The Noise Advisory Council

A Guide to Measurement and Prediction of the Equivalent Continuous Sound Level L_{eq}

Report by a Working Party for the Technical Sub-Committee of the Council

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PREFACE

This Guide was commissioned by the Noise Advisory Council, on behalf of all those who are concerned with the evaluation and control of environmental noise in the UK, to meet the need for a work of reference on the equivalent continuous sound level, L_{eq}. The Guide consolidates information which is, in the main, already available but which is widely scattered throughout the technical literature. It has been prepared by a Working Party of specialists under the auspices of the Council's Technical Sub-Committee.

2. The Council greatly appreciates the work done by the Working Party, the members of which were:

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Mr Berry, in addition to contributing several chapters of the Guide, also acted as its compiler and the editor was Mr Higginson.

3. The Guide deals only with environmental noise; this means that industrial noise is treated only insofar as it affects the neighbourhood outside the workplace. The Council is aware, however, that L_{eq} is also used for the characterisation of occupational noise. Chapter 3 describes measurement techniques which are similar to some of those set out in British Standard 5330, 'Method of Test for Estimating the Risk of Hearing Handicap due to Noise Exposure'.

4. The Guide is intended for use by practitioners with the appropriate technical background who need to measure or predict environmental noise. It is not concerned with the suitability or otherwise of L_{eq} for any particular application, nor is it concerned with the prediction of subjective reaction to noise. References in the Guide are quoted only for their factual content.

5. The Noise Advisory Council hopes that the Guide will be used in the making of proper comparisons between L_{eq}-based noise indices and existing

non-L_{eq} indices. Chapter 2 of the text deals with mathematical derivations and is therefore complete as it stands. Chapters 3 and 4, on the other hand, summarise current practices and these might be superseded in time. Supplements to the Guide, covering new areas of knowledge, may therefore be issued in the future.

6. The Guide gives the general procedures to be followed for the measurement and prediction of L_{eq}. The amount of detail given in Chapter 4 varies according to the state of the art between the four different types of noise source discussed, but in a volume of this size it cannot be exhaustive. For formal measurements for regulatory purposes it will be necessary to refer to other literature on specific regulations in conjunction with the Guide, eg, The Control of Noise (Measurement and Registers) Regulations 1976.

7. The Council hopes that the Guide will facilitate and encourage the wider adoption of L_{eq}. It hopes that in time L_{eq} will replace other noise measures, and in the meantime, where regulations already prescribe other noise measures it strongly recommends that L_{eq} is also used in parallel for the sake of gaining experience with it and enabling comparisons to be made between L_{eq} and other measures.

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A GUIDE TO MEASUREMENT AND PREDICTION OF THE EQUIVALENT CONTINUOUS SOUND LEVEL, L_{eq}

1 INTRODUCTION

1.1 Background

The Noise Advisory Council, concerned about the multiplicity of noise immission measures used in the United Kingdom for planning and regulatory purposes, has recommended[1] that these should all be replaced by a single measure of environmental noise, namely the Equivalent Continuous Sound Level, L_{eq}. The Council was aware that the different methods used to evaluate the noise of road traffic, aircraft, industrial premises and other sources took account of the various qualities of noise found to be disturbing to the community at large. At the same time it was felt that the different modes of evaluation led to confusion and that they made comparisons difficult. A resolution of these problems was seen as both necessary and practicable, although it was acknowledged that some time would have to elapse before this could be given full effect. The recommendation, therefore, was for a gradual transition to the use of L_{eq} for quantification of the noise environment due to each source and from all sources together.

The Department of the Environment issued a Note as a Supplement to the Council's report[1], referring to current uses of L_{eq} and to problems envisaged in extending its use. The Department endorsed the proposal for a phased adoption of the new means of quantifying noise. They pointed out that there would be opportunity to begin this process with L_{eq} in relation to sources of environmental noise which were subject to new legislation. Since that Note was issued, legislation has come into force in which the use of L_{eq} for measurement of noise around construction sites[2] and within noise abatement zones[3] is implicit. The Department pointed out, however, in their Supplement to the NAC report, that the transition to L_{eq} would be assisted by the issue of a reference work on methods of prediction and measurement. This Guide is intended to fulfil the need for such a reference.

1.2 Outline of the Guide

The Guide has been written for readers who are generally familiar with acoustical terminology and with the experimental and mathematical techniques used in the acquisition and analysis of acoustical data. Terms which may be new to the reader or which have a special meaning within the context of the Guide are defined in Chapter 2. Then in Chapter 3, instrumentation and techniques of measurement are described. Chapter 4 deals with the prediction of noise from road traffic, aircraft, railways and fixed sources (eg industrial sites). Finally, in Chapter 5, some information is given to help in translating between the noise measures in current use and L_{eq}.

L_{eq} can be measured directly and measurements are sufficient if they can be made at the receiver position which is of interest with the source fully operational. Chapter 3 of the Guide differentiates for the purposes of measurement between noise which is of steady level, noise which fluctuates with time and noise of an impulsive character. Measurement of the noise of a single event is also described, for use in calculation of total noise immission where individual source data are not available.

Reliance has to be placed on prediction where some new situation is being considered. The Guide advises on techniques and identifies the data to be supplied in order for the predictions to be made. The general approach to building up a value of L_{eq} over a period of time is to start from individual source noise emission data at a reference position, to allow for propagation over the distance to the receiver and then to sum for the succession of sources and events heard throughout the period. In general it is for the user of the Guide to supply the source data, though some information is given here in respect of road traffic and railway trains. Types of source which are not referred to in Chapter 4 of the Guide can be tackled by adaptation of the general principles and methods which are described, so long as source emission data are available and the operational modes of the source are known.

The Guide is not intended to be fully comprehensive. New information is continually becoming available to supplement that presented here. Therefore it is for the regulatory authorities, the operators of the noise sources concerned, the manufacturers of machinery and others involved to satisfy themselves in any particular case where the noise environment is to be evaluated that the correct detailed prescriptions are followed.

1.3 *References*

1 The Noise Advisory Council. *Noise Units.* Report by a Working Party for the Research Sub-Committee of the Noise Advisory Council. London, HMSO, 1975.

2 Statutory Instrument 1975 No. 2115. Public Health, England and Wales. The Control of Noise (Code of Practice for Construction Sites) Order 1975. London, HMSO, 1975.

3 Statutory Instrument 1976 No. 37. Public Health, England and Wales. The Control of Noise (Measurement and Registers) Regulations 1976. London, HMSO, 1976.

2 CONCEPTS AND DEFINITIONS

2.1 Auditory magnitude

The *auditory magnitude* of a noise is the immediate subjective impression of the strength of that noise, taking account of factors such as sound pressure and frequency content which affect the perception of sound. The auditory magnitude will in general vary from moment to moment if the noise itself does not remain constant.

The measure for the auditory magnitude of environmental noise which has been adopted in this Guide is the A-weighted sound pressure level, L_A. By definition:

$$L_A = 10 \log_{10} \left[\frac{\overline{p_A^2}}{p_{ref}^2} \right] \quad \text{dB} \qquad \text{Eq (1)}$$

where $\overline{p_A^2}$ is the mean square value of the A-weighted sound pressure and p_{ref} is the reference pressure, 20 micropascals. The A-weighted sound pressure level is commonly referred to by the term *"noise level"*.

For correctness the time period over which the mean of p_A^2 is determined (averaging time) should be specified. For measurements of L_A involving the use of conventional sound level meters the averaging period would correspond to twice the time constant of the dynamic response characteristic selected, either "fast" or "slow" (ie averaging period approximately 250 ms and 2000 ms respectively). The choice of response characteristic best suited to the measurement of the auditory magnitude of environmental noise continues to be the subject of debate. However, in the context of this Guide, the choice is not critical.

2.2 Noise scales and noise indices

A *noise scale* gives a composite measure of noise over a period of time, such that numerical values along the scale correspond with the annoyance potential of a noise. The factors which contribute to a scale measurement are of a wholly physical nature. These factors are not in general the only ones which go to determine people's actual reactions to a noise environment experienced in real life.

A *noise index* is a composite measure of noise over a period of time, derived from a noise scale to allow for additional factors which are relevant to rating or assessment for purposes of planning and regulations. This derivation is made by adjusting, or in some cases limiting, the scale according either to features to which the scale is insensitive (eg a bias against a particular type of noise source, character of the noise) or to features of the situation into which the noise intrudes (eg background noise, type of neighbourhood, time of day).

Consideration of particular features which are relevant to the determination of noise indices in different instances is beyond the scope of this Guide. The advice given here relates only to those features of a noise environment which can be measured and predicted along the selected noise scale, L_{eq}.

2.3 Equivalent continuous sound level

The *equivalent continuous sound level,* L_{eq}, is the level of a notional steady sound which, at a given position and over a defined period of time, would have the same A-weighted acoustic energy as the fluctuating noise. L_{eq} is therefore in itself a noise scale.

L_{eq} is defined in mathematical terms over an interval from time T_1 to time T_2 thus:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} \frac{p_A^2(t)}{p_{ref}^2} \, dt \right] \quad \text{dB} \qquad \text{Eq (2)}$$

where $p_A(t)$ is the A-weighted sound pressure as a function of time.

