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Legislation

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(1) Text with EEA relevance

Acts whose titles are printed in light type are those relating to day-to-day management of agricultural matters, and are generally valid for a limited period.

The titles of all other acts are printed in bold type and preceded by an asterisk.

Volume 58 1 July 2015

II

(Non-legislative acts)

DIRECTIVES

COMMISSION DIRECTIVE (EU) 2015/996

of 19 May 2015

establishing common noise assessment methods according to Directive 2002/49/EC of the European Parliament and of the Council

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

Having regard to the Treaty on the Functioning of the European Union,

Having regard to Directive 2002/49/EC of the European Parliament and of the Council of 25 June 2002 relating to the assessment and management of environmental noise (1), and in particular Article 6, paragraph 2 thereof,

Whereas:

- (1) According to its Article 1, the aim of Directive 2002/49/EC is to define a common approach intended to avoid, prevent or reduce on a prioritised basis the harmful effects, including annoyance, due to exposure to environmental noise. To that end the Member States shall determine the exposure to environmental noise, through noise mapping, by methods of assessment common to the Member States, shall ensure that information on environmental noise and its effects is made available to the public and shall adopt action plans based upon noisemapping results, with a view to preventing and reducing environmental noise where necessary and particularly where exposure levels can induce harmful effects on human health, and to preserving environmental noise quality where it is good.
- (2) According to Article 5 of Directive 2002/49/EC, Member States shall apply the noise indicators (L_{den} and L_{night}) referred to in Annex I to that Directive for the preparation and revision of strategic noise mapping in accordance with Article 7.
- (3) According to Article 6 of Directive 2002/49/EC, the values of the noise indicators (L_{den} and L_{ni}) shall be determined by means of the assessment methods defined in Annex II to that Directive.
- (4) According to Article 6 of Directive 2002/49/EC, the Commission shall establish common assessment methods for the determination of the noise indicators L_{den} and L_{nivht} through a revision of Annex II.
- (5) According to Article 7 of Directive 2002/49/EC, Member States shall ensure that strategic noise maps are made no later than 30 June 2007 and 30 June 2012 and thereafter reviewed, and revised if necessary, at least every 5 years.
- (6) Directive 2002/49/EC provides for action plans to be based on strategic noise maps. Strategic noise maps shall be drawn up with the common assessment methods when these methods have been adopted by Member States. However, Member States may use other methods to design measures addressing priorities identified by using the common methods as well as for assessment of other national measures to prevent and reduce environmental noise.

⁽ 1) OJ L 189, 18.7.2002, p. 12.

- (8) The Annex to this Commission Directive sets out the common assessment methods. Member States are required to use these methods from 31 December 2018 onwards.
- (9) The assessment methods provided for in the Annex to this Directive are, according to its Article 2, paragraph 1, to be adopted by 31 December 2018 at the latest and until that date Member States may, according to Article 6, paragraph 2 of Directive 2002/49/EC, continue to use the existing assessment methods that they have previously adopted at the national level.
- (10) In accordance with Article 12 of Directive 2002/49/EC, the Commission shall adapt Annex II to technical and scientific progress.
- (11) Apart from the adaptation to scientific and technical progress in accordance with Article 12 of Directive 2002/49/EC, the Commission shall endeavour to modify the Annex based on the experience from Member States.
- (12) The common assessment methods are also to be used for the purpose of other EU legislation where that legislation refers to Annex II to Directive 2002/49/EC.
- (13) The measures provided for in this Directive are in accordance with the opinion of the Committee established under Article 13 of Directive 2002/49/EC,

HAS ADOPTED THIS DIRECTIVE:

Article 1

Annex II to Directive 2002/49/EC is replaced by the text set out in the Annex to this Directive.

Article 2

1. Member States shall bring into force the laws, regulations and administrative provisions necessary to comply with this Directive by 31 December 2018 at the latest. They shall forthwith communicate to the Commission the text of those provisions.

When Member States adopt those provisions, they shall contain a reference to this Directive or be accompanied by such a reference on the occasion of their official publication. Member States shall determine how such reference is to be made.

2. Member States shall communicate to the Commission the text of the main provisions of national law which they adopt in the field covered by this Directive.

Article 3

This Directive shall enter into force on the day following that of its publication in the *Official Journal of the European Union*.

⁽ 1) Directive 2000/14/EC of the European Parliament and of the Council of 8 May 2000 on the approximation of the laws of the Member States relating to the noise emission in the environment by equipment for use outdoors (OJ L 162, 3.7.2000, p. 1).

⁽ 2) Common Noise Assessment Methods in Europe (CNOSSOS-EU) — JRC Reference Report, EUR 25379 EN. Luxembourg: Publications Office of the European Union, 2012, — ISBN 978-92-79-25281-5

Article 4

This Directive is addressed to the Member States.

Done at Brussels, 19 May 2015.

For the Commission, On behalf of the President, Karmenu VELLA *Member of the Commission*

ANNEX

ASSESSMENT METHODS FOR THE NOISE INDICATORS

(Referred to in Article 6 of Directive 2002/49/EC)

1. INTRODUCTION

The values of L_{den} and L_{night} shall be determined at the assessment positions by computation, according to the method set out in Chapter 2 and the data described in Chapter 3. Measurements may be performed according to Chapter 4.

2. COMMON NOISE ASSESSMENT METHODS

2.1. **General provisions — Road traffic, railway and industrial noise**

2.1.1. *Indicators, frequency range and band definitions*

Noise calculations shall be defined in the frequency range from 63 Hz to 8 kHz. Frequency band results shall be provided at the corresponding frequency interval.

Calculations are performed in octave bands for road traffic, railway traffic and industrial noise, except for the railway noise source sound power, that uses third octave bands. For road traffic, railway traffic and industrial noise, based on these octave band results, the A-weighted long term average sound pressure level for the day, evening and night period, as defined in Annex I and referred to in Art. 5 of Directive 2002/49/EC, is computed by summation over all frequencies:

$$
L_{\text{Aeq},T} = 10 \times \lg \sum_{i=1} 10^{(L_{\text{eq},T,i} + \text{A}_i)/10} \tag{2.1.1}
$$

where

Ai denotes the A-weighting correction according to IEC 61672-1

i = frequency band index

and *T* is the time period corresponding to day, evening or night.

Noise parameters:

Other physical parameters:

2.1.2. *Quality framework*

Accuracy of input values

All input values affecting the emission level of a source shall be determined with at least the accuracy corresponding to an uncertainty of \pm 2dB(A) in the emission level of the source (leaving all other parameters unchanged).

Use of default values

In the application of the method, the input data shall reflect the actual usage. In general there shall be no reliance on default input values or assumptions. Default input values and assumptions are accepted if the collection of real data is associated with disproportionately high costs.

Quality of the software used for the calculations

Software used to perform the calculations shall prove compliance with the methods herewith described by means of certification of results against test cases.

2.2. **Road traffic noise**

2.2.1. *Source description*

Classification of vehicles

The road traffic noise source shall be determined by combining the noise emission of each individual vehicle forming the traffic flow. These vehicles are grouped into five separate categories with regard to their characteristics of noise emission:

- Category 1: Light motor vehicles
- Category 2: Medium heavy vehicles
- Category 3: Heavy vehicles
- Category 4: Powered two-wheelers
- Category 5: Open category

In the case of powered two-wheelers, two separate subclasses are defined for mopeds and more powerful motorcycles, since they operate in very different driving modes and their numbers usually vary widely.

The first four categories shall be used, and the fifth category is optional. It is foreseen for new vehicles that may be developed in the future and may be sufficiently different in their noise emission to require an additional category to be defined. This category could cover, for example, electric or hybrid vehicles or any vehicle developed in the future substantially different from those in categories 1 to 4.

The details of the different vehicle classes are given in Table [2.2.a].

Table [2.2.a]

Vehicle classes

(1) Directive 2007/46/EC of the European Parliament and of the Council of 5 September 2007 establishing a framework for the approval of motor vehicles and their trailers, and of systems, components and separate technical units intended for such vehicles (OJ L 263, 9.10.2007, p. 1).

 (2) Sport Utility Vehicles.

(3) Multi-Purpose Vehicles.

Number and position of equivalent sound sources

In this method, each vehicle (category 1, 2, 3, 4 and 5) is represented by one single point source radiating uniformly into the $2-\pi$ half space above the ground. The first reflection on the road surface is treated implicitly. As depicted in Figure [2.2.a], this point source is placed 0,05 m above the road surface.

Figure [2.2.a]

Location of equivalent point source on light vehicles (category 1), heavy vehicles (categories 2 and 3) and two-wheelers (category 4)

The traffic flow is represented by a source line. In the modelling of a road with multiple lanes, each lane should ideally be represented by a source line placed in the centre of each lane. However, it is also acceptable to model one source line in the middle of a two way road or one source line per carriageway in the outer lane of multilane roads.

Sound power emission

General considerations

The sound power of the source is defined in the 'semi-free field', thus the sound power includes the effect of the reflection of the ground immediately under the modelled source where there are no disturbing objects in its immediate surroundings except for the reflection on the road surface not immediately under the modelled source.

Traffic f low

The noise emission of a traffic flow is represented by a source line characterised by its directional sound power per metre per frequency. This corresponds to the sum of the sound emission of the individual vehicles in the traffic flow, taking into account the time spent by the vehicles in the road section considered. The implementation of the individual vehicle in the flow requires the application of a traffic flow model.

If a steady traffic flow of Q_m vehicles of category m per hour is assumed, with an average speed v_m (in km/h), the directional sound power per metre in frequency band i of the source line *L_{W', eq,line,i,m}* is defined by:

$$
L_{W',eq,line,i,m} = L_{W,i,m} + 10 \times \lg \left(\frac{Q_m}{1\ 000 \times \nu_m} \right) \tag{2.2.1}
$$

where $L_{W,i,m}$ is the directional sound power of a single vehicle. $L_{W',m}$ is expressed in dB (re. 10⁻¹² W/m). These sound power levels are calculated for each octave band i from 125 Hz to 4 kHz.

Traffic flow data *Qm* shall be expressed as yearly average per hour, per time period (day-evening-night), per vehicle class and per source line. For all categories, input traffic flow data derived from traffic counting or from traffic models shall be used.

The speed v_m is a representative speed per vehicle category: in most cases the lower of the maximum legal speed for the section of road and the maximum legal speed for the vehicle category. If local measurement data is unavailable the maximum legal speed for the vehicle category shall be used.

Individual vehicle

In the traffic flow, all vehicles of category m are assumed to drive at the same speed, i.e. *v_m*, the average speed of the flow of vehicles of the category.

A road vehicle is modelled by a set of mathematical equations representing the two main noise sources:

- 1. Rolling noise due to the tyre/road interaction;
- 2. Propulsion noise produced by the driveline (engine, exhaust, etc.) of the vehicle.

Aerodynamic noise is incorporated in the rolling noise source.

For light, medium and heavy motor vehicles (categories 1, 2 and 3), the total sound power corresponds to the energetic sum of the rolling and the propulsion noise. Thus, the total sound power level of the source lines *m* = 1, 2 or 3 is defined by:

$$
L_{W,i,m}(v_m) = 10 \times \lg(10^{L_{WR,i,m}(v_m)/10} + 10^{L_{WP,i,m}(v_m)/10}) \tag{2.2.2}
$$

where $L_{\text{WR},i,m}$ is the sound power level for rolling noise and $L_{\text{WP},i,m}$ is the sound power level for propulsion noise. This is valid on all speed ranges. For speeds less than 20 km/h it shall have the same sound power level as defined by the formula for $v_m = 20 \text{ km/h}$.

For two-wheelers (category 4), only propulsion noise is considered for the source:

$$
L_{W,i,m=4}(v_{m=4}) = L_{WP,i,m=4}(v_{m=4})
$$
\n(2.2.3)

This is valid on all speed ranges. For speeds less than 20 km/h it shall have the same sound power level as defined by the formula for $v_m = 20 \text{ km/h}$.

2.2.2. *Reference conditions*

The source equations and coefficients are valid for the following reference conditions:

- a constant vehicle speed
- a flat road
- an air temperature τ_{ref} = 20 °C

- a virtual reference road surface, consisting of an average of dense asphalt concrete 0/11 and stone mastic asphalt 0/11, between 2 and 7 years old and in a representative maintenance condition
- a dry road surface
- no studded tyres.
- 2.2.3. *Rolling noise*

General equation

The rolling noise sound power level in the frequency band i for a vehicle of class $m = 1,2$ or 3 is defined as:

$$
L_{\text{WR},i,m} = A_{\text{R},i,m} + B_{\text{R},i,m} \times \lg \left(\frac{v_m}{v_{\text{ref}}} \right) + \Delta L_{\text{WR},i,m}
$$
\n(2.2.4)

The coefficients A_{R,im} and B_{R,im} are given in octave bands for each vehicle category and for a reference speed v_{ref} = 70 km/h. $\Delta L_{WR,i,m}^{r,s,m}$ corresponds to the sum of the correction coefficients to be applied to the rolling noise emission for specific road or vehicle conditions deviating from the reference conditions:

$$
\Delta L_{\text{WR},i,m} = \Delta L_{\text{WR},\text{road},i,m} + \Delta L_{\text{studdedtypes},i,m} + \Delta L_{\text{WR},\text{acc},i,m} + \Delta L_{\text{W},\text{temp}} \tag{2.2.5}
$$

Δ*LWR,road,i,m* accounts for the effect on rolling noise of a road surface with acoustic properties different from those of the virtual reference surface as defined in Chapter 2.2.2. It includes both the effect on propagation and on generation.

Δ*Lstudded tyres,i,m* is a correction coefficient accounting for the higher rolling noise of light vehicles equipped with studded tyres.

Δ*LWR,acc,i,m* accounts for the effect on rolling noise of a crossing with traffic lights or a roundabout. It integrates the effect on noise of the speed variation.

Δ*LW,temp* is a correction term for an average temperature *τ* different from the reference temperature *τref* = 20 °C.

Correction for studded tyres

In situations where a significant number of light vehicles in the traffic flow use studded tyres during several months every year, the induced effect on rolling noise shall be taken into account. For each vehicle of category $m = 1$ equipped with studded tyres, a speed-dependent increase in rolling noise emission is evaluated by:

$$
\Delta_{\text{stud,i}}(v) = \begin{cases} a_i + b_i \times \frac{1}{2}(50/70) & \text{for } v < 50 \text{ km/h} \\ a_i + b_i \times \frac{1}{2}(v/70) & \text{for } 50 \le v \le 90 \text{ km/h} \\ a_i + b_i \times \frac{1}{2}(90/70) & \text{for } v > 90 \text{ km/h} \end{cases} \tag{2.2.6}
$$

where coefficients *a_i* and *b_i* are given for each octave band.

The increase in rolling noise emission shall only be attributed according to the proportion of light vehicles with studded tyres and during a limited period T_s (in months) over the year. If Q_{quad} is the average ratio of the total volume of light vehicles per hour equipped with studded tyres during the period T_s (in months), then the yearly average proportion of vehicles equipped with studded tyres p_s is expressed by:

$$
p_s = Q_{\text{stud, ratio}} \times \frac{T_s}{12} \tag{2.2.7}
$$

The resulting correction to be applied to the rolling sound power emission due to the use of studded tyres for vehicles of category $m = 1$ in frequency band i shall be:

$$
\Delta L_{studedtypes,i,m=1} = 10 \times \lg \left[(1 - p_s) + p_s \, 10^{\frac{\Delta_{stud,i,m=1}}{10}} \right] \tag{2.2.8}
$$

For vehicles of all other categories no correction shall be applied:

$$
\Delta L_{\text{studdedtypes},i,m+1} = 0 \tag{2.2.9}
$$

Effect of air temperature on rolling noise correction

The air temperature affects rolling noise emission; the rolling sound power level decreases when the air temperature increases. This effect is introduced in the road surface correction. Road surface corrections are usually evaluated at an air temperature of τ_{ref} = 20 °C. In the case of a different yearly average air temperature °C, the road surface noise shall be corrected by:

$$
\Delta L_{W,temp,m}(\tau) = K_m \times (\tau_{ref} - \tau) \tag{2.2.10}
$$

The correction term is positive (i.e. noise increases) for temperatures lower than 20 $^{\circ}$ C and negative (i.e. noise decreases) for higher temperatures. The coefficient K depends on the road surface and the tyre characteristics and in general exhibits some frequency dependence. A generic coefficient $K_{m=1} = 0.08$ dB/°C for light vehicles (category 1) and $K_{m=2} = K_{m=3} = 0.04$ dB/°C for heavy vehicles (categories 2 and 3) shall be applied for all road surfaces. The correction coefficient shall be applied equally on all octave bands from 63 to 8 000 Hz.

2.2.4. *Propulsion noise*

General equation

The propulsion noise emission includes all contributions from engine, exhaust, gears, air intake, etc. The propulsion noise sound power level in the frequency band i for a vehicle of class m is defined as:

$$
L_{WP,i,m} = A_{P,i,m} + B_{P,i,m} \times \frac{(v_m - v_{ref})}{v_{ref}} + \Delta L_{WP,i,m}
$$
\n(2.2.11)

The coefficients $A_{p_{i,m}}$ and $B_{p_{i,m}}$ are given in octave bands for each vehicle category and for a reference speed v_{ref} = 70 km/h.

Δ*LWP,i,m* corresponds to the sum of the correction coefficients to be applied to the propulsion noise emission for specific driving conditions or regional conditions deviating from the reference conditions:

$$
\Delta L_{WP,i,m} = \Delta L_{WP,road,i,m} + \Delta L_{WP, grad,i,m} + \Delta L_{WP,acc,i,m}
$$
\n(2.2.12)

Δ*LWP,road,i,m* accounts for the effect of the road surface on the propulsion noise via absorption. The calculation shall be performed according to Chapter 2.2.6.

Δ*LWP,acc,i,m* and Δ*LWP,grad,i,m* account for the effect of road gradients and of vehicle acceleration and deceleration at intersections. They shall be calculated according to Chapters 2.2.4 and 2.2.5 respectively.

Effect of road gradients

The road gradient has two effects on the noise emission of the vehicle: first, it affects the vehicle speed and thus the rolling and propulsion noise emission of the vehicle; second, it affects both the engine load and the engine speed via the choice of gear and thus the propulsion noise emission of the vehicle. Only the effect on the propulsion noise is considered in this section, where a steady speed is assumed.

The effect of the road gradient on the propulsion noise is taken into account by a correction term Δ*LWP,grad,m* which is a function of the slope s (in %), the vehicle speed v_m (in km/h) and the vehicle class m . In the case of a bi-directional traffic flow, it is necessary to split the flow into two components and correct half for uphill and half for downhill. The correction term is attributed to all octave bands equally:

For
$$
m = 1
$$

$$
\Delta L_{WP, grad, i, m = 1}(v_m) = \begin{cases}\n\frac{\text{Min}(12\%; -s) - 6\%}{1\%} & \text{for } s < -6\% \\
0 & \text{for } -6\% \le s \le 2\% \\
\frac{\text{Min}(12\%; s) - 2\%}{1.5\%} \times \frac{v_m}{100} & \text{for } s > 2\% \n\end{cases}
$$
\n(2.2.13)

For $m = 2$

$$
\Delta L_{WPGrad,i,m=2}(v_m) = \begin{cases}\n\frac{\text{Min}(12\%; -s) - 4\%}{0.7\%} \times \frac{v_m - 20}{100} & \text{for } s < -4\% \\
0 & \text{for } -4\% \le s \le 0\% \\
\frac{\text{Min}(12\%;s)}{1\%} \times \frac{v_m}{100} & \text{for } s > 0\% \n\end{cases}
$$
\n(2.2.14)

For $m = 3$

$$
\Delta L_{w_{P,grad,i,m=3}}(v_m) = \begin{cases}\n\frac{\text{Min}(12\%; -s) - 4\%}{0.5\%} \times \frac{v_m - 10}{100} & \text{for } s < -4\% \\
0 & \text{for } -4\% \le s \le 0\% \\
\frac{\text{Min}(12\%;s)}{0.8\%} \times \frac{v_m}{100} & \text{for } s > 0\% \n\end{cases}
$$
\n(2.2.15)

For $m = 4$

$$
\Delta L_{WP,grad,i,m=4} = 0 \tag{2.2.16}
$$

The correction Δ*L_{WP,grad,m}* implicitly includes the effect of slope on speed.

2.2.5. *Effect of the acceleration and deceleration of vehicles*

Before and after crossings with traffic lights and roundabouts a correction shall be applied for the effect of acceleration and deceleration as described below.

The correction terms for rolling noise, Δ*LWR,acc,m,k*, and for propulsion noise, Δ*LWP,acc,m,k*, are linear functions of the distance *x* (in m) of the point source to the nearest intersection of the respective source line with another source line. They are attributed to all octave bands equally:

$$
\Delta L_{\text{WR},ac,m,k} = C_{\text{R},m,k} \times \text{Max}(1 - \frac{|x|}{100};0) \tag{2.2.17}
$$

$$
\Delta L_{WP,acc,m,k} = C_{P,m,k} \times \text{Max}(1 - \frac{|x|}{100};0)
$$
\n(2.2.18)

The coefficients $C_{R,m,k}$ and $C_{p,m,k}$ depend on the kind of junction *k* ($k = 1$ for a crossing with traffic lights; $k = 2$ for a roundabout) and are given for each vehicle category. The correction includes the effect of change in speed when approaching or moving away from a crossing or a roundabout.

Note that at a distance $|x| \ge 100$ m, $\Delta L_{WR,ac,m,k} = \Delta L_{WP,ac,m,k} = 0$.

2.2.6. *Effect of the type of road surface*

General principles

For road surfaces with acoustic properties different from those of the reference surface, a spectral correction term for both rolling noise and propulsion noise shall be applied.

The road surface correction term for the rolling noise emission is given by:

$$
\Delta L_{\text{WR},\text{road},i,m} = a_{i,m} + \beta_m \times \lg \left(\frac{\nu_m}{\nu_{\text{ref}}} \right) \tag{2.2.19}
$$

where

αi,m is the spectral correction in dB at reference speed *vref* for category *m* (1, 2 or 3) and spectral band *i*.

βm is the speed effect on the rolling noise reduction for category *m* (1, 2 or 3) and is identical for all frequency bands.

The road surface correction term for the propulsion noise emission is given by:

$$
\Delta L_{WP, road,i,m} = \min\{\alpha_{i,m};0\} \tag{2.2.20}
$$

Absorbing surfaces decrease the propulsion noise, while non-absorbing surfaces do not increase it.

Age effect on road surface noise properties

The noise characteristics of road surfaces vary with age and the level of maintenance, with a tendency to become louder over time. In this method the road surface parameters are derived to be representative for the acoustic performance of the road surface type averaged over its representative lifetime and assuming proper maintenance.

2.3. **Railway noise**

2.3.1. *Source description*

Classification of vehicles

Definition of vehicle and t rain

For the purposes of this noise calculation method, a vehicle is defined as any single railway sub-unit of a train (typically a locomotive, a self-propelled coach, a hauled coach or a freight wagon) that can be moved independently and can be detached from the rest of the train. Some specific circumstances may occur for sub-units of a train that are a part of a non-detachable set, e.g. share one bogie between them. For the purpose of this calculation method, all these sub-units are grouped into a single vehicle.

For the purpose of this calculation method, a train consists of a series of coupled vehicles.

Table [2.3.a] defines a common language to describe the vehicle types included in the source database. It presents the relevant descriptors to be used to classify the vehicles in full. These descriptors correspond to properties of the vehicle, which affect the acoustic directional sound power per metre length of the equivalent source line modelled.

The number of vehicles for each type shall be determined on each of the track sections for each of the time periods to be used in the noise calculation. It shall be expressed as an average number of vehicles per hour, which is obtained by dividing the total number of vehicles travelling in a given time period by the duration in hours of this time period (e.g. 24 vehicles in 4 hours means 6 vehicles per hour). All vehicle types travelling on each track section shall be used.

Table [2.3.a]

Classification and descriptors for railway vehicles

Classification of tracks and support structure

The existing tracks may differ because there are several elements contributing to and characterising their acoustic properties. The track types used in this method are listed in Table [2.3.b] below. Some of the elements have a large influence on acoustic properties, while others have only secondary effects. In general, the most relevant elements influencing the railway noise emission are: railhead roughness, rail pad stiffness, track base, rail joints and radius of curvature of the track. Alternatively, the overall track properties can be defined and, in this case, the railhead roughness and the track decay rate according to ISO 3095 are the two acoustically essential parameters, plus the radius of curvature of the track.

A track section is defined as a part of a single track, on a railway line or station or depot, on which the track's physical properties and basic components do not change.

Table [2.3.b] defines a common language to describe the track types included in the source database.

Table [2.3.b]

Number and position of the equivalent sound sources

Figure [2.3.a]

Equivalent noise sources position

The different equivalent noise line sources are placed at different heights and at the centre of the track. All heights are referred to the plane tangent to the two upper surfaces of the two rails.

The equivalent sources include different physical sources (index p). These physical sources are divided into different categories depending on the generation mechanism, and are: (1) rolling noise (including not only rail and track base vibration and wheel vibration but also, where present, superstructure noise of the freight vehicles); (2) traction noise; (3) aerodynamic noise; (4) impact noise (from crossings, switches and junctions); (5) squeal noise and (6) noise due to additional effects such as bridges and viaducts.

