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Doc 9911

Recommended Method for Computing Noise Contours Around Airports

Second Edition, 2018



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AMENDMENTS

Amendments are announced in the supplements to the *Products and Services Catalogue*; the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

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FOREWORD

This manual on the *Recommended Method for Computing Noise Contours Around Airports* (Doc 9911) replaces similar material contained in the *Recommended Method for Computing Noise Contours Around Airports* (Circular 205), which was approved by the ICAO Committee on Aviation Environmental Protection (CAEP) at its first meeting in 1986.

This first edition of Doc 9911 contains material developed by CAEP with the assistance of aviation stakeholders, including regulatory authorities, air traffic management providers, airport operators, manufacturers, airline associations and airlines, as well as the ICAO Secretariat. It was approved by CAEP at its seventh meeting in February 2007.

This manual is intended to assist States in the computation of noise contours around airports, using the most up-to-date procedures and the most recent aircraft noise and performance information available. It describes the major aspects of the calculation of noise contours for air traffic at an airport, including three ways in which most practical noise models calculate aeroplane single event noise levels.

This manual is an important advance on Circular 205 in that it is linked to an international aircraft noise and performance (ANP) database which is accessible online at <http://www.aircraftnoisemodel.org>. The methodology described in the manual is designed to make full use of this data source, which has been assembled over many years by aircraft manufacturers in collaboration with noise certification authorities and is fully endorsed by ICAO.

It is intended that this manual be kept up to date; future editions will be improved on the basis of work by CAEP and on comments and suggestions received from the users of the manual. Users are therefore invited to give their views, comments and suggestions on this edition, which should be directed to the Secretary General of ICAO.

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EXPLANATION OF TERMS AND SYMBOLS

DEFINITION OF TERMS

Note.— In keeping with established practice in the field of aeroplane noise modelling, the units of measurement used in this manual do not necessarily accord with the recommendations of ICAO Annex 5 — Units of Measurement to be Used in Air and Ground Operations.

When the following terms are used in this manual, they have the following meanings:

AIP. Aeronautical Information Publication.

Aeroplane configuration. The positions of slats, flaps and landing gear.

Aeroplane movement. An arrival, departure or other aeroplane action that affects noise exposure around an aerodrome.

Aeroplane noise and performance data. Data describing the acoustic and performance characteristics of different aeroplanes types that are required by the modelling process. They include noise-power-distance (NPD) relationships and information that allows engine thrust/power to be calculated as a function of the flight configuration. The data are usually supplied by the aeroplane manufacturer although when that is not possible it is sometimes obtained from other sources. When no data are available, it is usual to represent the aeroplane concerned by adapting data for a suitably similar aeroplane – this is referred to as substitution.

Altitude. Height above mean sea level.

ANP database. The international aircraft noise and performance database www.aircraftnoisemodel.org

A-weighted sound level, L_A . Basic sound/noise level scale used for measuring environmental noise including that from aeroplanes and on which most noise contour metrics are based.

Backbone ground track. A representative or nominal ground track which defines the centre of a swathe of tracks.

Baseline noise event level. The noise event level read from a noise-power-distance (NPD) database.

Brake release. Start-of-roll.

Corrected net thrust. At a given power setting (e.g. EPR or N1) net thrust falls with air density and thus with increasing aeroplane altitude; corrected net thrust is the value at sea level.

Cumulative sound/noise level. A decibel measure of the noise received over a specified period of time, at a point near an airport, from aeroplane traffic using normal operating conditions and flight paths. It is calculated by accumulating the event sound/noise levels occurring at that point.

Decibel sum or average. Sometimes referred to elsewhere as “energy” or “logarithmic” (as opposed to arithmetic) values. Used when it is appropriate to sum or average the underlying energy-like quantities, e.g. decibel sum.

Energy fraction, F . Ratio of sound energy received from a segment to energy received from infinite flight path.

Engine power setting. Value of the noise related power parameter used to determine noise emissions from the noise-power-distance (NPD) database.

Equivalent (continuous) sound level, L_{eq} . A measure of long-term sound. The level of a hypothetical steady sound, which over a specified period of time, contains the same total energy as the actual variable sound.

Event sound/noise level. A decibel measure of the finite quantity of sound (or noise) received from a passing aeroplane sound exposure level.

Flight configuration. Equals aeroplane configuration plus flight parameters.

Flight parameters. Aeroplane power setting, speed, bank angle and mass.

Flight path (or trajectory). A full description of the motion of the aeroplane in space (three dimensions) and time, which is accounted for via aeroplane speed. The flight path of an aeroplane is typically referenced to an origin at the start of the take-off roll or at the landing threshold.

Flight path segment. Part of an aeroplane flight path represented for noise modelling purposes by a straight line of finite length.

Flight procedure. The sequence of operational steps followed by the aeroplane crew or flight management system: expressed as changes of flight configuration as a function of distance along the ground track.

Flight profile. A description of the aeroplane motion in the vertical plane above the ground track, in terms of its position, speed, bank angle and engine power setting (sometimes also includes changes of flight configuration), described by a set of profile points.

Ground plane (or nominal ground plane). Horizontal ground surface through the aerodrome reference point on which the contours are normally calculated.

Ground speed. Aeroplane speed relative to a fixed point on the ground.

Ground track. Vertical projection of the flight path onto the ground plane.

Height. Vertical distance between aeroplane and ground plane.

Integrated sound level. Otherwise termed "single event sound exposure level".

International Standard Atmosphere (ISA). Defines variation of air temperature, pressure, and density with height above mean sea level. Used to normalize the results of aeroplane design calculations and to analyse test data. Defined by ICAO [ref. 11].

Lateral attenuation. Excess attenuation of sound with distance attributable, directly or indirectly, to the presence of the ground surface. Significant at low angles of elevation (of the aeroplane above the ground plane).

Mass. The quantity of matter (in an aircraft).

Maximum noise/sound level. The maximum sound level reached during an event.

Mean sea level (MSL). The standard earth surface elevation to which the ISA is referred.

Net thrust. The propulsive force exerted by an engine on the airframe.

Noise. Noise is defined as unwanted sound. But metrics such as A-weighted sound level (L_A) and effective perceived noise level (EPNL) effectively convert sound levels into noise levels. Despite a consequent lack of rigour, the terms “sound” and “noise” are sometimes used interchangeably in this manual.

Noise contour. A line of constant value of a cumulative aeroplane noise level or index around an airport.

Noise impact. The adverse effect(s) of noise on its recipients; importantly, it is implied that noise metrics are indicators of noise impact.

Noise index. A measure of long-term or cumulative sound which correlates with (i.e. is considered to be a predictor of) its effects on people. Other factors may be taken into account including the magnitude of the sound (especially time of day). An example is day-evening-night level, L_{DEN} .

Noise level. A decibel measure of sound on a scale which indicates its loudness or noisiness. For environmental noise from aeroplanes, two scales are generally used: A-weighted sound level and perceived noise level. These scales apply different weights to sound of different frequencies — to mimic human perception.

Noise metric. An expression used to describe any measure of quantity of noise at a receiver position whether it be a single event or an accumulation of noise over extended time. There are two commonly used measures of single event noise: the maximum level reached during the event, or its sound exposure level, which is a measure of its total sound energy determined by time integration.

Noise-power-distance (NPD) data. Noise event levels tabulated as a function of the distance below an aeroplane in steady level flight at a reference speed in a reference atmosphere, for each of a number of *engine power settings*. The data account for the effects of sound attenuation due to spherical wave spreading (inverse-square law) and atmospheric absorption. The distance is defined perpendicular to the aeroplane flight path and the aeroplane wing-axis (i.e. vertically below the aeroplane in non banked level flight).

Noise-related power parameter, power or power setting. Parameters that describe or indicate the propulsive effort generated by an aeroplane engine to which acoustic power emissions can logically be related; usually taken to be corrected net thrust.

Noise significance. The contribution from a flight path segment is “noise significant” if it affects the event noise level to an appreciable extent.

Observer. Receiver.

Procedural steps. Prescription for flying a profile — steps include changes of speed and/or altitude.

Profile point. Height of flight path segment end point — in vertical plane above the ground track.

Receiver. A recipient of noise that arrives from a source; principally at a point on or near the ground surface.

Reference day. A set of atmospheric conditions on which ANP data are standardized.

Reference duration. A nominal time interval used to standardize single event sound exposure level measurements; equal to 1 second in the case of *SEL*.

Reference speed. Aeroplane ground speed to which noise-power-distance (NPD) sound exposure level (SEL) data are normalized.

SEL. Sound exposure level.

Single event sound exposure level. The sound level an event would have if all its sound energy were compressed uniformly into a standard time interval known as the “reference duration”.

Soft ground. A ground surface that is acoustically “soft”, typically grassy, that surrounds most aerodromes. Acoustically hard, i.e. highly reflective, ground surfaces includes concrete and water. The noise contour methodology described herein applies to soft ground conditions.

Sound. Energy, or acoustic energy. The squared sound pressure (often frequency weighted), divided by the squared reference sound pressure of 20 μPa , the threshold of human hearing. It is algebraically equivalent to $10^{L/10}$, where L is the sound level, expressed in decibels.

Sound attenuation. The decrease in sound intensity with distance along a propagation path. For aeroplane noise, its causes include spherical wave spreading, atmospheric absorption and lateral attenuation.

Sound exposure. A measure of total sound energy emission over a period of time.

Sound exposure level, L_{AE} or SEL . A metric standardized in ISO 1996-1 [ref. 14] or ISO 3891 [ref. 15] = A-weighted single event sound exposure level referenced to 1 second.

Sound intensity. The strength of sound emission at a point — related to sound energy (and indicated by measured sound levels).

Sound level. A measure of sound energy expressed in decibels. Received sound is measured with or without “frequency weighting”; levels measured with a weighting are often termed “noise levels”.

Stage/trip length. Distance to first destination of departing aeroplane; taken to be an indicator of aeroplane mass.

Start-of-roll (SOR). The point on the runway from which a departing aeroplane commences its take-off. Also termed “brake release”.

True airspeed. Actual speed of aeroplane relative to air (= ground speed in still air).

Weight. The downward force of gravity exerted on an aeroplane. It is essentially proportional to the aeroplane's mass. Note, although strictly different entities, the terms “weight” and “mass” are used interchangeably throughout this manual.

Weighted equivalent sound level, $L_{eq,w}$. A modified version of L_{eq} in which different weights are assigned to noise occurring during different periods of the day (usually day, evening and night).

SYMBOLS

The mathematical symbols provided in the following list are the main ones used in the equations throughout this manual; they have the following meanings:

c	Speed of sound in air
C	A constant used in the computation of cumulative noise metrics that can have different meanings (normalizing constant, seasonal adjustment, metric-specific adjustment, etc.)
d	Shortest distance from an observation point to a flight path segment
d_p	Perpendicular distance from an observation point to the flight path (slant distance or slant range)
d_λ	Scaled distance
e	A mathematical constant, approximately equal to 2.718281828

F_n	Actual net thrust per engine
F_n/δ	Corrected net thrust per engine
h	Aeroplane altitude (above MSL)
h_{rel}	Relative humidity
$\text{int}(x)$	Function that returns the integer part of x
L	Event noise level (scale undefined)
$L(t)$	Sound level at time t (scale undefined)
$L_A, L_A(t)$	A-weighted sound pressure level (at time t) — measured on the slow sound level meter scale
L_{AE}	Sound exposure level (SEL) [refs. 2,3]
L_{Amax}	Maximum value of $L_A(t)$ during an event
L_E	Single event sound exposure level
$L_{E\infty}$	Single event sound exposure level determined from NPD database
L_{EPN}	Effective perceived noise level
L_{eq}	Equivalent (continuous) sound level
L_{max}	Maximum value of $L(t)$ during an event
$L_{max,seg}$	Maximum level generated by a segment
ℓ	Perpendicular distance from an observation point to the ground track
$\ln$	Logarithm to base e
$\log$	Logarithm to base 10
N	Number of segments or subsegments
N_{app}	Movement adjustment factor for modelling aircraft certified under ICAO Annex 16, Volume I Chapters 2, 3 and 4 [ref. 18] performing approach operations with a proxy aircraft
N_{certif}	Movement adjustment factor for modelling aircraft certified under ICAO Annex 16, Volume I Chapters 6 and 10 with a proxy aircraft
N_{dep}	Movement adjustment factor for modelling aircraft certified under ICAO Annex 16, Volume I Chapters 2, 3 and 4 performing departure operations with a proxy aircraft
NAT	Number of events with L_{max} exceeding a specified threshold
p	Atmospheric pressure
P	Power parameter in NPD variable $L(P,d)$
P_{seg}	Power parameter relevant to a particular segment
q	Distance from start of segment to closest point of approach
R	Radius of turn
S	Standard deviation
s	Distance along ground track
$SRWY$	Runway length
t	Time
T	Temperature
t_e	Effective duration of single sound event
t_0	Reference time for integrated sound level
V	Ground speed
V_{seg}	Equivalent segment ground speed
V_{ref}	Reference ground speed for which NPD data are defined
x,y,z	Local coordinates
x',y',z'	Aeroplane coordinates
$X_{ARP}, Y_{ARP}, Z_{ARP}$	Position of aerodrome reference point in geographical coordinates
z	Height of aeroplane above ground plane / aerodrome reference point
z'	Set of values of height of aircraft for subsegmentation
α	Parameter used for calculation of the finite segment correction Δ_F
$\alpha_{n,ref}$	Sound attenuation rate (dB/305 m) of the n -th one-third octave frequency band given reference atmospheric conditions. Parameter used for calculation of the atmospheric absorption correction
β	Elevation angle of aeroplane relative to ground plane
ϵ	Aeroplane bank angle