It is convenient to define L_{eq} by an alternative formula which is an approximation to the exact expression of Eq (2):

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T_2 - T_1} \int_{T_1}^{T_2} 10^{L_A(t)/10} \, dt \right] \quad \text{dB} \qquad \text{Eq (3)}$$

where L_A is the A-weighted sound pressure level. The two expressions, Eq (2) and Eq (3), are equivalent provided the time interval $T_2 - T_1$ is large compared to the averaging time associated with L_A. This condition will generally be satisfied for most practical measurements of L_{eq}.

These formulae provide the basis for the methods of measuring L_{eq} described in the next chapter. For the purposes of calculation of L_{eq} due to the operation of numbers of individual sources and mixtures of sources we need further to be able to characterize the noise of individual events in such a way that their effects can be combined. Conversely a characterization of individual events may be required for diagnostic purposes in an assessment of the relative magnitudes of contributions to a noise environment. Such a characterization is provided by the single event noise exposure level.

2.4 Single event noise exposure level

The *single event noise exposure level,* L_{AX}, is the level which, if maintained constant for a period of 1 second, would cause the same A-weighted sound energy to be received as is actually received from a given noise event. L_{AX} values for contributing noise sources can be considered as individual building blocks being used in the construction of a calculated value of L_{eq} for the total noise.

L_{AX} is defined mathematically thus:

$$L_{AX} = 10 \log_{10} \int_{-\infty}^{\infty} \frac{p_A^2(t)}{p_{ref}^2} \, dt/\tau_{ref} \quad \text{dB} \qquad \text{Eq (4)}$$

where $\tau_{ref} = 1$ second. As with L_{eq} there is an equivalent form

$$L_{AX} = 10 \log_{10} \int_{-\infty}^{\infty} 10^{L_A(t)/10} \, dt/\tau_{ref} \quad \text{dB} \qquad \text{Eq (5)}$$

The concept is illustrated graphically in Fig 2.4.1. for a hypothetical noise event. The noise level L_A is shown in part (a) of the figure rising steadily by 20dB over a time of 10s to a peak and then decaying at the same rate. By applying Eq (5) to this triangular time pattern it is found that L_{AX} has a value 6 dB above the peak noise level. A steady noise of this level lasting for 1s is shown superimposed on part (a) of the figure; this is equivalent in energy to the full event but clearly the area within the L_{AX} rectangle is not the same as that within the triangle of the event. The same event is illustrated in part (b) of the figure, drawn to the same time scale but to a *linear* vertical scale of $10^{L_A/10}$. The area under the curve is proportional to the energy of the event and is now equal to the area under the $10^{L_{AX}/10}$ rectangle.

During any given noise event most of the sound energy is concentrated in the time interval during which the value of L_A is within 10 dB of L_{Amax}, the maximum level during the event. This is evident in Fig 2.4.1. In practice, therefore, the integration for L_{AX} can usually be restricted to this limited time interval from time t_1 to time t_2, often referred to as the '10dB down' points. The definition thus becomes:

$$L_{AX} = 10 \log_{10} \int_{t_1}^{t_2} 10^{L_A(t)/10} \, dt \quad \text{dB} \qquad \text{Eq (6)*}$$

2.5 Procedure for calculating L_{eq}

The value of L_{eq} due to the combined effect of n events each with its own single event noise exposure level L_{AXi} is obtained from the expression:

$$L_{eq} = 10 \log_{10} \left[\frac{\tau_{ref}}{T} \sum_{i=1}^{n} 10^{L_{AXi}/10} \right] \quad \text{dB} \qquad \text{Eq (7)}$$

where T is the total time period in seconds and $t_{ref} = 1$ second.

Depending upon the circumstances, different forms of the above basic equation may be used. Thus where each event has the same value of L_{AX} and the total number of events is n, the equation may be rewritten

$$L_{eq} = 10 \log_{10} \left[\frac{1}{T} .n. 10^{L_{AX}/10} \right] = L_{AX} + 10 \log_{10} n - 10 \log_{10} T \quad \text{dB} \qquad \text{Eq (8)}$$

Where the total number in the period of interest is expressed as a flow rate, q events per hour (3600 seconds), be they motor vehicles or trains, the expression for the *hourly* value of L_{eq} becomes

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*Another approximation for L_{AX} has been used in a recent International Standard [1] dealing with the noise of conventional fixed-wing aircraft. This is only applicable where L_A versus time is roughly triangular and symmetrical about L_{Amax}. In this case L_{AX} is obtained by adding a duration correction to L_{Amax}, derived from the above time interval $t_2 - t_1$. Thus $L_{AX} = L_{Amax} + \Delta_A$, where $\Delta_A = 10 \log_{10} \left[\frac{\frac{1}{2}(t_2 - t_1)}{t_{ref}} \right]$ and $t_{ref} = 1$ second. There may be noise events other than aircraft for which this approximation to L_{AX} is adequate, but large errors may be introduced where the circumstances in which it is used diverge from those prescribed. It is recommended that L_{AX} values be determined, wherever possible, by integration following Eq (4) or Eq (6). Succeeding chapters of this Guide describe suitable procedures for measurement and prediction.

$$L_{eq} = L_{AX} + 10 \log_{10} q - 35.5 \qquad dB \qquad \text{Eq (9)}$$

Where the total period differs from 1 hour, the flow rate and the constant in the above equation ($10 \log_{10} 3600$) must be changed accordingly.

Where the total noise is due to a number of different sources Eq (7) can be used, together with the L_{AX} values for all the sources, to produce the value of L_{eq} for the total noise. Alternatively the L_{AX} values for each source can be used separately to produce the value of L_{eq} due to each source over the same total period; these values can then be combined to give the total L_{eq} and the relative contributions of the various sources to this total can be seen. The result is independent of the times of occurrence, that is the events may occur sequentially or simultaneously or they may overlap.

In a sense all noise environments are made up of a mixture of noises, since some background noise is always present. By convention L_{AX} values for events are uncontaminated by background noise. It is impractical to express background noise in terms of a value of L_{AX} and the use of a notional L_{eq} due to background noise is suggested. This is then combined with the value of L_{eq} due to the noise sources which itself is derived from one of the forms of equation discussed above.

Example

Consider the one-minute period illustrated in Fig 2.5.1 during which there occur three events separated by two 6-second periods at the background level of 60 dB(A). Although the time patterns shown in Fig 2.5.1 are in no way intended to be typical, events 1 and 3 might, for example, be aircraft overflights and event 2 a train pass-by.

Suppose L_{AX} for event 1 is 90 dB, for event 2 it is 85 dB and for event 3 it is 87 dB. The value of L_{eq} for the one-minute period, due to the events, is given by

$$L_{eq}\text{(events)} = 10 \log_{10} \left[\frac{1}{60}(10^{90/10} + 10^{85/10} + 10^{87/10})\right]$$

$$= 10 \log_{10} \left[\frac{1}{60}(\text{antilog } 9.0 + \text{antilog } 8.5 + \text{antilog } 8.7)\right]$$

$$= 74.8 \text{ dB}$$

The value of L_{eq} due to the background noise only is 60 dB, hence the total L_{eq} is given by

$$L_{eq}\text{(total)} = 10 \log_{10} \left[10^{74.8/10} + 10^{60/10}\right]$$

$$= 10 \log_{10} [\text{antilog } 7.48 + \text{antilog } 6.0]$$

$$= 74.9 \text{ dB}$$

2.6 *References*

1 International Organization for Standardization. ISO 3891: 1978. Procedure for describing aircraft noise heard on the ground.

