the sound energy recorded from an aircraft is concentrated in the highest sound levels. This means that SEL values can usually be accurately estimated (to better than 0.25 dB) by including only those sounds that lie within 10 dB of L_{max} . But even this may be impractical when measuring the noise of quieter aircraft at locations where the background noise level from other sources is relatively high. To reduce this kind of background interference, it is standard practice for airport noise monitoring systems to incorporate fixed threshold levels at which measuring instruments are triggered.
- A.9 SEL increases by 3dB if the duration of a sound is doubled, because the energy is doubled (assuming the pattern of rise and fall remains the same). Because most aircraft noise events have durations significantly greater than the reference time of 1 second, their SEL values are usually numerically greater than L_{max} – typically by around 10 dB.

Perceived Noise Level – PNL

- A.10 Different types of aircraft – jets, propeller and helicopters –have distinctive noise characteristics. These arise from particular combinations of sound from different noise sources having different frequency ranges, intensities and temporal features. The annoyance characteristics from an aircraft noise event are not fully matched by simple A-weighted sound level. Researchers concluded that a more complete measure of the complex signature of aircraft noise required a special scale. This is Perceived Noise Level (PNL), measured in PNdB units.
- A.11 PNL is defined as how unwanted, objectionable, disturbing or unpleasant is the sound. Like L_A , the PNL scale allows for the sensitivity of the human ear to different frequencies but it is much more complicated to calculate. PNL is determined by a combination of measurement and mathematical calculation involving frequency analysis. Each frequency band in the spectrum is converted to its noisiness value and these are then summed in a special way to obtain the total noisiness of the sound. As originally used, a single value of PNL for an event was recorded – the instantaneous maximum value – PNL_{max} .

Effective Perceived Noise Level – EPNL

- A.12 The noise made by a passing aircraft is complicated by its motion which causes its intensity and frequency to change with time. Research into the human perception of aircraft noise led to the conclusion that PNL did not completely reflect the true noisiness of a complete aircraft noise event. The missing ingredients were the effects of tones and duration. For example, sounds that exhibit distinct whistles and whines and/or have longer durations are generally more annoying than a simple PNL measure would indicate. EPNL is a measure that takes account of both tones and duration. It is currently used for aircraft certification and night noise quota schemes.
- A.13 EPNL measurements for certification purposes are taken under very specific circumstances, which do not necessarily reflect sound levels measured on the ground from that aircraft during normal operations. Recent research has revealed that some aircraft are responsible for significantly greater noise impact than would be anticipated from certification data measured in EPNL (CAA, 2003).

Long term noise exposure and Equivalent Continuous Sound Level – L_{eq}

- A.14 The levels of individual noise events are useful for many purposes including aircraft certification. However, in order to assess environmental noise exposure, it is necessary to consider and take into account the impact of many events over longer periods – days, months, years – living near an airport. These events will generally differ in magnitude; there will be different numbers in each hour or day; and they will occur at different times of day. Most indices for these assessments are L_{eq} – based.
- A.15 Equivalent continuous sound level or L_{eq} is defined as the level of hypothetical steady sound which, over the measurement period, would contain the same (frequency-weighted) sound energy as the actual variable sound. L_{eq} can be measured over any scale in practice, but L_A is the most widely used. The corresponding L_{eq} is sometimes abbreviated L_{Aeq} .
- A.16 L_{eq} can be measured or calculated in several ways. Thus, the total noise energy can be measured if the sound meter runs continuously during the measurement period,

and is then converted into L_{eq} . If the requirement is to monitor the contribution of aircraft noise only to the total, the meter can be programmed to operate when aircraft noise only is contributing the overall sound level.

- A.17 When noise comprises a sequence of discrete events, as with aircraft noise, L_{eq} can be expressed in terms of the number of events that occur during the measurement period and their average sound exposure level (SEL) using the following equation:

$$L_{eq} = \overline{SEL} + 10 \log_{10} N - 10 \log_{10} T$$

$$\text{where } \overline{SEL} = 10 \log_{10} \left[\frac{1}{N} \sum_{i=1}^N 10^{\frac{SEL_i}{10}} \right]$$

\overline{SEL} = logarithmic average of individual noise events with sound exposure level SEL_i ;

N = number of aircraft noise events;

SEL_i = the sound exposure level of the i^{th} event; and

T = measurement period in seconds.

- A.18 The above equation is particularly useful because it quantifies the relative contributions of the noise levels and number of events to the total noise exposure, embodies the equal energy principle.

- A.19 For a continuously varying sound levels, where it is not possible to employ the discrete formula for L_{eq} , a more rigorous mathematical description is shown by this formula:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T} \int_0^T 10^{\frac{L(t)}{10}} dt \right]$$

where $L(t)$ = the instantaneous sound level L at time t ; and

T = duration of the sound event in seconds.

This expression is the one used in noise monitors and models for the calculation of L_{eq} .

L_{DEN}

- A.20 The day-evening-night level L_{DEN} is a variant of L_{eq} . It essentially adds an extra artificial number of decibels to aircraft noise levels occurring in the evening and at night. These weightings are 5 dB and 10 dB for the evening and night periods respectively. It has three component parts – L_{Day} measured over a 12 hour day time period from 0700 to 1900 (the same as L_{eq} for that period), $L_{Evening}$ measured over a 4 hour evening period from 1900 to 2300 and L_{Night} measured over an 8 hour night period from 2300 to 0700 (all times local). Mathematically, L_{DEN} is defined by:

$$L_{DEN} = 10 \log_{10} \frac{1}{24} \left(12 * 10^{\frac{L_{Day}}{10}} + 4 * 10^{\frac{L_{Evening} + 5}{10}} + 8 * 10^{\frac{L_{Night} + 10}{10}} \right)$$

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APPENDIX B – NOISE MODELLING

Levels, footprints and contours

- B.1 Event levels such as L_{max} or SEL describe the noise of individual aircraft flights observed at particular points. To describe the noise impact over an area, footprints and contours are used. These are lines on a map or diagram joining points with the same value of the noise metric. The area inside this line shows all places where the noise impact is equal or greater than some value. A footprint is for single events; a contour is for noise exposure from many events.
- B.2 Footprints are used to compare the noise characteristics of different aircraft. They help to illustrate the effects of different operating procedures. Thus, they show how these modify footprint shapes and areas. They are also helpful in depicting the relative contributions of different aircraft types to noise exposure.
- B.3 Long-term noise exposure is usually measured by an index, such as equivalent continuous sound level or L_{eq} , spanning a suitable period of time (such as an average day or night). The extent of total noise exposure is illustrated by noise exposure contours. Contours, lines of equal L_{eq} , are effectively aggregations of SEL noise footprints of all the individual aircraft movements. Contours help to quantify the extent of aircraft noise exposure. As a start, they serve to illustrate its geographical distribution. The total impact is normally summarised in terms of the areas and numbers of people/households enclosed by the contours. Contours can be used to compare situations at different times, different places and under different circumstances.
- B.4 Event levels, footprints and contours are relatively simple concepts. But, their determination is complicated. They are subject to both measurement and statistical uncertainty. The areas of both contours and footprints are very sensitive to changes in noise emissions. Typically, the total area increases by approximately 20% for a 1 dB increase in average source levels

Noise monitoring

- B.5 For particular points, noise event levels and exposure levels can readily be measured using sound level meters. These meters may be portable, used for research studies, or fixed, used by airport operators. Modern noise monitors are robust and reliable. They function for long periods, in most weather conditions, with minimal attention -they are also increasingly sophisticated, and so, can be linked together to form noise monitoring systems. They can be further enhanced with radar data to provide noise and track keeping systems such as those installed at major airports.
- B.6 The analysis and interpretation of noise measurements is complicated by inherent variability. A particular aircraft type result can produce a wide range of noise levels at any particular point on the ground. This occurs, even when, the aircraft's ground tracks are very similar. The principal causes are differences in aircraft weights, flight operating procedures and atmospheric conditions. The weather affects the performance of aircraft, especially their climb rates. This is especially important for departures. The climb rate affects the distance the sound travels through the air. The meteorological conditions also affect the way in which sound propagates between aircraft and the ground. Atmospheric variation - of wind speed,

temperature, humidity and turbulence – can itself cause significant differences in event levels. These can be up to 10 dB or more. Noise data **must** therefore be expressed in statistical terms, as averages – which are susceptible to a degree of uncertainty.

- B.7 A further complication for the automated monitoring of aircraft noise is how to distinguish the noise of aircraft from background noise. This is mainly from road vehicles and other human activity. This is an increasingly difficult problem. Levels of aircraft noise generally continue to diminish in relation to noise from other sources. Thus, accurate aircraft noise exposure level estimation requires considerable scrutiny of environmental data. This is essential to ensure both reliable identification of aircraft events and exclusion of non-aircraft sources of noise.
- B.8 Noise exposure patterns around airports are normally determined, in large part, by computer modelling. The methods used need to be theoretically sound. But, they **must** incorporate real measured data on aircraft performance and noise characteristics. To ensure public confidence, the results of this modelling **must** be regularly validated. Hence, there **must** be regular checking through exposure measurement programmes.