γ	Climb/descent angle
ϕ	Depression angle (lateral directivity parameter)
λ	Total segment length
ψ	Angle between direction of aeroplane movement and direction to observer
ρ	Air density
ξ	Aeroplane heading, measured clockwise from magnetic north
π	A mathematical constant, approximately equal to 3.141592653
$\Lambda(\beta, \ell)$	Air-to-ground lateral attenuation
$\Lambda(\beta)$	Long-range air-to-ground lateral attenuation
$\Gamma(\ell)$	Lateral attenuation distance factor
Δ	Change in value of a quantity, or a correction (as indicated in the text)
Δ_{app}	Decibel level adjustment factor for modelling aircraft certified under ICAO Annex 16, Volume I Chapters 2, 3 and 4 performing approach operations with a proxy aircraft
Δ_{certif}	Decibel level adjustment factor for modelling aircraft certified under ICAO Annex 16, Volume I Chapters 6 and 10 with a proxy aircraft
Δ_{dep}	Decibel level adjustment factor for modelling aircraft certified under ICAO Annex 16, Volume I Chapters 2, 3 and 4 performing departure operations with a proxy aircraft
Δ_F	Finite segment correction
Δ_i	Engine installation correction
$\Delta_{Impedance}$	Acoustic impedance correction
$\Delta_L(T, p_a, h_{rel}, d_i)$	Atmospheric absorption correction for study-specific temperature T , atmospheric pressure p_a , relative humidity h_{rel} , and NPD distance d_i
Δ_{rev}	Reverse thrust
Δ_{SOR}	Start-of-roll correction
Δ_v	Duration (speed) correction

Subscripts

1, 2	Subscripts denoting start and end values of an interval or segment
A	A-weighted
certif	Certification
E	Exposure
i	Aeroplane type/category summation index
j	Ground track/sub-track summation index
k	Segment summation index
max	Maximum
miss	Missing aircraft (i.e. and aircraft not in the ANP database)
n	One-third octave band frequency index
proxy	Proxy or substitution aircraft
ref	Reference value
seg	Segment specific value
SOR	Related to start-of-roll
SC	Source
TO	Take-off

Chapter 1

GENERAL

1.1 INTRODUCTION

1.1.1 Contour maps are used to indicate the extent and magnitude of aeroplane noise impact around airports, indicated by values of a specified noise metric or index. A contour is a line along which the index value is constant. The index value aggregates all the individual aeroplane noise events that occur during a specified period of time, normally measured in days or months, according to a specific noise metric. More information on noise indices, including those in use in various countries is provided in Appendix A.

1.1.2 The reader is reminded periodically of the interchangeability of the words “sound” and “noise” in this manual. Although the word “noise” has subjective connotations, it is usually defined by acousticians as “unwanted sound”; in the field of aeroplane noise control, it is commonly taken to mean just sound — airborne energy transmitted by acoustic wave motion.

1.1.3 The noise at points on the ground from aeroplanes flying into and out of a nearby aerodrome depends on many factors. Principal among these are the types of aeroplanes and their power plants; the power, flap and airspeed management procedures used on the aeroplanes themselves; the distances from the points concerned to the various flight paths; and local topography and weather. Airport operations generally include different types of aeroplanes, various flight procedures and a range of operational masses.

1.1.4 This manual is written principally for aeroplane noise modellers, who develop and maintain the computer models and their databases. It fully describes a specific noise contour modelling system, which is considered by ICAO to represent current best practices. It does not prescribe a computer programme, but rather the equations and the logic that need to be programmed to construct a physical “working model”. Any physical model that complies fully with the methodology described can be expected to generate contours of aeroplane noise exposure around civil airports with reasonable accuracy. **The methodology applies only to long-term average noise exposure; it cannot be relied upon to predict with any accuracy the absolute level of noise from a single aeroplane movement and should not be used for that purpose.**

1.1.5 This manual details how to calculate, at one observer point, the individual aeroplane noise event levels, each for a specific aeroplane flight or type of flight, that are subsequently averaged, or accumulated, to yield index values at that point. The required surface of index values is generated by repeating the calculations as necessary for different aeroplane movements — taking care to maximize efficiency by excluding events that are not “noise-significant” (i.e. disregarding segments that do not contribute significantly to the total event level yields massive savings in computer processing).

1.1.6 This manual replaces ICAO Circular 205 published in 1988. Many essential features of the previously recommended process have been retained in this manual; only parts that have subsequently proved to be inadequate or inappropriate have been improved or replaced; it is not a programming document; it does not provide detailed step-by-step instructions for constructing a computer code. Such details are left to the modeller/programmer, who then has the flexibility to adapt the model to specific needs. Two important associated reference documents are the SAE

International's Aerospace Information Report No 1845 [ref. 1]¹ and the European Civil Aviation Conference's Document 29 [ref.2, 3]. The aviation industry specialists in the organizations publishing these documents have long been engaged in the development of aeroplane noise Standards and Recommended Practices.

1.1.7 An important advance on previous guidance is an international aircraft noise and performance (ANP) database available online (www.aircraftnoisemodel.org) and the recommended methodology is designed to make full use of this comprehensive ICAO-endorsed data source. It includes aeroplane and engine performance data and noise-power-distance (NPD) tables for the civil aeroplane types most commonly used at the world's busiest airports.

1.1.8 There are a number of noise-generating activities on operational airports which are excluded from the "air noise" calculation procedures given here. These include taxiing, engine testing and use of auxiliary power-units, which generally come under the heading of "ground noise". In practice, the effects of these activities are unlikely to affect the noise contours in regions beyond the airport boundary. This does not necessarily mean that their impact is insignificant; however assessments of ground noise are usually undertaken independently of air noise analyses.

1.2 OUTLINE

1.2.1 It is assumed that users are familiar with basic noise modelling principles. It is important to note that having a best practice modelling methodology is only one of three requirements for valid noise contour modelling. The others are an accurate aeroplane noise and performance database and a detailed understanding and description of the aeroplane operations that are the source of the noise. All three elements are covered in this manual.

1.2.2 The noise contour generation process is illustrated in Figure 1-1. Contours are produced for various purposes and tend to control the requirements for sources and pre-processing of input data. Contours that depict historical noise impact might be generated from actual records of aeroplane operations — of movements, masses, radar-measured flight paths, etc. Contours used for future planning purposes of necessity rely more on forecasts — of traffic and flight tracks and the performance and noise characteristics of future aeroplanes.

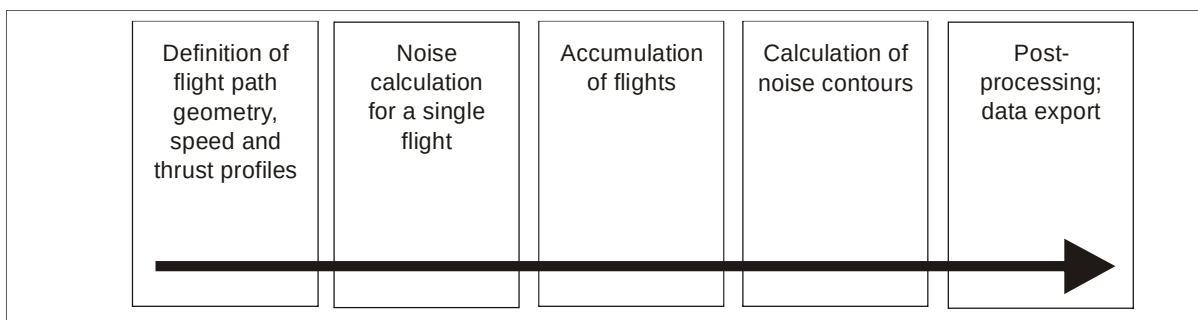


Figure 1-1. The noise contour generation process

1.2.3 Each different aeroplane movement, arrival or departure, is defined in terms of its flight path geometry and the noise emission from the aeroplane as it follows that path (movements that are essentially the same in noise and flight path terms are included by simple multiplication). The noise emission depends on the characteristics of the aeroplane — mainly on the power generated by its engines. The recommended methodology involves dividing the flight path into segments. Chapter 2 outlines the elements of the methodology. It explains the principle of segmentation on which it is based and that the observed event noise level is an aggregation of contributions from all "noise-significant"

1. All references can be found at the end of this manual.

segments of the flight path, each of which can be calculated independently of the others. Chapter 2 also outlines the input data requirements for producing a set of noise contours.

1.2.4 Chapter 3 describes the flight path segment calculations from pre-processed input data. This involves applications of aeroplane flight performance analysis, equations for which are detailed in Appendix C, using data from the ANP database. Flight paths are subject to significant variability — aeroplanes following any route are dispersed across a swathe due to the effects of differences in atmospheric conditions, aeroplane mass and operating procedures, air traffic control constraints, etc. This is taken into account by describing each flight path statistically — as a central or “backbone” path which is accompanied by a set of dispersed paths. This is also explained in Chapter 3 with reference to additional information in Appendix D.

1.2.5 Chapter 4 sets out the steps to be followed in calculating the noise level of a single event — the noise generated at a point on the ground by one aeroplane movement. Data in the international ANP database apply to specific reference conditions. Appendix E deals with the re-calculation of NPD data for non-reference conditions. The acoustic dipole source used in the model to define sound radiation from flight path segments of finite length is explained in Appendix F. Appendix G gives additional guidance for the case when the event level metric is L_{max} rather than L_E .

1.2.6 In addition to relevant flight paths, modelling applications described in Chapters 3 and 4 require appropriate noise and performance data for the aeroplane in question. The source of that information, the ICAO-endorsed international ANP database website, and how data can be obtained from it, is provided in Appendix H.

1.2.7 Determining the event level for a single aeroplane movement at a single observer point is the core noise calculation in this methodology. This process has to be repeated for all aeroplane movements at each of a prescribed array of points covering the expected extent of the required noise contours. At each point, the event levels are aggregated or averaged to arrive at a “cumulative level” or noise index value. This part of the process is described in Chapter 5.

1.2.8 Chapter 6 summarizes the options and requirements for fitting noise contours to arrays of noise index values. It provides guidance on contour generation and post-processing.

Chapter 2

SUMMARY AND APPLICABILITY OF METHOD

2.1 INTRODUCTION

2.1.1 This manual describes the major aspects of the calculation of noise contours for air traffic at an airport. It is primarily intended to be applied to civil commercial airports where operations consist mostly of jet-engine powered or propeller-driven heavy aeroplanes. If appropriate noise and performance data are available for propeller-driven light aeroplanes, these may also be included in the evaluation. Where the noise impact is derived mostly from helicopters, however, this manual is not applicable — the operational patterns for such aircraft often differ markedly from those covered here and the aircraft themselves have different noise directivity patterns from the other types.

2.1.2 This manual describes three different methods in which most practical noise models calculate aeroplane noise single event levels. In order of increasing complexity, these methods are the closest point of approach (CPA), segmentation and simulation methods. Each has its strengths and weaknesses, but it is considered that, on balance, segmentation (otherwise known as “integrated”) models represent the current best practice. This situation may change at some point in the future: “simulation” models have greater potential and it is only the lack of the comprehensive data they require, and their higher demands on computing capacity, that restrict them to special applications (such as research) at present.

2.1.3 Segmentation modelling is supported by a comprehensive aircraft noise and performance database, which has been assembled over many years by the aircraft manufacturing industry in collaboration with the noise certifying authorities. This international aircraft noise and performance (ANP) database is now accessible on the Internet at <http://www.aircraftnoisemodel.org>; the ANP website is a primary source of data for the methodology recommended in this manual.

2.1.4 The contour modelling system consists of a computer model that uses the recommended methodology and the ANP database together. This system is applied to a particular airport scenario with user-specified airport data and air traffic data specifying the aeroplane types, numbers, routings and operating procedures.

2.1.5 The basic elements of the noise contour generation process are summarized in this chapter, and are expanded upon in subsequent chapters and appendices.

2.2 THE CONCEPT OF SEGMENTATION

2.2.1 For any specific aeroplane, the database contains baseline noise-power-distance (NPD) relationships. These define, for steady straight flight at a reference speed in specified reference atmospheric conditions and in a specified flight configuration, the received sound event levels, both maximum and time-integrated, directly beneath the aeroplane¹ as a function of distance. For noise modelling purposes, propulsive power is represented by a noise-related power parameter; generally corrected net thrust. Baseline event levels determined from the database are adjusted to

1. Actually beneath the aeroplane perpendicular to the wing axis and direction of flight; taken to be vertically below the aeroplane when in non-turning (i.e. non-banked) flight.

account for differences between actual (i.e. modelled) and reference atmospheric conditions, aeroplane speed (in the case of sound exposure levels) and, for receiver points that are not directly beneath the aeroplane, differences between downwards and laterally radiated noise. This latter difference is due to lateral directivity (engine installation effects) and lateral attenuation. It is important to note that the event levels so adjusted still apply to the total noise from the aeroplane in steady level flight.

2.2.2 Segmentation is the process by which the recommended noise contour model adapts the infinite path NPD and lateral data to calculate the noise reaching a receiver from a non-uniform flight path, i.e. one along which the aeroplane flight configuration varies. For the purposes of calculating the event sound level of an aeroplane movement, the flight path is represented by a set of contiguous straight-line segments, each of which can be regarded as a finite part of an infinite path for which an NPD and the lateral adjustments are known. The maximum level of the event is simply the greatest of the individual segment values. The time integrated level of the whole noise event is calculated by summing the noise received from a sufficient number of segments, i.e. those which make a significant contribution to the total event noise.

