



ICAO

Doc 9911

Recommended Method for Computing Noise Contours Around Airports

Second Edition, 2018



Approved by and published under the authority of the Secretary General

INTERNATIONAL CIVIL AVIATION ORGANIZATION



| ICAO

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TABLE OF CONTENTS

	<i>Page</i>
Foreword	(vii)
Explanation of terms and symbols.....	(ix)
Chapter 1. General.....	1-1
1.1 Introduction.....	1-1
1.2 Outline.....	1-2
Chapter 2. Summary and applicability of method	2-1
2.1 Introduction.....	2-1
2.2 The concept of segmentation	2-1
2.3 Flight paths: tracks and profiles.....	2-2
2.4 Aircraft noise and performance database.....	2-3
2.5 Airport and aeroplane operations	2-4
2.6 The International Aircraft Noise and Performance (ANP) Database.....	2-5
2.7 ICAO-Recommended Aircraft Substitution Method	2-6
Chapter 3. Description of the flight path	3-1
3.1 Introduction.....	3-1
3.2 Relationships between flight path and flight configuration	3-1
3.3 Sources of flight path data.....	3-2
3.4 Coordinate systems.....	3-3
3.5 Ground tracks.....	3-5
3.6 Flight profiles.....	3-8
3.7 Construction of flight path segments	3-9
Chapter 4. Noise calculation for a single event	4-1
4.1 Introduction.....	4-1
4.2 Single event metrics	4-1
4.3 Determination of event levels from NPD data.....	4-2
4.4 General expressions.....	4-5
4.5 Flight path segment parameters.....	4-6
4.6 Segment event level correction terms	4-7
Chapter 5. Calculation of cumulative levels.....	5-1
5.1 Introduction.....	5-1
5.2 Weighted equivalent sound levels	5-1
5.3 The weighted number of operations	5-2
5.4 Estimation of cumulative maximum level based metrics.....	5-3
5.5 The use of level distributions for maximum level metrics.....	5-4

	<i>Page</i>
Chapter 6. Calculation of noise contours.....	6-1
6.1 Standard grid calculation and refinement	6-1
6.2 Use of rotated grids	6-2
6.3 Tracing of contours.....	6-3
6.4 Post-processing.....	6-5
Appendix A. Noise indices in use in ICAO Contracting States	App A-1
Appendix B. Approximate methods for determining effective perceived noise level (EPNL)	App B-1
Appendix C. Flight performance calculations.....	App C-1
Appendix D. Modelling of lateral ground track spreading	App D-1
Appendix E. Recalculation of noise-power-distance (NPD) data for non-reference conditions.....	App E-1
Appendix F. The finite segment correction	App F-1
Appendix G. Maximum level of noise metrics.....	App G-1
Appendix H. The International Aircraft Noise and Performance (ANP) Database	App H-1
Appendix I. ANP database submittal form	App I-1
Appendix J. ANP database submittal form for propeller-driven, fixed-wing aircraft.....	App J-1
Appendix K. Example studies for implementation confirmation.....	App K-1
References	Ref.-1

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.

The Secretary General
International Civil Aviation Organization
999 Robert-Bourassa Boulevard
Montréal, Québec
CANADA H3C 5H7

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 aeroplane 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
s_{RWY}	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.

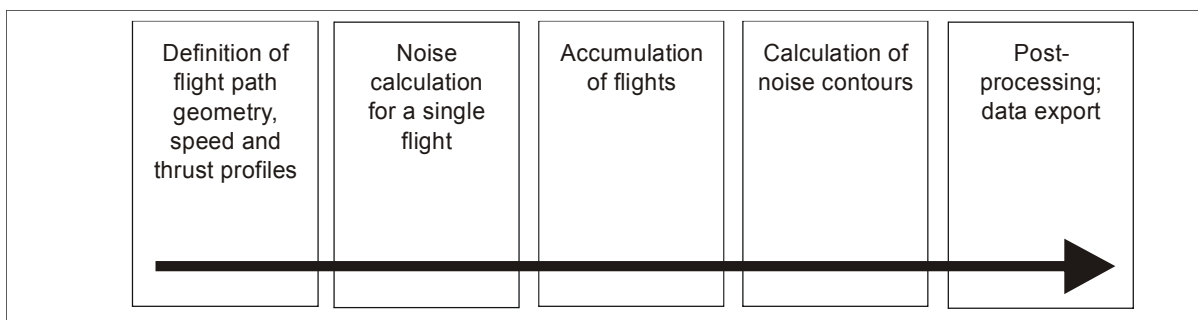


Figure 1-1. The noise contour generation process

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 certificating 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 ($\Delta = 0$, $N = 1$).

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).

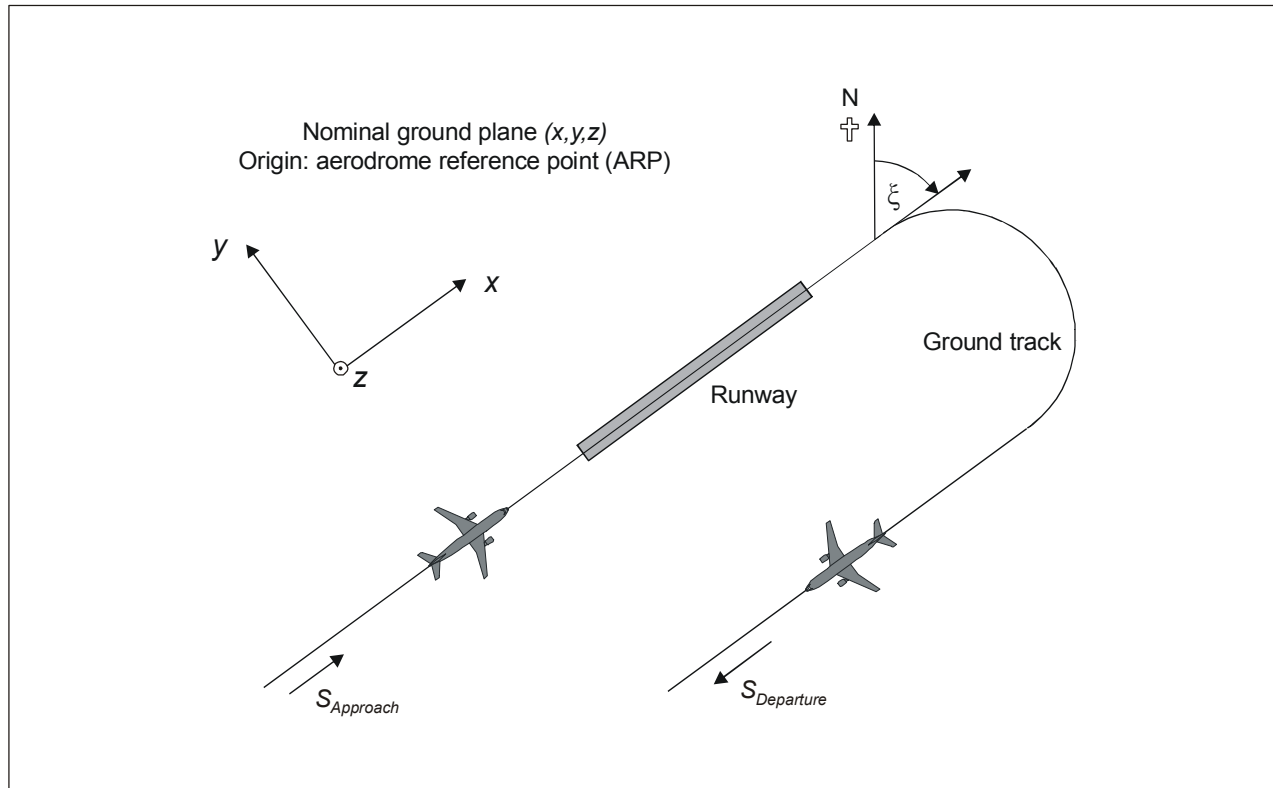


Figure 3-1. Local coordinate system (x,y,z) and ground track fixed coordinates

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).

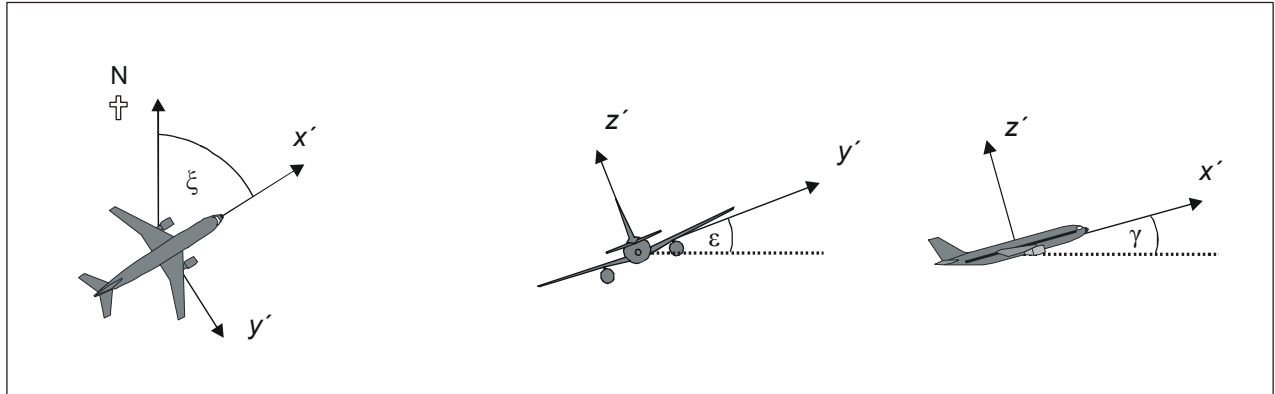


Figure 3-2. Aeroplane fixed coordinate system (x', y', z')

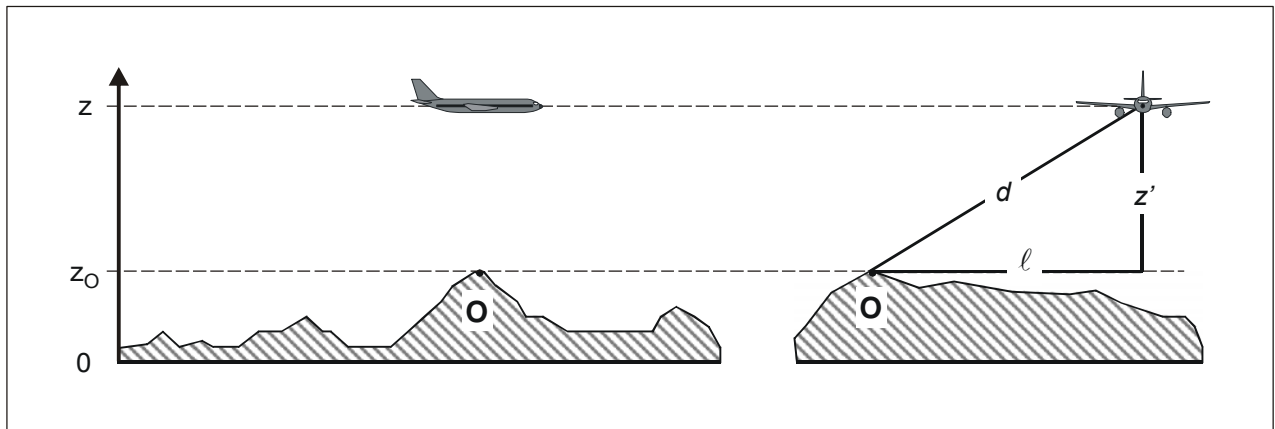


Figure 3-3. Ground elevation along (left) and lateral (right) to ground track. The nominal ground plane $z = 0$ passes through the aerodrome reference point. O is the observer location.

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).

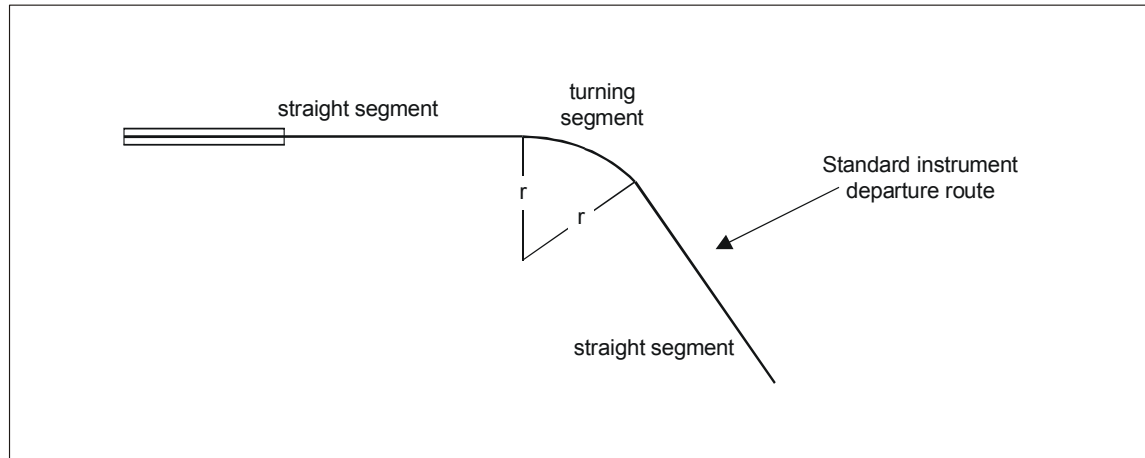


Figure 3-4. Ground track geometry in terms of turns and straight segments

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:

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

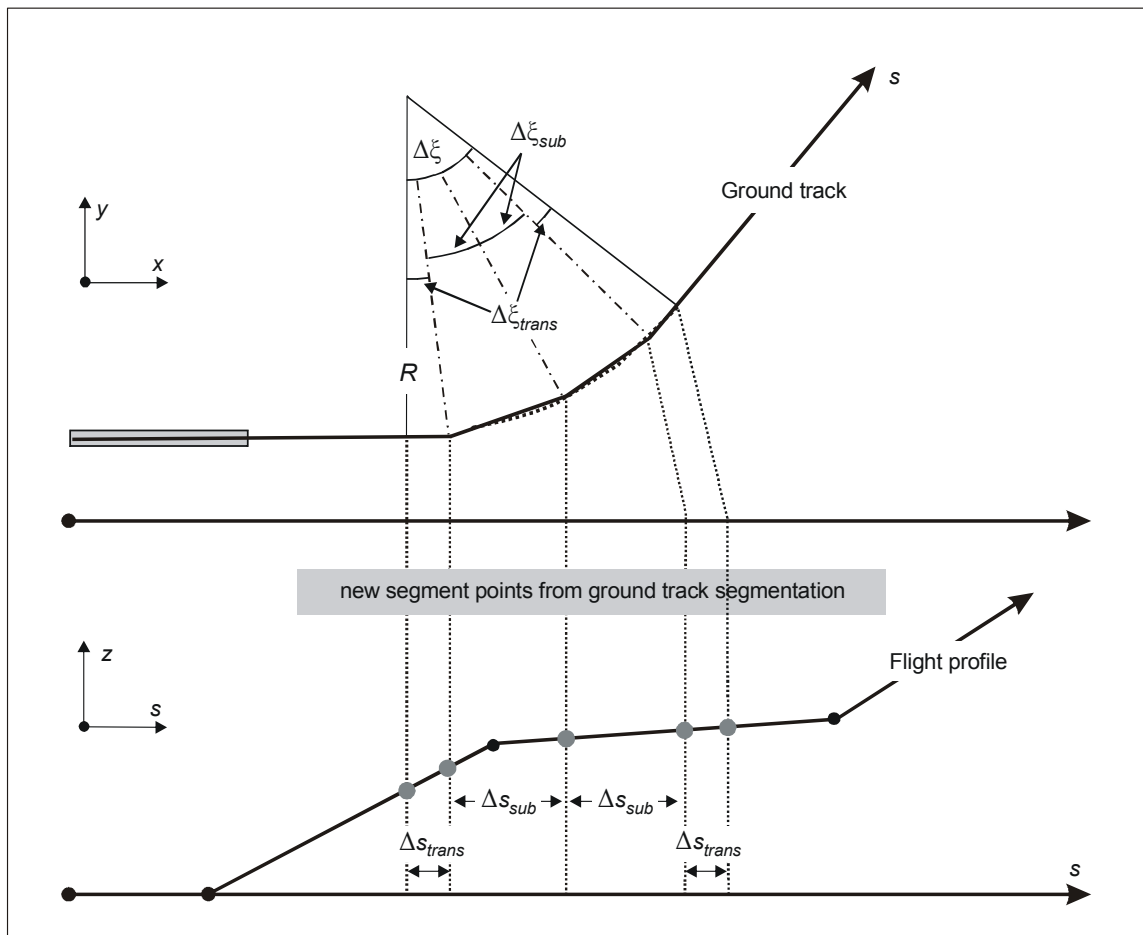


Figure 3-5. Construction of flight path segments dividing turn into segments of length Δs (upper view in horizontal plane, lower view in vertical plane)

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 ($1 \leq k \leq n$).

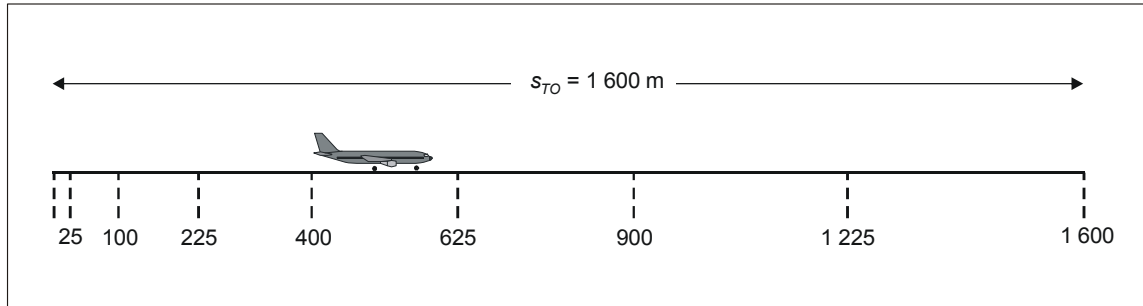


Figure 3-6. Segmentation of a take-off roll (example for 8 segments)

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.

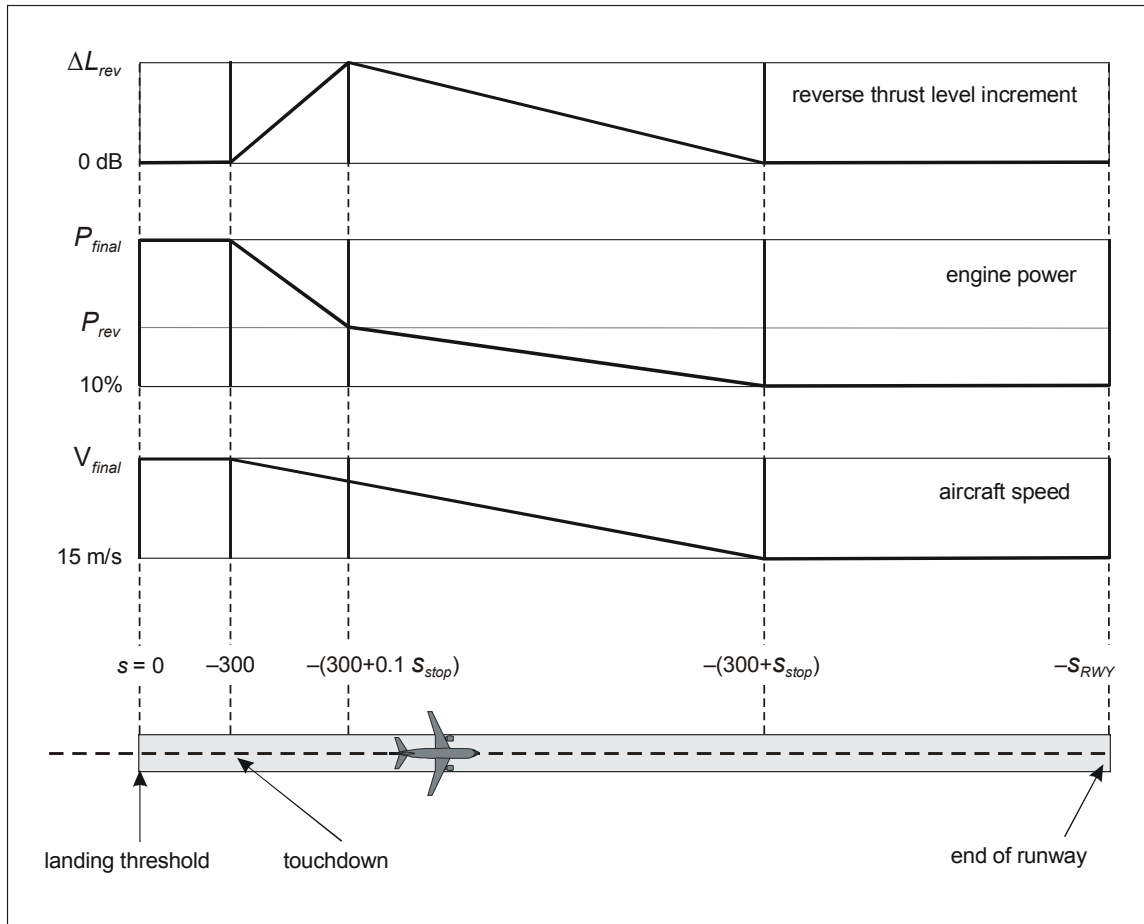


Figure 3-7. Modelling of landing ground roll

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.

$$L_{AE} = 10 \cdot \log \left(\frac{1}{t_0} \int_{t_1}^{t_2} 10^{L_A(t)/10} dt \right) \text{ with } t_0 = 1 \text{ second} \quad (4-2)$$

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 $L_{E\infty}(P,d)$. 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

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

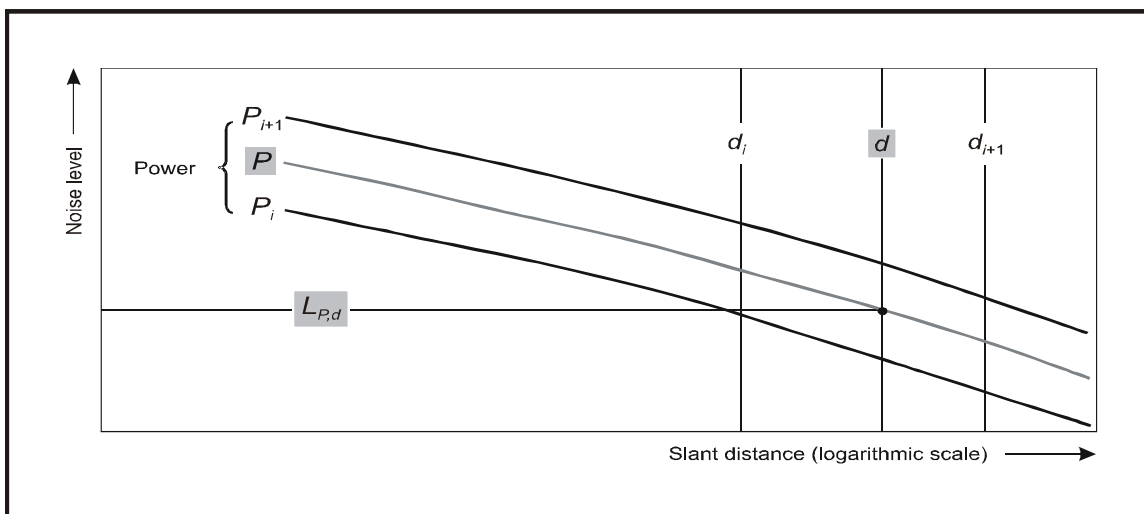


Figure 4-1. Interpolation in noise-power-distance curves

2. 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 $L(d_{l-1})$ and $L(d_l)$ where l 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:

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

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

4.3.8.5 The acoustic impedance adjustment is usually less than a few tenths of one dB. In particular, it should be noted that under the standard atmospheric conditions ($p = 101.325$ kPa and $T = 25.0$ °C), the impedance adjustment is approximately 0.0 dB (-0.000004 dB). However, when there is a significant variation in temperature and atmospheric pressure relative to the reference atmospheric conditions of the NPD data, the adjustment can be more substantial.

4.4 GENERAL EXPRESSIONS

4.4.1 Segment event level L_{seg}

4.4.1.1 The segment values are determined by applying adjustments to the baseline (infinite path) values read from the NPD data. The maximum noise level from one flight path segment $L_{max,seg}$ can be expressed in general as

$$L_{max,seg} = L_{max}(P,d) + \Delta_I(\phi) - \Lambda(\beta,\ell) \quad (4-7a)$$

and the contribution from one flight path segment to L_E as

$$L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\phi) - \Lambda(\beta,\ell) + \Delta_F \quad (4-7b)$$

4.4.1.2 The “correction terms” in equations 4-6a and 4-6b, which are described in detail in 4.5, account for the following effects:

- Δ_V *Duration correction*: the NPD data relate to a reference flight speed. This adjusts exposure levels to non-reference speeds. (It is not applied to $L_{max,seg}$.)
- $\Delta_I(\phi)$ *Installation effect*: describes a variation in *lateral directivity* due to shielding, refraction and reflection caused by the airframe, engines and surrounding flow fields.
- $\Lambda(\beta,\ell)$ *Lateral attenuation*: significant for sound propagating at low angles to the ground, this accounts for the interaction between direct and reflected sound waves (ground effect) and for the effects of atmospheric non-uniformities (primarily caused by the ground) that refract sound waves as they travel towards the observer to the side of the flight path.
- Δ_F *Finite segment correction (noise fraction)*: accounts for the finite length of the segment which obviously contributes less noise exposure than an infinite one. It is only applied to exposure metrics.

4.4.1.3 If the segment is part of the take-off or landing ground roll and the observer is located behind the segment under consideration, special steps are taken, depending on whether the observer is located behind the start or ahead of the end of the segment under consideration, to represent the directivity of engine noise. These special steps result, in particular, in the use of a particular form of the noise fraction for the exposure level:

$$L_{max,seg} = L_{max}(P,d) + \Delta_I(\phi) - \Lambda(\beta,\ell) + \Delta_{SOR} \quad (4-8a)$$

$$L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\phi) - \Lambda(\beta,\ell) + \Delta'_F + \Delta_{SOR} \quad (4-8b)$$

where:

- Δ'_F Particular form of the *segment correction* for ground roll segments
- Δ_{SOR} *Directivity correction*: accounts for the pronounced directionality of aircraft engine noise behind the ground roll segment

4.4.1.4 The specific treatment of ground roll segments is described in 4.6.7 and 4.6.8. Sections below describe the calculation of segment noise levels.

4.4.2 Event noise level L of an aeroplane movement

4.4.2.1 Maximum level L_{max} is simply the greatest of the segment values $L_{max,seg}$ (see equation 4-6a)

$$L_{max} = \max(L_{max,seg}) \quad (4-9)$$

where each segment value is determined from the aeroplane NPD data for power P and distance d . These parameters and the modifier terms $\Delta_l(\varphi)$ and $\Lambda(\beta, \ell)$ are explained in 4.6.

4.4.2.2 Exposure level L_E is calculated as the decibel sum of the contributions $L_{E,seg}$ from each noise-significant segment of its flight path; i.e.

$$L_E = 10 \cdot \lg\left(\sum 10^{L_{E,seg}/10}\right) \quad (4-10)$$

4.4.2.3 The summation proceeds step by step through the flight path segments.

4.4.2.4 The determination of the segment noise levels $L_{max,seg}$ and $L_{E,seg}$ are described in 4.5 and 4.6.

4.5 FLIGHT PATH SEGMENT PARAMETERS

4.5.1 The power P , and distance d , for which the baseline levels $L_{max,seg}(P, d)$ and $L_{E\infty}(P, d)$ are interpolated from the NPD tables, are determined from geometric and operational parameters that define the segment. This process is explained below.

4.5.2 Geometric parameters

4.5.2.1 Figures 4-2a to 4-2c show the source-receiver geometries when the observer O is (a) behind, (b) alongside and (c) ahead of the segment S_1S_2 where the flight direction is from S_1 to S_2 . In these diagrams

- O is the observer location;
- S_1, S_2 are the start and end of the segment;
- S_p is the point of perpendicular closest approach to the observer on the segment or its extension;
- d_1, d_2 are the distances between start, end of segment and observer;
- d_s is the shortest distance between observer and segment;
- d_p is the perpendicular distance between observer and extended segment (*minimum slant range*);
- λ is the length of flight path segment; and
- q is the distance from S_1 to S_p (negative if the observer position is behind the segment)...

4.5.2.2 In Figures 4-2a through 4-2c, the flight path segment is represented by a bold, solid line. The dotted line represents the flight path extension which stretches to infinity in both directions. For airborne segments, when the event metric is an exposure level L_E , the NPD distance parameter d is the distance d_p between S_p and the observer, called the minimum slant range (i.e. the perpendicular distance from the observer to the segment or its extension; in other words, to the (hypothetical) infinite flight path of which the segment is considered to be part).

4.5.2.3 However, for exposure level metrics where observer locations are behind the ground segments during the take-off roll and locations ahead of ground segments during the landing roll, the NPD distance parameter d becomes the distance d_s , the shortest distance from the observer to the segment (i.e. the same as for maximum level metrics).

4.5.2.4 For maximum level metrics, the NPD distance parameter d is d_s , the shortest distance from the observer to the segment.

4.5.3 Segment power P

4.5.3.1 The tabulated NPD data describe the noise of an aeroplane in steady straight flight on an infinite flight path, i.e. at constant engine power P . The recommended methodology breaks actual flight paths, along which speed and direction vary, into a number of finite segments, each of which is then taken to be part of a uniform, infinite flight path for which the NPD data are valid. However, the methodology provides for changes of power along the length of a segment, which is assumed to change quadratically with distance from P_1 at its start to P_2 at its end. It is therefore recommended to define an equivalent steady segment value P . This is taken to be the value at the point on the segment that is closest to the observer. If the observer is alongside the segment (Figure 4-2b), it is obtained by interpolation as given by equation 3-3d between the end values, i.e.

$$P = \sqrt{P_1^2 + \frac{q}{\lambda} \cdot (P_2^2 - P_1^2)} \quad (4-9)$$

4.5.3.2 If the observer is behind or ahead of the segment, it is that at the nearest end point, P_1 or P_2 .

4.6 SEGMENT EVENT LEVEL CORRECTION TERMS

4.6.1 The NPD data define noise event levels as a function of distance perpendicularly beneath an idealized straight level path of infinite length along which the aeroplane flies with steady power at a fixed reference speed³. The event level interpolated from the NPD table for a specific power setting and slant distance is thus described as a *baseline level*. It applies to an infinite flight path and has to be corrected to account for the effects of non-reference speed, engine installation effects (lateral directivity), lateral attenuation, finite segment length and longitudinal directivity behind start-of-roll on take-off (see equations 4-6a and 4-6b).

3. NPD specifications require that the data be based on measurements of steady *straight* flight, not necessarily level; to create the necessary flight conditions, the test aeroplane flight path can be inclined to the horizontal. However, as will be seen, inclined paths lead to computational difficulties and, when using the data for modelling, it is convenient to visualize the source paths as being both straight and level.

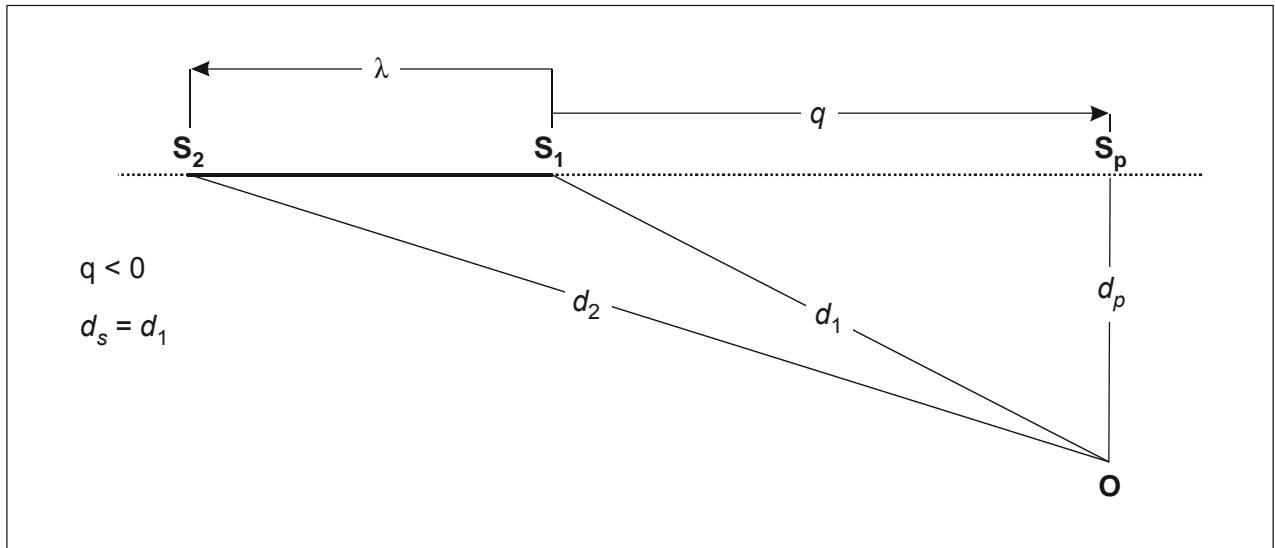


Figure 4-2a. Flight path segment geometry for observer behind segment

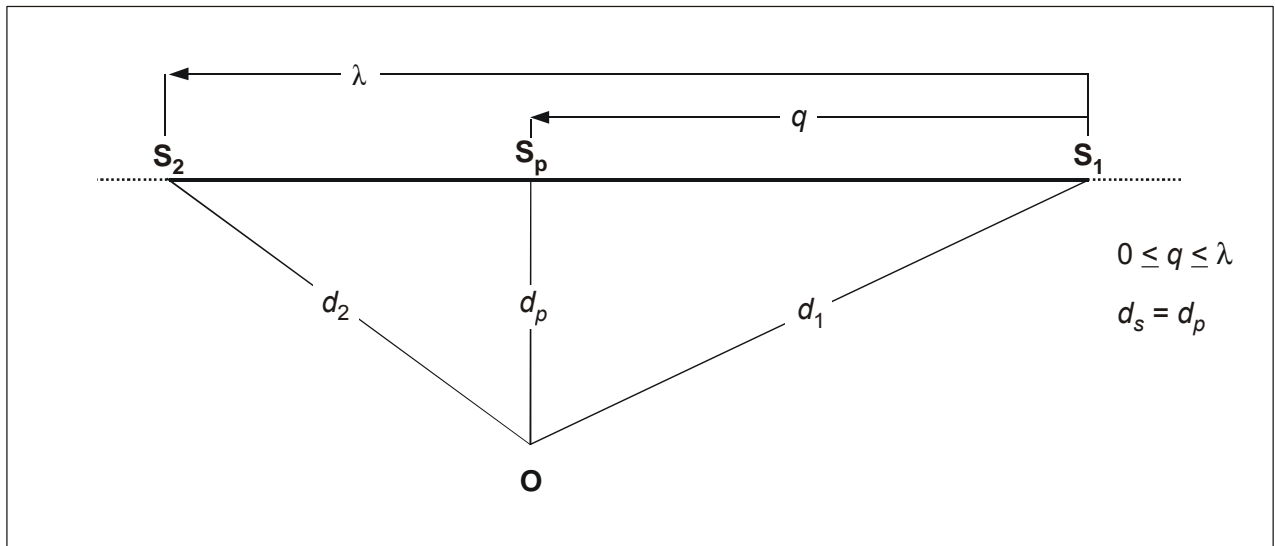


Figure 4-2b. Flight path segment geometry for observer alongside segment

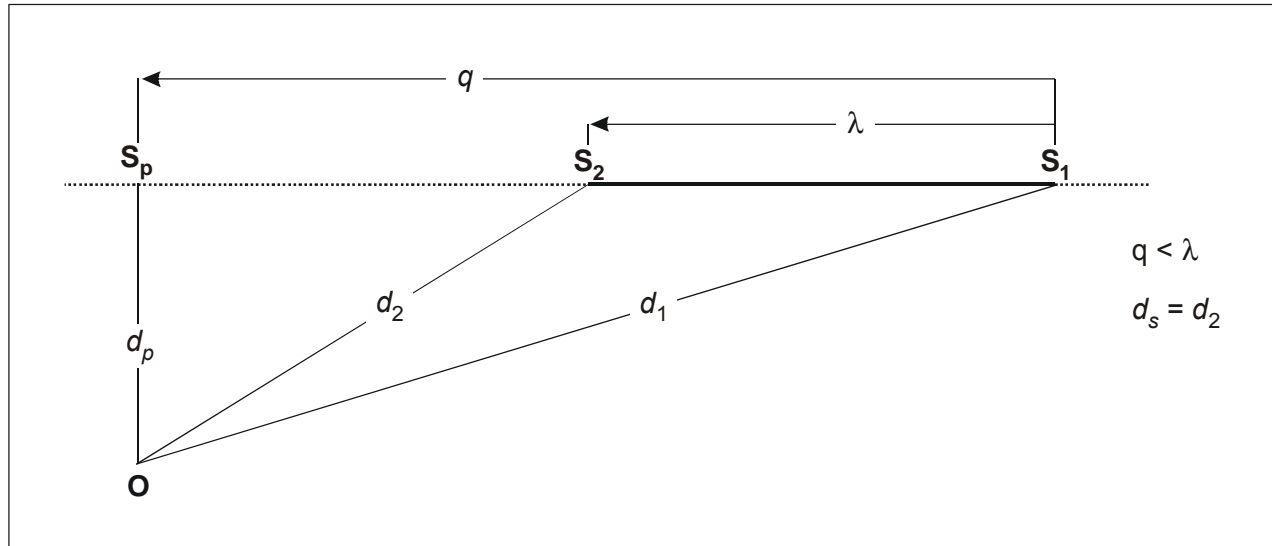


Figure 4-2c. Flight path segment geometry for observer ahead of segment

4.6.2 The duration correction Δ_V (exposure levels L_E only)

4.6.2.1 This correction⁴ accounts for a change in exposure levels if the actual segment speed is different to the aeroplane reference speed V_{ref} to which the basic NPD data relate. Like engine power, speed varies along the flight path segment (from V_1 to V_2).

4.6.2.2 For airborne segments, the recommended method for defining V is the segment speed at the closest point of approach S – interpolated between the segment end point values assuming it varies quadratically with time, i.e. if the observer is alongside the segment

$$V = \sqrt{V_1^2 + \frac{q}{\lambda} \cdot (V_2^2 - V_1^2)} \quad (4-10c)$$

4.6.2.3 If the observer is behind or ahead of the segment, it is the speed at the nearest end point, V_1 or V_2 .

4.6.2.4 For runway segments (parts of the take-off or landing ground rolls), V_{seg} is taken to be simply the average of the segment start and end-speeds; i.e.

$$V_{seg} = (V_1 + V_2)/2 \quad (4-10d)$$

4.6.2.5 In either case, the additive duration correction is then

$$\Delta_V = 10 \cdot \log(V_{ref} / V_{seg}) \quad (4-11)$$

4. This is known as the *duration correction* because it makes allowance for the effects of aeroplane *speed* on the duration of the sound event – implementing the simple assumption that, other things being equal, duration, and thus received event sound energy, is inversely proportional to source velocity.

4.6.3 Sound propagation geometry

Figure 4-3 shows the basic geometry in the plane normal to the aeroplane flight path. The ground line is the intersection of the normal plane and the level ground plane. (If the flight path is level, the ground line is an end view of the ground plane.) The parameters involved are:

- a) the aeroplane bank angle ε measured counterclockwise about its roll axis (i.e. starboard wing up). It is therefore positive for left turns and negative for right turns.
- b) the *elevation angle* β (between 0 and 90°) between the direct sound propagation path and the level ground line⁵. This determines, together with the flight path inclination and the lateral displacement ℓ of the observer from the ground track, the lateral attenuation. This is explained in 4.6.4 and 4.6.5.
- c) the *depression angle* φ between the wing plane and the propagation path. This determines the engine installation effects. With respect to the convention for the bank angle $\varphi = \beta \pm \varepsilon$, with the sign positive for observers to starboard (right) and negative for observers to port (left). The correction for engine installation effects is explained in 4.6.4. The elevation angle β , which is required to determine the depression angle φ , is defined in 4.6.6.

4.6.4 Engine installation correction Δ_I

4.6.4.1 An aeroplane in flight is a complex sound source. Not only are the engine (and airframe) sources complex in origin, but the airframe configuration, particularly the location of the engines, influences the noise radiation patterns through the processes of reflection, refraction and scattering by the solid surfaces and aerodynamic flow fields. This results in a non-uniform directionality of sound radiated laterally about the roll axis of the aeroplane, referred to here as *lateral directivity*.

4.6.4.2 There are significant differences in lateral directivity between aeroplanes with fuselage-mounted and underwing-mounted engines and these are allowed for in the following expressions. For aeroplanes with fuselage-mounted jet engines, the engine-installation effect, in decibels, is given by:

$$\Delta_I(\varphi) = 10 \cdot \log_{10} \left([0.1225 \cdot \cos^2(\varphi) + \sin^2(\varphi)]^{0.329} \right) \quad \text{for } -180^\circ \leq \varphi \leq 180^\circ \quad (4-14a)$$

where $\Delta_I(\varphi)$ is the correction, in dB, at depression angle φ (see Figure 4-3). For aeroplanes with wing-mounted jet engines, the engine-installation effect, in decibels, is given by:

$$\Delta_I(\varphi) = \begin{cases} 10 \cdot \log_{10} \left(\frac{[0.0039 \cdot \cos^2(\varphi) + \sin^2(\varphi)]^{0.062}}{[0.8786 \cdot \sin^2(\varphi) + \cos^2(\varphi)]} \right) & \text{for } 0^\circ \leq \varphi \leq 180^\circ \end{cases} \quad (4-14b)$$

4.6.4.3 For propeller aeroplanes, directivity variations are negligible and for these it may be assumed that

$$\Delta_I(\varphi) = 0 \quad (4-15)$$

5. In the case of non-flat terrain there can be different definitions of elevation angle. Here it is defined by the aircraft height above the observation point and the slant distance – hence neglecting local terrain gradients as well as obstacles on the sound propagation path (see Chapter 2, 2.5.8 and Chapter 3, 3.4.4). In the event that, due to ground elevation, the receiver point is above the aircraft, elevation angle β is set equal to zero.