Noise modelling

- B.9 The requirements to determine noise exposure levels have led to the development of various aircraft noise exposure models. These are computer programs that calculate noise contours as functions of information describing the aircraft traffic and the way in which aircraft are operated.
- B.10 Modelling means calculating noise exposure rather than measuring it. Calculating some aircraft noise characteristics from purely theoretical scientific principles is feasible, but it would be far too complex and computationally intensive for application in the production of noise contours. Instead, relatively simple mathematical tools combined with data about the generation and propagation of aircraft noise from a large body of measured data are used. The first step is to gather a large body of representative measured noise data for a range of aircraft types under different flight conditions. The next step is to create robust mathematical tools to estimate how noise will propagate from these noise sources. Modelling aircraft noise involves combining the noise from many individual aircraft movements. All the different types of aircraft and operations have to be taken fully into account. This includes their specific noise and performance characteristics, following different flight paths during both arrivals and departures. It is essential to have reliable ways of estimating how sound attenuates with distance along the propagation path.
- B.11 Models must sum the diverse sound energy inputs from the individual events over a time period that is sufficiently long. That is, usually months rather than days. This ensures that the results are statistically reliable enough to identify differences between one situation and another. Most models calculate noise exposure levels over an array of grid points around the airports. Contours are then fitted to these point levels by mathematical interpolation.
- B.12 These models need input information on aircraft performance and noise characteristics. Direct measurements of noise and flight paths are made. An important source of data is that collected by manufacturers as part of the certification process. Sufficient data are required to allow the model to represent all operations of importance. The data on aircraft flight paths must adequately represent actual operational air traffic patterns. This includes the way aircraft adhere to Noise Preferential Routes (NPRs) and Standard Instrument Departures (SIDs). But it must

also cover the way that traffic is dispersed by air traffic control intervention (known as radar vectoring) and is sequenced on arrival.

Noise-Power-Distance (NPD) curves

B.13 Noise-power-distance (NPD) curves are vital to noise modelling. These show the relationship between noise received on the ground as a function of distance from the sound source and engine power settings. NPD curves account for both noise emissions as well as atmospheric sound propagation effects. Different curves represent different specific power setting applied to the aircraft engines as illustrated in Figure B1. Producing a set of NPD curves for a specific aircraft/engine configuration requires very detailed analysis of large volumes of data. Assembling an adequate family of NPD curves is a very slow and painstaking process.

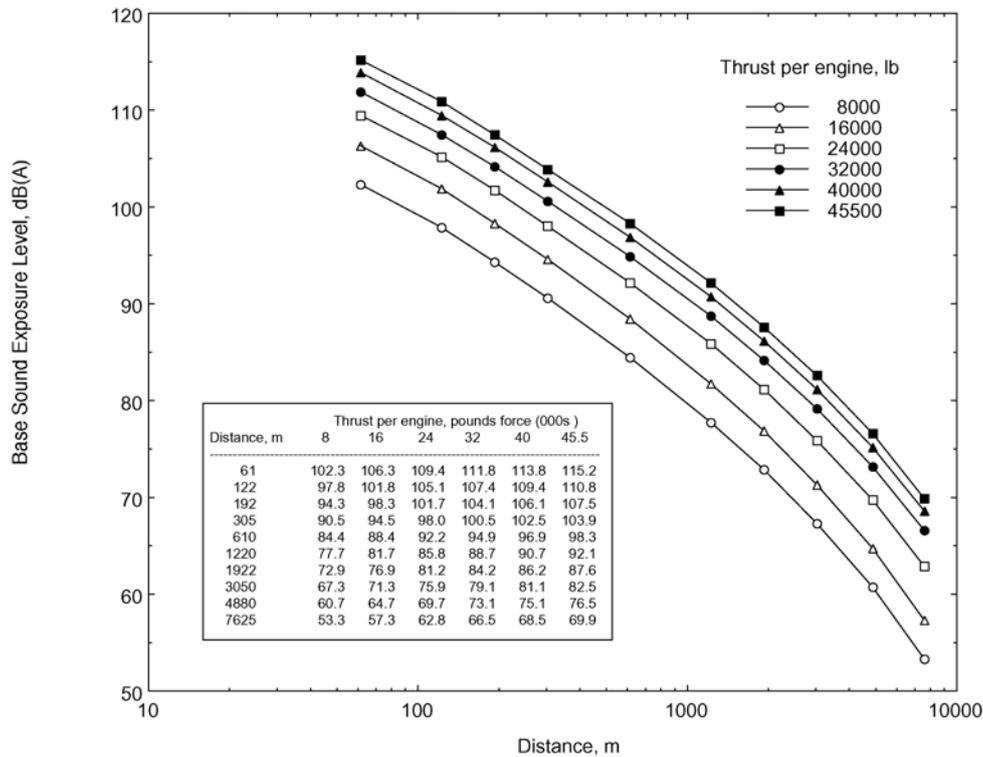


Figure B1 – Sample Noise-Power-Distance (NPD) curves (CAA, 1986)

UK Noise Modelling – ANCON 2

B.14 A full technical description of the aircraft noise exposure model used by the CAA is contained in DORA Report 9120 - The CAA Aircraft Noise Contour Model: ANCON1 (CAA, 1992), updated by R&D Report 9842 – The UK Civil Aircraft Noise Model ANCON – Improvements in Version 2 (CAA, 1998).

B.15 The CAA produces noise exposure contours each year for Heathrow, Gatwick and Stansted on behalf of DfT. The CAA also produce forecast noise exposure contours, in particular for the new runway/airport options considered in the Government consultation that led to its recent White Paper on the Future of Air Transport (DfT, 2003).

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APPENDIX C – EFFECTS OF NOISE

C.1 The two previous appendices have largely been concerned with well-specified technical issues concerning noise. The effects of noise, particularly aircraft noise, have straightforward technical aspects, but also raise much more complex issues about human response. This appendix is no more than a survey of some of the more important effects. The aim is to highlight, with a few paragraphs on each topic, some of the important issues. Appendices A and B are essential precursors to the more research-orientated material in this Appendix.

C.2 The paragraphs in the following text are grouped under a series of main and sub-headings:

- General Background
- Cause-effect Relationships
 - Noise induced hearing loss
 - Detection and distraction
 - Interference with communication
 - Impairment of task performance
- Annoyance
 - Annoyance as an indicator of aircraft noise community impact
 - Attributes of a noise index
 - Relationship between noise exposure and community annoyance
 - Aircraft Noise Index Study (ANIS)
 - Attitudes to noise from aviation sources in England (ANASE)
 - Recent Continental European studies
- Sleep Disturbance
 - Aircraft Noise and Sleep Disturbance Field Study
- WHO Guidelines

General Background

C.3 Noise is defined by the World Health Organization (WHO) as unwanted sound. Physically, there is no difference between sound and noise. The difference is one of human perception and is subject to individual variability. A number of possible distinct adverse effects have been identified by WHO:

- noise-induced hearing impairment;
- interference with speech communication;
- disturbance of rest and sleep;
- psycho-physiological, mental health and performance effects;
- effects on residential behaviour and annoyance; and
- interference with intended activities.

C.3 Noise can have a variety of possible effects on individuals. Hearing loss is the most extreme but others including direct disturbance to speech and tasks as well as less specific annoyance reactions. However, to reiterate, reactions vary between

individuals. Even for a specific person, where he or she is and what activity is in progress will have an effect on how that person reacts to noise. For these reasons, community annoyance - averaged over a large group of people or the proportion showing 'high' reactions - is widely used as a way of measuring the impact of noise on populations exposed to aircraft noise.

Cause-effect relationships

- C.4 Many different effects of noise can be identified. Individuals experience each of them to different degrees. For the practical assessment of any particular effect, it is necessary to define an appropriate indicator of reaction which can then be correlated with a noise exposure measure. Although there is no standard classification of effects, it is possible to divide them into (a) *behavioural* indicators of well-being showing how noise may interfere with normal living and (b) *physiological/medical* indicators of chronic health such as (in the extreme) noise induced hearing loss or other symptoms that may be caused by noise.
- C.5 The essential conclusions from aircraft noise effects research are that community annoyance is the most useful general criterion of overall, long-term aircraft noise impact, and that it can be correlated with long-term average noise exposure.