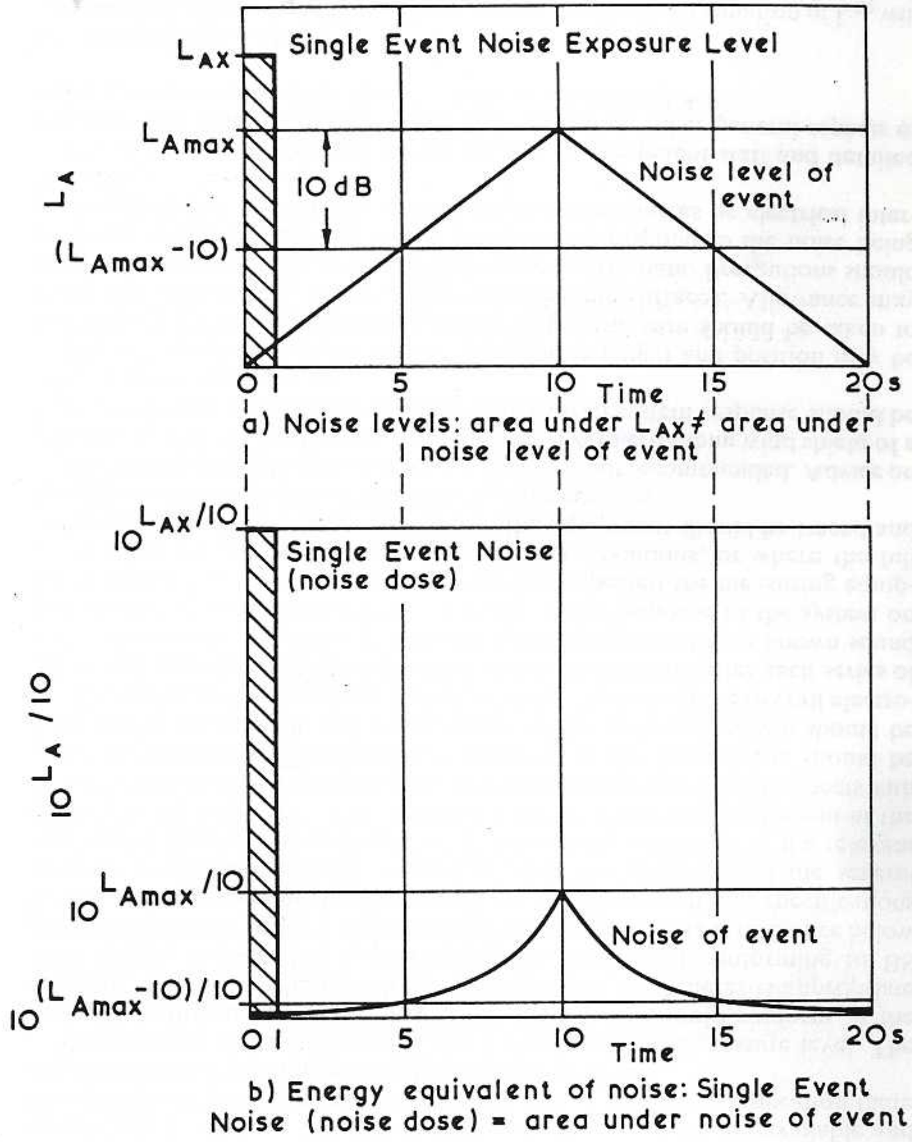

FIGURE 2.4.1. THE CONCEPT OF L_{AX}

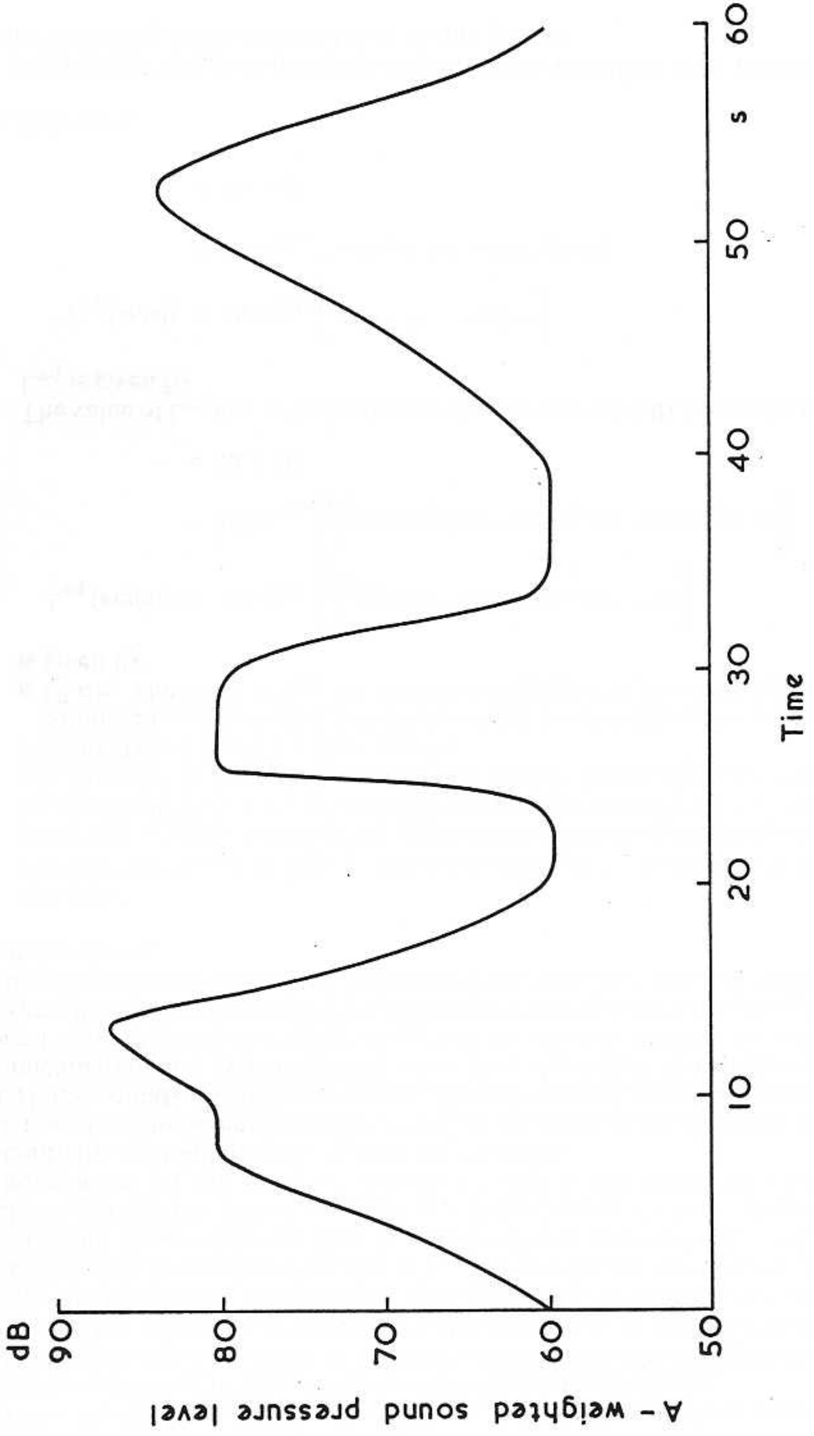

FIG. 2.5.1. IDEALISED NOISE PATTERN DURING ONE MINUTE PERIOD

3 MEASUREMENT OF THE NOISE

3.1 General

In this chapter guidance is given on methods of measuring L_{eq} for a noise environment and L_{AX} for a noise event. Various methods are available and irrespective of which one may be best suited to a particular application there are a number of general points which should be noted.

The quantity to be measured is the A-weighted sound pressure level. The acoustic performance of the measuring equipment should conform to the relevant standards: where a direct-reading sound level meter is appropriate (see below, Section 3.2) a precision-grade instrument conforming to BS 4197:1967[1] should be used. Other equipment to which there is reference below is still in the process of standardization and until performance specifications become available it should be ensured that the tolerances of the several sections of the measuring chain do not exceed the tolerances of the relevant clauses of BS 4197:1967. The calibration of the measuring equipment at the time of each series of measurements should be in accordance in all respects with these requirements. The frequency response of the microphone should be determined periodically and the response of the electrical system should be verified using an insert voltage technique. The response of the overall electro-acoustical system ought to be checked at least before and after each series of noise measurements, using an acoustic calibrator generating a known sound pressure level accurate to within ±0.5 dB. If the response of the system on being checked is not in accordance with that expected the measuring equipment might be adjusted. In the case of large deviations, or where the full adjustment cannot be made, the fault in the equipment should be traced and rectified and the equipment re-calibrated as necessary.

Measurement in adverse weather conditions is not recommended. Advice on suitable conditions has been given elsewhere[2]. A microphone wind shield of a type which does not appreciably affect the overall system response should be used in all measurements.

The choice of measurement site, microphone height and position may be dictated by particular circumstances but in general care should be taken to avoid the influence of obstructions and reflecting surfaces. Allowance may need to be made for the ground effect where appropriate. Precautions should be taken to ensure that the values measured correspond to the noise being investigated and are not due to extraneous noise sources or electrical interference.

The measurements should be carried out by competent staff and detailed records kept. Useful advice on such records and on other general aspects of noise measurement will be found in several references[3, 4, 5].

3.2 Determination of L_{eq}

The method adopted and the equipment used for the determination of L_{eq} will depend mostly on the temporal variations of noise level, but also in practice on the resources available and the period over which the noise is to be measured. The methods which are described in this chapter are the most straightforward ones available in the respective cases. It is of course possible to use the more sophisticated methods for simpler noises but large errors may result from attempting to apply the simpler kinds of measuring equipment to complex noises for which they are not intended, particularly where impulsive noise is concerned.

The methods of measurement described below are intended for use in continuous monitoring or recording of noise. Various sampling procedures can be employed to minimise the amount of magnetic tape used or, in the case of instrumentation giving a direct reading of L_{eq} to allow the use of a single instrument at more than one location in a given period. In the case of traffic noise optimum sampling procedures have been devised by Fisk[6] but little general advice can be given for other types of noise apart from construction noise.[7]

Steady Noise

When the noise is steady a sound level meter on its own, set to SLOW, may be used to measure L_{eq} directly. Steady noise is here defined as noise having maximum fluctuations of ±4 dB. Any fluctuations within the maximum of ± 4 dB should be averaged by eye. If this averaged level remains substantially unchanged throughout the period of interest, the indicated reading is numerically equal to L_{eq} for that period.

Noise which changes in level from time to time, remaining steady at each separate step, can also be measured adequately with a sound level meter. The separate levels should be determined and their durations ('on-times') noted from a stopwatch/timer. The period of measurement should be chosen so that the distinguishable levels observed during the measuring period can be combined to form L_{eq} for the period. To do this the duration of each distinguishable level should be expressed as a percentage of the total period of measurement. A correction should be made, using Fig 3.2.1, to convert each level to the equivalent continuous level over the period of measurement, and the corrected levels should then be combined to give a final value of L_{eq}. The procedure for combining the corrected levels is the conventional one for adding sound pressure levels. It can be readily seen from Fig 3.2.1 that the value of L_{eq} will remain unchanged if the noise level rises by 3 dB and the on-time is halved, or conversely if the noise level falls by 3 dB and the on-time is doubled.

