REPORT ON STANDARD METHOD OF COMPUTING NOISE CONTOURS AROUND CIVIL AIRPORTS

VOLUME 2: TECHNICAL GUIDE

ECAC.CEAC DOC 29

5TH Edition

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FOREWORD

This is the second of three volumes of updated guidance on aircraft noise contour modelling. The first volume provides a general and largely non-technical introduction to the topic, as well as practical advice to model users. Those for whom the subject is new might usefully treat **Volume 1** as a primer for **Volume 2**. This second volume recommends a specific methodology for calculating aircraft noise exposure around civil aerodromes; this is described in sufficient detail for computer modelling by competent programmers/analysts.

Since the 4th edition was published, a number of noise models have been developed based on the algorithms set out in Volume 2. Through the development of these models, some parts of the guidance were identified that required clarification to ensure consistency in calculation methodology.

The 5th edition replaces the previous (2016) 4th edition of ECAC-CEAC Doc 29 which should now be discarded. This Volume 2 gives the clarity needed to improve the harmonisation of noise models across ECAC member states.

The recommended approach to noise modelling is not the only way to produce accurate noise contours; indeed, for specific airports, different methods can sometimes be more effective. However, it is considered by ECAC, and the international aircraft noise modelling community as a whole, to represent current best practice for general application. When used diligently, it can be expected to deliver reasonably accurate noise contours for most airports in Europe and beyond. This does not mean that the guidance cannot be improved upon. Indeed, the methodology and the supporting data remain under constant review and development, and intermittent updates should be anticipated. Eventually, advances in computer technology and aircraft operations monitoring systems may well make segmentation-based models obsolete.

This new edition contains the first part of an additional two-part **Volume 3** covering the subjects of model verification and validation respectively. Nevertheless, it remains the responsibility of the model user to assure the quality of modelling outputs. The methodology and the Aircraft Noise and Performance (ANP) data are as accurate as understanding and facilities presently allow but, throughout this guidance, it is stressed that achieving reliable results requires meticulous collection and pre-processing of scenario data (describing airport and aircraft operations). Doing this in a measured and cost-effective way is perhaps the practitioner’s greatest challenge. Increasingly, noise contour calculations are compared with on-site measurements; discrepancies can point to modelling deficiencies, but it must always be remembered that obtaining appropriate, accurate measurements is at least as difficult as modelling itself. However, persistent disagreement may well be symptomatic of model or data deficiencies, and this should be reported via the feedback mechanisms of the ANP website.

The recommended methodology can be used to model airport and aircraft operations in minute detail, where necessary. But often, such detail is inappropriate, for example, when the accuracy and reliability of the data, or the required resources are limited. In this case, the scope of the modelling must be tailored accordingly, ensuring that attention is focused on the most noise-significant factors.

TABLE OF CONTENTS

EXPLANATION OF TERMS AND SYMBOLS

The important **terms** used throughout this document are described here. The list of terms is not exhaustive; only expressions and acronyms used frequently are included. Others are described where they first occur. Further detail can be found in **Volume 1**.

The mathematical **symbols** (listed after the terms) include those that are predominantly used in equations in the main text. Other symbols used locally in both the text and the appendices are defined where they are used.

The reader is reminded periodically of the interchangeability of the words *sound* and *noise* in this document (as in **Volume 1**). Although the word *noise* has subjective connotations, it is usually defined by acousticians as "unwanted sound". In the field of aircraft noise control, however, it commonly refers to general sound - airborne energy transmitted by acoustic wave motion. The arrow symbol (→) denotes cross references to other terms included in the list.

Terms

AIP	**Aeronautical Information Publication**
Aircraft configuration	The positions of slats, flaps and landing gear.
Aircraft movement	An arrival, departure or other aircraft action that affects noise exposure around an aerodrome.
Aircraft noise and performance data	Data describing the acoustic and performance characteristics of different aeroplane types that are required by the modelling process. They include → *NPD relationships* and information that allows engine thrust/power to be calculated as a function of → *Flight configuration*. The data are usually supplied by the aircraft 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 aircraft concerned by adapting data for a suitably similar aircraft - this is referred to as *substitution*.
Altitude	Height above mean sea level.
ANP database	The international Aircraft Noise and Performance database[1]
A-weighted sound level, L_A	Basic sound/noise level scale used for measuring environmental noise including that from aircraft 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 an NPD database.
Brake release	→ *Start of roll*
Corrected net thrust	At a given power setting (e.g. *EPR* or N_1) net thrust falls with air density and thus with increasing aircraft altitude; corrected net thrust is the value at sea level.
Cumulative sound/noise level	**A decibel measure of the noise received over a**

[1] Linked on the ECAC website

	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* $= 10 \cdot \lg \sum 10^{L_i/10}$
Effective Perceived Noise Level, *EPNL*	A scale that mimics human perception by applying different weightings to sound of different frequencies and by correcting for the tonal content and duration of the noise event.
Energy fraction, *F*	Ratio of sound energy received from segment to energy received from infinite flight path.
Engine power setting	Value of the → *Noise related power parameter* used to determine noise emission from the NPD database.
EPNL	→ *Effective Perceived Noise Level*
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	= → *Aircraft configuration* + → *Flight parameters*
Flight parameters	Aircraft power setting, speed, bank angle and weight.
Flight path	The path of an aeroplane through the air, defined in three dimensions, usually with reference to an origin at the start of take-off roll or at the landing threshold.
Flight path segment	Part of an aircraft flight path represented for noise modelling purposes by a straight line of finite length.
Flight procedure	The sequence of operational steps followed by the aircraft crew or flight management system, expressed as changes of flight configuration as a function of distance along the ground track.
Flight profile	Variation of aeroplane height along the ground track (sometimes includes changes of → *Flight configuration* too) - 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	Aircraft 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 aircraft and → *Ground plane*
Integrated sound level	Otherwise termed → *single event sound exposure level*.
International Standard Atmosphere, *ISA*	**Defined by ICAO [ref. 1]. ISA defines the variation of air temperature, pressure, and density with height above mean sea level and is used to normalise the results of aircraft design calculations and analysis of test data.**
Lateral attenuation	Excess attenuation of sound with distance attributable, directly or indirectly, to the presence of the ground surface. The lateral attenuation is significant at low angles of elevation (of the aircraft above the ground plane).
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 (see **Volume 1**). Despite a consequent lack of rigour, the terms sound and noise are sometimes used interchangeably in this document, as elsewhere - especially in conjunction with the word *level*.
Noise contour	A line of constant value of a cumulative aircraft 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 exposure. The noise index may take some account of factors in addition to the magnitude of 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 aircraft, two scales are generally used: A-weighted sound level and Perceived Noise Level (PNL). 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 Sound Level* reached during the event, or its → *Sound Exposure Level (SEL)*, a measure of its total sound energy determined by time integration.
Noise-power-distance (NPD) relationships/data	Noise event levels tabulated as a function of 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 aircraft wing-axis (i.e. vertically below the aircraft in non-banked flight).
Noise-related power parameter	A parameter that describes or indicates the propulsive effort generated by an aircraft engine to which acoustic power emission can logically be related; usually considered to be → *Corrected net thrust.* Loosely termed "power" or "power setting" throughout the text.
Noise significance	The contribution from a flight path segment is "noise significant" if it affects the event noise level to an appreciable extent. Disregarding segments that are not noise-significant yields large savings in computer processing.
Observer	→ *Receiver*
Perceived Noise Level	→ *PNL*. A scale that mimics human perception by applying different weights to sound of different frequencies and by correcting for tonal content.
PNL	→ *Perceived Noise Level*
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 a 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 atmosphere	A tabulation of sound absorption rates used to standardise NPD data (see **Appendix D**).
Reference day	A set of atmospheric conditions on which ANP data are standardised.
Reference duration	A nominal time interval used to standardise single event sound exposure level measurements; equal to 1 second in the case of → *SEL*.
Reference speed	Aeroplane groundspeed to which *NPD* → *SEL* data are normalised.
SEL	→ *Sound Exposure Level*
Soft ground	A ground surface that is acoustically "soft", typically grassy, that surrounds most aerodromes. Acoustically hard, i.e. highly reflective, ground surfaces include concrete and water. The noise contour methodology described herein applies to soft ground conditions.
Sound	Energy transmitted through air by (longitudinal) wave motion which is sensed by the ear.
Sound attenuation	The decrease in sound intensity with distance along a propagation path. For aircraft noise, its causes include spherical wave spreading, atmospheric absorption and → *Lateral attenuation.*

Sound exposure	A measure of total sound energy immission over a period of time.
Sound Exposure Level (SEL), L_{AE}	A metric standardised in ISO 1996-1 [ref. 2] or ISO 3891 [ref. 3] = A-weighted single event sound exposure level referenced to 1 second.
Sound intensity	The strength of sound immission at a point - related to acoustical energy.
Sound level	A measure of sound energy expressed in decibel units. Received sound is measured with or without "frequency weighting"; levels measured with a weighting are often termed → *Noise level.*
Stage/trip length	Distance to first destination of departing aircraft; taken to be an indicator of aircraft weight.
Start of Roll, *SOR*	The point on the runway from which a departing aircraft commences its take-off. Also termed "brake release".
True airspeed	Actual speed of aircraft relative to air (equivalent to groundspeed in still air during level flight).
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

c	Speed of sound
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
F_n	Actual net thrust per engine
F_n/δ	Corrected net thrust per engine
h	Aircraft altitude (above MSL)
L	Event sound pressure level (unweighted) - measured with *slow* time weighting
$L(t)$	Sound pressure level at time t (unweighted) – measured with *slow* time weighting
L_A, $L_A(t)$	A-weighted sound pressure level (at time t) - measured with *slow* time weighting
L_{AE}	(SEL) Sound Exposure Level [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
lg	Logarithm to base 10
N	Number of segments or sub-segments
NAT	Number Above Threshold, i.e. number of events with L_{max} exceeding a specified threshold
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_e	Effective duration of single sound event
t_0	Reference time for integrated sound level
V	Groundspeed
V_{seg}	Equivalent segment groundspeed
V_{ref}	Reference groundspeed for which NPD data are defined
x,y,z	Local coordinates
x',y',z'	Aircraft coordinates
X_{ARP},Y_{ARP},Z_{ARP}	Position of aerodrome reference point in geographical coordinates
z	Height of aircraft above ground plane / aerodrome reference point
z'	Set of values of height of aircraft for sub-segmentation
α	Parameter used for calculation of the finite segment correction Δ_F
β	Elevation angle of aircraft relative to ground plane
ε	Aircraft bank angle
γ	Climb/descent angle
φ	Depression angle (lateral directivity parameter)
λ	Total segment length
☐	Angle between direction of aircraft movement and direction to observer
ρ	Air density
ξ	Aircraft heading, measured clockwise from magnetic north
$\Lambda(\beta,\ell)$	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_F	Finite segment correction
$\Delta'_{F,a}$	Finite segment correction, reduced form for arrivals
$\Delta'_{F,d}$	Finite segment correction, reduced form for departures
Δ_I	Engine installation correction
Δ_i	Weighting for *i*-th time of day period
Δ_{LOSB}	Line-of-sight blockage correction
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
E	Exposure
i	Aircraft type/category summation index, or aircraft height index
j	Ground track/sub-track summation index
k	Segment summation index
max	Maximum
ref	Reference value
seg	Segment specific value
SOR	Related to start of roll
TO	Take-off

1 INTRODUCTION

1.1 AIM AND SCOPE OF DOCUMENT

Contour maps are used to indicate the extent and magnitude of aircraft 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 in some way all the individual aircraft noise events that occur during a specified time period, normally measured in days or months (see **Volume 1** [ref. 4] for a review).

The noise at points on the ground from aircraft flying into and out of a nearby aerodrome depends on many factors. Principal among these are the types of aeroplane and their powerplant; 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 weights.

Volume 1 of this ECAC guidance on aircraft noise contour modelling, an Applications Guide, is aimed primarily at noise model users who do not necessarily need a comprehensive understanding of the modelling process, but who require a good understanding of the principles, the problems involved, and the requirements for achieving results that adequately meet the objectives of particular noise impact assessments.

This second volume, a Technical Guide, is written for modellers themselves - those who develop and maintain the computer models and their databases. It fully describes a specific noise contour modelling system which is considered by ECAC to represent current best practice. It does not prescribe a computer program, but rather, the equations and 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 aircraft 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 aircraft movement and should not be used for that purpose.*

Contours are generated by calculating surfaces of local noise index values mathematically. This document explains in detail how to calculate, at one observer point, the individual aircraft noise event levels, each for a specific aircraft flight or type of flight, that are subsequently averaged in some way, or *accumulated*, to yield index values at that point. The required surface of index values is generated merely by repeating the calculations as necessary for different aircraft movements – taking care to maximise efficiency by excluding events that are not "noise-significant" (i.e. which do not contribute significantly to the total).

Volume 2, builds on, but replaces, ECAC.CEAC Document 29, the fourth edition of which was published in 2016 [ref. 5] and which should now be discarded. Many essential features of the previously recommended process have been retained; only parts that have subsequently proved to be inadequate or inappropriate have been improved or replaced. The document is not a programming manual; it does not provide detailed step-by-step instructions for constructing a computer code. Such details are left to the modeller/programmer who therefore has the flexibility to adapt the model to project needs. An important reference document is Aerospace Information Report No 1845 [ref. 6] published by the A-21 Aircraft Noise Subcommittee of SAE. That body of aviation industry specialists has long been engaged in the development of aircraft noise standards and recommended practices.

A linked international aircraft noise and performance (ANP) database is available online and the recommended methodology is designed to make full use of that comprehensive ECAC-endorsed data source. It includes aircraft and engine performance data and noise-power-distance (NPD) tables for the civil aircraft types that dominate the noise at most of the world's busy airports.

There are several 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, and their noise generally comes 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.

Aircraft engine testing (sometimes referred to as "engine run-ups") at airports is usually carried out for engineering purposes to check engine performance, and aircraft are safely positioned away from buildings, other aircraft, vehicular and/or personnel movements to avoid jet-blast related damage. However, 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", which are three-sided baffled enclosures specially designed to deflect and dissipate jet blast and noise. Investigating the ground 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.

1.2 OUTLINE OF THE DOCUMENT

It is assumed that users are familiar with basic noise modelling principles that are described in **Volume 1** - which may be regarded as a primer for **Volume 2**. That document stresses the fact that having a *best practice modelling methodology* is only one of three requirements for valid noise contour modelling. The others are *an accurate aircraft noise and performance database* and a detailed understanding and description of *the aircraft operations* that are the source of the subject noise. All three elements are covered in this volume.

The noise contour generation process is illustrated in **Figure 1-1**. General guidance on the acquisition and pre-processing of the input data is given in **Volume 1**. Contours are produced for various purposes and these tend to control the requirements for sources and pre-processing of input data. Contours that depict historical noise impact may be generated from actual records of aircraft operations – of movements, weights, 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 aircraft.

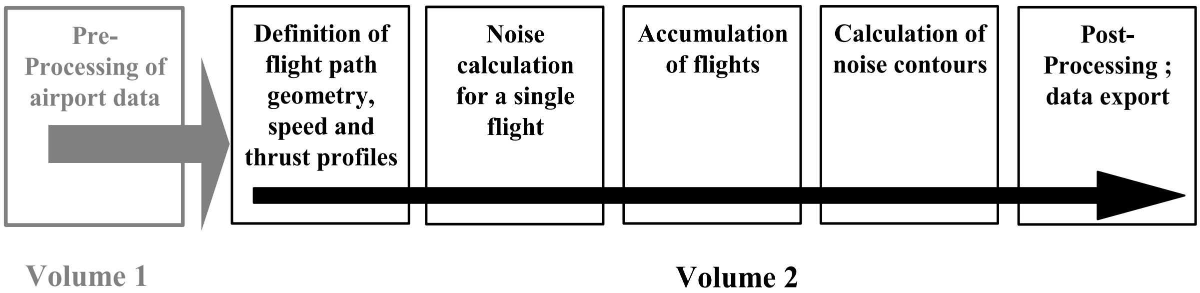

Figure 1-1: The noise contour generation process

Whatever the source of flight data, each different aircraft movement, arrival or departure, is defined in terms of its flight path geometry and the noise emission from the aircraft 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 aircraft - 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 and explains the principle of segmentation on which it is based; that the observed event noise level is an aggregation of contributions from all "noise-significant" 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. Detailed specifications for the operational data needed are set out in **Appendix A**.

The calculation of the flight path segments from pre-processed input data is described in **Chapter 3**, which involves applications of aircraft flight performance analysis. The associated equations are detailed in **Appendix B**, using data from the international Aircraft Noise and Performance (ANP) database. Flight paths are subject to significant variability - aircraft following any route are dispersed across a swathe due to the effects of differences in atmospheric conditions, aircraft weights 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 too is explained in **Chapter 3** with reference to additional information in **Appendix C**.

Chapter 4 sets out the steps to be followed in calculating the noise level of one single event – the noise generated at a point on the ground by one aircraft movement. Data in the international (ANP) database apply to specific reference conditions. **Appendix D** deals with the re-calculation of NPD-data for non-reference conditions. It presents two methods, the first, SAE-ARP-5534 provides an updated methodology (2013) to calculate atmospheric absorption which is consistent with current scientific information and is the recommended method. However, the flexibility is given for transition purposes to model non-standard atmospheric conditions with the legacy SAE-ARP-866A method (1975). **Appendix E** explains the acoustic dipole source used in the model to define sound radiation from flight path segments of finite length. **Appendix F** gives additional guidance for the case when the event level metric is L_{max} rather than L_E.

Applications of the modelling relationships described in Chapters 3 and 4 require, apart from the relevant flight paths, appropriate noise and performance data for the aircraft in question. The source of that information, the ECAC-endorsed international ANP database website, and how data can be obtained from it, is described in **Appendix G**.

Determining the event level for a single aircraft movement at a single observer point is the core calculation. It has to be repeated for all aircraft 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 in some way to arrive at a "cumulative level" or noise index value. This part of the process is described in **Chapter 5**.

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

Some existing aircraft noise contour models are based on previous ECAC guidance published in Doc 29 4th edition. For the benefit of users of that previous guidance, **Appendix H** lists and explains the changes that have now been made; this should allow existing models to be amended to incorporate this updated methodology. Finally, **Appendix I** lists conversions between the SI and US units that are used throughout.

2 SUMMARY AND APPLICABILITY OF THE METHOD

Volume 1 describes three different ways in which most practical noise models calculate aircraft noise single event levels. In order of increasing elaboration these are (1) *closest point of approach* (CPA), (2) *segmentation* and (3) *simulation* methods. Each has its strengths and weaknesses, but it is considered that, on balance, segmentation (otherwise known as "integrated") models represent current best practice. This situation may change at some point in the future: "simulation" models have greater potential, and it is only a shortage of the comprehensive data they require, and their higher demands on computing capacity, that presently restrict them to special applications (including research).

A crucial factor underpinning the ascendancy of segmentation modelling, and a principal reason why the recommended practice is based upon it, is that it is supported by a comprehensive aircraft noise and performance database of unparalleled depth and scope. This 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; the ANP website is a primary source of data for the methodology recommended in this guidance.

A computer model that implements the recommended methodology and the ANP database together comprise the contour modelling system. To apply it to a particular airport scenario, the user must supply a substantial quantity of data that describes, principally, the airport and the air traffic using it - in terms of the aircraft types, numbers, routeings and operating procedures.

These basic elements of the noise contour generation process are summarised in this chapter by way of introduction to the more detailed descriptions that comprise the rest of this document.

2.1 THE CONCEPT OF SEGMENTATION

For any specific aircraft, 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 aircraft[2] as a function of distance. For noise modelling purposes, the all-important propulsive power is represented by a *noise-related power parameter*; the parameter generally used is *corrected net thrust*. Baseline event levels determined from the database are adjusted to account for, firstly, differences between actual (i.e. modelled) and reference atmospheric conditions and (in the case of sound exposure levels) aircraft speed and, secondly, for receiver points that are not directly beneath the aircraft, differences between downwards and laterally radiated noise. This latter difference is due to *lateral directivity* (engine installation effects) and *lateral attenuation*. But the event levels appropriately adjusted still apply only to the total noise from the aircraft in steady level flight.

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 aircraft flight configuration varies. For the purposes of calculating the event sound level of an aircraft 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

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

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.

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 aircraft noise and the receiver's "view" of the segment. One reason that 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) t*o 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 approximate as they get further away from the receiver without compromising the accuracy significantly.

2.2 FLIGHT PATHS: TRACKS AND PROFILES

In the modelling context, a *flight path* (or trajectory) is a full description of the motion of the aircraft in space and time[3]. Together with the propulsive thrust (or other noise-related power parameter) this is the information required to calculate the noise generated. The gro*und 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 aircraft 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 whilst minimising the computational burden and data requirements. Each segment must be defined by the geometrical coordinates of its end points and the associated speed and engine power parameters of the aircraft (on which sound emission depends). Flight paths and engine power may be determined in various ways, the main ones involving (a) synthesis from a series of procedural steps and (b) analysis of measured flight profile data.

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

Analysis of measured data (b), e.g. from flight data recorders, radar or other aircraft tracking equipment, involves "reverse engineering", effectively a reversal of the synthesis process (a). Instead of estimating the aircraft and powerplant 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 **Section 3.5**.

[3] Time is accounted for via the aircraft speed.

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 very 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 aircraft weights on the vertical profiles.)

2.3 AIRCRAFT NOISE AND PERFORMANCE

To support this methodology, ECAC recommends use of data from the online international Aircraft Noise and Performance (ANP) database[4] which is fully described in **Appendix G**.

The ANP database contains aircraft and engine performance coefficients and NPD relationships for a substantial proportion of civil aircraft operating from airports in ECAC states. In particular, data on additional aircraft types, old and new, will be added as soon as they have been supplied to, and verified by, the database managers.

All new inputs are supplied or endorsed by the aircraft manufacturers and generated according to SAE specifications [ref. 6] that are approved by ECAC. For aircraft that are common to both, the data are identical to those in the US INM database [ref. 7]. For aircraft types or variants for which data are not currently listed, **Volume 1** provides guidance on how they can best be represented by data for other, normally similar, aircraft that are listed.

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.”*

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 within the province of the user; at present there is no practicable way in which the accuracy of the data entries can be systematically and independently checked. 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 suppliers then decide on the action required; only they can amend or approve database entries. To this end, it must be recognised that acquiring reliable measured data is a very demanding task and it is necessary for data users to demonstrate that the evidence they provide meets acceptable quality criteria. It is anticipated that a future Volume 3 of this guidance will specify appropriate procedures for comparing measured and modelled noise levels. These will be designed to provide assurance that the supporting information can be relied upon.

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.

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[4] The ANP database is linked on the ECAC website

2.4 AIRPORT AND AIRCRAFT OPERATIONS

Case-specific data from which to calculate the noise contours for a particular airport scenario includes the following:

2.4.1 General airport data

- The aerodrome reference point (simply 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.

- The aerodrome reference altitude (altitude of the 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.

- Average meteorological parameters at or close to the aerodrome reference point (temperature, relative humidity, average windspeed and wind direction).

Example datasheets for the presentation of airport data can be found in **Appendix A1**.

2.4.2 Runway data

For each runway:

- Runway designation
- Runway reference point (centre of runway expressed in local coordinates)
- Runway length, direction and mean gradient
- Location of start-of-roll and landing threshold[5]. Datasheets for runway data representation are shown in **Appendix A2**.

2.4.3 Ground track data

Aircraft ground tracks must be 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 or not. 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 Aeronautical Information Publications. This conventional description includes the following information:

- Designation of the runway that the track originates from
- Description of the track origin (start of roll, landing threshold)
- Length of segments (for turns, radius and change of direction)

This information is the minimum necessary to define the core (backbone) track. But average noise levels calculated on the assumption that aircraft follow the nominal routes exactly can be liable to localised errors of several decibels. Thus, lateral dispersion should be represented, and the following additional information is necessary:

- Width of the swathe (or other dispersion statistic) at each segment end

[5] Displaced thresholds can be taken into account by defining additional runways.

- Number of sub-tracks
- Distribution of movements perpendicular to the backbone track

Example datasheets for ground track representation can be found in **Appendix A3**.

2.4.4 Air traffic data

Air traffic data normally comprise the following information:

- the time period covered by the data and
- the number of movements (arrivals or departures) of each aircraft type on each flight track, sub-divided by (1) time of day as appropriate for specified noise descriptors, (2) for departures, operating weights or stage lengths, and (3), if necessary, operating procedures.

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

Air traffic example datasheets can be found in **Appendix A4**.

2.4.5 Topographical data

The terrain around most airports is relatively flat. However, this is not always the case and there may sometimes be a need to account for variations in terrain elevation relative to the airport reference elevation. The effect of terrain elevation can be especially important in the vicinity of approach tracks, where the aircraft is operating at relatively low altitudes.

Terrain elevation data are usually provided as a set of (x,y,z) coordinates for a rectangular grid of a 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.

Comprehensive analysis of the effects of markedly non-level ground on sound propagation is complex and 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 **Section 3.3.4**).

2.5 REFERENCE CONDITIONS

The international aircraft noise and performance (ANP) data are normalised to standard reference conditions that are widely used for airport noise studies (see **Appendices D** and **G**).

Reference conditions for NPD data

1)	Atmospheric pressure:	101.325 kPa (1013.25 mb)
2)	Atmospheric absorption:	Attenuation rates listed in **Table D-1** of **Appendix D**
3)	Precipitation:	None
4)	Windspeed:	Less than 8 m/s (15 knots)
5)	Groundspeed:	160 knots

6) Local terrain: Flat, soft ground free of large structures or other reflecting objects within several kilometres of aircraft ground tracks.

Standardised aircraft sound measurements are made 1.2m above the ground surface. However, no special account of this is necessary as, for modelling purposes, it may be assumed that event levels are relatively insensitive to receiver height[6].

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:

- Air temperature less than 30 C
- Product of air temperature (°C) and relative humidity (percent) greater than 500
- Wind speed less than 8 m/s (15 knots)

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

Reference conditions for aeroplane aerodynamic and engine data

1) Runway elevation: Mean sea level
2) Air temperature: 15 °C
3) Take-off gross weight: As defined as a function of stage length in the ANP database (see **Appendix G3.5**)
4) Landing gross weight: 90 percent of maximum landing gross weight
5) Engines supplying thrust: All

Although ANP aerodynamic and engine data are based on these conditions, they can be used as tabulated for non-reference runway elevations and average air temperatures in ECAC states without significantly affecting the accuracy of the calculated contours of cumulative average sound level (see **Appendix B**).

The ANP database tabulates aerodynamic data for the take-off and landing gross weights noted in items 3 and 4 above. Although, for cumulative noise calculations, the aerodynamic data themselves need not be adjusted for other gross weights, calculation of the take-off and climb-out flight profiles, using the procedures described in **Appendix B**, should be based on the appropriate operational take-off gross weights.

6 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 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.

3 DESCRIPTION OF THE FLIGHT PATH

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

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

3.1 RELATIONSHIPS BETWEEN FLIGHT PATH AND FLIGHT CONFIGURATION

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

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

It should be remembered that, for a given set of procedural steps, the profile depends on the ground track, e.g. at the same thrust and speed the aircraft climb rate is less when turning than in straight flight. Although this guidance explains how to take this dependency into account, it must be acknowledged that doing so would normally involve a very large computing overhead 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 that turns require, as this has an important bearing on the directionality of sound emission.

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

In a flight path synthesis, i.e. when constructing a flight path from a set of "procedural steps" 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 aircraft 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.

The operational steps followed by arriving and departing aircraft are explained in **Chapter 4** of **Volume 1**. **Appendix B** presents the equations that relate the forces acting on an aircraft 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 of **Appendix B** that cover them) are *take-off ground roll* (B5), *climb at constant speed* (B6), *power cutback* (B7), *accelerating climb and flap retraction* (B8), *accelerating climb after flap retraction* (B9), *descent and deceleration* (B10) and *final landing approach* (B11).

Inevitably, practical modelling involves varying degrees of simplification - the requirement for this depends on the nature of the application, the significance of the results and the resources available (see **Volume 1**). A general simplifying assumption, even in the most elaborate applications, is that when accounting for flight track dispersion, the flight profiles and configurations on all the sub-tracks are the same as those on the backbone track. As at least 6 sub-tracks are recommended (see **Section 3.4**) this reduces computations massively for an extremely small penalty in fidelity.

3.2 SOURCES OF FLIGHT PATH DATA

3.2.1 Radar data

Although aircraft flight data recorders can yield very high-quality data, this is difficult to obtain for noise modelling purposes and radar data must be regarded as the most readily accessible source of information on actual flight paths flown at airports[7]. As it is usually available from airport noise and flight path monitoring systems, it is now used increasingly for noise modelling purposes. However, the analysis of radar data is a complex task for which methods are still under development [ref. 8]. Thus, it is not possible at present to recommend a specific methodology. Only general guidance can be offered; it is for users to take stock of specific circumstances when deciding on an appropriate approach.

Secondary surveillance radar presents the flight path of an aircraft 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 aircraft over the ground is determined in polar coordinates - range and azimuth - from the reflected radar return (although the

[7] 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.

monitoring system normally transforms these to Cartesian coordinates); its height[8] is measured by the aeroplane's own altimeter and transmitted to the ATC computer by a radar-triggered transponder. But inherent positional errors due to radio interference and limited data resolution are significant (although of no consequence for the intended air traffic control purposes). Thus, if the flight path of a specific aircraft movement is required, it is necessary to smooth the data using an appropriate curve-fitting technique [e.g. refs. 9,10]. 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 aircraft type. Here the measurement errors associated with the relevant statistics can be reduced to insignificance by the averaging processes.

3.2.2 Procedural steps

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

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, for example instructions given to flight crews via AIPs and aircraft operating manuals - referred to here as *procedural steps*. Advice on interpreting this material should be sought from air traffic control authorities and the aircraft operators where necessary.

3.3 COORDINATE SYSTEMS

3.3.1 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 aircraft 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 coordinates[9].

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8 Usually measured as altitude above MSL (i.e. relative to 1013.25 mb) and corrected to airport elevation by the airport monitoring system.

9 Usually, the axes of the local coordinate are parallel to the axis of the map that 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**).

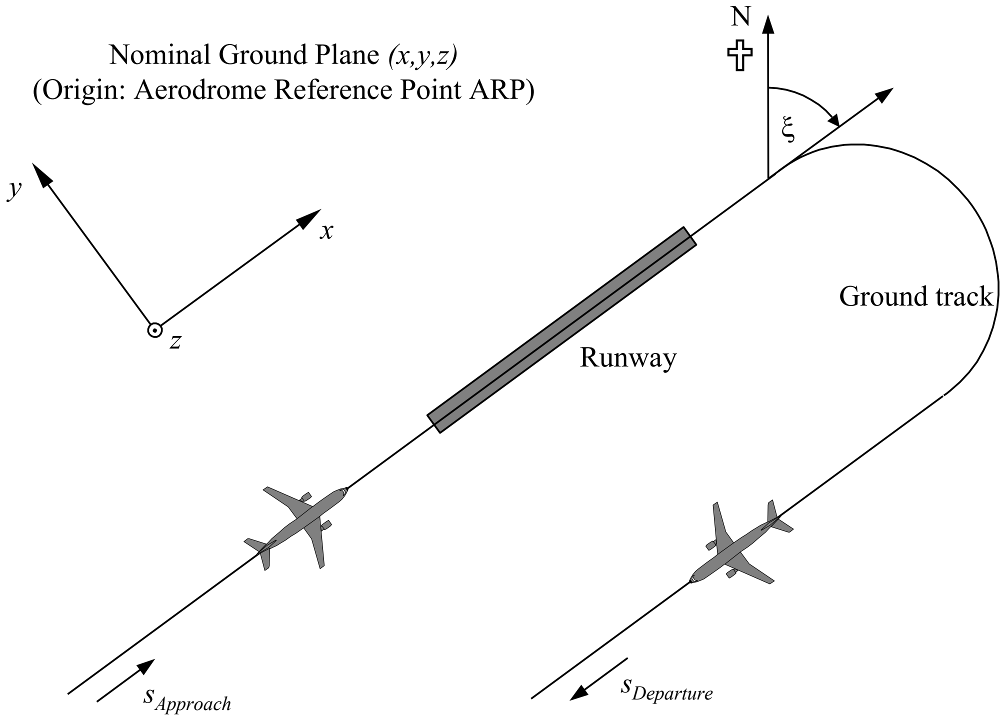

Figure 3-1: Local coordinate system (*x,y,z*) and ground-track fixed coordinate*s*

3.3.2 The ground-track fixed coordinate system

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 from the landing threshold. Thus, *s* becomes negative in areas

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

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

3.3.3 The aircraft coordinate system

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

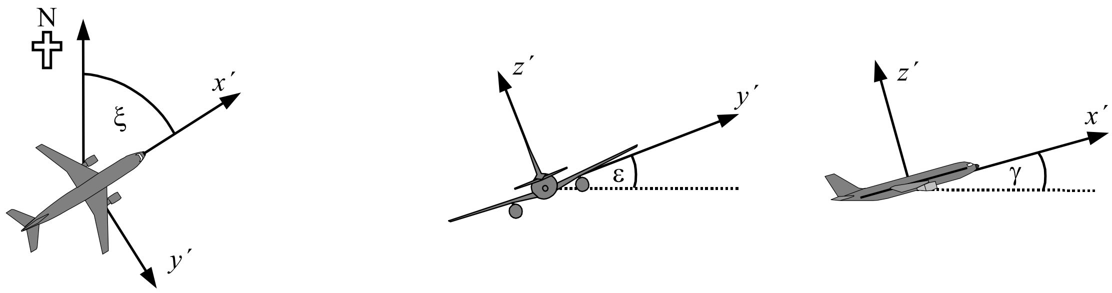

Figure 3-2: Aircraft fixed coordinate system (*x′,y′,z′*)

3.3.4 Accounting for topography

In cases where topography has to be taken into account (see **Section 2.4.5**), the aircraft height coordinate *z* has to be replaced by $z' = z - z_o$ (where z_o is the *z* coordinate of the observer location O) when estimating the propagation distance d. The geometry between aircraft and observer is shown in **Figure 3-3**. For the definitions of d and ℓ see **Chapter 4** [10].

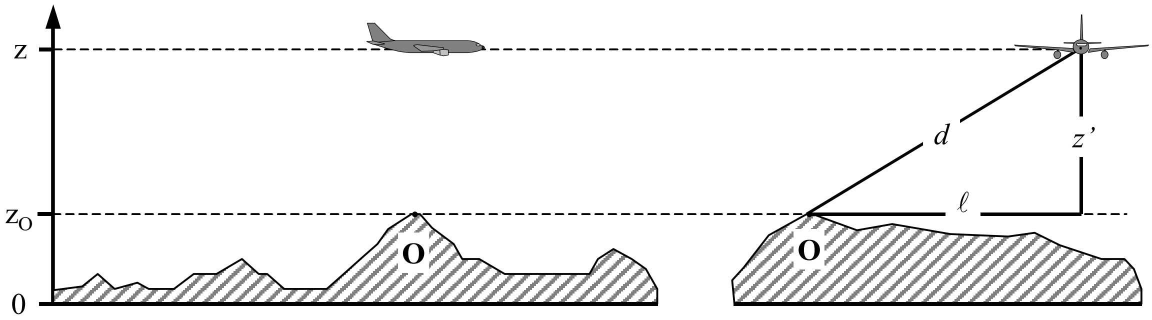

Figure 3-3: Ground elevation along (left) and lateral (right) to ground track. The nominal ground plane z = 0 passes through the aerodrome reference point. O is the observer location.