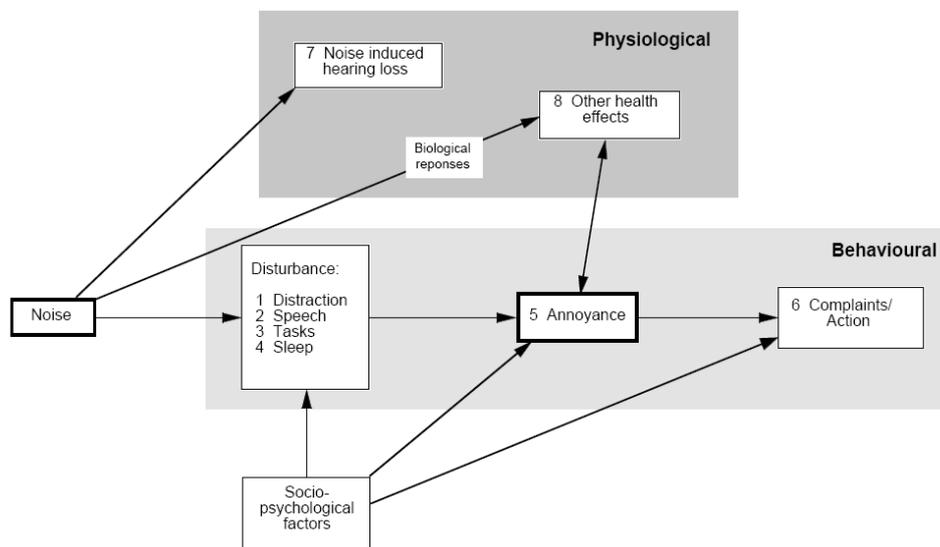


Figure C1 – Noise – Cause and Effect relationships

- C.6 At the primary level of behavioural reaction, noise disturbs human activities – by causing distraction or physically interfering with them. Four effects can be grouped together under the general heading of *disturbance*:
- (1) detection/distraction,
 - (2) speech interference,
 - (3) disruption of work/mental activity; and
 - (4) sleep disturbance.
- C.7 At the secondary level of behavioural reaction which can be viewed as an indirect or cumulative response to disturbance of different kinds is:
- (5) annoyance.
- C.8 A third level response would be:
- (6) overt reaction including the act of complaining.

- C.9 There are two principal physiological effects are:
- (7) noise induced hearing loss (although this is not likely to be caused by the noise of aircraft at locations that are beyond airport boundaries); and
 - (8) stress and other health effects.
- C.10 Noise induced hearing loss is a widely recognised and well-documented industrial problem. The nature of stress and health effects is much more complex. It is known that noise can cause a variety of biological reflexes and responses, which are referred to as stress reactions but it is unclear whether these could lead to clinically recognisable disease following a period of exposure.
- C.11 Some effects have been measured objectively and quantitatively, and correlate with noise exposure indicators. These include speech disturbance and noise induced levels of hearing loss. However, some behavioural indicators, including annoyance, are essentially subjective. Although quantifiable, people's responses are very sensitive to non-acoustic socio-psychological factors such as location, activity, state of well-being, familiarity with the noise, environmental expectations, and attitudes to noise makers. The effects of such modifying factors can dramatically weaken correlations between noise and response indicators by masking or confounding their dependency on noise. Such relationships are further obscured by variations in the actual noise exposure over time and space, because individuals move around and engage in different activities.
- C.12 Obvious physical factors governing intrusion into activities include time and situation – sleep disturbance occurs primarily at home during the night, speech interference during the day and so on. Equally important are those factors that control attitudes and sensibilities: whether or not a particular noise annoys may depend very much on the message that it conveys. Concerns about the source of noise can influence annoyance even more strongly than the physical noise exposure itself.
- C.13 Because of the combined influences of acoustical and non-acoustical factors, it is increasingly difficult to isolate the underlying noise-response relationship for the higher level responses. Thus, the probability of speech disturbance is strongly dependent on acoustical factors – the characteristics of the speech and the background noise. Whether or not this would result in annoyance depends on a set of modifying socio-psychological factors. Finally, the possibility of consequent overt reaction depends on the annoyance felt, but also on yet further modifying factors.
- C.14 The information in the research and policy literature on relationships between noise exposure and its potential adverse effects on people is of variable quality. Some proffered relationships stem from extensive research and are reasonable well corroborated and widely used: others are too fragmentary and insufficiently supported to offer reliable criteria. Practical noise assessment methodology has to be consistent with the understanding of the factors involved. Because effects on the community as a whole can only be described in broad statistical terms, noise exposures are commonly defined through long-term averages at representative locations.

Noise induced hearing loss

- C.15 Noise induced hearing loss has long been recognised as an industrial hazard. Recently, there has been increasing concern that many leisure activities such as discotheque music, noise from loudspeakers and headphones, shooting and motor sports have associated hearing risks. In combination with natural ageing effects, which reduce hearing acuity (presbycusis), damage caused by excessive noise can lead to severe impairment in later life.
- C.16 Although agreement is not universal, the assumption that cumulative damage is proportional to total noise energy emission (i.e. the summed product of intensity and time) has led to the common practice of defining workplace noise exposures in terms of average noise levels during working hours. It is generally believed that, even for working lives of up to 40 years, damage risk is negligible for $L_{eq, 8 \text{ hrs}}$ of less than 75 dBA.
- C.17 Such levels of noise exposure from aircraft are largely confined to people exposed within aerodrome boundaries who must wear protective equipment. The risks of consequent hearing damage to wider communities have not been a significant cause for concern.

Detection and distraction

- C.18 Human hearing is extremely acute: the ear and the brain can extract a great deal of information from sound, even at very low levels. Total silence is essentially a theoretical concept: in reality, some sound is always present – but background sound often remains unnoticed because it is unremarkable (in information terms) and hence of no concern. Sounds attract attention when they change or convey information, especially recognisable warnings of danger.
- C.19 For the moment, disregarding most of the perceptual complexities involved, a key question is whether a potentially offending noise is actually audible. It is only when it is sufficiently loud or intense to be detectable amid inoffensive background sound that it is likely to be audible. If an aircraft is heard, it may cause disturbance, depending on its level and the listener's activity. A loud aircraft will be detected by most people – whether or not it disturbs them. Some people may not be able to detect less noisy events: the quieter the aircraft noise events the fewer people will notice them. In general, aircraft noise will nearly always be audible if its noise level is somewhat above that of the masking background noise. If the noise contains irregularities such as whistles or thumps it may be quite audible at levels 10 dB *below* the background noise. Thus, close to aircraft flight paths near airports, where aircraft L_{max} is likely to exceed background levels by 20 dB or more, it will be highly audible. Only at very distant locations or in areas of high background noise will aircraft be inaudible.

Interference with communication

- C.20 Interference with speech communication is a common type of noise disturbance: the intelligibility of speech is impaired by masking noise. For listeners with normal hearing, the intelligibility of normal conversation is 100% in steady masking noise levels of 45 dBA or less, about 99% at 55 dBA and 95% at 65 dBA. At higher background levels intelligibility falls rapidly, reaching zero at about 75 dBA (Berglund and Lindvall, 1995). The WHO guidelines state that speech in relaxed conversation is 100% intelligible in background levels of about 35 dBA. The research reported by Stockholm University indicates that a satisfactory conversation can be conducted outdoors with a normal voice up to a distance of 2 metres under a steady masking level of 60 dBA. Voice levels obviously tend to be raised to overcome background

masking: the research indicates that satisfactory conversation with raised voice can be achieved up to 4 metres under a steady masking sound of 60 dBA.

- C.21 Indoor noise levels are governed by a variety of factors, including the size, shape and furnishings of the room, the activity inside it and the transmission of sound from adjacent areas. Inside homes, human voices, domestic appliances and entertainment systems are significant sources of noise, as can be that from road and rail traffic if there are busy roads or railway lines nearby. Outdoor sound is attenuated as it passes into the building, mainly through windows. If the windows are wide open, the attenuation is around 15 dB (i.e. noise levels heard in the room are reduced by 15 dB from the outdoor level). If windows are closed, this rises to between 20 dB and 30 dB depending on the weight of the glass, whether the glazing is single or double, and on the quality of the seals. Special windows designed to minimise the transmission of noise can increase attenuation to between 30 and 40 dB. Indoor noise levels span a very wide range, from perhaps 20 dBA inside quiet homes at night, through 40 dB to 60 dBA in homes and offices during daytime, to 70 dBA in noisier working situations and in homes with music playing.
- C.22 It must be remembered that, like most noise criteria, these reflect normal conditions. In specific situations, the degree of speech disturbance will be influenced by attention and motivation, clarity of speech, room acoustics and the listener's hearing acuity.