Example

Fig 3.2.2 shows the pattern of noise levels from a factory during the period 0700 to 1700 hours over which L_{eq} is to be determined. At a particular measuring position the sound pressure level assumes three values at different times during the period of measurement. Noise A has a continuous level of 60 dB(A) throughout the period. Noise B comprises this continuous noise plus noise from riveting, typically present for two separate half hour periods and has a measurable level of 65 dB(A). Noise C comprises the continuous noise plus the noise of hammering and occurs typically for one half hour period at a level of 75 dB(A).

The duration corrections should be applied as follows (using Fig 3.2.1):

Noise	Sound pressure level	Percentage 'on-time'	Correction	Corrected level
A	60 dB(A)	85%	−1 dB	59 dB(A)
B	65 dB(A)	10%	−10 dB	55 dB(A)
C	75 dB(A)	5%	−13 dB	62 dB(A)

Combining the corrected levels of 59, 55 and 62 dB(A) (by combining 59 and 55 dB(A) and then combining the result with 62 dB(A), using Fig 3.2.3) gives a single value of 64.3 dB(A) as L_{eq} for the period.

Fluctuating Noise

When the noise has fluctuations of level greater than ± 4 dB it no longer becomes possible to obtain an accurate measure of L_{eq} by a visual averaging from a sound level meter. In addition to the difficulty of reading widely fluctuating levels the visual average of the meter needle is in no fixed relation to L_{eq}; the error is unpredictable as it depends on the time-dependence of noise level, but the reading often turns out to be closer to L_{50} than L_{eq}. The difference between the reading and the true value of L_{eq} will increase as the noise becomes more variable and a common source of error results with impulsive noise when the electrical circuits of the meter become overloaded.

A sound level meter may still be used to obtain L_{eq} for fluctuating noise but it is necessary to sample the noise by taking spot readings of the meter at frequent intervals. An attachment which illuminates the meter scale every 4 seconds[8] makes the sampling of the noise somewhat easier. If the readings are grouped into 1 dB steps then L_{eq} is given by:

$$L_{eq} = 10 \log_{10} \left[\frac{1}{N} \Sigma f_i . 10^{L_{Ai}/10} \right] \text{ dB} \qquad \text{Eq (10)}$$

where A-weighted sound pressure level L_{Ai} occurs f_i times out of a total number of readings N. If a measure of L_{eq} is required over a long period then the use of a sound level meter on its own becomes impractical and it is necessary to sample the noise levels in another way.

There are three types of system which are in common use for statistical sampling of noise levels. The earliest of these employed an analogue tape recording and a block diagram of this system is shown in Fig 3.2.4. Tape recordings are replayed through a microphone amplifier and level recorder. Attached to the level recorder is a statistical analyser, which is a counter activated by the writing arm of the level recorder. The analyser enables the duration of exposure at various sound levels to be determined by automatically sampling the sound pressure level at fixed intervals during the measurement period. The numbers of counts are displayed in 12 channel counters with class intervals of 5, 2.5 or 1 dB. Provided that the class interval is not wider than 5 dB the class mid-point can be determined by the arithmetic mean of the end points of the interval. Larger intervals than 5 dB are not recommended. The value of L_{eq} is given by

$$L_{eq} = 10 \log_{10} \left[\frac{1}{100} \Sigma p_i.10^{L_{Ai}/10} \right] \quad dB \qquad Eq\,(11)$$

where L_{Ai} is the A-weighted sound pressure level of the mid-point of class i and p_i is the time interval (expressed as a percentage of the total time period) for which the sound level is within the limits of class i.

The second type of system uses a data logger which samples the sound pressure levels and converts them to digital form for recording on magnetic tape. Replay of the tape recording into a programmed desk calculator or computer yields L_{eq}. This method has the advantage of saving much replay time, economizing on tape and being suitable for long, unattended recordings; the disadvantage is that information is irretrievably lost, so that doubtful passages cannot be verified by replay.

The third type of system can be used either for direct measurements on site or for laboratory analysis of analogue tape recordings. This employs both sampling of sound pressure levels and parallel continuous integration and display of L_{eq}. Other statistical parameters, eg L_{10}, are calculated from the sampling data by the instrument itself and the results may be recorded by a printer. Two such systems have been described by Maling.[9]

Impulsive Noise

Noises which fluctuate rapidly in level over a wide range, including impulse and impact noise, can be measured by an integrating meter giving a direct reading of L_{eq}. This instrument combines within one unit a precision sound level meter, a signal accumulator store and an electronic clock. From the information held in the store, and the elapsed time, the meter calculates (and displays) L_{eq} for any desired time. The difference in this technique from those outlined in the previous sections is that noise levels are continuously processed (rather than sampled at intervals) throughout the whole period to yield a true overall value of L_{eq}. By sampling, the high energy content of some of the noise peaks of short duration might be missed. The meter should incorporate A-weighting in the measuring circuits and give a value of L_{eq} according to Eq (2) (see Chapter 2).

Specifications for integrating meters are in course of preparation. Meanwhile reference should be made to the requirements of BS 4197:1967 insofar as they apply. A dynamic range of at least 60 dB and preferably 80 dB is necessary when the instrument is required to measure impulsive noise. It is recommended that the instrument should be capable of measuring levels down to 40 dB(A) and that it should incorporate an instantaneous overload indicator. Equipment of this kind using digital circuitry and achieving the large dynamic range by fast autoranging techniques is available commercially.[10]

3.3 Measurement of L_{AX}

Elsewhere in the Guide some values of the single event noise exposure level L_{AX} are given but there will be a need to supplement these by measurement. There are two types of situation in which such measurements are liable to be required. The purpose might be to determine L_{eq}, at a particular location or locations, due to the repetition of a known number of measurable events. L_{AX} values can be obtained for the events and L_{eq} calculated using the equations in Chapter 2 without the necessity for long-term measurement. Alternatively values of L_{AX} at one position may be used in an estimation procedure to allow calculation of L_{AX} and hence L_{eq} at some other position(s). The general points about noise measurement already made apply in both these cases. In the latter case meteorological factors and non-acoustic variables characterizing the source, eg vehicle speed, distances, etc, must be carefully monitored and noted. In general peak sound pressure levels of events should be at least 10 dB and preferably 15 dB above the highest levels from other noise sources at the time of the measurement.

There are various approaches to the evaluation of L_{AX}, depending on the resources available. One approach is that of a direct determination from the integral form in Eq (6) or Eq (4) (see Chapter 2). This can be achieved with a purpose-built integrator or with a noise-dose type device similar to that described in Section 3.2 for measuring L_{eq} but omitting the electronic clock and the time averaging. Alternatively a data-logging type of device linked to a computer or calculator can be used to perform the integration by summation using the sampled values of A-weighted sound pressure level during a single event. A real time analyser/computer system of the kind employed in calculations of effective perceived noise level, L_{EPN}, can be used in this way.

The level recorder/statistical analyser combination referred to above for L_{eq} can also be used but with the result derived from a slightly different equation, thus:

$$L_{AX} = 10 \log_{10} \left[\frac{1}{R} \Sigma n_i.10^{L_{Ai}/10} \right] \quad dB \qquad Eq\,(12)$$

where L_{Ai} is as defined previously, n_i is the number of counts in class i and R is the sample rate. It is advisable to use a sample rate of at least 2 per second and the smallest possible class interval.

If a statistical analysis is not available the level recorder trace of A-weighted sound pressure level for a single event can be 'sampled' manually at intervals of Δt seconds and the resulting N samples of L_A used in the equation

$$L_{AX} = 10 \log_{10} \left[\Delta t \sum_{i=1}^{N} 10^{L_{Ai}/10} \right] \quad dB \qquad Eq\,(13)$$

Where equipment such as the integrating unit referred to above is used, giving a value of L_{eq} during a single event, L_{AX} can be determined if the time t (seconds) for which the integration is performed is known. It can be seen from Eq (3) and Eq (6) in Chapter 2 that in that case $L_{AX} = L_{eq} + 10 \log_{10} t$.