- (1) The roughness of wheels and railheads, through three transmission paths to the radiating surfaces (rails, wheels and superstructure), constitutes the rolling noise. This is allocated to $h = 0.5$ m (radiating surfaces A) to represent the track contribution, including the effects of the surface of the tracks, especially slab tracks (in accordance with the propagation part), to represent the wheel contribution and to represent the contribution of the superstructure of the vehicle to noise (in freight trains).
- (2) The equivalent source heights for traction noise vary between 0,5 m (source A) and 4,0 m (source B), depending on the physical position of the component concerned. Sources such as gear transmissions and electric motors will often be at an axle height of 0,5 m (source A). Louvres and cooling outlets can be at various heights; engine exhausts for diesel-powered vehicles are often at a roof height of 4,0 m (source B). Other traction sources such as fans or diesel engine blocks may be at a height of $0,\bar{5}$ m (source A) or 4,0 m (source B). If the exact source height is in between the model heights, the sound energy is distributed proportionately over the nearest adjacent source heights.

For this reason, two source heights are foreseen by the method at 0,5 m (source A), 4,0 m (source B), and the equivalent sound power associated with each is distributed between the two depending on the specific configuration of the sources on the unit type.

(3) Aerodynamic noise effects are associated with the source at 0,5 m (representing the shrouds and the screens, source A), and the source at 4,0 m (modelling all over roof apparatus and pantograph, source B). The choice of 4,0 m for pantograph effects is known to be a simple model, and has to be considered carefully if the objective is to choose an appropriate noise barrier height.

- (4) Impact noise is associated with the source at 0,5 m (source A).
- (5) Squeal noise is associated with the sources at 0,5 m (source A).
- (6) Bridge noise is associated with the source at 0,5 m (source A).
- 2.3.2. *Sound power emission*

General equations

Individual vehicle

The model for railway traffic noise, analogously to road traffic noise, describes the noise sound power emission of a specific combination of vehicle type and track type which fulfils a series of requirements described in the vehicle and track classification, in terms of a set of sound power per each vehicle (L_{w0}) .

Traffic f low

The noise emission of a traffic flow on each track shall be represented by a set of 2 source lines characterised by its directional sound power per metre per frequency band. This corresponds to the sum of the sound emissions due to the individual vehicles passing by in the traffic flow and, in the specific case of stationary vehicles, taking into account the time spent by the vehicles in the railway section under consideration.

The directional sound power per metre per frequency band, due to all the vehicles passing by each track section on the track type (j), is defined:

- for each frequency band (i),
- for each given source height (h) (for sources at 0.5 m h = 1, at 4.0 m h = 2),

and is the energy sum of all contributions from all vehicles running on the specific j-th track section. These contributions are:

- from all vehicle types (t)
- at their different speeds (s)
- under the particular running conditions (constant speed) (c)
- for each physical source type (rolling, impact, squeal, traction, aerodynamic and additional effects sources such as for example bridge noise) (p).

To calculate the directional sound power per metre (input to the propagation part) due to the average mix of traffic on the j-th track section, the following is used:

$$
L_{W',eq,T,dir,i} = 10 \cdot \lg \left(\sum_{x=1}^{X} 10^{L_{W',eq,lineX}/10} \right)
$$
 (2.3.1)

where

T_{ref} = reference time period for which the average traffic is considered

- *^X*= total number of existing combinations of i, t, s, c, p for each *j*-th track section
- *t* = index for vehicle types on the *j*-th track section
- *s* = index for train speed: there are as many indexes as the number of different average train speeds on the *j*-th track section
- $c =$ index for running conditions: 1 (for constant speed), 2 (idling)
- *p* = index for physical source types: 1 (for rolling and impact noise), 2 (curve squeal), 3 (traction noise), 4 (aerodynamic noise), 5 (additional effects)
- $L_{W,eq,line,x}$ = *x*-th directional sound power per metre for a source line of one combination of *t*, *s*, *c*, *p* on each *j*-th track section

If a steady flow of *Q* vehicles per hour is assumed, with an average speed *v*, on average at each moment in time there will be an equivalent number of *Q*/*v* vehicles per unit length of the railway section. The noise emission of the vehicle flow in terms of directional sound power per metre *L_{W',eq,line}* (expressed in dB/m (re. 10⁻¹² W)) is integrated by:

$$
L_{W',eq,line,i}(\psi,\varphi) = L_{W,0,dir,i}(\psi,\varphi) + 10 \times \lg \left(\frac{Q}{1\ 000 \nu} \right) \text{ (for } c = 1)
$$
 (2.3.2)

where

- *Q* is the average number of vehicles per hour on the *j*-th track section for vehicle type *t*, average train speed *s* and running condition *c*
- *v* is their speed on the *j*-th track section for vehicle type **t** and average train speed *s*
- *LW,0,dir* is the directional sound power level of the specific noise (rolling, impact, squeal, braking, traction, aerodynamic, other effects) of a single vehicle in the directions ψ, φ defined with respect to the vehicle's direction of movement (see Figure [2.3.b]).

In the case of a stationary source, as during idling, it is assumed that the vehicle will remain for an overall time *Tidle* at a location within a track section with length *L*. Therefore, with *Tref* as the reference time period for the noise assessment (e.g. 12 hours, 4 hours, 8 hours), the directional sound power per unit length on that track section is defined by:

$$
L_{W',eq,line,i}(\psi,\varphi)=L_{W,0,dir,i}(\psi,\varphi)+10\times\lg\left(\frac{T_{idle}}{T_{ref}L}\right) \text{ (for }c=2)
$$
\n(2.3.4)

In general, directional sound power is obtained from each specific source as:

$$
L_{W,0,dir,i}(\psi,\varphi) = L_{W,0,i} + \Delta L_{W,dir,vert,i} + \Delta L_{W,dir,hor,i}
$$
\n(2.3.5)

where

- **ΔL_{Wdir},** is the vertical directivity correction (dimensionless) function of ψ (Figure [2.3.b])
- *ΔLW,dir,hor,i* is the horizontal directivity correction (dimensionless) function of φ (Figure [2.3.b]).

And where $L_{W,0,dir,i(\psi,\varphi)}$ shall, after being derived in 1/3 octave bands, be expressed in octave bands by energetically adding each pertaining 1/3 octave band together into the corresponding octave band.

Figure [2.3.b]

Geometrical definition

For the purpose of the calculations, the source strength is then specifically expressed in terms of directional sound power per 1 m length of track *L_{W',tot,dir,i* to account for the directivity of the sources in their vertical and} horizontal direction, by means of the additional corrections.

Several *LW,0,dir,i* (*ψ,φ*) are considered for each vehicle-track-speed-running condition combination:

- for a 1/3 octave frequency band (*i*)
- for each track section (*j*)
- source height (*h*) (for sources at 0,5 m *h* = 1, at 4,0 m *h* = 2)
- directivity (*d*) of the source

A set of *LW,0,dir,i* (*ψ,φ*) are considered for each vehicle-track-speed-running condition combination, each track section, the heights corresponding to $h = 1$ and $h = 2$ and the directivity.

Rolling noise

The vehicle contribution and the track contribution to rolling noise are separated into four essential elements: wheel roughness, rail roughness, vehicle transfer function to the wheels and to the superstructure (vessels) and track transfer function. Wheel and rail roughness represent the cause of the excitation of the vibration at the contact point between the rail and the wheel, and the transfer functions are two empirical or modelled functions that represent the entire complex phenomena of the mechanical vibration and sound generation on the surfaces of the wheel, the rail, the sleeper and the track substructure. This separation reflects the physical evidence that roughness present on a rail may excite the vibration of the rail, but it will also excite the vibration of the wheel and vice versa. Not including one of these four parameters would prevent the decoupling of the classification of tracks and trains.

Wheel and rail roughness

Rolling noise is mainly excited by rail and wheel roughness in the wavelength range from 5-500 mm.

Definition

The roughness level L_r is defined as 10 times the logarithm to the base 10 of the square of the mean square value *r2* of the roughness of the running surface of a rail or a wheel in the direction of motion (longitudinal level) measured in μm over a certain rail length or the entire wheel diameter, divided by the square of the reference value r_0^2 :

$$
L_r = 10 \times \lg\left(\frac{r}{r_0}\right)^2 \, \mathrm{dB} \tag{2.3.6}
$$

where

 r_0 = 1 μm

r = r.m.s. of the vertical displacement difference of the contact surface to the mean level

The roughness level *L_r* is typically obtained as a spectrum of wavelength λ and it shall be converted to a frequency spectrum $f = v/\lambda$, where f is the centre band frequency of a given 1/3 octave band in Hz, λ is the wavelength in m, and *v* is the train speed in km/h. The roughness spectrum as a function of frequency shifts along the frequency axis for different speeds. In general cases, after conversion to the frequency spectrum by means of the speed, it is necessary to obtain new 1/3 octave band spectra values averaging between two corresponding 1/3 octave bands in the wavelength domain. To estimate the total effective roughness frequency spectrum corresponding to the appropriate train speed, the two corresponding 1/3 octave bands defined in the wavelength domain shall be averaged energetically and proportionally.

The rail roughness level (track side roughness) for the *i*-th wave-number band is defined as L_{true}

By analogy, *the wheel roughness level* (vehicle side roughness) for the *i*-th wave-number band is defined as $L_{r,VEH,i}$.

The total and effective roughness level for wave-number band *i* (*L_{R,tot,i}*) is defined as the energy sum of the roughness levels of the rail and that of the wheel plus the *A3*(*λ*) contact filter to take into account the filtering effect of the contact patch between the rail and the wheel, and is in dB:

$$
L_{R,TOT,i} = 10 \cdot \lg(10^{L_{r,TR,i}/10} + 10^{L_{r,VEL,i}/10}) + A_{3,i}
$$
\n(2.3.7)

where expressed as a function of the *i*-th wave-number band corresponding to the wavelength *λ*.

The contact filter depends on the rail and wheel type and the load.

The total effective roughness for the *j*-th track section and each *t*-th vehicle type at its corresponding *v* speed shall be used in the method.

Vehicle, track and superstructure transfer function

Three speed-independent transfer functions, *LH,TR,i LH,VEH,i* and *LH,VEH,SUP,i*, are defined: the first for each *j*-th track section and the second two for each *t*-th vehicle type. They relate the total effective roughness level with the sound power of the track, the wheels and the superstructure respectively.

The superstructure contribution is considered only for freight wagons, therefore only for vehicle type 'a'.

For rolling noise, therefore, the contributions from the track and from the vehicle are fully described by these transfer functions and by the total effective roughness level. When a train is idling, rolling noise shall be excluded.

For sound power per vehicle the rolling noise is calculated at axle height, and has as an input the total effective roughness level L_{R,TOT,i} as a function of the vehicle speed *v*, the track, vehicle and superstructure transfer functions $L_{H,TR,i}$, $L_{H,VEH,i}$ and $L_{H,VEH,SUP,i}$, and the total number of axles N_a .

for *h* = 1:

$$
L_{W,0,TE,1} = L_{R,TOT,i} + L_{H,TE,i} + 10 \times \lg(N_a)
$$
 dB (2.3.8)
\n
$$
L_{W,0,VEH,i} = L_{R,TOT,i} + L_{H,VEH,i} + 10 \times \lg(N_a)
$$
 dB (2.3.9)
\n
$$
L_{W,0,VEHSUP,i} = L_{R,TOT,i} + L_{H,VEHSUP,i} + 10 \times \lg(N_a)
$$
 dB (2.3.10)

where N_a is the number of axles per vehicle for the *t*-th vehicle type.

Figure [2.3.c]

Scheme of the use of the different roughness and transfer function definitions

A minimum speed of 50 km/h (30 km/h only for trams and light metro) shall be used to determine the total effective roughness and therefore the sound power of the vehicles (this speed does not affect the vehicle flow calculation) to compensate for the potential error introduced by the simplification of rolling noise definition, braking noise definition and impact noise from crossings and switches definition.

Impact noise (crossings, switches and junctions)

Impact noise can be caused by crossings, switches and rail joints or points. It can vary in magnitude and can dominate rolling noise. Impact noise shall be considered for jointed tracks. For impact noise due to switches, crossings and joints in track sections with a speed of less than 50 km/h (30 km/h only for trams and light metro), since the minimum speed of 50 km/h (30 km/h only for trams and light metro) is used to include more effects according to the description of the rolling noise chapter, modelling shall be avoided. Impact noise modelling shall also be avoided under running condition $c = 2$ (idling).

Impact noise is included in the rolling noise term by (energy) adding a supplementary fictitious impact roughness level to the total effective roughness level on each specific *j*-th track section where it is present. In this case a new $L_{R,TOT + IMPACT,i}$ shall be used in place of $L_{R,TOT,i}$ and it will then become:

LR,TOT ^þ*IMPACT,i* ¼ 10 � lgð10*LR,TOT,i=*¹⁰ þ 10*LR,IMPACT,i=*¹⁰Þ dB (2.3.11)

LR,IMPACT,i is a 1/3 octave band spectrum (as a function of frequency). To obtain this frequency spectrum, a spectrum is given as a function of wavelength *λ* and shall be converted to the required spectrum as a function of frequency using the relation $\lambda = v/f$, where f is the 1/3 octave band centre frequency in Hz and *v* is the *s*-th vehicle speed of the *t*-th vehicle type in km/h.

Impact noise will depend on the severity and number of impacts per unit length or joint density, so in the case where multiple impacts are given, the impact roughness level to be used in the equation above shall be calculated as follows:

$$
L_{R,IMPACT,i} = L_{R, IMPACT-SINGLE,i} + 10 \times \lg\left(\frac{n_i}{0.01}\right) \qquad \qquad \text{dB}
$$
 (2.3.12)

where $L_{R,IMPACT-SINGLE,i}$ is the impact roughness level as given for a single impact and n_i is the joint density.

The default impact roughness level is given for a joint density $n_1 = 0.01 \text{ m}^{-1}$, which is one joint per each 100 m of track. Situations with different numbers of joints shall be approximated by adjusting the joint density *n*_l. It should be noted that when modelling the track layout and segmentation, the rail joint density shall be taken into account, i.e. it may be necessary to take a separate source segment for a stretch of track with more joints. The *L_{W,0}* of track, wheel/bogie and superstructure contribution are incremented by means of the *L_{R,IMPACT,i}* for $+/-$ 50 m before and after the rail joint. In the case of a series of joints, the increase is extended to between – 50 m before the first joint and + 50 m after the last joint.

The applicability of these sound power spectra shall normally be verified on-site.

For jointed tracks, a default *n_l* of 0,01 shall be used.

Squeal

Curve squeal is a special source that is only relevant for curves and is therefore localised. As it can be significant, an appropriate description is required. Curve squeal is generally dependent on curvature, friction conditions, train speed and track-wheel geometry and dynamics. The emission level to be used is determined for curves with radius below or equal to 500 m and for sharper curves and branch-outs of points with radii below 300 m. The noise emission should be specific to each type of rolling stock, as certain wheel and bogie types may be significantly less prone to squeal than others.

The applicability of these sound power spectra shall normally be verified on-site, especially for trams.

Taking a simple approach, squeal noise shall be considered by adding 8 dB for $R < 300$ m and 5 dB for $300 \text{ m} < R < 500 \text{ m}$ to the rolling noise sound power spectra for all frequencies. Squeal contribution shall be applied on railway track sections where the radius is within the ranges mentioned above for at least a 50 m length of track.

Traction noise

Although traction noise is generally specific to each characteristic operating condition amongst constant speed, deceleration, acceleration and idling, the only two conditions modelled are constant speed (that is valid as well when the train is decelerating or when it is accelerating) and idling. The source strength modelled only corresponds to maximum load conditions and this results in the quantities $L_{W,0,const,i} = L_{W,0,idling,i}$. Also, the $L_{W,0,idling,i}$ corresponds to the contribution of all physical sources of a given vehicle attributable to a specific height, as described in 2.3.1.

The *L_{W,0,idling,i}* is expressed as a static noise source in the idling position, for the duration of the idling condition, and to be used modelled as a fixed point source as described in the following chapter for industrial noise. It shall be considered only if trains are idling for more than 0,5 hours.

These quantities can either be obtained from measurements of all sources at each operating condition, or the partial sources can be characterised individually, determining their parameter dependency and relative strength. This may be done by means of measurements on a stationary vehicle, by varying shaft speeds of the traction equipment, following ISO 3095:2005. As far as relevant, several traction noise sources have to be characterised which might not be all directly depending on the train speed:

- noise from the power train, such as diesel engines (including inlet, exhaust and engine block), gear transmission, electrical generators, mainly dependent on engine round per minute speed (rpm), and electrical sources such as converters, which may be mostly load-dependent,
- noise from fans and cooling systems, depending on fan rpm; in some cases fans can be directly coupled to the driveline,
- intermittent sources such as compressors, valves and others with a characteristic duration of operation and corresponding duty cycle correction for the noise emission.

As each of these sources can behave differently at each operating condition, the traction noise shall be specified accordingly. The source strength is obtained from measurements under controlled conditions. In general, locomotives will tend to show more variation in loading as the number of vehicles hauled and thereby the power output can vary significantly, whereas fixed train formations such as electric motored units (EMUs), diesel motored units (DMUs) and high-speed trains have a better defined load.

There is no a priori attribution of the source sound power to the source heights, and this choice shall depend on the specific noise and vehicle assessed. It shall be modelled to be at source A (h = 1) and at source B (h = 2).

A erodynamic noise

Aerodynamic noise is only relevant at high speeds above 200 km/h and therefore it should first be verified whether it is actually necessary for application purposes. If the rolling noise roughness and transfer functions are known, it can be extrapolated to higher speeds and a comparison can be made with existing high-speed data to check whether higher levels are produced by aerodynamic noise. If train speeds on a network are above 200 km/h but limited to 250 km/h, in some cases it may not be necessary to include aerodynamic noise, depending on the vehicle design.

The aerodynamic noise contribution is given as a function of speed:

$$
L_{W,0,i} = L_{W,0,1,i}(\nu_0) + \alpha_{1,i} \times \lg\left(\frac{\nu}{\nu_0}\right) \quad \text{dB} \quad \text{For } h = 1 \tag{2.3.13}
$$

$$
L_{w,0,i} = L_{w,0,2,i}(v_0) + \alpha_{2,i} \times \lg\left(\frac{v}{v_0}\right) \quad \text{dB} \quad \text{For } h = 2 \tag{2.3.14}
$$

where

 $v₀$ is a speed at which aerodynamic noise is dominant and is fixed at 300 km/h

L_{W01i} is a reference sound power determined from two or more measurement points, for sources at known source heights, for example the first bogie

L_{W0,2,i} is a reference sound power determined from two or more measurement points, for sources at known source heights, for example the pantograph recess heights

α1,i is a coefficient determined from two or more measurement points, for sources at known source heights, for example the first bogie

α2,i is a coefficient determined from two or more measurement points, for sources at known source heights, for example the pantograph recess heights.

Source directivity

The horizontal directivity ΔL_{W,dir,hor,i} in dB is given in the horizontal plane and by default can be assumed to be a dipole for rolling, impact (rail joints etc.), squeal, braking, fans and aerodynamic effects, given for each *i*-th frequency band by:

$$
\Delta L_{W,dir,hor,i} = 10 \times \lg(0.01 + 0.99 \cdot \sin^2\varphi) \tag{2.3.15}
$$

The ve rtical directivity ΔLW,dir,ver,i in dB is given in the vertical plane for source A (h = 1), as a function of the centre band frequency $f_{c,i}$ of each *i*-th frequency band, and for $-\pi/2 < \psi < \pi/2$ by:

$$
\Delta L_{W,dir,ver,i} = \left(\left| \frac{40}{3} \times \left[\frac{2}{3} \times \sin(2 \cdot \psi) - \sin \psi \right] \times \lg \left[\frac{f_{c,i} + 600}{200} \right] \right| \right) \tag{2.3.16}
$$

For source B $(h = 2)$ for the aerodynamic effect:

$$
\Delta L_{w,dir,ver,i} = 10 \times \lg(\cos^2 \psi) \qquad \text{for } \psi < 0 \tag{2.3.17}
$$

 $\Delta L_{W,dir,veri} = 0$ elsewhere

Directivity Δ*Ldir,ver,i* is not considered for source B (h = 2) for other effects, as omni-directionality is assumed for these sources in this position.

2.3.3. *Additional effects*

Correction for structural radiation (bridges and viaducts)

In the case where the track section is on a bridge, it is necessary to consider the additional noise generated by the vibration of the bridge as a result of the excitation caused by the presence of the train. Because it is not simple to model the bridge emission as an additional source, given the complex shapes of bridges, an increase in the rolling noise is used to account for the bridge noise. The increase shall be modelled exclusively by adding a fixed increase in the noise sound power per each third octave band. The sound power of only the rolling noise is modified when considering the correction and the new *L_{W,0,rolling–and–bridge,i* shall be used instead of *L_{W,0,rolling-only,i*:}}

$$
L_{\text{W},0,\text{rolling-and-bridge},i} = L_{\text{W},0,\text{rolling-only},i} + C_{\text{bridge}} \qquad \qquad \text{dB}
$$
\n
$$
(2.3.18)
$$

where C_{bridge} is a constant that depends on the bridge type, and $L_{W,0,rolling-only,i}$ is the rolling noise sound power on the given bridge that depends only on the vehicle and track properties.

Correction for other railway-related noise sources

Various sources like depots, loading/unloading areas, stations, bells, station loudspeakers, etc. can be present and are associated with the railway noise. These sources are to be treated as industrial noise sources (fixed noise sources) and shall be modelled, if relevant, according to the following chapter for industrial noise.

2.4. **Industrial noise**

2.4.1. *Source description*

Classification of source types (point, line, area)

The industrial sources are of very variable dimensions. They can be large industrial plants as well as small concentrated sources like small tools or operating machines used in factories. Therefore, it is necessary to use an appropriate modelling technique for the specific source under assessment. Depending on the dimensions and the way several single sources extend over an area, with each belonging to the same industrial site, these may be modelled as point sources, source lines or area sources. In practice, the calculations of the noise effect are always based on point sources, but several point sources can be used to represent a real complex source, which mainly extends over a line or an area.

Number and position of equivalent sound sources

The real sound sources are modelled by means of equivalent sound sources represented by one or more point sources so that the total sound power of the real source corresponds to the sum of the single sound powers attributed to the different point sources.

The general rules to be applied in defining the number of point sources to be used are:

- line or surface sources where the largest dimension is less than 1/2 of the distance between the source and the receiver can be modelled as single point sources,
- sources where the largest dimension is more than 1/2 of the distance between the source and the receiver should be modelled as a series of incoherent point sources in a line or as a series of incoherent point sources over an area, such that for each of these sources the condition of 1/2 is fulfilled. The distribution over an area can include vertical distribution of point sources,
- for sources where the largest dimensions in height are over 2 m or near the ground, special care should be administered to the height of the source. Doubling the number of sources, redistributing them only in the z-component, may not lead to a significantly better result for this source,
- in the case of any source, doubling the number of sources over the source area (in all dimensions) may not lead to a significantly better result.

The position of the equivalent sound sources cannot be fixed, given the large number of configurations that an industrial site can have. Best practices will normally apply.

Sound power emission

General

The following information constitutes the complete set of input data for sound propagation calculations with the methods to be used for noise mapping:

- Emitted sound power level spectrum in octave bands
- Working hours (day, evening, night, on a yearly averaged basis)
- Location (coordinates *x, y*) and elevation (*z*) of the noise source
- Type of source (point, line, area)
- Dimensions and orientation
- Operating conditions of the source
- Directivity of the source.

The point, line and area source sound power are required to be defined as:

- For a point source, sound power L_w and directivity as a function of the three orthogonal coordinates (x, y, z) ;
- Two types of source lines can be defined:
- source lines representing conveyor belts, pipe lines, etc., sound power per metre length $L_{W'}$ and directivity as a function of the two orthogonal coordinates to the axis of the source line,

— source lines representing moving vehicles, each associated with sound power *L_W* and directivity as a function of the two orthogonal coordinates to the axis of the source line and sound power per metre *L_{W'}* derived by means of the speed and number of vehicles travelling along this line during day, evening and night; The correction for the working hours, to be added to the source sound power to define the corrected sound power that is to be used for calculations over each time period, C_w in dB is calculated as follows:

$$
C_W = -10\lg\left(\frac{l \times n}{1.000 \times V \times T_0}\right) \tag{2.4.1}
$$

Where:

- V Speed of the vehicle [km/h];
- n Number of vehicles passages per period [-];
- l Total length of the source [m].
- For an area source, sound power per square metre $L_{W/m2}$, and no directivity (may be horizontal or vertical).

The working hours are an essential input for the calculation of noise levels. The working hours shall be given for the day, evening and night period and, if the propagation is using different meteorological classes defined during each of the day, night and evening periods, then a finer distribution of the working hours shall be given in sub-periods matching the distribution of meteorological classes. This information shall be based on a yearly average.

The correction for the working hours, to be added to the source sound power to define the corrected sound power that shall be used for calculations over each time period, C_w in dB is calculated as follows:

$$
C_W = 10 \times \lg\left(\frac{T}{T_{ref}}\right) \tag{2.4.2}
$$

where

T is the active source time per period based on a yearly averaged situation, in hours;

Tref is the reference period of time in hours (e.g. day is 12 hours, evening is 4 hours, night is 8 hours).

For the more dominant sources, the yearly average working hours correction shall be estimated at least within 0,5 dB tolerance in order to achieve an acceptable accuracy (this is equivalent to an uncertainty of less than 10 % in the definition of the active period of the source).

