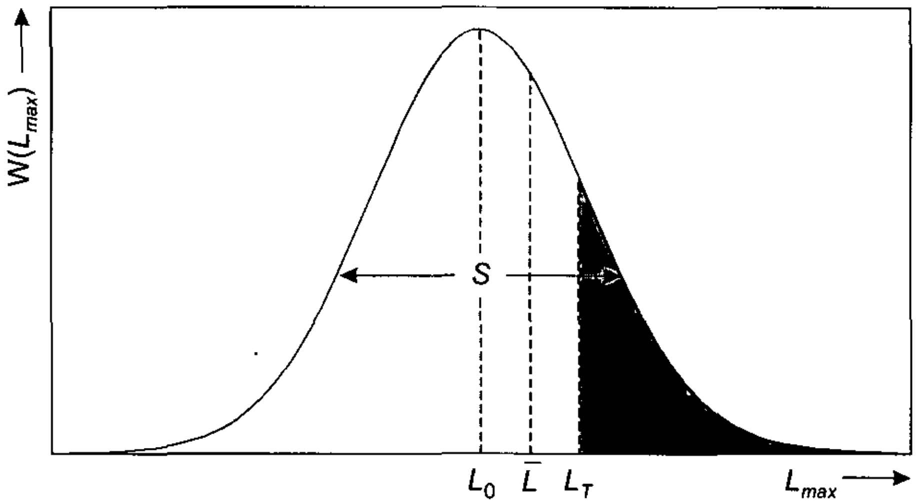

Figure 5-1. Maximum sound level distribution

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Chapter 6

CALCULATION OF NOISE CONTOURS

6.1 STANDARD GRID CALCULATION AND REFINEMENT

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

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

1) Define a refinement threshold difference ΔL_R for the noise index.

2) Calculate the basic grid for a spacing Δ_G .

3) Check the differences ΔL of the index values between adjacent grid nodes.

4) If there are any differences $\Delta L > \Delta L_R$, define a new grid with a spacing $\Delta_G/2$ and estimate the levels for the new nodes in the following way:

   If $\begin{cases} \Delta L \leq \Delta L_R \\ \Delta L < \Delta L_R \end{cases}$

   calculate the new value

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

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

6) Estimate the contours by linear interpolation.

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

6.2 USE OF ROTATED GRIDS

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

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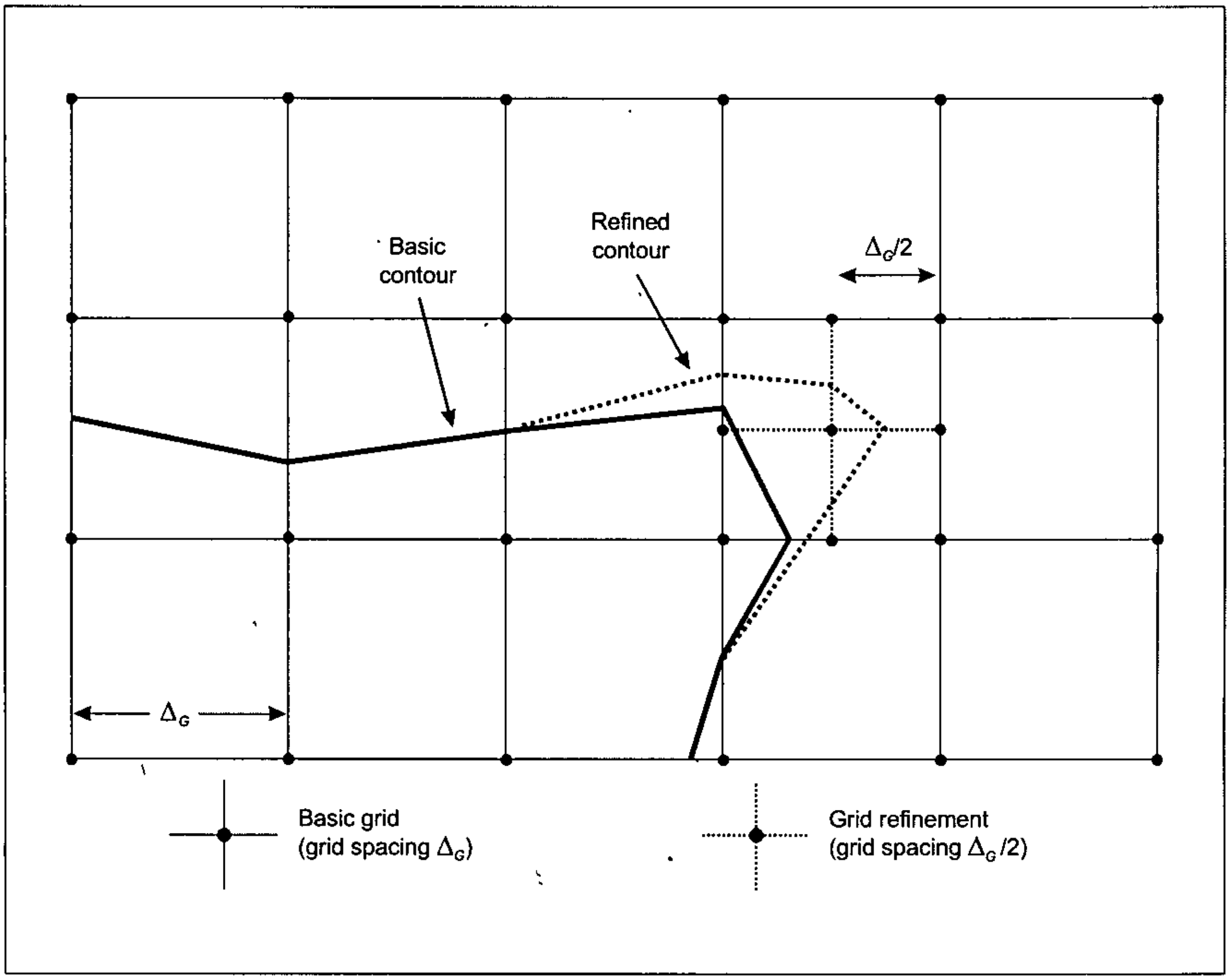