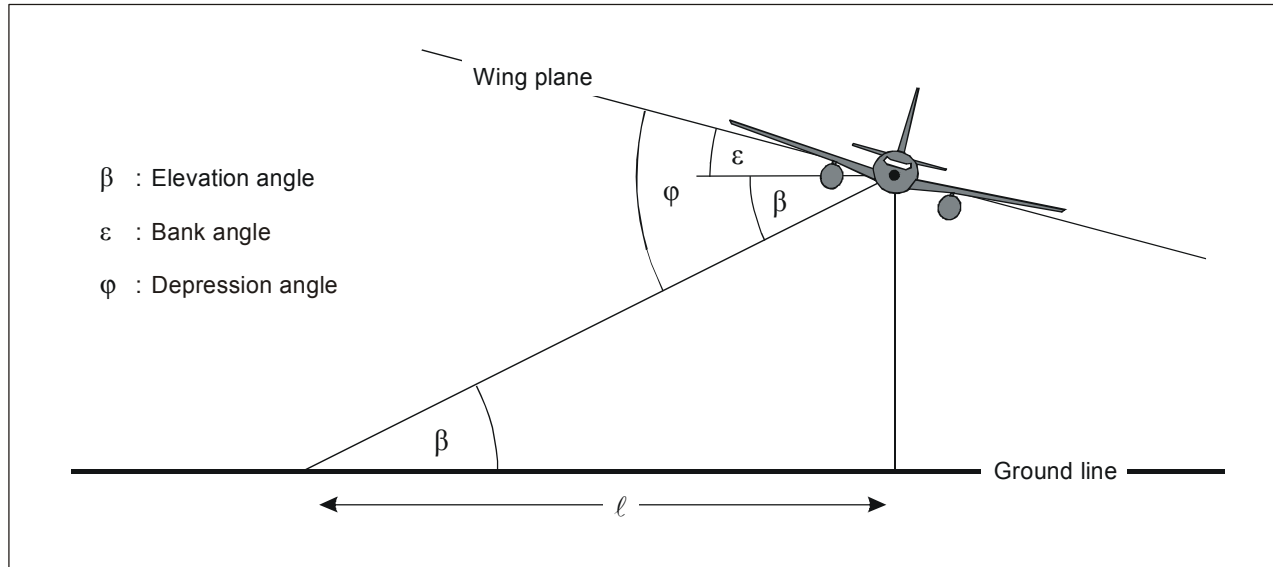


Figure 4-3. Aircraft-observer angles in plane normal to flight path

4.6.4.4 Figure 4-4 shows the variation of $\Delta_l(\varphi)$ about the aeroplane roll axis for the three-engine installations. These empirical relationships have been derived by the SAE from experimental measurements made mainly beneath the wing [ref. 8]. Until above-wing data have been analysed it is recommended that, for negative φ , $\Delta_l(\varphi) = \Delta_l(0)$ for all installations.

4.6.4.5 It is assumed that $\Delta_l(\varphi)$ is two-dimensional, i.e. it does not depend on any other parameter — and in particular that it does not vary with the longitudinal distance of the observer from the aeroplane. This means that the *elevation angle* β for $\Delta_l(\varphi)$ is defined as $\beta = \tan^{-1}(z/\ell)$. This is for modelling convenience until there is a better understanding of the mechanisms; in reality, installation effects are bound to be substantially three-dimensional. Despite that, a two-dimensional model is justified by the fact that event levels tend to be dominated by noise radiated sideways from the nearest segment.

4.6.5 Lateral attenuation $\Lambda(\beta, \ell)$ (infinite flight path)

4.6.5.1 Tabulated NPD event levels relate to steady level flight and are generally based on measurements made 1.2 m (4 ft) over soft level ground beneath the aeroplane; the distance parameter is effectively height above the surface. Any effect of the surface on event noise levels beneath the aeroplane, that might cause the tabulated levels to differ from free-field⁶ values, is assumed to be inherent in the data (i.e. in the shape of the level versus the distance relationships).

6. A “free-field” level is that which would be observed if the ground surface were not present.

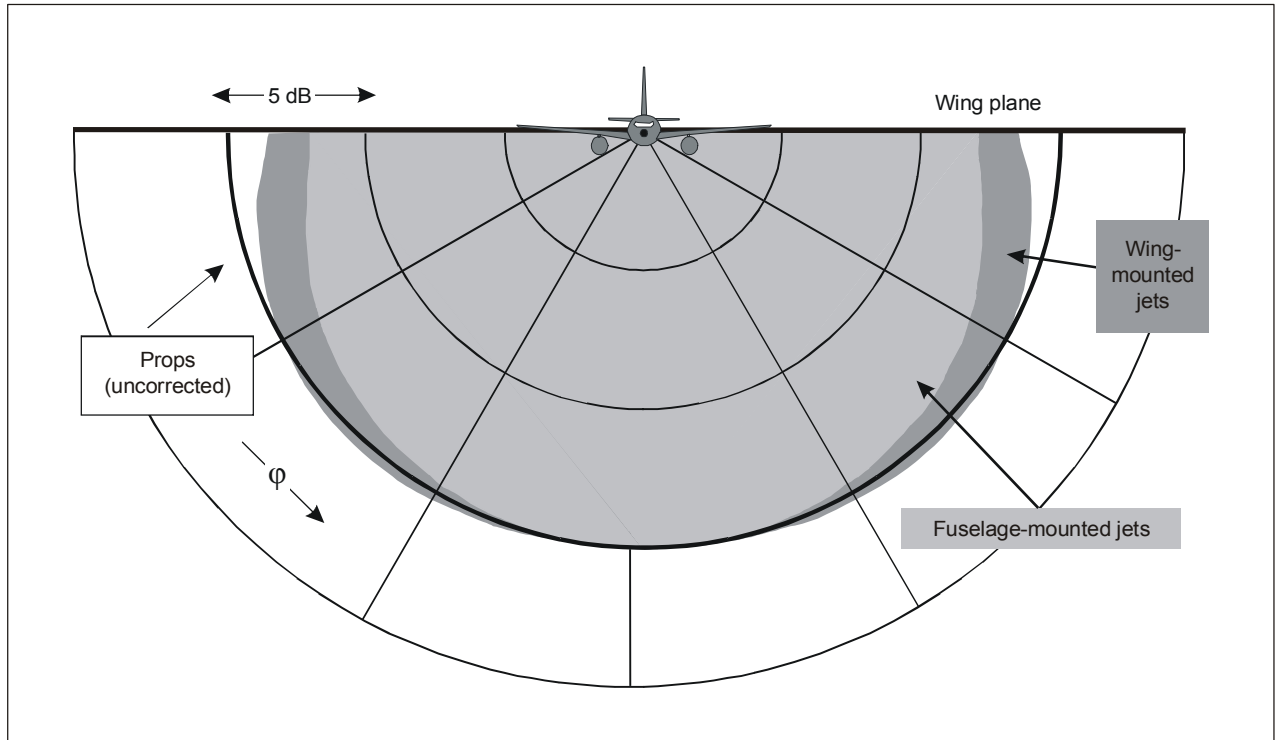


Figure 4-4. Lateral directivity of installation effects

4.6.5.2 To the side of the flight path, the distance parameter is the minimum slant distance — the length of the normal from the receiver to the flight path. At any lateral position the noise level will generally be less than at the same distance immediately below the aeroplane. Apart from lateral directivity or “installation effects” described in 4.6.4, this is due to an excess lateral attenuation which causes the sound level to fall more rapidly with distance than indicated by the NPD curves. A previous, widely used method for modelling lateral propagation of aeroplane noise was developed by the SAE International in SAE-AIR-1751 [ref. 9] and the algorithms described below are based on improvements the SAE International now recommends in SAE-AIR-5662 [ref. 8]. Lateral attenuation is a reflection effect, due to interference between directly radiated sound and that which reflects from the surface. It depends on the nature of the surface and can cause a significant reduction in observed sound levels at low elevation angles. It is also strongly affected by sound refraction, steady and unsteady, caused by wind and temperature gradients and turbulence, all of which are attributable to the presence of the surface.⁷ The mechanism of surface reflection is well understood and, for uniform atmospheric and surface conditions, it can be described theoretically with some precision. However, atmospheric and surface non-uniformities — which are not amenable to simple theoretical analysis — have a profound effect on the reflection effect, tending to “spread” it to higher elevation angles; thus the theory is of limited applicability. The SAE International continues to develop a better understanding of surface effects, which is expected to lead to better models. Until these are developed, the following methodology, described in SAE-AIR-5662, is recommended for calculating lateral attenuation. It is confined to the case of sound propagation over soft level ground which is appropriate for the great majority of civil airports. Adjustments to account for the effects of a hard ground surface (or, acoustically equivalent water) are still under development.

7. The wind and temperature gradients and turbulence depend in part upon the roughness and heat transfer characteristics of the surface.

4.6.5.3 The methodology is built on the substantial amount of experimental data on sound propagation from aeroplanes with fuselage-mounted engines in straight (non-turning), steady, level flight reported originally in SAE-AIR-1751. Making the assumption that, for level flight, air-to-ground attenuation depends on (i) elevation angle β measured in the vertical plane and (ii) lateral displacement from the aeroplane ground track ℓ , the data were analysed to obtain an empirical function for the *total* lateral adjustment $\Lambda_T(\beta, \ell)$ (i.e. the = lateral event level minus the level at the same distance beneath the aeroplane).

4.6.5.4 As the term $\Lambda_T(\beta, \ell)$ accounted for lateral directivity as well as lateral attenuation, the latter can be extracted by subtraction. Describing lateral directivity using equation 4-14, with the fuselage-mounted coefficients and with φ replaced by β (appropriate to non-turning flight), the lateral attenuation becomes

$$\Lambda(\beta, \ell) = \Lambda_T(\beta, \ell) - \Delta_l(\beta) \quad (4-16)$$

where β and ℓ are measured as depicted in Figure 4-3 in a plane normal to the infinite flight path which, for level flight, is also vertical.

4.6.5.5 Although $\Lambda(\beta, \ell)$ could be calculated directly using equation 4-16 with $\Lambda_T(\beta, \ell)$ taken from SAE-AIR-1751, a more efficient relationship is recommended. This is the following empirical approximation adapted from SAE-AIR-5662:

$$\Lambda(\beta, \ell) = \Gamma(\ell) \cdot \Lambda(\beta) \quad (4-17)$$

where $\Gamma(\ell)$ is a distance factor given by

$$\Gamma(\ell) = 1.089 \cdot [1 - \exp(-0.00274\ell)] \text{ for } 0 \leq \ell \leq 914 \text{ m} \quad (4-18a)$$

$$\Gamma(\ell) = 1 \text{ for } \ell > 914 \text{ m} \quad (4-18b)$$

and $\Lambda(\beta)$ is long-range air-to-ground lateral attenuation given by

$$\Lambda(\beta) = 1.137 - 0.0229\beta + 9.72 \cdot \exp(-0.142\beta) \text{ for } 0^\circ \leq \beta \leq 50^\circ \quad (4-18c)$$

$$\Lambda(\beta) = 0 \text{ for } 50^\circ \leq \beta \leq 90^\circ \quad (4-18d)$$

4.6.5.6 The expression for lateral attenuation $\Lambda(\beta, \ell)$, equation 4-17, which is assumed to function well for all aeroplanes, propeller aeroplanes as well as fuselage-mounted and wing-mounted jets, is shown graphically in Figure 4-5.

4.6.5.7 Under certain circumstances (with terrain), it is possible for β to be less than zero. In such cases, it is recommended that $\Lambda(\beta) = 10.857$.

4.6.6 Finite segment lateral attenuation

4.6.6.1 Equation 4-17 describes the lateral attenuation $\Lambda(\beta, \ell)$ of sound received by the observer from an aeroplane in steady flight along an infinite, level flight path. When applying these to finite path segments, which are not level, the attenuation has to be calculated for an equivalent level path — as the closest point on a simple extension of the inclined segment (that passes through the ground surface at some point) generally does not yield an appropriate elevation angle β .

4.6.6.2 The determination of lateral attenuation for finite segments differs markedly for L_{max} and L_E metrics. Segment maximum levels L_{max} are determined from NPD data as a function of propagation distance d from the nearest point on the segment; no corrections are required to account for the dimensions of the segment. Likewise, lateral attenuation of L_{max} is assumed to depend only on the elevation angle of, and ground distance to, the same point. Thus, only the coordinates of that point are required. But for L_E , the process is more complicated.

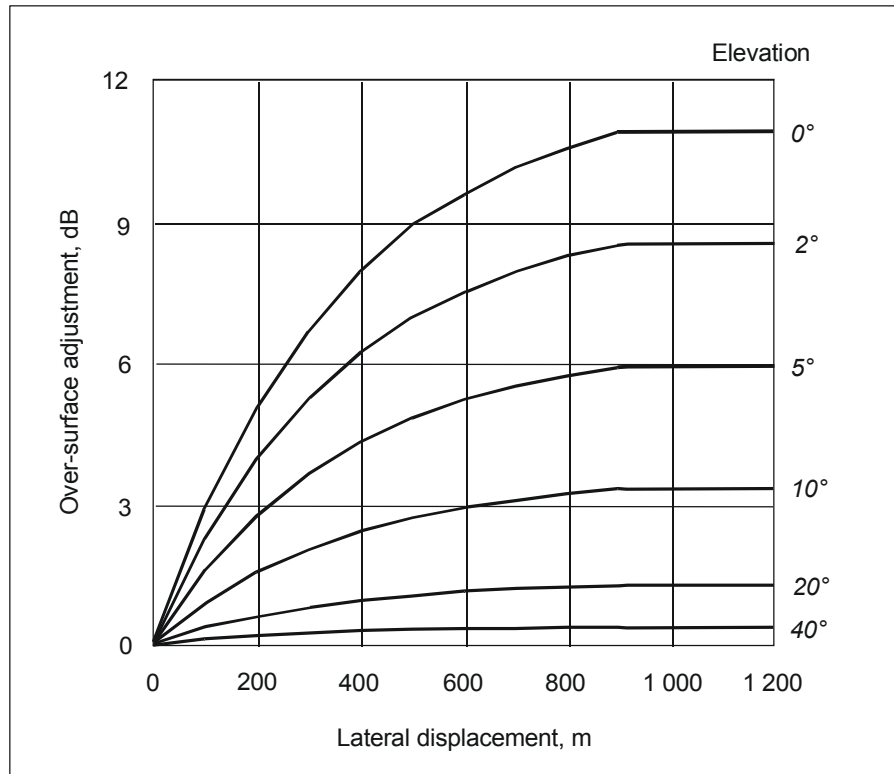


Figure 4-5. Variation of lateral attenuation $\Delta(\beta, \ell)$ with elevation angle and distance

4.6.6.3 The baseline event level $L_E(P, d)$ that is determined from the NPD data, even though for finite segment parameters, applies nevertheless to an infinite flight path. The event exposure level from a segment, $L_{E, seg}$, is of course less than the baseline level — by the amount of the finite segment correction defined later. That correction, a function of the geometry of triangles OS_1S_2 in Figure 4-2, defines what proportion of the total infinite path noise energy received at O comes from the segment; the same correction applies whether or not there is any lateral attenuation. But any lateral attenuation must be calculated for the infinite flight path, i.e. as a function of its displacement and elevation, not those of the finite segment.

4.6.6.4 Adding the corrections Δ_V and Δ_I , and subtracting lateral attenuation $\Delta(\beta, \ell)$ from the NPD *baseline level* gives the adjusted event noise level for equivalent steady *level* flight on an adjacent, infinite straight path. But the actual flight path segments being modelled, those that affect the noise contours, are rarely level; aeroplanes are usually climbing or descending.

4.6.6.5 Figure 4-6 illustrates a departure segment S_1S_2 — the aeroplane is climbing at an angle γ — but the considerations remain very similar for an arrival. The remainder of the “real” flight path is not shown; suffice it to state that S_1S_2 represents just a part of the whole path (which in general will be curved). In this case, the observer O is alongside, and to the left of, the segment. The aeroplane is banked (anti-clockwise with respect to the flight path) at an angle ε to the lateral horizontal axis. The depression angle φ from the wing plane, of which the installation effect Δ_I is a function (equation 4-15), lies in the plane normal to the flight path in which ε is defined. Thus $\varphi = \beta - \varepsilon$ where $\beta = \tan^{-1}(h/\ell)$ and ℓ is the perpendicular distance OR from the observer to the ground track; i.e. the lateral displacement of the

observer⁸. The aeroplane's closest point of approach to the observer, **S**, is defined by the perpendicular **OS**, of length (slant distance) d_p . The triangle **OS₁S₂** accords with Figure 4-2b, the geometry for calculating the segment correction Δ_F .

4.6.6.6 To calculate the lateral attenuation using equation 4-17 (where β is measured in a vertical plane), an *equivalent level flight path* is recommended. An *equivalent level flight path* is defined in the vertical plane through **S₁S₂** and with the same perpendicular slant distance d_p from the observer. This is visualized by rotating the triangle **ORS**, and its attached flight path about **OR** (see Figure 4-6) through angle γ thus forming the triangle **ORS'**. The elevation angle of this equivalent level path (now in a vertical plane) is $\beta = \tan^{-1}(h/\ell)$ (ℓ remains unchanged). In this case, for an observer alongside, angle β and the resulting lateral attenuation $\Lambda(\beta, \ell)$ are the same for L_E and L_{max} metrics.

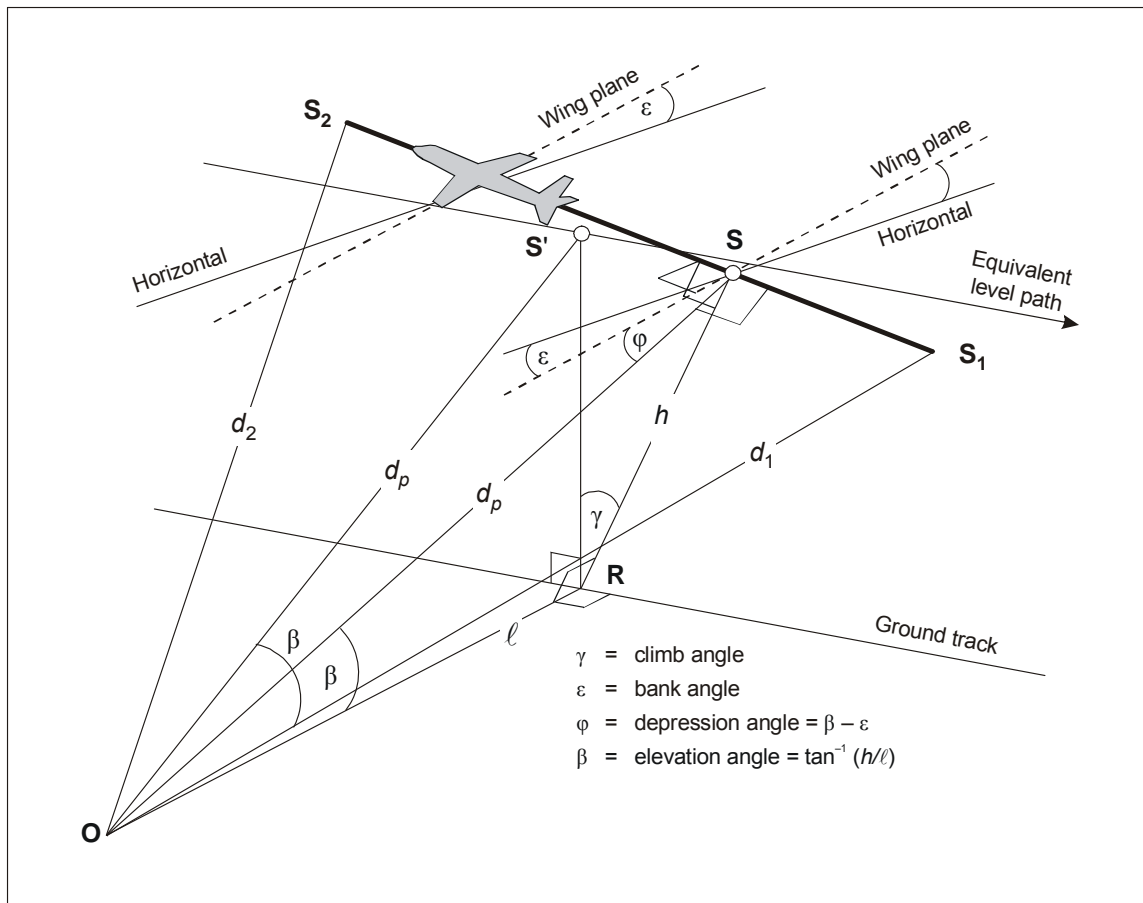


Figure 4-6. Observer alongside segment

8. For an observer located on the right side to the segment, ϕ would become $\beta + \epsilon$ (see 4.5.2).

4.6.6.7 Figure 4-7 illustrates the situation when the observer point O lies *behind the finite segment*, not alongside. Here the segment is observed as a more distant part of an infinite path; a perpendicular can only be drawn to point S_p on its extension. The triangle OS_1S_2 accords with Figure 4-2a which defines the segment correction Δ_F . But in this case the parameters for lateral directivity and attenuation are less obvious. For maximum level metrics, the NPD distance parameter is taken as the shortest distance to the segment, i.e. $d = d_1$. For exposure level metrics, it is the shortest distance d_p from O to S_p on the extended flight path, i.e. the level interpolated from the NPD table is $L_{E\infty}(P_1, d_p)$.

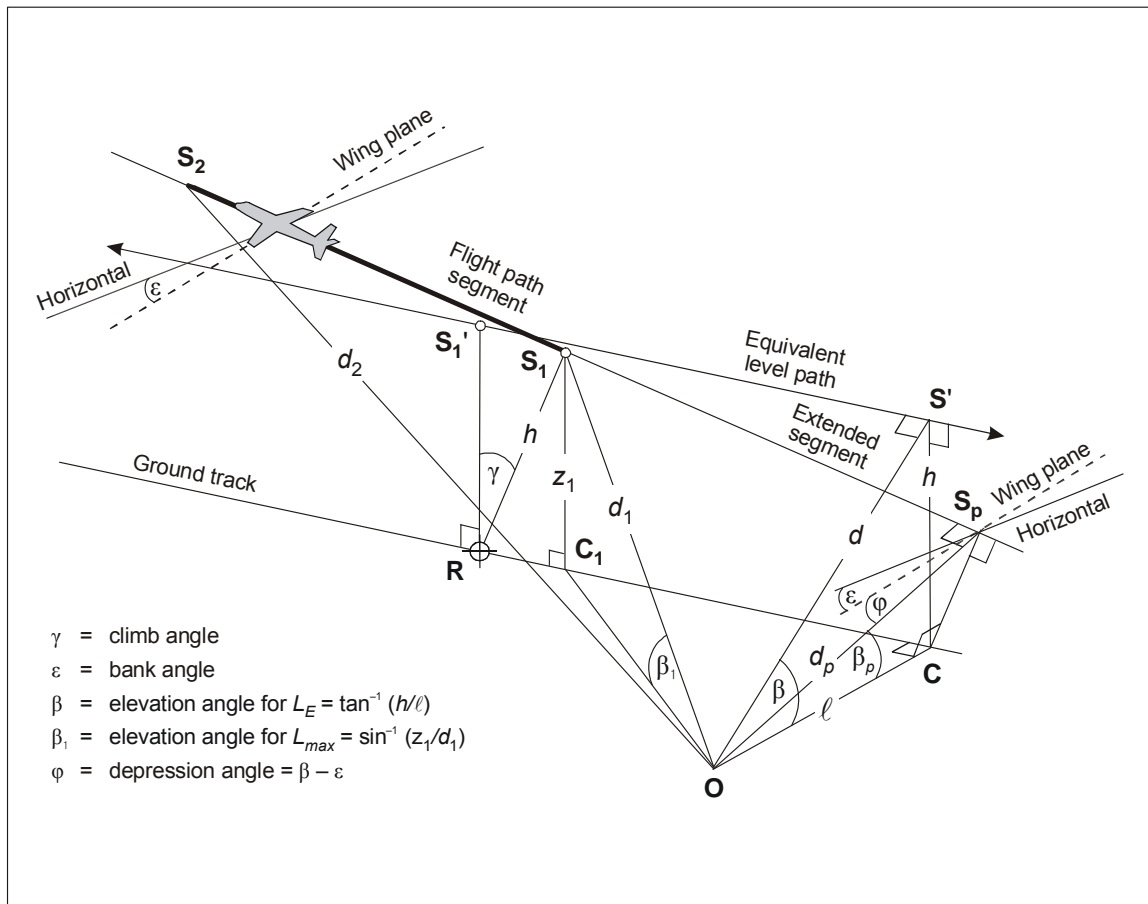


Figure 4-7. Observer behind segment

4.6.6.8 The geometrical parameters for lateral attenuation also differ for maximum and exposure level calculations. For maximum level metrics the adjustment $\Lambda(\beta, \ell)$ is given by equation 4-17 with $\beta = \beta_1 = \sin^{-1}(z_1 / d_1)$ and $\ell = OC_1 = \sqrt{d_1^2 - z_1^2}$ where β_1 and d_1 are defined by the triangle OC_1S_1 in the vertical plane through O and S_1 .

4.6.6.9 When calculating the lateral attenuation for exposure level metrics, ℓ remains the shortest lateral displacement from the segment extension (OC). However, to define an appropriate value of β it is again necessary to visualize an (infinite) equivalent level flight path of which the segment can be considered a part. This is drawn through S_1' , height h above the surface, where h is equal to the length of RS_1 — the perpendicular from the ground track to the segment. This is equivalent to rotating the actual extended flight path through angle γ about point R (see Figure 4-7). Insofar as R is on the perpendicular to S_1 , the point on the segment that is closest to O , the construction of the equivalent level path is the same as when O is alongside the segment.

4.6.6.10 The closest point of approach of the equivalent level path to the observer O is at S_1' , slant distance d , so that the triangle OCS_1' so formed in the vertical plane then defines the elevation angle $\beta = \cos^{-1}(\ell / d)$. Although this transformation might seem rather convoluted, it should be noted that the basic source geometry (defined by d_1 , d_2 and φ) remains untouched, the sound travelling from the segment *towards* the observer is simply what it would be if the entire flight along the infinitely extended inclined segment (of which for modelling purposes the segment forms a part) were at constant speed V (equation 4-10c) and power P_1 . The lateral attenuation of sound from the segment *received* by the observer, on the other hand, is related not to β_p , the elevation angle of the extended path, but to β , that of the equivalent level path.

4.6.6.11 Remembering that, as conceived for modelling purposes, lateral directivity (installation effect) is two-dimensional, the defining depression angle φ is still measured laterally from the aeroplane wing plane. (The baseline event level is still that generated by the aeroplane traversing the infinite flight path represented by the extended segment.) Thus, the depression angle is determined at the closest point of approach, i.e. $\varphi = \beta_p - \varepsilon$ where β_p is angle S_pOC .

4.6.6.12 The case of an observer ahead of the segment is not described separately; it is evident that this is essentially the same as the case of the observer behind.

4.6.6.13 However, it is important to note that, for exposure level metrics where observer locations are behind ground segments during either take-off roll or landing roll, the value of β becomes the same as that for maximum level metrics. For locations behind take-off roll segments:

$$\beta = \beta_1 = \sin^{-1}\left(\frac{z_1}{d_1}\right) \quad \text{and} \quad \ell = OC_1 = \sqrt{d_1^2 - z_1^2} \quad (4-19a)$$

For locations ahead of landing roll segments:

$$\beta = \beta_2 = \sin^{-1}\left(\frac{z_2}{d_2}\right) \quad \text{and} \quad \ell = OC_2 = \sqrt{d_2^2 - z_2^2} \quad (4-19b)$$

4.6.6.14 The rationale for using these particular expressions is related to the application of the start-of-roll directivity function behind take-off roll segments and a semi-circular directivity assumption ahead of landing roll segments (see 4.6.7 and 4.6.8 for further details).

4.6.7 The finite segment correction Δ_F (exposure levels L_E only)

4.6.7.1 The adjusted baseline noise exposure level relates to an aeroplane in continuous, straight, steady level flight (albeit with a bank angle ε that is inconsistent with straight flight). Applying the (negative) finite segment correction $\Delta_F = 10 \cdot \log(F)$, where F is the energy fraction, further adjusts the level to what it would be if the aeroplane traversed the finite segment only.

4.6.7.2 The energy fraction term accounts for the pronounced longitudinal directivity of aeroplane noise and the angle subtended by the segment at the observer position. Although the processes that cause the directionality are very complex, studies have shown that the resulting contours are quite insensitive to the precise directional characteristics assumed. The expression for Δ_F below is based on a fourth-power 90-degree dipole model of sound radiation. It is assumed to be unaffected by lateral directivity and attenuation. The derivation of this correction is described in detail in Appendix F.

4.6.7.3 The energy fraction F is a function of the “view” triangle OS_1S_2 defined in Figures 4-2a to 4-2c such that:

$$\Delta_F = 10 \cdot \log \left[\left(\frac{1}{\pi} \right) \cdot \left[\frac{\alpha_2}{(1 + \alpha_2^2)} + \tan^{-1}(\alpha_2) - \frac{\alpha_1}{(1 + \alpha_1^2)} - \tan^{-1}(\alpha_1) \right] \right] \quad (4-20a)$$

where

$$\begin{aligned} \alpha_1 &= -\frac{q}{d_\lambda}; \alpha_2 = -\frac{q - \lambda}{d_\lambda}; \\ d_\lambda &= d_0 \cdot 10^{[L_{E_{\max}}(P, d_p) - L_{\max}(P, d_p)]/10}; \\ d_0 &= \frac{2}{\pi} \cdot V_{\text{ref}} \cdot t_0 \end{aligned}$$

where d_λ is known as the “scaled distance” (see Appendix F), $V_{\text{ref}} = 270.05$ ft/s and $t_0 = 1$ sec for L_E . Note that $L_{\max}(P, d_p)$ is the maximum level, from NPD data, for perpendicular distance d_p , not the segment L_{\max} .

4.6.7.4 It is advised to apply a lower limit of -150 dB to Δ_F .

4.6.7.5 In the particular case of observer locations behind every take-off ground roll segment, a reduced form of the noise fraction expressed in equation 4-20a is used, which corresponds to the specific case of $q = 0$. This is denoted $\Delta'_{F,d}$ where ‘d’ clarifies its use for departure operations, and is computed using

$$\Delta'_{F,d} = 10 \cdot \log \left[\left(\frac{1}{\pi} \right) \cdot \left[\frac{\alpha_2}{(1 + \alpha_2^2)} + \tan^{-1}(\alpha_2) \right] \right] \quad (4-20b)$$

where $\alpha_2 = \lambda / d_\lambda$. The rationale for using this particular form of noise fraction is further explained in 4.6.8 below, as part of the start-of-roll directivity application method.

4.6.7.6 In the particular case of observer locations ahead of every landing ground roll segment, a reduced form of the noise fraction expressed in equation 4-20a is used, which corresponds to the specific case of $q = \lambda$. This is denoted $\Delta'_{F,a}$ where ‘a’ clarifies its use for arrival operations, and is computed as:

$$\Delta'_{F,a} = 10 \cdot \log \left[\left(\frac{1}{\pi} \right) \cdot \left[-\frac{\alpha_1}{(1 + \alpha_1^2)} - \tan^{-1}(\alpha_1) \right] \right] \quad (4-20c)$$

where $\alpha_1 = -\lambda / d_\lambda$.

4.6.8 Specific treatments of ground roll segments, including the start-of-roll directivity function Δ_{SOR}

4.6.8.1 The noise of aeroplanes — especially jet aeroplanes equipped with lower bypass ratio engines — exhibits a lobed radiation pattern in the rearward arc, which is characteristic of jet exhaust noise. This pattern is more pronounced when the jet velocity is higher and the aeroplane speed is lower. A less pronounced radiation pattern may be observed for turboprop aircraft, as well. This is of special significance for observer locations behind the start-of-roll, where both conditions are fulfilled. This effect is taken into account by a directivity function Δ_{SOR} . The function Δ_{SOR} has been derived from several noise measurement campaigns [ref. 16] using microphones positioned behind and on the side of the SOR of departing aircraft. Separate functions were derived for jet and turboprop aircraft.

4.6.8.2 Figure 4-8 shows the relevant geometry for the start-of-roll directivity function Δ_{SOR} . The azimuth angle Ψ between the aeroplane longitudinal axis and the vector to the observer is defined by

$$\Psi = \cos^{-1}\left(\frac{q}{d_{SOR}}\right) \quad (4-21)$$

4.6.8.3 The relative distance q is negative (see Figure 4-2a) so that Ψ ranges from 0° in the direction of the aeroplane forward heading to 180° in the reverse direction.

4.6.8.4 The function Δ_{SOR} represents the variation of the overall noise emanating from the take-off ground roll measured behind the start-of-roll, relatively to the overall noise from take-off ground roll measured on the side of the SOR, at the same distance:

$$L_{TGR}(d_{SOR}, \Psi) = L_{TGR}(d_{SOR}, 90^\circ) + \Delta_{SOR}(d_{SOR}, \Psi) \quad (4-22)$$

where

$L_{TGR}(d_{SOR}, 90^\circ)$ is the overall take-off ground roll noise level at the point distance d_{SOR} to the side of the SOR; and

Δ_{SOR} is implemented as an adjustment to the noise level from one flight path segment (e.g. $L_{max, seg}$ or $L_{E, seg}$), as described in equations 4-8a and 4-8b.

4.6.8.5 The SOR directivity function, in decibels, for turbofan-powered jet aircraft is given by the following equations:

if $90^\circ \leq \Psi < 180^\circ$ then

$$\Delta_{SOR}^\circ = 2329.44 - (8.0573 \cdot \Psi) + \left(11.51 \cdot \exp\left(\frac{\pi \cdot \Psi}{180}\right)\right) - \left(\frac{3.4601 \cdot \Psi}{\ln\left(\frac{\pi \cdot \Psi}{180}\right)}\right) - \left(\frac{17403338.3 \cdot \ln\left(\frac{\pi \cdot \Psi}{180}\right)}{\Psi^2}\right) \quad (4-23a)$$

4.6.8.6 The SOR directivity function, in decibels, for turboprop-powered aircraft is given by the following equations:

if $90^\circ \leq \Psi < 180^\circ$ then

$$\begin{aligned} \Delta_{SOR}^{\circ} = & -34643.898 + \left(\frac{30722161.987}{\Psi} \right) - \left(\frac{11491573930.510}{\Psi^2} \right) + \left(\frac{2349285669062}{\Psi^3} \right) \\ & - \left(\frac{283584441904272}{\Psi^4} \right) + \left(\frac{20227150391251300}{\Psi^5} \right) - \left(\frac{790084471305203000}{\Psi^6} \right) \\ & + \left(\frac{13050687178273800000}{\Psi^7} \right) \end{aligned} \quad (4-23b)$$

4.6.8.7 For all geometries where the receiver is in front of the jet or turboprop aircraft ($\Psi < 90^\circ$), Δ_{SOR} is set to 0.0 dB.

4.6.8.8 If the distance d_{SOR} exceeds the normalizing distance $d_{SOR,0}$ of 762 m (2 500 ft), the directivity correction is multiplied by a correction factor to account for the fact that the directivity becomes less pronounced for greater distances from the aeroplane; i.e.

$$\Delta_{SOR} = \Delta_{SOR}^0 \quad \text{if } d_{SOR} \leq d_{SOR,0} \quad (4-24a)$$

$$\Delta_{SOR} = \Delta_{SOR}^0 \cdot \frac{d_{SOR,0}}{d_{SOR}} \quad \text{if } d_{SOR} > d_{SOR,0} \quad (4-24b)$$

4.6.8.9 The Δ_{SOR} function described above mostly captures the pronounced directivity effect of the initial portion of the take-off roll at locations behind the SOR (because it is the closest to the receivers, with the highest jet velocity to aircraft speed ratio). However, the use of the hence established Δ_{SOR} is "generalized" to positions behind each individual take-off ground roll segment, so not only behind the start-of-roll point (in the case of take-off). The established Δ_{SOR} is not applied to positions ahead of individual take-off ground roll segments, nor is it applied to positions behind or ahead of individual landing ground roll segments.

4.6.8.10 The parameters d_{SOR} and ψ are calculated relative to the start of each individual ground roll segment. The event level L_{SEG} for a location behind a given take-off or landing ground roll segment is calculated to comply with the formalism of the Δ_{SOR} function: it is essentially calculated for the reference point located on the side of the start point of the segment, at the same distance d_{SOR} as the actual point, and is further adjusted with Δ_{SOR} to obtain the event level at the actual point.

4.6.8.11 Noise from aircraft engine tests (sometimes referred to as "engine run-ups") at airports can make a contribution to noise impacts. Usually carried out for engineering purposes to check engine performance, aircraft are safely positioned away from buildings, other aircraft, vehicular and/or personnel movements to avoid any jet-blast related damage. For additional safety and noise control reasons, airports, particularly those with maintenance facilities that can lead to frequent engine tests, can install so-called "noise pens", three-sided baffled enclosures specially designed to deflect and dissipate jet blast and noise. Investigating the noise impact of such facilities, which can be further attenuated and reduced by the use of additional earth bunds or substantial noise barrier fencing, can be accomplished by treating the noise pen as a source of industrial noise and using an appropriate noise and sound propagation model.

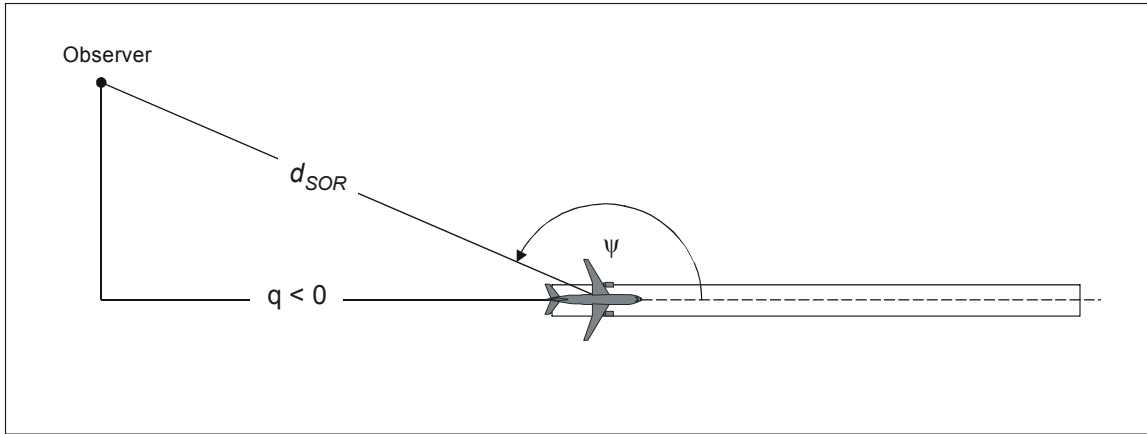


Figure 4-8. Aircraft-observer geometry for estimation of directivity correction

Chapter 5

CALCULATION OF CUMULATIVE LEVELS

5.1 INTRODUCTION

5.1.1 Chapter 4 describes the calculation of the event sound noise level of a single aeroplane movement at a single observer location. The total noise exposure at that location is calculated by accumulating the event levels of all noise-significant aeroplane movements, i.e. all movements, inbound or outbound, that influence the cumulative level. Some of the basic measures of cumulative noise are outlined below; for a general description of noise scales, metrics and indices, see Appendix A.

5.2 WEIGHTED EQUIVALENT SOUND LEVELS

5.2.1 Time-weighted equivalent sound levels, which account for all significant aeroplane sound energy received, can be expressed in a generic manner by the formula

$$L_{eq,W} = 10 \cdot \log \left[\frac{t_0}{T_0} \sum_{i=1}^N g_i \cdot 10^{L_{E,i}/10} \right] + C \quad (5-1a)$$

5.2.2 The summation is performed over all N noise events during the time interval T_0 to which the noise index applies. $L_{E,i}$ is the single event noise exposure level of the i -th noise event. g_i is a time-of-day dependent weighting factor (usually defined for day, evening and night periods). Effectively g_i is a multiplier for the number of flights occurring during the specific periods. The constant C can have different meanings (normalizing constant, seasonal adjustment, metric specific adjustment, etc.).

5.2.3 Using the relationship

$$g_i = 10^{\Delta_i/10} \quad (5-1b)$$

where Δ_i is the decibel weighting for the i -th period, equation 5-1a can be rewritten as

$$L_{eq,W} = 10 \cdot \log \left[\frac{t_0}{T_0} \sum_{i=1}^N 10^{(L_{E,i} + \Delta_i)/10} \right] + C \quad (5-1bc)$$

i.e. the time-of-day weighting is expressed by an additive level offset.

5.2.4 Some noise indices are based on maximum noise event levels rather than on time-integrated metrics. An example is the average maximum sound level:

$$\overline{L_{max}} = 10 \cdot \log \left[\frac{1}{N} \sum_{i=1}^N 10^{L_{max,i}/10} \right] \quad (5-2)$$

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

5.2.6 Some indices account for both $\overline{L_{max}}$ and event numbers N by a relationship of the form

$$\text{Index} = \overline{L_{max}} + K \cdot \log N \quad (5-3)$$

where the constant K defines the relative weight given to event numbers.

5.2.7 A special index is the “Number Above Threshold”, NAT. NAT_X is the number of noise events with maximum sound levels reaching or exceeding a threshold value X (dB). NAT criteria can be defined for specific times of day (e.g. $AT_{Night,70}$).