Source directivity

The source directivity is strongly related to the position of the equivalent sound source next to nearby surfaces. Because the propagation method considers the reflection of the nearby surface as well its sound absorption, it is necessary to consider carefully the location of the nearby surfaces. In general, these two cases will always be distinguished:

— a source sound power and directivity is determined and given relative to a certain real source when this is in free field (excluding the terrain effect). This is in agreement with the definitions concerning the propagation, if it is assumed that there is no nearby surface less than 0,01 m from the source and surfaces at 0,01 m or more are included in the calculation of the propagation,

— a source sound power and directivity is determined and given relative to a certain real source when this is placed in a specific location and therefore the source sound power and directivity is in fact an 'equivalent' one, since it includes the modelling of the effect of the nearby surfaces. This is defined in 'semi-free field' according to the definitions concerning the propagation. In this case, the nearby surfaces modelled shall be excluded from the calculation of propagation.

The directivity shall be expressed in the calculation as a factor Δ*LW,dir,xyz* (*x, y, z*) to be added to the sound power to obtain the right directional sound power of a reference sound source seen by the sound propagation in the direction given. The factor can be given as a function of the direction vector defined by (x, y, z) with

 $x^2 + y^2 + z^2 = 1$. This directivity can also be expressed by means of other coordinate systems such as angular coordinate systems.

2.5. **Calculation of noise propagation for road, railway, industrial sources.**

2.5.1. *Scope and applicability of the method*

This document specifies a method for calculating the attenuation of noise during its outdoor propagation. Knowing the characteristics of the source, this method predicts the equivalent continuous sound pressure level at a receiver point corresponding to two particular types of atmospheric conditions:

- downward-refraction propagation conditions (positive vertical gradient of effective sound celerity) from the source to the receiver,
- homogeneous atmospheric conditions (null vertical gradient of effective sound celerity) over the entire area of propagation.

The method of calculation described in this document applies to industrial infrastructures and land transport infrastructures. It therefore applies in particular to road and railway infrastructures. Aircraft transport is included in the scope of the method only for the noise produced during ground operations and excludes takeoff and landing.

Industrial infrastructures that emit impulsive or strong tonal noises as described in ISO 1996-2:2007 do not fall within the scope of this method.

The method of calculation does not provide results in upward-refraction propagation conditions (negative vertical gradient of effective sound speed) but these conditions are approximated by homogeneous conditions when computing L_{den} .

To calculate the attenuation due to atmospheric absorption in the case of transport infrastructure, the temperature and humidity conditions are calculated according to ISO 9613-1:1996.

The method provides results per octave band, from 63 Hz to 8 000 Hz. The calculations are made for each of the centre frequencies.

Partial covers and obstacles sloping, when modelled, more than 15° in relation to the vertical are out of the scope of this calculation method.

A single screen is calculated as a single diffraction calculation, two or more screens in a single path are treated as a subsequent set of single diffractions by applying the procedure described further.

2.5.2. *Definitions used*

All distances, heights, dimensions and altitudes used in this document are expressed in metres (m).

The notation *MN* stands for the distance in 3 dimensions (3D) between the points *M* and *N*, measured according to a straight line joining these points.

The notation $\hat{M}N$ stands for the curved path length between the points M and N , in favourable conditions.

It is customary for real heights to be measured vertically in a direction perpendicular to the horizontal plane. Heights of points above the local ground are denoted h, absolute heights of points and absolute height of the ground are to be noted by the letter H.

To take into account the actual relief of the land along a propagation path, the notion of 'equivalent height' is introduced, to be noted by the letter z. This substitutes real heights in the ground effect equations.

The sound levels, noted by the capital letter *L*, are expressed in decibels (dB) per frequency band when index A is omitted. The sound levels in decibels dB(A) are given the index A.

The sum of the sound levels due to mutually incoherent sources is noted by the sign \oplus in accordance with the following definition:

$$
L_1 \oplus L_2 = 10 \cdot \lg \left[10^{L_1/6} + 10^{L_2/6} \right] \tag{2.5.1}
$$

2.5.3. *Geometrical considerations*

Source segmentation

Real sources are described by a set of point sources or, in the case of railway traffic or road traffic, by incoherent source lines. The propagation method assumes that line or area sources have previously been split up to be represented by a series of equivalent point sources. This may have occurred as pre-processing of the source data, or may occur within the pathfinder component of the calculation software. The means by which this has occurred is outside the scope of the current methodology.

Propagation paths

The method operates on a geometrical model consisting of a set of connected ground and obstacles surfaces. A vertical propagation path is deployed on one or more vertical planes with respect to the horizontal plane. For trajectories including reflections onto vertical surfaces not orthogonal to the incident plane, another vertical plane is subsequently considered including the reflected part of the propagation path. In these cases, where more vertical planes are used to describe the entire trajectory from the source to the receiver, the vertical planes are then flattened, like an unfolding Chinese screen.

Significant heights above the ground

The equivalent heights are obtained from the mean ground plane between the source and the receiver. This replaces the actual ground with a fictitious plane representing the mean profile of the land.

Figure 2.5.a

Equivalent heights in relation to the ground

- 1: Actual relief
- 2: Mean plane

The equivalent height of a point is its orthogonal height in relation to the mean ground plane. The equivalent source height z_s and the equivalent receiver height z_r can therefore be defined. The distance between the source and receiver in projection over the mean ground plane is noted by *dp*.

If the equivalent height of a point becomes negative, i.e. if the point is located below the mean ground plane, a null height is retained, and the equivalent point is then identical with its possible image.

Calculation of the mean plane

In the plane of the path, the topography (including terrain, mounds, embankments and other manmade obstacles, buildings, ...) may be described by an ordered set of discrete points (x_k, H_k) ; $k \in \{1,...,n\}$. This set of points defines a polyline, or equivalently, a sequence of straight segments $H_k = a_k x + b_k$, $x \in [x_k, x_{k+1}]$; $k \in$ {1,…*n*}, where:

$$
\begin{cases} a_k = (H_{k+1} - H_k)/(x_{k+1} - x_k) \\ b_k = (H_k \cdot x_{k+1} - H_{k+1} \cdot x_k)/(x_{k+1} - x_k) \end{cases}
$$
 (2.5.2)

The mean plane is represented by the straight line $Z = ax + b$; $x \in [x_1, x_n]$, which is adjusted to the polyline by means of a least-square approximation. The equation of the mean line can be worked out analytically.

Using:

$$
\begin{cases}\nA = \frac{2}{3} \sum_{k=1}^{n-1} a_k (x_{k+1}^3 - x_k^3) + \sum_{k=1}^{n-1} b_k (x_{k+1}^2 - x_k^2) \\
B = \sum_{k=1}^{n-1} a_k (x_{k+1}^2 - x_k^2) + 2 \sum_{k=1}^{n-1} b_k (x_{k+1} - x_k)\n\end{cases}
$$
\n(2.5.3)

The coefficients of the straight line are given by:

$$
\begin{cases}\na = \frac{3(2A - B(x_n + x_1))}{(x_n - x_1)^3} \\
b = \frac{2(x_n^3 - x_1^3)}{(x_n - x_1)^4}B - \frac{3(x_n + x_1)}{(x_n - x_1)^3}A\n\end{cases}
$$
\n(2.5.4)

Where segments with $x_{k+1} = x_k$ shall be ignored when evaluating eq. 2.5.3.

Reflections by building façades and other vertical obstacles

Contributions from reflections are taken into account by the introduction of image sources as described further.

2.5.4. *Sound propagation model*

For a receiver *R* the calculations are made according to the following steps:

- (1) on each propagation path:
	- calculation of the attenuation in favourable conditions,
	- calculation of the attenuation in homogeneous conditions,
	- calculation of the long-term sound level for each path;

(2) accumulation of the long-term sound levels for all paths affecting a specific receiver, therefore allowing the total sound level to be calculated at the receiver point.

It should be noted that only the attenuations due to the ground effect (*A_{ground}*) and diffraction (*A_{dif}*) are affected by meteorological conditions.

2.5.5. *Calculation process*

For a point source *S* of directional sound power *L_{w,0,dir}* and for a given frequency band, the equivalent continuous sound pressure level at a receiver point *R* in given atmospheric conditions is obtained according to the equations following below.

Sound level in favourable conditions (L_F) for a path (S,R)

$$
L_{F} = L_{W,0,dir} - A_{F}
$$
\n(2.5.5)

The term A_F represents the total attenuation along the propagation path in favourable conditions, and is broken down as follows:

$$
LF = Adiv + Aatm + Aboundary,F
$$
 (2.5.6)

where

A_{div} is the attenuation due to geometrical divergence;

 A_{atm} is the attenuation due to atmospheric absorption;

Aboundary,F is the attenuation due to the boundary of the propagation medium in favourable conditions. It may contain the following terms:

A_{oround,F} which is the attenuation due to the ground in favourable conditions;

Adif,F which is the attenuation due to diffraction in favourable conditions.

For a given path and frequency band, the following two scenarios are possible:

- either $A_{ground,F}$ is calculated with no diffraction ($A_{diff,F} = 0$ dB) and $A_{boundary,F} = A_{ground,F}$;
- or *Adif,F* is calculated. The ground effect is taken into account in the *Adif,F* equation itself (*Aground,F* = 0 dB). This therefore gives $A_{boundary,F} = A_{diff}$.

Sound level in homogeneous conditions (L_H) for a path (S,R)

The procedure is strictly identical to the case of favourable conditions presented in the previous section.

$$
L_{H} = L_{W,0,dir} - A_{H}
$$
 (2.5.7)

The term A_H represents the total attenuation along the propagation path in homogeneous conditions and is broken down as follows:

$$
A_H = A_{div} + A_{atm} + A_{boundary,H}
$$
\n
$$
(2.5.8)
$$

where

 A_{div} is the attenuation due to geometrical divergence;

Αatm is the attenuation due to atmospheric absorption;

Aboundary,H is the attenuation due to the boundary of the propagation medium in homogeneous conditions. It may contain the following terms:

Αground,H which is the attenuation due to the ground in homogeneous conditions;

A_{dif.H} which is the attenuation due to diffraction in homogeneous conditions.

For a given path and frequency band, the following two scenarios are possible:

- either *Αground,H* (*Adif,H* = 0 dB) is calculated with no diffraction and *Aboundary,H* = *Αground,H*;
- or *A_{dif,H} (A_{ground,H} = 0 dB)* is calculated. The ground effect is taken into account in the *A_{dif,H}* equation itself. This therefore gives $A_{\tiny boundary,H}$ = $A_{\tiny diff,H}$

Statistical approach inside urban areas for a path (S,R)

Inside urban areas, a statistical approach to the calculation of the sound propagation behind the first line of buildings is also allowed, provided that such a method is duly documented, including relevant information on the quality of the method. This method may replace the calculation of the $A_{\text{boundary},H}$ and $A_{\text{boundary},F}$ by an approximation of the total attenuation for the direct path and all reflections. The calculation will be based on the average building density and the average height of all buildings in the area.

Long-term sound level for a path (S,R)

The 'long-term' sound level along a path starting from a given point source is obtained from the logarithmic sum of the weighted sound energy in homogeneous conditions and the sound energy in favourable conditions.

These sound levels are weighted by the mean occurrence *p* of favourable conditions in the direction of the path (*S,R*):

$$
L_{LT} = 10 \times \lg \left(p \cdot 10^{\frac{L_F}{10}} + (1-p) \cdot 10^{\frac{L_H}{10}} \right) \tag{2.5.9}
$$

NB: The occurrence values for *p* are expressed in percentages. So for example, if the occurrence value is 82 %, equation (2.5.9) would have $p = 0.82$.

Long-term sound level at point R for all paths

The total long-term sound level at the receiver for a frequency band is obtained by energy summing contributions from all N paths, all types included:

$$
L_{tot,LT} = 10 \times \lg \left(\sum_{n} 10^{\frac{L_{n,LT}}{10}} \right) \tag{2.5.10}
$$

where

n is the index of the paths between *S* and *R*.

Taking reflections into account by means of image sources is described further. The percentage of occurrences of favourable conditions in the case of a path reflected on a vertical obstacle is taken to be identical to the occurrence of the direct path.

If *S′* is the image source of *S*, then the occurrence *p′* of the path (*S′,R*) is taken to be equal to the occurrence *p* of the path (S_i, R) .

Long-term sound level at point R in decibels A (dBA)

The total sound level in decibels A (dBA) is obtained by summing levels in each frequency band:

$$
L_{Aeq,LT} = 10 \times \lg \sum_{i} 10^{(L_{tot,LT,i} + AWC_{fi})/10}
$$
\n(2.5.11)

where *i* is the index of the frequency band. *AWC* is the A-weighting correction according to the international standard IEC 61672-1:2003.

This level *L_{Aeq,LT}* constitutes the final result, i.e. the long-term A-weighted sound pressure level at the receiver point on a specific reference time interval (e.g. day or evening, or night or a shorter time during day, evening or night).

2.5.6. *Calculation of noise propagation for road, railway, industrial sources.*

Geometrical divergence

The attenuation due to geometrical divergence, A_{div} corresponds to a reduction in the sound level due to the propagation distance. For a point sound source in free field, the attenuation in dB is given by:

$$
A_{div} = 20 \times \lg(d) + 11 \tag{2.5.12}
$$

where d is the direct 3D slant distance between the source and the receiver.

A tmospheric absorption

The attenuation due to atmospheric absorption *Aatm* during propagation over a distance *d* is given in dB by the equation:

$$
A_{\text{atm}} = \alpha_{\text{atm}} \cdot d/1\ 000\tag{2.5.13}
$$

where

d is the direct 3D slant distance between the source and the receiver in m;

αatm is the atmospheric attenuation coefficient in dB/km at the nominal centre frequency for each frequency band, in accordance with ISO 9613-1.

The values of the *α_{atm}* coefficient are given for a temperature of 15 °C, a relative humidity of 70 % and an atmospheric pressure of 101 325 Pa. They are calculated with the exact centre frequencies of the frequency band. These values comply with ISO 9613-1. Meteorological average over the long term shall be used if meteorological data is available.

Ground effect

The attenuation due to the ground effect is mainly the result of the interference between the reflected sound and the sound that is propagated directly from the source to the receiver. It is physically linked to the acoustic absorption of the ground above which the sound wave is propagated. However, it is also significantly dependent on atmospheric conditions during propagation, as ray bending modifies the height of the path above the ground and makes the ground effects and land located near the source more or less significant.

In case the propagation between the source and the receiver is affected by any obstacle in the propagation plane, the ground effect is calculated separately on the source and receiver side. In this case, z_s and z_r refer to the equivalent source and/or receiver position as indicated further where the calculation of the diffraction A_{dif} is presented.

Acoustic characterisation of ground

The acoustic absorption properties of the ground are mainly linked to its porosity. Compact ground is generally reflective and porous ground is absorbent.

For operational calculation requirements, the acoustic absorption of a ground is represented by a dimensionless coefficient *G*, between 0 and 1. *G* is independent of the frequency. Table 2.5.a gives the *G* values for the ground outdoors. In general, the average of the coefficient *G* over a path takes values between 0 and 1.

Table 2.5.a

G values for different types of ground

Gpath is defined as the fraction of absorbent ground present over the entire path covered.

When the source and receiver are close-by so that $d_p \leq 30(z_s + z_r)$, the distinction between the type of ground located near the source and the type of ground located near the receiver is negligible. To take this comment into account, the ground factor *G_{path}* is therefore ultimately corrected as follows:

$$
G'_{\text{path}} = \begin{cases} G_{\text{path}} & \frac{d_p}{30(z_s + z_r)} + G_s \left(1 - \frac{d_p}{30(z_s + z_r)}\right) & \text{if } d_p \le 30(z_s + z_r) \\ G_{\text{path}} & \text{otherwise} \end{cases}
$$
(2.5.14)

where G_s is the ground factor of the source area. $G_s = 0$ for road platforms (¹), slab tracks. $G_s = 1$ for rail tracks on ballast. There is no general answer in the case of industrial sources and plants.

G may be linked to the flow resistivity.

Figure 2.5.b

Determination of the ground coefficient G_{path} over a propagation path

$$
d_p = d_1 + d_2 + d_3 + d_4
$$

\n
$$
G_{path} = \frac{(0 \cdot d_1 + 0 \cdot d_2 + 1 \cdot d_3 + 1 \cdot d_4)}{d_p} = \frac{(d_3 + d_4)}{d_p}
$$

The following two subsections on calculations in homogeneous and favourable conditions introduce the generic \overline{G}_w and \overline{G}_m notations for the absorption of the ground. Table 2.5.b gives the correspondence between these notations and the *Gpath* and *G′path* variables.

Table 2.5.b

Correspondence between \overline{G}_w and \overline{G}_m and (G_{path}, G'_{path})

(1) The absorption of porous road pavements is taken into account in the emission model.

Calculations in homogeneous conditions

The attenuation due to the ground effect in homogeneous conditions is calculated according to the following equations:

if
$$
G_{path} \neq 0
$$

$$
A_{ground,H} = \max\left(-10 \times \lg\left[4\frac{k^2}{d_p^2}\left(z_s^2 - \sqrt{\frac{2C_f}{k}}z_s + \frac{C_f}{k}\right)\left(z_r^2 - \sqrt{\frac{2C_f}{k}}z_r + \frac{C_f}{k}\right)\right], A_{ground,H,min}\right) \tag{2.5.15}
$$

where

$$
k=\frac{2\pi f_m}{c}
$$

fm is the nominal centre frequency of the frequency band considered, in Hz, *c* is the speed of the sound in the air, taken as equal to 340 m/s, and C_f is defined by:

$$
C_f = d_p \frac{1 + 3w d_p e^{-\sqrt{wd_p}}}{1 + w d_p} \tag{2.5.16}
$$

where the values of *w* are given by the equation below:

$$
w = 0,0185 \frac{f_m^{2.5} \overline{G}_w^{2.6}}{f_m^{1.5} \overline{G}_w^{2.6} + 1,3 \cdot 10^3 f_m^{0.75} \overline{G}_w^{1.3} + 1,16 \cdot 10^6}
$$
(2.5.17)

Gw may be equal to either *Gpath* or *G′path* depending on whether the ground effect is calculated with or without diffraction, and according to the nature of the ground under the source (real source or diffracted). This is specified in the following subsections and summarised in Table 2.5.b.

$$
A_{ground,H,\min} = -3(1 - \overline{G_m})
$$
\n(2.5.18)

is the lower bound of *Aground,H*.

For a path (S_i, R) in homogeneous conditions without diffraction:

$$
G_w = G'_{path}
$$

$$
\overline{G}_m = G'_{path}
$$

With diffraction, refer to the section on diffraction for the definitions of \overline{G}_w and \overline{G}_m .

if
$$
G_{path} = 0
$$
: $A_{ground,H} = -3 dB$

The term $-3(1-G_m)$ takes into account the fact that when the source and the receiver are far apart, the first reflection source side is no longer on the platform but on natural land.
Calculation in favourable conditions

The ground effect in favourable conditions is calculated with the equation of *Aground,H*, provided that the following modifications are made:

If $G_{path} \neq 0$

(a) In the equation of $A_{ground,H}$, the heights z_s and z_r are replaced by $z_s + \delta z_s + \delta z_r$ and $z_r + \delta z_r + \delta z_r$ respectively where

$$
\begin{cases}\n\delta z_{s} = a_{0} \left(\frac{z_{s}}{z_{s} + z_{r}}\right)^{2} \frac{d_{p}^{2}}{2} \\
\delta z_{r} = a_{0} \left(\frac{z_{r}}{z_{s} + z_{r}}\right)^{2} \frac{d_{p}^{2}}{2}\n\end{cases}
$$
\n(2.5.19)

 a_0 = 2 × 10⁻⁴ m⁻¹ is the reverse of the radius of curvature

$$
\delta z_T=6\cdot 10^{-3}\frac{d_p}{z_s+z_r}
$$

(b) The lower bound of *Aground,F* depends on the geometry of the path:

$$
A_{ground, F, min} = \begin{cases}\n-3\left(1 - \overline{G_m}\right) & \text{if } d_p \le 30\left(z_s + z_r\right) \\
-3\left(1 - \overline{G_m}\right) \cdot \left(1 + 2\left(1 - \frac{30\left(z_s + z_r\right)}{dp}\right)\right) & \text{otherwise}\n\end{cases}
$$
\n(2.5.20)

If $G_{path} = 0$

$$
A_{ground,F} = A_{ground,F,min}
$$

The height corrections δ z_c and δ z_r convey the effect of the sound ray bending. δ z_r accounts for the effect of the turbulence.

Gm may also be equal to either *Gpath* or *G′path* depending on whether the ground effect is calculated with or without diffraction, and according to the nature of the ground under the source (real source or diffracted). This is specified in the following subsections.

For a path (S_p, R) in favourable conditions without diffraction:

 $\overline{G}_w = G_{path}$ in equation (2.5.17);

$$
\overline{G}_m = G'_{path}.
$$

With diffraction, refer to the next section for the definitions of \overline{G}_w and \overline{G}_m .

Diffraction

As a general rule, the diffraction shall be studied at the top of each obstacle located on the propagation path. If the path passes 'high enough' over the diffraction edge, $A_{dif} = 0$ can be set and a direct view calculated, in particular by evaluating *Aground*.

In practice, for each frequency band centre frequency, the path difference δ is compared with the quantity – *λ*/20. If an obstacle does not produce diffraction, this for instance being determined according to Rayleigh's criterion, there is no need to calculate A_{dif} for the frequency band considered. In other words, $A_{dif} = 0$ in this case. Otherwise, A_{dif} is calculated as described in the remainder of this part. This rule applies in both homogeneous and favourable conditions, for both single and multiple diffraction.

When, for a given frequency band, a calculation is made according to the procedure described in this section, *Aground* is set as equal to 0 dB when calculating the total attenuation. The ground effect is taken into account directly in the general diffraction calculation equation.

The equations proposed here are used to process the diffraction on thin screens, thick screens, buildings, earth berms (natural or artificial), and by the edges of embankments, cuttings and viaducts.

When several diffracting obstacles are encountered on a propagation path, they are treated as a multiple diffraction by applying the procedure described in the following section on calculation of the path difference.

The procedures presented here are used to calculate the attenuations in both homogeneous conditions and favourable conditions. Ray bending is taken into account in the calculation of the path difference and to calculate the ground effects before and after diffraction.

General principles

Figure 2.5.c illustrates the general method of calculation of the attenuation due to diffraction. This method is based on breaking down the propagation path into two parts: the 'source side' path, located between the source and the diffraction point, and the 'receiver side' path, located between the diffraction point and the receiver.

The following are calculated:

- a ground effect, source side, Δ*ground(S,O)*
- a ground effect, receiver side, Δ*ground(O,R)*
- and three diffractions:
	- between the source *S* and the receiver *R*: Δ*dif(S,R)*
	- between the image source *S'* and *R*: Δ_{dif(S',R)}
	- between *S* and the image receiver *R'*: Δ_{dif(S,R')}.

Geometry of a calculation of the attenuation due to diffraction

1: Source side

2: Receiver side

where

S is the source;

R is the receiver;

S′ is the image source in relation to the mean ground plane source side;

R' is the image receiver in relation to the mean ground plane receiver side;

O is the diffraction point;

 z_s is the equivalent height of the source *S* in relation to the mean plane source side;

 $z_{0.5}$ is the equivalent height of the diffraction point *O* in relation to the mean ground plane source side;

 z_r is the equivalent height of the receiver *R* in relation to the mean plane receiver side;

 $z_{o,r}$ is the equivalent height of the diffraction point *O* in relation to the mean ground plane receiver side.

The irregularity of the ground between the source and the diffraction point, and between the diffraction point and the receiver, is taken into account by means of equivalent heights calculated in relation to the mean ground plane, source side first and receiver side second (two mean ground planes), according to the method described in the subsection on significant heights above the ground.

Pure diffraction

For pure diffraction, with no ground effects, the attenuation is given by:

$$
\Delta_{dif} = \begin{cases}\n10C_h \cdot \lg\left(3 + \frac{40}{\lambda}C''\delta\right) & \text{if } \frac{40}{\lambda}C''\delta \ge -2 \\
0 & \text{otherwise}\n\end{cases}
$$
\n(2.5.21)

where

$$
C_{h} = 1 \tag{2.5.22}
$$

λ is the wavelength at the nominal centre frequency of the frequency band considered;

δ is the path difference between the diffracted path and the direct path (see next subsection on calculation of the path difference);

C″ is a coefficient used to take into account multiple diffractions:

C″ = 1 for a single diffraction.

For a multiple diffraction, if e is the total distance along the path, O1 to O2 + O2 to O3 + O3 to O4 from the 'rubber band method', (see Figures 2.5.d and 2.5.f) and if *e* exceeds 0,3 m (otherwise *C″* = 1), this coefficient is defined by:

$$
C'' = \frac{1 + (5\lambda_e)^2}{\frac{1}{3} + (5\lambda_e)^2}
$$
 (2.5.23)

The values of Δ_{dif} shall be bound:

— if $\Delta_{dif}^{}$ < 0: $\Delta_{dif}^{}$ = 0 dB

— if Δ_{dif} > 25: Δ_{dif} = 25 dB for a diffraction on a horizontal edge and only on the term Δ_{dif} which figures in the calculation of *A_{dif.}* This upper bound shall not be applied in the Δ_{dif} terms that intervene in the calculation of Δ*ground*, or for a diffraction on a vertical edge (lateral diffraction) in the case of industrial noise mapping.