Figure 6-1. Standard grid and grid refinement

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

6.3 TRACING OF CONTOURS

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

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

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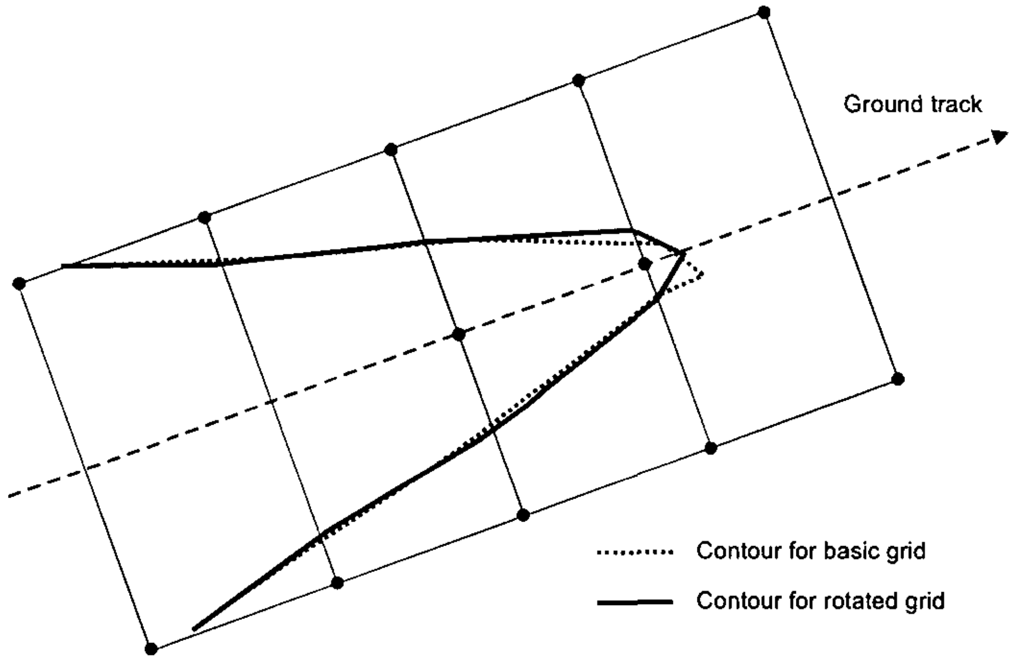