3.4 GROUND TRACKS

3.4.1 Backbone tracks

The backbone track defines the centre of the swathe of tracks followed by aircraft using a particular routeing. For the purposes of aircraft noise modelling it is defined either (i) by prescriptive operational data such as the instructions given to pilots in AIPs, or (ii) by statistical analysis of radar data as explained in **Section 3.2.1** - 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** for an illustration.

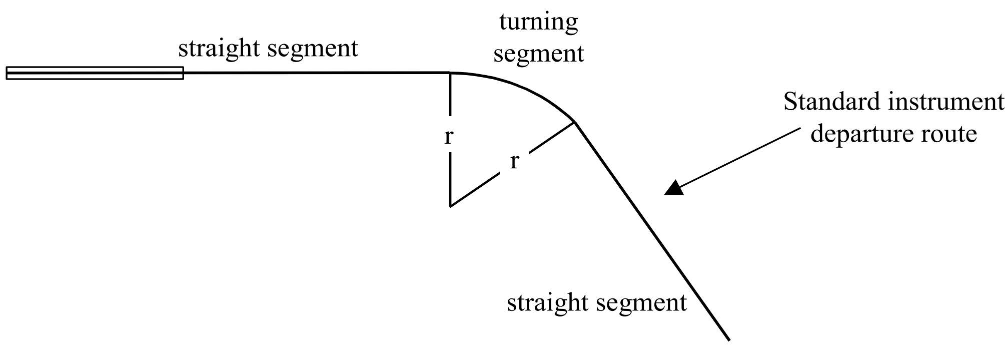

Figure 3-4: Ground track geometry in terms of turns and straight segments

Fitting a backbone track to radar data is more complex, firstly because actual turns are made at a varying rate and secondly because its line is obscured by the scatter of the

[10] 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 - see Chapter 4) is put equal to zero.

data. As explained, formalised procedures have not yet been developed and it is common practice to match segments, straight and curved, to the average positions calculated from cross-sections of radar tracks at intervals along the route. Computer algorithms to perform this task are likely to be developed in future but, for the present, it is for the modeller to decide how to use available data to best advantage. A major factor is that the aircraft speed and turn radius dictate the angle of bank and, as will be seen in **Section 4.5**, non-symmetries of sound radiation around the flight path govern noise on the ground, as well as the position of the flight path itself.

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 tightens from infinity to *r*. For modelling purposes, the radius transition can be disregarded and the bank angle 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 turn[11].

3.4.2 Lateral track dispersion

Where possible, definitions of lateral dispersion and representative sub-tracks should be based on relevant past experience from the study airport; normally via an analysis of radar data samples. The first step is to group the data by route. Departure tracks are characterised by substantial lateral dispersion which, for accurate modelling, must be accounted for. Arrival routes normally coalesce into a very narrow swathe about the final approach path, and it is usually sufficient to represent all arrivals by a single track. But 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.

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 aircraft or operations differ significantly (e.g. should large and small aircraft have substantially different turn radii), further sub-division 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 then being apportioned between a backbone track and a suitable number of dispersed sub-tracks on the basis of the distribution statistics.

As it is normally unwise to disregard the effects of track dispersion, 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. Calculated values of noise indices are not particularly sensitive to the precise shape of the lateral distribution: the normal distribution (i.e. Gaussian) provides an adequate description of many radar-measured swathes.

Typically, a 7-point discrete approximation is used (i.e. representing the lateral dispersion by 6 sub-tracks equally spaced around the backbone track). The spacing of the sub-tracks depends on the standard deviation of the lateral dispersion function.

[11] How best to implement this is left to the user as this 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 °/m or °/s).

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 C** 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 %

The standard deviation *S* is a function of the coordinate *s* along the backbone-track. It can be specified – together with the description of the backbone-track – in the flight track data sheet shown in **Appendix A3**. In the absence of any indicators of the standard deviation – e.g. from radar data describing comparable flight tracks – the following values are recommended:

For tracks involving turns of less than 45 degrees:

$$S(s) = 0.055 \cdot s - 150 \quad \text{for} \quad 2700\ \text{m} \leq s \leq 30000\ \text{m}$$
$$S(s) = 1500\ \text{m} \quad \text{for} \quad s > 30000\ \text{m} \qquad (3\text{-}1a)$$

For tracks involving turns of more than 45 degrees:

$$S(s) = 0.128 \cdot s - 420 \quad \text{for} \quad 3300\ \text{m} \leq s \leq 15000\ \text{m}$$
$$S(s) = 1500\ \text{m} \quad \text{for} \quad s > 15000\ \text{m} \qquad (3\text{-}1b)$$

For practical reasons, *S(s)* is assumed to be zero between the start of roll and *s* = 2700 m or *s* = 3300 m depending on the amount of turn. Routes involving more than one turn should be treated as per equation 3-1b. For arrivals, lateral dispersion can be neglected within 6000 m of touchdown.

3.5 FLIGHT PROFILES

The flight profile is a description of the aircraft motion in the vertical plane above the ground track, in terms of its position, speed, bank angle and engine power setting. One of the most important tasks facing the model user is that of defining aircraft flight profiles that adequately meet the requirements of the modelling application - efficiently, without consuming excessive time and resources. Naturally, to achieve high accuracy, the profiles have to reflect closely the aircraft operations they are intended to represent. This requires reliable information on the atmospheric conditions, aircraft types and variants, operating weights and the operating procedures – the variations of thrust and flap settings and the trade-offs between changes of height and speed – all appropriately averaged over the time period(s) of interest. Often such detailed information are not available but this is not necessarily an obstacle; even if they are, the modeller has to exercise judgement to balance the accuracy and detail of the input information with the needs for, and uses of, the contour outputs.

The synthesis of flight profiles from "procedural steps" obtained from the ANP database or from aircraft operators is described in **Section 3.6** and **Appendix B**. That process, usually the only recourse open to the modeller when no radar data are available, yields both the flight path geometry and the associated speed and thrust variations. It would normally be assumed that all (alike) aircraft in a swathe, whether assigned to the backbone or the dispersed sub-tracks, follow the backbone track profile.

Beyond the ANP database, which provides default information on procedural steps, the aircraft operators are the best source of reliable information, i.e. the procedures they use and the typical weights flown. For individual flights, the "gold standard" source is the aircraft flight data recorder (FDR) from which all relevant information can be obtained. But even if such data are available, the pre-processing task is formidable. Thus, and in keeping with the necessary modelling economies, the normal practical solution is to make educated assumptions about mean weights and operating procedures.

Caution must be exercised before adopting *default* procedural steps provided in the ANP database (customarily assumed when actual procedures are not known). These are standardised 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 to an extent 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 B** 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.

When modelling actual scenarios, improved accuracy can be achieved by using radar data 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 aircraft type and variant and sometimes by weight or stage length (but not by dispersion) - to yield for each sub-group a mean profile of height and speed against ground distance travelled. Again, when merging with the ground tracks subsequently, this single profile is normally assigned to the backbone and sub-tracks alike.

Knowing the aircraft weight, the variation of speed and propulsive thrust can be calculated via step-by-step solution of the equations of motion. Before doing so it is helpful to pre-process the data to minimise the effects of radar errors which can make acceleration estimates unreliable. The first step in each case is to redefine the profile by fitting straight line segments to represent the relevant stages of 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 aircraft weight and atmospheric state are also required inputs.

An aircraft noise source should be entered at a minimum height of 1.0 m (3.3 ft) above the aerodrome level, or above the terrain elevation levels of the runway, as relevant.

Section 3.4 makes it clear that special provision has to be made to account for the lateral dispersion of flight tracks about the nominal or backbone routeings. Radar data samples are characterised 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 aircraft weights and operating procedures that are taken into account when pre-processing traffic input data.

3.6 CONSTRUCTION OF FLIGHT PATH SEGMENTS

Each flight path has to be defined by a set of segment coordinates (nodes) and flight parameters. The flight profile is 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 aircraft climb rate is less in turns than in straight flight (**Section 3.6.1**). Sub-segmentation is then undertaken for the aircraft on the runway (take-off or landing ground roll, **Sections 3.6.2** and **3.6.3** respectively), and for the aircraft near to the runway (initial climb or final approach, **Section 3.6.4**). Airborne segments with significantly different speeds at their start and end points should then be sub-segmented (**Section 3.6.5**). The two-dimensional coordinates of the ground track segments are determined and merged with the two-dimensional flight profile to construct the three-dimensional flight path segments (**Section 3.6.6**). Finally, any flight path points that are too close together are removed (**Section 3.6.7**).

3.6.1 Flight profile

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
- ε_1, ε_2 bank angle.

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 aircraft flight manuals). 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 B**.

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). However ground tracks are rarely straight; they usually incorporate turns and, to achieve best results, these have to be accounted for when determining the 2-D 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 it 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 (see below). 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.

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.

Whether or not turn effects are fully modelled, each 3-D flight path is generated by merging its 2-D flight profile with its 2-D ground track. The result is a sequence of coordinate sets (*x,y,z*), each being either a node of the segmented ground track, 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*) which lies between the end points of a flight profile segment, the flight parameters are interpolated as follows:

$$z = z_1 + f \cdot (z_2 - z_1) \tag{3-2a}$$

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

$$\varepsilon = \varepsilon_1 + f \cdot (\varepsilon_2 - \varepsilon_1) \tag{3-2c}$$

When P_1 and P_2 are positive;

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

When P_1 and P_2 are negative;

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

When P_1 is negative and P_2 is positive:

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

When P_1 is positive and P_2 is negative:

$$P = P_2 + (P_1 - P_2) \cdot \sqrt{(1 - f)} \tag{3-2g}$$

Where;

$$f = (s - s_1)/(s_2 - s_1) \tag{3-2h}$$

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 acceleration[12]). Eq. 3-2e, 3-2f and 3-2g are necessary because values of *P* may be negative as calculated by Appendix B[13].

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.

3.6.2 Take-off ground roll

When taking off, as an aircraft accelerates between the point of brake release (alternatively termed Start-of-Roll *SOR*) and the point of lift-off, speed changes dramatically over a distance of 1500 to 2500 m, from zero to between around 80 and 100 m/s.

The take-off roll is thus divided into segments with variable lengths over each of which the aircraft speed changes by specific increment Δ*V* of no more than 10 m/s (about 20

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

[13] Note that unless there is a requirement to preserve negative power values for other purpose(s) than segment-noise level calculations, an alternative method to using equations 3-2e to 3-2g may consist in replacing any values of P_1 and P_2 of less than one pound (+1 lb) with a value of one pound and using only equation 3-2d to interpolate P afterwards. That will give equivalent noise results to resetting to one pound any negative power values at the time of calculating event levels form NPD data (see 4.3).

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 B**) and take-off speed V_{TO} (m/s), the number n_{TO} of segments for the ground roll is:

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

and hence the change of velocity along a segment is

$$\Delta V = V_{TO}/n_{TO} \tag{3-3b}$$

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

$$\Delta t = \frac{2 \cdot s_{TO}}{V_{TO} \cdot n_{TO}} \tag{3-3c}$$

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

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

Example: For a take-off distance s_{TO} = 1600 m and V_{TO} = 75 m/s, this yields n_{TO} = 8 segments with lengths ranging from 25 to 375 m (see **Figure 3-5**):

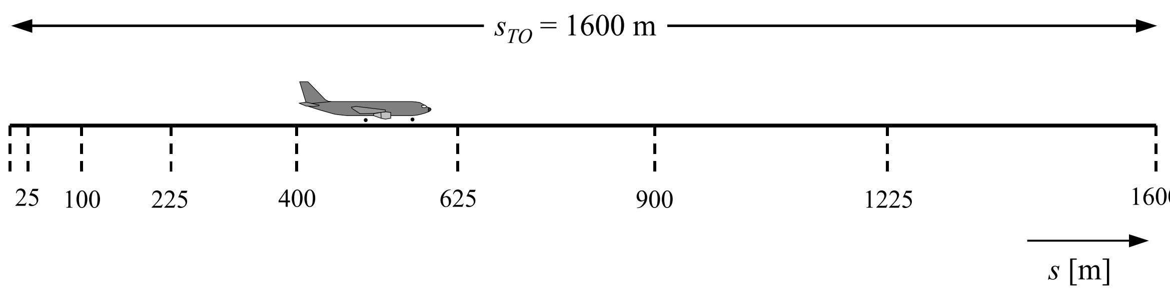

Figure 3-5: Segmentation of a take-off roll (example for 8 segments)

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

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

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-off roll.

The use of this constant thrust increment (instead of using the quadratic form equation 3-2d) aims at being consistent with the linear relationship between thrust and speed in the case of jet-engine aircraft (Eq. B-9).

Important note: The above equations and example implicitly assume that the initial speed of the aircraft at the start of the take-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 that case of non-zero initial speed V_{init} (m/s), the following "generalised" equations should be used in replacement of Eq. 3-3a, 3-3b, 3-3c and 3-3d.

$$n = int(1 + |V_2 - V_1|/10) \tag{3-3f}$$

$$\Delta V = (V_2 - V_1)/n \tag{3-3g}$$

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

$$s_k = \left(V_1 + \Delta V \cdot (k - 0.5)\right) \cdot \frac{2 \cdot s}{(V_2 + V_1) \cdot n} \qquad (3\text{-}3i)$$

In this case, for the take-off phase, V_1 (m/s) is initial speed V_{init}, V_2 (m/s) 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 ($1 \leq k \leq n$).

3.6.3 Landing ground roll

Although the landing ground roll is essentially a reversal of the take-off ground roll, special account has to be taken of *reverse thrust* which is sometimes applied to decelerate the aircraft and aeroplanes leaving the runway after deceleration (aircraft that leave the runway no longer contribute to air noise as noise from taxiing is disregarded).

The treatment of the phases described above is handled by the provision of procedure steps provided by the ANP data providers, as described in Appendix B.

NPD curves for reverse thrust are not currently included in the ANP database; it is therefore necessary to rely on the conventional curves for modelling this effect. Typically, the reverse thrust power P_{rev} is between 10 - 40% of the full power setting and 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 may be applied to the NPD-derived event level, however, there is no international consensus on the value at this time.

3.6.4 Segmentation of the initial climb and final approach segments

The segment-to-receiver geometry changes rapidly along the initial climb and final approach airborne segments, particularly with respect to observer locations to the side of the flight track, where the elevation angle (*beta angle*) also changes rapidly as the aircraft climbs or descends through these initial/final segments. Comparisons with very small segment calculations show that using a single (or a limited number of) climb or approach airborne segment(s) below a certain height (relative to the runway) results in a poor approximation of noise to the side of the flight track for integrated metrics. This is due to the application of a single lateral attenuation adjustment (see **Section 4.5.4**) on each segment, corresponding to a single segment-specific value of the elevation angle, whereas the rapid change of this parameter results in significant variations of the lateral attenuation effect along each segment. Calculation accuracy is improved by sub-segmenting the initial climb and last approach airborne segments. The number of sub-segments and their lengths determine the lateral attenuation change "granularity" which will be accounted for. Noting the expression of total lateral attenuation for aircraft with fuselage-mounted engines (**Section 4.5.4**), it can be shown that for a limiting change in lateral attenuation of 1.5 dB per sub-segment, the climb and approach airborne segments located below a height of 1289.6 m (4231 ft) above the runway should be sub-segmented 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} metres, or

z' = {62, 136, 224, 335, 484, 705, 1099, 2000, 4231} feet

For each original segment below 1289.6 m (4231 ft), the above heights are implemented by identifying which height in the set above is closest to the original endpoint height (for a climb segment) or start-point height (for an approach segment). The actual sub-segment heights, z_i, would then be calculated using:

$$z_i = z_e\,[z'_i / z'_N]\ (i = k..N) \qquad (3\text{-}4)$$

where:

z_e is the original segment endpoint height (climb) or start-point height (approach)

z'_i is the ith member of the set of height values listed above

z'_N is the closest height from the set of height values listed above to height z_e

k denotes the index of the first member of the set of height values for which the calculated z_k is strictly greater than the endpoint height of the previous original climb segment or the start-point height of the next original approach segment to be sub-segmented.

In the specific case of an initial climb segment or last approach segment, $k = 1$, but in the more general case of airborne segments not connected to the runway, k will be greater than 1.

This height scaling method ensures that the original segment endpoint heights (for climb) or start point heights (for approach) are preserved.

If the original endpoint height of a climb segment or start point height of an approach segment is greater than 1289.6 m (4231 ft), equation 3-4 should be applied using z_e = 1289.6 m.

This process results in a granularity of the lateral attenuation change across each sub-segment which does not exceed 1.5 dB, hence producing more accurate contours without the expense of using a large number of very short segments.

The speed and engine power values on the inserted points are interpolated using equations 3-2b and 3-2d respectively.

Example for an initial climb segment:

If the original segment endpoint height is z_e = 304.8 m, then from the set of height values, 214.9 m < z_e < 334.9 m and the closest height from the set to z_e is z'_7 = 334.9 m. The sub-segment endpoint heights are then computed by:

$$z_i = 304.8\ [z'_i / 334.9] \text{ for } i = 1 \text{ to } 7$$

(noting that k =*1* in that case, as this is an initial climb segment)

Thus, z_1 would be 17.2 m and z_2 would be 37.8 m, etc.

3.6.5 Segmentation of airborne segments

For airborne segments where there is a speed change along a segment of greater than 20 knots, this segment should be sub-divided as for the ground roll, i.e.

$$n_{seg} = int(1 + |V_2 - V_1|/10) \qquad (3\text{-}5)$$

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

3.6.6 Ground track

A ground track, whether a backbone track or a dispersed sub-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 $\Delta\xi$).

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 aircraft during turns influences their definition. **Appendix B4** explains how to calculate bank angles during a steady turn, however, these are not applied or removed instantaneously. The method of handling transitions between straight and turning flight, or between one turn and an immediately sequential one, is not prescribed. As a rule, the details, which are left to the user (see **Section 3.4.1**), are likely to have a negligible effect on the final contours. 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 that 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 aircraft types and to adopt appropriate roll rates. Here, 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:

$$n_{sub} = int(1 + (\Delta\xi - 2\cdot\Delta\xi_{trans})/10) \qquad (3\text{-}6a)$$

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

$$\Delta\xi_{sub} = (\Delta\xi - 2\cdot\Delta\xi_{trans})/n_{sub} \qquad (3\text{-}6b)$$

where n_{sub} must be large enough to ensure that $\Delta\xi_{sub} \le 30$ degrees, with a recommended implementation of $\Delta\xi_{sub} \le 10$ degrees (equation 3-6a calculates n_{sub} for the latter). The segmentation of an arc (excluding the terminating transition sub-segments) is illustrated in **Figure 3-7**[14].

[14] 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 30°.

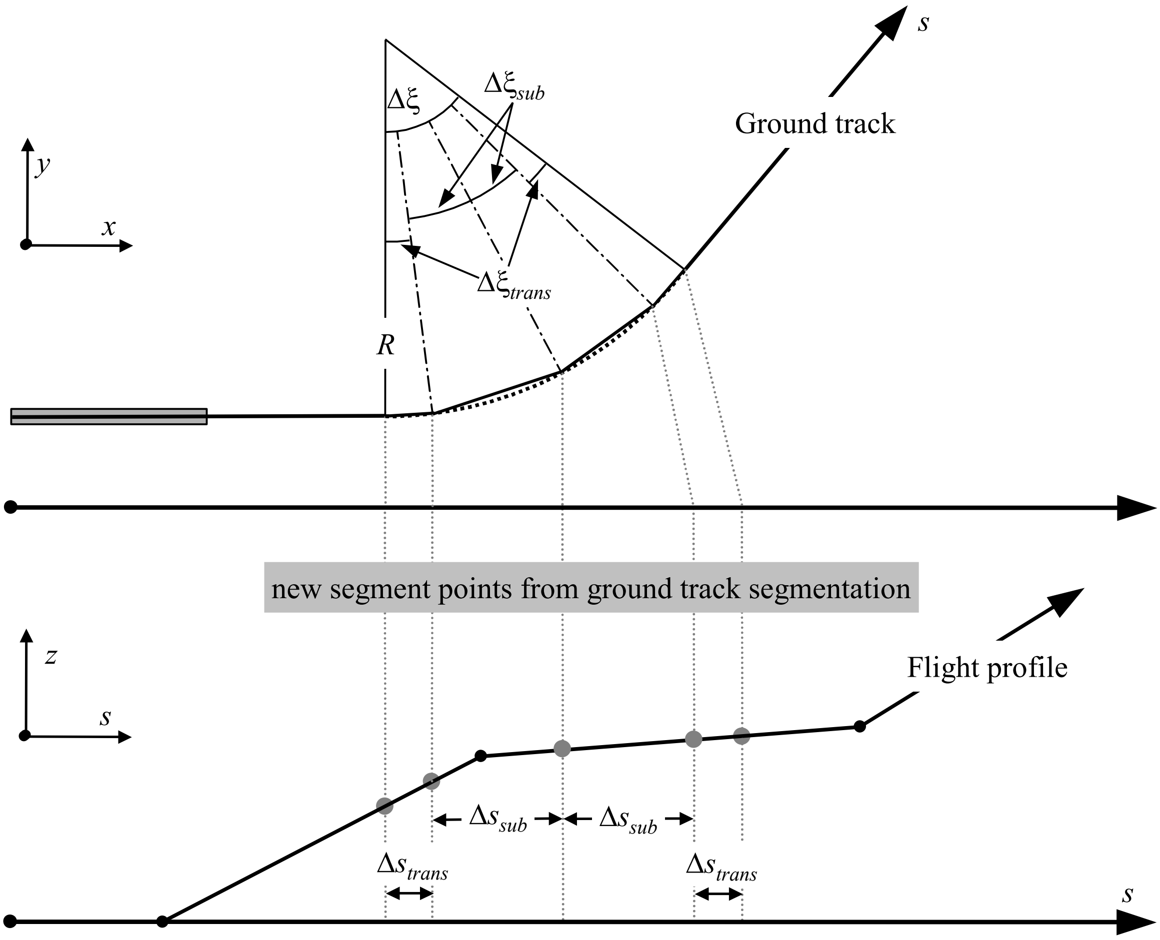

Figure 3-7: Construction of flight path segments dividing turn into segments of length Δ*s* (upper view in horizontal plane, lower view in vertical plane)

Once the ground track segments have been established in the x-y plane, the flight profile segments (in the s-z plane) are overlaid to produce the three-dimensional (x, y, z) track segments.

The ground track should always extend from the runway to beyond the extent of the calculation grid (see **Section 6**). This can be achieved, if necessary, by adding a straight segment of suitable length to the last segment of the ground track.

The total length of the flight profile, once merged with the ground track, must also extend from the runway to beyond the extent of the calculation grid. This can be achieved, if necessary, by adding an extra profile point:

- to the end of a departure profile with speed and thrust values equal to those of the last departure profile point, and height extrapolated linearly from the last and penultimate profile points; or
- to the beginning of an arrival profile with speed and thrust value equal to those of the first arrival profile point, and height extrapolated linearly back from the first and second profile points.

3.6.7 Segmentation adjustments of airborne segments

After the 3-D flight path segments have been derived according to the procedure described in **Sections 3.6.1** to **3.6.6** above, further segmentation adjustments may be necessary to remove flight path points which are too close together.

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

4 NOISE CALCULATION FOR A SINGLE EVENT

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**.

4.1 SINGLE EVENT METRICS

The sound generated by an aircraft movement at the observer location is expressed as a "single event sound (or noise) level", a quantity which is an indicator of its impact on people. The received sound is measured in noise terms using a basic decibel scale *L(t)* which applies a frequency weighting (or filter) to mimic a characteristic of human hearing. The scale of most importance in aircraft noise contour modelling is the A-weighted sound level, L_A [refs. 2,3].

The metrics most commonly used to encapsulate entire events are "single event sound (or noise) exposure levels", L_E, 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. Simpler to model is an alternative metric L_{max} which is the maximum instantaneous level occurring during the event; however, it is L_E which is the basic building block of most modern aircraft noise indices and practical models can in future be expected to embody both L_{max} and L_E. Either metric can be measured on different scales of noise; in this document, only A-weighted sound level is considered. Symbolically, the scale is usually indicated by extending the metric suffix, i.e. L_{AE}, L_{Amax}. **Section 3.2** of **Volume 1** provides a fuller description of noise metrics.

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

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

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 values[15].

For aircraft noise contour modelling, the main application of equation 4-1 is the standard metric *Sound Exposure Level* L_{AE} (acronym SEL) [refs. 2,3]:

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

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, partial event levels each of which defines the contribution from a single, finite segment of the flight path.

4.2 DETERMINATION OF EVENT LEVELS FROM NPD DATA

The principal source of aircraft noise data is the international Aircraft Noise and Performance (ANP) database which is described in **Appendix G**. This tabulates L_{max} and L_E as functions of propagation distance *d* for specific aircraft types, variants, flight

15 10dB-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.

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 path[16].

The specification of the independent variables *P* and *d* is described later. 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 $L_{E\infty}(P,d)$ (applicable to an infinite flight path). 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. A linear interpolation is used between tabulated power settings, whereas a logarithmic interpolation is used between tabulated distances (see **Figure 4-1**).

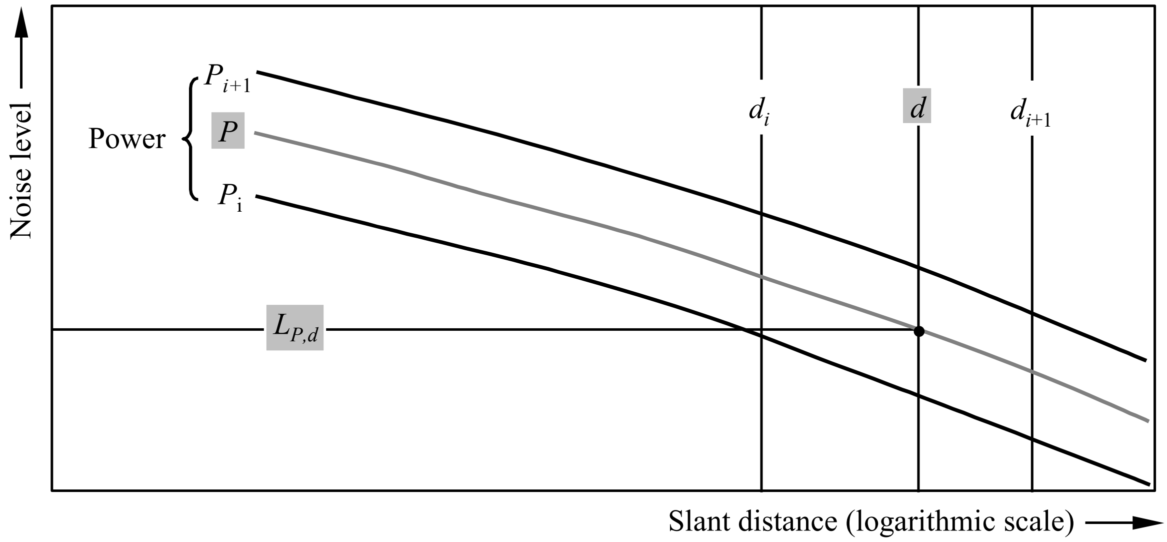

Figure 4-1: Interpolation in noise-power-distance curves

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:

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

There may be situations where the power value, P, calculated using Appendix B is negative. In such circumstances, the minimum power should be reset to one pound per engine, before any extrapolation is performed using Eq. 4-3. For engine power values P that lie outside the NPD envelope, equation 4-3 is used to extrapolate from the last or first two values. Users should be cautious of excessive power extrapolation leading to more than 5 dB difference from the NPD envelope that may result in unrealistic noise levels.

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

[16] 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.

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

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.

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

Inwards: $$L(d) = L(d_2) + \frac{L(d_1) - L(d_2)}{\log d_2 - \log d_1} \cdot (\log d_2 - \log d) \qquad (4\text{-}5a)$$

Outwards: $$L(d) = L(d_{I-1}) - \frac{L(d_{I-1}) - L(d_I)}{\log d_I - \log d_{I-1}} \cdot (\log d - \log d_{I-1}) \qquad (4\text{-}5b)$$

As, at short distances *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 m).

4.2.1 Impedance adjustment of standard NPD data

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.

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 L_{Amax} 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.

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

$$\Delta_{impedance} = 10 \cdot \log\left(\frac{\rho \cdot c}{409.81}\right) \qquad (4\text{-}6)$$

where:

$\Delta_{impedance}$	Impedance adjustment for the actual atmospheric conditions at the aerodrome (dB)
$\rho \cdot c$	Acoustic impedance (in units of Newton-seconds per cubic metre) of the air at the aerodrome (409.81 Ns/m^3 being the air impedance associated with the reference atmospheric conditions of the NPD data in the ANP database)

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

$$\rho \cdot c = 416.86 \cdot \left[\frac{\delta}{\theta^{1/2}}\right] \qquad (4\text{-}7)$$

where:

δ — p/p_O, the ratio of the ambient air pressure at the observer altitude to the standard air pressure at mean sea level: p_O = 101.325 kPa (or 1013.25 millibars)

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

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_O = 101.325 kPa and T_0 = 15.0 °C), the impedance adjustment is less than 0.1 dB (0.074 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.

4.3 GENERAL EXPRESSIONS

4.3.1 Segment event level L_{SEG}

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

$$L_{max,seg} = \mathrm{L}_{max}(P,d) + \Delta_I(\varphi) - \Lambda(\beta,l) + \Delta_{LOSB} \tag{4-8a}$$

and the contribution from one flight path segment to L_E as

$$L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\varphi) - \Lambda(\beta,l) + \Delta_{LOSB} \tag{4-8b}$$

The "correction terms" in equations 4-8 - which are described in detail in **Section 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 $L_{max,seg}$.)

$\Delta_I(\varphi)$ — *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 contributes less noise exposure than an infinite one. It is only applied to exposure metrics.

Δ_{LOSB} — *Optional line of sight blockage correction:* attenuation of sound based on the difference in propagation path length between the direct path and the propagation path over or around a terrain feature.

If the segment is part of the take-off or landing ground roll, 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 the use of a start-of-roll directivity correction term and a particular form of the noise fraction for the exposure level:

$$L_{max,seg} = L_{max}(P,d) + \Delta_I(\phi) - \Lambda(\beta,\ell) + \Delta_{SOR} + \Delta_{LOSB} \quad (4\text{-}9a)$$

$$L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\phi) - \Lambda(\beta,\ell) + \Delta'_F + \Delta_{SOR} + \Delta_{LOSB} \quad (4\text{-}9b)$$

Δ'_F Particular form of the *Segment correction*

Δ_{SOR} *Directivity correction*: accounts for the pronounced directionality of jet engine noise behind the ground roll segment

The specific treatment of ground roll segments is described in **Sections 4.5.6** and **4.5.7**.

Sections 4.4 to 4.5 describe in detail the calculation of segment noise levels.

4.3.2 Event noise level L of an aircraft movement

Maximum level L_{max} is simply the greatest of the segment values $L_{max,seg}$ (see equation 4-8a)

$$L_{max} = max(L_{max,seg}) \quad (4\text{-}10)$$

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

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.

$$L_E = 10 \cdot \log_{10}\left(\sum 10^{L_{E,seg}/10}\right) \quad (4\text{-}11)$$

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

The remainder of this chapter is concerned with the determination of the segment noise levels $L_{max,seg}$ and $L_{E,seg}$.

4.4 FLIGHT PATH SEGMENT PARAMETERS

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. The methodology for this is explained below with the aid of illustrations of the plane containing the segment and the observer.

4.4.1 Geometric parameters

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 $\mathbf{S_1S_2}$ where the flight direction is from $\mathbf{S_1}$ to $\mathbf{S_2}$. 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

q is the distance from **S_1** to **S_p** (negative if the observer position is behind the segment)

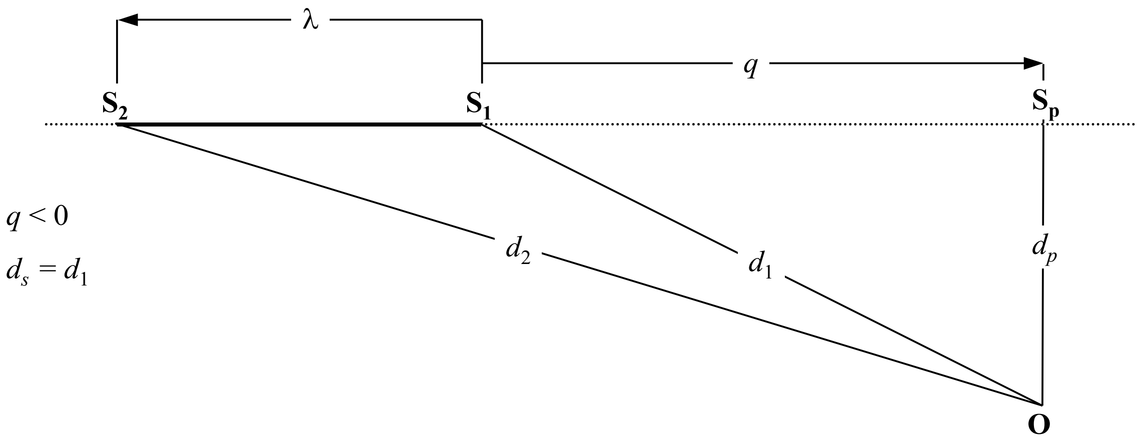

Figure 4-2a: Flight path segment geometry for observer behind segment

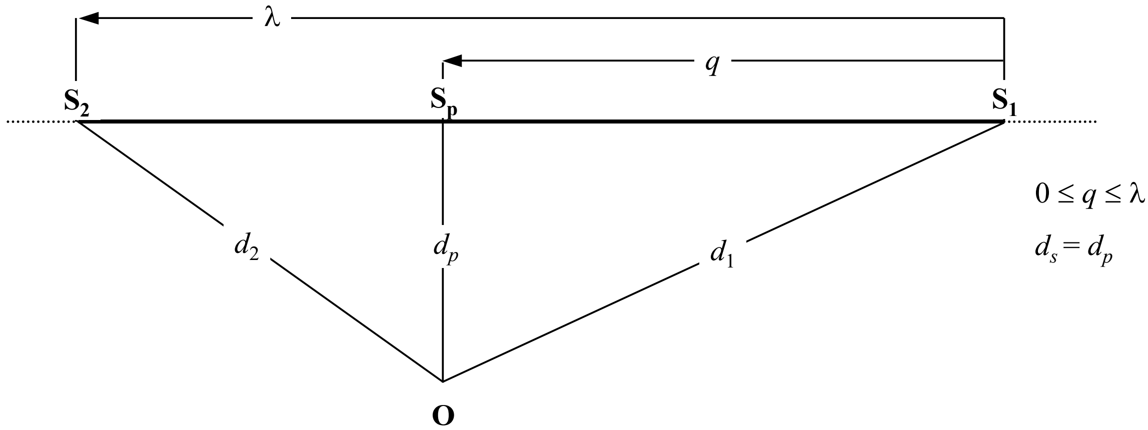

Figure 4-2b: Flight path segment geometry for observer alongside segment

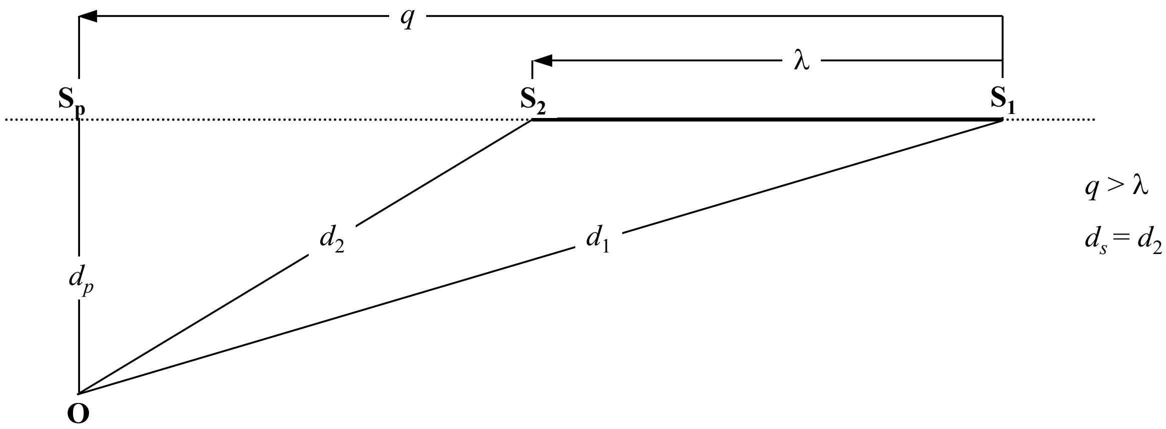

Figure 4-2c: Flight path segment geometry for observer ahead of segment

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 $\mathbf{S_p}$ 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).