Calculation of the path difference

The path difference *δ* is calculated in a vertical plane containing the source and the receiver. This is an approximation in relation to the Fermat principle. The approximation remains applicable here (source lines). The path difference *δ* is calculated as in the following Figures, based on the situations encountered.

Homogeneous conditions

Figure 2.5.d

Calculation of the path difference in homogeneous conditions. O , $O₁$, and $O₂$ are the diffraction points

Note: For each configuration, the expression of *δ* is given.

Favourable conditions

In favourable conditions, it is considered that the three curved sound rays *SO*, *OR*, and *SR* have an identical radius of curvature Γ defined by:

$$
\Gamma = \max(1 \ 000, 8d) \tag{2.5.24}
$$

The length of a sound ray curve MN is noted $\hat{M}N$ in favourable conditions. This length is equal to:

$$
\hat{M}N = 2\Gamma \arcsin\left(\frac{MN}{2\Gamma}\right) \tag{2.5.25}
$$

In principle, three scenarios should be considered in the calculation of the path difference in favourable conditions δ_F (see Figure 2.5.e). In practice, two equations are sufficient:

— if the straight sound ray *SR* is masked by the obstacle (1st and 2nd case in Figure 2.5.e):

$$
\delta_F = \hat{S}O + \hat{O}R - \hat{S}R \tag{2.5.26}
$$

— if the straight sound ray *SR* is not masked by the obstacle (3rd case in Figure 2.5.e):

$$
\delta_F = 2\hat{S}A + 2\hat{A}R - \hat{S}O - \hat{O}R - \hat{S}R
$$
\n(2.5.27)

where *A* is the intersection of the straight sound ray *SR* and the extension of the diffracting obstacle.

For the multiple diffractions in favourable conditions:

- determine the convex hull defined by the various potential diffraction edges;
- eliminate the diffraction edges which are not on the boundary of the convex hull;
- calculate δ_F based on the lengths of the curved sound ray, by breaking down the diffracted path into as many curved segments as necessary (see Figure 2.5.f)

$$
\delta_F = \hat{S}O_1 + \sum_{i=1}^{i=n-1} O_i \hat{O}_{i+1} + \hat{O}_n R - \hat{S}R
$$
\n(2.5.28)

Figure 2.5.f

Example of calculation of the path difference in favourable conditions, in the case of multiple diffractions

In the scenario presented in Figure 2.5.f, the path difference is:

$$
\delta_F = \hat{S}O_1 + O_1\hat{O}_2 + O_2\hat{O}_3 + O_3\hat{O}_4 + \hat{O}_4R - \hat{S}R
$$
\n(2.5.29)

Calculation of the attenuation *Adif*

The attenuation due to diffraction, taking the ground effects on the source side and receiver side into account, is calculated according to the following general equations:

$$
A_{\text{dif}} = \Delta_{\text{dif (S,R)}} + \Delta_{\text{ground (S,O)}} + \Delta_{\text{ground (O_{II},R)}} \tag{2.5.30}
$$

where

- Δ*dif (S,R)* is the attenuation due to the diffraction between the source *S* and the receiver *R*
- Δ*ground(S,O)* is the attenuation due to the ground effect on the source side, weighted by the diffraction on the source side; where it is understood that $O = O_1$ in case of multiple diffractions as in Figure 2.5.f
- Δ*ground(O,R)* is the attenuation due to the ground effect on the receiver side, weighted by the diffraction on the receiver side (see the following subsection on calculation of the term Δ*ground(O,R)*).

Calculation of the term $\Delta_{ground(S,0)}$

$$
\Delta_{ground(S,O)} = -20 \times \lg \left(1 + \left(10^{-A_{ground(S,O)}} / 20 - 1 \right) \cdot 10^{-\left(\Delta_{diff(S',R)} - \Delta_{diff(S,R)} \right)} / 20 \right) \tag{2.5.31}
$$

where

— *Aground(S,O)* is the attenuation due to the ground effect between the source *S* and the diffraction point *O*. This term is calculated as indicated in the previous subsection on calculations in homogeneous conditions and in the previous subsection on calculation in favourable conditions, with the following hypotheses:

 $z_r = z_{0,s}$

- *Gpath* is calculated between *S* and *O*,
- In homogeneous conditions: $\overline{G}_w = G'_{nath}$ in equation (2.5.17), $\overline{G}_m = G'_{nath}$ in equation (2.5.18),
- In favourable conditions: $\overline{G}_w = G_{path}$ in equation (2.5.17), $\overline{G}_m = G'_{path}$ in equation (2.5.20),
- $-\Delta_{diff(S',R)}$ is the attenuation due to the diffraction between the image source *S'* and *R*, calculated as in the previous subsection on pure diffraction,
- Δ*dif(S,R)* is the attenuation due to the diffraction between *S* and *R,* calculated as in Subsection VI.4.4.b.

Calculation of the term $Δ_{ground(O,R)}$

$$
\Delta_{ground(O,R)} = -20 \times \lg \left(1 + \left(10^{-\frac{A_{ground(O,R)}}{20}} - 1 \right) \cdot 10^{-\left(\Delta_{diff(S,R')} - \Delta_{diff(S,R)} \right) / 20} \right) \tag{2.5.32}
$$

where

— *Aground (O,R)* is the attenuation due to the ground effect between the diffraction point *O* and the receiver *R*. This term is calculated as indicated in the previous subsection on calculation in homogeneous conditions and in the previous subsection on calculation in favourable conditions, with the following hypotheses:

 $z_{s} = z_{o,r}$

— *Gpath* is calculated between *O* and *R.*

The *G'_{path}* correction does not need to be taken into account here as the source considered is the diffraction point. Therefore, *Gpath* shall indeed be used in the calculation of ground effects, including for the lower bound term of the equation which becomes – $3(1 - G_{path})$.

- In homogeneous conditions, $\overline{G}_w = G_{path}$ in equation (2.5.17) and $\overline{G}_m = G_{path}$ in equation (2.5.18);
- In favourable conditions, $\overline{G}_w = G_{path}$ in equation (2.5.17) and $\overline{G}_m = G_{path}$ in equation (2.5.20);
- Δ*dif(S,R′)* is the attenuation due to the diffraction between *S* and the image receiver *R′*, calculated as in the previous section on pure diffraction;
- $-\Delta_{\text{diffSR}}$ is the attenuation due to the diffraction between *S* and *R*, calculated as in the previous subsection on pure diffraction.

Vertical edge scenarios

Equation (2.5.21) may be used to calculate the diffractions on vertical edges (lateral diffractions) in case of industrial noise. If this is the case, *Adif* = Δ*dif(S,R)* is taken and the term *Aground* is kept. In addition, *Aatm* and *Aground* shall be calculated from the total length of the propagation path. *Adiv* is still calculated from the direct distance *d*. Equations (2.5.8) and (2.5.6) respectively become:

$$
A_H = A_{div} + A_{atm}^{path} + A_{ground,H}^{path} + \Delta_{diff,(S,R)} \tag{2.5.33}
$$

$$
A_F = A_{div} + A_{atm}^{path} + A_{ground,F}^{path} + \Delta_{diff,H(S,R)} \tag{2.5.34}
$$

Δ*dif* is indeed used in homogeneous conditions in equation (2.5.34).

Reflections on vertical obstacles

Attenuation through absor ption

The reflections on vertical obstacles are dealt with by means of image sources. Reflections on building façades and noise barriers are thus treated in this way.

An obstacle is considered to be vertical if its slope in relation to the vertical is less than 15°.

When dealing with reflections on objects which slope in relation to the vertical is more or equal to 15° the object is not considered.

The obstacles where at least one dimension is less than 0,5 m shall be ignored in the reflection calculation, except for special configurations (¹).

Note that reflections on the ground are not dealt with here. They are taken into account in the calculations of attenuation due to the boundary (ground, diffraction).

If *LWS* is the power level of the source *S* and *αr* the absorption coefficient of the surface of the obstacle as defined by the EN 1793-1:2013, then the power level of the image source *S′* is equal to:

$$
L_{WS'} = L_{WS} + 10 \cdot \lg(1 - \alpha_r) = L_{WS} + A_{refl} \tag{2.5.35}
$$

where $0 \leq \alpha_r \leq 1$

⁽ 1) A network of small obstacles in a plane and at regular intervals constitutes one example of a special configuration.

The propagation attenuations described above are then applied to this path (image source, receiver), as for a direct path.

Figure 2.5.g

Specular reflection on an obstacle dealt with by the image source method (*S***: source,** *S′***: image source,** *R***: receiver)**

Attenuation through retrodiffraction

In the geometrical research of sound paths, during reflection on a vertical obstacle (barrier wall, building), the position of the impact of the ray in relation to the upper edge of this obstacle determines the more or less significant proportion of energy effectively reflected. This loss of acoustic energy when the ray undergoes a reflection is called attenuation through retrodiffraction.

In the case of potential multiple reflections between two vertical walls, at least the first reflection shall be considered.

In the case of a trench (see for example Figure 2.5.h), the attenuation through retrodiffraction shall be applied to each reflection on the retaining walls.

Figure 2.5.h

Sound ray reflected to the order of 4 in a track in a trench: actual cross-section (top), unfolded crosssection (bottom)

In this representation, the sound ray reaches the receiver 'by successively passing through' the retaining walls of the trench, which can therefore be compared to openings.

When calculating propagation through an opening, the sound field at the receiver is the sum of the direct field and the field diffracted by the edges of the opening. This diffracted field ensures the continuity of the transition between the clear area and the shadow area. When the ray approaches the edge of the opening, the direct field is attenuated. The calculation is identical to that of the attenuation by a barrier in the clear area.

The path difference *δ′* associated with each retrodiffraction is the opposite of the path difference between *S* and *R* relatively at each upper edge *O*, and this in a view according to a deployed cross-section (see Figure 2.5.i).

$$
\delta' = - (SO + OR - SR) \tag{2.5.36}
$$

Figure 2.5.i

The path difference for the second reflection

The 'minus' sign of equation (2.5.36) means that the receiver is considered here in the clear area.

Attenuation through retrodiffraction Δ*retrodif* is obtained by equation (2.5.37), which is similar to equation (2.5.21) with reworked notations.

$$
\Delta_{retnodif} = \begin{cases}\n10C_h \cdot \lg\left(3 + \frac{40}{\lambda} \delta'\right) & \text{if } \frac{40}{\lambda} \delta' \ge -2 \\
0 & \text{otherwise}\n\end{cases}
$$
\n(2.5.37)

This attenuation is applied to the direct ray each time it 'passes through' (reflects on) a wall or building. The power level of the image source *S′* therefore becomes:

$$
L_{\mathbf{w}'} = L_{\mathbf{w}} + 10 \times \lg(1 - \alpha_r) - \Delta_{\text{retrodiff}} \tag{2.5.38}
$$

In complex propagation configurations, diffractions may exist between reflections, or between the receiver and the reflections. In this case, the retrodiffraction by the walls is estimated by considering the path between source and first diffraction point R′ (therefore considered as the receiver in equation (2.5.36)). This principle is illustrated in Figure 2.5.j.

Figure 2.5.j

The path difference in the presence of a diffraction: actual cross-section (top), unfolded cross-section (bottom)

In case of multiple reflections the reflections due to every single reflections are added.

2.6. **General provisions — Aircraft noise**

2.6.1. *Definitions and symbols*

Some important *terms* are described here by the general meanings attributed to them in this document. The list is not exhaustive; only expressions and acronyms used frequently are included. Others are described where they first occur.

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

The reader is reminded periodically of the interchangeability of the words *sound* and *noise* in this document. Although the word *noise* has subjective connotations — it is usually defined by acousticians as 'unwanted sound' — in the field of aircraft noise control it is commonly taken to mean just sound — airborne energy transmitted by acoustic wave motion. The symbol \rightarrow denotes cross references to other terms included in the list.

Terms

Symbols

L 168/48 EN CHECAL Journal of the European Union 1.7.2015

1.7.2015 EN **EN** Official Journal of the European Union L 168/49

Subscripts

2.6.2. *Quality framework*

Accuracy of input values

All input values affecting the emission level of a source, including the position of the source, shall be determined with at least the accuracy corresponding to an uncertainty of ± 2dB(A) in the emission level of the source (leaving all other parameters unchanged).

Use of default values

In the application of the method, the input data shall reflect the actual usage. In general there shall be no reliance on default input values or assumptions. Specifically, flight paths derived from radar data to derive the flight paths shall be used whenever they exist and is of sufficient quality. Default input values and assumptions are accepted, for example, to be used for modelled routes instead of radar derived flight paths, if the collection of real data is associated with disproportionately high costs.

Quality of the software used for the calculations

Software used to perform the calculations shall prove compliance with the methods herewith described by means of certification of results against test cases.

2.7. **Aircraft noise**

2.7.1. *Aim and scope of document*

Contour maps are used to indicate the extent and magnitude of aircraft noise impact around airports, that impact being indicated by values of a specified noise metric or index. A contour is a line along which the index value is constant. The index value aggregates in some way all the individual aircraft noise events that occur during some specified period of time, normally measured in days or months.

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

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

Where noise generating activities associated with airport operations do not contribute materially to the overall population exposure to aircraft noise and associated noise contours, they may be excluded. These activities include: helicopters, taxiing, engine testing and use of auxiliary power-units. This does not necessarily mean that their impact is insignificant and where these circumstances occur assessment of the sources can be undertaken as set out in paragraphs 2.7.21 and 2.7.22.

2.7.2. *Outline of the document*

The noise contour generation process is illustrated in **Figure 2.7.a**. Contours are produced for various purposes and these tend to control the requirements for sources and pre-processing of input data. Contours that depict historical noise impact might be generated from actual records of aircraft operations — of movements, weights, radar-measured flight paths, etc. Contours used for future planning purposes of necessity rely more on forecasts — of traffic and flight tracks and the performance and noise characteristics of future aircraft.

Figure 2.7.a

The noise contour generation process

Whatever the source of flight data, each different aircraft movement, arrival or departure, is defined in terms of its flight path geometry and the noise emission from the aircraft as it follows that path (movements that are essentially the same in noise and flight path terms are included by simple multiplication). The noise emission depends on the characteristics of the aircraft — mainly on the power generated by its engines. The recommended methodology involves dividing the flight path into segments. **Sections 2.7.3 to 2.7.6** outline the elements of the methodology and explain the principle of segmentation on which it is based; that the observed event noise level is an aggregation of contributions from all 'noise-significant' segments of the flight path, each of which can be calculated independently of the others. **Sections 2.7.3 to 2.7.6** also outline the input data requirements for producing a set of noise contours. Detailed specifications for the operational data needed are set out in **Appendix A**.

How the flight path segments are calculated from pre-processed input data is described in **Sections 2.7.7 to 2.7.13**. This involves applications of aircraft flight performance analysis, equations for which are detailed in **Appendix B**. Flight paths are subject to significant variability — aircraft following any route are dispersed across a swathe due to the effects of differences in atmospheric conditions, aircraft weights and operating procedures, air traffic control constraints, etc. This is taken into account by describing each flight path statistically — as a central or 'backbone' path which is accompanied by a set of dispersed paths. This too is explained in **Sections 2.7.7 to 2.7.13** with reference to additional information in **Appendix C**.

Sections 2.7.14 to 2.7.19 set out the steps to be followed in calculating the noise level of one single event the noise generated at a point on the ground by one aircraft movement. **Appendix D** deals with the re-calculation of NPD-data for non-reference conditions. **Appendix E** explains the acoustic dipole source used in the model to define sound radiation from flight path segments of finite length.

Applications of the modelling relationships described in Chapters 3 and 4 require, apart from the relevant flight paths, appropriate noise and performance data for the aircraft in question.

Determining the event level for a single aircraft movement at a single observer point is the core calculation. It has to be repeated for all aircraft movements at each of a prescribed array of points covering the expected extent of the required noise contours. At each point the event levels are aggregated or averaged in some way to arrive at a 'cumulative level' or noise index value. This part of the process is described in **Sections 2.7.20 and 2.7.23 to 2.7.25**.

Sections 2.7.26 to 2.7.28 summarise the options and requirement for fitting noise contours to arrays of noise index values. They provide guidance on contour generation and post-processing.

2.7.3. *The concept of segmentation*

For any specific aircraft, the database contains baseline Noise-Power-Distance (NPD) relationships. These define, for steady straight flight at a *reference speed* in specified *reference atmospheric conditions* and in a specified flight configuration, the received sound event levels, both maximum and time integrated, directly beneath the aircraft (1) as a function of distance. For noise modelling purposes, the all-important propulsive power is represented by a *noise-related power parameter*; the parameter generally used is *corrected net thrust*. Baseline event levels determined from the database are adjusted to account for, firstly, differences between actual (i.e. modelled) and reference atmospheric conditions and (in the case of sound exposure levels) aircraft speed and, secondly, for receiver points that are not directly beneath the aircraft, differences between downwards and laterally radiated noise. This latter difference is due to *lateral directivity* (engine installation effects) and *lateral attenuation*. But the event levels so adjusted still apply only to the total noise from the aircraft in steady level flight.

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

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

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

2.7.4. *Flight paths: Tracks and profiles*

In the modelling context, a *flight path* (or trajectory) is a full description of the motion of the aircraft in space and time (1). Together with the propulsive thrust (or other noise related power parameter) this is the information required to calculate the noise generated. The gro*und track* is the vertical projection of the flight path on level ground. This is combined with the vertical *flight profile* to construct the 3-D flight path. Segmentation modelling requires that the flight path of every different aircraft movement is described by a series of contiguous straight segments. The manner in which the segmentation is performed is dictated by a need to balance accuracy and efficiency — it is necessary to approximate the real curved flight path sufficiently closely while minimising the computational burden and data requirements. Each segment has to be defined by the geometrical coordinates of its end points and the associated speed and engine power parameters of the aircraft (on which sound emission depends). Flight paths and engine power may be determined in various ways, the main ones involving (a) synthesis from a series of procedural steps and (b) analysis of measured flight profile data.

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

Analysis of measured data (b), e.g. from flight data recorders, radar or other aircraft tracking equipment, involves 'reverse engineering', effectively a reversal of the synthesis process (a). Instead of estimating the aircraft and powerplant states at the ends of the flight segments by integrating the effects of the thrust and aerodynamic forces acting on the airframe, the forces are estimated by differentiating the changes of height and speed of the airframe. Procedures for processing the flight path information are described in Section 2.7.12.

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

⁽ 1) Time is accounted for via the aircraft speed.

2.7.5. *Aircraft noise and performance*

The ANP database provided in Appendix I covers most existing aircraft types. For aircraft types or variants for which data are not currently listed, they can best be represented by data for other, normally similar, aircraft that are listed.

The ANP database includes default 'procedural steps' to enable the construction of flight profiles for at least one common noise abatement departure procedure. More recent database entries cover two different noise abatement departure procedures.

2.7.6. *Airport and aircraft operations*

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

General airport data

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

Runway data

For each runway:

- Runway designation
- Runway reference point (centre of runway expressed in local coordinates)
- Runway length, direction and mean gradient
- Location of start-of-roll and landing threshold (1).

Ground track data

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

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

⁽ 1) Displaced thresholds can be taken into account by defining additional runways.

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

- Width of the swathe (or other dispersion statistic) at each segment end
- Number of subtracks
- Distribution of movements perpendicular to the backbone track.

Air traffic data

Air traffic data are

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

Most noise descriptors require that events (i.e. aircraft movements) are defined as average daily values during specified periods of the day (e.g. day, evening and night) — see **Sections 2.7.23 to 2.7.25**.

Topographical data

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

Terrain elevation data are usually provided as a set of (*x,y,z*) coordinates for a rectangular grid of certain meshsize. But the parameters of the elevation grid are likely to be different from those of the grid used for the noise computation. If so linear interpolation may be used to estimate the appropriate *z*-coordinates in the latter.

Comprehensive analysis of the effects of markedly non-level ground on sound propagation is complex and beyond the scope of this method. Moderate unevenness can be accounted for by assuming 'pseudo-level' ground; i.e. simply raising or lowering the level ground plane to the local ground elevation (relative to the reference ground plane) at each receiver point (see Section 2.7.4).

Reference conditions

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

Reference conditions for NPD data

- (1) Atmospheric pressure: 101,325 kPa (1 013,25 mb)
- (2) Atmospheric absorption: Attenuation rates listed in **Table D-1** of **Appendix D**
- (3) Precipitation: None
- (4) Wind Speed: Less than 8 m/s (15 knots)
- (5) Groundspeed: 160 knots
- (6) Local terrain: Flat, soft ground free of large structures or other reflecting objects within several kilometres of aircraft ground tracks.

Standardised aircraft sound measurements are made 1,2 m above the ground surface. However no special account of this is necessary as, for modelling purposes, it may be assumed that event levels are relatively insensitive to receiver height (1).

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

- Air temperature less than 30 °C
- Product of air temperature (°C), and relative humidity, (percent) greater than 500
- Wind speed less than 8 metres per second (15 knots).

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

Reference conditions for aeroplane aerodynamic and engine data

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

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

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

⁽ 1) Calculated levels at 4 m or higher are sometimes requested. Comparison of measurements at 1,2 m and 10 m and theoretical calculation of ground effects show that variations of the A-weighted sound exposure level are relatively insensitive to receiver height. The variations are in general smaller than one decibel, except if the maximum angle of sound incidence is below 10° and if the A-weighted spectrum at the receiver has its maximum in the range of 200 to 500 Hz. Such low frequency dominated spectra may occur e.g. at long distances for low-bypass ratio engines and for propeller engines with discrete low frequency tones.

2.7.7. *Description of the flight path*

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

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

2.7.8. *Relationships between flight path and flight configuration*

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

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

It should be remembered that, for a given set of procedural steps, the profile depends on the ground track; e.g. at the same thrust and speed the aircraft climb rate is less in turns than in straight flight. Although this guidance explains how to take this dependency into account, it has to be acknowledged that doing so would normally involve a very large computing overhead and users may prefer to assume that, for noise modelling purposes, the flight profile and ground track can be treated as independent entities; i.e. that the climb profile is unaffected by any turns. However, it is important to determine changes of bank angle that turns require as this has an important bearing on the directionality of sound emission.

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

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

Appendix B presents the equations that relate the forces acting on an aircraft and its motion and explains how they are solved to define the properties of the segments that make up the flight paths. The different kinds of segments (and the sections of **Appendix B** that cover them) are *take-off ground roll* (B5), *climb at constant speed* (B6), *power cutback* (B7), *accelerating climb and flap retraction* (B8), *accelerating climb after flap retraction* (B9), *descent and deceleration* (B10) and *final landing approach* (B11).

Inevitably, practical modelling involves varying degrees of simplification — the requirement for this depends on the nature of the application, the significance of the results and the resources available. A general simplifying assumption, even in the most elaborate applications, is that when accounting for flight track dispersion, the flight profiles and configurations on all the sub-tracks are the same as those on the backbone track. As at least 6 subtracks are to be used (see Section 2.7.11) this reduces computations massively for an extremely small penalty in fidelity.

2.7.9. *Sources of flight path data*

Radar data

Although aircraft flight data recorders can yield very high quality data, this is difficult to obtain for noise modelling purposes and radar data shall be regarded as the most readily accessible source of information on actual flight paths flown at airports (1). As it is usually available from airport noise and flight path monitoring systems, it is now used increasingly for noise modelling purposes.

Secondary surveillance radar presents the flight path of an aircraft as a sequence of positional coordinates at intervals equal to the period of rotation of the radar scanner, typically about 4 seconds. The position of the aircraft over the ground is determined in polar coordinates — range and azimuth — from the reflected radar return (although the monitoring system normally transforms these to Cartesian coordinates); its height (2) is measured by the aeroplane's own altimeter and transmitted to the ATC computer by a radar-triggered transponder. But inherent positional errors due to radio interference and limited data resolution are significant (although of no consequence for the intended air traffic control purposes). Thus, if the flight path of a specific aircraft movement is required, it is necessary to smooth the data using an appropriate curve-fitting technique. However, for noise modelling purposes the usual requirement is for a statistical description of a swathe of flight paths; e.g. for all movements on a route or for just those of a specific aircraft type. Here the measurement errors associated with the relevant statistics can be reduced to insignificance by the averaging processes.

Procedural steps

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

In the absence of radar data, or when its use is inappropriate, it is necessary to estimate the flight paths on the basis of operational guidance material, for example instructions given to flight crews via AIPs and aircraft operating manuals — referred to here as *procedural steps*. Advice on interpreting this material shall be sought from air traffic control authorities and the aircraft operators where necessary.

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

⁽ 2) Usually measured as altitude above MSL (i.e. relative to 1 013 mb) and corrected to airport elevation by the airport monitoring system.

2.7.10. *Coordinate systems*

The local coordinate system

The local coordinate system (*x,y,z*) is a Cartesian one and has its origin (0,0,0) at the aerodrome reference point $(X_{ARP}Y_{ARP}Z_{ARP})$, where Z_{ARP} is the airport reference altitude and $z = 0$ defines the nominal ground plane on which contours are usually calculated. The aircraft heading ξ in the *xy*-plane is measured clockwise from magnetic north (see **Figure 2.7.b**). All observer locations, the basic calculation grid and the noise contour points are expressed in local coordinates (1).

