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ECAC.CEAC Doc 29

Report on Standard Method of Computing Noise Contours around Civil Airports

ECAC.CEAC Doc. 29

Second Edition

(Adopted by the Twenty-First Plenary Session of ECAC, 2-3 July 1997)

Foreword

In 1982, the Eleventh Triennial Session of ECAC decided to add the following tasks to the terms of reference of the ECAC Group of Experts on the Abatement of Nuisances Caused by Air Transport (known as ANCAT):

a) determination of a common method for noise footprint calculation and contour, the work on contours being restricted to those technical problems that are common to different cumulative aircraft noise exposure contour calculation methods;

b) determination of a common procedure for collection and dissemination of the noise and performance data for individual aircraft types among ECAC Member States; and

c) review of the need to develop a common noise scale for use in ECAC policy considerations affecting noise exposure around airports.

The outcome of the work above was adopted in 1985 by the Twelfth Triennial Session, and published in 1986 as ECAC.CEAC Doc. 29. Apart from one amendment, published in 1987, the document has remained unchanged until now.

Developments within the field have established the need for a total revision of the document. Work has been undertaken by the APATSI Environmental Aspects (APENA) sub-group of ANCAT, comprising experts from Denmark, France, the Netherlands, Norway, the United Kingdom, the European Commission and the ECAC Secretariat. This proposed complete revision to ECAC.CEAC Doc. 29 is primarily based on ICAO Circular 205-AN/1/25, "Recommended Method for Computing Noise Contours around Airports" and Nord 1993:38, "Air Traffic Noise Calculation - Nordic Guidelines". The document is further based on material made available to the sub-group during its five meetings.

This Second Edition of ECAC.CEAC Doc.29, Standard Method of Computing Noise Contour around Civil Airports was adopted by the Twenty First Plenary Session of ECAC (Strasbourg, 2-3 July 1997).

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CHAPTER 1

INTRODUCTION

1.1 AIM OF DOCUMENT

The noise at points on the ground from aircraft flying into and out of a nearby airport depends on a number of 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, affecting sound propagation. Airport operations generally include different types of aeroplanes, various flight procedures and a range of operational weights. Because of the large quantity of aeroplane-specific data and airport operational information that would be required to compute the noise of each individual operation, it is customary in airport noise studies to make certain simplifications, leading to estimates of noise index values which are averages over long periods of time (typically several months). Calculations are usually repeated at each of a series of points around the airport and then interpolations are made to trace outlines of equal noise index values (noise "contours") which are then used for study purposes.

In view of the large number of variables and of the simplifications usually made in the calculations, it is desirable to standardize procedures for computing airport noise contours. The aim of this document is to provide an outline for such a standard method, to identify the major aspects and to supply specifications in respect of each of these. An explanation of terms is given, covering those terms where confusion might arise. A complication is that the calculation method has to allow different ECAC Member States to use different noise descriptors and scales as bases for their respective noise indices. Options are mentioned in certain sections, therefore, to allow this to take place. Given these provisos, the method of calculation described should allow Member States to compute noise contours for their airports which are consistent with one another and as accurate as can be attained at present. Experience has shown that individual organizations making such calculations will benefit from well documented test cases in order to verify the correct implementation of the different calculation routines. To fulfil this need a few test examples are included in **Appendix A**.

There are a number of noise-generating activities on operational airports which are excluded from the calculation procedures given here. These include taxiing, engine testing and use of auxiliary power-units. In practice, the effects of these activities are unlikely to affect the noise contours in regions beyond the airport boundary.

1.2 SCOPE OF DOCUMENT

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

1.3 OUTLINE OF THE METHOD

Chapter 2 gives an explanation of the terms and symbols used in this document.

Chapter 3 gives a summary of the method for the calculation of contours and its applicability.

Chapter 4 gives the ECAC format of aircraft noise and performance information which manufacturers should follow when supplying data on individual aeroplane types.

Chapter 5 gives a method of grouping aircraft types which are similar in noise and performance characteristics; all the aeroplanes in a given group are to be considered as of a single type at the airport to be studied, if desirable for reasons of economy in the calculations.

Chapter 6 gives guidance on suitable spacings for a grid of points around the airport, at each of which noise levels according to the chosen noise index have to be calculated for each aircraft movement (arrival or departure).

Chapter 7 gives the method of calculating the noise at a grid point from an individual aeroplane movement, depending on the distance to the aeroplane, the power setting selected, the aeroplane speed as it flies past and extra attenuation of the sound levels in propagation over an absorbing ground surface (lateral attenuation).

Chapter 8 gives a method of modelling the aeroplane noise during the take-off roll. Advice is also given in respect of the noise during landing ground roll.

Chapter 9 gives a method of adding sound exposure levels taking into account the time of day of the different operations.

Chapter 10 gives a method of modelling primarily lateral dispersion of aeroplanes about nominal approach and departure routes.

Chapter 11 gives a method of correction for track geometry, to be applied when an aeroplane makes a turn, but only in respect of noise descriptors which allow for duration.

Chapter 12 gives overall guidance on the computation of the noise contours, indicating those aspects which remain at the discretion of the organization making the calculations.

CHAPTER 2

EXPLANATION OF TERMS AND SYMBOLS

2.1 DEFINITIONS OF TERMS

2.1.1 Format of aircraft noise and performance data

The framework or skeleton, according to which data are to be derived and presented.

2.1.2 Basic noise and performance data

The data for different aeroplanes types, including measurements where these have been made, extrapolations where necessary and a statement of the quality of the data. Estimates have to be given for projected new aeroplanes types.

2.1.3 Noise — power — distance data

Noise levels over a range of distances from the aeroplane, for each of a number of engine power settings. The levels include allowance for the effects of sound attenuation due to spherical wave spreading (inverse-square law) and atmospheric absorption. The distance parameter is defined by the perpendicular distance to the aeroplane flight path (sometimes termed the slant distance or the slant range).

2.1.4 Noise attenuation rules

Sound propagation equations or rates, showing how values of a noise descriptor vary with distance and with direction from the source. The causes of noise attenuation include spherical wave spreading, atmospheric attenuation, extra ground attenuation and shielding by both the airframe and separate jet engine exhaust flows. The last two of these causes of attenuation are generally included in the term "lateral attenuation".

2.1.5 Noise unit

A unit measuring the magnitude of an instantaneous sound. For environmental noise from aircraft, two noise units are generally used: the A-weighted sound level (abbreviated AL) and the Perceived Noise (abbreviated PNL). The AL and the PNL scales adjust the values of the noise levels for different sound frequencies to approximate respectively the auditory sensitivity of the human ear and the annoyance felt by the person hearing the noise.

2.1.6 Noise descriptor

A quantity used to represent the noise of a single "event", such as an aircraft fly-past, as experienced by an observer. There are two ways commonly used to quantify the noise of the single event : either the maximum level is assumed, or the sound pressure levels from instant to instant during the course of the event are combined, with time, to give a measure of the total sound energy.

2.1.7 Noise scale

A measure of the noise of a series of events, or of continuous noise with a fluctuating level. A noise scale involves measurement of acoustical quantities only, in such a way as to correlate generally with subjective assessment of noise as determined, for instance, from laboratory experiments under controlled conditions. A scale is general in the sense that it relates to the noise itself and to average subjective assessment irrespective of cultural or other differences.

2.1.8 **Noise index**

An expression used to rate noise in terms of subjective annoyance over a defined period of time; an index can also incorporate weightings of the single-event levels according to the time of day or night at which they occur and/or a weighting of the number of events occurring within the time period. The time limits and weightings are often chosen to conform with public opinion, as determined from surveys.

2.1.9 **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.

2.1.10 **Flight track (or ground track)**

A vertical projection of the flight path onto the ground plane.

2.1.11 **Flight profile**

The elevation of the flight path, showing the variation of aeroplane height along the ground track.

2.1.12 **Noise footprint**

A line of constant noise level around a runway, due to the noise of one take-off and one landing of an aircraft, operating under prescribed conditions (including weather, atmospheric conditions, flight profile, etc.).

2.1.13 **Noise contour**

A line of constant value of a noise scale or index around an airport, due to the noise of a traffic mix of aeroplanes under normal operating conditions and using normal flight paths.

2.2 SYMBOLS

2.2.1 **Noise**

L_A	(AL)	A-weighted sound pressure level
L_{Amax}	(MAL)	Maximum value of L_A
L_{AE}	(SEL)	Sound exposure level (defined in ISO 1996/1)
L	L_{Amax} or L_{AE}, under conditions identified by means of a subscript (see Chapter 7)	
L_p	1/3-Octave band sound pressure level	
p	Sound pressure	
t	Time	
$G(\ell)$	Overground lateral attenuation	
$\Lambda(\beta)$	Air-to-ground lateral attenuation	

2.2.2 Aircraft performance

P	Take-off coefficient
Q	Flight speed coefficient
R	Climb/descent coefficient
X_N	Net thrust, all engines
$\bar{X}_N$	Net thrust averaged over segment
γ	Climb angle over segment
RC	Rate of climb
Sg	Equivalent take-off roll distance
W	Aeroplane weight
M	Aeroplane mass
V	Aeroplane speed
$\bar{V}$	Aeroplane speed averaged over segment
v_W	Wind velocity (headwind positive)
f	Acceleration factor
f_W, f'_W	Wind coefficients
s	Horizontal distance over a flight path segment
h	Aeroplane height
g	Gravitational acceleration
h_p	Pressure altitude

2.2.3 Atmosphere

ISA	International standard atmosphere
T	Ambient air temperature
p	Ambient air pressure
ρ	Ambient air density
θ	T/T_o
δ	P/P_o
σ	ρ / ρ_o (also δ / θ)

2.2.4 Engine noise-related thrust parameters

E_ξ Thrust/noise constant

F_ξ Flight speed coefficient

G_ξ Altitude coefficient

H_ξ Temperature coefficient

C_{M_t} Propeller tip rotational Mach number coefficient

A_ν Noise constant

B_ν Thrust coefficient

C_ν Speed-altitude coefficient

Y Second order engine speed coefficient

ξ Representation for parameters X_N / δ, $N / \sqrt{\theta}$, $SHP / \delta\sqrt{\theta}$ or N_p

$\Delta\xi$ Difference in ξ due to temperature difference representing parameters $\Delta X_N / \delta$ or $\Delta SHP / \delta\sqrt{\theta}$

M_t Propeller tip rotational Mach number

N Low pressure rotor speed or fan speed

N_p Propeller rotational speed

SHP Engine shaft horse power

ν Representation for noise parameters $N / \sqrt{\theta}$, $SHP / \delta\sqrt{\theta}$, EIS

BPR By-pass ratio (at maximum static take-off thrust)

2.2.5 Engine indicators

EIS Engine indicator setting

EPR Engine pressure ratio

EPD Engine pressure difference

2.2.6 Subscripts

L	Take-off roll directivity
r	Refers to reference conditions
AP	Approach
CL	Climb
FR	Flap retraction
TO	Take-off
TAS	True airspeed
EAS	Equivalent airspeed

2.2.7 Mathematical and algebraic quantities

log	Logarithm to base 10
Δ	Change in value of a quantity, or a correction (as indicated in the text)
d	Perpendicular distance from an observation point to the flight path (slant distance or slant range)
ℓ	Perpendicular distance from an observation point to the ground track
β	Angle of elevation from an observation point to a point on the flight path
s	Standard deviation
r	Radial distance
Φ	Angle from the aeroplane ground track to a radial passing through an observation point
Ψ	Angle of turn of an aeroplane ground track

CHAPTER 3

CALCULATION OF CONTOURS

3.1 SUMMARY AND APPLICABILITY OF THE METHOD

For an airport noise study, the calculations comprise the following, in order:

a) determination of the noise levels from individual aeroplane movements at observation points around the airport;

b) addition or combination of the individual noise levels at the respective points according to the formulation of the chosen noise index; and

c) interpolation and plotting of contours of selected index values.

The numbers of aeroplane movements to be included in a study and the operational details for each are matters for selection. Clearly, a set of calculated noise contours is valid only for the traffic assumptions on which it is based. At all airports, the pattern of operations varies from day to day, depending on the weather, scheduling and many external factors. Generally the noise index for which the contours are calculated is defined in terms of long-term average daily values, typically over a period of some months. It follows that the contours intended to show noise exposures around an airport defined in terms of such an index should similarly depict average conditions over a long period of time. The traffic and operational patterns used in the study are then selected accordingly.

The noise levels for individual movements are calculated, for given atmospheric conditions assuming flat terrain, from noise-power-distance and aeroplane performance data (see 4.2.5). The conditions for the noise data are defined by atmospheric attenuation rates, for which the yearly averages drawn from several major world airports are assumed. The performance data are for defined atmospheric temperature and humidity, airport altitude and wind speed. However, given that the calculated noise contours depict average conditions over a long period of time, the same basic data are assumed to apply over specified ranges of conditions. The form of presentation, methods of derivation and reference conditions for the aeroplane data are given in Chapter 4.

The specification for noise data in Chapter 4 includes two noise descriptors. These are the maximum A-weighted sound pressure level occurring at some instant during an aeroplane movement, and the sound exposure level, which is the level of an integral with time of the square of the A-weighted sound pressure during the aeroplane movement (see 4.1.2).

3.2 INPUT INFORMATION REQUIREMENTS

For an airport to produce a set of noise contours, the organization making the calculation will require the following information:

a) the aeroplane types which operate from the airport;

b) noise and performance data for each of the aeroplane types concerned, supplied in accordance with the specifications of Chapter 4;

c) the routes followed by arriving and departing aeroplanes including dispersion across nominal ground tracks;

d) the number of movements per aeroplane type on each route within the period chosen for the calculation including - depending on the actual index chosen - the time of day for each movement;

e) the operational data and flight procedures relating to each route (including aeroplane masses, power settings, speeds and configurations during different flight segments); and

f) airport data (including average meteorological conditions, number and alignment of runways).

3.3 NOISE FROM INDIVIDUAL AEROPLANE MOVEMENTS

For a movement on an arrival or departure route, aeroplane positional information and corrected engine thrusts are computed throughout the various flight operational segments (see Chapter 4). From a selected point (co-ordinates *x,y*) on a grid arranged on the ground around the airport, the shortest distance to the flight path is calculated and the noise data (L) are interpolated for the distance (*d*) and the thrust (ξ) concerned (see Chapter 7). The aeroplane positional information should allow for some lateral displacement of the actual ground track in a particular case, relative to the nominal route, due to inexact track-keeping which occurs in practice. Corrections are applied (see Chapter 7) for extra attenuation of sound during propagation lateral to the direction of aeroplane $\Lambda(\beta,\ell)$ for directivity behind the start of take-off ground roll (Δ_L) and, in the case of the sound exposure level, for aeroplane speed (Δ_V) and changes in the duration of the highest noise levels where an aeroplane makes a turn in its flight path (Δ_T). Hence the noise level at the point on the grid, from the individual aeroplane movement, L(*x,y*), is derived. The calculation is expressed in mathematical symbols as follows:

$$L(x,y)=L(\xi,d)+\Lambda(\beta,\ell)+\Delta_L+\Delta_V+\Delta_T \qquad (1)$$

where (Δ_L) is evaluated only behind the start of take-off ground roll, being zero everywhere else, and (Δ_V) and (Δ_T) are only evaluated where the descriptor L is the sound exposure level.

The above process is repeated at the same point for all the movements of all the aeroplane types occurring within the time period over which the noise contours are to be calculated, and then again at all the other grid points. In an airport noise study, it may not be practicable to account for each aeroplane type separately when calculating flight profiles and noise levels. In such cases, different aeroplane types having similar noise characteristics and also similar performance at a particular airport may be categorized or grouped as, effectively, a single type at that airport (see chapter 5). This is especially likely to be the case in studies with future fleet mix scenarios. For such categorized or grouped types on a given route, the calculations as above need only be made once and the resultant noise levels at the grid points are then factored according to the number of movements of the type in the noise index summation.

CHAPTER 4

FORMAT OF AIRCRAFT NOISE AND PERFORMANCE INFORMATION TO BE USED

The framework is described below according to which the "basic" noise and associated aircraft performance information on fixed-wing aircraft, for use in the computation of aircraft noise contours around an airport, should be obtained, composed and presented.

4.1 NOISE POWER-DISTANCE DATA

4.1.1 Form of presentation

The noise data should cover a range of noise-related thrust parameter values and perpendicular distances to the flight path. For each noise-related thrust parameter value from approach to take-off, the data should be given in numerical tabular form, as illustrated in **Figure 1**. In addition, a graphical presentation may be used for reference. The following information should also be provided.

Aeroplane : _________________

Engines : _________________

Configuration — flap angle : _________________

— slat angle : _________________

— landing gear up/down : _________________

Engine thrust — parameter specified : _________________

— "corrected" parameter value : _________________

Aeroplane mass : _________________

Airspeed : 160 knots

Figure 1 : **Format of noise data**

Slant distance (m)	80	100	125	160	200	250	315	400	500	630	800
L_{Amax} (dB)											
L_{AE} (dB)											

Slant distance (m)	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000
L_{Amax} (dB)										
L_{AE} (dB)										

Note : *All noise levels are to be normalized to conform with the attenuation rates of Table I.*

The noise levels given should be those occurring directly under the flight path during steady flight, that is, a constant speed of 160 knots, constant configuration and thrust setting, without banking. The aeroplane configuration and flight speed to which the noise levels correspond should be identified on the tables and graphs.

The physical quantity selected for the noise-related thrust parameter should be directly compatible with that presented in the performance information (see section 4.2). Typical parameters are, amongst others, corrected net thrust, fan speed, propeller speed and engine shaft horse power.

In the noise tables, the intervals of the relevant parameters should be adequately spaced to ensure that the deviation from directly-obtained graph readings is less than 0.1 dB, assuming a linear interpolation. The number of thrust parameter values for which data are to be tabulated depends on the aeroplane type, but data must be provided at least for the approach and take-off values of the thrust parameter.

