EUROPEAN CIVIL AVIATION CONFERENCE

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3rd Edition

Report on Standard Method of Computing
Noise Contours around Civil Airports

Volume 1: Applications Guide

December 2005

FOREWORD

Previous guidance on aircraft noise contour modelling, ECAC-CEAC Doc 29, originally published in 1986, described ‘best practice’ methodology as it had been developed up to that time. A revised 2nd Edition, released in 1997, introduced a number of additional features, but without changing the foundations. Much of the basic methodology - also described in guidance published by the Society of Automotive Engineers and the International Civil Aviation Organisation - is still embodied in numerous national and international noise models.

Apart from having been overtaken by actual technology improvements which have already been incorporated into some state-of-the-art models, Doc 29 2nd Edition, like the other publications, had two major limitations. Firstly it focused mainly on the algorithms that have to be programmed into physical computer models; it contained little advice on the practical application of the methodology. Secondly it provided none of the data that is an essential component of any real modelling system. Thus its practical value diminished with time: for noise modelling specialists it became obsolescent while for potential users it was too narrow and too theoretical.

This new guidance - which is split into two volumes[1] - attempts to overcome those limitations. **Volume 2**, designed principally for those who construct and maintain aircraft noise contour models, replaces Doc 29 2nd Edition. Its contents represent internationally agreed current best practice - as implemented in modern aircraft noise models. It does not list a computer code, but it does fully describe algorithms that can be programmed to create one. Changes to, and advances on, Doc 29 2nd Edition are identified for those who merely wish to update existing software. A major advance is that the recommended model links to a comprehensive international database website that provides the essential aircraft noise and performance data required to implement it.

Volume 1 is principally for noise model users - firstly the aviation policymakers and planners who need noise contour maps to inform their decision making and, secondly, the technical practitioners including aviation and environmental advisers and consultants whose job it is to produce the contours. Some of the latter will have backgrounds either in acoustics or in aircraft performance and operations, some will have both, some may have neither. The aims of **Volume 1** are to explain, as non-technically as possible, (1) the principles, applications and limitations of aircraft noise contour modelling; (2) the modelling options and the precautions necessary to ensure that valid results are produced reliably and cost-effectively.

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[1] A third, on the subject of model validation, is planned.

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EXPLANATION OF TERMS AND SYMBOLS

Terms are described here by the general meanings attributed to them in this document. Some of the terms are widely used in the fields of acoustics and noise control where they have very specific meanings, often subject to national and international standardisation. Some are used elsewhere in different ways and for different purposes: for example, the expression *sound level* is applied to different dimensions of sound including sound power emission, sound intensity received and the mean square pressure fluctuation in the air (or other propagation medium). It is not necessary for a non-specialist user of **Volume 1** to become familiar with such detail; only to appreciate general concepts the terms convey.

Particular mention must be made of the words *sound* and *noise*. In formal acoustic terminology these have very specific and different meanings: sound is a purely physical quantity - a form of energy - whilst noise is 'unwanted' sound and thus has a subjective dimension. To most people living near airports, aircraft sound is noise so, in much of what is written, there is no particular need to distinguish between the two words and they are often used interchangeably.

Attention is drawn to the difference between *acronyms*, used to abbreviate frequently used terms and *symbols* used (usually in italics) to represent terms in mathematical expressions; e.g. Sound Exposure Level is abbreviated as SEL but expressed mathematically as L_{AE}.

Terms used frequently are described below. Others occur only locally and are described where they first occur.

Aerodrome	A defined area of land or water (including any buildings, installations, and equipment) intended to be used either wholly or in part for the arrival, departure and surface movement of aircraft.
AIP	Aeronautical Information Publication - A publication issued by or with the authority of a State and containing aeronautical information of a lasting character essential to air navigation.
Aircraft configuration	The positions of slats, flaps and landing gear.
Airport	→ *Aerodrome* at which facilities are provided for the shelter, servicing or repair of aircraft, and for receiving and discharging passengers and cargo.
Air noise	The noise from aircraft in flight while departing from and arriving at an aerodrome. That includes the noise of the take-off ground roll and use of reverse thrust after landing. It excludes the noise of taxiing and from all other aircraft and non-aircraft sources within the aerodrome boundaries - which together are referred to as *ground-noise*.
Altitude	Vertical distance of an aircraft above mean sea level.
Annoyance	A feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with thoughts, feelings or activities. Average community annoyance is widely used as an indicator of long term environmental noise impact.

ANP	The international aircraft noise and performance database.
Assessment	The process of evaluating the disbenefits of a scenario that is attributable to noise.
ATC	Air traffic control
Attenuation	In open air, sound intensity diminishes with distance from the source because energy spreads in all directions. It is further reduced or attenuated by other processes, principally by absorption (which irreversibly turns noise into heat) by the air or other obstacles to propagation.
A-weighting	A standard, and very commonly used, frequency weighting or filter used to reflect the frequency response of the average human ear over a wide range of listening conditions. Measurements of A-weighted sound level L_A are usually abbreviated dBA or dB(A) [ref. 1].
Brake release	See → *start-of roll SOR*
Contour	A line of constant value of an aircraft noise index around an airport.
Decibel, dB	Unit of *level* - measurement on a logarithmic scale of *ratio*. Levels in dB relate the magnitude of a sound or noise to that of another. 'Absolute' levels (as read from a standard sound level meter) relate to a standard reference sound (notionally at the threshold of hearing). Changes or differences of level, relate one sound to another - which may be more or less intense. A single dB increment represents a single energy ratio. It is useful to remember some particular increments: 3dB is a ratio of 2, 6dB is a ratio of four and 10dB is a ratio of 10.
DENL	Acronym for Day-Evening-Night Level → L_{DEN}
Descriptor	Alternatively *metric*. A measure of quantity of sound or noise, e.g. in a single discrete sound event (examples L_{max}, L_E) or that received over a long period of time (example L_{eq}).
Effective duration	(Of an event) The duration t_e of a hypothetical sound event with a constant level L_{max} having the same sound energy as the actual event (described by the level-time-history *L(t)).*
Energy	Sound is energy transmitted through the air (or other media) by wave motion. The term tends to be used (non-rigorously) to describe various energy-like dimensions of sound, e.g. for an → *event*, the product of its average intensity and duration.
Energy average level	(Sometimes referred to as logarithmic or decibel average.) Two different averages (in dB) of a set of event levels have to be recognised: arithmetic and energy averages. The arithmetic average is a conventional mean value which tends to lie at the middle of the range. The energy average is calculated only after each decibel event level is 'anti-logged' back to an energy value; the result being re-converted to decibels as the energy average

	level. The energy average is always greater than the arithmetic average and therefore tends to lie above the middle of the range.
EPNL	Effective Perceived Noise Level → L_{EPN}
Equivalent sound level, L_{eq}	(Or equivalent continuous sound level) A measure of long term sound, e.g. of aircraft noise received over a period measured in hours. The level of a hypothetical steady sound which, over a specified period of time, contains the same total energy as the actual variable sound. It is, effectively, the average level (or more precisely the level of the average intensity) during the measurement period.
Event	A discrete noise occurrence caused by the passage of an aeroplane.
Event level	A decibel measure of a sound event such as L_{max} or L_E.
Exposure	Measure of long term, or cumulative, sound received: often/usually an average intensity.
Exposure level	Exposure measured on a decibel scale.
Flight configuration	→ *aircraft configuration* plus → *flight parameters*
Flight parameters	Power setting, speed, weight
Flight path	The trajectory of an aircraft in flight in 3-dimensional space.
Flight profile	Variation of altitude and speed (and sometimes flight parameters) along the → *ground track*
Footprint	→ *Contour* of constant event level for one approach and/or departure operation of a single aircraft.
Frequency weighting	A filter applied by a sound level meter to approximate the response of the human ear - which has different sensitivity to sounds of different frequency.
Ground noise	Sound or noise emanating from an aerodrome from sources *other than* aircraft taking off and landing. These include aircraft taxiing, maintenance activities, auxiliary power units, surface vehicles and any other sources within the aerodrome boundaries. It excludes the noise from aircraft on the runways and in flight while departing from and arriving at the aerodrome which is referred to as → *air noise*.
Ground plane	Notional level ground surface at aerodrome elevation on which noise contours are calculated.
Ground track	Projection of the → *flight path* on the → *ground plane.*
Height	Vertical distance of an aeroplane above aerodrome elevation.
ICAO	International Civil Aviation Organisation.
ILS	Instrument Landing System.
Immission	An expression used to describe sound received by an observer - as opposed to the sound emitted from the source.

Impact	An expression used to embrace all adverse effects of noise on people.
Intensity	‘Strength’ of sound received at a point (often described simply as ‘energy’) – measured in terms of sound power per unit area (watts/m^2) and essentially proportional to mean square pressure’ (that is measured by sound level meters).
L	Symbol for sound or noise *level*. Subscripts are used to denote particular scales e.g. L_A.
$\overline{L}$	Average of all event levels during a specified period (energy average).
$L(t)$	Sound level at time t. It may be thought of as an ‘instantaneous’ value although in practice sound intensity has to be measured over a finite period of time, no matter how short.
$L(t)$-*slow*	$L(t)$ averaged using the ‘slow’ setting of a standard sound level meter (which has an averaging time equivalent to about 1 second and smoothes out very short fluctuations in the instantaneous sound intensity).
L_A	Symbol for A-weighted sound pressure level (see A-weighting).
L_{AE}	Sound Exposure Level (acronym SEL) = A-weighted L_E with a reference duration of 1 second; a standard single event descriptor described e.g. in ISO 1996 [ref. 2]
L_{DEN}	Day-evening-night level DENL, a (L_{eq}-based) noise index adopted by the European Commission which weights evening noise by 5dB and night-time noise by 10dB.
L_E	Single event sound exposure level. The sound level an event defined would have if all its sound energy were compressed uniformly into a standard time interval (known as the ‘reference duration’). This scale thus takes account of the duration of the event as well as its maximum intensity. Effectively L_E increases by 3 dB with each doubling of its duration - because its total → *energy* then doubles).
L_{EPN}	Effective Perceived Noise Level EPNL, a single event descriptor equal to L_E with L measured as L_{PNT} *and a reference duration of 10 seconds.* The metric used for international aircraft noise certification (ICAO Annex 16 [ref. 3])
L_{eq}	→ *Equivalent sound level*. The subscript is sometimes extended to denote the scale and the measurement period, e.g. $L_{Aeq(24h)}$.
$L_{eq,W}$	Equivalent sound level with time-of-day weightings.
L_{max}	The maximum value of $L(t)$-slow that occurs during an event. The subscript is sometimes extended to denote the scale and the measurement period, e.g. L_{Amax}
L_{NIGHT}	Designation used by the European Commission for the night-

	time L_{eq}
L_{PNT}	Tone corrected perceived noise level L_{PNT} is a scale of aircraft noise which simulates the way in which different frequencies are understood to contribute to annoyance and gives emphasis to tones (the whines and whistles of fan and compressor noise). Described in ICAO Annex 16 [ref. 3].
Level	Magnitude of sound/noise intensity measured in decibels (dB) - abbreviated *L*. Subscripts are used to denote particular scales, e.g. L_A.
Level time-history	A record of the variation of sound level *L(t)* over some period of time, e.g. encompassing a complete noise event.
lg	Logarithm to the base 10
Loudness	The intensive attribute of an auditory sensation, in terms of which sound may be ordered on a → *scale* extending from soft to loud, expressed in units of sones (which are not used herein).
Mass	The quantity of matter (in an aircraft)
Metric	See *descriptor*.
Movement	An aircraft departure or arrival.
MTOM/W	Maximum take-off mass/weight.
N	Number of noise events within a specified time period
NAT	Number above threshold: the average numbers of events exceeding a specified critical level during specific time periods
Noise	Unwanted sound
Noise Index	(Sometimes called 'indicator'). A measure of long term, or cumulative sound or noise which correlates with (i.e. is considered to be a predictor of) its effects on people. May take some account of factors in addition to the magnitude of sound (especially time of day). An example is day-evening-night level → DENL
Noise significance	A flight, or part of a flight, is noise significant if its contribution affects the magnitude of the received sound level to an appreciable extent. Disregarding those parts of all flight paths that are not noise-significant can yield massive savings in computer processing.
Noise Engine	The central part of a → *noise model* (usually a computer program) which models the physics of sound emission and propagation.
Noise Model	A system for producing noise contours (and point event levels) comprising a calculation procedure (the → *noise engine*) and an associated database.
Noisiness	The attribute of noise that makes it unwanted. The adjective 'noisy' has been defined variously in psychoacoustic research as,

	for example, annoying, unwanted, objectionable, disturbing or unpleasant. Noisiness and loudness are considered to be different attributes: noisiness is considered to be dependent on the duration of an acoustic event; loudness is not.
NPD	Noise-Power-Distance (relationship).
Operating procedure	The way in which an aircraft is operated during an arrival or departure from an aerodrome.
Procedural steps	Prescription for flying a profile - steps include changes of speed and/or altitude.
Receiver	A recipient of noise arriving from a source; principally at a point (the observer location) on or near the ground surface.
Scale	An ordered arrangement of numbers used to quantify magnitude or dimensions of quantities in specified *units*. Thus *metres* are *units* of a *scale* of length. Acoustical examples are scales of A-weighted sound level (units dBA) and effective perceived noise level (units dB(EPN) or EPNdB)
Scenario	An aerodrome study case - encompassing all elements and factors involved in a noise impact assessment.
SEL	→ *Sound Exposure Level*
SID	Standard instrument departure route. A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated Air Traffic Services (ATS) route, at which the en-route phase of a flight commences.
Sound	Energy transmitted through air (or any other medium) by (longitudinal) wave motion which is sensed by the ear.
Sound Exposure Level	→ L_{AE}.
Sound/noise event	The totality of the noise received at an observer location from a single aircraft movement. (Related measure: → *event level*)
Sound level meter	An instrument for measuring sound - usually in terms of (at least) unweighted level L and A-weighted level L_A; see IEC 61672-1 [ref. 4]
STAR	Standard instrument arrival route. A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an Air Traffic Services (ATS) route, with a point from which a published instrument approach procedure can be commenced.
Start of roll, SOR	(Also termed → *brake release*). The point on the runway at which, notionally, the brakes are released and the aircraft starts its takeoff. (In practice aircraft sometimes commence take-off without stopping after taxiing onto the runway.)
t_e	→ *Effective duration*
Value	Point on a scale e.g. 10 metres, 0.001 watts/m^2, 80 dB etc.

Weight	The downward force of gravity exerted on an aeroplane. It is essentially proportional to the aeroplane's → *mass* and the terms mass and weight tend to be used interchangeably.

PART I INTRODUCTION

1 SCOPE OF GUIDANCE

Despite hugely successful efforts by aircraft and engine manufacturers to quieten their products, aircraft noise remains a significant adverse effect of airports large and small. It is a focus of attention for those concerned with airport development and operation as well as the people affected. Mitigating the noise impact continues to be a major challenge and the problem is attacked on many fronts. But success is very dependent on a good understanding of the relationships between the magnitude of the noise and the nature and extent of the effects. A common way of depicting the scale of the problem is by means of aircraft noise contour maps.

This document is the first of two volumes[2] which together provide comprehensive guidance on the calculation of aircraft noise exposure levels and the production of aircraft noise contours. Noise contours for a particular airport are normally produced as part of a noise impact assessment of some kind. The requirements can vary widely depending on the nature of the development under consideration but they will often be for an assessment of the adverse noise impact of a change, to the airport or its use, on local communities. Three separate parts of the assessment process are illustrated in **Figure 1-1.**

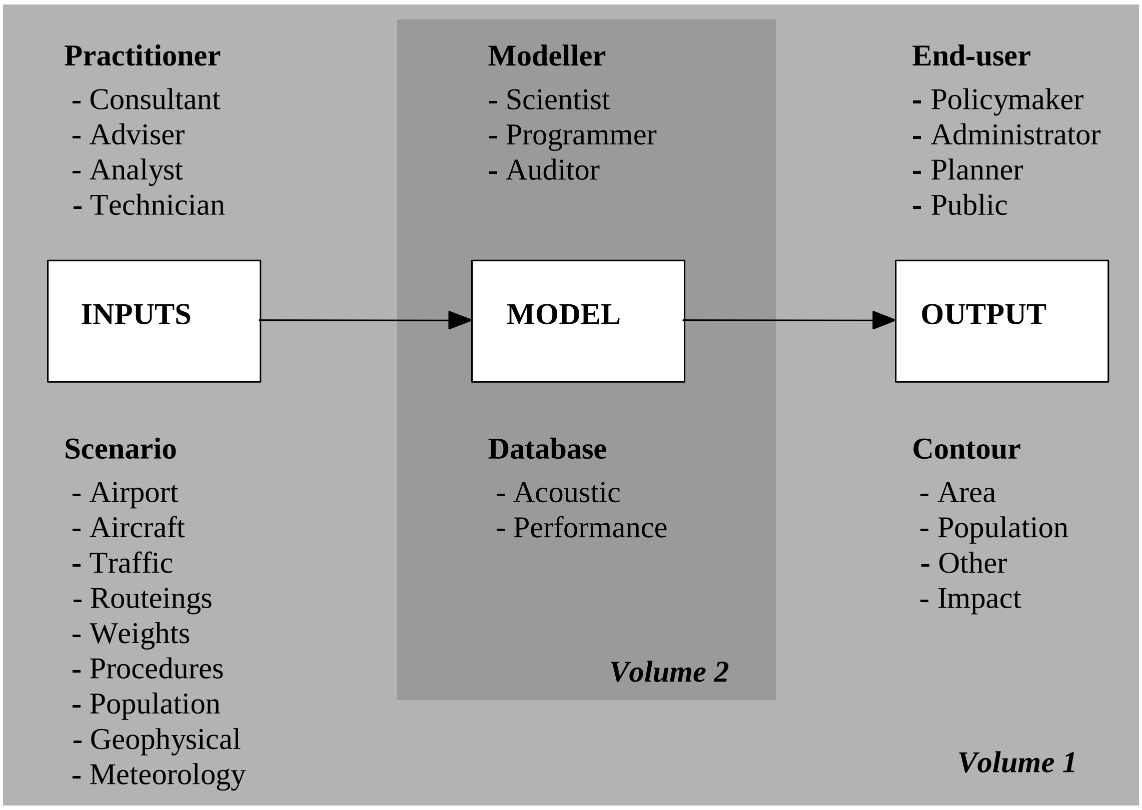

Figure 1-1: Three parts of the aircraft noise impact assessment process

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[2] A third volume, on the subject of model validation, is planned.

Although the end-user specifies the general requirements, the *practitioner* defines the problem in detail, selects an appropriate method of solution and then plans and conducts the analysis to provide the solution. The *modeller* is the specialist in aircraft noise and performance who builds and maintains the modelling system, normally a noise model and its database. The *end-user* specifies the problem in general terms: the airport, traffic and/or operational scenarios to be considered and the impact assessments that are required.

Volume 1: Applications Guide is primarily for noise model users involved in the first and third parts of the assessment process - those who have a need for contours for specific airports and those who have the job of producing them from information describing the airport and aircraft and their operation. **Volume 2: Technical Guide** is primarily for modellers - those who develop and maintain the computer packages and databases that comprise the noise contour models. It recommends to ECAC States a specific modelling system which incorporates current best practice.

But noise mapping methodology has to be matched to needs and resources and practical problems vary enormously in scale - principally dictated by airport size and traffic volume but also, sometimes, by the complexity of the noise generation and propagation processes involved. Noise impact assessments are necessarily constrained by the limitations of current methodology and the need to manage costs. Assessments of actual noise exposures around major international airports might be extremely expensive but affordable - while producing reliable estimates for small airports might still be complex and not be possible economically.

The guidance covers aircraft noise at civil, commercial airports, where the aeroplanes in operation are mostly jet-powered or propeller-driven transports. In such cases the operations and the noise performance characteristics of the aircraft tend to be ordered and predictable. If appropriate noise and performance data are available for other aircraft types including military aeroplanes, propeller-driven light aeroplanes or helicopters, these too may be included in the evaluation provided their contribution does not dominate the total noise exposure. Where the noise exposure derives mostly from military aeroplanes, propeller-driven light aeroplanes or helicopters however, this guidance is not applicable - the operations and noise performance characteristics of such aircraft are usually much less predictable than those of the transport types considered and the facilities from which they operate are very different, as explained in **Appendix B**. ECAC has not yet developed comparable guidance covering these classes of aircraft.

The guidance is also confined to *air noise* - the noise from aircraft in flight while departing from and arriving at the aerodrome. It includes the noise of the take-off ground roll and use of reverse thrust after landing. It excludes the noise of taxiing and from all other aircraft and non-aircraft sources within the aerodrome boundaries - which together are referred to as *ground-noise*. Whilst that might appear to be disregarding a significant part of the problem, it is usually the case that the contribution of ground noise to noise exposures outside the airport boundaries is negligibly small - at least with regard to its effects upon the noise contours. This does not mean that ground noise has no adverse effects upon local communities. But it is the reason why ground noise is usually assessed quite separately from air noise. However, ECAC has not yet developed comparable guidance on the assessment of ground noise.

2 USER NEEDS: HOW THIS GUIDANCE IS ARRANGED

The main body of **Volume 1** is divided into three Parts, as illustrated in **Figure 2-1**.

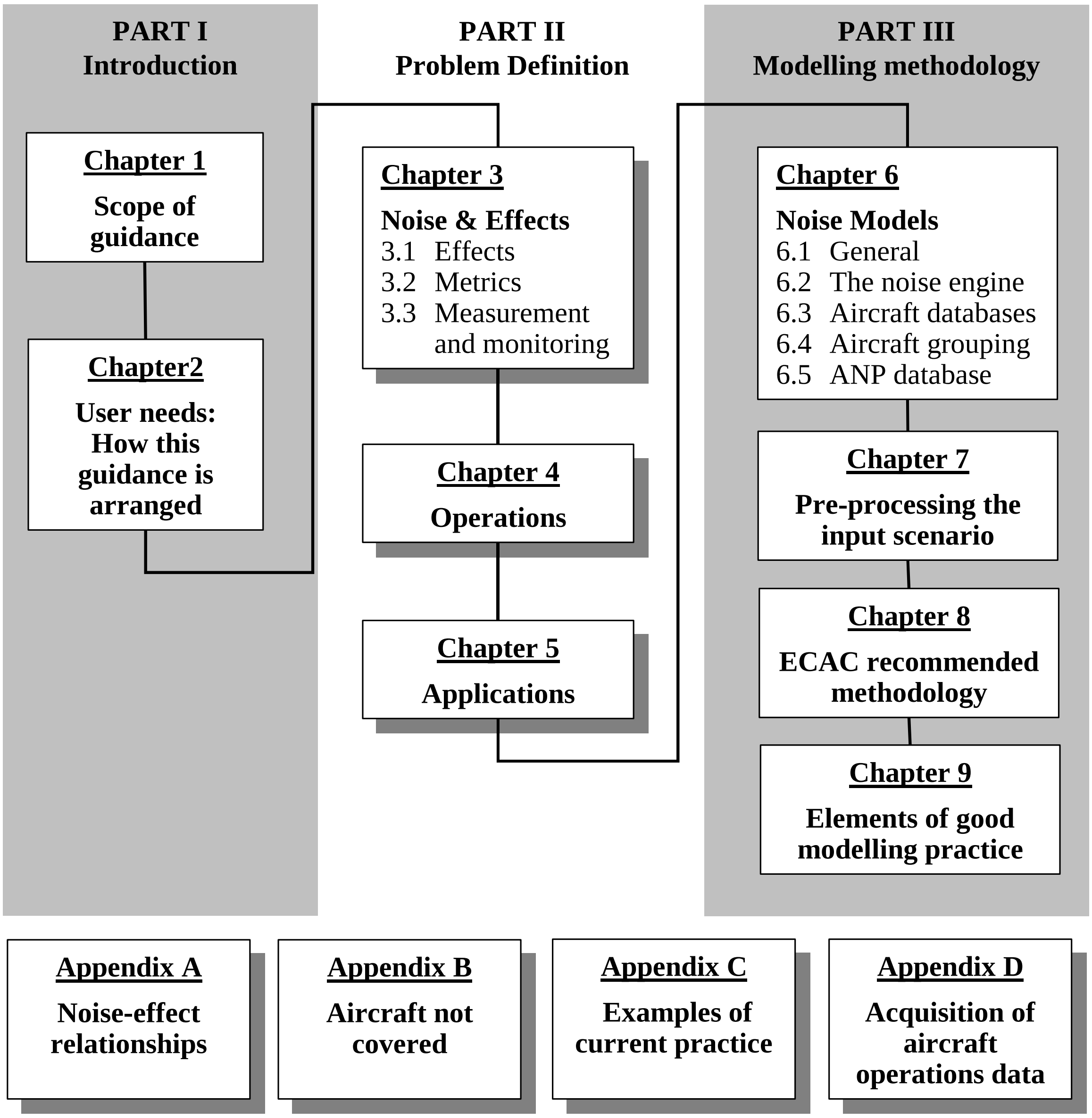

Figure 2-1: Volume 1 Contents

Part I: Chapters 1 and 2.

This provides an introduction to the scope of this guidance and the way it is presented within volumes 1 and 2.

Part II: Problem definition (Chapters 3 - 5 and Appendix A)

The first step in conducting a cost-effective noise assessment is to define the problem correctly: what exactly does the end-user need to know? Only after this is firmly established can a judgement be made on what factors need to be taken into account. These factors in turn dictate the basic noise modelling requirements.

The practitioner will probably consult and advise the end-user at all stages of the process to achieve a successful outcome. Although this guidance is concerned principally with calculations of noise exposure, the starting point - in **Chapter 3: Defining sound (noise) exposures in terms that relate to effects** - is a review of the adverse effects upon people and the definition and measurement of various scales, metrics and indices used to quantify the noise in physical terms which are indicators of those effects. **Appendix A** provides more background on the relationships between noise and its effects - of which all model users need a broad appreciation.

Although many acoustical consultants have the understanding of aircraft noise characteristics and propagation that is necessary to use a noise contour model and interpret the results, the noise modelling practitioner usually needs to have, or have access to, knowledge and expertise in airport and aircraft operations to achieve reliable results. This is because aircraft noise levels heard on the ground depend on the flight path of the aircraft (position vs. time) as well as its flight configuration - its weight, engine and flap settings, speed and rate of climb or descent. These in turn are determined not only by individual airline operating procedures but also by air traffic control requirements. **Chapter 4: Airport and aircraft operations and noise** provides an introduction to the operational considerations that need to be taken into account and the methods of acquiring the necessary data.

Which factors - the inputs in **Figure 1-1** - are the most important depends on the *application*, especially whether it is:

A to define the ‘absolute’ noise impact of a particular scenario, that is of an airport's operations

  1) at present or at some time in the past, or
  2) under some forecast future scenario (e.g. with expanded operations)

or

B to compare two or more different scenarios; for instance

  1) present with past and/or future, or
  2) future scenarios with alternative runway configurations traffic levels and mixes, routeings, operating procedures etc.

These four applications, A1, A2, B1 and B2, and the different demands and constraints they place on the model user, are described in **Chapter 5: Applications**.

Part III: Modelling Methodology (Chapters 6 - 9 and Appendices B, C and D)

The elements of modelling systems in general are reviewed in **Chapters 6** and **7**. There is no single, correct way to produce aircraft noise contours and many modelling systems have been developed in Europe and elsewhere. All involve the same elements and process: *input* ⇒ *noise model* ⇒ *output*. **Chapter 6: Noise models** describes the two component parts of a model: (1) an *engine* which performs the calculations and (2) a *database* which provides key information on aircraft noise and performance characteristics. It is neither possible nor necessary for this guidance to review, compare or contrast different models; the purpose is only to present what is presently considered to be ‘best available’, or at least good, practice. It is axiomatic that for any one scenario there is only one correct set of noise contours. Users must strive to achieve the best possible estimate of that ‘truth’, recognising that in most instances the contours will be the only estimate made available.

A physical model is a computer software package, which generates a noise contour map from *inputs* describing appropriate features of an airport and its operations. Provision might also be required to take account of the airport surroundings - e.g. the ground elevation and surface conditions and ambient meteorology. The modeller's job is to ensure that the calculations yield noise contours that meet specified requirements, normally via use of best available practice.

The practitioner's job is to ensure that the analysis adequately meets the end-user's needs efficiently and cost-effectively. This means matching the scope of the study to the magnitude of the problem and the resources available. Always, a major task for the practitioner is to provide the *inputs* (see **Figure 1-1**) - describing the airport (runway configuration), aircraft traffic (types and numbers), routeings (mean tracks and dispersions), operations (aircraft weights and operating procedures) and the surrounding environment. Together these comprise the *scenario*. The *outputs*, the sizes and shapes of the noise contours, are extremely sensitive to changes in those inputs and a crucial part of the assessment task is first to identify which factors are most critical and secondly to ensure that the variables used to quantify those factors are defined with sufficient accuracy. No matter how good the model, the results can only be as good as the inputs; whence the time-honoured adage - “rubbish in, rubbish out”!

The problems caused by the noise of transport aircraft operating from civil airports have long been recognised and a great deal of technical knowledge has been amassed. Other branches of aviation suffer problems too, but there is rather less technical understanding of them. The reasons why it has not yet been possible for ECAC to develop similar modelling guidance for other categories of aircraft is explained in **Appendix B**.