5.3 THE WEIGHTED NUMBER OF OPERATIONS

5.3.1 The cumulative noise level is estimated by summing the contributions from all different types or categories of aeroplane using the different flight routes appropriate to the airport.

5.3.2 To describe this summation process the following subscripts are introduced:

- i index for aeroplane type or category;
- j index for flight track or sub-track (if sub-tracks are defined); and
- k index for flight track segment.

5.3.3 Many noise indices include time-of-day weighting factors g_i in their definition (equation 5-1). For average maximum levels (equation 5-2), the weighting factors g_i are usually 1 or 0, depending on whether the metric covers specific times of the day or the whole 24 hours.

5.3.4 The summation process can be simplified by introducing a “weighted number of operations”

$$M_{ij} = (g_{day} \cdot N_{ij,day} + g_{evening} \cdot N_{ij,evening} + g_{night} \cdot N_{ij,night}) \quad (5-4)$$

where the values N_{ij} represent the numbers of operations of aeroplane type/category i on track (or sub-track) j during the day, evening and night periods, respectively.¹

5.3.5 From equation 5-1c, the (generic) cumulative equivalent sound level L_{eq} at the observation point (x,y) is

$$L_{eq,W}(x,y) = 10 \cdot \log \left[\frac{t_0}{T_0} \cdot \sum_i \sum_j \sum_k M_{ij} \cdot 10^{L_{E,ijk}(x,y)/10} \right] + C \quad (5-5)$$

where T_0 is the reference time period, and $L_{E,ijk}$ is the single event noise level contribution from segment k of the track or sub-track j for an operation of aeroplane of category i . The estimation of $L_{E,ijk}$ is described in detail in Chapter 4.

1. The time periods may differ from these three depending on the definition of the noise index used.

5.4 ESTIMATION OF CUMULATIVE MAXIMUM LEVEL BASED METRICS

5.4.1 Calculating a cumulative equivalent sound level is a straightforward aggregation of the event levels L_E of all noise-significant aeroplane movements. Cumulative maximum level metrics are less straightforward. By definition a maximum sound level is tied to a single noise event. However, a single aeroplane movement can generate more than one sound event at a given observer location (when its flight path causes more than one rise and fall in the received sound intensity).

5.4.2 Additionally, different metrics assign different meanings to the generic expression “maximum sound level” as illustrated by the following alternative definitions:

- the average maximum sound level, defined by equation 5-2, of all noise events occurring at the observer location;
- the average maximum sound level, defined by equation 5-2, of all noise events exceeding a specified threshold level L_T at the observer location; or
- the absolute maximum level (i.e. the “highest maximum” level). In this case, the noise contribution is from only one noise event.

This indicates the need for metric-specific aggregation of the maximum sound levels.

5.4.3 With no threshold, the average maximum sound level (5.4.2 a)) occurring at the observer location (x,y) can be expressed as

$$\overline{L_{\max}}(x,y) = 10 \cdot \log \left[\sum_i \sum_j \sum_k 10^{L_{\max,ijk}/10} \cdot u(k) \right] - 10 \cdot \log \left[\sum_i \sum_j \sum_k M_{ij} \cdot u(k) \right] \quad (5-6a)$$

where

$$u(k) = \begin{cases} 0 \\ 1 \end{cases} \text{ if } L_{\max,ijk} \begin{cases} \text{is not} \\ \text{is} \end{cases} \text{ the maximum level of a noise event} \quad (5-6b)$$

where the function $u(k)$ determines whether the maximum segment level $L_{\max,ijk}$ is the maximum level of a noise event or not (the derivation this function is described in detail in Appendix F).

5.4.4 With a threshold L_T , the average maximum sound level (defined in 5.4.2 b))

$$\overline{L_{\max}}(x,y) = 10 \cdot \log \left[\sum_i \sum_j \sum_k 10^{L_{\max,ijk}/10} \cdot v(k) \right] \left[\sum_i \sum_j \sum_k M_{ij} \cdot v(k) \right] \quad (5-7a)$$

where

$$u(k) = \begin{cases} 0 \\ 1 \end{cases} \text{ if } \begin{cases} L_{\max,ijk} < L_T \\ L_{\max,ijk} \geq L_T \end{cases} \quad (5-7b)$$

which guarantees that only noise events with maximum levels reaching or exceeding the threshold value L_T are included into the summation process.

5.4.5 If only the highest maximum level (5.4.2 c)) of all noise events occurring at the observation point has to be calculated, the corresponding equation is quite simple:

$$L_{\max}(x,y) = \max (L_{\max,ijk}) \quad (5-8)$$

5.4.6 The equation for the estimation of a number above threshold criterion is similar to that for an average maximum sound level. However, the weighted operations have to be summed rather than the level contributions:

$$NAT_{L_T}(x,y) = \sum_i \sum_j \sum_k M_{ij} \cdot u(k) \cdot v(k) \quad (5-9)$$

5.5 THE USE OF LEVEL DISTRIBUTIONS FOR MAXIMUM LEVEL METRICS

5.5.1 The methodology described in Chapter 4 yields the same maximum sound level for all movements of the same aeroplane type on the same track². This can lead to unrealistic discontinuities in \bar{L}_{\max} and *Number Above Threshold (NAT)* contours. In reality, there are no abrupt changes; the calculated \bar{L}_{\max} is just an estimated average of event levels that are scattered about a central value L_0 . This scatter can be realistically described by a Gaussian distribution function with a standard deviation S :

$$w(L_{\max}, L_0, S) = \frac{1}{\sqrt{2\pi} \cdot S} \cdot \exp \left[-\frac{1}{2} \left(\frac{L_{\max} - L_0}{S} \right)^2 \right] \quad (5-10)$$

5.5.2 Figure 5-1 shows a diagram of such a level distribution.

5.5.3 It must be noted that the median value L_0 of the distribution function is generally not equal to the value L , stored in NPD databases, as that is normally derived from measurements by decibel averaging. This is higher than the median value of the distribution by an amount which depends on the standard deviation:

$$\bar{L} = L_0 + \frac{S^2 \cdot \ln 10}{20} = L_0 + 0.115 \cdot S^2 \quad (5-11)$$

5.5.4 A characteristic type-specific value for the standard deviation S is observed from operational measurements to be approximately 2 dB³. This results in a level difference between logarithmic and arithmetic averages of about 0.5 dB.

5.5.5 For similar reasons, distributed levels should be taken into account when estimating *NAT* values. The reason is clear from Figure 5-1: for this case both L_0 and \bar{L} are less than the threshold level L_T . If the distribution is not taken into account, the contribution to *NAT* will equal zero. However, with distributed levels some are higher than the threshold and thus contribute to the total *NAT*. To account for the distribution, equation 5-9 has to be modified by replacing the discrete step represented by the function $v(k)$ by an integral over a continuous distribution function:

$$NAT_{L_T}(x,y) = \sum_i \sum_j \sum_k \left[M_{ij} \cdot u(k) \cdot \int_{L_T}^{\infty} w(L_{\max,ijk}, L_0, k, S) dL_{\max,ijk} \right] \quad (5-12)$$

Polynomial approximations of this integral for programming purposes can be found in mathematical handbooks [e.g. ref.10].

2. Assuming the same operating procedures and weight.

3. Rather lower scatter is achieved in certification tests.

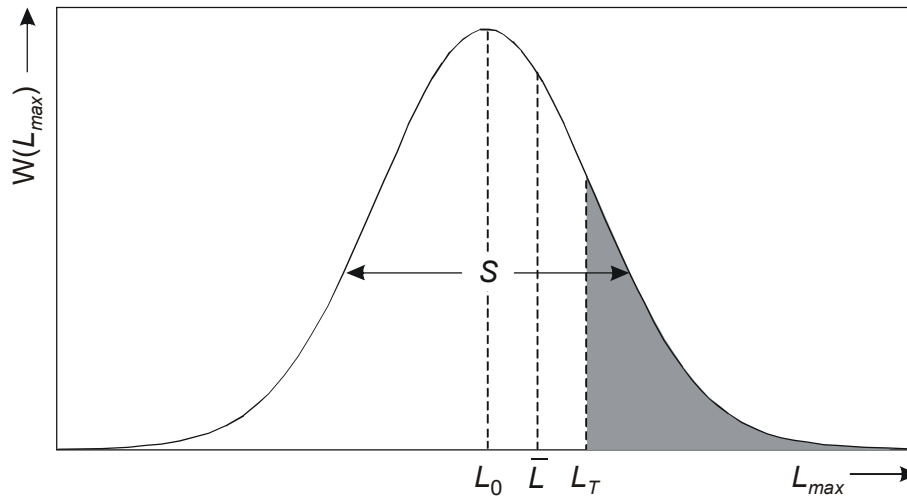


Figure 5-1. Maximum sound level distribution

5.5.6 It should be noted that the arithmetic mean $L_{0,k}$ has to be derived according to equation 5-11 if, as in the ANP database, the maximum values are estimated from measured data by logarithmic averaging.

Chapter 6

CALCULATION OF NOISE CONTOURS

6.1 STANDARD GRID CALCULATION AND REFINEMENT

6.1.1 When noise contours are obtained by interpolation between index values at rectangularly spaced grid points, their accuracy depends on the choice of the grid spacing (or mesh size) Δ_G , especially within cells where large gradients in the spatial distribution of the index cause tight curvature of the contours (see Figure 6-1). Interpolation errors are reduced by reducing the grid spacing, but as this increases the number of grid points, the computation time is increased. Optimizing a regular grid mesh involves balancing modelling accuracy and run-time.

6.1.2 A marked improvement in computing efficiency which also delivers more accurate results is to use an irregular grid to refine the interpolation in critical cells. The technique, depicted in Figure 6-1, tightens the mesh locally, leaving the bulk of the grid unchanged. This is very straightforward and achieved by the following steps:

- 1) Define a refinement threshold difference ΔL_R for the noise index.
- 2) Calculate the basic grid for a spacing Δ_G .
- 3) Check the differences ΔL of the index values between adjacent grid nodes.
- 4) If there are any differences $\Delta L > \Delta L_R$, define a new grid with a spacing $\Delta_G/2$ and estimate the levels for the new nodes in the following way:
 - i) If $\Delta L \leq \Delta L_R$, calculate the new value by linear interpolation from the adjacent values; and
 - ii) If $\Delta L > \Delta L_R$, calculate the new value completely anew from the basic input d .

$$\text{if } \begin{cases} \Delta L \leq \Delta L_R \\ \Delta L > \Delta L_R \end{cases}$$

calculate the new value

$$\begin{cases} \text{by linear interpolation from the adjacent values.} \\ \text{completely anew from the basic input data.} \end{cases}$$

- 5) Repeat steps 1) through 4) until all differences are less than the threshold difference.
- 6) Estimate the contours by linear interpolation.

6.1.3 If the array of index values is to be aggregated with others (e.g. when calculating weighted indices by summing separate day, evening and night contours), care is required to ensure that the separate grids are identical.

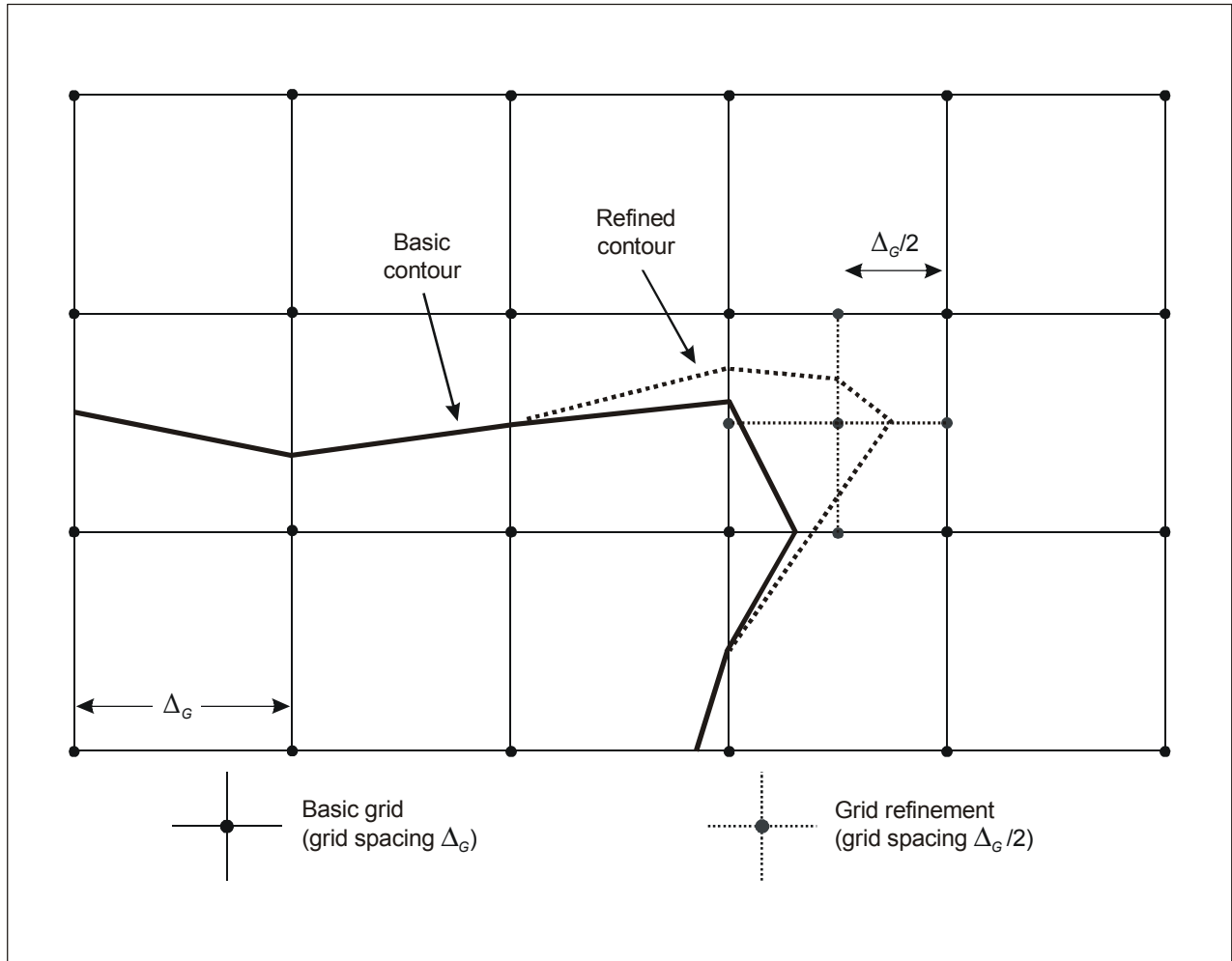


Figure 6-1. Standard grid and grid refinement

6.2 USE OF ROTATED GRIDS

6.2.1 In many practical cases, the true shape of a noise contour tends to be symmetrical about a ground track. However, if the direction of this track is not aligned with the calculation grid, this can result in an asymmetrical contour shape.

6.2.2 The straightforward way to avoid this effect is to tighten the grid. However, this increases computation time; a more elegant solution is to rotate the computation grid so that its direction is parallel to the main ground tracks (i.e. usually parallel to the main runway). Figure 6-2 shows the effect of such a grid rotation on the contour shape.

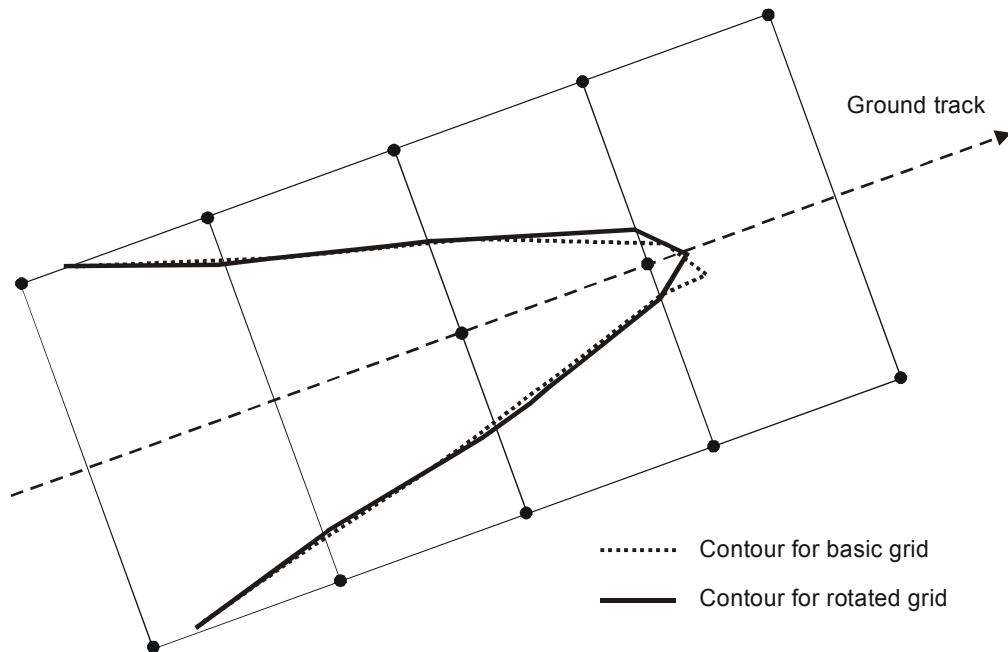


Figure 6-2. Use of a rotated grid

6.3 TRACING OF CONTOURS

6.3.1 A very time-efficient algorithm that eliminates the need to calculate a complete grid array of index values at the expense of a little more computational complexity is to trace the path of the contour, point by point. This option requires two basic steps to be performed and repeated (see Figure 6-3):

6.3.2 Step 1 is to find a first point P_1 on the contour. This is done by calculating the noise index levels L in equidistant steps along a “search ray” that is expected to cross the required contour of level L_C . When the contour is crossed, the difference $\delta = L_C - L$ changes sign. If this happens, the step-width along the ray is halved and the search direction is reversed. This is done until δ is smaller than a predefined accuracy threshold.

6.3.3 Step 2, which is repeated until the contour is sufficiently well-defined, is to find the next point on the contour L_C — which is at a specified straight line distance r from the current point. During consecutive angular steps, index levels and differences δ are calculated at the ends of vectors describing an arc with radius r . By similarly halving and reversing the increments in the directions of the vector, the next contour point is determined.

6.3.4 Some constraints should be imposed to guarantee that the contour is estimated with a sufficient degree of accuracy (see Figure 6-4):

- a) The length of the chord Δc (the distance between two contour points) should be within an interval $[\Delta c_{min}, \Delta c_{max}]$, e.g. [10 m, 200 m].
- b) The length ratio between two adjacent chords of lengths Δc_n and Δc_{n+1} should be limited, e.g. $0.5 < \Delta c_n / \Delta c_{n+1} < 2$.

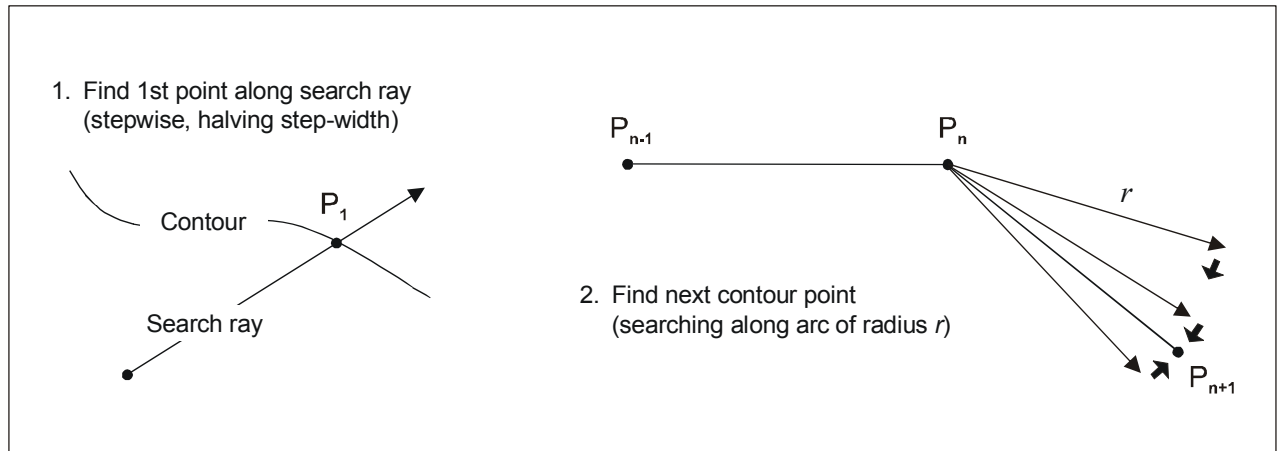


Figure 6-3. Concept of tracing algorithm

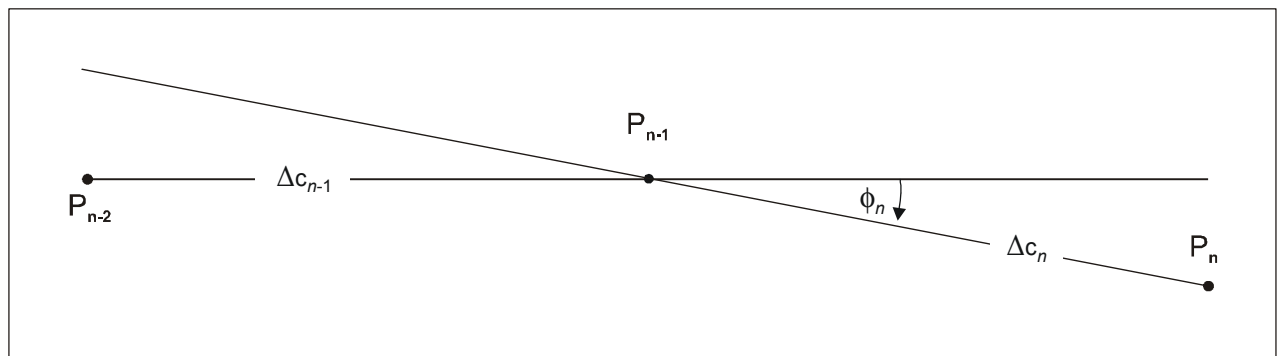


Figure 6-4. Geometric parameters defining conditions for the tracing algorithm

- c) With respect to a good fit of the chord length to the contour curvature, the following condition should be fulfilled:

$$\phi_n \cdot \max(\Delta c_{n-1}, \Delta c_n) \leq \varepsilon \quad (\varepsilon \approx 15 \text{ m})$$

where ϕ_n is the difference in the chord headings.

6.3.5 Experience with this algorithm has shown that, on an average, between 2 and 3 index values have to be calculated to determine a contour point with an accuracy of better than 0.01 dB.

6.3.6 This algorithm speeds up computation time dramatically, especially when large contours have to be calculated. However, it should be noted that its implementation requires experience, especially when a contour breaks down into separate islands.

6.4 POST-PROCESSING

6.4.1 Commonly the post-processing of calculated noise indices involves the following:

- a) interpolation and, if necessary, smoothing of noise contours (if the index was estimated for a grid);
- b) performing grid operations such as merging, adding, subtracting or converting;
- c) plotting (including representation of contours, runways, tracks, specific observer locations and/or topography); and
- d) integration of noise data into geographic information systems (GIS) (e.g. to estimate enclosed population numbers).

6.4.2 Currently, several post-processing tools and standardized data formats are in use, which are suitable for processing data from aeroplane noise calculation programs. Examples of such tools are:

- a) NMPLLOT: this programme is designed for viewing and editing geo-referenced data sets such as noise data stored in grids; and
- b) GIS software, such as ESRI ArcMap or MicroStation GeoGraphics (usually commercial software).

6.4.3 Data formats which are widely used are:

- a) ESRI shapefile format;
- b) AutoCAD data exchange format DXF;
- c) Intergraph and MicroStation standard file format ISFF (also known as DGN); and
- d) Noise model grid format (NMGF). The NMGF format was originally developed for use in conjunction with different noise models. It is used by NMPLLOT.

6.4.4 Many possibilities for the definition of interfaces therefore exist. This should be taken into account when a computer model, based on this manual, is developed.

Appendix A

NOISE INDICES IN USE IN ICAO CONTRACTING STATES

1. INTRODUCTION

1.1 Individual Contracting States have selected different noise indices for national use. The formulations of current indices are as follows:

2. DAY-EVENING-NIGHT SOUND LEVEL, L_{DEN}

$$L_{DEN} = 10 \log(1/24) \times [12 \times 10^{L_D/10} + 4 \times 10^{(L_E+5)/10} + 8 \times 10^{(L_N+10)/10}] \quad (A-1)$$

where L_D , L_E and L_N are the equivalent continuous A-weighted sound pressure levels¹ over, respectively, the 12-hour daytime period 0700 to 1900 hours, the 4-hour evening period 1900 to 2300 hours and the 8-hour night period 2300 to 0700 hours².

3. DAY-NIGHT AVERAGE SOUND LEVEL, L_{DN}

$$L_{DN} = 10 \log(1/24) \times [15 \times 10^{L_D/10} + 9 \times 10^{(L_N+10)/10}] \quad (A-2)$$

where L_D and L_N are the equivalent continuous A-weighted sound pressure levels over, respectively, the 15-hour daytime period 0700 to 2200 hours and the 9-hour night period 2200 to 0700 hours.

4. EQUIVALENT CONTINUOUS A-WEIGHTED SOUND PRESSURE LEVEL, $L_{A,eq}$, AS DEFINED IN AUSTRIA

$$L_{A,eq} = 10 \log \left[\left(1/t_{eq} \right) \int_0^{t_{eq}} 10^{L_A(t)/10} dt \right] \quad (A-3)$$

-
1. The equivalent continuous A-weighted sound pressure level is usually given the symbol $L_{A,eq,T}$ [ref. 1]. The symbols L_D , L_E and L_N used here are intended to indicate the time periods over which the levels are evaluated. This quantity is defined as follows:

$$L_{A,eq,T} = 10 \log \left\{ \left[1/(t_2 - t_1) \right] \times \int_{t_1}^{t_2} \left[p_A^2(t) / p_0^2 \right] dt \right\}$$

where $L_{A,eq,T}$ is the equivalent continuous A-weighted sound pressure level determined over a time interval T starting at t_1 and ending at t_2 , $p_A(t)$ is the instantaneous A-weighted sound pressure of the sound signal and p_0 is the reference sound pressure (20 μ Pa).

2. The LDEN time periods are different in the United States: the 12-hour daytime period 0700 to 1900 hours, the 3-hour evening period 1900 to 2200 hours and the 9-hour night period 2200 to 0700 hours.

where $L_A(t)$ is the instantaneous A-weighted sound pressure level and t_{eq} is the evaluation period in seconds; $L_{A,eq}$ is evaluated separately over the 16-hour daytime period 0600 to 2200 hours and the 8-hour night period 2200 to 0600 hours.

5. NOISE EXPOSURE FORECAST, NEF

$$NEF = 10 \log \sum_i \sum_j 10^{NEF_{ij}/10} \quad (A-4)$$

where NEF_{ij} is a partial value for a specific class of aeroplanes, i , on a flight path, j , defined as follows:

$$NEF_{ij} = L_{EPNij} = 10 \log(n_{Dij} + 16.67n_{Nij}) - 88 \quad (A-5)$$

where, in turn, L_{EPNij} is the effective perceived noise level (EPNL) at the observation point considered, for the aeroplanes and flight path concerned, n_{Dij} is the number of operations during the 15-hour day (0700 to 2200 hours) and n_{Nij} is the number during the 9-hour night (2200 to 0700 hours).

6. NOISE EXPOSURE INDEX, B

$$B = 20 \log \sum_i [n(10^{L_p/15})] - 157 \quad (A-6)$$

Where L_p is the maximum A-weighted sound pressure level of an aeroplane fly-past and n is a weighting factor which varies with different times during the day and night.

7. WEIGHTED EQUIVALENT CONTINUOUS PERCEIVED NOISE LEVEL, WECPNL, AS DEFINED IN JAPAN

$$WECPNL = \left(10 \log \left[(1/n) \sum_i 10^{L_i/10} \right] + 10 \log N \right) - 27 \quad (A-7)$$

where L_i is the maximum A-weighted sound pressure level of an aeroplane fly-past i , n is the number of operations within a 24-hour period, and N is based upon the number with weightings for the numbers during the daytime (0700 to 1900 hours), evening (1900 to 2200 hours) and night (2200 to 0700 hours).

8. AUSTRALIAN NOISE EXPOSURE FORECAST, ANEF

$$ANEF = 10 \log \sum_i \sum_j 10^{ANEF_{ij}/10} \quad (A-8)$$

where $ANEF_{ij}$ is a partial value for a specific class of aeroplanes, i , on a flight path, j , defined as follows:

$$ANEF_{ij} = L_{EPNij} + 10 \log(n_{Dij} + 4n_{Nij}) - 88 \quad (A-9)$$

where, in turn L_{EPNij} is the EPNL at the observation point considered for the aeroplane and flight path concerned, n_{Dij} is the number of operations during the 12-hour day (0700 to 1900 hours) and n_{Nij} is the number during the 12-hour night (1900 to 0700 hours).

9. APPLICATION OF EPNL-BASED INDICES

Historically, the EPNL data required for calculating certain indices have not been widely available from aircraft manufacturers. As a result, the approximation presented in Appendix B has been used instead. However, with the development of the ANP database, EPNL-based noise-power-distance (NPD) data are now much more widely available and it is recommended that EPNL NPD data are used directly in the calculation of indices based on EPNL. It is recognized that this may change the shape and size of contours; hence, Appendix B is retained, where its continued use may be relevant to maintain continuity.

Appendix B

APPROXIMATE METHODS FOR DETERMINING EFFECTIVE PERCEIVED NOISE LEVEL (EPNL)

1. APPROXIMATIONS TO OBTAIN TONE-CORRECTED PERCEIVED NOISE LEVEL (PNLTJ)

1.1 Approximation by use of PNL derived from octave band measurements:

1.1.1 Use the sound pressure level in each octave band as given in step 1 of Annex 16, Volume I, Appendix 2, 4.2 [ref.18] and for step 2, use the factor 0.3 instead of 0.15.

1.1.2 Omit the "Correction for Spectral Irregularities" given in Annex 16, Volume I, Appendix 2, 4.3. For approximate tone corrections, see Table B-1 (from PNL to PNLT).

1.2 Approximation by D- and A-weighted overall sound pressure level:

1.2.1 PNLT may be approximated by means of recordings with direct measuring equipment if an additional element is inserted in the measuring chain such that the overall frequency response of the measuring chain is:

- a) equal to the inverse of the 40 noy curve as described in Annex 16, Volume I, Appendix 5, Table A5-1:
or
- b) equal to the A-weighting as defined in International Electrotechnical Commission (IEC) Publication 179.¹

1.3 The addition of correction constant K to such measurements gives an approximation of PNLT. See Table B-1 for approximate values for K.

1. This publication was first issued in 1965 by the IEC Central Office, International Electrotechnical Commission, 3 rue de Varembe, Geneva, Switzerland.

Table B-1. Correction constant K to be added to D-weighted and A-weighted overall sound pressure measurements and to PNL values to obtain approximate PNLT values

Aeroplane		Constant K to be added to obtain				
		PNL		PNLT		PNL
		dB(A)	dB(D)	dB(A)	dB(D)	
Turbofan	Take-off	13	7	13	7	0
	Landing	13	7	15	9	2
Turbojet	Take-off	13	7	13	7	0
	Landing	13	7	13	7	0
Noise from unknown aeroplanes		13	7	13	7	0

1.4 The values in this table are considered the best available guidance at the present time and are to be used unless more nearly exact constants K for the particular application, such as aeroplane type, distance from flight paths, etc., are known. If values other than those in the table are used in approximation method b), the value used for K must be stated.

Note.— It is realized that the exact correction constant depends on such factors as aeroplane type, operational characteristics, meteorological conditions and the distance from the aeroplane flight path. The figures in Table B-1 are based on a considerable number of observations. In one study, the correction constant was found to range from 13 to 8 for obtaining PNL from dB(A) and from 8.5 to 4 from dB(D) respectively, the higher value being for a distance of 500 m from the flight path, the lower for 3 500 m. In another study [ref. 19], more than 4 000 flyovers measured in an area within a 19.3 km radius of an aerodrome, the following standard deviations for constants were found (see Table B-2):

Table B-2. Standard deviations for K values

PNL from		PNLT From	
dB(A)	dB(D)	dB(A)	dB(D)
2.2	1.8	3.0	2.6

2. APPROXIMATION TO OBTAIN DURATION CORRECTION D

2.1 An approximation to the duration allowance is given by the expression

$$D = 10 \cdot \log\{[t(2) - t(1)]/T(0)\} \quad (\text{B-1})$$

where:

$T(0)$ is a normalizing constant of 20 s; and

$[t(2) - t(1)]$ is the time interval during which a recording of PNL (or an approximation thereto) is within 10 dB of its maximum value. If the maximum value is less than 10 dB above the background level (or other limiting value such as that recommended in Annex 16, Volume 1, Appendix 1, 4.5), the time it exceeds the background level or other limiting value is taken into account.

2.2 In case of discrepancies between the various approximations, total noise exposure levels based on measurements made with a frequency weighting equal to the inverse of the 40 noy curve (D-weighting) are to be considered closer approximations to EPNL than measurements made with A-weighting. Total noise exposure levels derived from PNL determinations from octave band measurements are to be considered closer approximations to EPNL than determinations based either on D- or A-weighted measurements.

Appendix C

FLIGHT PERFORMANCE CALCULATIONS

1. TERMS AND SYMBOLS

1.1 The terms and symbols used in this appendix are consistent with those conventionally used by aeroplane performance engineers. Some terms are explained briefly below for the benefit of users not familiar with them. To minimize conflict with the main body of this manual, symbols are mostly defined separately within this appendix. Quantities that are referenced in the main body are assigned common symbols; a few that are used differently in this appendix are marked with an asterisk (*). There is some juxtaposition of US and SI units; again this is to preserve conventions that are familiar to users from different disciplines.

1.2 The terms used in this appendix are:

Break point	See Flat rating.
Calibrated airspeed	(Otherwise termed equivalent or indicated airspeed.) The speed of the aeroplane relative to the air as indicated by a calibrated instrument on the aeroplane. The true airspeed, which is normally greater, can be calculated from the calibrated airspeed knowing the air density.
Corrected net thrust	Net thrust is the propulsive force exerted by an engine on the airframe. At a given power setting (<i>EPR</i> or N_1), this falls with air density as altitude and temperature increase; corrected net thrust is equivalent to the thrust at sea level in ISA conditions.
Flat rating	For specific maximum component temperatures, the engine thrust falls as the ambient air temperature rises — and <i>vice versa</i> . This means that there is a critical air temperature above which the rated thrust cannot be achieved. For most modern engines this is called the “flat rated temperature” because, at lower air temperatures the thrust is automatically limited to the rated thrust to maximize service life; regardless, the thrust falls at temperatures above the flat rated temperature, which is often called the break point or break temperature.
Speed	Magnitude of aeroplane velocity vector (relative to aerodrome coordinate system).
Rated thrust	The service life of an aeroplane engine is dependent upon the operating temperatures of its components. The greater the power or thrust generated, the higher the temperatures and the shorter the life. To balance performance and life requirements, flat rated engines are assigned thrust ratings for take-off, climb and cruise which define normal maximum power settings.
Thrust setting parameter	Since thrust cannot be measured directly in flight, it is necessary to set and control thrust through the use of an alternative parameter which can be displayed in the cockpit. This is usually either the engine pressure ratio (<i>EPR</i>) or low-pressure rotor (or fan) rotational speed (N_1).

1.3 The symbols used in this appendix are included below. Quantities are dimensionless unless otherwise stated. Symbols and abbreviations not listed below are used only locally and are defined in the text. Subscripts 1 and 2 denote conditions at the start and end of a segment, respectively. Over-bars denote segment mean values, i.e. average of start and end values.

a	Average acceleration, ft/s ²
a _{max}	Maximum acceleration available, ft s ²
A, B, C, D	Flap coefficients
E, F, G _{A,B} , H	Engine thrust constants or coefficients for temperatures below the engine flat rating temperature at the thrust rating in use (on the current segment of the take-off/climb-out or approach flight path), lb.s/ft, lb/ft, lb/ft ² , and lb/°C, respectively, obtainable from the ANP database.
F _n	Net thrust per engine, lbf
F _n /δ	Corrected net thrust per engine, lbf
G	Climb gradient
G´	Engine-out climb gradient
G _R	Mean runway gradient, positive uphill
g	Gravitational acceleration, ft/s ²
ISA	International Standard Atmosphere
N	Number of engines supplying thrust
N ₁	Rotational speed of the engine's low-pressure compressor (or fan) and turbine stages, %
R	Drag-to-lift ratio C _D /C _L
ROC	Segment rate-of-climb (ft/min)
s	Ground distance covered along ground track, ft
s _{TO8}	Take-off distance into an 8 kt headwind, ft
s _{TOG}	Take-off distance corrected for w and G _R , ft
s _{TOW}	Take-off distance into headwind w, ft
T	Ambient air temperature in which the aeroplane is operating, °C
T _B	Breakpoint temperature, °C
V	Ground speed, kt
V _C	Calibrated airspeed, kt

V_T	True airspeed, kt
W	Aeroplane weight, lb
w	Headwind speed, kt
Δs	Still air segment length projected onto ground track, ft
Δs_w	Segment length ground projection corrected for headwind, ft
δ	p/p_0 , the ratio of the ambient air pressure at the aeroplane to the standard air pressure at mean sea level: $p_0 = 101.325$ kPa (or 1 013.25 mb) [ref. 11]
ε	Bank angle, radians
γ	Climb/descent angle, radians
θ	$(T + 273.15)/(T_0 + 273.15)$ the ratio of the air temperature at altitude to the standard air temperature at mean sea level: $T_0 = 15.0^\circ\text{C}$ [ref. 11]
σ	$\rho/\rho_0 =$ Ratio of air density at altitude to mean sea level value (also, $\sigma = \delta/\theta$)

2. INTRODUCTION

2.1 Flight path synthesis

2.1.1 This appendix recommends procedures for calculating an aeroplane flight profile based on specified aerodynamic and powerplant parameters, aeroplane mass, atmospheric conditions, ground track and operating procedures (flight configuration, power setting, forward speed, vertical speed, etc.). The operating procedures are described by a set of procedural steps that prescribe how to fly the profile.

2.1.2 The flight profile, for take-off or approach, is represented by a series of straight-line segments, the ends of which are termed profile points. It is calculated using aerodynamic and thrust equations containing numerous coefficients and constants which must be available for the specific combination of airframe and engine. This calculation process is described as the process of flight path synthesis.

2.1.3 Apart from the aeroplane performance parameters, which can be obtained from the ANP database (see Appendix H), these equations require specification of (1) aeroplane gross weight, (2) the number of engines, (3) air temperature, (4) runway elevation and atmospheric pressure, and (5) the procedural steps (expressed in terms of power settings, flap deflections, airspeed and, during acceleration, average rate-of-climb/descent) for each segment during take-off and approach. Each segment is then classified as a ground roll, take-off or landing, constant speed climb, power cutback, accelerating climb with or without flap retraction, descent with or without deceleration and/or flap deployment, or final landing approach. The flight profile is built up step by step, the starting parameters for each segment being equal to those at the end of the preceding segment.

2.1.4 The aerodynamic performance parameters in the ANP database are intended to yield a reasonably accurate representation of an aeroplane's actual flight path for the specified reference conditions (see 2.5). However, the aerodynamic parameters and engine coefficients have been shown to be adequate for air temperatures up to 43°C , aerodrome altitudes up to 4 000 ft and across the range of weights specified in the ANP database. The equations thus permit the calculation of flight paths for other conditions, i.e. non-reference aeroplane weight, wind speed, air

temperature, and runway elevation (air pressure), normally with sufficient accuracy for computing contours of average sound levels around an airport.

2.1.5 Paragraph 5 explains how the effects of turning flight are taken into account for departures. This allows bank angle to be accounted for when calculating the effects of lateral directivity (installation effects). Also, during turning flight, climb gradients will generally be reduced depending on the radius of the turn and the speed of the aeroplane. (The effects of turns during the landing approach are more complex and are not covered at present; however, these will rarely influence noise contours significantly.)

2.1.6 Paragraphs 6 to 10 describe the recommended methodology for generating departure flight profiles based on ANP database coefficients and procedural steps.

2.1.7 Paragraphs 11 and 12 describe the methodology used to generate approach flight profiles based on ANP database coefficients and flight procedures.

2.1.8 Paragraph 13 provides examples of the calculations.

2.1.9 Separate sets of equations are provided to determine the net thrust produced by jet engines and propellers, respectively. Unless noted otherwise, the equations for aerodynamic performance of an aeroplane apply equally to jet and propeller-powered aeroplanes.

2.1.10 Mathematical symbols used are defined at the beginning of this appendix and/or where they are first introduced. In all equations, the units of coefficients and constants must of course be consistent with the units of the corresponding parameters and variables. For consistency with the ANP database, the conventions of aeroplane performance engineering are followed in this appendix; distances and heights in feet (ft), speed in knots (kt), mass in pounds (lb), force in pounds-force (lbf), and so on — even though some dimensions (e.g. atmospheric) are expressed in SI units. Modellers using other unit systems should be very careful to apply appropriate conversion factors when adopting the equations to their needs.

2.2 Flight path analysis

2.2.1 In some modelling applications the flight path information is provided not as procedural steps but as coordinates in position and time, usually determined by analysis of radar data (see Chapter 3). In this case, the equations presented in this appendix are used “in reverse”; the engine thrust parameters are derived from the aeroplane motion rather than *vice versa*. In general, once the flight path data have been averaged and reduced to segment form, each segment being classified by climb or descent, acceleration or deceleration, and thrust and flap changes, it is relatively straightforward by comparison with synthesis which often involves iterative processes.

3. ENGINE THRUST

3.1 The propulsive force produced by each engine is one of five quantities that need to be defined at the ends of each flight path segment (the others being height, speed, power setting and bank angle). Net thrust represents the component of engine gross thrust that is available for propulsion. For aerodynamic and acoustical calculations, the net thrust is referred to as the standard air pressure at mean sea level. This is known as corrected net thrust, F_n/δ .

