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RECOMMENDED METHOD FOR COMPUTING NOISE CONTOURS AROUND AIRPORTS

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and published under his authority

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Foreword

The material for this circular was developed by the Committee on Aviation Environmental Protection at its first meeting held in Montreal in June 1986. It is intended to assist States in the computation of noise contours around airports. The scope of this circular is explained in Chapter 2.

The issuance of this circular was approved by the Council on 11 March 1987.

Comments on the contents of this circular, particularly with respect to its application and usefulness, would be appreciated from all States. These comments will be taken into account in the preparation of subsequent editions. Comments concerning this document should be addressed to:

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Chapter 1

Introduction

1.1 The noise at points on the ground from aeroplanes flying into and out of a nearby airport depends on a number of factors. Principal among these are the types of aeroplanes and their powerplants; the power, flap and airspeed management procedures used on the aeroplanes themselves; the distances from the points concerned to the various flight paths; and local topography and weather, affecting sound propagation. Airport operations generally include different types of aeroplanes, various flight procedures and a range of operational masses. Because of the large quantity of aeroplane-specific data and airport operational information that would be required to compute the noise of each individual operation, it is customary in airport noise studies to make certain simplifications, leading to estimates of noise index values which are averages over long periods of time, typically several months. Calculations are usually repeated at each of a series of points around the airport and then interpolations are made to trace lines of equal noise index values (noise "contours") which are used for study purposes.

1.2 In view of the large number of variables involved and the simplifications usually made in the calculations, it is desirable to recommend a single procedure for computing airport noise contours. The aim of this document is to provide an outline for such a recommended method, identifying the major aspects and supplying specifications in respect of each. An explanation of terms is given, covering those terms where confusion might arise. A complication is that the calculation method has to allow for the use of different noise descriptors as bases for national noise indices. Given this proviso, the method of calculation described should allow States to compute noise contours which are consistent with one another.

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

Chapter 2

Scope

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

Chapter 3

Explanation of Terms and Symbols

3.1 DEFINITIONS OF TERMS

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

Extra noise attenuation (lateral attenuation). Additional attenuation of noise in propagation away from the aeroplane, over and above that included in the noise-power-distance data, deriving from all the effects of non-ideal conditions. The causes include absorption of sound in transmission over a partially absorptive surface and source installation effects.

Flight path. The path of an aeroplane through the air, defined in three dimensions, usually with reference to an origin at the start of take-off roll or at the landing threshold.

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

Flight track (or ground track). The vertical projection of the flight path onto the ground plane.

Format of aeroplane noise and performance data. The framework or skeleton according to which data are to be derived and presented.

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

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

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

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

3.2 SYMBOLS

Noise

L_A	A-weighted sound pressure level
L_{Amax}	maximum value of L_A
L_{AE}	sound exposure level
L	L_{Amax} or L_{AE}, under conditions identified by means of a subscript (see Chapter 6)
L_p	1/3-octave band sound pressure level
p	sound pressure
t	time
$G(\ell)$	overground lateral attenuation
$\Lambda(\beta)$	air-to-ground lateral attenuation

Aeroplane performance

p	take-off coefficient
Q	flight speed coefficient
R	climb/descent coefficient
X_N	net thrust, all engines
$\boldsymbol{X}_N$	net thrust averaged over segment
γ	climb angle
RC	rate of climb
W	aeroplane weight
M	aeroplane mass
V	aeroplane speed
V	aeroplane speed averaged over segment
v_w	wind velocity (head wind positive)
f	acceleration factor
f_w	wind factor
s	horizontal distance over a flight path segment
h	aeroplane height
g	gravitational acceleration
h_p	pressure-altitude

Atmosphere

ISA	International Standard Atmosphere
T	ambient air temperature
p	ambient air pressure
ϱ	ambient air density
Θ	T/T_0
δ	P/P_0
σ	ϱ/ϱ_0 (also δ/Θ)

Engine noise-related thrust parameters

E_ξ	thrust/noise constant
F_ξ	flight speed coefficient
G_ξ	altitude coefficient
H_ξ	temperature coefficient
C_{M_t}	propeller tip rotational Mach number coefficient
A_v	noise constant
B_v	thrust coefficient
c_v	speed-altitude coefficient
Y	second order engine speed coefficient
ξ	representation for parameters X_N/δ, $N\sqrt{\Theta}$, SHP/$\delta\sqrt{\Theta}$ or N_p
$\Delta\xi$	difference in ξ due to temperature difference representing parameters $\Delta X_N/\delta$ or ΔSHP/$\delta\sqrt{\Theta}$
M_t	propeller tip rotational Mach number
N	low pressure rotor speed or fan speed
N_p	propeller rotational speed
SHP	shaft horse power
v	representation for parameters $N/\sqrt{\Theta}$, SHP/$\delta\sqrt{\Theta}$, EIS

Engine indicators

EIS	engine indicator setting
EPR	engine pressure ratio
EPD	engine pressure difference

Subscripts

L	take-off roll directivity
T	aeroplane turn
r	reference conditions
g	take-off roll
AP	approach
CL	climb
FR	flap retraction
TO	take-off
TAS	true airspeed
EAS	equivalent airspeed

Mathematical and algebraic quantities

log	logarithm to base 10
Δ	change in value of a quantity, or a correction (as indicated in the text)
d	perpendicular distance from an observation point to the flight path (slant distance or slant range)
ℓ	perpendicular distance from an observation point to the ground track
β	angle of elevation from an observation point to a point on the flight path
s	standard deviation
r	radial distance
ϕ	angle from the aeroplane ground track to a radial passing through an observation point
ψ	angle of turn of an aeroplane ground track.

Chapter 4

Calculation of Contours

4.1 SUMMARY AND APPLICABILITY OF THE METHOD

Note.— Noise indices which involve the perceived noise level or the effective perceived noise level can be derived from measurements of frequency-weighted noise level by use of the appropriate methods given in Appendix B.

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

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

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

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

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

4.1.3 The noise levels from individual movements are calculated, for given atmospheric conditions, from noise-power-distance and aeroplane performance data (see 5.2.5). The conditions for the noise data are defined by atmospheric attenuation rates, for which the yearly averages drawn from several major world airports are assumed. The performance data are for defined atmospheric temperature and humidity, airport altitude and wind speed. However, given that the calculated noise contours depict long-term averages, the same basic data are assumed to apply over specified ranges of conditions. The form of presentation, methods of derivation and reference conditions for the aeroplane data are given in Chapter 5.

4.1.4 The specification for noise data in Chapter 5 includes two noise descriptors. These are the maximum A-weighted sound pressure level occurring at some instant during an aeroplane movement, and the sound exposure level, which is the level of an integral with time of the square of the A-weighted sound pressure during the aeroplane movement (see 5.1.2). The two descriptors selected are believed to be sufficient to permit the calculation of most noise indices in use within ICAO Contracting States, either directly or with the use of empirical adjustments. The formulations for different noise indices are given in Appendix A. The summation process for noise levels from individual aeroplane movements and interpolation of noise index values for contour plotting are computer-programming matters only and are left to the discretion of the user.

4.2 INPUT INFORMATION REQUIREMENTS

For an airport noise study, the organization making the calculation will require the following information:

a) the aeroplane types which operate from the airport;

b) noise and performance data for each of the aeroplane types concerned, supplied in accordance with the specifications of Chapter 5;

c) the routes followed by arriving and departing aeroplanes;

d) the numbers of movements on each route within the period chosen for the calculations;

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

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

4.3 NOISE FROM INDIVIDUAL AEROPLANE MOVEMENTS

4.3.1 For a movement on an arrival or departure route, aeroplane positional information and corrected engine thrusts are computed throughout the various flight operational segments (see Chapter 5). From a selected point (co-ordinates x,y) on a grid arranged on the ground around the airport, the shortest distance to the flight path is calculated and the noise data (L) are interpolated for the distance (d) and thrust (ξ) concerned (see Chapter 6). The aeroplane positional information should allow for some lateral displacement of the actual ground track in a particular case, relative to the nominal route, due to inexact track-keeping which occurs in practice. Corrections are applied (see Chapter 6) for extra attenuation of sound during propagation lateral to the direction of aeroplane movement (Λ), for directivity behind the start of take-off ground roll (Δ_L) and, in the case of the sound exposure level, for aeroplane speed (Δ_V) and changes in the duration of the highest noise levels where an aeroplane makes a turn in its flight path (Δ_T). Hence the noise level at the point on the grid, from the individual aeroplane movement, $L(x,y)$, is derived. The calculation is expressed in mathematical symbols as follows:

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

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

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

Chapter 5

Aeroplane Noise and Performance Data

5.1 NOISE-POWER-DISTANCE DATA

5.1.1 *Form of presentation*

The noise data should cover a range of noise-related thrust parameter values and perpendicular distances to the flight path. For each noise-related thrust parameter value from approach to take-off, the data should be given in numerical tabular form, as illustrated in Figure 5-1. In addition, a graphic presentation may be used for reference. The following information should also be provided:

Aeroplane: ____________
Engines: ____________
Configuration — flap angle: ____________
— slat angle: ____________
— landing gear up/down: ____________
Engine thrust — parameter specified: ____________
— "corrected" parameter value: ____________
Aeroplane mass: ____________
Airspeed: 160 kt

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

The physical quantity selected for the noise-related thrust parameter should be directly compatible with that presented in the performance information (see 5.2). Typical parameters are, amongst others, corrected net thrust, fan speed, propeller speed and shaft horse power.

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

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

Slant distance (m)	1 000	1 250	1 600	2 000	2 500	3 150	4 000	5 000	6 300	8 000
L_{Amax} *(dB)*										
L_{AE} *(dB)*										

Note.— All noise levels are to be normalized to conform with the attenuation rates of Table 5-1.

Figure 5-1. Format of noise data

5.1.2 *Noise descriptor*

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

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

$$L_{AE} = 10 \log \{(1/t_0) \int_{t_1}^{t_2} [p_A^2 (t)/p_0^2]\, dt\}$$

where $p_A(t)$ is the instantaneous A-weighted sound pressure, $(t_2\text{-}t_1)$ is a stated time interval long enough to encompass all significant sound of a stated event, p_0 is the reference sound pressure (20 μPa) and t_0 is the reference duration (1 s).

5.1.3 *Noise data envelope*

The envelope of the noise data should contain:

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

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

5.1.4 *Data derivation*

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

For the computation of L_{Amax} and L_{AE}, measured aeroplane sound data are reduced to 1/3-octave band sound pressure levels in decibels relative to a reference pressure of 20 μPa. Sound pressure levels are obtained, for the 24 1/3-octave bands with centre frequencies ranging from 50 Hz to 10 000 Hz, at 0.5 s intervals throughout the duration of each flyover sound recording. After correction for instrument calibrations and background noise contamination, the measured 1/3-octave band sound pressure levels are adjusted to conform with the attenuation rates of Table 5-1.

For many jet- and propeller-powered aeroplanes, the preferred nominal flight altitude for noise measurements is of the order of 300 m (1 000 ft) for each engine power setting. However, practicality often results in the measurement altitude being different for each aeroplane type and may range from 100 m (330 ft) to 800 m (2 625 ft). This range of altitude encompasses those normally encountered in noise certification compliance demonstrations.

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

Table 5-1. Attenuation rates

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

a) *Type 1 data — full spectral time history*

1) Adjust measured data to conform with the attenuation rates of Table 5-1.

2) For source-to-observation distances of 800 m or less, establish noise-power-distance relationships at selected distances (see, for example, Figure 5-1) by extrapolation of the full time history pattern to obtain L_{Amax} and by performing time integration to obtain sound exposure level, L_{AE}, the "integrated" method of adjusting data (see Annex 16, Volume I, Appendix 2, Section 9.4). The atmospheric attenuation rates of Table 5-1 are used as references.