Obtaining reliable information necessary to ensure that proper account is taken of the key factors is usually the most difficult and time-consuming part of the practitioner's work. It often requires painstaking search, investigation, collection, and sometimes direct measurements, to obtain the necessary data. **Chapter 7: Scenario data** provides guidance on the requirements for and sources of airport, aircraft, operational, meteorological and other data.

The requirements may be specified formally, e.g. by government statute, and to varying degrees of detail in terms of the noise metrics and the quantification of the effects - how many people experience changes of what magnitude and under what circumstances etc. Or they might be informal and very general - requiring an appraisal which is responsive to interim study findings. The end-user needs a good appreciation of the limits of noise modelling and impact assessment - what can and cannot be expected of them.

The end-user may or may not have existing modelling service provision. If not, for example when there is no official or designated noise model, it might be necessary to choose between different modelling options depending on the scale of the problem - commission a new model, import (and possibly amend) an existing one, improvise (an ad-hoc analysis might be used to handle relatively simple problems) or to ‘buy in’ service from elsewhere.

Volume 2: Technical Guide fully documents a modelling system which incorporates current best practice. This is designed to make use of an international aircraft noise and performance (ANP) database that is endorsed by ECAC. An outline description is provided in **Chapter 8: ECAC-recommended methodology**. Applied correctly, this methodology will generate aircraft noise exposure contours that are considered to be as accurate as practicable under present levels of understanding of the processes involved. It is recommended to member states by ECAC, with the proviso that other methodologies that produce equivalent results are to be considered equally acceptable.

Although this guidance is intended to provide a reliable common basis for aircraft noise modelling, at present, different states have adopted different approaches and **Appendix C** summarises current practice in a number of ECAC states.

Because accuracy depends on the integrity of all three parts of the modelling process - the inputs, the engine and the aircraft data, at present it is not practicable[3] for ECAC to specify or provide tests which can be used to evaluate modelling performance against standard benchmarks. For the foreseeable future, it will be part of the end-user's job to be satisfied that the modelling system is adequate. The criteria to be considered are accuracy, reliability, consistency, auditability and cost. The requirements for assessment are reviewed in **Chapter 9: Elements of good modelling practice**. In many circumstances it will be desirable for the practitioner and end-user to collaborate closely at the project definition stage (and seek advice from the modeller when necessary). Throughout, it is stressed that a crucial modelling need that is not always fully appreciated is for adequate reliable data on the aircraft operations that exert a dominant influence on the noise exposure patterns around airports. **Appendix D** gives advice on acquiring it.

Technical material

Although **Volume 1** generally avoids it, the mathematical background of some modelling methodologies are included for the benefit of technical readers. These are enclosed in grey panels like this. Non-technical readers may skip these as they are not necessary for a general understanding of the concepts

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[3] Because a very large number of test cases would be necessary to demonstrate that a modelling system delivered accurate results for a reasonable range of scenarios. Validation for one scenario would not necessarily be evidence of validity for another. The issue of model validation is a very complex one which it is proposed will be covered in a future third volume of ECAC guidance.

PART II PROBLEM DEFINITION

3 DEFINING SOUND (NOISE) EXPOSURES IN TERMS THAT RELATE TO EFFECTS

As stressed in the Explanation of Terms and Symbols, *sound* refers to the physical description of an event, whereas *noise* reflects human reaction to it. Noise is usually defined as unwanted sound. Strictly speaking, this guidance deals principally with aircraft sound and sound levels. However here, as elsewhere, the word *noise* is generally used as a synonym for sound, especially when - as is the case for aircraft - the sound is unwanted by the receiver.

3.1 NOISE EFFECTS

There are many different effects of noise on people and individuals experience them to different degrees. The effects can be separated into two broad categories as illustrated in **Figure 3-1**: (a) behavioural - the interference of noise with normal living - and (b) physiological - including possible health effects. At a *first* level of behavioural reaction, noise disturbs human activity - by causing distraction or by physically interfering with it. Grouped together under the general heading of disturbance, these effects include detection/distraction, speech interference, disruption of work/mental activity, and sleep disturbance. A *second* level of behavioural reaction, sometimes viewed as an indirect response to disturbance of different kinds, is annoyance. A *third* level response is overt reaction including complaints.

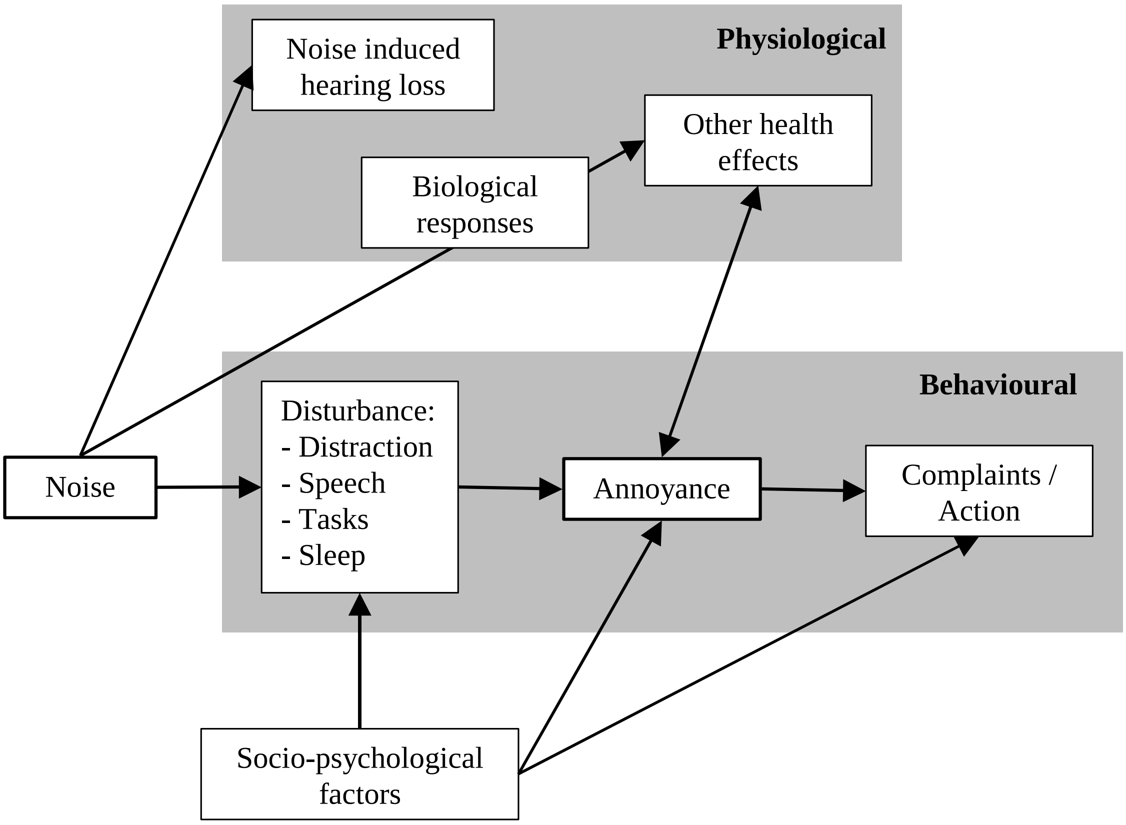

Figure 3-1: General cause and effect relationships

Possible health effects that might be caused by noise over a period of time include (1) noise induced hearing loss and (2) other, indirect, risks to physiological and psychological well-being. The first, which is a consequence of very high levels of sound exposure, is well-documented and is not considered likely to be caused by the levels of aircraft noise experienced beyond airport boundaries. The nature of the second is much less certain; it is known that noise can cause a variety of biological reflexes and responses referred to as *stress* reactions but whether, over a period of time, these could lead to clinically recognisable illness is unclear. Research into these continues in many countries.

The effects of noise have been extensively researched, particularly with the aim of establishing quantitative relationships between the amount of noise and the severity and extent of the effects. But behavioural reactions are essentially subjective and 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 the noise makers. The effects of such *modifying factors* dramatically weaken correlations between noise and response by masking or confounding their dependency on noise. Such relationships are further obscured by variations in noise exposure over time and space, because individuals move around and engage in different activities.

Obvious physical factors include time and situation which govern intrusions into activities - sleep disturbance occurs primarily at night, speech interference during the day and so on. But equally important are those that control attitudes and susceptibilities; whether or not a particular noise annoys may depend very much upon the message it carries; concerns about the sources of noise can influence annoyance reactions more strongly than physical sound exposure itself. Ultimately noise might give rise to complaints (or in more extreme cases other overt reactions such as petitions or public demonstrations) depending on various sociological factors such as historical events, the expectations of affected communities, publicity and beliefs that progress can be achieved via protest.

Because of the combined influences of acoustical and non-acoustical factors, it is difficult to isolate the underlying noise-response relationships. <u>In general, practical noise assessment methodology needs 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 only as long-term averages at representative locations.</u>

An essential conclusion from aircraft noise effects research is that *community annoyance* is the most useful general criterion of overall, long-term aircraft noise impact[4] and that it can be correlated with long-term average sound exposure. However, before considering community annoyance and noise-annoyance relationships, it is worthwhile reviewing the various effects of noise, and their interrelationships - with each other and with sound exposure.

Some noise-effect relationships - the connecting lines in **Figure 3-1** - can be quantified, others cannot. They are considered in **Appendix A**. Noise disturbance and short-term annoyance - immediate responses to individual noise events of relatively short duration - have been studied extensively in research laboratories. Laboratory experiments can be performed with great accuracy and they have provided a wealth of knowledge about the fundamental characteristics of human hearing and perception of sound.

But a detailed understanding of specific disturbance criteria is not particularly helpful when it comes to assessing the day-by-day impact of environmental noise on communities. The noise

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[4] The possibility that severe annoyance might itself induce stress is indicated in **Figure 3-1.**

experienced by individuals obviously depends on where they live and work and upon their lifestyles; no two people experience exactly the same sound exposure patterns over a period of time or the same interference with their activities. And different people react differently to the same sound; some are a great deal more sensitive than others. Coupled with the multiplicity of potential disturbance effects, these variations make studies in the community intrinsically much more complex than laboratory work. Yet it is only in that real world that the relationships between cause and long-term annoyance - as a consequence of total long-term sound exposure from all sources - can be investigated.

This long-term aspect of cause and effect has been the primary influence on the direction that field research on noise effects in the community has taken. Community annoyance has been adopted as a general indicator for all of the possible impacts of environmental noise. In social survey studies, individuals' annoyance has been measured in a variety of ways - quantifying it on simple numerical or category scales or via elaborate multi-question procedures. These measurements have then been correlated with various measures of typical sound exposure, first to decide what is the appropriate scale or metric, and then to 'calibrate' the scale, that is to determine the exposure-response relationship. In such correlations, the overall impact of noise is sometimes expressed as an average across individuals or, alternatively, as the incidence of high annoyance (such as the percentage of respondents 'very much annoyed').

3.2 NOISE SCALES AND LEVELS, METRICS AND INDICES

3.2.1 NOISE SCALES: FREQUENCY WEIGHTING

Fundamental products of psychoacoustic research are the various decibel *scales* used to define and measure sound in terms that can be related to human perception. An important property of sound is its *frequency spectrum* - the way that its acoustic energy is distributed across the audible frequency range (from 20 Hz to 20 kHz approximately). Two particular scales are important for aircraft noise - *A-weighted sound level* and *Tone-corrected Perceived Noise Level*. These account for frequency spectra in different ways.

The A-weighting is a simple filter applied to sound measurements which applies more or less emphasis to different frequencies to mirror the frequency sensitivity of the human ear at moderate sound energy levels [ref. 4]. A-weighted sound level is an almost universally used scale of environmental noise level: it is used for most aircraft noise monitoring applications as well as for the description of road, rail and industrial noise. A-weighted levels are usually denoted as L_A.

Tone corrected perceived noise levels (denoted L_{PNT}) are used uniquely for precision aircraft noise measurement. They account for intricacies of human perception of noise from broadband sources containing pure tones or other spectral irregularities. L_{PNT} is calculated by a rather complicated procedure from 1/3-octave spectra [ref. 3].

The noise impact assessments that generate the need for noise exposure contours generally rely on A-weighted metrics and these are therefore of primary interest in this guidance; although there are exceptions, Perceived Noise Level applications are confined mostly to aircraft design and certification.

3.2.2 NOISE METRICS

Noise *metrics* may be thought of as measures of noise 'dose'. There are two main types, describing (1) single noise events (*Single Event Noise Metrics*) and (2) total noise experienced over longer time periods (*Cumulative Noise Metrics*). Note that all decibel values, whether they relate to basic scales, event metrics or cumulative metrics, are generally referred to as *levels* - indeed in acoustic measurement, a *level* is always a decibel value.

Noise levels are usually defined at fixed observer locations or mapped as contours (i.e. iso-lines) depicting the area where the specified levels are exceeded. They are used - especially cumulative metrics - in all domains of transportation noise: road, railway and air-traffic, as well as for the description of the noise produced from industrial sources, recreational activities etc. In practice, contours are almost always estimated via calculation whereas values at specific locations can also be measured directly (except in the case of forecasts).

3.2.3 SINGLE EVENT NOISE METRICS

These are used to describe the acoustic event caused by a single aircraft movement[5]. Two types are in common usage, both can be determined by measurements as well as by calculations using suitable models (that are the principle subject of this guidance). They are (1) L_{max}, based on (1) the maximum sound intensity during the event and (2) L_E, based on the total sound energy in the event. The total sound energy can be expressed as the product of the maximum sound intensity and an 'effective duration' of the event.

An aircraft noise event can be described by its observed level-time-history *L(t)*.

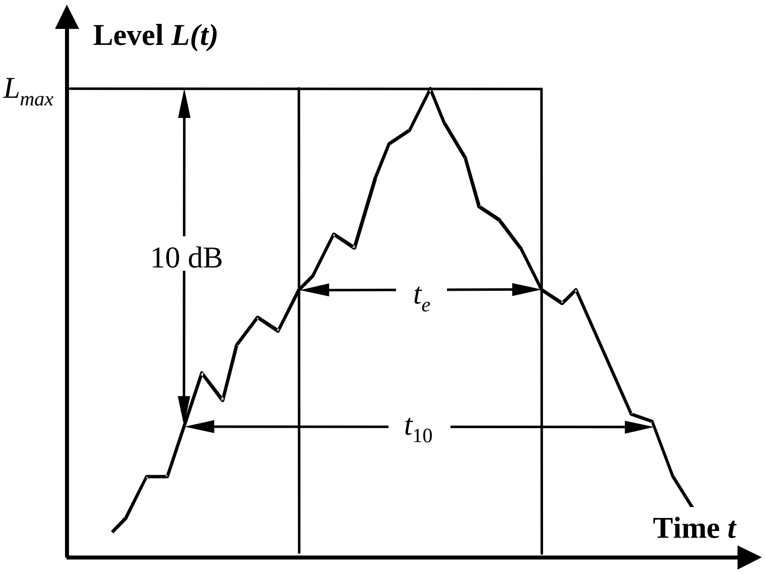

Figure 3-2: Level-time-history of a noise event and noise-related parameters.

In **Figure 3-2** the characteristic properties of a representative noise event are illustrated in relation to the time history of L(t)[6]. These are the maximum (frequency-weighted) sound level L_{max} and a duration *t*. Common definitions of the duration are:

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[5] In general one aircraft movement generates a single event at an observer location. However if the aircraft passes by more than once, e.g. before and after a turn, there might be more than one discrete event.

[6] The 'instantaneous' sound level *L(t)* is conventionally measured using the *slow* response setting of standard sound level meters.

- The *effective duration, t_e*, i.e. the duration of a noise event with the constant level L_{max} that contains the same sound energy as the noise event[7] described by the level-time-history *L(t)*.

- The *10dB-down-time, t_{10}*, is the time period during which the sound level *L(t)* lies within 10 dB of the maximum sound level L_{max}. The 10dB-down-time is typically twice as long as the effective duration t_e.

Three corresponding single event metrics of particular importance in aircraft noise [refs. 1,2,3] are (1) Maximum A-weighted Sound level (abbreviation L_{Amax}), (2) *Sound Exposure Level* (acronym SEL, abbreviation L_{AE}) and (3) *Effective Perceived Noise Level* (acronym EPNL, abbreviation L_{EPN}).

Two of these, L_{AE} and L_{Amax}, can be measured directly with a standard precision sound level meter. Theoretically, L_{AE} is generally preferable because it accounts for the duration of the event as well as its intensity[8] and is a building block of L_{eq} the primary cumulative noise measure (see Para 3.2.4). But, for aircraft noise, L_{AE} measurements are more susceptible to interference from *background* noise and, moreover, many non-specialists find the L_{AE} concept difficult to grasp, especially because - for the same event - L_{AE} usually exceeds L_{Amax} numerically, typically by around 10dB. Thus L_{Amax} is still the favoured metric for day to day noise monitoring at airports.

EPNL is the metric for aircraft noise certification limits laid down by ICAO Annex 16 [ref. 3], which all new civil aircraft have to meet. The certification process involves comprehensive flight tests in which single event noise levels are measured and subsequently adjusted to standard day conditions. Certificated noise levels are determined at three specified reference points during standardised take-off and approach profiles, one under the approach path and two near to the departure path[9]. But the process yields large quantities of data in addition to these three basic numbers, in A-weighted as well as PNL form; those are an important source of data for noise modelling.

Certification gives noise levels at specific points rather than information on the total noise in the general vicinity of the flight path. An indication of the latter is provided by contours of constant single event noise level - so-called “noise footprints”. Noise footprints are useful performance indicators for noise abatement flight procedures since they reflect the impact of noise on the ground of the whole flight path (flight altitude, engine power setting and aircraft speed at all points) rather than only from a part of it.

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[7] The effective duration depends on how the start and end of the event are defined. As a minimum the highest 10dB of the event should be included, and this is commonly adopted. If energy outside that interval is included the reference duration tends to be a little higher; of course the convention adopted should always be made clear.

[8] Values of L_{AE} depend on the measurement threshold - see panel on *time integrated levels*.

[9] Noise certification is part of the process by which the implementation of optimum aircraft noise control technology is assured. It involves tests which employ special flight test procedures which may or may not reflect normal airline practice. Although EPNL data can be obtained from aircraft noise and performance databases, point EPNLs calculated using noise contour models are generally not comparable to certificated values.

TIME-INTEGRATED LEVELS (SINGLE EVENT SOUND EXPOSURE LEVELS)

An integration of the level-time-history results in a “Single Event Sound Exposure Level” L_E which can be expressed as

$$L_E = 10 \cdot \lg\left(\frac{1}{t_0} \int_{t_1}^{t_2} 10^{L(t)/10} \, dt \right) \tag{3-1}$$

where t_0 denotes a reference time. The integration interval $[t_1,t_2]$ should be chosen to guarantee that all significant sound of the stated event is encompassed.

Using the effective duration t_e, which can be defined by

$$t_e \cdot 10^{L_{max}/10} = \int_{t_1}^{t_2} 10^{L(t)/10} \, dt \tag{3-2}$$

equation (3-1) can be rewritten approximately as:

$$L_E \cong L_{max} + 10 \cdot \lg\left(\frac{t_e}{t_0} \right) . \tag{3-3}$$

For the A-weighting and perceived noisiness equation (3-1) results in the “Sound Exposure Level” L_{AE} (acronym SEL) and the “Effective Perceived Noise Level” L_{EPN} (acronym EPNL):

$$L_{AE} = 10 \cdot \lg\left(\frac{1}{t_0} \int_{t_1}^{t_2} 10^{L_A(t)/10} \, dt \right) \quad \text{with } t_0 = 1 \text{ second} \tag{3-4a}$$

For practical reasons, the limits t_1 and t_2 are chosen at the times when the level *L(t)* is 10 dB below $L_{A,max}$*(slow)*. This "10 dB down" L_{AE} (which the ANP database provides) may be up to 0.5 dB lower than the L_{AE} evaluated over a longer duration.

$$L_{EPN} = 10 \cdot \lg\left(\frac{1}{t_0} \int_{t_1}^{t_2} 10^{L_{PNT}(t)/10} \, dt \right) \quad \text{with } t_0 = 10 \text{ seconds} \tag{3-4b}$$

Using the simplifying notation of equation 3-3, equations 3-4a and 3-4b can be written as:

$$L_{AE} \cong L_{A,max} + 10 \cdot \lg\left(\frac{t_e}{t_0} \right) \quad \text{with } t_0 = 1 \text{ second} \tag{3-5a}$$

$$L_{EPN} \cong L_{PNT,max} + 10 \cdot \lg\left(\frac{t_e}{t_0} \right) \quad \text{with } t_0 = 10 \text{ seconds} \tag{3-5b}$$

3.2.4 CUMULATIVE NOISE METRICS AND INDICES

The practical benefits of being able to express both long- and short-term noise exposures and limits by simple, single-valued indices are obvious. Equally, it is desirable that the long- and short-term measures can be linked effectively. Without such tools it would be very difficult to make informed comparisons of noise exposure changes over time, whether these are concerned with historical trends or making judgements about the effectiveness of alternative noise control measures and/or changes in the number and intensity of noise events.

Single event metrics are indicators of the intrusiveness, loudness, or noisiness of individual aircraft noises. Cumulative metrics used to measure long-term noise are indicators of community annoyance. But for aircraft noise it is logical that they represent aggregations of single events in some way. A practical noise index must 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.

Community annoyance research (much of which has been concerned with the noise of aircraft and road traffic), and the search for reliable long-term noise rating procedures, started in the mid 1950s. As instrumentation for measuring long term noise was very limited then and for some time afterwards, early noise indices tended to incorporate measures that could be obtained manually or by simple mechanical means. Aircraft noise near airports could (and still can) be characterised by statistics describing individual noise events, such as their average levels and numbers. The noise of heavy road traffic, on the other hand, is made up of a very large number of overlapping events and it was then more appropriate to determine level distribution statistics such as L_{10}, the level exceeded for 10% of the time.

On the whole, aircraft noise affects far fewer people than road traffic noise but can reach high exposure levels close to busy airports. Here a separate identification of event levels and numbers of events focuses attention on the relative contributions of these two variables to annoyance. As the decibel scale is logarithmic, long term aircraft noise exposure indices can be logically and conveniently expressed in the form $\overline{L} + K \lg N$, where $\overline{L}$ is the average event level (in decibels of some kind), N is the number of events during the time period of interest, and K is a constant which quantifies the relative importance of noise level and number. Many different indices have been investigated, involving varying degrees of elaboration (some very complex), and a variety remain in use in different countries. However, most embody the same basic form - the main difference of significance is the value of the constant K.

Various ‘tradeoffs’ between $\overline{L}$ and N have been postulated, but putting K exactly equal to 10 embodies the ‘energy principle’, that the adverse effects of noise depend upon the total amount of noise energy involved. A 3 dB increase in noise exposure represents a doubling of total noise energy. This could be caused by, for example, a doubling of numbers, a doubling of the average noise energy per event or some intermediate changes in each. The ‘trade-off’ is that, in terms of overall noise impact, a 3 dB change of average event level has the same amount of effect as a twofold change of numbers of events.

The energy principle is the basis of *Equivalent Sound Level,* L_{eq} and derived indices:

$$L_{eq} = \overline{L_E} + 10 \lg N - \text{const.} \tag{3-6}$$

where $\overline{L}_E$ is the average single event level of the N events experienced during the specified time interval. The constant term depends on that time interval; for 24 hours it is 49.4dB (= 10·lg[number of seconds in 24 hours]).

As a simple, logical and a convenient measure of average sound energy, L_{eq} fully meets the requirements of an indicator of long-term environmental noise exposure. Although uniquely defined, it can be used flexibly to meet particular needs and circumstances; for instance it can be averaged over short, medium or long periods of time.

Some situations however cannot readily be dealt with by simple L_{eq} assessments. This is especially true when contributory noise events vary substantially and/or irregularly. Care has to be taken to consider the distribution of events when choosing the most appropriate assessment period. For example (outside aviation) 8-hour L_{eq} may provide a good indication of noise exposure on a factory production line if the pattern of noise changes little from hour to hour during an 8-hour working day. It may also provide a good basis for comparing noise exposures between different production lines. But care must be taken to ensure that the period chosen is reasonable for all the production lines being compared. In other words, the period over which L_{eq} is calculated has to be relevant to the pattern of noise exposure and any comparisons have to be on the basis of like for like. The same principle applies to noise from aircraft and from other sources.

A factor of obvious importance is *where* sound levels are defined or measured. Sometimes this should be at the listener's ear - and this is common practice in special laboratory investigations of the fundamental relationships between sound level, frequency, and human judgements of loudness. Here suitable placements of measuring microphones can readily be arranged. But this is much more difficult when dealing with community noise exposures over substantial periods of time and, often, over large areas. Different people experience very different patterns of noise exposure as they move about - even within a small area - in and out of buildings and between rooms inside buildings. Therefore, when establishing noise-response relationships and planning criteria, it is usually necessary to limit the degrees of freedom and specify indicative noise levels.

Thus aircraft noise contours describe outdoor levels - because circumstances would vary greatly indoors according to the shape, size, orientation and layout of buildings and the types of construction, whether sound insulated as well as whether windows were open or closed. And the outdoor conditions themselves have to be carefully specified so as to avoid further confounding local effects[10]. It is also very important to consider the consequences of measurement position when evaluating research data or applying planning criteria in specific situations.

A final important point about A-weighted sound levels is that their numerical magnitudes are very dependent on the metric concerned. For example if, during a particular hour, four aircraft noise events occurred each with $Lmax$ = 80 dBA, $L_A\ (t)$ would vary between the background level, which might be 55 dBA, and the maximum event levels of 80 dBA. Because of its duration, each event SEL would be some 10 dB higher, around 90 dBA. The aircraft noise L_{eq} would be about 60.5 dBA. The total L_{eq}, combining the background and aircraft components, would be about 61.5 dBA. This shows how the higher levels of sound

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[10] Usually these outdoor levels are measured by a microphone positioned a few feet above 'soft' level ground in an area away from extraneous sources of noise and sound-reflecting surfaces which could otherwise distort sound level readings (of the kind that give rise to the need for a façade correction' when calculating road traffic noise levels close to building surfaces).

energy of the aircraft events dominate the exposure assessment. It should also be noted however that the L_{eq} values are substantially lower than the event levels, both $Lmax$ and SEL. This is because L_{eq} reflects time-averaged sound energy and, in this example, the aircraft events endure for perhaps 2% of the hour.

3.2.5 RELATIONSHIPS BETWEEN SOUND EXPOSURE AND COMMUNITY ANNOYANCE: NOISE INDICES

The search for noise annoyance predictors has revealed that although average long-term annoyance is readily determined (one way is to ask social survey respondents to rate their individual annoyance on a numerical or category scale such as ‘not at all’, ‘a little’, ‘moderately’, ‘very much’), this is only weakly governed by the magnitude of the sound exposure. In statistical terms, only about one quarter of the observed inter-individual variation in annoyance can be related to the average level of sound exposure (however defined). This low correlation reflects very large differences between individuals’ reactions to the same amount of sound energy (due to the modifying non-acoustic factors) rather than a failure of experimental design. Uncertainty also arises due to inevitable inaccuracies in the definitions of both noise and annoyance and to simplifications of the cause-effect process**.**

Researchers have tried to identify and quantify the sources of this human variation because it masks the true nature of any underlying noise effect. It is this research which 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 which have accounted for socio-psychological factors as well as noise exposure, have been found to explain as much as 50% of the variation in annoyance (although these predictors are of little more practical value than noise-only metrics because in most circumstances the non-acoustical factors are themselves unknown).

Attempts have been made to define multi-dimensional noise rating indices which make suitable allowance for some of the more obvious influences. Among these influences are

(a) situational factors - environmental expectations are greater at home than at work for example,

(b) time of day - probably linked to (a) but, for example, recognising that noise is less tolerable by night than by day, and

(c) the source of the noise - it has been found that, dB for dB, people are more tolerant of railway trains than road vehicles for example - and that aircraft can be considered more annoying than either.

Some authorities have introduced weightings into L_{eq} to account for a variation of community noise sensitivity across the 24-hour day. Acceptance that noise is less tolerable during the evening and even less at night than during the day is reflected in a modified version of L_{eq} that has been adopted to describe environmental noise exposure. Known as *Day-Evening-Night Level*, DENL (symbolised L_{DEN}), this includes a 5dB evening weighting and a 10 dB night weighting. All noise occurring during the evening is augmented by 5dB and during the night by 10 dB before the noise energy level is averaged over a full 24 hours. For aircraft noise this means that evening and night flights contribute as much to DENL as, respectively, three and ten identical daytime flights. A similar, widely used index is *Day-Night Level* DNL (symbolised L_{DN}) which applies the night weighting only.

In recognition of the special problem of sleep disturbance, night-time limits are sometimes applied to the noise of single events. To implement this kind of control, whilst at the same time limiting the total noise dose generated by several flight events L_{eq} limits can be specified for successive periods of one hour.