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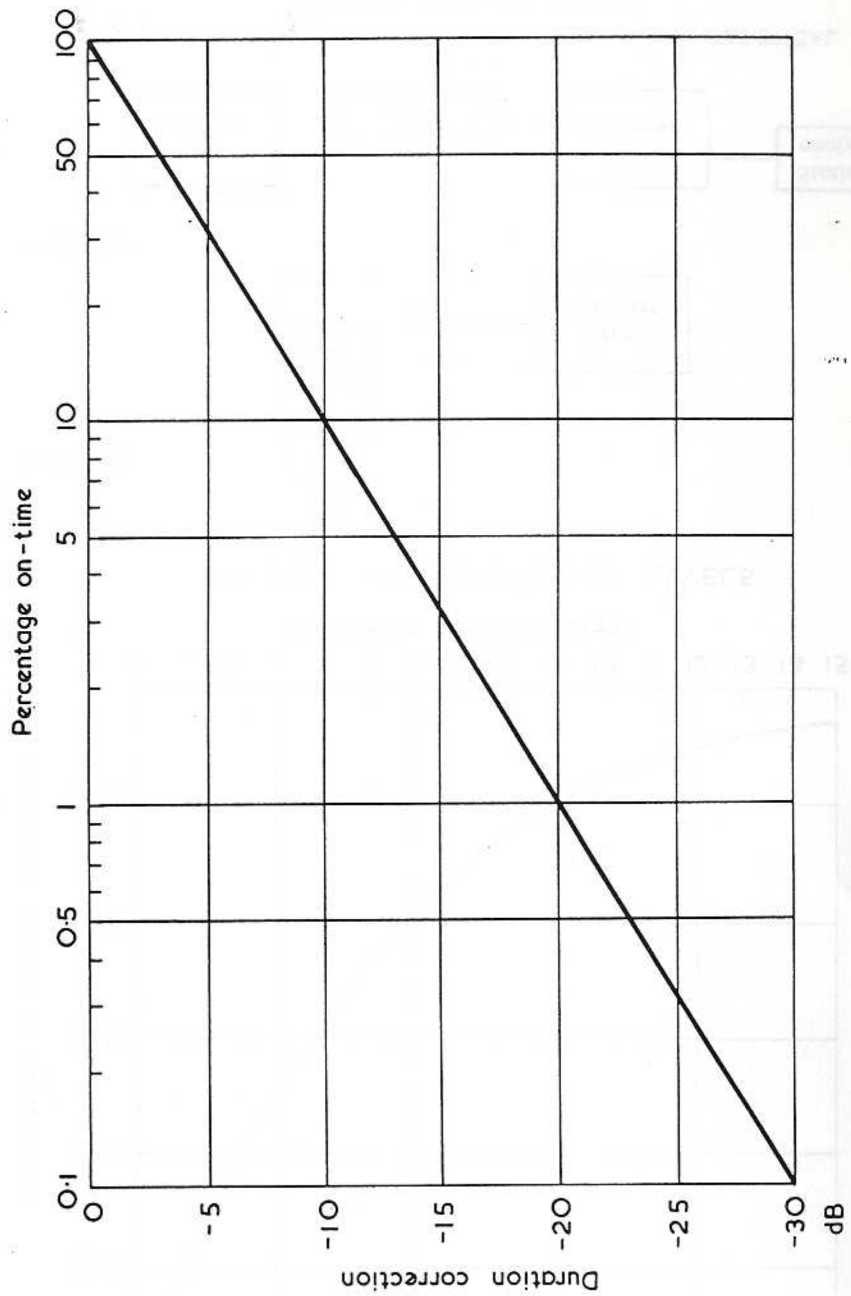