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

4) For distances, d, greater than 800 m, compute L_{Amax} for the adjusted spectral data, using the 800 m data as reference, by accounting for spherical divergence and atmospheric attenuation according to Table 5-1. L_{AE} for the new distance is determined by adding a 7.5 dB/decade duration factor for distance according to the following relation:

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

Note.— The above procedure is illustrated in Figure 5-2.

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

1) Adjust measured spectral data corresponding to L_{Amax} to conform with the attenuation rates of Table 5-1.

2) For the measurement distance define the sound exposure level, L_{AEr}, the maximum value of A-weighted sound pressure level, L_{Amaxr}, and the

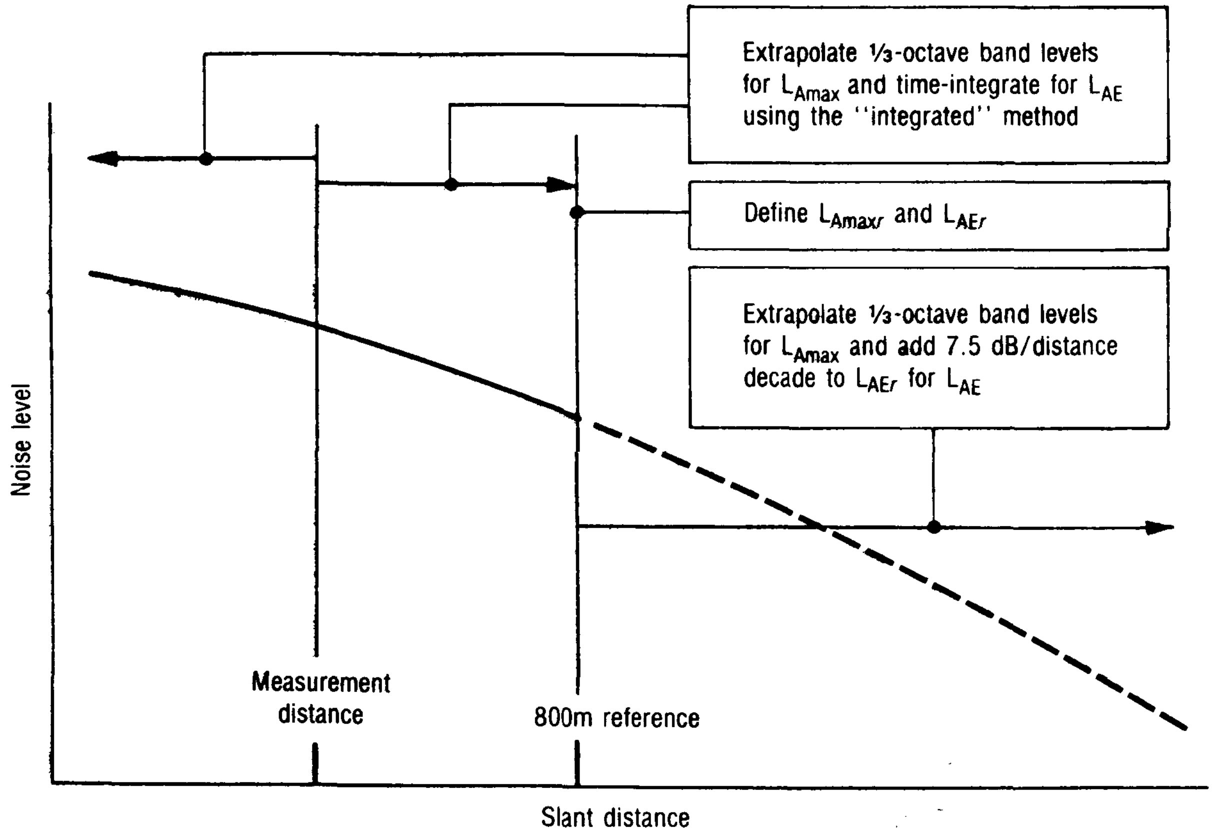

Figure 5-2. Development of noise-versus-distance data from Type 1 measurements (attenuation rates from Table 5-1 throughout)

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

3) For distances, d, other than the measurement distance, d_r, compute L_{Amax} for the adjusted spectral data by accounting for spherical divergence and atmospheric attenuation according to Table 5-1. L_{AE} for the new distance is determined from the following relation:

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

Note.— The above procedure is illustrated in Figure 5-3.

5.1.5 *Range of atmospheric conditions for data validity*

Experience in estimating airport noise levels and comparison of the estimates with measured data has led to the establishment of an envelope of near-surface long-term average conditions, within which noise-power-distance data obtained in accordance with the procedures of 5.1.4 above can be assumed to be applicable. This envelope is defined as follows:

— air temperature less than 30°C;

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

— wind speed less than 8 m/s (15 kt).

The acceptable envelope for average local conditions defined above is believed to encompass conditions encountered at most of the world's major airports. For situations

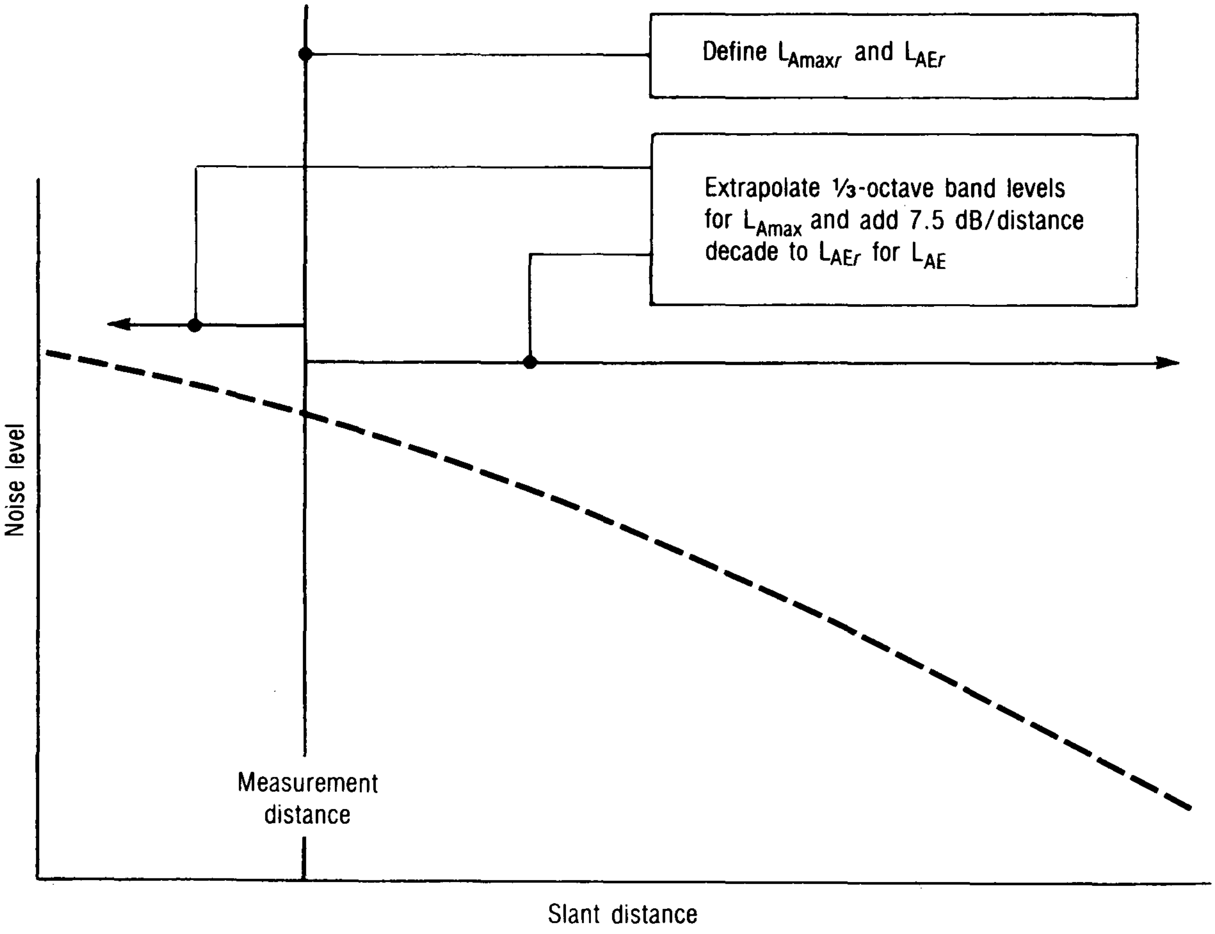

Figure 5-3. Development of noise-versus-distance data from Type 2 measurements (attenuation rates from Table 5-1 throughout)

where average local conditions fall outside the noted envelope, it is suggested that the relevant aeroplane manufacturers be consulted.

5.2 PERFORMANCE DATA

5.2.1 *Form of presentation*

Aeroplane flight profiles are required in order to allow the determination of slant distances from the observation points to the flight paths. The variations of engine thrust, or other noise-related thrust parameter, and aeroplane speed along the flight path are also required (see 5.1). The slant distances and thrusts are then used for entry into and interpolation of the noise-power-distance data. For purposes of noise contour computations, take-off and approach flight paths are assumed to be represented by a series of straight-line segments, as illustrated in Figure 5-4. The ground tracks of the aeroplane are also represented by straight-line segments and arcs of circles.

Flight profiles, engine thrusts and aeroplane flight speeds might be supplied directly for an aeroplane type undergoing reference flight procedures (see 5.2.2). Then, for operations at an airport where the actual procedures in use are unknown, these reference procedures can be assumed. The information for other procedures known to be used, or for different operating conditions of the aeroplane, can be calculated using aerodynamic and thrust equations. The equations contain coefficients and constants which should also be made available for each combination of engine and aeroplane (see 5.2.3). The equations themselves are set out in Appendix C.