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).

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

4.4.2 Segment power P

The tabulated NPD data describe the noise of an aircraft 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; it is taken 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 3-2d between the end values, i.e.

$$P = \sqrt{P_1^2 + \frac{q}{\lambda} \cdot \left(P_2^{\,2} - P_1^2\right)} \qquad (4\text{-}12)$$

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

4.5 SEGMENT EVENT LEVEL CORRECTION TERMS

The NPD data define noise event levels as a function of distance perpendicularly beneath an idealised straight level path of infinite length along which the aircraft flies with steady power at a fixed reference speed[17]. 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 must be corrected to account for the effects of (1) non-reference speed, (2) engine installation effects (lateral directivity), (3) lateral attenuation, (4) finite segment length, (5) longitudinal directivity behind start of roll on take-off, and (6) line of sight blockage - see equations 4-8.

4.5.1 The duration correction Δ_V (Exposure levels L_E only)

This correction[18] accounts for a change in exposure levels if the actual segment speed is different to the aircraft reference speed V_{ref} to which the basic NPD data relate.

Like engine power, speed varies along the flight path segment (from V_{T1} to V_{T2}, which are the speeds output from Appendix B or from a previously pre-calculated flight profile).

For airborne segments, V_{seg} is the segment speed at the closest point of approach, **S**, interpolated between the segment end-point values assuming it varies quadratically with distance, i.e. if the observer is alongside the segment:

$$V_{seg} = \sqrt{{V_{T1}}^2 + \frac{q}{\lambda} \cdot \left({V_{T2}}^2 - {V_{T1}}^2\right)} \qquad \text{(4-13a)}$$

If the observer is behind or ahead of the segment, it is that at the nearest end point, V_{T1} or V_{T2}.

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.

$$V_{seg} = (V_{T1} + V_{T2})/2 \qquad \text{(4-13b)}$$

In either case the additive duration correction is then:

$$\Delta_V = 10 \cdot log(V_{ref}/V_{seg}) \qquad \text{(4-14)}$$

4.5.2 Sound propagation geometry

Figure 4-3 shows the basic geometry in the plane normal to the aircraft 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 aircraft is banked at 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.

[17] 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 aircraft 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 visualise the source paths as being both straight and level.

[18] This is known as the *duration correction* because it makes allowance for the effects of aircraft *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.

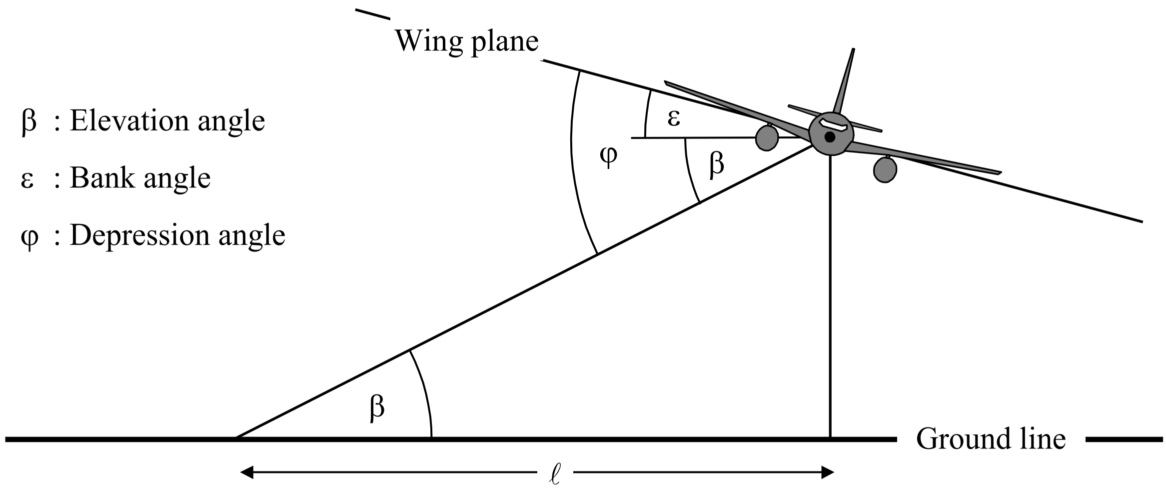

Figure 4-3: Aircraft-observer angles in plane normal to flight path

- The *elevation angle β* (between 0 and 90°) between the direct sound propagation path and the level ground line[19] 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 **Sections 4.5.4** and **4.5.5**.
- The *depression angle* φ between the wing plane and the propagation path, 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 **Section 4.5.3**. The *elevation angle β*, which is required to determine the *depression angle* φ, is defined in **Section 4.5.5**.

4.5.3 Engine installation correction Δ_I

An aircraft 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 aircraft, referred to here as *lateral directivity*.

There are significant differences in lateral directivity between aircraft with fuselage-mounted and underwing-mounted engines and these are allowed for in the following expression:

$$\Delta_I(\varphi) = 10 \cdot \log_{10}[(a \cdot \cos^2 \varphi + \sin^2 \varphi)^b / (c \cdot \sin^2 2\varphi + \cos^2 2\varphi)] \text{ dB} \qquad (4\text{-}15)$$

where Δ_I (φ) is the correction, in dB, at depression angle φ (see **Figure 4-3**) and

a = 0.0039, *b* = 0.062, *c* = 0.8786 for wing-mounted engines and

a = 0.1225, *b* = 0.329, *c* = 1 for fuselage-mounted engines.

[19] 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 **Sections 2.4.5** and **3.3.4**). In the event that, due to ground elevation, the receiver point is above the aircraft, elevation angle β is set equal to zero.

For propeller aircraft directivity variations are negligible and for these it may be assumed that

$$\Delta_I(\varphi) = 0 \qquad (4\text{-}16)$$

Figure 4-4 shows the variation of $\Delta_I(\varphi)$ about the aircraft 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. 11]. Until above-wing data have been analysed it is recommended that, for negative φ, $\Delta_I(\varphi) = \Delta_I(0)$for all installations.

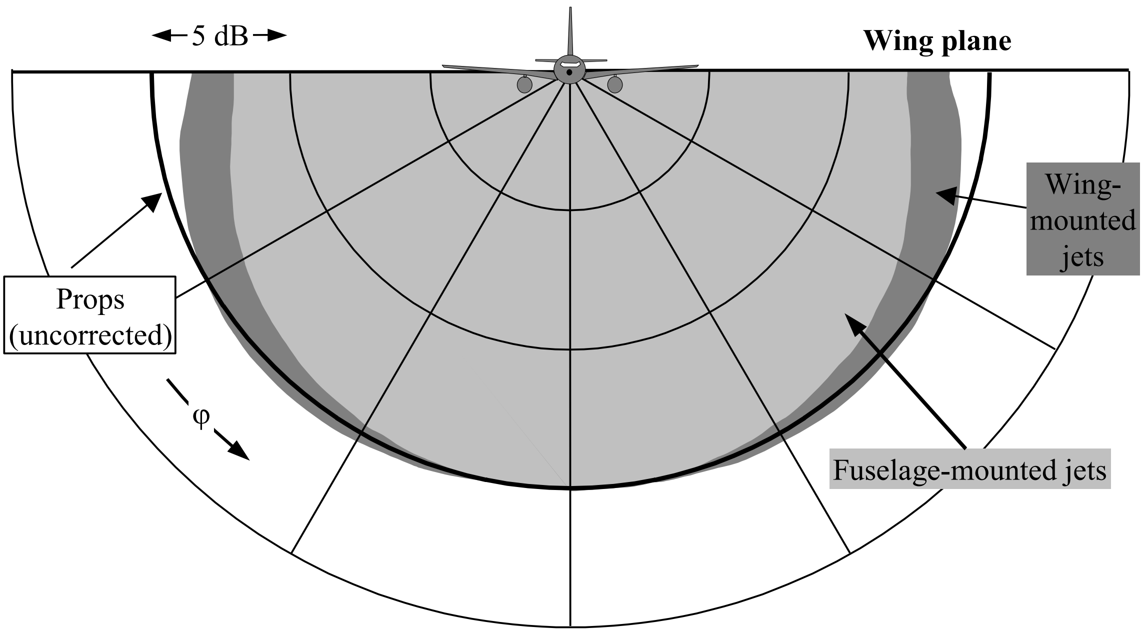

Figure 4-4: Lateral directivity of installation effects

It is assumed that Δ_I (φ) 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 aircraft. 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.

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

Tabulated NPD event levels relate to steady level flight and are generally based on measurements made 1.2m above soft level ground beneath the aircraft; the distance parameter is effectively height above the surface. Any effect of the surface on event noise levels beneath the aircraft, that might cause the tabulated levels to differ from free-field values[20], is assumed to be inherent in the data (i.e. in the shape of the level vs. distance relationships).

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 aircraft.

[20] A "free-field" level is that which would be observed if the ground surface were not there.

Apart from *lateral directivity* or "installation effects" described in **Section 4.5.3** 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 aircraft noise was developed by SAE in AIR-1751 [ref. 12] and the algorithms described below are based on improvements that SAE now recommends AIR-5662 [ref. 11]. 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 significant reductions in observed sound levels at low elevation angles. It is also very strongly affected by sound refraction, steady and unsteady, caused by wind and temperature gradients and turbulence which are themselves attributable to the presence of the surface[21]. 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. SAE work to develop a better understanding of surface effects is continuing and this is expected to lead to better models. Until these are developed, the following methodology, described in AIR-5662 [ref. 11], 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.

The methodology is built on the substantial body of experimental data on sound propagation from aircraft with fuselage-mounted engines in straight (non-turning), steady, level flight reported originally in AIR-1751 [ref. 12]. 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 aircraft 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 aircraft).

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 by equation 4-15, with the fuselage-mount coefficients and with φ replaced by β (appropriate to non-turning flight), the lateral attenuation becomes:

$$\Lambda(\beta,\ell) = \Lambda_T(\beta,\ell) - \Delta_I(\beta) \qquad (4\text{-}17)$$

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.

Although $\Lambda(\beta,\ell)$ could be calculated directly using equation 4-17 with $\Lambda_T(\beta,\ell)$ taken from AIR-1751, a more efficient relationship is recommended. This is the following empirical approximation adapted from AIR-5662:

$$\Lambda(\beta,\ell) = \Gamma(\ell)\cdot\Lambda(\beta) \qquad (4\text{-}18)$$

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

$$\Gamma(\ell) = 1.089\cdot\left[1-\exp(-0.00274\ell)\right] \quad \text{for} \quad 0 \le \ell \le 914\text{ m} \qquad (4\text{-}19a)$$

$$\Gamma(\ell) = 1 \quad \text{for} \quad \ell > 914\text{ m} \qquad (4\text{-}19b)$$

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

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

$$\Lambda(\beta) = 1.137 - 0.0229\beta + 9.72 \cdot \exp(-0.142\beta) \qquad \text{for} \quad 0° \le \beta \le 50° \qquad (4\text{-}19c)$$

$$\Lambda(\beta) = 0 \qquad \text{for} \quad 50° \le \beta \le 90° \qquad (4\text{-}19d)$$

The expression for lateral attenuation $\Lambda(\beta,\ell)$, equation 4-18, which is assumed to hold true for all aircraft, i.e. propeller aircraft as well as fuselage-mounted and wing-mounted jets, is shown graphically in **Figure 4-5**.

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

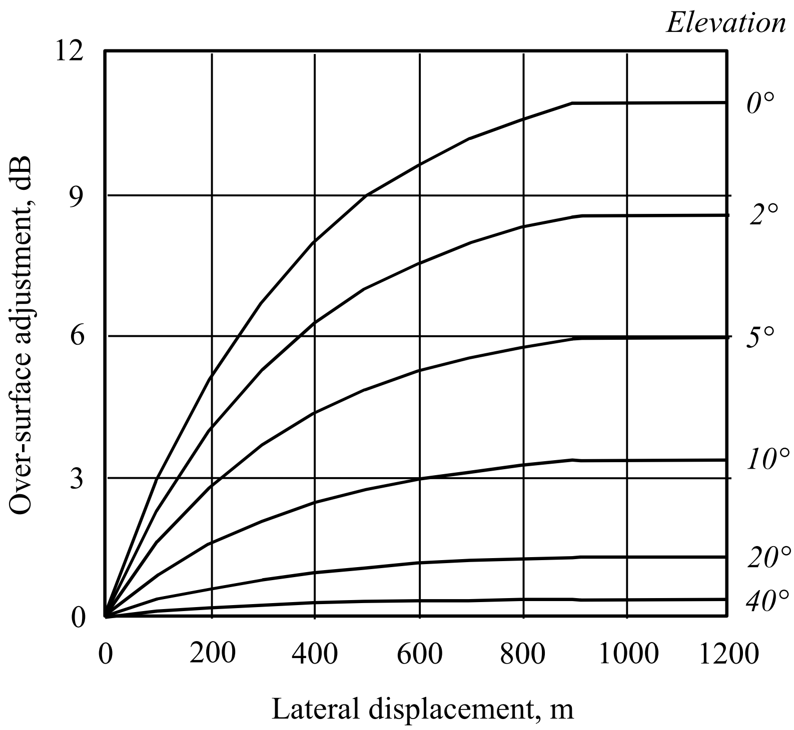

Figure 4-5: Variation of lateral attenuation $\Lambda(\beta, \ell)$ with elevation angle and distance

4.5.5 Finite segment lateral attenuation

Equations 4-19 describe the lateral attenuation $\Lambda(\beta,\ell)$ of sound arriving at the observer from an aeroplane in steady flight along an infinite, level flight path. When applying them to finite path segments that 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.

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.

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 in **Section 4.5.6**. 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.

Adding the corrections Δ_V and Δ_I, and subtracting lateral attenuation $\Lambda(\beta,\ell)$ 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; aircraft are usually climbing or descending.

Figure 4-6 illustrates a departure segment **S_1S_2** - the aircraft 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; sufficient 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 aircraft is banked (anti-clockwise about 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 4-17), 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 observer[22]. 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 **OS_1S_2** accords with **Figure 4-2b**, the geometry for calculating the segment correction Δ_F.

[22] For an observer located on the right side to the segment φ would become $\beta + \varepsilon$ (see **Section 4.5.2**).

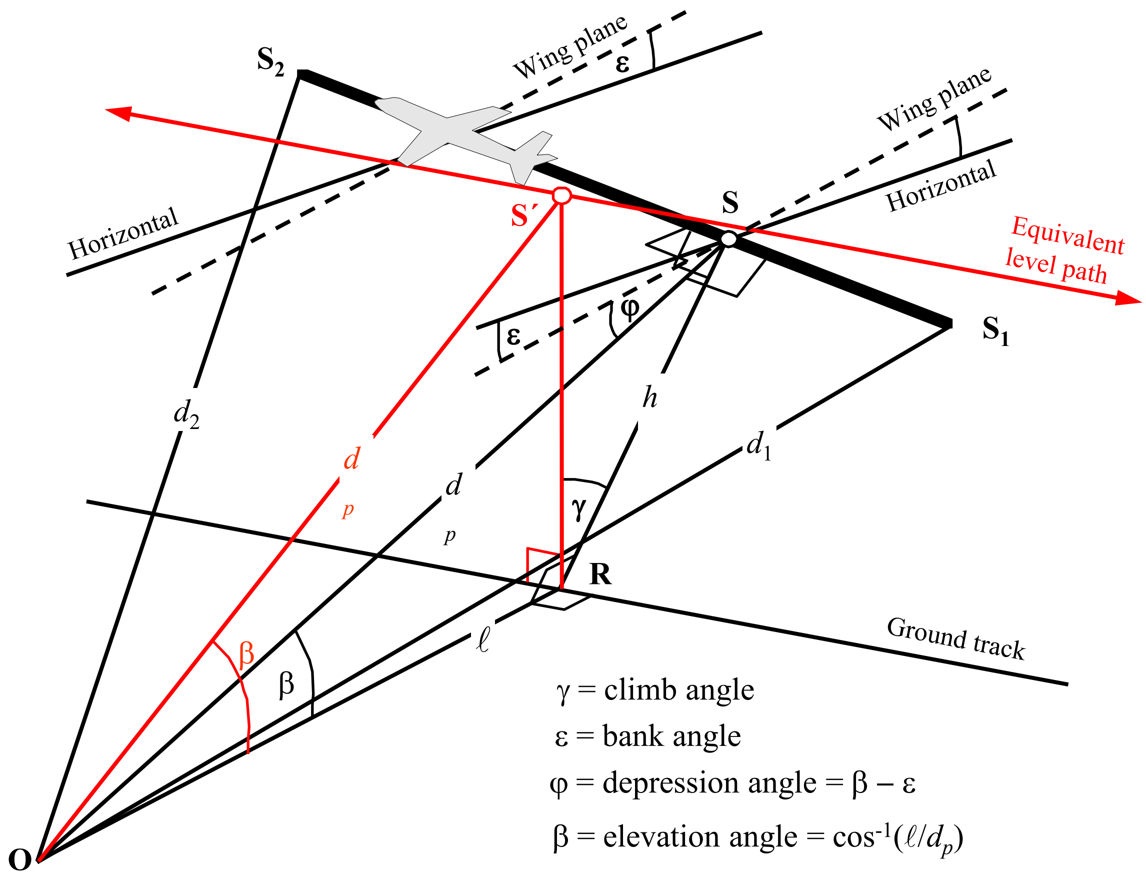

Figure 4-6: Observer alongside segment

To calculate the lateral attenuation using equation 4-18 (where β is measured in a vertical plane), an extended *level* flight path is recommended. An extended 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 visualised 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 4.7 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.

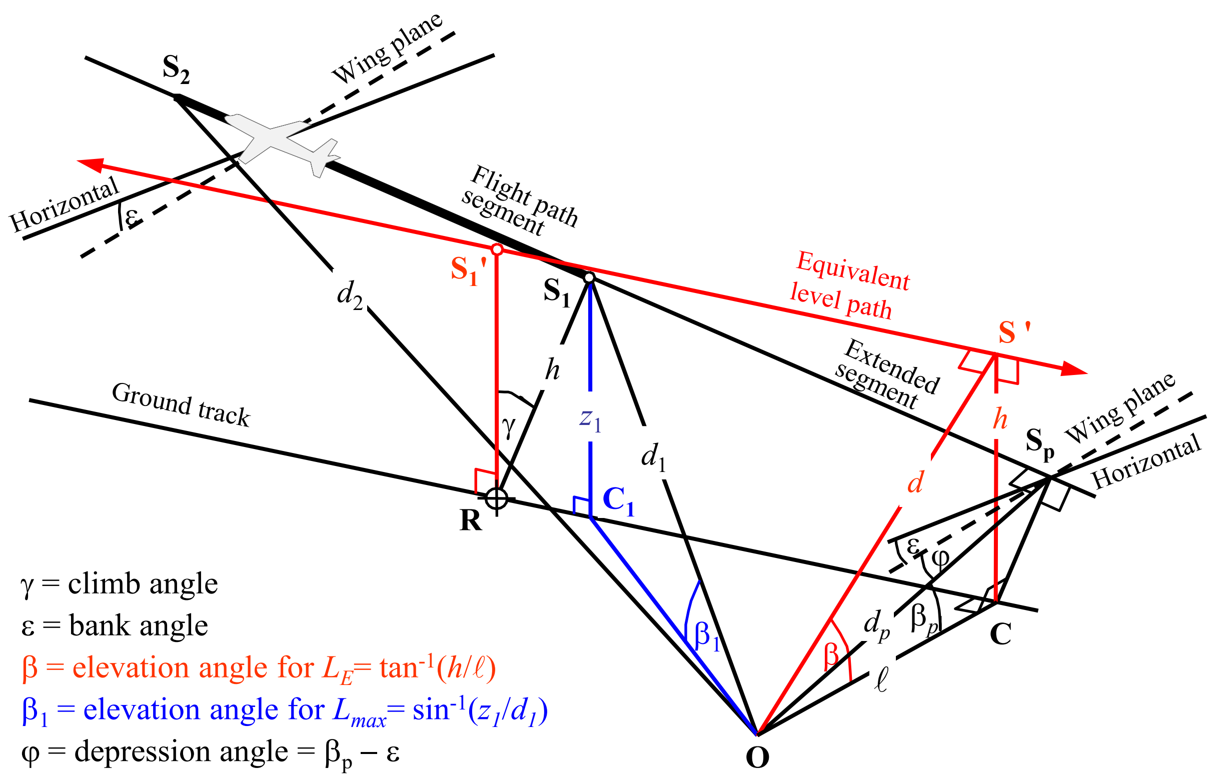

Figure 4-7: Observer behind segment

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 $L_{E\infty}(P_1, d_p)$.

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 4-18 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**.

When calculating the lateral attenuation for exposure level metrics, ℓ remains the shortest lateral displacement from the segment extension (**OC**). But to define an appropriate value of β it is again necessary to visualise an (infinite) *equivalent level flight path* of which the segment can be considered 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.

The closest point of approach of the equivalent level path to the observer **O** is at **S´**, slant distance *d*, so that the triangle **OCS´** 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 part) were at constant speed *V* 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.

Considering that, as conceived for modelling purposes, the engine installation effect Δ_I is two-dimensional, the defining depression angle φ is still measured laterally from the aircraft wing plane (the baseline event level is still that generated by the aircraft 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**.

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.

However, for exposure level metrics *where observer locations are behind ground segments during the take-off roll and ahead of ground segments during the landing roll*, the value of β becomes the same as that for maximum level metrics.

For locations behind take-off roll segments:

$$\beta = \beta_1 = \sin^{-1}(z_1/d_1) \text{ and } \ell = OC_1 = \sqrt{d_1^2 - z_1^2}$$

For locations ahead of landing roll segments:

$$\beta = \beta_2 = \sin^{-1}(z_2/d_2) \text{ and } \ell = OC_2 = \sqrt{d_2^2 - z_2^2}$$

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 **Sections 4.5.6** and **4.5.7** for further details).

4.5.6 The finite segment correction Δ_F (Exposure levels L_E only)

The adjusted baseline noise exposure level relates to an aircraft in continuous, straight, steady level flight (albeit with a bank angle ε that is inconsistent with straight flight). Applying the (negative) *finite segment correction* $\Delta_F = 10 \cdot \lg(F)$, where F is the *energy fraction*, further adjusts the level to what it would be if the aircraft traversed the finite segment only (or were completely silent for the remainder of the infinite flight path).

The energy fraction term accounts for the pronounced longitudinal directivity of aircraft 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. How this correction is derived is described in detail in **Appendix E**.

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

$$\Delta_F = 10 \cdot log\left[\frac{1}{\pi}\left(\frac{\alpha_2}{1+\alpha_2^2} + arctan\,\alpha_2 - \frac{\alpha_1}{1+\alpha_1^2} - arctan\,\alpha_1\right)\right] \qquad (4\text{-}20)$$

with

$$\alpha_1 = -\frac{q}{d_\lambda}\ ; \quad \alpha_2 = -\frac{q-\lambda}{d_\lambda}\ ; \quad d_\lambda = d_0 \cdot 10^{\left[L_{E\infty}(P,d_p)-L_{max}(P,d_p)\right]/10}\ ; \quad d_0 = \frac{2}{\pi} \cdot V_{ref} \cdot t_0 .$$

where d_λ is known as the "scaled distance" (see **Appendix E**) and V_{ref} = 270.05 ft/s (for the 160 knots reference speed). Note that $L_{max}(P, d_p)$ is the maximum level, from NPD data, for perpendicular distance d_p, *not* the segment L_{max}. It is advised to apply a lower limit of -150 dB to Δ_F.

In the particular case of observer locations behind every take-off ground-roll segment, a reduced form of the noise fraction expressed in equation 4-20 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 as:

$$\Delta'_{F,d} = 10 \cdot log_{10}\left[\frac{1}{\pi}\left(\frac{\alpha_2}{1+\alpha_2^2} + arctan\,\alpha_2\right)\right] \tag{4-21a}$$

where $\alpha_2 = \lambda / d_\lambda$.

This particular form of the noise fraction is used in conjunction with the start-of-roll directivity function, whose application method is further explained in **Section 4.5.7** below.

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

$$\boldsymbol{\Delta'_{F,a} = 10 \cdot log_{10}\left[\frac{1}{\pi}\left(-\frac{\alpha_1}{1+\alpha_1^2} - arctan\,\alpha_1\right)\right]} \quad \text{.......} \quad \textbf{(4-21b)}$$

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

The use of this form, without the application of any further horizontal directivity adjustment (unlike the case of locations behind take-off ground-roll segments – see **Section 4.5.7**), implicitly assumes a semi-circular horizontal directivity ahead of landing ground roll segments.

4.5.7 The start-of-roll directivity function Δ_{SOR}

The noise of aircraft, especially jet aircraft 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 the higher the jet velocity and the lower the aircraft speed. Additionally, a less pronounced radiation pattern may be observed for turboprop aircraft. This is of particular 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. 13] using microphones adequately positioned behind and to the side of the SOR of departing jet aircraft. Separate functions were derived for jet and turbo-prop aircraft.

Figure 4-8 shows the relevant geometry. The azimuth angle ψ between the aircraft longitudinal axis and the vector to the observer is defined by:

$$\psi = arccos\left(\frac{q}{d_{SOR}}\right) \tag{4-22}$$

The relative distance q is negative (see **Figure 4-2a**) so that ψ ranges from 90° relative to the aircraft forward heading, to 180° in the reverse direction.

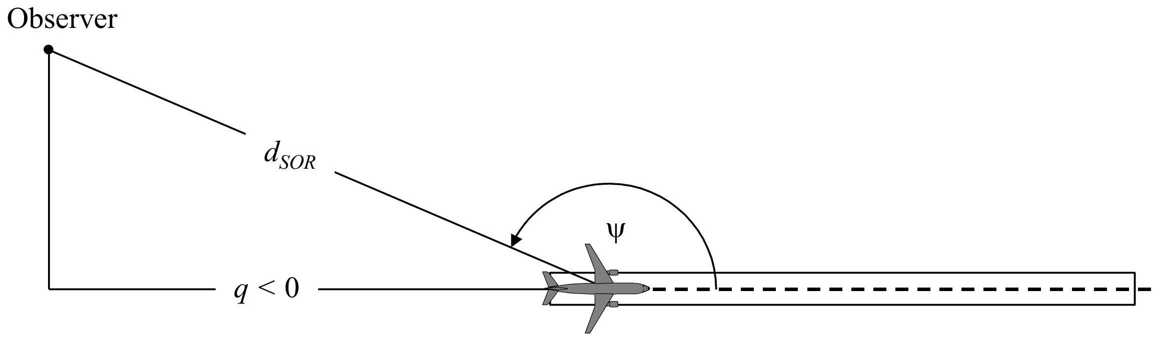

Figure 4-8: Aircraft-observer geometry for estimation of directivity correction

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

$$L_{TGR}(d_{SOR},\psi) = L_{TGR}(d_{SOR},90°) + \Delta_{SOR}(d_{SOR},\psi) \quad (4\text{-}23)$$

where $L_{TGR}(d_{SOR},90°)$ is the overall take-off ground roll noise level at the point distance d_{SOR} to the side of the SOR. 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 equation 4-9b.

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

For 90° ≤ Ψ < 180° then:

$$\Delta_{SOR}^{0} = 2329.44 - (8.0573 \cdot \psi) + \left(11.51 \cdot exp\left(\frac{\pi \cdot \psi}{180}\right)\right) - \left(\frac{3.4601 \cdot \psi}{ln\left(\frac{\pi \cdot \psi}{180}\right)}\right) - \left(\frac{17403338.3 \cdot ln\left(\frac{\pi \cdot \psi}{180}\right)}{\psi^2}\right) \quad (4\text{-}24a)$$

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

For 90° ≤ Ψ < 180° then:

$$\Delta_{SOR}^{0} = -34643.898 + \left(\frac{30722162}{\psi}\right) - \left(\frac{11491573931}{\psi^2}\right) + \left(\frac{2.34928567 \cdot 10^{12}}{\psi^3}\right) - \left(\frac{2.83584442 \cdot 10^{14}}{\psi^4}\right) + \left(\frac{2.02271504 \cdot 10^{16}}{\psi^5}\right) - \left(\frac{7.90084471 \cdot 10^{17}}{\psi^6}\right) + \left(\frac{1.30506872 \cdot 10^{19}}{\psi^7}\right) \quad (4\text{-}24b)$$

If the distance d_{SOR} exceeds the normalising distance $d_{SOR,0}$, 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 aircraft; i.e.

$$\Delta_{SOR} = \Delta_{SOR}^{0} \quad \text{if} \quad d_{SOR} \le d_{SOR,0} \quad (4\text{-}25a)$$

$$\Delta_{SOR} = \Delta_{SOR}^{0} \cdot \frac{d_{SOR,0}}{d_{SOR}} \quad \text{if} \quad d_{SOR} > d_{SOR,0} \quad (4\text{-}25b)$$

The normalising distance $d_{SOR,0}$ equals 762 m (2500 ft). 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 "generalised" to positions behind *each* individual take-off ground roll segment; 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*.

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 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.

4.5.8 Line-of-Sight Blockage Δ_{LOSB}

This adjustment accounts for the attenuation due to line-of-sight blockage (LOSB) from terrain features. The LOSB calculation is based on the difference in propagation path length between the direct path and propagation over the top of terrain features. This adjustment is compliant with the method described in SAE-AIR-6501 "Method for Modelling Line-of-Sight Blockage of Aircraft Noise" [ref. 14]. The path length difference is used to compute the Fresnel Number (N_0), which is a dimensionless value used in predicting the attenuation provided by a noise barrier positioned between a source and a receiver.

If line-of-sight blockage is selected for the noise calculations, LOSB is compared to $\Lambda(\beta,l)$ on a point-by-point basis and the larger of the two values is applied to the calculations. For each segment-based noise calculation, either Δ_{LOSB} or $\Lambda(\beta,l)$ are implemented, but not both. This allows for a seamless transition between Δ_{LOSB} and $\Lambda(\beta,l)$, although it does not handle their interaction. As stated in the Federal Interagency Committee on Aviation Noise (FICAN) report "Assessment of Tools for Modelling Aircraft Noise in the National Parks" [ref. 15], this approach has been validated for distances up to 1,000 feet, beyond which a practical limit between 18 and 25 dB of attenuation can be expected due to refraction and scattering effects. Therefore, an 18 dB attenuation cap is recommended for Δ_{LOSB} as a practical upper limit on barrier attenuation.

Practical implementations of LOSB have shown that in airport specific scenarios it reduces contour area by up to 5%. This comes at the cost of a 5-10-fold increase in calculation time, which may be mitigated through model (software) optimisation or scenario simplification. For most scenarios this trade-off between calculation and contour precision is not justified[23], except for very specific local situations. It is therefore recommended that LOSB is not applied as a default adjustment, but only where appropriate to local circumstances and the scenario being assessed.

[23] Especially where it occurs at the expense of scenario simplification, e.g. simplified fleet or flight track representation, and/or coarser grid resolution.

5 CALCULATION OF CUMULATIVE LEVELS

Chapter 4 describes the calculation of the event sound noise level of a single aircraft movement at a single observer location. The total noise exposure at that location is calculated by accumulating the event levels of all noise-significant aircraft 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 **Section 3.2** of **Volume 1**.

5.1 WEIGHTED EQUIVALENT SOUND LEVELS

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

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

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 (normalising constant, seasonal adjustment etc.).

Using the relationship:

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

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

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

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

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

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

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

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

$$Index = \overline{L_{max}} + K \cdot \lg N \tag{5-3}$$

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

A special index is the *Number Above Threshold* – abbreviated *NAT*. Thus, 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. $NAT_{Night,70}$).

5.2 THE WEIGHTED NUMBER OF OPERATIONS

The cumulative noise level is estimated by summing the contributions from all different types or categories of aircraft using the different flight routes which comprise the airport scenario.

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

- *i* index for aircraft type or category
- *j* index for flight track or sub-track (if sub-tracks are defined)
- *k* index for flight track segment

Many noise indices – especially equivalent sound levels – 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.

The summation process can be simplified by introducing a "weighted number of operations":

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

The values N_{ij} represent the numbers of operations of aircraft type/category *i* on track (or sub-track) *j* during the day, evening, and night period respectively[24].

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

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

T_0 is the reference time period. It depends on, as well as the weighting factors g_i, the specific definition of the weighted index used (e.g. L_{den} or L_{DN} - see **Volume 1** for definitions of weighted equivalent sound levels). $L_{E,ijk}$ is the single event noise level contribution from segment *k* of track or sub-track *j* for an operation of aircraft of category *i*. The estimation of $L_{E,ijk}$ is described in detail in **Chapter 4**.

5.3 ESTIMATION OF CUMULATIVE MAXIMUM LEVEL BASED METRICS

Calculating a cumulative equivalent sound level is a straightforward aggregation of the event levels L_E of all noise-significant aircraft movements. Cumulative maximum level metrics are less straightforward; care is required when estimating maximum sound levels. By definition, a maximum sound level is tied to a single noise event. However, a single aircraft 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).

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

(a) The average maximum sound level, defined by equation 5-2, of all noise events occurring at the observer location.

[24] The time periods may differ from these three, depending on the definition of the noise index used.

(b) 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.

(c) The absolute maximum level (i.e. the "maximum" maximum level). In this case *only one noise event* contributes.

This points to a need for metric-specific aggregation of the maximum sound levels.

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

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

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

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

With a threshold L_T, the average maximum sound level (b) can be expressed as:

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

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

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

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

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

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

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

5.4 THE USE OF LEVEL DISTRIBUTIONS FOR MAXIMUM LEVEL METRICS

The methodology described in **Chapter 4** yields the same maximum sound level for all movements of the same aircraft type on the same track[25]. This can lead to unrealistic discontinuities in $\overline{L_{max}}$ and *NAT* contours. In reality, there are no sharp changes; the calculated $\overline{L_{max}}$ 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*:

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

Figure 5-1 shows a sketch of such a level distribution.