4.1.2 **Noise descriptor**

The noise data should be supplied in terms of the maximum A-weighted sound pressure level, L_{Amax}, and the sound exposure level, L_{AE}.

Note *: The sound exposure level, L_{AE}, is defined (see ref. 1) as follows :*

$$L_{AE} = 10\log\left\{(1/t_0)\int_{t_1}^{t_2}\left[p_A^2(t)/p_O^2\right]dt\right\}$$

where p_A (t) is the instantaneous A-weighted sound pressure, (t_2 - t_1) is a stated time interval long enough to encompass all significant sound of a stated event, p_O is the reference sound pressure (20 μPa) and t_O is the reference duration (1 s)

4.1.3 **Noise data envelope**

The envelope of the noise data should contain :

a) a range of thrust-related noise parameter values which encompasses all the values likely to be selected on the aeroplane during flight operations at and in the vicinity of an airport; and

b) perpendicular distances to the flight path ranging from 80 m to a maximum corresponding to a cut-off noise level of L_{Amax} = 65 dB or L_{AE} = 70 dB.

4.1.4 Data derivation

Whenever possible the data should be based on the results of tests conducted under controlled conditions and should be comparable in quality to data acquired for aeroplane noise certification purposes (cf. ref. 2). During controlled flyover noise tests, the position of the aeroplane along the flight path is measured and synchronised with the sound recordings. The aeroplane's engine power setting, flap deflection, landing gear setting, and airspeed are maintained at nominally constant values throughout the duration of each sound recording.

For the computation of L_{Amax} and L_{AE}, measured aeroplane sound data are reduced to 1/3-octave-band sound pressure levels in decibels relative to a reference pressure of 20 micropascals. Sound pressure levels are obtained, for the 24 1/3-octave bands with centre frequencies ranging from 50 to 10 000 Hz, at 0.5 s intervals throughout the duration of each flyover sound recording. After correction for instrument calibrations and background noise contamination, the measured 1/3-octave-band sound pressure levels are adjusted to conform with the attenuation rates of **Table 1**.

Note: *The attenuation rates given in Table 1 refers to 25°C and 70% relative humidity.*

For many jet- and propeller-powered aeroplanes, the preferred nominal flight altitude for noise measurements is of the order of 300 m (1000 ft) for each engine power setting. However, practicality often results in the measurement altitude being different for each aeroplane type and may range from 100 m (330 ft) to 800 m (2625 ft). This range of altitude encompasses those normally encountered in noise certification compliance demonstrations.

Measured aeroplane noise data are sometimes available for only one distance (altitude) per engine power setting. Thus, to develop a generalized noise-power-distance table it is necessary to make adjustments. The extent of data available will vary between aeroplane types. Full spectral time history information is to be preferred when available. Otherwise, use has to be made of peak spectrum and duration information. These two types of data are referred to below, as respectively, Type 1 and Type 2 and a broad overview follows of the procedures recommended for the development of generalized noise-power-distance data.

TABLE 1 – ATTENUATION RATES

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

(i) **Type 1 data — full spectral time history**

1. Adjust measured data to conform with the attenuation rates of Table 1.

2. For source-to-observation distances of 800 m or less, establish noise-power-distance relationships at selected distances (see, for example, Figure 1) by extrapolation of the full time history pattern to obtain L_{Amax} and by performing time integration to obtain sound exposure level, L_{AE} (the "integrated" method of adjusting data, see Annex 16, Volume 1, Appendix 2, Section 9.4 (ref. 2). The atmospheric attenuation rates of Table 1 are used as references.

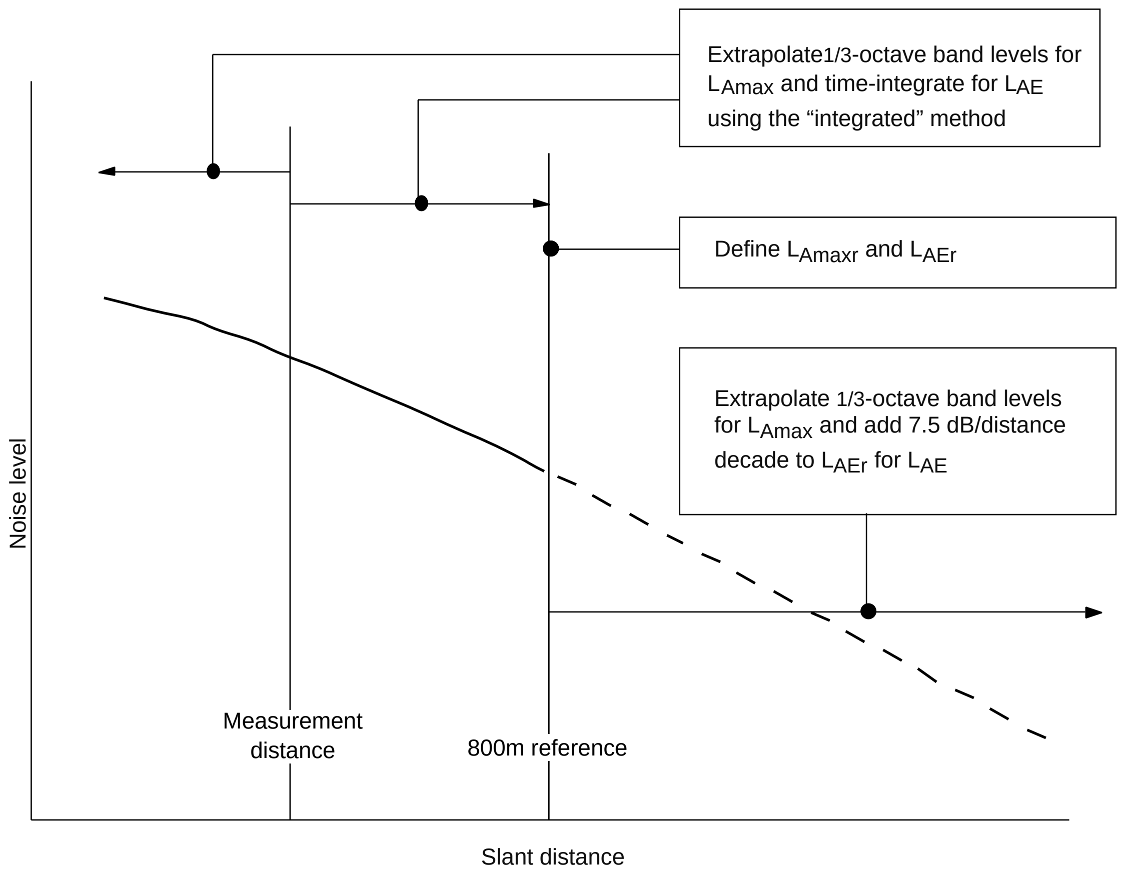
3. For a distance of 800 m define the sound exposure level, L_{AEr} , the maximum value of A-weighted sound pressure level, L_{Amaxr} , and the 24 1/3-octave band sound pressure levels, $L_{pr(i)}$ (for i= 1 to 24).

4. For distances, d, greater than 800 m, compute L_{Amax} for the adjusted spectral data, using the 800 m data as reference, by accounting for spherical divergence and atmospheric attenuation according to Table 1. L_{AE} for the new distance is determined by adding a 7.5 dB/decade duration factor for distance according to the following relation :

$$L_{AE} = L_{Amax} + (L_{AEr} - L_{Amaxr}) + 7.5 \log (d/800) \qquad (2)$$

Note *: The above procedure is illustrated in* ***Figure 2****.*

Figure 2 – Development of noise-versus-distance data from Type 1 measurements (attenuation rates from Table 1 throughout)



ii) **Type 2 data — spectrum at L_{Amax} plus measured L_{AE}**

1. Adjust measured spectral data corresponding to L_{Amax} to conform with the attenuation rates of Table 1.

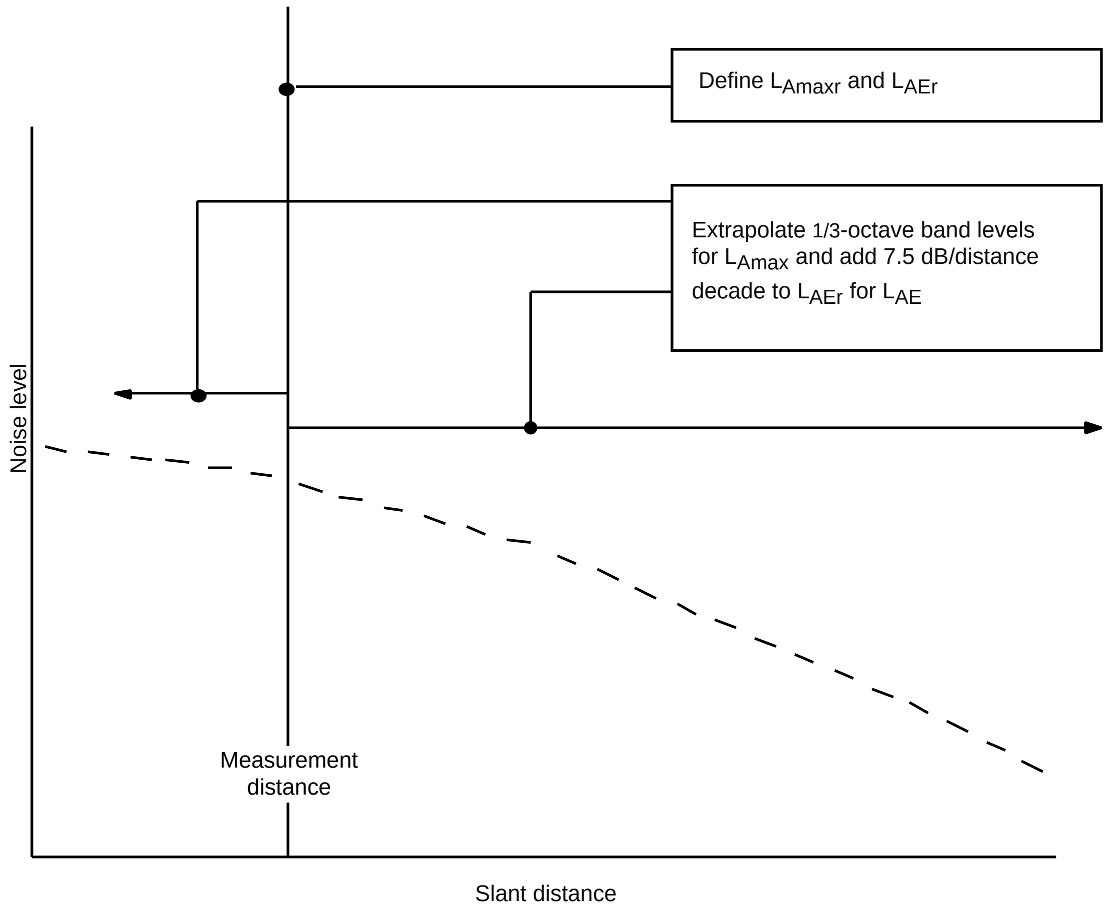
2. For the measurement distance define the sound exposure level, L_{AEr} , the maximum value of A-weighted sound pressure level, L_{Amax} , and the 1/3-octave-band sound pressure levels corresponding to L_{Amax}. The reference sound exposure level, L_{AEr} , is derived from the test day L_{AE} adjusted by the incremental difference between L_{Amax} corrected to the reference atmosphere and test day L_{Amax} , i.e. L_{AEr} for the measurement distance = $L_{AE} + (L_{Amaxr} - L_{Amax})$.

3. For distances, d, other than the measurement distance d_r , compute L_{Amax} for the adjusted spectral data by accounting for spherical divergence and atmospheric attenuation according to Table 1. L_{AE} for the new distance is determined from the following relation :

$$L_{AE} = L_{Amax} + (L_{AEr} - L_{Amaxr}) + 7.5 \log (d/d_r) \qquad (3)$$

Note *: The above procedure is illustrated in **Figure 3**.*

Figure 3 – Development of noise-versus-distance data from Type 2 measurements (attenuation rates from Table 1 throughout)



4.1.5 Range of atmospheric conditions for data validity

Experience in estimating airport noise levels and comparison of the estimates with measured data has led to the establishment of an envelope of near-surface long-term average conditions, within which noise-power-distance data obtained in accordance with the procedures of 4.1.4 above can be assumed to be applicable. This envelope is defined as follows :

— Air temperature less than 30°C

— Product of air temperature (°C) and relative humidity (per cent) greater than 500.

— Wind speed less than 8 m/s (15 knots).

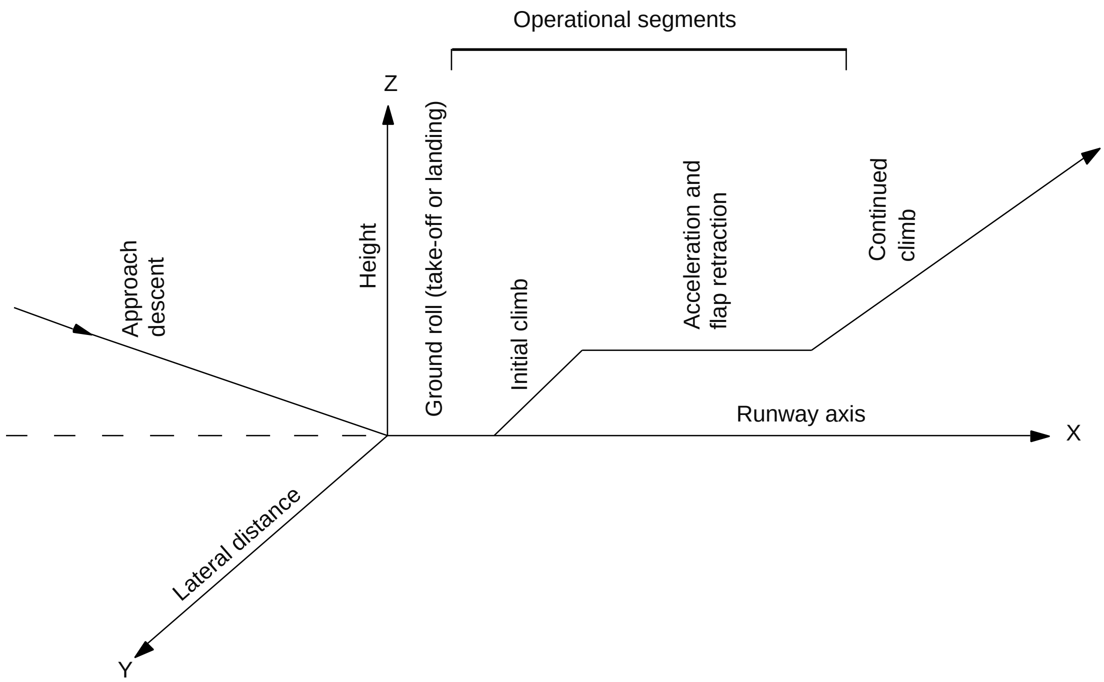
The acceptable envelope for average local conditions defined above is believed to encompass conditions encountered at most of the world's major airports. For situations where average local conditions fall outside the noted envelope, it is suggested that the relevant aeroplane manufacturers should be consulted.

4.2 PERFORMANCE DATA

4.2.1 Form of presentation

Aeroplane flight profiles are required in order to allow the determination of slant distances from the observation points to the flight paths. The variations of engine thrust, or other noise-related thrust parameter, and aeroplane speed along the flight path are also required (see 4.1). The slant distances and thrusts are then used for entry into and interpolation of the noise-power-distance data. For purposes of noise contour computations, take-off and approach flight paths are assumed to be represented by a series of straight-line segments, as illustrated in **Figure 4**. The ground tracks of the aeroplane are also represented by straight-line segments and arcs of circles.

Figure 4 – Typical flight path segments for performance calculations



Flight profiles, engine thrusts and aeroplane flight speeds might be supplied directly for an aeroplane type undergoing reference flight procedures (see 4.2.2). Then, for operations at an airport where the actual procedures in use are unknown, these reference procedures can be assumed. The information for other procedures known to be used, or for different operating conditions of the aeroplane, can be calculated using aerodynamic and thrust equations. The equations contain coefficients and constants which should also be made available for each combination of engine and aeroplane (see 4.2.3). The equations themselves are set out in **Appendix C**.

4.2.2 Reference flight procedures

Where possible, flight profiles, associated engine thrust information and aeroplane speeds should be supplied for an aeroplane type as it undergoes the following reference flight procedures:

a) ICAO Noise Abatement Take-off Procedure A and/or Procedure B (see Reference 3) at 85 per cent of maximum take-off mass;

b) ICAO Annex 16 Noise Compliance Approach (see Reference 2) at 90 per cent of maximum landing mass, but with the normal flap setting.

4.2.3 Characteristic aerodynamic and thrust/noise coefficients

The coefficients relating aeroplane performance to altitude, temperature, wind, aeroplane mass and total net thrust (see Appendix C) are as follows:

P Take-off coefficient

Q Flight speed coefficient

R Climb/descent coefficient

The coefficients relating the relevant thrust/noise parameter for a specific power setting (representing a stated engine performance such as "take-off power" or "normal climb power") to flight speed, altitude and ambient temperature, are as follows:

E_ξ Thrust/noise constant

F_ξ Flight speed coefficient

G_ξ Altitude coefficient

H_ξ Temperature coefficient

C_{M_t} Propeller-tip mach number coefficient

The subscript ξ above represents whichever engine noise-related corrected thrust parameter (X_N / δ, $N / \sqrt{\theta}$, $SHP/ \delta\sqrt{\theta}$ or M_t) that might be appropriate to a particular case.