Impairment of task performance

- C.23 Any work that depends upon aural communication is sensitive to noise disturbance. If that communication is speech, the criteria outlined in the preceding paragraphs apply.
- C.24 A quiet environment is a frequently postulated requirement for mental concentration and creative activity. Very high levels of noise can affect a variety of tasks but the effects are complex. Intellectually simple tasks that do not involve aural communication are generally not degraded by noise, but this is less true of more challenging ones. Thus, because variations depend on the task being performed, research results cannot be expressed as generalised criteria.

Annoyance

- C.25 Noise annoyance is a feeling of resentment, displeasure, discomfort, dissatisfaction or offence, which occurs when noise interferes with thoughts, feelings or activities. There are both short-term and long-term impacts. A single noisy event may be described as annoying: equally, a resident might describe the level of ambient noise as an annoying feature of local living conditions in general. The former annoyance is related to the loudness, duration and setting of the specific event: the latter may be thought of as the consequence of repeated disturbances of various kinds.
- C.26 Annoyance can result from different causes. Some noises, like unpleasant odours, are simply disliked because of their intrinsically disagreeable character, e.g. harsh sounds imbued with high frequency tones. Others are disliked because of their consequences – noises that startle, awaken or interfere with conversation, for example. Yet again, others may simply emanate from sources that are considered unwelcome for other reasons. Thus, road traffic might be perceived to cause congestion or air pollution; people might worry that aircraft could crash on them; and commercial premises might be considered inappropriate in residential areas.
- C.27 From a noise control perspective, the cause of the annoyance is important. If it is the very existence of the noise that produces direct and immediate annoyance, then

reduction of its level might do little to diminish the adverse reaction. The same could be true if the specific type of noise source aggravates. In such cases, mere 'detectability' might be the criterion of annoyance. In contrast, if annoyance is related to intensity, so that the character of the noise itself is disagreeable or because of the severity of the resulting disturbance, then it will help matters to abate the noise.

- C.28 The capacity of a given sound to annoy depends on its physical characteristics including sound level, spectral characteristics and variations with time. These variables are characterised by onset times, durations and repetition rates. However, as already indicated, annoyance also depends on non-acoustical, cognitive factors, such as wider concerns over (personal) safety or indeed a conviction that the noise exposure could be reduced by third parties 'if they did their job properly'. Other cognitive factors are individual noise sensitivity, the degree to which the individual feels able to control the noise, whether the noise stems from a new situation or technology, or if it results from an important economic activity providing local employment.

Annoyance as an indicator of aircraft noise community impact

- C.29 Noise disturbance and short-term annoyance have been studied extensively in research laboratories. Such experiments can be performed with great accuracy and have provided a wealth of knowledge about the fundamental characteristics of human hearing and perception of sound. However, a detailed understanding of specific disturbance criteria is not particularly helpful in the assessment of the day-by-day impact of environmental noise on communities. The noise experienced by individuals depends on where they live and work and upon their lifestyles – aspects that cannot be addressed within the confines of a research laboratory. No two people experience exactly the same noise exposure patterns over a period of time; nor do they experience the same interference with their activities. Different people react differently to the same noise: some are a great deal more sensitive and others are much less sensitive than the average person. Coupled with the multiplicity of potential disturbance effects, these variations make studies in the community intrinsically more complex than laboratory work. Yet it is only in the real world that relationships between cause and long-term annoyance – arising from total long-term noise exposure from all sources – can be investigated.
- C.30 Community annoyance has been adopted as a general indicator for all of the possible impacts of environmental noise. In social surveys, individual annoyance has been measured in a variety of ways – quantifying it on simple numerical or category scales or via elaborate multi-question procedures.

Attributes of a noise index

- C.31 A noise index should be simple, practical, unambiguous, and capable of accurate measurement (using conventional, standard instrumentation). It must also be suitable for estimation by calculation from underlying source variables and robust - not over-sensitive to small changes in input variables.
- C.32 The family of A-weighted metrics is now in widespread use around the world for quantifying environmental noise for both single events and longer-term exposure. This includes L_A , L_{max} , SEL and L_{eq} – where L_A , alternatively denoted by $L_{A(t)}$, is the instantaneous level at any time (t). Of these, L_{max} and SEL describe the level of an individual noise event. Theoretically, SEL is generally preferable because it accounts for the duration of the event as well as its intensity and is the building block of L_{eq} . Many non-specialists often find the SEL concept difficult to grasp, especially because – for the same event – SEL usually exceeds L_{max} numerically. Thus, L_{max} is sometimes favoured as a metric for day-to-day noise monitoring and indeed it is

used to regulate noise limits for departing aircraft at Heathrow, Gatwick and Stansted.

- C.33 L_{eq} fully meets the requirements of an indicator of long-term environmental noise exposure. It is a simple, logical and convenient measure of average sound energy which is at least as good as any alternative index as a predictor of adverse effects and community annoyance. It takes account of the sound levels within each event, the duration of those events and the number of events. These features are explained in later sections of this Appendix.

Relationship between noise exposure and community annoyance

- C.34 The search for annoyance indices has revealed that average long-term annoyance can readily be determined. One simple way, which has many merits, is to ask social survey respondents to rate their individual annoyance on a numerical or categorical scale such as 'not at all, a little, moderately, very much). However, the individual responses are only weakly governed by the magnitude of the noise exposure. In statistical terms, only about one quarter of the inter-individual variance in annoyance can be attributed to the average level of noise exposure (however defined). This low correlation reflects the very large differences between individual reactions to the same amount of noise (due to non-acoustic factors). Uncertainty also arises because of inevitable measurement and prediction inaccuracies in the estimates of both noise exposure and annoyance.
- C.35 Researchers have tried to identify and quantify the sources of this human variation because it masks the true nature of any underlying noise effect. This research demonstrated that noise annoyance is very sensitive to people's views on: (a) the importance of the noise generating activity; and (b) the noisemakers' concerns about any nuisance they might cause. Composite annoyance predictors accounting for socio-psychological factors in addition to noise exposure have been found to account for as much as 50% of the variance in annoyance. But these are of little more practical value than 'noise-only' indices because, in most circumstances, the non-acoustical factors are themselves unknown.
- C.36 Attempts have been made to substantiate 'multi-dimensional' noise rating indices that make suitable allowance for some of the more obvious influences. Among these influences are:
- i. situational factors – environmental expectations are greater at home than at work, for example;
 - ii. time of day – probably linked to (a) but, for example, assuming noise is less tolerable by evening and night than day; and
 - iii. source of noise – it has been found that, dB for dB, people are more tolerant of railway trains than road vehicles and that aircraft can be judged as more annoying than either. (Miedema and Oudshoorn, 2001)
- C.37 There is little scientific basis for any specific adjustments or weightings: the statistical evidence is too weak. The main justification for applying them as part of the decision-making process is to address public concern that their perceived importance has not been overlooked. The precise manner of application is left to common sense and judgement. Generalised noise-annoyance relationships provide guidance to planners and policy makers but they are likely to be less reliable than the results of properly designed and executed studies.
- C.38 Some authorities have introduced weightings into L_{eq} , i.e. adjustment to L_{eq} values, to recognise the view – strong in some environmental organisations - that

sensitivities vary across the day. Belief that noise is 'less tolerable' at night than during the day is reflected in a modified version of L_{eq} , which is used in some countries for aircraft noise exposure. One measure that is widely used in the USA is known as Day-Night Level, DNL or L_{DN} . DNL includes a 10 dB night weighting. All noise events occurring during the night are artificially increased by 10 dB before the noise energy level is averaged over the full 24 hours. This means that one night flight contributes as much to DNL as do ten identical daytime flights.

- C.39 The European Commission has introduced a directive (European Commission, 2002b) that requires member states to produce noise exposure contours using a variant of L_{eq} known as L_{DEN} or DENL. This includes a 10 dB weighting for noise events at night and a 5 dB weighting for events during the evening, with special definitions for what are night and evening periods. As in the case of L_{DN} , the night weighting has the effect that one night flight contributes as much to L_{DEN} as ten identical daytime flights. The evening weighting of 5 dB has the effect that one evening flight contributes as much to L_{DEN} as just over three identical daytime events – (because $10^{5/10} = 3.162$). There is little scientific evidence supporting the use of time-of-day weightings. Indeed, UK research has indicated that there is no need for such weightings (CAA, 1985). However, one Dutch study has lent support for the inclusion of a night-time 10 dB penalty (Miedema, 2000).
- C.40 There is in general no direct relationship between $L_{eq, 16 \text{ hrs}}$ and L_{DN} or L_{DEN} . Without any aircraft noise events during the night period, L_{DN} is identical to $L_{eq, 24 \text{ hrs}}$. In the absence of night flights, $L_{eq, 16 \text{ hrs}}$ will be approximately 1.8 dB higher than L_{DN} *ceteris paribus*.