[25] Assuming the same operating procedures and weight.

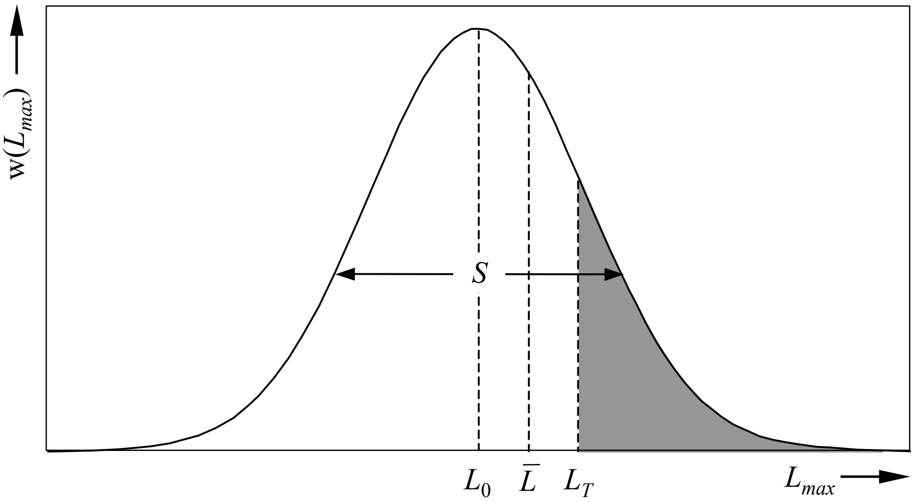

Figure 5-1: Maximum sound level distribution

It must be noted that the median value L_0 of the distribution function is generally not equal to the value $\overline{L}$ 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:

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

A characteristic type-specific value for the standard deviation *S* is observed from operational measurements to be around 2 dB[26]. This results in a level difference between logarithmic and arithmetic averages of around 0.5 dB.

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 $\overline{L}$ 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 must be modified by replacing the discrete step represented by the function v(k) by an integral over a continuous distribution function:

$$NAT_{L_T}(x,y) = \sum_i \sum_j \sum_k M_{ij} \cdot u(k) \cdot \int_{L_T}^{\infty} w\left(L_{max,ijk}, L_{0,k}, s\right)\, dL_{max,ijk} \qquad (5\text{-}12)$$

Polynomial approximations of this integral for programming purposes can be found in mathematical handbooks (e.g. ref. 16).

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

26 Rather lower scatter is achieved in certification tests.

6 CALCULATION OF NOISE CONTOURS

6.1 STANDARD GRID CALCULATION AND REFINEMENT

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 narrowing the grid spacing, but since this increases the number of grid points, the computation time is increased. Optimising a regular grid mesh involves balancing modelling accuracy and run time.

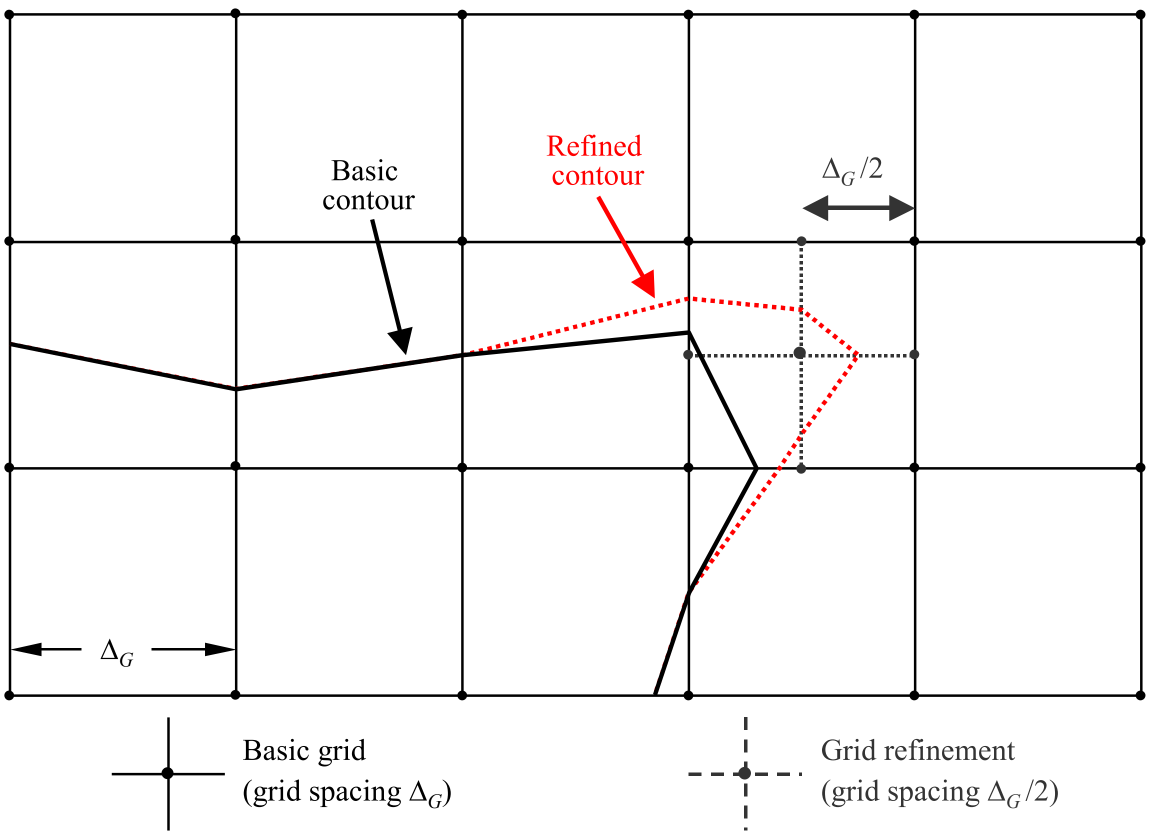

Figure 6-1: Standard grid and grid refinement

A marked improvement in computing efficiency that delivers more accurate results is to use an irregular grid to refine the interpolation in critical cells. The technique, depicted in **Figure 6-1**, is to tighten 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:

$$\text{If}\begin{cases}\Delta L \le \Delta L_R \\ \Delta L > \Delta L_R\end{cases} \text{calculate the new value} \begin{cases}\text{by linear interpolation from the adjacent ones.} \\ \text{completely anew from the basic input data.}\end{cases}$$

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

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.

6.2 USE OF ROTATED GRIDS

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 cause result in an asymmetric contour shape:

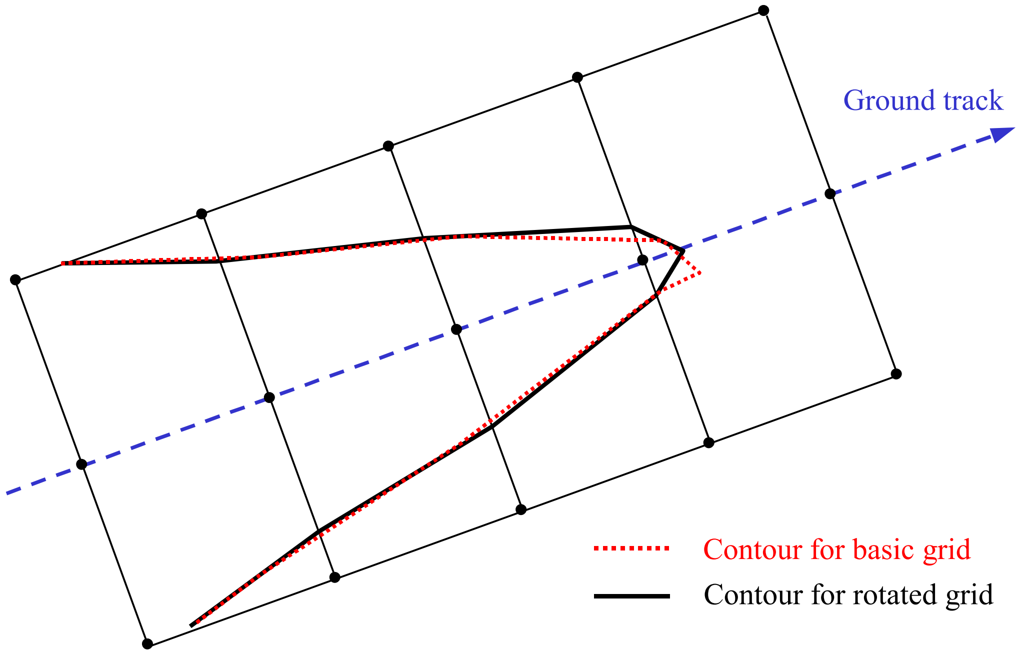

Figure 6-2: Use of a rotated grid

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.

6.3 TRACING OF CONTOURS

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**):

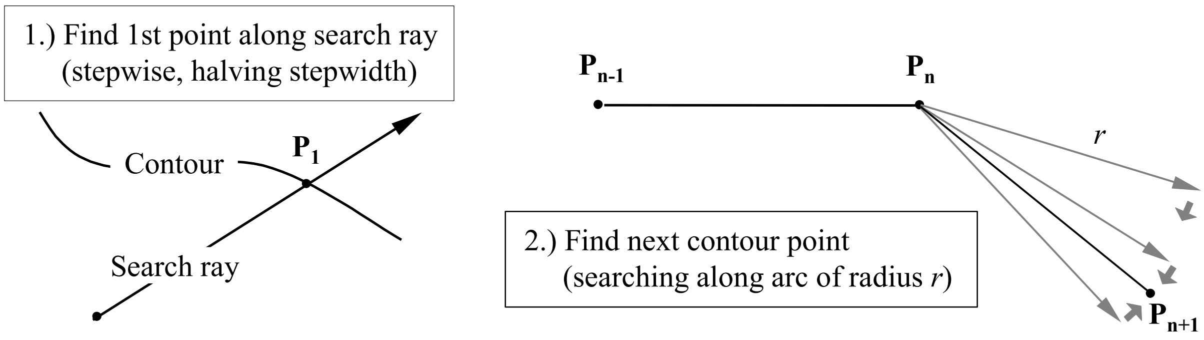

Figure 6-3: Concept of tracing algorithm

Step 1 is to find a first point $\mathbf{P_1}$ 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 pre-defined accuracy threshold.

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, this time in the directions of the vector, the next contour point is determined within a predefined accuracy.

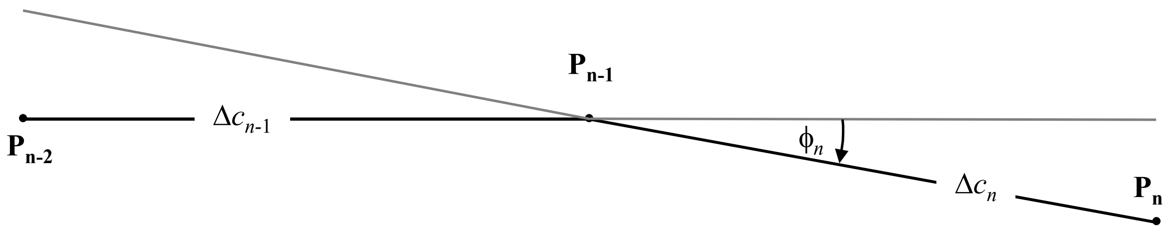

Figure 6-4: Geometric parameters defining conditions for the tracing algorithm

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

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

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

   where φ_n is the difference in the chord headings.

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.

This algorithm speeds up computation time dramatically, particularly 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

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

- Interpolation and, if necessary, smoothing of noise contours (if the index was estimated for a grid).
- Performing grid operations such as merging, adding, subtracting or converting.
- Plotting (including representation of contours, runways, tracks, specific observer locations and/or topography).
- Integration of noise data into geographic information systems (GIS) to estimate enclosed population numbers for example.

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

- NMPLOT: this program is designed to view and edit sets of geo-referenced data sets such as noise data stored in grids.
- GIS software such as ArcView or MicroStation GeoGraphics (usually commercial software).

Data formats which are widely used are:

- ARC/INFO shapefile format used by ArcView.
- AutoCAD data exchange format DXF.
- Intergraph and MicroStation standard file format ISFF (also known as DGN).
- Noise model grid format, NMGF. The NMGF was originally developed for use in conjunction with different noise models. It is used by NMPLOT.

Hence, a lot of possibilities for the definition of interfaces exist. This should be taken into account when a computer model based on this document is developed.

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APPENDIX A DATA REQUIREMENTS

Section 2.4 of the main text describes, in general terms, the requirements for case-specific data describing an airport and its operations that are required for noise contour calculations. The following datasheets are filled with example data for a hypothetical airport. Specific data formats will generally depend on the requirements and needs for the particular noise modelling system as well as the study scenario.

Note: It is recommended that geographic information (reference points etc.) be specified in Cartesian coordinates. The choice of the particular coordinate system usually depends on the maps available.

A1 GENERAL AIRPORT DATA

Aerodrome designation	Hypothetical Airport	
Coordinate system	UTM, Zone 15, Datum WGS-84	
Aerodrome reference point, ARP	3 600 000 m E Mid-point of runway 09L-27R	6 300 000 m N
Altitude of ARP	120 m	
Average air temperature at ARP*	12.0 ºC	
Average relative humidity at ARP*	60 %	
Average wind speed & direction*	5 kt	270 degrees
Source of topographical data	Unknown	

* Repeat for each time interval of interest (time of day, season etc.)

A2 RUNWAY DESCRIPTION

Runway designation	09L	
Start of runway	3 599 000 m E	6 302 000 m N
End of runway	3 603 000 m E	6 302 000 m N
Start of roll	3 599 000 m E	6 302 000 m N
Landing threshold	3 599 700 m E	6 302 000 m N
Altitude of start of runway	110 m	
Mean runway gradient	0.001	

For displaced thresholds, runway description may be repeated or displaced thresholds can be described in the ground track description section.

A3 GROUND TRACK DESCRIPTION

In the absence of radar data the following information is needed to describe particular ground tracks.

Track No.			001		
Track designation			Dep 01 – 09L		
From runway			09L		
Type of track			Departure		
Displacement from start of roll			0 m		
Number of sub-tracks:			7		
Backbone track description					
Segment no.	Straight [m]	Curve			Standard deviation for lateral dispersion at segment end [m]
		L/R	Heading change [°]	Radius [m]	
1	10000				2000
3		R	90.00	3000	2500
4	20000				3000

Track No.			002		
Track designation			App 01 – 09L – Disp 300		
From runway			09L		
Type of track			Approach		
Displacement from landing threshold			300 m		
Number of sub-tracks:			1		
Backbone track description					
Segment no.	Straight [m]	Curve			Standard deviation for lateral dispersion at segment end [m]
		L/R	Heading change [°]	Radius [m]	
1	30000				0
Approach track information					
Glide angle for approach tracks			2.7°		
Flight altitude at glide slope interception			4000 ft		

A4 AIR TRAFFIC DESCRIPTION

Reference time period	366 d (01-01-2000 to 31-12-2000)	= 8748 h
Time of day period I	From 0600 to 1800 h	= 12 h
Time of day period II	From 1800 to 2200 h	= 4 h
Time of day period III	From 2200 to 0600 h	= 8 h

AIR TRAFFIC DESCRIPTION DATA SHEET – MOVEMENTS PER TRACK			
Ground track no.	001		
Track designation	Dep 01 – 09L		
Aircraft designation	**Movements during time period**		
	I	**II**	**III**
A/C 1, Dep.1	20000	4000	1000
A/C 2, Dep.4	10000	5000	500
A/C 4, Dep.3	2000	300	0
Ground track no.	002		
Track designation	Dep 01 – 09L – Disp 300		
Aircraft designation	**Movements during time period**		
	I	**II**	**III**
A/C 1, App.1	18000	2000	5000
A/C 2, App.1	10000	3000	2500
A/C 4, App.1	1300	0	1000

A5 FLIGHT PROCEDURE DATA SHEET

Example aircraft for a Chapter 3 Boeing 727-200 as derived from radar using the guidance set out in vol. 2.

Aircraft designation	B727C3
NPD-Identifier from ANP database	JT8E5
No. of engines	3
Mode of operation	Departure
Actual aircraft mass [t]	71.5
Headwind [m/s]	5
Temperature [°C]	20
Airport elevation [m]	83

Segment No.	Dist. from RP[27] [m]	Height [m]	Ground speed [m/s]	Engine Power [[28]]
1	0	0	0	14568
2	2500	0	83	13335
3	3000	117	88	13120
4	4000	279	90	13134
5	4500	356	90	13147
6	5000	431	90	13076
7	6000	543	90	13021
8	7000	632	93	12454
9	8000	715	95	10837
10	10000	866	97	10405
11	12000	990	102	10460
12	14000	1122	111	10485
13	16000	1272	119	10637
14	18000	1425	125	10877
15	20000	1581	130	10870
16	25000	1946	134	10842
17	30000	2242	142	10763

[27] The reference point RP is the start of roll for departures and the landing threshold for approaches.

[28] Units corresponding to ^{units} in ANP database

Example for a procedural profile based on aircraft data stored in ANP database:

Aircraft designation from ANP database	B727C3
NPD-Identifier from ANP database	JT8E5
No. of engines	3
Mode of operation	Departure
Actual aircraft mass [t]	71.5
Headwind [m/s]	5
Temperature [°C]	15
Airport elevation [m]	100

Segment No.	Mode	Target	Flaps	Engine Power
1	Take-off		5	Take-off
2	Initial Climb	Altitude 1500 ft	5	Take-off
3	Retract Flaps	210 kt IAS ROC 750 ft/min	0	Max Climb
4	Accelerate	250 kt IAS ROC 1500 ft/min	0	Max Climb
5	Climb	10000 ft	0	Max Climb

APPENDIX B FLIGHT PERFORMANCE CALCULATIONS

TERMS AND SYMBOLS

The terms and symbols used in this appendix are consistent with those conventionally used by aircraft performance engineers. Some basic terms are explained briefly below for the benefit of users that are unfamiliar with them. To minimise conflict with the main body of the document, 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.

Terms

Break point	**See Flat Rating**
Calibrated Airspeed	**(Otherwise termed equivalent or indicated airspeed.) The speed of the aircraft relative to the air as indicated by a calibrated instrument on the aircraft. 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 (*EPR* or N_1) this falls with air density as altitude increases; corrected net thrust is the thrust at sea level.
Flat rating	For specific maximum component temperatures, the engine thrust falls as the ambient air temperature rises, and *vice-versa*. 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" since, at lower air temperatures, the thrust is automatically limited to the rated thrust to maximise service life. The thrust decreases at temperatures above the flat rated temperature - which is often called the *break point* or *break temperature*.
Speed	Magnitude of aircraft velocity vector (relative to aerodrome coordinate system).
Rated thrust	The service life of an aircraft engine is very 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	The pilot cannot select a particular engine thrust, but instead chooses an appropriate setting of this parameter which is displayed in the cockpit. It is usually either the engine pressure ratio (*EPR*) or low-pressure rotor (or fan) rotational speed (N_1).

Symbols

Quantities are dimensionless unless otherwise stated. Symbols and abbreviations not listed below are used only locally and defined in the text. Subscripts 1 and 2 denote conditions at the start and end of a segment, respectively. Overbars denote segment mean values, i.e. the average of start and end values.

a	Average acceleration, ft/s^2
a_{max}	Maximum acceleration available, ft s^2
B, C, D	Flap coefficients for different flight configurations, units of ft/√lb, kt/√lb and kt/√lb, respectively, obtainable from the ANP database. B is the takeoff ground roll coefficient, C is the takeoff speed coefficient and D is the landing speed coefficient.
E, F, G_A, G_B, H	Engine thrust 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, lb/kt, 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	Standard gravitational acceleration, 32.174 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, %
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	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	Air temperature (ambient air temperature in which the aeroplane is operating), °C unless otherwise stated
T_B	Breakpoint temperature, °C
V	Groundspeed, 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_O, the ratio of the ambient air pressure at the aeroplane to the standard air pressure at mean sea level: p_O = 29.92 inHg (equivalent to 101.325 kPa, or 1013.25 mb) [ref. 1]
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 = 59 °F (15.0 °C) [ref. 1]
σ	ρ/ρ_0 = Ratio of air density at altitude to the mean sea level value (also, $\sigma = \delta/\theta$

B1 OVERVIEW

Flight path synthesis

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

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 in the text as the process of flight path *synthesis*.

Aside from the aircraft performance parameters, which can be obtained from the ANP database (see **Appendix G**), these equations require specification of (1) aeroplane gross weight, (2) the number of engines, (3) air temperature, (4) runway elevation, 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.

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 **Section 2.5**). But the aerodynamic parameters and engine coefficients have been shown to be adequate for air temperatures up to 43°C, aerodrome altitudes up to 6,000 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, windspeed, air temperature, and runway elevation (air pressure), normally with sufficient accuracy for computing contours of average sound levels around an airport.

Section B-4 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.)

Section B-6 describes the recommended methodology for generating departure flight profiles, based on ANP database coefficients and procedural steps.

Section B-7 describes the methodology used to generate approach flight profiles, based on ANP database coefficients and flight procedures.

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.

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 be consistent with the units of the corresponding parameters and variables. For consistency* *with the ANP database, the conventions of aircraft 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, although some dimensions (e.g. atmospheric ones) are expressed in SI units. Modellers using other unit systems must be very careful to apply appropriate conversion factors when adopting the equations to their needs.*

Flight path analysis

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. This is discussed in **Chapter 3** of Volume 2. In this case, the equations presented in this appendix are used "in reverse" - the engine thrust parameters are derived from the aircraft motion rather than vice-versa. Once the flight path data have been averaged and reduced to segment form, each segment has been classified as a climb or descent, acceleration or deceleration, and thrust and flap changes are identified, it is relatively straightforward to apply the equations "in reverse", by comparison with synthesis which often involves iterative processes.

This section describes the step-by-step calculation method to convert the default procedural step profiles of the ANP database[29] into fixed-point profiles.

Fixed-point profiles consist of ordered series of altitude (AFE), speed (TAS) and corrected net thrust (CNT) values as a function of the travelled ground distance along the track for each operating mode. Combined with the ground tracks, these allow the further construction of the flight path segments of the aircraft trajectory.

The ground distance values in the calculated fixed-point profiles are expressed in feet and follow different conventions for departure and approach profiles:

- For departure profiles, distances are positive and start from zero, which corresponds to the brake release point on the runway.
- For approach profiles, distances are negative when the aircraft is airborne until the touchdown point, at which the distance is zero. Distance values beyond the touchdown point become positive, which correspond to the rolling (deceleration) portion of the runway.

It should be noted that the definition of procedural step profiles and their further conversion into fixed-point profiles (as per the calculation method described here) requires the availability of engine and aerodynamic coefficients for a given ANP aircraft. These are provided in the following tables of the ANP database:

- *Jet_Engine_Coefficients* (engine coefficients for jet and certain turboprop aircraft)
- *Propeller_Engine_Coefficients* (for piston/propeller engines)
- *Aerodynamic_Coefficients*

[29] The same calculation method is applicable to user-defined procedural step profiles that would replace the default profiles of the ANP database.

The calculation method takes into account the following parameters, which affect the resulting vertical profile:

- Aircraft take-off / landing weight
- Engine power settings (ratings)
- Aircraft flap settings
- Airport elevation, temperature and pressure (lapsing based on the ISA)
- Headwind

List of procedural step types:

The step types listed below cover the reference/default departure and approach procedural step profiles provided in the ANP database (tables *Default_Departure_Procedural_Steps* and *Default_Approach_Procedural_Steps*).

This list also includes several additional steps, which can help practitioners to define their own, more specific, flight procedures.

Departure

- Take-off
- Climb
- Accelerate
- Level
- Level-Accelerate

Approach

- Descend and Descend-Decel
- Descend-Idle
- Level and Level-Decel
- Level-Idle
- Land
- Decelerate (on the ground)

B2 GENERAL CONVERSION PARAMETERS

Due to the history of the overarching method described in ECAC.CEAC Doc. 29 and the strong association that aviation has with English units, the calculation method presented here is based around English units. This may result in some loss of precision compared to parameters defined using precision SI units and definitions, however, the consequences are not material to the outputs and aircraft noise calculation. Developers should keep this in mind when implementing this method in software and validating software against the test cases provided in Doc. 29 Volume 3.

Where it may be necessary or appropriate to convert from one unit to another, the following conversion factors are recommended:

B2.1 CONSTANTS

Symbol, name	Parameter	Reference value
Standard gravitational acceleration	g	32.174 ft/s²

B2.2 CONVERSION FACTORS

Symbol, name	Parameter	Input unit	Factor	Output unit
Foot, feet		1 ft =	0.3048000	m
Nautical mile		1 nm =	1852.000	m
Knot (nautical mile per hour)		1 kt =	0.5144	m/s
Knot (nautical mile per hour)		1 kt =	1.852	km/h
Knot (nautical mile per hour)	k	1 kt =	1.68781	ft/s
Kilometres per hour		1 km/h =	0.277777778	m/s
Pound (mass)		1 lb =	0.4535924	Kg

Other conversion factors that may be useful, but that are not directly required to implement the method are given below. Note that converting SI pressure to inHg using the factor given will result in differences, since the recommended method assumes a sea-level pressure of 29.92 inHg[30].

[30] The precise value for standard sea-level pressure is 29.9212553. The less precise value of 29.92 inHg has been retained for legacy purposes and must be used to match calculations from this method.

Supplementary conversion factors

Symbol, name	**Parameter**	**Input unit**	**Factor**	**Output unit**
Power		1 hp =	745.7	W
Force		1 lbf =	4.44822	N
Pressure		1 inHg =	3386.531[31]	Pa

[31] This factor is intentionally less precise in order to give a standard sea-level pressure of 29.92 inHg. The precise conversion factor is 3386.389, but must not be used in order to match calculations from this method.

B3 ATMOSPHERIC PARAMETERS & RATIOS

The input parameters for the calculation of atmospheric ratios and other atmospheric-related quantities are:

- T_{apt} airport temperature (°F),
- P_{apt} airport pressure at sea-level (equivalent to the airport QNH) (inHg),
- E_{apt} airport elevation (feet) above mean sea level (MSL),
- Alt aircraft altitude (feet) above mean sea level (MSL).

°F to °C temperature conversion:

$$TC = (\frac{5}{9}) * (TF - 32) \quad \text{(B-1)}$$

Temperature (°F) at the aircraft altitude:

$$TF\ (Alt) = Tapt - 0.003566\ (Alt - Eapt) \quad \text{(B-2)}$$

Temperature ratio:

Ratio of the air temperature at the aircraft altitude *Alt* to the standard air temperature at mean sea level: T0 = 15°C (59°F)

$$\theta = \frac{\left(459.67 + T_{apt} - 0.003566\ (Alt\text{-}E_{apt})\right)}{518.67} \quad \text{(B-3)}$$

Pressure ratio:

p/p_O, the ratio of the ambient air pressure at the aircraft altitude *Alt* to the standard air pressure at mean sea level: p_O = 29.92 inHg[32] (equivalent to 101.325 kPa (or 1013.25 mb)

$$\delta = \left[\left(\frac{P_{apt}}{29.92}\right)^{1/5.256} - \left(\frac{0.003566 * Alt}{518.67}\right)\right]^{5.256} \quad \text{(B-4)}$$

Air density ratio:

ρ/ρ_0= Ratio of air density at the aircraft altitude *Alt* to mean sea level value: ρ_0=1.225 kg/m³

$$\boldsymbol{\sigma} = \frac{\boldsymbol{\delta}}{\boldsymbol{\theta}} \quad \text{(B-5)}$$

Pressure Altitude *h* (ft) at the aircraft altitude *Alt:*

$$h = \left(\frac{518.67}{0.003566}\right) * \left(1 - \delta^{1/5.256}\right) \quad \text{(B-6)}$$

TAS-CAS conversion:

[32] The precise value for standard sea-level pressure is 29.9212553. The less precise value of 29.92 inHg has been retained for legacy purposes and must be used to match calculations from this method.

$$V_T = V_C/\sqrt{\sigma} \qquad \text{(B-7)}$$

Rearranging, CAS equals:

$$V_c = \sqrt{\sigma}.V_T \qquad \text{(B-8)}$$

where

V_T True Airspeed (or TAS) (kt)

V_C Calibrated Airspeed (or CAS) (kt)

σ Air density ratio at the aircraft altitude *Alt* (Eq. B-5)

B4 ENGINE THRUST CALCULATION

B4.1 JET AND (CERTAIN) TURBOPROP ENGINE-POWERED AIRCRAFT

The Corrected Net Thrust[33] per engine for jet and certain turboprop aircraft is calculated based on the following equations[34]:

$$CNT = E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 + H \cdot T \quad \text{(B-9)}$$

$$CNT_{High} = E_{High} + F_{High} \cdot V_C + G_{A-High} \cdot h + G_{B-High} \cdot h^2 + H_{High} \cdot T \quad \text{(B-10)}$$

Where:

CNT	Corrected Net Thrust per engine (lb) for ambient temperature below the engine breakpoint temperature
CNT_{High}	High temperature Corrected Net Thrust per engine (lb) - e.g. above the engine breakpoint temperature
V_C	is the Calibrated Airspeed, kt
h	is the aircraft **pressure altitude** (ft) (see Eq. B-6 in Section B3)
T	is the ambient air temperature at the aircraft altitude, **in °C**
E, F, G_A, G_B, H	are jet engine coefficients provided in the ANP "Jet_Engine_Coefficient" table for different Thrust Ratings below the temperature break point (i.e. for Thrust Ratings IDs without the "HighTemp" suffix)
E_{High}, F_{High}, G_{A-High}, G_{B-High}, H_{High}	are jet engine coefficients provided in the ANP "Jet_Engine_Coefficient" table for different Thrust Ratings above the temperature break point (i.e. for Thrust Ratings IDs with the "HighTemp" suffix)

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33 The Corrected Net Thrust (per engine) is expressed as F_n/δ where F_n is the Net Thrust per engine (lb) and δ is the ratio of the ambient air pressure at the aeroplane to the standard air pressure at mean sea level, i.e. to 101.325 kPa (or 1013.25 mb).

34 Certain aeroplanes of the ANP database include additional jet engine coefficients, which 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, N1. When that parameter is EPR, equation B-9 is replaced by:

$$CNT = E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 + H \cdot T + K_1 . EPR + K_2 . EPR^2 \quad \text{(B-9a)}$$

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.

When engine rotational speed N_1 is the parameter used by the cockpit crew to set thrust, the generalized thrust equation B-9 becomes:

$$CNT = E + F \cdot V_C + G_A \cdot h + G_B \cdot h^2 + H \cdot T + K_3 . \left(\frac{N_1}{\sqrt{\theta}}\right) + K_4 . \left(\frac{N_1}{\sqrt{\theta}}\right)^2 \quad \text{(B-9b)}$$

where $N_1/\sqrt{\theta}$ is the corrected low pressure rotor speed, %; and K_3 and 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 B-9a and B-9b might have different values from those in equation B-9.

For any profile point where the CNT has to be calculated based on a Thrust Rating information on a given step ("MaxTake-off", "MaxClimb", "IdleApproach", …), the calculation process is as follows:

- Calculate the CNT value for the ambient temperature (at the aircraft) assuming that it is below the engine breakpoint temperature, using Eq. B-9
- Calculate the CNT_{High} value for the ambient temperature (at the aircraft) assuming that it is above the engine breakpoint temperature, using Eq. B-10 and "HighTemp" engine coefficients
- Retain the smaller of the two values calculated above as the Corrected Net Thrust value to be assigned to the profile-point

If high-temperature coefficients are not available in the "Jet_Engine_Coefficient" table for a given aircraft type, Eq. B-11 below is used to calculate CNT_{High} for departure procedures:

$$CNT_{High} = F \cdot V_C + (E + H \cdot T_B) \cdot \frac{(1-0.006 \cdot T)}{(1-0.006 \cdot T_B)} \qquad \text{(B-11)}$$

where:

CNT_{High}	High temperature Corrected Net Thrust per engine (lb) – e.g. above the engine breakpoint temperature
V_C	is the Calibrated Airspeed, kt
T	is the ambient air temperature at the aircraft altitude, **in °C**
T_B	is the breakpoint temperature **in °C**, T_B = 30°C
E, F & H	are jet engine coefficients provided in the ANP "Jet_Engine_Coefficient" table for different Thrust Ratings below the temperature break point (i.e. for Thrust Ratings IDs without the "HighTemp" suffix)

For approach procedures, high-temperature thrust estimation is less relevant. Therefore, CNT_{High} is assumed to be equal to CNT if the high-temperature coefficients are not available for the considered aircraft type and thrust rating (typically Idle).

B4.2 PISTON AND (SOME) TURBOPROP ENGINE-POWERED AIRCRAFT

$$CNT = \left(326 \cdot \eta \cdot P_p / V_T\right) / \delta \qquad \text{(B-12)}$$

where

η	is the propeller efficiency associated to the Thrust Rating, e.g. "MaxTake-off" or "MaxClimb" – this is obtained from the ANP "Propeller_engine_coefficients" table
V_T	is the True Airspeed, kt
P_p	is the propulsive power associated to the Thrust Rating, e.g. "MaxTake-off" or "MaxClimb" – this is obtained from the ANP "Propeller_engine_coefficients" table

During the ground roll in this equation, the minimum value of V_T is assumed to be the initial climb speed.

B4.3 MINIMUM CLIMB THRUST (DEEP THRUST CUTBACK)

In normal operation, the engine thrust is reduced to the maximum climb thrust setting. Unlike the take-off thrust, climb thrust can be sustained indefinitely. The rated maximum climb thrust level is determined as described in section B4.1 using the manufacturer-supplied maximum climb 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 to an amount determined by the performance of the aeroplane and the number of engines.

The "Minimum Reduced-thrust" level is defined by safety requirements with one engine inoperative that specify a minimum climb gradient. The thrust level calculated is then applied with all engines operating to determine the actual climb gradient. The "Minimum Reduced-thrust" level does not apply to singled engine aeroplanes.

$$CNT_{engineout} = \frac{(W/\delta)}{(N-1)} \times \left[\frac{sin\left(atan\left(0.01 \cdot G'\right)\right)}{K} + \frac{R}{\cos \varepsilon}\right] \qquad \text{(B-13)}$$

where:

W — is the aeroplane take-off weight (lb), available in the ANP *Default Weight* table for each stage length

N — is the number of engines supplying thrust. This information is available in the ANP *Aircraft* table

δ — is the pressure ratio at the aircraft altitude

G' — is the engine-out percentage climb gradient:

= 1.2% for a 2-engine aeroplane

= 1.5% for a 3-engine aeroplane

= 1.7% for a 4-engine aeroplane

In the special case of aeroplanes with automatic thrust restoration systems[35] = 0%

K — is a speed-dependent constant

K = 1.01 for $V_C \leq 200$ kt,

K = 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)[36].

R — is the drag-over-lift coefficient associated to the specific Flap_ID used on the **Climb** step. The value of this coefficient is obtained from the ANP *Aerodynamic Coefficients* table. Note, the effects of

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[35] Note that the ANP database does not include the field identifying aeroplanes with automatic thrust restoration systems. Only five aeroplane types have been supplied with such systems and all have been out of production for many years.

[36] When applying Equation B-13, the *R* coefficient should normally be adjusted to account for the increased drag associated with a failed engine. However, the *R* coefficient is not adjusted, and thus the thrust calculated by equation B-13 will be lower than in practice.

asymmetric thrust on aeroplane drag are ignored.