Further thrust/noise coefficients can be used, to establish the relation between thrust parameter and noise at "general" thrust settings, or the relationship between thrust and indicator setting, as follows:

A_ν Noise constant

B_ν Thrust coefficient

C_ν Speed/altitude coefficient

The subscript ν above represents either of the corrected engine parameters $N / \sqrt{\theta}$, or $SHP/ \delta\sqrt{\theta}$ or an engine indicator setting (such as EPR or EPD). The derivation of these coefficients for an aeroplane type is discussed below.

4.2.4 Derivation of coefficients

The aeroplane performance coefficients, P, Q and R, the thrust coefficients for typical power settings, E_ξ, F_ξ, G_ξ and H_ξ and those for non-typical power settings, A_ν, B_ν and C_ν, have to be evaluated for each model of an aeroplane, generally by the manufacturer. The evaluations should be performed for the reference conditions specified below. The procedure is to make detailed performance calculations for the model concerned and then to derive the coefficients by use of the equations given in Appendix C with known values of the all-engine net thrust, aeroplane gross weight, speed, etc., inserted.

The flight speed coefficient, Q, has to be determined for each flap setting used in the different flight path segments. The climb/descent coefficient, R, is the non-dimensional ratio of the aeroplane drag coefficient to lift coefficient for a given flap setting and aeroplane configuration.

Care must be taken to ensure that the coefficients and constants are presented in dimensional units consistent with those of the variables calculated from the equations in Appendix C.

4.2.5 Performance reference conditions

All aeroplane performance information should be derived for reference conditions as follows:

- ISA atmospheric conditions;
- runway altitude sea-level;
- no runway slope;
- 4.1 m/s (8 kt) headwind, with no wind gradient;
- aeroplane take-off mass 85 per cent of maximum take-off mass;
- aeroplane landing mass 90 per cent of maximum landing mass;
- all engines operating; and
- normal aeroplane configurations.

4.2.6 Envelope of conditions for performance data validity

Unless an aeroplane manufacturer specifies otherwise, the performance information (i.e. coefficients derived from the reference flight profile or provided by the manufacturer) can be used as given, without correction, over a range of conditions as follows:

- air temperature less than 30°C;
- any runway altitude, provided the temperature and altitude are within the engine flat-rating range;
- wind speed less than 8 m/s (15 kt); and
- all practical operational aeroplane masses.

CHAPTER 5

GROUPING OF AIRCRAFT TYPES

5.1 INTRODUCTION

As many types of aircraft are normally operating at an aerodrome, the amount of computations would be tremendous, if each individual aircraft type was included in a noise study. For some aircraft noise data are not available. In practice, some kind of grouping is therefore necessary, but utmost care should be taken in order to keep the reliability of the study.

It is generally recommended that for commercial aeroplanes (jets and turboprops) and/or military aircraft grouping is only to be used in case of types having a limited number of operations. An approach to include such types by grouping with frequently operating types is presented in this chapter.

In case of general aviation aeroplanes (piston engine and turboprops with a MTOM below 5,700 kg) grouping would be the normal approach in a noise study, due to the amount of types in service. A possible approach is set out in **Appendix D** including noise and performance data, etc..

In case of helicopters grouping with other types of aeroplanes is impossible, as operations normally follow separate tracks. Noise calculations for helicopters are discussed in **Appendix B**.

5.2 APPROACH TO AIRCRAFT GROUPING

The aim of grouping different aircraft types is to identify certain characteristic parameters in order to use a limited amount of specific aircraft noise and performance data for the calculation of noise contours around an airport. In defining aircraft groups, use is made of characteristic parameters related to the noise emission and performance of aircraft.

Noise related and flight performance parameters are:

- Type of aircraft propulsion (jet, fan, or turbo-prop)
- Number of engines (1, 2, 3, or 4)
- By-pass ratio for fan engines
- Maximum Take Off Mass (in kg)

Identifying aircraft type by its utilization purposes, such as commercial aeroplanes, business and military transport aeroplanes has no meaning for noise exposure studies. So these are grouped together. The relevant parameter is MTOM. The number of ranges for MTOM is extended to include business jets and new large aircraft:

	MTOM (in kg)	
General Aviation (GA)		≤ 5,700
Light aircraft	5,700	- 10,000
Medium aircraft	10,000	- 50,000
Heavy aircraft	50,000	- 200,000
Very heavy aircraft	200,000	- 400,000
Ultra heavy aircraft	≥ 400,000	

Turbojets and turbofans are also grouped. Here the relevant parameter is the by-pass ratio (BPR). The obvious relation between engine by-pass ratio and noise emission leads to a further distinction amongst turbojet and turbofan aeroplanes:

- pure turbojet (BPR = 0)
- low by-pass ratio (LBRP) (0 < BPR ≤ 1.5)
- medium by-pass ratio (MBPR) (1.5 < BPR ≤ 4)
- high by-pass ratio (HBPR) (BPR > 4)

Another relevant parameter for aeroplanes in relation to the performance and the noise emission is the number of engines:

- 2 - engined
- 3 - engined
- 4 - engined

Finally, a distinction can be made by the ICAO ANNEX 16, Vol. 1 (see ref. 2), noise certification data of each aeroplane depending on the mass category and the first date of application for Certificate of Airworthiness:

- non noise certificate (certification date before January 1972)
- Chapter 2 - aircraft (certification date before 6 October 1977)
- Chapter 3 - aircraft (first certification date from 6 October 1977)

Such a grouping of aeroplanes is often used for distinction in airport noise levies and (government) regulations against aircraft noise.

5.3 PROPOSED AIRCRAFT GROUPING

A system of aircraft groups has been derived, based on physical parameters related to performance and noise emission and on the present ICAO Code and Type Description (see **Tables 2 and 3**).

For the calculation of noise contours around airports a selection of aircraft type can be chosen from the proposed grouping representing the fleet mix for a certain airport. Some aircraft type can be found in different groups. The reason for this is that models of that aircraft type differ in weight, engine model with another by-pass ratio or certification procedure. The same is valid for the ICAO Codes because various models have the same code. In such cases the actual aircraft type should be chosen that fits best into the fleet mix for that specific airport.

Note: *Within a group flight profiles might differ significantly. This should be taken into account when a representative type is chosen.*

TABLE 2: JET AIRCRAFT

GROUP DESCRIPTION	ICAO CODE [1] AND TYPE DESCRIPTION		
	NOISE CERTIFICATION		
	NOT CERTIFIED [2]	CHAPTER 2 [2]	CHAPTER 3
Turbojet 2 engines (GA)	S760 MS 760C Paris III	LR23 Learjet 23 Mk 2	
Turbojet 2 engines (light)	AC21 Jet Commander HF20 HFB 320 Hansa Jet P808 PD 808/526	LR24 Learjet 24 F LR25 Learjet 25 D WW23 IAI 1123 Westwind	
Turbojet 4 engines (heavy)	CONC Concorde		
LBPR turbofan 2 engines (medium)		B737 B737-200 NON ADV. BA11 1-11-500 FK28 Fellowhip F28 Mk 4000 G2 Gulfstream II/IIB G3 Gulfstream III TU34 TU-134/134A/B	
LBPR turbofan 2 engines (heavy)	DC9 DC-9/10/20/30/40	B737 B737-100/200 DC9 DC-9-50 S210 Caravelle 12	MD80 MD-80/81/82/83/ 84/85/86/87
LBPR turbofan 3 engines (heavy)		B727 B727-200	
LBPR turbofan 4 engines (very heavy)		IL86 IL-86 Camber	
MBPR turbofan 2 engines (GA)		C500 Citation I	C501 Citation I/SP Model 501

TABLE 2: JET AIRCRAFT (continued)

GROUP DESCRIPTION	ICAO CODE [1] AND TYPE DESCRIPTION		
	NOISE CERTIFICATION		
	NOT CERTIFIED [2]	CHAPTER 2 [2]	CHAPTER 3
MBPR turbofan 2 engines (light)			BJ40 Beechjet 400A C550 Citation II-S2 C551 Citation II/SP C560 Citation V C650 Citation III DA10 Falcon 10 HS25 HS-125 SERIE 1A LR35 Learjet 35 A LR36 Learjet 36 A LR 54 Learjet 54 LR 55 Learjet 55 MU30 Mu-300 Diamond IA S601 SN 601 Corvette
MBPR turbofan 2 engines (medium)		HS25 HS-125 SERIE 700A VF14 VFW 614 DA20 Falcon 20-C/D/E/F	DA20 Falcon 20F5 DA21 Falcon 20G/20GF Mystere Falcon 200 FK10 Fokker 100 FK70 Fokker 70 G4 Gulfstream IV HS25 HS-125-700 Dominie N265 Sabreliner 65 WW24 IAI 1124/1124A Westwind II AJ25 1125 ASTRA
MBPR turbofan 2 engines(heavy)			MD 80 MD-81, MD-83
MBPR turbofan 3 engines (medium)		YK40 Yak-40	DA50 Falcon 50 DA90 Falcon 900 B

TABLE 2: JET AIRCRAFT (continued)

GROUP DESCRIPTION	ICAO CODE [1] AND TYPE DESCRIPTION		
	NOISE CERTIFICATION		
	NOT CERTIFIED [2]	CHAPTER 2 [2]	CHAPTER 3
MBPR turbofan 3 engines (heavy)	TU54 TU-154	TU54 TU-154	B727 B727-200 RE
MBPR turbofan 4 engines (medium)	L329 Jetstar	IL76 IL-76 T	
MBPR turbofan 4 engines (heavy)	B720 Stratoliner 720 CV88 Convair 880 CV99 Coronado 990	B707 B707-320C DC8 DC-8-55 DC8S Super DC-8-63 IL62 IL-62M zonder hushkit	
HBPR turbofan 2 engines (medium)		AN72 AN-72, -74 Coaler	BA10 Bae 125 series 1000 CL60 Challenger CL601-3R CL65 Regional jet - Citation X - Falcon 2000 - Gulfstream V
HBPR turbofan 2 engines (heavy)		EA30 A300 B4-101	B73F B737-400 LR B73S B737-300 LR B73V B737-500 LR - B737-600/700/800 B757 B757-200 B767 B767-200/-300 ER EA30 A300-600/600 R EA31 A310-200/-300 EA32 A320-200 - MD-90 TUP4 TU-204
HBPR turbofan 2 engines (very heavy)			- B777-200 A/B EA33 A330-300/-300 LR

TABLE 2: JET AIRCRAFT (concluded)

GROUP DESCRIPTION	ICAO CODE [1] AND TYPE DESCRIPTION		
	NOISE CERTIFICATION		
	NOT CERTIFIED [2]	CHAPTER 2 [2]	CHAPTER 3
HBPR turbofan 3 engines (heavy)		YK42 Yak-42 Clobber	YK42 Yak-42 Clobber
HBPR turbofan 3 engines (very heavy)		DC10 DC-10-10/30/40	DC10 DC10-15/30ER L101 Tri-Star all series MD11 MD-11 ER
HBPR turbofan 4 engines (medium)			BA46 BAe 146-300 - Avroliner
HBPR turbofan 4 engines (heavy)			DC8S Super D-8-73 F
HBPR turbofan 4 engines (very heavy)		B747 B747-200/-200 B	B74F B747-400 B74S B 747-SP EA34 A340-200/-300 LR IL96 IL-96-300
HBPR turbofan 4 engines (ultra heavy)		AN4R AN-124 Condor	

1 If the ICAO code is -, no code is known (yet)
2 Hushkitted or reengined aircraft can be certified as chapter 2 or 3

TABLE 3: TURBOPROP AIRCRAFT

GROUP DESCRIPTION	ICAO CODE AND TYPE DESCRIPTION		
	NOISE CERTIFICATION		
		CHAPTER 2 [2]	CHAPTER 3
Turboprop (light)	BA31[0] Jetstream Super 31 BE02[0] M.1900C Airliner Model 1900 Executive BE30[0] Super King Air 300 BEST[0] Starship, Model 2000 D228[0] Do-228-212 SH7[0] Skyvan SC.7-3/3M SW2[0] Merlin IIA/B III/B/C, IVA SW3[0] Merlin IVC, Metro III/IIIA	O410 Turbolet L-410 RV01 Arava 202	CS12 C-212/200 Aviocar
Turboprop (medium)	CV60[1] Convair 600 CV64[1] Convair 640 HP7[1] Herald HPR7-200/-400 ND26 Nord 262/A/B/C/D Super Broussard 260 VC7[1] Viscount VC2-700/-800	AN24 An-24 Coke AN26 An-26/-26B Curl DH5 DHC-5D Buffalo DHC-5E Transporter G159 Gulfstream I/IC HS74 Andover HS748/2B (excl. hushkit) ILL4 ILL-114	AT42 ATR42-300 AT72 ATR72-200 BATP ATP adv. turboprop CN35 Airtech CN-235-200 CV58 Convair 580 D328 Do-328-100 DH8 Dash 8 DHC-8-100B E120 Brasilia EMB-1-20/RT FK27 Friendship F27 Mk 500 FK50 Fokker 50

TABLE 3: TURBOPROP AIRCRAFT (concluded)

GROUP DESCRIPTION	ICAO CODE AND TYPE DESCRIPTION		
	NOISE CERTIFICATION		
		CHAPTER 2 [2]	CHAPTER 3
Turboprop (medium) (continued)			HS74 Andover HS748/2B (incl. hushkit) SB20 Saab 2000 SF34 SF 340 SH33 Shorts 330-200/ UTT/Sherpa SH36 Shorts 360 DH7 Dash 7 DHC-7 150
Turboprop (heavy)	CL44 [1] Yukon/CL 44 L188 Electra	AN12 AN-12/-12BP Cub IL18 IL-18 ND16 Transall C-160 SH5 Belfast SC.-5/10	L382 Hercules C-130H - AN-70, 77
Turboprop (very heavy)		AN22 AN-22 Antheus	

0 Certified as small airplane (FAR Pt 36, Appendix F)
1 Possibly no noise certification
2 Most aircrafts are not certified but are expected to meet chapter 2

5.4. WEIGHTING OF NUMBERS OF MOVEMENTS TO ALLOW FOR DIFFERENCES OF NOISE LEVEL

Within a particular group (see Table 2 and 3) noise and performance data for frequently operating aeroplane types can be used to represent other types having a limited number of operations. However, the number of operations should be corrected carefully in order to take differences in actual noise emission into account.

If noise (and performance) data are available for the aeroplane to be represented by another aeroplane, these data should be used to find an equivalent number of operations. This should be done by producing noise footprints for both types and correcting the number of operations until a suitable conversion factor is found. One simple approach which may be found convenient is to make use of the FAA area conversion model (see ref. 6). In this case it is recommended that the 65 L_{DN} contour be used as a basis for conversion. An alternative approach could be summing up in decibels the noise emission received on the ground per operation (cf. Ref. 7). In this case the conversion of the number of operations can be made separately for takeoffs and landings.

In case no noise (and performance data) are available for the aeroplane to be represented by another aeroplane, certification levels could be used in order to estimate a suitable weighting number. In this case, it is recommended to proceed as follows :

a) Determine, for both aircraft types, the arithmetic mean L_{EPN} of the three noise certification levels at the reference positions;

b) Calculate the difference between these mean L_{EPN} values (ΔL) and hence a weighting number antilog ($\Delta L/10$);

c) Convert the number of movements of the one aircraft type to an equivalent number of movements of the other by a factor of this weighting number.

A further refinement of this latter procedure might be to introduce separate weighting numbers in respect of approaches and takeoffs, if appropriate.

Finally, in case of future aeroplane types (yet not certified) it is recommended to make a special evaluation including in particular the propulsion technique before noise and performance data for existing types are used as preliminary data.

CHAPTER 6

CALCULATION GRID

Noise contours are curves shown on a map illustrating how the noise index varies from location to location as the result of a given aircraft traffic pattern at an airport. Noise contours are normally obtained by interpolation of discrete values of the noise index at the intersection points of a regular observation grid centred on the airport.

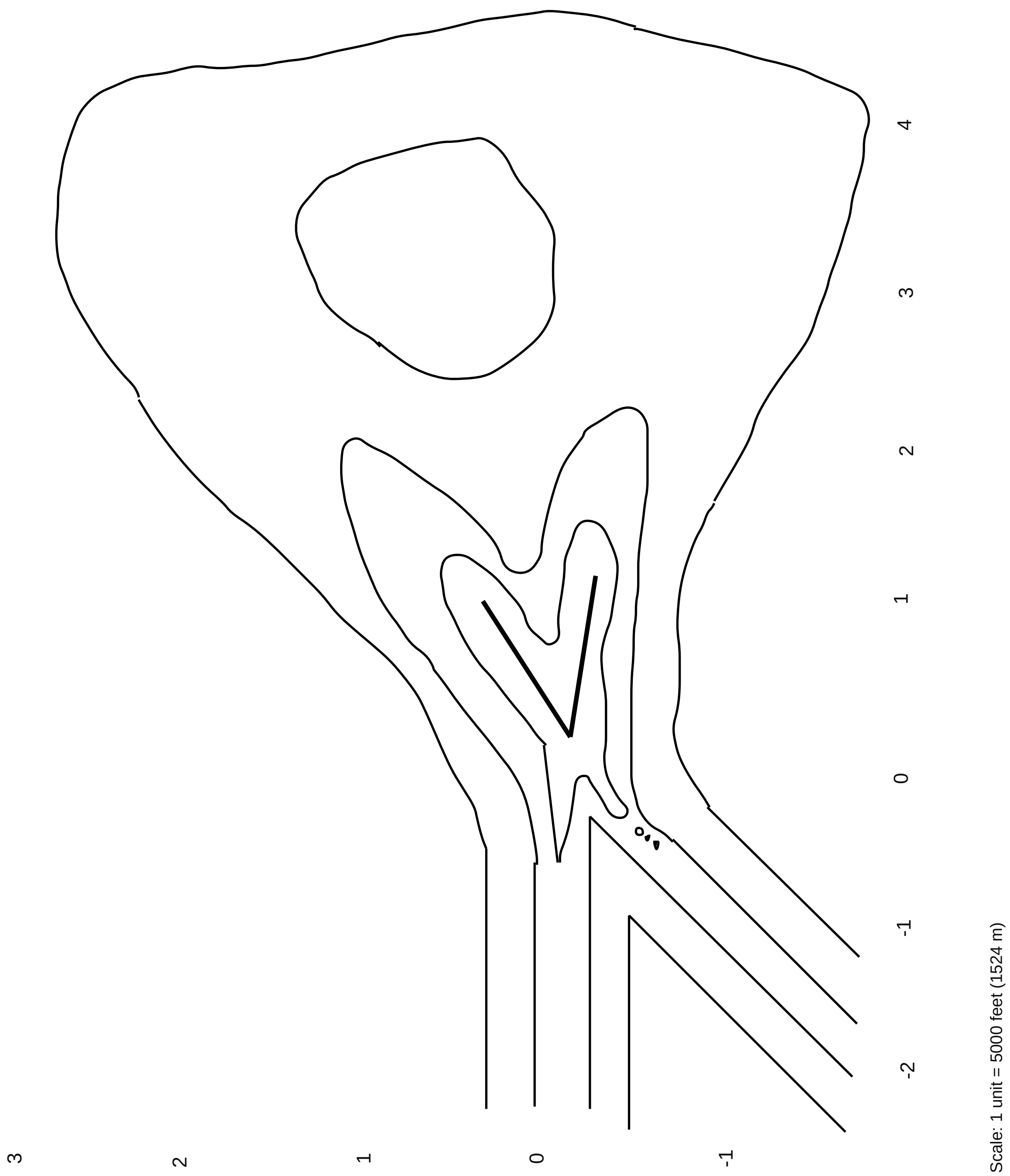
The choice of spacing between the grid points determines the extent to which fluctuations of the noise index are taken into account. Consequently, the quality of the noise contours will depend on the choice of the grid spacing, especially in such zones where sharp changes occur in the noise contours (see circled areas in **Figure 5**).