CUMULATIVE NOISE INDICES

Time-weighted equivalent sound levels can be expressed in a generic manner by the formula

$$L_{eq,W} = 10 \cdot \lg\left[\frac{t_0}{T_0} \cdot \sum_{i=1}^{N} g_i \cdot 10^{L_{E,i}/10}\right] + C \quad . \tag{3-7}$$

The summation is performed over all N aircraft noise events that occur during the specified reference time period T_0. The level $L_{E,i}$ is the single event noise exposure level of the i-th noise event. The coefficient g_i is a time-of-day dependent weighting factor (usually defined for day, evening and night periods). The constant C can have different meanings (normalising constant, seasonal adjustment etc.). In fact g_i is simply a multiplier which indicates relative impact: one event during the i-th period is equivalent in noise impact terms to g_i events. Using the relationship

$$g_i = 10^{\Delta_i/10}$$

equation 3-7 can be rewritten as

$$L_{eq,W} = 10 \cdot \lg\left[\frac{t_0}{T_0} \sum_{i=1}^{N} 10^{(L_{E,i} + \Delta_i)/10}\right] + C \tag{3-8}$$

where the impact weighting is expressed alternatively by an additive level offset Δ_i.

Table 3-1 lists a number of time-weighted equivalent sound levels currently in use and shows the parameters needed for their calculation.

Table 3-1: Parameters for different forms of equivalent sound levels L_{eq} according to equation 3-7 [refs. 1,2,5]

L_{eq}	$L_{E,i}$ [dB]	t_o [s]	C [dB]	T_O⁽¹⁾ [s]	g_i⁽²⁾		
					day	evening	night
$L_{Aeq,24h}$	L_{AE}	1	0	86400 N_{Tr}	1	1	0
$L_{Aeq,day}$ (3)	L_{AE}	1	0	57600 N_{Tr}	1	0	0
$L_{Aeq,night}$	L_{AE}	1	0	28800 N_{Tr}	0	0	1
L_{DN}	L_{AE}	1	0	86400 N_{Tr}	1	1	10
L_{DEN} (4)	L_{AE}	1	0	86400 N_{Tr}	1	3.162(5)	10

$L_{Aeq,24h}$	24-hour average sound level
$L_{Aeq,day}$	16-hour day-average sound level
$L_{Aeq,night}$	8-hour night-average sound level
L_{DN}	Day-night average sound level
L_{DEN}	Day-evening-night sound level

(1) The reference time period T_0 is the product of the number of seconds of the part of the day the descriptor is defined for and the number of days N_{Tr} the basic scenario air traffic is defined for.

(2) Day, evening and night intervals are specified to accommodate local lifestyles.

(3) $L_{Aeq,day}$ is defined for the combined 16 h of day and evening period .

(4) The index L_{DEN} adopted as a harmonised descriptor by the European Commission is defined for day, evening and night periods of 12h, 4 h and 8 h (although some flexibility is allowed for) [ref. 6].

(5) The value g_i = 3.162 corresponds to a level offset Δ_i = 5 dB in equation 3-8.

INDICES BASED ON MAXIMUM LEVELS

Some (nationally used) noise descriptors are based on event maximum noise levels rather than on time integrated metrics. An example is the average maximum sound level:

$$\overline{L_{max}} = 10 \cdot \lg\left[\frac{1}{N}\sum_{i=1}^{N} 10^{L_{max,i}/10}\right] \tag{3-9}$$

Fields of application are situations with a relatively low equivalent sound level but high maximum levels (e.g. aerodromes with a relatively small number of jet operations).

Once popular but now largely supplanted by equivalent continuous sound levels, some indices account for both $\overline{L_{max}}$ and event numbers N by a relationship of the form

$$I = \overline{L_{max}} + K \cdot \lg N \tag{3-10}$$

where the coefficient K defines the relative weight given to event numbers rather than event levels.

The index *"Number Above Threshold"* NAT_X represents the number of noise events reaching or exceeding a threshold value X of the maximum sound level. *NAT*-criteria can be defined for specific parts of the 24-h day; some states consider night values (e.g. $NAT_{Night,70}$) to be suitable indicators of wakeup reactions.

TIME ABOVE THRESHOLD

The descriptor *Time Above Threshold, TA,* is used in some non-ECAC states. TA_X denotes the time for which a threshold level value X is exceeded by aircraft noise. Although this appears similar to *NAT* criteria, there is a fundamental difference: for the estimation of *NAT* only the maximum sound levels of noise events have to be determined. Values of *TA* on the other hand depend on the complete noise time histories of the events and these are more difficult to estimate accurately. Simulation models can be capable of calculating reasonably accurate time-histories, but *TA* is otherwise modelled on the basis of simplifying assumptions which inevitably are less accurate. As there is no known use of *TA*-metrics in ECAC member states, they are not covered by this guidance.

Figure 3-3 shows a typical graph of 'percentage highly annoyed' people plotted against noise exposure level based on data from numerous social survey studies of public reactions to aircraft noise carried out in different countries[11]. Each point in the diagram represents the response of a sample of respondents exposed to a particular level of noise.

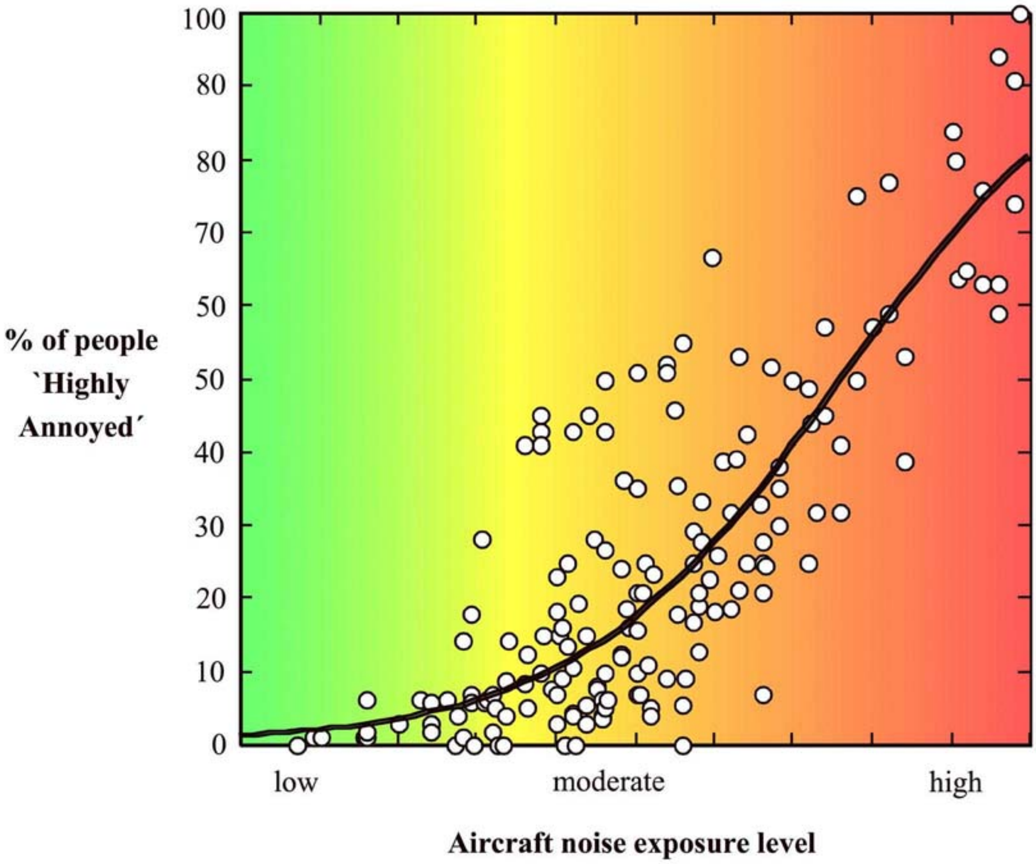

Figure 3-3: Incidence of community annoyance from social survey data

The curve is a 'best fit' to the data points[12]. It is a statistical estimate of the underlying trend between annoyance and the noise index. However, it is evident that the scatter of the data is high; deviations of many individual points from the trend line are substantial. At least three reasons for this scatter can be postulated. *First*, the substantial variations in individual reactions attributable to the many modifying non-acoustical factors mean that the measured group responses also vary more than would be expected on noise grounds alone. *Second*, the group responses, as statistical estimates of 'population characteristics', are subject to marked sampling errors due to limited sample sizes. *Third*, merging data from different studies is inevitably confounded to some extent by inevitable differences in the definitions of annoyance (especially where different languages are involved), thresholds of high annoyance, and noise exposure variables. Despite these limitations, the curve illustrates the probable form of the relationship between community noise exposure and community annoyance. It

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[11] This particular analysis was first published in 1978 and updated in 1991 (Schultz, T.J: J. Acoust. Soc. America, 64, 377-405, 1978; Fidell, S., Barber, D.S., Schultz, T. J: J. Acoust. Soc. America, 89, 221 - 233, 1991).

[12] This is a 'logistic regression' curve - used to depict an underlying trend in 'proportional' data in which values cannot lie outside the range 0 - 100%. Thus the curve is asymptotic to 0% at low noise exposure levels and to 100% at high levels.

aggregates results from many surveys in different countries and it may be considered typical, if not average.

3.2.6 PRACTICAL NOISE IMPACT ASSESSMENT

The well-documented community effects of aircraft noise include disturbance of various kinds and annoyance. The possibility of wider 'health effects' has been postulated but, as yet, scientific conclusions are much less clear. With regard to noise impact assessment, the practice is to use 'community annoyance' as the principal response measure. If there are stress-related health effects, then annoyance is likely to be a significant contributor, as indicated in **Figure 3-1**.

Environmental noise assessment is not, and never can be, an exact science at the level of the individual. Noise event levels and noise exposure contours provide indications of the likely extent and severity of the general effects of aircraft noise on communities or people, but they cannot indicate accurately how particular individuals will react. Nor is it usually possible to determine absolute environmental goals or limits of acceptability. The main application of current aircraft noise assessment methodology is in comparing the effects of different noise exposures that might result from changes to an airport and its operations (or between different possible future scenarios). It is usual practice to compare, for the *before* and *after* situations, the numbers of people resident between noise exposure contours depicting low, moderate and high levels of exposure and thus determine the changes in the extent of annoyance in the community.

3.2.7 SETTING AIRCRAFT NOISE GOALS AND LIMITS

It is stressed that **Figure 3-3** is presented here, not as a definitive relationship between noise and annoyance - other such compilations of data exist and choice of database as well as interpretation of critical levels of annoyance are matters for local decision by those conducting noise assessments, but as an illustration of the nature of such relationships. It is likely that across the very varied societies and climates of the ECAC States, attitudes to noise from aircraft and other sources vary markedly and what criteria are appropriate for one state might not be so for another.

Despite such differences, the problems faced by policymakers, planners and legislators are everywhere very similar. Because of the relatively low statistical correlation between noise exposure and effects, exemplified by the data in **Figure 3-3**, it is not possible to identify unequivocal limits of acceptability. At best, noise goals and limits can only be expressed in statistical terms - e.g. the percentages of the exposed populations likely to be adversely affected to specified degrees. Thus aircraft noise contours usually define the boundaries of areas where residents experience outdoor noise levels greater than specified index values - normally taken to represent 'low', 'medium' and 'high' levels of exposure (typically separated by 5 or 6 dB).

Figure 3-4 shows an example set of contours. As in **Figure 3-3**, the colours indicate low (green), moderate (yellow) and high (red) levels of noise impact. The transition from one colour to another reflects the obvious reality that there are really no clear dividing lines between shades of impact. For practical (e.g. 'head counting') purposes it is necessary to draw precise boundaries but the two diagrams are reminders that they are not definitive.

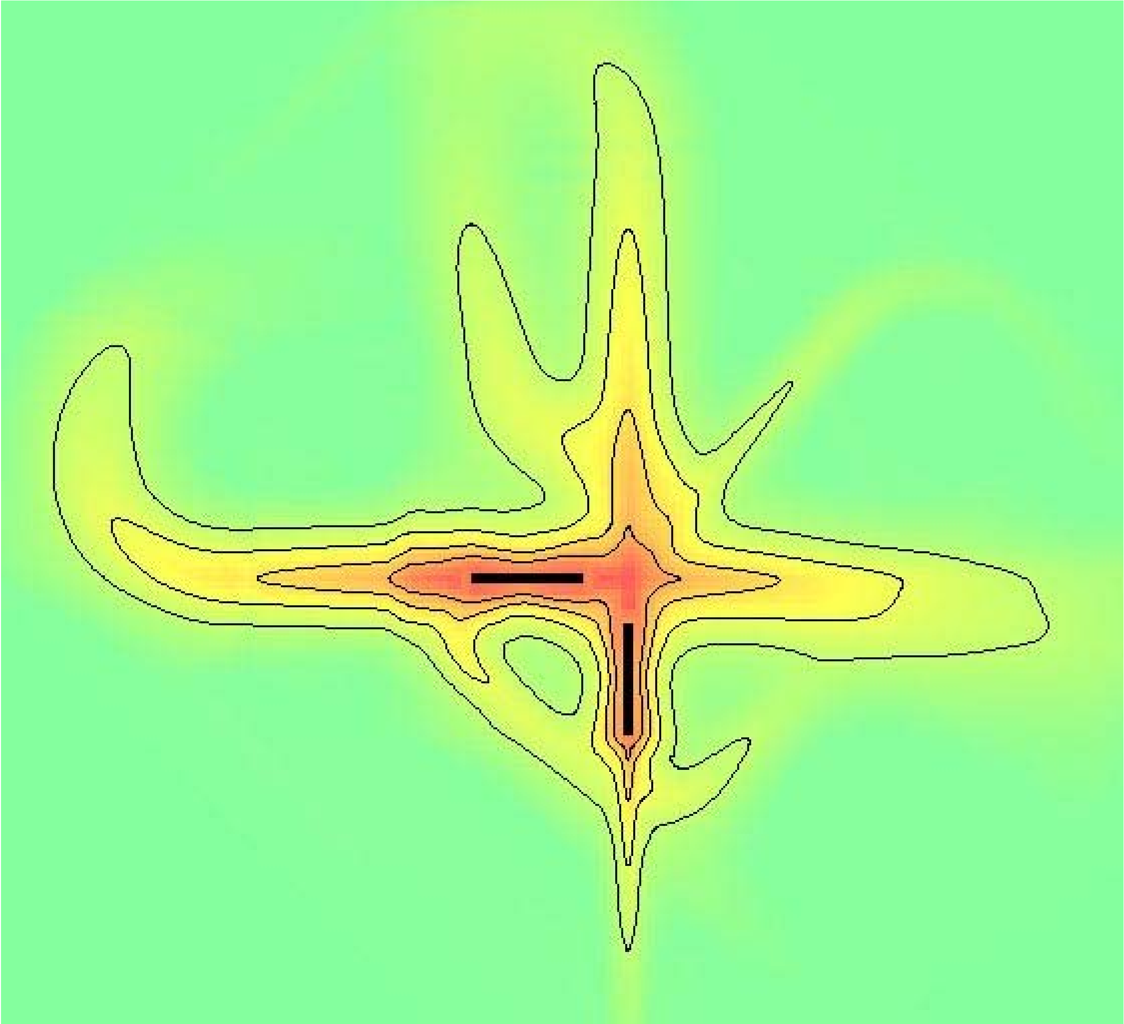

Figure 3-4: Illustrative aircraft noise contours for a hypothetical 2-runway airport

Different states use different noise metrics and indices, different interpretations and different contour conventions. **Appendix C** outlines examples of practice in some ECAC States.

Although noise contouring is a well established practice for depicting the extent and severity of aircraft noise impact around airports, contours are often criticised by those impacted for being too coarse and for not revealing important features of the noise such as the balance between the levels and numbers of individual events and their distribution across the hours of the day and night. It is of course true that they do not; it has been explained that noise exposures are commonly defined only as long-term averages because effects on the community too can only be described in broad statistical terms. More information can be made available but that might be impossible to interpret in terms of community impact.

Nevertheless, despite that obstacle, many authorities have found that providing additional information helps to inform the public discussions and consultations that are such an important part of effective noise mitigation programmes. Examples of additional information that can be obtained via noise modelling include:

- The average event levels ($\overline{L_{\max}}$, L_{AE}) during specific time periods (such as day, evening and night)

- The average numbers of events during specific time periods
- The average numbers of events exceeding certain critical levels during specific time periods ('number above threshold' NAT)
- The amount of time for which aircraft noise rises above certain noise level thresholds ('time above threshold') during specific time periods

'Additional information' which is commonly presented is average *event* level at night because that is sometimes considered to be a more appropriate indicator of sleep disturbance potential than any cumulative noise index level. Thus noise impact boundaries are sometimes defined as the envelope of exposure level contours and event level footprints.

3.3 NOISE MEASUREMENT & MONITORING

3.3.1 GENERAL

Although the subject of this guidance is noise modelling, essential parts of the practical modelling process include provision of aircraft noise data and validation of the modelling outputs. Both involve physical measurement of noise metrics.

It needs to be understood from the outset that the measurement of long-term sound exposures from aircraft is not normally possible as it would require acceptable weather conditions and 100% functional instrumentation and data collection for the entire time period of interest - normally up to 12 continuous months. (And to generate even rudimentary contours this would have to be done at a very large number of locations.) Thus, in practice, to determine cumulative sound levels at appropriate locations by measurement, it is necessary to estimate them statistically from analyses of data samples. There are normally two options: first to measure the cumulative noise for extended periods during which the mix of aircraft traffic and operations mirror long term averages. The measured averages would then be statistical estimates of the long-term values over the time period the measurements were performed. The second is to collect data separately for each individual noise-significant aircraft type and operation. Values of cumulative metrics and indices can then be constructed by weighted aggregation of the aircraft type data, where that data are appropriately averaged single event levels. This option allows extrapolation of the noise exposure to air traffic scenarios that differ from that during the measurement period.

It is not a purpose of this document to specify aircraft noise measurement and monitoring requirements.[13] However, this chapter outlines the practicalities and pitfalls of collecting noise data for use in aircraft noise modelling, whether as input data themselves or for validating a model for practical application.

3.3.2 REQUIREMENTS

Single event noise levels are dependent on the following variables (amongst others):

- the aircraft type;

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[13] Technical information on aircraft noise monitoring systems can be found elsewhere, such as ICAO Annex 16, Appendix 5: *Monitoring Aircraft Noise on and in the Vicinity of Aerodromes* [ref. 7], SAE Draft Aerospace Recommended Practice ARP 4721: *Monitoring Noise from Aircraft Operations in the Vicinity of Airports* [ref. 8], and ISO-standards 1996 and 20906 [refs. 1,2], as well as from equipment manufacturers.

- the engine type;
- the flight configuration along the flight path (weight, speed, flap positions, position of landing gear, etc.);
- the power setting;
- the meteorological conditions which influence the performance of the aircraft as well as the propagation of its noise;
- the distance between the aircraft and the microphone;
- the type of ground (hard and/or soft acoustical surface)
- the presence of other reflecting surfaces

For energy-based metrics, the time-histories of some of these variables are also of relevance because sound reaches the observer from a finite length of the flight path, not just along the shortest path between flight path and observer (the assumption made when considering L_{max} metrics).

Because of all these variables, event levels at any ground location vary markedly, even for a single airframe/engine combination. Some of the variance is predictable - and can effectively be eliminated by ‘normalising’ the data, classifying it into sub-categories (e.g. of aircraft weight) and applying accepted theory to correct the measurements to standard values of the input variables (e.g. to standard atmospheric conditions and specific slant distances). Other contributions to the variance, especially those due to along-path configuration changes, has more complex origins and can only be handled iteratively; i.e. by trial-and-error refinements to the corrections. When all known factors have been accounted for in this way, the residual variance which will appear quite random has to be attributed to unknown or unpredictable effects - whether operational or environmental. The magnitude of this uncertainly can be reduced by increasing the sample size - the number of measurements for analysis - and whence narrowing the confidence interval about the estimated mean values.

The most common way of normalising aircraft noise data is to reduce it to so-called ‘noise-power-distance’ (NPD) relationships: tables or graphs of single event level versus slant distance from the flight path, for a standard flight speed but different power settings[14]. For max-intensity metrics this is demonstrably straightforward. For energy metrics, the levels are conventionally defined as those generated by an aircraft in steady flight along an infinite straight flight path. To what extent this ideal is approximated in the field obviously depends on a lot of operational factors. As a minimum, it is necessary to check that deviations from them, due for example to changing velocity (speed and/or direction), are likely to be negligibly small - or to account for them in some way when comparing measurement and model.

Measurements, using various kinds of sound level meters, are made in a variety of ways and circumstances depending on needs and precision required. For the purposes of this guidance, three basic measurement regimes need to be recognised - (1) standard aircraft noise certification, (2) special field measurement and (3) airport noise monitoring.

Noise certification is carried out to ICAO standards by the aircraft manufacturers under the scrutiny of national airworthiness certification authorities and is thus recognised as meeting the highest quality standards. *Special field measurements* are sometimes carried out by national aeronautical laboratories, or similar, under equally stringent test conditions,

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[14] The noise also varies with lateral direction (lateral directivity) but this is handled separately. NPDs are conventionally defined directly below the aircraft - i.e. normal to the wing flight-path plane.

specifically to provide high quality noise modelling data. The primary purpose of *airport noise monitoring* is usually to provide information to airport operators and others involved in operational noise mitigation, not to provide noise modelling data. However, modern monitoring systems are often extensive and sophisticated and, although the aircraft operations and other factors are not under the control of the analyst, the data from them, supplemented as necessary by information from other sources, is widely used for noise modelling purposes. All three data sources are considered here. Reference is also made to radar-measurement of aircraft flight paths which is covered in **Chapter 4**.

3.3.3 NOISE CERTIFICATION

Noise certification tests are specified by ICAO [ref. 3] and adopted by all aircraft manufacturing states. Single event noise levels are determined at three reference points: *approach*, under the descent path 2000m before landing threshold, *lateral* (or sideline), at the point where noise is greatest on a line 450m to the side of the initial climb after lift-off, and *flyover*, under the departure climb path, 6500m from SOR[15]. These are shown in **Figure 3-5** in relation to illustrative noise footprint components. Test aircraft are required to perform prescribed arrival and departure procedures past microphones located at these reference points. Noise levels in EPNL are measured under stringent test conditions which are subject to the scrutiny of the certificating authorities. The conditions relate to the instrumentation, test environment and aircraft operation. The measurements have to be repeated sufficient times to ensure that the mean values are accurate; the results are then adjusted to standard atmospheric conditions.

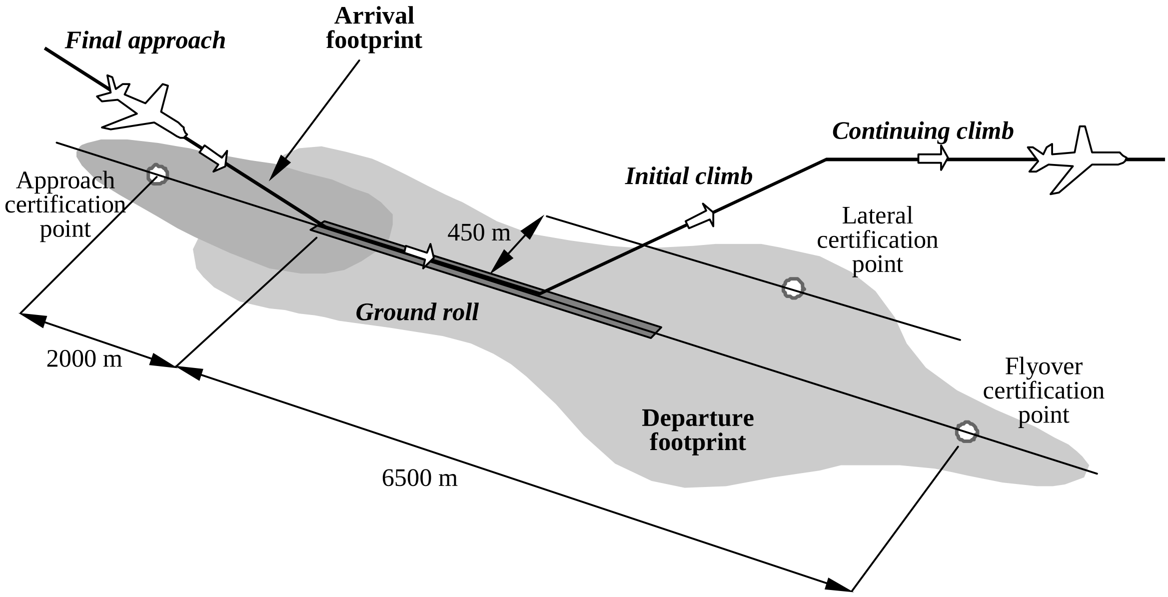

Figure 3-5: Certification reference points

In fact modern certification tests are performed as part of a wider programme of acoustic qualification testing, in which the aircraft is flown under a matrix of test conditions. This

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[15] Start of roll (alternatively termed ‘brake-release’) is the point on the departure runway deemed to be the start of the take-off run (the ground roll segment of the take-off).

yields a large quantity of data from which the required results are derived by subsequent processing. Apart from the standard certificated EPNLs, these include normalised NPD relationships, for L_{AE} and L_{Amax} as well as L_{EPN}, for a variety of aircraft weights and aircraft configurations including climb and descent at different flap angles etc. It is from this data that the manufacturers extract the data for storage in the ANP database - along with other aircraft performance data (see **Section 6.3**).

This data provides the necessary basis for the subsequent prediction of the noise footprints of the aircraft generated by most normal flight operations in any climatic conditions.

3.3.4 SPECIAL FIELD MEASUREMENTS

The quality of modern certification data can only be matched by measurements made under similarly controlled test conditions. These are only likely to be made for modelling purposes under the auspices of national programmes as, like certification itself, they require very substantial resources including extensive test sites, meteorological and acoustic instrumentation, control of test aircraft (and access to flight data recordings) and facilities for accurate measurement of flight paths. The requirements are very similar to those of certification except that the official flight procedures and measurement points do not have to be replicated. Rather, test matrices are designed to span a range of typical in-service operating conditions and flight profiles. They would normally be made to supplement the ANP database, for example to cover (a) aircraft or (b) operating or environmental conditions that are not included but are highly noise-significant at airports of local or national importance. Special field measurements are also necessary to acquire the spectral lateral and longitudinal directivity information that are required by simulation models.

3.3.5 AIRPORT NOISE MONITORING

Aircraft noise data for use in aircraft noise modelling has been acquired at operational airports for many decades. Indeed, the practice predates the introduction of aircraft noise certification by twenty years or more.

Measuring the noise of a passing aircraft is - in itself - a simple activity and can be done with hand-held sound level meters. Measurers know when the aircraft is passing and read the meter. They can also tell what other noise sources might be present at the moment of measurement, detect reflections and observe weather conditions (wind, temperature, rain) and make the necessary allowances. The results will be the approximate noise levels of specific aircraft, at specific times and positions, under specific conditions.

Such *ad hoc* measurements are made sometimes to supplement data obtained from elsewhere, and sometimes because it is the only practical way to obtain data of any kind, e.g. at smaller aerodromes which have no facilities of their own. The noise data has to be complemented by information describing the aircraft operations and test conditions - this can be and is acquired by means of varying degrees of sophistication ranging from handwritten observation notes, through optical or photographic aircraft tracking - and both with and without the co-operation of the aircraft operators and/or air traffic and runway controllers. Of course the limitations of data obtained in this way for modelling have to be fully recognised; often they could only be used for extrapolating from an existing situation to an alternative but still rather similar one.

Many larger airports and some smaller ones now operate automated noise and flight path monitoring systems which collect much of the necessary data routinely. Access to such systems has provided noise model builders and users with important new sources of data. However, despite their sophistication, the systems need to be understood in detail if reliable modelling data is to be extracted from them[16].

Monitoring noise immissions from all aircraft using an airport involves handling large quantities of data. To process the flow of information a number of hardware and software tools are required. The system is controlled by a central computer which also stores the results in a database. The different functions of such a system include:

- measurement of aircraft noise at different locations
- recording of aircraft ground tracks
- positive identification of individual aircraft
- correlation of noise measurements and aircraft movements
- storage of the results in an appropriate format in a database

The devices and information services needed to perform these include:

- noise/environmental monitoring terminals, positioned at suitable locations around the airport
- airport radars and interface facilities
- information to identify specific aircraft, e.g. links to airport flight information systems and aircraft registration databases
- other information relevant to sound propagation such as meteorological data, and elevation
- GIS-data (location of housing, hospitals, schools, recreation areas, etc.)

Airport monitoring is often the only source of noise data that is directly available to the practitioner. Modern systems record aircraft noise event levels from a number of monitors, usually at fixed locations, but sometimes from mobile monitors that can be deployed at will.

Elaborate software has been developed by monitoring system suppliers that mimics the discrimination powers of a human operator. It is designed to identify aircraft-like noise events e.g. from temporal characteristics. These are then matched to radar and airport flight information data for confirmation. Subsequently, the noise data (event levels and other available information such as current background noise level, weather conditions etc.) are filed by specific aircraft type - including engine and airframe (often by tail number). Post processing delivers a host of noise exposure statistics for airport use.

Despite this elaboration, airport monitoring data has to be treated and processed with very great care as there are many potential sources of error and inconsistency, including:

- Contamination of event noise by extraneous noise (i.e. from non-aircraft sources)
- Coincidence of two (or more) aircraft events
- Event not an aircraft
- Radar data corrupted
- Inadequate monitor location - received sound influenced by reflections from ground or other surfaces

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[16] Guidance on these matters is published by the SAE [ref. 8] and the ISO [ref. 1]

- Weather conditions outside acceptable range
- Incorrect matching of data from different sources - noise, radar, flight recorders, meteorology, flight information, ATC, runway logs, etc.
- Inaccurate or incorrectly logged data
- Failure to account for individual variations of the flight paths (variations in the slant distance)
- Maximum level of the event below measuring threshold (or less than the top 10dB above the threshold)

The last item is a common source of error in the process of averaging the raw data to obtain average levels – when lower level events are missed because they lie below the measuring threshold of the monitoring system, the resulting average levels are too high.