ε Bank angle, radians

B4.4 VERTICAL PROFILES OF AIR TEMPERATURE, PRESSURE, DENSITY AND WIND SPEED

For the purposes of this guidance, the variations of temperature, pressure and density, with height above mean sea level, are taken to be those of the International Standard Atmosphere [ref. 1]. The methodologies described below have been validated for aerodrome altitudes up to 6,000 ft above sea level and for air temperatures up to 43°C (109°F).

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.

B5 THE EFFECT OF TURNS

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.

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.

The construction of the ground track is described in Chapter 3, 3.6.6. 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.

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:

$$\varepsilon = \tan^{-1}\left\{\frac{2.85 \cdot V^2}{r.g}\right\} \qquad \text{(B-14)}$$

where V is the ground speed, kt

r is the turn radius, ft

g is the acceleration due to gravity, ft/s2.

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.

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 (B-14) 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.

But if the provisional segment crosses one or more starts or ends of turns (where ε changes)[37], the flight parameters at the first such point are estimated by interpolation (see Chapter 3, 3.6.1), 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.

B6 DEPARTURE PROCEDURAL STEP PROFILES

B6.1.1 TAKE-OFF

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.

For the purpose of this document, 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 B-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.

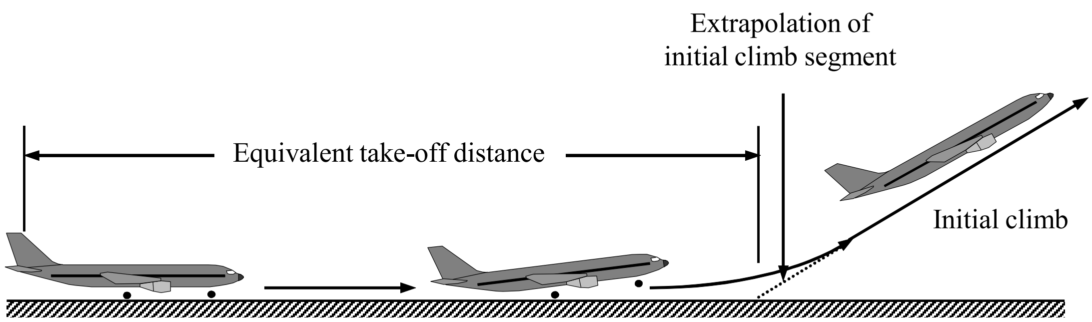


Figure B-1: Equivalent take-off distance

A **Take-off** step produces <u>two profile points</u>:

[37] 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 B-14.

- *Point1*, which corresponds to the brake release point (start-of-roll)
- *Point2*, which corresponds to the equivalent ground-roll distance

Point1

Point1_Distance = 0

Point1_Height Above Airfield = 0

Point1_TAS = 0[38]

Point1_Corrected net thrust is calculated using either equations and method described in section B4.1 (jet and certain turboprop) or Eq. B-12. (piston and some turboprop), with the engine coefficients corresponding to the specific Thrust Rating on the step (normally, "MaxTake-off")

- In the case of equations and method described in section B4.1, V_C = 0 and h = pressure altitude for the aircraft is equal to the airfield height above mean sea-level, $Alt = E_{apt}$
- In the case of Eq. B-12 (some turboprops), V_T cannot be set to zero (even though *Point1_TAS* = 0). It is actually assumed to be the True Airspeed at the take-off rotation point (*Point2* – see below).

Point2

Point2_Height Above Airfield = 0

Point2_TAS is calculated using the following equation for Calibrated Airspeed V_{CTO} (which is further converted into *Point2_TAS* using Eq. B-7)

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

where:

V_{CTO} Initial climb speed (kt)

C is the take-off speed coefficient obtained from the ANP "Aerodynamic Coefficients" table, for the particular take-off Flap_ID used on the **Take-off** step (kt/lb)

W is the aeroplane take-off weight (lb)

Point2_Corrected net thrust is calculated using either the equations and method described in section B4.1 (jet and certain turboprop) or Eq. B-12. (piston and some turboprop), with the engine coefficients corresponding to the specific Thrust Rating on the step (e.g. "MaxTake-off" or "MaxClimb")

- In the case of equations and method described in section B4.1, $V_C = V_{CTO}$ (calculated above) and h = pressure altitude for aircraft $Alt = E_{apt}$
- In the case of Eq. B-12, V_T = *Point2_TAS*

Point2 _Distance

This is the equivalent take-off ground-roll distance s_{TO8} in feet, determined by

$$S_{TO8} = \frac{B_8 \cdot \theta \cdot (W/\delta)^2}{N \cdot (F_n/\delta)} \qquad \text{(B-16)}$$

[38] The take-off segments in the ANP database do not provide any start speed information, implicitly meaning that it is zero (brake release point) for the performance calculation. In practice, the speed value must be non-zero for the acoustic calculation in order to avoid problems with duration dependent noise metrics. In addition, modellers might prefer to introduce more flexibility, with the possibility to specify a non-zero – e.g. taxiing speed instead, depending on the local situation.

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/lb) – this coefficient is obtained from the ANP "Aerodynamic Coefficients" table, for the specific take-off Flap_ID used on the **Take-off** step
W	is the aeroplane take-off weight (lb), available in the ANP *Default Weight* table for each stage length
N	is the number of engines supplying thrust. This information is available in the ANP *Aircraft* table
θ	is the temperature ratio at the airport elevation E_{apt} (Eq. B-3)
δ	is the pressure ratio at the airport elevation E_{apt} (Eq. B-4)
F_N/δ	is the Corrected Net Thrust (CNT) calculated at *Point2* (i.e. *Point2_ Corrected net thrust)*

For headwind other than the default 8 kt, the take-off ground-roll distance s_{TO8} is corrected by using:

$$S_{TOw} = S_{TO8}\frac{(V_C-w)^2}{(V_C-8)^2} \qquad \text{(B-17)}$$

where:

S_{TOw}	is the ground-roll distance (ft) corrected for headwind *w*
w	is the headwind (kt)
V_C	is the Calibrated Airspeed at ***Point2*** (i.e. V_{CTO}) (kt)
s_{TO8}	is the take-off ground-roll distance for the default 8 kt headwind (ft)

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

$$S_{TOG} = S_{TOw}\cdot\frac{a}{(a-g\cdot G_R)} \qquad \text{(B-18)}$$

where:

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

a — is the average acceleration (ft/s^2) along the runway, equal to:

$$a = \left(V_C/\sqrt{\sigma}\right)^2/(2\cdot s_{TOw})$$

where

- V_C is the Calibrated Airspeed (kt) at ***Point2*** (i.e. V_{CTO})
- σ is the air density ratio at the airport elevation E_{apt} (Eq. B-5)
- S_{Tow} is the ground-roll distance (ft) corrected for headwind

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

$$G_R = \frac{(Elev\_2-Elev\_1)}{L}$$

where

- Elev_2 is the elevation (ft) of Runway_end #2
- Elev_1 is the elevation (ft) of Runway_end #1
- L is the length (ft) of the runway

g is the standard gravitational acceleration: 32.174 ft/s^2

B6.1.2 CLIMB

A **Climb** step is flown at constant Calibrated Airspeed. It generally produces a single profile point *Point2*, corresponding to the end of the step. The initial height (AFE), airspeed and corrected net thrust at *Point1* are given from the previous step. The final height (AFE) (at *Point2*) is an input parameter of the **Climb** step.

Point2_Height = input "End_Point_Altitude" value.

Point2_TAS is calculated as follows:

$$Point2\_TAS = Point1\_TAS * \frac{\sqrt{\sigma_{Po\,int\,1}}}{\sqrt{\sigma_{Po\,int\,2}}} \qquad \text{(B-19)}$$

Note that climb at constant CAS results in an increase in TAS at *Point2*, due to changing air density. This is taken account using factor *K* in Eq. B-13.

Where:

*Point1*_TAS True Airspeed (kt) at *Point1*, obtained from the previous step

$\sigma_{Po\,int\,1}$ is the air density ratio at the aircraft altitude corresponding to *Point1* (i.e. E_{apt} + *Point1_Height*); *Point1_Height* is obtained from the previous step

$\sigma_{Po\,int\,2}$ is the air density ratio at the aircraft altitude corresponding to *Point2* (i.e. E_{apt} + *Point2_Height*)

Point2_Corrected net thrust is calculated using either the equations and method described in Section B4.1 (jet and certain turboprop) or Eq. B-12. provided in Section B4.2 (piston and some turboprop), with the engine coefficients corresponding to the specific Thrust Rating on the step (for example: "MaxTake-off" or "MaxClimb"). If a "Minimum Reduced-thrust" is used on the step, then Eq. B-13 provided in Section B4.3 must be used.

In the case of equations and method described in Section B4.1,

$$V_C = Point\,2\_TAS * \sqrt{\sigma_{Point\,2}} \qquad \text{(B-20)}$$

where:

V_C is the calibrated airspeed, σ_{Point2} is the air density ratio at the aircraft altitude corresponding to *Point2* (i.e. *Alt* = E_{apt} + *Point2_Height*).

In the case of Eq. B-9 provided in Section B4.1, V_T = *Point2_TAS.*

In the case of Eq. B-13 provided in Section B4.3, the pressure ratio δ should be calculated for the altitude at the end of the step (e.g. at *Point2*).

The remaining parameter to be calculated is the distance at *Point2*. It is done by calculating the average climb angle first:

$$\gamma = arcsin\left(K \cdot \left[N \cdot \frac{\overline{CNT}}{\overline{W/\delta}} - \frac{R}{\cos\varepsilon}\right]\right) \qquad \text{(rad)} \qquad \text{(B-21)}$$

where:

K	is a speed-dependent constant K = 1.01 for $V_C \leq 200$ kt, (V_C is the climb segment-specific CAS) K = 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 Airspeed increases as air density diminishes with height). It avoids the otherwise need for an iterative solution to calculate the segment length and end altitude, instead approximating the effect into a K factor.
N	is the number of engines supplying thrust. This information is available in the ANP *Aircraft* table
$\overline{W/\delta}$	is the aircraft take-off weight (lb), available in the ANP *Default Weight* table for each stage length, divided by the pressure ratio δ at the aircraft mid-point altitude on the step, i.e. $Alt = E_{Apt} + \frac{(Point\,1\_Height + Point\,2\_Height)}{2}$
$\overline{CNT}$	is the Corrected Net Thrust of the aircraft when being located at mid-step, i.e. at the altitude $Alt = E_{Apt} + \frac{(Point\,1\_Height + Point\,2\_Height)}{2}$ $\overline{CNT}$ is calculated using either equations and method described in Section B4.1 (jet and certain turboprop) or Eq. B-12. (piston and some turboprop), with the engine coefficients corresponding to the specific Thrust Rating on the step ("MaxTake-off" or "MaxClimb") In the case of equations and method described in Section B4.1, $V_C = Point\,2\_TAS * \sqrt{\sigma_{Point\,2}}$ where: σ_{Point2} is the air density ratio at the aircraft altitude corresponding to *Point2* (i.e. *Alt* = E_{apt} + *Point2_Height*) h = pressure altitude (Eq. B-6) for the aircraft altitude *Alt* provided above (at mid-step) In the case of Eq. B-12, $V_T = \sqrt{0.5 * ((Point\,2\_TAS)^2 + (Point\,1\_TAS)^2)}$
R	is the drag-over-lift coefficient associated to the specific take-off Flap_ID used on the **Climb** step. The value of this coefficient is obtained from the ANP *Aerodynamic Coefficients* table.
ε	Bank angle, radians

The above climb angle γ is corrected for headwind *w* other than an 8-knot headwind, using:

$$\gamma_w = \gamma \cdot \frac{(V_C - 8)}{(V_C - w)} \quad \text{(rad)} \qquad \text{(B-22)}$$

where:

γ_w	is the average climb angle corrected for headwind (rad)
w	is the actual headwind (kt)
V_C	is the Calibrated Airspeed on the **Climb** step (kt)
	$V_C = Point\ 2\_TAS * \sqrt{\sigma_{Point\ 2}}$

Finally, *Point2_Distance* is calculated using:

$$Point2\_Distance = Point1\_Distance + \frac{(Point2\_Height - Point1\_Height)}{\tan \gamma_w} \qquad \text{(B-23)}$$

If there is a change in the Thrust Rating between the previous step and the current **Climb** step, as in the case of a power cutback from "MaxTake-off" to "MaxClimb" or "MaxTake-off" to "Minimum Reduced-thrust" (also applicable to the case of a thrust increase from "Minimum Reduced-thrust" to "MaxClimb"), then an additional intermediate profile point P_i is created and inserted at the start of the current **Climb** step to model the transition step from the previous to the current Thrust Ratings. The method to create this intermediate profile point P_i is described in

B6.1.6 Change of Thrust Rating.

B6.1.3 ACCELERATE

An **Accelerate** step consists of making the aircraft accelerate to a given target speed (CAS) whilst continuing to climb at a certain Rate of Climb (ROC) or Energy Share Factor (ESF).

For a large number of aircraft types available in the ANP database, the **Accelerate** steps of the default procedural-step profiles include pre-calculated ROC values. These are provided by the aircraft manufacturers as a function of the specific default take-off weights (Stage Lengths), flap settings and engine power settings. Additionally, these pre-calculated ROC values are only valid under ISA conditions and for an airport at zero MSL. These ROC values reflect an underlying Energy Share Factor (ESF) assumption defined by the manufacturers, depending on the aircraft types.

However, it should be noted that more recently delivered ANP datasets directly provide the ESF assumption associated to each **Accelerate** step, in replacement, or in complement, of the ROC values. This parameter specifies the percentage of the available thrust which is allocated to accelerating, whilst the remainder is dedicated to climbing. The ROC-values are altitude and atmosphere conditions dependent whereas ESF values adapt to changing airport elevations and atmosphere conditions. In contrast, ESF values are non-dimensional and thus adapt to changing airport elevations and/or atmosphere conditions. Consequently, where both ROC and ESF values are provided in ANP datasets, it is preferable to use ESF values.

The availability of this information makes the computation of fixed-point profiles from procedural-step profiles more flexible and more representative of different aircraft weights, aerodynamic configurations and engine power settings, along with local (non-ISA) atmospheric conditions and actual airport elevation.

ROC and/or ESF parameters intervene in the calculation of an average climb gradient, which is further specified in this section.

An **Accelerate** step generally produces a single profile point *Point2*, which corresponds to the end of the step. The start AFE (Height), True Airspeed and CNT values at *Point1* are those at the end of the previous step.

Since they are interdependent, the output height above airfield elevation, True Airspeed, CNT and ground Distance at *Point2* must be calculated by iteration. Height at *Point2* is estimated initially and then recalculated repeatedly using Eq. B-24 and Eq. B-26 below, until the difference between successive estimates of height at *Point2* is less than (or equal to) one foot.

The initial estimate is *Point2_Height = Point1_Height + 250 feet*.

The horizontal distance covered by the **Accelerate** step is estimated as:

$$s_{seg} = \frac{0.95 \cdot k^2 \cdot (V_{T2}^2 - V_{T1}^2)}{2(a_{max} - G \cdot g)} \qquad \text{(B-24)}$$

where:

0.95	is a factor to account for effect of 8 kt headwind when climbing at 160 kt
k	is a constant to convert knots to ft/sec = 1.68781, correcting for TAS being defined in knots, whereas the output distance unit is in

feet

V_{T2} calculated True Airspeed (kt) at *Point2* for the current iteration of altitude *Alt_P2*:

$$V_{T2} = V_{C2}/\sqrt{\sigma_2}$$

where

V_{C2} is the Calibrated Airspeed at the end of the **Accelerate** step, i.e. the input "End Point CAS" value obtained from the Departure Procedural Steps table

σ_2 = air density ratio at the estimated altitude *Alt_P2*

V_{T1} True Airspeed (kt) at Point1, i.e. *Point1_TAS*

a_{max} is the maximum acceleration in level flight (ft/s^2), i.e.

$$a_{max} = g\left(N \cdot \overline{CNT}/(\overline{W/\delta}) - R/\cos\varepsilon\right)$$

where:

N = number of engines delivering thrust (see ANP "Aircraft" table)

$\overline{CNT}$ is the Corrected Net Thrust of the aircraft when being located at mid-step for the current iteration, i.e. at the altitude

$$Alt = \frac{\left(E_{Apt} + Point\,1\_Height + Alt\_P2\right)}{2}$$

$\overline{CNT}$ is calculated using either equations and method described in Section B4.1 (jet and certain turboprop) or Eq. B-12. provided in Section B4.2 (piston and some turboprop), with the engine coefficients corresponding to the specific Thrust Rating on the step ("MaxTake-off" or "MaxClimb").

In the case of equations and method described in Section B4.1,

$$\overline{V_C} = \sqrt{\frac{V_{T2}^2 + V_{T1}^2}{2}} * \sqrt{\sigma_{Alt}}$$

where σ_{Alt} is the air density ratio at the aircraft mid-step altitude *Alt* calculated above

h = pressure altitude (Eq. B-6) for the aircraft altitude *Alt* provided above (at mid-step)

In the case of Eq. B-12 provided in Section B4.2 (piston and some turboprop)

$$\overline{V_T} = \sqrt{\frac{V_{T2}^2 + V_{T1}^2}{2}}$$

$\overline{W/\delta}$ is the aircraft take-off weight (lb), available in the ANP *Default Weight* table for each stage length, divided by the pressure ratio δ at the aircraft mid-point altitude *Alt* defined above

R is the drag-over-lift coefficient associated to the specific take-off Flap_ID used on the **Accelerate** step. This coefficient is obtained from the ANP *Aerodynamic Coefficients* table.

ε is the bank angle, radians

g is the gravitational acceleration (= 32.174 ft/s^2)

G — is the average climb gradient $\approx \frac{ROC}{60 \cdot k \cdot \overline{V_T}}$

where:

ROC is the input "Rate of Climb" value (ft/min) obtained from the Departure Procedural Steps table and:

$$\overline{V_T} = \sqrt{\frac{V_{T2}^2 + V_{T1}^2}{2}}$$

k = 1.68781

If, instead of a ROC value, the **Accelerate** step provides an ESF value ("Accel Percentage"), ***G*** is calculated as follows:

$$G = \frac{1}{g} a_{max} \times (1 - Accel\ percentage/100) \qquad \text{(B-25)}$$

where a_{max} is the maximum acceleration in level flight.

Using the estimated S_{seg}, the end-altitude Alt_P2' is then re-calculated using:

$$Alt\_P2' = E_{Apt} + Point1\_Height + S_{seg} * G/0.95 \qquad \text{(B-26)}$$

As long as the error | $Alt\_P2' - Alt\_P2$ | is strictly greater than 1 feet, the above steps using Eq. B-24 and Eq. B-26 are repeated using the current iteration values at *Point2* of altitude, True Airspeed and corrected net thrust per engine. When the difference between Alt_P2' and Alt_P2 is less than (or equal to) 1 foot, the iteration process is stopped and the **Accelerate** step is defined by the values corresponding to Alt_P2'.

The True Airspeed at *Point2* is:

$$Point2\_TAS = EndPointCAS/\sqrt{\sigma_{Point2}} \qquad \text{(B-27)}$$

where:

End Point CAS — Is the Calibrated Airspeed at the end of the acceleration step, i.e. the input "End Point CAS" value obtained from the Departure Procedural Steps table

σ_{Point2} — is the air density ratio at the final aircraft altitude of *Point2* (i.e. *Alt_P2)*

Note:

If during the iteration process (a_{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 $G = a_{max}/g - 0.02$, in effect reducing the desired climb rate in order to maintain acceptable acceleration. If $G < 0.01$ it should be concluded there is not enough thrust to achieve the acceleration and climb specified; the calculation should be terminated, and the procedure steps revised.

The horizontal distance of the **Accelerate** step is finally corrected for headwind *w* by using:

$$S_{seg_w} = S_{seg} \cdot \frac{(V_T - w)}{(V_T - 8)} \qquad \text{(B-28)}$$

where V_T is the interpolated True Airspeed at midpoint of the step, i.e.

$$V_T = \sqrt{\frac{(Point1\_TAS)^2 + (Point2\_TAS)^2}{2}}$$

and $Point2\_Distance = Point1\_Distance + S_{seg_w}$

If there is a change in the Thrust Rating between the previous step and the current **Accelerate** step, like for instance in the case of the power cutback from "MaxTake-off" to "MaxClimb", then an additional intermediate profile point P_i is created and inserted at the start of the current **Accelerate** step to model the transition between the previous and the current Thrust Ratings. The method to create this intermediate profile point P_i is described in

B6.1.6 Change of Thrust Rating.

As described above, the end-point altitude of an **Accelerate** step is calculated iteratively based on ESF assumption, target speed, aircraft mass, airport elevation, atmospheric conditions, and engine rating. In some cases, this calculated altitude may be higher than the input (end-point) altitude of subsequent **Climb** steps. Therefore, any subsequent **Climb** step with an input altitude lower than the end point altitude of the current **Accelerate** step shall be skipped in the calculations.

B6.1.4 LEVEL

A **Level** step type is flown at constant altitude and speed, which results in the thrust required to be reduced or "adapted" to the level flight constant speed parameters. This step produces a *Point2* at the end of the step, which has the same altitude and speed (TAS) values as *Point1*, the endpoint calculated for the previous step, i.e.

$$Point2\_TAS = Point1\_TAS$$

$$Point2\_Height = Point1\_Height$$

The distance value to be assigned to *Point2* is based on the distance *L* defined as an input of the **Level** step:

$$Point2\_Distance = Point1\_Distance + L \qquad \text{(B-29)}$$

Point2_Corrected net thrust is calculated by rearranging Eq. B-21 for the case where the climb angle gamma is zero, giving:

$$Point2\_Corrected\ net\ thrust = \frac{R}{N.\cos\varepsilon}.W/\delta \qquad \text{(B-30)}$$

where:

N — is the number of engines supplying thrust. This information is available in the ANP *Aircraft* table

W/δ — is the aircraft take-off weight (lb), available in the ANP *Default Weight* table for each stage length, divided by the pressure ratio δ at the aircraft **Level** step altitude, i.e.

$$Alt = E_{Apt} + Point2\_Height$$

R — is the drag-over-lift coefficient associated to the specific take-off Flap_ID used on the **Level** step. The value of this R coefficient is obtained from the ANP *Aerodynamic Coefficients* table.

ε — is the bank angle, radians

Since the thrust is adapted – e.g. reduced compared with a previous **Climb** or **Accelerate** step type -, a **Level** step type must always include a transition segment (e.g. an intermediate point P_i) at its start, to be calculated according to the method described in

B6.1.6 Change of Thrust Rating.

B6.1.5 LEVEL-ACCELERATE

A **Level-Accelerate** step type is similar to the **Accelerate** step type, except that the Rate of Climb (ROC) is zero. Mathematically, this step type may be implemented using an **Accelerate** step type with a zero ROC value or a 100% Energy Share Factor.

The maximum acceleration in a **Level-Accelerate** step (ft/s^2) is:

$$a_{max} = g\left(N \cdot \overline{CNT}/(\mathrm{W}/\delta) - R/\cos\varepsilon\right) \quad \text{(B-31)}$$

where:

N = number of engines delivering thrust (see ANP "Aircraft" table)

$\overline{CNT}$ is the Corrected Net Thrust of the aircraft when being located at the altitude of the Level-Accelerate step, i.e:

$Alt = \left(E_{Apt} + Point1\_Height\right)$, with ***Point1*** being the endpoint of the previous step,

$\overline{CNT}$ is calculated using either the equations and method described in Section B4.1 (jet and certain turboprop) or Eq. B-12. provided in Section B4.2, with the engine coefficients corresponding to the specific Thrust Rating on the step ("MaxTake-off" or "MaxClimb").

In the case of equations and method described in Section B4.1, the calibrated airspeed at mid-step is calculated as:

$$V_C = \sqrt{\frac{(Point1\_TAS)^2 + (Point2\_TAS)^2}{2}} * \sqrt{\sigma_{Alt}}$$

where σ_{Alt} is the air density ratio at the altitude of the Level-Accelerate step *Alt* calculated above, and $Point2_{TAS} = \frac{EndPointCAS}{\sqrt{\sigma_{Alt}}}$

The pressure altitude is calculated (with Eq. B-6) for the Level- Accelerate step Alt provided above

In the case of Eq. B-12 provided in Section B4.2 (piston and some turboprop),

$$V_T = \sqrt{\frac{(Point1\_TAS)^2 + (Point2\_TAS)^2}{2}}$$

W/δ is the aircraft take-off weight (lb), available in the ANP *Default Weight* table for each stage length, divided by the pressure ratio δ at the altitude *Alt* defined above

R is the drag-over-lift coefficient associated with the specific take-off Flap_ID used on the **Climb** step. This coefficient is obtained from the ANP *Aerodynamic Coefficients* table.

ε is the bank angle, radians

g is the gravitational acceleration (= 32.174 ft/s^2)

Since air density does not change during a **Level-Accelerate** step type, iteration is not required and the segment horizontal distance is directly calculated using:

$$s_{seg} = \frac{0.95 \cdot k^2 \cdot (V_{T2}^2 - V_{T1}^2)}{2(a_{max})} \quad \text{(B-32)}$$

The horizontal distance of the **Level-Accelerate** step is finally corrected for headwind *w* by using:

$$S_{seg_w} = S_{seg} \cdot \frac{(V_T - w)}{(V_T - 8)} \quad \text{(B-33)}$$

where V_T is the interpolated True Airspeed at midpoint of the step, i.e.

$V_T = \sqrt{\frac{(Point1\_TAS)^2 + (Point2\_TAS)^2}{2}}$

and $Point2\_Distance = Point1\_Distance + S_{seg_w}$

The potential inclusion of a transition segment (e.g. an intermediate point P_i) at the start of a **Level-Accelerate** step follows the same rules as for an **Accelerate** step.

B6.1.6 CHANGE OF THRUST RATING

If there are any changes in the Thrust Rating between the previous step and the current step, typically from "MaxTake-off" to "MaxClimb", then a short segment, 1,000 ft in length, is inserted at the start of the step, in the form of an intermediate point P_i. The characteristics of this segment are interpolated based on the same flight path gradient of that of the overall segment, i.e. the additional segment has the same climb gradient as that for the whole segment, after the thrust change. This is illustrated in **Figure B-2** for a constant speed climb segment. If the segment is an acceleration segment, then speed is interpolated accordingly for the 1,000 ft transition segment.

Note that the additional segment added takes the form of the following segment, i.e. it can be a **Climb** step at constant speed, an **Accelerate** step, or a **Level-Accelerate** step. However, as explained in the previous paragraph the parameters (i.e. altitude, speed and corrected net thrust) are calculated through interpolation from the current step.

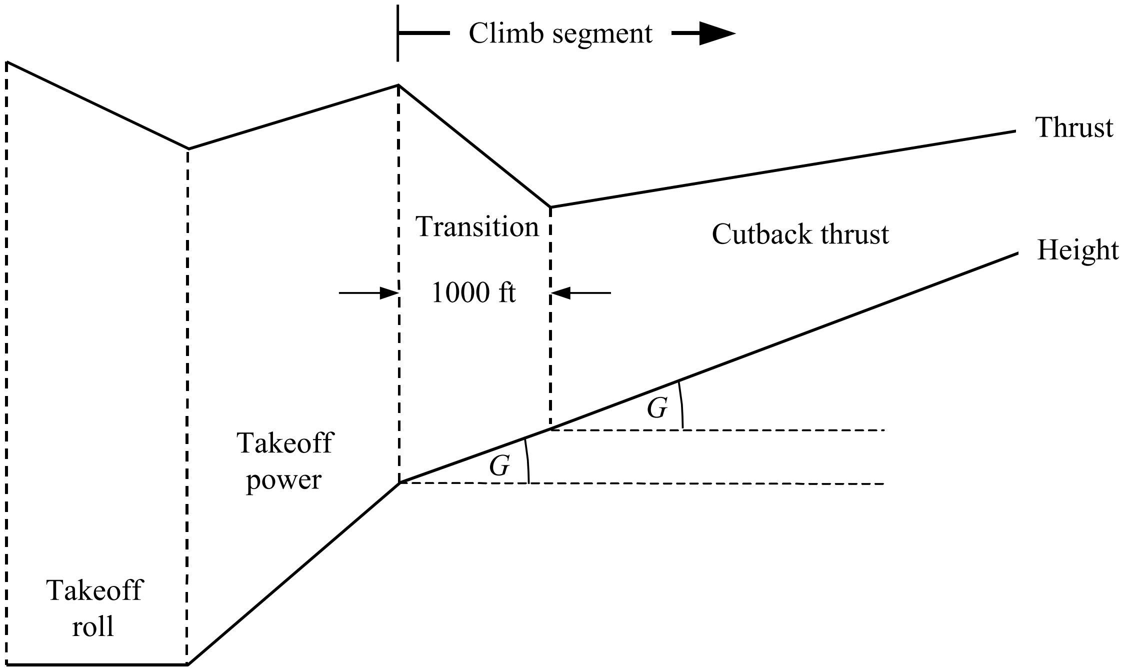


Figure B-2: Constant speed Climb step or Accelerate step with cutback (illustration – not to scale)

The horizontal (ground) length of this additional sub-segment is 1,000 ft (if the original horizontal distance is less than 2,000 ft, one half of the segment distance is used). The following characteristics apply:

$$P_i\_Distance = min(L/2, 1000ft) + Point\ 1\_Distance \qquad \text{(B-34)}$$

where:

L denotes the horizontal (ground) length of the current step

i.e. $L = Point2\_Distance - Point1\_Distance$

Next calculate *P_i_Height*:

$$P_i\_Height \ = \ Point1\_Height + tan\,\gamma_w * (P_i\_Distance - Point1\_Distance) \qquad \text{(B-35)}$$

where, γ_w is the gradient of the current step after thrust change. Note, for an **Accelerate** step the calculated gradient G must be corrected for headwind and converted to an angle when using equation (B-35).

The True Airspeed at P_i is calculated differently depending on the current step type.

If the current step type is a **Climb** step:

$$P_{i_{TAS}} = Point1\_TAS.\frac{\sqrt{\sigma_{Point1}}}{\sqrt{\sigma_{P_i}}} \qquad \text{(B-36)}$$

If the current step type is a **Level** step:

$$P_{i_{TAS}} = Point1\_TAS$$

If the current step type is an **Accelerate** step or a **Level-Accelerate** step:

$$P_{i_{TAS}} = \sqrt{(Point1\_TAS)^2 + \left(\frac{(Point2\_TAS)^2 - (Point1\_TAS)^2}{Point2\_Distance - Point1\_Distance}\right) \times (P_i\_Distance - Point1\_Distance)}$$

P_i_Corrected net thrust is calculated using either the equations and method described in Section B4.1 (jet and certain turboprop) or Eq. B-12. provided in Section B4.2, with the engine (jet or propeller) coefficients corresponding to the specific Thrust Rating on the current step (whereas the *Point1_Correted net Thrust* value has been calculated as part of the previous step, so for the Thrust Rating associated to that previous step). If a "Minimum Reduced-thrust" is used on the current step, then Eq. B-13 provided in Section B4.3 should be used to calculate *P_i_Corrected net thrust*.

In the case of equations and method described in Section B4.1,

$$V_C = P_i\_TAS * \sqrt{\sigma_{P_i}} \qquad \text{(B-37)}$$

where:

σ_{Pi} is the air density ratio at the aircraft pressure altitude associated to the altitude *Alt* of point P_i (i.e. $Alt = E_{apt} + P_i\_Height$) using Eq. B-6.

In the case of Eq. B-12 provided in Section B4.2 (piston and some turboprop):

$$V_T = P_i\_TAS \qquad \text{(B-38)}$$

In the case of Eq. B-13 provided in Section B4.3, the pressure ratio δ should be calculated at the altitude *Alt* of point P_i (i.e. $= E_{apt} + P_i\_Height$).

B7 APPROACH PROCEDURAL STEP PROFILES

B7.1.1 DESCEND AND DESCEND-DECEL

The justification for regrouping **Descend** and **Descend-Decel** steps in this same section is that the associated calculations and specific treatments are essentially identical, except for the calculation of the magnitude of the thrust.

A **Descend** step is assumed to be flown at a fixed (user-defined) descent angle and constant (user-defined) Calibrated Airspeed (CAS) for the purposes of calculating thrust. The thrust is calculated (adapted) to achieve the descent angle at the specified flap angle and at constant CAS. Its magnitude depends in particular on the aircraft weight and the flap setting along the step, which is also an input parameter. Several aircraft in the ANP database use the **Descend** step types where speed decreases between each **Descend** step. In order to avoid discontinuities in speed values between these **Descend** steps, it should be assumed that speed decreases linearly along each descend segment, but the deceleration component is ignored when calculating thrust. This has the consequence of artificially increasing thrust values, and also making the thrust values less sensitive to the segment speed input parameters. Consequently, the only effect of speed on thrust is indirectly via flap setting[39] and the calculated corrected net thrust is therefore conservative.

A **Descend-Decel** step is also flown at a fixed (user-defined) descent angle, but this time with a deceleration along the step. The associated thrust is calculated (adapted) to accord with the deceleration in question. Again, its magnitude also depends on the aircraft weight and the flap setting along the step, which is also an input parameter. The amount of deceleration is derived from the input speed on the current step and the input speed on the following step.

Depending on the cases described below, a **Descend** or **Descend-Decel** step produces one or two profile points (with associated parameters).

Case 1: the following step is of the same type as the current step (e.g. either a Descend or Descend-Decel type) and is flown with the same flap setting

In this case, the current step produces a single profile point *Point1*, corresponding to the start of the step. The final AFE (Height), True Airspeed (TAS) and CNT values at the end of the current step correspond to the first profile point produced by the following step.

Point1_Height = *Start_altitude* value provided in the ANP Approach Procedural Steps table for the current **Descend** or **Descend-Decel** step.

$$Point1\_TAS = StartCAS \;/\; \sqrt{\sigma_{Point1}} \qquad \text{(B-39)}$$

where:

Start CAS is the input value of the Calibrated Airspeed, obtained from the Approach Procedural Steps table.

σ_{Point1} is the air density ratio at the aircraft altitude corresponding to *Point1* (i.e. *Point1_Height*+ E_{apt}).

If the step is a **Descend** step, the thrust at *Point1* is calculated as follows

[39] As each flap setting has a specific speed range of use.

$$Point\ 1\_CNT = \frac{W/\delta_{Point1}}{N}\left(\frac{R}{\cos\varepsilon} - \frac{\sin\gamma}{1.03}\right) \qquad \text{(B-40)}$$

where:

W	is the aircraft approach weight (lb), which corresponds to 90% of the MLW (Max Landing Weight) available in the ANP "Aircraft" table
δ_{Point1}	is the pressure ratio at the aircraft altitude corresponding to *Point1* (i.e. *Point1_Height* + E_{apt})
N	is the number of engines supplying thrust. This information is available in the ANP "Aircraft" table
R	is the drag-over-lift coefficient corresponding to the input Flap_ID associated to the **Descend** step (obtained from the Approach Procedural Steps table). The value of the coefficient is obtained from the ANP "Aerodynamic Coefficients" table
γ	is the input descent angle (converted into radians), obtained from the Approach Procedural Steps table for the current **Descend** step, and is positive by convention
ε	Bank angle, in radians

The value of 1.03 in eq. B-40 is a constant that accounts for the effects thrust of descending into an 8-knot headwind and the deceleration inherent in descending at constant Calibrated Airspeed (True Airspeed increases as air density diminishes with height). It avoids the otherwise need for an iterative solution, instead approximating the effect into a constant.