Interpolation errors on the noise contours are minimized by a close grid spacing, but this increases on the other hand the computation time as the noise index then has to be calculated in a large number of grid points. Comparative studies have shown that a maximum value of about 300 m for the grid spacing constitutes a good compromise between accuracy (standard deviation less than 0.5 dB for low and medium noise contours) of the interpolated noise contours and the computation time spent.

It is recommended that if a regular grid is used, the grid spacing should correspond to 2 mm on the map on which the noise contours are drawn. This implies that the grid spacing should be 200 m if the scale is 1 : 100 000, 100 m if the scale is 1 : 50 000, and 50 m if the scale is 1 : 25 000. This will allow linear interpolation between the grid points without further contour smoothing.

If, however, an irregular grid, and/or a sophisticated interpolation technique, and/or some kind of contour smoothing is applied, the number of calculations points may be reduced without significant loss in accuracy of the noise contours.

Figure 5 – Typical noise contours, showing zones having large gradients of noise index values in which small grid spacing might be needed for a proper plotting of the curves



CHAPTER 7

BASIC CALCULATION OF THE NOISE FROM INDIVIDUAL AIRCRAFT MOVEMENTS

7.1 DETERMINATION OF THE SHORTEST DISTANCE TO THE FLIGHT PATH

In this method, the noise level from individual aeroplane movements at a certain observation point is determined by a single calculation, corresponding to the moment when the aeroplane reaches the closest distance to the observation point. More accurate, but also more complicated methods using segmentation or simulation, are discussed in section 7.5.

During the flypast the sound level grows, reaches a maximum value, and decreases again. Both in the case of a noise descriptor based on the maximum level and in the case of a time-integrated noise descriptor, the shortest distance between the point of observation and the flight path is used as the distance parameter.

The noise-power-distance data described in Chapter 4 apply to an aeroplane in straight and level flight with a constant power-setting and a reference speed.

In the case of an actual movement, the aeroplane will normally be climbing or descending. However, it is assumed that the noise versus distance data still properly estimates the sound level or sound exposure level, if the shortest distance to the flight path is considered, and the corresponding power-setting and velocity used.

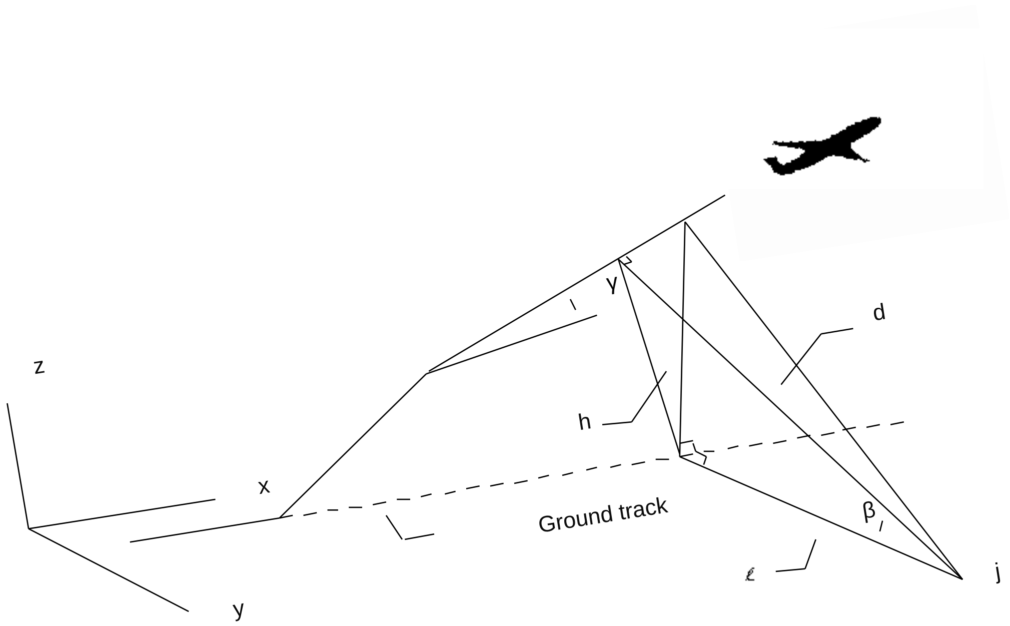
The symbols used to represent the different distances and angles are shown in **Figure 6**.

The shortest distance to the flight path (sometimes termed the slant range) is given by :

$$d = \sqrt{l^2 + (h \cos\gamma)^2} \qquad (4)$$

where l is the perpendicular distance from the point to the ground track, h is the aeroplane height as it flies over the intersection of the perpendicular to the ground track and γ is the climb angle of the flight path.

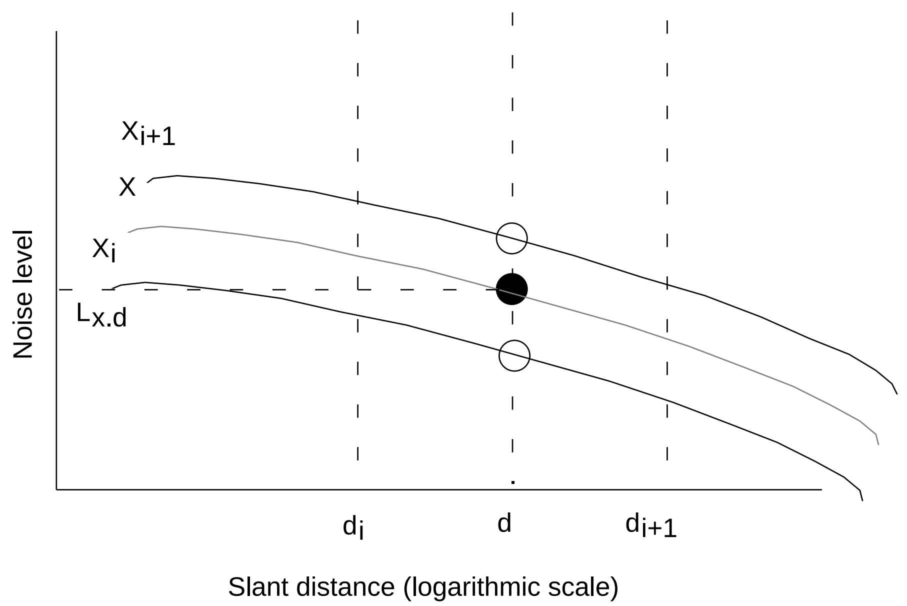
Figure 6 – Identification of the different distances and angles used for calculation of the sound level or sound exposure level and for the calculation of ground attenuation



7.2 INTERPOLATION OF THE NOISE-POWER-DISTANCE DATA

As the tabulated noise versus distance data will normally not correspond to the actual power-setting and/or the actual shortest distance, it will generally be necessary to estimate the sound level or sound exposure level by interpolation. A linear interpolation is used between tabulated power-settings, whereas a logarithmic interpolation is used between tabulated distances (see **Figure 7**).

Figure 7 – Noise-power-distance curves



Let X_i and X_{i+1} be tabulated net thrust values for which noise data are provided at some distance. The noise level at the same distance for intermediate thrust X, between X_i and X_{i+1} is given by :

$$L_X = L_{X_i} + \left(L_{X_{i+1}} - L_{X_i}\right)\frac{(X - X_i)}{(X_{i+1} - X_i)} \qquad (5)$$

Let d_i and d_{i+1} be tabulated distances for which noise data are provided at some power setting. The noise level at the same net thrust for an intermediate distance d, between d_i and d_{i+1} is given by :

$$L_d = L_{d_i} + \left(L_{d_{i+1}} - L_{d_i}\right)\frac{(\log d - \log d_i)}{(\log d_{i+1} - \log d_i)} \qquad (6)$$

By using Equations (5) and (6), a noise level $L_{X,d}$ can be obtained for any net thrust X and any distance d that is within the envelope of the reference data base, i.e., use of Equation (5) at d_i and d_{i+1} gives the level at thrust X, at d_i and d_{i+1} for use in Equation (6).

7.3 DURATION CORRECTION

Where L_{AE} data are presented, a duration correction due to a difference from the ground speed implicit in the basic noise data should be made according to the following formula :

$$\Delta_V = 10 \log V_{ref} / V \qquad (7)$$

where V_{ref} is the reference airspeed, V is the ground speed of the relevant flight segment and Δ_V is the duration correction.

The effect of speed changes on source noise is covered by entering the basic noise data at the thrust-related noise parameter appropriate to the flight condition.

Note : *In turning flight, there is an effect on the duration correction both inside and outside the flight track which is separately accountable (see Chapter 11).*

7.4 LATERAL ATTENUATION FOR CALM WIND CONDITIONS

Procedures for determining lateral attenuation for calm wind conditions (i.e., no wind), for an average aeroplane, are given in SAE AIR 1751 (1981) (cf. Reference 4). This is the procedure normally applied. A method to determine lateral attenuation for moderate downwind conditions (2 m/s perpendicular to the flight track) is given in **Appendix E**.

The adjustment consists of three equations which apply in the following cases :

a) when the aeroplane is on the ground;

b) when the aeroplane is airborne and the lateral (or sideline) distance is greater than 914 m (3000 ft); or

c) when the aeroplane is airborne and the lateral distance is less than 914 m.

The equations for specifying lateral attenuation when the aeroplane is on the ground are :

$$G(\ell) = 15.09 \left[1 - e^{-0.00274 \ell} \right] \quad \text{for } 0 < \ell < 914 \text{ m}, \qquad (8)$$

and

$$G(\ell) = 13.86 \quad \text{for } \ell \geq 914 \text{ m} \qquad (9)$$

where $G(\ell)$ is the overground lateral attenuation in decibels as a function of the horizontal lateral distance ℓ in metres.

When the aeroplane is airborne and the horizontal lateral distance is greater than 914 m, air-to-ground lateral attenuation is given by :

$$\Lambda(\beta) = 3.96 - 0.066\beta + 9.9 e^{-0.13\beta} \quad \text{for } 0° \leq \beta \leq 60° \qquad (10)$$

and

$$\Lambda(\beta) = 0 \quad \text{for } \beta > 60°, \qquad (11)$$

where $\Lambda(\beta)$ is in decibels and elevation angle $\beta = \cos^{-1}(\ell / d)$, is in degrees.

Lateral attenuation is given by a transition equation when the aeroplane is airborne and the horizontal lateral distance is less than, or equal to, 914 m, namely :

$$\Lambda(\beta, \ell) = [G(\ell)][\Lambda(\beta)] / 13.86 \qquad (12)$$

where $G(\ell)$ and $\Lambda(\beta)$ are given by Equations (8) to (11).

Regarding the applicability of the above formulae to different kinds of noise descriptor, SAE AIR 1751 states as follows :

> "A difficulty is encountered when consideration is given to the quantity used to measure lateral attenuation in the overground and transition regions. All overground attenuation data was for engines operating under static conditions, and clearly a duration correction in this context is not appropriate. Hence, the curves derived for overground attenuation were not in terms of time-integrated measures such as Effective Perceived Noise Level (EPNL) or Sound Exposure Level (SEL). However, there was a fair amount of evidence that the decay with distance of Maximum Perceived Noise Level (PNLM) is similar to the decay of EPNL or SEL. In most cases, the decay of maximum A-weighted sound level (ALM) was within 1 dB of the decay of the time-integrated measures. Therefore, it was concluded that the prediction methods for the overground and transition regions could be applied to maximum as well as time-integrated quantities. This is, in fact, a pessimistic assumption in terms of the time-weighted measures, since overground attenuation will reduce the forward and aft-radiated noise produced by an aeroplane accelerating or decelerating along a runway more than it reduces the maximum value. Thus, the duration term decreases more rapidly with lateral distance than the maximum noise level."

7.5 SEGMENTATION/SIMULATION

The ordinary method outlined is based on the fundamental assumption that the noise can be calculated as if the aeroplane was following a straight track and was flying at a constant height with constant power setting and constant speed. Approximate methods to correct the calculated noise level (L_{AE} or L_{max}) in certain sectors are supplementary given throughout the document.

For the sake of completeness two possibilities for improving the calculation accuracy shall be mentioned in this section. Two advanced calculation techniques denoted segmentation and simulation will briefly be described below (see Reference 8).

A technique used in several more advanced computer programs for calculation of the sound exposure level is segmentation. The flight path is divided into segments each of which fulfils the requirements for using the noise data format (straight flight path, constant speed, and power setting). The sound exposure level is calculated for each segment and corrected for the finite length of the segment before the contributions from all segments are added. The use of segmentation solves many of the computational problems as e. g. the effect of change in power setting described in Section 7.6 and the effect of changed duration in connection with a turning flight track as described in Chapter 11. The costs for high degree of segmentation are increased computer time compared to the ordinary method.

Another technique which provides even better results than the segmentation technique is simulation. In the simulation technique the instantaneous sound pressure level is calculated at small time intervals as a function of time during a take-off or landing, and the sound exposure level or maximum level is determined from the time history. If simulation is used, corrections are not applied as described throughout this document, but the physical aspects behind the corrections become an integrated part of the simulation. The disadvantage of the simulation technique is a substantial increase in computation time even compared to the segmentation technique.

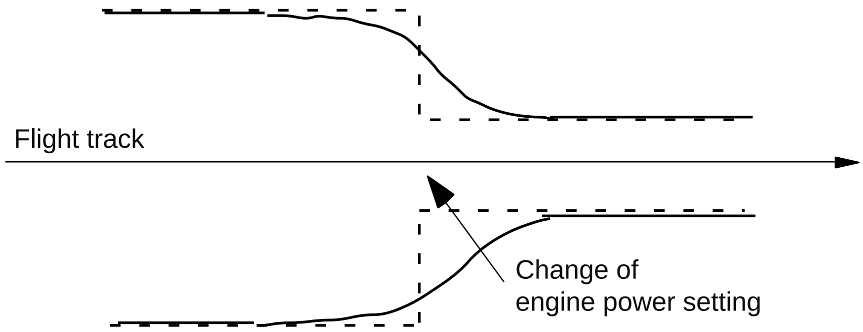
7.6 CORRECTION FOR CHANGE IN POWER SETTING

If segmentation (as described in Section 7.5 above) is not used, it may be necessary to make provisions for the changes on the L_{AE} and L_{amax} due to step changes in the power setting.

The following method is reproduced from the document "Air Traffic Noise Calculation — Nordic Guidelines" (see Reference 8). If the power setting and hence the noise emission is constant or changing very slowly within the section of relevance to the noise metric of current interest, the assumption of using the power setting in the point P as a representative of the whole fly-by is reasonable.

However, if fast, significant changes in the power setting take place, this principle will lead to discontinuities in the calculated noise contours as shown in **Figure 8** with dashed lines. This is, of course, not correct, and for the sound exposure level L_{AE} which is a time integrated level based on the entire fly-by the noise exposure contours should look more like the solid lines in Figure 8. The contours in Figure 8 are only examples presenting the problem. Very often programmes, which do not contain a method for calculating the effect of changes in the engine power setting, use gradual changes of the power settings in the input performance data to simulate the changes in the noise contours.

Figure 8 — Correction for changes in power setting



In the case of maximum levels the contours shall be without discontinuities, too. The maximum level in the area influenced by the change in power setting may be determined by other parts of the flight path than that closest to the calculation point.

The calculation method should therefore include an algorithm which predicts the effect of changes in power settings with a reasonable accuracy.