5.2.2 *Reference flight procedures*

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

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

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

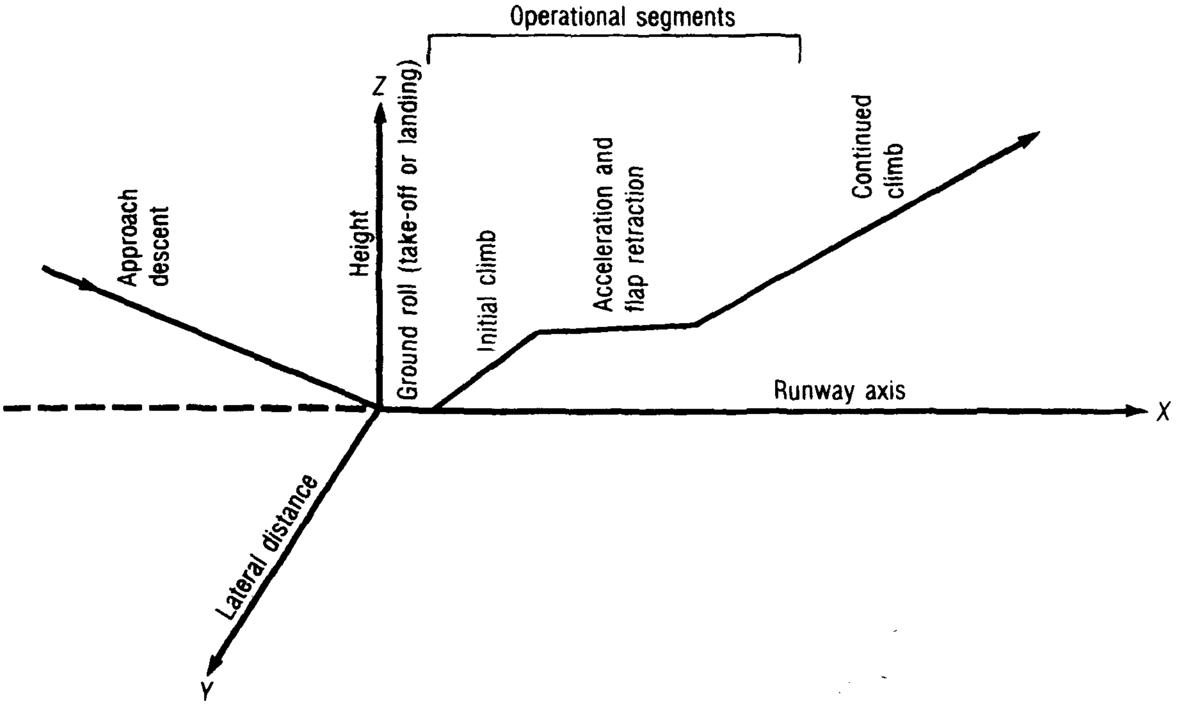

Figure 5-4. Typical flight-path segments for performance calculations

5.2.3 *Characteristic aerodynamic and thrust/noise coefficients*

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

P Take-off coefficient

Q Flight speed coefficient

R Climb/descent coefficient

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

E_ξ Thrust/noise constant

F_ξ Flight speed coefficient

G_ξ Altitude coefficient

H_ξ Temperature coefficient

C_{M_t} Propeller-tip Mach-number coefficient

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

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

A_v Noise constant

B_v Thrust coefficient

C_v Speed/altitude coefficient

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

5.2.4 *Derivation of coefficients*

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

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

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

5.2.5 *Performance reference conditions*

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

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

5.2.6 *Envelope of conditions for performance data validity*

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

- air temperature less than 30°C;
- any runway altitude, provided the temperature and altitude are within the engine flat-rating range;
- wind speed less than 8 m/s (16 kt); and
- all practical operational aeroplane masses.

Chapter 6

Calculation of Noise from Individual Aeroplane Movements

6.1 CALCULATION GRID

The noise contours are obtained by interpolation of discrete values of the noise index, resulting from a given traffic pattern, at the intersection points of an observation grid centred on the airport. The choice of spacing of the grid points determines the extent to which fluctuations of the noise index are taken into account. This is especially important where sharp changes occur in the noise contours (see circled areas in Figure 6-1).

Interpolation errors are minimized by a close grid spacing, but the cost of computer running time is increased through the greater number of points to be covered. A maximum value of about 300 m for the grid spacing constitutes a good compromise. This maximum value will ensure, in addition to a high level of accuracy (standard deviation less than 0.5 dB for low- and medium-noise contours), good comparability in the results of the contour plotting, even when linear interpolation between the discrete noise index values is used to locate the contours.

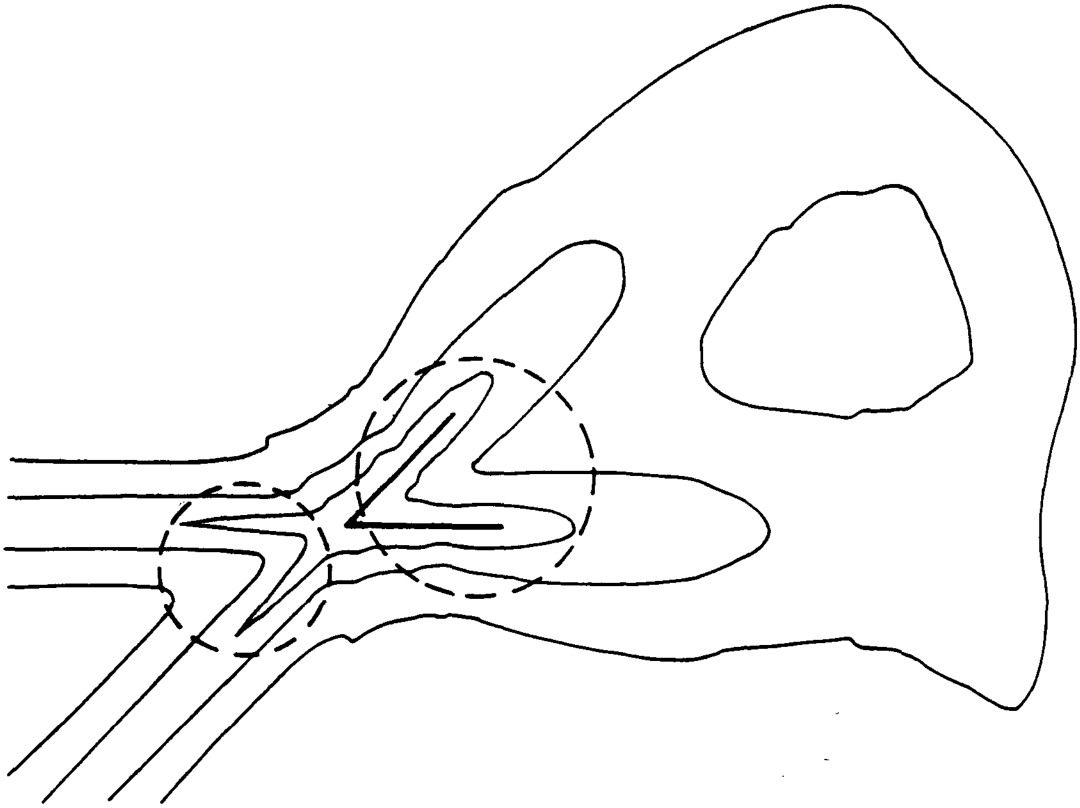

Figure 6-1. Typical noise contours, showing zones where a small grid spacing might be needed

For specific needs or for the plotting of noise contours located in zones close to the runways and the flight paths (see Figure 6-1) small values of the grid spacing should be chosen in order to obtain the desired level of accuracy.

6.2 MODELLING OF LATERAL DISPERSION ACROSS NOMINAL GROUND TRACKS

6.2.1 *Use of measurements*

Noise contours calculated on the assumption that all aeroplane departure ground tracks follow exactly the nominal routes may be liable to localized errors, due to the effects of the dispersion which occurs in practice. It is recommended that, for greatest reliability, the forms and parameters of the distributions of departure and arrival/departure ground tracks be measured on each route at particular airports.

6.2.2 *Assumptions to be used in the absence of measurements*

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

a) Routes involving turns of less than 45°:

$$\left.\begin{aligned} s(y) &= 0.055\,x - 0.150, \text{ for } 5 \text{ km} < x < 30 \text{ km} \\ s(y) &= 1.5 \text{ for } x > 30 \text{ km} \end{aligned}\right\} \quad (4)$$

b) Routes involving turns of more than 45°:

$$\left.\begin{aligned} s(y) &= 0.128\,x - 0.42, \text{ for } 5 \text{ km} < x < 15 \text{ km} \\ s(y) &= 1.5 \text{ for } x > 15 \text{ km} \end{aligned}\right\} \quad (5)$$

In these expressions, $s(y)$ is the standard deviation and x is the distance from start of roll. All distances are expressed in kilometres. In both cases, linear interpolation can be used to determine the standard deviation between the lift-off point [where $s(y) = 0$] and $x = 5$ km. Routes involving more than one turn should be treated using Equation 5. For arrivals, lateral dispersion can be neglected within 6 km of touchdown. Otherwise, dispersion depends upon each individual runway and aeroplane type.

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

Calculated values of noise indices are not particularly sensitive to the shape of the lateral distribution. The Gaussian form gives the best fit to many observed distributions. Although continuous distributions can be simulated, an approximate model is preferable on grounds of computing cost. As a minimum a 5-point discrete approximation should be used. The accuracy of the 5-point discrete approximation given in Table 6-1 generally gives values within 1 dB of those obtained from a continuous (Gaussian) distribution, and is recommended.

Table 6-1. Proportion of aeroplanes to be assumed following different ground tracks spaced about a nominal track (Y_m = mean track or nominal track as appropriate and $s(y)$ = standard deviation)

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

6.3 DETERMINATION OF THE SHORTEST DISTANCE TO THE FLIGHT PATH

The next step in the calculations is to determine the respective distances from the grid points to the aeroplane flight paths. The symbols used to represent the different distances and angles are shown in Figure 6-2. The perpendicular distance from an observation-grid point, J, to the flight path (the slant distance or range) is given by:

$$d = \sqrt{\ell^2 + h^2 \cos^2 \gamma} \qquad (6)$$

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

6.4 INTERPOLATION OF THE NOISE-POWER-DISTANCE DATA

6.4.1 The noise-power-distance data described in Chapter 5 apply to an aeroplane in straight and level flight with a constant power-setting and reference speed. In operation at an airport the aeroplane may be climbing or descending during the flight segments of interest. However, it

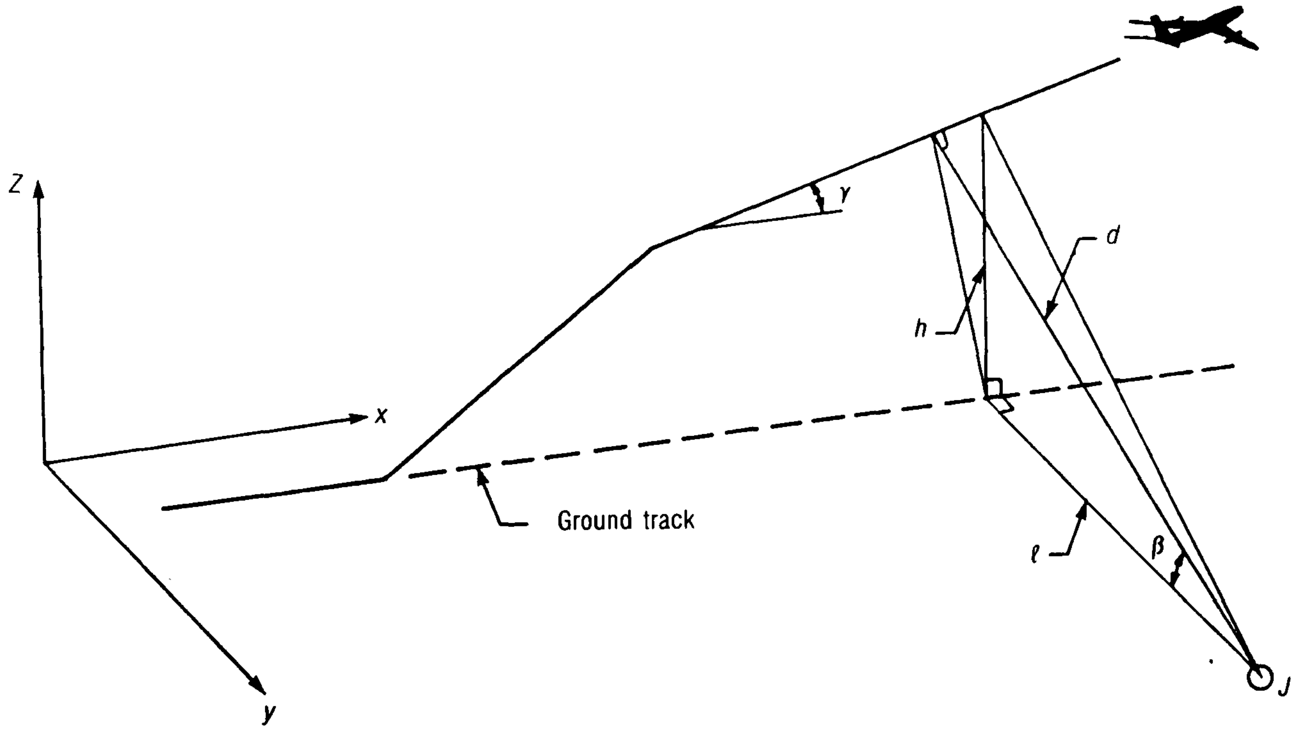

Figure 6-2. Identification of the distances and angles used for calculation of the noise from an aeroplane fly-past