3.2 This will be either the net thrust available when operating at a specified thrust rating, or the net thrust that results when the thrust setting parameter is set to a particular value. For a turbojet or turbofan engine operating at a specific thrust rating, corrected net thrust is given by the equation

$$F_n / \delta = E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 + H \cdot T \quad (C-1)$$

3.3 Data are also provided in the ANP database to allow calculation of non-rated thrust as a function of a thrust setting parameter. This is defined by some manufacturers as engine pressure ratio (EPR), and by others as low-pressure rotor speed, or fan speed, N_1 . When that parameter is EPR, equation C-1 is replaced by

$$F_n / \delta = E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 + H \cdot T + K_1 \cdot \text{EPR} + K_2 \cdot \text{EPR}^2 \quad (\text{C-2})$$

where K_1 and K_2 are coefficients from the ANP database that relate corrected net thrust and engine pressure ratio in the vicinity of the engine pressure ratio of interest for the specified aeroplane Mach number.

3.4 When engine rotational speed N_1 is the parameter used by the cockpit crew to set thrust, the generalized thrust equation becomes

$$F_n / \delta = E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 + H \cdot T + K_3 \cdot \left(\frac{N_1}{\sqrt{\theta}} \right) + K_4 \cdot \left(\frac{N_1}{\sqrt{\theta}} \right)^2 \quad (\text{C-3})$$

where

$\frac{N_1}{\sqrt{\theta}}$ is the corrected low pressure rotor speed, %; and

K_3, K_4 are constants derived from installed engine data encompassing the N_1 speeds of interest.

Note that for a particular aeroplane, E, F, G_A, G_B and H in equations C-2 and C-3 might have different values from those in equation C-1.

3.5 Not every term in the equation will always be significant. For example, for flat-rated engines operating in air temperatures below the break point (typically 30°C), the temperature term may not be required. For engines not flat-rated, the ambient temperature must be considered when designating rated thrust. For an ambient temperature above the engine flat-rating temperature, a different set of engine thrust coefficients (E, F, G_A, G_B and H_{high}) must be used to determine the thrust level available. Normal practice would then be to compute F_n/δ using both the low temperature and high temperature coefficients and to use the higher thrust level for temperatures below the flat-rating temperature and use the lower calculated thrust level for temperatures above the flat-rating temperature.

3.6 Where only low temperature thrust coefficients are available, the following relationship may be used:

$$(F_n / \delta)_{high} = F \cdot V_c + (E + H \cdot T_B) \cdot (1 - 0.006 \cdot T) / (1 - 0.006 \cdot T_B) \quad (\text{C-4})$$

where

$(F_n/\delta)_{high}$ high-temperature corrected net thrust (pounds)

T_B break point temperature (in the absence of a definitive value, assume a default value of 30°C).

3.7 The ANP database provides values for the constants and coefficients in equations C-1 to C-4.

3.8 For propeller-driven aeroplanes, corrected net thrust per engine should be read from graphs or calculated using the equation

$$F_n / \delta = (326 \cdot \eta \cdot P_p / V_T) / \delta \quad (\text{C-5})$$

where

η is the propeller efficiency for a particular propeller installation and is a function of propeller rotational speed and aeroplane flight speed

V_T is the true airspeed, kt

P_p is net propulsive power for the given flight condition, e.g. maximum take-off or maximum climb power, hp

3.9 Parameters in equation C-5 are provided in the ANP database for maximum take-off thrust and maximum climb thrust settings.

3.10 True airspeed V_T is estimated from the calibrated airspeed V_C using the relationship

$$V_T = V_C / \sqrt{\sigma} \quad (\text{C-6})$$

where σ is the ratio of the air density at the aeroplane to the mean sea level value.

3.11 Guidance on modelling an operation with reduced take-off thrust

3.11.1 Often, aeroplane take-off masses are below the maximum allowable and/or the available runway field length exceeds the minimum required with the use of maximum take-off thrust. In these cases, it is common practice to reduce engine thrust below maximum levels in order to prolong engine life and, sometimes, for noise abatement purposes. Engine thrust can only be reduced to levels that maintain a required margin of safety. The calculation procedure used by airline operators to determine the amount of thrust reduction is regulated accordingly: it is complex and takes into account numerous factors including take-off weight, ambient air temperature, declared runway distances, runway elevation and runway obstacle clearance criteria. Therefore the amount of thrust reduction varies from flight to flight.

3.11.2 As these factors can have a profound effect upon departure noise contours, modellers should take reasonable account of reduced thrust operations and seek practical advice from operators.

3.11.3 If such advice is not available, it is still advisable to make some allowance by alternative means. It is impractical to mirror the operators' calculations for noise modelling purposes; nor would it be appropriate alongside the conventional simplifications and approximations, which are made for the purposes of calculating long-term average noise levels. As a practicable alternative the following guidance is provided, however, it should be emphasized that considerable research is ongoing in this area and thus this guidance is subject to change.

3.11.4 Analysis of FDR data has shown that the level of thrust reduction is strongly correlated with ratio of the actual take-off weight to the regulated take-off weight (RTOW), down to a fixed lower limit¹; i.e.

$$F_n / \delta = (F_n / \delta)_{\max} \cdot W / W_{\text{RTOW}} \quad (\text{C-7})$$

where $(F_n/\delta)_{\max}$ is the maximum rated thrust, W is the actual gross take-off weight and W_{RTOW} is the RTOW.

3.11.5 The RTOW is the maximum take-off weight that can be safely used, whilst satisfying take-off field length, engine-out and obstacle requirements. It is a function of the available runway length, airfield elevation, temperature, headwind, and flap angle. This information can be obtained from operators and should be more readily available than data on actual levels of reduced thrust. Alternatively, it may be computed using data contained in aeroplane flight manuals.

1. Airworthiness authorities normally stipulate a lower thrust limit, often 25 per cent below the maximum.

3.12 Guidance on modelling an operation with reduced climb

When employing reduced take-off thrust, operators often, but not always, reduce climb thrust from below maximum levels². This prevents situations occurring where, at the end of the initial climb at take-off thrust, power has to be increased rather than cut back. However, it is more difficult to establish a rationale for a common basis here. Some operators use fixed detents below maximum climb thrust, sometimes referred to as Climb 1 and Climb 2, typically reducing climb thrust by 10 and 20 per cent, respectively, relative to the maximum. It is recommended that whenever reduced take-off thrust is used, climb thrust levels also be reduced by 10 per cent.

4. VERTICAL PROFILES OF AIR TEMPERATURE, PRESSURE, DENSITY AND WIND SPEED

4.1 For the purposes of this manual, the variations of temperature, pressure and density, with height above mean sea level, are taken to be those of the International Standard Atmosphere [ref. 11]. The methodologies described below have been validated for aerodrome altitudes up to 4 000 ft above sea level and for air temperatures up to 43°C (109°F).

4.2 Although, in reality, mean wind velocity varies with both height and time, it is not usually practicable to take account of this for noise contour modelling purposes. Instead, the flight performance equations given below are based on the common assumption that the aeroplane is heading directly into a (default) headwind of 8 kt at all times — regardless of compass bearing (although no explicit account of mean wind velocity is taken in sound propagation calculations). Methods for adjusting the results for other headwind speeds are provided.

5. THE EFFECTS OF TURNS

5.1 The remainder of this appendix explains how to calculate the required properties of the segments joining the profile points s, z that define the two-dimensional flight path in the vertical plane above the flight track. Segments are defined in sequence in the direction of motion. At the end of any one segment (or at the start-of-roll in the case of the first for a departure) where the operational parameters and the next procedural step are defined, the climb angle and track distance to the point where the required height and/or speed are reached need to be calculated.

5.2 If the track is straight, this will be covered by a single profile segment, the geometry of which can then be determined directly (albeit sometimes with a degree of iteration). But if a turn starts or ends, or changes in radius or direction, before the required end conditions are reached, a single segment would be insufficient because the aeroplane lift and drag change with bank angle. To account for the effects of the turn on the climb, additional profile segments are required to implement the procedural step as follows.

5.3 The construction of the ground track is described in Chapter 3, 3.7.2. This is done independently of any aeroplane flight profile (although with care not to define turns that could not be flown under normal operating constraints). But as the flight profile — height and speed as a function of track distance — is affected by turns so that the flight profile cannot be determined independently of the ground track.

2. To which thrust is reduced after the initial climb at take-off power.

5.4 To maintain speed in a turn the aerodynamic wing lift has to be increased to balance centrifugal force as well as the aeroplane mass. This in turn increases drag and consequently the propulsive thrust required. The effects of the turn are expressed in the performance equations as functions of bank angle ε which, for an aeroplane in level flight turning at constant speed on a circular path, is given by

$$\varepsilon = \tan^{-1} \left\{ \frac{2.85 \cdot V^2}{r \cdot g} \right\} \quad (\text{C-8})$$

where V is the ground speed, kt
 r is the turn radius, ft
 g is the acceleration due to gravity, ft/s².

5.5 All turns are assumed to have a constant radius and second-order effects associated with non-level flight paths are disregarded; bank angles are based on the turn radius r of the ground track only.

5.6 To implement a procedural step, a provisional profile segment is first calculated using the bank angle ε at the start point — as defined by equation C-8 for the track segment radius r . If the calculated length of the provisional segment is such that it does not cross the start or end of a turn, the provisional segment is confirmed and attention turns to the next step.

5.7 But if the provisional segment crosses one or more starts or ends of turns (where ε changes)³, the flight parameters at the first such point are estimated by interpolation (see Chapter 3, 3.7.3), saved along with its coordinates as end point values, and the segment truncated. The second part of the procedural step is then applied from that point — once more assuming provisionally that it can be completed in a single segment with the same end conditions but with a new start point and new bank angle. If this second segment then passes another change of turn radius/direction, a third segment will be required and so on until the end-conditions are achieved.

5.8 Approximate method

The following guidance should be used when modelling the effects of turns with the approximate method. It will be apparent that accounting fully for the effects of turns, as described above, involves considerable computational complexity because the climb profile of any aeroplane has to be calculated separately for each ground track that it follows. But changes to the vertical profile caused by turns usually have a markedly smaller influence on the contours than the changes of bank angle, and some users may prefer to avoid the complexity — at the cost of some loss of precision — by disregarding the effects of turns on profiles while still accounting for the bank angle in the calculation of lateral sound emission (see Chapter 4, 4.6.3 and 4.6.4). Under this approximation, profile points for a particular aeroplane operation are calculated once only, assuming a straight ground track (for which $\varepsilon = 0$).

6. TAKE-OFF GROUND ROLL

6.1 Take-off thrust accelerates the aeroplane along the runway until lift-off. Calibrated airspeed is then assumed to be constant throughout the initial part of the climb-out. Landing gear, if retractable, is assumed to be retracted shortly after lift-off.

3. To avoid contour discontinuities caused by instantaneous changes of bank angle at the junctions between straight and turning flight, subsegments are introduced into the noise calculations to allow linear transitions of bank angle over the first and last 5° of the turn. These are not necessary in the performance calculations; the bank angle is always given by equation C-8.

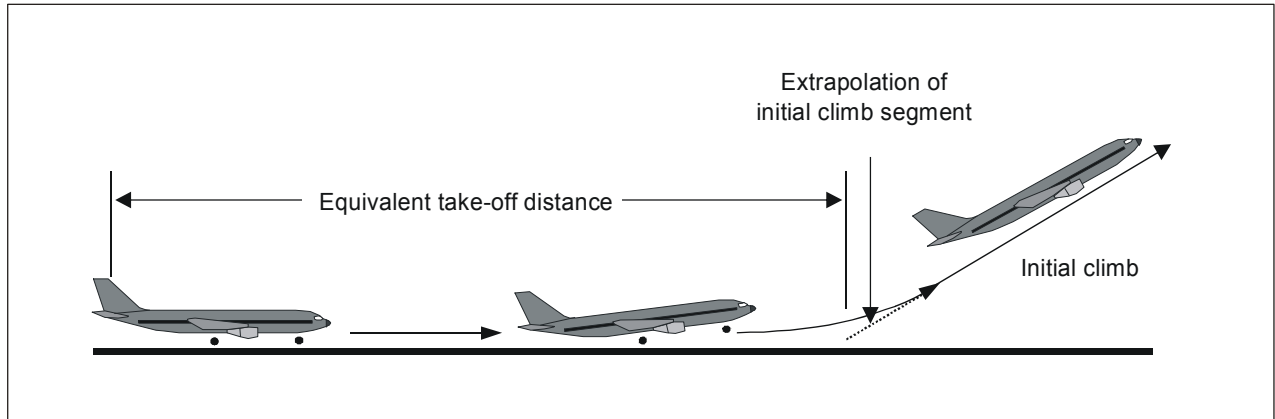


Figure C-1. Equivalent take-off distance

6.2 For the purpose of this manual, the actual take-off ground roll is approximated by an equivalent take-off distance (into a default headwind of 8 kt), s_{TO8} , defined as shown in Figure C-1, as the distance along the runway from brake release to the point where a straight line extension of the initial landing-gear-retracted climb flight path intersects the runway.

6.3 On a level runway, the equivalent take-off ground roll distance s_{TO8} in feet is determined from

$$s_{TO8} = \frac{B_8 \cdot \theta \cdot (W / \delta)^2}{N \cdot (F_n / \delta)} \quad (C-9)$$

where

B_8 is a coefficient appropriate to a specific aeroplane/flap-deflection combination for the ISA reference conditions, including the 8-knot headwind, ft/lbf

W is the aeroplane gross weight at brake release, lbf

N is the number of engines supplying thrust.

Note.— Since equation C-9 accounts for variation of thrust with airspeed and runway elevation for a given aeroplane, the coefficient B_8 depends only on flap deflection.

6.4 For headwind other than the default 8 kt, the take-off ground roll distance is corrected by using:

$$s_{TOW} = s_{TO8} \frac{(V_C - w)^2}{(V_C - 8)^2} \quad (C-10)$$

where

s_{TOW} is the ground roll distance corrected for headwind w , ft

V_C (in this equation) is the calibrated speed at take-off rotation, kt

w is the headwind, kt.

6.5 The take-off ground roll distance is also corrected for runway gradient as follows:

$$S_{TOG} = S_{TOW} \cdot \frac{a}{(a - g \cdot G_R)} \quad (C-11)$$

where

S_{TOG} is the ground roll distance (ft) corrected for headwind and runway gradient,

a is the average acceleration along the runway, equal to $(VC \cdot \sqrt{\sigma})^2 / (2 \cdot S_{TOW})$, ft/s²

G_R is the runway gradient; positive when taking off uphill.

7. CLIMB AT CONSTANT SPEED

7.1 This type of segment is defined by the aeroplane's calibrated airspeed, flap setting, and the height and bank angle at its end, together with the headwind speed (default 8 kt). As for any segment, the segment start parameters including corrected net thrust are put equal to those at the end of the preceding segment — there are no discontinuities (except of flap angle and bank angle which, in these calculations, are allowed to change in steps). The net thrusts at the segment end are first calculated using the appropriate equation from C-1 to C-5. The average geometric climb angle γ (see Figure C-1) is then given by

$$\gamma = \arcsin \left(K \cdot \left[N \cdot \frac{\overline{F_n / \delta}}{\overline{W / \delta}} - \frac{R}{\cos \varepsilon} \right] \right) \quad (C-12)$$

where the over-bars denote mid-segment values (= average of start-point and end point values — generally the mid-segment values) and

K is a speed-dependent constant equal to 1.01 when $V_C \leq 200$ kt or 0.95 otherwise. This constant accounts for the effects on climb gradient of climbing into an 8-knot headwind and the acceleration inherent in climbing at constant calibrated airspeed (true speed increases as air density diminishes with height).

R is the ratio of the aeroplane's drag coefficient to its lift coefficient appropriate to the given flap setting. The landing gear is assumed to be retracted.

ε Bank angle, radians

7.2 The climb angle is corrected for headwind w using:

$$\gamma_w = \gamma \cdot \frac{(V_C - 8)}{V_C - w} \quad (C-13)$$

where γ_w is the average climb angle corrected for headwind.

7.3 The distance that the aeroplane traverses along the ground track, Δs , while climbing at angle γ_w , from an initial altitude h_1 to a final altitude h_2 is given by

$$\Delta s = \frac{(h_2 - h_1)}{\tan \gamma_w} \quad (\text{C-14})$$

7.4 As a rule, two distinct phases of a departure profile involve climb at constant airspeed. The first, sometimes referred to as the initial climb segment is immediately after lift-off, where safety requirements dictate that the aeroplane is flown at a minimum airspeed of at least the take-off safety speed. This is a regulated speed and should be achieved by 35 ft above the runway during normal operation. However, it is common practice to maintain an initial climb speed slightly beyond the take-off safety speed, usually by 10-20 kt, as this tends to improve the initial climb gradient. The second is after flap retraction and initial acceleration, referred to as continuing climb.

During the initial climb, the airspeed is dependent on the take-off flap setting and the aeroplane gross weight. The calibrated initial climb speed V_{CTO} is calculated using the first order approximation:

$$V_{CTO} = C \cdot \sqrt{W} \quad (\text{C-15})$$

where C is a coefficient appropriate to the flap setting (kt/ $\sqrt{\text{lbf}}$), taken from the ANP database.

7.5 For continuing climb after acceleration, the calibrated airspeed is a user input parameter.

8. POWER CUTBACK (TRANSITION SEGMENT)

8.1 Power is reduced, or cut back, from take-off setting at some point after take-off in order to extend engine life and often to reduce noise in certain areas. Thrust is normally cut back during either a constant speed climb segment (section 6) or an acceleration segment (section 9). As it is a relatively brief process, typically of only 3 to 5 seconds duration, is it modelled by adding a “transition segment” to the primary segment. This usually covers a horizontal ground distance of 1 000 ft (305 m).

8.2 Amount of thrust reduction

8.2.1 During normal operations, the engine thrust is reduced to the maximum climb thrust setting. Unlike the take-off thrust, climb thrust can be sustained indefinitely, usually in practice until the aeroplane has reached its initial cruise altitude. The maximum climb thrust level is determined with equation C-1 using the manufacturer-supplied maximum thrust coefficients. However, noise abatement requirements may call for additional thrust reduction, sometimes referred to as a deep cutback. For safety purposes, the maximum thrust reduction is limited [ref. 20] to an amount determined by the performance of the aeroplane and the number of engines.

8.2.2 The minimum “reduced-thrust” level is sometimes referred to as the engine-out “reduced thrust”:

$$(F_n / \delta)_{\text{engine-out}} = \frac{W / \delta_2}{(N-1)} \cdot \left[\frac{\sin(\tan^{-1}(0.01 \cdot G'))}{K} + \frac{R}{\cos \epsilon} \right] \quad (\text{C-16})$$

where

δ_2 is the pressure ratio at altitude h_2

G' is the engine-out percentage climb gradient:
 = 0% for aeroplanes with automatic thrust restoration systems; otherwise,
 = 1.2% for a 2-engine aeroplane
 = 1.5% for a 3-engine aeroplane
 = 1.7% for a 4-engine aeroplane.

8.3 Constant speed climb segment with cutback

8.3.1 The climb segment gradient is calculated using equation C-12, with thrust calculated using either equation C-1 with maximum climb coefficients, or equation C-16 for reduced thrust. The climb segment is then broken into two subsegments, both having the same climb angle. This is illustrated in Figure C-2.

8.3.2 The first subsegment is assigned a 305 m (1 000 ft) ground distance, and the corrected net thrust per engine at the end of 305 m (1 000 ft) is set equal to the cutback value. (If the original horizontal distance is less than 610 m (2 000 ft), one half of the segment is used to cutback thrust.) The final thrust on the second subsegment is also set equal to the cutback thrust. Thus, the second subsegment is flown at constant thrust.

9. ACCELERATING CLIMB AND FLAP RETRACTION

9.1 This usually follows the initial climb. As for all flight segments, the start-point altitude h_1 , true airspeed V_{T1} , and thrust $(F_n/\delta)_1$ are those from the end of the preceding segment. The end point calibrated airspeed V_{C2} and the average climb rate (ROC) are user inputs (bank angle ϵ is a function of speed and radius of turn). As they are interdependent, the end-altitude h_2 , end-true airspeed V_{T2} , end-thrust $(F_n/\delta)_2$ and segment track length Δs have to be calculated by iteration; the end-altitude h_2 is guessed initially and then recalculated repeatedly using equations C-16 and C-17 until the difference between successive estimates is less than a specified tolerance, e.g. one foot. A practical initial estimate is $h_2 = h_1 + 250$ ft.

9.2 The segment track length (horizontal distance covered) is estimated as:

$$S_{\text{seg}} = 0.95 \cdot k \cdot k^2 \cdot (V_{T2}^2 - V_{T1}^2) / 2(a_{\text{max}} - G \cdot g) \quad (\text{C-17})$$

where

0.95 is a factor to account for the effect of an 8 kt headwind when climbing at 160 kt

k is a constant to convert kt to ft/sec = 1.688 ft/s per kt

V_{T2} = true airspeed at segment end, kt: $V_{T2} = V_{C2} / \sqrt{\sigma_2}$

where σ_2 = air density ratio at end-altitude h_2

a_{max} = maximum acceleration in level flight (ft/s^2) = $g \left[N \cdot \overline{F_n / \delta} / (\overline{W / \delta}) - R / \cos \epsilon \right]$

G = climb gradient $\approx \frac{\text{ROC}}{60 \cdot k \cdot V_T}$

where ROC = climb rate, ft/min

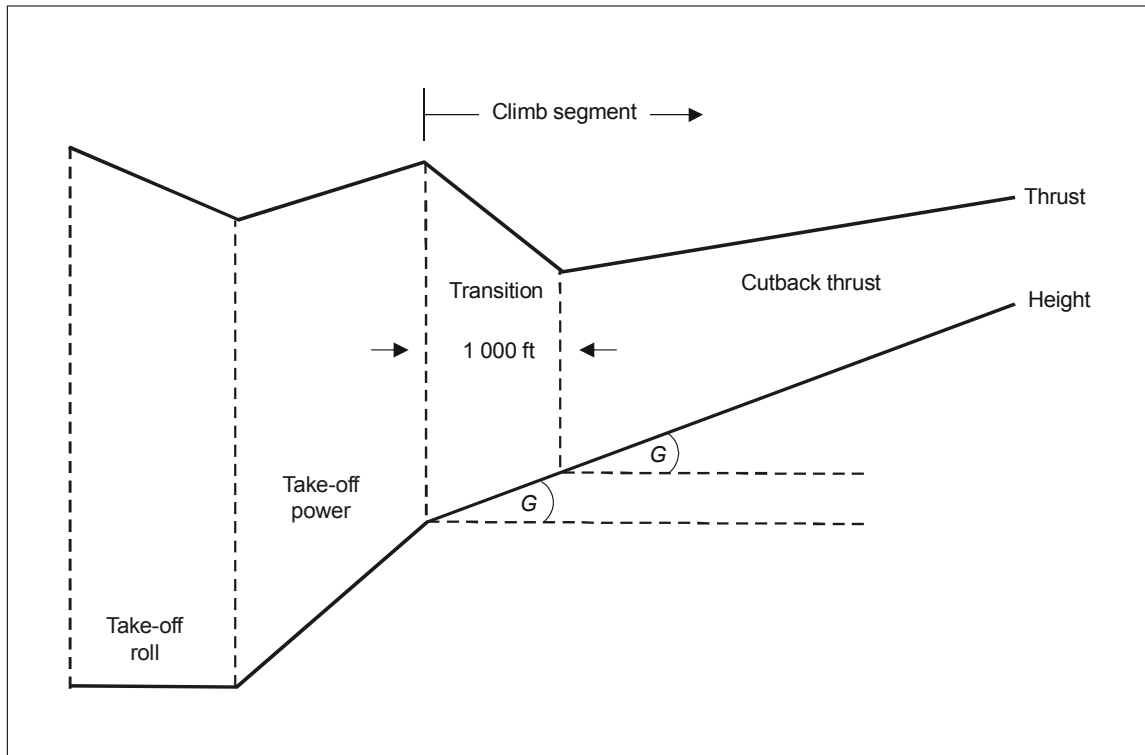


Figure C-2. Constant speed climb segment with cutback (illustration — not to scale)

9.3 Using this estimate of Δs , the end-altitude h_2' is then re-estimated using:

$$h_2' = h_1 + s \cdot G / 0.95 \quad (\text{C-18})$$

9.4 As long as the error $|h_2' - h_2|$ is outside the specified tolerance, the steps in equations C-17 and C-18 are repeated using the current iteration segment-end values of altitude h_2 , true airspeed V_{T2} , corrected net thrust per engine $(F_n/\delta)_2$. When the error is within the tolerance, the iterative cycle is terminated and the acceleration segment is defined by the final segment-end values.

Note.— If during the iteration process $(\alpha_{max} - G \cdot g) < 0.02g$, the acceleration may be too small to achieve the desired V_{C2} in a reasonable distance. In this case, the climb gradient can be limited to $G = \alpha_{max} g - 0.02$, in effect reducing the desired climb rate in order to maintain acceptable acceleration. If $G < 0.01$ it should be concluded that there is not enough thrust to achieve the acceleration and climb specified; the calculation should be terminated and the procedure steps revised⁴.

9.5 The acceleration segment length is corrected for headwind w by using:

$$\Delta s_w = \Delta s \cdot \frac{(V_T - w)}{(V_T - 8)} \quad (\text{C-19})$$

4. In either case, the computer model should be programmed to inform the user of the inconsistency.

9.6 Accelerating segment with cutback

Thrust cutback is inserted into an acceleration segment in the same way as for a constant speed segment — by turning its first part into a transition segment. The cutback thrust level is calculated as for the constant-speed cutback thrust procedure, using equation C-1 only. Note it is not generally possible to accelerate and climb while maintaining the minimum engine-out thrust setting. The thrust transition is assigned a 305 m (1 000 ft) ground distance, and the corrected net thrust per engine at the end of 305 m (1 000 ft) is set equal to the cutback value. The speed at the end of the segment is determined by iteration for a segment length of 305 m (1 000 ft). (If the original horizontal distance is less than 610 m (2 000 ft), one half of the segment is used for thrust change.) The final thrust on the second subsegment is also set equal to the cutback thrust. Thus, the second subsegment is flown at constant thrust.

10. ADDITIONAL CLIMB AND ACCELERATION SEGMENTS AFTER FLAP RETRACTION

If additional acceleration segments are included in the climb-out flight path, equations C-12 to C-19 should be used again to calculate the ground track distance, average climb angle, and height gain for each, and the final segment height must be estimated by iteration.

11. DESCENT AND DECELERATION

11.1 Approach flight normally requires the aeroplane to descend and decelerate in preparation for the final approach segment where the aeroplane is configured with the approach flap and gear down. The flight mechanics are unchanged from the departure case; the main difference is that the height and speed profile is generally known, and it is the engine thrust levels that must be estimated for each segment. The basic force balance equation is:

$$F_n / \delta = W \cdot \frac{R \cdot \cos \gamma + \sin \gamma + a / g}{N \cdot \delta} \quad (\text{C-20})$$

11.2 Equation C-20 may be used in two distinct ways. First, the aeroplane speeds at the start and end of a segment may be defined, along with a descent angle (or level segment distance) and initial and final segment altitudes. In this case, the deceleration may be calculated using:

$$a = \frac{(V_2 / \cos \gamma)^2 - (V_1 / \cos \gamma)^2}{(2 \cdot \Delta s / \cos \gamma)} \quad (\text{C-21})$$

where Δs is the ground distance covered and V_1 and V_2 are the initial and final ground speeds calculated using

$$V = \frac{V_C \cdot \cos \gamma}{\sqrt{\sigma}} \quad (\text{C-22})$$

11.3 Equations C-20, C-21 and C-22 confirm that while decelerating over a specified distance at a constant rate of descent, a stronger headwind will result in more thrust being required to maintain the same deceleration, while a tailwind will require less thrust to maintain the same deceleration. The most commonly practiced are decelerations during approach flight performed at idle thrust. Thus, for the second application of equation C-20, thrust is defined at an idle setting and the equation is solved iteratively to determine (1) the deceleration, and (2) the height at the end of the deceleration segment — in a similar manner to the departure acceleration segments. In this case, the deceleration distance can be very different with headwinds and tailwinds; it is sometimes necessary to reduce the descent angle in

order to obtain reasonable results.

11.4 For most aeroplanes, idle thrust is not zero and, for many, it is also a function of flight speed. Thus, equation C-20 is solved for the deceleration by inputting an idle thrust; the idle thrust is calculated using an equation of the form:

$$(F_n / \delta)_{idle} = E_{idle} + F_{idle} \cdot V_C + G_{A,idle} \cdot h + G_{B,idle} \cdot h^2 + H_{idle} \cdot T \quad (C-23)$$

where (E_{idle} , F_{idle} , $G_{A,idle}$, $G_{B,idle}$ and H_{idle}) are idle thrust engine coefficients available in the ANP database.

12. LANDING APPROACH

12.1 The landing approach calibrated airspeed, V_{CA} , is related to the landing gross weight by an equation of the same form as equation C-11, namely

$$V_{CA} \approx D \cdot \sqrt{W} \quad (C-24)$$

where the coefficient D (kt/ $\sqrt{\text{lbf}}$) corresponds to the landing flap setting.

12.2 The corrected net thrust per engine during descent along the approach glideslope is calculated by solving equation C-12 for the landing weight W and a drag-to-lift ratio R appropriate for the flap setting with landing gear extended. The flap setting should be that typically used in actual operations. During landing approach, the glideslope descent angle γ may be assumed constant. For jet-powered and multi-engine propeller aeroplanes, γ is typically -3° . For single-engine, propeller-powered aeroplanes, γ is typically -5° .

12.3 The average corrected net thrust is calculated by inverting equation C-12 using $K=1.03$ to account for the deceleration inherent in flying a descending flight path into an 8-knot reference headwind at the constant calibrated airspeed given by equation C-24, i.e.

$$\overline{F_n / \delta} = \frac{\overline{W / \delta}}{N} \cdot \left(R + \frac{\sin \gamma}{1.03} \right) \quad (C-25)$$

For headwinds other than 8 kt, average corrected net thrust becomes

$$\left(\overline{F_n / \delta} \right)_w = \overline{F_n / \delta} + 1.03 \cdot \overline{W / \delta} \cdot \frac{\sin \gamma \cdot (w - 8)}{N \cdot V_{CA}} \quad (C-26)$$

The horizontal distance covered is calculated by

$$\Delta s = \frac{(h_2 - h_1)}{\tan \gamma} \quad (C-27)$$

(positive since $h_1 > h_2$ and γ is negative).

13. EXAMPLES

13.1 The following examples for the Boeing 737-300 illustrate how the various equations are used with parameters defining aeroplane departure and approach “procedures” to construct flight profiles together with power

settings.

13.2 Departure profile

13.2.1 This example is for a Boeing 737-300 departure: take-off mass of 53 968 kg (119 000 lb), ISA conditions at sea level, headwind component 8 kt.

13.2.2 The procedural steps are:

1. Take-off, flap 5, full take-off thrust.
2. Maintain take-off power, climb at $V_2 + 10$ kt to 1 000 ft.
3. Maintain take-off power, accelerate to 185 kt CAS, climbing at 1 544 ft/min.
4. Maintain take-off power, select flap 1, accelerate to 190 kt CAS, climbing at 1 544 ft/min.
5. Reduce thrust to maximum climb thrust, select zero flap, accelerate to 220 kt CAS, climbing at 1 000 ft/min.
6. Maintain maximum climb thrust, 220 kt CAS, zero flap and climb to 3 000 ft.
7. Maintain maximum climb thrust, accelerate to 250 kt CAS, climbing at 1 000 ft/min.
8. Maintain maximum climb thrust and 250 kt CAS, zero flap and climb to 5 500 ft.
9. Maintain maximum climb thrust, 250 kt CAS, zero flap and climb to 7 500 ft⁵.
10. Maintain maximum climb thrust, 250 kt CAS, zero flap and climb to 10 000 ft.

13.2.3 The calculation steps and results are shown in Table C-1. Note that step 5 is split into two parts, the initial part including a 1 000-ft long segment to account for thrust reduction. The length of the segment following acceleration at the specified climb rate determines the end-speed for this segment.

13.3 Approach profile

13.3.1 This example is for a Boeing 737-300 on a relatively conventional approach with a long decelerating segment in level flight: landing mass 46 636 kg (102 600 lb), ISA conditions at sea level, 8 kt headwind.

13.3.2 The procedural steps are:

1. Descend from 6 000 ft to 3 000 ft with a descent angle of 3°, while maintaining 250 kt CAS, flap code zero.
2. At 3 000 ft, level off, select flap code 5 and decelerate to 170 kt CAS over a distance of 21 000 ft.
3. Maintain altitude of 3 000 ft, flap code 5 and decelerate to 148.6 kt CAS over a distance of 5 000 ft.

5. Although apparently redundant as step 10 supplants it, step 9, like much ANP content, dates from a time when models had to be less sophisticated. In this particular case, the original need was to reduce the risk of using excessively long segments. Modern tools designed for more capable computers can be designed to warn of such risks automatically.

4. Descend at 3°, select flap code D-15 and decelerate to 139 kt CAS by an altitude of 2 500 ft.
5. Descend at 3°, select flap code D-30 and maintain 139 kt (reference landing speed).
6. Touchdown roll out for 294 ft, decelerate to 132.1 kt.
7. Touchdown roll for 2 940 ft, thrust at 60% maximum.
8. End of procedure, speed at 30 kt, thrust at 10% maximum.

Note.— The approach example features a level flight segment at 3 000 ft along which speed is reduced and illustrates how the improved methodology may be applied. However, the specified “procedural steps” are not at present tabulated in the ANP database⁶. Data for the Boeing 737-300 were generated some years ago when the SAE data specifications called only for a continuous 3° descent from 6 000 ft to touchdown, while continuously decelerating. Such a flight profile is rarely typical of operations at most airports. Although the aerodynamic coefficients necessary to calculate more realistic approach profiles have still not been provided, more recent data entries remedy the problem via tabulations of “profile points” data for an approach with a 3 000 ft level flight segment. (A remaining difficulty with “profile points” is that they are fixed; alternative profiles cannot be created.) In future, the methodology described in section 9, will enable the provision of “procedural steps” data for profiles incorporating level flight segments and deceleration.

Table C-1. Example departure profile

Segment	Start of roll	Take-off ground roll	Climb to 1 000 ft	Accelerate to 185 kt	Accelerate to 190 kt	Thrust cutback	Accelerate to 220 kt	Climb to 3 000 ft	Accelerate to 250 kt	Climb to 5 500 ft	Climb to 7 500 ft	Climb to 10 000 ft
Start-speed (CAS) (kt)		0	164.6	164.6	185.0	190.0	196.7	220.0	220.0	250.0	250.0	250.0
End-speed (CAS) (kt)		164.6	164.6	185.0	190.0	196.7	220.0	220.0	250.0	250.0	250.0	250.0
Start-height (ft)		–	–	–	–	–	–	–	–	–	–	–
End-height (ft)		–	1 000	1 331	1 408	1 461	1 646	3 000	3 268	5 500	7 500	10 000
Input climb rate (ft/min)		–	–	1 544	1 544	1 000	1 000	–	1 000	–	–	–
Flap (°)		5	5	5	1	zero	zero	zero	zero	zero	zero	zero
Thrust rating (-)		Max take-off	Max take-off	Max take-off	Max take-off	Max climb	Max climb	Max climb	Max climb	Max climb	Max climb	Max climb
Start FN/δ (lb/eng)	18 745	18 745	15 433	15 837	15 561	14 376	14 269	13 894	14 105	13 627	13 974	14 286
End FN/δ (lb/eng)	–	15 433	15 837	15 561	15 492	14 269	13 894	14 105	13 627	13 974	14 286	14 675
Start θ (-)	1.000	1.000	1.000	0.993	0.991	0.990	0.990	0.989	0.979	0.978	0.962	0.948
End θ (-)	1.000	1.000	0.993	0.991	0.990	0.990	0.989	0.979	0.978	0.962	0.948	0.931
Start δ (-)	1.000	1.000	1.000	0.964	0.953	0.950	0.948	0.942	0.896	0.887	0.817	0.757
End δ (-)	1.000	1.000	0.964	0.953	0.950	0.948	0.942	0.896	0.887	0.817	0.757	0.688
Start σ (-)	1.000	1.000	1.000	0.971	0.962	0.959	0.958	0.953	0.915	0.908	0.849	0.798
End σ (-)	1.000	1.000	0.971	0.962	0.959	0.958	0.953	0.915	0.908	0.849	0.798	0.738
Weight/δ (mean) (lb)	119 000	119 000	121 173	124 140	125 067	125 365	125 910	129 509	133 435	139 768	151 324	164 882
Climb factor (-)	–	–	1.01	1.01	1.01	1.01	0.95	0.95	0.95	0.95	0.95	0.95
Climb gradient (-)	–	–	0.1817	0.1765	0.1748	0.1690	0.1542	0.1470	0.1390	0.1291	0.1188	0.1082

6. However, it is consistent with the current ANP database “procedural steps” to the extent that the flap deployment has been sequenced based on the same speeds.

Segment	Start of roll	Take-off ground roll	Climb to 1 000 ft	Accelerate to 185 kt	Accelerate to 190 kt	Thrust cutback	Accelerate to 220 kt	Climb to 3 000 ft	Accelerate to 250 kt	Climb to 5 500 ft	Climb to 7 500 ft	Climb to 10 000 ft
							(Accelerate to 220 kt)					
Wind adjustment (-)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Eq. take-off distance (ft)	-	5 506	-	-	-	-	-	-	-	-	-	-
Start VTAS (kt)	0.0	0.0	164.6	167.1	188.7	194.0	201.0	225.4	230.0	262.4	271.4	279.8
End VTAS (kt)	-	164.6	167.1	188.7	194.0	201.0	225.4	230.0	262.4	271.4	279.8	290.9
Sector distance gain (ft)	0	5 506	5 441	3 671	926	999	3 801	9 143	6 357	17 197	16 757	23 021
Sector height gain (ft)	0	0	1 000	331	78	53	185	1 354	268	2 232	2 000	2 500
Total distance gain (ft)	0	5 506	10 947	14 618	15 544	16 543	20 344	29 487	35 844	53 041	69 798	92 818
Total height gain (ft)	0	0	1 000	1 331	1 408	1 461	1 646	3 000	3 268	5 500	7 500	10 000

Table C-2. Example approach profile⁷

	Units	Step 1	Step 2		Step 3		Step 4		Step 5		Step 6	Step 7	Step 8
Flap code		zero	5	5	5	5	D-15	D-15	D-15	D-30	D-30	D-30	D-30
D		0	0	0	0	0	0	0	0	0.434	0.434	0.434	0.434
R		0.062	0.0791	0.0791	0.0791	0.0791	0.1103	0.1103	0.1103	0.1247	0.1247	0.1247	0.1247
Segment:		Descend	Level	Level	Level	Level	Descend	Descend	Descend	Descend	Land	Decelerate	Decelerate
Descent angle	(°)	-3	-	-	-	-	-3	-3	-3	-3	-3	-	-
Distance	(ft)		1 000	20 000	1 000	4 000	-	-	-	-	294	2 940	0
Ground thrust	(%)	-	-	-	-	-	-	-	-	-	-	60	10
Start:													
CAS	(kt)	<u>250.0</u>	<u>250.0</u>	<u>246.2</u>	<u>170.0</u>	<u>165.7</u>	<u>148.6</u>	147.6	<u>139.0</u>	139.0	139.0	<u>132.1</u>	30.0
Altitude (h)	(ft)	<u>6 000</u>	<u>3 000</u>	<u>3 000</u>	<u>3 000</u>	<u>3 000</u>	<u>3 000</u>	2 948	<u>2 500</u>	2 448	0	0	0
Δ h	(ft)	3 000	0	0	0	0	52.4	447.6	52.4	2 447.6	0	0	0
θ	(-)	0.959	0.979	0.979	0.979	0.979	0.979	0.980	0.983	0.983	1.000	1.000	1.000
δ	(-)	0.801	0.896	0.896	0.896	0.896	0.896	0.898	0.913	0.915	1.000	1.000	1.000
σ	(-)	0.836	0.915	0.915	0.915	0.915	0.915	0.917	0.929	0.930	1.000	1.000	1.000
TAS	(kt)	273.4	261.3	257.4	177.7	173.2	155.3	154.2	144.2	144.1	139.0	132.1	30.0
GSP	(kt)	265.5	253.3	249.4	169.7	165.2	147.3	146.2	136.2	136.1	131.0	0.0	0.0
RoD (ft/min)	(ft/min)	-1 258.6	0.0	0.0	0.0	0.0	-745.6	-721.4	-699.8	-699.8	0.0	0.0	0.0
Mid-values:													
θ	(-)	0.969	0.979	0.979	0.979	0.979	0.980	0.981	0.983	0.992	1.000	1.000	1.000
δ	(-)	0.849	0.896	0.896	0.896	0.896	0.897	0.905	0.914	0.957	1.000	1.000	1.000
σ	(-)	0.875	0.915	0.915	0.915	0.915	0.916	0.923	0.930	0.965	1.000	1.000	1.000
Calculation:													
Segment length (ft)	(ft)	57 243	1 000	20 000	1 000	4 000	1 000	8 541	1 000	46 703	-294	-2 940	0
Deceleration (m/s ²)	(m/s ²)	-0.048	-0.731	-0.731	-0.731	-0.615	0.000	-0.143	-0.143	0.000	-	-	-
Track distance	(ft)	140 487	83 243	82 243	62 243	61 243	57 243	56 243	47 703	46 703	0	-294	-3 234
FN/δ	(lb/eng)	302.1	260.8	260.8	260.8	936.5	936.5	2 467.6	2 427.3	4 144.0	3 790.4	8 000.0	2 000.0

7. Underlined figures are input procedural step values, other numbers are calculated.

Appendix D

MODELLING OF LATERAL GROUND TRACK SPREADING

1. It is recommended that, in the absence of radar data, lateral ground track dispersion be modelled on the assumption that the spread of tracks perpendicular to the backbone track follows a Gaussian normal distribution. Experience has shown that this assumption is reasonable in most cases.
2. Assuming a Gaussian distribution with a standard deviation S , illustrated in Figure D-1, about 98.8 per cent of all movements fall within boundaries of $\pm 2.5 \cdot S$ (i.e. within a swathe of width of $5 \cdot S$).
3. A Gaussian distribution can normally be modelled adequately using seven discrete sub-tracks evenly spaced between the $\pm 2.5 \cdot S$ boundaries of the swathe as shown in Figure D-1.
4. However, the adequacy of the approximation depends on the relationship of the sub-track track separation to the heights of the aeroplanes above. There may be situations (very tight or very dispersed tracks) where a different number of sub-tracks is more appropriate. Too few sub-tracks cause “fingers” to appear in the contour. Tables D-1 and D-2 show the parameters for a subdivision into between 5 and 13 sub-tracks. Table D-1 shows the location of the particular sub-tracks and Table D-2 shows the corresponding percentage of movements on each sub-track.