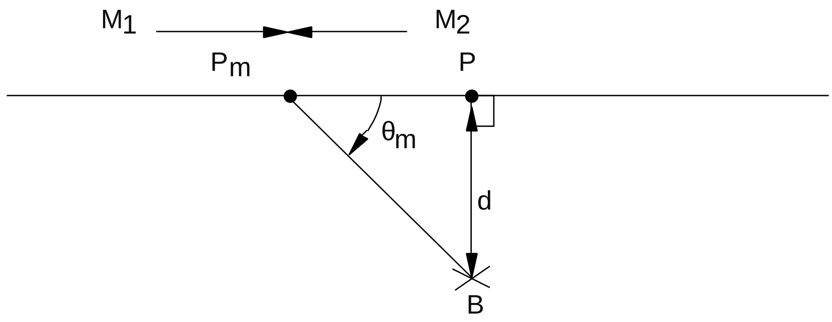
A very accurate prediction of the noise level in a calculation point close to parts of the flight path on which changes in power settings take place is a highly complicated matter. Such a prediction has to take into account the directivity pattern of each individual aircraft and all changes in power settings during the flight. The directivity pattern will vary from one aircraft to another, and large differences will be found, especially between jet aircraft with maximum in noise emissions 30-60° from the tail, propeller aircraft which are closer to be omnidirectional, and helicopters which can have a maximum nearly anywhere and a directivity pattern which is not symmetrical around the length axis as for fixed-wing aircraft types.

Differences in directivity patterns are not considered in this method. The method is based on algorithms from the document "Integrated Noise Model (INM), Version 3, User's Guide — Revision 1, FAA Report No. DOT/FAA/EE 92/02 by M.C. Flythe (1992)" for a generalized directivity pattern.

The first step is to determine the angle θ_m (in °) between the direction of the aircraft and the direction P_mB. P_m is the point where the power setting is changed, and B is the calculation point as shown in **Figure 9**.

If P_mB is more than three times PB, the effect of changes in power setting may usually be ignored when calculating L_{AE} whereas twice is usually enough when calculating L_{AMAX}.

Figure 9 — Definition of geometrical parameters for prediction of the changes in power setting.



The effect of changes in power setting on the sound exposure level L_{AE} is calculated according to Equation 13.

$$L_{AE}(d) = 10\ \log\left[(F(\theta_m)10^{\frac{L_{AE,1(d)}}{10}} + (1-F(\theta_m))10^{\frac{L_{AE,2(d)}}{10}}\right] \qquad (13)$$

where $L_{AE,1}(d)$ is the sound exposure level in distance d at the power setting before P_m.

$L_{AE,2}(d)$ is the sound exposure level in distance d at the power setting after P_m.

$F(\theta_m)$ is the proportion of the sound energy from $\theta = 0°$ to $\theta = \theta_m$.

The proportion of the sound energy $F(\theta)$ from 0° to θ is calculated according to Equation 14.

$$F(\theta) = \frac{\theta}{180} - \frac{\sin(\theta)\cos(\theta)}{\pi} \qquad (14)$$

The principle may easily be extended to cover two or more changes in engine power settings as the proportion of the energy from θ_{m1} to θ_{m2} is equal to $F(\theta_{m2}) - F(\theta_{m1})$.

The effect of changes in power setting on the maximum L_{Amax} is calculated according to Equation 15. The highest of the two alternative values in Equation 15 is used.

$$L_{Amax}(d) = L_{Amax,1}(d)$$

$$L_{Amax}(d) = L_{Amax,2}(d) = +10\ \log\left(\sin^4(\theta_m)\right) \qquad (15)$$

where $L_{Amax,1}(d)$ is the maximum level in distance d at the power setting corresponding to the segment which contains P.

$L_{Amax,2}(d)$ is the maximum level in distance d at the power setting corresponding to the adjoining segment.

Also in the case of maximum levels the principle may easily be extended to cover two or more changes in engine power settings as the second alternative in Equation 15 is repeated for each power setting.

CHAPTER 8

NOISE DURING THE TAKE-OFF AND LANDING GROUND ROLL

8.1 INTRODUCTION

Modelling of the noise at ground positions near the airport runway during the take-off roll requires several modifications of the basic noise-power-distance data. The modifications result from the fact that the aeroplane is on the ground accelerating from essentially zero velocity to its initial climb speed, whereas the basic data are representative of overflight operations at constant airspeed. To accommodate these differences, consideration must be given to changes in generated sound resulting from jet relative-velocity effects, varying directivity patterns from the moving aeroplane, the modified effective duration with increased speed and extra attenuation of sound during over-ground propagation at near-zero elevation angles. The present model is applicable only to jet aeroplanes and is subject to further development in the light of continuing research. Further work will also be required to determine its applicability to propeller-driven aeroplanes or to establish an alternative method.

Several factors can effect the accuracy of the modelling. Principal among these are wind and temperature gradients and variability in the operational procedures employed during take-off. The present model does not include any allowance for wind and temperature effects, even though these can cause significant changes in ground-to-ground attenuation and can even result in shadow zones in special cases. Experience has shown that different pilot techniques are employed at the start of the take-off roll, including a rolling start with no pause after taxiing, an early or a later selection of full take-off power, or even on occasion the application of full power while the brakes are still on. Noise contour calculations are intended to determine averages from a number of operations and so an overall method is given which is intended to give an envelope enclosing all these effects.

The method of modelling described below was developed from measurements of the sound exposure level, L_{AE}. However, it is believed from limited available experimental data that the method is applicable also in the case of maximum noise level descriptors.

8.2 TAKE-OFF ROLL NOISE MODELLING FOR JET AEROPLANES

Using the co-ordinate system of **Figure 10**, the noise level for negative values of x (i.e. behind the start-of-roll point) is computed as follows :

a) The radial distance, r, from the start-of-roll position of the aeroplane to an observation point, K, at (-x, y) and the angle Φ in degrees between the radius to K and the runway axis, are determined.

b) A directivity function, Δ_L, for the region behind the start-of-roll, is evaluated as follows (Φ expressed in degrees) :

For 90° < Φ < 148.4°

$$\Delta_L = 51.44 - 1.553\Phi + 0.015147\Phi^2 - 0.000047173\Phi^3 \qquad (16)$$

For 148.4° < $\Phi \leq$ 180°

$$\Delta_L = 339.18 - 2.5802\Phi - 0.0045545\Phi^2 + 0.000044193\Phi^3 \qquad (17)$$

c) The noise level at K, L_K, is then determined as follows :

$$L_K = L_{X_{TO}} + \Delta_V - G(r) + \Delta_L \qquad (18)$$

where:

$L_{X_{TO}}$ = noise level corresponding to distance r and net thrust X_{TO} (at lift-off from the runway) interpolated from the noise-power-distance data,

Δ_V = duration correction to allow for the difference between the local speed and the reference speed for which the noise-power-distance data are quoted, (see Equation 7)

G(r) = lateral attenuation adjustment corresponding to distance r (see Section 7 4), and

Δ_L = directivity factor determined from Equation (16) or (17) as appropriate.

Note that Equation (18) applies to noise descriptors including a duration allowance.

In the case of a maximum noise level descriptor, the same formula applies (see Reference 8), except that in this case Δ_V is a correction for flight effect only, as duration is not taken into account for maximum levels:

$$\Delta_V = 0.036(V_L - V) \text{ in dB} \qquad (19)$$

where:

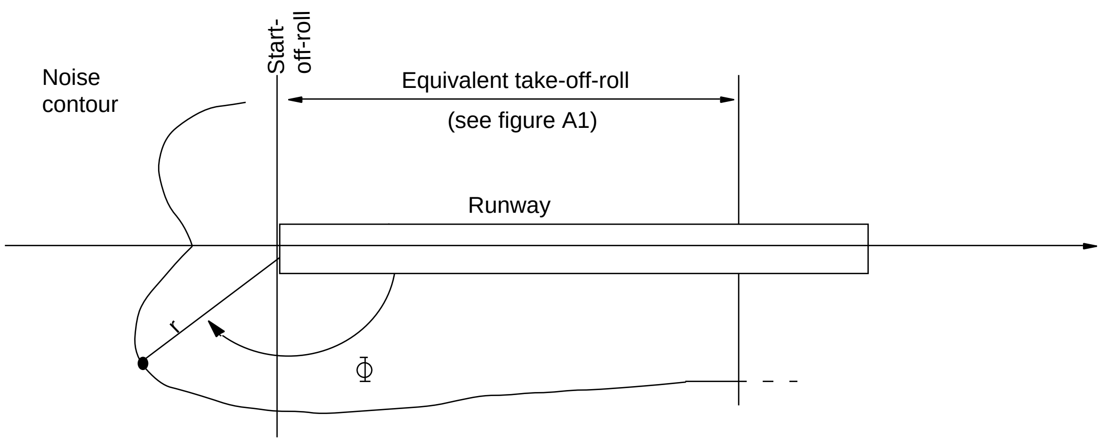
V_L = speed at lift-off in kts

V = actual speed in kts

The noise level for positive values of x (i.e. to the side of the runway during the take-off roll) is also given by Equation (18) (with the determinate or zero values of the duration correction, depending on the noise descriptor), except that in this case $\Delta_L = 0$

Note : *The duration correction calculated at points to the side of the runway is to be determined on the assumption of constant aeroplane acceleration, from a typical minimum speed to the lift-off speed.*

Figure 10 – Geometry for construction of take-off roll contours



8.3 NOISE DURING LANDING GROUND ROLL

Noise from landing ground roll is not as important to the total noise exposure as noise from take-off ground roll. (This text is partly reproduced from Reference 8)

If thrust reversal is not used, the engines are normally running at idle power during ground roll, and the noise will therefore be insignificant. There are two possible approaches for this part of a landing. Ground roll can be ignored or the same equations can be used as for a take-off (see Section 8.2). In the latter case L_{AE} and L_{Amax} are assumed to correspond to a low power setting, normally idle power, and ΔL is assumed to be 0 (the contour is ended by a half circle).

When the thrust reversers are activated, the aerodynamics are changed resulting in increased noise even for an unchanged power setting. No models are so far available for calculation of this, but it is recommended to determine the noise from the noise data format corresponding to the nominal power setting and add a correction for the change in aerodynamics. For aircraft with external thrust reversers the correction will normally be within the range of 5-10 dB. For Chapter 2-aircraft a suitable average value will be 8 dB whereas it is recommended to use 5 dB for Chapter 3-aircraft. For aircraft with internal thrust reversers the increase of the noise due to the aerodynamics is less important and it is recommended not to make any correction in this case. It must be emphasized that these estimations are rough and based on a very limited number of data.

For propeller aircraft which are able to use the propellers for reversal, it has not been possible to make similar simple principles. The effect of propeller reversal has to be estimated in each individual case. If the traffic is a mix of jet and propeller aircraft in which the jet aircraft are dominating the noise exposure, it is possible to ignore propeller reversal.

Furthermore, in connection with thrust or propeller reversal it is recommended that Δ_V and ΔL are set to 0, in which case the contours become parallel to the runway and are closed by half circles behind end-of-roll (compare Section 8.2).

CHAPTER 9

SUMMATION OF NOISE LEVELS

Before the noise exposure in a calculation point from the total traffic can be determined, the sound exposure level or maximum level has to be calculated for each individual aircraft operation. (This text is partly reproduced from Reference 8).

If the purpose is to determine the maximum level from the total traffic, this should be done according to the national formulation of the noise index. However, it is recommended to use the envelope of the noise foot print for the noisiest aeroplane on each track.

If the purpose is to determine the equivalent sound pressure level $L_{Aeq,w}$, the sound exposure levels for each individual operation on an average day are added on an energy basis. The time period for determining an average day is defined in the national methods. The sound exposure level for each operation is weighted for the time-of-day and in some countries time-of-week in accordance with the national method. The summation is defined as follows :

$$L_{Aeq,W} = 10 \log \left[\frac{1}{T} \sum_{j=1}^{N} W \, 10^{\frac{L_{AE,j}}{10}} \right] \qquad (20)$$

where $L_{AE,j}$ is the sound exposure level from the j'th aircraft operation out of N,

W is the weighting factor depending on the time-of-day and in some countries time-of-week,

T is the reference time for L_{Aeq} in seconds. If the reference time is one day (24 hours), T is to 86 400 sec.

CHAPTER 10

MODELLING OF LATERAL AND VERTICAL DISPERSION OF FLIGHT PATHS

10.1 LATERAL DISPERSION ACROSS NOMINAL GROUND TRACKS

10.1.1 Use of measurements

Noise contours calculated on the assumption that all aircraft departure and approach ground tracks follow exactly the nominal routes may be liable to localized errors of several dB. It is recommended that, for greatest reliability, the forms and parameters of the distributions of approach and departure ground tracks should be measured on each route at particular airports.

10.1.2 Assumptions to be used in the absence of measurements

If measurements are not available, nominal departure routes may be assumed or a judgement made about the route. In this case, standard deviations about the route should be used, derived from the following expressions :

a) Routes involving turns of less than 45 degrees :

$$s(y) = 0.055\,x - 0.150 \qquad \text{for } 2.7\text{ km} \leq x \leq 30\text{ km}$$

$$s(y) = 1{,}5\text{ km} \quad \text{for } x > 30\text{ km} \qquad (21)$$

b) Routes involving turns of more than 45 degrees

$$s(y) = 0.128\,x - 0.42 \text{ for } 3.3\text{ km} \leq x \leq 15\text{ km}$$

$$s(y) = 1{,}5\text{ km} \quad \text{for } x > 15\text{ km} \qquad (22)$$

In these expressions, s(y) is the standard deviation and x is the distance from start of roll. All distances are expressed in kilometres. For practical reasons, s(y) is assumed to be zero between the lift-off point and x = 2.7 km or x = 3.3 km depending on the amount of turn. Routes involving more than one turn should be treated as per Equation (22). For arrivals, lateral dispersion can be neglected within 6 km of touchdown. Otherwise, dispersion depends upon each individual runway and aircraft type.

If substantial vectoring by air traffic control occurs for departures or arrivals, much larger dispersion should be assumed. For vectored departing aircraft, standard deviations are typically twice those for non-vectored aircraft.

Calculated values of noise indices are not particularly sensitive to the shape of the lateral distribution. The Gaussian form gives the best fit to many observed distributions. Although continuous distributions can be simulated, an approximate model is preferable on grounds of computing cost. As a minimum, a 5-point discrete approximation should be used. The accuracy of the 5-point discrete approximation given in **Table 4** generally gives values within 1 dB of those obtained from a continuous (Gaussian) distribution, and is recommended.

Table 4 – Proportions of aircraft to be assumed following different ground tracks spaced about a nominal track

Spacing	Proportion
$y_m - 2.0\, s(y)$	0.065
$y_m - 1.0\, s(y)$	0.24
y_m	0.39
$y_m + 1.0\, s(y)$	0.24
$y_m + 2.0\, s(y)$	0.065

In Table 4, y_m = mean track or nominal track as appropriate, and s(y) = standard deviation.

Having found the actual shortest distance (ℓ) from a grid point to the nominal ground track (see Chapter 7), ℓ replaces y_m in Table 4. Using the aeroplane height (h) for a nominal flight path, the noise from the aeroplane flypast is calculated according to Chapter 7 for the five discrete positions of the aeroplane. The proportions given in Table 4 are taken into account before adding the contributions together.

The effect of lateral attenuation could be taken into account for the discrete positions of the aeroplane, or an overall effect could be calculated corresponding to zero lateral dispersion from the nominal flight path.

10.2 VERTICAL DISPERSION

As well as dispersed laterally the traffic will also be dispersed vertically. (This text is partly reproduced from Reference 8). This is due to variations in take-off weight, headwind (or tailwind) component, take-off procedure, and how the pilot is executing the procedure. The influence of the headwind component is not a parameter if calculations are made in accordance with this document as a headwind component of 8 kts is assumed in Section 4.2.5. The vertical dispersion is mainly due to the variation in take-off weight, and the dispersion will therefore be different for short-range aircraft compared to long-range. It is not possible to elaborate a model for vertical dispersion as it will be strongly dependent of the aircraft type. Furthermore, the vertical dispersion does not influence the calculation result to the same extent as the lateral dispersion. It is in general sufficient to choose a typical flight profile which is normally the average profile when calculating equivalent sound levels and the flight profile corresponding to the largest take-off weight in the case of maximum levels. If the vertical dispersion is very large due to large differences in take-off weight, it may be necessary when calculating equivalent sound levels to divide the traffic on two or more take-off profiles corresponding to different stage lengths.

Because of possible differences in flight profiles, grouping of aircraft should be done with great care.

CHAPTER 11

COMPUTATION OF SOUND EXPOSURE LEVEL WITH CORRECTION FOR TRACK GEOMETRY

11.1 THE NEED FOR CORRECTIONS

In practice, flight tracks will not always be straight, but will include turns as well. For the SEL noise descriptor, it will in general not be sufficient to take into account only the contribution from the closest segment, assuming a straight flypast. Close to a track such a simplification would normally be satisfactory. However, in some sectors within the computation grid, significant errors would occur. For instance the estimated SEL would be too low inside a turn, whereas it would be too high outside the turn.

Failure to take into account the sound energy contributions from other than the closest segment of flight path is liable also to result in severe discontinuities in sectors where two track sections are almost equally close to the computation points. This effect would be magnified, if the power settings used in the two segments were substantially different.

A rather simple, but reasonably accurate, computation procedure overcoming the problems dealt with above is given below (a different method is given in Reference 5). This still allows the basic calculation to be made according to Chapter 7 and the effect of lateral dispersion to be included according to Chapter 10. If segmentation is used (see Section 7.5), this takes into account the effect of track geometry.

11.2 THE CORRECTION PROCEDURE

The computation procedure can be divided into three steps :

Step 1 : The SEL is calculated taking the contribution from the closest segment into account assuming a straight flypast, constant height and power setting.

If the computation point is located on the outer side of a turn a (negative) correction given in dB is added.

Step 2 : If the computation point is located anywhere within a circle defined by the centre and radius of a turn, a (positive) correction given in dB is added.

Step 3 : In cases where a next-to-closest segment exists, the contribution from this segment is also taken into account. However, a distance to track is used which is different from the actual one.

Note : *Apart from adding two sorts of corrections in different sectors and taking the contribution from the next-to-closest segment into account, no change of basic principles has been introduced.*

In the following sections, more details on the different steps in the computation procedure are given.