If the step is a **Descend-Decel** step, the Thrust at *Point1* includes a deceleration term as follows:

$$Point\ 1\_CNT = \frac{W/\delta_{Point1}}{N}\left(\frac{R\cos\gamma}{\cos\varepsilon} - \sin\gamma + \frac{a}{g}\right) \qquad \text{(B-41)}$$

where:

a is the deceleration of the aircraft along the **Descend-Decel** step. It is calculated as follows:

$$a = \frac{k^2.\left(\left((\mathrm{Pt1}(NextSeg)_{TAS} - w)/(\cos\gamma)\right)^2 - \left((Point1_{TAS} - w)/(\cos\gamma)\right)^2\right)}{2\cdot(Point1\_Height - Pt1NextSeg)\_Height)/\sin\gamma}$$

where:

$Pt1(NextSeg)\_TAS$	is the profile point True Airspeed assigned to the first point of the following step
$Pt1(NextSeg)\_Height$	is the profile point height assigned to the first point of the following step
g	standard gravitational acceleration (= 32.174 ft/s^2)

w — is the headwind (kt)

γ — is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend-Decel** step, and is positive by convention

Point1_Distance is calculated using:

$$Point1_{Distance} = Pt1(NextSeg)_{Distance} - \left(\frac{Point1_{Height} - Pt1(NextSeg)_{Height}}{tan(\gamma)}\right) \quad \text{(B-42)}$$

where:

$Pt1(NextSeg)\_Distance$ — is the profile point distance assigned to the first point of the following **Descend** step

$Pt1(NextSeg)\_Height$ — is the profile point height assigned to the first point of the following **Descend** step

γ — is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend** or **Descend-Decel** step, and is positive by convention

Case 2: the step following the current Descend or Descend-Decel step is of different type and/or uses a different flap setting and/or descent angle

In this second, more general, case, the current step produces, in addition to *Point1,* a second profile point *Point2*, corresponding to the end of the **Descend** or **Descend-Decel** step.

This second point is located at a maximum distance of 1,000 ft ahead of the first point of the following step. The reason for adding this point is to reflect a rapid change in the thrust between the two consecutive steps.

$$Point2\_Distance = Pt1(NextSeg)\_Distance - Min\left(\frac{L}{2}, 1000ft\right) \quad \text{(B-43)}$$

where:

$Pt1(NextSeg)\_Distance$ — is the profile point distance assigned to the first point of the following step

L — is the travelled ground distance associated to the current **Descend** or **Descend-Decel** step

where:

$$L = \left(\frac{Point1\_Height - Pt1(NextSeg)\_Height}{tan(\gamma)}\right) \quad \text{(B-44)}$$

where:

$Pt1(NextSeg)\_Height$ — is the profile point height assigned to the first point of the following step

γ — is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend** step, and is positive by convention

$$Point2\_Height = Pt1(NextSeg)\_Height \ + \ Min\ (\frac{L}{2}, 1000ft).tan(\gamma) \qquad \text{(B-45)}$$

The True Airspeed at *Point2* is calculated as follows:

$$Point2\_TAS = \sqrt{(Pt1(NextSeg)\_TAS)^2 + \frac{Min(L/2, 1000ft))}{L} * ((Point1\_TAS)^2 - (Pt1(NextSeg)\_TAS)^2)} \qquad \text{(B-46)}$$

where:

$Pt1(NextSeg)\_TAS$	is the profile point True Airspeed assigned to the first point of the following step

The thrust on *Point2* is derived from the thrust previously calculated on *Point1* as follows:

$$Point2\_CNT = \frac{\delta_{Point1}}{\delta_{Point2}} \times Point1\_CNT \qquad \text{(B-47)}$$

where:

δ_{Point1}, δ_{Point2}	are the pressure ratios at the aircraft altitude corresponding respectively to *Point1* (i.e. *Point1_Height* + E_{apt}), and *Point2* (i.e. *Point2_Height*+ E_{apt})

CNT correction for non-standard headwind for DESCEND step type only

For wind speed that differs from the standard 8 kt headwind, the following adjustment is applied to the initially calculated thrust for the DESCEND step type only (equation B-40) (i.e. under standard 8 kt headwind conditions) at:

$$\Delta CNT_w = \frac{1.03 \cdot (W/\delta_{Point1}) \cdot sin(\gamma) \cdot (w-8)}{N \cdot Vc_1} \qquad \text{(B-48)}$$

where:

W	is the aircraft approach weight (lb), which corresponds to 90% of the MLW (Max Landing Weight) available in the ANP "Aircraft" table
δ_{Point1}	is the pressure ratio at the aircraft altitude corresponding to Point 1 (i.e. *Point1_Height* + E_{apt})
w	is the headwind value (kt)
γ	is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend** step, and is positive by convention
N	is the number of engines supplying thrust. This information is available in the ANP "Aircraft" table
Vc_1	is the Calibrated Airspeed (kt) at *Point 1* $Vc_1 = \text{Point 1}\_TAS.\sqrt{\sigma_{Point1}}$

Please note that the CNT correction for non-standard headwind is not applied to *Point2*, as the *Point2* thrust is derived from the *Point1* thrust (see equation B-47). The *Point2* thrust should be derived after the *Point1* thrust has been corrected for non-standard headwind.

B7.1.2 DESCEND-IDLE

A **Descend-Idle** step is flown at a fixed (user-defined) descent angle, using engine rated idle-thrust setting. Since the propulsive force associated to idle-thrust mode is very small (if the engines provide additional drag, it can even be negative), the aircraft is likely to decelerate over a **Descend-Idle** step (depending on the descent angle).

Depending on the cases described below, a **Descend-Idle** step produces one or two profile points (with associated parameters). The descent angle of the step is an input parameter.

The *Start Altitude* and *Start CAS* of the step are also input parameters, used "as is" under ISA-conditions. However, for non-ISA conditions, one of these input parameters is re-calculated (adjusted) according to the method and assumptions further described in this section.

Important note: The presence of a **Descend-Idle** step in the approach procedural step profile of a given aircraft type requires the availability, for that aircraft, of jet coefficients (in the ANP "Jet_Engine_Coefficient" table) for the "IdleApproach" thrust rating.

Case 1: the step following the current Descend-Idle is either a Descend-Idle or a Level-Idle step

In this case, the current **Descend-Idle** step produces a single profile point *Point1*, corresponding to the start of the step. The final AFE (Height), True Airspeed (TAS) and CNT values at the end of the current **Level** step correspond to the first point of the following **Descend-Idle** step.

Point1_Height = *Start_altitude* value provided in the ANP Approach Procedural Steps table for the current **Descend-Idle** step.

$$Point1\_TAS = StartCAS \ / \ \sqrt{\sigma_{Point1}} \qquad \text{(B-49)}$$

where:

Start CAS	is the input value of the Calibrated Airspeed, obtained from the Approach Procedural Steps table
σ_{Point1}	is the air density ratio at the aircraft altitude corresponding to *Point1* (i.e. *Point1_Height*+ E_{apt})

Important note: the input *Start CAS* value of the current **Descend** step should be greater than or equal to the input Start CAS value of the following **Descend-Idle** step.

$$Point1\_Distance = Pt1(NextSeg)\_Distance - \left(\frac{Point1\_Height - Pt1(NextSeg)\_Height}{tan(\gamma)}\right) \qquad \text{(B-50)}$$

where:

$Pt1(NextSeg)\_Distance$	is the profile point distance assigned to the first point of the following **Descend-Idle** step
$Pt1(NextSeg)\_Height$	is the profile point height assigned to the first point of the following **Descend-Idle** step
γ	is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend-**

Idle step, and is positive by convention

Point1_CNT is calculated using the equations and method described in Section B4.1 with the jet engine coefficients associated to the "IdleApproach" Thrust Rating.

Case 2: the step following the current Descend-Idle step is neither a Descend-Idle nor a Level-Idle step

In this second case, the current **Descend-Idle** step produces two profile points:

- *Point1*, corresponding to the start of the **Descend-Idle** step,
- *Point2*, corresponding to the end of the **Descend-Idle** step – this second point being located at a maximum distance of 1,000 ft ahead of the first point of the following step. The reason for adding this point is to reflect a rapid change in the thrust between the two consecutive steps.

Point1_Height = *Start_altitude* value provided in the ANP Approach Procedural Steps table for the current **Descend-Idle** step.

$$L = \left(\frac{Point1\_Height - Pt1(NextSeg)\_Height}{tan(\gamma)}\right) \quad \text{(B-51)}$$

$$Point1\_Distance = Pt1(NextSeg)\_Distance - L \quad \text{(B-52)}$$

$$Point2\_Distance = Pt1(NextSeg)\_Distance - Min\ (\tfrac{L}{2}, 1000ft) \quad \text{(B-53)}$$

where:

L	is the calculated horizontal distance of the current **Descend-Idle** step
$Pt1(NextSeg)\_Height$	is the profile point height assigned to the first point of the following step
$Pt1(NextSeg)\_Distance$	is the profile point distance assigned to the first point of the following step
γ	is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend-Idle** step, and is positive by convention

$$Point2\_Height = Pt1(NextSeg)\_Height\ +\ Min\ (\tfrac{L}{2}, 1000ft).tan(\gamma) \quad \text{(B-54)}$$

$$Point1\_TAS = StartCAS\ /\ \sqrt{\sigma_{Point1}} \quad \text{(B-55)}$$

$$Point2\_TAS = \sqrt{(Pt1(NextSeg)\_TAS)^2 + \frac{Min\left(\frac{L}{2}, 1000ft\right)}{L} * ((Point1\_TAS)^2 - (Pt1(NextSeg)\_TAS)^2)} \quad \text{(B-56)}$$

where:

Start CAS	is the input value of the Calibrated Airspeed, obtained from the Approach Procedural Steps table for the current **Descend-Idle** step
σ_{Point1}	is the air density ratio at the aircraft altitude corresponding

	to *Point1* (i.e. *Point1_Height*+ E_{apt})
$Pt1(NextSeg)\_TAS$	is the True Airspeed at the first point of the following step
L	is the calculated horizontal distance of the current **Descend-Idle** step

Point1_CNT and *Point2_CNT* are calculated using equations and method described in Section B4.1 with the jet engine coefficients associated to the "IdleApproach" Thrust Rating.

Start Altitude or Start TAS adjustment for non-ISA conditions

The input *Start Altitude* and *Start CAS* values of the Default Approach Procedural Steps table for the current **Descend-Idle** step are provided for ISA reference conditions at a sea-level airport. The resulting deceleration (for the given sea-level ISA conditions) is then assumed to remain unchanged even under non-sea level, non-ISA conditions. Other step parameters have therefore to be adjusted for consistency purpose under these conditions.

Deceleration over the **Descend-Idle** step for ISA conditions and airport at sea level is calculated as:

$$Decel_{ISA} = \frac{\left(\left((\mathrm{Pt1(NextSeg)\_TAS_{ISA}})^2 - w^2 \cdot sin^2(\gamma)\right)^{1/2} - w \cdot cos(\gamma)\right)^2 - \left(\left((\mathrm{Point1\_TAS_{ISA}})^2 - w^2 \cdot sin^2(\gamma)\right)^{1/2} - w \cdot cos(\gamma)\right)^2}{2 \cdot S_D} \tag{B-57}$$

where:

$Decel_{ISA}$	is the deceleration over the current **Descend-Idle** step under ISA conditions (feet/s^2)
$Pt1(NextSeg)\_TAS_{ISA}$	is the True Airspeed (in feet/s) at the first point of the following step under ISA conditions. It is calculated as follows: $Pt1(NextSeg)\_TAS_{ISA} = k \cdot \left(\frac{Pt1(NextSeg)\_Start\_CAS}{\sqrt{\sigma_{Pt1(NextSeg)_{ISA}}}}\right)$ $\sigma_{Pt1(NextSeg)_{ISA}}$ is the air density ratio at the first point of the following step, under ISA conditions
$Point1\_TAS_{ISA}$	is the True Airspeed (in feet/s) at *Point1* of the current **Descend-Idle** step under ISA conditions. It is calculated as follows: $Point1\_TAS_{ISA} = 1.68781 \cdot \left(\frac{Start\_CAS}{\sqrt{\sigma_{Point1\,ISA}}}\right)$ $\sigma_{Point1\,ISA}$ is the air density ratio at *Point1* of the current **Descend-Idle** step under ISA conditions
k	is a constant to convert knots to ft/sec = 1.68781
w	is the headwind value (in feet/s)
γ	is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend-**

Idle step, and is positive by convention

S_D is the distance (in feet) along the descent-idle step; it is calculated as follows:

$$S_D = \left(\frac{Point1\_Height - Pt1(NextSeg)\_Height}{sin(\gamma)}\right)$$

For non-ISA conditions, the above ISA deceleration and the input descent angle are held constant. In such conditions, either *Point1_TAS* or the step length (and therefore *Point1_Height*) must be adjusted, depending on the type of step following the current **Descend-Idle** step.

When the step following the current **Descend-Idle** step is a **Level, Level-Idle, or Land** step, *Point1_Height* is maintained and *Point1_TAS* is re-calculated (for non-ISA conditions) as follows:

$$Point1\_TAS_{New} = \left(\left(\left(\left(\left((Pt1(NextSeg)\_TAS_{Non-ISA})^2 - w^2 \cdot sin^2(\gamma)\right)^{1/2} - w \cdot cos(\gamma)\right)^2 + 2 \cdot S_D \cdot Decel_{ISA}\right)^{1/2} + w \cdot cos(\gamma)\right)^2 + w^2 \cdot sin^2(\gamma)\right)^{1/2} \quad \text{(B-58)}$$

where:

$Decel_{ISA}$ is the deceleration over the current **Descend-Idle** step under ISA conditions (feet/s^2)

$Pt1(NextSeg)\_TAS_{Non-ISA}$ is the True Airspeed (in feet/s) at the first point of the following step under actual (non-ISA) conditions.

It is calculated as follows:

$$Pt1(NextSeg)\_TAS_{Non-ISA} = k \cdot \left(\frac{Pt1(NextSeg)\_Start\_CAS}{\sqrt{\sigma_{Pt1(NextSeg)}{}_{Non-ISA}}}\right)$$

$\sigma_{Pt1(NextSeg)}{}_{Non-ISA}$ is the air density ratio at the first point of the following step, under actual (non-ISA) conditions

k is a constant to convert knots to ft/sec = 1.68781

w is the headwind value (kt)

γ is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend-Idle** step, and is positive by convention

S_D is the distance along the descent-idle step; it is calculated as follows:

$$S_D = \left(\frac{Point1\_Height - Pt1(NextSeg)\_Height}{sin(\gamma)}\right)$$

Note: *Point1_CNT* should also be re-calculated, using the new *Point1_TAS* value calculated above.

When the step following the current **Descend-Idle** step is a **Descend** or **Descend-Idle** step, the initially calculated *Point1_TAS* (for non-ISA conditions) is maintained; the step length and hence *Point1_Height* are re-calculated (for non-ISA conditions) as follows:

$$S_{D\ New} = \frac{\left(\left(\left(Pt1(NextSeg)_{TAS_{Non-ISA}}\right)^2 - w^2 \cdot sin^2(\gamma)\right)^{1/2} - w \cdot cos(\gamma)\right)^2 - \left(\left(\left(Point1_{TAS_{Non-ISA}}\right)^2 - w^2 \cdot sin^2(\gamma)\right)^{1/2} - w \cdot cos(\gamma)\right)^2}{2 \ . \ Decel_{ISA}} \quad \text{(B-59)}$$

where:

$Decel_{ISA}$	is the deceleration over the current **Descend-Idle** step under ISA conditions (feet/s^2)
$Pt1(NextSeg)\_TAS_{Non-ISA}$	is the True Airspeed (in feet/s) at the first point of the following step under actual (non-ISA) conditions. It is calculated as follows: $Pt1(NextSeg)\_TAS_{Non-ISA} = k \cdot \left(\frac{Pt1(NextSeg)\_Start\_CAS}{\sqrt{\sigma_{Pt1(NextSeg)_{Non-ISA}}}}\right)$ $\sigma_{Pt1(NextSeg)_{Non-ISA}}$ is the air density ratio at the first point of the following step, under actual (non-ISA) conditions
$Point1\_TAS_{Non-ISA}$	is the True Airspeed (in feet/s) at *Point1* of the current **Descend-Idle** step under actual (non-ISA) conditions. It is calculated as follows: $Point1\_TAS_{Non-ISA} = k \cdot \left(\frac{Start\_CAS}{\sqrt{\sigma_{Point1_{Non-ISA}}}}\right)$ $\sigma_{Point1\ Non-ISA}$ is the air density ratio at *Point1*, under actual (non-ISA) conditions
k	1.68781
w	is the headwind value (kt)
γ	is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend-Idle** step, and is positive by convention

The new value of *Point1_Height* is then calculated as:

$$Point1\_Height_{New} = Pt1(NextSeg)\_Height + S_{D\ New} \cdot sin(\gamma) \quad \text{(B-60)}$$

Note: *Point1_CNT* should also be re-calculated, using the new *Point1_Height* value calculated above.

B7.1.3 LEVEL AND LEVEL-DECEL

The reason for regrouping **Level** and **Level-Decel** steps in this same section is that the associated calculations and specific treatments are essentially identical, except for the calculation of the magnitude of the thrust.

A **Level** step is flown horizontally at a user-defined altitude and at a constant (also user-defined) speed. The thrust is calculated (adapted) to achieve the constant speed. Its magnitude depends, in particular, on the aircraft weight and the flap setting along the step, which is also an input parameter.

A **Level-Decel** step is also flown horizontally at a user-defined altitude, this time, with a deceleration along the step. The associated thrust is calculated (adapted) to accord with the deceleration in question. Again, its magnitude also depends on the aircraft weight and the flap setting along the step, which is also an input parameter. The amount of deceleration is derived from the input speed on the current step and the input speed on the following step.

Depending on the cases described below, a **Level** or **Level-Decel** step produces one or two profile points (with associated parameters).

The length of the step is an input parameter.

Case 1: the following step is of the same type as the current step (e.g. either a Level or Level-Decel type) and is flown with the same flap setting

In this case, the current step produces a single profile point *Point1*, corresponding to the start of the current step. The final AFE (Height), True Airspeed (TAS) and CNT values at the end of the current step correspond to the first point of the following step.

Point1_Height = Start_altitude value provided in the ANP Approach Procedural Steps table for the current step.

$$Point1\_TAS = StartCAS \;/\; \sqrt{\sigma_{Point1}} \qquad \text{(B-61)}$$

where:

Start CAS — is the input value of the Calibrated Airspeed, obtained from the Approach Procedural Steps table for the current segment

σ_{Point1} — is the air density ratio at the aircraft altitude corresponding to *Point1* (i.e. *Point1_Height*+ E_{apt})

If the step is a **Level** step, the thrust at *Point1* is calculated as follows:

$$Point\ 1\_CNT = \frac{W/\delta}{N}\left(\frac{R}{\cos\varepsilon}\right) \qquad \text{(B-62)}$$

where:

W — is the aircraft approach weight (lb).

δ — is the pressure ratio δ at the altitude of the step level (i.e. *Start_altitude* + E_{Apt})

N — is the number of engines supplying thrust. This information is available in the ANP “Aircraft” table.

R	is the drag-over-lift coefficient corresponding to the input Flap_ID of the current step. The value of this coefficient is obtained from the ANP "Aerodynamic Coefficients" table.
ε	Bank angle, in radians

If the step is a **Level-Decel** step, the Thrust at *Point1* includes a deceleration term as follows:

$$Point\ 1\_CNT = \frac{W/\delta}{N}\left(\frac{R}{\cos\varepsilon} + \frac{a}{g}\right) \qquad \text{(B-63)}$$

where:

a — is the deceleration in ft/s² of the aircraft over the **Level-Decel** Step. It is calculated as:

$$a = \frac{k^2 \cdot ((Pt1(NextSeg)\_TAS - w)^2 - (Point1\_TAS - w)^2)}{2 \cdot L}$$

g	standard gravitational acceleration (= 32.174 ft/s²)
k	1.68781
$Pt1(NextSeg)\_TAS$	is the profile point True Airspeed assigned to the first point of the following step
L	is the input distance value provided in the ANP "Default_Approach_Procedural_Steps" table for the **Level-Decel** step

Point1_Distance is calculated as:

$$Point1\_Distance = Pt1(NextSeg)\_Distance - L \qquad \text{(B-64)}$$

where:

$Pt1(NextSeg)\_Distance$	is the profile point distance assigned to the first point of the following step
L	is the input distance value provided in the ANP "Default_Approach_Procedural_Steps" table for the **Level** or **Level-Decel** step

Case 2: the step following the current Level or Level-Decel step is of different type and/or uses a different flap setting

In this second (more general) case, the current step produces, in addition to *Point1,* a second profile point *Point2,* corresponding to the end of the **Level** or **Level-Decel** step.

This second point is located at a maximum distance of 1,000 ft ahead of the first point of the following step. The reason for adding this point is to reflect a rapid change in the thrust between the two consecutive steps.

$$Point2\_Distance = Pt1(NextSeg)\_Distance - Min\ (\frac{L}{2}, 1000ft) \qquad \text{(B-65)}$$

where:

$Pt1(NextSeg)\_Distance$	is the profile point distance assigned to the first point of the following step
L	is the input distance value provided in the ANP “Default_Approach_Procedural_Steps” table for the current **Level** or **Level-Decel** step

Point2_Height is assigned the *Start_altitude* value provided in the ANP Approach Procedural Steps table for the current **Level** or **Level-Decel** step.

If the current step is a **Level** step, the True Airspeed at *Point2* is the same as at *Point1*:

$Point2\_TAS = Point1\_TAS$

If the current step is a **Level-Decel** step, the True Airspeed at *Point2* is calculated as follows:

$$Point2_{TAS} = \sqrt{(Pt1(NextSeg)_{TAS})^2 + \frac{Min(L/2, 1000ft))}{L} * ((Point\ 1_{TAS})^2 - (Pt1(NextSeg)_{TAS})^2)} \qquad \text{(B-66)}$$

where:

$Pt1(NextSeg)\_TAS$	is the profile point True Airspeed assigned to the first point of the following step

In the case of both a **Level** step and a **Level-Decel** step, the thrust at *Point2* is the same as at *Point1*:

$Point2\_CNT = Point1\_CNT$

B7.1.4 LEVEL-IDLE

A **Level-Idle** step is flown at constant altitude using the engine rated idle-thrust setting. Since the propulsive force associated to idle-thrust mode is very small (it can even be negative, meaning that the engines provide additional drag in that case), the aircraft is expected to decelerate on a **Level-Idle** step.

Depending on the cases described below, a **Level-Idle** or **Level-Decel** step produces one or two profile points (with associated parameters).

The length of the step is an input parameter, used "as is" under ISA-conditions. The Level-Idle step type was available to manufacturers some years before the Level-Decel step type was defined. Consequently, some ANP data submissions used the Level-Idle as a decelerating level segment, where the manufacturer calculated appropriate values for the step length, start and end speeds, under ISA-conditions. The input step length and start and end speeds are not physically linked together. This is fundamentally different from all other in-flight procedural steps in the performance model in this appendix. Changing the length of the Level-Idle step will not modify or adjust the "idle" thrust to balance the change in distance flown. Users should therefore take care when making any adjustment to the segment length parameter. However, for non-ISA conditions, this input step length is re-calculated according to the method and assumptions further described in this section in order to account for the change from ISA conditions used by the manufacturer to determine the Level-Idle step length.

Important note: The presence of a Level-Idle step in the approach procedural step profile of a given aircraft type requires the availability, for that aircraft, of jet coefficients (in the ANP "Jet_Engine_Coefficient" table) for the "IdleApproach" thrust rating.

Case 1: the step following the current Level-Idle step is either a Level-Idle or a Descend-Idle step

In this case, the current **Level-Idle** step produces a single profile point <u>*Point1*</u>, corresponding to the start of the step. The final AFE (Height), True Airspeed (TAS) and CNT values at the end of the current **Level-Idle** step correspond to the first point of the following **Level-Idle** step.

Point1_Height = *Start_altitude* value provided in the ANP Approach Procedural Steps table for the current **Level-Idle** step.

Important note: the input *Start_altitude* value of the current **Level-Idle** step should be the same as the *Start_altitude* value associated to the following **Level-Idle** step. <u>If not, the system should warn the user</u>.

$$Point1\_TAS = StartCAS \ / \ \sqrt{\sigma_{Point1}} \qquad \text{(B-67)}$$

where:

Start CAS	is the input value of the Calibrated Airspeed, obtained from the Approach Procedural Steps table
σ_{Point1}	is the air density ratio at the aircraft altitude corresponding to *Point1* (i.e. *Point1_Height*+ E_{apt})

Important note: the input *Start CAS* value of the current **Level-Idle** step should be greater than or equal to the input Start CAS value of the following **Level-Idle** step.

$$Point1\_Distance = Pt1(NextSeg)\_Distance - L \qquad \text{(B-68)}$$

where:

$Pt1(NextSeg)\_Distance$	is the profile point distance assigned to the first point of the following **Level-Idle** step
L	is the input distance value provided in the ANP Approach Procedural Steps table for the **Level-Idle** step

Point1_CNT is calculated using equations and method described in Section B4.1 with the jet engine coefficients associated to the "IdleApproach" Thrust Rating.

with:

V_C	is the *Start_CAS* value obtained from the Approach Procedural Steps table for the current **Level-Idle** step
h	is the aircraft *pressure altitude* (ft) associated to the current **Level-Idle** step (see Eq. B-6 in Section B3)

Case 2: the step following the current Level-Idle step is neither a Level-Idle nor a Descend-Idle step

In this second (more general) case, the current **Level-Idle** step produces two profile points:

- *Point1*, corresponding to the start of the **Level-Idle** step,
- *Point2*, corresponding to the end of the **Level-Idle** step – this second point being located at a maximum distance of 1,000 ft ahead of the first point of the following step. The reason for adding this point is to reflect a rapid change in the thrust between the two consecutive steps.

$$Point1\_Distance = Pt1(NextSeg)\_Distance - L \quad \text{(B-69)}$$

$$Point2\_Distance = Pt1(NextSeg)\_Distance - Min\ (\tfrac{L}{2}, 1000ft) \quad \text{(B-70)}$$

where:

$Pt1(NextSeg)\_Distance$	is the profile point distance assigned to the first point of the following step
L	is the input distance value provided in the ANP Default Approach Procedural Steps table for the current **Level-Idle** step

Point1_Height and *Point2_Height* are both assigned the *Start_altitude* value provided in the ANP Approach Procedural Steps table for the current **Level-Idle** step.

Important note: the input *Start_altitude* value of the current **Level-Idle** step should be the same as the *Start_altitude* value associated to the following step. <u>If not, the system should warn the user.</u>

$$Point1\_TAS = StartCAS\ /\ \sqrt{\sigma_{Point1}} \quad \text{(B-71)}$$

$$Point2\_TAS = \sqrt{(Pt1(NextSeg)_{TAS})^2 + \frac{Min(L/2,1000ft))}{L} * ((Point1_{TAS})^2 - (Pt1(NextSeg)_{TAS})^2)}$$

(B-72)

where:

Start CAS	is the input value of the Calibrated Airspeed, obtained from the Approach Procedural Steps table for the current **Level-Idle** step
σ_{Point1}	is the air density ratio at the **Level-Idle** step altitude (i.e. *Point1_Height*+ E_{apt})
$Pt1(NextSeg)\_TAS$	is the profile point True Airspeed assigned to the first point of the following step
L	is the input distance value provided in the ANP Default Approach Procedural Steps table for the current **Level-Idle** step

Important note: the input *Start CAS* value of the current **Level-Idle** step should be greater than or equal to the Start CAS value of the following step.

Point1_CNT and *Point2_CNT* are calculated using equations and method described in Section B4.1 with the jet engine coefficients associated to the *IdleApproach* Thrust Rating.

Level-Idle step length adjustment for non-ISA conditions

The input distance value provided in the Default Approach Procedural Steps table for the current **Level-Idle** step is defined for ISA reference conditions at a sea-level airport. The associated deceleration (for the given sea-level ISA conditions) is then assumed to remain constant even under non-sea level, non-ISA conditions. Other step parameters have therefore to be modified for consistency under these conditions.

Deceleration over the **Level-Idle** step for ISA conditions and airport at sea level is calculated as:

$$Decel_{ISA} = \frac{\left(k\cdot\left(\frac{Pt1(NextSeg)\_Start\_CAS}{\sqrt{\sigma_{ISA}}} - w\right)\right)^2 - \left(k\cdot\left(\frac{Start\_CAS}{\sqrt{\sigma_{ISA}}} - w\right)\right)^2}{2.L} \qquad \text{(B-73)}$$

where:

$Decel_{ISA}$	is the deceleration over the current **Level-Idle** step under ISA conditions (feet/s^2)
k	is a constant to convert knots to ft/sec = 1.68781
$Pt1(NextSeg)\_Start\_CAS$	is the Calibrated Airspeed (kt) assigned to the first point of the following step
Start CAS	is the input value of the Calibrated Airspeed (kt), obtained from the Approach Procedural Steps table for the current

	Level-Idle step
w	is the headwind value (kt)
σ_{ISA}	is the air density ratio at the **Level-Idle** step altitude under ISA conditions
L	is the input distance value provided in the ANP Approach Procedural Steps table for the **Level-Idle** step

For non-ISA conditions, the **Level-Idle** step length is re-calculated as follows to hold the above ISA deceleration constant:

$$L_{adjusted} = \frac{\left(k \cdot \left(\frac{Pt1(NextSeg)\_Start\_CAS}{\sqrt{\sigma_{actual}}} - w\right)\right)^2 - \left(k \cdot \left(\frac{Start\_CAS}{\sqrt{\sigma_{actual}}} - w\right)\right)^2}{2 \ . \ Decel_{ISA}} \quad \text{(B-74)}$$

where:

$L_{adjusted}$	Is the adjusted **Level-Idle** step length under the actual non-ISA conditions (ft)
k	is a constant to convert knots to ft/sec = 1.68781
$Pt1(NextSeg)\_Start\_CAS$	is the Calibrated Airspeed (kt) assigned to the first point of the following step
Start CAS	is the input value of the Calibrated Airspeed (kt), obtained from the Approach Procedural Steps table for the current **Level-Idle** step
w	is the headwind value (kt)
σ_{actual}	is the air density ratio at the **Level-Idle** step altitude for the actual non-ISA conditions
$Decel_{ISA}$	is the deceleration over the current **Level-Idle** step under ISA conditions (feet/s^2)

B7.1.5 LAND

A **Land** step represents the rolling portion between the touchdown point on the runway and the start of the deceleration (braking and/or reverse-thrust).

The **Land** step produces two profile points:

- *Point1*, representing the touchdown point,
- *Point2*, corresponding to the end of the **Land** step.

Point1_Distance = 0

Point1_Height = 0

$$Point1\_TAS = \left(D \cdot \sqrt{W}\right) / \sqrt{\sigma_{Point1}} \qquad \text{(B-75)}$$

where:

W	is the aircraft approach weight (lb), which corresponds to 90% of the MLW (Max Landing Weight) available in the ANP "Aircraft" table.
D	is the land speed coefficient obtained from the ANP "Aerodynamic Coefficients" table for the specific landing Flap_ID used on the **Land** step (kt/√lb)
σ_{Point1}	is the air density ratio at the aircraft altitude corresponding to *Point1* (i.e. E_{apt})

$$Point1\_CNT = \frac{W/\delta_{Point1}}{N} \cdot \left(R - \frac{\sin\gamma}{1.03}\right) \qquad \text{(B-76)}$$

where:

W	is the aircraft approach weight (lb), which corresponds to 90% of the MLW (Max Landing Weight) available in the ANP "Aircraft" table.
δ_{Point1}	is the pressure ratio at the aircraft altitude corresponding to *Point1* (i.e. E_{apt})
N	is the number of engines supplying thrust. This information is available in the ANP "Aircraft" table
R	is the drag-over-lift coefficient corresponding to the input Flap_ID associated to the **Land** step. The value of the coefficient is obtained from the ANP "Aerodynamic Coefficients" table.
γ	is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the last **Descend** step preceding the current **Land** step, and is positive by convention.

CNT correction for non-standard headwind

For wind speed that differs from the standard 8 kt headwind, the following adjustment is applied to the initially calculated thrust (i.e. under standard 8 kt headwind conditions) at *Point1*:

$$\Delta CNT_w = \frac{1.03 \cdot (W/\delta_{Point1}) \cdot sin(\gamma) \cdot (w-8)}{N \cdot Vc_1} \qquad \text{(B-77)}$$

where:

W	is the aircraft approach weight (lb), which corresponds to 90% of the MLW (Max Landing Weight) available in the ANP "Aircraft" table
δ_{Point1}	is the pressure ratio at the aircraft altitude corresponding to Point1 (i.e. *Point1_Height* + E_{apt})
w	is the headwind value (kt)
γ	is the input descent angle (in radians), obtained from the Approach Procedural Steps table for the current **Descend** step, and is positive by convention
N	is the number of engines supplying thrust. This information is available in the ANP "Aircraft" table
Vc_1	is the Calibrated Airspeed (kt) at *Point1*

$$Vc_1 = \text{Point 1\_}TAS.\sqrt{\sigma_{Point1}}$$

Point2_Distance = *Touchdown Roll* parameter (obtained from the *Approach Procedural Steps* table for the **Land** step)

Point2_Height = 0

Point2_TAS and *Point2_CNT* are obtained from the following **Decelerate** step:

$$Point2\_TAS = Start\ CAS_{Decel\ Seg} \ / \ \sqrt{\sigma_{Point2}} \qquad \text{(B-78)}$$

where:

$Start\ CAS_{Decel\ Seg}$	is the *Start CAS* obtained from the Approach Procedural Steps table for the next **Decelerate** step
σ_{Point2}	is the air density ratio at the aircraft altitude corresponding to *Point2* (i.e. E_{apt})

$$Point2\_CNT = \frac{Start\_Thrust_{Decel\ Seg} * Max\ Sea\ Level\ Static\ Thrust}{100} \qquad \text{(B-79)}$$

where:

$Start\_Thrust_{Decel\ Seg}$	is the *Start_Thrust* parameter (% Max Sea Level Static Thrust) obtained from the Approach Procedural Steps table for the next **Decelerate** step
Max Sea Level Static Thrust	is obtained from the ANP "Aircraft" table

B7.1.6 DECELERATE

A **Decelerate** step represents the rolling portion where the aircraft reduces its speed from landing speed to taxiing speed, using brakes and/or reverse thrust.

The **Decelerate** step produces a single point (*Point2*) at the end of the step:

Point2_Distance = Point1_Distance + Distance parameter, obtained from the Approach Procedural Steps table for the current **Decelerate** step, where *Point1_Distance*, is the distance at the end of the previous **Land** or **Decelerate** step.