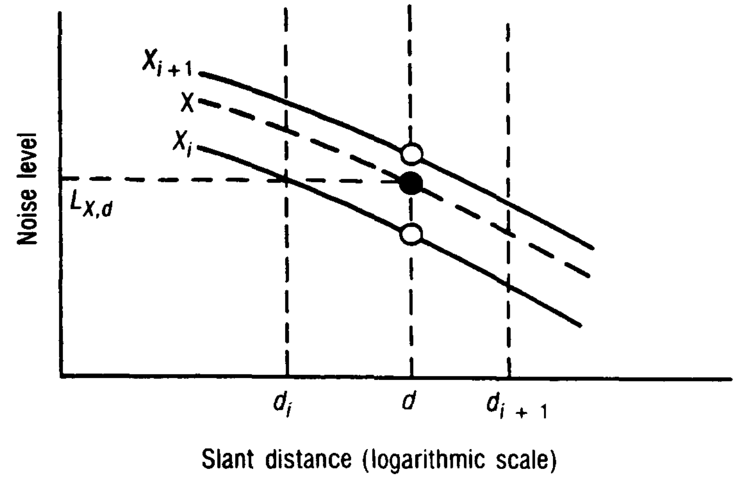

Figure 6-3. Noise-power-distance curves

is assumed that the noise-versus-distance data still properly estimate L_{Amax} or L_{AE}, if the shortest distance to the flight path is considered and the corresponding power-setting and velocity used.

6.4.2 As the tabulated noise-power-distance data points will not normally correspond to the actual power-setting and/or the actual shortest distance relevant to an observation point, it will generally be necessary to estimate the sound level or sound exposure level by interpolation. A linear interpolation is used between tabulated power-settings, whereas a logarithmic interpolation is used between tabulated distances (see Figure 6-3).

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

$$L_X = L_{X_i} + (L_{X_{i+1}} - L_{X_i}) \, [(X - X_i)/(X_{i+1} - X_i)] \quad (7)$$

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

$$L_d = L_{d_i} + (L_{d_{i+1}} - L_{d_i}) \, [(\log d - \log d_i)/ /(\log d_{i+1} - \log d_i)] \quad (8)$$

By using Equations 7 and 8, a noise level $L_{x,d}$ can be obtained for any net thrust X and any distance d that is within the envelope of the reference data base, i.e. use of Equation 7 at d_i and d_{i+1} gives the levels at thrust X, at d_i and d_{i+1}, for use in Equation 8.

6.4.3 The noise levels at certain points on the observation grid will be affected by changes of engine power-setting on the aeroplane. In practice these do not occur instantaneously at the end of individual flight segments, but unless allowance is made in the computations for the smoothness of the aeroplane operation, unrealistic discontinuities are liable to appear in the noise contours. Suitable methods of including allowance for this effect are the definition of a series of short profile segments with small incremental changes in thrust and the inclusion of a smoothing algorithm in the computer program for contour plotting.

6.5 CORRECTION TO THE SOUND EXPOSURE LEVEL FOR AEROPLANE SPEED

Where L_{AE} data are presented, a correction will be necessary where the aeroplane speed differs from the reference speed of 160 kt for which the basic noise-power-distance data have been derived. The correction, Δ_V, is given by the following formula:

$$\Delta_V = 10 \log(V_r/V) \quad (9)$$

where V_r = reference airspeed

V = groundspeed of the relevant flight segment.

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

Note.— In turning flight, further corrections inside and outside the flight track will be required (see 6.8 below).

6.6 LATERAL ATTENUATION

6.6.1 Procedures for determining lateral attenuation for an average aeroplane consist (see Reference 4) of three equations which apply when the aeroplane is on the ground, when the aeroplane is airborne and the lateral (or sideline) distance is greater than 914 m, or when the aeroplane is airborne and the lateral distance is less than 914 m.

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

$$G(\ell) = 15.09 \, [1 - e^{-0.00274\ell}] \text{ for } 0 < \ell < 914 \text{ m} \quad (10)$$

and

$$G(\ell) = 13.86 \text{ for } \ell \geq 914 \text{ m} \quad (11)$$

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

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

$$\Lambda(\beta) = 3.96 - 0.066\beta + 9.9e^{-0.13\beta} \quad (12)$$

for 0° $\leq \beta \leq 60°$, and

$$\Lambda(\beta) = 0 \text{ for } \beta > 60° \quad (13)$$

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

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

$$\Lambda(\beta,\ell) = [G(\ell)][\Lambda(\beta)]/13.86 \qquad (14)$$

where $G(\ell)$ and $\Lambda(\beta)$ are given by Equations 10 to 13.

Note.— Equations 10 to 14 were developed using data from jet-propelled aeroplanes. In the case of propeller-driven aeroplanes, they might be subject to error.

6.7 NOISE DURING THE TAKE-OFF ROLL

6.7.1 Modelling of the noise at ground positions near the airport runway during the take-off roll requires several modifications of the basic noise-power-distance data. The modifications result from the fact that the aeroplane is on the ground accelerating from essentially zero velocity to its initial climb speed, whereas the basic data are representative of overflight operations at constant airspeed. To accommodate these differences, consideration must be given to changes in generated sound resulting from jet relative-velocity effects, varying directivity patterns from the moving aeroplane, the modified effective duration with increased speed and extra attenuation of sound during over-ground propagation at near-zero elevation angles. As yet, insufficient data are available to allow all these effects to be taken fully into account. The present model is applicable to jet aeroplanes and is subject to further development in the light of continuing research. It may be used for propeller-driven aeroplanes until improved methods are developed.

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

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

6.7.4 *Take-off roll noise modelling for jet aeroplanes*

Using the co-ordinate system of Figure 6-4, the noise level behind the start-of-roll point is computed as follows:

a) the radial distance, r, from the start-of-roll position of the aeroplane to an observation point, K, and the angle ϕ in degrees between the radius to K and the runway axis, are determined;

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

For $90° \le \phi < 148.4°$

$$\Delta_L = 51.44 - 1.553\phi + 0.015147\phi^2 - 0.000047173\phi^3 \qquad (15)$$

For $148.4° \le \phi \le 180°$

$$\Delta_L = 339.18 - 2.5802\phi - 0.0045545\phi^2 + 0.000044193\phi^3 \qquad (16)$$

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

$$L_K = L_{X_{TO}} + \Delta_V - G(r) + \Delta_L \qquad (17)$$

where $L_{X_{TO}}$ is the noise level corresponding to distance r and net thrust X_{TO} (at lift-off from the runway) interpolated from the noise-power-distance data, Δ_V is a correction for the difference between a notional 32-kt speed near the start-of-roll and the reference airspeed for which the noise-power-distance data are quoted, $G(r)$ is the lateral attenuation adjustment corresponding to distance r (see 6.6), and Δ_L is the directivity factor determined from Equation 15 or 16 as appropriate.

The noise levels after brake-release, at y-values to the side of the runway during the take-off roll, are also given by Equation 17 except that in this case $\Delta_L = 0$.

Note 1.— Equation 17 applies to the L_{AE} noise descriptor. In the case of the L_{Amax} descriptor the same formula applies, except that in that case $\Delta_V = 0$.

Note 2.— The correction to L_{AE} for aeroplane speed calculated at points to the side of the runway is to be determined on the assumption of constant aeroplane acceleration, from a typical minimum speed of 32 kt to the lift-off speed.

6.8 CORRECTION TO THE SOUND EXPOSURE LEVEL AT AN OBSERVATION POINT OPPOSITE A TURN IN THE AEROPLANE FLIGHT TRACK

The sound exposure level (see 5.1.2) includes an integral over time of the square of the instantaneous A-weighted sound pressure. The time limits of integration are such as to encompass all significant sound of a stated event (an aeroplane fly-past). "All significant sound" is usually interpreted to mean sound of levels within 10 dB of the maximum during the fly-past. The noise-power-distance data as described in Chapter 5 are for aeroplanes in straight and level flight. In practice, flight tracks are not always straight, but include turns. At an observation point to the inside of a turn in the flight track, the duration of the 10 dB-below-maximum sound levels (and hence the sound exposure level) will be greater than for a point at the same slant distance from a straight flight path, and at an observation point to the outside of a turn the duration (and the sound exposure level) will be less. Sound exposure levels derived according to Chapter 5 can be adjusted for this effect by the arithmetic addition of a correction, Δ_T. There are a number of possible methods of deriving such a correction, one of which is described in Appendix D.

References

1. International Organization for Standardization, 1982. *Acoustics — Description and Measurement of Environmental Noise.* Part 1: *Basic Quantities and Procedures.* ISO 1996/1 — 1982.

2. International Civil Aviation Organization, 1981. *Annex 16* to the *Convention on International Civil Aviation — Environmental Protection.* Volume I — *Aircraft Noise.*

3. International Civil Aviation Organization, 1982. *Procedures for Air Navigation Services — Aircraft Operations (PANS-OPS)* (Doc 8168). Volume I — *Flight Procedures.* Part V — Noise Abatement Procedures.

4. Society of Automotive Engineers, 1981. *Prediction Method for Lateral Attenuation of Airplane Noise During Take-off and Landing.* Aerospace Information Report AIR 1751.

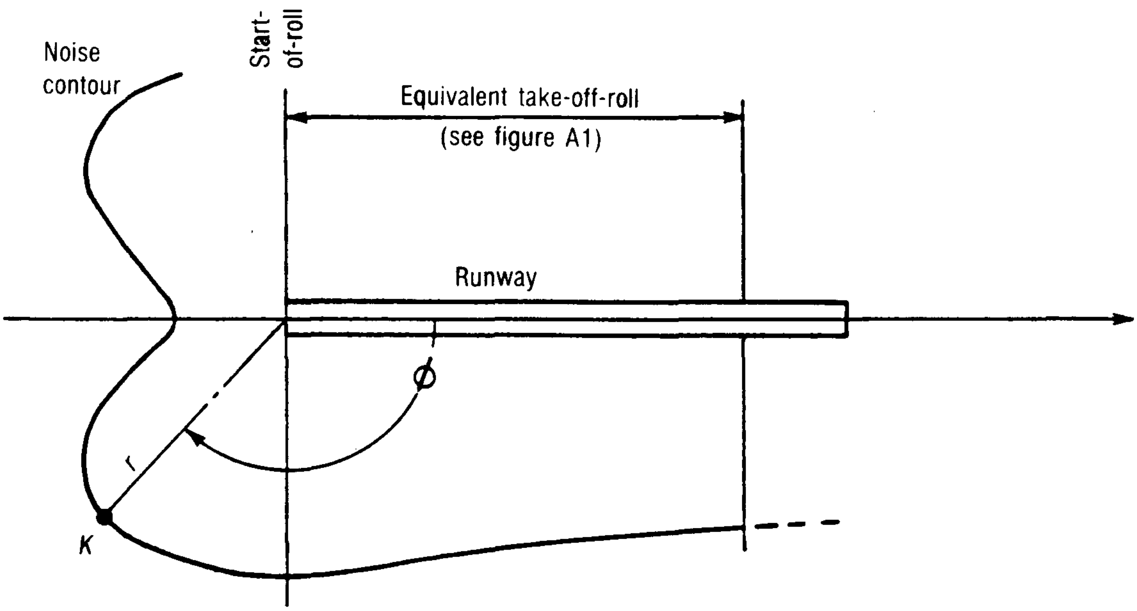

Figure 6-4. Geometry for construction of take-off roll noise contours

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}*

$$\mathrm{L_{DEN}} = 10 \log (1/24) \Big[12 \times 10^{\mathrm{L_D}/10} + 3 \times 10^{(\mathrm{L_E}+5)/10} + 9 \times 10^{(\mathrm{L_N}+10)/10}\Big]$$

where $\mathrm{L_D}$, $\mathrm{L_E}$ and $\mathrm{L_N}$ are the equivalent continuous A-weighted sound pressure levels* over, respectively, 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.