**Table D-1. Location of 5, 7, 9, 11 or 13 sub-tracks
(containing 98% of all movements)**

Sub-track number	Location of sub-tracks for subdivision into				
	5 sub-tracks	7 sub-tracks	9 sub-tracks	11 sub-tracks	13 sub-tracks
12 / 13					$\pm 2.31 \cdot S$
10 / 11				$\pm 2.27 \cdot S$	$\pm 1.92 \cdot S$
8 / 9			$\pm 2.22 \cdot S$	$\pm 1.82 \cdot S$	$\pm 1.54 \cdot S$
6 / 7		$\pm 2.14 \cdot S$	$\pm 1.67 \cdot S$	$\pm 1.36 \cdot S$	$\pm 1.15 \cdot S$
4 / 5	$\pm 2.00 \cdot S$	$\pm 1.43 \cdot S$	$\pm 1.11 \cdot S$	$\pm 0.91 \cdot S$	$\pm 0.77 \cdot S$
2 / 3	$\pm 1.00 \cdot S$	$\pm 0.71 \cdot S$	$\pm 0.56 \cdot S$	$\pm 0.45 \cdot S$	$\pm 0.38 \cdot S$
1	0	0	0	0	0

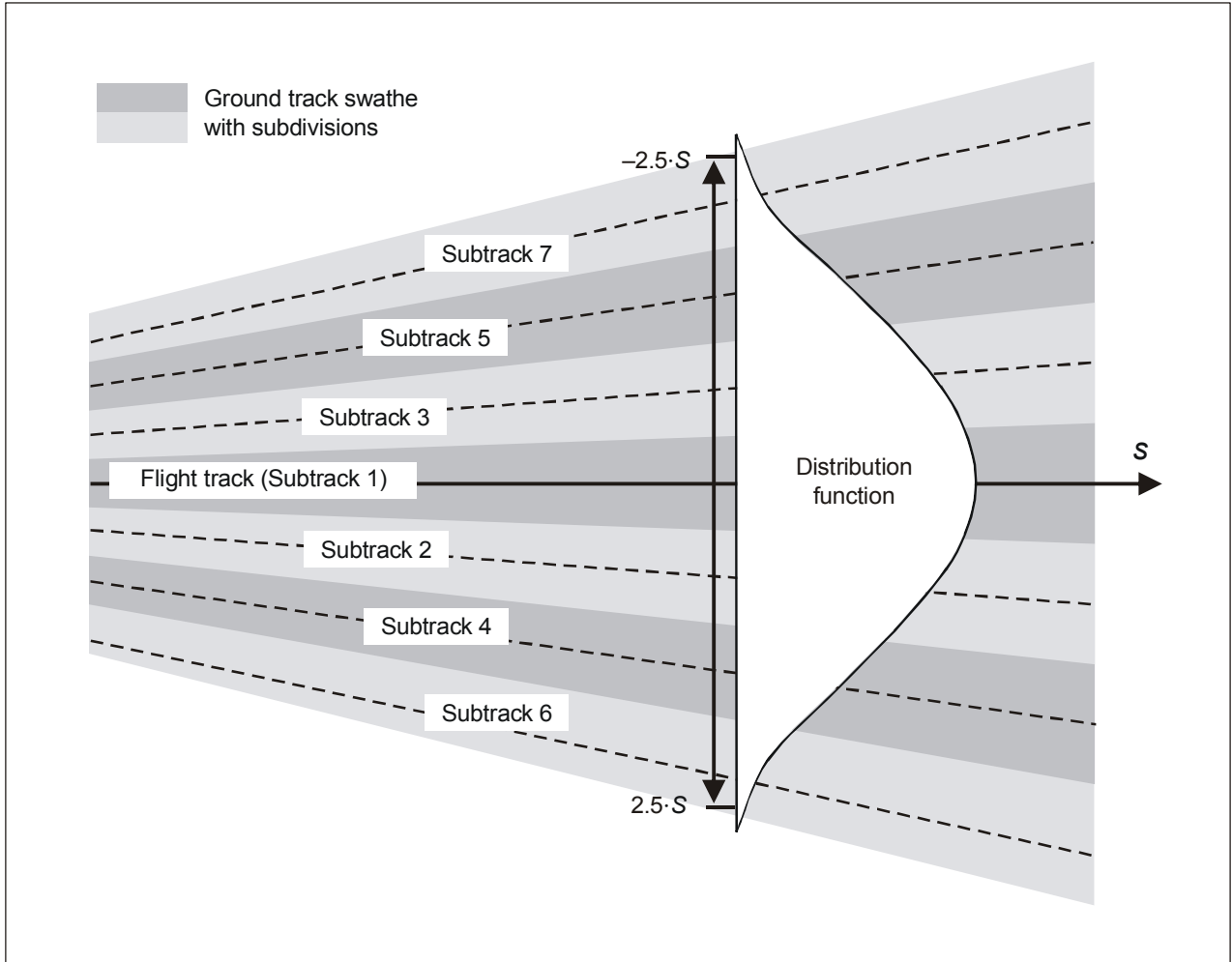


Figure D-1. Subdivision of a ground track into 7 sub-tracks (containing 98% of all movements)

**Table D-2. Percentage of movements on 5, 7, 9, 11 or 13 sub-tracks
(containing 98% of all movements)**

Sub-track number	Percentage of movements on sub-track for subdivision into				
	5 sub-tracks	7 sub-tracks	9 sub-tracks	11 sub-tracks	13 sub-tracks
12 / 13					1.1 %
10 / 11				1.4 %	2.5 %
8 / 9			2.0 %	3.5 %	4.7 %
6 / 7		3.1 %	5.7 %	7.1 %	8.0 %
4 / 5	6.3 %	10.6 %	12.1 %	12.1 %	11.5 %
2 / 3	24.4 %	22.2 %	19.1 %	16.6 %	14.4 %
1	38.6 %	28.2 %	22.2 %	18.6 %	15.6 %

Appendix E

RECALCULATION OF NOISE-POWER-DISTANCE (NPD) DATA FOR NON-REFERENCE CONDITIONS

1. The noise level contributions from each segment of the flight path are derived from the NPD data stored in the international ANP database. However, it is important to note that these data have been normalized using average atmospheric attenuation rates defined in SAE-AIR-1845 [ref. 1] based on analysis done during the seventh meeting of the ICAO Committee on Aircraft Noise [ref. 12]. Those rates are averages of values determined during aeroplane noise certification testing in Europe and the United States. The wide variation of atmospheric conditions (temperature and relative humidity) in those tests is shown in Figure E-1 (taken from [ref. 12]).

2. An atmospheric absorption adjustment accounts for changes in noise levels due to the atmospheric absorption for study or airport-specific atmospheric conditions that differ from the reference atmospheric conditions. The curves overlaid on Figure E-1, calculated using an industry standard atmospheric attenuation model SAE-ARP-866A [ref. 13], illustrate that across the test conditions a substantial variation of high frequency (8 kHz) sound absorption would be expected (although the variation of overall absorption would be less). SAE-ARP-5534 [ref. 17] is being evaluated as a possible replacement for SAE-ARP-866A for aircraft noise certification, as described in 4.3.7. Since this manual provides the flexibility to model non-standard atmospheric conditions with either SAE-ARP-5534 or SAE-ARP-866A, both methods are presented in this appendix.

3. Because the attenuation rates [ref. 1], given in Table E-1, are arithmetic averages, the complete set cannot be associated with a single reference atmosphere (i.e. with specific values of temperature and relative humidity). They should be thought of as properties of a purely notional atmosphere — referred to as the “SAE-AIR-1845 atmosphere”.

Table E-1. Average atmospheric attenuation rates from SAE-AIR-1845 [ref. 1]

Centre frequency of 1/3-octave band [Hz]	Attenuation rate [dB/100m]	Centre frequency of 1/3-octave band [Hz]	Attenuation rate [dB/100m]
50	0.033	800	0.459
63	0.033	1 000	0.590
80	0.033	1 250	0.754
100	0.066	1 600	0.983
125	0.066	2 000	1.311
160	0.098	2 500	1.705
200	0.131	3 150	2.295
250	0.131	4 000	3.115
315	0.197	5 000	3.607
400	0.230	6 300	5.246
500	0.295	8 000	7.213
630	0.361	10 000	9.836

ACTUAL DAY CONDITIONS RECORDED
DURING CERTIFICATION TESTING

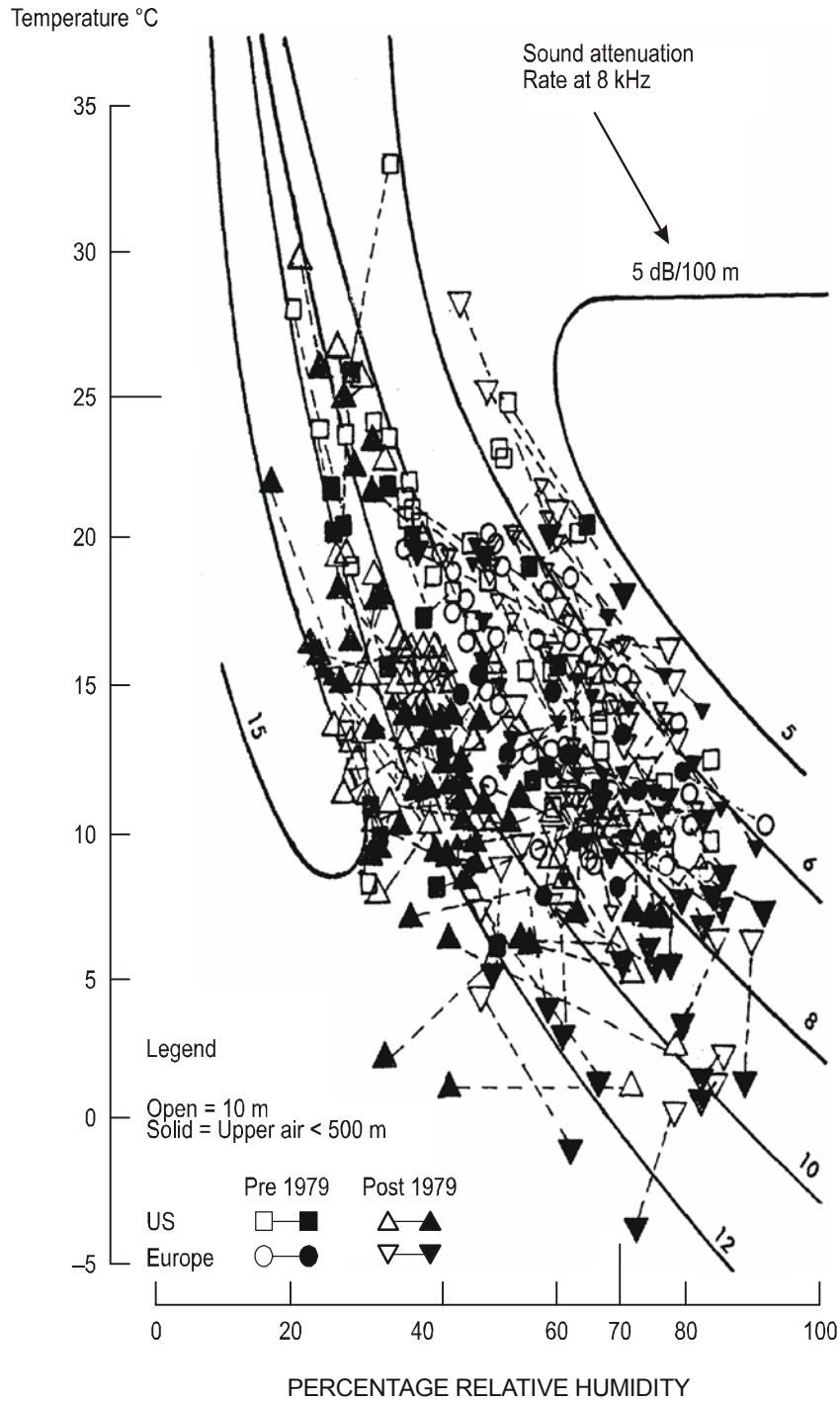


Figure E-1. Meteorological conditions recorded during noise certification tests [ref. 12]

4. The attenuation coefficients in Table E-1 should be considered valid over reasonable ranges of temperature and humidity. However, to check whether adjustments may be necessary, SAE-ARP-5534 or SAE-ARP-866A should be used to calculate the atmospheric absorption for the specific airport temperature T , relative humidity RH and atmospheric pressure p . If a comparison of these attenuation rates with those in Table E-1 indicates that an adjustment is required, the following methodology should be used.

5. The ANP database provides the following NPD data for each power setting (all data being normalized to the reference atmosphere):

- a) maximum sound level versus slant distance, $L_{\max}(d)$;
- b) time integrated level versus distance for the reference airspeed, $L_E(d)$; and
- c) unweighted reference sound spectrum at a slant distance of 305 m (1 000 ft), $L_{n,\text{ref}}(d_{\text{ref}})$ where n = frequency band (ranging from 1 to 24 for 1/3-octave bands with centre frequencies from 50 Hz to 10 kHz).

6. Adjustment of the NPD curves to user-specified conditions T and RH is performed in three steps:

6.1 The reference spectrum is corrected to remove the reference atmospheric attenuation $\alpha_{n,\text{ref}}$:

$$L_n(d_{\text{ref}}) = L_{n,\text{ref}}(d_{\text{ref}}) + \alpha_{n,\text{ref}} \cdot d_{\text{ref}} \quad (\text{E-1})$$

where $L_n(d_{\text{ref}})$ is the unattenuated spectrum at $d_{\text{ref}} = 305$ m (1 000 ft) and $\alpha_{n,\text{ref}}$ is the coefficient of atmospheric absorption for the frequency band n taken from Table E-1 (but expressed in dB/m).

6.2 The corrected spectrum is adjusted to each of the ten standard NPD distances¹ d_i using attenuation rates for both (1) the reference atmosphere; and (2) the specified atmosphere (based on either SAE-ARP-5534 or SAE-ARP-866A).

6.2.1 For the reference atmosphere:

$$L_{n,\text{ref}}(d_i) = L_n(d_{\text{ref}}) - 20 \cdot \lg(d_i / d_{\text{ref}}) - \alpha_{n,\text{ref}} \cdot d_i \quad (\text{E-2})$$

6.2.2 For the specified atmosphere:

$$L_{n,\text{atm}}(T, p_a, h_{\text{rel}}, d_i) = L_n(d_{\text{ref}}) - 20 \cdot \log\left(\frac{d_i}{d_{\text{ref}}}\right) - \delta_n(T, p_a, h_{\text{rel}}) \cdot d_i$$

$$L_{n,\text{atm}}(T, p_a, h_{\text{rel}}, d_i) = L_n(d_{\text{ref}}) - 20 \cdot \log\left(\frac{d_i}{d_{\text{ref}}}\right) - \delta_n(T, p_a, h_{\text{rel}}) \cdot d_i \quad (\text{E-3})$$

where $\delta_n(T, p_a, h_{\text{rel}})$ is the coefficient of atmospheric absorption for the frequency band n (expressed in dB/m) calculated using either SAE-ARP-5534 or SAE-ARP-866A with temperature T , atmospheric pressure p_a and relative humidity h_{rel} .

6.3 At each NPD distance d_i the two spectra are A-weighted and decibel-summed to determine the resulting A-weighted levels $L_{A,\text{atm}}$ and $L_{A,\text{ref}}$ which are then subtracted arithmetically:

1. The NPD distances are 200, 400, 630, 1 000, 2 000, 4 000, 6 300, 10 000, 16 000 and 25 000 ft.

$$\begin{aligned} \Delta_L(T, p_a, h_{rel}, d_i) &= L_{A,ATM}(T, p_a, h_{rel}, d_i) - L_{A,ref}(d_i) \\ &= 10 \cdot \log \left(\sum_{n=17}^{40} \frac{10^{(L_{n,atm}(T, p_a, h_{rel}, d_i) - A_n)}}{10} \right) - 10 \cdot \log \left(\sum_{n=17}^{40} 10^{(L_{n,ref}(d_i) - A_n)} / 10 \right) \end{aligned} \quad (E-4)$$

7. The increment $\Delta_L(T, p_a, h_{rel}, d_i)$ is the difference between the NPD in the specified atmosphere and the reference atmosphere at the NPD distance d_i . This is added to the ANP database NPD data value to derive the adjusted NPD data.

8. Applying $\Delta_L(T, p_a, h_{rel}, d_i)$ to adjust both L_{max} and L_E NPDs effectively assumes that different atmospheric conditions affect the reference spectrum only and have no effect on the shape of the level-time-history. This may be considered valid for typical propagation ranges and typical atmospheric conditions.

9. The following is an example of the application of the NPD spectral adjustment: adjust standard NPD data to the atmosphere 10°C, 80 per cent relative humidity and sea level atmospheric pressure.

9.1 Using the SEL NPD data presented in Appendix H for the V2527A, the matching spectral classes in the ANP database are 103 and 205 for departure and arrival, respectively. The spectra data are tabulated in Table E-2.

9.2 First the spectrum levels (referenced to 305 m (1 000 ft)) are corrected back to the source to remove the reference atmosphere, ignoring spherical spreading effects. This is done using equation E-1. The corresponding spectra at source are also tabulated in Table E-2.

Table E-2. Spectra for V2527 NPD from ANP database and calculated source spectra

Frequency (Hz)	At 1 000 ft		At source	
	DEP_103 (dB)	ARR_205 (dB)	DEP_103 (dB)	ARR_205 (dB)
50	56.7	68.3	56.8	68.4
63	66.1	60.7	66.2	60.8
80	70.1	64.6	70.2	64.7
100	72.8	67.4	73.0	67.6
125	76.6	78.4	76.8	78.6
160	73.0	74.8	73.3	75.1
200	74.5	71.4	74.9	71.8
250	77.0	72.4	77.4	72.8
315	75.3	72.0	75.9	72.6
400	72.2	72.4	72.9	73.1
500	72.2	71.6	73.1	72.5
630	71.2	72.0	72.3	73.1
800	70.2	71.0	71.6	72.4
1 000	70.0	70.0	71.8	71.8
1 250	69.6	68.9	71.9	71.2
1 600	71.1	67.2	74.1	70.2
2 000	70.6	65.8	74.6	69.8
2 500	67.1	64.4	72.3	69.6
3 150	63.4	63.0	70.4	70.0
4 000	63.5	62.0	73.0	71.5

Frequency (Hz)	At 1 000 ft		At source	
	DEP_103 (dB)	ARR_205 (dB)	DEP_103 (dB)	ARR_205 (dB)
5 000	58.2	60.6	69.2	71.6
6 300	51.5	54.4	67.5	70.4
8 000	42.3	48.5	64.3	70.5
10 000	37.7	39.0	67.7	69.0

9.3 The source spectra data are then propagated out to the standard NPD data distances using equations E-2 and E-3, together with the absorption coefficients in Table E-1 for the reference atmosphere and using absorption coefficients calculated using SAE ARP-866A [ref. 15] and SAE ARP-5534 [ref. 17] for the atmosphere, 10°C, 80% relative humidity, 101.325 kPa (sea level). All three sets of absorption coefficients are listed in Table E-3.

Table E-3. Reference absorption coefficients (from Table E-1) and coefficients for 10°C/80% relative humidity/101.325 kPa calculated using SAE-ARP-866A and SAE-ARP-5534

Frequency (Hz)	Reference absorption (dB/100 m)	ARP-866A 10°C/80% relative humidity (dB/100 m)	ARP-5534 10°C/80% relative humidity /101.325 kPa (dB/100 m)
50	0.033	0.021	0.007
63	0.033	0.027	0.011
80	0.033	0.034	0.017
100	0.066	0.043	0.026
125	0.066	0.053	0.039
160	0.098	0.068	0.056
200	0.131	0.086	0.078
250	0.131	0.107	0.104
315	0.197	0.135	0.134
400	0.230	0.172	0.166
500	0.295	0.216	0.201
630	0.361	0.273	0.241
800	0.459	0.349	0.292
1 000	0.590	0.439	0.364
1 250	0.754	0.552	0.471
1 600	0.983	0.738	0.636
2 000	1.311	0.985	0.893
2 500	1.705	1.322	1.297
3 150	2.295	1.853	1.931
4 000	3.115	2.682	2.922
5 000	3.607	3.216	4.461
6 300	5.246	4.580	6.826
8 000	7.213	6.722	10.398
10 000	9.836	9.774	15.661

9.4 At each NPD distance, the 1/3-octave band levels are A-weighted and decibel-summed to give the overall A-weighted level at each distance. This is repeated for both the departure spectrum (103) and the approach spectrum (205). For each NPD distance, the A-weighted levels are then subtracted to give the increment, Δ_L . The A-weighted levels and increments Δ_{AA} are shown in Table E-5 for SAE-ARP-866A and Table E-6 for SAE-ARP-5534.

Table E-4. A-weighted levels for reference and SAE-ARP-866A atmosphere and difference between each atmosphere, Δ_L

Distance (ft)	DEP_103			ARR_205		
	$L_{A,ref}$ (dBA)	$L_{A,866A}$ (dBA)	Δ_L (dB)	$L_{A,ref}$ (dBA)	$L_{A,866A}$ (dBA)	Δ_L (dB)
200	97.0	97.2	0.2	95.8	95.9	0.1
400	90.3	90.6	0.3	88.9	89.2	0.3
630	85.6	86.0	0.4	84.2	84.6	0.4
1 000	80.6	81.2	0.6	79.2	79.8	0.5
2 000	72.5	73.4	0.9	71.3	72.2	0.8
4 000	63.6	64.9	1.3	62.7	63.9	1.2
6 300	57.4	59.0	1.5	56.4	58.0	1.6
10 000	50.7	52.5	1.8	49.5	51.4	2.0
16 000	43.3	45.5	2.2	41.8	44.1	2.3
25 000	35.3	38.2	2.8	34.0	36.7	2.7

Table E-5. A-weighted levels for reference and SAE-ARP-5534 atmosphere and difference between each atmosphere, Δ_L

Distance (ft)	DEP_103			ARR_205		
	$L_{A,ref}$ (dBA)	$L_{A,5534}$ (dBA)	Δ_L (dB)	$L_{A,ref}$ (dBA)	$L_{A,5534}$ (dBA)	Δ_L (dB)
200	97.0	97.1	0.1	95.8	95.8	0.0
400	90.3	90.6	0.3	88.9	89.1	0.2
630	85.6	86.1	0.4	84.2	84.6	0.3
1 000	80.6	81.3	0.7	79.2	79.8	0.6
2 000	72.5	73.7	1.2	71.3	72.4	1.1
4 000	63.6	65.4	1.8	62.7	64.4	1.7
6 300	57.4	59.6	2.1	56.4	58.6	2.2
10 000	50.7	53.2	2.4	49.5	52.2	2.7
16 000	43.3	46.2	2.9	41.8	45.0	3.2
25 000	35.3	38.9	3.6	34.0	37.7	3.7

9.5 The departure and approach increments shown in Tables E-4 and E-5 are then added to the departure and approach ANP database NPD thrust levels (Table E-6a) to construct the new NPD with SAE-AIR-866A shown in Table E-6b atmospheric absorption and new NPD with SAE-AIR-5534 atmospheric absorption shown in Table E-6c.

Table E-6a. Original NPD data

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	Power									
				L_200ft	L_400ft	L_630ft	L_1 000ft	L_2 000ft	L_4 000ft	L_6 300ft	L_10 000ft	L_16000ft	L_25 000ft
V2527A SEL	A	2 000	93.1	89.1	86.1	82.9	77.7	71.7	67.1	61.9	55.8	49.2	
V2527A SEL	A	2 700	93.3	89.2	86.2	83.0	77.7	71.8	67.2	62.0	55.8	49.3	
V2527A SEL	A	6 000	94.7	90.5	87.4	83.9	78.5	72.3	67.7	62.5	56.3	49.7	
V2527A SEL	D	10 000	95.4	90.7	87.3	83.5	77.7	71.1	66.3	60.9	54.6	47.4	
V2527A SEL	D	14 000	100.4	96.1	93.0	89.4	83.5	77.0	72.2	66.7	60.1	53.0	
V2527A SEL	D	18 000	103.2	99.1	96.2	92.9	87.4	81.1	76.5	71.1	64.9	57.9	
V2527A SEL	D	22 500	105.1	101.2	98.5	95.4	90.3	84.3	79.9	74.8	68.7	62.0	

Table E-6b. Revised NPD data using SAE-ARP-866A

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	Power									
				L_200ft	L_400ft	L_630ft	L_1 000ft	L_2 000ft	L_4 000ft	L_6 300ft	L_10 000ft	L_16 000ft	L_25 000ft
V2527A SEL	A	2 000	93.2	89.4	86.5	83.4	78.5	72.9	68.7	63.9	58.1	51.9	
V2527A SEL	A	2 700	93.4	89.5	86.6	83.5	78.5	73.0	68.8	64.0	58.1	52.0	
V2527A SEL	A	6 000	94.8	90.8	87.8	84.4	79.3	73.5	69.3	64.5	58.6	52.4	
V2527A SEL	D	10 000	95.6	91.0	87.7	84.1	78.6	72.4	67.8	62.7	56.8	50.2	
V2527A SEL	D	14 000	100.6	96.4	93.4	90.0	84.4	78.3	73.7	68.5	62.3	55.8	
V2527A SEL	D	18 000	103.4	99.4	96.6	93.5	88.3	82.4	78.0	72.9	67.1	60.7	
V2527A SEL	D	22 500	105.3	101.5	98.9	96.0	91.2	85.6	81.4	76.6	70.9	64.8	

Table E-6c. Revised NPD data using SAE-ARP-5534

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	Power									
				L_200ft	L_400ft	L_630ft	L_1 000ft	L_2 000ft	L_4 000ft	L_6 300ft	L_10 000ft	L_16 000ft	L_25 000ft
V2527A SEL	A	2 000	93.1	89.3	86.4	83.5	78.8	73.4	69.3	64.6	59.0	52.9	
V2527A SEL	A	2 700	93.3	89.4	86.5	83.6	78.8	73.5	69.4	64.7	59.0	53.0	
V2527A SEL	A	6 000	94.7	90.7	87.7	84.5	79.6	74.0	69.9	65.2	59.5	53.4	
V2527A SEL	D	10 000	95.5	91.0	87.7	84.2	78.9	72.9	68.4	63.3	57.5	51.0	
V2527A SEL	D	14 000	100.5	96.4	93.4	90.1	84.7	78.8	74.3	69.1	63.0	56.6	
V2527A SEL	D	18 000	103.3	99.4	96.6	93.6	88.6	82.9	78.6	73.5	67.8	61.5	
V2527A SEL	D	22 500	105.2	101.5	98.9	96.1	91.5	86.1	82.0	77.2	71.6	65.6	

Appendix F

THE FINITE SEGMENT CORRECTION

1. INTRODUCTION

1.1 This appendix outlines the derivation of the finite segment correction and the associated energy fraction algorithm described in Chapter 4, 4.6.7.

2. GEOMETRY

2.1 The energy fraction algorithm is based on the sound radiation of a “fourth-power” 90-degree dipole sound source. This has directional characteristics, which approximate those of jet aeroplane sound, in the angular region that most influences sound event levels beneath and to the side of the aeroplane flight path.

2.2 Figure F-1 illustrates the geometry of sound propagation between the flight path and the observer location **O**. The aeroplane at **P** is flying in still uniform air with a constant speed on a straight, level flight path. Its closest point of approach to the observer is **P_p**. The parameters are:

- d distance from the observer to the aeroplane
- d_p perpendicular distance from the observer to the flight path (slant distance)
- q distance from **P** to **P_p** = $-V \cdot \tau$
- V speed of the aeroplane
- t time at which the aeroplane is at point **P**
- t_p time at which the aeroplane is located at the point of closest approach **P_p**
- τ flight time = time relative to time at **P_p** = $t - t_p$
- Ψ angle between flight path and aeroplane-observer vector

2.3 It should be noted that, since the flight time τ relative to the point of closest approach is negative when the aeroplane is before the observer position (as shown in Figure F-1), the relative distance q to the point of closest approach becomes positive. If the aeroplane is ahead of the observer, q becomes negative.

3. ESTIMATION OF THE ENERGY FRACTION

3.1 The basic concept of the energy fraction is to express the noise exposure E produced at the observer position from a flight path segment **P₁P₂** (with a start-point **P₁** and an end point **P₂**) by multiplying the exposure E_∞ from the whole infinite path fly-by by a simple factor — the energy fraction factor F :

$$E = F \cdot E_\infty \quad (\text{F-1})$$

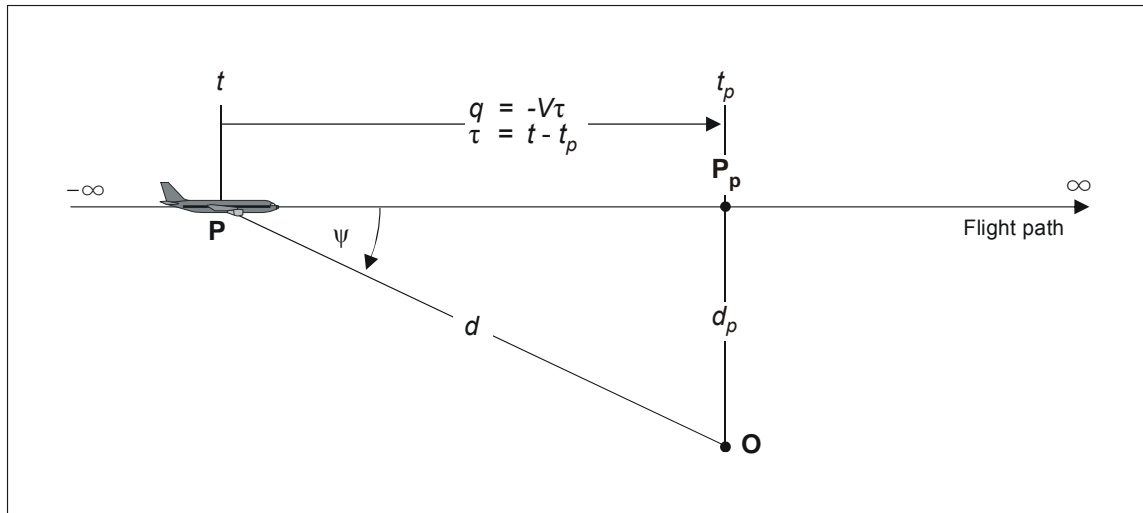


Figure F-1. Geometry between flight path and observer location O

3.2 Since the exposure can be expressed in terms of the time integral of the mean-square (weighted) sound pressure level, i.e.

$$E = \text{const} \cdot \int p^2(\tau) d\tau \quad (\text{F-2})$$

the mean-square pressure has to be expressed as a function of the known geometric and operational parameters. For a 90° dipole source,

$$p^2 = p_p^2 \cdot \frac{d_p^2}{d^2} \cdot \sin^2 \psi = p_p^2 \cdot \frac{d_p^4}{d^4} \quad (\text{F-3})$$

where p^2 and p_p^2 are the observed mean-square sound pressures produced by the aeroplane as it passes points **P** and **P_p**.

3.3 This relationship provides a satisfactory simulation of civil jet aeroplane noise, even though the real mechanisms involved are extremely complex. The term d_p^2/d^2 in equation F-3 describes only the mechanism of spherical spreading appropriate to a point source, an infinite sound speed and a uniform, non-dissipative atmosphere. All other physical effects — source directivity, finite sound speed, atmospheric absorption, Doppler-shift, etc. — are implicitly covered by the $\sin^2 \psi$ term. This factor causes the mean-square pressure to decrease inversely as d^4 ; whence the expression “fourth power” source.

3.4 By introducing the substitutions

$$d^2 = d_p^2 + q^2 = d_p^2 + (V \cdot \tau)^2 \quad (\text{F-4})$$

$$\text{and} \quad \left(\frac{d}{d_p} \right)^2 = 1 + \left(\frac{V \cdot \tau}{d_p} \right)^2 \quad (\text{F-5})$$

the mean-square pressure can be expressed as a function of time (again disregarding sound propagation time):

$$p^2 = p_p^2 \cdot \left(1 + \left(\frac{V \cdot \tau}{d_p} \right)^2 \right)^{-2} \quad (\text{F-6})$$

3.5 By putting this into an equation (F-2) and performing the substitution

$$\alpha = \frac{V \cdot \tau}{d_p} \quad (\text{F-7})$$

the sound exposure at the observer from the fly-by between the time interval $[\tau_1, \tau_2]$ can be expressed as

$$E = \text{const} \cdot p_p^2 \cdot \frac{d_p}{V} \int_{\alpha_1}^{\alpha_2} \frac{1}{(1 + \alpha^2)^2} d\alpha \quad (\text{F-8})$$

3.6 The solution of this integral is:

$$E = \text{const} \cdot p_p^2 \cdot \frac{d_p}{V} \cdot \frac{1}{2} \left(\frac{\alpha_2}{1 + \alpha_2^2} + \tan^{-1} \alpha_2 - \frac{\alpha_1}{1 + \alpha_1^2} - \tan^{-1} \alpha_1 \right) \quad (\text{F-9})$$

3.7 Integration over the interval $[-\infty, +\infty]$ (i.e. over the whole infinite flight path) yields the following expression for the total exposure E_∞ :

$$E_\infty = \text{const} \cdot \frac{\pi}{2} \cdot p_p^2 \cdot \frac{d_p}{V} \quad (\text{F-10})$$

and hence the energy fraction according to equation F-1 is

$$F = \frac{1}{\pi} \left(\frac{\alpha_2}{1 + \alpha_2^2} + \tan^{-1} \alpha_2 - \frac{\alpha_1}{1 + \alpha_1^2} - \tan^{-1} \alpha_1 \right) \quad (\text{F-11})$$

4. CONSISTENCY OF MAXIMUM- AND TIME-INTEGRATED METRICS — THE SCALED DISTANCE

4.1 A consequence of using the simple dipole model to define the energy fraction is that it implies a specific theoretical difference Δ_L between the event noise levels L_{max} and L_E . If the contour model is to be internally consistent, this needs to equal the difference of the values determined from the NPD curves. A problem is that the NPD data are derived from actual aeroplane noise measurements which do not necessarily comply with the simple theory. The theory therefore needs an added element of flexibility, but, in principal, the variables α_1 and α_2 are determined by geometry and aeroplane speed, thus leaving no further degrees of freedom. A solution is provided by the concept of a *scaled distance* d_s as follows.

4.2 The exposure level $L_{E,\infty}$ as tabulated as a function of d_p in the ANP database for a reference speed V_{ref} , can be expressed as

$$L_{E,\infty}(V_{ref}) = 10 \cdot \log \left[\frac{\int_{-\infty}^{\infty} p^2 \cdot dt}{p_0^2 \cdot t_{ref}} \right] \quad (F-12)$$

where p_0 is a standard reference pressure and t_{ref} is a reference time (= 1 s for SEL). For the actual speed V it becomes

$$L_{E,\infty}(V) = L_{E,\infty}(V_{ref}) + 10 \cdot \log \left[\frac{V_{ref}}{V} \right] \quad (F-13)$$

4.3 Similarly, the maximum event level L_{max} can be written

$$L_{max} = 10 \cdot \log \left[\frac{p_p^2}{p_0^2} \right] \quad (F-14)$$

4.4 For the dipole source, using equations F-10, F-13 and F-14, noting that (equations F-2 and F-8)

$$\int_{-\infty}^{\infty} p^2 \cdot dt = \frac{\pi}{2} \cdot p_p^2 \cdot \frac{d_p}{V} \quad (F-15)$$

the difference Δ_L can be written:

$$\Delta L = L_{E,\infty} - L_{max} = 10 \cdot \log \left[\frac{V}{V_{ref}} \cdot \frac{\pi}{2} \cdot p_p^2 \cdot \frac{d_p}{V} \right] \cdot \frac{1}{p_0^2 \cdot t_{ref}} - 10 \cdot \log \left[\frac{p_p^2}{p_0^2} \right] \quad (F-16)$$

4.5 This can only be equated to the value of Δ_L determined from the NPD data if the slant distance d_p used to calculate the energy fraction is substituted by a *scaled distance* d_λ given by

$$d_\lambda = \frac{\pi}{2} \cdot V_{ref} \cdot t_{ref} \cdot 10^{(L_{E,\infty} - L_{max})/10} \quad (F-17)$$

4.6 Replacing d_p by d_λ in equation F-7 and using the definition $q = V\tau$ from Figure F-1 the parameters α_1 and α_2 in equation F-9 can be written (putting $q = q_1$ at the start-point and $q - \lambda = q_2$ at the end point of a flight path segment of length λ) as

$$\alpha_1 = \frac{-q_1}{d_\lambda} \quad \text{and} \quad \alpha_2 = \frac{-q_1 + \lambda}{d_\lambda} \quad (F-18)$$

4.7 Having to replace the slant actual distance by scaled distance diminishes the simplicity of the fourth-power 90 degree dipole model. But as it is effectively calibrated using data derived from measurements, the energy fraction algorithm can be regarded as semi-empirical rather than purely theoretical.

Appendix G

MAXIMUM LEVEL OF NOISE EVENTS

1. In Chapter 5, equation 5-6 introduces a step-function $u(k)$ which determines whether the maximum level contribution from flight path segment k is the maximum level of a noise event or not:

$$u(k) = \begin{cases} 0 \\ 1 \end{cases} \text{ if } L_{\max,k} \begin{cases} \text{is not} \\ \text{is} \end{cases} \text{ the maximum level of a noise event} \quad (\text{G-1})$$

2. In Figure G-1 a flow diagram shows the steps by which this function can be estimated for each aeroplane type and ground track (or sub-track).

3. The procedure uses four variables:

k is the number of the current track (or sub-track) segment

$L_{\max,k}$ is the maximum level from the current track (or sub-track) segment

L is the maximum level of the actual noise event

i is a pointer to the segment which produces the maximum level L

4. The procedure is presented below:

❶ Initialize the variables: set the sub-track counter k to one, set the pointer i to the actual maximum event level to one and set the variable L representing the maximum level of the actual noise event to $L_{\max,1}$. This means that the maximum level of the first track segment is to be assumed the maximum level of the first noise event. Additionally, initialize the variable $u(1)$ with zero.

❷ Perform a loop over all segments of the actual ground (sub-track) increasing the segment number by one.

❸ If the last segment is processed, leave the loop. Set the variable $u(i)$ for the last marked maximum level to one. If the current segment is not the last one, set the variable $u(k)$ for this segment to zero (i.e. initialize it).

❹ Check if the maximum level $L_{\max,k}$ from the actual segment is higher than the maximum level L of the current noise event. If so, set $L = L_{\max,k}$ and set the marker i to the current segment number ($i = k$). Then branch to the next segment (i.e. to step ❷).

❺ Estimate the difference between the maximum level L of the current noise event and the maximum level of the current segment. If it is less than 10 dB, the event is not yet finished — branch to step ❷.

❻ The actual noise event is finished. Start a new event by setting the maximum level of this new event to $L = L_{\max,k}$ and set the counter $i = k$. This is similar to step ❶.

5. Steps ⑤ and ⑥ are not necessary if only the highest maximum level produced by the actual aeroplane type on the actual (sub-track) has to be estimated. In this case, branch directly from step ④ to step ②.