Point2_Height = 0

Point2_TAS and *Point2_CNT* are obtained from the next **Decelerate** step:

$$Point2\_TAS = \ Start\ CAS_{Following\ Decel\ Seg}\ /\ \sqrt{\sigma_{Point2}} \qquad \text{(B-80)}$$

where:

$Start\ CAS_{Following\ Decel\ Seg}$	is the *Start CAS* obtained from the *Approach Procedural Steps* table for the following **Decelerate** step
σ_{Point2}	is the air density ratio at the aircraft altitude corresponding to *Point2* (i.e. E_{apt})

$$Point2\_CNT = \frac{Start_{Thrust_{Following\ Decel\ Seg}} . Max\ Sea\ Level\ Static\ Thrust}{100} \qquad \text{(B-81)}$$

where:

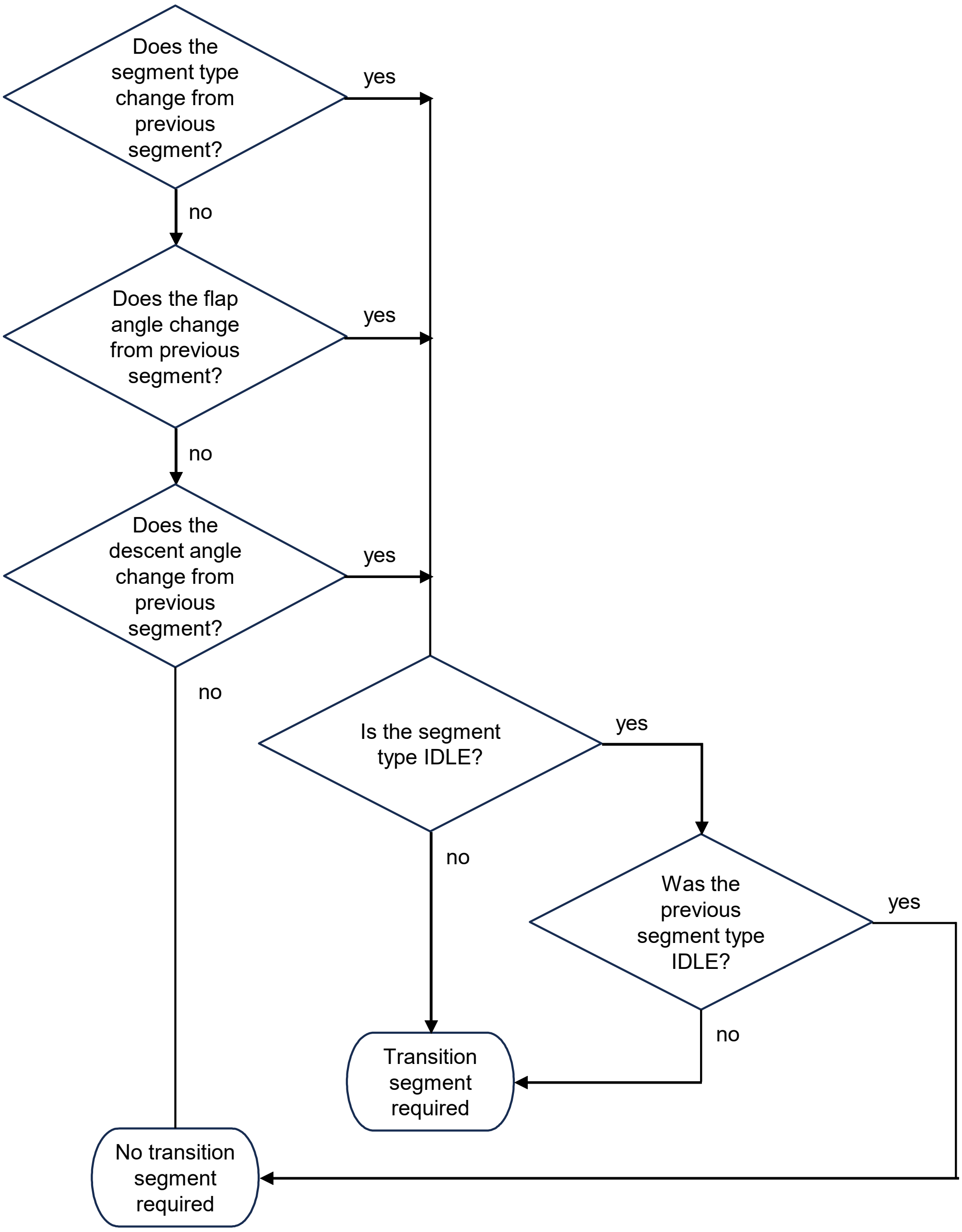
$Start\_Thrust_{Following\ Decel\ Seg}$	is the *Start_Thrust* parameter (% Max Sea Level Static Thrust) obtained from the Approach Procedural Steps table for the following **Decelerate** step
$Max\ Sea\ Level\ Static\ Thrust$	is obtained from the ANP "Aircraft" table and is defined in pounds

Note: the last **Decelerate** step of the Approach Procedural Steps table, which has its Distance parameter equal to zero, does not produce any profile point.

B7.1.7 ARRIVAL TRANSITION SEGMENTS

Figure B-3 presents a flow chart to describe the situations where transition segments are required, in order to take account of situations where thrust changes will occur between arrival segments. Whilst most of the transition segment scenarios are described in the main text, this section presents a comprehensive overview of when transition segments should be applied. As illustrated, the thrust will generally change between segments when the procedure step type changes, but also when the descent angle changes between segments of a certain step type and also when the flap angle changes, with the exception of procedure step types where the thrust is Idle.

Figure B-3: Flow chart showing situations where transitions are and are not required during an arrival



APPENDIX C: MODELLING OF LATERAL GROUND TRACK SPREADING

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 a reasonable one in most cases.

Assuming a Gaussian distribution with a standard deviation *S*, illustrated in **Figure C-1**, about 98.8 percent of all movements fall within boundaries of $\pm 2.5 \cdot S$ (i.e. within a swathe of width of $5 \cdot S$).

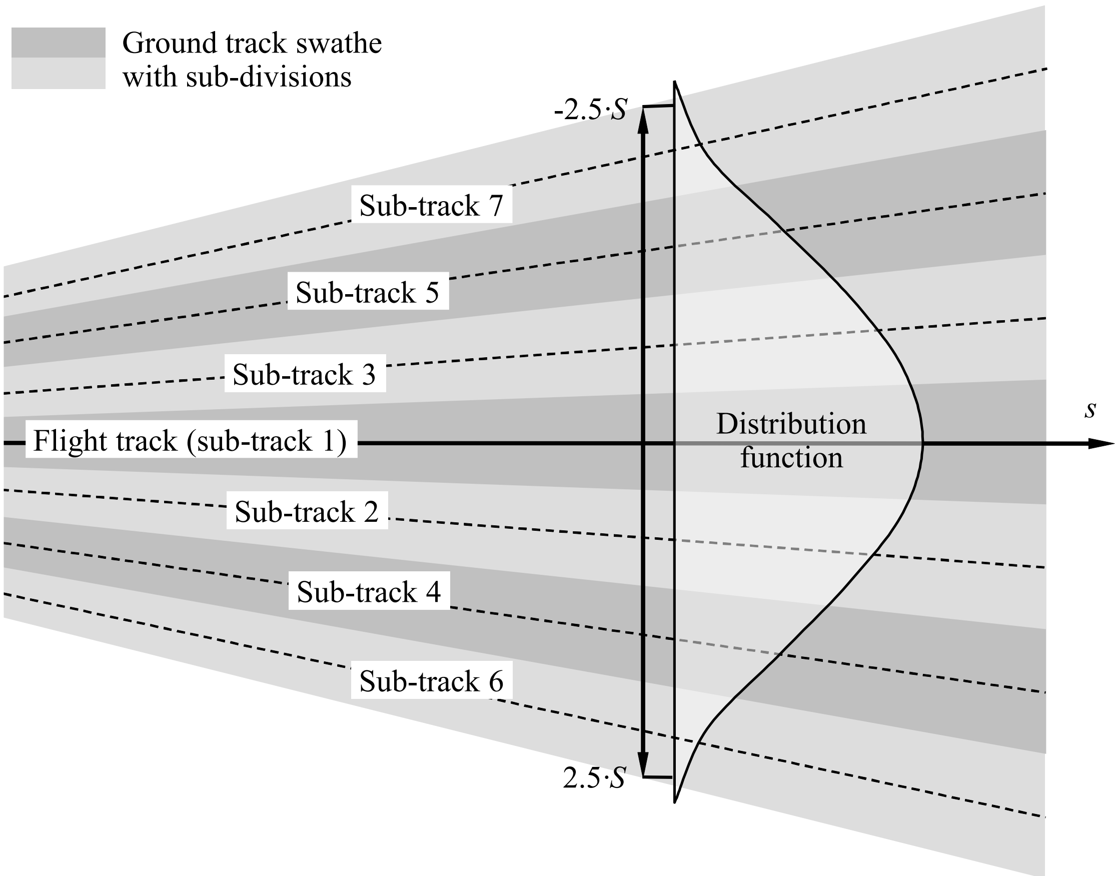


Figure C-1: Sub-division of a ground track into 7 sub-tracks. The width of the swathe is 5 times the standard deviation of the flight track spreading

A Gaussian distribution can usually be modelled adequately using 7 discrete sub-tracks evenly spaced between the $\pm 2.5 \cdot S$ boundaries of the swathe as shown in **Figure C-1**.

However, the adequacy of the approximation depends on the relationship of the sub-track track separation to the heights of the aircraft 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 C-1** and **C-2** show the parameters for a sub-division into between 5 and 13 sub-tracks. **Table C-1** shows the location of the particular sub-tracks, **Table C-2** the corresponding percentage of movements on each sub-track.

Table C-1: Location of 5, 7, 9, 11 or 13 sub-tracks. The overall width of the swathe (containing 98% of all movements) is 5 times the standard deviation

Sub-track number	Location of sub-tracks for sub-division 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

Table C-2: Percentage of movements on 5, 7, 9, 11 or 13 sub-tracks. The overall width of the swathe (containing 98% of all movements) is 5 times the standard deviation

Sub-track number	Percentage of movements on sub-track for sub-division 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 D: RECALCULATION OF NPD DATA FOR NON-REFERENCE CONDITIONS

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 must be noted that these data have been normalised using average atmospheric attenuation rates defined in SAE AIR-1845 [ref. 6] and revised in CAN/7-WP/59 [ref. 17]. Those rates are averages of values determined during aircraft noise certification testing in Europe and the USA. The wide variation of atmospheric conditions (temperature and relative humidity) in those tests is shown in **Figure D-1** (taken from [ref. 17]).

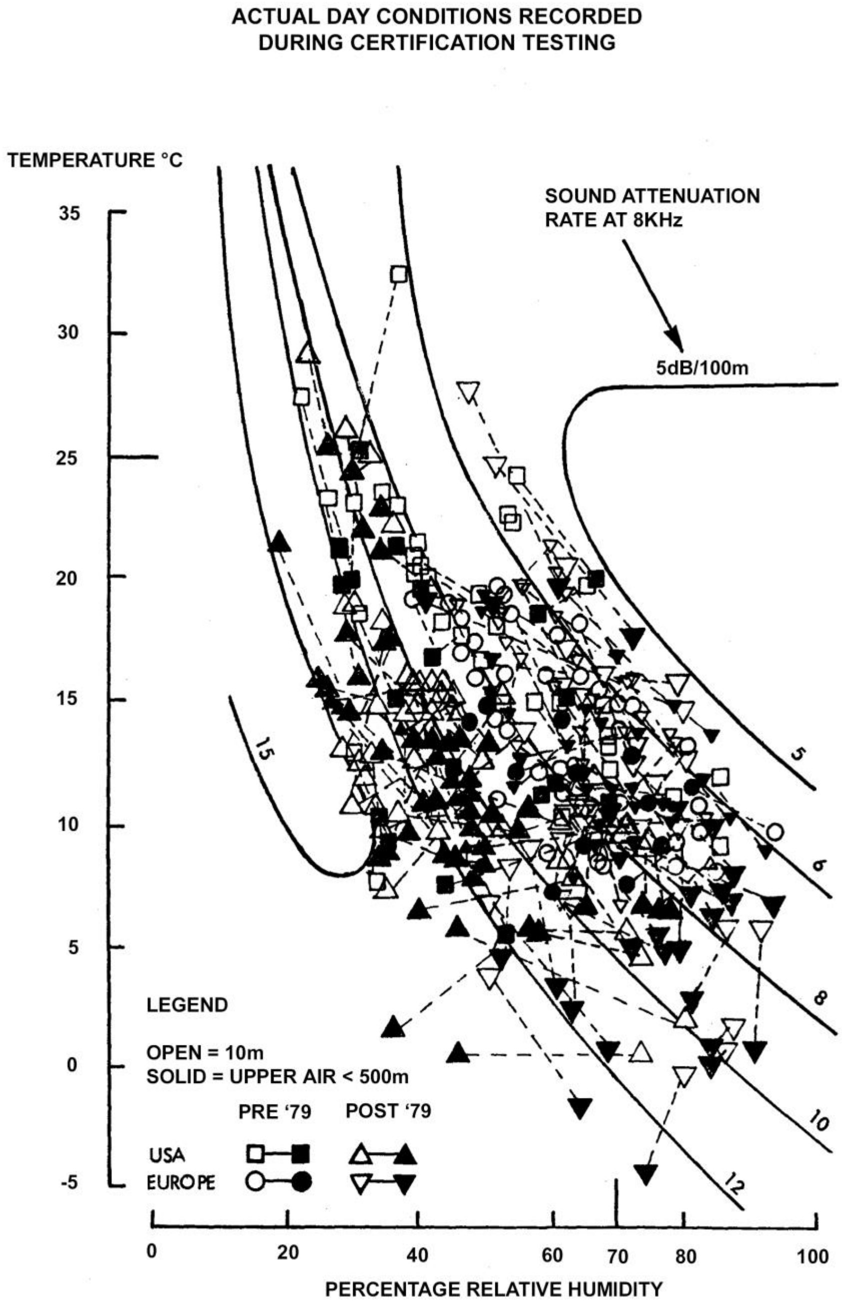


Figure D-1: Meteorological conditions recorded during noise certification tests

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 D-1**, calculated using an industry standard atmospheric attenuation model SAE-ARP-866A [ref. 18], 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 rather less).

SAE-ARP-5534 [ref. 19] provides an updated methodology (2013) to calculate atmospheric absorption which is consistent with current scientific information and is the recommended method. However, the flexibility is given for transition purposes to model non-standard atmospheric conditions with the legacy SAE-ARP-866A method (1975).

Since the attenuation rates [ref. 6], given in **Table D-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). Rather, they should be considered properties of a purely notional atmosphere - referred to as the “AIR-1845 atmosphere”.

Table D-1: Average atmospheric attenuation rates used to normalise NPD data in the ANP database [ref. 6]

Centre frequency of 1/3-octave band [Hz]	Attenuation rate [dB/100 m]	Centre frequency of 1/3-octave band [Hz]	Attenuation rate [dB/100 m]
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

The attenuation coefficients in **Table D-1** may be assumed 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 D-1** indicates that adjustment is required, the following methodology should be used.

The ANP database provides the following NPD data for each power setting:

- maximum sound level versus slant distance, $L_{max}(d)$
- time integrated level versus distance for the reference airspeed, $L_E(d)$, and
- unweighted reference sound spectrum at a slant distance of 305 m (1,000 ft), $L_{n,ref}(d_{ref})$ where n = frequency band (ranging from 17 to 40 for 1/3-octave bands with centre frequencies from 50 Hz to 10 kHz),

- all data being normalised to the SAE-AIR-1845 atmosphere.

Adjustment of the NPD curves to specified conditions (temperature, pressure and relative humidity) is performed in three steps:

1. The reference spectrum is corrected to remove the SAE AIR-1845 atmospheric attenuation $\alpha_{n,ref}$:

$$L_n\left(d_{ref}\right)=L_{n,ref}\left(d_{ref}\right)+\alpha_{n,ref}\cdot d_{ref} \tag{D-1}$$

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

2. The corrected spectrum is adjusted to each of the ten standard NPD distances[40] d_i using attenuation rates for both (i) the SAE AIR-1845 atmosphere and (ii) the specified atmosphere (based on either SAE-ARP-5534 or SAE-ARP-866A).

(i) For the SAE AIR-1845 atmosphere:

$$L_{n,ref}(d_i) = L_n\left(d_{ref}\right) - 20.lg(d_i/d_{ref}) - \alpha_{n,ref}\cdot d_i \tag{D-2}$$

(ii) For the specified atmosphere:

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

where $\delta_n(T,p_a,h_{rel},d_i)$ is the coefficient of atmospheric absorption for the frequency band n (expressed in dB/m) calculated using SAE ARP-5534 or SAE-ARP-866A with temperature T, atmospheric pressure p_a, relative humidity h_{rel} and path-length distance, d_i. Note that unlike the ARP-866A attenuation rates, the ARP-5534 third octave band attenuation rates are a function of both atmospheric pressure, p_a, and the attenuation path-length distance, d_i.

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

$$\begin{aligned}\Delta L(T,p_a,h_{rel},d_i) &= L_{A,atm}(T,p_a,h_{rel},d_i) - L_{A,ref}(d_i)\\ &= 10\cdot lg\sum_{n=17}^{40}10^{(L_{n,atm}(T,p_a,h_{rel},d_i)-A_n)/10} - 10\cdot lg\sum_{n=17}^{40}10^{(L_{n,ref}(d_i)-A_n)/10}\end{aligned} \tag{D-4}$$

The increment $\Delta L(T,p_a,h_{rel},d_i)$ is the difference between the NPDs 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.

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.

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

Example:

The following is an example of the application of the NPD spectral adjustment: Adjust standard NPD data to the atmosphere 10 °C, 80% relative humidity and sea level atmospheric pressure using both the SAE-ARP-5534 and SAE-ARP-866A methodologies.

The SEL NPD data are presented in **Table D-6a** (end of Appendix D) for the JETW reference aeroplane, and corresponding departure and arrival spectral class data (IDs 103 & 205) are tabulated in **Table D-2**.

First the spectrum levels, which are referenced to 305 m (1000 ft), are corrected back to the source (distance 1m) to remove the SAE AIR-1845 atmosphere, ignoring spherical spreading effects. This is done using equation D-1. The corresponding spectra at source are also tabulated in **Table D-2**.

Table D-2: Spectral classes 103 and 205 at 1,000 ft and calculated at the source

Frequency (Hz)	At 1000 ft DEP_103 (dB)	ARR_205 (dB)	At source 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
1000	70.0	70.0	71.8	71.8
1250	69.6	68.9	71.9	71.2
1600	71.1	67.2	74.1	70.2
2000	70.6	65.8	74.6	69.8
2500	67.1	64.4	72.3	69.6
3150	63.4	63.0	70.4	70.0
4000	63.5	62.0	73.0	71.5
5000	58.2	60.6	69.2	71.6
6300	51.5	54.4	67.5	70.4
8000	42.3	48.5	64.3	70.5
10000	37.7	39.0	67.7	69.0

The source spectral data are then propagated out to the standard NPD data distances (200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000 and 25000 ft) using equations D-2 and D-3, together with the absorption coefficients in **Table D-1** for the AIR-1845 atmosphere and using attenuation values calculated using SAE-ARP-5534 and SAE-ARP-866A for the specified atmosphere: 10°C, 80% relative humidity and 101.325 kPa (sea level). All three sets of attenuation values are listed in **Tables D-3a, D-3b and D-3c** respectively.

Table D-3a: Attenuation values (dB) calculated using SAE-AIR-1845

Frequency (Hz)	NPD Data Distance (ft) 200	400	630	1000	2000	4000	6300	10000	16000	25000
50	0.020	0.040	0.063	0.101	0.201	0.402	0.634	1.006	1.609	2.515
63	0.020	0.040	0.063	0.101	0.201	0.402	0.634	1.006	1.609	2.515
80	0.020	0.040	0.063	0.101	0.201	0.402	0.634	1.006	1.609	2.515
100	0.040	0.080	0.127	0.201	0.402	0.805	1.267	2.012	3.219	5.029
125	0.040	0.080	0.127	0.201	0.402	0.805	1.267	2.012	3.219	5.029
160	0.060	0.119	0.188	0.299	0.597	1.195	1.882	2.987	4.779	7.468
200	0.080	0.160	0.252	0.399	0.799	1.597	2.516	3.993	6.389	9.982
250	0.080	0.160	0.252	0.399	0.799	1.597	2.516	3.993	6.389	9.982
315	0.120	0.240	0.378	0.600	1.201	2.402	3.783	6.005	9.607	15.011
400	0.140	0.280	0.442	0.701	1.402	2.804	4.417	7.010	11.217	17.526
500	0.180	0.360	0.566	0.899	1.798	3.597	5.665	8.992	14.387	22.479
630	0.220	0.440	0.693	1.100	2.201	4.401	6.932	11.003	17.605	27.508
800	0.280	0.560	0.881	1.399	2.798	5.596	8.814	13.990	22.385	34.976
1000	0.360	0.719	1.133	1.798	3.597	7.193	11.329	17.983	28.773	44.958
1250	0.460	0.919	1.448	2.298	4.596	9.193	14.479	22.982	36.771	57.455
1600	0.599	1.198	1.888	2.996	5.992	11.985	18.876	29.962	47.939	74.905
2000	0.799	1.598	2.517	3.996	7.992	15.984	25.174	39.959	63.935	99.898
2500	1.039	2.079	3.274	5.197	10.394	20.787	32.740	51.968	83.149	129.921
3150	1.399	2.798	4.407	6.995	13.990	27.981	44.070	69.952	111.923	174.879
4000	1.899	3.798	5.982	9.495	18.989	37.978	59.815	94.945	151.912	237.363
5000	2.199	4.398	6.926	10.994	21.988	43.977	69.263	109.941	175.906	274.853
6300	3.198	6.396	10.074	15.990	31.980	63.959	100.736	159.898	255.837	399.745
8000	4.397	8.794	13.851	21.985	43.970	87.941	138.507	219.852	351.764	549.631
10000	5.996	11.992	18.887	29.980	59.960	119.921	188.875	299.801	479.682	749.503

Table D-3b: Attenuation values (dB) for 10°C/80% relative humidity/101.325 kPa calculated using SAE-ARP-866A

Frequency (Hz)	NPD Data Distance (ft) 200	400	630	1000	2000	4000	6300	10000	16000	25000
50	0.013	0.026	0.041	0.065	0.130	0.260	0.410	0.650	1.041	1.626
63	0.016	0.033	0.052	0.082	0.164	0.328	0.517	0.820	1.312	2.050
80	0.021	0.042	0.066	0.104	0.208	0.417	0.656	1.042	1.667	2.604
100	0.026	0.052	0.082	0.130	0.261	0.521	0.821	1.303	2.084	3.257
125	0.033	0.065	0.103	0.163	0.326	0.652	1.027	1.629	2.607	4.074
160	0.042	0.084	0.132	0.209	0.418	0.835	1.315	2.088	3.340	5.219
200	0.052	0.105	0.165	0.261	0.523	1.045	1.646	2.613	4.180	6.532
250	0.065	0.131	0.206	0.327	0.654	1.308	2.060	3.270	5.233	8.176
315	0.083	0.165	0.260	0.413	0.826	1.651	2.601	4.128	6.605	10.321
400	0.105	0.210	0.331	0.526	1.051	2.102	3.311	5.255	8.408	13.138
500	0.132	0.264	0.415	0.659	1.318	2.635	4.151	6.588	10.541	16.470
630	0.167	0.333	0.525	0.833	1.667	3.333	5.250	8.333	13.332	20.832
800	0.213	0.425	0.670	1.063	2.127	4.254	6.700	10.634	17.015	26.586
1000	0.267	0.535	0.842	1.337	2.674	5.349	8.424	13.372	21.395	33.430
1250	0.337	0.674	1.061	1.684	3.368	6.736	10.609	16.840	26.944	42.100
1600	0.450	0.900	1.417	2.250	4.499	8.998	14.173	22.496	35.994	56.240
2000	0.601	1.201	1.892	3.003	6.005	12.010	18.916	30.026	48.042	75.065
2500	0.806	1.611	2.538	4.028	8.057	16.114	25.379	40.285	64.455	100.712
3150	1.130	2.259	3.559	5.649	11.297	22.595	35.587	56.487	90.379	141.217
4000	1.635	3.270	5.150	8.174	16.348	32.697	51.498	81.742	130.787	204.355
5000	1.961	3.921	6.176	9.804	19.607	39.215	61.763	98.036	156.858	245.091
6300	2.792	5.584	8.795	13.961	27.922	55.843	87.953	139.608	223.373	349.020
8000	4.098	8.195	12.908	20.488	40.977	81.953	129.076	204.883	327.813	512.208
10000	5.958	11.917	18.769	29.792	59.585	119.170	187.692	297.924	476.678	744.810

Table D-3c: Attenuation values (dB) for 10°C/80% relative humidity/101.325 kPa calculated using SAE-ARP-5534

Frequency (Hz)	NPD Data Distance (ft) 200	400	630	1000	2000	4000	6300	10000	16000	25000
50	0.004	0.009	0.014	0.022	0.043	0.087	0.136	0.216	0.346	0.541
63	0.007	0.013	0.021	0.034	0.067	0.135	0.212	0.337	0.539	0.842
80	0.010	0.021	0.033	0.052	0.104	0.208	0.327	0.520	0.831	1.297
100	0.016	0.032	0.050	0.079	0.158	0.316	0.497	0.789	1.262	1.970
125	0.024	0.047	0.074	0.118	0.235	0.470	0.740	1.174	1.877	2.929
160	0.034	0.068	0.107	0.170	0.340	0.680	1.071	1.699	2.714	4.233
200	0.048	0.095	0.150	0.238	0.475	0.950	1.495	2.370	3.785	5.898
250	0.064	0.127	0.201	0.318	0.637	1.272	2.002	3.172	5.063	7.882
315	0.082	0.164	0.258	0.409	0.817	1.633	2.569	4.070	6.491	10.093
400	0.101	0.203	0.319	0.506	1.012	2.021	3.179	5.033	8.021	12.459
500	0.122	0.245	0.386	0.612	1.223	2.442	3.838	6.075	9.673	15.006
630	0.147	0.294	0.463	0.734	1.467	2.927	4.601	7.277	11.576	17.931
800	0.178	0.356	0.561	0.890	1.778	3.548	5.573	8.808	13.994	21.636
1000	0.222	0.444	0.699	1.109	2.214	4.416	6.931	10.943	17.357	26.765
1250	0.287	0.574	0.904	1.434	2.863	5.705	8.947	14.104	22.311	34.268
1600	0.388	0.775	1.220	1.935	3.861	7.683	12.030	18.916	29.804	45.492
2000	0.545	1.089	1.714	2.717	5.414	10.751	16.794	26.305	41.180	62.238
2500	0.791	1.581	2.487	3.940	7.840	15.519	24.151	37.594	58.250	86.626
3150	1.178	2.353	3.699	5.855	11.621	22.884	35.399	54.559	83.129	120.351
4000	1.784	3.559	5.591	8.837	17.468	34.118	52.269	79.274	117.472	176.598
5000	2.726	5.432	8.521	13.435	26.391	50.883	76.751	113.357	173.102	265.298
6300	4.176	8.306	12.999	20.425	39.725	75.025	110.335	166.432	260.771	402.280
8000	6.373	12.640	19.715	30.805	58.999	107.808	160.820	249.867	394.268	610.868
10000	9.625	19.006	29.494	45.700	85.467	155.224	239.188	374.260	593.296	921.851

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 from the reference level to give the increment, ΔL. The A-weighted levels and increments ΔL are shown in **Table D-4** for SAE-ARP-5534 and **Table D-5** for SAE-ARP-866A.

Table D-4: A-weighted levels for reference and SAE-ARP-5534 specified atmosphere and difference between each atmosphere, ΔL

Distance (ft)	DEP_103 $L_{A,ref}$ (dBA)	DEP_103 $L_{A,atm}$ (dBA)	DEP_103 ΔL (dB)	ARR_205 $L_{A,ref}$ (dBA)	ARR_205 $L_{A,atm}$ (dBA)	ARR_205 ΔL (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
1000	80.6	81.3	+0.7	79.2	79.8	+0.6
2000	72.5	73.7	+1.2	71.3	72.4	+1.1
4000	63.6	65.4	+1.8	62.7	64.4	+1.7
6300	57.4	59.6	+2.1	56.4	58.6	+2.2
10000	50.7	53.2	+2.4	49.5	52.2	+2.7
16000	43.3	46.2	+2.9	41.8	45.0	+3.2
25000	35.3	38.9	+3.6	34.0	37.7	+3.7

Table D-5: A-weighted levels for reference and SAE-ARP-866A specified atmosphere and difference between each atmosphere, ΔL

Distance (ft)	DEP_103 $L_{A,ref}$ (dBA)	DEP_103 $L_{A,atm}$ (dBA)	DEP_103 ΔL (dB)	ARR_205 $L_{A,ref}$ (dBA)	ARR_205 $L_{A,atm}$ (dBA)	ARR_205 ΔL (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
1000	80.6	81.2	+0.6	79.2	79.8	+0.5
2000	72.5	73.4	+0.9	71.3	72.2	+0.8
4000	63.6	64.9	+1.3	62.7	63.9	+1.2
6300	57.4	58.9	+1.5	56.4	58.0	+1.6
10000	50.7	52.5	+1.8	49.5	51.4	+1.9
16000	43.3	45.5	+2.2	41.8	44.1	+2.3
25000	35.3	38.1	+2.8	34.0	36.7	+2.7

The departure and approach increments shown in **Table D-4** or **D-5** are then added to the departure and approach ANP database NPD noise levels (**Table D-6a**) to construct the revised NPD data with SAE-ARP-5534 atmospheric absorption shown in **Table D-6b** or revised NPD data with SAE-ARP-866A atmospheric absorption shown in **Table D-6c**. Note that the data in Tables D-4 through to D-6c have been rounded for presentation purposes, however, but the full precision should be used for noise calculations.

Table D-6a: Original reference JETW NPD data

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	L_200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
JETW	SEL	A	2000	100.7	96.7	93.8	90.5	85.0	79.0	74.7	70.0	64.9	59.7
JETW	SEL	A	2500	100.9	96.9	94.0	90.7	85.2	79.2	74.9	70.2	65.1	59.9
JETW	SEL	A	7500	102.5	98.5	95.6	92.3	86.8	80.8	76.5	71.8	66.7	61.5
JETW	SEL	D	10000	100.5	96.5	93.6	90.3	84.8	78.8	74.5	69.8	64.7	59.5
JETW	SEL	D	15000	103.8	99.8	96.9	93.6	88.1	82.1	77.8	73.1	68.0	62.8
JETW	SEL	D	20000	108.0	104.0	101.1	97.8	92.3	86.3	82.0	77.3	72.2	67.0
JETW	SEL	D	22500	109.7	105.7	102.8	99.5	94.0	88.0	83.7	79.0	73.9	68.7

Table D-6b: Revised JETW NPD data using SAE-ARP-5534

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	L_200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
JETW	SEL	A	2000	100.7	96.9	94.1	91.1	86.1	80.7	76.9	72.7	68.1	63.4
JETW	SEL	A	2500	100.9	97.1	94.3	91.3	86.3	80.9	77.1	72.9	68.3	63.6
JETW	SEL	A	7500	102.5	98.7	95.9	92.9	87.9	82.5	78.7	74.5	69.9	65.2
JETW	SEL	D	10000	100.6	96.8	94.0	91.0	86.0	80.6	76.6	72.2	67.6	63.1
JETW	SEL	D	15000	103.9	100.1	97.3	94.3	89.3	83.9	79.9	75.5	70.9	66.4
JETW	SEL	D	20000	108.1	104.3	101.5	98.5	93.5	88.1	84.1	79.7	75.1	70.6
JETW	SEL	D	22500	109.8	106.0	103.2	100.2	95.2	89.8	85.8	81.4	76.8	72.3

Table D-6c: Revised JETW NPD data using SAE-ARP-866A

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	L_200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
JETW	SEL	A	2000	100.8	97.0	94.2	91.0	85.8	80.2	76.3	71.9	67.2	62.4
JETW	SEL	A	2500	101.0	97.2	94.4	91.2	86.0	80.4	76.5	72.1	67.4	62.6
JETW	SEL	A	7500	102.6	98.8	96.0	92.8	87.6	82.0	78.1	73.7	69.0	64.2
JETW	SEL	D	10000	100.7	96.8	94.0	90.9	85.7	80.1	76.0	71.6	66.9	62.3
JETW	SEL	D	15000	104.0	100.1	97.3	94.2	89.0	83.4	79.3	74.9	70.2	65.6
JETW	SEL	D	20000	108.2	104.3	101.5	98.4	93.2	87.6	83.5	79.1	74.4	69.8
JETW	SEL	D	22500	109.8	106.0	103.2	100.2	95.2	89.8	85.8	81.4	76.8	72.3

APPENDIX E: THE FINITE SEGMENT CORRECTION

This appendix outlines the derivation of the finite segment correction and the associated energy fraction algorithm described in **Section 4.5.6**.

E1 GEOMETRY

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 aircraft sound, in the angular region that most influences sound event levels beneath and to the side of the aircraft flight path.

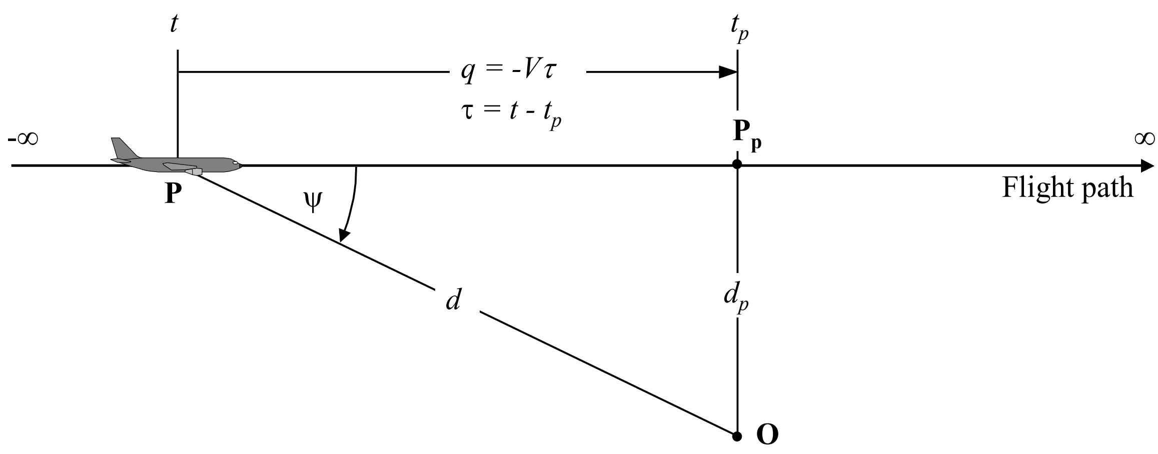


Figure E-1: Geometry between flight path and observer location O

Figure E-1 illustrates the geometry of sound propagation between the flight path and the observer location **O**. The aircraft 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 $\mathbf{P_p}$. The parameters are:

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

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

E2 ESTIMATION OF THE ENERGY FRACTION

The basic concept of the energy fraction is to express the noise exposure *E* produced at the observer position from a flight path segment $\mathbf{P_1P_2}$ (with a start-point $\mathbf{P_1}$ and an end-point $\mathbf{P_2}$) by multiplying the exposure E_∞ from the whole infinite path fly-by by a simple factor – the *energy fraction* factor *F*:

$$E = F \cdot E_\infty \tag{E-1}$$

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

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

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

$$p^2 = p_p^2 \cdot \frac{d_p^2}{d^2} \cdot \sin^2\psi = p_p^2 \cdot \frac{d_p^4}{d^4} \tag{E-3}$$

where p^2 and p_p^2 are the observed mean-square sound pressures produced by the aircraft as it passes points **P** and $\mathbf{P_p}$.