Figure 6-2. Use of a rotated grid

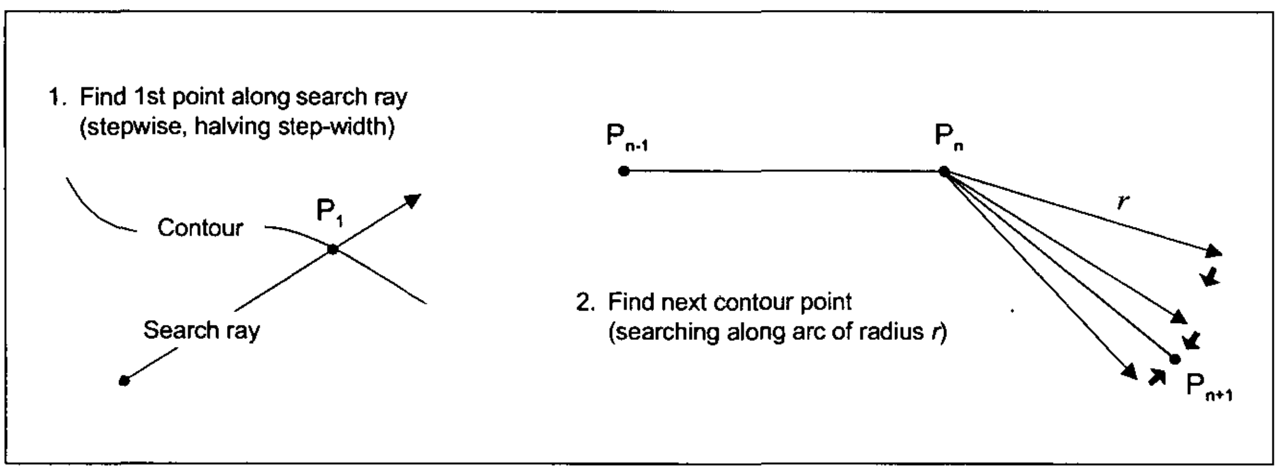

Figure 6-3. Concept of tracing algorithm

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

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

a) The length of the chord Δc (the distance between two contour points) should be within an interval $[\Delta c_{min}, \Delta c_{max}]$, e.g. [10 m, 200 m].

b) The length ratio between two adjacent chords of lengths Δc_n and Δc_{n+1} should be limited, e.g. $0.5 < \Delta c_n / \Delta c_{n+1} < 2$.

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

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

where ϕ_n is the difference in the chord headings.

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

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

6.4 POST-PROCESSING

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

a) interpolation and, if necessary, smoothing of noise contours (if the index was estimated for a grid);

b) performing grid operations such as merging, adding, subtracting or converting;

c) plotting (including representation of contours, runways, tracks, specific observer locations and/or topography); and

d) integration of noise data into geographic information systems (GIS) (e.g. to estimate enclosed population numbers).

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

a) NMPLOT: this programme is designed for viewing and editing geo-referenced data sets such as noise data stored in grids; and

b) GIS software, such as ESRI ArcView or MicroStation GeoGraphics (usually commercial software).

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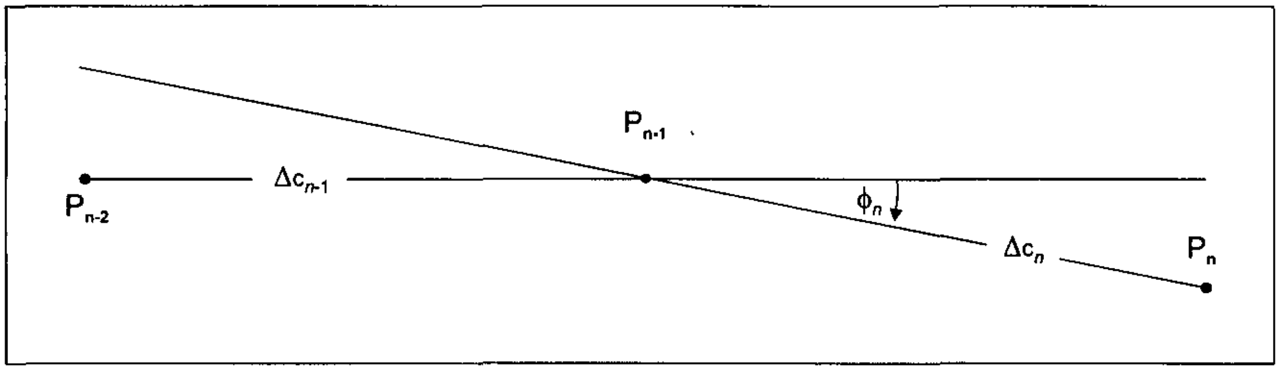

Figure 6-4. Geometric parameters defining conditions for the tracing algorithm

6.4.3 Data formats which are widely used are:

a) ArcView shapefile format;

b) AutoCAD data exchange format DXF;

c) Intergraph and MicroStation standard file format ISFF (also known as DGN); and

d) Noise model grid format (NMGF). The NMGF format was originally developed for use in conjunction with different noise models. It is used by NMPLOT.

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

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Appendix A

NOISE INDICES IN USE IN ICAO CONTRACTING STATES

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

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

$$L_{DEN} = 10\log(1/24)\times\left[12\times10^{L_D/10} + 4\times10^{(L_E+5)/10} + 8\times10^{(L_N+10)/10}\right]$$

where L_D, L_E and L_N are the equivalent continuous A-weighted sound pressure levels[1] over, respectively, the 12-hour daytime period 0700 to 1900 hours, the 4-hour evening period 1900 to 2300 hours and the 8-hour night period 2300 to 0700 hours[2].