Schultz Curve

- C.41 There is now substantial acceptance by researchers and noise policy makers that L_{eq} , or simple variants of L_{eq} , are appropriate noise exposure indicators. L_{eq} is at least as good as any other noise-based indicator for predicting average noise annoyance or the likely percentage incidence of high noise annoyance. A widely quoted relationship is the Schultz curve. This curve is a graph of 'percentage highly annoyed' against noise exposure level. It was originally based on data from numerous social survey studies of public reactions to transport noise (aircraft, road and rail traffic) carried out in different countries.
- C.42 This analysis (Schultz, 1978) provided much of the evidence for two far-reaching conclusions: first, that daytime noise exposure levels less than 50 dBA L_{DN} cause little or no serious annoyance in the community; and second that 55 dBA L_{DN} might be considered as a general environmental health goal for outdoor noise levels in residential areas. The latter conclusion, in fact, assumes that transport would continue to dominate outdoor ambient noise levels in most inhabited areas. This analysis, which was updated in 1991 (Fidell *et al*, 1991), is illustrated in Figure C2. Each point in the diagram represents the response of a sample of respondents exposed to a particular level of noise. The different symbols are used to distinguish between results for aircraft noise and surface transport.

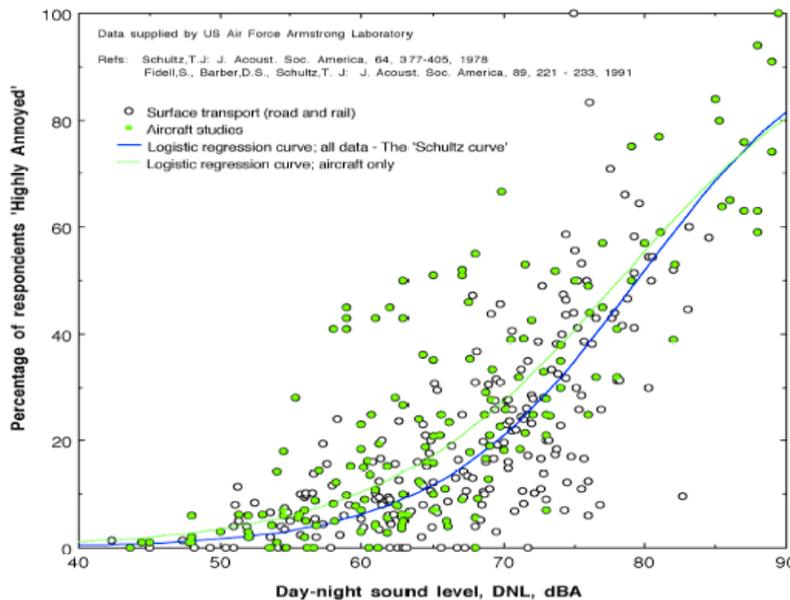


Figure C2 – Schultz curve

- C.43 The Schultz curve, which is a 'best fit' to all the data in the diagram. It is a statistical estimate of the underlying trend between annoyance and the noise exposure level, expressed as Day-Night Level, L_{dn} . It is given by the mathematical expression:

$$\% \text{ Highly Annoyed} = \frac{100}{1 + e^{(11.13 - 0.14L_{DN})}}$$

The form of the Schultz curve is a so called 'logistic regression' curve. It is used to depict an underlying trend in proportional data, i.e. where values cannot lie outside the range 0 -100%. The curve is asymptotic to 0% at low noise exposure levels and to 100% at high noise levels.

- C.44 However, it is evident that there is much scatter in Schultz's data –many individual points deviate considerably from the trend line. It is suggested that there are at least three reasons for this scatter:
- i. Substantial variations in individual reactions attributable to the many modifying non-acoustical factors. One such factor, that is apparent from Figure C2, is that aircraft causes a generally higher incidence of annoyance than surface transport noise. This means that the dose-response relationship, which applies to general transportation noise, is likely to underestimate reactions to aircraft noise alone.
 - ii. The group responses, as statistical estimates of population characteristics are subject to marked sampling errors due to limited sample sizes.
 - iii. Merging data from different studies is invariably confounded to some extent by differences in the definitions of annoyance (especially where different languages are involved), thresholds of high annoyance and noise exposure variables.

Despite these limitations, the Schultz curve illustrates the probable form of the relationship between noise exposure and community annoyance.

Aircraft Noise Index Study (ANIS)

- C.45 In 1980 the CAA began an extensive programme of social survey and noise measurements (CAA, 1985) commissioned by the Civil Aviation Policy Division of the DfT. The aim of this study was either to substantiate the Noise and Number Index (NNI) – the previous UK noise index - or, if necessary, devise a new index of annoyance due to aircraft noise. A review of ANIS and subsequent UK developments is Brooker (2004).
- C.46 The surveys were carried out using a questionnaire in summer 1980. Each respondent was given an introductory letter from the Department of Trade and Industry which introduced the survey as one that was examining people's attitudes towards the area in which they live. No specific mention was made of aircraft noise in this letter. Out of 3140 addresses selected for interview, 2097 people were successfully interviewed.
- C.47 The sample design used was one in which several small geographical areas, approximately 1 km² - known as 'common noise areas' - were intensively sampled. These areas were chosen to provide the greatest independent variation between sound level and number. This was because an important aspect of the study was to separate the effects of noise and number, in order to provide evidence to support NNI or assist in the design of its replacement.
- C.48 The electoral register was used to select households randomly for the survey. The sampling method was designed to give equal probability of selection for all adults over the age of 18 living within that common noise area. The numbers of areas surveyed during the study were Heathrow (20), Gatwick (2), Luton (2), Manchester (1) and Aberdeen (1).

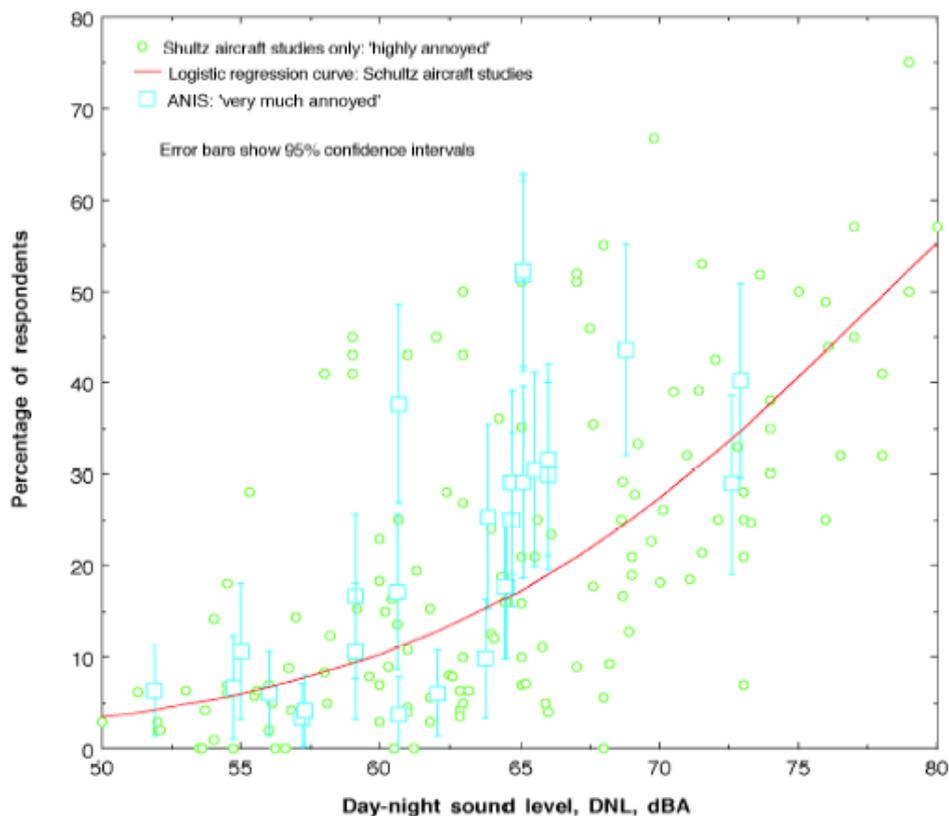


Figure C3 – Comparison of ANIS and Schultz Aircraft Data

- C.49 Figure C3 shows a comparison between aircraft data used in the Schultz curve and data from ANIS. The percentages on the vertical axis show residents who reported that they were 'very much bothered or annoyed by aircraft noise'. In order to achieve this comparison, L_{DN} values for the ANIS cases have been estimated. The logistic curve is that fitted to the aircraft data in Figure C3. The error bars attached to the ANIS points represent estimated 95% confidence intervals – the range in which the bulk of true reaction values are likely to fall. These show that sampling errors may explain a substantial part of the data scatter. It is clear that the ANIS results exhibit the same general trends as the aircraft studies included in the Schultz analysis.