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

The ground-track fixed coordinate system

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

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

⁽ 1) Usually the axes of the local coordinate are parallel to the axis of the map that contours are drawn on. However it is sometimes useful to choose the *x*-axis parallel to a runway in order to get symmetrical contours without using a fine computational grid (see **Sections 2.7.26 to 2.7.28**).

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

The aircraft coordinate system

The aircraft-fixed Cartesian coordinate system (*x′,y′,z′*) has its origin at the actual aircraft location. The axissystem is defined by the climb-angle γ, the flight direction ξ and the bank-angle ε (see **Figure 2.7.c**).

Figure 2.7.c

Aircraft fixed coordinate system (*x′,y′,z′***)**

Accounting for topography

In cases where topography has to be taken into account (see Section 2.7.6), the aircraft height coordinate z has to be replaced by $z' = z - z_0$ (where z_0 is the z-coordinate of the observer location O) when estimating the propagation distance d. The geometry between aircraft and observer is shown in **Figure 2.7.d**. For the definitions of d and ℓ see Sections 2.7.14 to 2.7.19 (ℓ).

Figure 2.7.d

Ground elevation along (left) and lateral (right) to ground track

(The nominal ground plane z = 0 passes through the aerodrome reference point. O is the observer location.)

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

2.7.11. *Ground Tracks*

Backbone tracks

The backbone track defines the centre of the swathe of tracks followed by aircraft using a particular routeing. For the purposes of aircraft noise modelling it is defined either (i) by prescriptive operational data such as the instructions given to pilots in AIPs, or (ii) by statistical analysis of radar data as explained in Section 2.7.9 when this is available and appropriate to the needs of the modelling study. Constructing the track from operational instructions is normally quite straightforward as these prescribe a sequence of legs which are either straight — defined by length and heading, or circular arcs defined by turn rate and change of heading; see **Figure 2.7.e** for an illustration.

Figure 2.7.e

Ground track geometry in terms of turns and straight segments

Fitting a backbone track to radar data is more complex, firstly because actual turns are made at a varying rate and secondly because its line is obscured by the scatter of the data. As explained, formalised procedures have not yet been developed and it is common practice to match segments, straight and curved, to the average positions calculated from cross-sections of radar tracks at intervals along the route. Computer algorithms to perform this task are likely to be developed in future but, for the present, it is for the modeller to decide how to use available data to best advantage. A major factor is that the aircraft speed and turn radius dictate the angle of bank and, as will be seen in Section 2.7.19, non-symmetries of sound radiation around the flight path govern noise on the ground, as well as the position of the flight path itself.

Theoretically, seamless transition from straight flight to fixed radius turn would require an instantaneous application of bank angle ε, which is physically impossible. In reality it takes a finite time for the bank angle to reach the value required to maintain a specified speed and turn radius *r*, during which the turn radius tightens from infinity to *r*. For modelling purposes the radius transition can be disregarded and the bank angle assumed to increase steadily from zero (or other initial value) to ε at the start of the turn and to be the next value of ε at the end of the turn (1) .

Track dispersion

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

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

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

As it is normally unwise to disregard the effects of track dispersion, in the absence of measured swathe data a nominal lateral spread across and perpendicular to the backbone track shall be defined by a conventional distribution function. Calculated values of noise indices are not particularly sensitive to the precise shape of the lateral distribution: the Normal (Gaussian) Distribution provides an adequate description of many radarmeasured swathes.

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

For normally distributed tracks with a standard deviation *S*, 98,8 % of the tracks are located within a corridor with boundaries located at ± 2,5 · *S*. **Table 2.7.a** gives the spacing of the six subtracks and the percentage of the total movements assigned to each. **Appendix C** gives values for other numbers of subtracks.

Table 2.7.a

Percentages of movements for a normal distribution function with standard deviation *S* **for 7 subtracks (backbone track is subtrack 1)**

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

For tracks involving turns of less than 45 degrees:

$$
S(s) = 0.055 \cdot s - 150 \qquad \text{for } 2\ 700 \text{ m} \le s \le 30\ 000 \text{ m}
$$

```
S(s) = 1,500 for s > 30,000 m
```
For tracks involving turns of more than 45 degrees:

$$
S(s) = 0,128 \cdot s - 420 \qquad \text{for } 3 \text{ } 300 \text{ m} \le s \le 15 \text{ } 000 \text{ m}
$$
\n
$$
S(s) = 1 \text{ } 500 \text{ m} \qquad \text{for } s > 15 \text{ } 000 \text{ m}
$$
\n
$$
(2.7.2)
$$

For practical reasons, *S(s)* is assumed to be zero between the start of roll and *s* = 2 700 m or *s* = 3 300 m depending on the amount of turn. Routes involving more than one turn shall be treated as per equation (2.7.2). For arrivals, lateral dispersion can be neglected within 6 000 m of touchdown.

2.7.12. *Flight profiles*

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

The synthesis of flight profiles from 'procedural steps' obtained from the ANP database or from aircraft operators is described in Section 2.7.13 and **Appendix B**. That process, usually the only recourse open to the modeller when no radar data are available, yields both the flight path geometry and the associated speed and thrust variations. It would normally be assumed that all (alike) aircraft in a swathe, whether assigned to the backbone or the dispersed subtracks, follow the backbone track profile.

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

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

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

Knowing the aircraft weight, the variation of speed and propulsive thrust can be calculated via step-by-step solution of the equations of motion. Before doing so it is helpful to pre-process the data to minimise the effects of radar errors which can make acceleration estimates unreliable. The first step in each case is to redefine the profile by fitting straight line segments to represent the relevant stages of flight; with each segment being appropriately classified; i.e. as a ground roll, constant speed climb or descent, thrust cutback, or acceleration/ deceleration with or without flap change. The aircraft weight and atmospheric state are also required inputs.

Section 2.7.11 makes it clear that special provision has to be made to account for the lateral dispersion of flight tracks about the nominal or backbone routeings. Radar data samples are characterised by similar dispersions of flight paths in the vertical plane. However it is not usual practice to model vertical dispersion as an independent variable; it arises mainly due to differences in aircraft weights and operating procedures that are taken into account when pre-processing traffic input data.

2.7.13. *Construction of flight path segments*

Each flight path has to be defined by a set of segment coordinates (nodes) and flight parameters. The starting point is to determine the coordinates of the ground track segments. The flight profile is then calculated, remembering that for a given set of procedural steps, the profile depends on the ground track; e.g. at the same thrust and speed the aircraft climb rate is less in turns than in straight flight. Finally the 3-D flight path segments are constructed by merging the 2-D flight profile with the 2-D ground track (1).

Ground track

A ground track, whether a backbone track or a dispersed sub-track, is defined by a series of (*x,y*) coordinates in the ground plane (e.g. from radar information) or by a sequence of vectoring commands describing straight segments and circular arcs (turns of defined radius *r* and change of heading Δξ).

For segmentation modelling, an arc is represented by a sequence of straight segments fitted to sub-arcs. Although they do not appear explicitly in the ground-track segments, the banking of aircraft during turns influences their definition. **Appendix B4** explains how to calculate bank angles during a steady turn but of course these are not actually applied or removed instantaneously. How to handle the transitions between straight and turning flight, or between one turn and an immediately sequential one, is not prescribed. As a rule, the details, which are left to the user (see Section 2.7.11), are likely to have a negligible effect on the final contours; the requirement is mainly to avoid sharp discontinuities at the ends of the turn and this can be achieved simply, for example, by inserting short transition segments over which the bank angle changes linearly with distance. Only in the special case that a particular turn is likely to have a dominating effect on the final contours would it be necessary to model the dynamics of the transition more realistically, to relate bank angle to particular aircraft types and to adopt appropriate roll rates. Here it is sufficient to state that the end sub-arcs Δξtrans in any turn are dictated by bank angle change requirements. The remainder of the arc with change of heading $\Delta \xi - 2 \cdot \Delta \xi_{trans}$ degrees is divided into n_{sub} sub-arcs according to the equation:

$$
n_{\rm sub} = \text{int}(1 + (\Delta \xi - 2 \cdot \Delta \xi_{\rm trans})/30) \tag{2.7.3}
$$

where int(*x*) is a function that returns the integer part of *x*. Then the change of heading Δ*ξsub* of each sub-arc is computed as

$$
\Delta \xi_{\text{sub}} = (\Delta \xi - 2 \cdot \Delta \xi_{\text{trans}}) / n_{\text{sub}} \tag{2.7.4}
$$

where *nsub* needs to be large enough to ensure that Δ*ξsub* ≤ 30 degrees. The segmentation of an arc (excluding the terminating transition sub-segments) is illustrated in **Figure 2.7.f** (2).

⁽ 1) For this purpose the total length of the ground track should always exceed that of the flight profile. This can be achieved, if necessary, by adding straight segments of suitable length to the last segment of the ground track.

⁽ 2) Defined in this simple way, the total length of the segmented path is slightly less than that of the circular path. However the consequent contour error is negligible if the angular increments are below 30°.

Figure 2.7.f

Construction of flight path segments dividing turn into segments of length D*s* **(upper view in horizontal plane, lower view in vertical plane)**

Flight profile

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

- s_1, s_2 distance along the ground track,
- *z*₁, *z*₂ aeroplane height,
- *V*₁, *V*₂ groundspeed,
- *P*₁, *P*₂ noise-related power parameter (matching that for which the NPD-curves are defined), and
- $\varepsilon_1, \varepsilon_2$ bank angle.

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

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

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

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

$$
z = z_1 + f \cdot (z_2 - z_1) \tag{2.7.5}
$$

$$
V = \sqrt{V_1^2 + f \cdot (V_2^2 - V_1^2)}
$$
\n(2.7.6)

$$
\varepsilon = \varepsilon_1 + f \cdot (\varepsilon_2 - \varepsilon_1) \tag{2.7.7}
$$

$$
P = \sqrt{P_1^2 + f \cdot (P_2^2 - P_1^2)}
$$
\n(2.7.8)

Where

$$
f = (s - s_1)/(s_2 - s_1) \tag{2.7.9}
$$

Note that whilst *z* and ε are assumed to vary linearly with distance, *V* and *P* are assumed to vary linearly with time (i.e. constant acceleration (1)).

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

Segmentation of the takeoff ground roll

When taking off, as an aircraft accelerates between the point of brake release (alternatively termed Start-of-Roll *SOR*) and the point of lift-off, speed changes dramatically over a distance of 1 500 to 2 500 m, from zero to between around 80 and 100 m/s.

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

The takeoff roll is thus divided into segments with variable lengths over each of which the aircraft speed changes by specific increment Δ*V* of no more than 10 m/s (about 20 kt). Although it actually varies during the takeoff roll, an assumption of constant acceleration is adequate for this purpose. In this case, for the takeoff phase, V_1 is initial speed, V_2 is the takeoff speed, n_{TO} is the number of takeoff segment and s_{TO} is the equivalent takeoff distance. For equivalent takeoff distance s_{ro} (see **Appendix B**), start speed V₁ and takeoff speed V₂ the number n_{TO} of segments for the ground roll is

$$
n_{\text{TO}} = \text{int}(1 + (V_2 - V_1)/10) \tag{2.7.10}
$$

and hence the change of velocity along a segment is

$$
\Delta V = (V_2 - V_1)/n_{\text{TO}} \tag{2.7.11}
$$

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

$$
\Delta t = \frac{2 \cdot s_{\text{TO}}}{(V_2 + V_1) \cdot n_{\text{TO}}}
$$
\n(2.7.12)

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

$$
s_{\text{TO},k} = (k - 0.5) \cdot \Delta V \cdot \Delta t = \frac{(2k - 1) \cdot s_{\text{TO}}}{n_{\text{TO}}^2}
$$
\n(2.7.13)

Example:

For a takeoff distance $s_{\text{TO}} = 1$ 600 m, $V_1 = 0$ m/s and $V_2 = 75$ m/s, this yields $n_{\text{TO}} = 8$ segments with lengths ranging from 25 to 375 meters (see **Figure 2.7.g**):

Segmentation of a takeoff roll (example for 8 segments)

Similarly to the speed changes, the aircraft thrust changes over each segment by a constant increment Δ*P*, calculated as

$$
\Delta P = (P_{\text{TO}} - P_{\text{init}})/n_{\text{TO}} \tag{2.7.14}
$$

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

The use of this constant thrust increment (instead of using the quadratic form (equation (2.7.8)) aims at being consistent with the linear relationship between thrust and speed in the case of jet-engine aircraft (eq. B-1).

Segmentation of the initial climb segment

During the initial climb segment the geometry is changing rapidly particularly with respect to observer locations to the side of the flight track, where *beta angle* will change rapidly as the aircraft climbs through this initial segment. Comparisons with very small segment calculations show that a single climb segment results in a poor approximation of noise to the side of the flight track for integrated metrics. Calculation accuracy is improved by sub-segmenting the first lift-off segment. The length of each segment and number is strongly influenced by lateral attenuation. Noting the expression of total lateral attenuation for aircraft with fuselage-mounted engines, it can be shown that for a limiting change in lateral attenuation of 1,5 dB per sub-segment, that the initial climb segment shall be sub-segmented based on the following set of height values:

z = {18,9, 41,5, 68,3, 102,1, 147,5, 214,9, 334,9, 609,6, 1 0289,6} metres, or

z = {62, 136, 224, 335, 484, 705, 1 099, 2 000, 4 231} feet

The above heights are implemented by identifying which height in the set above is closest to the original segment endpoint. The actual sub-segment heights would then be calculated using:

$$
z'_{i} = z [z_{i}/z_{N}] (i = 1...N)
$$
 (2.7.15)

where z is the original segment end height, z_i is the ith member of the set of height values and z_N is the closest upper bound to height z. This process results in the lateral attenuation change across each sub-segment remaining constant, producing more accurate contours, but without the expense of using very short segments.

Example:

If the original segment endpoint height is at $z = 304.8$ m, then from the set of height values, 214,9 < 304,8 < 334,9 and the closest upper bound is to z = 304,8 m is z_7 = 334,9 m. The sub-segment endpoint heights are then computed by:

$$
z_i' = 304.8 [z_i/334.9] (i = 1..N)
$$

Thus z_1' would be 17,2 m and z_2' would be 37,8 m, etc.

The speed and engine power values on the inserted points are interpolated using respectively equations (2.7.11) and (2.7.13)

Segmentation of airborne segments

After the segmented flight path has been derived according to the procedure described in Section 2.7.13 and the sub-segmenting described is applied, further segmentation adjustments may be necessary. These include

— the removal of flight path points which are too close together and

— the insertion of additional points when speed changes along segments are too long.

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

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

$$
n_{\rm{seg}} = \text{int}(1 + |V_2 - V_1|/10) \tag{2.7.16}
$$

where V_1 and V_2 are the segment start and end speeds respectively. The corresponding sub-segment parameters are calculated in a similar manner as for the takeoff ground roll, using equations (2.7.11) to (2.7.13).

The landing ground roll

Although the landing ground roll is essentially a reversal of the takeoff ground roll, special account has to be taken of

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

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

The use of reverse thrust is not a standard procedure — it is only applied if the needed deceleration cannot be achieved by the use of the wheel brakes. (Reverse thrust can be exceptionally disturbing as a rapid change of engine power from idle to reverse settings produces a sudden burst of noise.)

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

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

It is clear that modelling the landing ground roll is less straightforward than for takeoff roll noise. The following simplified modelling assumptions are recommended for general use, when no detailed information is available (see **Figure 2.7.h**).

Modelling of landing ground roll

The aeroplane touches down 300 meters beyond the landing threshold (which has the coordinate *s* = 0 along the approach ground track). The aircraft is then decelerated over a stop-distance $s_{\rm stop}$ — aircraft specific values of which are given in the ANP database — from final approach speed *Vfinal* to 15 m/s. Because of the rapid changes in speed during this segment it shall be sub-segmented in the same manner as for the takeoff ground roll (or airborne segments with rapid speed changes), using equations (2.7.10) to (2.7.13).

The engine power changes from final approach power at touchdown to a reverse thrust power setting *P_{rev}* over a distance $0, \hat{1} \cdot s_{\text{atom}}$, then decreases to 10% of the maximum available power over the remaining 90 percent of the stop distance. Up to the end of the runway (at $s = -s_{RWY}$) aircraft speed remains constant.

NPD curves for reverse thrust are not at present included in the ANP database, and it is therefore necessary to rely on the conventional curves for modelling this effect. Typically the reverse thrust power *Prev* is around 20 % of the full power setting and this is recommended when no operational information is available. However, at a given power setting, reverse thrust tends to generate significantly more noise than forward thrust and an increment Δ*L* shall be applied to the NPD-derived event level, increasing from zero to a value Δ*Lrev* (5 dB is recommended provisionally (1)) along 0,1 · *sstop* and then falling linearly to zero along the remainder of the stop distance.

2.7.14. *Noise calculation for a single event*

The core of the modelling process, described here in full, is the calculation of the event noise level from the flight path information described in **Sections 2.7.7 to 2.7.13**.

⁽ 1) This was recommended in the previous edition of ECAC Doc 29 but is still considered provisional pending the acquisition of further corroborative experimental data.

2.7.15. *Single event metrics*

The sound generated by an aircraft movement at the observer location is expressed as a 'single event sound (or noise) level', a quantity which is an indicator of its impact on people. The received sound is measured in noise terms using a basic decibel scale *L(t)* which applies a frequency weighting (or filter) to mimic a characteristic of human hearing. The scale of most importance in aircraft noise contour modelling is A-weighted sound level, *L*_A.

The metric most commonly used to encapsulate entire events is 'single event sound (or noise) exposure levels', *LE*, which account for all (or most of) the sound energy in the events. Making provisions for the time integration that this involves gives rise to the main complexities of segmentation (or simulation) modelling. Simpler to model is an alternative metric *Lmax* which is the maximum instantaneous level occurring during the event; however it is *LE* which is the basic building block of most modern aircraft noise indices and practical models can in future be expected to embody both *Lmax* and *LE*. Either metric can be measured on different scales of noise; in this document only A-weighted sound level is considered. Symbolically, the scale is usually indicated by extending the metric suffix, i.e. L_{AF} , L_{Amax} .

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

$$
L_{E} = 10 \cdot \lg \left(\frac{1}{t_0} \int_{t_1}^{t_2} 10^{L(t)/10} dt \right) \tag{2.7.17}
$$

where t_0 denotes a reference time. The integration interval $[t_1,t_2]$ is chosen to ensure that (nearly) all significant sound in the event is encompassed. Very often, the limits t_1 and t_2 are chosen to span the period for which the level *L(t)* is within 10 dB of *Lmax*. This period is known as the '10-dB down' time. Sound (noise) exposure levels tabulated in the ANP database are 10-dB down values (1).

For aircraft noise contour modelling, the main application of equation (2.7.17) is the standard metric *Sound Exposure Level L_{AE}* (acronym SEL):

$$
L_{AE} = 10 \cdot \lg \left(\frac{1}{t_0} \int_{t_1}^{t_2} 10^{L_A(t)/10} dt \right) \text{ with } t_0 = 1 \text{ second}
$$
 (2.7.18)

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

2.7.16. *Determination of event levels from NPD-data*

The principal source of aircraft noise data is the international Aircraft Noise and Performance (ANP) database. This tabulates L_{max} and L_E as functions of propagation distance d — for specific aircraft types, variants, flight configurations (approach, departure, flap settings), and power settings *P*. They relate to steady flight at specific reference speeds V_{ref} along a notionally infinite, straight flight path (α).

^{(&}lt;sup>1</sup>) 10dB-down *L_E* may be up to 0,5 dB lower than *L_E* evaluated over a longer duration. However, except at short slant distances where event levels are high, extraneous ambient noise often makes longer measurement intervals impractical and 10-dB down values are the norm. As studies of the effects of noise (used to 'calibrate' the noise contours) also tend to rely on 10-dB down values, the ANP tabulations are considered to be entirely appropriate.

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

How values of the independent variables *P* and *d* are specified is described later. In a single look-up, with input values *P* and *d*, the output values required are the *baseline levels Lmax(P,d)* and/or *LE∞(P,d)* (applicable to an infinite flight path). Unless values happen to be tabulated for *P* and/or *d* exactly, it will generally be necessary to estimate the required event noise level(s) by interpolation. A linear interpolation is used between tabulated power-settings, whereas a logarithmic interpolation is used between tabulated distances (see **Figure 2.7.i**).

Figure 2.7.i

Interpolation in noise-power-distance curves

Slant distance (logarithmic scale)

If *P_i* and *P_{i+1}* are engine power values for which noise level versus distance data are tabulated, the noise level *L(P)* at a given distance for intermediate power *P*, between P_i and P_{i+1} , is given by:

$$
L(P) = L(P_i) + \frac{L(P_{i+1}) - L(P_i)}{P_{i+1} - P_i} \cdot (P - P_i)
$$
\n(2.7.19)

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

$$
L(d) = L(d_i) + \frac{L(d_{i+1}) - L(d_i)}{\lg d_{i+1} - \lg d_i} \cdot (\lg d - \lg d_i)
$$
\n(2.7.20)

By using equations (2.7.19) and (2.7.20), a noise level *L(P,d)* can be obtained for any power setting *P* and any distance *d* that is within the envelope of the NPD data base.

For distances *d* that lie outside the NPD envelope, equation (2.7.20) is used to extrapolate from the last two values, i.e. inwards from $L(d_1)$ and $L(d_2)$ or outwards from $L(d_{1-1})$ and $L(d_1)$ where I is the total number of NPD points on the curve. Thus

$$
L(d) = L(d_2) + \frac{L(d_1) - L(d_2)}{\lg d_2 - \lg d_1} \cdot (\lg d_2 - \lg d) \tag{2.7.21}
$$

Outwards:
$$
L(d) = L(d_{t-1}) - \frac{L(d_{t-1}) - L(d_t)}{\lg d_t - \lg d_{t-1}} \cdot (\lg d - \lg d_{t-1})
$$
 (2.7.22)

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

Impedance adjustment of standard NPD data

The NPD data provided in the ANP database are normalised to specific atmospheric conditions (temperature of 25 °C and pressure of 101,325 kPa). Before applying the interpolation/extrapolation method previously described, an acoustic impedance adjustment shall be applied to these standard NPD data.

Acoustic impedance is related to the propagation of sound waves in an acoustic medium, and is defined as the product of the density of air and the speed of sound. For a given sound intensity (power per unit area) perceived at a specific distance from the source, the associated sound pressure (used to define SEL and L_{Amax} metrics) depends on the acoustic impedance of the air at the measurement location. It is a function of temperature, atmospheric pressure (and indirectly altitude). There is therefore a need to adjust the standard NPD data of the ANP database to account for the actual temperature and pressure conditions at the receiver point, which are generally different from the normalised conditions of the ANP data.

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

$$
\Delta_{\text{Impedance}} = 10 \cdot \lg \left(\frac{\rho \cdot c}{409,81} \right) \tag{2.7.23}
$$

where:

 $\Delta_{\text{Impedance}}$ Impedance adjustment for the actual atmospheric conditions at the receiver point (dB)

ρ · c Acoustic impedance (newton · seconds/m³) of the air at the receiver point (409,81 being the air impedance associated to the reference atmospheric conditions of the NPD data in the ANP database).

Impedance *ρ · c* is calculated as follows:

$$
\rho \cdot \mathbf{c} = 416,86 \cdot \left[\frac{\delta}{\theta^{1/2}} \right] \tag{2.7.24}
$$

- *δ p*/*p_o*, the ratio of the ambient air pressure at the observer altitude to the standard air pressure at mean sea level: $p_0 = 101,325$ kPa (or $1013,25$ mb)
- *θ* (T + 273,15)/(T₀ + 273,15) the ratio of the air temperature at the observer altitude to the standard air temperature at mean sea level: $T_0 = 15.0$ °C

The acoustic impedance adjustment is usually less than a few tenths of one dB. In particular, it should be noted that under the standard atmospheric conditions (p_o = 101,325 kPa and T_o = 15,0 °C), the impedance adjustment is less than 0,1 dB (0,074 dB). However, when there is a significant variation in temperature and atmospheric pressure relative to the reference atmospheric conditions of the NPD data, the adjustment can be more substantial.

2.7.17. *General expressions*

Segment event level *Lseg*

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

$$
L_{\text{max.} \text{seg}} = L_{\text{max}}(P, d) + \Delta_I(\varphi) - \Lambda(\beta, \ell) \tag{2.7.25}
$$

and the contribution from one flight path segment to L_E as

$$
L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\varphi) - \Lambda(\beta,\ell) + \Delta_F
$$
\n(2.7.26)

The 'correction terms' in equations $(2.7.25)$ and $(2.7.26)$ — which are described in detail in Section 2.7.19 account for the following effects:

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

If the segment is part of the take-off or landing ground roll and the observer is located behind the segment under consideration, special steps are taken to represent the pronounced directionality of jet engine noise that is observed behind an aircraft about to takeoff. These special steps result in particular in the use of a particular form of the noise for the exposure level:

$$
L_{\max,seg} = L_{\max}(P,d) + \Delta_I(\varphi) - \Lambda(\beta,\ell) + \Delta_{\text{SOR}} \tag{2.7.27}
$$

$$
L_{E,seg} = L_{E\infty}(P,d) + \Delta_V + \Delta_I(\varphi) - \Lambda(\beta,\ell) + \Delta_F + \Delta_{SOR}
$$
\n(2.7.28)

- Δ′*F* Particular form of the *Segment correction*
- Δ*SOR Directivity correction*: accounts for the pronounced directionality of jet engine noise behind the ground roll segment

The specific treatment of ground roll segments is described in Section 2.7.19.