2. *Day-night average sound level, L_{dn}*

$$\mathrm{L_{dn}} = 10 \log (1/24) \Big[15 \times 10^{\mathrm{L_D}/10} + 9 \times 10^{(\mathrm{L_N}+10)/10}\Big]$$

where $\mathrm{L_D}$ and $\mathrm{L_N}$ 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 sound level, L_{eq}, as defined in the Federal Republic of Germany:*

$$\mathrm{L_{eq}} = 13.3 \log \sum_i \Big[g_i\,(t_i/T)10^{\mathrm{L}_i/13.3}\Big]$$

where L_i is the maximum A-weighted sound pressure level of an aeroplane fly-past i, t_i is the time interval within which the levels during the fly-past are within 10 dB of the maximum, g_i is a weighting factor, different during the daytime (0600 to 2200 hours) from the night (2200 to 0600 hours) and T is the duration of evaluation (24 hours).

4. *Equivalent continuous A-weighted sound pressure level, $L_{A,eq}$, as defined in Austria:*

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

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

5. *Noise and number index, NNI*

$$\mathrm{NNI} = 10 \log\left\{\sum_i (1/N)\left[10^{\mathrm{L_{PN\mathit{i}}}/10}\right]\right\} + 15 \log N - 80$$

where $\mathrm{L_{PN\mathit{i}}}$ is the maximum perceived noise level of an aeroplane fly-past i and N is the total number occurring within the time period of evaluation (12-hour daytime in some States, 24 hours in others). In some States using this index, N is limited to the number of operations exceeding a certain value of $\mathrm{L_{PN\mathit{i}}}$.

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* The equivalent continuous A-weighted sound pressure level is usually given the symbol $\mathrm{L_{A,\mathit{eq,T}}}$ (see Reference 1 to main text). The symbols $\mathrm{L_D}$, $\mathrm{L_E}$ and $\mathrm{L_N}$ used here are intended to indicate the time periods over which the levels are evaluated. This quantity is defined as follows:

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

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

6. *Noise exposure forecast, NEF*

$$\mathrm{NEF} = 10 \log \sum_i \sum_j 10^{\mathrm{NEF}_{ij}/10}$$

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

$$\mathrm{NEF}_{ij} = \mathrm{L}_{\mathrm{EPN}ij} + 10 \log (n_{Dij} + 16.67 n_{Nij}) - 88$$

where, in turn, $\mathrm{L}_{\mathrm{EPN}ij}$ is the Effective Perceived Noise Level at the observation point considered, for the aeroplanes and flight path concerned, n_{Dij} is the number of operations during the 15-hour day (0700 to 2200 hours) and n_{Nij} is the number during the 9-hour night (2200 to 0700 hours).

7. *Noise exposure index, B*

$$\mathrm{B} = 20 \log \sum_i \left[n \left(10^{\mathrm{L}_p/15} \right) \right] - 157$$

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

8. *Psophic index, Ip*

$$\mathrm{Ip} = \left\{ 10 \log \left[\left(\sum_i 10^{\mathrm{L}_{Di}/10} \right) + \left(\sum_j 10^{(\mathrm{L}_{Nj} + 10)/10} \right) \right] \right\} - 32$$

where L_{Di} is the maximum perceived noise level of an aeroplane fly-past *i* during the 16-hour day (0600 to 2200 hours) and L_{Nj} is that of aeroplane fly-past *j* during the 8-hour night (2200 to 0600 hours).

9. *Weighted equivalent continuous perceived noise level, WECPNL, as defined in Japan:*

$$\mathrm{WECPNL} = \left\{ 10 \log \left[(1/n) \sum_i 10^{\mathrm{L}_i/10} \right] \right\} + 10 \log N - 27$$

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

10. *Australian noise exposure forecast, ANEF*

$$\mathrm{ANEF} = 10 \log \sum_i \sum_j 10^{\mathrm{ANEF}_{ij}/10}$$

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

$$\mathrm{ANEF}_{ij} = \mathrm{L}_{\mathrm{EPN}ij} + 10 \log (n_{Dij} + 4 n_{Nij}) - 88$$

where, in turn $\mathrm{L}_{\mathrm{EPN}ij}$ is the Effective Perceived Noise Level at the observation point considered for the aeroplane and flight path concerned, n_{Dij} is the number of operations during the 12-hour day (0700 to 1900 hours) and n_{Nij} is the number during the 12-hour night (1900 to 0700 hours).

Appendix B

Approximate Methods for Determining Effective Perceived Noise Level (EPNL)

1. Approximate methods for arriving at the effective perceived noise level at a specified location from actual noise level measurements, as allowed for in the note to 4.1 are provided herewith.

I. *Approximations to obtain Tone Corrected Perceived Noise Level (PNLT)* (as defined in Annex 16, Volume I)

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 correction see Table B-1 below (from PNL to PNLT).

b) *Approximation by D- and A-weighted over-all 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 over-all 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 5-1; or
2) equal to the A-Weighting as defined in IEC Recommendation 179.*

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

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

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 aircraft type, distance from flight paths, etc., are known. If values other than the ones in the table are used in approximate method I b) above, the value used for *K* must be stated.

		Constant K to be added to obtain				
		PNL from		*PNLT from*		
Aircraft		*dB(A)*	*dB(D)*	*dB(A)*	*dB(D)*	*PNL*
Turbofan	Take-off	13	7	13	7	0
	Landing	13	7	15	9	2
Turbo-jet	Take-off	13	7	13	7	0
	Landing	13	7	13	7	0
Noise from unknown aircraft		13	7	13	7	0

Note.— It is realized that the exact correction constant depends on such factors as aircraft type, operational characteristics, meteorological conditions and the distance from the aircraft flight path. The figures in the above table are based on a considerable number of observations. In one study the correction constant was found to range from 13 to 8 for

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* This publication was first issued in 1965 by the Bureau central de la Commission électrotechnique internationale, 1 rue de Varembé, Geneva, Switzerland.

*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** averaging 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:*

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

II. *Approximation to Obtain Duration Correction D* (as defined in Annex 16, Volume I, Appendix 1, 4.5)

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 having the dimensions of time and equalling 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 I, Appendix 1, 4.5), the time it exceeds the background level or other limiting value is taken into account.

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

** W.K. Connor, Community Reactions to Aircraft Noise, 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).

Appendix C

Equations for Performance Calculations

1. EQUATIONS FOR THRUST AND NOISE-RELATED THRUST PARAMETERS

1.1 *Specific departure thrust settings*

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

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

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

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

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

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

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

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

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

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

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

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

1.2 *General thrust settings*

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

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

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

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

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

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

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

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

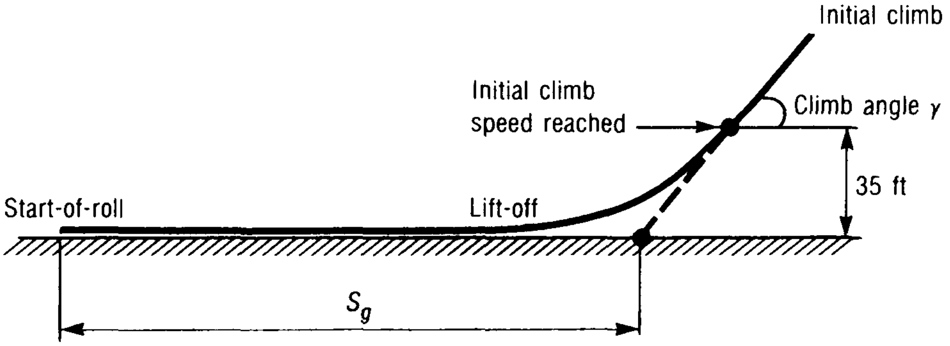


Figure C1. Aeroplane take-off, showing equivalent take-off roll

2. FLIGHT PROFILE AND FLIGHT SPEEDS

2.1 *Equivalent take-off roll*

The equivalent take-off roll, S_g, is the distance along the runway from the start of the take-off roll to the intersection point of the runway and the initial climb path projected downwards (see Figure C1).

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

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

where p is the take-off performance coefficient (see 5.2.3), evaluated for the reference conditions of 5.2.5, Θ and δ are the ratios of ambient air pressure and temperature to the respective ISA sea-level values, W is the gross weight of the aeroplane at the start of roll, X_N is the all-engine net thrust for the initial climb and f_w is a wind coefficient given by the following expression:

$$f_w = (\overline{V}_{EAS} - v_w)/(\overline{V}_{EAS} - 4.1) \qquad \text{(C9)}$$

In Equation C9, v_w is the wind velocity and $\overline{V}_{EAS}$ is the mean airspeed over the initial climb segment.

2.2 *Flight speeds*

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

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

where Q is the flight speed coefficient (see 5.2.3) for which different values are applicable during the climb (Q_{CL}), flap retraction (Q_{FR}) and approach (Q_{AP}).

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

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

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

2.3 *Climb (descent) angle*

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

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

where f_w is the wind coefficient (Equation C9), R is the climb/descent performance coefficient (see 5.2.3) and f is an acceleration coefficient over the flight-path segment, as follows:

For an accelerated climb from position 1 to 2

$$1/f = 1 + ({V_{TAS}}_2^2 - {V_{TAS}}_1^2)/[2g(\Delta h)] \qquad \text{(C13)}$$

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

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

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

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

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

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

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

2.4 *Horizontal distance covered in a flight segment*

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

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

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

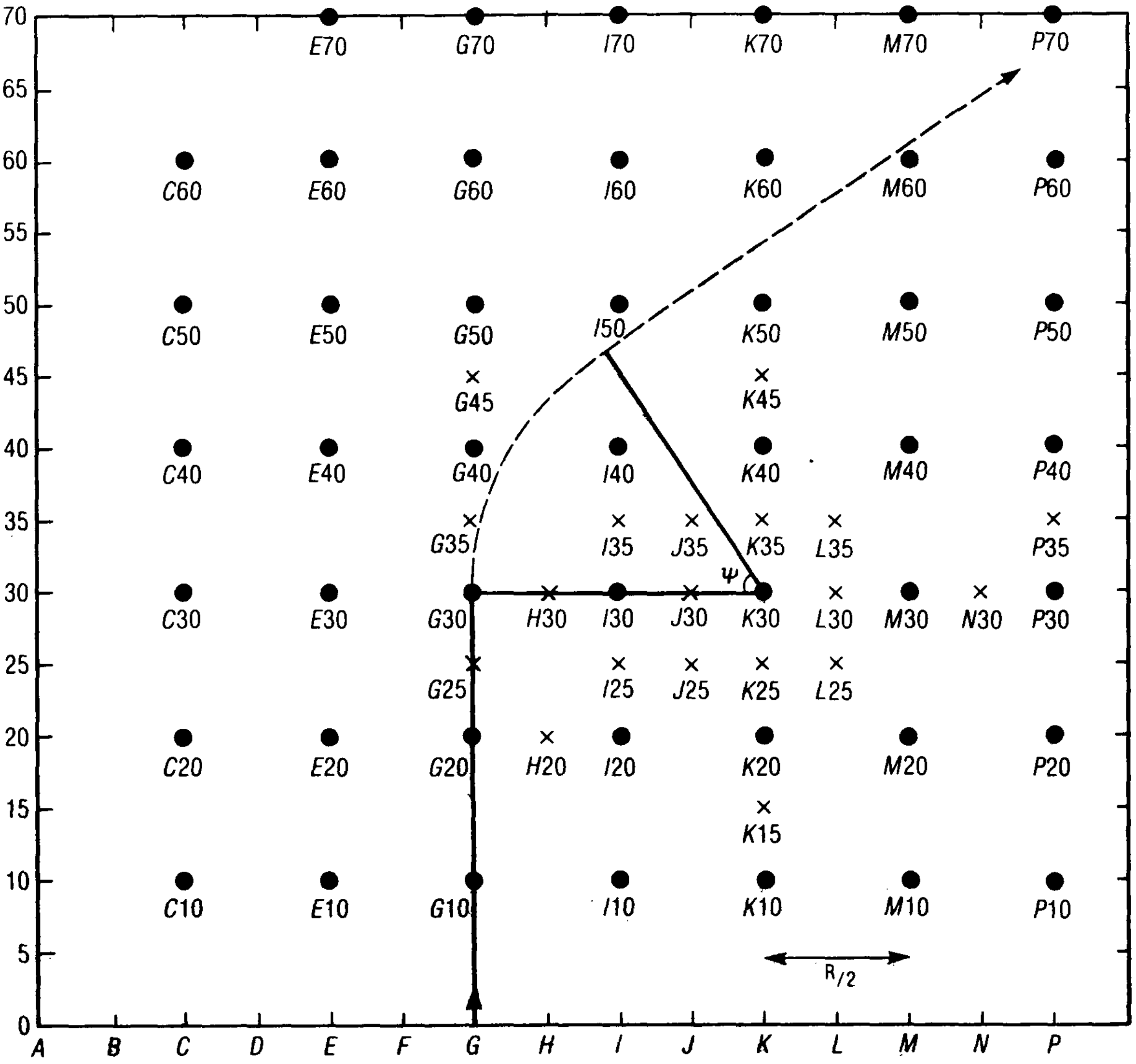
$$S = f_w\,({V_{TAS}}_2^2 - {V_{TAS}}_1^2)/2g[(\overline{X}_N/W) - R] \qquad \text{(C17)}$$

Appendix D

Graphic Method for Correcting the Sound Exposure Level Near Turns in the Flight Track

1. Corrections are given graphically for points on a secondary grid arranged to suit the geometry of the turn (Figure D1). Grid line *G* is aligned with the straight length of flight track leading to the turn and the start of turn is arranged to coincide with point *G*30. The turn then follows a circular arc and the main grid points are spaced at one-half radius of turn, with intermediate grid points at one-quarter radius. The centre of the arc of turn therefore falls on point *K*30.

2. The corrections to be applied at the main points of the secondary grid are presented graphically in Figures D2 to D8 and those at the intermediate points are given in Figures D9 to D11. The curves of corrections labelled *P* in the figures apply to propeller-driven aeroplanes and those labelled *J* are for jet-engined aeroplanes. The points of a primary grid used for airport noise contour evaluations will in general be interspersed between the points of the secondary grid. The corrections due to flight track turns to be applied at the primary grid points are then established by interpolation within the secondary grid, usually between the main points on the latter, but making use of the intermediate points where necessary for greater accuracy.



Key:

● *Main grid points*

× *Intermediate grid points*

Start of turn at G30

Centre of turn at K30

Turn angle ψ

Figure D1. Secondary grid for geometry of an aeroplane turn

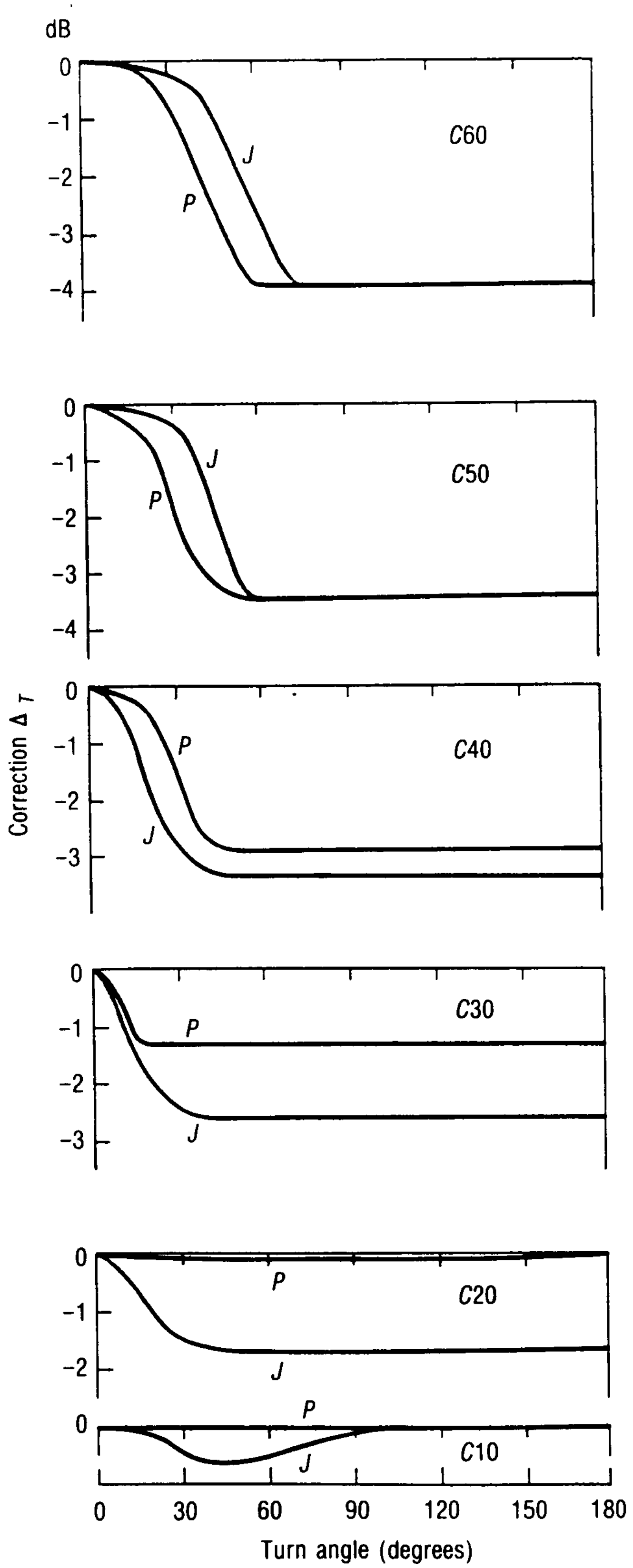


Figure D2. Corrections along gride-line C

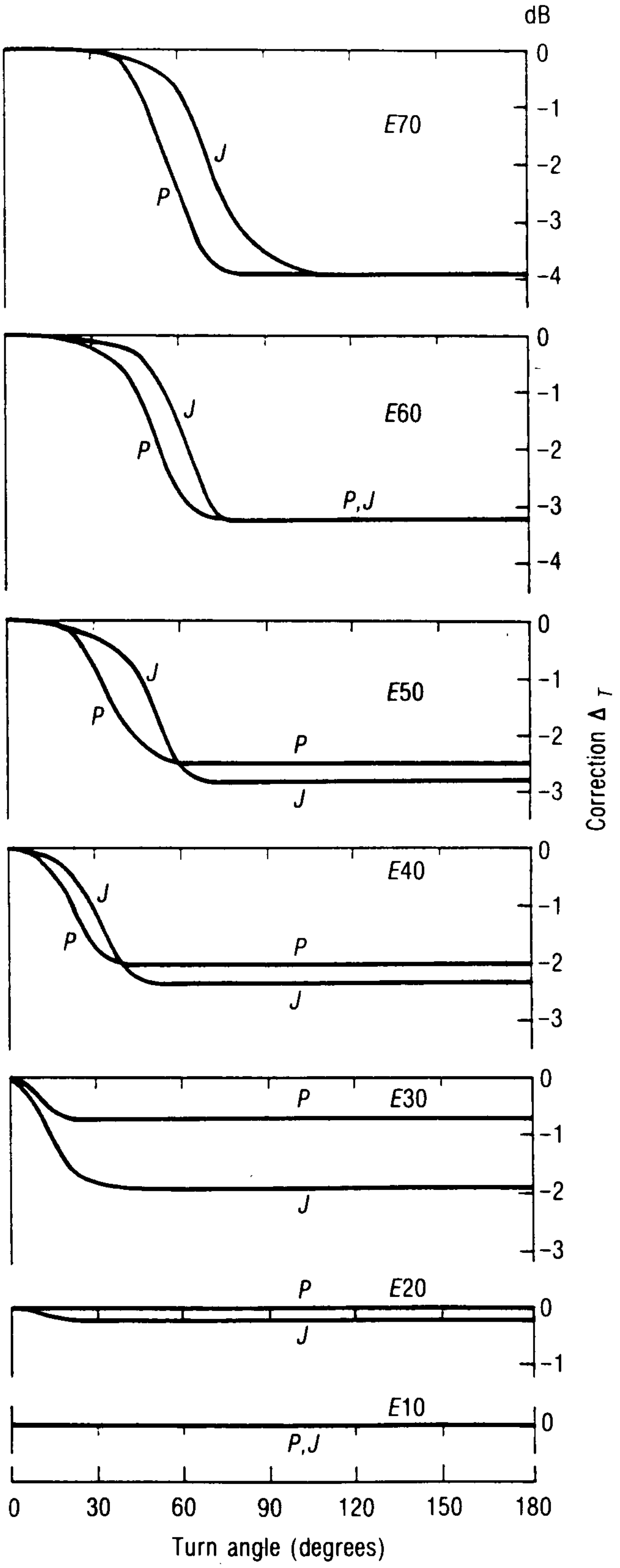


Figure D3. Corrections along grid-line E

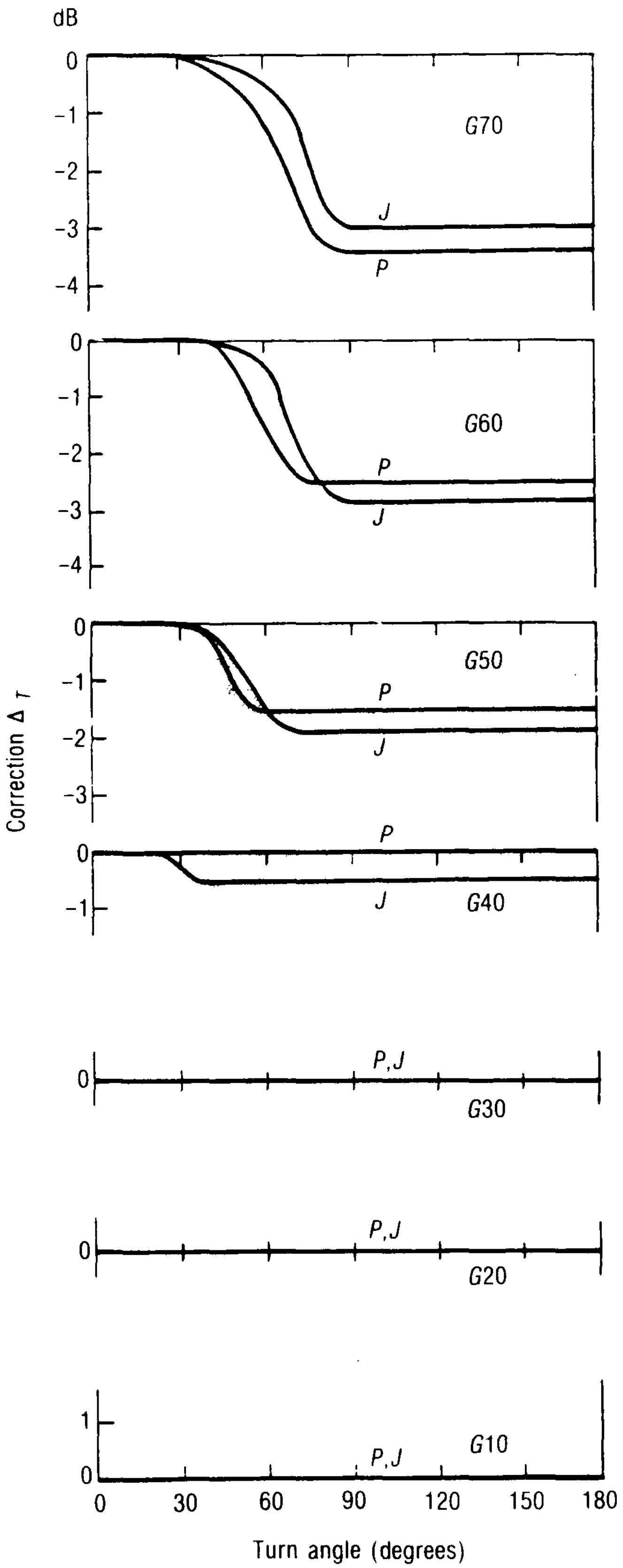


Figure D4. Corrections along grid-line G

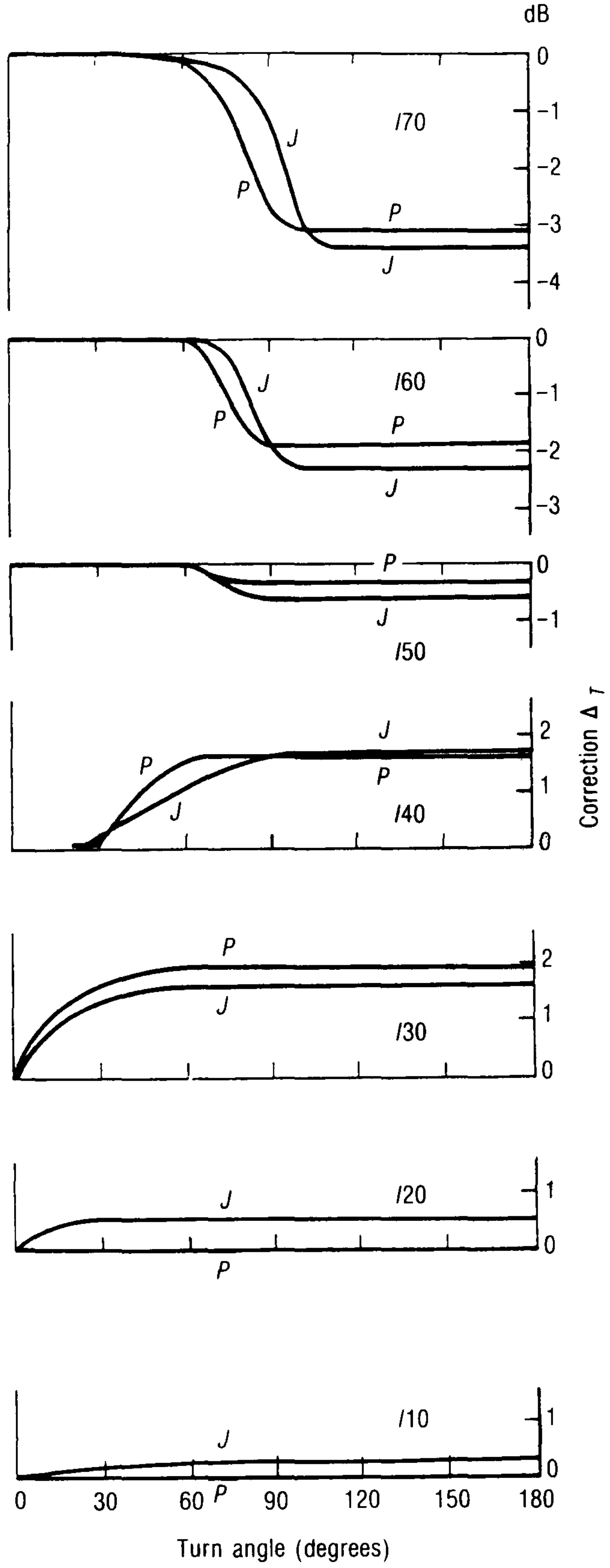


Figure D5. Corrections along grid-line I

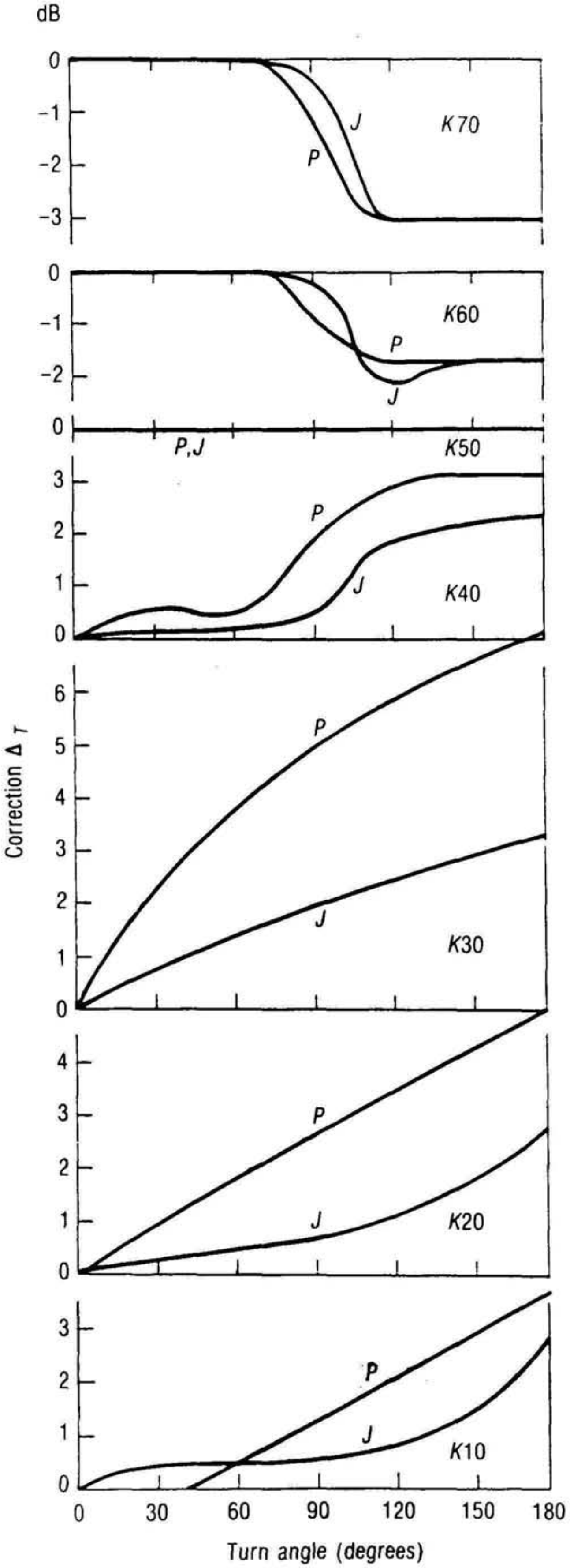