11.2.1 Contribution from the closest segment (Step 1)

It is assumed that the nominal track is formed by straight and circular sections. Perpendiculars to the track are drawn through the computation point, and the shortest distance between the track and the computation point is selected for calculations of the SEL according to Chapter 7 with the possibility of including the effect of lateral dispersion according to Chapter 10.

11.2.2 Correction on the outer side of a turn (Step 1)

In **Figure 11**, a track including a curved section is shown. The curved section is defined by the centre (C), the turning angle (Ψ) and the radius (r). A correction is applied if the computation point J (on the outer side of the turn) is located within the angle Ψ. A line through C and J divides Ψ (measured in radians) into subangles Ψ_1 and Ψ_2.

Note: $\Psi = \Psi_1 + \Psi_2$

The distance from J to the track is denoted JT, whereas the distance from J to C is denoted JC.

Note : *JC= J T+ r*

The correction is given by :

$$\Delta L_{AE}(outer) = 10[\sin(\Psi/2)] \log [1 - 2.75 (JT/JC)\Psi_1.\Psi_2/\Psi^2] \qquad (23)$$

Note : *ΔLA_E(outer) is negative or zero. ΔL_{AE} (outer) equals zero in the following cases :*

JT= 0 (no distance to track)

Ψ.= 0 (no turn exists)

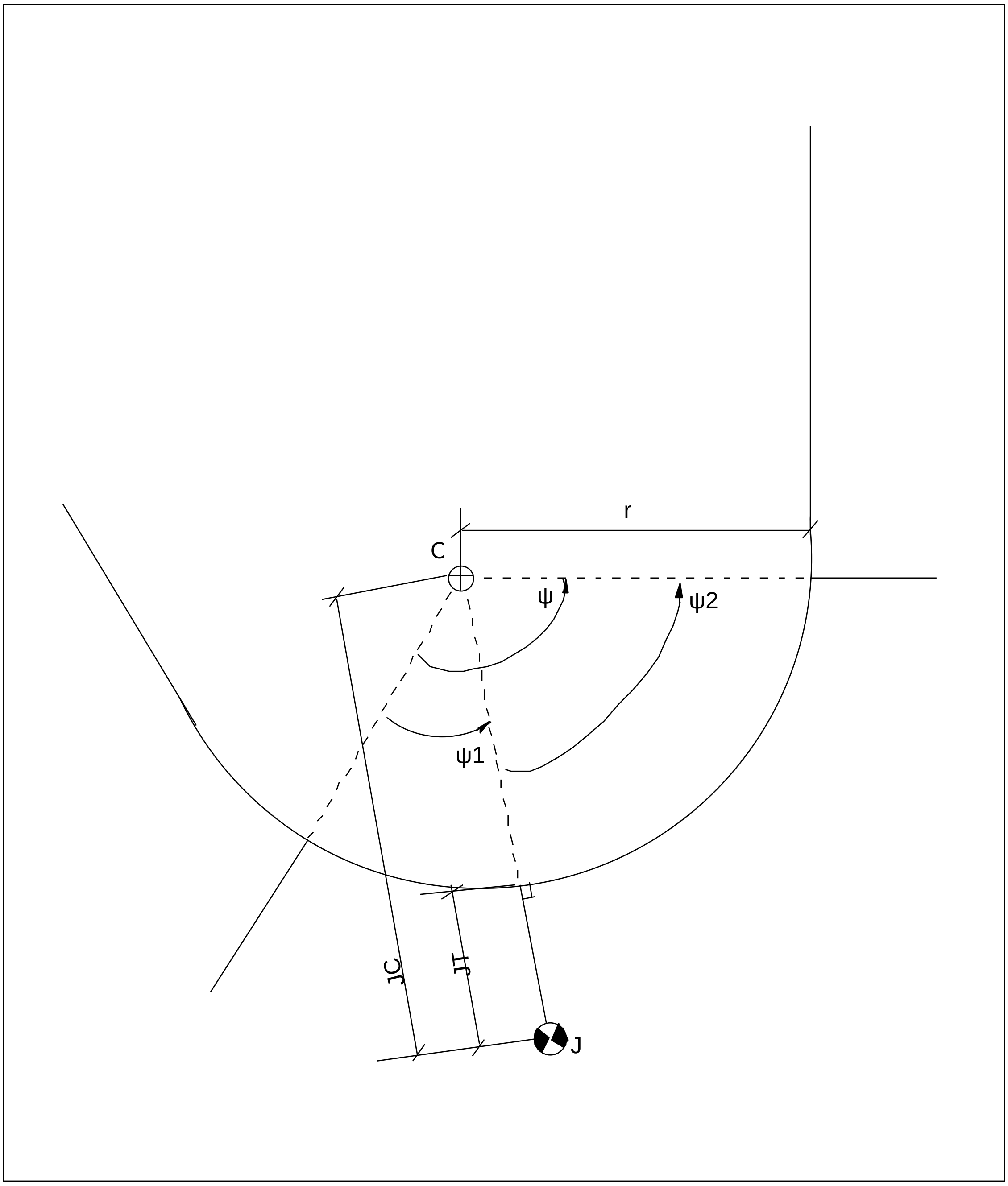
Ψ_1= 0 or Ψ_2= 0.

As the distance to the track increases, JT/JC will approach unity and a constant correction depending on Ψ, Ψ_1 and Ψ_2, will be reached. If Ψ_1 equals Ψ_2, the correction would in the limit be -3.5 dB for a 90° turn and -5 dB for a 180° turn.

Note : *If Ψ exceeds 180°, the correction will decrease again.*

In order to minimize computer time, small turns might be disregarded. A limiting correction of -1 dB would correspond to a turn of approximately 23°, whereas a limiting correction of -2 dB would correspond to a turn of approximately 47°.

Figure 11 – SEL computation, Step 1



11.2.3 Correction on the inner side of a turn, within the circle defined by the turn (Step 2)

In **Figure 12**, the track from Figure 11 is shown again, this time with the full circle defined by the turn shown. A correction is applied to those computation points which are located within the circle, i.e. if JC < r, where r is the radius of the turn and JC is the distance from the computation point to the centre of the turn. The correction is given by :

$$\Delta L_{AE}(\text{inner}) = 10 \log \{1 + (\Psi/\pi)\ [(r - JC)/r]^2\} \qquad (24)$$

Note: *L_{AE}(inner) is zero or positive. ΔL_{AE} (inner) equals zero in the following cases :*

JC= r (no distance to track circle)

Ψ = 0 (no turn exists)

In the centre of the turn, a correction of + 2 dB would be found for a 90° turn and + 3 dB for a 180° turn. In order to minimize computer time, small turns might again be disregarded. A limiting correction of + 1 dB would correspond to a turn of approximately 45°.

Note: *The possibility exists that J is located within more than one circle. If that is the case, the largest correction is used in this step.*

11.2.4 Contribution from a next-to-closest segment (Step 3)

In **Figure 13**, the track from Figure 11 is shown again. In the sector behind the centre of the turn, a next-to-closest section exists. The perpendiculars from the computation point J intercept the track at points A and B. The distance to the track is denoted AJ (closest) and JB (next-to-closest).

Instead of using the actual next-to-closest distance to the track, JB, in computing the SEL from the next-to-closest section, a corrected (and larger) distance J'B is used, as follows :

- The distance measured via J from A to B, AJB, is AJ +JB.
- The distance measured via the track from A to B, ATB, is measured by taking into account only the lengths of straight sections.

In Figure 13, the turn starts at point E and ends at point F. In this case, where there is only one turn between A and B, ATB is AE + FB. The corrected next-to-closest distance is then given as follows :

$$J'B = JB/\sin [\ \arctan 4(ATB/AJB)] \qquad (25)$$

Using J'B as the next-to-closest distance to the track, the slant distance is found and the SEL for the next-to-closest section is computed as described in Step 1.

Finally the total SEL at J is found by adding the components from the closest and next-to-closest track sections.

J'B will always be larger than JB. If J is rather close to C, J'B will be much larger than JB and the contribution from the next-to-closest section will be insignificant. However, in this case a correction has already been introduced by Step 2 of the computation procedure.

In order to minimize computer time, once more small turns might be disregarded. However, in this case no general rules can be given, as was the case in Step 1 and Step 2. Assuming constant height and no shift in power-setting, and disregarding ground attenuation, the contribution from the next-to-closest section would increase the SEL by less than 1 dB if JB > 2JA, independent of the extent of the turn. If the turn is smaller than about 17°, the correction would be less than 1 dB, independent of the ratio between JB and JA.

Figure 12 – SEL computation, Step 2

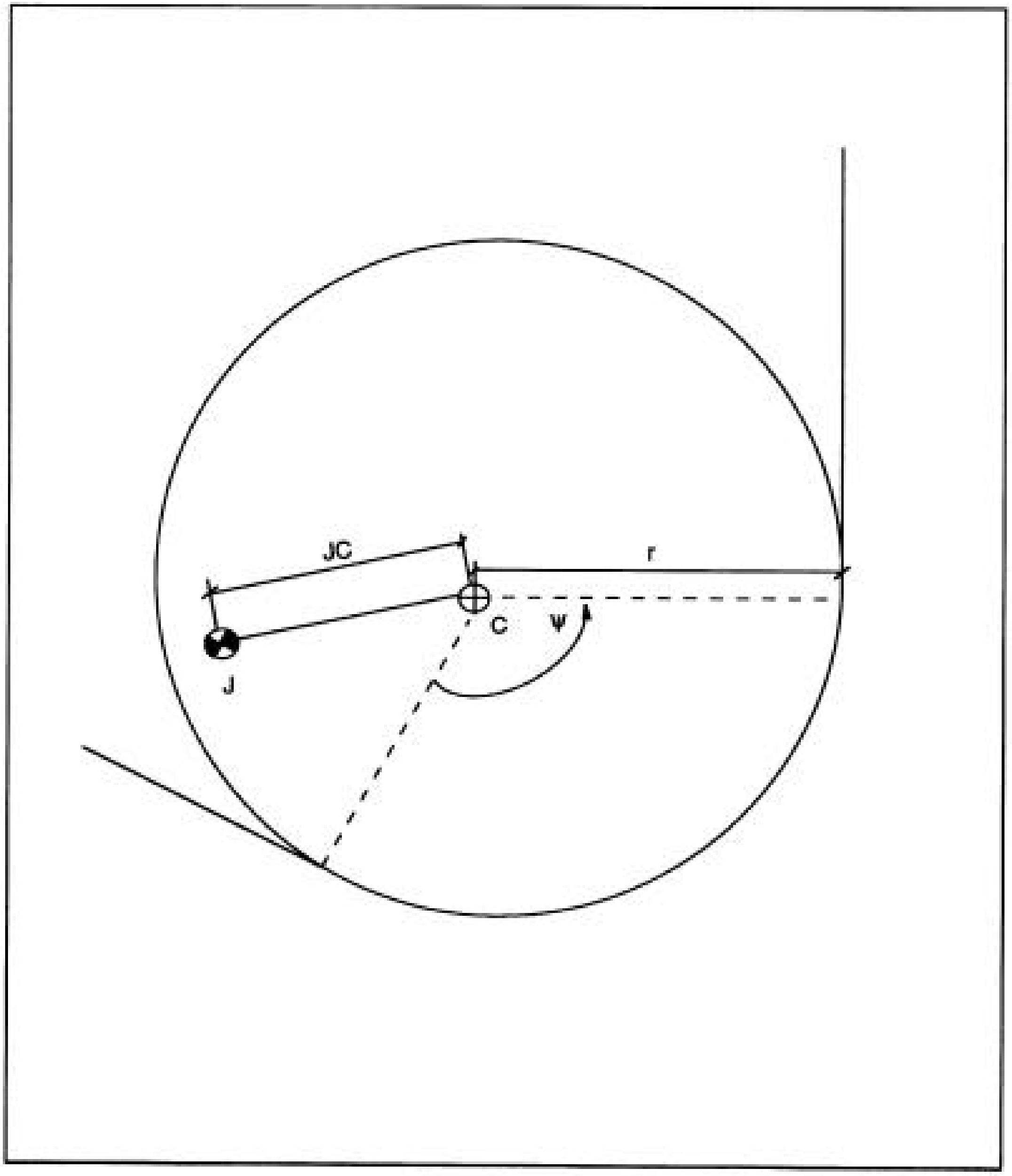
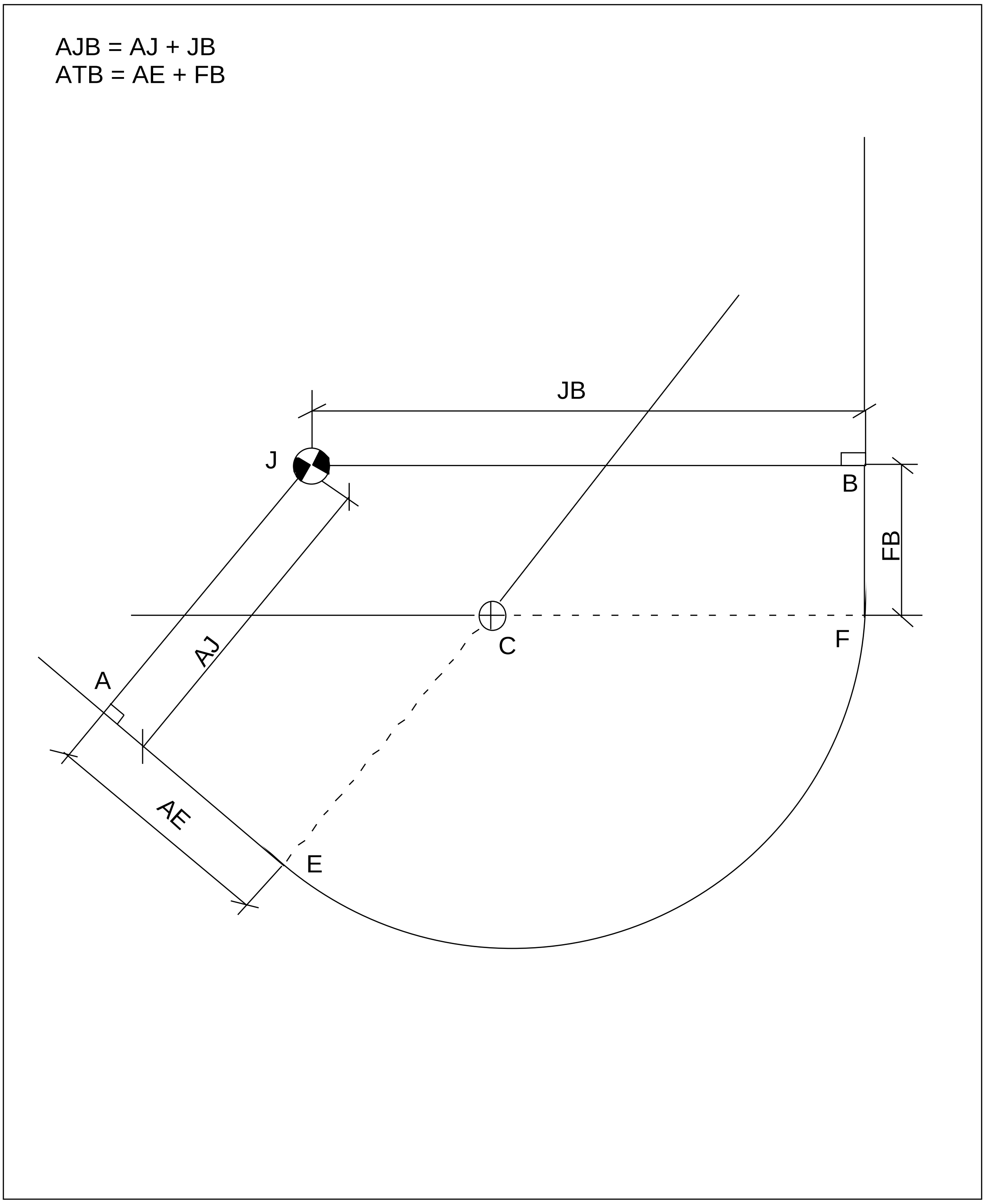


Figure 13 – SEL computation, Step 3



CHAPTER 12

OVERALL GUIDANCE ON THE COMPUTATION OF THE NOISE CONTOURS

For an airport noise study, the following information is required :

i) the aeroplane types which operate from the airport;

ii) noise and performance data for each of the aeroplane types concerned, supplied in accordance with the specifications of Chapter 4;

iii) the routes and/or procedures followed by arriving and departing aeroplanes including dispersion across ground tracks;

iv) the numbers of movements per aeroplane type on each route within the period chosen for the calculations including - depending on the actual index chosen - the time of day for each movement;

v) the operational data and flight procedures relating to each route (including aeroplane masses, power settings, speeds and configurations during different flight segments); and

vi) airport data (including average meteorological conditions, number and alignment of runways, displaced threshold etc.).

From the respective data on noise and performance, the aeroplanes are grouped and representative data are selected. The calculation grid is arranged and the calculations of noise levels at the grid points, for the individual aeroplane movements and the chosen noise descriptor, proceed according to the specifications given here. The noise levels at each grid point are summed or combined according to the formulation of the chosen noise scale or index. Finally, interpolations are made between noise index values at the grid points, to locate the contours.

In a number of detailed respects, the computation procedures remain at the discretion of the user, since they may be specific to the airport or there might be constraints due to computational capability. Such detailed aspects include the following :

a) The optimum number of aeroplane groups to be selected.

b) The formulation for combining noise levels from individual aeroplane movements according to the chosen noise index.

c) The method of interpolation to be used between grid points, to locate the noise contours. An iterative process can be used to find the exact location of a contour, subject to the limitation of the cost of computer running time. It is possible for iterations to proceed to an accuracy of 0.005 dB, in order to keep the positional accuracy of the contours to within 1 m. Such accuracy might be necessary with respect to financial compensation or other action to deal with the noise problem.