FIG. 3.2.1. CORRECTION TO MEASURED NOISE LEVEL FOR PERCENTAGE ON-TIME

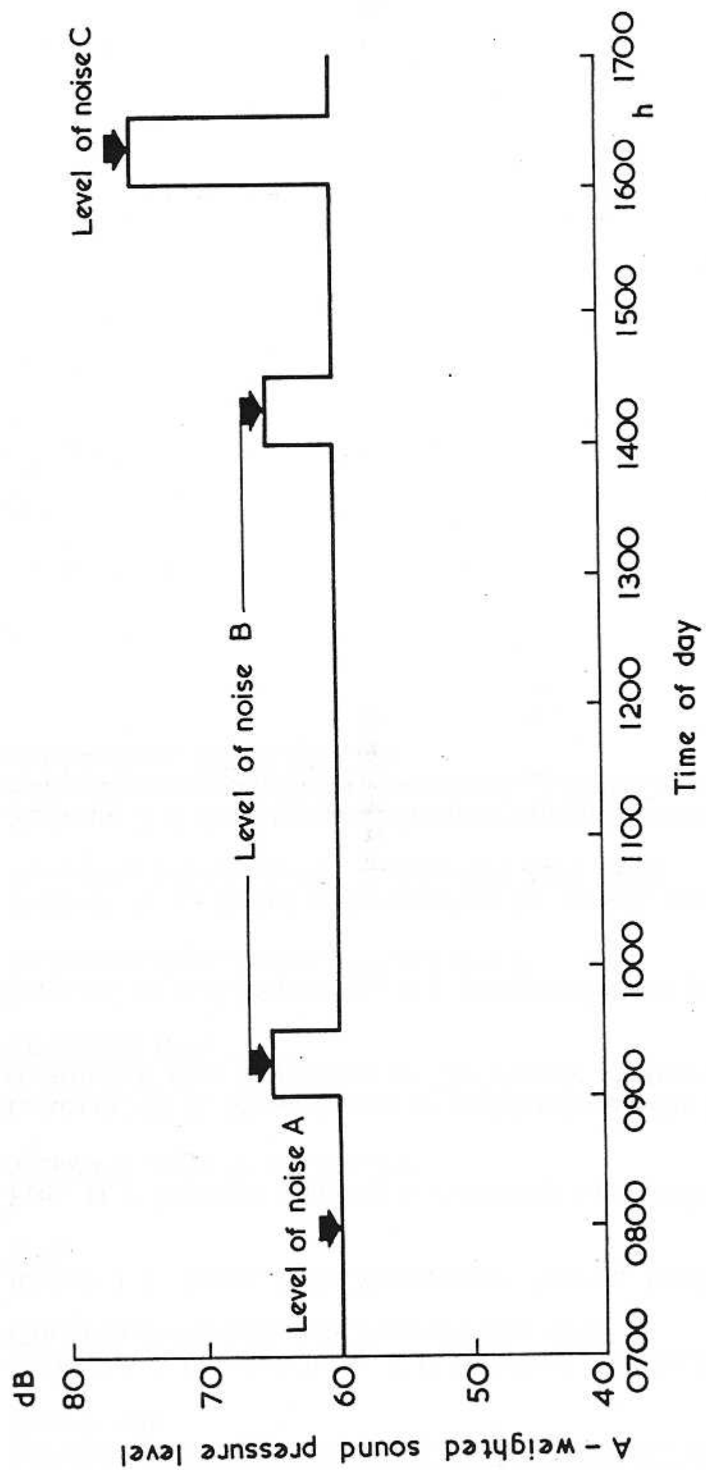

FIG. 3.2.2. HYPOTHETICAL NOISE PATTERN

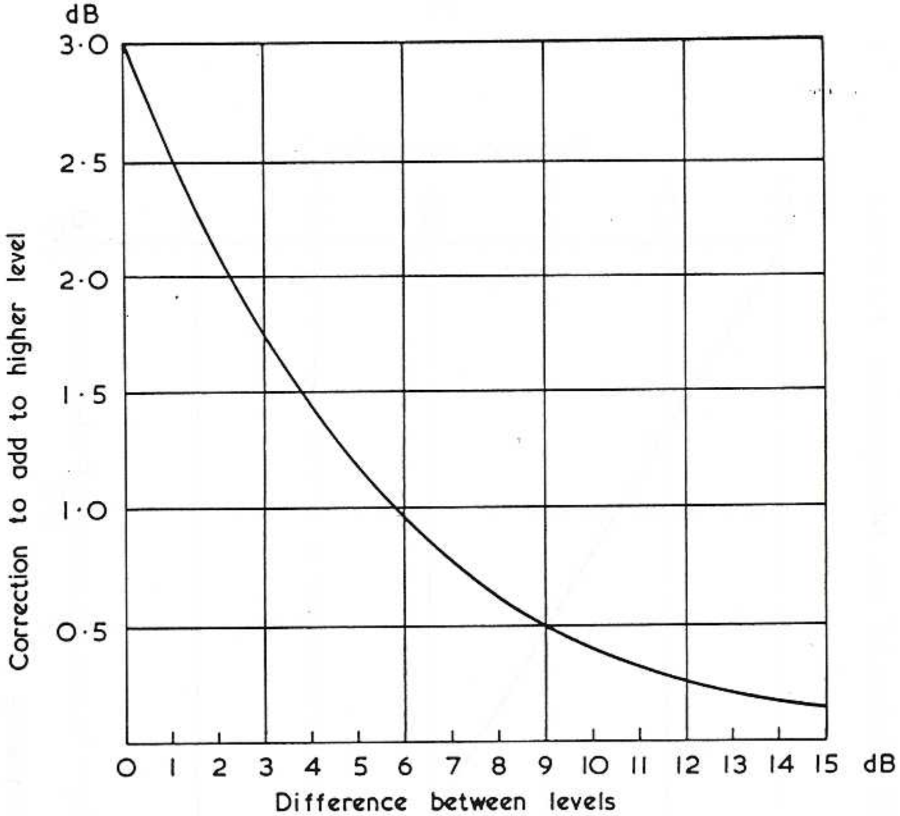

FIG. 3.2.3. COMBINATION OF LEVELS

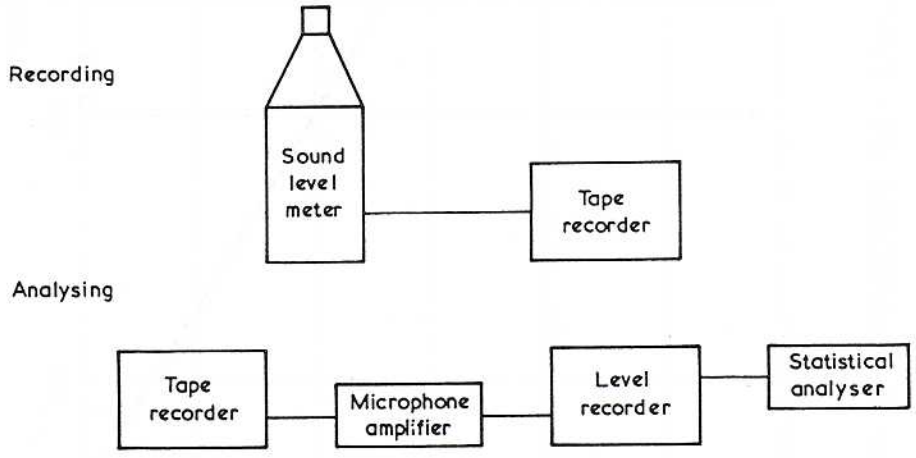

FIG. 3.2.4. BLOCK DIAGRAM OF EQUIPMENT FOR STATISTICAL ANALYSIS OF NOISE LEVELS

4 PREDICTION OF THE NOISE

4.1 Road traffic noise

General model for L_{AX}

Road traffic consists of the movement of a collection of discrete vehicles and traffic noise is the sum of the individual vehicle noises. Thus if the energy* associated with a single event (passage of one vehicle) is known it is easy to calculate L_{AX} for the event and hence L_{eq} for any number of events.

It is shown in Appendix 4.1.A that the single event noise exposure level for an idealized vehicle may be expressed as:

$$L_{AX} = L_o(v) - 10\log_{10}v - 10(F-1)\log_{10}d + 10\log\theta + 5.5 \quad \text{dB} \qquad \text{Eq (14)}$$

where $L_o(v)$ is the A-weighted sound pressure level as measured at 7.5 m from the vehicle centre line expressed as a function of vehicle speed v in km/h, F is an attenuation parameter, the value of which depends on the type of ground cover, d is the shortest distance from the position of interest to the vehicle trajectory (see Fig 4.1.A) and θ is the angle subtended by the trajectory in degrees. Specific forms of the function $L_o(v)$ are given in Fig 4.1.1 for various vehicle categories[1] and Fig 4.1.2 shows values of F for various ground cover types[2].

This model could be applied in various situations, involving different vehicle types, provided information on speed-level relationships of the form of Fig 4.1.1 was available or obtainable by measurement. A similar model has recently been developed for application to road construction noise[3].

Prediction of L_{eq}

It is possible, using as a basis the general model for L_{AX} discussed above, to develop a prediction scheme for L_{eq} which is an adaptation of the scheme[4, 5] developed for L_{10}. Thus a 'basic noise level', L_{eq}, at 10 m from a road is first derived. It is helpful to this end to reduce the number of categories of vehicles for which values of L_{AX} are to be established.

In traffic forecasts for long term forward planning the composition of the future traffic stream can usually be estimated in terms of only two vehicle categories, light vehicles with unladen weight up to 1525 kg and heavy vehicles above this. Thus the heavy vehicle class will include the five heaviest categories shown in Fig 4.1.1. Using 1974 traffic data on the composition of the heavy vehicle class in terms of the five categories it is possible to weight the 'energies' corresponding to the levels in Fig 4.1.1 and sum them to derive the speed-level relation for an 'average' heavy vehicle. This is shown in Fig 4.1.3, which also reproduces the relation for the light vehicle class.

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*Strictly the quantity concerned here is (sound pressure)^2 × time, unit Pa^2.s, which is proportional to the sound energy received at the point.

L_{AX} values for heavy vehicles and light vehicles can now be established by using Eq (14). It is assumed that the ground between the kerb and the reference point at 10 m is hard, in which case F = 2. θ takes its limiting value for a complete linear trajectory, 180°. The 10 m is measured from the kerb and the traffic from multi-lane roadways is considered as being compounded into a single lane 3.5 m from the kerb, hence d = 13.5 m. Because of this compounding of traffic lanes the resulting values of L_{AX} must be reduced by 0.4 dB to allow for the reduction in level with distance going from near to far lanes. The function $L_o(v)$ in equation 4.1.1 is obtained from Fig 4.1.3, for the two classes of vehicle. Thus values of L_{AX} are obtained as a function of speed and these are plotted in Fig 4.1.4.

In any particular case, if the mean traffic speeds for each vehicle category are known, the values of L_{AX1} and L_{AX2} for light and heavy vehicles respectively can be derived from Fig 4.1.4. Then, if the total vehicle flow is N in the period of interest T (seconds) and the percentage of heavy vehicles is p, the value of L_{eq} at 10 m is given by:

$$L_{eq} = 10\log_{10}\left\{\frac{1}{T}\,\frac{N}{100}\left[p.10^{L_{AX2}/10} + (100-p)10^{L_{AX1}/10}\right]\right\} \qquad \text{Eq (15)}$$

This procedure emulates charts 2, 3 and 4 of the L_{10} procedure[4] and, with the addition of corrections for gradient and road surface (charts 5 and 6 of the L_{10} procedure[4]) the 'basic noise level' at 10 m is determined.

Finally the remaining steps in the L_{10} procedure can be applied to take account of distance, screening etc between the reference position at 10 m from the kerb and the observer. However it should be appreciated that the specific form of these corrections[5] is derived from work on L_{10} and there are minor differences in the influence of propagation effects as between L_{10} and L_{eq}. On the question of barriers see for example the work of Fisk[6]. Further work is necessary to evaluate these differences in detail but in the meantime the procedure outlined above forms a useful basis for the calculation of L_{eq}.

Alternative approaches

One alternative to the above is to predict the L_{10} value using the existing procedure and then to perform a conversion to L_{eq} at the final stage using, for example, the methods discussed in Chapter 5 of this Guide. It should be noted that the uncertainty involved in predicting L_{10} by the current procedure is generally greater than the uncertainty in the translation from L_{10} to L_{eq}. The use of a 'final stage' translation approach does not therefore have a great effect on the overall prediction accuracy.

It is interesting to consider the methods used in other countries where L_{eq} is already the accepted noise scale. A Swedish design guide has been published[7]. This makes use of a mathematical model, similar to that described in Appendix A from which analytical expressions for L_{eq} as a function of speed, distance etc are derived. To fix design curves to absolute levels use is made of empirical data from measurements of L_{eq} at various distances. By this process a design diagram is developed giving L_{eq} at 100 m as a function of mean speed and number of vehicles. Further corrections are then made for other distances, receiver heights (incorporating ground effects), gradients, façades and barriers.

A different approach has been taken by Jonasson[8] in that the concept of L_{AX} is in effect retained in the treatment of propagation effects, distance, barriers, etc. L_{eq} at the required point is obtained by combining the corrected L_{AX} values.

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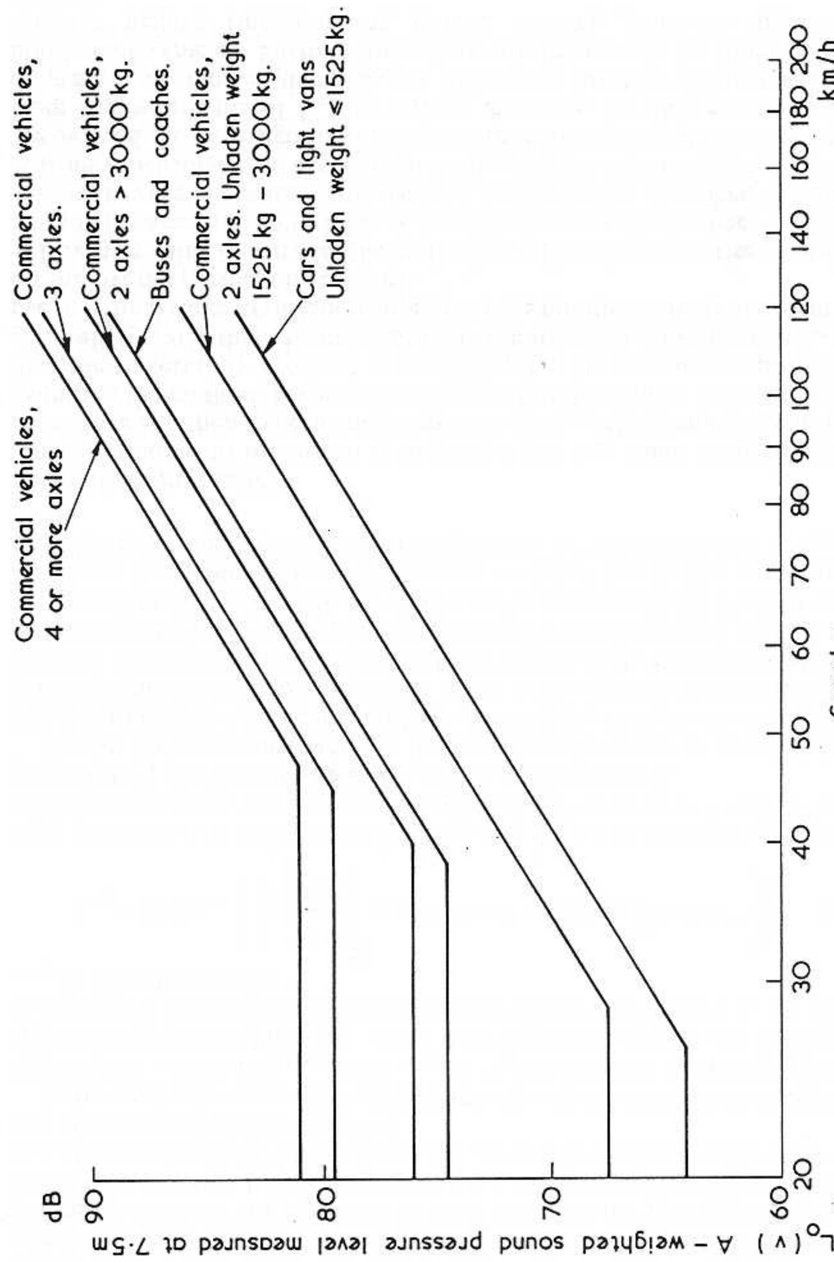