Figure D6. Corrections along grid-line K

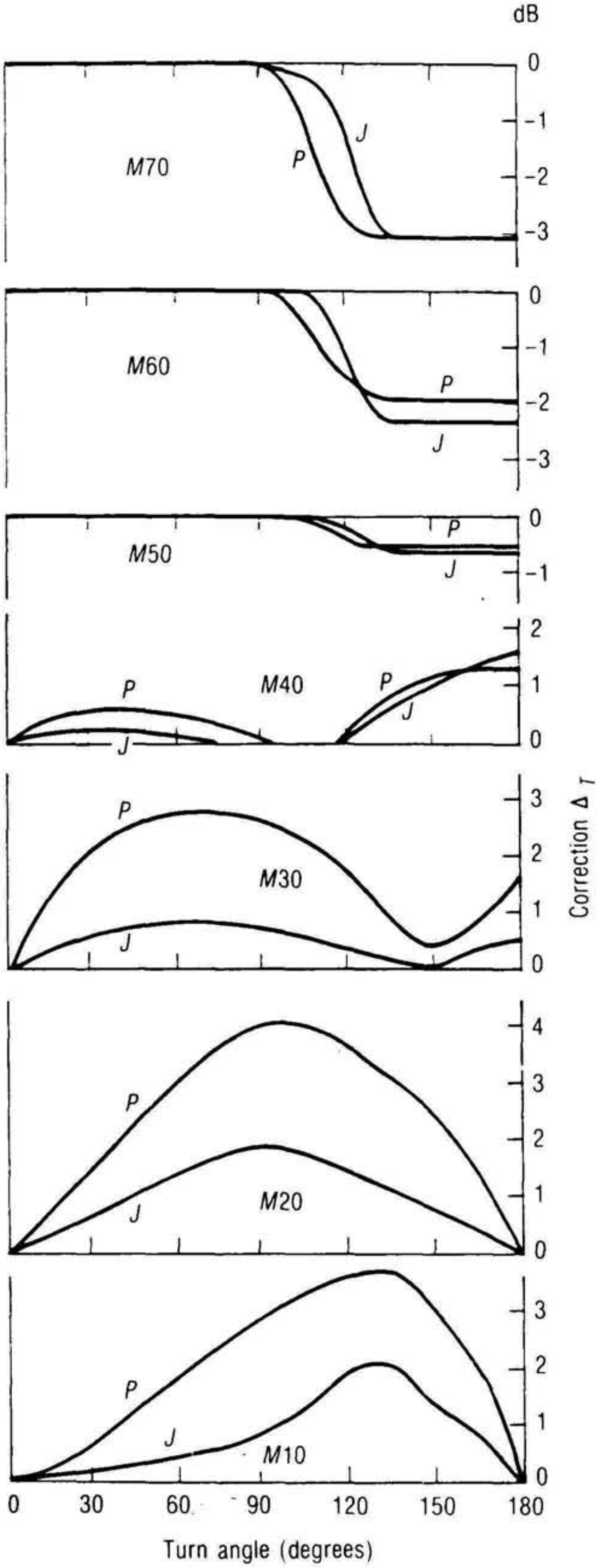


Figure D7. Corrections along grid-line M

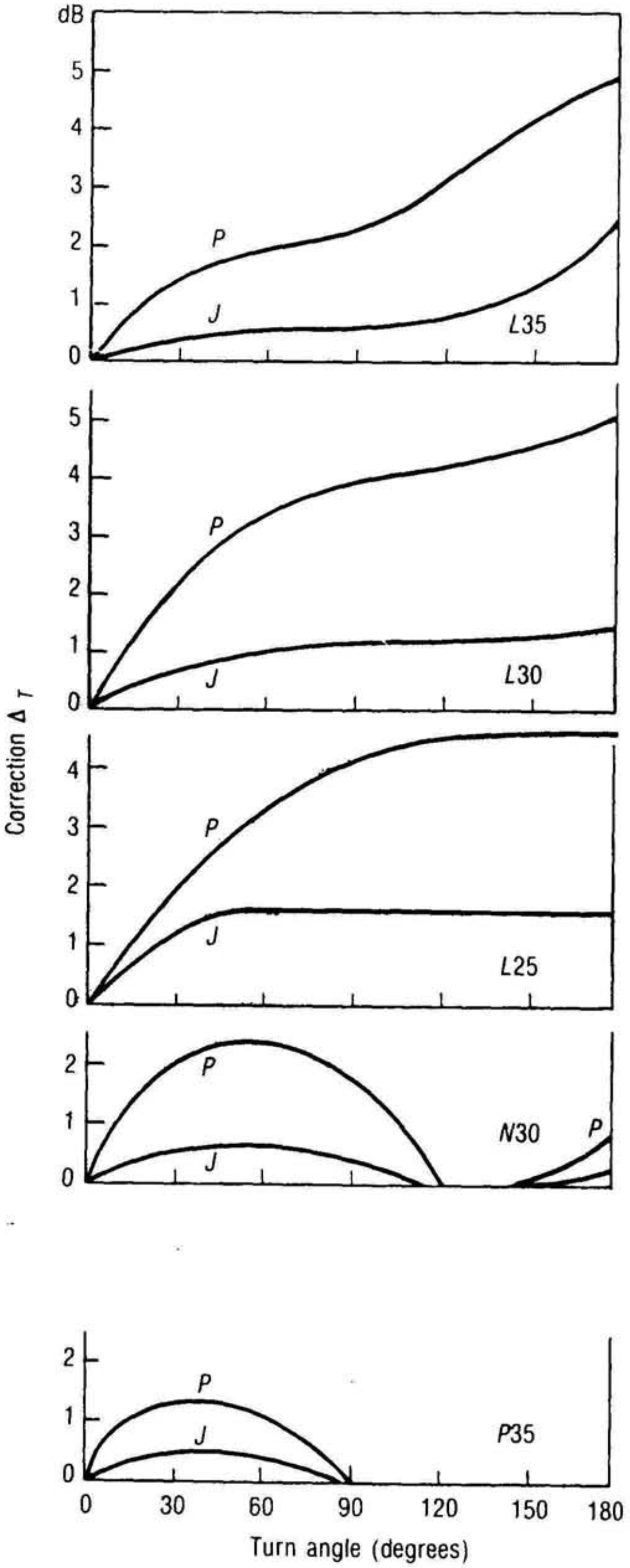


Figure D8. Corrections along grid-line P

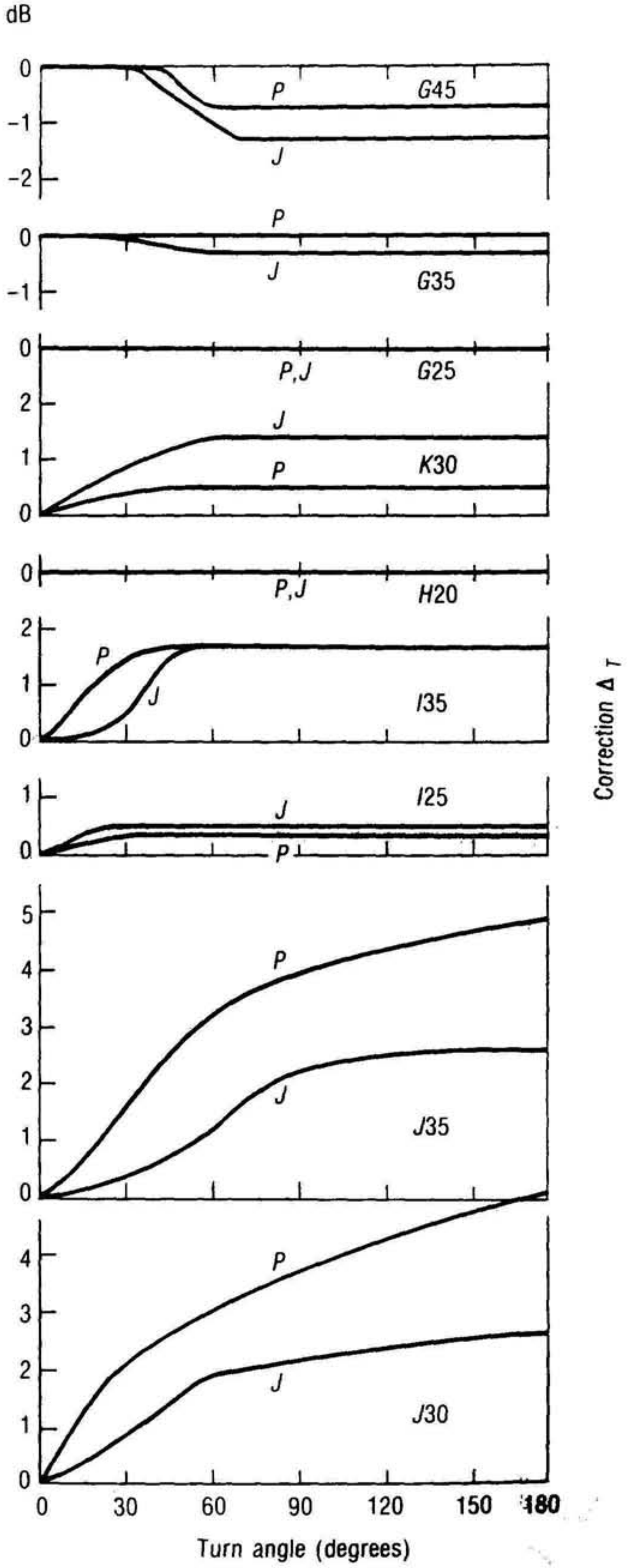


Figure D9. Corrections along intermediate grid-lines

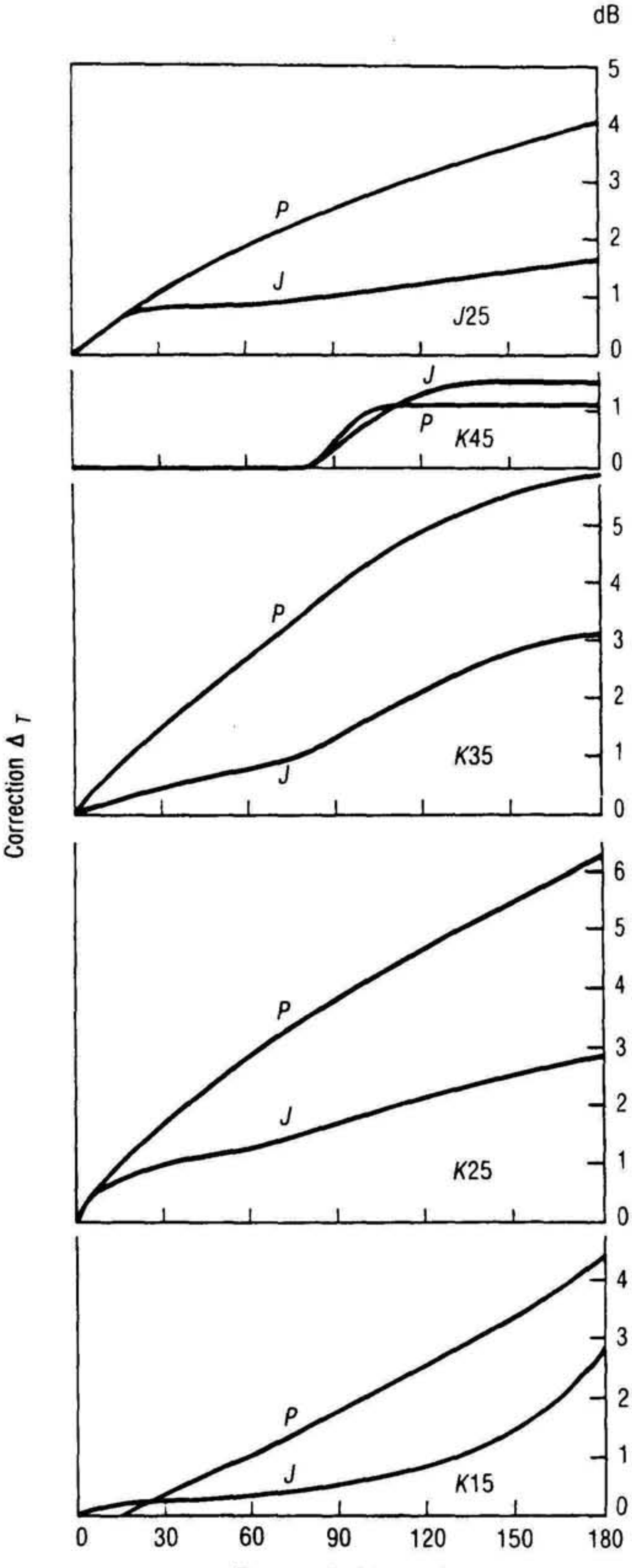


Figure D10. Corrections along intermediate grid-lines

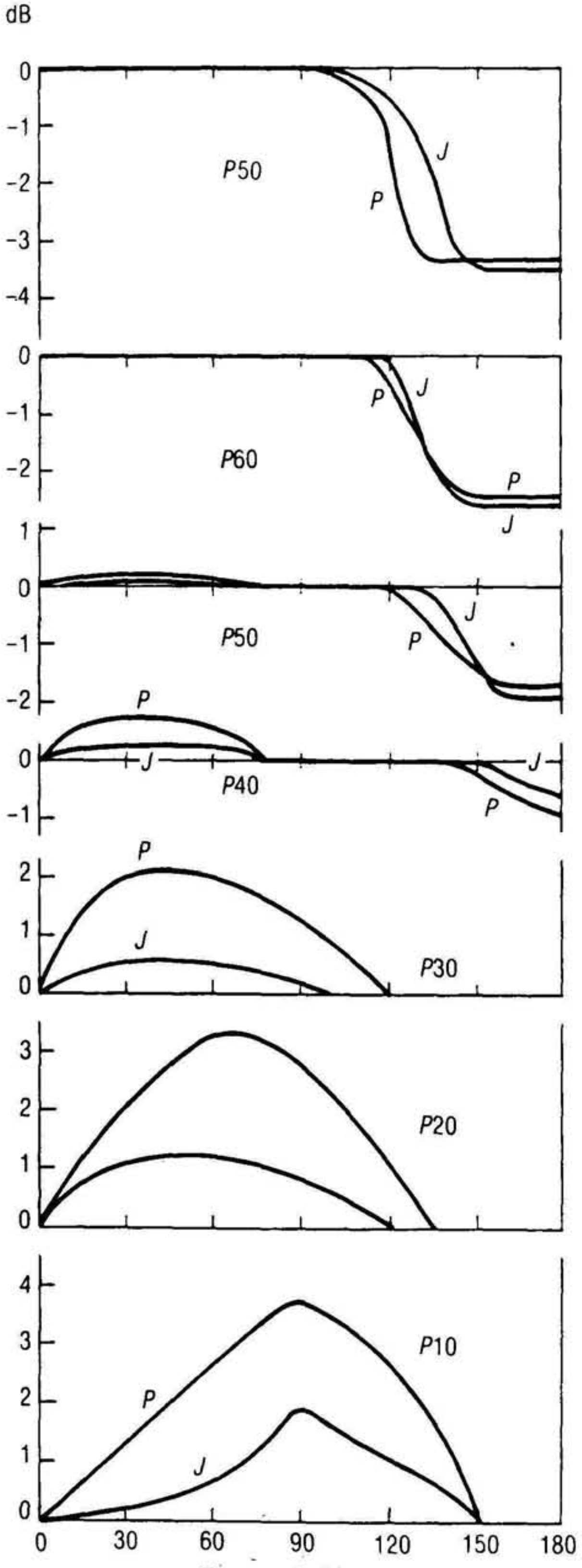


Figure D11. Corrections along intermediate grid-lines

— E N D —

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