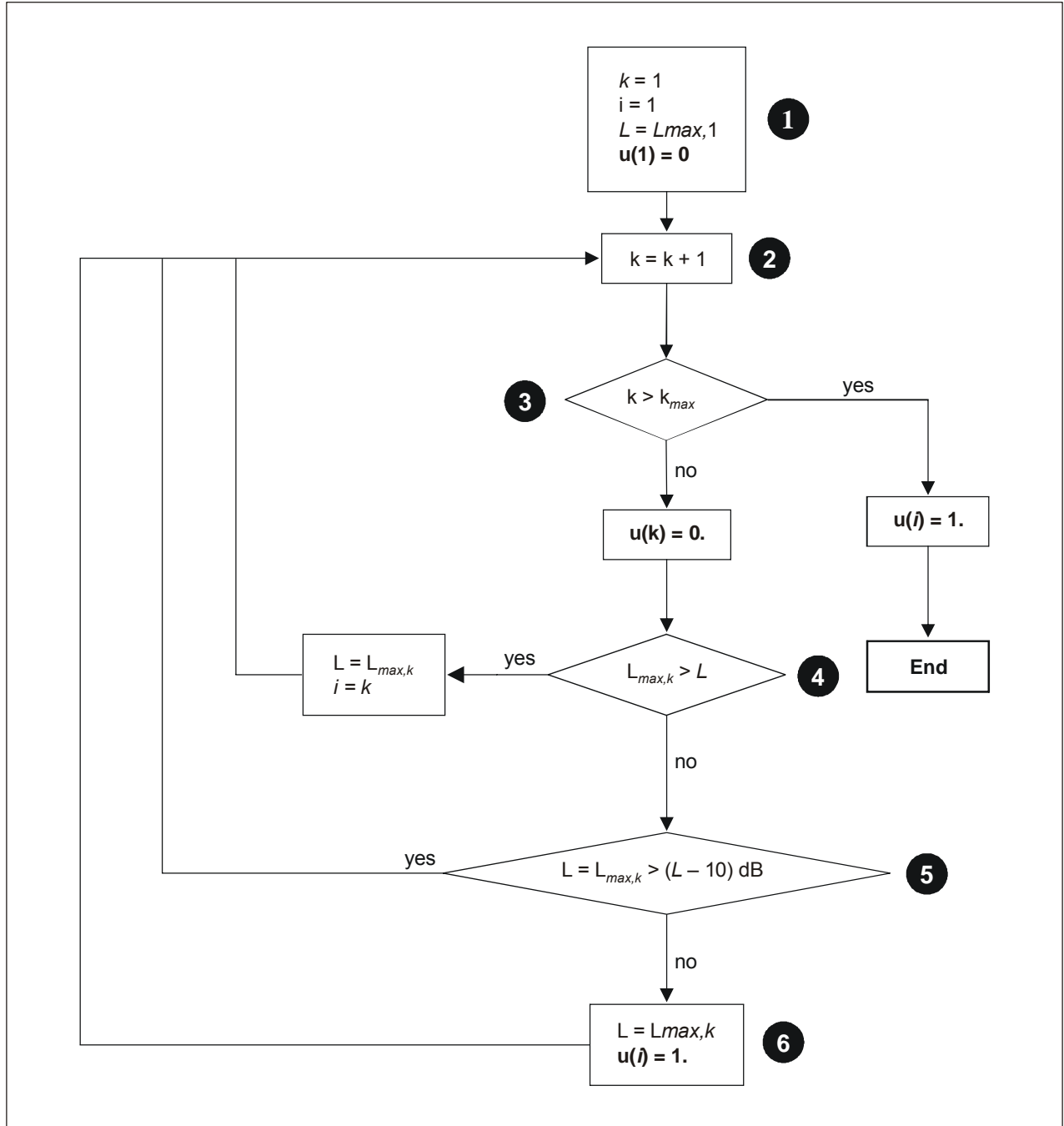


Figure G-1. Flow diagram for the estimation of the function $u(k)$

Appendix H

THE INTERNATIONAL AIRCRAFT NOISE AND PERFORMANCE (ANP) DATABASE

1. INTRODUCTION

1.1 To support the development of accurate aeroplane noise contour models, an online aircraft noise and performance (ANP) database has been established, accessible at www.aircraftnoisemodel.org.

1.2 Data sources

1.2.1 The data accord with specifications and formats laid down by the international Society of Automotive Engineers (SAE) in AIR 1845 [ref. 1], which are designed to achieve best practicable levels of data quality and consistency. By preference, entries are supplied by the aeroplane manufacturers and these cover most of the larger, modern aeroplane models and variants in the world's airline fleets and therefore govern the noise at most major airports. Those entries usually include noise data acquired during noise certification tests carried out under stringent internationally standardized procedures that are regulated by national and international certification agencies. Data for some other aeroplanes, mainly those of less general noise significance, have been obtained from other sources, principally, controlled tests, similar to those of certification undertaken by national noise modelling agencies in various countries.

1.2.2 An ANP data submittal form is included in this manual (see Appendix I), which sets out the data requirements for new aircraft entries in the ANP database. Separate forms are provided for turbofan fixed-wing aircraft (see Appendix I) and propeller-driven fixed-wing aircraft (see Appendix J) due to the differences in some performance parameters.

1.3 Aeroplane coverage

1.3.1 With respect to aeroplane entries, the ANP database is identical to that of the AEDT/INM database [ref. 4] excluding at present only data that are not covered by this guidance, i.e. military aeroplanes and helicopters.

1.3.2 Aeroplane models and variants that are not presently covered by the database have to be represented by substitutes (often referred to as 'proxy' aircraft), i.e. aeroplanes with similar noise and performance characteristics that are included in the database that can be adequately scaled (in terms of "equivalent number of movements") to represent the missing aeroplanes. Instructions for making the necessary substitutions are provided in 2.7. These involve examining carefully the aeroplane description and associated parameters such as maximum take-off weight and thrust rating to best represent the in-service fleet operating at a given airport. To facilitate the substitution process, the ANP database includes a table that maps currently operating commercial aeroplanes — with detailed airframe-engine combinations — which is compared to the aeroplanes listed in the actual database. In addition, the ANP database website includes a substitutions table providing a list of suggested aircraft substitutions, which is further described in section 5 of this appendix.

1.3.3 The database continues to be expanded so that the need for substitution can be reduced over time. Users who consider that their modelling work is compromised by a lack of coverage are urged to communicate their needs to the database managers via the website.

1.4 Data scrutiny

1.4.1 With each update the database developers check entries for consistency and reasonableness as resources allow. However, inconsistencies and deficiencies may be discovered by users in their model applications; users may report these to the ANP database managers.

1.5 Terms and conditions for accessing the database

1.5.1 Users have to be registered to access the database (the website includes an online registration form for new users). Use of data is subject to terms and conditions posted on the website.

1.6 Database content

1.6.1 The ANP data meet in full the requirements of the ICAO contour modelling methodology. The content of the database and the procedures for downloading the data from the ANP website are described below. The data are provided in a near "ready-to-use" format; it is only necessary for the software developer to match the model parameters and variables to those of the data.

1.6.2 The database includes several tables of data that are described in the following sections, as they are at the time of publication of this guidance. The content and format of these tables are likely to evolve with time, depending on the needs of the aviation community.

1.6.3 Users are cautioned that quantities, dimensions and units are those generally used by the data suppliers; modellers must be especially careful to ensure that, where necessary, appropriate conversions are applied at the point of use.

2. AIRCRAFT TABLE

2.1 This tabulates the aeroplanes represented along with descriptive parameters. Some parameters are required for noise modelling purposes whilst others are for general information only, enabling the user to further classify the aeroplanes according to selected criteria (e.g. source of the data, weight categories, noise certification status, etc.), and to assist with establishing aircraft substitutions.

2.2 For some aeroplanes, additional technical information, including in particular the assumptions that were made to derive the aeroplane-specific data, is provided in a downloadable PDF document.

2.3 The different fields/parameters of the aircraft table are listed below. Parameters that are required inputs to the noise contour model are underlined in the table.

- a) Aircraft identifier: the ANP aircraft name which labels the associated performance data and by which it is accessed.
- b) Description of the aircraft: manufacturer, airframe, engine, etc.

- c) Engine type: jet, turboprop or piston.
- d) Number of engines: used in various equations of Appendix C.
- e) Weight class: small, large or heavy.
- f) Owner category: commercial or general aviation.
- g) Maximum gross take-off weight (lb): used to calculate reduced take-off thrust (see Appendix C).
- h) Maximum gross landing weight (MGLW) (lb): default approach profiles are usually provided for 90% of MGLW.
- i) Maximum landing distance (ft).
- j) Maximum sea level static thrust (lb): provided for standard day conditions.
- k) Noise chapter (noise certification standard).
- l) NPD identifier: associates the aeroplane with a set of NPD data stored in the NPD table. (As NPDs tend to be powerplant related, similar aeroplane types may be assigned the same set of NPD data.).
- m) Power parameter: indicates which noise related power parameter is used to access the NPD data (corrected net thrust, shaft horse power, etc.) and the associated unit (pounds, per cent, etc.).
- n) Approach and departure spectral class identifiers: identifiers associating the aircraft with reference sound spectral shapes, one for approach and one for departure, stored in the spectral classes table.
- o) Lateral directivity identifier: fuselage-mounted, wing-mounted or prop. Indicates the engine installation correction to be applied (see Chapter 4, 4.6.4).
- p) The certified noise levels of each ANP aircraft type, which include:
 - 1) lateral level (EPNdB);
 - 2) flyover level (EPNdB);
 - 3) approach level (EPNdB);
 - 4) overflight level (dBA);
 - 5) take-off level (dBA);
 - 6) noise certification data source.
- q) Link to any accompanying PDF document.

3. AIRCRAFT PERFORMANCE TABLES

3.1 These provide the engine and aerodynamic data required to implement the performance equations presented in Appendix C. These data (coefficients) may not be available for all the aeroplanes of the database. For aeroplanes with missing coefficients, or for specific flight procedures which cannot be well modelled using the methodology described in Appendix C, the database may include a supplementary table providing default fixed-point profiles — a set of height, speed and thrust values as a function of ground distance.

3.2 Additionally, the database includes a table providing, for each aeroplane, default take-off weight values as a function of the trip length.

3.3 Reference conditions for performance data

3.3.1 The performance data (engine coefficients) are provided by manufacturers for the reference conditions in Table H-1.

Table H-1. Reference conditions for performance data

Atmosphere:	International Standard Atmosphere (ISA) [ref. 11]
Surface air temperature:	15 °C (59 °F)
Wind:	4 m/s (8 kt) headwind, constant with height above ground
Runway elevation:	mean sea level (MSL)
Runway gradient:	none
Number of engines supplying thrust:	all

3.3.2 The engine coefficients, along with the thrust equations described in Appendix C, may be used also for aerodrome conditions other than 15°C, sea level (temperatures up to 43°C (109 °F) and airport elevations up to 6 000 ft above sea level). The database includes high temperature jet coefficients enabling thrust calculations above temperature break point. The flap coefficients are also available for other reference conditions.

3.4 Jet engine coefficients table

3.4.1 This table provides, for each aeroplane and for up to five different rated thrusts, the jet coefficients E, F, GA, GB and H for use with thrust equation C-1. The thrust ratings encompass max-take-off, hi-temp max-take-off, max-climb, hi-temp max-climb and idle approach (the last for approach see Appendix C, equation C-23).

3.4.2 Additionally, the table may provide (depending on the aeroplane) a set of general jet coefficients enabling the calculation of non-rated thrust as a function of either EPR or N1, using equations C-2 and C-3. These general jet coefficients include in particular the additional coefficients K1, – K4.

3.4.3 The content of a data row in this table is (each parameter occupying a column):

- a) aircraft ID;
- b) thrust rating: includes “general thrust” for non-rated thrust calculation;
- c) E (lb);
- d) F (lb/kt);
- e) Ga (lb/ft);
- f) Gb (lb/ft²);
- g) H (lb/°C);
- h) K1 (lb/EPR);
- i) K2 (lb/EPR²);
- j) K3 (lb/(N1/√θ)); and
- k) K4 (lb/(N1/√θ)²).

Note. — Rated thrust coefficients are provided for at least max-take-off and max-climb thrust ratings. The general thrust K coefficients are provided either for EPR (K1,2) or N1 (K3,4), depending on the aeroplane/engine.

3.5 Propeller engine coefficients table

3.5.1 This provides propeller efficiency and installed net propulsive power data for the calculation of corrected net thrust for propeller-driven aeroplanes (see equation C-5). The data are usually provided for two thrust ratings: max-take-off and max-climb.

3.5.2 A data row of this table contains:

- a) aircraft ID;
- b) thrust rating: max-take-off or max-climb;
- d) η : propeller efficiency; and
- e) Pp (hp) : installed net propulsive power.

3.6 Aerodynamic coefficients table

3.6.1 This table provides, for each aeroplane, the aerodynamic coefficients B8, C/D and R (see Appendix C, equations C-9, C-12, C-15 and C-24) associated with different flap settings on arrival and departure. The number of flap settings and the flap identifiers are aeroplane-specific. The flap settings for which aerodynamic data are available normally cover the complete sequence used by aeroplanes under operational conditions (from clean configuration to full landing configuration-gear down during approach for instance). The flap identifiers include, where necessary, an indication on gear position (up or down).

3.6.2 Each row of the table contains the following (each parameter representing a column):

- a) aircraft ID;
- b) operation: arrival (A) or departure (D);
- c) flap ID;
- d) B (ft/lb);
- e) C (initial climb speed) or D (landing speed) (kt³/lb); and
- f) R.

Note — Coefficients B and C are provided only for take-off flap settings.

3.7 Default weights table

3.7.1 This provides, for each aeroplane, suggested default take-off weights assigned to different trip length (or stage length) ranges. These are for use when the operational take-off weights at the studied airport are unknown. The trip length stages are defined as follows:

Table H-2. Trip length stage definitions

Stage length	1	2	3	4	5	6	7	8	9
Trip length range (NM x 1 000)	0-0.5	0.5-1	1-1.5	1.5-2.5	2.5-3.5	3.5-4.5	4.5-5.5	5.5-6.5	> 6.5
Representative range (NM)	350	850	1 350	2 200	3 200	4 200	5 200	6 200	
Take-off weight (lb)									

3.7.2 The representative range, for which the take-off weight is calculated, is defined as follows:

$$\text{Representative range} = \text{min range} + 0.70 * (\text{max range} - \text{min range}) \quad (\text{H-1})$$

3.7.3 The assumptions made to arrive at the default take-off weights associated to each of the above representative ranges may depend on the aeroplane category and/or weight class, and may even vary from one manufacturer to another. Additional information is given on the website.

3.7.4 Each row of the table contains the following (each parameter representing a column):

- a) aircraft ID;
- b) stage length;
- c) weight (lb);

3.8 Default departure procedural steps table

3.8.1 This table provides a description of default departure procedures (i.e. description of successive steps, as flown by the crew). It includes all the required parameters which, combined with data from the performance tables, allow calculation of the resulting flight profiles (altitude, speed and thrust as a function of ground distance) using equations described in Appendix C.

3.8.2 Each row of the table contains the following (each parameter representing a column):

- a) aircraft ID;
- b) profile ID;
- c) stage length;
- d) step number;
- e) step type: take-off, climb or accelerate;
- f) flap ID: flap settings used on each step;
- g) thrust rating: max-take-off, max-climb, etc.;
- h) end point altitude (ft): altitude to be reached at the end of the segment;
- i) rate-of-climb (ft/min); and
- j) end point CAS (kt): calibrated airspeed to be reached at the end of the segment.

Note.— Each of the last three parameters is assigned a value or not (field “empty”), depending on the step type that is flown (e.g. a rate of climb value is provided only for an acceleration step; the field being empty for the other step types).

3.9 Default approach procedural steps table

3.9.1 This table, in a similar way as the previous one, provides a description of default approach procedures (normally one default procedure by aeroplane — for 90% of maximum gross landing weight — using step-by-step flight instructions.

3.9.2 For many aircraft, the default approach procedures currently available in the ANP database describe a continuous 3° descent from 6 000 ft to touchdown. Some aircraft include default procedures, incorporating level flight segments and deceleration.

3.9.3 The table contains the following fields (each field representing a column):

- a) Aircraft ID;
- b) Profile ID;
- c) Step number;
- d) Step type: descend, descend-Idle, level, etc.;

- e) Flap ID;
- f) Start altitude (ft);
- g) Start CAS (kt);
- h) Descent angle (deg);
- i) Touchdown roll (ft);
- j) Distance (ft);
- k) Start thrust (% max thrust).

Note.— The last three parameters are used to model the runway rolling portion of the procedure.

3.10 Default fixed-points profiles table

3.10.1 This table provides default fixed-point profiles for aeroplanes, for which the required performance data to calculate flight profiles based on the methodology described in Appendix C are unavailable and will be progressively phased out (in favour of the procedural profiles) as soon as the aeroplane performance data, which are required for a full implementation of Appendix C, become available.

3.10.2 The structure is described below (each parameter representing a column in the table):

- a) Aircraft ID;
- b) Operation type: arrival (A) or departure (D);
- c) Profile ID;
- d) Stage length;
- e) Point number;
- f) Distance (ft);
- g) Height above field elevation (ft);
- h) Speed TAS (kt);
- i) Corrected net thrust (lb);

Note.— Some tables have all the coefficients required to calculate departure profiles, but no aerodynamic coefficients enabling the calculation of approach profiles. For these aeroplanes, default fixed-point profiles are provided for approach only.

4. AIRCRAFT NOISE TABLES

4.1 These provide the acoustic data required to calculate the single event noise as described in Chapter 4. For each aeroplane, there are two sets of data: (1) a noise-power-distance (NPD) table and (2) two spectral classes —

reference sound spectra (used to adjust NPDs for non-reference atmospheric conditions).

4.2 NPD table

4.2.1 This table provides, for each aeroplane type (through its NPD identifier) and a number of values of the noise-related power parameter (mostly corrected net thrust values), a set of noise event levels at a number of slant distances. Several similar aeroplanes may be assigned the same NPD data set.

4.2.2 The noise event levels are given for various single event noise metrics, including at least L_{Amax} and SEL ten slant distances: 200, 400, 630, 1 000, 2 000, 4 000, 6 300, 10 000, 16 000 and 25 000 ft.

4.2.3 The power settings span normal operating values, both for approach and departures, in order to avoid the need for large modelling extrapolations. NPD data are distinguished by operating mode (approach or departure) as, due to airframe effects, noise depends on flight configuration as well as power setting.

4.2.4 Each row of the table contains the following (each parameter representing a column):

- a) Noise identifier;
- b) Noise index: maximum or exposure-based metric;
- c) Operating mode: 'A' or 'D';
- d) Noise-related power parameter value;
- e) L_n noise levels at distances d_n for $n = 1$ to 10;

4.3 Reference conditions for NPD data

4.3.1 NPD data are normalized for the following conditions are in Table H-3:

Table H-3. Reference conditions for NPD data

Atmospheric pressure:	101.325 kPa (1 013.25 mb)
Atmospheric absorption:	attenuation rates listed in Table E-1 of Appendix E
Precipitation:	none
Wind speed:	less than 8 m/s (15 kt)
Reference speed (for exposure-based metrics):	160 kt

4.4 Spectral classes table

4.4.1 Spectral classes represent average noise spectra for groups of aeroplanes that have similar spectral characteristics.

4.4.2 The spectral classes represent average spectral shapes at the time of maximum sound level, at a reference distance of 1 000 ft, and for the same reference conditions of air temperature and humidity as the NPDs. They are un-weighted (unlike NPD) and — for historical reasons — normalized to 70 dB at 1 000 Hz. Sound levels are provided for 24 one-third octave bands, with nominal centre frequencies from 50 to 10 000 Hz.

4.4.3 A detailed description of the method used to develop spectral class data can be found on the website.

4.4.4 The table provides separate spectral shapes for approach and departure conditions. Thus a given aeroplane is assigned two spectral classes (through its two spectral class identifiers). Each row of this table contains (each parameter representing a column in the table):

- a) Spectral class ID;
- b) Operation type: 'A' or 'D';
- c) Description: general characteristics of the aeroplane family that is assigned this spectral shape; and
- d) 24 relative one-third octave band sound levels for the centre frequencies from 50 to 10 000 Hz.

5. THE ANP SUBSTITUTION TABLE

5.1 To facilitate the work of aircraft noise modellers, the ANP database provides a list of suggested substitutions, which was derived in line with the method described in 2.7. The table substitutions give a recommended proxy and corresponding decibel and movement adjustments (Δ , N) for a large set of aircraft types, including multiple engine and MTOW variants. Airframe and engines are designated using the terminology in the aircraft type certificates. In principle, all variants of the same type are assigned the same proxy recommendation, unless the ANP database already includes multiple variants. The variants are therefore provided to refine the decibel and movement adjustments when the MTOW or engine variant of the missing aircraft is known. When the variant to be modelled is unknown, e.g. when only the aircraft ICAO code or airframe is available, modellers wishing to apply decibel or movement adjustments may either select the largest value of Δ or N across all variants (conservative approach) or take the average of the values. Modellers who cannot find a proxy recommendation for certain of their missing aircraft types in the Substitutions table are encouraged to contact the ANP database managers via the ANP website so that the table can be updated in a next release.

5.2 The substitution table contains the following fields (each field representing a column):

- a) ICAO code;
- b) Aircraft manufacturer;
- c) Airframe type: aircraft type designation as in the aircraft type certificate;
- d) Engine manufacturer;
- e) Engine type: engine type designation as in the aircraft type certificate;

- f) Other information: may include, for instance, propeller type designation, as in the aircraft type certificate for turboprop aircraft;
- g) Number of engines;
- h) MTOW (kg): maximum take-off weight;
- i) MLW (kg): maximum landing weight;
- j) Noise chapter: noise certification category according to the Annex 16, Volume I;
- k) Lateral level (EPNdB): certified noise level on the lateral certification point;
- l) Flyover level (EPNdB): certified noise level on the flyover certification point;
- m) Approach level (EPNdB): certified noise level on the approach certification point;
- n) Overflight level (dBA): certified noise level under overflight conditions for Chapter 6 aircraft;
- o) Take-off level (dBA): certified noise level under take-off conditions for Chapter 10 aircraft;
- p) ANP proxy: ANP proxy aircraft (i.e. ACFT_ID in the ANP aircraft table);
- q) Δ_{dep} (dB): noise adjustment to be applied to the departure NPD data of the ANP proxy aircraft;
- r) Δ_{arr} (dB): noise adjustment to be applied to the approach NPD data of the ANP proxy aircraft;
- s) N_{dep} : movement adjustment factor to be applied to departure operations of the aircraft to be substituted;
- t) N_{arr} : movement adjustment factor to be applied to arrival operations of the aircraft to be substituted.

6. HOW TO DOWNLOAD THE DATA

- 6.1 Registered users may download the following aeroplane noise and performance data from the website:
 - a) the whole database;
 - b) noise and performance tables related to one or several specific aeroplane types; and
 - c) a specific table.
- 6.2 The downloaded data are provided in CSV files, with one file per table.
- 6.3 Registered users are automatically informed (by e-mail) of any update of the database (i.e. new entries).

7. EXAMPLE DATA

7.1 Example data from the ANP database are provided in Tables H-4 through H-14.

Table H-4. Example aircraft table

ACFT_ID	Description	Source of data	Engine type	Number of engines	Weight class	Owner category	Maximum gross take-off weight (lb)	Maximum gross landing weight (lb)
737300	Boeing B737-300/CFM56-3B-1 Engines	Manufacturer	Jet	2	Large	Commercial	135 000	114 000
A320-232	Airbus A320-232/V2527-A5 Engines	Manufacturer	Jet	2	Large	Commercial	169 756	145 505
SF340	Saab SF340B/CT7-9B Engines	Manufacturer	Turboprop	2	Large	Commercial	27 300	26 500

Table H-4. Example aircraft table (continued)

ACFT_ID	Maximum landing distance (ft)	Maximum sea level static thrust (lb)	Noise chapter	NPD identifier	Power parameter	Approach spectral class identifier	Departure spectral class identifier	Lateral directivity identifier
737300	4 580	20 000	3	CFM563	CNT (lb)	202	102	Wing
A32023	4 704	26 500	3	V2527A	CNT (lb)	205	103	Wing
SF340	3 470	4 067	3	CT75	CNT (% of Max Static Thrust)	211	110	Prop

Table H-4. Example aircraft table (continued)

ACFT_ID	Lateral level (EPNdB)	Flyover level (EPNdB)	Approach level (EPNdB)	Overflight level (dBA)	Take-off level (dBA)	Noise certification data source
737300	90.2	86.5	99.9	-	-	EASA TCDSN Jets Issue 23 (A4142)
A320-232	91.3	84.6	94.4	-	-	EASA TCDSN Jets Issue 23 (A604)
SF340	85.5	77.6	93.0	-	-	EASA TCDSN Heavy Props Issue 21 (B18)

Table H-5. Example jet engine coefficients table

ACFT_ID	Thrust rating	E (lb)	F (lb/kt)	Ga (lb/ft)	Gb (lb/ft ²)	H (lb/ °C)	K1 (lb/EPR)	K2 (lb/EPR ²)	K3 (lb/(N1/ $\sqrt{\theta}$))	K4 (lb/(N1/ $\sqrt{\theta}$) ²)
737300	MaxClimb	17383.1	-15.61	0.148043	-1.0e-06	-24.2000				
737300	MaxTakeoff	19347.0	-25.87	0.456499	-1.12e-05	-14.7800				
737300	General	11106.0	-10.09000	-4.09000e-02	0.00000e+00	0.000e+00			-3.69800e+02	+4.83500e+00
A320-232	IdleApproach	1138.9	-6.53000	0.166700	-9.2579e-06	-1.331e+02				
A320-232	MaxClimb	15539.2	-4.09000	0.438331	-1.439e-05	0.000e+00	8.78176e+04	-1.86931e+04		
A320-232	MaxTakeoff	24746.2	-25.25000	0.304165	9.2451e-06	0.000e+00				
A320-232	General	-65083.3	-7.25000	-1.91800e-02	2.57500e-08	0.000e+00	8.78176e+04	-1.86931e+04		

Table H-6. Example propeller engine coefficients table

ACFT_ID	Thrust rating	Propeller efficiency	Installed net propulsive power (hp)
SF340	MaxClimb	0.90	1 587.0
SF340	MaxTakeoff	0.90	1 763.0

Table H-7. Example aerodynamic coefficients table

ACFT_ID	Op type	Flap identifier	B (ft/lb)	C/D (kt/ $\sqrt{\text{lb}}$)	R
737300	A	D-15	-	0.463900	0.110300
737300	A	D-30	-	0.434000	0.124700
737300	A	D-40	-	0.421500	0.147100
737300	D	1	0.012600	0.495800	0.076100
737300	D	15	0.011100	0.457200	0.087200
737300	D	5	0.012000	0.477200	0.079100
737300	D	Zero	-	-	0.062000
A32023	D	1	-	-	0.061500
A32023	D	1+F	0.007858	0.398300	0.072500
A32023	D	Zero	0.000000	0.000000	0.053900

Table H-8. Example default weights table

ACFT_ID	Stage length	Weight (lb)
737300	1	96 000
737300	2	102 000
737300	3	108 000
737300	4	119 000
A32023	1	135 700
A32023	2	141 600
A32023	3	147 700
A32023	4	158 600
A32023	5	162 000

Table H-9. Example default departure procedural profiles table

ACFT_ID	Profile ID	Stage length	STEP_NUM	STEP_TYPE	FLAP_ID	THR_RATING	End point altitude (ft)	Rate-of-climb (ft/min)	End point CAS (kt)
A32023	ICAO_A	1	1	Take-off	1+F	MaxTakeoff			
A32023	ICAO_A	1	2	Climb	1+F	MaxTakeoff	300.0		
A32023	ICAO_A	1	3	Climb	1+F	MaxTakeoff	1 500.0		
A32023	ICAO_A	1	4	Climb	1+F	MaxClimb	3 000.0		
A32023	ICAO_A	1	5	Accelerate	1+F	MaxClimb		751.0	187.3
A32023	ICAO_A	1	6	Accelerate	1	MaxClimb		890.0	201.6
A32023	ICAO_A	1	7	Accelerate	ZERO	MaxClimb		1 041.0	226.9
A32023	ICAO_A	1	8	Accelerate	ZERO	MaxClimb		1 191.0	250.0
A32023	ICAO_A	1	9	Climb	ZERO	MaxClimb	5 500.0		
A33202	ICAO_A	1	10	Climb	ZERO	MaxClimb	7 500.0		
A32023	ICAO_A	1	11	Climb	ZERO	MaxClimb	10 000.0		
737300	STANDARD	4	1	Take-off	5	MaxTakeoff			
737300	STANDARD	4	2	Climb	5	MaxTakeoff	1 000.0		
737300	STANDARD	4	3	Accelerate	5	MaxTakeoff		1 544.0	185.0
737300	STANDARD	4	4	Accelerate	1	MaxTakeoff		1 544.0	190.0
737300	STANDARD	4	5	Accelerate	ZERO	MaxClimb		1 000.0	220.0

ACFT_ID	Profile ID	Stage length	STEP_NUM	STEP_TYPE	FLAP_ID	THR_RATING	End point altitude (ft)	Rate-of-climb (ft/min)	End point CAS (kt)
737300	STANDARD	4	6	Climb	ZERO	MaxClimb	3 000.0		
737300	STANDARD	4	7	Accelerate	ZERO	MaxClimb		1 000.0	250.0
737300	STANDARD	4	8	Climb	ZERO	MaxClimb	5 500.0		
737300	STANDARD	4	9	Climb	ZERO	MaxClimb	7 500.0		
737300	STANDARD	4	10	Climb	ZERO	MaxClimb	10 000.0		

Table H-10. Example default approach procedural profiles table

ACFT_ID	Profile_ID	Step number	Step type	Flap_ID	Start altitude(ft)	Start CAS (kt)	Descent angle (deg)	Touchdown roll (ft)	Distance (ft)	Start thrust (% max thrust)
A320-232	DEFAULT	1	Descend-Idle		6000.0	250.0	2.8			
A320-232	DEFAULT	2	Level-Idle		3000.0	250.0			20003.3	
A320-232	DEFAULT	3	Level-Idle		3000.0	198.7			4629.3	
A320-232	DEFAULT	4	Descend-Idle		3000.0	183.5	3.0			
A320-232	DEFAULT	5	Descend-Idle		2613.0	172.8	3.0			
A320-232	DEFAULT	6	Descend-Idle		2033.0	142.2	3.0			
A320-232	DEFAULT	7	Descend	FULL_D	1819.0	133.8	3.0			
A320-232	DEFAULT	8	Descend	FULL_D	50.0	133.8	3.0			
A320-232	DEFAULT	9	Land	FULL_D				311.0		
A320-232	DEFAULT	10	Decelerate			130.8			2799.4	40.0
A320-232	DEFAULT	11	Decelerate			30.0			0	10.0

Table H-11. Example default fixed-points profiles table

ACFT_ID	Op type	Profile ID	Stage length	Point number	Distance (ft)	Altitude (ft)	TAS (kt)	Corrected net thrust (lb)
A32023	A	STANDARD	1	1	-162 381.0	6 000.0	272.3	1 091.30
A32023	A	STANDARD	1	2	-112 299.0	4 009.0	264.7	912.70
A32023	A	STANDARD	1	3	-87 765.0	3 000.0	260.9	802.70
A32023	A	STANDARD	1	4	-61 823.0	3 000.0	204.6	456.50
A32023	A	STANDARD	1	5	-57 240.0	3 000.0	190.7	362.50
A32023	A	STANDARD	1	6	-54 773.0	2 871.0	189.8	358.20
A32023	A	STANDARD	1	7	-51 725.0	2 711.0	187.5	351.20
A32023	A	STANDARD	1	8	-47 460.0	2 487.0	177.7	391.40
A32023	A	STANDARD	1	9	-36 430.0	1 909.0	144.6	654.20
A32023	A	STANDARD	1	10	-35 298.0	1 850.0	139.6	708.10
A32023	A	STANDARD	1	11	-33 710.0	1 767.0	130.9	817.50
A32023	A	STANDARD	1	12	-33 503.0	1 756.0	130.9	4 888.50
A32023	A	STANDARD	1	13	-19 077.0	1 000.0	129.5	4 753.10
A32023	A	STANDARD	1	14	-1 794.0	94.0	127.8	4 598.30
A32023	A	STANDARD	1	15	-954.0	50.0	127.7	4 570.80
A32023	A	STANDARD	1	16	0.0	0.0	126.7	4 570.80
A32023	A	STANDARD	1	17	470.0	0.0	119.7	10 600.00
A32023	A	STANDARD	1	18	4 704.0	0.0	30.0	2 650.00

Table H-12. Example NPD table

NPD identifier	Noise descriptor	Op mode	Power setting	L_200 ft	L_400 ft	L_630 ft	L_1 000 ft	L_2 000 ft	L_4 000 ft	L_6 300 ft	L_10 000 ft	L_16 000 ft	L_25 000 ft
V2527A	SEL	A	2 000.00	93.1	89.1	86.1	82.9	77.7	71.7	67.1	61.9	55.8	49.2
V2527A	SEL	A	2 700.00	93.3	89.2	86.2	83.0	77.7	71.8	67.2	62.0	55.8	49.3
V2527A	SEL	A	6 000.00	94.7	90.5	87.4	83.9	78.5	72.3	67.7	62.5	56.3	49.7
V2527A	SEL	D	10 000.00	95.4	90.7	87.3	83.5	77.7	71.1	66.3	60.9	54.6	47.4
V2527A	SEL	D	14 000.00	100.4	96.1	93.0	89.4	83.5	77.0	72.2	66.7	60.1	53.0
V2527A	SEL	D	18 000.00	103.2	99.1	96.2	92.9	87.4	81.1	76.5	71.1	64.9	57.9
V2527A	SEL	D	22 500.00	105.1	101.2	98.5	95.4	90.3	84.3	79.9	74.8	68.7	62.0
V2527A	LAmx	A	2 000.00	89.3	82.8	78.2	73.4	65.8	57.4	51.2	44.4	36.7	28.6
V2527A	LAmx	A	2 700.00	89.5	83.0	78.3	73.5	65.8	57.4	51.3	44.4	36.7	28.6
V2527A	LAmx	A	6 000.00	91.6	84.7	79.5	74.2	66.5	58.0	51.9	45.0	37.2	29.1
V2527A	LAmx	D	10 000.00	94.5	86.7	81.1	75.1	66.1	56.9	50.3	43.1	35.0	26.5
V2527A	LAmx	D	14 000.00	98.0	90.4	85.3	80.1	72.0	63.1	56.6	49.2	40.9	32.0
V2527A	LAmx	D	18 000.00	101.9	94.7	89.7	84.3	76.1	67.2	60.7	53.4	45.3	36.7
V2527A	LAmx	D	22 500.00	104.1	97.1	92.4	87.4	79.4	70.6	64.4	57.5	49.5	40.5
V2527A	EPNL	A	2 000.00	96.9	92.3	88.5	84.6	78.6	71.5	66.3	59.8	51.5	40.7
V2527A	EPNL	A	2 700.00	97.0	92.4	88.6	84.7	78.6	71.5	66.3	59.9	51.5	40.8
V2527A	EPNL	A	6 000.00	99.0	94.3	90.4	86.2	79.7	72.3	67.0	60.4	52.2	41.6
V2527A	EPNL	D	10 000.00	100.7	96.0	92.1	87.6	80.5	72.8	66.0	59.1	49.7	36.8
V2527A	EPNL	D	14 000.00	106.1	101.4	97.8	93.4	86.2	78.1	72.2	66.0	57.7	46.9
V2527A	EPNL	D	18 000.00	107.7	103.3	99.9	96.1	89.6	82.5	77.2	71.2	63.6	53.8
V2527A	EPNL	D	22 500.00	109.8	105.5	102.5	98.9	93.0	86.4	81.2	75.5	68.3	59.3
V2527A	PNLTmax	A	2 000.00	103.3	96.5	91.3	85.5	76.9	67.6	60.9	53.0	43.6	32.3
V2527A	PNLTmax	A	2 700.00	103.8	96.7	91.1	85.3	76.9	67.7	60.9	53.0	43.6	32.1
V2527A	PNLTmax	A	6 000.00	106.3	99.2	93.4	87.0	78.8	68.3	61.4	53.5	44.0	32.6
V2527A	PNLTmax	D	10 000.00	112.7	105.0	99.3	92.6	80.9	71.0	59.9	52.0	41.0	27.0
V2527A	PNLTmax	D	14 000.00	114.9	107.1	101.4	94.8	84.1	74.0	66.4	58.4	48.6	37.1
V2527A	PNLTmax	D	18 000.00	116.6	109.5	104.3	98.5	88.5	78.7	71.2	63.3	54.3	43.5
V2527A	PNLTmax	D	22 500.00	118.6	111.4	106.3	100.3	91.5	82.7	76.0	68.4	59.3	48.5

Table H-13. Example spectral class table

Spectral class identifier	Operation type	Description	L_50 Hz	L_63 Hz	L_80 Hz	L_100 Hz	L_125 Hz	L_160 Hz	L_200 Hz	L_250 Hz	L_315 Hz	L_400 Hz	L_500 Hz
103	Departure	Two engine high bypass ratio turbofan	56.7	66.1	70.1	72.8	76.6	73.0	74.5	77.0	75.3	72.2	72.2

Table H-13: Example spectral class table (continued)

Spectral class identifier	Operation type	Description	L_630Hz	L_800Hz	L_1000Hz	L_1250Hz	L_1600Hz	L_2000Hz	L_2500Hz	L_3150Hz	L_4000Hz	L_5000Hz	L_6300Hz	L_8000Hz	L_10000Hz
103	Departure	Two engine high bypass ratio turbofan	71.2	70.2	70.0	69.6	71.1	70.6	67.1	63.4	63.5	58.2	51.5	42.3	37.7

Table H-14. Example substitutions table

ICAO code	Aircraft manufacturer	Airframe type	Engine manufacturer	Engine type	Other information	Number of engines	MTOW (kg)	MLW (kg)	Noise chapter
A318	Airbus	A318-121	Pratt & Whitney	PW6122A	-	2	68 000	57 500	4
AT43	ATR-GIE Avions de Transport Regional	ATR 42-320	Pratt & Whitney Canada	PW121	-	2	17 000	16 850	4
B736	Boeing Company	737-600	CFM	CFM56-7B18	-	2	65 998	55 111	4

Table H-14. Example substitutions table (continued)

ICAO code	Lateral level (EPNdB)	Flyover level (EPNdB)	Approach level (EPNdB)	Overflight level (dBA)	Take-off level (dBA)	ANP proxy	Δ_{dep} (dB)	Δ_{arr} (dB)	N_{dep}	N_{arr}
A318	93.0	86.5	92.4	-	-	A319-131	2.5	-1.9	1.76	0.65
AT43	84.9	76.7	96.7	-	-	DHC8	-2.2	2.0	0.61	1.58
B736	89.0	86.1	95.6	-	-	737700	-1.8	-0.2	0.67	0.95

Appendix I

ANP DATABASE SUBMITTAL FORM

1. DATA SUBMITTAL OVERVIEW

1.1 This database request form implements the data requirements for a noise model as described in this report, as well as in the following supporting documents: Society of Automotive Engineers (SAE) Airspace Information Report (AIR) SAE-AIR-1845 “Procedure for the Calculation of Airplane Noise in the Vicinity of Airports” [ref. 1]; and European Civil Aviation Conference ECAC/CEAC Doc 29 “Report on Standard Method of Computing Noise Contours around Civil Airports” [refs. 2 and 3]. The following describes the aircraft performance and noise data required for aircraft to be included in the ANP database. This Appendix may be used for either jet or propeller aircraft database submittals. A simplified form that may be used for only propeller aircraft database submittals is included in Appendix J. Additional guidance for developing aircraft performance and noise data submittals is found in SAE-AIR-1845 (see SAE-AIR-1845 Appendices A and B). Some items in this request form include enhancements to these documents, which are currently under review.

2. REFERENCE CONDITIONS FOR PERFORMANCE AND NOISE DATA

2.1 Table I-1 presents the standard reference conditions that are used for the development of all aircraft performance and noise data submittals to the ANP database. The use of these reference conditions during data development ensures consistency across the ANP database. It is important to note that different atmospheric conditions are referenced for developing aircraft performance and aircraft noise data.

Table I-1. Reference conditions for performance data

Wind	4 m/s (8 knots) headwind, constant with height above ground
Runway elevation	Mean sea level (MSL)
Runway gradient	None
Surface air temperature	15°C (59°F)
Number of engines supplying thrust	All
Atmosphere	For performance: International Standard Atmosphere (ISA) For noise: SAE-AIR-1845 atmosphere updated according to ICAO CAEP (see Appendix E)

2.2 The jet thrust coefficients of section 6 may be validated for conditions other than 15°C, sea level. For these equations, it has been shown that coefficients may be developed for temperatures of 15°C to temperatures up to the engine break point, and for take-off altitudes of sea level up until 5 000 ft above sea level.

2.3 Other input parameters, such as rate-of-climb, are not as flexible in their use and should be developed for a specific atmosphere. As per SAE-AIR-1845, the default operating procedures described in sections 7 and 8 will be provided for airports at 15°C, sea level condition assuming the International Standard Atmosphere. As an example, the parameters for rate-of-climb, target speed, and cutback height for a procedure will be developed specifically for sea level ISA.

3. AIRCRAFT AND ENGINE DATA

3.1 Where there are variations in certification weights and engine thrusts for a given model, provide data for the heaviest aircraft in terms of maximum gross take-off weight in the model classification (Table I-2).

Note.— Aircraft should reference a certification equivalent.

Table I-2. General aircraft and engine data

Airframe model ¹			
Engine model ¹			
Number of engines			
Engine type (jet, turboprop, piston)			
Propeller model, if applicable ¹			
Engine installation (tail- or wing-mounted)			
Noise stage number (2, 3, 4)			
Maximum static thrust (lb/engine)			
Automated thrust restoration (yes, no)			
Weight class (small, large, heavy)			
Maximum gross take-off weight (kg)			
Maximum gross landing weight (kg)			
Maximum landing distance (m)			
Annex 16 reference certification levels (dB)	TO ² :	SL: ²	AP: ²
<p>1. As in the aircraft's type certificate. 2. TO = take-off; SL = sideline during take-off; and AP = approach.</p>			

4. GUIDANCE FOR DEFAULT WEIGHTS AND PROCEDURES

4.1 Default procedures should be developed for ranges suitable for representing the normal operating range of the aircraft. In this way, users may interpolate to other weights provided they have justification or other data. In the absence of more detailed data, users will resort to default weights corresponding to the trip length of the aircraft. Take-off weights should be developed so as to increase in mission trip length. Weight assumptions should use industry planning assumptions for load factor, average passenger weight, excess cargo beyond passenger weight, and fuel required to complete mission trip length (see Tables I-3 and I-4). Weights should be developed for the trip length ranges using the default mission planning rules below. Stage “M” represents the maximum trip length (in nmi) of the individual aircraft at MTOW, and it should be submitted separately, even if the maximum trip length falls within one of the other stage number categories.