Finally, there must be enough measurements to allow mean (normalised) sound levels to be estimated with adequate statistical confidence (depending on the degree of normalisation, up to 50 or more measurements for each combination of aircraft type and ground track might be needed).

It will be evident from this outline that using airport monitoring data in support of noise modelling activity is a very onerous task. And even after all reasonable precautions have been taken to minimise error, it must be remembered that - as a rule - the results have limited applicability, principally to the airport(s) from which the data were acquired or to others with very similar characteristics (in terms of climate, traffic and type of operations). If they are considered for wider application, it is essential to establish and meet the needs for scaling the data when applying it to different conditions.

4 AIRPORT AND AIRCRAFT OPERATIONS AND NOISE

4.1 GENERAL

The purpose of this chapter is to explain to aircraft noise model users, in broad terms, how operational factors influence aircraft noise contours - not to provide methodology for taking these factors into account but to explain to non-experts why specialist assistance is often required to produce acceptable contours - or even to decide how a particular problem should be tackled.

Aircraft noise problems tend to be concentrated in localities over which aircraft are descending into or climbing out of aerodromes; it is certainly these operations that dictate the size and shape of the contours. In simple terms, contours are generated by calculating the sound received on the ground from aircraft as they follow specified flight paths in specified flight configurations. The contours are, at best, only as accurate as those inputs.

Unfortunately, although airport plans and maps, AIPs and other published information sometimes suggest that the aircraft operations are relatively clearly defined, the reality is that a host of factors cause variations in arrival and departure procedures, which sometimes are very large. To produce acceptable contours, these variations have to be adequately accounted for.

Patterns of aircraft operation depend on the size of the aerodrome and its location relative to regional airways systems, and the nature and volume of its traffic. This outline covers operations at larger civil airports which accommodate commercial traffic; these are the facilities which tend to have the most serious noise problems and towards which this guidance is aimed. At such an airport, the noise-critical stages of flight are mostly confined to the terminal manoeuvring area (TMA) within which aircraft movements, inbound and outbound, are tightly controlled by the responsible air traffic control (ATC) authority.

The noise level generated at any point on the ground by a passing aircraft depends on numerous variables, principally upon the aircraft slant distance and elevation angle and the engine thrust or power settings at the time. Factors of secondary importance include the aircraft speed and attitude and the atmospheric conditions - temperature and humidity, wind speed and direction (which affect aircraft height as well as sound propagation), and the presence of turbulence - and the way all these vary with height above the ground.

The noise calculations rely on information describing the performance of aircraft and their engines. The engine thrust required depends upon the speed, weight, climb rate and ‘configuration’ (flap settings and undercarriage position) of the aircraft and the atmospheric state. All these vary along the flight path; the sound levels on the ground depend upon the ‘history’ of the aircraft motion.

4.2 AIR TRAFFIC CONTROL (ATC) CONSTRAINTS

Aircraft usually leave airports following Standard Instrument Departure (SID) procedures. These are sets of navigational instructions to pilots which direct them along a limited number of specific routes. Sequential departures are dispersed between the SIDs to maintain safe separation distances. Often, the initial parts of these are so-called *noise preferential routeings* which are intended, as far as possible, to keep aircraft away from noise-sensitive localities.

This does not mean that aircraft fly along a few narrow corridors. Indeed differences in aircraft performance, navigational aids and equipment and weather conditions ensure that flight tracks are fairly well dispersed laterally. To add to this, ATC sometimes expedites departures by directing aircraft away from SIDs. This is known as radar vectoring. Vertical (flight) profiles too can be influenced by ATC. When unconstrained, a pilot follows standardised departure procedures and these dictate the variation of aircraft height and speed along the flight track. However, an aircraft might in some circumstances be ‘held down’ by ATC in order to keep clear of arriving traffic above.

During the final stages of their approach to landing, arriving aircraft follow a straight glide path defined by the radio beam of an instrument landing system (ILS); thus there is negligible dispersion. During earlier stages aircraft are usually directed along standard instrument arrival routes (STARs). A STAR will normally provide a link from en-route airspace to a point within the TMA from which a published instrument approach procedure can be commenced. In some states the end of a STAR will be the ILS intercept point, thus essentially defining the ground track all the way from en-route flight path to touchdown. In other states the STAR will terminate at an intermediate reporting point where, depending on the amount of arriving traffic at the time, the aircraft may be cleared to continue its approach or instructed to fly a racetrack shaped holding pattern (often within a ‘stack’ of aircraft queuing to land). When cleared, the aircraft is then radar-vectored by ATC which sequences aircraft from the hold/initial approach fix to the ILS intercept point. In this intermediate region, the ground track is not defined and there can be considerable dispersion between the approach ground tracks of individual aircraft.

4.3 DEPARTURE PROCEDURES

Although operating procedures vary in detail, an aircraft departure can normally be divided into two main phases, (1) *take-off and initial climb* and (2) *continuing climb*. Phase 1 involves a high *take-off* power or thrust setting; in phase 2 a reduced or *cut-back* level is used. The latter is usually the engines’ designated *maximum climb power*. Power cutback is necessary because the extended use of take-off power would shorten engine life. Maximum climb power can be sustained for extended periods.

Wing flaps are deployed to increase lift at lower speeds, e.g. during take-off and landing. During take-off they shorten the ground roll and enable the aircraft to climb steeply to the thrust cutback point. However, flaps also increase drag, which reduces acceleration. The same is true of the extended undercarriage which adds greatly to drag; this is why it is retracted as soon as possible after lift-off. Thrust is usually cut back at heights between 800 and 1500 ft above aerodrome level. Thereafter, during continuing climb, flaps are gradually retracted as speed is increased, a process referred to as ‘clean-up’. In general, the thrust, flap angle, speed, turn rate and climb gradient are all inter-dependent, and they can, to a degree, be traded off one against another - e.g. exchanging height gain for increased speed. But the ways in which the ‘trade-offs’ are made affect sound levels, fuel economy and other operating costs.

Remembering that airframe lift and drag and the performance of the engines also vary with the state of the atmosphere which changes with altitude, it will be evident that defining the flight profile - the way in which the factors that determine sound levels vary along the ground track - is complex.

4.4 REDUCED OR FLEXIBLE TAKE-OFF THRUST

The take-off distance or ground roll of a departing aircraft and its initial rate of climb is governed by the take-off weight (TOW) and engine thrust. The shorter the ground roll and the steeper the climb gradient, the sooner an aircraft reaches the power cutback point. At high aircraft weights, or on short runways, take-off engine thrust is at or near to the maximum thrust available. If this maximum thrust is retained when an aircraft takes off at less than maximum weight, then the cutback point can be reached within a shorter track distance.

But, because more use of high engine thrust levels increases maintenance costs, operators prefer to reduce the level of take-off thrust as much as possible. Depending on the facilities available for its implementation, this common practice is referred to as using *reduced* or *flexible* thrust. At a given aerodrome, at lower TOWs, thrust can safely be reduced to the point at which the take-off profile, including the position and height of the cutback point, is essentially the same as that at maximum take-off weight and thrust. But this means that the aircraft is lower than it might otherwise be and, at least beyond the cutback point, noisier at ground level; the net effect is to narrow the noise footprint at takeoff and initial climb but lengthen it under the continuing flight path. The power used for continuing climb might also be set to less than the maximum climb thrust rating.

4.5 NOISE ABATEMENT OPERATING PROCEDURES FOR DEPARTURES

ICAO guidance on aircraft operations [ref. 9] describes two general types of noise abatement take-off procedure, each described by a sequence of procedural steps. One aims to reduce noise closer to the airport, the other further away. The differences are in the heights at which engine power is reduced from the take-off setting and the way in which flaps and engine power are subsequently managed to balance speed and rate of climb which influence the sound level on the ground below.

ICAO recommended procedures are widely followed. Procedural steps are specified by individual airlines to meet their own operational requirements as well as those of the aircraft manufacturers and the relevant safety regulators. There will be no more than two departure procedures to be used by one operator for an aircraft type, one of which should be identified as the normal departure procedure and the other as the noise abatement departure procedure. Both procedures will normally be defined in the airline’s standard operating procedures manual. But ultimately any one departure flight profile - the variation of engine power, height and speed with track distance - depends not only on the procedural steps but also on the aircraft weight and the atmospheric conditions of the day.

4.6 ARRIVAL PROCEDURES

There are four ‘approach’ phases. The arrival phase is the descent from the en-route airway to the initial approach fix and will normally be defined by Standard Instrument Arrival (STAR) route(s). With or without a hold, the initial approach segment commences at the initial approach fix and the aircraft is manoeuvred to enter the intermediate approach segment. The intermediate phase blends the initial approach into the final approach segment. It is the segment in which aircraft configuration, speed and positioning adjustments are made for entry into the final approach segment. The final approach segment is where the aircraft alignment for descent and landing are accomplished. For an ILS approach the final approach segment begins at the final approach point and ends at the missed approach point.

Usually it is the final approach segment that determines the contribution of arriving aircraft to the noise contours; i.e. while it flies in a straight line towards the touchdown. But although then the track is well-defined, the aircraft speed and flap setting can vary and these control the engine power requirement and thus the noise. Prior to the final approach segment the aircraft might execute various turns and height changes in following ATC instructions to join the stream of arriving aircraft at the height, speed and time necessary to maintain adequate separation between flights. These manoeuvres, which vary from flight to flight and depend on the initial approach fix (of which there may be several), may sometimes have to be modelled, at least in part, to define arrival noise adequately.

4.7 OTHER FACTORS

Other operational circumstances that need to be taken into account include circuit flights and 'missed approaches' under which for various ATC reasons aircraft abort their final approaches and 'go around' to rejoin the landing process and circuit flights. Go-arounds are relatively infrequent but circuit flying might be common at aerodromes which accommodate a significant amount of training flights. Both can involve flight profiles which differ from normal operations, but in all other respects they are modelled in the same way as normal arrivals and departures. Another is the use of intersection take-offs in which lightly loaded aircraft enter the departure runway part way along its length.

4.8 FLIGHT PATH DEFINITION

Each different aircraft movement is described by its three-dimensional flight path and the varying engine power and speed along it. As a rule, one modelled movement represents a subset of the total airport traffic, e.g. a number of (assumed) identical movements, with the same aircraft type, weight and operating procedure, on a single ground track. That track may itself be one of several dispersed 'sub-tracks' used to model what is really a swathe of tracks following one designated route. The ground track swathes, the vertical profiles and the aircraft operational parameters are all determined from the input scenario data - in conjunction with aircraft noise and performance data.

The three-dimensional flight path of an aircraft movement determines the geometrical aspects of sound radiation and propagation between aircraft and observer. At a particular aircraft weight and in particular atmospheric conditions, the flight path is governed entirely by the sequence of power, flap and attitude changes that are applied by the pilot (or automatic flight management system) in order to follow routes and maintain heights specified by ATC - in accordance with the aircraft operator's standard operating procedures. These instructions and actions divide the flight path into distinct phases which form natural segments. In the horizontal plane they involve straight legs, specified as a distance to the next turn, and turns, defined by radius and change of heading. In the vertical plane, segments are defined by the time and/or distance taken to achieve required changes of forward speed and/or height at specified power and flap settings.

For noise modelling, flight path information is generated either by *synthesis* from a set of procedural steps (i.e. those followed by the pilot) or by *analysis* of radar data - physical measurements of actual flight paths flown. Its horizontal shape (i.e. its 2-dimensional projection on the ground) is the *ground track* defined by the inbound and outbound routeings. Its vertical shape, given by the profile points, and the associated flight parameters speed, bank angle and power setting, together define the *flight profile* which depends on the *operating procedure* that is normally prescribed by the aircraft manufacturer and/or the operator. The flight path is constructed by merging the 2-D flight profile with the 2-D ground track, usually to form a sequence of 3-D flight path segments (see **Figure 4.1**)

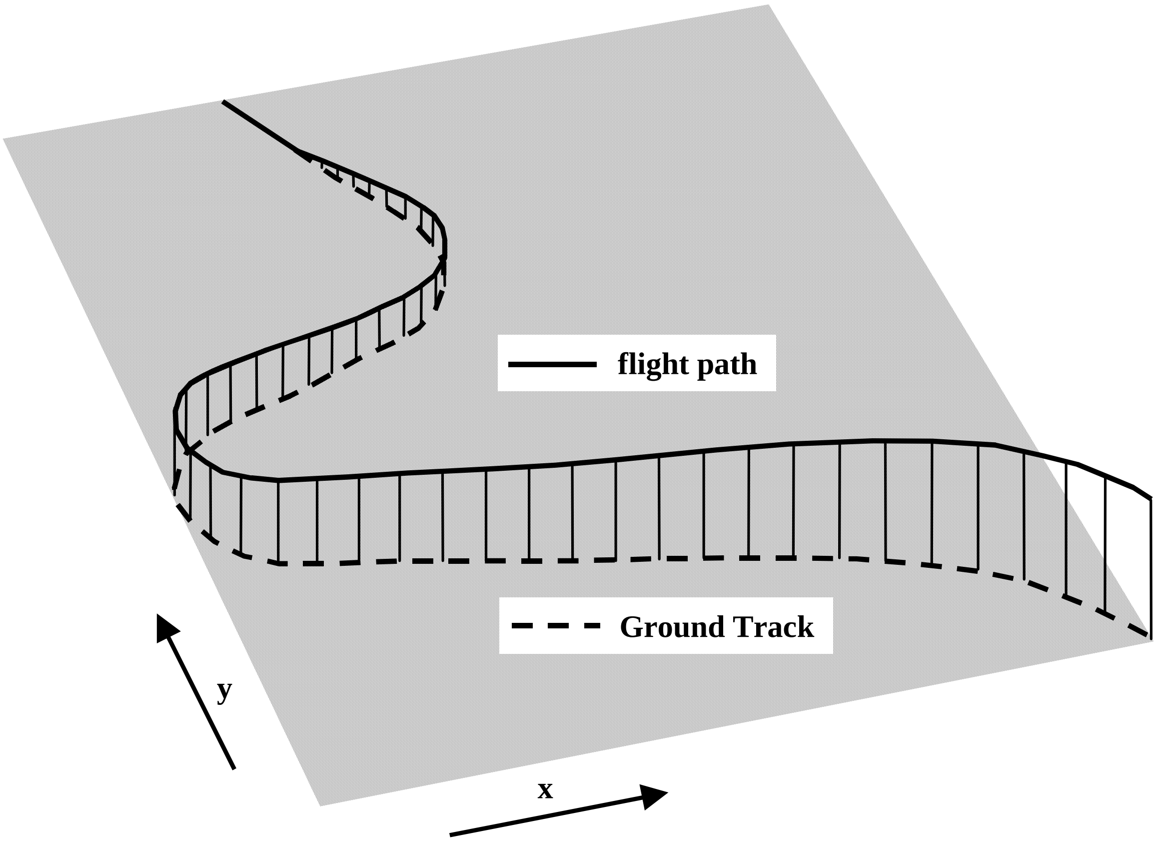

Figure 4-1: Representation of a 3-dimensional flight path

The noise received from a flight path segment depends on its geometry and the aircraft flight configuration. But these are interrelated - a change in one causes a change in the other and it is necessary to ensure that, at all points on the path, the configuration of the aircraft is consistent with its motion along the path.

In a flight path synthesis, i.e. when constructing a flight path from a set of 'procedural steps' describing the pilot's selections of engine power, flap angle, and acceleration/vertical speed, it is the motion that has to be calculated. In a flight path analysis, the reverse is the case: the engine power settings have to be estimated from the observed motion of the aeroplane - as determined from radar data, or sometimes, in special studies, from aircraft flight recorder data. In either case, the need is for the complete definition of the aircraft state at all segment end points that has to be fed into the noise calculation.

5 APPLICATIONS

Noise impact assessments commonly requiring the preparation of noise contours can be grouped under the following headings:

A) Defining the 'absolute' noise impact of a particular scenario (of an airport's operations)

  1) at present or at some time in the past
  2) under some forecast future scenario (e.g. with expanded operations)

B) Comparing two or more different scenarios; for instance

  1) the present with past and/or future situations, or
  2) future scenarios with alternative runway configurations, traffic levels and mixes, routeings, operating procedures etc.

Types of noise impact assessment		
Absolute	A1: Present* only	A2: Future only
Comparative	B1: Present* v. future	B2: Future v. future

* or past

The different modelling considerations these generate are illustrated below by example.

5.1 APPLICATION A1: ABSOLUTE IMPACT / PAST OR PRESENT

An example is the publication of 'historical' contours, e.g. annually - describing a situation already experienced. Essentially this is a noise monitoring application. This is perhaps the most demanding of all applications because the contours are required to record actual sound exposures which can, and often will have been, subject to spot checks by long-term sound level monitoring.

It is possible to imagine an 'exact' calculation in which every single aircraft movement, arrivals and departures, together with corresponding atmospheric conditions, are accurately modelled in complete detail. This is theoretically possible, within the limits of current knowledge, assuming that all the required input data - aircraft movements by specific aircraft types and variants, take off and landing weights, operating procedures and/or flight profiles, ground tracks and weather (air temperatures, humidity, wind velocities as functions of time, position and height) are fully recorded and accessible.

At present this is not yet practicable and it is necessary to simplify the contour modelling process in order to make best use of data that are available whilst confining the computations to an acceptable scale. Data sources include manufacturers' aircraft noise and performance databases, bespoke noise and flight profile measurements, airport noise and flight path monitoring systems, airline flight data records, airport flight data systems, ATC records, and AIPs. Even with ready access to data, for large airports the magnitude of the task can be very large and involve many hundreds of working hours.

What is an acceptable approach is dictated not only by the accuracy required but also by the resources available, and inevitably some compromise is necessary - involving some streamlining of the modelling process. The major practical simplifications are (1) to make best use of readily accessible data (for example to rely on flight path data from airport radar monitoring rather than flight data recorded on the aircraft), (2) to assume uniform average atmospheric conditions appropriate to the specific airport and time period (season(s)) and (3) to group aircraft operations into classes, each of which can be represented by an average or typical operation. Other economies can be achieved by (4) focussing on factors that are most significant with respect to noise. Thus for example, whilst an airport might be used by a large number of different aircraft types/variants, most of the total sound energy is likely to come from just a handful of them - normally those of operators with bases at the airport. It is thus most efficient to concentrate effort on those types and cover the remainder in a less precise manner.

5.2 APPLICATION A2: ABSOLUTE IMPACT / FORECAST SCENARIO

A common application under this heading, and one of great importance to public planning bodies, is in the development of statutory noise limits and constraints. Examples include the specification of noise ‘caps’ on future airport expansion, land-use planning zones and sound insulation scheme boundaries. A less common requirement is for absolute sound exposures likely to be experienced in future for use in the assessments of entirely new airports; i.e. forecasting the impact of aircraft noise on an area which at present has none.

The production of noise contours for a future scenario is similar to Application A1 except for the crucial difference that, information describing the noise performance of currently existing aircraft apart, all modelling inputs are *forecasts* rather than historical measurements or statistics. Thus the scope of the analysis needs to be tailored to the reliability of the forecast. For example, there is no point in describing flight paths and operating procedures to a high level of detail when estimates of the traffic - including aircraft types, weights, routeings and operating procedures - are subject to uncertainty. As a rule, the need for input detail diminishes with the lead time. That might be quite short when planning sound insulation schemes but for the planning of new airports, the lead time is likely to be considerable.

A common problem when the lead time is long is that of specifying the noise performance characteristics of yet to be designed or built aircraft. It is usual to assume that they will be similar to those of current aircraft with similar configurations, using simple interpolation or extrapolation to account of differences in capacity. However, for ‘new generation’ aircraft which might be expected to differ fundamentally from today’s aircraft it is necessary to take advice from manufacturers or aeronautical research organisations.

In studies of this kind it is normally a requirement to undertake sensitivity analyses - to examine the effects on the contours of different input assumptions.

5.3 APPLICATION B1: COMPARATIVE IMPACT / PAST V. PRESENT/FUTURE

This effectively combines Applications A1 and A2 but choosing an optimum solution will depend on available data and resources. For example, if one or more contour sets already exists, e.g. for a ‘base case’, it is likely that the most effective approach would be to match the comparison case(s) appropriately - only making changes to variables that can be predicted with appropriate confidence. For example, assumptions about traffic growth - in terms of numbers and sizes of aircraft - would normally be agreed readily whilst changes to routeings, and assignments of aircraft movements to them (departures by stage length), might be more contentious. A potential solution would be to assume no significant changes, merely applying forecast growth factors to traffic elements by route. If this cannot be agreed, sensitivity tests might be appropriate - producing contours under alternative assumptions.

If no base case exists (and in some circumstances even if it does), it might well be appropriate to reduce costs by considering simplified scenarios in which only factors of agreed importance are subject to comparative assessments. This would be appropriate when it is agreed that the consequent changes in sound exposure are much more important than absolute levels (which will often be the case). Examples of efficient simplifications would be to minimise the number of different aircraft types and operational procedures.

5.4 APPLICATION B2: COMPARATIVE IMPACT / DIFFERENT FUTURE SCENARIOS

This is a common application as it covers ‘what if’ studies; those designed to assess the relative merits of different noise mitigation options - e.g. different routeings, runway utilisations, operating procedures and operating restrictions. Here it would normally be quite inappropriate to attempt any simulation of actual operational scenarios - all that is required is to define the simplest possible representative base case that allows all factors of interest to be varied in the comparative cases.

5.5 POLICY CONSTRAINTS

Although it is important to strive for results with high accuracy, it has to be recognised that in some instances, consistency with earlier results might be more important than absolute accuracy. In others, for example when calculating the numbers of people affected by scenario changes the choice of the contour level might be a somewhat arbitrarily political choice. It might for instance be dependent on the costs for insulation of houses. If model improvements were to result in changes to average sound exposure levels, the choice of threshold contour level might change also. In other words, noise modelling is not only the art of manipulating data in the right way but also of recognising the role of political judgement which might transform an assessment from an absolute one to a comparative one. Comparative assessments do not ask primarily for absolute accuracy but for consistency. That is why there has always been interest in international harmonisation of noise models and why many states have chosen to delay model upgrades. This has simply left ‘old-fashioned’ models in place as reliable counting machines rather than high precision sound exposure estimators. There is always a possibility that allocating substantial resources to improving a noise model will be a poor investment if the subsequent evaluation levels are simply changed accordingly.

PART III MODELLING METHODOLOGY

6 ELEMENTS OF THE NOISE MODELLING SYSTEM

6.1 GENERAL STRUCTURE

The elements of the noise calculation process (or “noise modelling system”) are illustrated in **Figure 6-1**. The *noise model* may be thought of as a “black box” which operates on *input data* describing the scenario - the airport and its air traffic - to produce an output in the form of sound levels at discrete points (usually for a calculation grid) of specified *noise metrics*. These values are the inputs to a *post-processor* which performs further analysis such as contour generation.

The input data which are scenario-specific define the airport geometry (i.e. description of runways and ground tracks) and the air traffic using the airport (i.e. the number of movements of particular aircraft or aircraft categories on the particular ground tracks during different time periods). They are generated from the raw scenario information by a *pre-processing system*. This pre-processing is needed since the raw information usually does not conform to the input requirements of the noise model. This pre-processing – which is one of the most demanding tasks in the modelling process - is described in detail in **Chapter 7**.

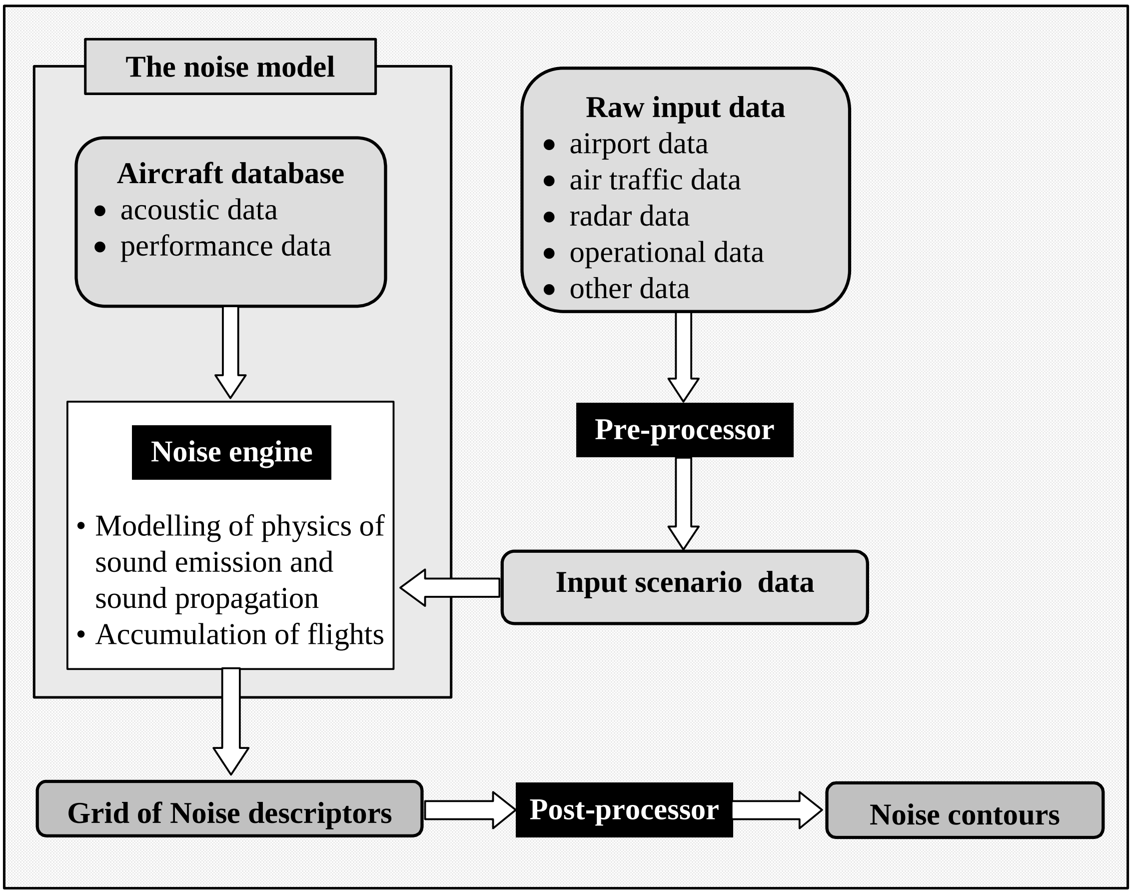

Figure 6-1: Elements of an aircraft noise modelling system

The noise model is usually embodied in a computer program. It consists of two components, the *noise engine* and an *aircraft database*. The noise engine is the core processor that models the physical processes of sound emission and propagation. Its functionality as well as different modelling approaches are discussed in **Section 6.2**. The database describes (i) the acoustic properties of the aircraft as well as (ii) its performance and operational characteristics. These are explained in **Section 6.3**.

6.2 THE NOISE ENGINE

The generation of noise contours is a separate stage from the basic noise modelling process when, as is common, these are mathematically fitted to a suitable grid array of single point noise values. That array is generated simply by repeating the single-point calculations for every grid point. The contour fitting process - which is part of the post-processing - is discussed in detail in **Volume 2**. For cumulative noise descriptors, each single point calculation involves an aggregation of single event values for all noise-significant aircraft movements. Therefore, at the heart of any modelling process is the calculation of the aircraft event level.

Traffic is broken down into aircraft types or categories with different noise and performance characteristics which have to be stored in the aircraft database. To minimise computation, individual aircraft types having very similar noise and performance characteristics can be grouped into representative categories. Existing models use between about 10 and 200 categories. However grouping is not necessary if individual flight path information (e.g. from radar data) and adequate noise data are available. Aspects of grouping are discussed in **Section 6.4**.

6.2.1 CALCULATION OF THE AIRCRAFT EVENT LEVEL

Although there are at least three basically different approaches to aircraft noise modelling which are explained in **Section 6.2.2**, they share common components. How these are interlinked in the sub-process by which an aircraft event level (L_{max} or L_E) is calculated is illustrated simplistically in **Figure 6-2**. Each component is described below with reference to that diagram.

1) *Aircraft operation:* The aircraft operation, a departure or arrival of a particular aircraft type or category, has to be defined in terms of its operating weight, the operating procedure and the atmospheric state. Its noise and performance characteristics have to be specified in the aircraft database.

2) *Ground tracks:* Ground track information is needed to define two of the three co-ordinates of the flight path of an aircraft. Central tracks are often based on nominal SIDs and STARs; in some cases they are determined from operational radar data. Good practice requires adequate account of lateral dispersion as well as differences between nominal and actual central tracks. This factor is discussed in **Chapter 7**.