2.2.3 The method for estimating how much noise one finite segment contributes to the integrated event level is a purely empirical one. The energy fraction F – the segment noise expressed as a proportion of the total infinite path noise – is described by a relatively simple expression which allows for the longitudinal directivity of aeroplane noise and the receiver's "view" of the segment. One reason why a simple empirical method is generally adequate is that, as a rule, most of the noise comes from the nearest, usually, adjacent segment – for which the closest point of approach (CPA) to the receiver lies within the segment (not at one of its ends). This means that estimates of the noise from non-adjacent segments can be increasingly approximated as they get further away from the receiver without compromising the accuracy significantly.

2.3 FLIGHT PATHS: TRACKS AND PROFILES

2.3.1 In the modelling context, a flight path (or trajectory) is a full description of the motion of the aeroplane in space and time². Together with the propulsive thrust (or other noise related power parameter), this is the information needed to calculate the noise generated. The ground track is the vertical projection of the flight path on level ground. This is combined with the vertical flight profile to construct the 3-D flight path. Segmentation modelling requires that the flight path of every different aeroplane movement is described by a series of contiguous straight segments. The manner in which the segmentation is performed is dictated by a need to balance accuracy and efficiency – it is necessary to approximate the real curved flight path sufficiently closely while minimizing the computational burden and data requirements. Each segment has to be defined by the geometrical coordinates of its end points and the associated speed and engine power parameters of the aeroplane (on which sound emission depends). Flight paths and engine power may be determined in various ways, the most common involving synthesis from a series of procedural steps and analysis of measured flight profile data.

2.3.2 Synthesis of the flight path requires knowledge of (or assumptions of) ground tracks and their lateral dispersions, aeroplane mass, speed, flap and thrust-management procedures, airport elevation, atmospheric pressure, wind and air temperature. Equations for calculating the flight profile from the required propulsion and aerodynamic parameters are given in Appendix C. Each equation contains coefficients (and/or constants) which are based on empirical data for each specific aeroplane type. The aerodynamic-performance equations in Appendix C permit the consideration of any reasonable combination of aeroplane operational mass and flight procedure, including operations at different take-off masses.

2. Time is accounted for via the aeroplane speed.

2.3.3 Analysis of measured data, e.g. from flight data recorders, radar or other aeroplane tracking equipment, involves “reverse engineering”, effectively a reversal of the synthesis process, as described in 2.3.2. Instead of estimating the aeroplane and power plant states at the ends of the flight segments by integrating the effects of the thrust and aerodynamic forces acting on the airframe, the forces are estimated by differentiating the changes of height and speed of the airframe. Procedures for processing the flight path information are described in 3.5.

2.3.4 In an ultimate noise modelling application, each individual flight could, theoretically, be represented independently; this would guarantee accurate accounting for the spatial dispersion of flight paths, which can be significant. However, to keep data preparation and computer time within reasonable bounds, it is normal practice to represent flight path swathes by a small number of laterally displaced “sub-tracks”. (Vertical dispersion is usually represented satisfactorily by accounting for the effects of varying aeroplane masses on the vertical profiles.)

2.4 AIRCRAFT NOISE AND PERFORMANCE DATABASE

2.4.1 To support this methodology, use of data from the online international aircraft noise and performance (ANP) database (www.aircraftnoisemodel.org), which is fully described in Appendix H, is recommended.

2.4.2 The ANP database contains aeroplane and engine performance coefficients and NPD relationships for a substantial proportion of the civil aeroplane types operating worldwide. Data on additional aeroplane types, old and new, will be added as soon as they have been supplied to, and verified by, the database managers.

2.4.3 All new inputs are supplied or endorsed by the aeroplane manufacturers and generated according to SAE International's specifications [ref. 1] that are approved by ICAO. For aeroplanes that are common to both specifications, the data are identical to those in the United States International Noise Model (INM) database [ref. 4]. For aeroplane types or variants for which data are not currently listed, the ANP database provides guidance on how they can best be represented by data for other similar aeroplanes that are listed.

2.4.4 The ANP database includes default “procedural steps” to enable the construction of flight profiles for at least one common noise abatement departure procedure. More recent database entries cover two different noise abatement departure procedures. However, it should be noted that these carry the caveat:

“Users should examine the applicability of ANP database default ‘procedural steps’ to the airport under consideration. These data are generic and in some cases may not realistically represent flight operations at your airport.”

2.4.5 Although the manufacturers and database managers strive to ensure that the data are generated in strict accordance with the standard specifications, ultimate validation of the ANP data lies effectively with the user. Inconsistencies or deficiencies are most likely to be discovered by users who compare model predictions with measured data. Evidence of inconsistencies is fed back to the data suppliers through the database managers. The data suppliers then decide on the action required; only they can amend or approve database entries. To this end, it must be recognized that acquiring reliable measured data is a very demanding task as it is necessary for data suppliers to demonstrate that the data meets acceptable quality criteria.

2.4.6 Access to the database is subject to terms and conditions designed to prevent misuse. User registration and password protection are overseen by the database managers.

2.5 AIRPORT AND AEROPLANE OPERATIONS

2.5.1 Case-specific data required for a particular airport scenario are described in the following paragraphs.

2.5.2 General airport data, including:

- a) the aerodrome reference point in order to locate the aerodrome in appropriate geographic coordinates. The reference point is set as the origin of the local Cartesian coordinate system used by the calculation procedure;
- b) the aerodrome reference altitude (the altitude of aerodrome reference point). This is the altitude of the nominal ground plane on which, in the absence of topography corrections, the noise contours are defined; and
- c) average meteorological parameters at or close to the aerodrome reference point (temperature, relative humidity, average wind speed and wind direction).

2.5.3 Runway data for each runway, including:

- a) runway designation;
- b) runway reference point (centre of runway expressed in local coordinates);
- c) runway length, direction and mean gradient; and
- d) location of start-of-roll and landing threshold³.

2.5.4 Ground track data consist of a series of track coordinates and a description of the track dispersion.

2.5.5 Aeroplane ground tracks are described by a series of coordinates in the (horizontal) ground-plane. The source of ground track data depends on whether relevant radar data are available. If they are, a reliable backbone track and suitable associated (dispersed) sub-tracks can be established by statistical analysis of the data. If not, backbone tracks are usually constructed from appropriate procedural information, e.g. using standard instrument departure procedures from AIPs. This conventional description includes the following information:

- a) designation of the runway the track originates from;
- b) description of the track origin (start-of-roll, landing threshold); and
- c) length of segments (for turns, radius and change of direction).

2.5.6 This information is the minimum necessary to define the core (backbone) track. It is important to note that average noise levels calculated on the assumption that aeroplanes which follow the nominal routes exactly may be liable to localized errors of several decibels. Thus lateral dispersion should be represented by the following information:

- a) width of the swathe (or other dispersion statistic) at each segment end;
- b) number of sub-tracks; and
- c) distribution of movements perpendicular to the backbone track.

3. Displaced thresholds can be taken into account by defining additional runways.

2.5.7 Air traffic data, including:

- a) the time period covered by the data; and
- b) the number of movements (arrivals or departures) of each aeroplane type on each flight track, subdivided by the time of day, as appropriate, for specified noise descriptors⁴, for departures, operating masses or stage lengths, and, if necessary, operating procedures.

2.5.8 Topographical data meeting the following criteria:

- a) the terrain around most airports is relatively flat. However, there are cases where variations in terrain elevation relative to the airport reference elevation may need to be taken into account. The effect of terrain elevation can be especially important in the vicinity of approach tracks, where the aeroplane is operating at relatively low altitudes;
- b) terrain elevation data are usually provided as a set of (x,y,z) coordinates for a rectangular grid of certain mesh-size; but the parameters of the elevation grid are likely to be different from those of the grid used for the noise computation. If so, linear interpolation may be used to estimate the appropriate z coordinates in the latter; and
- c) comprehensive analysis of the effects of non-level ground on sound propagation is beyond the scope of this guidance. Moderate unevenness can be accounted for by assuming “pseudo-level” ground, i.e. simply raising or lowering the level ground plane to the local ground elevation (relative to the reference ground plane) at each receiver point (see Chapter 3, 3.4.4).

2.6 THE INTERNATIONAL AIRCRAFT NOISE AND PERFORMANCE (ANP) DATABASE

2.6.1 The ANP data are normalized to standard reference conditions that are widely used for airport noise studies (see Appendices E and H). Specific reference conditions apply to aeroplane noise-power-distance (NPD) data and aeroplane aerodynamic and engine data.

2.6.2 Reference conditions for NPD data include the following:

- a) atmospheric pressure: 101.325 kPa (1 013.25 mb);
- b) atmospheric absorption: attenuation rates listed in Table E-1 of Appendix E;
- c) precipitation: none;
- d) wind speed: less than 8 m/s (15 kt);
- e) ground speed: 160 kt; and
- f) local terrain: flat, soft ground, free of large structures or other reflecting objects, within several kilometres of aeroplane ground tracks.

4. Most noise descriptors require that events (i.e. aeroplane movements) are defined as average daily values during specified periods of the day (e.g. day, evening and night) – see Chapter 5.

2.6.3 In addition, standardized aeroplane sound measurements are made 1.2 m above the ground surface. However, for modelling purposes, it may be assumed that event levels are relatively insensitive to the receiver height⁵.

2.6.4 Comparisons of estimated and measured airport noise levels indicate that the NPD data can be assumed applicable when the near surface average conditions lie within the following envelope:

- a) air temperature is less than 30°C;
- b) the product of air temperature (°C) and relative humidity (per cent) is greater than 500; and
- c) wind speed is less than 8 m per second (15 kt).

2.6.5 This envelope is believed to encompass conditions encountered at most of the world's major airports. Appendix E provides a method for converting NPD data to average local conditions which fall outside this envelope. In extreme cases, it is suggested that the relevant aeroplane manufacturers be consulted.

2.6.6 Reference conditions for aeroplane aerodynamic and engine data include the following:

- a) runway elevation: mean sea level;
- b) air temperature: 15°C;
- c) take-off gross weight: as defined as a function of stage length in the ANP database (see Appendix H, 3.7);
- d) landing gross weight: 90 per cent of maximum landing gross weight; and
- e) engines supplying thrust: all.

2.6.7 Although ANP aerodynamic and engine data are based on these conditions, they can be tabulated for non-reference runway elevations and average air temperatures (see Appendix C).

2.6.8 The ANP database tabulates aerodynamic data for the take-off and landing gross weights noted above. Although the aerodynamic data themselves need not be adjusted for other gross weights when calculating cumulative noise levels, calculation of the take-off and climb-out flight profiles should be based on the appropriate operational take-off gross weights (see Appendix C).

2.7 ICAO-RECOMMENDED AIRCRAFT SUBSTITUTION METHOD

2.7.1 The ANP database provides performance and NPD data for a list of specific airframe-engine combinations which represent a large proportion of the aircraft types that make up today's commercial civil aircraft fleets. However, the ANP database does not include all the existing types, models and variants which are operated around the world. Therefore, the available ANP aircraft may not always be sufficient to model the full set of operations at a given airport, hence the need for the noise modellers to use aircraft substitutions. Substitution means replacing a missing aircraft with

5. Calculated levels at 4 m or higher are sometimes requested. Comparison of measurements at 1.2 m and 10 m and theoretical calculation of ground effects show that variations of the A-weighted sound exposure level are relatively insensitive to the receiver height. The variations are, in general, smaller than one decibel, except if the maximum angle of sound incidence is below 10° and if the A-weighted spectrum at the receiver has its maximum in the range of 200 to 500 Hz. Such low frequency-dominated spectra may occur, e.g. at long distances for low-bypass ratio engines and for propeller engines with discrete low frequency tones.

a similar ANP one, also named a proxy aircraft. One option uses a proxy to model the operations of the missing aircraft. This is referred to as a 'one-to-one' substitution. However, it is recommended to perform some adjustments to take into account possible differences between the noise levels of the missing and the proxy aircraft. This can be done using either of the following methods:

- a) Method A: by creating a new entry in the ANP database defined as a duplicate of the proxy aircraft with adjusted NPD data.
- b) Method B: by adjusting the number of movements of the proxy aircraft in the input operations, i.e. one movement by the missing aircraft is replaced by N movements of the proxy aircraft (N can be a decimal number).

2.7.2 The calculation of the adjustments for each method is described hereafter. Method A may be more resource-intensive, as it implies modifying the ANP database in the model; however, it allows adjusting the calculation of all noise metrics, including maximum sound levels such as L_{Amax} . Method B may be easier to implement as only the input operations need to be modified; however, it only applies to the calculation of equivalent sound levels, such as L_{Aeq} .

2.7.3 Identifying proxy aircraft

2.7.3.1 The selection of the most suitable proxy aircraft within the list of aircraft in the ANP database can be a complex task, as it is based on multiple criteria. The criteria against which the missing and proxy aircraft should be compared are:

- a) engine category (jet, turboprop, piston);
- b) number of engines;
- c) engine installation (wing or fuselage);
- d) aircraft maximum take-off weight (MTOW);
- e) thrust-to-weight ratio (maximum static thrust of all engines divided by the MTOW⁶);
- f) certified noise levels;
- g) airframe manufacturer; and
- h) engine manufacturer.

2.7.3.2 The first step consists of identifying detailed characteristics related to the above criteria for the missing aircraft. When the MTOW or engine type of the missing aircraft is unknown, the variant with the highest MTOW should be assumed (as a conservative approach), with its corresponding engine type and static thrust.