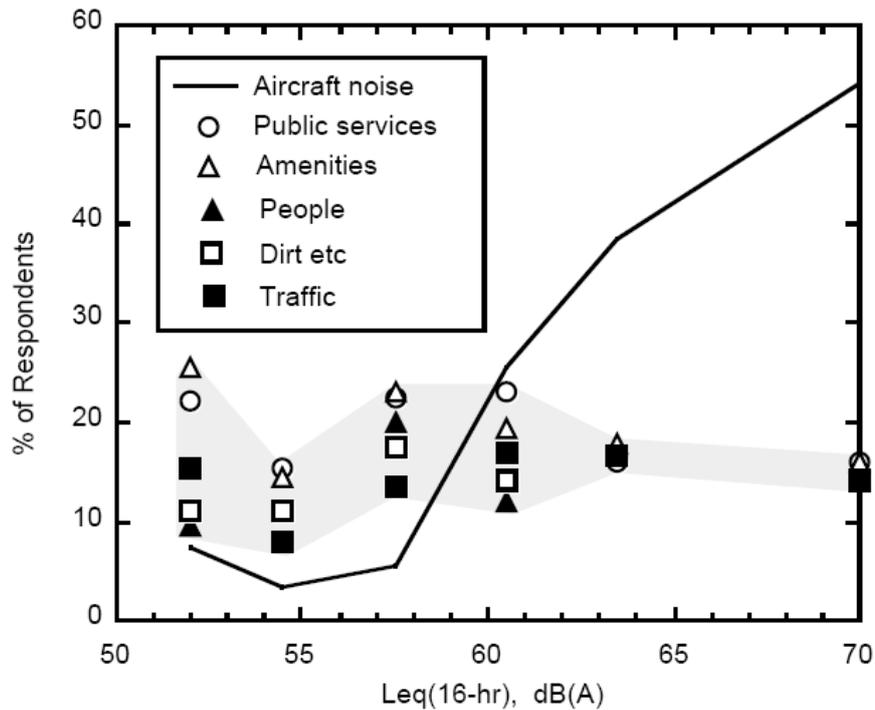


Figure C4 – Dislikes spontaneously mentioned by ANIS respondents

- C.50 In Figure C4 shows $L_{eq, 16 \text{ hours}}$ on the horizontal axis and the percentage of respondents reporting 'a spontaneous dislike of various aspects of life' on the vertical axis. It gives a clear indication of how aircraft noise changes from a minor feature of the environment below about 57 dB(A) $L_{eq, 16 \text{ hours}}$ to a significant one above 60 dB(A) $L_{eq, 16 \text{ hours}}$.
- C.51 The study was successful in disentangling the effects of aircraft sound level and number of noise events. The trade-off implicit in NNI was not substantiated – the study suggested that NNI placed too much weight on the number of aircraft (it applied a coefficient 15 before $\log_{10} N$ rather than the coefficient of 10 implicit in L_{eq}). The study found no evidence to support the inclusion of time-of-day weightings. It found that a good fit to disturbance responses is given by $L_{eq, 24 \text{ hours}}$. Also, the averaging of L_{eq} was found to be statistically preferable to L_{eq} calculated on a worst mode basis, - that is, assuming that the runway is operated solely in the worst direction in noise terms for each respondent. A major confounding factor affecting responses is the proportion of people who work at the airport or who have business at the airport. Data from the five airports did not reveal any marked 'airport-specific' effects.
- C.52 Following the publication of the ANIS report, the Department of Transport undertook a substantial formal consultation on a proposal to change from NNI to L_{eq} as the

index for monitoring aircraft noise. The results of the consultation (CAA, 1990) showed substantial support for the adoption of L_{eq} with many advantages being recognised. However, many consultees expressed reservations about the details – in particular, the time-of-day factor.

- C.53 ANIS revealed no better predictor of annoyance than $L_{eq, 24 \text{ hours}}$. But the consultation indicated that the adoption of a 24-hour index was seen to be too radical a change from the 12-hour period specified for NNI and, without special weightings for evening and night-time periods, would not recognise the somewhat different considerations applying to evaluation of noise outside the 'working day' period. Consultees were, in general, against switching from a daytime-only $L_{eq, 8 \text{ hrs}}$ index to 24 hour L_{eq} .
- C.54 ANIS had shown that, as a predictor of annoyance $L_{eq, 16 \text{ hours}}$ is statistically indistinguishable from $L_{eq, 24 \text{ hours}}$ while most aircraft movements occur between the hours of 0700 and 2300. The conclusion was to adopt $L_{eq, 16 \text{ hours}}$ for the period 0700 to 2300, as the aircraft noise index. Furthermore, the Government decided that 57 dBA $L_{eq, 16 \text{ hours}}$ should mark the approximate onset of significant community annoyance.

Attitudes to noise from aviation sources in England (ANASE)

- C.55 In 2001 the Government announced that it was to commission a major study into aircraft noise during the day and night. The study researches how people feel about aircraft noise. It will focus on how people perceive the relationship between noise levels and annoyance, or sleep disturbance at night, and how they would value lower noise levels relative to other environmental factors.
- C.56 In announcing this study, the Minister explained that current policy was based on the results of the ANIS study, of the previous section, which had been broadly confirmed by other studies in UK and abroad, he had no reason to doubt the validity of this research. However, in light of the Government's commitment to develop a new air transport policy, of changes to [air] traffic patterns and the general reductions in noise levels of new aircraft, the Minister stated that it was timely to commission a new study. The study is being conducted by a consortium led by MVA Ltd: the CAA is not involved in this research.

Sleep Disturbance

- C.57 Everyday experience indicates that noise interferes with sleep. Most people have been awakened by sudden, unusual sounds and regularly use alarm clocks to awaken themselves. But they also get used to high levels of noise and sleep through it, especially when it is steady – as inside trains and planes, for example. It is possible that noise only disturbs sleep when it is unfamiliar or conveys a special message – for example, a parent is awakened by the stirring of a child but may sleep through a thunderstorm.
- C.58 Sleep is, in fact, a complicated series of states, not a single uniform one. Sleep is essential for general well-being, even though the reasons remain obscure. People feel strong resentment when they perceive their sleep to be disturbed: indeed this is a major cause of annoyance. Disturbance at night can take many forms – prevention from falling asleep, physiological arousals and changes of sleep state, and awakenings. Serious sleep deprivation could lead to day-time tiredness and have consequences on a person's ability to function normally. Thus, there is little disagreement that extensive noise-induced awakenings could have a definitive adverse effect. It is less clear whether and to what extent noise can cause harmful loss of sleep, or whether lesser reactions, which do not involve awakening, can affect general well-being in similar ways.

- C.59 It is difficult to measure the effects of noise on sleep without the measurement process affecting sleep itself. Many studies have been carried out. Some of these are in the laboratory: where physiological responses to specially presented sounds can be readily measured. Others are field studies, mainly using social survey methods but sometimes by physical measurement. Different kinds of studies lead to different conclusions, with consequent variability in the measured cause-effect relationships. Some laboratory studies have associated awakenings with noise events as low as 40 dBA L_{max} , while some field studies show very few awakenings at indoor levels of 60 dBA L_{max} . These differences are believed to reflect important effects of familiarity and habituation: people sleep more soundly at home in their normal surroundings.
- C.60 These uncertainties mean that it is difficult to derive definitive noise exposure criteria governing sleep disturbance. Given that some effects have been measured in the laboratory at levels from about 30 dBA L_{eq} , it has been argued that to avoid any negative effects, exposure levels inside the bedroom should not exceed this threshold. However, if the noise is steady and familiar, for example, from a ventilator or air conditioning system, higher levels might be judged to be tolerable. The same may be true of less steady but unexceptional, non-threatening noise – for example, the sound of ocean waves on a beach. The more intermittent and unfamiliar the noise, then, in general, the more likely it is to disturb. In particular, if noise exposure, e.g. as measured by L_{eq} is governed by a few very noisy events, then the level of those individual events might well be the major concern.
- C.61 It is generally agreed that, in the home, the effects of familiar events would be small below indoor event levels of about 45 dBA L_{max} . Awakenings would be infrequent below 55 dBA L_{max} . All these levels apply to indoor conditions. If sleep effects are being related to outdoor sound levels, then about 15 dB should be added in the case of partially open windows and about 25 dB for typically closed windows.
- C.62 A fuller exposition of the adverse effects of night-time noise was published by the CAA in 2000 (CAA, 2000).