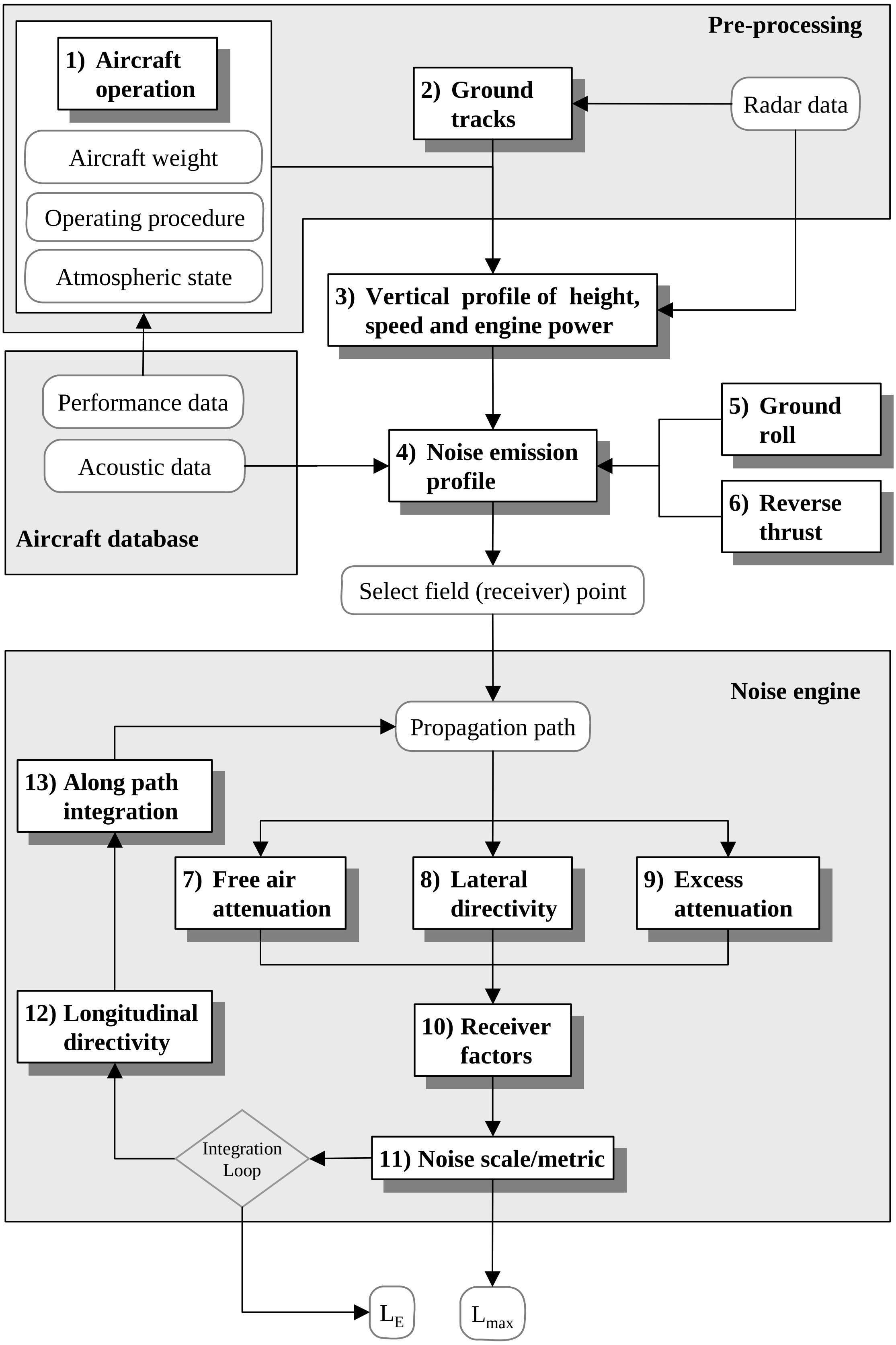

Figure 6-2: **Determination of aircraft noise event level (showing the elements of a noise modelling system identified in Figure 6-1).**

3) *Vertical profile of height, speed and engine power:* The information on aircraft speed and engine power as well as source-to-receiver distance and geometry are key parameters required by the noise engine. The vertical flight profile information can be calculated by consideration of aircraft weight, performance characteristics, operating procedures and atmospheric state using the aircraft performance component of the aircraft database. Alternatively it can be measured, e.g. using surveillance radar or information from FDR data.

   Models sometimes rely on 'default' flight profiles representing typical or average modes of operation. Before these are used, it is necessary to ensure that they reflect actual practice of the operators concerned. Experience indicates that failure to take full account of actual operating procedures is a major source of discrepancy between the outputs from different models. This problem is also discussed in **Chapter 7**.

4) *Noise emission profile:* Noise from an aircraft may be described in sound power terms, as a level at a specified distance or as a curve of sound level against distance. Noise emission depends on engine power (see above) which in turn may depend on the aircraft weight and flight path. This may be taken into account in the modelling process or the two variables may be defined independently (e.g. derived from direct measurements). Obtaining accurate aircraft noise source data is often a difficult part of the noise modeller's task

5) *Ground roll:* The noise emission profile depends on whether the aircraft is on the runway or airborne. When an aircraft is on the runway, during take-off or landing, it undergoes rapid accelerations which require special consideration. At start of take-off, while stationary or at very low speed, aircraft generate high levels of noise whose directional propagation needs to be taken into account. Ground roll noise can be critical for areas close to the runway(s) where noise is not dominated by other modes.

6) *Reverse thrust:* This generates bursts of high level noise. Although a small fraction of total air noise energy, it may have significant local impact depending on where people live at a given airport. Hence reverse thrust also has an influence on the noise emission profile.

When the noise emission characteristic is defined, the *receiver point* has to be selected. This defines the *geometry between source and receiver* (i.e. distance, angles of radiation as well as angles of incidence at the receiver) as well as the sound propagation path with its atmospheric properties (temperature and humidity[17]). Based on this geometry the following effects have to be taken into account:

7) *Free-air attenuation:* This is the rate at which the sound level decays with distance from the source in still, free air. Free-air attenuation consists of two mechanisms: (1) The effect of *geometric spreading,* which results in a 6 dB decrease of sound level per doubling of propagation distance and (2) the effect of *atmospheric absorption* which describes the dissipation of energy caused from interaction between the sound wave and the molecules of the air. This effect varies with sound frequency, air temperature and relative humidity and available theory allows it to be described mathematically so that local airport conditions can be taken into account.

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[17] Atmospheric conditions, both steady and unsteady, strongly influence sound propagation but, at present, only mean surface values of temperature and humidity can be taken into account practicably.

8) *Lateral directivity (engine installation effects):* This refers to directionality in sound propagation about the aircraft roll axis. It results primarily from acoustic interactions between the engine noise sources and/or the aircraft structure. This directivity has often been combined with *lateral attenuation* (see below). However, separate treatment of lateral directivity is logical as it is defined with respect to the aircraft axes (lateral attenuation depends on fixed axis geometry). But this requires that angles of bank in turns have to be accounted for.

9) *Lateral attenuation:* This affects sound propagating at acute angles to the ground surface. It is largely caused by interference between directly radiated sound and reflection from the ground surface - which depends on the angle of sound incidence, ground properties and receiver height. But the geometry of sound reflection is influenced by refractions caused by wind and temperature variations so that attenuation is difficult to model theoretically.

10) *Receiver factors:* Apart from the aircraft flight profiles, ground surface and atmospheric conditions, local factors including topography and ground cover may have significant effects upon contours in certain circumstances and may sometimes warrant special treatment[18]. Although it is normally disregarded, the built environment around an airport will also influence the amount of noise received locally, especially from aircraft on runways. Theoretically, receiver height above the surface has an influence on lateral attenuation but, over soft ground in real non-uniform atmospheres, the effect on event levels is small.

11) *Noise metric:* How received event levels are determined depends on whether the event metric is L_{max} or L_E. For L_{max}, it is usually considered sufficient to describe conditions at the closest point of approach of the aircraft to the receiver whereas L_E is influenced by sound arriving from an extended part of the flight path. This difference is indicated in **Figure 6-2** by the repeated calculations involved in constructing L_E. For L_{max}, the propagation path is a single straight line; its length (the minimum slant distance) and angle of elevation determine the sound attenuation. It is recognised that practical choices are matters for local decision and research.

12) *Longitudinal directivity:* Noise radiated varies markedly in the longitudinal (fore/aft) direction usually with higher emissions to the rear of aircraft. However, along most of an aircraft flight path, it may not matter: essentially, directivity affects only the timing of an event (relative to the aircraft's passing). But it can have a marked effect on the size and shape of the contours (and particularly the footprints for individual aircraft operations) near the start of take-off or with the application of reverse thrust.

13) *Integration along the flight path*: Computing duration dependent event levels L_E means summing the contributions from different parts of the flight path. There are two basically different approaches:

    - *Simulation models* integrate the received sound level over time after calculating it for a sequence of intervals; computationally, this is the most time consuming.

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[18] Topography corrections are very important for airports located in mountainous districts: major effort has been directed to this by some modellers.

- Somewhat faster are *integrated models* which sum contributions from discrete segments of the flight path (hence they are also sometimes referred to as *segmentation* models). These are essentially 'pre-integrated'. Other integrated models, simpler still and referred to as *Closest Point of Approach (CPA)* models, first calculate L_E as though the aircraft were flying steadily along a straight path. The result is then adjusted to allow for the effects of any turns. Both approaches have strengths and weaknesses. But the key practical difference lies in the input data upon which the models depend.

6.2.2 MODELLING APPROACHES

The different ways of approaching along-path integration divide noise modelling algorithms into the three different types:

- Closest Point of Approach (CPA)
- Segmentation
- Simulation

CPA models were developed before the widespread adoption of time-integrated noise metrics to calculate L_{max}-based descriptors. Their algorithms were relatively simple, being based on the assumption that, for given source characteristics, L_{max} depends only on the shortest distance between aircraft and receiver (i.e. time integration was not required). Although they have been adapted to handle L_E-based descriptors, for that application they have been largely superseded by segmentation algorithms.

The *CPA* algorithm is the simplest and fastest. Principally it divides a ground track into straight segments and circular arcs. The vertical flight profile is represented by contiguous straight segments. The distance from the observer to the closest point of approach, and whence L_{max}, are then calculated quite readily using co-ordinate geometry. But to estimate L_E an extended part of the flight path has to be taken into account. CPA models tend to use NPD curves that are stored for infinite line segments and specific aircraft speeds. To allow for the curvature of the flight path and aircraft speed variations, empirical adjustments are made to the infinite segment L_E.

Segmentation algorithms are developments of CPA-algorithms which calculate the separate contributions to L_E from all noise-significant flight path segments. For each, this is done by calculating what fraction of the infinite segment noise - determined from the NPD data - is radiated from the finite segment. All segments are straight; i.e. circular segments are described by a series of chords. However, for segmentation models, assumptions on the directional characteristics of aircraft sound radiation have to be introduced.

The logical and straightforward way to calculate aircraft noise is by *simulation*. A simulation model describes the real flight path of an aircraft by a series of discrete points in space which are passed by the aircraft after successive small intervals of time. (This is similar to a segmentation model with small segment lengths.) The level-time-history at any specific observer location is then constructed by calculating the sound radiated towards it from each flight path point. From this any noise metric can be derived. Two disadvantages of simulation modelling are (1) heavy demands on computer processing power and time and (2) the need for very detailed acoustic input data, including information on the 3-D directional characteristics of the source noise, perhaps as a function of frequency (spectral directivity data) and flight configuration. Such data are currently not available in the quantities needed for day-to-day aircraft noise modelling at different airports.

Thus segmentation models currently represent best practice for general aircraft noise calculation. They provide a reasonable compromise between the requirements on input data and the quality and accuracy of the output produced by the computation algorithm. Moreover, comprehensive databases for such models have been assembled over many years for a large number of different aircraft types. **Volume 2** of this guidance provides a detailed description of a recommended segmentation modelling process.

6.3 AIRCRAFT DATA

6.3.1 ACOUSTIC DATABASES

The content and format of the acoustic part of an aircraft database (see **Figure 6-2**) depends on the noise engine algorithm and the sophistication of the model. Over the years the amount and complexity of data required (acoustic as well as operational) has steadily increased - see **Figure 6-3** where sequential stages of model development are referred to as basic, intermediate, advanced (current) and ultimate.

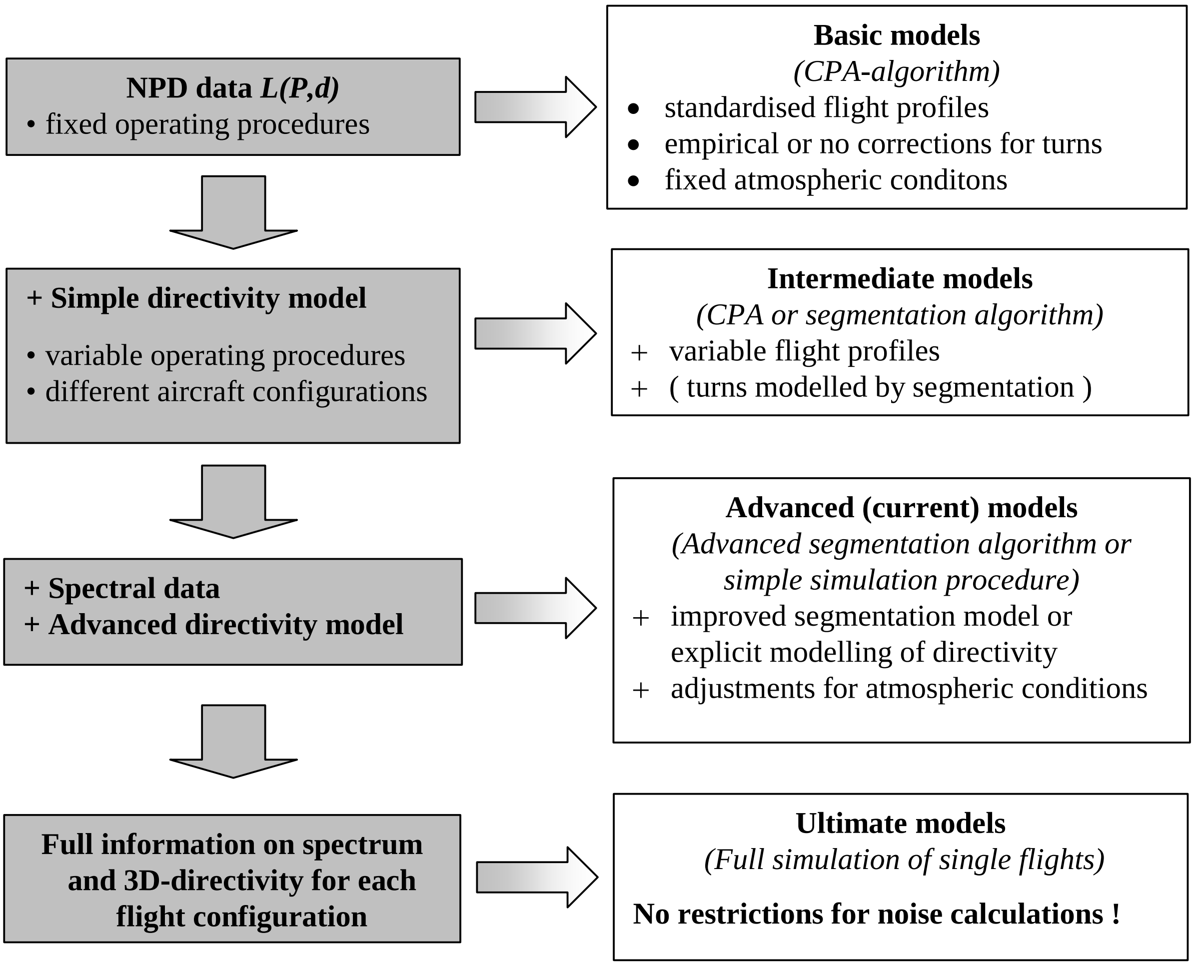

Figure 6-3: Noise model development

Simple models using CPA algorithms have been widely applied at individual airports, often using locally measured data. At the most basic level, for each aircraft type or category and for each phase of a standardised flight profile, L_{max} only is stored as a function of slant distance - for one atmospheric state, specified or unspecified. CPA models that are adapted to calculate L_E use tables or curves of L_E versus slant distance from 'infinite' straight flight paths - where necessary the model applies relatively simple geometrical corrections to account for turning flight.

Intermediate models, both CPA and Segmentation, use tabulations of Noise-Power-Distance (NPD) relationships. These give, for a specific aircraft speed and an infinite flight path, noise event level versus slant distance as a function of engine power levels. There is one set of NPD graphs or tables for any one aircraft type or category in a particular flight configuration. Separate NPD sets may be provided for different flight configurations to reflect noise-significant changes in the aircraft state not captured by power setting alone, e.g., approach and departure conditions. Approach NPDs may also cover a "landing gear/flaps deployed" and a "clean" condition to reflect changes in sound level due to aircraft configuration. NPD data apply to a reference atmosphere. NPD data for specific airframe/engine combinations are generally compiled and supplied by the aircraft manufacturer from noise certification test data, but can also be derived from other sources (see **Section 3.3**).

Among advanced (current best practice) noise models are second-generation segmentation algorithms (as described in **Volume 2**) and simple simulation procedures. The acoustic databases for segmentation models contain standard NPD tables and spectral information (or 'spectral classes'). The latter allow the NPDs to be adjusted in cases of non-standard atmospheric conditions. Source directionality characteristics are generalised within the models. In future, databases for segmentation models may include aircraft specific source directionality that will enhance modelling accuracy. Current simulation databases, derived from local measurements, provide 3-D source emission characteristics for some aircraft and flight configurations.

The 'ultimate' stage of aircraft noise modelling is likely to be a simulation that provides total sound power emissions and 3-dimensional source directivities, as functions of frequency, for different combinations of engine power levels and flight configurations. This would require a great deal more data than CPA or segmentation models. Data for simulation models are not presently available from aircraft manufacturers as they are not acquired in such form during the noise certification process. Therefore, it seems probable that they would have to be obtained by conducting special flight tests under controlled conditions.

Considering the difficulties of data acquisition, it is unrealistic to suppose that 'ultimate' simulation models will be realised in the near future. However the transition from simple to ultimate simulation models will not be a discrete step: already, different approaches for simulation – often based on a separate modelling of specific aircraft noise sources such as jet-, fan- or airframe-noise – are under development or already in use for scientific purposes.

6.3.2 PERFORMANCE DATABASES

For each aircraft type these are required to relate the engine power, for which noise emission is obtained from the NPD data, to the motion of the aeroplane along its flight path. Engine power (usually in the form of propulsive thrust) depends on aircraft weight, configuration and motion as well as the atmospheric state. The relationships between these variables, that are used to solve the equations of aircraft motion, are defined in terms of a number of aircraft and engine performance parameters, coefficients and constants, which can only be supplied by the manufacturers.

6.3.3 OPERATIONAL DATA

Operational data comprise that part of the modelling inputs for a particular application that is used to generate the aircraft flight paths and associated flight configurations. Aircraft *ground tracks* are described by a sequence of coordinates in the ground plane, usually for a nominal centre or 'backbone' track but with associated dispersion information. 'Vertical' data are generally supplied in one of two forms, either

- as *a set of profile points* (i.e. as set of altitude, speed and thrust values as a function of ground distance along the track), or
- as *procedural steps* (i.e. the successive steps of a flight procedure, as flown by the aircraft crew).

Principal sources of information are radar flight path monitoring systems and the aircraft operators. Radar recordings cover specific airports and actual operational conditions. The raw radar data are sets of flight path co-ordinates; much statistical pre-processing is necessary to turn these into usable average ground tracks and flight profiles.

Procedural steps allow flight profiles to be constructed as functions of user-defined procedures and operational parameters (aircraft takeoff weight, atmospheric conditions, etc.). The information is best obtained from the aircraft operators; depending on the application it may be used independently or in combination with radar-derived data.

'Gold standard' operational data can be obtained from the flight data recorders (FDRs) carried by the aircraft themselves. FDR data can provide very comprehensive time histories of actual individual flight paths and aircraft configurations - but it is very expensive to acquire and analyse and it is generally only used for special studies associated with model development.

In the absence of airport or operator supplied data, 'default' flight profiles are commonly based on representative aircraft weights and operating procedures.

6.3.4 QUALITY STANDARDS AND DOMAINS OF VALIDITY

Noise and performance data for larger transport category aircraft are normally obtained from the manufacturers who acquire it under the aircraft noise certification programme. That data is developed under well-controlled conditions to meet internationally specified quality requirements. Additionally, the domain of validity within which manufacturer data can be used is usually specified.

For data derived from other sources, especially measurements made under operational conditions at airports, the domain of validity is likely to be more restricted. Often, these data are developed for use with individual models to obtain the best possible estimate of actual noise contours at specific airports. The conditions under which they are obtained are usually representative for that situation, even if not all relevant parameters are known explicitly. Before such data could be applied reliably to significantly different scenarios (e.g. different airport altitude, temperature, procedures) they would need to be scaled to the new parameters (in the same way the data from manufacturers can be scaled).

6.3.5 DATABASE SIZE AND COVERAGE

There are a large number of acoustically different aircraft types. Moreover, most aircraft types (e.g. B737 or A320) exist in numerous different variants (i.e. combinations of different airframes and engines). For any particular modelling system, the main factor governing the size and utility of the associated noise and performance database is its coverage; i.e. the numbers of different aircraft types and variants represented.

And coverage is dictated by the model's applicability. Local databases that are developed for individual models used to perform noise assessments at specific airports need cover only the specific aircraft types in operation. This is especially true for local databases for simulation models that require more detailed data than NPDs. Resource limitations normally restrict their coverage much more than for segmentation models.

The coverage also depends on the source of the data: manufacturer-supplied data usually apply to very specific airframe/engine combinations, while data derived from other sources may cover fewer and broader aircraft categories, not distinguishing between different variants and engines for example. Due to limited database coverage it is often necessary to resort to aircraft grouping or substitution.

6.4 AIRCRAFT GROUPING AND SUBSTITUTION

6.4.1 REASONS FOR GROUPING

A manufacturer-supplied acoustic and performance database (e.g. the ANP database) contains noise and performance characteristics for specific aircraft types i.e. for particular airframe/engine combinations. Theoretically, this allows the input data for an air traffic scenario to be generated with a high degree of detail or accuracy.

Nevertheless, it may sometimes be necessary or advantageous to group together individual aircraft types having similar noise and performance characteristics so that they can be represented by a single aircraft category. Reasons for this are usually

- insufficient information on the detailed aircraft mix (especially for forecast scenarios),
- a lack of separate data for different aircraft models or variants, or
- a need to reduce the cost and time required.

The third of these is especially important. Not only can it be very tedious to include in the calculations many individual aircraft variants operating at an airport (even if the data are available) – often, the noise performance differences between variants of similar aircraft are of no practical significance. Moreover as, at any one airport, the noise contours tend to be dominated by a relatively small number of aircraft types or variants (a function of the principal airline(s) and the mix of traffic) it will normally be beneficial – in the interests of efficiency – to concentrate modelling effort on the most noise significant types and categories. Grouping can be particularly useful, and indeed necessary, when the fundamental application of the noise model is forecasting future scenarios.

The aircraft categories can be based on engine number and type, sound levels, performance and other criteria of the individual aircraft as explained below.

6.4.2 PARAMETERS FOR AIRCRAFT GROUPING

Aircraft types are usually grouped in the first instance according to characteristic parameters related to sound emission and/or performance of aircraft. Such parameters include:

Maximum takeoff mass: This is the simplest and most widely used parameter. It is often based on divisions between *light*, *medium,* and *heavy* aircraft.

Type of engine: Common engine types for commercial aircraft are turbojet, turbofan and turboprop.

Number of engines

By-pass ratio: The obvious relation between engine by-pass ratio and sound emission leads to a further distinction amongst turbojet and turbofan aeroplanes with *low, medium* and *high by-pass ratio*.

Installation of the engines: Recent studies have shown differences in lateral sound emission depending on the installation of the engines. Particular distinctions can be made between aircraft with rear-fuselage-mounted engines and wing-mounted engines.

Type of operation: Grouping might also differ between departures and arrivals. However the term of "type of operation" may also be extended with respect to takeoff procedures (especially for modern wide-bodied twins, where reduced takeoff thrust is widely used).

ICAO noise certificate: Clearly, grouping for noise classes must be based on identifiable noise characteristics. If no other information is available, grouping is sometimes based on noise certification according to *ICAO Annex 16, Volume 1* [ref. 3]. For landing operations, the certificated approach noise level is a reliable indicator of operational noise. But for departures, the flyover level is measured for a deep-cutback procedure which is not representative for real operations. As the value of the lateral noise level reflects noise at maximum power, this is likely to be a better basis for classification.

6.4.3 AIRCRAFT GROUPING IN PRACTICE

But the parameters listed above cannot be used in isolation – only combinations make sense (e.g. a heavy aeroplane with high by-pass ratio (BPR) engines usually produces less noise than a low BPR engined aircraft of the same MTOM - whereas for the same BPR the aircraft mass strongly influences the sound emission). The question is, which combinations of parameters should be used for grouping. A general approach, i.e. using all possible combinations, can generate a large number of groups, many with similar noise characteristics, thus defeating the object of grouping.

To meet the aim of decreasing the number of aircraft categories without compromising accuracy, consideration should be given to both acoustic equivalency and noise significance when grouping aircraft for a particular assessment.

Acoustic equivalency: Two aircraft might be assumed to be acoustically equivalent if they produce comparable noise – expressed in terms of event level L_{max} or L_E – at a number of points on the ground, or comparable noise footprints. Notionally all acoustically equivalent aircraft should be grouped. However equivalency depends on the operating procedure as well as on the actual aircraft mass and hence on conditions specific for the actual noise study. Thus use of an acoustic equivalency criterion might be very demanding in resource terms.

Noise significance: It has already been noted that the total noise at an airport is usually dominated by a relative small number of aircraft types. So these in particular have to be represented accurately. Non-significant types (much less noisy aircraft or aircraft with negligible numbers of movements) can be grouped approximately (e.g. engine type plus MTOM). This is relatively simple and can increase the efficiency of a noise study with little loss of accuracy.

Hence a practical 3-step approach to grouping might be:

1) Introduce a fundamental aircraft category scheme based on all combinations of parameters which can be used for grouping.

2) Identify aircraft categories of low noise-significance and try to combine them, based on a simplified grouping scheme (e.g. engine type and takeoff mass).

3) For the remaining groups, try to identify acoustic equivalencies and combine the corresponding groups.

6.4.4 ECAC RECOMMENDED SUBSTITUTION METHOD

In modelling calculations, substitution means replacing an actual aircraft by a similar one. Such substitutions are made when the actual aircraft type (subtype, airframe/engine combination) is not available in the database. The ‘missing’ aircraft is replaced by a type that is available and that is acoustically equivalent, if necessary by an appropriately scaled number of them.

The ANP database covers a high proportion of the aircraft types, models and variants that make up today’s civil aircraft fleets. This allows most cumulative noise contours to be generated with reasonable accuracy - unlisted aircraft simply being replaced by listed types with the nearest combination of size and performance. However, when the unlisted aircraft contribute a significant proportion of the total noise, aircraft selected on the basis of this criterion are unlikely to have sufficiently similar noise footprints to those they are replacing.

The approach recommended by ECAC is to select as a proxy the listed aircraft with the closest weight, same number of engines and installed thrust-to-weight ratio to the unlisted aircraft. Preferably the proxy aircraft should also be from the same manufacturer as the unlisted aircraft, although it is accepted this will not be possible in cases. Each required flight profile for this proxy aircraft (when following the same flight procedure) is then generated as described in Chapter 3; this should be very similar to that of the unlisted aircraft. But its noise footprint is unlikely to be similar if its engines have markedly different thrust and propulsive efficiency.

Such powerplant differences can be taken into account subsequently by applying adjustments based on certificated noise levels assuming (reasonably) that the unlisted and proxy aircraft flew similar profiles during noise certification. The adjustments take the form of equivalent numbers of operations N. Thus, for example if the unlisted aircraft had a certificated noise level 3dB greater than that of the proxy, two movements ($N = 2$) of the proxy aircraft would be substituted for each unlisted aircraft movement. In general, $N = 10^{\Delta L/10}$ where ΔL is the noise level difference (unlisted - proxy).

For each unlisted aircraft two substitutions should be made, one for arrivals, the other for departures. For arrivals, ΔL is simply the difference, in dB, between the certificated approach noise levels. For departures ΔL is the difference between the arithmetic averages of the certificated lateral and flyover levels. If that average ΔL differed substantially from the individual lateral and/or flyover ΔLs, it would be an indication that the certification conditions for the unlisted and proxy aircraft were dissimilar and other proxies should be considered.