2.7.3.3 In the ideal situation, criteria a), b) and c) should be identical for the missing and proxy aircraft, while criteria d), e) and f) should be as close as possible. Criteria g) and h) can be used to decide between equally satisfying proxy candidates. However, it may not always be possible to find a proxy in the ANP database that meets all of these criteria simultaneously, hence the need to relax some of them in certain situations. Modellers should nevertheless try to apply the following principles when looking for a proxy aircraft:

6. The single engine maximum static thrust should be multiplied by the number of engines to account for the situation where the missing and proxy aircraft have different engine numbers.

- a) the engine category (jet, turboprop, piston) and installation (wing, fuselage) of the source and proxy aircraft should be identical;
- b) different variants (engine, MTOW, etc.) of the same aircraft type should be assigned the same proxy, except when the variants are present in the ANP database; and
- c) consequently, when the missing aircraft type exists in the ANP, but in another engine or MTOW variant, this other variant should be used as a proxy.

2.7.4 Computing decibel and movement adjustments

2.7.4.1 However comparable the missing and selected proxy aircraft may be, their respective noise footprints will always differ to some extent. This difference can be mitigated by applying some adjustments either to the proxy aircraft's NPD data (Method A), or to its number of operations (Method B).

2.7.4.2 Under Method A, all NPD curves of the proxy aircraft should be corrected by adding specific decibel adjustments. For aircraft certified under the Annex 16, Volume I, Chapters 2, 3 and 4 [ref. 18], distinct decibel adjustments should be computed for departure and arrival, as follows:

$$\Delta_{\text{dep}} = (\text{FO_LEVEL}_{\text{miss}} + \text{LAT_LEVEL}_{\text{miss}} - \text{FO_LEVEL}_{\text{proxy}} - \text{LAT_LEVEL}_{\text{proxy}})/2 \quad (2-1a)$$

$$\Delta_{\text{arr}} = \text{APP_LEVEL}_{\text{miss}} - \text{APP_LEVEL}_{\text{proxy}} \quad (2-1b)$$

where *FO_LEVEL*, *LAT_LEVEL* and *APP_LEVEL* respectively, stand for the flyover, lateral and approach certified noise levels in EPNdB.

2.7.4.3 For aircraft certified under the Annex 16, Volume I, Chapters 6 and 10, a single decibel adjustment is computed for both departure and arrival curves:

$$\Delta_{\text{certif}} = \text{CERTIF_LEVEL}_{\text{miss}} - \text{CERTIF_LEVEL}_{\text{proxy}} \quad (2-1c)$$

where *CERTIF_LEVEL* stands for the overflight and take-off levels in dBA for Chapter 6 and Chapter 10 aircraft respectively.

2.7.4.5 Under Method B, the number of operations of the missing aircraft should be multiplied by a movement adjustment factor *N*. *N* is derived by comparing the certified noise levels of both the missing and proxy aircraft. Thus, for example, if the missing aircraft has a certified noise level 3 EPNdB greater than that of the proxy, two movements (*N* = 2) of the proxy aircraft will be substituted for each missing aircraft movement. For aircraft certified under the Annex 16, Volume I, Chapters 2, 3 and 4, distinct movement adjustment factors should be computed for departure and arrival, as follows:

$$N_{\text{dep}} = 10^{(\Delta_{\text{dep}} / 10)} \quad (2-1d)$$

$$N_{\text{arr}} = 10^{(\Delta_{\text{arr}} / 10)} \quad (2-1e)$$

2.7.4.6 For aircraft certified under Annex 16, Volume I, Chapters 6 and 10, a single movement adjustment factor is computed for both departure and arrival:

$$N_{\text{certif}} = 10^{(\Delta_{\text{certif}} / 10)} \quad (2-1f)$$

Note 1.— The certified noise levels of the proxy aircraft can be found in the aircraft table of the ANP database.

Note 2.— If the Δ decibel adjustments are large or if the N factors significantly deviate from 1, this is an indication that the selected proxy may not be appropriate (i.e. if criterion f in the previous section has not been met).

Note 3.— When no certified noise levels can be found for the missing aircraft, modellers may decide to apply a one-to-one substitution ($\Delta = 0$, $N = 1$).

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Chapter 3

DESCRIPTION OF THE FLIGHT PATH

3.1 INTRODUCTION

3.1.1 Each different aeroplane movement in a noise model is described by its three-dimensional flight path and the varying engine power and speed along the path. 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 aeroplane type, mass and operating procedure, on a single ground track. That track may itself be one of several dispersed “sub-tracks” used to model a swathe of tracks following one designated route. The ground track swathes, the vertical profiles and the aeroplane operational parameters are all determined from the input scenario data, in conjunction with aeroplane data from the ANP database.

3.1.2 The noise-power-distance (NPD) data (in the ANP database) define noise from aeroplanes traversing idealized horizontal flight paths of infinite length at constant speed and power. To adapt this data to terminal area flight paths that are characterized by frequent changes of power and speed, every path is broken into finite straight-line segments. The noise contributions from each of these segments are subsequently summed at the observer position.

3.2 RELATIONSHIPS BETWEEN FLIGHT PATH AND FLIGHT CONFIGURATION

3.2.1 The three-dimensional flight path of an aeroplane movement determines the geometrical aspects of sound radiation and propagation between aeroplane and observer. At a particular aeroplane mass and in particular atmospheric conditions, the flight path is governed entirely by the sequence of power, flap and attitude changes, in order to follow routes and maintain heights and speeds specified by air traffic control (ATC).¹ These 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. The corresponding vertical coordinates are often referred to as profile points.

3.2.2 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, i.e. physical measurements of actual flight paths flown. Whichever method is used, both horizontal and vertical shapes of the flight path, are reduced to segmented forms. The horizontal shape is the ground track defined by the inbound or outbound routing. Its vertical shape, given by the profile points, and the associated flight parameter speed, bank angle and power setting, together define the flight profile which depends on the flight procedure that is normally prescribed by the aeroplane manufacturer and/or operator. The flight path is constructed by merging the two-dimensional (2-D) flight profile with the 2-D ground track to form a sequence of three-dimensional (3-D) flight path segments.

3.2.3 It is important to note that, for a given set of procedural steps, the profile depends on the ground track, e.g. at the same thrust and speed, the aeroplane climb rate is less in turns than in straight flight. Although this guidance explains how to take this dependency into account, it has to be acknowledged that doing so would normally involve a

1. These specifications are in accordance with the aircraft operator's standard operating procedures.

very large computing effort and users may prefer to assume that, for noise modelling purposes, the flight profile and ground track can be treated as independent entities, i.e. that the climb profile is unaffected by any turns. However, it is important to determine changes of bank angle, which affects the directionality of sound emission.

3.2.4 The noise received from a flight path segment depends on the geometry of the segment in relation to the observer and the aeroplane flight configuration. It is important to note that these parameters are interrelated — a change in one causes a change in the other. It is necessary to ensure that, at all points on the path, the configuration of the aeroplane is consistent with its motion along the path.

3.2.5 In a flight path synthesis, i.e. the construction of a flight path from a set of “procedural steps” that describe 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 aeroplane flight recorder data (although in the latter case engine power is usually part of the data). In either case, the coordinates and flight parameters at all segment end points have to be fed into the noise calculation.

3.2.6 The operational steps followed by arriving and departing aeroplanes are explained in Chapter 4 of Volume 1. Appendix C presents the equations that relate the forces acting on an aeroplane and its motion and explains how they are solved to define the properties of the segments that make up the flight paths. The different kinds of segments (and the sections in Appendix C that cover them) are take-off ground roll (section 6), climb at constant speed (section 7), power cutback (section 8), accelerating climb and flap retraction (section 9), accelerating climb after flap retraction (section 10), descent and deceleration (section 11), and final landing approach (section 12).

3.2.7 Practical modelling involves varying degrees of simplification depending on the nature of the application, the significance of the results and the resources available. A general simplifying assumption, even in the most elaborate applications, is that the flight track dispersion, the flight profiles and configurations on all the sub-tracks are the same as those on the backbone track. A minimum of six sub-tracks is recommended (see 3.5.2), which will greatly reduce computations.

3.3 SOURCES OF FLIGHT PATH DATA

3.3.1 Radar data

3.3.1.1 Radar data are the most readily accessible source of information on actual flight paths flown at airports². Radar data are usually available from airport noise and flight path monitoring systems, and are increasingly used for noise modelling purposes. However, the analysis of radar data is a complex task for which methods are still under development [ref. 5]. Therefore, only general guidance can be offered and it is left to the modeller to determine the appropriate approach.

3.3.1.2 Secondary surveillance radar presents the flight path of an aeroplane as a sequence of positional coordinates at intervals equal to the period of rotation of the radar scanner, typically about 4 seconds. The position of the aeroplane over the ground is determined in polar coordinates — range and azimuth — from the reflected radar return; its height³ is measured by the aeroplane’s own altimeter and transmitted to the ATC computer by a radar-triggered transponder. However, inherent positional errors due to radio interference and limited data resolution may be

2. Aircraft flight data recorders provide comprehensive operational data. However, this is not readily accessible and is costly to provide; thus its use for noise modelling purposes is normally restricted to special projects and model development studies.

3. Usually measured as altitude above MSL (i.e. relative to 1 013.25 mb) and corrected to airport elevation by the airport monitoring system.

significant⁴. Thus, if the flight path of a specific aeroplane movement is required, it is necessary to smooth the data using an appropriate curve-fitting technique [e.g. refs. 6, 7]. However for noise modelling purposes, the usual requirement is for a statistical description of a swathe of flight paths, e.g. for all movements on a route or for just those of a specific aeroplane type. In such cases, the measurement errors associated with the relevant statistics become negligible due to the averaging processes.

3.3.2 Procedural steps

3.3.2.1 In many cases it is not possible to model flight paths on the basis of radar data — because the necessary resources are not available or because the scenario is a future one for which there are no relevant radar data.

3.3.2.2 In the absence of radar data, or when its use is inappropriate, it is necessary to estimate the flight paths on the basis of operational guidance material, e.g. instructions given to flight crews via AIPs and aeroplane operating documents — referred to here as procedural steps. Advice on interpreting this material should be sought from air traffic control authorities and the aeroplane operators when necessary.

3.4 COORDINATE SYSTEMS

3.4.1 The local coordinate system

The local coordinate system (x,y,z) is a Cartesian one and has its origin $(0,0,0)$ at the aerodrome reference point $(X_{ARP}, Y_{ARP}, Z_{ARP})$, where Z_{ARP} is the airport reference altitude and $z = 0$ defines the nominal ground plane on which contours are usually calculated. The aeroplane heading ξ in the xy -plane is measured clockwise from magnetic north (see Figure 3-1). All observer locations, the basic calculation grid and the noise contour points are expressed in local coordinates⁵.

3.4.2 The ground track fixed coordinate system

3.4.2.1 This coordinate is specific for each ground track and represents distance s measured along the track in the flight direction. For departure tracks, s is measured from the start-of-roll, for approach tracks, s is measured from the touchdown point. Thus, s becomes negative in areas:

- a) behind the start-of-roll for departures; and
- b) before crossing the runway landing threshold for approaches.

3.4.2.2 Flight operational parameters such as height, speed and power setting are expressed as functions of s .

4. These issues are of no consequence for the intended air traffic control purposes.

5. Usually the axes of the local coordinates are parallel to the axis of the map that the contours are drawn on. However, it is sometimes useful to choose the x -axis parallel to a runway in order to get symmetrical contours without using a fine computational grid (see Chapter 6).