It should be noted that there can be an extremely low rate of change of noise index value with distance, especially far away from the runway, possibly leading to a positional uncertainty of up to 1 km for a tolerance of 1 dB.

A further point to note is that there are a number of noise-making activities by aeroplanes for which no method of calculation is given here. These include taxiing, engine testing and use of auxiliary power units.

APPENDIX A

Test Examples

Experience has shown that individual organizations making aircraft noise contour calculations will benefit from well documented test cases in order to verify the correct implementation of the different calculation routines. To fulfil this need a few test cases are included in this Appendix.

They are based on test cases in the document "Air Traffic Noise Calculation — Nordic Guidelines" (see Reference 8) referred to in that document as the *minitest*. The text below is based almost entirely on the above material.

The minitest aims at a simple evaluation of calculation programmes under consideration. Use of the minitest ensures that the main calculation routines and the plotting routine satisfy the accuracy demands of the authorities if the specified calculation result limits are not violated.

The minitest includes the calculation of noise exposure contours ($L_{Aeq,24h}$ = 35-50 dB) for two different aircraft types each following two different departure routes and one straight approach. The noise exposure in 9 specific positions must prove to be within a specified interval ± 1dB relative to the interval formed by the values calculated with INM 3 and DANSIM[1].

A comparison of noise exposure contours calculated for a B737-200 departure using DANSIM and INM 3, respectively, shows deviations of up to 5 dB in an area on both sides of the runway. The deviations are due to the use of different algorithms for the directivity of the noise source.

Input data for the minitest and the maximum acceptable deviations of the calculation results are specified in Sections A.1 to A.3 below.

A.1 MINITEST. INPUT DATA

The minitest consists of the calculation of the 24-hour equivalent level $L_{Aeq,24h}$ from movements of the following types :

a) : one arrival of a B737-200 with two P&W JT8D-17Q engines

b) : one arrival of a B767-300 with two P&W PW-4060 engines

c) : one departure of a B737-200 with two P&W JT8D-17Q engines

d) : one departure of a B767-300 with two P&W PW-4060 engines

The noise exposure is calculated as discrete values in 9 calculation positions A-I.

Flight tracks and calculation positions are defined in Figure A.1 and Table A.1.

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[1] INM Integrated Noise Model available from FAA.
DANSIM Danish Airport Noise Simulation Model available from DELTA.

Figure A.1 – Flight tracks

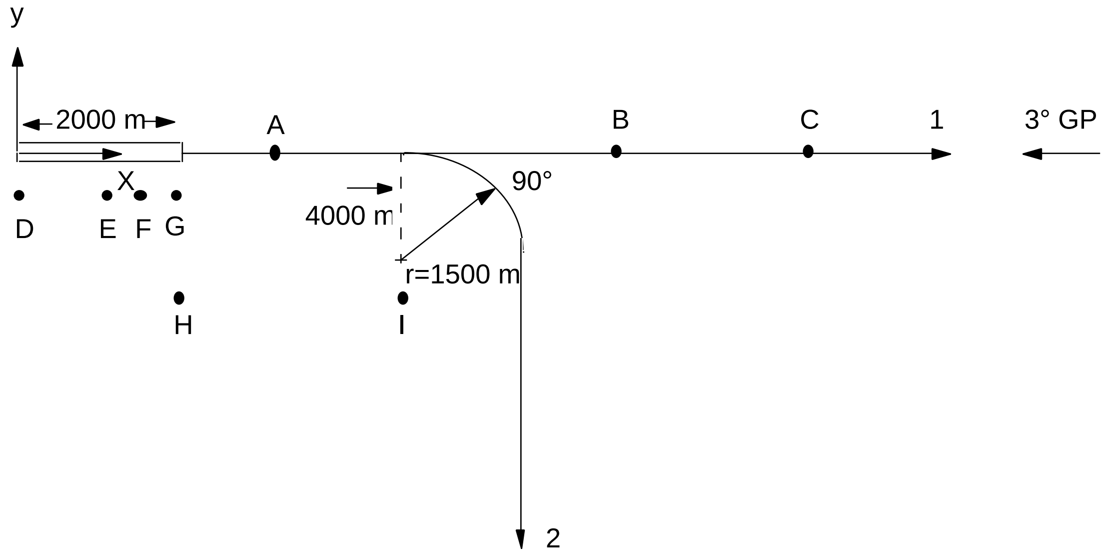


Table A.1 — Calculation position co-ordinates

Calculation position	x m	y m
A	3000	0
B	6000	0
C	10000	0
D	-500	-500
E	1000	-500
F	1500	-500
G	2000	-500
H	2000	-2000
I	4000	-2000

Common input data for all calculations are :

a) Air temperature : 15°C

b) Runway elevation : Sea level

c) Lateral attenuation as per SAE AIR 1751

14 separate calculation cases are defined in Table A.2.

Table A.2 — Definition of calculation cases

Calc. No.	Type of movement(s)	Flight track No.	Flight track dispersion : number of tracks	Take-off / landing mass lbs	Thrust reversal
1 2	a b	3°GP 3°GP	1 1	96300 288000	1) 2)
3 4 5 6	c d c d	1 1 1 1	1 1 1 1	90000 265000 105000 3) 305700 3)	— — — —
7 8	c d	1 1	5 (ref Table 4) 5	90000 265000	— —
9 10 11 12	c d c d	2 2 2 2	1 1 1 1	90000 265000 105000 3) 305700 3)	— — — —
13	c + d	2	1	90000 165000	—
14	c + d	2	1	105000 3) 305700 3)	

1) *3° glide path ending 954 ft after runway threshold. Power setting : 3584 lbs/eng. during final approach. Thrust reversal : from 954 ft to 1241 ft : power setting increased linearly from 3584 lbs/eng. to 9600 lbs/eng. From 1241 ft to 9820 ft after runway threshold : power setting reduced linearly from 9600 lbs/eng. to 1600 lbs/eng.*

2) *Same glide path as 1). Power setting during final approach : 11821 lbs/eng. Thrust reversal : from 954 ft to 1283 ft : power setting increased linearly from 11821 lbs/eng. to 36000 lbs/eng. From 1283 ft to 4239 ft after runway threshold : power setting reduced linearly from 36000 lbs/eng. to 6000 lbs/eng.*

3) *To be calculated only in positions A-I.*

Noise and performance data from INM Data Base 10 are stated in Tables A.3-A.10.

Table A.3 — B 737-200/JT8D-17 : L_{AE} as function of thrust per engine and distance.

Thrust lbs	Distance (ft)									
	200	400	630	1000	2000	4000	6300	10000	16000	25000
3000	94.6	90.8	87.9	84.8	79.8	73.4	69.0	63.6	57.2	50.2
6000	99.8	96.0	93.1	90.0	85.0	78.9	74.2	68.8	62.4	55.4
8000	104.3	100.6	97.7	94.7	89.7	83.7	79.1	73.8	67.6	60.8
1000	109.0	105.2	102.5	99.5	94.6	88.6	84.1	79.0	72.9	66.3
12000	113.8	110.1	107.4	104.5	99.6	93.8	89.3	84.2	78.4	72,1
14000	119.1	115.4	112.8	110.0	105.1	99.4	95.0	90.1	84.4	78.4

Table A.4 — B737-200/JT8D-17 : Take-off profile, speed and power setting at a take-off mass of 90,000 lbs

Distance (ft)	Altitude (ft)	Speed (kts)	Thrust (lbs/eng.)
0.	0.	16.	15384.
3303.	0.	142.	14319.
7539.	1000.	144.	14524.
9472.	1306.	155.	14489.
12392.	1615.	181.	14323.
13392.	1667.	189.	12075.
16635.	1837.	216.	11864.
23403.	3000.	220.	11955.
30161.	3291.	262.	11682.
44823.	5500.	271.	11639.
60019.	7500.	280.	11394.
82894.	10000.	291.	

Table A.5 — B737-200/JT8D-17 : Take-off profile, speed and power setting at a take off mass of 105,000 lbs.

Distance (ft)	Altitude (ft)	Speed (kts)	Thrust (lbs/eng.)
0.	0.	16.	15384.
4526.	0.	153.	14223.
9913.	1000.	156.	14427.
12438.	1316.	166.	14397.
16321.	1642.	193.	14234.
17321.	1693.	198.	11999.
20275.	1844.	216.	11865.
28674.	3000.	220.	11955.
37931.	3399.	263.	11685.
55526.	5500.	271.	11639.
74818.	7500.	280.	11394.
104334.	10000.	291.	

Table A.6— B737-200/JT8D-17 : Speed and power setting during landing (abbreviations according to INM Data Base 10)

		STOP (ft)		REVDS (ft)		
		-3820.		-1241.		
TAXI (kts)	REVSP (kts)	LNDSP (kts)	FINSP (kts)	APPSP (kts)	INTSP (kts)	TERMSP (kts)
30.	131.	138.	140.	143.	178.	273.
IDLE (lbs/eng.)	REV (lbs/eng.)	LNDFLS (lbs/eng.)	LNDFFS (lbs/eng.)	APPFAS (lbs/eng.)	INTFIS (lbs/eng.)	ZERFTS (lbs/eng.)
1600.	9600.	3584.	3716.	3170.	1967.	811.

Table A.7— B767-300/PW 4060 : L_{AE} as function of thrust per engine and distance.

Thrust (lbs)	Distance (ft)									
	200	400	630	1000	2000	4000	6300	10000	16000	25000
7000	98.1	93.9	90.8	87.4	81.4	75.0	70.3	65.7	60.6	55.7
12000	99.3	95.0	91.9	88.5	82.5	76.2	71.7	67.2	62.3	57.6
17000	100.0	95.6	92.6	89.3	83.7	77.6	73.1	68.5	63.4	58.4
25000	100.3	96.7	93.9	90.9	85.9	79.8	75.4	70.5	65.2	59.8
33000	103.3	99.9	97.3	94.5	89.7	83.6	79.2	74.3	69.0	63.5
41000	106.2	103.1	100.8	98.2	93.6	87.6	83.1	78.1	72.5	66.8

Table A.8— B767-300/PW 4060 : Take-off profile, speed and power setting at a take-off mass of 265,000 lbs.

Distance (ft)	Altitude (ft)	Speed (kts)	Thrust (lbs/eng.)
0.	0.	16.	55522.
2753.	0.	147.	48586.
6163.	1000.	149.	48837.
6698.	1081.	154.	48585.
8776.	1368.	175.	47598.
9776.	1421.	185.	39038.
13447.	1614.	220.	37374.
15873.	1723.	241.	36597.
22375.	3000.	246.	37311.
24540.	3089.	262.	36732.
37819.	5500.	271.	38080.
49599.	7500.	280.	39198.
65430.	10000.	291.	

Table A.9 — B767-300/PW 4060 : Take-off profile, speed and power setting at a take-off mass of 305,700 lbs.

Distance (ft)	Altitude (ft)	Speed (kts)	Thrust (lbs/eng.)
0.	0.	16.	55522.
3708.	0.	158.	48010.
7956.	1000.	160.	48261.
8673.	1087.	166.	48004.
11376.	1389.	187.	47020.
12376.	1439.	194.	38589.
17678.	1703.	231.	37004.
20945.	1844.	252.	36245.
28188.	3000.	256.	36892.
29129.	3038.	261.	36703.
45551.	5500.	271.	38080.
59865.	7500.	280.	39198.
79158.	10000.	291.	

Table A.10 — B767-300/PW 4060 : Speed and power setting during landing (abbreviations according to INM Data Base 10).

		STOP (ft)		REVDS (ft)		
		-4239.		-1283.		
TAXI (kts)	REVSP (kts)	LNDSP (kts)	FINSP (kts)	APPSP (kts)	INTSP (kts)	TERMSP (kts)
30.	130.	137.	139.	144.	175.	273.
IDLE (lbs/eng.)	REV (lbs/eng.)	LNDFLS (lbs/eng.)	LNDFFS (lbs/eng.)	APPFAS (lbs/eng.)	INTFIS (lbs/eng.)	ZERFTS (lbs/eng.)
6000.	36000.	11821.	12256.	10672.	3886.	411.

A.2 MINITEST. SINGLE POINT CALCULATION ACCURACY

If the principles of the calculation programme used are not identical to the method outlined in this document, the single point calculation results must fulfil the requirements stated in Tables A.11-A.24.

Each table represents one of the 14 calculation cases defined in Table A.2 and contains the single point $L_{Aeq,24h}$ for positions A-I calculated by DANSIM and by INM 3. In each table the third column shows the acceptance interval for the calculation result. The acceptable interval is defined as the interval between the DANSIM- and the INM 3-result ± 1 dB.

***Table A.11** — Single point values of $L_{Aeq,24h}$*
B737-200/JT8D-17 landing
(Calculation No. 1)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	46.4	45.4 - 47.5	46.5
B	39.0	38.0 - 40.3	39.3
C	34.4	32.7 - 35.4	33.7
D	10.0	7.9 - 11.0	8.9
E	27.2	23.8 - 28.2	24.8
F	30.0	29.0 - 31.3	30.3
G	26.3	25.3 - 28.2	27.2
H	9.5	8.5 - 12.6	11.6
I	10.1	9.1 - 12.3	11.3

***Table A.12** — Single point values of $L_{aeq,24h}$*
B767-300/PW 4060 landing
(Calculation No. 2)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	49.8	48.8 - 51.0	50.0
B	41.8	40.8 - 43.0	42.0
C	36.4	35.2 - 37.4	36.2
D	11.7	10.7 - 12.7	11.7
E	28.9	26.0 - 29.9	27.0
F	29.4	28.4 - 30.4	29.4
G	26.4	25.4 - 28.1	27.1
H	9.8	8.8 - 12.2	11.2
I	11.5	10.5 - 13.5	12.5

Table A. 13 *— Single point values of* $L_{aeq,24h}$
B737-200/JT8D-17 take-off
TOM : 90,000 lbs
(Calculation No. 3)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	59.4	58.4 - 60.8	59.8
B	47.3	46.2 - 48.3	47.2
C	42.0	40.8 - 43.0	41.8
D	50.5	48.9 - 51.5	49.9
E	53.2	46.9 - 54.2	47.9
F	55.8	52.8 - 56.8	53.8
G	56.4	54.7 - 57.4	55.7
H	39.7	37.1 - 40.7	38.1
I	35.8	34.8 - 38.3	37.3

Table A.14 *— Single point values of* $L_{Aeq,24h}$
B767-300/PW 4060 take-off
TOM : 265,000 lbs
(Calculation No. 4)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	44.8	43.8 - 46.9	45.9
B	38.8	37.5 - 39.8	38.5
C	33.0	31.8 - 34.0	32.8
D	41.3	40.3 - 43.1	42.1
E	45.8	40.6 - 46.8	41.6
F	47.0	44.9 - 48.0	45.9
G	46.1	45.1 - 47.4	46.4
H	28.3	27.3 - 29.4	28.4
I	25.9	24.9 - 26.9	25.9

Table A. 15 *— Single point values of $L_{Aeq,24h}$*
B737-200/JT8D-17 take-off
TOM : 105,000 lbs
(Calculation No. 5)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	61.8	60.8 - 63.1	62.1
B	49.2	48.2 - 50.6	49.6
C	43.6	42.6 - 45.0	44.0
D	51.0	49.6 - 52.0	50.6
E	48.9	47.6 - 49.9	48.6
F	52.8	47.5 - 53.8	48.5
G	55.0	52.4 - 56.0	53.4
H	39.2	39.0 - 40.2	36.0
I	38.2	37.2 - 39.8	38.8

Table A.16 *— Single point values of $L_{Aeq,24h}$*
B767-300/PW 4060 take-off
TOM : 305,700 lbs
(Calculation No. 6)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	49.7	48.7 - 51.0	50.0
B	40.3	39.3 - 41.7	40.7
C	35.0	33.7 - 36 .0	34.7
D	41.8	40.8 - 42.8	41.8
E	42.3	37.8 - 43.3	38.8
F	45.6	42.1 - 46.6	43.1
G	46.4	44.6 - 47.4	45.6
H	29.0	26.4 - 30.0	27.4
I	26.1	25.1 - 27.8	26.8

Table A. 17 *— Single point values of $L_{Aeq,24h}$*
B737-200/JT8D-17 take-off
TOM : 90,000 lbs
(Calculation No. 7)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	59.3	58.3 - 60.8	59.8
B	47.1	45.9 - 48.1	46.9
C	41.5	40.3 - 42.5	41.3
D	50.5	48.8 - 51.5	49.8
E	53.2	46.9 - 54.2	47.9
F	55.8	52.8 - 56.8	53.8
G	56.4	54.6 - 57.4	55.6
H	39.7	37.1 - 40.7	38.1
I	35.8	34.8 - 38.3	37.3

Table A.18 *— Single point values of $L_{Aeq,24h}$*
B767-300/PW 4060 take-off
TOM : 265,000 lbs
(Calculation No. 8)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	44.8	43.8 - 47.0	46.0
B	38.5	37.2 - 39.5	38.2
C	32.6	31.4 - 33.6	32.4
D	41.3	40.3 - 43.1	42.1
E	45.8	40.5 - 46.8	41.5
F	47.0	44.8 - 48.0	45.8
G	46.1	45.1 - 47.3	46.3
H	28.3	27.3 - 29.3	28.3
I	26.0	24.9 - 27.0	25.9

Table A. 19 *— Single point values of $L_{Aeq,24h}$*
B737-200/JT8D-17 take-off
TOM : 90,000 lbs
(Calculation No. 9)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	59.4	58.4 - 60.8	59.8
B	39.9	38.9 - 41.3	40.3
C	19.8	18.8 - 22.8	21.8
D	50.5	48.9 - 51.5	49.9
E	53.2	46.9 - 54.2	47.9
F	55.8	52.8 - 56.8	53.8
G	56.4	54.7 - 57.4	55.7
H	39.8	37.2 - 40.8	38.2
I	38.8	37.8 - 40.8	39.8