Sections below describe the calculation of segment noise levels.

Event noise level L of an aircraft movement

Maximum level *Lmax* is simply the greatest of the segment values *Lmax,seg* (see equations **(2.7.25) and (2.7.27)**)

$$
L_{\text{max}} = \max(L_{\text{max,seg}}) \tag{2.7.29}
$$

where each segment value is determined from the aircraft NPD data for power *P* and distance *d*. These parameters and the modifier terms $Δ_1$ (φ) and $Λ(β,ℓ)$ are explained below.

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

$$
L_E = 10 \cdot \lg \left(\sum 10^{L_{E,seg}/10} \right) \tag{2.7.30}
$$

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

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

2.7.18. *Flight path segment parameters*

The power *P*, and distance *d*, for which the baseline levels *Lmax,seg(P,d)* and *LE∞(P,d)* are interpolated from the NPD tables, are determined from geometric and operational parameters that define the segment. How this is done is explained below with the aid of illustrations of the plane containing the segment and the observer.

Geometric parameters

Figures 2.7.j to 2.7.l show the source-receiver geometries when the observer **O** is (a) behind, (b) alongside and (c) ahead of the segment S_1S_2 where the flight direction is from S_1 to S_2 . In these diagrams

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

Figure 2.7.j

Flight path segment geometry for observer behind segment

Flight path segment geometry for observer alongside segment

Figure 2.7.l

Flight path segment geometry for observer ahead of segment

The flight path segment is represented by a bold, solid line. The dotted line represents the *flight path extension* which stretches to infinity in both directions. For airborne segments, when the event metric is an exposure level L_E , the NPD distance parameter *d* is the distance d_p between \tilde{S}_p and the observer, called the *minimum slant range* (i.e. the perpendicular distance from the observer to the segment or its extension, in other words to the (hypothetical) infinite flight path of which the segment is considered to be part).

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

For maximum level metrics, the NPD distance parameter d is d_{φ} the shortest distance from the observer to the segment.

Segment power P

The tabulated NPD data describe the noise of an aircraft in steady straight flight on an infinite flight path, i.e. at constant engine power *P*. The recommended methodology breaks actual flight paths, along which speed and direction vary, into a number of finite segments, each of which is then taken to be part of a uniform, infinite flight path for which the NPD data are valid. But the methodology provides for changes of power along the length of a segment; it is taken to change linearly with distance from P_1 at its start to P_2 at its end. It is therefore necessary to define an equivalent steady segment value *P*. This is taken to be the value at the point on the segment that is closest to the observer. If the observer is alongside the segment (Figure 2.7.k) it is obtained by interpolation as given by equation (2.7.8) between the end values, i.e.

$$
P = \sqrt{P_1^2 + \frac{q}{\lambda} \cdot (P_2^2 - P_1^2)}
$$
\n(2.7.31)

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

2.7.19. *Segment Event level correction terms*

The NPD data define noise event levels as a function of distance perpendicularly beneath an idealised straight level path of infinite length along which the aircraft flies with steady power at a fixed reference speed (1). The event level interpolated from the NPD table for a specific power setting and slant distance is thus described as a *baseline level*. It applies to an infinite flight path and has to be corrected to account for the effects of (1) nonreference speed, (2) engine installation effects (lateral directivity), (3) lateral attenuation, (4) finite segment length and (5) longitudinal directivity behind start of roll on takeoff — see equations $(2.7.25)$ and $(2.7.26)$.

The duration correction DV (Exposure levels LE only)

This correction (2) accounts for a change in exposure levels if the actual segment groundspeed is different to the aircraft reference speed V_{ref} to which the basic NPD-data relate. Like engine power, speed varies along the segment (groundspeed varies from V_1 to V_2) and it is necessary to define an equivalent segment speed V_{sep} remembering that the segment is inclined to the ground; i.e.

$$
V_{seg} = V / cos \gamma \tag{2.7.32}
$$

where here *V* is an equivalent segment groundspeed (for information, see equation B-22 which expresses *V* in terms of calibrated airspeed, V_c and

$$
\gamma = \tan^{-1}\left(\frac{z_2 - z_1}{s_2 - s_1}\right) \tag{2.7.33}
$$

For airborne segments, *V* is taken to be the groundspeed at the closest point of approach **S** — interpolated between the segment end-point values assuming it varies linearly with time; i.e. if the observer is alongside the segment:

$$
V = \sqrt{V_1^2 + \frac{q}{\lambda} \cdot (V_2^2 - V_1^2)}
$$
 (2.7.34)

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

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

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

For runway segments (parts of the take-off or landing ground rolls for which $\gamma = 0$) V_{sg} is taken to be simply the average of the segment start and end speeds; i.e.

$$
V_{\rm seg} = (V_1 + V_2)/2 \tag{2.7.35}
$$

In either case the additive duration correction is then

$$
\Delta_{\rm V} = 10 \cdot \lg(V_{\rm ref}/V_{\rm seg}) \tag{2.7.36}
$$

Sound propagation geometry

Figure 2.7.l shows the basic geometry in the plane normal to the aircraft flight path. The ground line is the intersection of the normal plane and the level ground plane. (If the flight path is level the ground line is an end view of the ground plane.) The aircraft is banked at angle ε measured counter-clockwise about its roll axis (i.e. starboard wing up). It is therefore positive for left turns and negative for right turns.

Aircraft-observer angles in plane normal to flight path

- The *elevation angle β* (between 0 and 90°) between the direct sound propagation path and the level ground line ($'$) determines, together with the flight path inclination and the lateral displacement ℓ of the observer from the ground track, the lateral attenuation.
- The *depression angle* φ between the wing plane and the propagation path, determines the engine installation effects. With respect to the convention for the bank angle $\varphi = \beta \pm \varepsilon$ with the sign positive for observers to starboard (right) and negative for observers to port (left).

⁽ 1) In the case of non-flat terrain there can be different definitions of elevation angle. Here it is defined by the aircraft height above the observation point and the slant distance — hence neglecting local terrain gradients as well as obstacles on the sound propagation path (see Sections 2.7.6 and 2.7.10). In the event that, due to ground elevation, the receiver point is above the aircraft, elevation angle β is set equal to zero.

Engine installation correction Δ*I*

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

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

$$
\Delta_I(\varphi) = 10 \cdot \lg \left[(a \cdot \cos^2 \varphi + \sin^2 \varphi)^b / (c \cdot \sin^2 2\varphi + \cos^2 2\varphi) \right] \quad \text{dB} \tag{2.7.37}
$$

where Δ _{*I*} (φ) is the correction, in dB, at depression angle φ (see **Figure 2.7.m**) and

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

$$
\Delta_i(\varphi) = 0 \tag{2.7.38}
$$

Figure 2.7.n shows the variation of Δ*^I* (*φ*) about the aircraft roll axis for the three engine installations. These empirical relationships have been derived by the SAE from experimental measurements made mainly beneath the wing. Until above-wing data have been analysed it is recommended that, for negative *φ*, Δ*^I* (*φ*) = Δ*^I (0)* for all installations.

Figure 2.7.n

Lateral directivity of installation effects

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

Lateral attenuation *Λ(β, ')* (infinite f light path)

Tabulated NPD event levels relate to steady level flight and are generally based on measurements made 1,2 m over soft level ground beneath the aircraft; the distance parameter is effectively height above the surface. Any effect of the surface on event noise levels beneath the aircraft, that might cause the tabulated levels to differ from free-field values (1), is assumed to be inherent in the data (i.e. in the shape of the level vs. distance relationships).

To the side of the flight path, the distance parameter is the minimum slant distance — the length of the normal from the receiver to the flight path. At any lateral position the noise level will generally be less than at the same distance immediately below the aircraft. Apart from *lateral directivity* or 'installation effects' described above is due to an excess *lateral attenuation* which causes the sound level to fall more rapidly with distance than indicated by the NPD curves. A previous, widely used method for modelling lateral propagation of aircraft noise was developed by the Society of Automotive Engineers (SAE) in AIR-1751 and the algorithms described below are based on improvements SAE now recommends AIR-5662. Lateral attenuation is a reflection effect, due to interference between directly radiated sound and that which reflects from the surface. It depends on the nature of the surface and can cause significant reductions in observed sound levels at low elevation angles. It is also very strongly affected by sound refraction, steady and unsteady, caused by wind and temperature gradients and turbulence which are themselves attributable to the presence of the surface (2) . The mechanism of surface reflection is well understood and, for uniform atmospheric and surface conditions, it can be described theoretically with some precision. However, atmospheric and surface non-uniformities — which are not amenable to simple theoretical analysis — have a profound effect on the reflection effect, tending to 'spread' it to higher elevation angles; thus the theory is of limited applicability. SAE work to develop a better understanding of surface effects is continuing and this is expected to lead to better models. Until these are developed, the following methodology, described in AIR-5662, is recommended for calculating lateral attenuation. It is confined to the case of sound propagation over soft level ground which is appropriate for the great majority of civil airports. Adjustments to account for the effects of a hard ground surface (or, acoustically equivalent, water) are still under development.

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

As the term $\Lambda_{\tau}(\beta,\ell)$ accounted for lateral directivity as well as lateral attenuation, the latter can be extracted by subtraction. Describing lateral directivity by equation (2.7.37), with the fuselage-mount coefficients and with *φ* replaced by *β* (appropriate to non-turning flight), the lateral attenuation becomes:

$$
\Lambda(\beta,\ell) = \Lambda_T(\beta,\ell) - \Delta_I(\beta) \tag{2.7.39}
$$

where *β* and *'* are measured as depicted in **Figure 2.7.m** in a plane normal to the infinite flight path which, for level flight, is also vertical.

⁽ 1) A 'free-field' level is that which would be observed if the ground surface were not there.

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

Although Λ(*β*,*'*) could be calculated directly using equation (2.7.39) with Λ*T*(*β*,*'*) taken from AIR-1751, a more efficient relationship is recommended. This is the following empirical approximation adapted from AIR-5662:

$$
\Lambda(\beta,\ell) = \Gamma(\ell) \cdot \Lambda(\beta) \tag{2.7.40}
$$

where Γ(*'*) is a distance factor given by

$$
\Gamma(\ell) = 1,089 \cdot [1 - \exp(-0.00274\ell)] \qquad \text{for } 0 \le \ell \le 914 \text{ m} \tag{2.7.41}
$$

$$
\text{for } \ell > 914 \text{ m} \tag{2.7.42}
$$

and Λ(*β*) is long-range air-to-ground lateral attenuation given by

$$
\Lambda(\beta) = 1,137 - 0,0229\beta + 9,72 \cdot \exp(-0,142\beta) \qquad \text{for } 0^{\circ} \le \beta \le 50^{\circ} \tag{2.7.43}
$$

$$
\Lambda(\beta) = 0 \qquad \text{for } 50^{\circ} \le \beta \le 90^{\circ} \qquad (2.7.44)
$$

The expression for lateral attenuation Λ(*β*,*'*), equation (2.7.40), which is assumed to hold good for all aircraft, propeller aircraft as well as fuselage-mount and wing-mount jets, is shown graphically in **Figure 2.7.o**.

Under certain circumstances (with terrain), it is possible for *β* to be less than zero. In such cases it is recommended that $Λ(β) = 10,57$.

Figure 2.7.o

Variation of lateral attenuation Λ(β,*'***) with elevation angle and distance**

Finite segment lateral attenuation

Equations (2.7.41) to (2.7.44) describe the lateral attenuation Λ(β,*'*) of sound arriving at the observer from an aeroplane in steady flight along an infinite, level flight path. When applying them to finite path segments that are not level, the attenuation has to be calculated for an *equivalent* level path — as the closest point on a simple extension of the inclined segment (that passes through the ground surface at some point) generally does not yield an appropriate elevation angle *β*.

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

The baseline event level $L_F(P,d)$ that is determined from the NPD data, even though for finite segment parameters, applies nevertheless to an infinite flight path. The event exposure level from a segment, *LE,seg*, is of course less than the baseline level — by the amount of the finite segment correction defined later in Section 2.7.19. That correction, a function of the geometry of triangles OS₁S₂ in **Figures 2.7.j to 2.7.l**, defines what proportion of the total infinite path noise energy received at O comes from the segment; the same correction applies, whether or not there is any lateral attenuation. But any lateral attenuation shall be calculated for the infinite flight path, i.e. as a function of its displacement and elevation, not those of the finite segment.

Adding the corrections Δ*V* and Δ*^I* , and subtracting lateral attenuation Λ(*β*,*'*) from the NPD *baseline level* gives the adjusted event noise level for equivalent steady *level* flight on an adjacent, infinite straight path. But the actual flight path segments being modelled, those that affect the noise contours, are rarely level; aircraft are usually climbing or descending.

Figure 2.7.p illustrates a departure segment S_1S_2 — the aircraft is climbing at an angle γ — but the considerations remain very similar for an arrival. The remainder of the 'real' flight path is not shown; suffice it to state that **S1S2** represents just a part of the whole path (which in general will be curved). In this case, the observer **O** is alongside, and to the left of, the segment. The aircraft is banked (anti-clockwise about the flight path) at an angle ε to the lateral horizontal axis. The depression angle *φ* from the wing plane, of which the installation effect $Δ_l$ is a function (equation (2.7.39)), lies in the plane normal to the flight path in which ε is defined. Thus *φ = β – ε* where *β* = tan–1(*h*/*'*) and *'* is the perpendicular distance **OR** from the observer to the ground track; i.e. the lateral displacement of the observer (1). The aeroplane's closest point of approach to the observer, **S**, is defined by the perpendicular **OS**, of length (slant distance) d_p . The triangle **OS₁S₂** accords with **Figure 2.7.k**, the geometry for calculating the segment correction Δ*^F* .

Figure 2.7.p

Observer alongside segment

To calculate the lateral attenuation using equation (2.7.40) (where *β* is measured in a vertical plane), an *equivalent level flight path is defined in the vertical plane through* S_1S_2 and with the same perpendicular slant distance d_n from the observer. This is visualised by rotating the triangle **ORS**, and its attached flight path about **OR** (see **Figure 2.7.p**) through angle γ thus forming the triangle **ORS′**. The elevation angle of this equivalent level path (now in a vertical plane) is $\beta = \tan^{-1}(h/\ell)$ (ℓ remains unchanged). In this case, observer alongside, the lateral attenuation $Λ(β,ℓ)$ is the same for L_F and L_{max} metrics.

^{(&}lt;sup>1</sup>) For an observer located on the right side to the segment φ would become β + ε (see Section 2.7.19).

Figure 2.7.q illustrates the situation when the observer point **O** lies *behind the finite segment*, not alongside. Here the segment is observed as a more distant part of an infinite path; a perpendicular can only be drawn to point S_p on its extension. The triangle OS_1S_2 accords with **Figure 2.7.j** which defines the segment correction Δ_F . But in this case the parameters for lateral directivity and attenuation are less obvious.

Figure 2.7.q

Observer behind segment

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

For maximum level metrics, the NPD distance parameter is taken as the shortest distance to the segment, i.e. $d = d_1$. For exposure level metrics, it is the shortest distance d_p from **O** to S_p on the extended flight path; i.e. the level interpolated from the NPD table is $L_{E\infty}$ (P_1 , d_p).

The geometrical parameters for lateral attenuation also differ for maximum and exposure level calculations. For *maximum level metrics* the adjustment L(β , ℓ) is given by equation (2.7.40) with $\beta = \beta_1 = \sin^{-1}(z_1/d_1)$ and $\ell = \mathbf{OC}_1 = \sqrt{d_1^2 - z_1^2}$ where β_1 and d_1 are defined by the triangle $\mathbf{OC}_1\mathbf{S}_1$ in the vertical plane through **O** and S_1 .

When calculating the lateral attenuation for airborne segments only and *exposure level* metrics, *'* remains the shortest lateral displacement from the segment extension (**OC**). But to define an appropriate value of β it is again necessary to visualise an (infinite) *equivalent level flight path* of which the segment can be considered part. This is drawn through S_1' , height *h* above the surface, where h is equal to the length of RS_1 the perpendicular from the ground track to the segment. This is equivalent to rotating the actual extended flight path through angle γ about point **R** (see **Figure 2.7.q**). Insofar as **R** is on the perpendicular to **S**₁, the point on the segment that is closest to **O**, the construction of the equivalent level path is the same as when **O** is alongside the segment.

The closest point of approach of the equivalent level path to the observer **O** is at **S′**, slant distance *d*, so that the triangle **OCS′** so formed in the vertical plane then defines the elevation angle β = cos–1(*'*/*d*). Although this transformation might seem rather convoluted, it should be noted that the basic source geometry (defined by d_1 , d_2 and φ) remains untouched, the sound travelling from the segment *towards* the observer is simply what it would be if the entire flight along the infinitely extended inclined segment (of which for modelling purposes the segment forms part) were at constant speed *V* and power *P₁*. The lateral attenuation of sound from the segment *received* by the observer, on the other hand, is related not to β_p , the elevation angle of the extended path, but to *β*, that of the equivalent level path.

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

However, for exposure level metrics where observer locations are behind ground segments during the takeoff roll and locations ahead of ground segments during the landing roll, the value of β becomes the same as that for maximum level metrics, i.e. $\beta = \beta_1 = \sin^{-1}(z_1/d_1)$ and $\ell = OC_1 = \sqrt{d_1^2 - z_1^2}$

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

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

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

The energy fraction *F* is a function of the 'view' triangle OS_1S , defined in **Figures 2.7.j to 2.7.l** such that:

$$
\Delta_{F} = 10 \cdot \lg \left[\frac{1}{\pi} \left(\frac{a_{2}}{1 + a_{2}^{2}} + \arctan a_{2} - \frac{a_{1}}{1 + a_{1}^{2}} - \arctan a_{1} \right) \right]
$$
 (2.7.45)

with

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

where d_{λ} is known as the 'scaled distance' (see **Appendix E**). Note that $L_{max}(P, d_n)$ is the maximum level, from NPD data, for perpendicular distance d_n , NOT the segment L_{max} .

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

In the particular case of observer locations behind every takeoff ground-roll segment and every landing groundroll segment, a reduced form of the noise fraction expressed in equation (2.7.45) is used, which corresponds to the specific case of $q = 0$. This is computed using

$$
\Delta_{F'} = 10 \log_{10} \left[(1/\pi) \left[\alpha_2 / (1 + \alpha_2^2) + \tan^{-1} \alpha_2 \right] 10^{\Delta SOR/10} \right]
$$
\n(2.7.46)

where $\alpha_2 = \lambda/d_\lambda$ and Δ_{SOR} is the start-of-roll directivity function defined by equations (2.7.51) and (2.7.52).

The rationale for using this particular form of noise fraction is further explained in the section below, as part of the start-of-roll directivity application method.

Specific Treatments of Ground-roll Segments, including the start-of-roll directivity function Δ_{SOR}

In the case of ground roll segments, both for takeoff and landing, specific treatments are applied, which are described below.

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

The noise of jet aircraft — especially those equipped with lower by-pass ratio engines — exhibits a lobed radiation pattern in the rearward arc, which is characteristic of jet exhaust noise. This pattern is the more pronounced the higher the jet velocity and the lower the aircraft speed. This is of special significance for observer locations behind the start of roll, where both conditions are fulfilled. This effect is taken into account by a directivity function Δ_{SOR} .

The function Δ*SOR* has been derived from several noise measurement campaigns using microphones adequately positioned behind and on the side of the SOR of departing jet aircraft.

Figure 2.7.r shows the relevant geometry. The azimuth angle *ψ* between the aircraft longitudinal axis and the vector to the observer is defined by

$$
\psi = \arccos\left(\frac{q}{d_{\text{SOR}}}\right). \tag{2.7.47}
$$

The relative distance *q* is negative (see **Figure 2.7.j**) so that ψ ranges from 0° in the direction of the aircraft forward heading to 180° in the reverse direction.

Figure 2.7.r

Aircraft-observer geometry at ground for estimation of directivity correction

Observer d_{SOR} W $\,<\,$

The function Δ*SOR* represents the variation of the overall noise emanating from the takeoff ground roll measured behind the start of roll, relatively to the overall noise from takeoff ground roll measured on the side of the SOR, at the same distance:

$$
L_{TGR}(d_{SOR}, \psi) = L_{TGR}(d_{SOR}, 90^{\circ}) + \Delta_{SOR}(d_{SOR}, \psi)
$$
\n(2.7.48)

where $L_{TGR}(d_{SOR}, 90^{\circ})$ is the overall takeoff ground roll noise level generated by all takeoff ground roll segments at the point distance d_{SOR} to the side of the SOR. At distances d_{SOR} less than a normalising distance $d_{SOR,0}$, the SOR directivity function is given by

$$
\Delta_{\text{SOR}}^{0} = 51,47 - 1,553 \cdot \psi + 0,015147 \cdot \psi^{2} - 0,000047173 \cdot \psi^{3} \qquad \text{if } 90^{\circ} \le \psi < 148,4^{\circ} \tag{2.7.49}
$$
\n
$$
\Delta_{\text{SOR}}^{0} = 339,18 - 2,5802 \cdot \psi - 0,0045545 \cdot \psi^{2} + 0,000044193 \cdot \psi^{3} \qquad \text{if } 148,4^{\circ} \le \psi \le 180^{\circ} \tag{2.7.50}
$$

If the distance d_{SOR} exceeds the normalising distance $d_{SOR,0}$, the directivity correction is multiplied by a correction factor to account for the fact that the directivity becomes less pronounced for greater distances from the aircraft; i.e.

$$
\Delta_{SOR} = \Delta_{SOR}^0 \qquad \qquad \text{if } d_{SOR} \leq d_{SOR,0} \tag{2.7.51}
$$

$$
\Delta_{SOR} = \Delta_{SOR}^{0} \cdot \frac{d_{SOR,0}}{d_{SOR}} \qquad \qquad \text{if } d_{SOR} > d_{SOR,0} \qquad (2.7.52)
$$

The normalising distance $d_{SOR,0}$ equals 762 m (2 500 ft).

Treatment of receivers located behind each takeoff and landing ground-roll segment

The Δ_{SOR} function described above mostly captures the pronounced directivity effect of the initial portion of the takeoff roll at locations behind the SOR (because it is the closest to the receivers, with the highest jet velocity to aircraft speed ratio). However, the use of the hence established Δ_{sore} is 'generalised' to positions behind each individual ground roll segment — both takeoff and landing —, so not only behind the Start-of-Roll point (in the case of takeoff).

The parameters d_s and ψ are calculated relative to the start of each individual ground roll segment.

The event level *Lseg* for a location behind a given takeoff or landing ground-roll segment is calculated to comply with the formalism of the Δ_{SOR} function: it is essentially calculated for the reference point located on the side of the start point of the segment, at the same distance d_s as the actual point, and is further adjusted with Δ_{SOR} to obtain the event level at the actual point.

This means that the different correction terms in the equations below shall use the geometric parameters corresponding to this reference point located on the side of the start point:

$$
L_{\text{max,seg}} = L_{\text{max}}(P, d = d_s) + \Delta_l(\varphi) - \Lambda(\beta, l = d_s) + \Delta_{\text{SOR}} \tag{2.7.53}
$$

$$
L_{E,seg} = L_{E,eq}(P,d = d_s) + \Delta_V + \Delta_l(\varphi) - \Lambda(\beta,l = d_s) + \Delta'_{F} + \Delta_{SOR}
$$
\n(2.7.54)

where Δ′*F* is the reduced form of the noise fraction expressed in equation (2.7.46) for the case of *q* = 0 (as the reference point is located on the side of the start point) and remembering that d_3 shall be calculated using d_5 (and not \bar{d}_n):

$$
d_{\lambda} = d_0 \cdot 10^{\left[L_{\text{E}\infty}(P,d_S) - L_{\text{max}}(P,d_S)\right]/10} \tag{2.7.55}
$$

2.7.20. *Event noise level L of a general-aviation aircraft movement*

The method described in Section 2.7.19 is applicable to propeller-engined general-aviation aircraft when they are treated as propeller aircraft with regard to engine installation effects.

The ANP database includes entries for several general aviation aircraft. Whilst these are often the most common general-aviation aircraft operating, there may be occasions when it is appropriate to use additional data.

Where the specific general aviation aircraft are either not known or not in the ANP database, it is recommended to use the more generic aircraft data, GASEPF and GASEPV respectively. These data sets represent a small singleengined general aviation aircraft with fixed-pitch and variable-pitch propellers respectively. Tables of entries are presented in Annex I (Tables I-11 I-17)

2.7.21. *Method for the Calculation of Helicopter Noise*

For the calculation of helicopter noise, the same calculation method used for fixed-wing aircraft (outlined in Section 2.7.14) may be used, provided helicopters are treated as propeller aircraft and engine-installation effects, associated with jet aircraft are not applied. Tables of entries for two different data sets are presented in Annex I (Tables I-18 I-27).

2.7.22. *Noise associated with Engine Testing (Run-Up) Operations, taxiing and auxiliary power units*

In such cases where it is considered that noise associated with engine testing and auxiliary power-units are to be modelled, these are modelled according to the chapter on industrial noise. Although it is normally not the case, noise from aircraft engine tests (sometimes referred to as 'engine run-ups') at airports can make a contribution to noise impacts. Usually carried out for engineering purposes to check engine performance, aircraft are safely positioned away from buildings, aircraft, vehicular and/or personnel movements to avoid any jet-blast related damage.