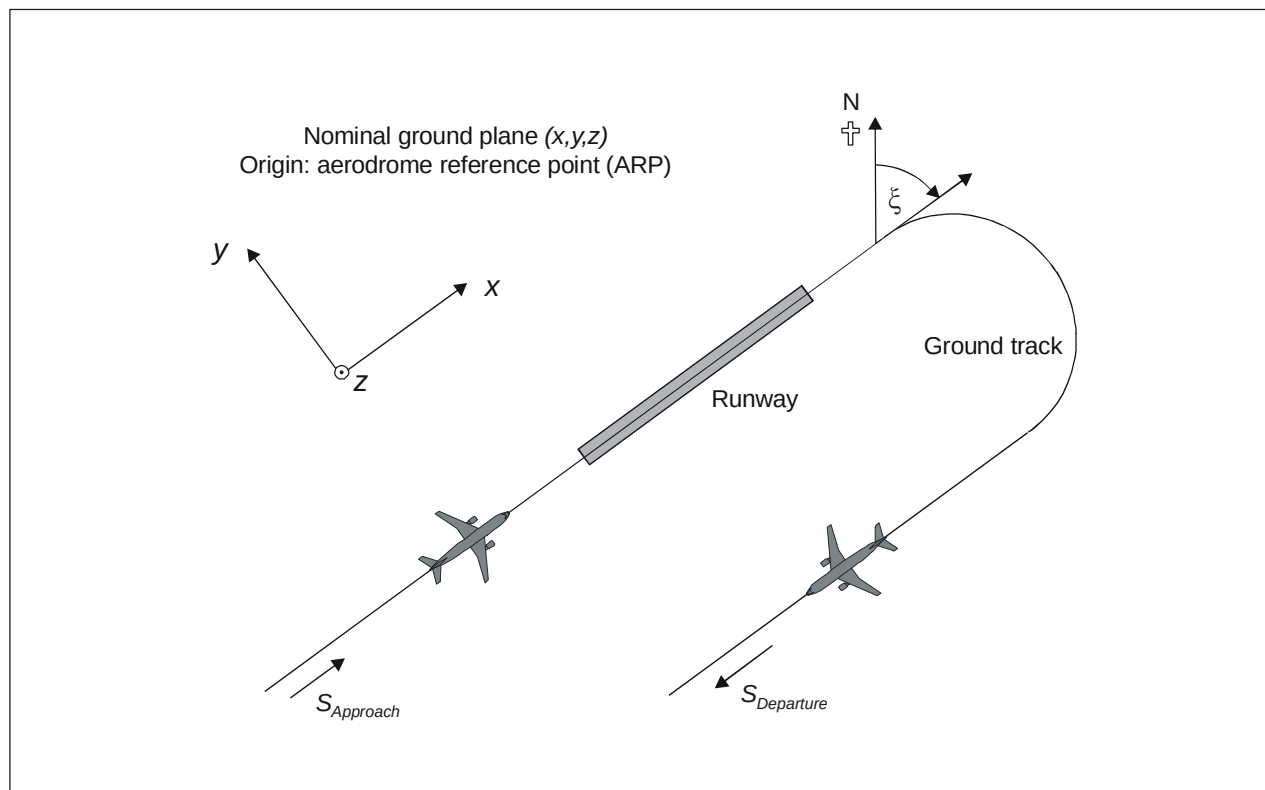


Figure 3-1. Local coordinate system (x,y,z) and ground track fixed coordinates

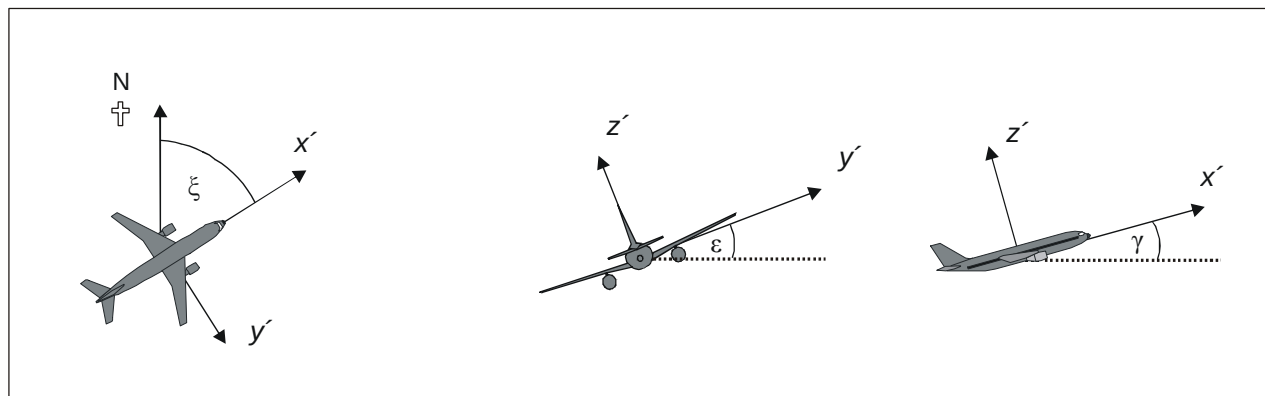
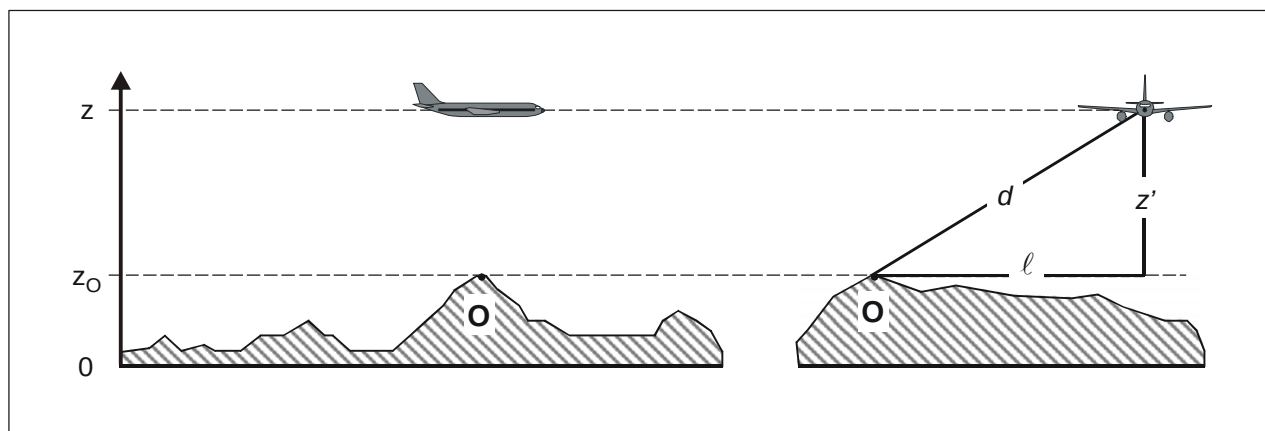
3.4.3 The aeroplane coordinate system

The aeroplane-fixed Cartesian coordinate system (x',y',z') has its origin at the actual aeroplane location. The axis-system is defined by the climb angle γ , the flight direction ξ and the bank angle ε (see Figure 3-2).

3.4.4 Accounting for topography

In cases where topography has to be taken into account (see Chapter 2, 2.5), the aeroplane height coordinate z has to be replaced by $z' = z - z_0$ (where z_0 is the z coordinate of the observer location O) when estimating the propagation distance d . The geometry between aeroplane and observer is shown in Figure 3-3⁶.

6. For non-level ground it is possible for the observer to be above the aircraft, in which case, for calculating sound propagation z' (and the corresponding elevation angle β) is put equal to zero (see Chapter 4).

Figure 3-2. Aeroplane fixed coordinate system (x', y', z')Figure 3-3. Ground elevation along (left) and lateral (right) to ground track. The nominal ground plane $z = 0$ passes through the aerodrome reference point. O is the observer location.

3.5 GROUND TRACKS

3.5.1 Backbone tracks

3.5.1.1 The backbone track defines the centre of the swathe of tracks followed by aeroplanes using a particular routing. For the purposes of aeroplane noise modelling it is defined either by prescriptive operational data such as the instructions given to pilots in AIPs, or by statistical analysis of radar data as explained in 3.3, when this is available and appropriate to the needs of the modelling study. Constructing the track from operational instructions is normally quite straightforward as these prescribe a sequence of legs which are either straight, defined by length and heading, or circular arcs, defined by turn rate and change of heading (see Figure 3-4).

3.5.1.2 Fitting a backbone track to radar data is more complex, because actual turns are made at a varying rate and its line is obscured by the scatter of the data. Since formalized procedures have yet to be developed, it is common practice to match segments to the average positions calculated from cross-sections of radar tracks at intervals along the route. It is for the modeller to decide how best to use the available data. A major factor is that the aeroplane speed and turn radius dictate the bank angle, which may affect the sound radiation around the flight path as observed on the ground (see Chapter 4, 4.5).

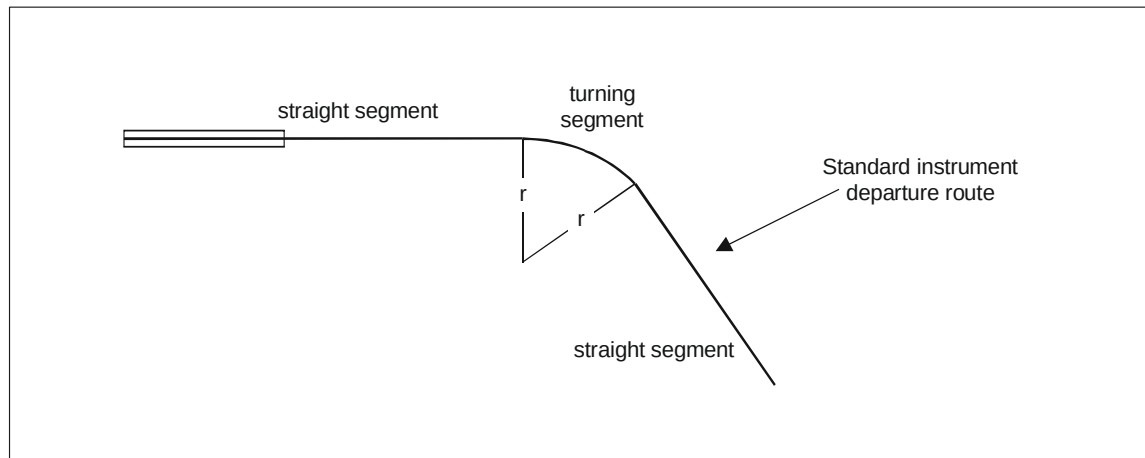


Figure 3-4. Ground track geometry in terms of turns and straight segments

3.5.1.3 Theoretically, seamless transition from straight flight to fixed radius turn would require an instantaneous application of bank angle ε , which is physically impossible. In reality, it takes a finite time for the bank angle to reach the value required to maintain a specified speed and turn radius r , during which the turn radius reduces from infinity to r . For modelling purposes, the radius transition can be disregarded and the bank angle can be assumed to increase steadily from zero (or other initial value) to ε at the start of the turn and to the next value of ε at the end of the turn⁷.

3.5.2 Track dispersion

3.5.2.1 Where possible, definitions of lateral dispersion and representative sub-tracks should be based on relevant past experience from the study airport, i.e. normally via an analysis of radar data samples. The first step is to group the data by route. Departure tracks are characterized by substantial lateral dispersion which, for accurate modelling, has to be taken into account. Arrival routes normally coalesce into a very narrow swathe around the final approach path and it is usually sufficient to represent all arrivals by a single track. However, if the approach swathes are wide within the region of the noise contours they may need to be represented by sub-tracks in the same way as departure routes.

3.5.2.2 It is common practice to treat the data for a single route as a sample from a single population; i.e. to be represented by one backbone track and one set of dispersed sub-tracks. However, if inspection indicates that the data for different categories of aeroplane or operations differ significantly (e.g. if large and small aeroplanes have substantially different turn radii), further subdivision of the data into different swathes may be desirable. For each swathe, the lateral track dispersions are determined as a function of distance from the origin; movements are then apportioned between a backbone track and a suitable number of dispersed sub-tracks on the basis of the distribution statistics.

3.5.2.3 In the absence of measured swathe data, a nominal lateral spread across and perpendicular to the backbone track should be defined by a conventional distribution function. Normal (Gaussian) distribution should provide an adequate description of most radar-measured swathes.

7. How best to implement this is left to the user as it will depend on the way in which turn radii are defined. When the starting point is a sequence of straight or circular legs, a relatively simple option is to insert bank angle transition segments at the start of the turn and at its end in which the aircraft rolls at a constant rate (e.g. expressed in $^{\circ}/m$ or $^{\circ}/s$).

3.5.2.4 Typically a 7-point discrete approximation is used to model a swathe of aeroplane tracks, which represent the lateral dispersion by six sub-tracks equally spaced around the backbone track. The spacing of the sub-tracks depends on the standard deviation of the lateral dispersion function.

3.5.2.5 For normally distributed tracks with a standard deviation S , 98.8% of the tracks are located within a corridor with boundaries located at $\pm 2.5 \cdot S$. Table 3-1 gives the spacing of the six sub-tracks and the percentage of the total movements assigned to each. Appendix D gives values for other numbers of sub-tracks.

Table 3-1. Percentages of movements for a normal distribution function with standard deviation S for 7 sub-tracks (backbone track is sub-track 1)

Sub-track number	Location of sub-track	Percentage of movements on sub-track
7	$-2.14 \cdot S$	3 %
5	$-1.43 \cdot S$	11 %
3	$-0.71 \cdot S$	22 %
1	0	28 %
2	$0.71 \cdot S$	22 %
4	$1.43 \cdot S$	11 %
6	$2.14 \cdot S$	3 %

3.5.2.6 The standard deviation S is a function of the coordinate s along the backbone track. In the absence of any indicators of the standard deviation (e.g. from radar data describing comparable flight tracks), the following values are recommended:

3.5.2.6.1 For tracks involving turns of less than 45 degrees:

$$\begin{aligned} S(s) &= 0.055 s - 150 && \text{for } 2\,700 \text{ m} \leq s \leq 30\,000 \text{ m} \\ S(s) &= 1\,500 \text{ m} && \text{for } s > 30\,000 \text{ m} \end{aligned} \quad (3-1a)$$

3.5.2.6.2 For tracks involving turns of more than 45 degrees:

$$\begin{aligned} S(s) &= 0.128 s - 420 && \text{for } 3\,300 \text{ m} \leq s \leq 15\,000 \text{ m} \\ S(s) &= 1\,500 \text{ m} && \text{for } s > 15\,000 \text{ m} \end{aligned} \quad (3-1b)$$

3.5.2.7 For practical reasons, $S(s)$ is assumed to be zero between the start-of-roll and $s = 2\,700 \text{ m}$ or $s = 3\,300 \text{ m}$ depending on the amount of turn.

3.5.2.8 Routes involving more than one turn should be treated as per equation 3-1b. For arrivals, lateral dispersion can be neglected within 6 000 m of touchdown.

3.6 FLIGHT PROFILES

3.6.1 The flight profile is a description of the aeroplane motion in the vertical plane above the ground track, in terms of its position, speed, bank angle and engine power setting. Aeroplane flight profiles should be defined to meet the requirements of the modelling application. In order to achieve high accuracy, the profiles should closely reflect the aeroplane operations they are intended to represent. This calls for reliable information on the atmospheric conditions, aeroplane types and variants, operating masses and the operating procedures (i.e. the variations of thrust and flap settings and the trade-offs between changes of height and speed) averaged over the time period(s) of interest. The modeller should exercise good engineering judgement to balance the accuracy and detail of the input information with the needs for, and uses of, the contour outputs.