7 SCENARIO DATA

7.1 GENERAL REMARKS ON PRE-PROCESSING

As illustrated in **Figure 6-1**, the *model* (comprising a noise engine and an aircraft database) is fed by *scenario-specific input data* (i.e. airport and air-traffic data) and *outputs* to a post-processor. This chapter addresses the question of how to transform the complex details of the airport scenario into a manageable set of variables which can be handled by the noise model. The process is illustrated in **Figure 7-1.**

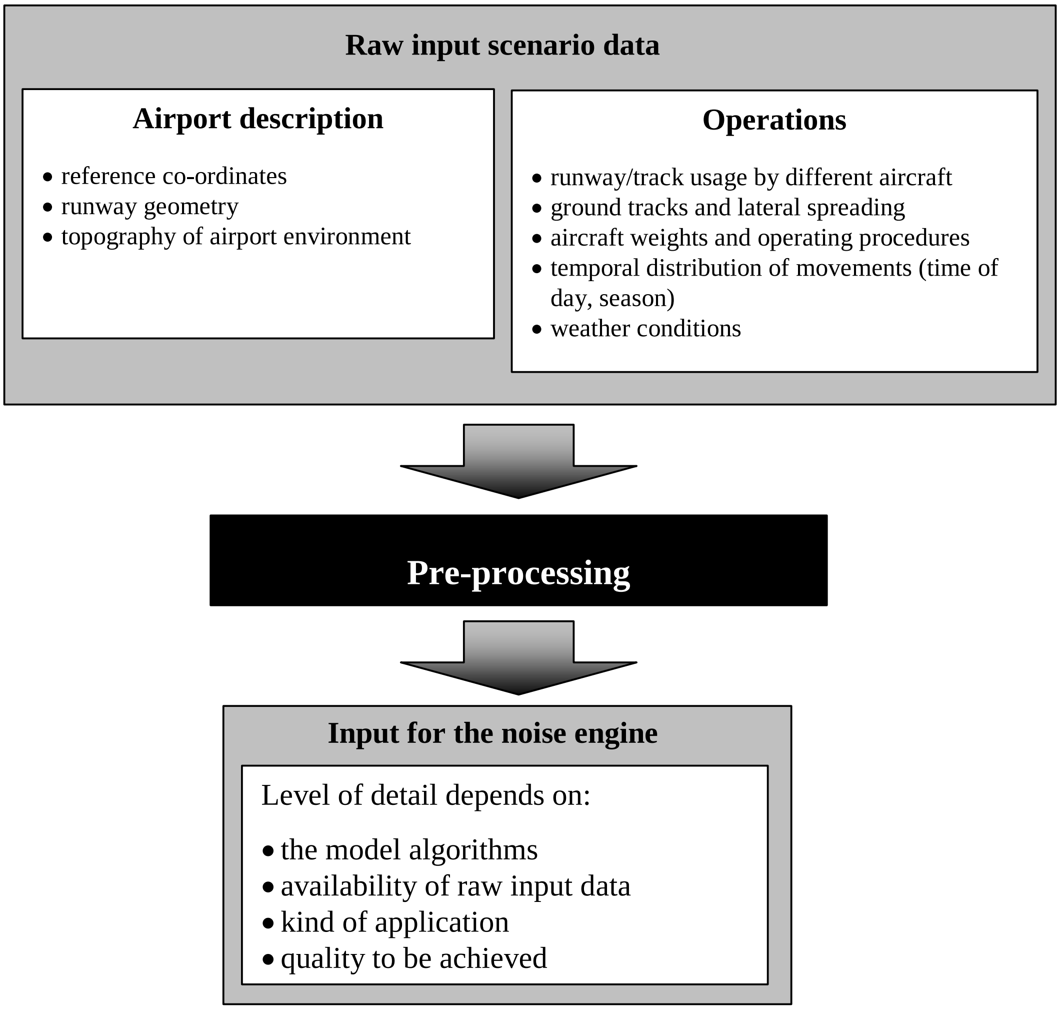

Figure 7-1: Generating the input scenario data by pre-processing.

The reliability of the overall noise calculation depends on (1) the quality of the input data, (2) the reliability of the noise engine and (3) the accuracy of the respective databases. The second and third elements are simply *tools,* whereas the first is arranging the *working material* in a way that fulfils the requirements of the job to be done (i.e. the *application*). No matter how good the tools, the output can be no more reliable than the inputs. So the preparation of the scenario input data is usually the most critical and demanding part of a particular noise study. And it must be remembered that the tools must also match the needs of the application (do not use a small hammer on a big nail or *vice-versa*). Current best practice noise engines and databases are designed to fulfil the requirements of major noise modelling studies; applying them in a sensible way to smaller studies can require considerable care and judgement.

Here it is neither possible nor necessary to specify input data requirements for any particular noise calculation engine. However the general rules for pre-processing the input data apply to any engine. The main questions are how to obtain the raw input information required (as identified in **Figure 7-1**) and how to estimate parameters when information cannot be obtained within reasonable cost and effort. The necessary level of detail will depend on the type of assessment required (i.e. A1 - B2, as described in **Chapter 5**). Usually the most detailed input data are required for “monitoring” purposes whereas for forecasting, representative data or procedures can be adequate.

In principle the input data have to be very detailed to achieve a high quality output. But this cannot be generalized – practical experience has shown that good results can also be obtained using less detailed input data. This requires a lot of experience in noise modelling and data preparation. On the other hand, if lower quality input data is sufficient for an assessment, scenario simplifications may reduce the amount of time and effort required to generate adequate aircraft noise contours.

To summarise, the accuracy of noise modelling strongly depends on the quality and detail of the input data. The following sections deal with these aspects. Special attention is paid to the flight path data, information on which can be obtained from a range of sources from representative ‘default’ assumptions to radar-recordings and high quality FDR data.

7.2 AIRPORT DESCRIPTION DATA

The airport and its environment are usually described quite readily for the purposes of noise modelling. Reference co-ordinates as well as the exact location can be taken from the AIP publications or national sources of geodetic data. In the case of future, new airports (or new runways to be built), the information is a fundamental part of the planning process.

Topographical data – when they have to be included – are also available in high quality from digital terrain models.

7.3 BASIC DATA ON OPERATIONS

7.3.1 NUMBERS AND DISTRIBUTION OF MOVEMENTS

The numbers of operations by aircraft type/category, runway and route (inbound and outbound) are always required - for the overall time period of interest (e.g. year or season). And as noise indices (such as L_{DEN}) often include time-of-day dependent weightings there is usually a need to break down the data by specific time intervals within the total period, e.g. day/evening/night, specific months of operation or sensitive peak hours.

For present or past scenarios – these data are usually available from the airport authorities’ data files, from runway controllers’ logs and/or from ATC radar recordings. They should be carefully checked for consistency, by comparing data acquired from more that one source where possible.

For future scenarios they are part of the traffic forecast and hence not subject to the modeller’s control. However basic checks should be made on the consistency of such forecast data (are the numbers of departures and approaches matching, does the track usage match to the average weather conditions etc?). Forecasts usually define aircraft movements by aircraft seating capacity and destination served rather than by explicit aircraft types and operational weights. It is then the job of the modeller or practitioner to match the forecast data to representative aircraft types or categories. Close collaboration with the forecaster is recommended to ensure adequate conversions to noise model inputs.

7.3.2 WEATHER CONDITIONS

Weather conditions have an influence on the usage of runways and routeings and hence on total air traffic - as well as on the individual flight paths of the aircraft. Additionally the weather directly affects sound propagation through the atmosphere. Although atmospheric state changes with height above the aerodrome, it is not usually practicable to account for this; contour calculations are usually based on average or nominal conditions at aerodrome elevation.

Since weather data are recorded at all airports it is theoretically possible to perform a noise calculation accounting for all weather conditions which occurred during any past time period. However this would require a very large amount of data preparation and computation time which would be disproportionate to any accuracy gains against the use of averaged meteorological conditions. This latter course is likely to be the only practicable approach for analysing future scenarios.

7.4 FLIGHT PATH DATA

7.4.1 SOURCES

Flight path data include information on ground tracks and the corresponding lateral dispersion of ground tracks, as well as on the vertical trajectories of the aircraft and related parameters like speed and engine power. There are different sources of flight path information which – with respect to their quality – can be ranked as follows:

- The most detailed is *flight data recorder (FDR)* information for individual operations[19].
- Less detail is provided by *radar data* from which can be estimated both flight paths and (knowing or estimating aircraft weight and solving the equations of motion) associated thrust levels. These can be estimated for (a) individual operations or for (b) average operations (averaged over many flights).
- In the absence of radar data, the next best information would be *real time or fast time simulation data*[20] generated by air traffic simulation tools. Like the radar data they simulate, these could be for (a) individual operations or (b) averaged operations.
- If neither radar data nor real/fast time simulation data are available, the next resort could be to use *'customised' procedural steps data*[21] (a method for this is described in

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[19] Quality of geographic position provided by inertial navigation systems (of older aircraft not using GPS) may be limited.

[20] Although the purpose of real/fast time simulation is mainly to enable ATC planners to model traffic flows at and around airports (in a real time scenario or under accelerated time conditions) these tools can be – and in practice have already been used to generate input data for noise models. It could be argued that for forecast scenarios, simulation is the best way to generate flight paths. However it is an extremely costly process and noise analysis would normally only be an adjunct to the safety studies for which simulation is used.

[21] Essentially the specific instructions followed by pilots for achieving height and speed changes. They allow the flight path to be calculated as a series of straight segments at the beginning/end of which the aeroplane's operational parameters are defined.

Volume 2). The customised profile data could be coupled with either (a) radar based ground tracks and appropriate dispersion, or (b) in the absence of such data, with nominal ground tracks and standardised dispersion characteristics.

- The last resort would be to use *default procedure profiles*[22] with (a) radar based ground tracks and appropriate dispersion or, (b) in the absence of such data, nominal ground tracks (based on navigation instructions) and characteristic assumptions on lateral dispersion.

There are many subtle variations in the ways of handling flight path data (technical aspects are considered in **Volume 2 Section 3.5**), but the practitioner must strive for the best possible estimation of (i) aircraft position and (ii) aircraft motion which in turn dictates source sound emission, i.e. engine thrust/power settings. The possible effects of any limitations (on the expected quality of the output) must be made clear to the end-user.

7.4.2 APPLICABILITY

Clearly some of the options described in the previous section are only applicable for A1 assessments where actual data is available. Put another way, what is the best possible input description depends on the type of assessment. But quality and cost are strongly related.

In the following, the different ways of generating input data are discussed, including their advantages and disadvantages, the database requirements and the status of current practice. More technical aspects – which may not be of interest for the end-user – can be found in **Section 7.5**.

7.4.2.1 Flight data recorder (FDR) data

FDR data provide the most detailed and accurate description of aircraft position (and attitude - angles of pitch, roll and yaw), aircraft speed, engine power setting and flight configuration (flaps, gear). They are the highest quality input data for use in any noise calculation engine.

Although at first sight it might seem that FDR data could only be used for historical (A1) scenarios, there are ways of extending the range of application (see **Section 7.5**). However a major disadvantage is that they are only obtainable at very high cost and effort - especially since each record describes only one aircraft movement. Hence, up to now, they have only been used in special and limited model and data development studies.

7.4.2.2 Radar data

Radar data provide a record of aircraft position and speed but not complementary engine power settings. However, in the absence of information from elsewhere, that can be derived using tools called *thrust estimators* described in **Section 7.5**. Radar data (like FDR data) account implicitly for meteorological influences on the flight path since they represent the real position of the aircraft.

Radar data may be input (to thrust estimators and the noise model) as position coordinates at discrete time intervals or in the form of flight path segments derived from the raw data - as required by the noise calculation engine.

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[22] *Default profiles* are based on nominal operating procedures, i.e. sets of typical or representative procedural steps. Default profiles were widely used in early noise modelling studies.

To reduce computation time, radar data (as well as the corresponding thrust data) may be averaged across a sample of measurements (see **Section 7.5**).

The main noise applications of radar data are historical or monitoring studies (A1 assessments). Since radar data is monitored at most major airports (although its availability is restricted in some countries) its use in noise modelling is increasing even though the amount of effort required is relatively high.

7.4.2.3 Real time or fast time simulation data

ATC real/fast time simulation provides high quality data on aircraft position as well as on engine power settings (including meteorological effects). However simulations do not reflect *real* operations. There are no restrictions on the use of these data in any modelling application; indeed they can be regarded as the best inputs for assessments of future scenarios (B1). However they have the disadvantage that they are very costly and time-consuming.

The most effective use of simulation for noise modelling would be ‘what-if’ (B1/2) studies, especially when the effects of operational procedures or ATC measures have to be investigated.

7.4.2.4 Customised procedural steps

Essentially, these mirror the operating instructions followed by the pilot to achieve a specified sequence of height and speed changes. Calculations of the consequent vertical flight profiles also make use of information from the noise model’s aircraft performance database (i.e. aerodynamic and engine performance coefficients) as well as information on the atmospheric conditions. It is the procedural steps that are ‘customised’ - based on information provided by the aircraft operators. A procedural step is defined by characteristic target, or transition, values of engine power, climb gradient or acceleration. Advice on seeking information on operators’ procedural steps is given in **Appendix D**. Detailed instructions on how to generate customised procedures from the ANP database are provided in **Volume 2**.

The corresponding modelling of the ground tracks (i.e. the projections of the flight path on the ground) and their lateral spreading depends on whether corresponding radar information is available or not. More on that can be found in **Section 7.5**. Use of radar data will usually increase the accuracy of the contours.

The use of customized procedures is a relatively inexpensive way to generate flight profiles and so it is fairly common practice - in combination with varying degrees of grouping by aircraft type and weight. Other advantages are that (1) different operational procedures used by different airlines can be taken into account and (2) the effect of turns on the vertical profiles can be modelled. Where radar data is available but has not been used for some reason, e.g. processing cost, the customised flight profiles can be checked against the measured flight profiles.

7.4.2.5 Default procedures

Some modellers use ‘default procedures’ when no information on actual aircraft operations is available. Although this is a simple and even less expensive option for the model user, it runs a risk of generating unrealistic results when default and actual procedures differ markedly. Indeed, this is believed to be a major source of error in contours produced by inexpert or inexperienced model users.

Otherwise, used expeditiously, the default option can yield quite accurate results – and has been found to do so when combined with the process of grouping, which introduces a further element of averaging. What averaging is appropriate depends strongly on the actual airport scenario and fleet-mix, procedures used, distribution of the movements between different operators, and so on. If the average and real default flight procedures are reasonably matched, the noise computation can achieve a comparable degree of accuracy to the use of customised procedures. Needless to say, this requires that the averaging process is performed very carefully and one member state has found that the generation of reliable default procedures and corresponding databases required several person-years of effort. Moreover, default procedures determined in this way may be valid only for specific airport(s) and standardised weather conditions – not being more widely usable.

As is the case for customised procedures, the modelling of the ground tracks and their spreading can be based on radar information or on nominal tracks and generic assumptions on dispersion.

7.5 SCENARIO DATA: SOME TECHNICAL ISSUES

THRUST ESTIMATORS

These are mathematical models used to estimate propulsive thrust from measurements of an aeroplane’s flight path. The availability of radar data from airport noise and flight monitoring systems provides the potential to model aircraft performance quite adequately. Radar data provides information on aircraft operations at a particular airport. It incorporates the effects of airlines’ procedures and local ATC factors.

Depending on its mass, the forces of lift, weight, thrust and drag act on the aircraft to change its velocity or height. Resulting changes in potential and/or kinetic energy can be calculated from successive radar returns or between segments points identified from radar data. Thus thrust may be equated to the sum of the drag force and the force required to change the aeroplane’s potential and kinetic energy (PE and KE). But as all three parameters, drag, PE and KE, are dependent on aircraft mass (= weight/gravitational acceleration), any thrust estimate is only as good as the weight estimate.

Radar data provides two inputs to this analysis; the climb or descent angle and the rate of change of aircraft velocity (acceleration). These are derived from the changes of time, distance, speed and height between successive radar returns or segment points. But the quality and treatment of radar data is critical. In most cases the radar data will need to be filtered to remove non-aircraft returns and then smoothed by curve-fitting to minimise the effects of intrinsic positional errors (see below).

The speed determined from radar data is aircraft ground speed. This differs from airspeed due to the effect of wind. When airspeed is required, wind speed and direction has to be allowed for. This is complicated if it is to be recognised that wind speed and direction vary with time and with height above ground. (However, it is common noise modelling practice to disregard windspeed except during take-off, initial climb and final approach - see Volume 2.)

To estimate aircraft drag with precision would require reference to aircraft *drag polars* (showing relationships between aircraft lift and drag) which are not readily available. However, there are simplified methods that are adequate for noise modelling, details of which are provided in **Volume 2**.

When developing or testing thrust estimators, it is useful to test the results against FDR data as the accuracy and suitability of radar data varies from system to system. Used with appropriate care, thrust estimators have been shown to deliver reasonably accurate estimates of aircraft thrust levels during takeoff/climb-out or initial descent/landing.

RADAR DATA

Characteristics

The air traffic control radar at airports is used for safe guidance of aircraft. Usually the main information comes from a local rotating radar head, in the form of aircraft position, usually about every 4 seconds. The passive radar return provides only range and azimuth (direction) of the aircraft from the radar head. The altitude is determined by a facility of *secondary surveillance radar*: when hit by the radar beam, the aircraft's transponder answers by transmitting the pressure altitude measured on board.

Below 5000 feet this is the height above ground, otherwise it is the altitude above mean sea level. For safety reasons, data from the local radar station is combined in a so-called "multi tracker" with data from other, more remote, radar stations. In general, this introduces some bias due to the less accurate data from more distant stations. If feasible, data should be taken only from the local station. In this case, the range of the aircraft from the radar head can be determined with an accuracy of typically ± 60 m.

Processing

Invalid data from ground reflections and from taxiing aircraft are filtered out. For a departure, the first flight path point appears only after the aircraft is around 50 m or more above ground. Depending on the system used, the radar data points may be fitted by a spline algorithm to produce a smooth curve and to extrapolate the flight path backwards to the runway. Altitude corrections above 5000 ft must be applied using the local, actual air pressure to get the height above the runway for the whole flight.

Finally, each individual recording is associated with the corresponding aircraft type. Information from the airport flight information system or elsewhere is used to complete the data set, e.g. take-off weight, flight number, sound levels at monitoring locations etc.

Use of radar data

Radar data can be used in various ways to describe aircraft positions and velocities. The various levels are, in decreasing order of resolution:

- Use each individual recorded radar data in the noise calculation
- Use a statistically selected subset of recorded radar data for noise calculations (Appendix C5 describes a specific method used by one member state.)
- Use measured ground track with predefined or average[23] climb profiles
- Replace the measured ground tracks by a small number of dispersed subtracks (see **7.6**)

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[23] Analyse radar data to define average climb/speed profiles (but note that speed information derived from positional data generally has a rather high scatter. due to errors of differentiation).

7.6 MODELLING OF LATERAL GROUND TRACK DISPERSION

Lateral ground track dispersion depends on ATC directions, individual piloting, use of flight management systems, and variable winds. As dispersion can have a significant effect on the shape of the noise contours, it is important to take proper account of it (see **Section 4.6**). There are several approaches to modelling lateral track spreading, depending on the type of scenario (historic or forecast) and the information available.

One is to make use of radar track information. It is usual to represent a swathe of tracks on a flight route by a centre track (‘*backbone track*’) and several side tracks (‘*subtracks*’). Example radar data of the kind from which the modelling tracks are derived are shown in **Figure 7.2**.

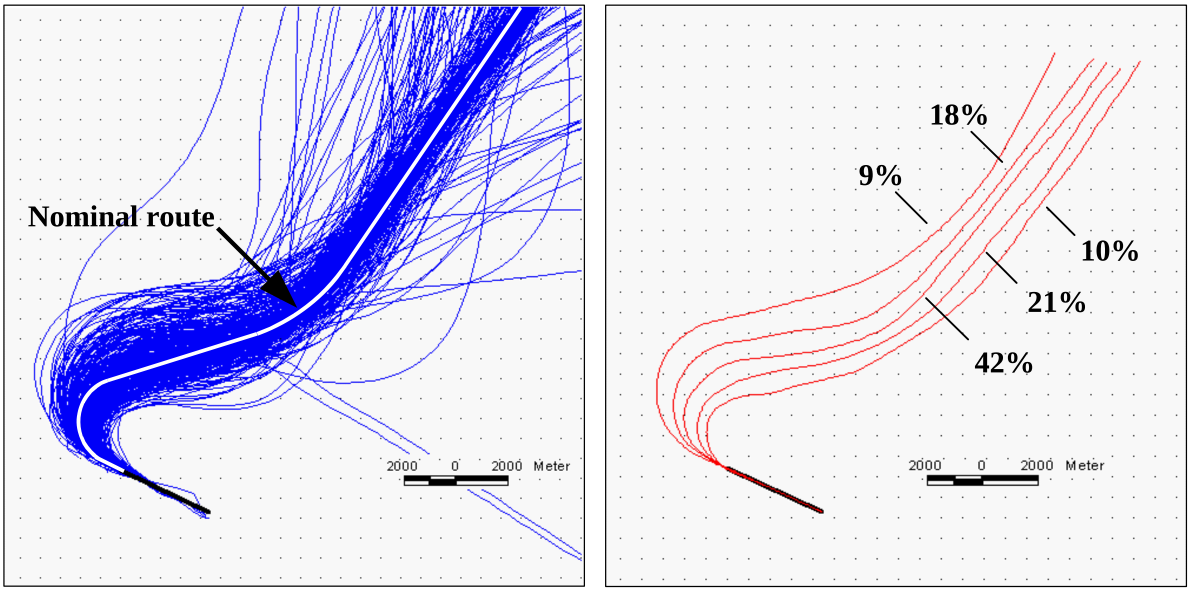

Figure 7-2: Radar tracks of individual departures (left) and average tracks of the same situation with the percentage of movements (right).

The total movements on the route are distributed between the backbone track and subtracks. The spacing of the subtracks and the percentages of traffic assigned to them depend on the distribution of the movements across the swathe (perpendicular to the backbone track). If the information is available, this percentage may be defined separately for each aircraft type or category. Otherwise (or if computation time has to be reduced) the same distribution may be used for all types or categories.

A second approach is to use the radar data to define only the backbone track and the boundaries of the radar track swathe. The distribution of the movements across the swathe is then described by a specific distribution function – usually a symmetric one of Gaussian type.

A third approach – which is commonly used when no radar data are available – is to base the backbone track on information from the AIP and to use a typical spreading (i.e. a swathe width defined as a function of distance along the (backbone) track together with a characteristic distribution function (usually of Gaussian type). An example can be found in **Volume 2**. A disadvantage of this approach is, that the information on standard flight routes published in the AIP might not depict accurately the actual backbone track; AIP routings are nominal from which average flight tracks might deviate consistently.

It is sometimes found that the shape of the contours is not particularly sensitive to the shape of the lateral distribution function, as long as the width of the flight corridor is modelled accurately. The Gaussian form gives a good fit to many observed distributions. Although continuous distributions can be simulated, an approximate model is preferable on grounds of computing cost.

8 ECAC RECOMMENDED METHOD

This document, **Volume 1**, provides general guidance on aircraft noise modelling. It covers topics from noise assessment through general concepts of noise modelling systems up to fields and limits of their application. It is addressed to all users of noise models from the *practitioner*, who has to apply the noise modelling tools, to the *end-user*, who has to know what he can expect from the noise modelling process and what are its limits. However **Volume 1** does not cover explicit technical or mathematical descriptions of a noise modelling system – it tries only to explain how such a system works.

A specific methodology is described in detail in **Volume 2** which is addressed mainly to the *noise modeller* and *program developer*. This gives a technical description of a recommended method for the calculation of aircraft noise around civil airports that is recommended by ECAC and which completely replaces ECAC.CEAC Doc.29 2nd Edition [ref. 10]. It is not the only way to implement the ideals set out in this volume but it incorporates internationally agreed current best practice - as implemented in advanced aircraft noise models. It does not list a computer code, but it does fully describe algorithms that can be programmed to create one. Changes to, and advances on Doc.29, 2nd Edition are identified for those who wish merely to update existing software.

A major advance from earlier versions is that it now links to a comprehensive, on-line international aircraft noise and performance (ANP) database at www.aircraftnoisemodel.org. The database and its use are fully described in **Volume 2**.

The ECAC model employs segmentation methodology. Aircraft flight routeings to and from the aerodrome are represented by groups of ground tracks comprising sets of contiguous straight-line segments. Each group contains a central backbone track and a number of dispersed subtracks. Different aircraft types or categories using a route generally follow the same tracks; however a routeing can embody different track sets if it is necessary to model varying aircraft track-keeping performance. Appropriate routeings and tracks can be determined from radar data, if available, or from procedural information e.g. from AIPs. The profile points, the path coordinates in the vertical planes above the ground tracks are also connected by straight-line segments; these are merged with the ground tracks to create sequences of segments that fully depict the flight paths in three dimensions.

The flight profile of any aircraft type or category on a particular route, i.e. the profile points and the corresponding velocity, bank angle, propulsive power and aircraft configuration, are calculated as functions of aircraft weight and the operating procedure (described by a set of procedural steps). The necessary aircraft performance relationships are fully described; ways of applying them depend on the input data - particularly whether these include profile points and speeds (e.g. determined from radar data) or procedural steps (obtained from aircraft operators or based on default assumptions). These calculations require information on the aeroplane performance characteristics including lift-to-drag ratios for different aircraft configurations and the variations of propulsive power with height, speed and air temperature. How to obtain this information from the international aircraft noise and performance (ANP) database is fully described.

The ECAC model calculates the aircraft noise exposure levels on the ground beneath and around the flight paths. L_{max}-based noise indices are computed relatively simply: the event level for any aircraft movement is calculated as that generated by the single 'noisiest segment'. In other respects the L_{max} process is much the same as that for sound exposure indices.

Exposure indices based on L_{eq} are calculated by summing the packets of sound energy received from each and every aircraft type or category (multiplied by their numbers) on each and every segment. (The amount of computation required for this can be reduced substantially by discounting contributions from aircraft-segments that are not 'noise significant'.) Calculating the sound energy received by one observer - from one aircraft on one segment - therefore lies at the heart of the modelling process and **Volume 2** explains this in detail.

The starting point for a segment noise calculation is to define representative segment values of speed and propulsive power and, using those, to extract from the NPD table of the ANP database the SEL that, hypothetically, would be generated at the receiver point, in the absence of the ground surface, if the segment were extending infinitely in both directions; i.e. if the whole flight path involved no changes of direction or flight configuration. The NPD levels account for atmospheric attenuation in a reference atmosphere but they are those observed directly beneath the aircraft perpendicular to the wing-fuselage plane. They have to be adjusted to account for atmospheric conditions that deviate substantially from the reference state and for the fact that, due to engine installation effects, sound radiation is not symmetrical about the flight path; this is done by adding a lateral directivity correction (different for aircraft with rear-fusealge-mounted and wing-mounted engines). Next, allowance is made for excess lateral attenuation of sound propagating to the side of the flight track which is a function of elevation angle (appropriate to an infinitely extended flight path). Finally, a correction is applied to allow for the fact that the segment really has a finite length. It also accounts for the longitudinal directivity of aircraft noise.

Although data acquisition lies in the province of the model user rather than its developer, **Volume 2** provides advice of a general nature on acquiring and pre-processing the large quantities of case, or scenario, data required to undertake reliable airport noise assessments. Advice also covers the construction of special noise indices and practical aspects of fitting contours to the surfaces of noise index values.

Noise models that accord with the recommended practices set out in **Volume 2** of this guidance are supported by an ECAC-endorsed on-line aircraft noise and performance database at www.aircraftnoisemodel.org. The database and its use are fully described in **Volume 2** of this guidance.

9 ELEMENTS OF GOOD MODELLING PRACTICE

9.1 REQUIREMENTS

Previous Chapters have described the principles and applications of modern aircraft noise contour modelling culminating, in **Chapter 8**, in a brief introduction to the ECAC recommended methodology that is detailed in **Volume 2**. The purpose of this final Chapter is to further acquaint the reader with the practical difficulties, introduced in **Chapters 5 and 7**, that are faced by modelling practitioners, especially (1) the limitations of actual models and (2) the precautions necessary to ensure that adequate results are produced cost-effectively - by getting a sensible match between the modelling process and both the end-user needs and the resources available. Good modelling practice demands careful attention to the potential effects of a host of contributing factors, most of which have already been identified. Unfortunately, this involves many considerations that lie beyond the scope of Volumes 1 and 2 and it is intended that these will be covered in a third volume of guidance - on the subject of Model Validation. For now, it is only possible to highlight the problems, leaving the user to devise best practicable means for dealing with them.

9.2 QUALITY CONTROL AND VALIDATION

9.2.1 QUALITY GOALS

The quality goals of an individual noise modelling study depends on the needs of the end-user, on the availability of validated data and on the intrinsic performance of the system model and other tools used for the study. So the goals and the means to achieve them should be established at the beginning of the study to provide a baseline for performance validation. The effort and formality which need be dedicated to this exercise should be matched to the importance, status and significance of the study. As a rule the factors to be considered include

- the scope and purpose of the study,
- legal and regulatory requirements,
- performance criteria,
- data and data source authentication,
- validation of the tools used for the study.

9.2.2 VALIDATION PLAN

The practitioner and end-user should agree a validation plan at the outset of the study. This should describe actions (tests, document audits, measurements…) which are needed to verify each individual requirement. It should be ensured that resources (effort, equipment, logistics,...) are allocated to perform these actions and to record the results. If required for legal or practical reasons (guarantee of independence, resources,…) the end-user may allocate some or all of the tasks and responsibilities to a third (public or private) party.

The validation work can be considerably reduced if the end-user adheres to standard terms of reference and if the practitioner uses a standard methodology with a high level of built in quality assurance. In that situation validation could be limited to confirming compliance with the agreed conditions and methodology.

9.2.3 VALIDATION EVIDENCE

Evidence that the noise modelling study meets its quality goals needs to be documented, e.g. as part of the technical report. This written evidence should include, or identify the whereabouts of

- the quality goals,
- the validation plan,
- a summary of the results of the validation actions, and
- a validation case which proposes a finding of compliance, compliance with conditions, or non-compliance.

It might be appropriate for public body end-users to establish a central repository for some of this validation evidence in order to promote consistency between noise impact assessments and to improve their quality over time. This would also help organisations to evaluate and validate new modelling systems or improvements to existing models against the state-of-the-art best practice.