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 E-3 describes 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; from which the expression "fourth power" source.

By introducing the substitutions:

$$d^2 = d_p^2 + q^2 = d_p^2 + (V \cdot \tau)^2 \tag{E-4}$$

and

$$\left(\frac{d}{d_p}\right)^2 = 1 + \left(\frac{V \cdot \tau}{d_p}\right)^2 \tag{E-5}$$

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

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

By putting this into equation E-2 and performing the substitution:

$$\alpha = \frac{V \cdot \tau}{d_p} \tag{E-7}$$

the sound exposure at the observer from the fly-by between the time interval [τ_1, τ_2] can be expressed as:

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

The solution of this integral is:

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

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

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

and hence the energy fraction according to equation E-1 is:

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

E3 CONSISTENCY OF MAXIMUM AND TIME INTEGRATED METRICS – THE SCALED DISTANCE

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

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:

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

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:

$$L_{E,\infty}(V) = L_{E,\infty}(V_{ref}) + 10 \cdot \log\left(\frac{V_{ref}}{V}\right) \qquad \text{(E-13)}$$

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

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

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

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

the difference ΔL can be written:

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

This can only be equated to the value of ΔL 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:

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

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

$$\alpha_1 = \frac{-q_1}{d_\lambda} \quad \text{and} \quad \alpha_2 = \frac{-q_1 + \lambda}{d_\lambda} \tag{E-18}$$

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

APPENDIX F: MAXIMUM LEVEL OF NOISE EVENTS

In **Chapter 5**, eq. 5-6a and eq. 5-6b introduce a step-function u(k) which determines whether or not the maximum level contribution from flight path segment k is the maximum level of a noise event:

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

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

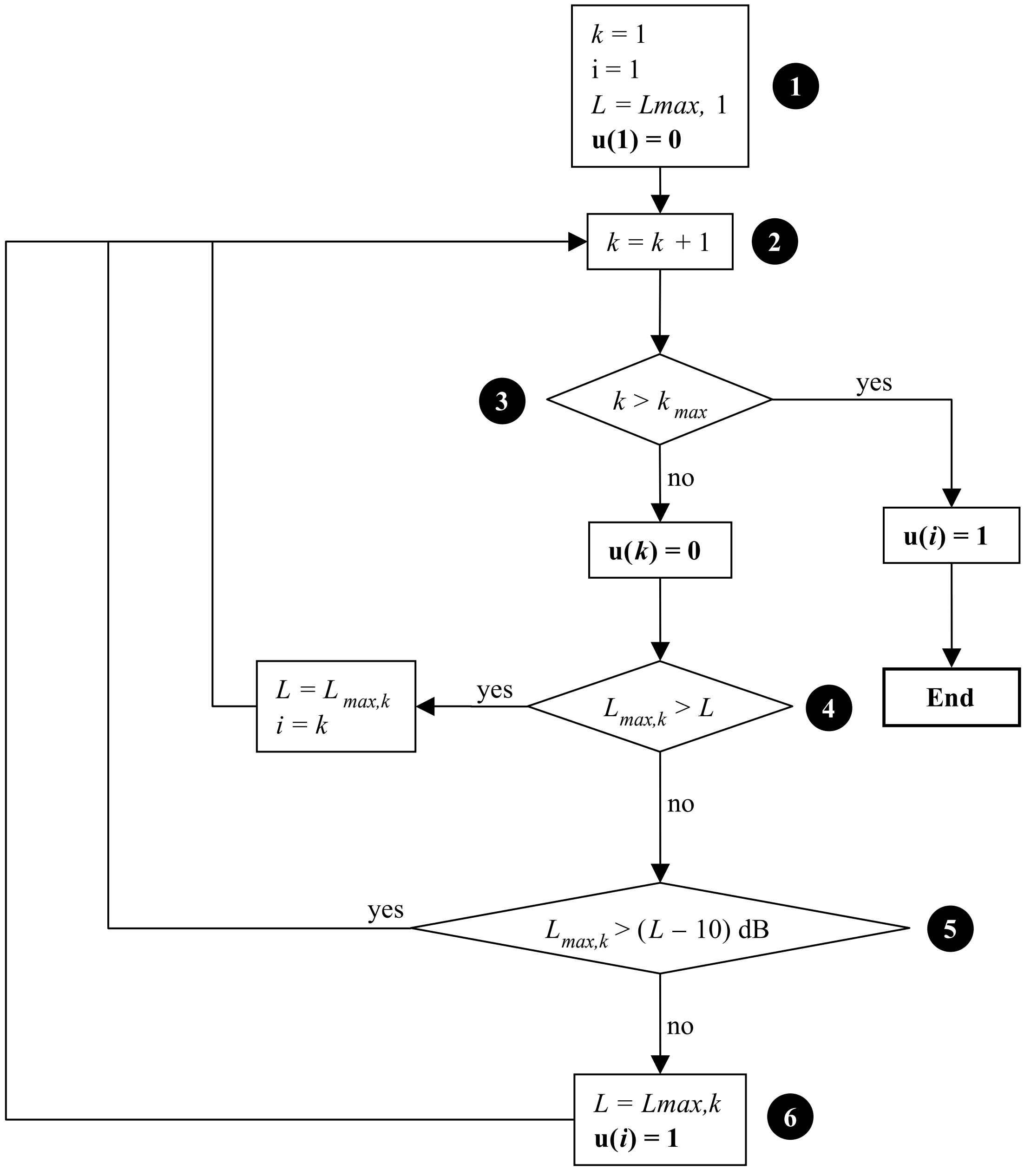


Figure F-1: Flow-diagram for the estimation of the function u(k)

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*.

❶ Initialise 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, initialise 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. initialise 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 step❷).

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.

Steps ❺ and ❻ are not necessary if only the highest maximum level produced by the actual aircraft type on the actual (sub)track has to be estimated. In this case, branch directly from step ❹ to step ❷.

APPENDIX G: THE INTERNATIONAL AIRCRAFT NOISE AND PERFORMANCE (ANP) DATABASE

G1 INTRODUCTION

To support the development of accurate aircraft noise contour models, an online aircraft noise and performance (ANP) database has been established. The current ANP database is available from EASA[41].

Data sources

The data accord with specifications and formats defined by the SAE International in AIR 1845 [ref. 6] and endorsed by ECAC, that are designed to achieve best practicable levels of data quality and consistency. By preference, entries are supplied by the aircraft manufacturers and these cover most of the larger, modern aircraft models and variants in the global airline fleet and that therefore govern the noise at most major airports. These entries usually include noise data acquired during noise certification tests carried out under stringent internationally standardised procedures that are regulated by national or international certification agencies. Data for some other aircraft, 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, which may not necessarily occur during official noise certification tests, and may include additional measurements and operations.

An ANP data submittal form is available via the EASA website which sets out the data requirements for new aircraft entries in the ANP database. Separate forms are provided for turbofan and propeller-driven fixed-wing aircraft due to the differences in some performance parameters.

Aircraft coverage and substitutions

With respect to aircraft entries, the ANP database includes a wide range of publically available data commercial jet, turboprop and propeller aircraft data that represent the current aircraft fleet that is used for environmental modelling purposes. The data exclude at present only data that are not required by ECAC; i.e., currently data for military aircraft and helicopters.

Aircraft models and variants that are not covered by the ANP database must be represented by substitutes (often referred to as "proxy" aircraft), i.e. aircraft with similar noise and performance characteristics that are included in the ANP database, and that can be adequately scaled (in terms of "equivalent number of movements") to represent the missing aeroplanes. Instructions for making the necessary substitutions are described in Volume 1 – section 6.4.4 – of this ECAC Guidance (ref. 4). 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 G5 of this appendix.

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

[41] The ANP database is linked on the ECAC website

coverage are urged to communicate their needs to the managers, via the website. Likewise, aircraft manufacturers that feel that data representing specific models of their aeroplanes with either new or updated ANP data should communicate their needs to the database managers via the website.

Data scrutiny

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. Likewise, aircraft manufacturers that feel that data representing specific models of their aeroplanes with either new or updated ANP data should communicate their needs to the database managers via the website.

Terms and conditions for accessing the database

Users must 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.

The use of the legacy ANP data are not subject to the ANP terms and conditions. They are available on the website.

Database content

The ANP data meet in full the requirements of the ECAC 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.

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.

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.

G2 AIRCRAFT TABLE

This tabulates the aircraft 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 aircraft according to selected criteria (e.g. source of the data, weight categories, noise certification status, etc.), and to assist with establishing aircraft substitutions.

The different fields/parameters of the Aircraft Table are listed below. Parameters that are required inputs to the noise contour model are <u>underlined</u>.

- <u>Aircraft Identifier (Aircraft ID)</u>: the ANP aircraft identifier which labels the associated performance data and by which it is accessed.
- Description of the aircraft: manufacturer, airframe, engine, etc.
- <u>Engine Type</u>: Jet, Turboprop or Piston.
- <u>Number of Engines</u>: used in various equations of **Appendix B**.

- Weight Class: Small, Large or Heavy.
- Owner Category: Commercial or General Aviation.
- Maximum Gross Take-off Weight (lb): used to calculate reduced take-off thrust (see **Appendix B**).
- Maximum Gross Landing Weight (lb): default approach profiles are usually provided for 90% of MGLW.
- Maximum Landing Distance (ft).
- Maximum Sea Level Static Thrust (lb): provided for standard day conditions.
- Noise Chapter (Noise certification standard).
- NPD ID: identifier associating the aircraft (ACFT_ID) with a set of NPD data, stored in the NPD table. (As NPDs tend to be powerplant-related, similar aircraft types may be assigned the same set of NPD data).
- Power Parameter: indicates which noise-related power parameter is used to access the NPD data (corrected net thrust, shaft horsepower, etc.) and the associated unit (pounds, percent, other).
- Approach and Departure Spectral Class IDs: identifiers associating the aircraft (ACFT_ID) with reference sound spectral shapes, one for approach and one for departure, stored in the Spectral Classes table.
- Lateral Directivity Identifier: Fuselage-mounted, Wing-mounted or Prop. Indicates the engine installation correction to be applied – see **Section 4.5.3**.

G3 AIRCRAFT PERFORMANCE TABLES

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

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

G3.1 Reference conditions for performance data

The performance data (engine coefficients) are provided by manufacturers for the following reference conditions:

Atmosphere:	International Standard Atmosphere (ISA) [ref. 1]
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

The engine coefficients, along with the thrust equations described in **Appendix B**, may be used also for aerodrome conditions other than 15°C, mean sea level and 4 m/s headwind (temperatures up to 43 °C (109 °F) and airport elevations up to 6,000 feet above mean sea level). The database also includes high temperature jet engine coefficients enabling thrust calculations above temperature breakpoint. The aerodynamic (flap) coefficients may also be used for other aerodrome conditions other than the reference conditions (with the same temperature and elevation limitations as for the engine coefficients). Both high temperature engine coefficients and supplemental flap coefficients are common supplemental data in the ANP database. Data developers are not required to provide high-temperature engine coefficients, although they are recommended. However, if such data are provided, then they will be included in the ANP database.

G3.2 Jet engine coefficients table

This table provides, for each different aircraft thrust rating, the jet coefficients E, F, G_A, G_B and H for use with thrust equation B-1 of **Appendix B** to compute the corrected net thrust per engine. The thrust ratings encompass ”MaxTake-off”, “MaxClimb”, and “IdleApproach” (the last one being used for approach procedures - see equation B-23). Some aircraft may also feature jet coefficients for thrust calculation above the temperature breakpoint (the corresponding thrust rating label includes a “HiTemp” suffix – e.g. “MaxTake-offHiTemp”).

Additionally, the table may provide (depending on the aircraft) a set of general jet coefficients (labelled “General”) enabling the calculation of non-rated thrust as a function of either EPR or N1, using equations B-2 and B-3 of **Appendix B**. These general jet coefficients include additional coefficients K_1-K_2 (for EPR) or K_3-K_4 (for N_1). All thrust ratings included in the aircraft’s profiles must be represented in the Jet engine coefficients table.

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

- Aircraft ID;
- Thrust rating – includes “general thrust” for non-rated thrust calculation;
- *E* (lbf);
- *F* (lbf/kt);
- G_A (lbf/ft);
- G_B (lbf/ft^2);
- *H* (lbf/°C);
- K_1 (lbf/EPR);
- K_2 (lbf/EPR^2);
- K_3 (lbf/(N1/$\sqrt{\theta}$)); and
- K_4 (lbf/(N1/$\sqrt{\theta}$)^2).

Note: Rated thrust coefficients are provided for at least ”MaxTake-off” and ”MaxClimb” thrust ratings. The general thrust K-coefficients are provided either for EPR ($K_{1,2}$) or N1 ($K_{3,4}$), depending on the aircraft/engine.

G3.3 Propeller engine coefficients table

This provides propeller efficiency and installed net propulsive power data for the calculation of corrected net thrust for propeller-driven aeroplanes (**Appendix B**, equation B-5). The data are usually provided for two thrust ratings: ”MaxTake-off” and ”MaxClimb”.

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

- Aircraft ID;
- Thrust rating: ”MaxTake-off” or ”MaxClimb”;
- η: Propeller Efficiency; and
- P_p (hp): Installed Net Propulsive Power.

G3.4 Aerodynamic coefficients table

This table provides, for each aircraft, the aerodynamic coefficients B_8, *C/D* and *R* (see **Appendix B**, equations B-9, B-12, B-15 and B-24) associated with different flap settings on arrival and departure. The number of flap settings and the flap identifiers are aircraft-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).

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

- Aircraft ID;
- Operation Mode: Arrival (A) or Departure (D);
- Flap ID, which can include an indication on gear position (up or down);
- *B* (ft/lb);
- *C* (initial climb speed calculation) or *D* (landing speed calculation) (kt/$lb^{0.5}$); and
- *R* (drag over lift ratio).

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

G3.5 Default weights table

This provides, for each aircraft, 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. Stage “M” represents the maximum trip length (in nmi) of the individual aircraft at MTOW, and it is documented separately, even if the maximum trip length falls within one of the other stage number categories. It is important to note that not all aircraft will be able to fly all trip lengths. The ANP for a given aircraft only includes stage lengths that represent the maximum range for the aircraft. However, all stage lengths included in the aircraft's profiles are represented in the Default weights table. The trip length stages are defined as follows:

Stage length number	Trip length (nmi)	Representative range (nmi)	Weight (lb)
1	0-500	350	lb
2	500-1 000	850	lb
3	1 000-1 500	1 350	lb
4	1 500-2 500	2 200	lb
5	2 500-3 500	3 200	lb
6	3 500-4 500	4 200	lb
7	4 500-5 500	5 200	lb
8	5 500-6 500	6 200	lb
9	6 500-7 500	7 200	lb

10	7 500-8 500	8 200	lb
11	>8 500		lb
M	Maximum range at MTOW		lb

The Representative Range of stage length, for which the take-off weight is calculated, is defined as follows:

Representative Range = Min Range + 0.70*(Max Range – Min Range)

The assumptions made to arrive at the default take-off weights associated with each of the above representative ranges may depend on the aircraft category and/or weight class, and may even vary from one manufacturer to another. Weight assumptions use industry planning assumptions for load factor, average passenger weight, excess cargo beyond passenger weight, and fuel required to complete mission trip length.

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

- Aircraft ID;
- Stage length number; and
- Weight (lb).

Note: Not all aircraft will be able to fly all trip lengths. The ANP for a given aircraft should only include stage lengths that represent the maximum range for the aircraft. However, all stage lengths included in the aircraft's profiles are represented in the Default weights table.

G3.6 Default departure procedural steps table

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 B**.

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

- Aircraft ID;
- Profile ID;
- Stage length:
- Step number;
- Step type: Take-off, Climb or Accelerate;
- Thrust rating: "MaxTake-off", "MaxClimb", other;
- Flap ID: flap settings used on each step;
- End point altitude (ft): altitude to be reached at the end of the segment;
- Rate of climb (ft/min): a pre-calculated vertical speed value reflecting a given Energy Share Factor assumption under the reference conditions of G3.1;
- Accel percentage (%): Energy Share Factor defining the percentage of available thrust dedicated to accelerating, whilst the rest is used for climbing[42]; and
- End point CAS (kt): calibrated airspeed to be reached at the end of an acceleration step.

[42] When both rate of climb and accel-percentage values are provided for a given acceleration step of a given aeroplane, it is recommended to use the accel-percentage value for aerodrome conditions differing from the reference conditions defined in G3.1.

Note: Each of the last four parameters is assigned a value or not (field "empty"), depending on the step type that is flown (example: a rate of climb and/or an accel percentage value is provided only for an **Accelerate** step, these fields being empty for other step types).

G3.7 Default approach procedural steps table

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

It is important to note that default approach profiles are the minimum set of approach profiles that may be listed for an aircraft in the ANP database. Additional profiles (such as continuous descent approach or CDA) may also be included for an aircraft in the ANP database.

Most of the modern aeroplanes recently included in the ANP database feature a default approach procedure incorporating level and deceleration step(s) before the final 3° descent steps along the ILS[43].

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

- Aircraft ID;
- Profile ID;
- Step number;
- Step type: Descend, Descend-Idle, Level, etc.;
- Flap ID;
- Start altitude(ft);
- Start CAS (kt);
- Descent angle (deg);
- Touchdown roll (ft);
- Distance (ft); and
- Start Thrust (% Max thrust)

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

G3.8 Default fixed-point profiles table

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

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

- Aircraft ID
- Operation mode: Arrival (A) or Departure (D)
- Profile ID
- Stage Length
- Point Number
- Distance (ft): travelled ground distance from start of take-off roll (positive values) for departure, or distance to go to touchdown point for approach

[43] Whereas older ANP aircraft entries often have a default approach procedure describing a continuous 3° descent from 6 000 ft to touchdown.

(negative values ahead of touchdown, positive values afterwards on the runway rolling portion)

- Height above field elevation (ft) at the profile point
- Speed TAS (kt): true airspeed at the profile point
- Corrected Net Thrust (lbf)

Note: Some tables have all the coefficients required to calculate departure profiles from the procedural step definition, but no aerodynamic coefficients enabling the calculation of approach configurations (flap settings) enabling the calculation of approach profiles from the procedural step definition. For these aircraft, default fixed-point profiles are provided for approach only.

G4 AIRCRAFT NOISE TABLES

These provide the acoustic data required to calculate the single event noise as described in **Chapter 4**. For each aircraft, 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).

G4.1 NPD table

This table provides, for each aircraft 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 aircraft may be assigned the same NPD data set.

The noise event levels are given for various single event noise metrics, including at least L_{Amax} and SEL, at ten slant distances: 200, 400, 630, 1000, 2000, 4000, 6300, 10000, 16000, and 25000 feet.

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.

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

- Noise Identifier (NPD_ID)
- Noise metric: maximum or exposure-based metric (LAmax, SEL, EPNL and PNLTmax)
- Operating mode: “A” or “D”
- Noise-related power parameter value
- L_n noise levels at distances d_n for n = 1 to 10

G4.2 Reference conditions for NPD and spectra data

NPD and spectral data are normalized for the atmospheric and operational conditions provided below. It is important to note that the noise reference conditions are slightly different from the performance reference conditions in G3.1.

- Atmospheric pressure: 101.325 kPa (1013.25 mb)
- Atmospheric absorption: attenuation rates listed in **Table D-1** of **Appendix D**
- Precipitation: none
- Windspeed: less than 8 m/s (15 kt)
- Aircraft reference speed (for the duration correction of the exposure-based metrics): 160 kt

G4.3 Spectral classes table

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

The spectral classes represent average spectral shapes at the time of maximum sound level, at a reference distance of 1,000 ft, and are normalised according to the same attenuation rates as the NPDs (listed in Table D-1 of Appendix D) Sound levels are provided for 24 one-third octave bands, with nominal centre-frequencies from 50 to 10,000 Hz. Each spectrum is unweighted by frequency band (unlike NPDs) and, for historical reasons, normalized to 70 dB at 1,000 Hz band, and the remaining on-third octave-bands in the spectrum should be adjusted by the difference between the level of the unadjusted 1,000 Hz band and 70 dB.

At the data developer discretion, the aeroplane may have standard, representative spectral classes assigned during the data review process, or it may have unique spectral classes (aircraft-specific spectral classes created from the submitted spectral data). A detailed description of the method used to develop spectral class data can be found on the website.

The table provides separate spectral shapes for approach and departure conditions. Thus, a given aircraft is assigned two spectral classes (through its two spectral class identifiers).

This table contains the following fields (each field representing a column in the table):

- Spectral Class ID
- Operation mode: "A" or "D"
- Description: general characteristics of the aircraft family that is assigned this spectral shape
- 24 relative one-third octave band sound levels for the centre-frequencies from 50 to 10,000 Hz.

G5 SUBSTITUTIONS TABLE

The Substitutions table available on the ANP database website gives 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.

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

- ICAO Code
- Aircraft Manufacturer
- Airframe Type: Aircraft type designation as in the aircraft type certificate
- Engine Manufacturer
- Engine Type: Engine type designation as in the aircraft type certificate
- Other Information: may include, for instance, propeller type designation as in the aircraft type certificate in the case of turboprop aircraft
- Number of engines
- MTOW (kg): Maximum Take-Off Weight
- MLW (kg): Maximum Landing Weight
- Noise Chapter: Noise certification category according to the ICAO Annex 16 Volume 1
- Lateral Level (EPNdB): Certified noise level on the lateral certification point
- Flyover Level (EPNdB): Certified noise level on the flyover certification point
- Approach Level (EPNdB): Certified noise level on the approach certification point
- Overflight Level (dBA): Certified noise level under overflight conditions for Chapter 6 aircraft
- Take-off Level (dBA): Certified noise level under take-off conditions for Chapter 10 aircraft
- ANP proxy: ANP proxy aircraft (i.e. ACFT_ID in the ANP Aircraft table)
- Δdep (dB): Noise adjustment to be applied to the departure NPD data of the ANP proxy aircraft
- Δarr (dB): Noise adjustment to be applied to the approach NPD data of the ANP proxy aircraft
- Ndep: Movement adjustment factor to be applied to departure operations of the aircraft to be substituted
- Narr: Movement adjustment factor to be applied to arrival operations of the aircraft to be substituted

G6 EXAMPLE DATA

Table G-1: Example aircraft table

ACFT_ID	Description	Source of data	Engine Type	Number of Engines	Weight Class	Owner Category	Max Gross Take-off Weight (lb)	Max Gross Landing Weight (lb)
737300	Boeing B737-300/CFM56-3B-1 Engines	Manufacturer	Jet	2	Large	Commercial	135000	114000
A320-232	Airbus A320-232 / V2527-A5 Engines	Manufacturer	Jet	2	Large	Commercial	169756	145505
SF340	Saab SF340B/CT7-9B Engines	Manufacturer	Turbo Prop	2	Large	Commercial	27300	26500

Table G-1 (continued)

ACFT_ID	Max Landing Distance (ft)	Maximum Sea Level Static Thrust (lb)	Noise Chapter	NPD Identifier	Power Parameter	App Spectral Class Identifier	Dep Spectral Class Identifier	Lateral Directivity Identifier
737300	4580	20000	3	CFM563	CNT (lb)	202	102	Wing
A32023	4704	26500	3	V2527A	CNT (lb)	205	103	Wing
SF340	3470	4067	3	CT75	CNT (% of Max Static Thrust)	211	110	Prop

Table G-1 (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 G-2: Example jet engine coefficients table

ACFT_ID	Thrust Rating	E (lb)	F (lb/kt)	Ga (lb/ft)	Gb (lb/ft²)	H (lb/ °C)	K1 (lb/EPR)	K2 (lb/EPR²)	K3 (lb/(N1/√θ))	K4 (lb/(N1/√θ)²)
737300	MaxClimb	17383.1	-15.61	0.148043	-1.0E-06	-24.2000				
737300	MaxTake-off	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					
A320-232	MaxClimb	15539.2	-4.09000	0.438331	-1.439E-05	0.000e+00				
A320-232	MaxTake-off	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 G-3: Example propeller engine coefficients table

ACFT_ID	Thrust Rating	Propeller Efficiency	Installed Net Propulsive Power (hp)
SF340	MaxClimb	0.90	1587.0
SF340	MaxTake-off	0.90	1763.0

Table G-4: Example aerodynamic coefficients table

ACFT_ID	Op Type	Flap Identifier	B (ft/lb)	C/D (kt/√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 G-5: Example default weights table

ACFT_ID	Stage Length	Weight (lb)
737300	1	96000
737300	2	102000
737300	3	108000
737300	4	119000
A32023	1	135700
A32023	2	141600
A32023	3	147700
A32023	4	158600
A32023	5	162000

Table G-6: Example default departure procedural steps 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	MaxTake-off			
A32023	ICAO_A	1	2	Climb	1+F	MaxTake-off	300.0		
A32023	ICAO_A	1	3	Climb	1+F	MaxTake-off	1500.0		
A32023	ICAO_A	1	4	Climb	1+F	MaxClimb	3000.0		
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		1041.0	226.9
A32023	ICAO_A	1	8	Accelerate	ZERO	MaxClimb		1191.0	250.0
A32023	ICAO_A	1	9	Climb	ZERO	MaxClimb	5500.0		
A32023	ICAO_A	1	10	Climb	ZERO	MaxClimb	7500.0		
A32023	ICAO_A	1	11	Climb	ZERO	MaxClimb	10000.0		
737300	STANDARD	4	1	Take-off	5	MaxTake-off			
737300	STANDARD	4	2	Climb	5	MaxTake-off	1000.0		
737300	STANDARD	4	3	Accelerate	5	MaxTake-off		1544.0	185.0
737300	STANDARD	4	4	Accelerate	1	MaxTake-off		1544.0	190.0
737300	STANDARD	4	5	Accelerate	ZERO	MaxClimb		1000.0	220.0
737300	STANDARD	4	6	Climb	ZERO	MaxClimb	3000.0		
737300	STANDARD	4	7	Accelerate	ZERO	MaxClimb		1000.0	250.0
737300	STANDARD	4	8	Climb	ZERO	MaxClimb	5500.0		
737300	STANDARD	4	9	Climb	ZERO	MaxClimb	7500.0		
737300	STANDARD	4	10	Climb	ZERO	MaxClimb	10000.0		

Table G-7: Example default approach procedural steps 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 G-8: 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	-162381.0	6000.0	272.3	1091.30
A32023	A	STANDARD	1	2	-112299.0	4009.0	264.7	912.70
A32023	A	STANDARD	1	3	-87765.0	3000.0	260.9	802.70
A32023	A	STANDARD	1	4	-61823.0	3000.0	204.6	456.50
A32023	A	STANDARD	1	5	-57240.0	3000.0	190.7	362.50
A32023	A	STANDARD	1	6	-54773.0	2871.0	189.8	358.20
A32023	A	STANDARD	1	7	-51725.0	2711.0	187.5	351.20
A32023	A	STANDARD	1	8	-47460.0	2487.0	177.7	391.40
A32023	A	STANDARD	1	9	-36430.0	1909.0	144.6	654.20
A32023	A	STANDARD	1	10	-35298.0	1850.0	139.6	708.10
A32023	A	STANDARD	1	11	-33710.0	1767.0	130.9	817.50
A32023	A	STANDARD	1	12	-33503.0	1756.0	130.9	4888.50
A32023	A	STANDARD	1	13	-19077.0	1000.0	129.5	4753.10
A32023	A	STANDARD	1	14	-1794.0	94.0	127.8	4598.30
A32023	A	STANDARD	1	15	-954.0	50.0	127.7	4570.80
A32023	A	STANDARD	1	16	0.0	0.0	126.7	4570.80
A32023	A	STANDARD	1	17	470.0	0.0	119.7	15900.00
A32023	A	STANDARD	1	18	4704.0	0.0	30.0	2650.00

Table G-9: Example NPD table

NPD Identifier	Noise Descriptor	Op Mode	Power Setting	L _200ft	L_400ft	L_630ft	L_1000ft	L_2000ft	L_4000ft	L_6300ft	L_10000ft	L_16000ft	L_25000ft
V2527A	SEL	A	2000.00	93.1	89.1	86.1	82.9	77.7	71.7	67.1	61.9	55.8	49.2
V2527A	SEL	A	2700.00	93.3	89.2	86.2	83.0	77.7	71.8	67.2	62.0	55.8	49.3
V2527A	SEL	A	6000.00	94.7	90.5	87.4	83.9	78.5	72.3	67.7	62.5	56.3	49.7
V2527A	SEL	D	10000.00	95.4	90.7	87.3	83.5	77.7	71.1	66.3	60.9	54.6	47.4
V2527A	SEL	D	14000.00	100.4	96.1	93.0	89.4	83.5	77.0	72.2	66.7	60.1	53.0
V2527A	SEL	D	18000.00	103.2	99.1	96.2	92.9	87.4	81.1	76.5	71.1	64.9	57.9
V2527A	SEL	D	22500.00	105.1	101.2	98.5	95.4	90.3	84.3	79.9	74.8	68.7	62.0
V2527A	LAmax	A	2000.00	89.3	82.8	78.2	73.4	65.8	57.4	51.2	44.4	36.7	28.6
V2527A	LAmax	A	2700.00	89.5	83.0	78.3	73.5	65.8	57.4	51.3	44.4	36.7	28.6
V2527A	LAmax	A	6000.00	91.6	84.7	79.5	74.2	66.5	58.0	51.9	45.0	37.2	29.1
V2527A	LAmax	D	10000.00	94.5	86.7	81.1	75.1	66.1	56.9	50.3	43.1	35.0	26.5
V2527A	LAmax	D	14000.00	98.0	90.4	85.3	80.1	72.0	63.1	56.6	49.2	40.9	32.0
V2527A	LAmax	D	18000.00	101.9	94.7	89.7	84.3	76.1	67.2	60.7	53.4	45.3	36.7
V2527A	LAmax	D	22500.00	104.1	97.1	92.4	87.4	79.4	70.6	64.4	57.5	49.5	40.5
V2527A	EPNL	A	2000.00	96.9	92.3	88.5	84.6	78.6	71.5	66.3	59.8	51.5	40.7
V2527A	EPNL	A	2700.00	97.0	92.4	88.6	84.7	78.6	71.5	66.3	59.9	51.5	40.8
V2527A	EPNL	A	6000.00	99.0	94.3	90.4	86.2	79.7	72.3	67.0	60.4	52.2	41.6
V2527A	EPNL	D	10000.00	100.7	96.0	92.1	87.6	80.5	72.8	66.0	59.1	49.7	36.8
V2527A	EPNL	D	14000.00	106.1	101.4	97.8	93.4	86.2	78.1	72.2	66.0	57.7	46.9
V2527A	EPNL	D	18000.00	107.7	103.3	99.9	96.1	89.6	82.5	77.2	71.2	63.6	53.8
V2527A	EPNL	D	22500.00	109.8	105.5	102.5	98.9	93.0	86.4	81.2	75.5	68.3	59.3
V2527A	PNLTmax	A	2000.00	103.3	96.5	91.3	85.5	76.9	67.6	60.9	53.0	43.6	32.3
V2527A	PNLTmax	A	2700.00	103.8	96.7	91.1	85.3	76.9	67.7	60.9	53.0	43.6	32.1
V2527A	PNLTmax	A	6000.00	106.3	99.2	93.4	87.0	78.8	68.3	61.4	53.5	44.0	32.6
V2527A	PNLTmax	D	10000.00	112.7	105.0	99.3	92.6	80.9	71.0	59.9	52.0	41.0	27.0
V2527A	PNLTmax	D	14000.00	114.9	107.1	101.4	94.8	84.1	74.0	66.4	58.4	48.6	37.1
V2527A	PNLTmax	D	18000.00	116.6	109.5	104.3	98.5	88.5	78.7	71.2	63.3	54.3	43.5
V2527A	PNLTmax	D	22500.00	118.6	111.4	106.3	100.3	91.5	82.7	76.0	68.4	59.3	48.5

Table G-10: Example spectral class table

Spectral Class Identifier	Operation Type	Description	L_50Hz	L_63Hz	L_80Hz	L_100Hz	L_125Hz	L_160Hz	L_200Hz	L_250Hz	L_315Hz	L_400Hz	L_500Hz
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 G-10: Example spectral class table (continued)

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
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 G-11: Example Substitutions Table

ICAO Code	Aircraft Manufacturer	Airframe Type	Engine Manufacturer	Engine Type	Other Information	Number of engines	MTOW (kg)	MLW (kg)	Noise Chapter	Lateral Level (EPNdB)	Flyover Level (EPNdB)	Approach Level (EPNdB)
A318	Airbus	A318-121	Pratt & Whitney	PW6122A	-	2	68000	57500	4	93.0	86.5	92.4
AT43	ATR-GIE Avions de Transport Regional	ATR 42-320	Pratt & Whitney Canada	PW121	-	2	17000	16850	4	84.9	76.7	96.7
B736	Boeing Company	737-600	CFM	CFM56-7B18	-	2	65998	55111	4	89.0	86.1	95.6

Table G-11: Example Substitutions Table (continued)

ICAO Code	Overflight Level (dBA)	Take-off Level (dBA)	ANP proxy	Δdep (dB)	Δarr (dB)	Ndep	Narr
A318	-	-	A319-131	2.5	-1.9	1.76	0.65
AT43	-	-	DHC8	-2.2	2.0	0.61	1.58
B736	-	-	737700	-1.8	-0.2	0.67	0.95

APPENDIX H: SUMMARY OF DIFFERENCES FROM DOC 29, 4TH EDITION (2016)

Table H-1: Chapter-by-chapter comparison of the present and previous edition of Doc 29

(Chapters not referred to are materially unchanged)

Volume 2 Chapter	Volume 2 Section	Comment/change from Doc 29 4th Edition
n/a	n/a	Grammatical and formatting changes throughout and improvement of standardised values and conversion factors between standardised values
n/a	n/a	Differences identified between previous and current equation formats
n/a	Explanation of Terms and Symbols	Added definitions of Perceived Noise Level (PNL) and Effective Perceived Noise Level (EPNL)
Chapter 3	3.6.3	Revision of landing ground roll segmentation description
Chapter 4	4.3.1	Defined and added Line of Sight Blockage (LOSB) to text and equations 4-8 and 4-9
Chapter 4	4.5.8	Added paragraph on Line of Sight Blockage
Appendix B	Appendix B	Comprehensive re-write of methodology New arrival and departure procedure steps added
Appendix B	Appendix B	Increase in airport elevation from 5,000 to 6,000 ft for applicability of ANP database
Appendix D	Appendix D	Method updated to improve clarity and reflected in revised example calculation
Appendix G	Appendix G	Updated EASA reference for ANP database

APPENDIX I: CONVERSION OF UNITS

In general, the units used in this document adhere to the *International System of Units* (SI), using metres and kilograms. The SI system was adopted by the 11th General Conference on Weights and Measures (1960) and it is described in the standard ISO 31 "Quantities and Units" (1992). However, flight parameters are mostly defined in units of feet, knots and pounds. The conversion factors are:

Symbol	**Name**	**Conversion**
ft	foot, feet	1 ft = 0.3048000 m
nm	nautical mile	1 nm = 1.852000 km
kt	knot (= nm/h)	1 kt = 1.852 km/h = 0.5144 m/s
lb	pound	1 lb = 0.4535924 kg
°F	Degree Fahrenheit	°F = °C *9/5 + 32

— END —