3.6.2 The synthesis of flight profiles from “procedural steps” obtained from the ANP database or from aeroplane operators is described in 3.7 and Appendix C. This process yields both the flight path geometry and the associated speed and thrust variations based on the database, instead of radar data. In this case, it would normally be assumed that all (alike) aeroplanes in a swathe follow the backbone track profile.

3.6.3 Beyond the default information on “procedural steps” found in the ANP database, the aeroplane operators are the best source of reliable aeroplane operational information. For individual flights, the optimum source is the aeroplane flight data recorder (FDR) from which all relevant information can be obtained. However, even if such data are available, the pre-processing task is formidable. Thus, the normal practical solution is to make educated assumptions about mean masses and operating procedures.

3.6.4 Caution should be exercised before adopting the *default* procedural steps provided in the ANP database. These are standardized procedures that are widely followed but which may or may not be used by operators in particular cases. A major factor is the definition of take-off (and sometimes climb) engine thrust that can depend on prevailing circumstances. In particular, it is common practice to reduce thrust levels during departure (from maximum available) in order to extend engine life. Appendix C gives guidance on representing typical practice; this will generally produce more realistic contours than a full-thrust assumption. However, if, for example, runways are short and/or average air temperatures are high, full-thrust is likely to be a more realistic assumption.

3.6.5 When modelling actual scenarios, radar data are often used to supplement or replace this nominal information. Flight profiles can be determined from radar data in a similar way to the lateral backbone tracks – but only after segregating the traffic by aeroplane type and variant and sometimes by mass or stage length (but not by dispersion) — to yield for each subgroup a mean profile of height and speed against ground distance travelled. Again, when subsequently merging with the ground tracks, this single profile is normally assigned to the backbone and sub-tracks alike.

3.6.6 When the aeroplane mass is known, the variation of speed and propulsive thrust can be calculated via a step-by-step solution using the equations of motion. Before doing so, it is helpful to pre-process the data to minimize the effects of radar errors by redefining the profile with straight line segments to represent the relevant stages of the flight; with each segment being appropriately classified, i.e. as a ground roll, constant speed climb or descent, thrust cutback, or acceleration/deceleration with or without flap change. The aeroplane mass and atmospheric state are also required inputs.

3.6.7 A recommended minimum height for modelling an aircraft noise source is 1.0 m (3.3 ft) above the aerodrome level or local topography, as relevant. This minimum height could help prevent any computational issues that might arise from dividing by 0.0 m.

3.6.8 Paragraph 3.5 clearly states that a special provision has to be made to account for the lateral dispersion of flight tracks around the nominal or backbone routings. Radar data samples are characterized by similar dispersions of flight paths in the vertical plane. However, it is not usual practice to model vertical dispersion as an independent variable; it arises mainly due to differences in aeroplane masses and operating procedures that are taken into account when pre-processing traffic input data.

3.7 CONSTRUCTION OF FLIGHT PATH SEGMENTS

3.7.1 Each flight path has to be defined by a set of segment coordinates (nodes) and flight parameters. The flight profile is then calculated, remembering that for a given set of procedural steps, the profile depends on the ground track, e.g. at the same thrust and speed, the aeroplane climb rate is less in turns than in straight flight (see 3.7.3). Subsegmentation is then undertaken for the aircraft on the runway (take-off or landing ground roll, see 3.7.4 and 3.7.7, respectively), for the aircraft near to the runway (initial climb or final approach, see 3.7.5), and finally for airborne segments (see 3.7.6). The coordinates of the ground track segments are determined (see 3.7.2), after which the 3-D flight path segments are constructed by merging the 2-D flight profile with the 2-D ground track.⁸

3.7.2 Ground track

3.7.2.1 Each ground track is defined by a series of (x,y) coordinates in the ground plane (e.g. from radar information) or by a sequence of vectoring commands describing straight segments and circular arcs (turns of defined radius r and change of heading $\Delta\xi$).

3.7.2.2 For segmentation modelling, an arc is represented by a sequence of straight segments fitted to sub-arcs. Although they do not appear explicitly in the ground track segments, the banking of aeroplanes during turns influences their definition. In Appendix C, it is explained how to calculate bank angles during a steady turn but of course these are not actually applied or removed instantaneously. How to handle the transitions between straight and turning flight, or between one turn and an immediately sequential one, is not prescribed. The details of the transitions between straight and turning flight are likely to have a negligible effect on the final contours and are left up to the user (see 3.5); the requirement is mainly to avoid sharp discontinuities at the ends of the turn and this can be achieved simply, for example, by inserting short transition segments over which the bank angle changes linearly with distance. Only in the special case where a particular turn is likely to have a dominating effect on the final contours would it be necessary to model the dynamics of the transition more realistically, to relate bank angle to particular aeroplane types and to adopt appropriate roll rates. In such cases, it is sufficient to state that the end sub-arcs $\Delta\xi_{trans}$ in any turn are dictated by bank angle change requirements. The remainder of the arc with change of heading $\Delta\xi - 2 \cdot \Delta\xi_{trans}$ degrees is divided into n_{sub} sub-arcs according to the equation:

$$n_{sub} = \text{int} (1 + (\Delta\xi - 2 \cdot \Delta\xi_{trans}) / 10) \quad (3-2a)$$

where $\text{int}(x)$ is a function that returns the integer part of x . Then the change of heading $\Delta\xi_{sub}$ of each sub-arc is computed as

$$\Delta\xi_{sub} = (\Delta\xi - 2 \cdot \Delta\xi_{trans}) / n_{sub} \quad (3-2b)$$

where n_{sub} should be large enough so that $\Delta\xi_{sub} \leq 30$ degrees, with a recommended implementation of $\Delta\xi_{sub} \leq 10$ degrees. The segmentation of an arc (excluding the terminating transition subsegments) is illustrated in Figure 3-5⁹.

8. For this purpose, the total length of the ground track should always exceed that of the flight profile. This can be achieved, if necessary, by adding straight segments of suitable length to the last segment of the ground track.
9. Defined in this simple way, the total length of the segmented path is slightly less than that of the circular path. However, the consequent contour error is negligible if the angular increments are below 10°.

3.7.3 Flight profile

3.7.3.1 The parameters describing each flight profile segment at the start (suffix 1) and end (suffix 2) of the segment are:

- a) s_1, s_2 distance along the ground track;
- b) z_1, z_2 aeroplane height;
- c) V_1, V_2 ground speed;
- d) P_1, P_2 noise-related power parameter (matching that for which the NPD curves are defined); and
- e) $\varepsilon_1, \varepsilon_2$ bank angle.

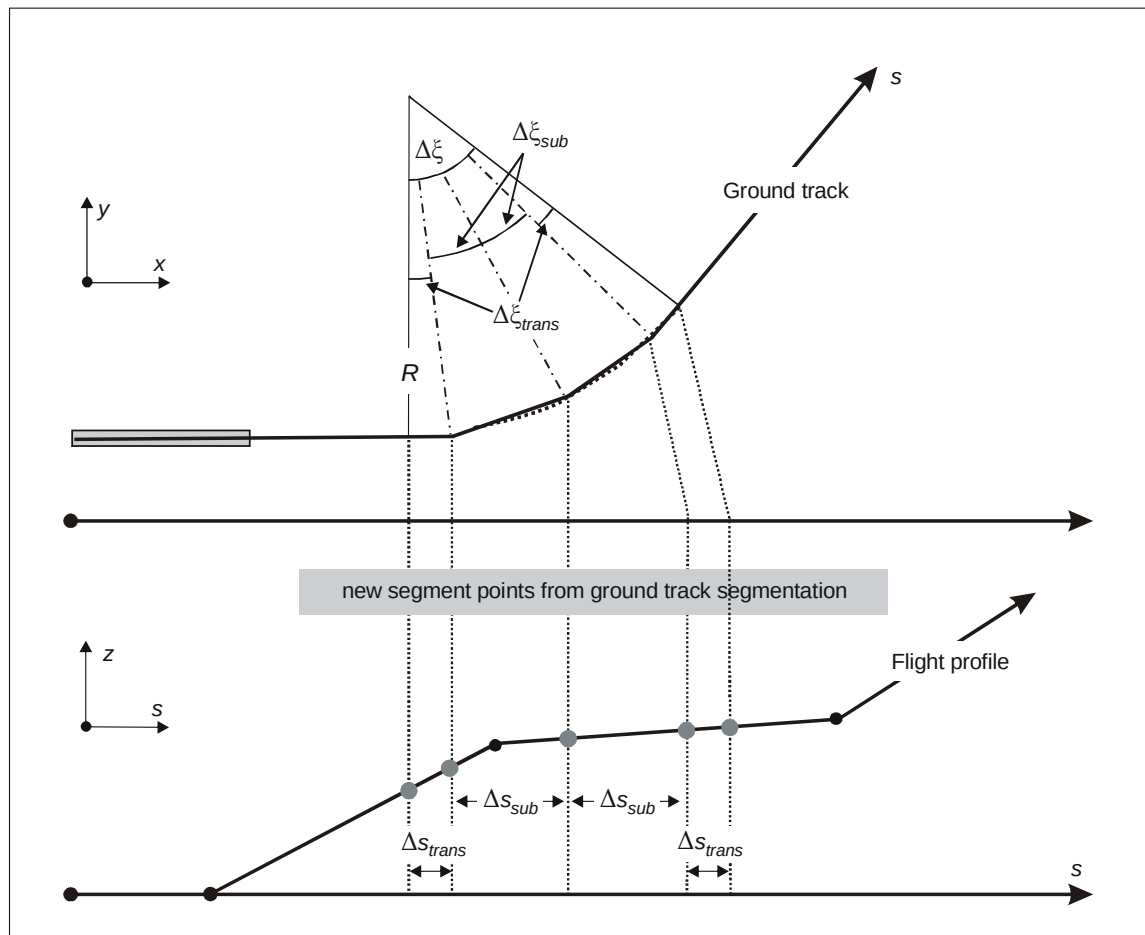


Figure 3-5. Construction of flight path segments dividing turn into segments of length Δs (upper view in horizontal plane, lower view in vertical plane)

3.7.3.2 To build a flight profile from a set of procedural steps (*flight path synthesis*), segments are constructed in sequence to achieve required conditions at the end points. The end point parameters for each segment become the start-point parameters for the next segment. In any segment calculation the parameters are known at the start; required conditions at the end are specified by the procedural step. The steps themselves are defined either by the ANP defaults or by the user (e.g. from aeroplane flight documents). The end conditions are usually height and speed; the profile building task is to determine the track distance covered in reaching those conditions. The undefined parameters are determined via flight performance calculations described in Appendix C.

3.7.3.3 If the ground track is straight, the profile points and associated flight parameters can be determined independently of the ground track (bank angle is always zero). Ground tracks are, however, rarely straight; they usually incorporate turns and, to achieve best results, these have to be accounted for when determining the 2-dimensional flight profile; where necessary, splitting profile segments at ground track nodes to inject changes of bank angle. As a rule, the length of the next segment is unknown at the outset and is calculated provisionally assuming no change of bank angle. If the provisional segment is then found to span one or more ground track nodes, the first being at s , i.e. $s_1 < s < s_2$, the segment is truncated at s , calculating the parameters there by interpolation as described in 3.7.3.5. These become the end point parameters of the current segment and the start-point parameters of a new segment – which still has the same target-end conditions. If there is no intervening ground track node the provisional segment is confirmed.

3.7.3.4 If the effects of turns on the flight profile are to be disregarded, the straight flight, single segment solution is adopted although the bank angle information is retained for subsequent use.

3.7.3.5 Whether or not turn effects are fully modelled, each 3-dimensional flight path is generated by merging its 2-dimensional flight profile with its 2-dimensional ground track. The result is a sequence of coordinate sets (x,y,z) , each being either a node of the segmented ground track or a node of the flight profile, or both; the profile points being accompanied by the corresponding values of height z , ground speed V , bank angle ε and engine power P . For a track point (x,y) that lies between the end points of a flight profile segment, the flight parameters are interpolated as follows:

$$z = z_1 + f \cdot (z_2 - z_1) \quad (3-3a)$$

$$V = \sqrt{V_1^2 + f \cdot (V_2^2 - V_1^2)} \quad (3-3b)$$

$$\varepsilon = \varepsilon_1 + f \cdot (\varepsilon_2 - \varepsilon_1) \quad (3-3c)$$

$$P = \sqrt{P_1^2 + f \cdot (P_2^2 - P_1^2)} \quad (3-3d)$$

where

$$f = (s - s_1) / (s_2 - s_1) \quad (3-3e)$$

3.7.3.6 Note that while z and ε are assumed to vary linearly with distance, V and P are assumed to vary linearly with time (i.e. constant acceleration¹⁰).

3.7.3.7 When matching flight profile segments to radar data (*flight path analysis*) all end point distances, heights, speeds and bank angles are determined directly from the data; only the power settings have to be calculated using the performance equations. As the ground track and flight profile coordinates can also be matched appropriately, this is usually quite straightforward.

10. Even if engine power settings remain constant along a segment, propulsive force and acceleration can change due to the variation of air density with height. However, for the purposes of noise modelling, these changes are normally negligible.

3.7.4 Segmentation of the take-off ground roll

3.7.4.1 During take-off, an aeroplane accelerates between the point of brake release (alternatively termed start-of-roll) and the point of lift-off, where speed changes dramatically over a distance of 1 500 to 2 500 m (4 921 to 8 202 ft), from zero to between 80 and 100 m/s.