For additional safety and noise control reasons, airports, particularly those with maintenance facilities that can lead to frequent engine tests, can install so-called 'noise pens', 3-sided baffled enclosures specially designed to deflect and dissipate jet blast and noise. Investigating the noise impact of such facilities, which can be further attenuated and reduced by the use of additional earth bunds or substantial noise barrier fencing, is best accomplished by treating the noise pen as a source of industrial noise and using an appropriate noise and sound propagation model.

2.7.23. *Calculation of cumulative levels*

Sections 2.7.14 to 2.7.19 describe the calculation of the event sound noise level of a single aircraft movement at a single observer location. The total noise exposure at that location is calculated by accumulating the event levels of all noise-significant aircraft movements, i.e. all movements, inbound or outbound, that influence the cumulative level.

2.7.24. *Weighted equivalent sound levels*

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

$$
L_{eq,W} = 10 \cdot \lg \left[\frac{t_0}{T_0} \cdot \sum_{i=1}^{N} g_i \cdot 10^{L_{E,i}/10} \right] + C \qquad (2.7.56)
$$

The summation is performed over all *N* noise events during the time interval $T₀$ to which the noise index applies. *LE,i* is the single event noise exposure level of the *i*-th noise event. *gi* is a time-of-day dependent weighting factor (usually defined for day, evening and night periods). Effectively *gi* is a multiplier for the number of flights occurring during the specific periods. The constant *C* can have different meanings (normalising constant, seasonal adjustment etc.).

Using the relationship

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

where Δ_i is the decibel weighting for the i-th period, equation (2.7.56) can be rewritten as

$$
L_{eq,W} = 10 \cdot \lg \left[\frac{t_0}{T_0} \sum_{i=1}^{N} 10^{(L_{E,i} + \Delta_i)/10} \right] + C \tag{2.7.57}
$$

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

2.7.25. *The weighted number of operations*

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

To describe this summation process the following subscripts are introduced:

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

Many noise indices — especially equivalent sound levels — include time-of-day weighting factors *gi* in their definition (equations $(2.7.56)$ and $(2.7.57)$).

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

$$
M_{ij} = (g_{day} \cdot N_{ij,day} + g_{evening} \cdot N_{ij,evening} + g_{night} \cdot N_{ij,night})
$$
\n(2.7.58)

The values *Nij* represent the numbers of operations of aircraft type/category *i* on track (or subtrack) *j* during the day, evening and night period respectively (1).

From equation (2.7.57) the (generic) cumulative equivalent sound level L_{eq} at the observation point (*x,y*) is

$$
L_{eq,W}(x,y) = 10 \cdot \lg \left[\frac{t_0}{T_0} \cdot \sum_i \sum_j \sum_k M_{ij} \cdot 10^{L_{E,ijk}(x,y)/10} \right] + C \qquad (2.7.59)
$$

 T_0 is the reference time period. It depends on — as well as the weighting factors g_i — the specific definition of the weighted index used (e.g. *L_{DEN}*). *L_{E,ijk}* is the single event noise level contribution from segment *k* of track or subtrack *j* for an operation of aircraft of category *i*. The estimation of *LE,ijk* is described in detail in Sections 2.7.14 to 2.7.19.

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

2.7.26. *Standard grid calculation and refinement*

When noise contours are obtained by interpolation between index values at rectangularly spaced grid points, their accuracy depends on the choice of the grid spacing (or mesh size) Δ_{*G}*, especially within cells where large</sub> gradients in the spatial distribution of the index cause tight curvature of the contours (see **Figure 2.7.s**). Interpolation errors are reduced by narrowing the grid spacing, but as this increases the number of grid points, the computation time is increased. Optimising a regular grid mesh involves balancing modelling accuracy and run time.

Figure 2.7.s

Standard grid and grid refinement

A marked improvement in computing efficiency that delivers more accurate results is to use an irregular grid to refine the interpolation in critical cells. The technique, depicted in **Figure 2.7.s**, is to tighten the mesh locally, leaving the bulk of the grid unchanged. This is very straightforward and achieved by the following steps:

- (1) Define a refinement threshold difference ΔL_R for the noise index.
- (2) Calculate the basic grid for a spacing Δ*G*.
- (3) Check the differences Δ*L* of the index values between adjacent grid nodes.
- (4) If there are any differences $\Delta L > DL_R$, define a new grid with a spacing $\Delta_G/2$ and estimate the levels for the new nodes in the following way:

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

(5) Repeat steps 1-4 until all differences are less than the threshold difference.

(6) Estimate the contours by linear interpolation.

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

2.7.27. *Use of rotated grids*

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

Figure 2.7.t

The straightforward way to avoid this effect is to tighten the grid. However this increases computation time. A more elegant solution is to rotate the computation grid so that its direction is parallel to the main ground tracks (i.e. usually parallel to the main runway). **Figure 2.7.t** shows the effect of such a grid rotation on the contour shape.

2.7.28. *Tracing of contours*

A very time-efficient algorithm that eliminates the need to calculate a complete grid array of index values at the expense of a little more computational complexity is to trace the path of the contour, point by point. This option requires two basic steps to be performed and repeated (see **Figure 2.7.u**):

Figure 2.7.u

Concept of tracing algorithm

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

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

Geometric parameters defining conditions for the tracing algorithm $\mathbf{P_{n-1}}$ Δc_{n-1} $\overline{\phi_n}$ P_{n-2}

Some constraints shall be imposed to guarantee that the contour is estimated with a sufficient degree of accuracy (see **Figure 2.7.v**):

 Δc_n .

 P_{n}

- (1) The length of the chord Δ*c* (the distance between two contour points) shall be within an interval [Δ*cmin*, Δ*cmax*], e.g. [10 m, 200 m].
- (2) The length ratio between two adjacent chords of lengths Δc_n and Δc_{n+1} shall be limited, e.g. 0,5 < Δc_n / Δc_{n+1} < 2.

(3) With respect to a good fit of the chord length to the contour curvature the following condition shall be fulfilled:

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

where Φ_n is the difference in the chord headings.

Experience with this algorithm has shown that, on an average, between 2 and 3 index values have to be calculated to determine a contour point with an accuracy of better than 0,01 dB.

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

2.8. **Assigning noise levels and population to buildings**

For the assessment of the noise exposure of the population only residential buildings shall be considered. No people shall be assigned to other buildings without residential use such as schools, hospitals, office buildings or factories. The assignment of the population to the residential buildings shall be based on the latest official data (depending on the Member State's relevant regulations).

Because aircraft calculation are performed on a $100 \text{ m} \times 100 \text{ m}$ resolution grid, the specific case of aircraft noise, levels shall be interpolated based on the nearest grid noise levels.

Determination of the number of inhabitants of a building

The number of inhabitants of a residential building is an important intermediate parameter for the estimation of the exposure to noise. Unfortunately, data on this parameter is not always available. Below it is specified how this parameter can be derived from data more readily available.

Symbols used in the following are:

- *BA* = base area of the building
- *DFS* = dwelling floor space
- *DUFS* = dwelling unit floor space
- *H* = height of the building
- *FSI* = dwelling floor space per inhabitant
- *Inh* = number of inhabitants
- *NF* = number of floors
- *V* = volume of residential buildings

For the calculation of the number of inhabitants, either the following case 1 procedure or the case 2 procedure shall be used, depending on the availability of data.

CASE 1: the data on the number of inhabitants is available

1A: The number of inhabitants is known or has been estimated on the basis of dwelling units. In this case the number of inhabitants of a building is the sum of the number of inhabitants of all dwelling units in the building:

$$
Inhbuilding = \sum_{i=1}^{n} Inhdwellinguniti
$$
 (2.8.1)

1B: The number of inhabitants is known only for entities larger than a building, e.g. sides of city blocks, city blocks, districts or even an entire municipality. In this case the number of inhabitants of a building is estimated based on the volume of the building:

$$
Inhbuilding = \frac{Vbuilding}{Vtotal} \times Inhtotal
$$
 (2.8.2)

The index '*total*' here refers to the respective entity considered. The volume of the building is the product of its base area and its height:

$$
V_{building} = BA_{building} \times H_{building}
$$
 (2.8.3)

If the height of the building is not known, it shall be estimated based on the number of floors *NFbuilding*, assuming an average height per floor of 3 m:

$$
H_{building} = NF_{building} \times 3 \text{ m} \tag{2.8.4}
$$

If the number of floors is also not known, a default value for the number of floors representative of the district or the borough shall be used.

The total volume of residential buildings in the entity considered *Vtotal* is calculated as the sum of the volumes of all residential buildings in the entity:

$$
V_{\text{total}} = \sum_{i=1}^{n} V_{\text{building}_i}
$$
 (2.8.5)

CASE 2: no data on the number of inhabitants is available

In this case the number of inhabitants is estimated based on the average dwelling floor space per inhabitant *FSI*. If this parameter is not known, a national default value shall be used.

2A: The dwelling floor space is known on the basis of dwelling units. In this case the number of inhabitants of each dwelling unit is estimated as follows:

$$
Inh_{\text{dwelling}_{\text{unit}_i}} = \frac{\text{DUFS}_i}{\text{FSI}} \tag{2.8.6}
$$

The number of inhabitants of the building can now be estimated as in CASE 1A above.

2B: The dwelling floor space is known for the entire building, i.e. the sum of the dwelling floor spaces of all dwelling units in the building is known. In this case the number of inhabitants is estimated as follows:

$$
Inhbuilding = \frac{DFS_{building}}{FSI}
$$
 (2.8.7)

2C: The dwelling floor space is known only for entities larger than a building, e.g. sides of city blocks, city blocks, districts or even an entire municipality.

In this case the number of inhabitants of a building is estimated based on the volume of the building as described in CASE 1B above with the total number of inhabitants estimated as follows:

$$
Inh_{\text{total}} = \frac{DFS_{\text{total}}}{FSI} \tag{2.8.8}
$$

2D: The dwelling floor space is unknown. In this case the number of inhabitants of a building is estimated as described in CASE 2B above with the dwelling floor space estimated as follows:

$$
DFS_{building} = BA_{building} \times 0.8 \times NF_{building}
$$
 (2.8.9)

The factor 0,8 is the conversion factor *gross floor area* \rightarrow *dwelling floor space*. If a different factor is known to be representative of the area it shall be used instead and clearly documented.

If the number of floors of the building is not known, it shall be estimated based on the height of the building, *H*_{building}, typically resulting in a non-integer number of floors:

$$
NF_{building} = \frac{H_{building}}{3 \text{ m}} \tag{2.8.10}
$$

If neither the height of the building nor the number of floors is known, a default value for the number of floors representative of the district or the borough shall be used.

Assigning receiver points to the façades of buildings

The assessment of population exposure to noise is based on receiver point levels at 4 m above the terrain level in front of building façades of residential buildings.

For the calculation of the number of inhabitants, either the following case 1 procedure or the case 2 procedure shall be used for land based noise sources. For aircraft noise calculated according to 2.6, all population of a building is associated to the nearest noise calculation point on the grid.

CASE 1

Figure a

Example of location of receivers around a building following CASE 1 procedure

- (a) Segments of a length of more than 5 m are split up into regular intervals of the longest possible length, but less than or equal to 5 m. Receiver points are placed in the middle of each regular interval.
- (b) Remaining segments above a length of 2,5 m are represented by one receiver point in the middle of each segment.
- (c) Remaining adjacent segments with a total length of more than 5 m are treated as polyline objects in a manner similar to that described in (a) and (b).
- (d) The number of inhabitants allocated to a receiver point, shall be weighted by the length of the represented façade so that the sum over all receiver points represents the total number of inhabitants.
- (e) Only for buildings with floor sizes that indicate a single dwelling per floor level, the most exposed façade noise level is directly used for the statistics and related to the number of inhabitants.

CASE 2

Figure b

Example of location of receivers around a building following CASE 2 procedure

- (a) Façades are considered separately or are split up every 5 m from the start position onwards, with a receiver position placed at the half-way distance of the façade or the 5 m segment
- (b) The remaining section has its receiver point in its mid-point.
- (c) The number of inhabitants allocated to a receiver point, shall be weighted by the length of the represented façade so that the sum over all receiver points represents the total number of inhabitants.
- (d) Only for buildings with floor sizes that indicate a single dwelling per floor level, the most exposed façade noise level is directly used for the statistics and related to the number of inhabitants.

3. INPUT DATA

Input data to be used as appropriate in association with the methods described above are given in Appendix F to Appendix I.

In cases where input data provided in Appendix F to Appendix I are not applicable or cause deviations from the true value that do not meet the conditions presented under 2.1.2 and 2.6.2, other values can be used, provided that the values used and the methodology used to derive them are sufficiently documented, including demonstrating their suitability. This information shall be made publicly available.

4. MEASUREMENT METHODS

In cases when, for any reason, measurements are performed, these shall be in accordance with the principles governing long term average measurements stated in ISO 1996-1:2003 and ISO 1996-2:2007 or, for aircraft noise, ISO 20906:2009.

Appendix A

Data requirements

Section 2.7.6 of the main text describes in general terms the requirements for case-specific data describing an airport and its operations that are needed for noise contour calculations. The following datasheets are filled with example data for a hypothetical airport. Specific data formats will generally depend on the requirements and needs for the particular noise modelling system as well as the study scenario.

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

A1 GENERAL AIRPORT DATA

A2 RUNWAY DESCRIPTION

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

A3 GROUND TRACK DESCRIPTION

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

A4 AIR TRAFFIC DESCRIPTION

A5 FLIGHT PROCEDURE DATA SHEET

Example aircraft for a Chapter 3 Boeing 727-200 as derived from radar using the guidance set out in Section 2.7.9 of the main text.

Example for a procedural profile based on A/C-data stored in ANP database:

Appendix B

Flight performance calculations

Terms and symbols

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

Terms

Symbols

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

B1 INTRODUCTION

Flight path synthesis

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

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

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

The aerodynamic-performance parameters in the ANP database are intended to yield a reasonably accurate representation of an aeroplane's actual flight path for the specified reference conditions (see **Section 2.7.6 of the main text**). But the aerodynamic parameters and engine coefficients have been shown to be adequate for air temperatures up to 43 °C, aerodrome altitudes up to 4 000 ft and across the range of weights specified in the ANP database. The equations thus permit the calculation of flight paths for other conditions; i.e. non-reference aeroplane weight, wind speed, air temperature, and runway elevation (air pressure), normally with sufficient accuracy for computing contours of average sound levels around an airport.

Section B-4 explains how the effects of turning flight are taken into account for departures. This allows bank angle to be accounted for when calculating the effects of lateral directivity (installation effects). Also, during turning flight, climb gradients will generally be reduced depending in the radius of the turn and the speed of the aeroplane. (The effects of turns during the landing approach are more complex and are not covered at present. However these will rarely influence noise contours significantly.)

Sections B-5 to **B-9** describe the recommended methodology for generating departure flight profiles, based on ANP database coefficients and procedural steps.

Sections B-10 and **B-11** describe the methodology used to generate approach flight profiles, based on ANP database coefficients and flight procedures.

Section B-12 provides worked examples of the calculations.

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

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

Flight path analysis

In some modelling applications the flight path information is provided not as procedural steps but as coordinates in position and time, usually determined by analysis of radar data. This is discussed in **Section 2.7.7** of the main text. In this case the equations presented in this Appendix are used 'in reverse'; the engine thrust parameters are derived from the aircraft motion rather than vice-versa. In general, once the flight path data has been averaged and reduced to segment form, each segment being classified by climb or descent, acceleration or deceleration, and thrust and flap changes, this is relatively straightforward by comparison with synthesis which often involves iterative processes.

B2 ENGINE THRUST

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

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

$$
F_n/\delta = E + F \cdot V_c + G_A \cdot h + G_B \cdot h^2 + H \cdot T \tag{B-1}
$$

where

- *F_n* is the net thrust per engine, lbf
- δ is the ratio of the ambient air pressure at the aeroplane to the standard air pressure at mean sea level, i.e., to 101,325 kPa (or 1 013,25 mb) [ref. 1]
- *F_n*/δ is the corrected net thrust per engine, lbf
- *V_c* is the calibrated airspeed, kt
- *T* is the ambient air temperature in which the aeroplane is operating, °C, and
- *E, F, G_A, G_B, H* are engine thrust constants or coefficients for temperatures below the engine flat rating temperature at the thrust rating in use (on the current segment of the takeoff/climbout or approach flight path), lb.s/ft, lb/ft, lb/ft2, lb/°C. Obtainable from the ANP database.

Data are also provided in the ANP database to allow calculation of non-rated thrust as a function of a thrust setting parameter. This is defined by some manufacturers as engine pressure ratio *EPR*, and by others as low-pressure rotor speed, or fan speed, *N1*. When that parameter is *EPR*, equation B-1 is replaced by

$$
F_n/\delta = E + F \cdot V_c + G_A \cdot h + G_B \cdot h^2 + H \cdot T + K_1 \cdot EPR + K_2 \cdot EPR^2
$$
 (B-2)

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

When engine rotational speed $N₁$ is the parameter used by the cockpit crew to set thrust, the generalised thrust equation becomes

$$
F_n/\delta = E + F \cdot V_c + G_A \cdot h + G_B \cdot h^2 + H \cdot T + K_3 \cdot \left(\frac{N_1}{\sqrt{\vartheta}}\right) + K_4 \cdot \left(\frac{N_1}{\sqrt{\vartheta}}\right)^2 \tag{B-3}
$$

where

- *N₁* is the rotational speed of the engine's low-pressure compressor (or fan) and turbine stages, %
- θ = $(T + 273)/288,15$, the ratio of the absolute total temperature at the engine inlet to the absolute standard air temperature at mean sea level [ref. 1].
- $\frac{N_1}{4}$ *θ* is the corrected low pressure rotor speed, %; and
- $K₃$, $K₄$ are constants derived from installed engine data encompassing the $N₁$ speeds of interest.

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

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

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

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

where

(*Fn*/δ)*high* high-temperature corrected net thrust (lbf),

T_R breakpoint temperature (in the absence of a definitive value assume a default value of 30 °C).

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

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

$$
F_n/\delta = (326 \cdot \eta \cdot P_p/V_T)/\delta \tag{B-5}
$$

where

- *η* is the propeller efficiency for a particular propeller installation and is a function of propeller rotational speed and aeroplane flight speed
- V_T is the true airspeed, kt
- *P_p* is net propulsive power for the given flight condition, e.g. max takeoff or max climb power, hp

Parameters in equation B-5 are provided in the ANP database for maximum takeoff thrust and maximum climb thrust settings.

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

$$
V_T = V_c / \sqrt{\sigma} \tag{B-6}
$$

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

Guidance on operation with reduced takeoff thrust

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

As they can have a profound effect upon departure noise contours, modellers should take reasonable account of reduced thrust operations and, to make best possible provision, to seek practical advice from operators.

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

Analysis of FDR data has shown that the level of thrust reduction is strongly correlated with ratio of the actual takeoff weight to the Regulated Takeoff Weight (RTOW), down to a fixed lower limit (1); i.e.

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

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

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

Reduced Climb Thrust

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

B3 VERTICAL PROFILES OF AIR TEMPERATURE, PRESSURE, DENSITY AND WINDSPEED

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

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

B4 THE EFFECTS OF TURNS

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

⁽ 1) Airworthiness authorities normally stipulate a lower thrust limit, often 25 percent below maximum.

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

The construction of the ground track is described in Section **2.7.13** of the text. This is done independently of any aircraft flight profile (although with care not to define turns that could not be flown under normal operating constraints). But as the flight profile — height and speed as a function of track distance — is affected by turns so that the flight profile cannot be determined independently of the ground track.

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

$$
\varepsilon = \tan^{-1}\left\{\frac{2,85 \cdot V^2}{r \cdot g}\right\} \tag{B-8}
$$

where *V* is the groundspeed, kt

r is the turn radius, ft

and *g* is the acceleration due to gravity, ft/s²

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

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

But if the provisional segment crosses one or more starts or ends of turns (where ε changes) (1), the flight parameters at the first such point are estimated by interpolation (see Section **2.7.13**), saved along with its coordinates as end-point values, and the segment truncated. The second part of the procedural step is then applied from that point — once more assuming provisionally that it can be completed in a single segment with the same end conditions but with the new start point and new bank angle. If this second segment then passes another change of turn radius/direction, a third segment will be required — and so on until the end-conditions are achieved.

Approximate method

It will be apparent that accounting fully for the effects of turns, as described above, involves considerable computational complexity because the climb profile of any aircraft has to be calculated separately for each ground track that it follows. But changes to the vertical profile caused by turns usually have a markedly smaller influence on the contours than the changes of bank angle, and some users may prefer to avoid the complexity — at the cost of some loss of precision by disregarding the effects of turns on profiles while still accounting for the bank angle in the calculation of lateral sound emission (see Section 2.7.19). Under this approximation profile points for a particular aircraft operation are calculated once only, assuming a straight ground track (for which $\varepsilon = 0$).

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

B5 TAKEOFF GROUND ROLL

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

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

Figure B-1

Equivalent takeoff distance

On a level runway, the equivalent takeoff ground-roll distance s_{TOS} in feet is determined from

$$
S_{TOS} = \frac{B_s \cdot \vartheta \cdot (W/\delta)^2}{N \cdot (F_n/\delta)}
$$
 (B-9)

where

- *B8* is a coefficient appropriate to a specific aeroplane/flap-deflection combination for the ISA reference conditions, including the 8-knot headwind, ft/lbf
- *W* is the aeroplane gross weight at brake release, lbf
- *N* is the number of engines supplying thrust.
- *Note:* Since equation B-9 accounts for variation of thrust with airspeed and runway elevation, for a given aeroplane the coefficient *B₈* depends only on flap deflection.

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

$$
S_{\text{TOw}} = S_{\text{TO8}} \cdot \frac{(V_{\text{C}} - w)^2}{(V_{\text{C}} - 8)^2}
$$
 (B-10)

where

- *STOw* is the ground-roll distance corrected for headwind *w*, ft
- *V_c* (in this equation) is the calibrated speed at takeoff rotation, kt
- *w* is the headwind, kt

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

$$
S_{TOG} = S_{TOw} \cdot \frac{\alpha}{(\alpha - g \cdot G_R)} \tag{B-11}
$$

where

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

- *a* is the average acceleration along the runway, equal to $(V_c \cdot \sqrt{\sigma})^2/(2 \cdot s_{\text{row}})$, ft/s²
- *GR* is the runway gradient; positive when taking-off uphill

B6 CLIMB AT CONSTANT SPEED

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

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

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

- *K* is a speed-dependent constant equal to 1,01 when $V_c \le 200$ kt or 0,95 otherwise. This constant accounts for the effects on climb gradient of climbing into an 8-knot headwind and the acceleration inherent in climbing at constant calibrated airspeed (true speed increases as air density diminishes with height).
- *R* is the ratio of the aeroplane's drag coefficient to its lift coefficient appropriate to the given flap setting. The landing gear is assumed to be retracted.
- *ε* Bank angle, radians

The climb angle is corrected for headwind *w* using:

$$
\gamma_w = \gamma \cdot \frac{(V_c - 8)}{(V_c - w)}
$$
\n(B-13)

where *γ_w* is the average climb angle corrected for headwind.

The distance that the aeroplane traverses along the ground track, Δ*s*, while climbing at angle γ*w*, from an initial altitude h_1 to a final altitude h_2 is given by

$$
\Delta_{\rm S} = \frac{(h_2 - h_1)}{\tan \gamma_{\rm w}}\tag{B-14}
$$

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

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

$$
V_{\text{CTO}} = C \cdot \sqrt{W} \tag{B-15}
$$

where *C* is a coefficient appropriate to the flap setting (kt/√lbf), read from the ANP database.

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

B7 POWER CUTBACK (TRANSITION SEGMENT)

Power is reduced, or *cut back*, from take-off setting at some point after takeoff in order to extend engine life and often to reduce noise in certain areas. Thrust is normally cut back during either a constant speed climb segment (**Section B6**) or an acceleration segment (**Section B8**). As it is a relatively brief process, typically of only 3-5 seconds′ duration, is it modelled by adding a 'transition segment' to the primary segment. This is usually taken to cover a horizontal ground distance of 1 000 ft (305 m).

Amount of thrust reduction

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

The minimum 'reduced-thrust' level is sometimes referred to as the engine-out 'reduced thrust':

$$
(F_n/\delta)_{\text{engine.out}} = \frac{(W/\delta_2)}{(N-1)} \cdot \left[\frac{\sin(\arctan(0.01 \cdot G'))}{K} + \frac{R}{\cos \varepsilon} \right] \tag{B-16}
$$

where

- δ , is the pressure ratio at altitude h₂
- *G′* is the engine-out percentage climb gradient:
	- = 0 % for aeroplanes with automatic thrust restoration systems; otherwise,
	- = 1,2 % for 2-engine aeroplane
	- = 1,5 % for 3-engine aeroplane
	- = 1,7 % for 4-engine aeroplane

⁽ 1) 'Noise Abatement Procedures', ICAO Document 8168 'PANS-OPS' Vol.1 Part V, Chapter 3, ICAO 2004.

Constant speed climb segment with cutback

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

Figure B-2

Constant speed climb segment with cutback (illustration — not to scale)

The first sub-segment is assigned a 1 000 ft (304 m) ground distance, and the corrected net thrust per engine at the end of 1 000 ft is set equal to the cutback value. (If the original horizontal distance is less than 2 000 ft, one half of the segment is used to cutback thrust.) The final thrust on the second sub-segment is also set equal to the cutback thrust. Thus, the second sub-segment is flown at constant thrust.