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

$$L_{DN} = 10\log(1/24)\times\left[15\times10^{L_D/10} + 9\times10^{(L_N+10)/10}\right]$$

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

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

$$L_{Aeq} = 10\log\left[(1/t_{eq})\int_0^{t_{eq}} 10^{L_A(t)/10}dt\right]$$

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

---

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

$$L_{A,eq,T} = 10\log\left\{\left[1/(t_2-t_1)\right]\times\int_{t_1}^{t_2}\left[p^2{}_A\left(t/p^2{}_0\right)\right]dt\right\}$$

   where LA,eq,T is the equivalent continuous A-weighted sound pressure level determined over a time interval T starting at t_1 and ending at t_2. pA(t) is the instantaneous A-weighted sound pressure of the sound signal and p0 is the reference sound pressure (20 μPa).
2. The LDEN time periods are different in the United States: the 12-hour daytime period 0700 to 1900 hours, the 3-hour evening period 1900 to 2200 hours and the 9-hour night period 2200 to 0700 hours.

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4. NOISE EXPOSURE FORECAST, NEF

$$NEF = 10\log\sum_{i}\sum_{j}10^{NEF_{ij}/10}$$

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

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

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

5. NOISE EXPOSURE INDEX, B

$$B = 20\log\sum_{i}\left[n\left(10^{L_P/15}\right)\right] - 157$$

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

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

$$WECPNL = \left(10\log\left[(1/n)\sum_{i}10^{L_i/10}\right] + 10\log N\right) - 27$$

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

7. AUSTRALIAN NOISE EXPOSURE FORECAST, ANEF

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

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

where, in turn $\mathbf{L_{EPNij}}$ is the EPNL at the observation point considered for the aeroplane and flight path concerned, $\mathbf{n_{Dij}}$ is the number of operations during the 11-hour day (0700 to 1900 hours) and $\mathbf{n_{Nij}}$ is the number during the 12-hour night (1900 to 0700 hours).

8. APPLICATION OF EPNL-BASED INDICES

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

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Appendix B

APPROXIMATE METHODS FOR DETERMINING EFFECTIVE PERCEIVED NOISE LEVEL (EPNL)

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

a) Approximation by use of PNL derived from octave band measurements

Use the sound pressure level in each octave band as given in step 1 of Annex 16, Volume I, 4 2 1 and for step 2, use the factor 0 3 instead of 0 15 Omit the "Correction for Spectral Irregularities" given in Annex 16, Volume I, 4 3 For approximate tone corrections, see Table B-1 (from PNL to PNLT)

b) Approximation by D- and A-weighted overall sound pressure level

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

1) equal to the inverse of the 40 noy curve as described in Annex 16, Volume I, Appendix 5, Table A5-1 or

2) equal to the A-weighting as defined in International Electrotechnical Commission (IEC) Publication 179 [1]

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

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

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

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

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

Note — It is realized that the exact correction constant depends on such factors as aeroplane type, operational characteristics, meteorological conditions and the distance from the aeroplane flight path The figures in the Table B-1 are based on a considerable number of observations In one study, the correction constant was found to range from 13 to 8 for obtaining PNL from dB(A) and from 8 5 to 4 from dB(D) respectively, the higher value being for a distance of 500 m from the flight path, the lower for 3 500 m In another study[2] more than 4 000 flyovers measured in an area within a 19 3 km radius of an aerodrome, the following standard deviations for constants were found (see Table B-2)

Table B-2. STANDARD DEVIATIONS FOR K VALUES

PNL from		PNLT from	
dB(A)	dB(D)	dB(A)	dB(D)
2 2	1 8	3 0	2 6

2. APPROXIMATION TO OBTAIN DURATION CORRECTION D

An approximation to the duration allowance is given by the expression

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

where

T(0) is a normalizing constant of 20 s, and *[t(2) – t(1)]* is the time interval during which a recording of PNLT (or an approximation thereto) is within 10 dB of its maximum value If the maximum value is less than 10 dB above the background level (or other limiting value such as that recommended in Annex 16, Volume 1, Appendix 1, 4 5), the time it exceeds the background level or other limiting value is taken into account

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

2 W K Connor, Community Reactions to Aircraft Noise Measurements, in *Progress of NASA Research Relating to Noise Alleviation of Large Subsonic Jet Aircraft*, National Aeronautics and Space Administration, Washington D C , 1968 (NASA SP-189)

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Appendix C

FLIGHT PERFORMANCE CALCULATIONS

1. TERMS AND SYMBOLS

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

1.1 Terms

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

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