Report on a Field Study of Aircraft Noise and Sleep Disturbance

- C.63 In 1990 the Department of Transport commissioned the CAA to carry out research into aircraft noise and sleep disturbance (DoT, 1992) in preparation for a review of the London airports night restrictions scheme. The objectives of the study were to determine (a) the relationships between outdoor noise levels and the probability of sleep disturbance, and (b) the variation of these relationships with time of night.
- C.64 It was necessary to investigate the influence of non-acoustical factors upon disturbance of people's sleep including their age, sex and personal characteristics, their general views about the neighbourhood, their perceptions about sleep quality and the ways in which this might be affected by aircraft noise.
- C.65 The CAA managed this research programme which was undertaken by research teams from Loughborough University Sleep Laboratory, the Department of Biological Sciences of Manchester Metropolitan University and the Department of Social Statistics of Southampton University. The research team was advised by a steering group chaired by the DoT including representation from airlines, airports and local people. The study drew on the views of a panel of leading experts in the field of sleep research.

- C.66 The traditional method of monitoring sleep is electroencephalography or 'sleep EEG' in which brain waves are measured by electrodes attached to the scalp. A hypnogram is a record of sleep stages during the night obtained from EEG data. Sleep stages in the hypnogram include light, deep and REM (rapid eye movement – indicative of dreaming) as well as wakefulness. However, the method is complex and expensive and, partly for these reasons, most EEG work has been carried out in laboratory situations. In order to avoid the statistical constraints of such limited studies and because of the strong possibility that laboratory studies are not truly representative of the way people react in their homes, this study made use of actimeters to gather a large quantity of field data. Actimeters are small, relatively inexpensive devices that measure movement (motility) - worn like a wrist watch, they are easily used in the home without supervision. They log and store data for many nights which are subsequently transferred to a computer for conversion to actigrams, the graphical record of limb movements.
- C.67 Actimetry is widely used in sleep research but an important part of this study was to validate its use for measuring the effects of aircraft noise on sleep. This was done by a direct comparison of EEG and actimetry measured disturbance for a sub sample within the study.
- C.68 The main study involved field measurements at 8 sites, 2 each around Heathrow, Gatwick, Stansted and Manchester airports. The site chosen provided a range of noise exposure levels – their selection was guided by needs for sufficient local population with similar noise exposures within the site and avoidance of confounding noise sources such as busy roads and railways. Fieldwork was conducted between February and October of 1991, commencing with social surveys to identify a pool of subjects from which to select participants for the actimetry work. The selected subjects (50 per site) wore actimeters for 15 nights and also completed 'sleep diaries' covering both the night and any daytime sleepiness. In addition, 6 of the 50 subjects were monitored using EEG for 4 of their actimetry nights – the EEG data were required to calibrate the actimetry results. Throughout the survey period, a concurrent programme of outdoor noise measurement provided aircraft noise data for correlation with measured sleep disturbance.
- C.69 For the EEG sample, agreement between actimetrically determined arousals (onsets of limb movement) and EEG measured awakenings was high – 88% of all awakenings coincided with actimetric arousals. The agreement in the case of undisturbed 'epochs' (30 second measurement periods) was even higher, 97% overall. This was seen as important support for the actimetry method, given that undisturbed epochs were 95% of the total.
- C.70 From the actimetry data it was estimated that per subject, for all causes, all nights and all epochs during the average sleeping period of 7 hours, there were about 18 awakenings per night lasting for 10-15 seconds or more. Most of these were not remembered the morning after. On 57% of measurement nights, no awakenings were reported. In the remaining 43% of cases, subjects recalled an average of three awakenings, from all causes, during the previous night. Aircraft noise was given as a relatively minor cause (less than 4% of reported awakenings). About one quarter of all actimetry subjects specifically reported being disturbed by aircraft noise during the study – on average by these subjects, once every five nights. The incidence of aircraft noise events ranged between averages of 3 and 48 events per night.

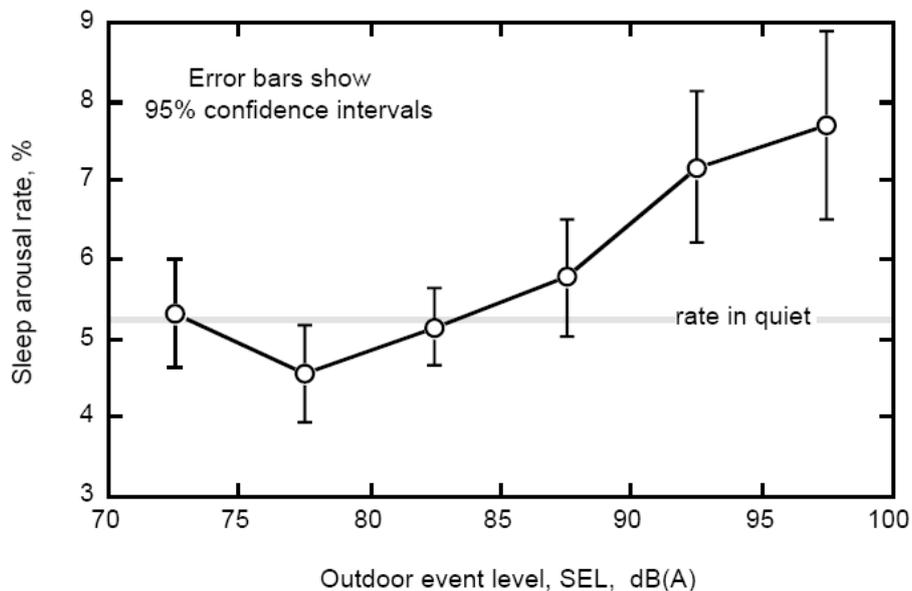


Figure C5 – Relation between actimetrically measured sleep disturbance and noise

- C.71 Figure C5 shows the estimated average disturbance rate (based on actimetric arousals) as a function of outdoor aircraft noise event level (SEL). The results indicated that, below 90 dBA SEL (approximately 80 dBA L_{max}), aircraft noise events are unlikely to cause any measurable increase in overall rates of sleep disturbance experienced during normal sleep: in the range 85-90 dBA SEL, the arousal rate associated with aircraft noise events was not significantly different from the rate during the absence of aircraft noise events, shown as a line marked 'rate in quiet' on the diagram.
- C.72 It is only above 90 dBA SEL (approximately 80 dBA L_{max}) that the differences between sleep arousal rates with and without aircraft noise are statistically significant at the 95% level. This means that there is a one in twenty probability that the results were obtained as the result of pure chance. At higher noise levels, between 90 and 100 dBA SEL (approximately 80 and 90 dBA L_{max}), the chance of the average person being awakened by an aircraft noise event was about 1 in 75. This risk of arousal due to aircraft noise must be compared with an average of 18 nightly awakenings from all causes. Thus, even large numbers of night movements would be likely to cause very little increase in the average person's nightly awakenings. Susceptibility to sleep disturbance varied markedly. For aircraft noise related disturbance, the 2-3% most sensitive people could be over twice as likely to be disturbed as the average person and the 2-3% least sensitive less than half as likely.
- C.73 The actimetry results related only to disturbance from sleep: they did not answer the questions of whether aircraft noise delays sleep onset (either at the beginning of the night or after awakening during the night) or causes premature awakening at the end of a night's sleep.
- C.74 Statistically, time of night and time from sleep onset were found to be significant factors affecting arousal from sleep. The data indicated that people appear to be most resistant to disturbance, from any cause, after first falling asleep. Then, starting with a pronounced fluctuation having a cycle time of about 90 minutes, the overall disturbance rate increases steadily, from the equivalent of about two awakenings an hour at the beginning of the night to about three per hour at the end of the night.

World Health Organisation (WHO) Guidelines

C.75 The World Health Organisation published a set of guidelines for community noise (WHO, 1999). These guidelines are essentially values for the onset of health effects. These are levels that would produce no significant health effects for the population at large. The WHO considers that the extent of the community noise problem is large. It notes that

‘When all transportation noise is considered, about half of all European Union citizens live in zones that do not ensure acoustical comfort to residents. At night, it is estimated that more than 30% is exposed to equivalent sound pressure levels exceeding 55 dBA, which are disturbing to sleep.’

C.76 The UK Government considers that the guideline values are very low i.e. extremely cautious (DfT, 2004a). It has stated that it would be difficult to achieve them in the short to medium term without draconian measures but that is not what the WHO proposed. The recommendation was that the *Guidelines for Community Noise* should be adopted as long term targets for improving human health which the Government have stated that they will take into account.

C.77 The WHO guidelines (WHO, 1999) relevant to aircraft noise and residential areas are as follows:

Specific Environment	Critical Health Effect(s)	L _{Aeq} (dB)	Time Base (Hrs)	L _{Amax} , fast (dB)
Outdoor living area	Serious annoyance, daytime and evening	55	16	-
	Moderate annoyance, daytime and evening	50	16	-
Dwelling indoors	Speech intelligibility and moderate annoyance, daytime and evening	35	16	-
	Sleep disturbance, night time	30	8	45
Outside bedrooms	Sleep disturbance, window open (outdoor values)	45	8	60
Outdoors in parkland and conservation areas	Disruption of tranquillity	See note		

Notes:

- a. Existing quiet outdoor areas should be preserved and the ratio of intruding noise to natural background sound should be kept low.
- b. There are additional guidelines for schools, hospitals, industrial areas and ceremonies/entertainment.