3.7.4.2 The take-off roll is thus divided into segments with variable lengths over each of which the aeroplane speed changes by a specific increment ΔV of no more than 10 m/s (about 20 kt). Although it actually varies during the take-off roll, an assumption of constant acceleration is adequate for this purpose. For equivalent take-off distance s_{TO} (see Appendix C) and take-off speed V_{TO} , the number n_{TO} of segments for the ground roll is

$$n_{TO} = \text{int} (1 + V_{TO}/10) \quad (3-4a)$$

and hence the change of velocity along a segment is

$$\Delta V = V_{TO} / n_{TO} \quad (3-4b)$$

and the time Δt on each segment is (constant acceleration assumed)

$$\Delta t = \frac{2 \cdot s_{TO}}{V_{TO} \cdot n_{TO}} \quad (3-4c)$$

3.7.4.3 The length $s_{TO,k}$ of segment k ($1 \leq k \leq n_{TO}$) of the take-off roll is then:

$$s_{TO,k} = (k - 0.5) \cdot \Delta V \cdot \Delta t = \frac{(2k - 1) \cdot s_{TO}}{n_{TO}^2} \quad (3-4d)$$

3.7.4.4 For example, for a take-off distance $s_{TO} = 1\,600$ m and $V_{TO} = 75$ m/s, this yields $n_{TO} = 8$ segments with lengths ranging from 25 to 375 m (see Figure 3-6).

3.7.4.5 Similar to the speed changes, the aircraft thrust changes over each segment by a constant increment ΔP , calculated as

$$\Delta P = (P_{TO} - P_{init}) / n_{TO} \quad (3-4e)$$

where P_{TO} and P_{init} , respectively, designate the aircraft thrust at the point of lift-off and the aircraft thrust at the start of take-offtake-off roll.

3.7.4.6 The use of this constant thrust increment (instead of using the quadratic form equation 3-3d) aims at being consistent with the linear relationship between thrust and speed in the case of jet-engine aircraft (equation C-1).

Note.— The above equations and example implicitly assume that the initial speed of the aircraft at the start of the take-offtake-off phase is zero. This corresponds to the common situation where the aircraft starts to roll and accelerate from the brake release point. However, there are also situations where the aircraft may start to accelerate from its taxiing speed, without stopping at the runway threshold. In the case of non-zero initial speed V_{init} , the following generalized equations should be used in replacement of equations 3-4a, 3-4b, 3-4c and 3-4d.

$$n = \text{int} (1 + (V_2 - V_1) / 10) \quad (3-4f)$$

$$\Delta V = (V_2 - V_1) / n \quad (3-4g)$$

...

$$\Delta t = \frac{2 \cdot s}{(V_2 + V_1) \cdot n} \quad (3-4h)$$

$$s_k = (V_1 + \Delta V \cdot (k - 0.5)) \cdot \frac{2 \cdot s}{(V_2 + V_1) \cdot n} \quad (3-4i)$$

In this case, for the take-off phase, V_1 is initial speed V_{init} , V_2 is the take-off speed V_{TO} , n is the number of take-off segment n_{TO} , s is the equivalent take-off distance s_{TO} , and s_k is the length $s_{TO,k}$ of segment k ($1 \leq k \leq n$).

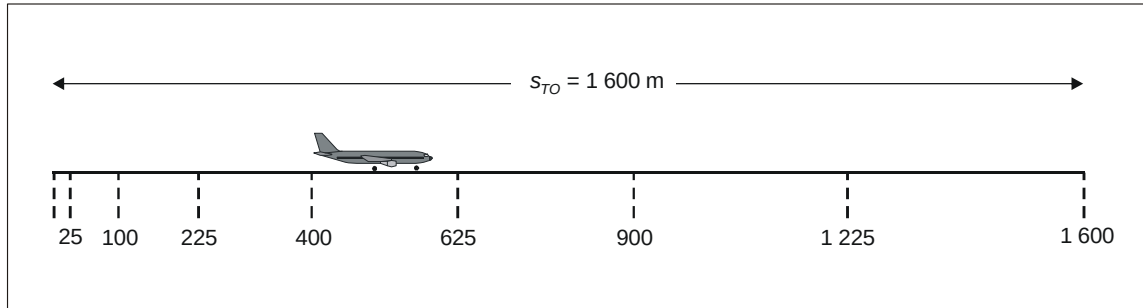


Figure 3-6. Segmentation of a take-off roll (example for 8 segments)

3.7.5 Segmentation of the initial climb and final approach segments

3.7.5.1 During the initial climb segment, the geometry is changing rapidly particularly with respect to observer locations to the side of the flight track, where *elevation angle* will change rapidly as the aeroplane climbs through this initial segment. Comparisons with very small segment calculations show that a single climb segment results in a poor approximation of noise to the side of the flight track for integrated metrics. Calculation accuracy is improved by subsegmenting the initial lift-off and last airborne segments. The length of each segment and number is strongly influenced by lateral attenuation. Noting the expression of total lateral attenuation for aeroplanes with fuselage-mounted engines (see Chapter 4, 4.6.4), it can be shown that for a limiting change in lateral attenuation of 1.5 dB per subsegment, that the initial climb and last airborne segments should be subsegmented based on the following set of height values:

$$z = \{18.9, 41.5, 68.3, 102.1, 147.5, 214.9, 334.9, 609.6, 1289.6\} \text{ metres, or} \\ z' = \{62, 136, 224, 335, 484, 705, 1099, 2000, 4231\} \text{ feet}$$

3.7.5.2 The above heights are implemented by identifying which height in the set above is closest to the original segment end point. The actual subsegment heights, z_i , would then be calculated using:

$$z_i = z_e [z_i / z_N] \quad (i = 1..N) \quad (3-5)$$

where z_e is the original segment end point height, z_i is the i^{th} member of the set of height values and z'_N is the closest height from the set of height values to height z_e . This process results in the lateral attenuation change across each subsegment remaining constant, producing more accurate contours, but without the expense of using very short segments.

3.7.5.3 Where there are multiple segments below 1 289.6 m (4 231 ft), the segmentation methodology above should be applied sequentially to each of these segments starting from the segment end point at the runway height.

3.7.5.4 If the first lift-off segment end point height (or last airborne approach segment start height) is greater than 1 289.6 m (4 231 ft), equation 3-5 is not applied, and segmentation is undertaken at the set of height values listed above, i.e. $z_i = z'_i$.

3.7.5.5 This process results in the lateral attenuation change across each subsegment remaining constant, producing more accurate contours, but without the expense of using very short segments.

For example: If the original segment end point height is at $z_e = 304.8$ m, then from the set of height values, $214.9 \text{ m} < z_e < 334.9 \text{ m}$ and the closest height from the set to z_e is $z'_7 = 334.9$ m. The sub-segment end point heights are then computed by:

$$z_i = 304.8 [z'_i / 334.9] \quad (i = 1 \dots N)$$

Thus for $i = 1$, z_1 would be 17.2 m and z_2 would be 37.8 m, etc. The speed and engine power values on the inserted points are interpolated using, respectively, equations 3-3b and 3-3d.

3.7.6 Segmentation of airborne segments

3.7.6.1 After the segmented flight path has been derived according to the procedure described in 3.7.1 and the subsegmenting described in 3.7.4 and 3.7.5 has been applied, further segmentation adjustments may be necessary. These include:

- a) the removal of flight path points which are too close together; and
- b) the insertion of additional points when speed changes along segments are too large.

3.7.6.2 When adjacent points are within 10 m of each other, and when the associated speeds and thrusts are the same, one of the points should be eliminated.

3.7.6.3 For airborne segments where there is a significant speed change along the segment, this should be subdivided as for the ground roll, i.e.

$$n_{\text{seg}} = \text{int} (1 + |V_2 - V_1|/10) \quad (3-6)$$

where V_1 and V_2 are the segment start and end speeds respectively. The corresponding subsegment parameters are calculated in a similar manner as for the take-off ground roll, using the generalized equations 3-4f to 3-4i.

3.7.7 The landing ground roll

3.7.7.1 Although the landing ground roll is essentially a reversal of the take-off ground roll, special account has to be taken of:

- a) *reverse thrust* which is sometimes applied to decelerate the aeroplane; and
- b) aeroplanes leaving the runway after deceleration (aeroplanes that leave the runway no longer contribute to air noise since noise from taxiing is disregarded).

3.7.7.2 In contrast to the take-off roll distance, which is derived from aeroplane performance parameters, the stop distance s_{stop} (i.e. the distance from touchdown to the point where the aeroplane leaves the runway) is not purely specific to aeroplanes. Although a minimum stop distance can be estimated from aeroplane mass and performance (and available reverse thrust), the actual stop distance depends also on the location of the taxiways, on the traffic situation, and on airport-specific regulations on the use of reverse thrust.

3.7.7.3 The use of reverse thrust is not a standard procedure — it is only applied if the needed deceleration cannot be achieved by the use of the wheel brakes. Reverse thrust, due to a rapid change of engine power from idle to reverse settings, often produces a sudden burst of noise.

3.7.7.4 However, most runways are used for departures as well as for landings so that reverse thrust has a very small effect on the noise contours since the total sound energy in the vicinity of the runway is dominated by the noise produced from take-off operations. Reverse thrust contributions to contours may only be significant when runway use is limited to landing operations.

3.7.7.5 Physically, reverse thrust noise is very complex, but because of its relatively minor significance to air noise contours it can be modelled simplistically as the rapid change in engine power being taken into account by suitable segmentation.

3.7.7.6 It is clear that modelling the landing ground roll is less straightforward than modelling for the take-off roll. The following simplified modelling assumptions are recommended for general use, when no detailed information is available (see Figure 3-7):

- a) The aeroplane touches down 300 m beyond the landing threshold (which has the coordinate $s = 0$ along the approach ground track). The aeroplane is then decelerated over a stop-distance s_{stop} – aeroplane specific values of which are given in the ANP database – from final approach speed V_{final} to 15 m/s. Because of the rapid changes in speed during this segment, it should be subsegmented in the same manner as for the take-off ground roll (or airborne segments with rapid speed changes) using the generalized equations 3-4f to 3-4i (as taxi-in speed is not equal to zero).
- b) The engine power changes from final approach power at touchdown to a reverse thrust power setting P_{rev} over a distance $0.1 \cdot s_{stop}$, then decreases to 10 per cent of the maximum available power over the remaining 90 per cent of the stop distance. Up to the end of the runway (at $s = -s_{RWY}$) aeroplane speed remains constant.
- c) NPD curves for reverse thrust are not at present included in the ANP database, and it is therefore necessary to rely on the conventional curves for modelling this effect. Typically, the reverse thrust power P_{rev} is around 40 per cent of the full power setting for narrow-body aeroplanes and 10 per cent of the full power setting for wide-body aeroplanes. This is recommended when no operational information is available. However, at a given power setting, reverse thrust tends to generate significantly more noise than forward thrust and an increment ΔL should be applied to the NPD-derived event level, increasing from zero to a value ΔL_{rev} (5 dB is recommended provisionally¹¹) along $0.1 \cdot s_{stop}$ and then falling linearly to zero along the remainder of the stop distance.

11. This is based on a recommendation made in ECAC Document 29, 3rd Edition, but is still considered provisional pending the acquisition of further corroborative experimental data.

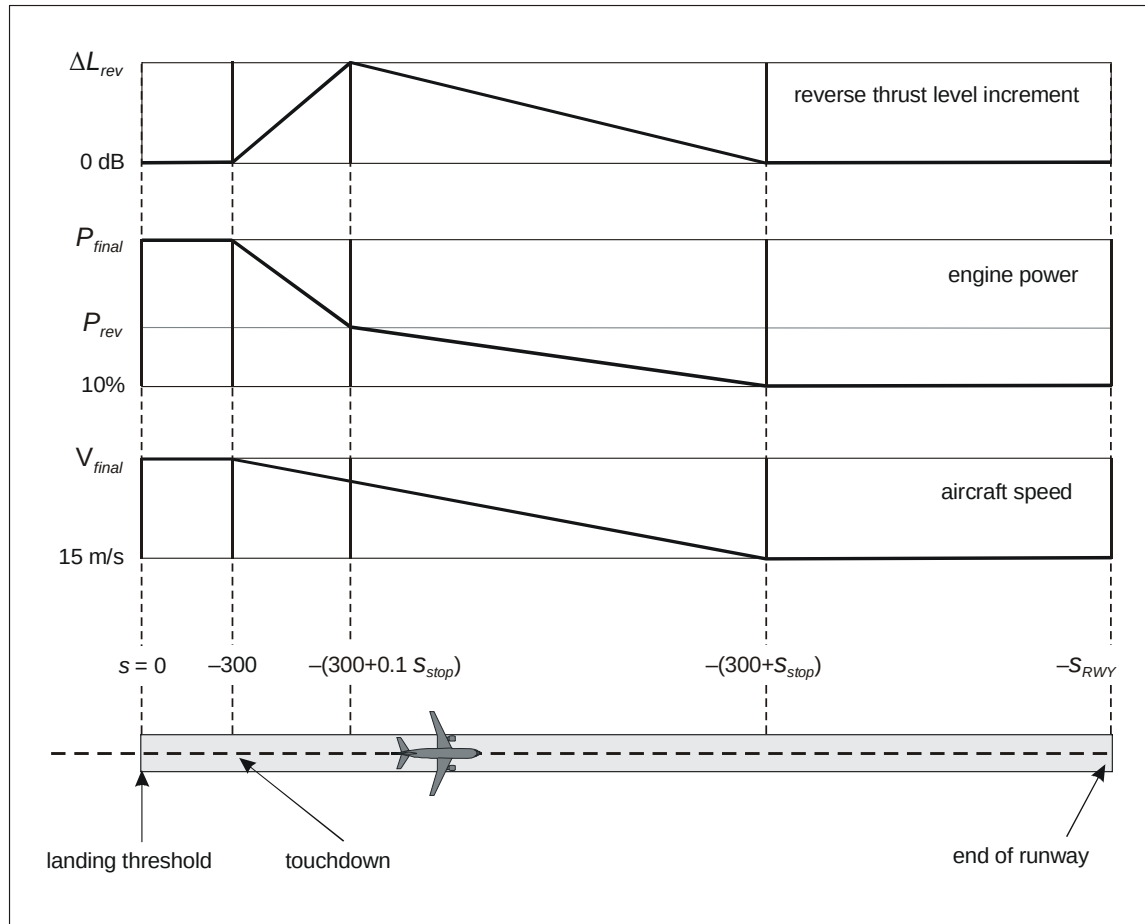


Figure 3-7. Modelling of landing ground roll

Chapter 4

NOISE CALCULATION FOR A SINGLE EVENT

4.1 INTRODUCTION

4.1.1 The core of the modelling process, described here in full, is the calculation of the event noise level from the flight path information described in Chapter 3.