9.3 END-USER NEEDS

The end product is generally one or more sets of aircraft noise contours that depict the extent of noise impact upon the community. The required quality of the product has to be measured against performance criteria that need to be agreed before the modelling can begin; these in turn depend on the end-user's needs. **Chapter 5** categorises noise modelling applications according to the kinds of impact assessments being undertaken. In order of increasing modelling complexity these are:

- *Comparative impact (applications B1 and B2)*

  The end-user needs assurance that the noise contours reflect, and allow proper assessment of the relative merits and drawbacks of the different scenarios

- *Absolute impact: forecast scenario (application A2)*

  The end-user needs to be confident that airport neighbours and relevant authorities will be able to agree the output

- *Absolute impact: past or present (application A1) - which may require comparison with noise measurements, for instance for the validation of a noise model.*

  The end-user requires that apparent inconsistencies or inaccurate results are kept to a minimum and that they are explained in a sensible and credible manner.

Although perfect accuracy might seem to be the ultimate goal, it is clear that this is presently elusive or at least in most cases unaffordable. Quality assurance processes need to cope with imperfections of the real world and provide a reasonable guarantee that products meet customer needs. They rely upon predefined quality criteria which are judged relevant by the customer and apply to specific parts/characteristics of the product or of the production process.

9.4 PERFORMANCE CRITERIA

For aircraft noise modelling there are five key modelling performance criteria: auditability, reliability, consistency, accuracy and cost.

9.4.1 AUDITABILITY

The noise modelling process together with its inputs and outputs needs to be auditable, requiring that all the facilities needed to verify the pertinence and validity of the results are in place. The raw and processed input data, together with data source identification, intermediate results, assumptions made, final output and commentaries/conclusions, should be documented in sufficient detail and in a transparent and accessible manner. The process and contribution/responsibilities in the process should be recorded and accessible.

9.4.2 RELIABILITY

The noise modelling process needs to be reliable so that decisions taken on the basis of its results can withstand scientific scrutiny and possible legal action. To protect the integrity of both practitioner and end-user, careful attention should be paid to the collection of input data and conditions for use. The modelling process should deliver the same results when repeated with the same inputs. This has to be confirmed throughout the range of applications for which the process is intended. The noise modelling process should also provide consistent intermediate and final results so that any peculiarity of a noise contour can be explained in a satisfactory manner.

9.4.3 CONSISTENCY

The noise modelling process needs to be internally consistent as well as between different applications. Some of the requirements for consistency are the same as those for reliability but, in addition, evidence is also required that all factors are corrected for or, as a minimum, just accounted for. The relationships between inputs and outputs have to be consistent for different scenarios at a single airport and for comparable scenarios at different airports across Europe.

9.4.4 ACCURACY

Noise models calculate noise exposures by simplified mathematical representations of the real, complex processes of aircraft noise generation and propagation. Very many variables influence the noise levels around an airport and their complete description, even if that were possible, would not be technically reasonable or economically affordable. As a rule, only the most significant variables need to be taken into account, each in a manner that is sufficient to meet the purpose and accuracy requirements of specific studies.

Applications A2 and A1 require modelled results that match actual, measurable, reality. When considering comparisons of modelled and measured noise levels it must be remembered that acquiring reliable measurements is essentially as difficult as producing accurate contours and therefore requires a similar degree of care and attention. The technical issues are described in **Section 3.3**.

Applications B1 and B2 involve scenario comparisons for which absolute accuracy might be less important than realistic sensitivity to key input variables. Accuracy might thus need to be defined in terms of

- fidelity
- sensitivity
- relative accuracy

Care should be exercised when interpreting and using noise contours, especially with respect to the definition of land-use planning zones. When noise contours intersect residential areas, it is often sensible, noting the inherent uncertainty of the noise contours, to adjust land-use planning zones to follow natural boundaries, although it is accepted this may not be practical in all cases.

9.4.5 COST

The principal costs of aircraft noise modelling are those of the labour required (i) to develop and maintain the modelling tools and databases, (ii) to collect and pre-process scenario data and (iii) to perform, interpret and report upon individual studies. As is generally true of any problem solving, costs increase with the stringency of other performance criteria and acceptable solutions inevitably involve substantial compromise. A significant factor is that technical complexity tends to be independent of the scale of the noise impact; e.g. it can be as difficult to model accurately the noise of light traffic at smaller aerodromes - for which study resources are likely to be severely limited - as it is for major airports. In such cases lower levels of performance are unavoidable.

9.4.6 OTHER CRITERIA

Other criteria which may be important for, and special to, certain applications should be agreed and registered prior to the modelling process; these might for example include the following.

Comprehensiveness: local communities around an airport may press for all noise sources (jet aircraft, helicopters, small aircraft, ground vehicles, etc.) to be taken into account because the focus of their annoyance varies. The noise modelling process might have to accommodate these needs whatever the limitations of the available systems and data.

Compliance: the end-user may focus on compliance with specific requirements (e.g. exclusion of noisier aircraft types), disregarding the impact on other performance criteria (e.g. accuracy, consistency,...), or the modelling process might have to comply with national or local legislation, which may impose, for example, formal public consultation for the establishment of the traffic scenarios.

Traceability: the end-user may need, for instance, to trace the influence of weight or procedure limitations across the modelling process in order to ascertain the pertinence of these limitations.

9.5 FACTORS INFLUENCING PERFORMANCE

Figure 9-1 is a flow diagram of the noise modelling process (illustrated previously in Figures 6-1, 6-2 and 7-1). The performance of the process depends on (1) the accuracy of the model, (2) the reliability of the input data, and (3) post-processing of the output.

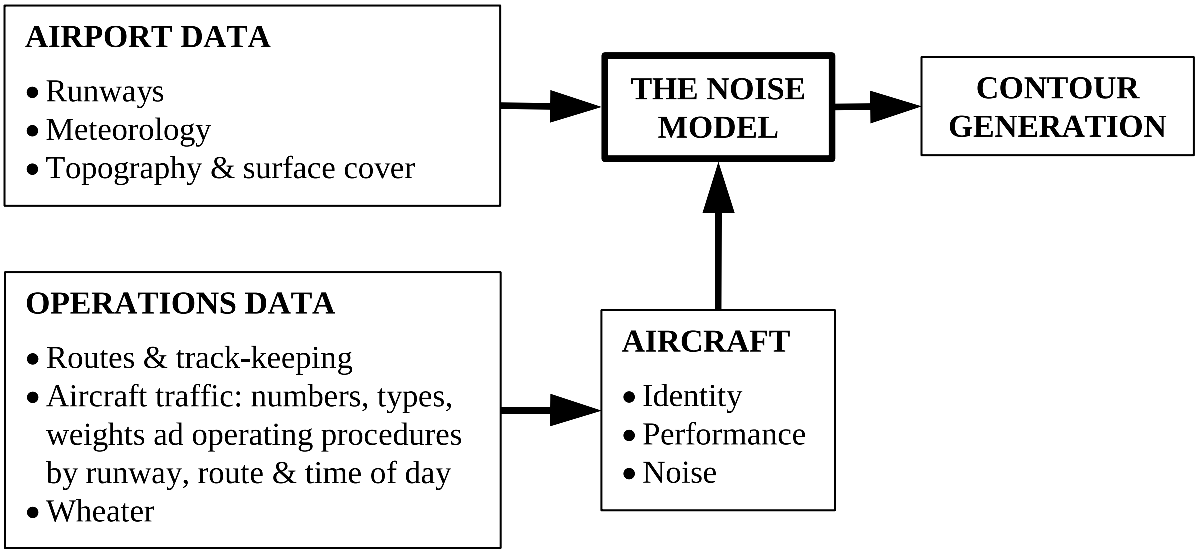

Figure 9-1: The noise modelling process

9.5.1 THE NOISE MODEL

To meet reliability and consistency goals it is preferable for the practitioner to use a standard methodology that is formally acceptable to the end-user (where appropriate, as specified by the relevant authority). **Volume 2** provides such a methodology. Should any deviation from the standard methodology be necessary for a particular noise modelling study, this should be underlined. The performance of the model, considered separately from the input data on which it depends, is governed firstly by the veracity of its algorithms - the accuracy with which they represent real physical processes they model - and secondly by the fidelity of the computer software into which they have been programmed. These are matters for the modeller; however, the practitioner needs to remember that mathematical models can, at best, only approximate real physical processes, some of which are not well understood.

Matters that are internal to the model itself are normally beyond the control of the practitioner; s/he is primarily responsible for acquiring and pre-processing adequate input data according to the requirements described in **Chapter 7**.

Although their effects are not normally modelled, it should be remembered that noise from aircraft on the airport runways might in reality be shielded by local buildings. Also, the level at the receiver is very sensitive to the acoustic properties of the ground as well as to wind and temperature gradients when sound is propagating close to the earth surface. At distances greater than several hundred metres, sound levels might vary by 10 dB or more depending on meteorological conditions. Usually, calculations are made for average or worst case conditions.

9.5.2 AIRPORT DATA

When compiling airport data, the practitioner should, wherever possible, make use of public and verified data (e.g. from AIPs, met offices, national mapping agencies and government statistics) - unless required by the end-user to do otherwise. Where data cannot be obtained from official publications, or where there may be doubts about the validity of data, this should be made clear. Depending on the scale of the study, responsible authorities including the airport operator and local government offices might be asked to verify the modelling input data.

9.5.3 OPERATIONS DATA

Assembling the data describing the aircraft operations in time and space is usually the most onerous task to be undertaken by the practitioner. Aircraft noise assessments are required for a very wide range of facilities and scenarios - from small general aviation aerodromes to major national airports, and from minor traffic changes to the construction of new runways, terminals or, sometimes, entirely new airports. The sources of data, and the quantities required, will be governed by the nature and scale of the assessment and the uses to which it will be put - as explained in **Chapter 5**.

Past traffic

At the smallest aerodromes, data on historical aircraft movements is generally basic, consisting principally of air traffic controller records of aircraft movements by date, runway, approximate time, aircraft tail number, and type of movement - take-off, landing, touch and go, etc. Information on flight tracks and operating procedures is minimal; these must be inferred from AIPs and advice from local controllers and aircraft operators. If resources allow, it is helpful to observe operations over a period of time, collecting visual data from which to build a picture of typical operating patterns. But even if this can be done, a major limitation on modelling accuracy when noise is dominated by aircraft other than civil jets is a lack of reliable aircraft noise and performance data (see Appendix B).

At the other end of the spectrum, most large airports and their service providers (especially airlines and air traffic control) have large quantities of data from which very detailed noise modelling input data can be developed. The problem in this case is not lack of information but obtaining and organising the resources necessary to acquire and process it for noise modelling purposes.

A resource of major benefit, now deployed at most large airports, is an aircraft noise and flight monitoring system (see 3.3.5) which records comprehensive details of aircraft movements including radar-measured flight paths, weather conditions and noise levels at various ground positions. Access to such a system provides the noise modelling practitioner with a single source of much of the needed data on aircraft movements, by flight number, aircraft type, time, meteorology and flight path. However, processing this data is a large-scale undertaking not least because there is a crucial need to screen the data for errors - of which there can be many kinds, particularly mis-matching of flight and radar information and missing data. Consideration then has to be given to possible modelling bias caused by screening out bad data. When this has been done the screened data can be analysed to construct flight routeings (backbone and dispersed tracks) and flight profiles for different aircraft types/categories as explained in **Volume 2**.

In the absence of automated flight monitoring equipment the practitioner has to reach the same point by different means. Radar data might be obtainable independently from ATC providers. If not, flight tracks and profiles have to be synthesised from procedural information from AIPs and aircraft flight manuals - i.e. instructions to aircrew on how and where to fly (see **Volume 2**). Assistance from aircraft operators should be sought on this.

Key information which is only obtainable from operators, if they are prepared to release it, is aircraft weight data. In the absence of authenticated data, weights can only be inferred from other operational data; for example, for departures, from the distance to be flown. But the limitations of such estimates are obvious.

Traffic forecasts

Estimates of future traffic provided by airport and air transport planners are often broken down by aircraft size and origin/destination only; it might be left to the practitioner to distribute this between aircraft types/categories, runways and routeings. As the reliability of the results is totally dependent on the input data assumptions the practitioner should obtain from the end-user formal acceptance of them. In return, the practitioner should advise the end-user about the impact of possible data deficiencies and uncertainties.

9.5.4 AIRCRAFT DATA

The ANP data, like all similar information, relate to specific aircraft types or categories and it is important that aircraft to be modelled are correctly matched to the source aircraft. If no direct match can be made then great care is required to ensure that acceptable substitutions are made - especially for noise-critical aircraft (i.e. types that are likely to have a dominant effect upon the total noise exposure).

Manufacturers' noise data are normally obtained by measurements made during aircraft noise certification programmes. They – as well as data from airport noise monitoring stations – normally correspond to relatively short propagation distances. Due to the difficulty of predicting the various effects of atmospheric and ground influences on the sound propagation, the levels for long propagation distances, calculated by extrapolation from short distance data, are subject to an increasing degradation of accuracy. Due to this effect – and to the effect described in the previous section – the accuracy of noise contours tends to decrease with increasing distance from the airport.

9.5.5 CONTOUR GENERATION

In order to provide accurate and reliable results, the practitioner must pay attention to the quality of the postprocessor used for the production of geographical maps, population counting or other outputs: quality of the background maps, size of the grid and accuracy of the lattice, compatibility of geodetic references with the model, code for colour, etc. The whole process should be documented in a report which references all the tools and data used to ensure auditability, justifies all assumptions made and underlines uncertainty areas.

9.6 PRACTICAL RECOMMENDATIONS

The performance requirements for a noise modelling study have to be matched to its purpose and also to available human, budgetary and other resources. Resource intensive activities in airport noise impact assessment studies are:

(i) maintenance and management of the modelling system, notably the databases.

(ii) collection and pre-processing of scenario (airport and traffic) data, and

(iii) management of the modelling process and communication of the results.

The costs of activities (i) and to a lesser extent of (ii) can be reduced by standardising the methodologies as much as possible. This enhances the re-usability of the studies and has a beneficial impact on auditability, reliability and consistency. Additionally, it tends to make computerisation of the processes more cost-effective.

In order to improve the efficiency of activity (iii), standard terms of reference should be adopted for different study categories; these might include detailed templates for the outputs.

To achieve these aims, users might consider the use of a comprehensive modelling system capable of covering any type of assessment - recognising that all its features would not be required for every application. This could reduce the costs of the model maintenance and use (software maintenance, support, implementation, training, etc).

This modelling system would need to be qualified against internationally agreed requirements (see **Volume 2**). Apart from increasing confidence in the results, this would encourage use of the ANP database, thus reducing the cost of database maintenance and updates.

With these general considerations in mind, preparations for any aircraft noise impact assessment study can be broken down into the following sequence of tasks.

1) Define the problem: identify and rank factors of importance.
2) Establish model performance criteria.
3) Assess and cost alternative modelling approaches against the performance criteria and make (and explain) choice.
4) Enumerate assumptions and their limitations.
5) Identify sources of data.
6) Compare model with measurement where practicable.
7) Undertake sensitivity analysis where appropriate.

When the findings of this preliminary investigation have been communicated to and accepted by the end-user, the study can be undertaken and reported.

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APPENDIX A NOISE CAUSE-AND-EFFECT RELATIONSHIPS

Various cause-effect relationships are illustrated diagrammatically in **Figure 3-1**. To provide a background and assist understanding of the factors that contribute to overall community noise impact, this Appendix discusses some of the relationships illustrated in that diagram. Unless noise exposure metrics are otherwise specified, dBA values refer to steady conditions, that is constant $L_A(t)$. Attention is confined largely to behavioural effects; the possible link between noise and health effects is not addressed.

Some effects have been measured objectively and quantitatively, and related to noise exposure indicators. These include speech disturbance and noise induced levels of hearing loss. However, some behavioural indicators, including annoyance, are essentially subjective and, although quantifiable, can be 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 the noise makers. The effects of such *modifying factors* dramatically weaken correlations between noise and response indicators by masking or confounding their dependency on noise. Such relationships are further obscured by variations in noise exposure over time and space, because individuals move around and engage in different activities.

Obvious physical factors include time and situation which govern intrusions into activities - sleep disturbance occurs primarily at night, speech interference during the day and so on. But equally important are those that control attitudes and susceptibilities; whether or not a particular noise annoys may depend very much upon the message it carries; concerns about the sources of noise can influence annoyance reactions more strongly than physical noise exposure itself. **Figure 3-1** shows the influence of these modifying factors and how they interact at each level of response, becoming increasingly important by comparison with the noise exposure. Thus the probability of overt reaction, including complaints, is only weakly governed by the actual noise exposure

A1 DISTURBANCE CAUSED BY NOISE

Detection and distraction

Human hearing is extremely acute; the ear and 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 and of no concern. Sound attracts attention when it changes or conveys information, especially recognisable warnings of danger.

Disregarding most of the perceptual complexities involved, a key question is whether a potentially offending noise is actually audible. Is it sufficiently loud or intense to be detected amid inoffensive background sound? If not, it is unlikely to cause adverse effects. A person listening to loud music indoors may not notice a passing aircraft in the same way that a loud aircraft noise could mask quieter music. Or its noise may be totally masked by the outdoor sound of local road traffic. Outdoor noise can also be blocked by the sound insulation afforded by the building fabric.

If an aircraft noise event is heard, it may cause disturbance, depending upon its level and the listener’s activity. Aural detectability is well understood but, like all noise factors, is difficult to generalise with reference to community situations. A noisy 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 sound level is at or above that of the masking background noise. If the noise contains irregularities such as whistles or thumps it may be quite audible at levels around 10 dB *below* the background noise. Thus, close to aircraft flight paths near airports, where aircraft event L_{max} is likely to exceed outdoors 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 the aircraft be unidentifiable.

Interference with communication

Interference with speech communication is a common type of noise disturbance; the intelligibility of speech is impaired by masking noise. Inside typical living rooms *reverberation* (repeated sound reflection) causes the sound level of speech to be spatially fairly uniform at distances more than a metre or so from the speaker. For listeners with normal hearing, the intelligibility of relaxed conversation throughout the room is 100% in 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. The larger the room, the lower these masking thresholds become although there is a natural tendency for speakers to raise their voice levels to compensate. To put the above levels into context, relaxed speech indoors normally reaches the listener at a level of around 60 dBA.

Indoor noise levels can be governed by a variety of sources depending on 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 important, as is road traffic noise if there are busy roads nearby. Outdoor sound is attenuated as it passes into a building, mainly through windows. If the windows are wide open, the attenuation is around 10 dB; if closed it rises to 20 - 30 dB depending upon 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 30 - 40 dB. Indoor noise levels thus span a very wide range, from perhaps 20 dBA inside quiet homes at night, through 40 dBA - 60 dBA in homes and offices during daytime to 70 dBA+ in noisier working situations and in homes with music playing.

Outdoors, the relationships between intelligibility and background noise levels are similar; however, speech level at the listener's ears is controlled by the inverse square law rather than reverberation. This means that indoor criteria apply up to a distance of about 1 m. Beyond that, the thresholds fall by 6 dB per doubling of distance; thus, at 2 m, relaxed speech is 95% intelligible in background levels of about 59 dBA. Again voice levels tend to be raised to overcome background masking.

It must of course 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

Any work that depends upon aural communication is naturally sensitive to noise disturbance. If the communication is speech, the criteria outlined above apply although there are special considerations if artificial aids, such as intercom headphones, are used. Detectability criteria need to be applied if audible warning signals are important.

A quiet environment is a frequently postulated requirement for mental concentration and creative activity. At very high sound levels 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 but this is less true of more challenging ones. Therefore, because variations depend on the task being performed, research results cannot be expressed as generalised criteria

At relatively low levels, the disruptive nature of any such noise must be assumed to be a function of the information it conveys rather than of the physical characteristics of the noise exposure.

Sleep disturbance

Everyday experience indicates that noise interferes with sleep. Most people have been awakened by sudden, unusual sounds and regularly use alarm clocks to wake themselves up. But they can 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 special messages; thus a parent is awakened by the stirring of a child but may sleep through a thunderstorm. This is further evidence of the great complexity of noise perception.

Sleep is in fact a complicated series of states, not a single uniform one. It is widely understood that sleep is essential for general well-being even though the reasons remain obscure. This widespread belief means that people feel strong resentment when they perceive their sleep to be disturbed; this is a major cause of annoyance. Disturbance can take many forms - prevention from falling asleep, physiological arousals such as body movements and changes of sleep state, and awakenings. Serious sleep deprivation could lead to daytime tiredness and have consequent effects on a person’s ability to function normally. Thus there is little disagreement that extensive noise-induced awakenings could have a definite 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.

It is difficult to measure the effects of noise on sleep without the measurement process affecting sleep. Many studies have been made; some in the laboratory where physiological responses to specially presented sounds can readily be measured, others in the field, largely using social survey methods but also 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 event levels as low as 40 dBA L_{max}; some field studies show very few awakenings at indoor event levels of 60 dBA L_{max}. These differences are thought to reflect important effects of familiarity and habituation - particularly that people sleep more soundly at home, in their normal surroundings.

These uncertainties mean it is difficult to define firm noise exposure criteria governing sleep disturbance. Effects have been measured in the laboratory at levels from about 30 dBA L_{eq} and 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, rather higher levels may be quite tolerable. The same may be true of less steady but unexceptional, non-threatening noise, for example the sound of ocean waves on a beach. In general, the more intermittent and unfamiliar the noise, the more likely it is to disturb. In particular, if L_{eq} is governed by a few very noisy events, the levels of those individual events might be the major concern.

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, about 15 dB should be added in the case of partially open windows and about 25 dB for typical closed windows (although increments for individual premises might lie outside the 15 - 25 dB range).

Field data indicate that the great majority of people are not likely to have their sleep disturbed by every day noise exposures. Nevertheless, the belief that noise intrusion has disturbed sleep can give rise to significant levels of annoyance. As sleep naturally gets shallower towards normal awakening, noises heard in the early morning will inevitably focus such annoyance.

A2 ANNOYANCE

Noise *annoyance* is a feeling of resentment, displeasure, discomfort, dissatisfaction or offence which occurs when noise interferes with thoughts, feelings or activities. The expression has both short-term and long-term connotations. 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. 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 - as depicted in **Figure 3-1**.

Annoyance may result from different causes. Some noises, like unpleasant odours, are simply disliked because of their intrinsically disagreeable character, such as sounds that are harsh or imbued with particular tones. Others are disliked because of their consequences: noises that startle, awaken or interfere with conversation for example. Yet others may simply emanate from *sources* that are considered unwelcome for other reasons - such as noise from road traffic that is perceived to cause severance or air pollution, from aircraft where there is a perception that they may crash, or from commercial premises considered to be incongruous in residential areas.

From a noise control viewpoint, the cause of annoyance is important. If it is the very existence of the noise that produces direct and immediate annoyance, then reduction of its level may do little to diminish the adverse reaction (unless it can be made inaudible or unidentifiable). The same may be true if the *source* of the noise aggravates. In such cases, mere detectability may be the criterion of annoyance.

If, on the other hand, annoyance is related to intensity, such as when the character of the noise is disagreeable or because of the severity of the resulting disturbance, then it will help matters to abate the noise. Lower levels or less frequent events will reduce interference with activity and hence annoyance.

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, annoyance also depends on non-acoustical, cognitive factors, such as wider concerns over (personal) safety or, to a lesser extent, the conviction that the noise exposure could be reduced by third parties. Other cognitive factors are individual noise sensitivity, the degree to which an individual feels able to control the noise, whether the noise stems from a new situation or technology or results from an important economic activity. These are some of the modifying ‘socio-psychological’ factors in **Figure 3-1**.

A3 SOUND INDUCED HEARING LOSS

Sound-induced hearing loss has long been recognised as an industrial hazard; there is increasing concern that many leisure activities such as disco music, sound from loudspeakers and hi-fi headphones, shooting and motor sports have associated hearing risks. In combination with natural ageing effects which reduce hearing acuity (presbyacusis), damage caused by excessive sound levels can lead to severe impairment in later life.

Although agreement is not entirely universal, the assumption that cumulative damage is proportional to total sound energy immission (integrated product of intensity and time) has led to the common practice of defining workplace sound exposures in terms of average sound levels during working hours. It is generally believed that, even for working lives of up to 40 years, damage risk is negligible for $L_{eq}(8h)$ < 75 dBA. Above this threshold, the risk increases with increase in sound exposure level.

As such levels of sound exposure from aircraft are largely confined to the aerodrome, risks of consequent hearing damage to the community have not been a significant cause of concern.

APPENDIX B AIRCRAFT NOT COVERED EXPLICITLY BY THIS GUIDANCE

B1 MILITARY AIRCRAFT

Military aircraft undertake an extremely wide range of missions and encompass equally wide ranges of size, configuration and performance. This guidance is addressed at civil aerodromes only; noise problems at purely military facilities are generally addressed separately by military authorities.

However, a number of civil aerodromes accommodate military aircraft operations and, for these, noise impact assessments would necessarily have to account for both elements of air traffic. In this case, military aircraft having similar noise, performance and operational characteristics to existing civil aircraft might be represented by appropriate substitution - if indeed those military aircraft are not already listed specifically in the noise and performance database.

Parallel operations of military aircraft with very different noise, performance and operational characteristics - and most fall into this category - could not be modelled in this way and it can only be recommended that the relevant military authorities be asked to produce compatible noise maps that can be merged with those of the civil operations. Naturally, for this purpose, it would be necessary for the civil and military modellers to adopt the same reference conditions, grid dimensions and noise indices.

Those producing joint contour maps of this kind would have to consider carefully how to interpret the results: public reactions to the noise of civil and military aircraft might be markedly different.

B2 PROPELLER DRIVEN LIGHT AEROPLANES

The ECAC modelling methodology and the ANP database cover larger propeller-driven aeroplanes, especially transport category aircraft powered by turboprop powerplants that generally have to be noise-certificated under Chapters 3 and 4 of Annex 16 [ref. 3]. Model-compatible data also exist for smaller propeller aeroplanes described in general terms - e.g. small single and twin piston engined aircraft. These data allow some account to be taken of the effects of light aircraft traffic (e.g. those not certificated under chapters 3 and 4) at aerodromes where noise is dominated by larger transport traffic. However, generally they are not suitable for application to general aviation (GA) aerodromes where they control noise exposure.

This is because the noise and performance characteristics of light aircraft differ greatly from those of larger business and transport aircraft and vary significantly between types and models. Moreover operations at GA aerodromes which serve sport and leisure aviation are much more variable - in terms of flight tracks and procedural steps - than those at busy civil airports which are subject to a much higher level of air traffic control.

Although many of the noise impact assessment principles covered by this document apply generally to these smaller aerodromes, accurate noise contour maps could only be generated by placing much greater reliance on the use of measured data. As resources for such studies are likely to be relatively meagre, this is rarely a practical option and decisions often have to be made on the basis of limited information.

B3 ROTARY WING AIRCRAFT

Helicopters, and other rotary wing aircraft such as tilt rotors, can make a very significant contribution to the noise environment of the localities in which they operate, and therefore require special attention in environmental impact assessments.

Unfortunately, at present, progress in the development of reliable and practicable noise modelling methodology is not as advanced as in the case of fixed wing aircraft. There are two principal reasons for this, the first of which is that helicopter noise generation and propagation is rather more complex. In the case of fixed wing aircraft, it is the engines which generate most of the noise. This noise can be reasonably well defined as a function of engine power setting, and, within particular aircraft categories, its spectral and directional characteristics do not vary markedly between aircraft types. This is particularly true of the larger jet aircraft which dominate the aircraft noise contours of most major airports.

In the case of helicopters, noise emanates from their lifting, propulsion and control systems. The principal noise source is the main rotor. This has complex spectral and directional characteristics which are very sensitive to the numbers of blades, the tip speed, the forward speed, accelerations and turns. Unlike fixed wing noise which radiates mainly sideways and backwards, rotor noise tends to propagate forwards, often with pronounced impulsiveness at the blade passing rate. The tail rotor, if fitted, is much smaller but has similar noise generating mechanisms and can be very noticeable because of its much higher blade passing frequency. Some helicopters obtain directional control (and torque balance) using fans, either directly or indirectly, which have yet further noise differences. Some helicopters avoid the need for torque balance by having two main rotors; flow interactions between them further complicate the noise generation. Finally, although all larger helicopters are powered by turbine engines, these are installed in a variety of ways; some smaller helicopters have piston engines.

The consequence of this design variety is a wide range of noise characteristics which are not readily accommodated in practical noise models. Advanced computer codes have been developed for helicopter noise design, but these are unlikely to be of benefit for general environmental noise modelling in the foreseeable future.

The second reason for the lack of reliable helicopter noise contour methodology is that, again unlike the fixed wing case, these can be dominated by “ground noise”, the noise generated by helicopters during terminal operations on or over the ground surface. These involve hovering and taxiing manoeuvres as well as idling with rotors running, which, by comparison with overflight noise events, are very lengthy with durations measured in minutes rather than seconds. As ground operation can generate as much sound energy as flight, its contribution to sound exposure (in L_{eq}) can be an order of magnitude greater.

The difficulty is that noise from a hovering helicopter varies with its height above the ground, its loading, with azimuth angle and with the prevailing wind (small wind changes can have large effects upon rotor flow patterns that influence noise). Furthermore, ground-to-ground sound propagation depends upon wind speed and direction, air temperature and humidity (and the way these vary above the ground), local topography and the nature of the ground surface, and the presence of buildings and other similar obstacles. Of course, these propagational factors affect ground noise from fixed-wing airports but this is less problematical because it is generally much less significant than “air noise” from arriving and departing aircraft. Many urban helicopter facilities have a controlling influence on the surrounding noise exposure patterns.