C.78 The WHO guideline targets and the Government definition of significant community annoyance are not incompatible. The WHO values are set at the level below which there is no impact from annoyance on human health – the Government value is set at the level where the effect in terms of community annoyance becomes significant.

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APPENDIX D - CONTINUOUS DESCENT APPROACHES AND LOW POWER/LOW DRAG PROCEDURES

Introduction

- D1. A continuous descent approach (CDA) is defined (DTLR *et al*, 2001; NATS, 2004) as 'a noise abatement technique for arriving aircraft in which the pilot, when given descent clearance below the transition altitude by air traffic control (ATC), will descend at the rate he judges will be best suited to the achievement of continuous descent, whilst meeting the ATC speed control requirements, the objective being to join the glide-path at the appropriate height for the distance without recourse to level flight'. The ideal CDA profile is a descent at 3 degrees from 6,000 feet. The industry code of practice (DTLR *et al*, 2001) recommends that an arrival is classed as a CDA if it contains, at or below 6,000 feet:
- no level flight; or
 - one phase of level flight not longer than 2.5 nm.
- D2. Level flight is defined as any segment of flight having a height change of not more than 50 feet over a track distance of 2 nm or more, as recorded in the airport noise and track-keeping system.
- D3. A low power/low drag procedure is defined as 'a noise abatement technique for arriving aircraft in which the pilot delays the extension of wing flaps and undercarriage until the final stages of the approach, subject to ATC speed control requirements and the safe operation of the aircraft'.

Implementation

- D4. On being instructed to leave the holding facility (stack), headings and flight levels/altitudes will be passed to the aircraft by ATC. Descent clearance will include an estimate of the track distance to touchdown. Pilots are expected to use this information to manage their rate of descent to achieve a continuous descent to touchdown. Guidance, in the form of graphs and tables, is published in the code of practice (DTLR *et al*, 2001) with advice on the use of flight management systems. Additional distance information will be passed by ATC, normally on first contact with the final director, before intercept heading for the ILS.
- D5. Performance of a CDA relies on a combination of factors and cooperation between individuals and organisations. In order to carry out a CDA, the pilot needs accurate information on distance to touchdown from ATC. ATC require knowledge of the planned track to be followed by the aircraft. The planned track will take into account separation and sequencing between aircraft and it is possible that 'path stretching' will be required in order to maintain minimum separation between aircraft and achieve an efficient flow of aircraft to the runway.

Costs

- D6. CDA procedures involve some additional radio traffic in the form of distance to touchdown estimates and the associated cognitive effort by the air traffic controller in making this prediction. It will also involve the pilot in additional workload in determining the optimal descent position having been given descent clearance and a protracted period of descent during a busy phase of flight. Other workload factors will include monitoring busy radio circuits, manoeuvres required for separation and

sequencing, surveillance of proximate traffic including the possibility of TCAS alerts, establishment on the ILS localiser and pre-landing cockpit checks.

Benefits

- D7. CDA achievement generates a number of benefits. It reduces the amount of fuel burned by approaching aircraft – this was the reason for its original implementation during the fuel crisis of the 1970s (Morris, 2004). This will reduce aircraft engine emissions – both carbon dioxide and oxides of nitrogen. Aircraft flying a CDA procedure will also produce lower noise levels experienced on the ground than an aircraft flying the approach with significant periods of level flight. This reduction in noise impact is due to:

lower power settings on the engines required for descent as opposed to level flight; and

aircraft maintaining a higher altitude than would otherwise be the case with greater attenuation between the source and the ground.

- D8. Figure D1 shows the sound exposure level (SEL) in dBA at different distances from touchdown with CDA compared against profiles with level segments of flight at different altitudes. SEL of an aircraft noise event is the sound level of a one second event that contains the same total A-weighted sound energy as the whole event – in other words, the sound level that would be measured if all the noise energy were to be compressed into a reference time of one second.

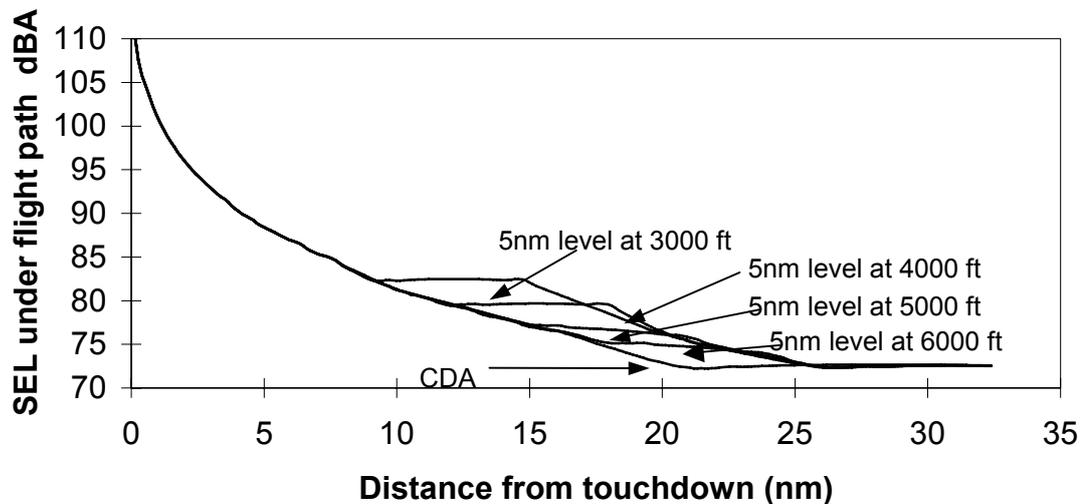


Figure D1 B747-400 SEL under flight path

- D9. Figure D2 shows the difference between a CDA profile and the approaches with level segments described in the previous paragraph. The CDA profile is the 0 dBA line in this diagram

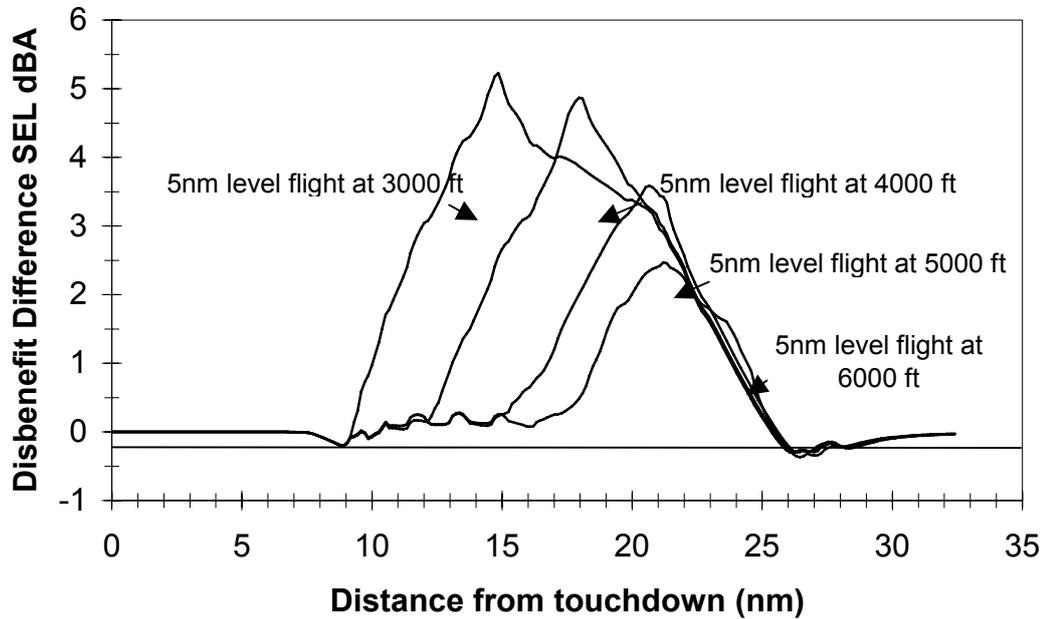


Figure D2 Disbenefit of level flight intercept relative to 'pure' CDA approach

Conclusion

- D10. Both diagrams demonstrate that there is a significant benefit in noise terms deriving from CDA achievement. This benefit occurs between 25 and 8 nm from touchdown and can be as much as 5 dBA. It should be recognised that the benefits will not have any significant impact on the size or shape of noise exposure contours because aircraft are normally established on the 3 degree glide slope before 8 nm from touchdown irrespective of whether a CDA has been achieved.

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