4.2 SINGLE EVENT METRICS

4.2.1 The sound generated by an aeroplane movement at the observer location is expressed as a “single event sound (or noise) level”, which is an indicator of its impact on people. The received sound is measured on a decibel scale [refs. 14, 15].

4.2.2 The metrics most commonly used to encapsulate entire aeroplane events are “single event sound (or noise) exposure levels”, L_{AE} , which account for all (or most of) the sound energy in the events. Making provisions for the time integration that this involves gives rise to the main complexities of segmentation (or simulation) modelling. An alternative metric is L_{Amax} , which is the maximum instantaneous level occurring during the event, and is simpler to model. In the future, practical models can be expected to embody both L_{Amax} and L_{AE} . Either metric can be measured on different scales of noise and in this manual only A-weighted sound level is considered. This applies a frequency weighting (or filter) to mimic a characteristic of human hearing. Symbolically, the scale is usually indicated by extending the metric suffix, i.e. L_{AE} , L_{Amax} . Appendix A provides a description of the various noise metrics in use in ICAO Contracting States.

4.2.3 The single event sound (or noise) exposure level is expressed as

$$L_E = 10 \cdot \log \left(\frac{1}{t_0} \int_{t_1}^{t_2} 10^{L(t)/10} dt \right) \quad (4-1)$$

where t_0 denotes a reference time. The integration interval $[t_1, t_2]$ is chosen to ensure that (nearly) all significant sound in the event is encompassed. Very often, the limits t_1 and t_2 are chosen to span the period for which the level $L(t)$ is within 10 dB of L_{max} . This period is known as the “10-dB down” time. Sound (noise) exposure levels tabulated in the ANP database are 10-dB down values¹.

4.2.4 For aeroplane noise contour modelling, the main application of equation 4-1 is the standard metric sound exposure level (SEL) L_{AE} [refs. 14, 15]:

1. 10 dB down L_E may be up to 0.5 dB lower than L_E evaluated over a longer duration. However, except at short slant distances where event levels are high, extraneous ambient noise often makes longer measurement intervals impractical and 10-dB down values are the norm. As studies of the effects of noise (used to “calibrate” the noise contours) also tend to rely on 10-dB down values, the ANP tabulations are considered to be entirely appropriate.

$$L_{AE} = 10 \cdot \log \left(\frac{1}{t_0} \int_{t_0}^{t_2} 10^{L_A(t)/10} dt \right) \text{ with } t_0 = 1 \text{ second} \quad (4-2)$$

4.2.5 The exposure level equations above can be used to determine event levels when the entire time history of $L(t)$ is known. Within the recommended noise modelling methodology, such time histories are not defined; event exposure levels are calculated by summing segment values. These are partial event levels, each of which defines the contribution from a single, finite segment of the flight path.

4.3 DETERMINATION OF EVENT LEVELS FROM NPD DATA

4.3.1 The principal source of aeroplane noise data is the international aircraft noise and performance (ANP) database which is described in Appendix H. This tabulates L_{max} and L_E as functions of propagation distance d – for specific aeroplane types, variants, flight configurations (approach, departure, flap settings), and power settings P . They relate to steady flight at specific reference speeds V_{ref} along a notionally infinite, straight flight path².

4.3.2 In a single look-up with input values P and d , the output values required are the *baseline levels* $L_{max}(P, d)$ and/or $L_E(P, d)$. Unless values happen to be tabulated for P and/or d exactly, it will generally be necessary to estimate the required event noise level(s) by interpolation in the ANP database. A linear interpolation is used between tabulated power settings, but a logarithmic interpolation is used between tabulated distances (see Figure 4-1). If P_i and P_{i+1} are engine power values for which noise level versus distance data are tabulated, the noise level $L(P)$ at a given distance for intermediate power P , between P_i and P_{i+1} , is given by

$$L(P) = L(P_i) + \frac{L(P_{i+1}) - L(P_i)}{P_{i+1} - P_i} \cdot (P - P_i) \quad (4-3)$$

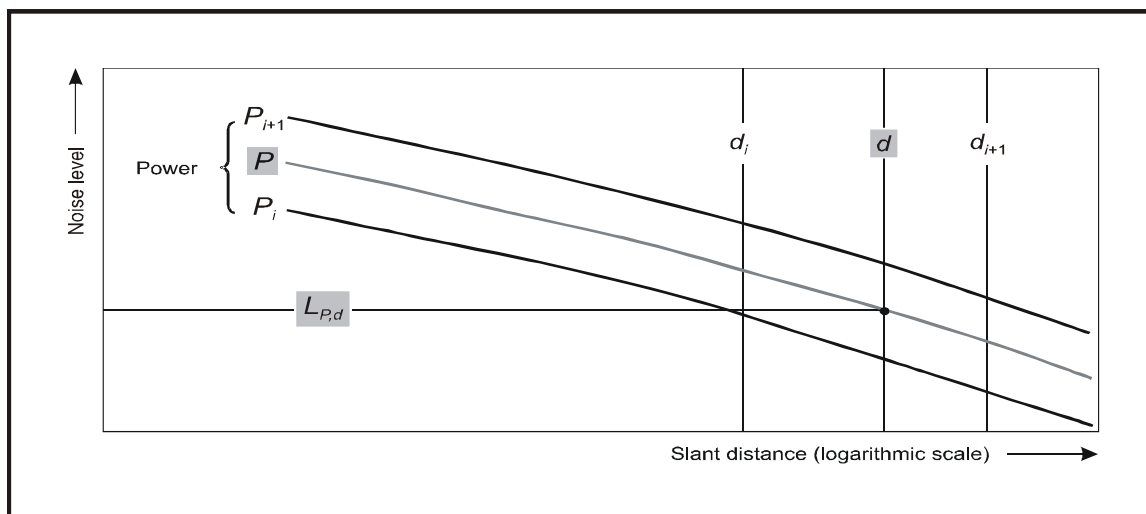


Figure 4-1. Interpolation in noise-power-distance curves

- Although the notion of an infinitely long flight path is important to the definition of event sound exposure level L_E , it has less relevance in the case of event maximum level L_{max} , which is governed by the noise emitted by the aircraft when at a particular position at or near its closest point of approach to the observer. For modelling purposes, the NPD distance parameter is taken to be the minimum distance between the observer and segment.

4.3.3 If, at any power setting, d_i and d_{i+1} are distances for which noise data are tabulated, the noise level $L(d)$ for an intermediate distance d , between d_i and d_{i+1} is given by

$$L(d) = L(d_i) + \frac{L(d_{i+1}) - L(d_i)}{\log d_{i+1} - \log d_i} \cdot (\log d - \log d_i) \quad (4-4)$$

4.3.4 By using equations 4-3 and 4-4, a noise level $L(P, d)$ can be obtained for any power setting P and any distance d that is within the envelope of the NPD database.

4.3.5 For distances d that lie outside the NPD envelope, equation 4-4 is also used to extrapolate from the last two values, i.e. inwards from $L(d_1)$ and $L(d_2)$ or outwards from $L(d_{i-1})$ and $L(d_i)$ where i is the total number of NPD points on the curve. Thus,

Inwards:

$$L(d) = L(d_2) + \frac{L(d_1) - L(d_2)}{\log d_2 - \log d_1} \cdot (\log d_2 - \log d) \quad (4-5a)$$

Outwards:

$$L(d) = L(d_{i-1}) + \frac{L(d_i) - L(d_{i-1})}{\log d_i - \log d_{i-1}} \cdot (\log d - \log d_{i-1}) \quad (4-5b)$$

4.3.6 Since, at short distances (i.e. low values of d), noise levels increase very rapidly with decreasing propagation distance, it is recommended that a lower limit of 30 m be imposed on d , i.e. $d = \max(d, 30 \text{ m})$.

4.3.7 Sections below describe the calculation of adjustments to the standard NPD data.

4.3.7 Atmospheric absorption adjustment of standard NPD data

4.3.7.1 The NPD data provided in the ANP database are normalized to the reference day atmospheric conditions as defined by using the reference atmosphere as defined by SAE-AIR-1845 [ref. 1] and included in Appendix E. These conditions represent a standard atmospheric lapse rate that can be roughly approximated at sea level by a temperature of 25°C (reference atmosphere of ISA + 10), relative humidity of 70 per cent and pressure of 101.325 kPa. By leveraging the spectral data found in the ICAO ANP database, change in noise levels due to the atmospheric absorption for study or airport-specific atmospheric conditions (temperature, relative humidity and atmospheric pressure) may be accounted for using an atmospheric absorption adjustment, as defined by either SAE-ARP-5534 [ref. 17] or SAE-ARP-866A [ref. 13]. Before applying the interpolation/extrapolation method previously described, an atmospheric absorption adjustment shall be applied to these standard NPD data, if non-standard atmospheric conditions are being modelled.

4.3.7.2 The spectral data in the ICAO ANP database have been corrected to reference day atmospheric conditions at a distance of 305 m (1 000 ft) using a procedure similar to the simplified method from ICAO Annex 16 [ref. 18]. Because the spectral data in the ICAO ANP database are representative of groups of similar aircraft performing similar operations and not specific aircraft performing specific operations at specific power settings, the difference between each ANP aircraft spectrum propagated through the reference atmosphere and the same spectrum propagated through the study/airport-specific atmosphere using either SAE-ARP-5534 or SAE-ARP-866A must be computed. This is the atmospheric absorption adjustment, which can then be applied to the NPDs in the ICAO ANP database to account for specific, non-standard atmospheric conditions.

4.3.7.3 Consideration of non-reference (or airport-specific) atmospheric conditions is not required when using the methodology provided in this manual, however, it may be useful to consider airport-specific conditions for some analyses (e.g. evaluating seasonal operations). When modelling non-reference atmospheric conditions, the effects of a study on

airport-specific atmospheric conditions (temperature, relative humidity and atmospheric pressure) on noise levels may be accounted for using an atmospheric absorption adjustment, as defined by either SAE-ARP-5534 or SAE-ARP-866A. SAE-ARP-5534 is currently being evaluated for use with aircraft noise certification and is intended to replace SAE-ARP-866A.

4.3.7.4 A detailed procedure for recalculating NPD data for modelling non-reference conditions in an airport study, thereby accounting for study-specific atmospheric conditions and the corresponding atmospheric absorption, are presented in Appendix E.

4.3.8 Impedance adjustment of standard NPD data

4.3.8.1 The NPD data provided in the ANP database are normalized to reference day atmospheric conditions. Before applying the interpolation/extrapolation method previously described, an acoustic impedance adjustment shall be applied to these standard NPD data.

4.3.8.2 Acoustic impedance is related to the propagation of sound waves in an acoustic medium, and is defined as the product of the density of air and the speed of sound. For a given sound intensity (power per unit area) perceived at a specific distance from the source, the associated sound pressure (used to define SEL and maximum noise metrics) depends on the acoustic impedance of the air at the measurement location. It is a function of temperature, atmospheric pressure and, indirectly, altitude. There is therefore a need to adjust the standard NPD data of the ANP database to account for the actual temperature and pressure conditions at the receiver point, which are generally different from the normalized conditions of the ANP data. To avoid excessive computational demands, the adjustment should be made to actual temperature and pressure conditions at the aerodrome and applied to calculations at all receiver points.

4.3.8.3 The impedance adjustment to be applied to the standard NPD levels is expressed as follows:

$$\Delta_{\text{Impedance}} = 10 \cdot \lg \left(\frac{\rho \cdot c}{409.81} \right) \quad (4-6a)$$

where:

$\Delta_{\text{Impedance}}$	Impedance adjustment for the actual atmospheric conditions at the aerodrome (dB); and
$\rho \cdot c$	Acoustic impedance (newton-seconds/m ³) of the air at the aerodrome (409.81 being the air impedance associated to the reference atmospheric conditions of the NPD data in the ANP database).

4.3.8.4 Impedance $\rho \cdot c$ is calculated as follows:

$$\rho \cdot c = 416.86 \cdot \left[\frac{\delta}{\theta^{1/2}} \right] \quad (4-6b)$$

where:

δ	p/p_0 , the ratio of the ambient air pressure at the observer altitude to the standard air pressure at mean sea level: $p_0 = 101.325$ kPa (or 1 013.25 mb); and
θ	$(T + 273.15)/(T_0 + 273.15)$, the ratio of the air temperature at the observer altitude to the air temperature constant: $T_0 = 15.0$ °C