B8 ACCELERATING CLIMB AND FLAP RETRACTION

This usually follows the initial climb. As for all flight segments, the start-point altitude h_1 , true airspeed V_{T1} , and thrust (F_n/δ) are those from the end of the preceding segment. The end-point calibrated airspeed V_{C2} and the average climb rate *ROC* are user inputs (bank angle ε is a function of speed and radius of turn). As they are interdependent, the end altitude *h₂*, end true airspeed *V_{T2}*, end thrust (*F_n*/δ)₂ and segment track length Δs have to be calculated by iteration; the end altitude h_2 is guessed initially and then recalculated repeatedly using equations B-16 and B-17 until the difference between successive estimates is less than a specified tolerance, e.g. one foot. A practical initial estimate is $h_2 = h_1 + 250$ feet.

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

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

where

0,95 is a factor to account for effect of 8 kt headwind when climbing at 160 kt

k is a constant to convert knots to ft/sec = 1,688 ft/s per kt

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

where σ ₂ = air density ratio at end altitude *h*₂

 a_{max} = maximum acceleration in level flight (ft/s²)

$$
= g\big[N \cdot \overline{F_n/\delta}/(\overline{W/\delta}) - R/\cos \varepsilon\big]
$$

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

where *ROC* = climb rate, ft/min

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

$$
h_2' = h_1 + s \cdot G/0.95 \tag{B-18}
$$

As long as the error $|h'_{2} - h_{2}|$ is outside the specified tolerance, the steps B-17 and B-18 are repeated using the current iteration segment-end values of altitude *h*₂, true airspeed *V*₇₂, corrected net thrust per engine (*F_n*/δ)₂. When the error is within the tolerance, the iterative cycle is terminated and the acceleration segment is defined by the final segment-end values.

Note: If during the iteration process $(a_{max} - G·g) < 0.02$ g, the acceleration may be too small to achieve the desired V_{C2} in a reasonable distance. In this case, the climb gradient can be limited to $G = a_{max}/g - 0.02$, in effect reducing the desired climb rate in order to maintain acceptable acceleration. If *G* < 0,01 it should be concluded there is not enough thrust to achieve the acceleration and climb rate specified; the calculation should be terminated and the procedure steps revised (1).

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

$$
\Delta S_w = \Delta_S \cdot \frac{(V_T - w)}{(V_T - 8)}
$$
\n(B-19)

Accelerating segment with cutback

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

B9 ADDITIONAL CLIMB AND ACCELERATION SEGMENTS AFTER FLAP RETRACTION

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

B10 DESCENT AND DECELERATION

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

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

⁽ 1) In either case the computer model should be programmed to inform the user of the inconsistency.

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

$$
\alpha = \frac{(V_2/\cos\gamma)^2 - (V_1/\cos\gamma)^2}{(2 \cdot \Delta_S/\cos\gamma)}
$$
 (B-21)

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

$$
V = \frac{V_c \cdot \cos \gamma}{\sqrt{\sigma}} - w \tag{B-22}
$$

Equations B-20, B-21 and B-22 confirm that whilst decelerating over a specified distance at a constant rate of descent, a stronger headwind will result in more thrust being required to maintain the same deceleration, whilst a tailwind will require less thrust to maintain the same deceleration.

In practice most, if not all decelerations during approach flight are performed at idle thrust. Thus for the second application of equation B-20, thrust is defined at an idle setting and the equation is solved iteratively to determine (1) the deceleration and (2) the height at the end of the deceleration segment — in a similar manner to the departure acceleration segments. In this case, deceleration distance can be very different with head and tail winds and it is sometimes necessary to reduce the descent angle in order to obtain reasonable results.

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

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

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

B11 LANDING APPROACH

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

$$
V_{CA} \approx D \cdot \sqrt{W} \tag{B-24}
$$

where the coefficient *D* (kt/√lbf) corresponds to the landing flap setting.

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

The average corrected net thrust is calculated by inverting equation B-12 using $K = 1,03$ to account for the deceleration inherent in flying a descending flight path into an 8-knot reference headwind at the constant calibrated airspeed given by equation B-24, i.e.

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

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

$$
\left(\overline{F_n \cdot \delta}\right)_w = \overline{F_n \cdot \delta} + 1,03 \cdot \overline{W \cdot \delta} \cdot \frac{\sin \gamma \cdot (w-8)}{N \cdot V_{C4}} \tag{B-26}
$$

The horizontal distance covered is calculated by:

$$
\Delta_s = \frac{(h_2 - h_1)}{\tan \gamma} \tag{B-27}
$$

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

Appendix C

Modelling of lateral ground track spreading

It is recommended that, in the absence of radar data, lateral ground track dispersion be modelled on the assumption that the spread of tracks perpendicular to the backbone track follows a Gaussian normal distribution. Experience has shown that this assumption is a reasonable one in most cases.

Assuming a Gaussian distribution with a standard deviation *S*, illustrated in **Figure C-1**, about 98,8 percent of all movements fall within boundaries of ± 2,5·*S* (i.e. within a swathe of width of 5·*S*).

Figure C-1

Subdivision of a ground track into 7 subtracks

(The width of the swathe is 5 times the standard deviation of the ground track spreading)

A Gaussian distribution can normally be modelled adequately using 7 discrete sub-tracks evenly spaced between the ± 2,5·*S* boundaries of the swathe as shown in **Figure C-1**.

However, the adequacy of the approximation depends on the relationship of the sub-track track separation to the heights of the aircraft above. There may be situations (very tight or very dispersed tracks) where a different number of subtracks is more appropriate. Too few subtracks cause 'fingers' to appear in the contour. **Tables C-1** and **C-2** show the parameters for a subdivision into between 5 and 13 subtracks. Table C-1 shows the location of the particular subtracks, **Table C-2** the corresponding percentage of movements on each subtrack.

Table C-1

Location of 5, 7, 9, 11 or 13 subtracks

(The overall width of the swathe (containing 98 % of all movements) is 5 times the standard deviation)

Table C-2

Percentage of movements on 5, 7, 9, 11 or 13 subtracks

(The overall width of the swathe (containing 98 % of all movements) is 5 times the standard deviation)

Appendix D

Recalculation of NPD-data for non-reference conditions

The noise level contributions from each segment of the flight path are derived from the NPD-data stored in the international ANP database. However it must be noted that these data have been normalised using average atmospheric attenuation rates defined in SAE AIR-1845. Those rates are averages of values determined during aircraft noise certification testing in Europe and the USA. The wide variation of atmospheric conditions (temperature and relative humidity) in those tests is shown in **Figure D-1**.

Figure D-1

Meteorological conditions recorded during noise certification tests

ACTUAL DAY CONDITIONS RECORDED DURING CERTIFICATION TESTING

The curves overlaid on **Figure D-1**, calculated using an industry standard atmospheric attenuation model ARP 866A, illustrate that across the test conditions a substantial variation of high frequency (8 kHz) sound absorption would be expected (although the variation of overall absorption would be rather less).

Because the attenuation rates, given in **Table D-1**, are arithmetic averages, the complete set cannot be associated with a single reference atmosphere (i.e. with specific values of temperature and relative humidity). They can only thought of as properties of a purely notional atmosphere — referred to as the 'AIR-1845 atmosphere'.

Table D-1

Average atmospheric attenuation rates used to normalise NPD data in the ANP database

The attenuation coefficients in **Table D-1** may be assumed valid over reasonable ranges of temperature and humidity. However, to check whether adjustments may be necessary, ARP-866A should be used to calculate average atmospheric absorption coefficients for the average airport temperature *T* and relative humidity *RH*. Where, from a comparison of these with those in **Table D-1**, it is judged that adjustment is required the following methodology should be used.

The ANP database provides the following NPD data for each power setting:

- maximum sound level versus slant distance, *Lmax(d)*
- time integrated level versus distance for the reference airspeed, $L_{E}(d)$, and
- unweighted reference sound spectrum at a slant distance of 305 m (1 000 ft), *Ln,ref(dref)* where *n* = frequency band (ranging from 1 to 24 for $1/3$ -octave bands with centre frequencies from 50 Hz to 10 kHz),

all data being normalised to the AIR-1845 atmosphere.

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

1. First the reference spectrum is corrected to remove the SAE AIR-1845 atmospheric attenuation α*n,ref*:

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

where *Ln(dref)* is the unattenuated spectrum at *dref* = 305 m and α*n,ref* is the coefficient of atmospheric absorption for the frequency band *n* taken from **Table D-1** (but expressed in dB/m).

- 2. Next the corrected spectrum is adjusted to each of the 10 standard NPD distances d_i using attenuation rates for both (i) the SAE AIR-1845 atmosphere and (ii) the user-specified atmosphere (based on SAE ARP-866A).
	- (i) For the SAE AIR-1845 atmosphere:

$$
L_{n,ref}(d_i) = L_n(d_{ref}) - 20 \text{,} \lg(d_i/d_{ref}) - a_{n,ref} \cdot d_i \tag{D-2}
$$

(ii) For the user atmosphere:

$$
L_{n,866A}(T,RH,d_i) = L_n(d_{ref}) - 20, \lg(d_i/d_{ref}) - \alpha_{n,866A}(T,RH) \cdot d_i
$$
 (D-3)

where α*n,866A* is the coefficient of atmospheric absorption for the frequency band *n* (expressed in dB/m) calculated using SAE ARP-866A with temperature *T*, and relative humidity *RH*.

3. At each NPD distance *di* the two spectra are A-weighted and decibel-summed to determine the resulting A-weighted levels $L_{A,866A}$ and $L_{A,ref}$ — which are then subtracted arithmetically:

$$
\Delta L(T, RH, d_{i}) = L_{A,866A} - L_{A,ref} = 10 \cdot \lg \sum_{n=1}^{24} 10^{(L_{n,866A}(T,RH, d_{i}) - A_{n})/10} - 10 \cdot \lg \sum_{n=1}^{24} 10^{(L_{n,ref}(d_{i}) - A_{n})/10}
$$
(D-4)

The increment Δ*L* is the difference between the NPDs in the user-specified atmosphere and the reference atmosphere. This is added to the ANP database NPD data value to derive the adjusted NPD data.

Applying Δ*L* to adjust both *L_{max}* and *L_E* NPDs effectively assumes that different atmospheric conditions affect the reference spectrum only and have no effect on the shape of the level-time-history This may be considered valid for typical propagation ranges and typical atmospheric conditions.

Appendix E

The finite segment correction

This appendix outlines the derivation of the finite segment correction and the associated energy fraction algorithm described in Section 2.7.19.

E1 GEOMETRY

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

Figure E-1

Geometry between flight path and observer location O

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

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

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

E2 ESTIMATION OF THE ENERGY FRACTION

The basic concept of the energy fraction is to express the noise exposure *E* produced at the observer position from a flight path segment P_1P_2 (with a start-point P_1 and an end-point $\hat{P_2}$) by multiplying the exposure E_{∞} from the whole infinite path flyby by a simple factor — the *energy fraction* factor *F*:

$$
E = F \cdot E_{\infty} \tag{E-1}
$$

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

$$
E = const \cdot \int p^2(\tau) d\tau
$$
 (E-2)

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

$$
p^{2} = p_{p}^{2} \cdot \frac{d_{p}^{2}}{d^{2}} \cdot \sin^{2} \psi = p_{p}^{2} \cdot \frac{d_{p}^{4}}{d^{4}}
$$
 (E-3)

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

This relatively simple relationship has been found to provide a good simulation of jet aircraft noise, even though the real mechanisms involved are extremely complex. The term d_p^2/d^2 in equation E-3 describes just the mechanism of spherical spreading appropriate to a point source, an infinite sound speed and a uniform, non-dissipative atmosphere. All other physical effects — source directivity, finite sound speed, atmospheric absorption, Doppler-shift etc. — are implicitly covered by the *sin2ψ* term. This factor causes the mean square pressure to decrease inversely as *d4*; whence the expression 'fourth power' source.

Introducing the substitutions

$$
d^{2} = d_{p}^{2} + q^{2} = d_{p}^{2} + (V \cdot \tau)^{2}
$$
 and $\left(\frac{d}{d_{p}}\right)^{2} = 1 + \left(\frac{V \cdot \tau}{d_{p}}\right)^{2}$

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

$$
p^2 = p_p^2 \cdot \left(1 + \left(\frac{V \cdot \tau}{d_p}\right)^2\right)^{-2}
$$
 (E-4)

Putting this into equation (E-2) and performing the substitution

$$
a = \frac{V \cdot \tau}{d_p} \tag{E-5}
$$

the sound exposure at the observer from the flypast between the time interval $[\tau_i, \tau_j]$ can be expressed as

$$
E = const \cdot p_p^2 \cdot \frac{d_p}{V} \cdot \int_{\alpha_1}^{\alpha_2} \frac{1}{(1 + \alpha^2)^2} d\alpha
$$
 (E-6)

The solution of this integral is:

$$
E = \text{const} \cdot p_p^2 \cdot \frac{d_p}{V} \cdot \frac{1}{2} \left(\frac{a_2}{1 + a_2^2} + \arctan a_2 - \frac{a_1}{1 + a_1^2} - \arctan a_1 \right) \tag{E-7}
$$

Integration over the interval [–∞,+∞] (i.e. over the whole infinite flight path) yields the following expression for the total exposure *E∞*:

$$
E_{\infty} = const \cdot \frac{\pi}{2} \cdot p_p^2 \cdot \frac{d_p}{V}
$$
 (E-8)

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

$$
F = \frac{1}{\pi} \left(\frac{\alpha_2}{1 + \alpha_2^2} + \arctan \alpha_2 - \frac{\alpha_1}{1 + \alpha_1^2} - \arctan \alpha_1 \right)
$$
 (E-9)

E3 CONSISTENCY OF MAXIMUM AND TIME INTEGRATED METRICS — THE SCALED DISTANCE

A consequence of using the simple dipole model to define the energy fraction is that it implies a specific theoretical difference Δ*L* between the event noise levels *Lmax* and *LE*. If the contour model is to be internally consistent, this needs to equal the difference of the values determined from the NPD curves. A problem is that the NPD data are derived from actual aircraft noise measurements — which do not necessarily accord with the simple theory. The theory therefore needs an added element of flexibility. But in principal the variables *α₁* and *α₂* are determined by geometry and aircraft speed — thus leaving no further degrees of freedom. A solution is provided by the concept of a *scaled distance dλ* as follows.

The exposure level $L_{F_{\infty}}$ as tabulated as a function of d_n in the ANP database for a reference speed $V_{\nu\rho}$ can be expressed as

$$
L_{E_{\infty}}(V_{\text{ref}}) = 10 \cdot \lg \left[\frac{\int\limits_{-\infty}^{\infty} p^2 \cdot dt}{p_0^2 \cdot t_{\text{ref}}}\right]
$$
(E-10)

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

$$
L_{E,\infty}(V) = L_{E,\infty}(V_{\text{ref}}) + 10 \cdot \lg \left(\frac{V_{\text{ref}}}{V}\right)
$$
\n(E-11)

Similarly the maximum event level *Lmax* can be written

$$
L_{\text{max}} = 10 \cdot \lg \left[\frac{p_p^2}{p_0^2} \right] \tag{E-12}
$$

For the dipole source, using equations E-8, E-11 and E-12, noting that (from equations E-2 and E-8) Z∞ − ∞ $p^2 \cdot dt = \frac{\pi}{2} \cdot p_p^2 \cdot \frac{d_p}{V}$ $\frac{M}{V}$, the difference ΔL can be written:

$$
\Delta L = L_{E,\infty} - L_{max} = 10 \cdot \lg \left[\frac{V}{V_{ref}} \cdot \left(\frac{\pi}{2} p_p^2 \frac{d_p}{V} \right) \cdot \frac{1}{p_0^2 \cdot t_{ref}} \right] - 10 \cdot \lg \left[\frac{p_p^2}{p_0^2} \right]
$$
(E-13)

This can only be equated to the value of Δ*L* determined from the NPD data if the slant distance *dp* used to calculate the energy fraction is substituted by a *scaled distance dλ* given by

$$
d_{\lambda} = \frac{2}{\pi} \cdot V_{\text{ref}} \cdot t_{\text{ref}} \cdot 10^{(L_{E,\infty} - L_{\text{max}})/10}
$$
 (E-14a)

or

$$
d_{\lambda} = d_0 \cdot 10^{(L_{E,\infty}-L_{max})/10} \text{ with } d_0 = \frac{2}{\pi} \cdot V_{\text{ref}} \cdot t_{\text{ref}}
$$
 (E-14b)

Replacing d_p by d_λ in equation E-5 and using the definition $q = V\tau$ from **Figure E-1** the parameters a_1 and a_2 in equation E-9 can be written (putting $q = q_1$ at the start-point and $q - \lambda = q_2$ at the endpoint of a flight path segment of length λ) as

$$
a_1 = \frac{-q_1}{d_\lambda} \text{ and } a_2 = \frac{-q_1 + \lambda}{d_\lambda} \tag{E-15}
$$

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

Appendix F

Database for road traffic source

This appendix presents the database for most of the existing road noise sources to be used to calculate road traffic noise following the method described in 2.2 Road traffic noise.

Table F-1

Table F-2

Table F-3

Coefficients $C_{R,m,k}$ and $C_{P,m,k}$ for acceleration and deceleration

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-----	--

Coefficients $a_{i,m}$ and β_m for road surface

Appendix G

Database for railway source

This appendix presents the database for most of the existing railway noise sources to be used to calculate railway noise following the method described in 2.3 Railway noise.

Table G-1

Coefficients $L_{r,TR,i}$ and $L_{r,VEL,i}$ for rail and wheel roughness

 $\overline{}$

Coefficients *A3,i* **for the contact filter**

Coefficients $L_{H,TR,i}$ $L_{H,VEH,i}$ and $L_{H,VEH,SUP}$ for transfer functions

(Values are expressed in Sound Power Level per axle)

Coefficients *LR,IMPACT,i* **for impact noise**

Coefficients *LW,0,idling* **for traction noise**

(Values are expressed in Sound Power Level per vehicle)

Coefficients $L_{w,0,1}$, $L_{w,0,2}$, α_1 , α_2 for aerodynamic noise

(Values are expressed in Sound Power Level per vehicle (for a vehicle length of 20 m))

Coefficients *Cbridge* **for structural radiation**

Appendix H

Database for industrial source

This appendix presents a few examples for input values for some industrial noise sources that may be used to calculate industrial noise following the method described in 2.4 Industrial noise. As industrial noise sources are extremely specific for each industrial site, appropriate values are obtained from local, national or international databases or measurements as appropriate.

Table H-1

Coefficients L_{W} , $L_{W'}$ and $\Delta L_{W,dir,xyz}$ (*x, y, z*) for sound power

 $\Delta L_{w,dir,xyz}$ (x, y, z)=0

 L_{W} is expressed as sound power per metre for line source, or per squared metre for area source.

Appendix I

Database for aircraft source — NPD data

This appendix presents the database for most of the existing aircraft noise sources to be used to calculate aircraft noise following the method described in 2.6 Aircraft noise.

Table I-1

Aerodynamic coefficients

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Table I-2

Aircrafts

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Table I-3

Default approach procedural steps

Table I-4 (part 1)

Default departures procedural steps

Table I-4 (part 2)

Default departures procedural steps

Table I-4 (part 3)

Default departures procedural steps

Table I-4 (part 4)

Default departures procedural steps

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Table I-5

Default fixed points profiles

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Table I-6

Default weights

Table I-7

Jet engine coefficients

Table I-8

Propeller engine coefficients

ACFT_ID	Thrust rating	Propeller Efficiency	Installed Net Propulsive Power (hp)
BEC58P	MaxClimb	0,90	261,3
BEC58P	MaxTakeoff	0,90	310,0
CNA172	MaxClimb	0,69	140,0
CNA172	MaxTakeoff	0,67	155,0
CNA182	MaxClimb	0,78	189,8
CNA182	MaxTakeoff	0,75	222,4
CNA206	MaxClimb	0,77	234,0
CNA206	MaxTakeoff	0,70	300,0
CNA20T	MaxClimb	0,77	238,0
CNA20T	MaxTakeoff	0,69	310,0
CNA441	MaxClimb	0,90	620,0
CNA441	MaxTakeoff	0,90	635,5
CVR580	MaxClimb	0,85	3 3 4 4 , 0
CVR580	MaxTakeoff	0,85	3 800,0
DC3	MaxClimb	0,85	1 1 3 0 , 0
DC3	MaxTakeoff	0,85	1 302,0
DC ₆	MaxClimb	0,90	1 750,0
DC6	MaxTakeoff	0,90	1 900,0
DHC ₆	MaxClimb	0,90	557,5
DHC ₆	MaxTakeoff	0,90	587,0
DHC6QP	MaxClimb	0,90	557,5
DHC6QP	MaxTakeoff	0,90	587,0
DHC7	MaxClimb	0,90	846,0
DHC7	MaxTakeoff	0,90	940,0
HS748A	MaxClimb	0,90	1 805,0
HS748A	MaxTakeoff	0,90	2 006,0
L188	MaxClimb	0,90	3 180,0
L188	MaxTakeoff	0,90	3 460,0
PA30	MaxClimb	0,80	130,5
PA30	MaxTakeoff	0,80	139,5
SD330	MaxClimb	0,90	972,0
SD330	MaxTakeoff	0,90	1 080,0
SF340	MaxClimb	0,90	1 587,0
SF340	MaxTakeoff	0,90	1 763,0

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Noise power distance data (NPD data)

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Spectral classes

Table I-10

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GASEPF and GASEPV data

Table I-11

GASEPF and GASEPV aircraft types

(the associated spectral data are available in the ANP 'Spectral Classes' table)

Table I-12

Departure and Arrival flight profile data for GASEPF and GASEPV aircraft

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NPD data for GASEPF and GASEPV aircraft

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Aircraft classes data

Aircraft Noise and Performance data for the four classes are presented in the following tables:

Table I-14

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ACFT_ID,C,12	OP_TYPE,C,1	PROF_ID1,C,8 PROF_ID2,C,1		WEIGHT,N,7,0	
P1.0	A	DEFAULT	т	100	
P _{1.0}	D	DEFAULT		100	
P _{1.1}	A	DEFAULT 1		100	
P _{1.1}	D	DEFAULT 1		100	
P1.2	A	DEFAULT 1		100	
P1.2	D	DEFAULT 1		100	
P1.3	A	DEFAULT	1		
P _{1.3}	D	DEFAULT		100	

Arrival and Departure flight profile data for P 1.0, P 1.1, P 1.2, P 1.3 aircraft classes

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NPD data for P 1.0, P 1.1, P 1.2, P 1.3 aircraft classes

NOISE_ID, C ₁₂	NOISE TYPE,C,1	OP_MODE, C ₁	THR_SET, N, 9, 2	$L_200,N,5,1$	$L_400,N,5,1$	$L_630,N,5,1$	L_{1000} , N, 5, 1	L_{2000} N, 5, 1	$L_4000,$ N, 5, 1	L 6300, N, 5, 1	$L_10000,$ N, 5, 1	L 16000, N, 5, 1	L 25000, N, 5, 1
P1.0	M	A	30	55,2	49	44,8	40,4	33,6	26,3	21,2	15,6	9,3	2,8
P1.0	M	A	70	65,2	59	54,8	50,4	43,6	36,3	31,2	25,6	19,3	12,8
P1.0	M	D	88	71,2	65	60,8	56,4	49,6	42,3	37,2	31,6	25,3	18,8
P1.0	M	D	100	75,2	69	64,8	60,4	53,6	46,3	41,2	35,6	29,3	22,8
P1.0	S	A	30	54,7	51,4	49,1	46,7	42,8	38,4	35,2	31,4	27,1	22,3
P1.0	S	A	70	64,7	61,4	59,1	56,7	52,8	48,4	45,2	41,4	37,1	32,3
P1.0	S	D	88	70,7	67,4	65,1	62,7	58,8	54,4	51,2	47,4	43,1	38,3

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Helicopter Noise and Performance Data Set 1

This includes data for five helicopters classes, based on helicopter MTOM:

Table I-18

Helicopter Data Set 1 Description Table

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Helicopter Data Set 1 Departure Profiles

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Helicopter Data Set 1 Ar rival Profiles

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Noise Characteristic data for Helicopter Data Set 1

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Noise Power Distance (NPD) data for Helicopter Data Set 1

Helicopter Noise and Performance Data Set 2

Data is provided for three helicopter classes, based on maximum take-off mass:

- 1. Light helicopter (LHEL) MTOM < 3 000 kg
- 2. Medium helicopter (MHEL) 3 000 kg < MTOM < 6 000 kg
- 3. Heavy helicopter (THEL) MTOM > 6 000 kg

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Default arrival and departure flight profiles are provided as fixed point profiles. Default departure flight profiles assume climb to a level flight altitude of 1 000 ft (305 m) for each helicopter class. Where the level flight portion on departure or arrival differs locally from these values, it is recommended that the default profiles are adapted to reflect local circumstances.

Table I-23

Helicopter Data Set 2 Description Table

Table I-24

Helicopter Data Set 2 Departure Profiles

Helicopter Data Set 2 Ar rival Profiles

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Noise Characteristic data for Helicopter Data Set 2

NOISE_ID	THRSET TYP	MODEL TYPE	SPECT APP	SPECT DEP	SPECT AFB
LHEL			215	109	
MHEL			215	109	
THEL			215	109	

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Table I-27

Noise Power Distance (NPD) data for three helicopter classes

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