Table A.20 *— Single point values of $L_{Aeq,24h}$*
B767-300/PW 4060 take-off
TOM : 265,000 lbs
(Calculation No. 10)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	44.9	43.9 - 47.0	46.0
B	31.4	30.2 - 32.4	31.2
C	12.5	11.5 - 13.7	12.7
D	41.3	40.3 - 43.1	42.1
E	45.8	40.6 - 46.8	41.6
F	47.0	44.9 - 48.0	45.9
G	46.1	45.1 - 47.4	46.4
H	28.7	27.6 - 29.7	28.6
I	29.9	28.9 - 30.9	29.9

Table A.21 *— Single point values of $L_{Aeq,24h}$*
B737-200/JT8D-17 take-off
TOM : 105,000 lbs
(Calculation No. 11)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	61.8	60.8 - 63.1	62.1
B	40.2	39.2 - 44.5	43.5
C	19.8	18.8 - 23.7	22.7
D	51.0	49.6 - 52.0	50.6
E	48.9	47.6 - 49.9	48.6
F	52.8	47.5 - 53.8	48.5
G	55.1	52.4 - 56.1	53.4
H	39.4	35.2 - 40.4	36.2
I	40.0	39.0 - 41.8	40.8

Table A.22 *— Single point values of $L_{Aeq,24h}$*
B767-300/PW 4060 take-off
TOM : 305,700 lbs
(Calculation No. 12)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	49.8	48.9 - 51.0	50.0
B	31.0	30.0 - 32.9	31.9
C	11.5	10.5 - 13.3	12.3
D	41.8	40.8 - 42.8	41.8
E	42.4	37.8 - 43.4	38.8
F	45.6	42.1 - 46.6	43.1
G	46.4	44.6 - 47.4	45.6
H	29.3	26.6 - 30.3	27.6
I	30.0	29.0 - 31.1	30.1

Table A.23 *— Single point values of $L_{Aeq,24h}$*
Two takeoffs :
B737-200/JT8D-17, TOM : 90,000 lbs
B767-300/PW 4060, TOM : 265,000 lbs
(Calculation No. 13)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	59.5	58.5 - 61.0	60.0
B	40.5	39.5 - 41.8	40.8
C	20.6	19.6 - 23.3	22.3
D	51.0	49.5 - 52.0	50.5
E	53.9	47.8 - 54.9	48.8
F	56.3	53.5 - 57.3	54.5
G	56.7	55.2 - 57.7	56.2
H	40.2	37.7 - 41.2	38.7
I	39.4	38.4 - 41.2	40.2

Table A.24 *— Single point values of $L_{Aeq,24h}$*
Two takeoffs :
B737-200/JT8D-17, TOM : 105,000 lbs
B767-300/PW 4060, TOM : 305,700 lbs
(Calculation No. 14)

Calculation position	Calculated $L_{aeq,24h}$		
	DANSIM	Acceptance interval	INM3
A	62.1	61.1 - 63.4	62.4
B	40.7	39.7 - 44.8	43.8
C	20.4	19.4 - 24.1	23.1
D	51.5	50.1 - 52.5	51.1
E	49.8	48.0 - 50.8	49.0
F	53.6	48.6 - 54.6	49.6
G	55.6	53.1 - 56.6	54.1
H	39.8	35.7 - 40.8	36.7
I	40.4	39.4 - 42.1	41.1

APPENDIX B

HELICOPTER NOISE MODELLING

Helicopters can make a very significant contribution to the noise environment of the localities in which they operate, and therefore require special attention in environmental impact assessments.

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

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

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

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

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

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

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

APPENDIX C

EQUATIONS FOR PERFORMANCE CALCULATIONS

C.1 EQUATIONS FOR THRUST AND NOISE-RELATED THRUST PARAMETERS

C.1.1 **Specific departure thrust settings**

Thrust and relevant noise-related thrust parameters are given by the following:

$$\xi = E_\xi + F_\xi \times V_{EAS} + G_\xi \times h_p \qquad \text{(C1)}$$

where ξ represents X_N / δ, $N / \sqrt{\theta}$, $SHP/ \delta\sqrt{\theta}$ or N_p.

As the majority of current aero-engines are "flat-rated", Equation C1 will generally be applicable to ISA as well as non-ISA conditions. However, if the engine speed N is held constant (independent of temperature, altitude and flight speed) the following corrections for non-ISA temperature can be applied to X_N / δ and $SHP/ \delta\sqrt{\theta}$ as obtained from Equation C1:

$$\Delta\xi = H_\xi\left[(1/\sqrt{\Theta}) - (1/\sqrt{\Theta_{ISA}})\right] \qquad \text{(C2)}$$

where $\Delta\xi$ represents $\Delta X_N / \delta$ or $\Delta SHP/ \delta\sqrt{\theta}$. The coefficient H_ξ is obtained from the coefficient F_ξ and G_ξ and the flight speed V_{EAS} according to the following:

$$H_\xi = -5.2F_\xi \times V_{EAS} + 8.7 \times 10^4 G_\xi \qquad \text{(C3)}$$

For a constant engine speed N, $N / \sqrt{\theta}$, is obtained as follows:

$$N / \sqrt{\Theta} = \sqrt{(\Theta_{ISA} / \Theta)}\left[(E_N / \sqrt{\Theta}) + (F_N / \sqrt{\Theta})V_{EAS} + (G_N / \sqrt{\Theta})h_p\right] \qquad \text{(C4)}$$

For a propeller-driven aeroplane, the propeller speed N_p is assumed to be constant at constant engine speed. The rotational tip Mach number for propeller-driven aeroplanes is determined according to the following equation, which is applicable to ISA as well non-ISA temperatures:

$$M_t = C_{M_t} / \sqrt{\Theta} \qquad \text{(C5)}$$

Equation C5 is based on the assumption of a constant propeller speed, N_p, which implies that F_N and G_N are zero (see Equation C1). this assumption is valid for most turboprop engines.

C.1.2 **General thrust settings**

For a "general" thrust setting, e.g. during the approach or at cut-back during the climb, the relation between the thrust and the thrust parameters is given by the following formula, in which ν represents the thrust parameters $N/\sqrt{\theta}$ and $SHP/\delta\sqrt{\theta}$:

$$\nu = A_\nu + B_\nu (X_N / \delta) + C_\nu \left[V_{EAS} (1 + 6.0 \times 10^{-5} h_p) \right] \qquad \text{(C6)}$$

Where ν represents $N/\sqrt{\theta}$, a more precise approximation would be obtained if a second-order term is introduced, i.e. ν then becomes $\left[N/\sqrt{\Theta} + Y(N/\sqrt{\Theta})^2 \right]$.

***Note**: Equation C6 is unsuitable to determine the propeller rotational speed, N_p. For the approach, N_p is assumed constant (and equal to the reference N_p).*

If a general thrust setting is defined by an engine indicator setting EIS (such as EPR, EPD or fan speed) the associated thrust can be obtained through Equation C6 by allowing ν to represent the EIS. When an indicator setting represents an engine speed, the Note following Equation C6 applies.

The effect of de-rated (flexible) take-off thrust can be taken into account by reducing the coefficient E_X / δ in Equation C1 by an amount determined as follows:

$$\Delta E_{X_N} / \delta = (\Delta E_N / \sqrt{\Theta}) / (B_N / \sqrt{\Theta}) \qquad \text{(C7)}$$

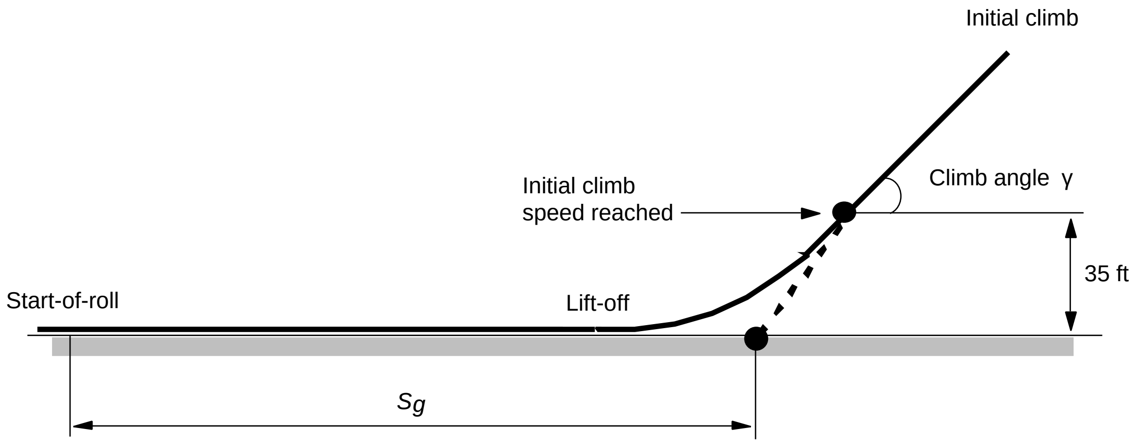
where the coefficient $B_N/\sqrt{\theta}$ is obtained from Equation C6.

C.2 FLIGHT PROFILE AND FLIGHT SPEEDS

C.2.1 **Equivalent take-off roll**

The equivalent take-off roll, S_g, is the distance along the runway from the start of the take-off roll to the intersection point of the runway and the initial climb path projected downwards (see **Figure C.1**).

Figure C.1 – Aeroplane take-off, showing equivalent take-off roll



The equivalent take-off roll is then given as follows:

$$S_g = p\Theta\left[f_w\left(W/\delta\right)\right]^2 / \left(X_{N_{TO}} / \delta\right) \qquad \text{(C8)}$$

where p is the take-off performance coefficient (see 4.2.3) evaluated for the reference conditions of 4.2.5, Θ and δ are the ratios of ambient air pressure and temperature to the respective ISA sea-level values, W is the gross weight of the aeroplane at the start of roll, X_N is the all-engine net thrust for the initial climb and f_W is a wind coefficient given by the following expression:

$$f_W = (\bar{V}_{EAS} - V_W) / (\bar{V}_{EAS} - 4.1) \qquad \text{(C9)}$$

In Equation C9, vw is the wind velocity and $\bar{V}$ is the mean air speed over the initial climb segment.

C.2.2 **Flight speeds**

The speed over a particular flight path segment is given as follows:

$$V_{EAS} = Q\sqrt{w} \qquad \text{(C10)}$$

where Q is the flight speed coefficient (see 4.2.3) for which different values are applicable during the climb (Q_{CL}), flap retraction (Q_{FR}) and approach (Q_{AP}).

The relation between the true and equivalent airspeeds is given by the following expression:

$$V_{TAS} = V_{EAS} / \sqrt{\sigma} \qquad \text{(C11)}$$

where σ is the ratio of air density to the ISA sea-level value.

C.2.3 **Climb (descent) angle**

The climb (descent) angle of the flight path is determined as follows:

$$\gamma = \sin^{-1}\left\{ \left(f / f_w\right)\left[\left(\overline{X}_N / W\right) - R\right]\right\} \qquad \text{(C12)}$$

where f_W is the wind coefficient (Equation C9), R is the climb/descent performance coefficient (see 4.2.3) and f is an acceleration coefficient over the flight path segment as follows:

For an accelerated climb from position 1 to 2

$$1 / f = 1 + \left(V^2_{TAS_2} - V^2_{TAS_1}\right) / \left[2g\left(\Delta h\right)\right] \qquad \text{(C13)}$$

For a climb at constant V_{EAS} expressed in m/s

$$1 / f = 1 + 5.2 \times 10^{-6} V^2_{EAS} \qquad \text{(C14)}$$

The angle γ takes a positive value during the climb and a negative value during descent.

For a flap retraction segment, the climb angle should be approximated by the average of the values of the coefficient R at the beginning and end of the segment.

If a rate of climb (RC) is given, the climb angle becomes

$$\gamma = \sin^{-1}\left\{ (RC) / \left[V_{TAS}\left(f_w\right)\right]\right\} \qquad \text{(C15)}$$

If a constant attitude is specified, the climb angle should be assumed constant for the purpose of flight-path schematization.

C.2.4 **Horizontal distance covered in a flight segment**

During climb or descent, the horizontal distance covered is determined as follows:

$$S = \Delta h / \tan\gamma \qquad \text{(C16)}$$

While the aeroplane is accelerating in level flight, the horizontal distance covered is as follows:

$$S = f_w\left(V^2_{TAS_2} - V^2_{TAS_1}\right) / 2g\left[\left(\overline{X}_N / W\right) - R\right] \qquad \text{(C17)}$$

APPENDIX D

GENERAL AVIATION AEROPLANES (PISTON ENGINE AND TURBOPROPS WITH MTOM BELOW 5 700 KG)

The methodology described is a summary of the methodology used in Denmark for many years. In Reference 9 the background for the method is described in details. An up-to-date version is found in Reference 10 including the latest statistics in relation to aeroplanes on Danish register as per 1 January 1992.

Based on data from noise certification, piston engine and turboprops with MTOM below 5 700 kg are divided into 4 noise classes each 5 dB wide. The measured maximum A-weighted sound pressure level during a level overflight in a height of 300 meters with the highest power in the normal operating range is used without any performance correction. Except for the performance correction not included, this corresponds to certification according to ICAO Annex 16, Chapter 6 (see Reference 2).

Table D.1 – Noise classes

Noise Class	L_{Amax}	Noise figure representing the class
I	≤70	68 dB
II	71 - 75 dB	73 dB
III	76 - 80 dB	78 dB
IV	81 - 85 dB	83 dB

In case of take-off, 3 profile classes are used in order to reduce the number of profiles. Above 2000 feet level flight is assumed.

Table D.2 – Profile classes

Profile Class	Gradient Range	Gradient and ground roll to 50 feet representing the class	
A	≤9%	8%	600 m
B	10 - 12%	11%	500 m
C	≥ 13 %	14%	400 m

In case of VMC-landings, level flight in 1000 feet is assumed followed by a glide slope of 6° for aeroplanes with MTOM below 2 500 kg and 4° if above. In case of IMC-landings the glide angle is 3°, and the interception height depends on local conditions.

Assuming a reference speed of 80 knots the sound exposure level (L_{AE}) as function of distance during take-off or climb is given in the table below. During level flight 5 dB lower values are assumed, whereas during landing 8 dB lower values are assumed. The ordinary correction for the actual speed is further to be added.

Table D.3 – L_{AE} as function of the shortest distance to the flight path for take-off and climb

Shortest distance to flight path, d		L_{AE} - L_{AMAX} (300 m) (v=80 knots)
feet	meter	
200	61.0	20.8
250	76.2	19.8
315	96.0	18.7
400	121.9	17.5
500	152.4	16.4
630	192.0	15.2
800	243.8	13.9
1000	304.8	12.7
1250	381	11.3
1600	488	9.9
2000	610	8.6
2500	762	7.2
3150	960	5.6
4000	1219	3.9
5000	1524	2.2
6300	1920	.4
8000	2438	-1.5
10000	3048	-3.5

The number of calculations can be reduced if for a given profile class the number of operations in each noise class are converted to an equivalent number of operations in one of the noise classes (normally noise class II). Correspondingly, in case of landings the number of calculations can be reduced, as an equivalent number of operations for one of the noise classes can be found for each glide slope.

Lateral dispersion is modelled as described in Chapter 10, except that in case of VMC-takeoffs the dispersion is generally assumed to equal that given for turns of more than 45°. As an alternative to tracks, sectors could be used instead. No dispersion is generally assumed for the landing circuit, normally 5 000 m long and 1 200 m wide.

The full benefit of the method outlined above can only be achieved if sufficient statistical data are available for the aeroplanes in question. A survey was carried out for the piston- and turboprop aeroplanes (with MTOM below 5 700 kg) on the Danish register by 1 January 1992. Noise data were available for 89% of the aeroplanes (866, comprising 273 types).

Table D.4 – Percentage of aeroplanes divided in noise classes. Danish register as per 1 January 1992

Noise class	Percentage All aeroplanes	Percentage based on weight classes		
		< 1500 kg	1500 - 2500 kg	2500 - 5700 kg
I	19%	24%	2%	-
II	54%	68%	11%	2%
III	18%	8%	78%	23%
IV	9%	-	9%	75%
Total	100%	100%	100%	100%

Table D.5 – Percentage of aeroplanes divided in profile classes. Danish register as per 1 January 1992

Noise class	Gradient class			Total
	A	B	C	
I	30%	42%	28%	100%
II	54%	42%	4%	100%
III	2%	43%	55%	100%
IV	-	32%	68%	100%

A list of aeroplane types on Danish register as per 1 January 1992 summarizing their respective noise figures and gradient classes are included in Reference 9.

APPENDIX E

Lateral attenuation for moderate downwind conditions

For moderate downwind conditions (2 m/s perpendicular to the flight track) a supplementary method is included in the document "Air Traffic Noise Calculation — Nordic Guidelines" (see Reference 8) based on a model described in the document "Aircraft noise in the Nordic countries. Analysis of calculation methods (in Danish). (B. Plovsing and C. Svane Report No. 137, July 1987)". The model is based on the model for calm wind conditions described in Section 7.4. Equations 8 to 12 are also used for the prediction of the lateral attenuation in this case, but the elevation angle is modified. The modified elevation angle β' is calculated according to Equations E.1 and E.2.

$$\beta' = \beta + \Delta\beta(\ell) \qquad \text{(E.1)}$$

where

$$\Delta\beta(\ell) = 1.13(\ell^2 + 525) - 3.03 \qquad \ell < 914 \text{ m} \qquad \text{(E.2)}$$

$$\Delta\beta(\ell) = 3.66 \qquad \ell \geq 914 \text{ m}$$

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