Table I-3. Departure take-off weights

Stage number	Trip length (nmi)	Representative range (nmi)	Weight (kg)
1	0-500	350	kg
2	500-1 000	850	kg
3	1 000-1 500	1 350	kg
4	1 500-2 500	2 200	kg
5	2 500-3 500	3 200	kg
6	3 500-4 500	4 200	kg
7	4 500-5 500	5 200	kg
8	5 500-6 500	6 200	kg
9	6 500-7 500	7 200	kg
10	7 500-8 500	8 200	kg
11	>8 500		kg
M	Maximum range at MTOW		kg

Table I-4. Guidance for determining departure take-off weights

Parameter	Planning rule
Representative trip length	$\text{Min Range} + 0.70 \times (\text{Max Range} - \text{Min Range})$
Load factor	65% total payload.
Fuel load	Fuel required for representative trip length + ATA Continental up to 3 000 nmi and transcontinental reserves for trip length > 3 000 nmi. As an example, typical continental reserves include 5% contingency fuel, 200 nmi alternate landing with 30 minutes of holding.
Cargo	No additional cargo over and above the assumed payload percentage. ANP weights do not assume belly-hold weights, just passenger weights.

4.2 The following guidance has been established to provide common mission planning rules for determining default weights to the stage lengths given in the table above. For stage length “M”, the maximum range with maximum fuel and no additional cargo other than that which is already included in the payload assumption.

4.2 Not all trip lengths will be required for every aircraft as not all aircraft will be able to fly the higher trip length ranges. In addition to providing the trip length ranges for which an aircraft is able to fly, weights and procedures should also be developed for the aircraft maximum take-off weight, M, which is intended for modelling the maximum range (full fuel) of the aircraft. If relevant, a lower bound weight may also be provided that would be more representative of operations that would occur at weights below trip lengths of 350 nautical miles using the mission planning rules above.

5. AERODYNAMIC COEFFICIENTS

5.1 Aerodynamic coefficients in accordance with the methodology provided in this manual are required for available flap settings. The flap settings may be identified in degrees and abbreviations. Please provide data for all flap settings specified in sections 7 and 8 and include separate coefficients per flap setting for cases with landing gear up and with landing gear down as appropriate (Table I-5).

Table I-5. Aerodynamic coefficients

Flap configuration identifier	Operation (A, D) ¹	Gear	Take-off B (ft/lb)	Take-off C (kt/ $\sqrt{\text{lb}}$)	Land D (kt/ $\sqrt{\text{lb}}$)	Drag/lift R
	D	down			N/A ²	
	D	down			N/A	
	D	up	N/A	N/A	N/A	
	D	up	N/A	N/A	N/A	
	D	up	N/A	N/A	N/A	
	A	up	N/A	N/A	N/A	
	A	up	N/A	N/A	N/A	
	A	down	N/A	N/A		
	A	down	N/A	N/A		
	A	down	N/A	N/A		

1. A = Approach, D = Depart
2. Not applicable.

6. ENGINE COEFFICIENTS

6.1 For jet aircraft, engine coefficients in accordance with the methodology provided in this manual are required for maximum take-off, maximum climb, and general thrust in terms of EPR or N1. The Max-Take-off coefficients should be valid to 6 000 ft MSL, the Max-Climb and General Thrust coefficients should be valid to 16 000 ft MSL. This is necessary so that the methodology accurately models operations at high altitude airports (Table I-6).

Table I-6. Jet engine coefficients

Thrust Type	E (lb)	F (lb/kt)	Ga (lb/ft)	Gb (lb/ft ²)	H (lb/°C)
Max-Takeoff					
Hi-Temp Max-Takeoff					
Max-Climb					
Hi-Temp Max-Climb					
General Thrust					
Hi-Temp General Thrust					
	K1a (lb/EPR)	K1b (lb/EPR ²)	or	K2 lb/(N1/√θ)	K3 lb/(N1/√θ) ²
General Thrust					
Hi-Temp General Thrust					

6.2 In addition, high temperature coefficients are required for operations above the thrust break temperature. Max-Takeoff and Max-Climb coefficients are used below the breakpoint temperature, and Hi-Temp coefficients are used above the breakpoint temperature. The breakpoint temperature is at the intersection of the two curves. An example of Max-Takeoff and Hi-Temp Max-Takeoff curves is shown in Figure I-1.

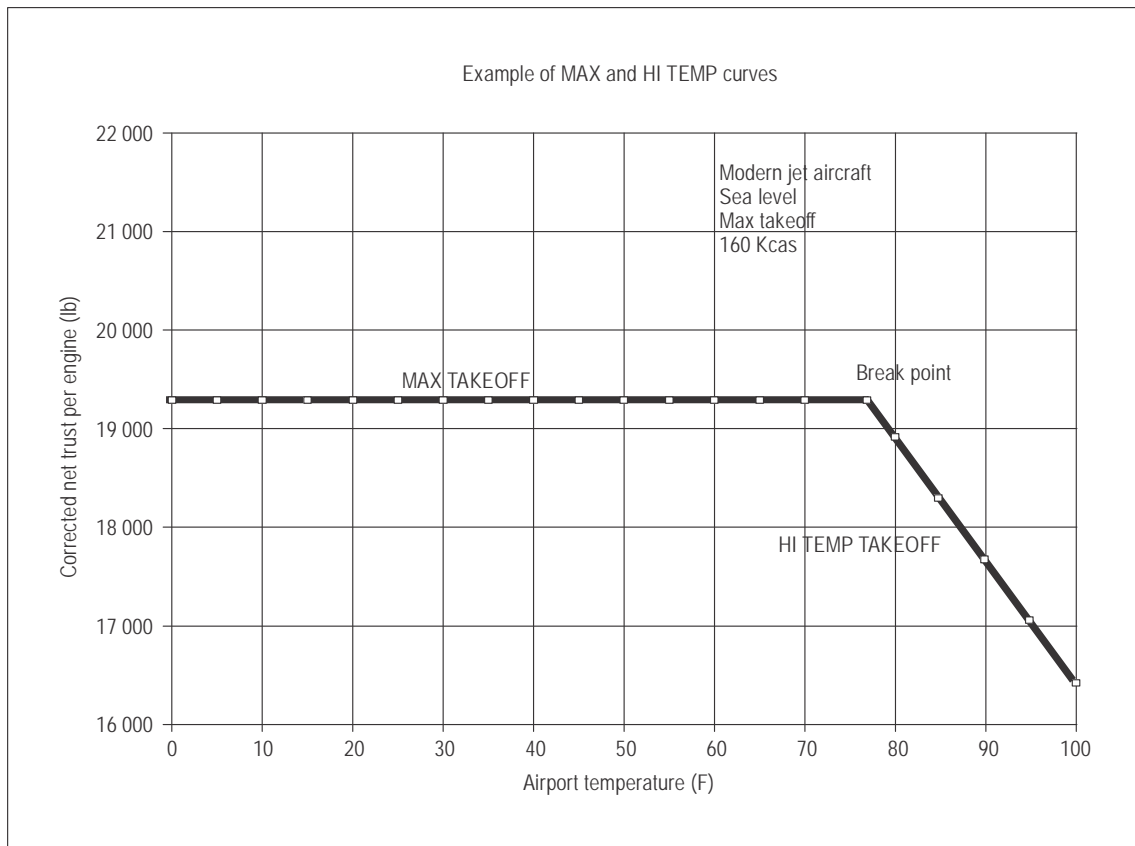


Figure I-1. Example maximum take-off thrust vs. temperature

6.3 For propeller-driven aircraft, engine coefficients in accordance with the methodology provided in this manual are required for propeller efficiency and installed net propulsive power (see Table I-7). Note that turboprop engine performance may be better modelled with the jet engine coefficients in given Table I-6.

Table I-7. Propeller engine coefficients

Thrust type	Propeller efficiency	Installed net propulsive horsepower (hp)
Max-Take-off		
Max-Climb		

7. DEPARTURE PROCEDURES

7.1 Departure procedures consist of a take-off segment, and a combination of climb and acceleration segments up to an altitude of 10 000 ft AFE. A climb segment is defined by its endpoint altitude. An acceleration segment is defined by its rate-of-climb and the calibrated airspeed at its endpoint. The flap settings are indicated for endpoints of segments. These flap settings should coincide with those given in section 5. Please provide procedural data for each stage length given in section 4.

7.2 Default take-off procedures include an ICAO A, an ICAO B, and a BBN/AAAI reference procedure.* Guidelines for all three procedures are included in Table I-8. In developing these procedures, manufacturers should use their best judgement based on experience with their customers in determining a default take-off flap setting and an appropriate power cutback point. Manufacturers of propeller-driven aircraft should use their own recommended procedures.

* Historically, the BBN/AAAI reference procedure is known as the "DEFAULT" or "STANDARD" procedure.

Table I-8. Default take-off procedure descriptions

Default procedure¹ modified BBN/AAAI procedure	ICAO A	ICAO B
Takeoff at MaxToPower (full power) and Climb to 1 000 ft AFE	Takeoff MaxToPower (full power)	Takeoff at MaxToPower (full power)
Pitch over and cutback to climb power. Accelerate to zero flaps, retracting flaps on schedule (clean configuration) ²	Climb at constant speed to 1 500 ft AFE	Climb to 1 000 ft AFE and pitch-over to accelerate at full power to clean configuration
Climb at constant speed to 3 000 ft AFE	Reduce thrust to Climb Power	At Clean Configuration, cutback top climb power
	Climb at constant speed to 3 000 ft AFE	Climb at constant speed to 3 000 ft
Upon achieving 3 000 ft AFE, accelerate to 250 knots ²	Accelerate while retracting flaps to Zero (clean configuration)	Upon achieving 3 000 ft AFE, accelerate to 250 knots
	Continue accelerating to 250 knots	
Upon achieving 250 knots, climb to 10 000 ft AFE	Upon achieving 250 knots, climb to 10 000 ft	Upon achieving 250 knots, climb to 10 000 ft
<p>1. In many cases, the "Default" procedure is the same as the ICAO B procedure. Manufacturers of propeller-driven aircraft should use their own recommended procedures.</p> <p>2. During acceleration steps, flaps are retracted on schedule according to the published guidance for the aeroplane. Power is distributed between climb and acceleration according to the flight management system for the aircraft. This distribution between climb and acceleration should be provided as part of the data submission. As an example, a parameter of 55/45 would signify that 55% power would be for climb and 45% would be for acceleration .</p>		

7.3 The ANP database supports two types of departure procedures: procedural profiles and profile points. Procedural profiles utilize the aircraft performance methods described in Appendix C, and they take into account atmospheric effects on the aircraft performance. Profile points are an ordered set of fixed profile points that specify a two-dimensional trajectory for the aircraft, and they do not take into account atmospheric effects on the aircraft performance. Procedural profiles are considered to be of a higher data quality than the profile points because they allow for more modelling flexibility. Therefore, the development of procedural profiles is recommended. If possible, both procedural profiles and the corresponding profile point should be submitted for each submitted take-off procedure, to aid in the review of the data submittal

7.4 Table I-9 should be completed for each submitted procedural profile (ICAO A, BBN/AAAI, etc.) over each take-off weight given in section 4. Table I-10 should be completed for each corresponding submitted profile points. For both tables, the number and sequence of the procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Database submittals should comply with the manufacturer's recommended departure procedures. Additional information on CLIMB and ACCELERATION procedures steps is provided in 3.7. Note that certain SAE parameters, such as rate-of-climb, are not flexible in their use and should be developed for a specific atmosphere.

Table I-9. Take-off procedural profile

Stage number		Procedure type (procedural or points)			Procedure name		
Profile steps	Segment Type ¹	Thrust Type ² (T/C)	Flap configuration identifier	Endpoint altitude (ft AFE)	Rate-of-climb (ft/min)	Endpoint speed (KCAS)	Start thrust ³ (lb)
1	Take-off			N/A	N/A	N/A	lb
2	Climb			ft	N/A	N/A	lb
3	Climb			ft	N/A	N/A	lb
4	Accelerate			N/A	ft/min	kt	lb
5	Accelerate			N/A	ft/min	kt	lb
6	Climb			ft	N/A	N/A	lb
7	Climb			ft	N/A	N/A	lb
8	Accelerate			N/A	ft/min	kt	lb
9	Accelerate			N/A	ft/min	kt	lb
10	Climb			10 000 ft	N/A	N/A	lb

1. Add, delete, and sequence the segments, as necessary, to represent a take-off procedure.
2. T = Max-Take-off, C = Max-Climb.
3. These data are used to compare to computed thrust values.

Table I-10. Take-off profile points

Stage number		Procedure type (procedural or points)			Procedure name	
Profile points	Segment type	Thrust type (T/C)	Start altitude (ft AFE)	Horizontal coordinate (m) relative to the start-roll point on a runway	Aircraft true airspeed (KCAS)	Start thrust (lb)
1	Take-off		ft	m	kt	lb
2	Climb		ft	m	kt	lb
3	Climb		ft	m	kt	lb
4	Accelerate		ft	m	kt	lb
5	Accelerate		ft	m	kt	lb
6	Climb		ft	m	kt	lb
7	Climb		ft	m	kt	lb
8	Accelerate		ft	m	kt	lb
9	Accelerate		ft	m	kt	lb
10	Climb		10 000 ft	m	kt	lb

8. APPROACH PROCEDURES

8.1 A landing (or approach) profile should be calculated for a starting altitude of 6 000 ft above field elevation (AFE) following a 3-degree approach glide slope with a level segment at 3 000 ft AFE. The flap setting identifiers should coincide with those given in section 5. Reverse thrust distance is nominally 10 per cent of ground roll distance, which is 90 per cent of the stop distance minus 291 m (954 ft). Reverse corrected net thrust is nominally 40 per cent of maximum static thrust for narrow-body aircraft and 10 per cent of maximum static thrust for wide-body aircraft. The idle/taxi distance is 90 per cent of the stop distance minus 291 m (954 ft). Stop distance can be smaller than the maximum landing distance reported in section 3. Taxi/idle corrected net thrust is nominally 10 per cent of maximum static thrust reported in section 3.

8.2 Similar to the departure procedures, the ANP database supports both procedural profiles and profile points . Procedural profiles are considered to be of a higher data quality than the profile points because they allow for more modelling flexibility. Therefore, the development of procedural profiles is recommended. If possible, both procedural profiles and the corresponding profile point should be submitted for each submitted approach procedure, to aid in the review of the data submittal.

8.3 Table I-11 below should be completed for each submitted landing procedure. Table I-12 should be completed for each corresponding submitted profile points. For both tables, the number and sequence of the procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Additional information on landing procedures steps is provided in 3.7.7.

Table I-11. Approach procedural profile

Landing weight (kg)					Stopping distance (m)			
Procedure type (procedural or points)					Procedure name			
Profile step	Operation	Starting flap configuration	Starting altitude (ft AFE)	Descent angle (deg)	Start speed ¹ (KTAS)	Track distance (horizontal length) (m)	Start thrust (% of static thrust)	Start thrust ² (lb)
1	Descend					N/A	N/A	
2	Descend					N/A	N/A	
3	Level-Decel			N/A			N/A	
4	Descend					N/A	N/A	
5	Land		0 ft	N/A	N/A		N/A	
6	Decelerate	N/A	0 ft	N/A				
7	Decelerate	N/A	0 ft	N/A		0 m		

1. Landing speed is for reference only; the methods provided in this manual calculate landing speed using the D coefficient and landing weight.
 2. These data are used to compare to computed thrust values.

Table I-12. Approach profile points

Landing weight (kg)			Stopping distance (m)		
Procedure type (procedural or points)			Procedure name		
Profile points	Segment type	Start altitude (ft AFE)	Horizontal coordinate (m) relative to the touchdown point ¹	Aircraft true airspeed (KCAS)	Start thrust (lb)
1	Descend	ft	m	kt	lb
2	Descend	ft	m	kt	lb
3	Level-Decel	ft	m	kt	lb
4	Descend	ft	m	kt	lb
5	Land	0 ft	0 m	kt	lb
6	Decelerate	0 ft	m	kt	lb
7	Decelerate	0 ft	m	kt	lb

1. These horizontal coordinate values are negative during descent and positive during the landing ground roll.

9. NOISE DATA

9.1 Noise power distance (NPD) data are requested for noise exposure levels (sound exposure level (SEL) and effective perceived noise level (EPNL)) and maximum noise levels (maximum A-weighted sound level and maximum tone-corrected perceived noise level). Specific guidelines for developing NPD data are provided in SAE-AIR-1845. NPDs should be provided for representative corrected net thrust values that span the procedures given in sections 7 and 8.

9.2 Two different SEL NPD calculation adjustment procedures are defined in SAE-AIR-1845: the integrated procedure and the simplified procedure. The integrated procedure requires a higher quality of data, where measured noise and performance data include spectral data available for the complete flyover time period of interest, whereas the simplified procedure is typically used with measured noise and performance data, where spectral data are available only for the time of occurrence of the maximum sound level. The integrated procedure is recommended for computing NPDs for the data submittal form, although NPDs computed using either integrated or simplified will be accepted. Where applicable, be sure to differentiate between NPDs generated using integrated and simplified procedures.

9.3 In general, noise measurements are collected under certification-like conditions and then are adjusted to different distances based on spherical divergence, altitude duration, time-varying aircraft speed, and atmospheric absorption. Noise data should be normalized to standard reference conditions specified in 2.6. Where applicable, be sure to differentiate between approach and take-off configuration noise data. For example, "6000-A" would be 6 000 lbs of corrected net thrust under an approach configuration.

9.4 It is important to note that SAE-AIR-1845 references SAE-ARP-866A [ref. 13] for computing the atmospheric absorption adjustment during the NPD computation process. As mentioned in 4.3.7, SAE-ARP-5534 [ref. 17] is being evaluated for use with noise certification, and is intended to replace SAE-ARP-866A. In the meantime, the effects of study of 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 in the noise modelling. When developing NPDs from empirical data, SAE-ARP-866A should still be used to correct the empirical data to the source using the measurement day atmospheric conditions, and the reference atmospheric adjustment (in Appendix E) should be used to compute the noise levels at the ten NPD distances using standard atmospheric conditions, as specified in SAE-AIR-1845.

9.5 Noise data for approach conditions should use the final approach landing speed as the reference speed for the noise data. All exposure-based metrics, such as EPNL and SEL, should be further normalized to 160 knots using the duration correction equation in SAE-AIR-1845.

9.6 Sound exposure levels should be calculated for the distances given on the tables, below which range from 200 ft to 25 000 ft. SEL values less than 75 dB at 1 000 ft may require additional extrapolation and may not be consistently derived or accessed for accuracy across all aircraft types. When modelling propeller aircraft, the propeller rotations per minute (RPM) should also be provided for each NPD.

9.7 Repeat Table I-13 for each combination of four noise types and two operation mode (i.e. eight tables). Where applicable, be sure to differentiate between approach and take-off configuration noise data. In each table, a minimum of two NPDs per operation mode and noise type is required, in order to have the minimum number of NPDs required for NPD interpolation and extrapolation as described in 4.3. The development of more than two NPDs for each combination of noise type and operation mode is strongly recommended. A larger NPD data set results in both the noise levels of the aircraft being more comprehensively represented, and noise levels being extrapolated over smaller ranges, thus improving the accuracy of the noise model utilizing those data. It is not uncommon for aircraft in the ANP database to have three or four approach NPDs and six or more departure NPDs for each noise metric type.

9.8 Unweighted one-third octave-band spectral data corresponding to the time of $L_{PNTS_{mx}}$ and the time of $L_{AS_{mx}}$ should be provided for each thrust level represented in the NPDs. The spectra should be at the same corrected net thrust values as provided in the noise exposure and maximum noise tables, and span the one-third octave-bands from 50 to 10 000 Hz. The spectra should be measured at a speed close to 160 knots and adjusted to a reference distance of 1 000 ft using the atmospheric absorption table in Appendix E. Repeat Table I-14 for each combination of noise type and operation (eight tables). Where applicable, be sure to differentiate between approach and take-off configuration spectral data.

Table I-13. NPD data

Noise type ¹		Operation ²					
Atmospheric absorption method		SAE-AIR-1845 integrated or simplified procedure					
Distance (ft)	Corrected net thrust per engine (lb)						
	lb	lb	lb	lb	Lb	lb	
	rpm	rpm	rpm	rpm	rpm	rpm	
200	dB	dB	dB	dB	dB	dB	
400	dB	dB	dB	dB	dB	dB	
630	dB	dB	dB	dB	dB	dB	
1 000	dB	dB	dB	dB	dB	dB	
2 000	dB	dB	dB	dB	dB	dB	
4 000	dB	dB	dB	dB	dB	dB	
6 300	dB	dB	dB	dB	dB	dB	
10 000	dB	dB	dB	dB	dB	dB	
16 000	dB	dB	dB	dB	dB	dB	
25 000	dB	dB	dB	dB	dB	dB	

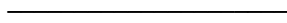
1. Noise types:
 L_{AE} = Sound exposure level (reference speed 160 knots)
 L_{EPN} = Effective perceived noise level (reference speed 160 knots)
 L_{ASmx} = Maximum A-weighted sound level (at speed close to 160 knots)
 L_{PNTSmx} = Maximum tone-corrected perceived noise level (at speed close to 160 knots)

2. Operations:
A = Approach
D = Depart

Table I-14. Spectral data

Noise type ¹		Operation				
One-third octave band (Hz)	Corrected net thrust per engine (lb)					
	lb	lb	lb	lb	lb	lb
50	dB	dB	dB	dB	dB	dB
63	dB	dB	dB	dB	dB	dB
80	dB	dB	dB	dB	dB	dB
100	dB	dB	dB	dB	dB	dB
125	dB	dB	dB	dB	dB	dB
160	dB	dB	dB	dB	dB	dB
200	dB	dB	dB	dB	dB	dB
250	dB	dB	dB	dB	dB	dB
315	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
500	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
800	dB	dB	dB	dB	dB	dB
1 000	dB	dB	dB	dB	dB	dB
1 250	dB	dB	dB	dB	dB	dB
1 600	dB	dB	dB	dB	dB	dB
2 000	dB	dB	dB	dB	dB	dB
2 500	dB	dB	dB	dB	dB	dB
3 150	dB	dB	dB	dB	dB	dB
4 000	dB	dB	dB	dB	dB	dB
5 000	dB	dB	dB	dB	dB	dB
6 300	dB	dB	dB	dB	dB	dB
8 000	dB	dB	dB	dB	dB	dB
10 000	dB	dB	dB	dB	dB	dB

1. At time of L_{ASmx} and L_{PNTSmx}.



Appendix J

ANP DATABASE SUBMITTAL FORM FOR PROPELLER-DRIVEN, FIXED-WING AIRCRAFT

1. SUBMITTAL FORM FORMAT

Since the form in Appendix I may be used for either jet or propeller fixed-wing aircraft, it is formatted to allow for the entry of information that may be extraneous for propeller aircraft. Therefore, an abbreviated version of that form specific to propeller-driven aircraft is presented in this appendix. It is intended for the submittal of propeller-driven, fixed-wing aircraft noise and performance data for the ANP database.

2. REFERENCE CONDITIONS FOR PERFORMANCE DATA

As per SAE-AIR-1845 [ref. 1], the default operating procedures described in section 5 will be provided for airports at 15°C, sea level condition assuming the International Standard Atmosphere. As an example, the parameters for rate-of-climb, target speed, and cutback height for a procedure will be developed specifically for sea level ISA.

Table J-1. Reference conditions for performance data

Wind	4 m/s (8 knots) headwind, constant with height above ground
Runway elevation	Mean sea level (MSL)
Runway gradient	None
Surface air temperature	15°C (59°F)
Number of engines supplying thrust	All
Atmosphere	For performance: International Standard Atmosphere (ISA) For noise: SAE-AIR-1845 atmosphere updated according to ICAO CAEP (see Appendix E)

3. AIRCRAFT AND ENGINE DATA

Where there are variations in certification weights and engine thrusts for a given model, provide data for the heaviest aircraft in terms of maximum gross take-off weight in the model classification.

Note.— Aircraft should reference a certification equivalent. Furthermore, power should be presented in the form of horsepower.

Table J-2. General aircraft and engine data

Airframe model ¹			
Engine model ¹			
Number of engines			
Engine type (turboprop, piston)			
Propeller model ¹			
Engine installation (tail- or wing-mounted)			
Noise stage number (2, 3, 4)			
Sea Level rated horsepower (per engine)			
Automated thrust restoration (yes, no)			
Weight class (small, large, heavy)			
Maximum gross take-off weight (kg)			
Maximum gross landing weight (kg)			
Maximum landing distance (m)			
Annex 16 reference certification Levels, either:			
a) Chapter 4 (or 3 or 14), or	TO: ²	SL: ²	AP: ²
b) Chapter 6, or	LV: ²		
c) Chapter 10	TO:		
1. As in the aircraft's type certificate.			
2. TO = take-off; SL = sideline during take-off; AP = approach; and LV = level flyover.			

4. GUIDANCE FOR DEFAULT WEIGHTS AND PROCEDURES

4.1 Default procedures should be developed for ranges suitable for representing the normal operating range of the aircraft. In this way, users may interpolate to other weights provided they have justification or other data. In the absence of more detailed data, users will resort to default weights corresponding to the trip length of the aircraft. Take-off weights should be developed so as to increase with an increase in mission trip length. Weight assumptions should use industry planning assumptions for load factor, average passenger weight, excess cargo beyond passenger weight, and fuel required to complete mission trip length. Weights should be developed for the trip length ranges using the default mission planning rules below. Stage “M” represents the maximum trip length (in nmi) of the individual aircraft at MTOW, and it should be submitted separately, even if the maximum trip length falls within one of the other stage number categories.

Table J-3. Departure take-off weights

Stage number	Trip length (nmi)	Representative range	Weight (kg)
1	0-500	350	kg
2	500-1 000	850	kg
3	1 000-1 500	1 350	kg
4	1 500-2 500	2 200	kg
5	2 500-3 500	3 200	kg
6	3 500-4 500	4 200	kg
7	4 500-5 500	5 200	kg
8	5 500-6 500	6 200	kg
9	6 500-7 500	7 200	kg
10	7 500-8 500	8 200	kg
11	>8 500		kg
M	Maximum range at MTOW		kg

4.2 The following guidance has been established to provide common mission planning rules for determining default weights to the stage lengths given in the table above. For stage length “M”, the maximum range with maximum fuel and no additional cargo other than that which is already included in the payload assumption.

Table J-4. Guidance for determining departure take-off weights

Parameter	Planning rule
Representative trip length	Min Range + 0.70*(Max Range – Min Range)
Load factor	65% total payload.
Fuel load	Fuel required for representative trip length + ATA continental up to 3 000 nmi and Transcontinental Reserves for trip length > 3 000 nmi. As an example, typical continental reserves include 5% contingency fuel, 200 nmi alternate landing with 30 minutes of holding.
Cargo	No additional cargo over and above the assumed payload percentage. ANP weights do not assume belly-hold weights, just passenger weights.

4.3 Not all trip lengths will be required for every aircraft as not all aircraft will be able to fly the higher trip length ranges. In addition to providing the trip length ranges for which an aircraft is able to fly, weights and procedures should also be developed for the aircraft maximum take-off weight, M, which is intended for modelling the maximum range (full fuel) of the aircraft. If relevant, a lower bound weight may also be provided that would be more representative of operations that would occur at weights below trip lengths of 350 nautical miles using the mission planning rules above.

5. AERODYNAMIC COEFFICIENTS

5.1 Aerodynamic coefficients for use with the SAE-AIR-1845 equations are required for available flap settings. The flap settings may be identified in degrees and/or abbreviations. Please provide data for all flap settings specified in sections 6 and 7, and include separate coefficients per flap setting for cases with landing gear up and with landing gear down as appropriate. Fixed gear aircraft do not require gear position information.

Table J-5. Aerodynamic coefficients

Flap configuration identifier	Operation (A, D) ¹	Gear	Take-off B (ft/lb)	Take-off C (kt/ $\sqrt{\text{lb}}$)	Land D (kt/ $\sqrt{\text{lb}}$)	Drag/lift R
	D	down			N/A ²	
	D	down			N/A	
	D	up	N/A	N/A	N/A	
	D	up	N/A	N/A	N/A	
	D	up	N/A	N/A	N/A	
	A	up	N/A	N/A	N/A	
	A	up	N/A	N/A	N/A	
	A	down	N/A	N/A		
	A	down	N/A	N/A		
	A	down	N/A	N/A		

1. A = Approach, D = Depart.
2. Not applicable.

6. ENGINE COEFFICIENTS

6.1 For propeller-driven aircraft, engine coefficients in accordance with SAE-AIR-1845 equations are required for propeller efficiency and installed net propulsive power. In many cases, turboprop engine performance may be better modelled with the jet engine coefficients given in Appendix I.

6.2 Note that the Max-Climb power setting are used from the thrust reduction point up to 10 000 ft AFE. If the aircraft engine is flat-rated, no change is required. If the engine is normally aspirated, the average power in the climb should be used. Propeller efficiencies should also be averaged over the conditions when the different power settings are used.

Table J-6. Propeller engine coefficients

Power setting	Propeller efficiency	Installed net propulsive horsepower (hp)
Max-Take-off		
Max-Climb		

7. DEPARTURE PROCEDURES

7.1 Departure procedures consist of a take-off segment, and a combination of climb and acceleration segments up to an altitude of 10 000 ft AFE. A climb segment is defined by its endpoint altitude. An acceleration segment is defined by its rate-of-climb and the calibrated airspeed at its endpoint. The flap settings are indicated for endpoints of segments. These flap settings should coincide with those given in section 4. Please provide procedural data for each stage length given in section 3.

7.2 Default take-off procedures for jet aircraft include an ICAO A, an ICAO B, and a BBN/AAAI reference procedure, included in Appendix I, Table I-8. However, these procedures may not be appropriate for propeller-driven aircraft. Manufacturers of propeller-driven aircraft should use their own recommended procedures. In developing these procedures, manufacturers should use their best judgement based on experience with their customers in determining a default take-off flap setting and an appropriate power cutback point.

7.3 The ANP database supports two types of departure procedures: procedural profiles and profile points. Procedural profiles utilize the aircraft performance methods described in Appendix C, and they take into account atmospheric effects on the aircraft performance. Profile points are an ordered set of fixed profile points that specify a two-dimensional trajectory for the aircraft, and they do not take into account atmospheric effects on the aircraft performance. Procedural profiles are considered to be of a higher data quality than the profile points because they allow for more modelling flexibility. Therefore, the development of procedural profiles is recommended. If possible, both procedural profiles and the corresponding profile point should be submitted for each submitted take-off procedure, to aid in the review of the data submittal

7.4 Table J-7 should be completed for each submitted procedural profile verses each take-off weight given in section 4. Table J-8 should be completed for each corresponding submitted profile points. For both tables, the number and sequence of the procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Database submittals should comply with the manufacturer's recommended departure procedures. Additional information on CLIMB and ACCELERATION procedures steps is provided in 3.7. Note that certain performance parameters, such as rate-of-climb, are not flexible in their use and should be developed for a specific atmosphere.

Table J-7. Take-off procedural profile

Stage number		Procedure type (procedural or points)			Procedure name		
Profile steps	Segment Type ¹	Thrust Type ² (T/C)	Flap configuration identifier	Endpoint altitude (ft AFE)	Rate-of-climb (ft/min)	Endpoint speed (KCAS)	Start thrust ³ (lb or %hp)
1	Take-off			N/A	N/A	N/A	
2	Climb			ft	N/A	N/A	
3	Climb			ft	N/A	N/A	
4	Accelerate			N/A	ft/min	kt	
5	Accelerate			N/A	ft/min	kt	
6	Climb			ft	N/A	N/A	
7	Climb			ft	N/A	N/A	
8	Accelerate			N/A	ft/min	kt	
9	Accelerate			N/A	ft/min	kt	
10	Climb			10 000 ft	N/A	N/A	lb

1. Add, delete, and sequence the segments as necessary to represent a take-off procedure.
2. T = Max-Take-off, C = Max-Climb.
3. Start thrust data may be presented in either corrected net thrust (lb) or per cent horsepower (%hp). These data are used to compare to computed thrust values.

Table J-8. Take-off profile points

Stage number		Procedure type (procedural or points)			Procedure name	
Profile points	Segment type	Thrust type (T/C)	Start altitude (ft AFE)	Horizontal coordinate (m) relative to the start- roll point on a runway	Aircraft true airspeed (KCAS)	Start thrust (lb or %hp)
1	Take-off		ft	m	kt	lb
2	Climb		ft	m	kt	lb
3	Climb		ft	m	kt	lb
4	Accelerate		ft	m	kt	lb
5	Accelerate		ft	m	kt	lb
6	Climb		ft	m	kt	lb
7	Climb		ft	m	kt	lb
8	Accelerate		ft	m	kt	lb
9	Accelerate		ft	m	kt	lb
10	Climb		10 000 ft	m	kt	lb

8. APPROACH PROCEDURES

8.1 A landing (or approach) profile should be calculated for a starting altitude of 10 000 ft AFE following a 3-degree approach glide slope with a level segment at 3 000 ft AFE. The flap setting identifiers should coincide with those given in section 4. Reverse thrust distance is nominally 10 per cent of ground roll distance, which is 90 per cent of the stop distance minus 291 m (954 ft), if applicable. Stop distance can be smaller than the maximum landing distance reported in section 3. Reverse corrected net thrust is nominally 40 per cent of maximum static thrust for narrow-body aircraft and 10 per cent of maximum static thrust for wide-body aircraft. The idle/taxi distance is 90 per cent of the stop distance minus 291 m (954 ft). Taxi/idle corrected net thrust is nominally 10 per cent of maximum static thrust reported in section 3.

8.2 Similar to the departure procedures, the ANP database supports both procedural profiles and profile points. Procedural profiles are considered to be of a higher data quality than the profile points because they allow for more modelling flexibility. Therefore, the development of procedural profiles is recommended. If possible, both procedural profiles and the corresponding profile point should be submitted for each submitted approach procedure, to aid in the review of the data submittal.

8.3 Table J-9 below should be completed for each submitted landing procedure. Table J-10 should be completed for each corresponding submitted profile points. For both tables, the number and sequence of the procedure steps given below is for example purposes only and will vary depending on the aircraft and operating procedure. Additional information on landing procedures steps is provided in 3.7.7.

Table J-9. Approach procedural profile

Landing weight (kg)					Stopping distance (m)			
Procedure type (procedural or points)					Procedure name			
Profile step	Operation	Starting flap configuration	Starting altitude (ft AFE)	Descent angle (deg)	Start speed ¹ (KTAS)	Track distance (horizontal length) (m)	Start thrust (% of static thrust)	Start thrust ² (lb or %hp)
1	Descend					N/A	N/A	
2	Descend					N/A	N/A	
3	Descend					N/A	N/A	
4	Level-Decel			N/A			N/A	
5	Descend					N/A	N/A	
6	Land		0 ft	N/A	N/A		N/A	
7	Decelerate	N/A	0 ft	N/A				
8	Decelerate	N/A	0 ft	N/A		0 m		

1. Landing speed is for reference only; the methods provided in this manual calculate landing speed using the D coefficient and landing weight.

2. These data are used to compare to computed thrust values.

Table J-10. Approach profile points

Landing weight (kg)			Stopping distance (m)		
Procedure type (procedural or points)			Procedure name		
Profile points	Segment type	Start altitude (ft AFE)	Horizontal coordinate (m) relative to the touchdown point ¹	Aircraft true airspeed (KCAS)	Start thrust (lb or %hp)
1	Descend	ft	m	kt	lb
2	Descend	ft	m	kt	lb
3	Descend	ft	m	kt	lb
4	Level-Decel	ft	m	kt	lb
5	Descend	ft	m	kt	lb
6	Land	0 ft	0 m	kt	lb
7	Decelerate	0 ft	m	kt	lb
8	Decelerate	0 ft	m	kt	lb

1. These horizontal coordinate values are negative during descent and positive during the landing ground roll.

9. NOISE DATA

9.1 Noise power distance (NPD) data are requested for noise exposure levels (sound exposure level (SEL) and effective perceived noise level (EPNL)) and maximum noise levels (maximum A-weighted sound level and maximum tone-corrected perceived noise level). Specific guidelines for developing NPD data are provided in SAE-AIR-1845. NPDs should be provided for representative power setting values that span the procedures given in sections 7 and 8. When computing corrected net thrust for propeller-driven aircraft, the SAE-AIR-1845 equations should be used and the corresponding coefficients should be provided in this data submittal (see Appendix C).

9.2 Two different SEL NPD calculation adjustment procedures are defined in SAE-AIR-1845: the integrated procedure and the simplified procedure. The integrated procedure requires a higher quality of data, where measured noise and performance data include spectral data available for the complete flyover time period of interest, whereas the simplified procedure is typically used with measured noise and performance data where spectral data are available only for the time of occurrence of the maximum sound level. The integrated procedure is recommended for computing NPDs for the data submittal form, although NPDs computed using either integrated or simplified will be accepted. Where applicable, be sure to differentiate between NPDs generated using integrated and simplified procedures.

9.3 In general, noise measurements are collected under certification-like conditions and then are adjusted to different distances based on spherical divergence, altitude duration, time-varying aircraft speed, and atmospheric absorption. Noise data should be normalized to standard reference conditions specified in 2.6. Where applicable, be sure to differentiate between approach and take-off configuration noise data. For example, "200-A" would be 200 lb of corrected net thrust per engine under an approach configuration.

9.4 It is important to note that SAE-AIR-1845 references SAE-ARP-866A [ref. 13] for computing the atmospheric absorption adjustment during the NPD computation process. As mentioned in 4.3.7, SAE-ARP-5534 [ref. 17] is being evaluated for use with noise certification, and is intended to replace SAE-ARP-866A. In the meantime, the effects of the 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 in the noise modelling. When developing NPDs from empirical data, SAE-ARP-866A should still be used to correct the empirical data to the source using the measurement day atmospheric conditions, and the reference atmospheric adjustment in Appendix E should be used to compute the noise levels at the ten NPD distances using standard atmospheric conditions, as specified in SAE-AIR-1845.

9.5 Noise data for approach conditions should use the final approach landing speed as the reference speed for the noise data. All exposure-based metrics, such as EPNL and SEL, should be further normalized to 160 knots using the duration correction equation in SAE-AIR-1845.

9.6 Sound exposure levels should be calculated for the distances given on the tables, below which range from 200 ft to 25 000 ft. When modelling propeller aircraft, the propeller rotations per minute (RPM) should also be provided for each NPD.

9.7 Repeat Table J-11 for each combination of four noise types and two operation mode (i.e. eight tables). Where applicable, be sure to differentiate between approach and take-off configuration noise data. In each table, a minimum of two NPDs per operation mode and noise type is required, in order to have the minimum number of NPDs required for NPD interpolation and extrapolation, as described in 4.3. The development of more than two NPDs for each combination of noise type and operation mode is strongly recommended. A larger NPD data set results in both the noise levels of the aircraft being more comprehensively represented, and noise levels being extrapolated over smaller ranges, thus improving the accuracy of the noise model utilizing those data. It is not uncommon for aircraft in the ANP database to have three or four approach NPDs and six or more departure NPDs for each noise metric type.

Table J-11. NPD data

Noise type ¹		Operation ²					
Atmospheric absorption method		SAE-AIR-1845 integrated or simplified procedure					
Distance (ft)	Power setting (lb or %hp)						
	lb	lb	lb	lb	lb	lb	
	rpm	rpm	rpm	rpm	rpm	rpm	
200	dB	dB	dB	dB	dB	dB	
400	dB	dB	dB	dB	dB	dB	
630	dB	dB	dB	dB	dB	dB	
1 000	dB	dB	dB	dB	dB	dB	
2 000	dB	dB	dB	dB	dB	dB	
4 000	dB	dB	dB	dB	dB	dB	
6 300	dB	dB	dB	dB	dB	dB	
10 000	dB	dB	dB	dB	dB	dB	
16 000	dB	dB	dB	dB	dB	dB	
25 000	dB	dB	dB	dB	dB	dB	

1. Noise types:
 L_{AE} = Sound exposure level (reference speed 160 knots)
 L_{EPN} = Effective perceived noise level (reference speed 160 knots)
 L_{ASmx} = Maximum A-weighted sound level (at speed close to 160 knots)
 L_{PNTSmx} = Maximum tone-corrected perceived noise level (at speed close to 160 knots)

2. Operations:
A = Approach
D = Depart

9.8 Unweighted one-third octave-band spectral data corresponding to the time of L_{PNTSmx} and the time of L_{ASmx} should be provided for each thrust level represented in the NPDs. The spectra should be at the same corrected net thrust values as provided in the noise exposure and maximum noise tables, and span the one-third octave-bands from 50 to 10 000 Hz. The spectra should be measured at a speed close to 160 knots, if possible, and adjusted to a reference distance of 1 000 ft using the atmospheric absorption table in Appendix E. Repeat Table J-12 for each combination of noise type and operation (eight tables). Where applicable, be sure to differentiate between approach and take-off configuration spectral data.

Table J-12. Spectral data

Noise type ¹		Operation				
One-third octave band (Hz)	Corrected net thrust per engine (lb)					
	lb	lb	lb	lb	lb	lb
50	dB	dB	dB	dB	dB	dB
63	dB	dB	dB	dB	dB	dB
80	dB	dB	dB	dB	dB	dB
100	dB	dB	dB	dB	dB	dB
125	dB	dB	dB	dB	dB	dB
160	dB	dB	dB	dB	dB	dB
200	dB	dB	dB	dB	dB	dB
250	dB	dB	dB	dB	dB	dB
315	dB	dB	dB	dB	dB	dB
400	dB	dB	dB	dB	dB	dB
500	dB	dB	dB	dB	dB	dB
630	dB	dB	dB	dB	dB	dB
800	dB	dB	dB	dB	dB	dB
1 000	dB	dB	dB	dB	dB	dB
1 250	dB	dB	dB	dB	dB	dB
1 600	dB	dB	dB	dB	dB	dB
2 000	dB	dB	dB	dB	dB	dB
2 500	dB	dB	dB	dB	dB	dB
3 150	dB	dB	dB	dB	dB	dB
4 000	dB	dB	dB	dB	dB	dB
5 000	dB	dB	dB	dB	dB	dB
6 300	dB	dB	dB	dB	dB	dB
8 000	dB	dB	dB	dB	dB	dB
10 000	dB	dB	dB	dB	dB	dB

1. At time of L_{ASmx} and L_{PNTSmx}.

Appendix K

EXAMPLE STUDIES FOR IMPLEMENTATION CONFIRMATION

1. INTRODUCTION

1.1 This appendix is primarily to be used by noise model developers implementing the methodology provided in this manual in a new noise model. It should be used during the software implementation of a model to check against the noise calculation methodology for a single event. This will also serve to check the coding of the construction of flight path segments, which will need to have been implemented in order to calculate noise for a single event.