These modelling difficulties, together with the additional problem that helicopter fight paths can be extremely variable and unpredictable, cannot and do not prevent attempts to assess the noise impact of helicopter operations in planning studies but, inevitably, these involve *ad hoc* analyses tailored to specific problems. Factors which govern the approach taken include the type of terminal facility (e.g. airport, heliport, helipad, etc.), its layout and local environment, the mix of air traffic, helicopter types and whether fixed wing movements are involved and in what proportion.

Whatever approach is taken, it has to be accepted that helicopter noise exposure estimates are inevitably less reliable and subject to much greater day-to-day variability than those of fixed wing aircraft. For this reason, it is not possible at present to recommend any general procedures.

APPENDIX C EXAMPLES OF CURRENT AIRCRAFT NOISE MODELLING IN ECAC MEMBER STATES

C1 FRANCE

General

Mitigation measures in France include movement restrictions, night-time restrictions, land-use planning, noise insulation schemes, “low noise” departure procedures and noise preferential routeings.

Land-use planning policy aims at reducing aircraft noise impact by limiting the number of residents affected by aircraft noise around aerodromes. This policy has to be applied to aerodromes designated by the French civil aviation authority (more than 250 aerodromes). It both controls the development of the aerodrome and limits new building in the noisiest zones. A noise exposure plan is adopted after a public inquiry. The noise exposure plan defines four land-use planning zones (A, B, C, D) around the aerodrome. These four zones are delineated by L_{DEN} noise contours as described in the following table.

Zone	Upper limit (dBA)	Lower limit (dBA)
A	n.a.	70
B	70	Between 65 and 62
C	Between 65 and 62	Between 57 and 55
D	Between 57 and 55	50

Table C-1: Zones of a French noise exposure plan

Definitive limits of zones B and C are set by the local state representative after consultation with a commission made up of resident associations, local communities and aviation stakeholders. The noise exposure plan is based on the envelope of three forecast scenarios: short, medium and long-term. The reference time is a typical day of the year, divided into three periods (day, evening and night).

A noise annoyance map defines noise insulation scheme boundaries. The noise annoyance map is based on one short-term (one year) forecast scenario. Contours of 70, 62 to 65, and 55 dBA L_{DEN} are taken to delineate zones I, II, and III. These zones are generally different from the land use planning zones.

Zone	Upper limit (dBA)	Lower limit (dBA)
I	n.a.	70
II	70	Between 65 and 62
III	Between 65 and 62	55

Table C-2: Zones of a French noise annoyance map

A noise impact analysis has to be performed before any change of routeing or before establishing a noise preferential routeing.

Noise Index

Since April 2002, the psophic index has been replaced by the L_{den} (decree n° 2002-626) which is now the French official index for land-use planning applications such as noise exposure plan or noise annoyance map. Its definition is identical to that specified in the European directive n° 2002-49 CE [ref. 6], and is given below :

$$L_{DEN} = 10 \cdot \lg \frac{1}{24} \left[12 \times 10^{\frac{L_{day}}{10}} + 4 \times 10^{\frac{L_{evening}+5}{10}} + 8 \times 10^{\frac{L_{night}+10}{10}} \right]$$

where L_{day} (or *evening*, or *night*) is the A-weighted long-term average sound level as defined in ISO 1996-2 [ref. C1], determined over all the day (or evening, or night) periods of a year.

In France, the day-time is 06h00-18h00, the evening-time is 18h00-22h00 and the night-time is 22h00-06h00.

$L_{A,max}$ is used for comparing the noise impact of two different trajectories when assessing a change of routeing (noise impact analysis).

Noise Model

Noise contours for civil and military airports are produced by the French civil aviation authority (or by Aéroports de Paris for the Paris airports), using the Integrated Noise Model (INM, [ref. C2]) developed by the US Federal Aviation Administration. Two pre-processors have been developed by the STNA (Service Technique de la Navigation Aérienne) and are used together with INM: a radar track data analysis pre-processor (ELVIRA), and a track and traffic data pre-processor (MOSTRA, [ref. C3]). A ray-tracing model (MITHRAVION [ref. C4]) has also been developed by the STBA (Service Technique des Bases Aériennes) to calculate noise contours, or façade noise on a building taking into account building reflections, relief and masking effects.

Noise database:	INM noise database.
Performance database:	Pre-defined INM default flight profiles. The profile type (standard, ICAO A, ICAO B) and its number is chosen according to the results of a recent national noise measuring campaign.
Aircraft types:	Following the banning of Chapter 2 aircraft in EU, only aircraft most recently added to the INM database are used. About 80 civil aircraft can be modelled.
Flight path description:	Combination of ground tracks and flight profiles. Ground tracks and dispersion are modelled according to radar track data. In the absence of information, standard procedures (published in AIP) with a lateral dispersion (Gaussian normal distribution) are

	modelled. Touch and go and level at a prescribe altitude are taken into account.
Lateral attenuation:	According to SAE AIR 1751 [ref. C5].
Contour generation:	Grid and computation parameters are set to obtain smooth contours at the regulatory scale (1:25000).
Special features:	Relief is taken into account, in terms of distance between the noise source and the receiver.

Applications (see Chapter 5)

A1 Annual (historical) contours are published for Paris airports (Roissy, Orly). Annual (historical) contours are developed at other major French airports also for study purpose.

A2 Definition of land-use planning zones (noise exposure plans) and noise insulation scheme boundaries (noise annoyance plans).

B1 Noise impact analysis.

B2 Noise impact analysis.

C2 GERMANY

General

In April 1971 the German Air Traffic Noise Act came into effect. This act prescribes the establishment of noise protection zones for all commercial airports connected to the airline traffic network and for all military airfields used for the operation of jet aircraft. The noise protection zones are described by contours of constant equivalent sound level $L_{eq(4)}$ (see below). In March 1975 the minister of the interior published a description of a calculation procedure (AzB) as well as a description of a data acquisition system (DES) [ref. C6]. The AzB procedure includes a description of the mathematical model which has to be used for the calculations as well as a corresponding set of flight operational and acoustic data. The data acquisition system DES describes a data format for the air traffic and ground track information needed for the calculation of the protection zones.

Noise Index

The equivalent sound level defined under the German Air Traffic Noise Act (outside Germany sometimes called “Störindex”) is defined as:

$$L_{eq(4)} = 13.3 \cdot \lg\left[\frac{1}{T} \cdot \sum_{i=1}^{N} g_i \cdot 10^{L_{Amax,i}/13.3} \cdot t_{10}\right]$$

$L_{Amax,i}$ is the maximum A-weighted sound level of the i-th noise event, $t_{10,i}$ is the corresponding 10dB-down-time). T is the reference time period representing the 6 months with the highest amount of air traffic during one year. The summation is performed over all noise events occurring during this reference time period. The tradeoff-factor of 13.3 results in a 4 dB increase of $L_{eq(4)}$ per doubling of traffic amount.

The factor g_i is a weighting factor which depends on time of day (6-22 h and 22-6 h). The calculation has to be performed with two different sets of these weighting factors (representing traffic situations which are dominated by day operations or by night operations respectively). The resulting $L_{eq(4)}$ is taken as the highest of the two values.

Noise Model

The German AzB only prescribes how the noise contours have to be calculated and which input data have to be used. The AzB is not related to a specific computer program. So different calculation programs (for commercial as well as for scientific purposes) are available or in use. However the AzB defines a set of conditions which have to be fulfilled (programs can be certified by the Federal Environmental Agency).

The current version of AzB uses a CPA-Algorithm without segmentation and hence is *not compliant with ECAC recommended methodology*. However this version is expected to be updated at some point in the future. Key features are as follows:

Noise database:	Spectrum data for each aircraft category (separately for departure and approach) based on manufacturers data as well as on comprehensive evaluation of monitored noise data at German airports. Engine power changes are modelled by noise level increments. 10dB-down time is calculated separately as a function of slant distance and aircraft velocity (using a semi-empirical equation with aircraft-specific coefficients).
Performance database:	Pre-defined default profiles based on information from local aircraft operators.
Aircraft types:	Aircraft types are currently grouped into about 20 categories of civil aircraft, 2 helicopter groups and a set of military aircraft groups.
Flight path description:	Combination of ground tracks and flight profiles. Lateral spreading is modelled using an analytical expression for the distribution of movements perpendicular to the ground track. For each ground track flight corridor boundaries have to be defined in the data acquisition system.
Lateral attenuation:	Only overground attenuation (not according to SAE AIR1751). Attenuation rates are depending on distance, elevation angle and source spectrum.
Contour generation:	Some conditions must be fulfilled generating contours (e.g. distance between two adjacent contour points, length ratio of

	adjacent chords of the contour). Grid algorithms as well as contour tracing algorithms are in use.
Special features:	The separate calculation of maximum level and noise duration provides a high flexibility – any commonly used noise index can be estimated. The use of spectral data allows to account for different atmospheric conditions.

Applications (see Chapter 5)

A1 For some airports annual contours have to be estimated (partly for monitoring purposes, partly in connection with local noise restrictions).

A2 Main application – the German Air Traffic Noise Act requires the definition of noise protection zones based on a traffic forecast (about 10 years in the future).

B1 Assessment of airport and air transport development plans.

B2 As B1 plus comparison of alternative noise mitigation options (‘what if’ studies).

C3 THE NETHERLANDS

General

Under the Dutch Aviation Act (1978 revision), in order to reduce the annoyance caused by aircraft noise, regulations require, around Dutch airports:

- the establishment of noise zones;
- the establishment of rules for measurement, registration and calculation of the noise exposure;
- enforcement of the noise zones;
- insulation of dwellings located within specific noise contours.

In February 2003, a new Aviation Act came into effect for Amsterdam Airport Schiphol. The main differences from the existing act are:

- the replacement of a prior national noise index by the European L_{den} noise index;
- the replacement of the L_{Aeq} (23.00-06.00) night-time noise index by the European L_{night} (23.00-07.00) index;
- the replacement of the noise zone by a limited number of control points around the airport with a specific noise exposure limit at each point;
- the introduction of a total noise volume.

In the event that either the noise limit at any control point or the total noise volume is exceeded by the actual noise exposure, suitable measures have to be taken to prevent any further increase in the noise exposure. Suitable measures might be the closure of specific runways, a change in the runway preferential system, fleet volume measures, etc.

It is expected that a comparable noise control system similar to Schiphol's will be implemented at other airports in the Netherlands in the near future. At present, the following description is limited to Schiphol studies.

Noise Index

For Schiphol studies the European L_{den} and L_{night} noise indices are used which are based on the sound exposure level (SEL).

Noise Model

Prescriptions are only given on how the noise exposure have to be calculated and which noise and performance data have to be used. They are prescribed by the Dutch Aviation Act but not related to any specific computer program. So different calculation programs (for commercial as well as for scientific purposes) are available or in use. No official procedure is available to validate specific computer programs.

The L_{den} and L_{night} indices are calculated by a simple simulation technique based on L_{Amax} NPD tables. The SEL-value of a noise event is calculated by integration of the discrete noise contributions of the aircraft along the flight path. Typical integration steps are between 2 and 10 seconds.

The key features are as follows:

Noise database:	L_{Amax} NPD tables based on aircraft manufacturers' data.
Performance database:	Standard modelling data made available by manufacturers based on information of local aircraft operators.
Aircraft types:	Aircraft types are grouped into 9 weight classes and 4 noise classes. Classification is based on noise certification levels and limits. In addition three helicopter groups are used.
Flight path description:	Combination of ground tracks and flight profiles. For Schiphol studies no specific dispersion procedure is prescribed. In general lateral dispersion is bounded by using two dispersion tracks and discretised in a maximum of 243 sub-routes with a weighted contribution in the calculated noise level (L_{Amax} or SEL) based on a Gaussian probability density function.
Lateral attenuation:	Lateral attenuation is calculated according to SAE AIR 923 [ref. C7] .
Contour generation:	L_{den} and L_{night} contours are calculated over a rectangular grid at 500 m spacing.
Special features:	Enforcement calculations are based on individual radar ground tracks.

Applications (see Chapter 5)

A1 Publication of actual noise exposure as part of enforcement.

A2 Calculation of noise limits at control points and the total noise volume.

B1 Enforcement: comparison of actual noise exposure versus noise limits. Assessment of airport and air transport development plans.

B2 Assessment of airport and air transport development plans versus noise limits.

C4 NORWAY

General

In 1999, the Norwegian Environmental Department introduced a revised set of guidelines for land use planning in areas exposed to aircraft noise. These guidelines define a special Norwegian noise metric for aircraft noise, including recommendations on how to calculate it. The guidelines apply to all kinds of air traffic (fixed wing and helicopter, civil and military, commercial and non-commercial) at airports having a total of more than 25 operations during the busiest three summer months.

Noise Index

Two indices are used for evaluating aircraft noise. Equivalent aircraft noise (EFN) is a composite index based on the equivalent continuous A-weighted sound level comparable to DENL, but including a continuous time weighting factor shown in **Figure C-1**. This applies the commonly used night weighting factor of 10 but avoids discontinuities at the beginning and end of the night period. In addition, a Sunday daytime penalty in introduced. These functions are based on considerations of both sleep disturbance and annoyance.

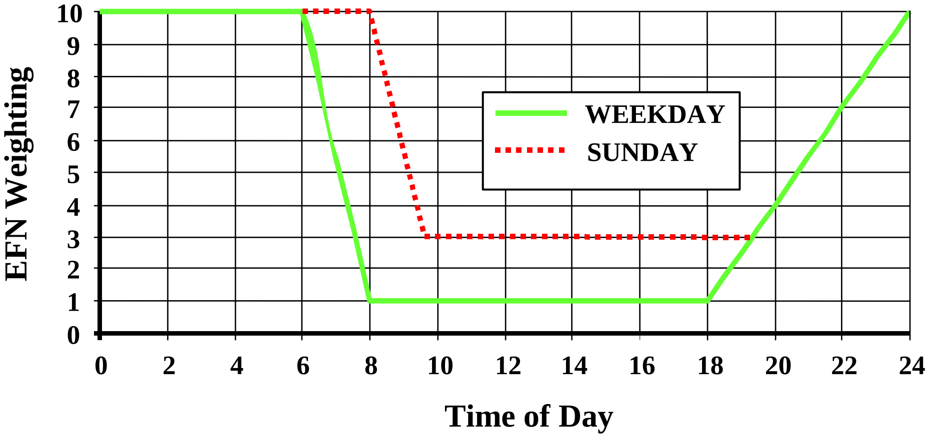

Figure C-1: EFN Time weighting factor

Maximum aircraft noise (MFN) is used as a supplementary metric to EFN. For the average seven-day period that form the basis for noise calculation MFN is defined as the third highest of the seven daily maximum levels measured during each 24 hour period. This definition gives a typical maximum level for regular traffic, random events occurring less than three times a week being suppressed as non-typical for the area.

Noise Zoning

Areas surrounding an airport, airfield or heliport are divided into noise zones defined as:

Noise zone IV:	EFN > 70 dB ***or*** EFN > 105 dB during daytime (07-22) ***or*** MFN> 100 dB during nighttime (22-07)
Noise Zone III:	Area outside of zone IV where EFN > 65 dB ***or*** MFN >100 dB during daytime (07-22) ***or*** MFN > 85 dB during nighttime (22-07)
Noise Zone II:	Area outside of zone III where EFN > 60 dB ***or*** MFN> 95 dB during daytime (07-22) ***or*** MFN> 80 dB during nighttime (22-07)
Noise zone I:	Area outside of zone II where EFN > 50 dB ***or*** MFN> 80 dB during daytime (07-22)

Noise Model

Since 1995 NORTIM [ref. C8] has been the official Norwegian model for aircraft noise calculation. Originally, NORTIM was based on the US FAA model INM. After several revisions, the latest updated aircraft noise and performance database is the only INM remnant. Lately NORTIM has been updated with respect to ground attenuation effects, engine installation effects and noise data for some aircraft types [ref. C9].

Special features of NORTIM include modelling of terrain effects on sound propagation, special routines for lateral attenuation, and provision for aircraft-type dependent directivity characteristics.

Noise database:	NPD tables from the latest updated INM database, including military data from NOISEMAP, are the main source for NORTIM. Other information can also be entered as user defined data. So far, no spectral information is used.
Performance database:	Default profiles from the latest INM database are the main performance source. When found necessary, modifications based on operator information can be implemented.
Aircraft types:	As the model is based on INM database, calculations are mainly based on individual aircraft information. When found necessary,

approved substitutions of aircraft (from the INM database) are used.

Flight path description: This is a combination of ground track and flight profiles. Dispersion along the backbone track is modelled according to ECAC Doc.29 2nd Edition. Backbone tracks are modelled separately for comparable aircraft types with similar performance. Dispersion tracks are not used when radar tracks are available.

Lateral attenuation: A modification to SAE AIR 1751 is implemented, introducing engine installation as a new parameter. Thereby, the new routines distinguish between lateral directivity and over ground attenuation.

Contour generation: Commercial software is used to interpolate contours from a regular grid point calculation. The grid resolution is normally 39m (128 feet), or a multiple of that.

Special features: NORTIM takes terrain effect into consideration when calculating sound propagation. That includes both topography (i.e. elevation of receiver point) and terrain slope effect on ground absorption.

Commonly used GIS formatted contour files are generated.

NORTIM calculates the following metrics: TA, L_{DN}, L_{eq}, $L_{eq,day}$, $L_{eq,night}$, EFN, $\mathrm{MFN}_{\mathrm{day}}$, $\mathrm{MFN}_{\mathrm{night}}$, Noise Zone.

Detailed grid point information gives calculation results for all metrics available from NORTIM. A sorted contribution list can be generated, based on user selected metrics.

C5 SWITZERLAND

General

Based on a Swiss environmental act to "protect humans from annoying or harmful immissions", the regulations for noise protection define a common framework for noise limits not only for aircraft noise, but also for noise from road, rail, industry and shooting ranges. There are different limit values according to time (day / night) and to the noise sensitivity of the area (very noise sensitive (e.g. hospital) / residential / downtown / industrial).

For aircraft noise, limits with different requirements for small airfields, for civil and for military airports apply. For civil airports, the limit for daytime (06 to 22 h) is a sixteen-hour L_{eq}, whereas for nighttime three one-hour L_{eq} values, for 22-23 h, 23-24 h and 05-06 h, apply. There is a night ban between 00 and 05 h. The one-hour L_{eq}*'s* at night have a twofold function: they impose a limitation on the maximum allowable noise from a single event to minimise sleep disturbance, whilst on the other hand they are also sensitive to the number of movements. When noise limits are exceeded in a specific area, land use restrictions apply for new developments and soundproof windows must be installed in existing houses at the airport's expense. The noise limits applicable to civil airports for daytime range from 53 dBA L_{eq} for land use planning in the most noise sensitive area to 75 dBA to launch immediate noise protections in industrial areas. The typical noise limit is 60 dBA (Immission limit for residential areas). Noise limits for the one-hour L_{eq} at night are typically 10 dB lower than the 16 hour L_{eq} of the day.

Mitigation measures at international airports include noise dependent landing fees, preferential runway usage, the use of the "low noise" departure procedure according to "ICAO A", and a night ban from 00 to 05 h.

Noise Index

All noise indices used in Switzerland are based on the A-weighted L_{eq}. For civil airports, the following regulations apply:

One L_{eq} is calculated for the 16 hours of daytime (06 - 22 h). As mentioned above, for the night-time there are three one-hour L_{eq}*'s* for 22-23 h, 23-24 h and 05-06 h. All L_{eq}s are calculated for an "average day" or an "average night hour", based on all aircraft movements of the year taking place in the corresponding time period of the day or night.

Noise Model

The Swiss noise modelling system FLULA2 [ref. C10] has been developed continuously over the last 20 years by EMPA (Swiss Federal Laboratories for Materials Testing and Research). Its noise calculation engine is a simulation (time step) model. EMPA maintains and runs FLULA to produce noise contours for civil and military airports for the Government and for airport operators. Its key features are as follows:

Noise database:	"In-flight directivity characteristics" for 75 individual aircraft types for take-off and landing. The EMPA data is based on measurements at Zurich Airport. The "directivity characteristics" provide the A-weighted sound level as a function of distance and the longitudinal angle of emission at the aircraft. The issue of longitudinal directivity covered by the simulation model is primarily important for curved flights and for military aircraft with pronounced directivity characteristics. The database takes into account the direction dependent spectral characteristics of the aircraft, the spectral air absorption (based on ISO 9613-1 [ref. C11] for 15°C / 70% relative humidity) and provides the resulting A-weighted level at the receiver in the specified distance at a receiver height of 10 m above ground. The rather high receiver position alleviates adverse ground effects at low frequencies.
Performance database:	Currently, four situations are modelled: one landing performance (based on measurements in the final approach), two take-off performances according to take off weight (full thrust and "standard" thrust), and climb performance. The landing and the two take-off conditions have individual noise characteristics. Climb condition is accounted for by a global reduction of the noise level ("cut back").
Aircraft types:	There are specific noise data for the 75 most frequently used aircraft types in Switzerland. Other aircraft are substituted by one of the 75 aircraft types where noise data exists.

Flight path description:	(1) If radar data are available, i.e. for historic calculations the method of "single flight simulation" is used (see below). (2) If no radar information is available: combination of ground tracks (based on airport information) and average flight profiles (based on best sources available).
Lateral attenuation:	There is no global correction of the SEL or L_{max} level for "lateral attenuation". In the simulation program FLULA a "ground effect" attenuation is applied to those sound components from the level-time history, which arrive at the receiver at angles below 15°. As this has nothing to do with the aircraft, this ground attenuation is applied for all sound incidences below 15°, even if the aircraft is seen from front or rear. The maximum ground effect at grazing incidence (0°) is 10 dB. The directivity characteristics used in FLULA2 only model longitudinal directivity of the aircraft. EMPA is working on three-dimensional, spectral source descriptions, which will also include lateral directivity.
Contour generation:	L_{eq} values are calculated over a rectangular grid at spacings between 100 and 250m over an area large enough to contain the entire 45 dBA contour. The interpolations for contours is based on B-spline functions.
Special features:	- Topography (i.e. the elevation of receiver points) is included in all calculations. - FLULA can calculate various metrics derived from the simulated level-time histories, like e.g. for historic reasons the NNI, the French Indice Psophique, the German L_{eq}(4), time durations and sound statistics at receiver points. - FLULA2 is also used for military airports and in some cases for lightweight aviation on airfields. - For three types of helicopters there exist three-dimensional source diagrams, which are used with a new research version called FLULA3. In this research version, spectral source characterisation, spectral propagation using ISO 9613-1 and spectral ground effects are investigated.

Calculations based on “single flight simulations”

The method of “single flight simulation” is applied for situations where radar data from flights during a whole year are available. The basic idea is to calculate the sound of a number of statistically selected flights and to average the resulting sound of the single events in the same way as flight events are averaged at monitoring stations. Thus, averaging is performed on sound levels in contrast to the usual method of defining average geometries (tracks). The “single flight simulation” is very well suited for modelling the interleaved flight paths on curved routes where the flight paths show all kind of variations in radius and climb profiles, that is for those situations where it is difficult to define average tracks and average climb profiles. Another advantage is that this method can be explained easily to the public. Most importantly, statistical selection produces a representative sample of all flight conditions of the year (wind speeds and wind directions, temperatures, take-off weights, climb performances due to varying power and flap settings, pilot's variations). For each group of aircraft and for each specific route, the calculation is made in the following way:

- From the radar data of all eligible flights of one year, a set between thirty to one hundred individual flights is selected randomly.
- For each of the selected flights, a sound calculation is made, using the flight path defined by the radar recording.
- All individual results are added energetically (to yield the decibel sum).
- Finally, the results are normalised to one flight (= footprint of the sound for yearly average aircraft operation) and then the resulting levels are calculated by taking into account the total number of flights of this aircraft on this route.

Applications (see Chapter 5)

A1 Published annual contours of actual (historical) noise exposures to monitor noise trends and definition of noise insulation scheme boundaries.

A2 Environmental Impact Assessment for proposed changes in operation and definition of land-use planning zones.

B1 Assessment of airport and air transport development plans

B2 As B1 plus comparison of alternative noise mitigation options ('what if' studies)

C6 UNITED KINGDOM

General

Mitigation measures in the UK include noise preferential routeings, departure noise limits, runway alternation, noise related charges, land use planning, noise insulation schemes, and night movement quotas. Their implementation at three 'designated' London airports, Heathrow, Gatwick and Stansted are subject to Government controls. At other airports measures are established and administered locally although they are commonly based on those of the Designated Airports. Land use planning at all airports is based on Government advice to local authorities. Noise contours are widely used - for a variety of purposes. The following summaries relate specifically to the Designated Airports but are relevant to most other major airports in the UK.

Noise Index

Daytime (0700 - 2300hrs) and night-time noise (2300 - 0700 hrs) are assessed separately. The primary index is $L_{eq}(16h)$ for the 'average summer day' from mid-June to mid-September - this is used as an indicator of public annoyance. Contours of 57, 63 and 69 dBA are taken to delineate zones of low, moderate and high levels of average community annoyance; this interpretation is based on the results of national social surveys. Land use planning guidelines also take separate account of night-time noise measured in terms of $L_{eq}(8h)$ although, as yet, no associated annoyance criteria for night noise have been established. Some noise insulation schemes take account of night-time noise exposures expressed in terms of both L_{eq} and average SEL. The latter recognises research evidence that the probability of sleep disturbance is linked to single event noise levels.

Noise Model

Noise contours are produced for the Government, and by arrangement for other bodies including airport operators, by the Civil Aviation Authority using its ANCON 2 noise modelling system [refs. C12, C13] which is the product of around 35 years of development. Its noise calculation engine is a segmentation model which is fully compliant with the ECAC recommended methodology. Its key features are as follows:

Noise database:	NPD tables based on aircraft manufacturers' data (ANP database) and adjusted as necessary using local measurements.
Performance database:	Standard modelling data made available by manufacturers (ANP database).
Aircraft types:	Aircraft types are currently grouped into 70 categories.
Flight path description:	Combination of ground tracks and flight profiles. For historical contours, backbone tracks and up to 12 subtracks on each departure route are based on large samples of radar data; subject to annual review. For arrivals, evenly spaced 'spurs' are used to model dispersion about the extended runway centre-lines.
Lateral attenuation:	Divided into lateral directivity and overground attenuation which are modelled independently.
Contour generation:	L_{eq} values are calculated over a rectangular grid at spacings between 50 and 500m over an area large enough to contain the entire 57 dBA contour.
Special features:	Hundreds of thousands of SEL measurements and radar traces (from the airports' monitoring systems) are analysed annually to validate the noise database. For departures in each aircraft category, engine power settings are calculated from estimated take-off masses and measured mean flight profiles. SELs calculated by the model using these inputs are compared with the measured mean SELs; NPDs are subsequently adjusted as necessary to obtain best possible matches.

Applications (see Chapter 5)

A1 Published annual contours of actual (historical) noise exposures (to monitor) noise trends and effectiveness of noise mitigation measures.

A2 Definition of land-use planning zones and noise insulation scheme boundaries.

B1 Assessment of airport and air transport development plans

B2 As B1 plus comparison of alternative noise mitigation options (‘what if’ studies)

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APPENDIX D AQUISITION OF AIRCRAFT OPERATIONS DATA

The best sources aircraft operations data are the aircraft operators themselves but the effort needed for them to provide it could be substantial. The modelling team therefore needs to consider carefully how much detail is required to meet the objectives of any particular study - as explained in **Chapter 5**. It will often be necessary for the modellers and operators to determine together how best to achieve the necessary accuracy as efficiently as possible; i.e. to minimise demands on resources. The information generally required to produce accurate noise contours is summarised below; this is intended to provide a basis for those discussions.

Aircraft

- Aircraft / Engine Configurations
  - By Aircraft registration number (including specific engine rating and any modifications, e.g. specific engine acoustic treatment)

Operations

- Actual Takeoff Weight Data, including either associated stage length or destination information
- Performance Limit Weights
  - Regulated Takeoff Weight; noting this varies with atmospheric conditions and specific runway available, give either specific data (with date/time, or typical values for given routes).
  - De-Rated Thrust Takeoffs (as above but for when fixed engine thrust de-rates have been applied)
- Takeoff Thrust
  - Full Rated
  - Reduced Thrust
    - Assumed Temperature Methodology (if so give typical assumed temperatures)
    - Fixed De-Rate (if so specify typical percent reduction)
- Takeoff Flap Setting
  - Primary Flap Setting
  - Dial-a-Flap (if variable flap setting used, e.g. dependent on weight, give typical values as a function of weight).
- Departure Profile
  - Acceleration Height / Altitude
  - Initial Thrust Reduction Point
    - At fixed height/altitude
    - At Zero Flap (if so give typical height and speed at this point)
    - Other (e.g. at flap 5 etc.)
  - Thrust Reduction Level
    - Maximum Climb Thrust
    - De-Rated Climb Power (e.g. CLB1 or CLB2)
    - Other (e.g. as determined by FMS)
  - Is the procedure adjusted in any way?

    - E.g. For turning routes/SIDs takeoff thrust is maintained until completion of turn.
  - Climb rates during acceleration
    - Based on body pitch angle, if so specify, or based on FMS energy split between climbing and accelerating – if so specify typical split, e.g. 45% climb, 55% acceleration.

- END -