1.2 This appendix defines the reference cases to be used for implementation confirmation (see section 2), along with three sets of reference results (see section 3): reference SEL results, reference segment results, and reference grid results. The data defined in this appendix are also available in tabular form on the ANP database website (www.aircraftnoisemodel.org).

1.3 The reference SEL results are intended to enable a relatively quick and efficient check to be made of development model results against the reference results. The reference segment results present the results for the main parameters at each step in the calculation. Developers may use these results to diagnose any discrepancies between the results of a development model and the reference SEL results. It would be expected that a developer would be able to achieve a model which faithfully reproduces the reference SEL and segment results. These results consider only 18 receptors at key locations relative to single aircraft departure and arrival operations.

1.4 In practice, noise models are used not only to calculate noise levels at receptors, but also to calculate noise footprints and contours. For noise contour calculation, noise levels are calculated across a grid of receptors, and then post-processed to produce a series of noise contours. Chapters 5 and 6 present methodologies for calculating cumulative levels and for calculating noise contours from a results grid respectively. The reference grid results are intended to be used by noise model developers to test the ability of a development model to generate noise level results at grid points that are equivalent to those generated by a compliant model.

1.5 All of the above reference results may also be used by noise modelling practitioners to investigate the effect of varying certain model parameters. Practitioners using non-compliant models may also use this information to quantify the differences between such models and models which meet the guidance provided in this manual.

2. REFERENCE CASES

2.1 The reference cases provide a comprehensive and established set of inputs for use in testing noise model calculations. To date, reference cases have been based on actual aircraft, the parameters of which are subject to changes in the ANP database. The reference cases presented here are based on hypothetical aircraft parameters which do not rely on the ANP database, therefore serve as a fixed reference.

2.2 The reference cases comprise combinations of three hypothetical reference aircraft, on curved and straight notional routes, for arrival and departure operations. A total of twelve combinations therefore make up the reference cases. A coding convention is used to identify the aircraft types and routes. The codes are introduced in the following sections and summarized in 2.4. Prevailing meteorological conditions at the virtual aerodrome, and the runway end and route coordinates are presented in 2.6. The reference case, which combine aircraft, runway and route information, are presented in 2.6, and the receptors are presented in 2.7.

2.3 All coordinates are given in terms of x and y coordinates with units of metres on a flat-earth grid. Each table is replicated in tabular form on the ANP website (www.aircraftnoisemodel.org). Each table is presented in a separate worksheet, named with reference to the table numbering and titles in this appendix.

2.4 Reference aircraft

2.4.1 The three hypothetical reference aircraft types comprise the following:

- a) a turbofan (jet) aircraft with engines mounted on the rear-fuselage (code/NPD ID: JETF);
- b) a turbofan (jet) aircraft with engines mounted under the wings (code/NPD ID: JETW); and
- c) a propeller aircraft (code/NPD ID: PROP).

2.4.2 The three hypothetical aircraft are defined in modelling terms using parameters described in Appendix I. Tables K-1 to K-8 include the following reference aircraft input data:

- a) Table K-1: general aircraft characteristics, e.g. number of engines, installation, take-off and landing weights, etc.;
- b) Table K-2: jet coefficients (for JETF and JETW);
- c) Table K-3: propeller coefficients (for PROP);
- d) Table K-4: aerodynamic coefficients, i.e. flap settings;
- e) Table K-5: default weights;
- f) Table K-6: fixed point profiles;
- g) Table K-7: NPD (noise power distance) curves; and
- h) Table K-8: spectral class.

Table K-1. Aircraft (general characteristics)

Aircraft identifier	Description	Engine type	Number of engines	Weight class	Maximum gross take-off weight (lb)	Maximum gross landing weight (lb)	Maximum landing distance (ft)	Maximum sea level static thrust (lb)	NPD identifier	Power parameter	Approach spectral class identifier	Departure spectral class identifier	Lateral directivity identifier
JETF	Reference aircraft with two fuselage-mounted turbofan engines	Jet	2	Large	165 347	143 300	4 921	25 000	JETF	Corrected net thrust (lb)	204	133	Fuselage
JETW	Reference aircraft with wing-mounted turbofan engines	Jet	2	Large	165 347	143 300	4 921	25 000	JETW	Corrected net thrust (lb)	205	103	Wing
PROP	Reference aircraft with wing-mounted turboprop engines	Turboprop	2	Large	165 347	143 300	4 921	16 500	PROP	Shaft horse power (%)	234	112	Prop

Table K-2. Jet coefficients

Aircraft identifier	Thrust rating	E (lb)	F (lb/kt)	Ga (lb/ft)	Gb (lb/ft ²)	H (lb/degC)	K1 (lb/EPR)	K2 (lb/EPR ²)	K3 (lb/(N1/sqrt(theta)))	K4 (lb/(N1/sqrt(theta)) ²)
JETF	MaxClimb	16000.0	-4.00000	0.40000	-0.00001	0.000	n/a	n/a	n/a	n/a
JETF	IdleApproach	1100.0	-6.50000	0.18000	0	0.000	n/a	n/a	n/a	n/a
JETF	MaxTakeOff	25000.0	-25.00000	0.30000	0.00001	0.000	n/a	n/a	n/a	n/a
JETW	MaxClimb	16000.0	-4.00000	0.40000	-0.00001	0.000	n/a	n/a	n/a	n/a
JETW	IdleApproach	1100.0	-6.50000	0.17000	-0.00001	0.000	n/a	n/a	n/a	n/a
JETW	MaxTakeOff	25000.0	-25.00000	0.30000	0.00001	0.000	n/a	n/a	n/a	n/a

Table K-3. Propeller coefficients

Aircraft identifier	Thrust rating	Propeller efficiency	Installed net propulsive power (hp)
PROP	MaxClimb	0.85	7800.0
PROP	MaxTakeOff	0.85	9500.0

Table K-4. Aerodynamic coefficients

Aircraft identifier	Operation type	Flap identifier	B	C/D (kt/sqrt(lb))	R
JETF	D	1	-	-	0.060000
JETF	A	15	-	-	0.075000
JETF	A	25	-	0.375000	0.100000
JETF	A	30	-	0.350000	0.120000
JETF	D	5	0.007500	0.400000	0.070000
JETF	D	ZERO	-	-	0.055000
JETW	D	1	-	-	0.060000
JETW	A	15	-	-	0.075000
JETW	A	25	-	0.375000	0.100000
JETW	A	30	-	0.350000	0.120000
JETW	D	5	0.007500	0.400000	0.070000
JETW	D	ZERO	-	-	0.055000
PROP	D	17	0.009100	0.365000	0.110000
PROP	A	D-35	-	0.360000	0.109000
PROP	A	U-INTR	-	-	0.094500
PROP	D	ZERO	-	-	0.080000

Table K-5. Default weights

Aircraft identifier	Operation	Stage length	Weight (lb)
JETF	A	1	143 300
JETF	D	1	165 347
JETW	A	1	143 300
JETW	D	1	165 347
PROP	A	1	143 300
PROP	D	1	165 347

Table K-6. Fixed point profiles

Aircraft identifier	Operation mode	Profile identifier	Stage length	Point number	Distance (m)	Altitude (m)	True airspeed (m/s)	Corrected net thrust (lb or % per engine)
JETF	A	FPP	1	1	-45644.2	1828.8	143.19	533.14
JETF	A	FPP	1	2	-26947.9	914.4	136.81	476.71
JETF	A	FPP	1	3	-26643.1	914.4	135.72	450.59
JETF	A	FPP	1	4	-18664.4	914.4	103.42	450.59
JETF	A	FPP	1	5	-18359.6	914.4	101.97	417.90
JETF	A	FPP	1	6	-17447.8	914.4	97.53	417.90
JETF	A	FPP	1	7	-17143.0	898.4	96.92	235.08
JETF	A	FPP	1	8	-14196.7	744.0	90.86	230.29
JETF	A	FPP	1	9	-13891.9	728.0	89.42	306.54
JETF	A	FPP	1	10	-11238.6	589.0	75.64	300.87
JETF	A	FPP	1	11	-10933.8	573.0	75.14	765.00
JETF	A	FPP	1	12	-9286.6	486.7	72.39	755.66
JETF	A	FPP	1	13	-8981.8	470.7	72.33	5011.09
JETF	A	FPP	1	14	-290.2	15.2	70.69	4737.00
JETF	A	FPP	1	15	0.0	0.0	69.33	4724.14
JETF	A	FPP	1	16	92.7	0.0	67.81	10000.00
JETF	A	FPP	1	17	1292.7	0.0	14.14	2500.00
JETF	D	FPP	1	1	0.0	0.0	0.01	25000.00
JETF	D	FPP	1	2	1708.5	0.0	85.11	20933.71
JETF	D	FPP	1	3	3439.5	304.8	86.39	21243.71
JETF	D	FPP	1	4	3744.3	320.2	88.50	15739.39
JETF	D	FPP	1	5	7811.4	526.0	113.06	15818.11
JETF	D	FPP	1	6	9152.0	580.0	122.08	15817.80
JETF	D	FPP	1	7	12119.6	914.4	124.11	16202.80
JETF	D	FPP	1	8	14218.7	986.6	137.89	16185.53
JETF	D	FPP	1	9	20671.6	1676.4	142.72	16846.58
JETF	D	FPP	1	10	26809.8	2286.0	147.19	17307.95
JETF	D	FPP	1	11	35175.9	3048.0	153.08	17884.66
JETW	A	FPP	1	1	-45644.2	1828.8	143.19	533.14
JETW	A	FPP	1	2	-26947.9	914.4	136.81	476.71
JETW	A	FPP	1	3	-26643.1	914.4	135.72	450.59
JETW	A	FPP	1	4	-18664.4	914.4	103.42	450.59
JETW	A	FPP	1	5	-18359.6	914.4	101.97	417.90
JETW	A	FPP	1	6	-17447.8	914.4	97.53	417.90
JETW	A	FPP	1	7	-17143.0	898.4	96.92	235.08
JETW	A	FPP	1	8	-14196.7	744.0	90.86	230.29
JETW	A	FPP	1	9	-13891.9	728.0	89.42	306.54

Aircraft identifier	Operation mode	Profile identifier	Stage length	Point number	Distance (m)	Altitude (m)	True airspeed (m/s)	Corrected net thrust (lb or % per engine)
JETW	A	FPP	1	10	-11238.6	589.0	75.64	300.87
JETW	A	FPP	1	11	-10933.8	573.0	75.14	765.00
JETW	A	FPP	1	12	-9286.6	486.7	72.39	755.66
JETW	A	FPP	1	13	-8981.8	470.7	72.33	5011.09
JETW	A	FPP	1	14	-290.2	15.2	70.69	4737.00
JETW	A	FPP	1	15	0.0	0.0	69.33	4724.14
JETW	A	FPP	1	16	92.7	0.0	67.81	10000.00
JETW	A	FPP	1	17	1292.7	0.0	14.14	2500.00
JETW	D	FPP	1	1	0.0	0.0	0.01	25000.00
JETW	D	FPP	1	2	1708.5	0.0	85.11	20933.71
JETW	D	FPP	1	3	3439.5	304.8	86.39	21243.71
JETW	D	FPP	1	4	3744.3	320.2	88.50	15739.39
JETW	D	FPP	1	5	7811.4	526.0	113.06	15818.11
JETW	D	FPP	1	6	9152.0	580.0	122.08	15817.80
JETW	D	FPP	1	7	12119.6	914.4	124.11	16202.80
JETW	D	FPP	1	8	14218.7	986.6	137.89	16185.53
JETW	D	FPP	1	9	20671.6	1676.4	142.72	16846.58
JETW	D	FPP	1	10	26809.8	2286.0	147.19	17307.95
JETW	D	FPP	1	11	35175.9	3048.0	153.08	17884.66
PROP	A	FPP	1	1	-34895.6	1828.8	114.44	14.65
PROP	A	FPP	1	2	-17447.8	914.4	91.61	12.89
PROP	A	FPP	1	3	-8723.9	457.2	78.00	18.68
PROP	A	FPP	1	4	-5815.9	304.8	71.69	24.76
PROP	A	FPP	1	5	0.0	0.0	71.31	23.89
PROP	A	FPP	1	6	92.7	0.0	67.81	40.00
PROP	A	FPP	1	7	1292.7	0.0	15.56	10.00
PROP	D	FPP	1	1	0.0	0.0	0.01	105.63
PROP	D	FPP	1	2	2514.6	0.0	77.67	105.63
PROP	D	FPP	1	3	5712.7	304.8	78.83	107.93
PROP	D	FPP	1	4	6386.1	355.4	80.50	106.32
PROP	D	FPP	1	5	6690.9	374.0	81.25	87.30
PROP	D	FPP	1	6	9135.1	522.5	86.94	82.45
PROP	D	FPP	1	7	14703.1	914.4	88.64	84.78
PROP	D	FPP	1	8	26268.2	1330.2	111.61	70.83
PROP	D	FPP	1	9	35321.8	1676.4	113.56	72.64
PROP	D	FPP	1	10	52502.3	2286.0	117.14	75.96
PROP	D	FPP	1	11	76628.0	3048.0	121.81	80.41

Table K-7. NPD curves

NPD identifier	Noise descriptor	Operation mode	Power setting (lb)	L_200 (ft)	L_400 (ft)	L_630 (ft)	L_1000 (ft)	L_2000 (ft)	L_4000 (ft)	L_6300 (ft)	L_10000 (ft)	L_16000 (ft)	L_25000 (ft)
JETF	LAmx	A	2 000	97.4	90.1	85.2	80.1	72.1	63.6	57.4	50.4	42.6	34.6
JETF	LAmx	A	2 500	97.6	90.3	85.4	80.3	72.3	63.8	57.6	50.6	42.8	34.8
JETF	LAmx	A	7 500	99.9	92.6	87.7	82.6	74.6	66.1	59.9	52.9	45.1	37.1
JETF	LAmx	D	10 000	100.2	92.9	88.0	82.9	74.9	66.4	60.2	53.2	45.4	37.4
JETF	LAmx	D	15 000	102.4	95.1	90.2	85.1	77.1	68.6	62.4	55.4	47.6	39.6
JETF	LAmx	D	20 000	106.9	99.6	94.7	89.6	81.6	73.1	66.9	59.9	52.1	44.1
JETF	LAmx	D	22 500	109.1	101.8	96.9	91.8	83.8	75.3	69.1	62.1	54.3	46.3
JETF	SEL	A	2 000	101.2	97.2	94.3	91.0	85.5	79.5	75.2	70.5	65.4	60.2
JETF	SEL	A	2 500	101.4	97.4	94.5	91.2	85.7	79.7	75.4	70.7	65.6	60.4
JETF	SEL	A	7 500	103.0	99.0	96.1	92.8	87.3	81.3	77.0	72.3	67.2	62.0
JETF	SEL	D	10 000	100.6	96.6	93.7	90.4	84.9	78.9	74.6	69.9	64.8	59.6
JETF	SEL	D	15 000	103.9	99.9	97.0	93.7	88.2	82.2	77.9	73.2	68.1	62.9
JETF	SEL	D	20 000	108.1	104.1	101.2	97.9	92.4	86.4	82.1	77.4	72.3	67.1
JETF	SEL	D	22 500	109.8	105.8	102.9	99.6	94.1	88.1	83.8	79.1	74.0	68.8
JETW	LAmx	A	2 000	96.9	89.6	84.7	79.6	71.6	63.1	56.9	49.9	42.1	34.1
JETW	LAmx	A	2 500	97.1	89.8	84.9	79.8	71.8	63.3	57.1	50.1	42.3	34.3
JETW	LAmx	A	7 500	99.4	92.1	87.2	82.1	74.1	65.6	59.4	52.4	44.6	36.6
JETW	LAmx	D	10 000	100.1	92.8	87.9	82.8	74.8	66.3	60.1	53.1	45.3	37.3

NPD identifier	Noise descriptor	Operation mode	Power setting (lb)	L_200 (ft)	L_400 (ft)	L_630 (ft)	L_1000 (ft)	L_2000 (ft)	L_4000 (ft)	L_6300 (ft)	L_10000 (ft)	L_16000 (ft)	L_25000 (ft)
JETW	LAmix	D	15 000	102.3	95.0	90.1	85.0	77.0	68.5	62.3	55.3	47.5	39.5
JETW	LAmix	D	20 000	106.8	99.5	94.6	89.5	81.5	73.0	66.8	59.8	52.0	44.0
JETW	LAmix	D	22 500	109.0	101.7	96.8	91.7	83.7	75.2	69.0	62.0	54.2	46.2
JETW	SEL	A	2 000	100.7	96.7	93.8	90.5	85.0	79.0	74.7	70.0	64.9	59.7
JETW	SEL	A	2 500	100.9	96.9	94.0	90.7	85.2	79.2	74.9	70.2	65.1	59.9
JETW	SEL	A	7 500	102.5	98.5	95.6	92.3	86.8	80.8	76.5	71.8	66.7	61.5
JETW	SEL	D	10 000	100.5	96.5	93.6	90.3	84.8	78.8	74.5	69.8	64.7	59.5
JETW	SEL	D	15 000	103.8	99.8	96.9	93.6	88.1	82.1	77.8	73.1	68.0	62.8
JETW	SEL	D	20 000	108.0	104.0	101.1	97.8	92.3	86.3	82.0	77.3	72.2	67.0
JETW	SEL	D	22 500	109.7	105.7	102.8	99.5	94.0	88.0	83.7	79.0	73.9	68.7
PROP	LAmix	A	28	99.0	93.0	88.7	84.0	76.2	67.6	61.6	55.1	48.0	40.8
PROP	LAmix	D	28	92.1	86.1	81.8	77.1	69.3	60.7	54.7	48.2	41.1	33.9
PROP	LAmix	A	100	108.0	102.0	97.7	93.0	85.2	76.6	70.6	64.1	57.0	49.8
PROP	LAmix	D	100	101.1	95.1	90.8	86.1	78.3	69.7	63.7	57.2	50.1	42.9
PROP	SEL	A	28	102.0	98.0	95.1	91.8	86.3	80.1	75.5	70.4	64.8	59.0
PROP	SEL	D	28	95.1	91.1	88.2	84.9	79.4	73.2	68.6	63.5	57.9	52.1
PROP	SEL	A	100	110.0	106.0	103.1	99.8	94.3	88.1	83.5	78.4	72.8	67.0
PROP	SEL	D	100	103.1	99.1	96.2	92.9	87.4	81.2	76.6	71.5	65.9	60.1

Table K-8. Spectral class

Spectral class identifier	Operation mode	Description	L_50Hz	L_63Hz	L_80Hz	L_100Hz	L_125Hz	L_160Hz	L_200Hz	L_250Hz	L_315Hz	L_400Hz	L_500Hz	L_630Hz	L_800Hz	L_1000Hz	L_1250Hz	L_1600Hz	L_2000Hz	L_2500Hz	L_3150Hz	L_4000Hz	L_5000Hz	L_6300Hz	L_8000Hz	L_10000Hz
133	Departure	2-Engine.Tail.Low/MidBy.Tfan	57.3	56.3	61.5	67.7	71.4	73.7	67.0	72.1	73.8	74.1	71.3	70.4	70.9	70.0	68.2	67.3	63.4	60.9	56.6	53.2	47.8	40.5	31.7	27.9
103	Departure	2-Engine.HighByPass.Tfan	56.7	66.1	70.1	72.8	76.6	73.0	74.5	77.0	75.3	72.2	72.2	71.2	70.2	70.0	69.6	71.1	70.6	67.1	63.4	63.5	58.2	51.5	42.3	37.7
112	Departure	2/4-Engine.Tprop	74.0	95.0	92.0	75.0	96.0	90.0	74.9	78.0	75.0	75.0	74.1	74.0	72.0	70.0	71.0	72.0	71.0	70.0	66.0	64.0	60.0	54.0	46.0	39.9
204	Approach	2-Engine.Low/MidByPass.Tfan	58.8	57.1	59.4	68.0	72.8	73.7	69.1	72.3	74.8	75.6	73.6	72.1	72.1	70.0	66.3	63.6	59.9	57.5	54.8	51.8	48.8	45.8	42.8	39.8
205	Approach	2-Engine.HighByPass.Tfan	68.3	60.7	64.6	67.4	78.4	74.8	71.4	72.4	72.0	72.4	71.6	72.0	71.0	70.0	68.9	67.2	65.8	64.4	63.0	62.0	60.6	54.4	48.5	39.0
234	Approach	Military	56.3	77.3	80.3	74.2	74.3	70.2	72.2	69.3	69.1	71.2	69.1	72.1	69.1	70	69.9	67.7	67.4	65.1	63.7	61.4	55.3	49.1	42.9	33.5

2.5 Meteorological conditions, runway and routes

2.5.1 The reference cases also define a hypothetical aerodrome from which to model the reference aircraft. This is defined in terms of prevailing meteorological conditions, presented in Table K-9, and runway end coordinates given in terms of x and y coordinates on a flat-earth grid (see Table K-10).

Table K-9. Aerodrome meteorological conditions

Metric units					
Temperature (°C)	Pressure (mmHg)	Headwind (m/s)	Elevation (m)	Do humidity	Humidity (%)
15	759.97	0	0	N	70

Table K-9. Aerodrome meteorological conditions (continued)

US units					
Temperature (°F)	Pressure (in Hg)	Headwind (kt)	Elevation (ft)	Do humidity	Humidity (%)
59	29.92	0	0	N	70

Table K-10. Runway ends

Runway identifier	Metric units			
	SOR X-coordinate (m)	SOR Y-coordinate (m)	End X-coordinate (m)	End Y-coordinate (m)
09	0	0	3000	0

Table K-10. Runway ends (continued)

Runway identifier	US units			
	SOR X-coordinate (nmi)	SOR Y-coordinate (nmi)	End X-coordinate (nmi)	End Y-coordinate (nmi)
09	0.0000	0.0000	1.6199	0.0000

2.5.2 There are four reference routes, all operating in an easterly direction, which are defined in terms of x and y coordinates on a flat-earth grid. There is a curved route and a straight route (represented by codes 'C' and 'S' respectively) for both arrival and departure operations (represented by codes 'A' and 'D' respectively). The four routes are therefore identified by the following route identifiers (IDs): **AC** and **AS** for curved and straight arrival routes respectively, and **DC** and **DS** for curved and straight departure routes respectively.

2.5.3 The routes and coordinates are presented in Figure K-1 and Table K-11.

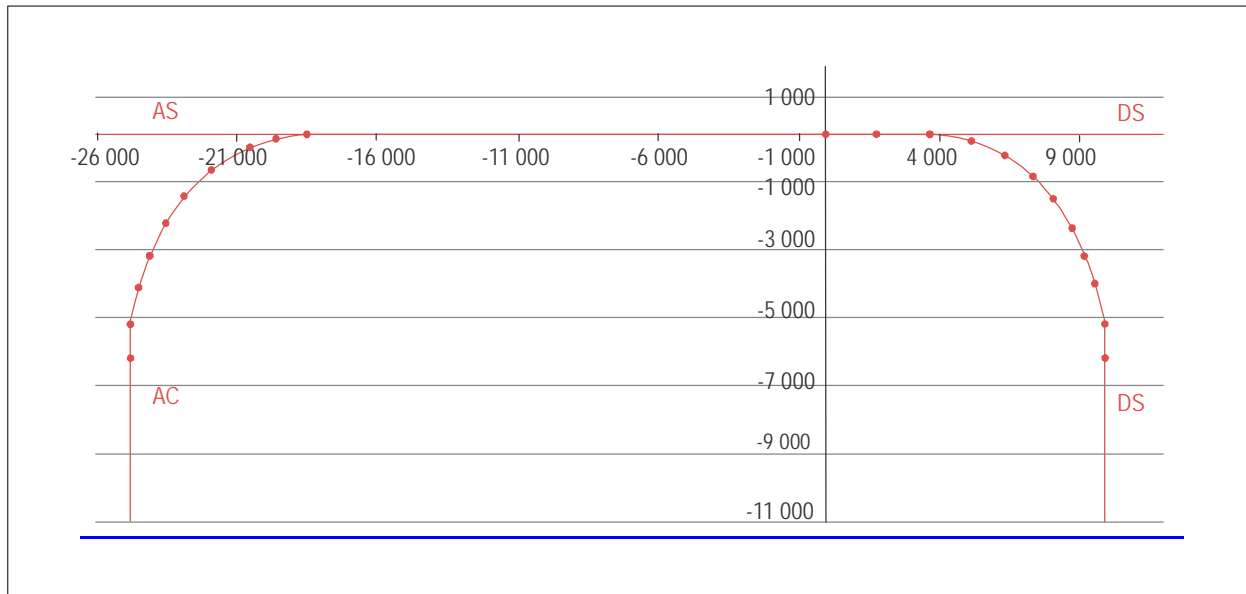


Figure K-1. Reference case routes

Table K-11. Reference case routes (coordinates)

Track identifier	Track points	Track description	Metric units		US units	
			X-coordinate (m)	Y-coordinate (m)	X-coordinate (nmi)	Y-coordinate (nmi)
AC	1	Arrival, curved	-24 800	-100 000	-13.3909	-53.9957
AC	2	Arrival, curved	-24 800	-6 300	-13.3909	-3.4017
AC	3	Arrival, curved	-24 704	-5 206	-13.3391	-2.8110
AC	4	Arrival, curved	-24 420	-4 145	-13.1857	-2.2381
AC	5	Arrival, curved	-23 956	-3 150	-12.9352	-1.7009
AC	6	Arrival, curved	-23 326	-2 250	-12.5950	-1.2149
AC	7	Arrival, curved	-22 550	-1 474	-12.1760	-0.7959
AC	8	Arrival, curved	-21 650	-844	-11.6901	-0.4557
AC	9	Arrival, curved	-20 655	-380	-11.1528	-0.2052
AC	10	Arrival, curved	-19 594	-96	-10.5799	-0.0518
AC	11	Arrival, curved	-18 500	0	-9.9892	0.0000
AC	12	Arrival, curved	1 300	0	0.7019	0.0000
AS	1	Arrival, straight	-100 000	0	-53.9957	0.0000
AS	2	Arrival, straight	1 300	0	0.7019	0.0000
DC	1	Departure, curved	0	0	0.0000	0.0000
DC	2	Departure, curved	3 700	0	1.9978	0.0000

Track identifier	Track points	Track description	Metric units		US units	
			X-coordinate (m)	Y-coordinate (m)	X-coordinate (nmi)	Y-coordinate (nmi)
DC	3	Departure, curved	4 794	-96	2.5886	-0.0518
DC	4	Departure, curved	5 855	-380	3.1614	-0.2052
DC	5	Departure, curved	6 850	-844	3.6987	-0.4557
DC	6	Departure, curved	7 750	-1 474	4.1847	-0.7959
DC	7	Departure, curved	8 526	-2 250	4.6037	-1.2149
DC	8	Departure, curved	9 156	-3 150	4.9438	-1.7009
DC	9	Departure, curved	9 620	-4 145	5.1944	-2.2381
DC	10	Departure, curved	9 904	-5 206	5.3477	-2.8110
DC	11	Departure, curved	10 000	-6 300	5.3996	-3.4017
DC	12	Departure, curved	10 000	-100 000	5.3996	-53.9957
DS	1	Departure, straight	0	0	0.0000	0.0000
DS	2	Departure, straight	100 000	0	53.9957	0.0000

2.6 Reference cases — twelve combinations

The full list of twelve reference cases is given in Table K-12. Each case has a unique case ID based on the aircraft and route codes given in the preceding sections.

Table K-12. Reference case combinations

Aircraft	Operation	Route	Case ID
Jet fuselage-mounted engines	Arrival	Curved	JETFAC
Jet fuselage-mounted engines	Arrival	Straight	JETFAS
Jet fuselage-mounted engines	Departure	Curved	JETFDC
Jet fuselage-mounted engines	Departure	Straight	JETFDS
Jet wing-mounted engines	Arrival	Curved	JETWAC
Jet wing-mounted engines	Arrival	Straight	JETWAS
Jet wing-mounted engines	Departure	Curved	JETWDC
Jet wing-mounted engines	Departure	Straight	JETWDS
Propeller engines	Arrival	Curved	PROPAC
Propeller engines	Arrival	Straight	PROPAS
Propeller engines	Departure	Curved	PROPDC
Propeller engines	Departure	Straight	PROPDS

2.7 Receptors

2.7.1 Reference results are provided for each of the cases presented in 2.6. A series of 18 receptors is defined, in terms of x and y coordinates on a flat-earth grid, at which the reference results are given. These receptors are identified by a unique receptor ID, from **R01** to **R18**, presented in blue in Figure K-2 and in Table K-13.

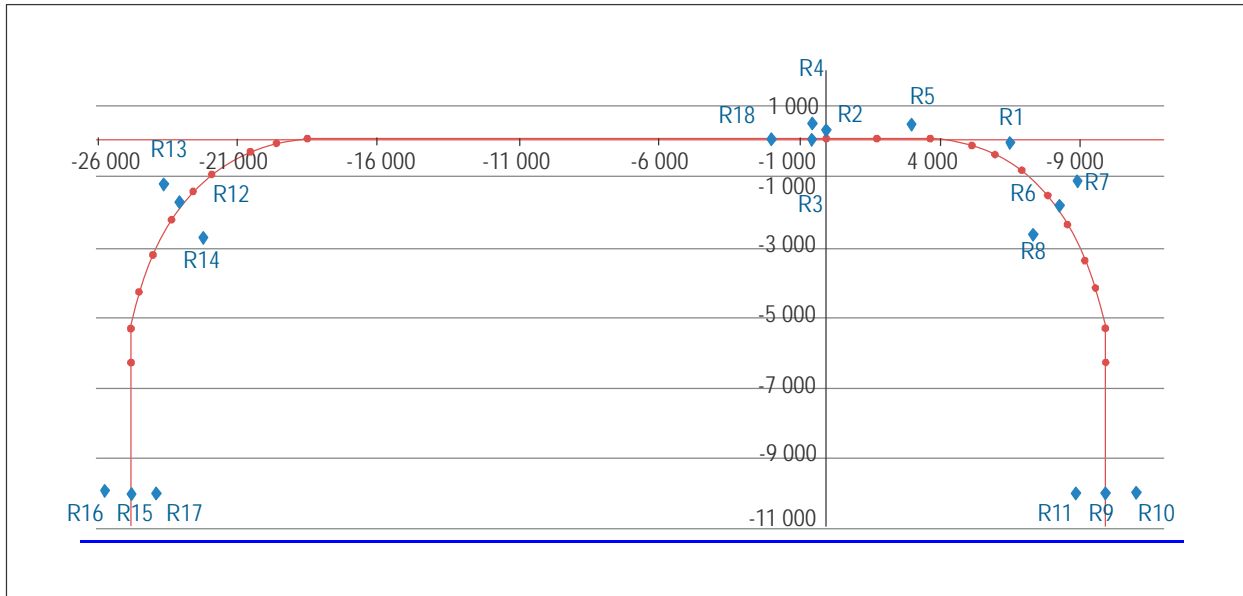


Figure K-2. Receptors

Table K-13. Receptors

Receptor identifier	Receptor description	Relevant to track identifiers	Metric units			US units		
			X-coordinate (m)	Y-coordinate (m)	Height (m)	X-coordinate (nmi)	Y-coordinate (nmi)	Height (ft)
R01	Take-off, 6.5 km from SOR	DC, DS	6 500	0	0	3.5097	0.0000	0
R02	SOR, to the side	AC, AS, DC, DS	0	200	0	0.0000	0.1080	0
R03	SOR, behind	AC, AS, DC, DS	-500	0	0	-0.2700	0.0000	0
R04	SOR, behind and to the side	AC, AS, DC, DS	-500	500	0	-0.2700	0.2700	0
R05	Sideline, at runway end	AC, AS, DC, DS	3 000	500	0	1.6199	0.2700	0
R06	Departure curve, beneath	DC	8 200	-1 800	0	4.4276	-0.9719	0
R07	Departure curve, outside	DC	9 600	-400	0	5.1836	-0.2160	0
R08	Departure curve, inside	DC	6 700	-3 300	0	3.6177	-1.7819	0
R09	Departure curve end, beneath	DC	10 000	-10 000	0	5.3996	-5.3996	0

3. REFERENCE CASE RESULTS

3.1 There are three categories of reference case results: SEL results, segmental results and grid results. These are described in the following sections.

3.2 Reference SEL results

3.2.1 The reference SEL results are sound exposure levels calculated for each of the reference cases listed in Table K-12, at the relevant receptors given in Table K-14. Overall SEL reference results are presented in Table K-15 for each case and relevant receptor. These results are presented in section 4 and are available in tabular form on the ANP database website (www.aircraftnoisemodel.org).

3.2.2 Computing overall SEL results is a relatively quick and simple modelling task. These results therefore provide a benchmark against which noise model developers can check the performance of a new model. Making such a comparison will highlight where differences exist between the overall outputs of a development model and the reference results.

3.2.3 Results at different locations are sensitive to different elements of the noise calculation. For instance, receptors **R06-R11** are affected by aircraft in flight, so outputs may match the reference SEL results even if there are errors in the ground roll adjustment algorithms. **R02-R05**, however, are near to the runway and therefore require the ground roll adjustments to be correctly implemented for the outputs to match the reference SEL results.

3.2.4 Comparing the SEL results at different receptors will therefore help developers identify areas where a development model deviates from the methodology provided in this manual.

Table K-15. SEL results

Receptor Identifier	JETFAC	JETFAS	JETFDC	JETFDS	JETWAC	JETWAS	JETWDC	JETWDS	PROPAC	PROPAS	PROPDC	PROPS
R01	-	-	84.35	90.13	-	-	85.61	90.03	-	-	86.10	91.88
R02	89.91	89.91	101.41	101.41	91.09	91.09	102.82	102.82	92.35	92.35	98.42	98.42
R03	105.09	105.09	74.76	74.73	104.59	104.59	76.17	76.13	104.22	104.22	75.53	75.53
R04	80.90	80.90	81.79	81.79	82.11	82.11	83.20	83.20	83.32	83.32	78.63	78.63
R05	63.21	63.22	91.07	91.09	64.22	64.22	92.65	92.68	65.99	65.99	85.31	85.32
R06	-	-	87.91	-	-	-	87.88	-	-	-	87.04	-
R07	-	-	71.16	-	-	-	72.82	-	-	-	70.48	-
R08	-	-	72.79	-	-	-	74.56	-	-	-	72.83	-
R09	-	-	80.55	-	-	-	80.46	-	-	-	80.34	-
R10	-	-	72.83	-	-	-	74.23	-	-	-	71.58	-
R11	-	-	72.84	-	-	-	74.26	-	-	-	71.58	-
R12	79.54	-	-	-	79.16	-	-	-	77.47	-	-	-
R13	69.25	78.07	-	-	70.14	78.22	-	-	69.57	76.35	-	-
R14	68.47	-	-	-	69.72	-	-	-	71.45	-	-	-
R15	76.98	-	-	-	76.50	-	-	-	74.01	-	-	-

Receptor Identifier	JETFAC	JETFAS	JETFDC	JETFDS	JETWAC	JETWAS	JETWDC	JETWDS	PROPAC	PROPAS	PROPCD	PROPSD
R16	68.42	-	-	-	69.45	-	-	-	69.06	-	-	-
R17	68.23	-	-	-	69.31	-	-	-	69.08	-	-	-
R18	98.95	98.95	-	-	98.45	98.45	-	-	98.27	98.27	-	-

3.3 Reference segment results

3.3.1 Once these areas where a development model deviates from the methodology provided in this manual are identified uses the SEL results, focussed diagnosis can be undertaken using the reference segment results. The reference segmental results comprise the results for the main calculation parameters for each segment of the trajectories of each of the twelve reference cases. These parameters cover:

- a) profile geometry;
- b) the distance and thrust for interpolating NPD curves;
the baseline SEL;
- c) distances and angles for calculating the noise adjustments;
- d) the noise adjustments; and
- e) the segment SEL.

3.3.2 The full list of parameters is presented in Table K-16, along with their associated mathematical symbol and the section reference in this manual, where the parameter is introduced or defined. It is recommended that noise models are implemented with a means for exporting calculation data in precisely this format. This will facilitate the comparison of a development model's outputs with the reference results, and therefore the development of the model.

Table K-16. Reference segment results parameters

Parameter name	Mathematical symbol	Doc 9911 reference
case_ID	n/a	n/a
receptor_ID	n/a	n/a
segment_ID	n/a	n/a
segment_start_x(ft)	x_1	3.7 Construction of flight path segments
segment_start_y(ft)	y_1	3.7 Construction of flight path segments
segment_start_z(ft)	z_1	3.7 Construction of flight path segments
segment_end_x(ft)	x_2	3.7 Construction of flight path segments
segment_end_y(ft)	y_2	3.7 Construction of flight path segments
segment_end_z(ft)	z_2	3.7 Construction of flight path segments
segment_length(ft)	Λ	4.5.2 Geometric parameters
slant_distance(ft)	d_p	4.5.2 Geometric parameters

Parameter name	Mathematical symbol	Doc 9911 reference
distance_d1(ft)	d_1	4.5.2 Geometric parameters
distance_d2(ft)	d_2	4.5.2 Geometric parameters
distance_q(ft)	Q	4.5.2 Geometric parameters
lateral_displacement(ft)	ℓ	4.6.3 Sound propagation geometry
NPD_interpolation_distance(ft)	D	4.3 Determination of event levels from NPD data
NPD_interpolation_thrust(lb/e)	P	4.3 Determination of event levels from NPD data
angle_beta(°)	B	4.6.3 Sound propagation geometry
angle_gamma(°)	Γ	3.4 Coordinate systems
angle_phi(°)	Φ	4.6.3 Sound propagation geometry
bank_angle(°)	E	3.4 Coordinate systems
engine_install_correction(dB)	Δ_I	4.6.4 Engine installation correction
lateral_attenuation(dB)	Λ	4.6.5 Lateral attenuation
baseline_SEL(dB)	$L_{E\infty}$	4.3 Determination of event levels from NPD data
speed_corr(dB)	Δ_V	4.6.2 The duration correction Δ_V (exposure levels L_E only)
Lmax_noise_fraction	Δ_F	Appendix F, section 4, Consistency of maximum- and time-integrated metrics – the scaled difference
noise_fraction	Δ_F	4.6.7 The finite segment correction Δ_F (exposure levels L_E only)
start_of_roll_correction(dB)	Δ_{SOR}	4.6.8 Specific treatments of ground roll segments, including the start-of-roll directivity function Δ_{SOR}
acoustic_impedance_adjustment(dB)	$\Delta_{Impedance}$	4.3.8 Impedance adjustment of standard NPD data
segment_SEL(dB)	$L_{E,seg}$	4.4 General expressions

3.3.3 The segment results are available in tabular form on the ANP database website: www.aircraftnoisemodel.org.

3.3.4 After the reference SEL results have been used to identify areas where development model outputs deviate from the reference results (see 3.2), detailed comparisons using the reference segment results can be used to pinpoint which specific part(s) of the calculation are giving rise to the discrepancies. The relevant parts of this manual can then be consulted to check the accuracy of the implementation of those algorithms. If noise model developers iterate their model such to achieve these results to the degree of accuracy to which they are presented, the developer can be confident that the development model is aligned with the methodology provided in this manual, at least at the discrete receptor locations.

3.4 Reference grid results

3.4.1 The reference grid results are sound exposure levels across a grid of receptors covering an area that is representative of a large airport noise contour. To reduce the data-handling requirements and to simplify the analysis, the reference grid results are considered only at grid points which have significant influence on calculated noise contours, and at locations which are meaningful in terms of assessing noise impact at real airports. Grid results are therefore:

- a) included for grid points where the reference grid result is greater than or equal to 80 dB SEL; and
- b) not included for grid points located on the runway.

3.4.2 The reference grid results are available in tabular form on the ANP database website (www.aircraftnoisemodel.org). These tables contains the reference grid results according to the above criteria. There is a set for each of the twelve reference cases, identified by the case ID, and presented according to grid point coordinates. Because the different reference cases give rise to different noise calculation results, the list of reference grid points also varies between the different cases. Owing to the quantity of data, the reference grid results are provided only on the website.

3.4.3 Table K-17 defines a rectangular grid that is large enough to include all reference grid points for all twelve reference cases. Calculating SEL noise levels for this rectangular grid is a simple method which noise model developers can use to generate grid outputs from a development model.

Table K-17. Rectangular grid containing reference grid points

Parameter	x-axis (m)	y-axis (m)
Minimum value	-30 000	-15 000
Maximum value	25 000	4 000
Distance between grid points	100	100
Number of grid points	551	191
Distance between maximum and minimum value points	55 000	19 000

3.4.4 This grid also includes many grid points that do not form part of the reference set, i.e. grid points where resulting reference SELs are below 80 dB SEL, or that are on the runway. This will therefore require more computer processing than is strictly necessary to run each case.

3.4.5 Grid outputs from a development model are to be compared with the reference grid results. Whereas the reference segment results enable the elements of the calculation to be scrutinized in detail, the grid results provide the means to check that a development model is predicting the correct values at every relevant grid point, as is needed for contour generation.

3.4.6 If there are differences at one or a number of grid points, a convenient way of quantitatively summarizing the difference is to calculate the root-mean-square of the differences, δ_{RMS} , between the development model output $L_{Edev-mod}$ and the reference result L_{Eref} at each grid point, where there is a total of n grid points, according to equation K-1. While refining the model as described in the sections above, δ_{RMS} may be calculated periodically to monitor progress towards calculating results that equal the reference grid results. The aim is to reduce δ_{RMS} to the smallest value possible, ideally zero.

$$\delta_{RMS} = \sqrt{\frac{\sum_1^n (L_{Edev-mod,i} - L_{Eref,i})^2}{n}}$$

(K-1)

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