FIG. 4.1.1. RELATIONSHIPS BETWEEN NOISE LEVEL AND SPEED FOR VARIOUS VEHICLE CATEGORIES

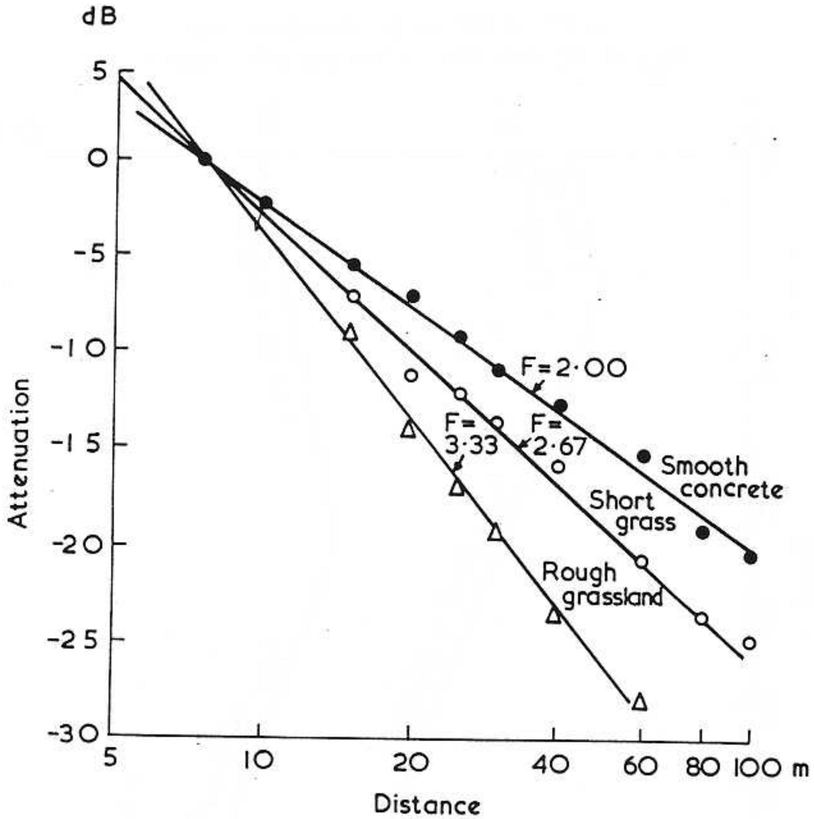

FIG. 4.1.2. ATTENUATION WITH DISTANCE CHARACTERISTICS FOR VARIOUS GROUND SURFACES

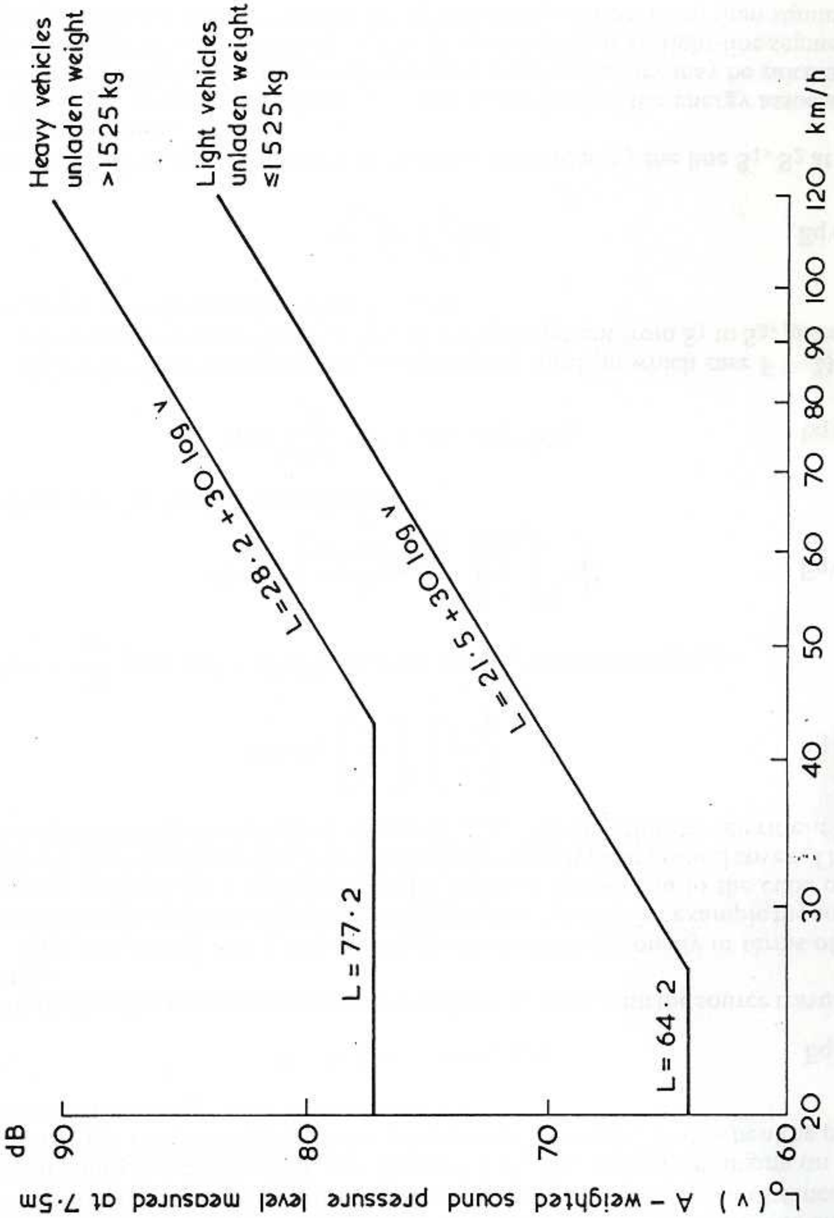

FIG. 4.1.3. RELATIONSHIPS BETWEEN NOISE LEVEL AND SPEED; 2 CATEGORIES BY WEIGHT

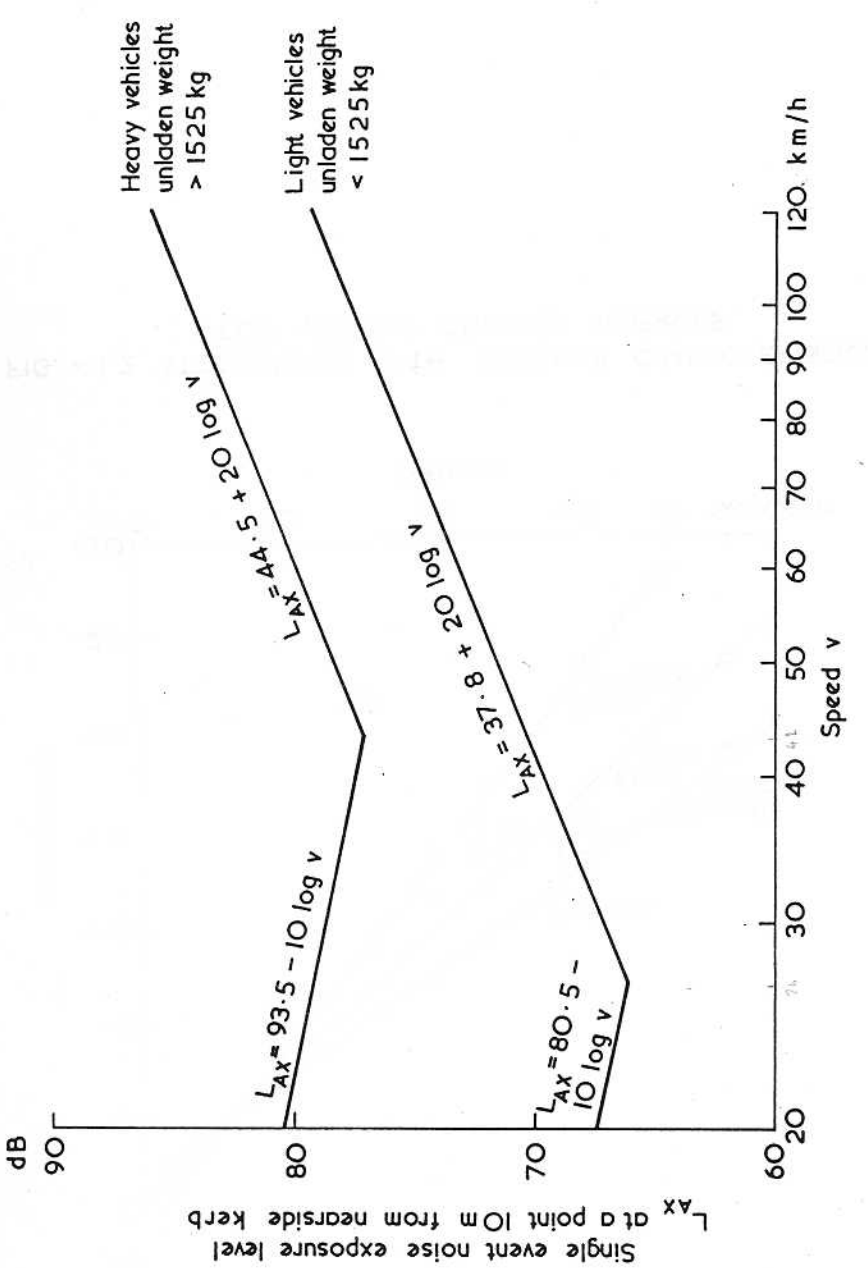

FIG. 4.1.4. RELATIONSHIPS BETWEEN L_{AX} (AT 10 m) AND SPEED

Appendix 4.1.A. Single event noise exposure level (L_{AX}) for an idealized vehicle.

The sound energy received at a specified point due to a single vehicle may be calculated if the vehicle is idealized as a point source of sound, moving at uniform velocity v along the straight trajectory S_1, S_2 which is a distance, d, from some reception point, see Figure 4.1.A. The energy impinging on unit area at the reception point in the infinitesimal interval t, t+dt when the point source is at range r may be expressed as:

$$dE = I_o \, f(r, r_o) \, g(v, v_o) \, dt \qquad \text{Eq (16)}$$

where I_o is the source intensity measured at a range r_o with the source travelling at v_o.

The functions f and g can be expressed non-dimensionally in terms of the variables r/r_o and v/v_o raised to certain powers F and G. For example the sound power radiated by a vehicle generally varies in proportion to the cube of its speed. The variation with distance depends on the type of ground cover. This is incorporated by changing the value of F. Eq (16) may thus be rewritten:

$$dE = I_o \left[\frac{r_o}{r}\right]^F \left[\frac{v}{v_o}\right]^G dt \qquad \text{Eq (17)}$$

Now $v = \dfrac{ds}{dt}$ and $r = (s^2 + d^2)^{1/2}$, thus Eq (17) may be transformed to

$$dE = I_o \left[\frac{r_o}{(s^2 + d^2)^{1/2}}\right]^F \left[\frac{v}{v_o}\right]^G \frac{ds}{v} \qquad \text{Eq (18)}$$

which may be further simplified to:

$$dE = \frac{I_o r_o{}^F}{v_o{}^G} \, v^{G-1} (s^2 + d^2)^{-F/2} ds \qquad \text{Eq (19)}$$

When the intervening terrain is acoustically hard (in which case F = 2) the total energy E received during the vehicle's movement from S_1 to S_2, given by integration with respect to distance s, is:

$$E = \frac{I_o r_o{}^2}{v_o{}^G} \, \frac{v^{G-1}}{d} \, \theta \qquad \text{Eq (20)}$$

where θ is the angle, measured in radians, subtended by the line S_1, S_2 at the reception point.

Provided appropriate values of I_o and G are known the energy associated with movement at varying speeds along a curved trajectory may be calculated by dividing the trajectory into a series of approximately straight-line segments along which the vehicle velocity is approximately uniform and then summing the segment energies.

The integral expression given in Eq (20) is rigorously valid only for the case where sound is transmitted to the receiver over acoustically hard ground.

However experience with the prediction of L_{10}, the level exceeded for ten percent of time, suggests than an adequate prediction may be obtained by only a slight modification to Eq (20), to allow for other types of ground cover:

$$E = \frac{I_o r_o^2}{v_o^G} \frac{v^{G-1}}{d^{F-1}} \theta \qquad \text{Eq (21)}$$

The single event noise exposure level, L_{AX}, is given by

$$L_{AX} = L_o + 20 \log_{10} r_o - 10G \log_{10} v_o + 10(G-1)\log_{10} v - 10(F-1)\log_{10} d + 10 \log_{10}\theta \qquad \text{Eq (22)}$$

where L_o is the maximum A-weighted sound pressure level of a vehicle travelling at v_o(m/s) at a range r_o(m) and the units of the other variables are m, m/s and radians.

If the speeds are expressed in km/h and θ in degrees, and the value $r_o = 7.5$ m is inserted, we obtain:

$$L_{AX} = L_o(v) - 10 \log_{10} v - 10(F-1) \log_{10} d + 10 \log_{10}\theta + 5.5 \qquad \text{Eq (23)}$$

where $L_o(v) = L_o + 10G \log_{10} (v/v_o)$.

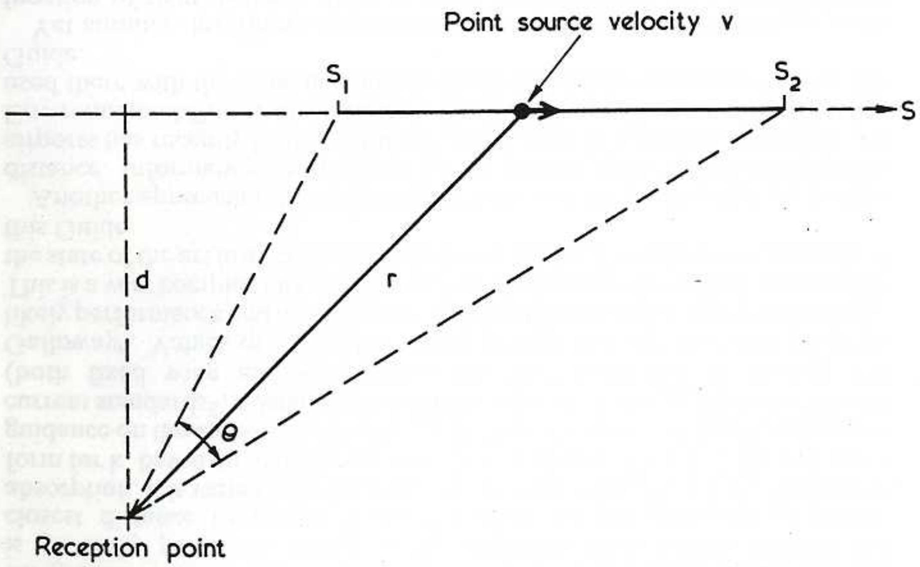

FIG. 4.1.A IDEALISED VEHICLE TRAJECTORY

4.2 Aircraft noise

Introduction

There are a number of basically similar methods for estimation of L_{eq} for the noise environment due to air traffic. These are accepted and used outside the UK, for example in West Germany[1], and the topic is the subject of current research both in the UK and elsewhere[2]. The task is inherently more complex than in the case of road traffic noise, because the number of categories into which aircraft types fall for noise purposes is greater, take-off and landing procedures are such that a number of phases of the flight envelope have to be considered separately, and propagation has to be considered in three dimensions rather than in two. The procedure essentially is to estimate L_{AX} for aircraft (identified either by individual type or by some broad categorization) affecting each position of interest and then to combine such data according to the operational pattern which is to be followed to obtain the value of L_{eq} during the period of interest. This section of the Guide only describes the broad approaches to be followed and reference is made to sources of information.

Determination of L_{AX} values

There are a number of acoustical factors to be considered, including the source noise levels of each aircraft or class of aircraft, the propagation of noise from aircraft to observer, and duration effects. Different methods are available for incorporating these factors in the estimation of L_{AX}. Thus complex methods have been developed, for example by van Niekerk[3], in which propagation effects are calculated on the basis of noise source characteristics in terms of ⅓-octave band sound pressure levels. Approximate methods, which treat both noise source characteristics and propagation effects in terms of weighted sound pressure levels, are simpler but are more restricted in application. The choice between these various methods is a question of balancing the degree of complexity with the accuracy required of the final estimate and the availability of input information. For the purposes of this Guide methods are described which are adequate for general planning purposes.

One method is a modification of the current Civil Aviation Authority (CAA) procedure for estimating NNI[4]. The noise level of an aircraft is expressed as a reference single event noise exposure level (L_{AXO}) at a reference distance (d_o) using the procedure specified in ISO 3891[5]. Separate values of L_{AXO} are required for different types or classes of aircraft and for the different power or thrust settings used in the various phases of flight. For general planning purposes these reference levels could be averaged to take account of slight differences in noise characteristics of aircraft types within a class and of variation in aircraft weight, airline operating procedures and weather conditions. The reference level may be regarded as that which would be received on the ground directly under the flight path from an aircraft overflying at a height of d_o.

The value of L_{AX} at a point of interest is then obtained from the equation:–

$$L_{AX} = L_{AXO} - k \log(d/d_o) \qquad \text{Eq (24)}$$

where d is the estimated slant distance and k is an attenuation constant incorporating wave divergence and the approximate effects of atmospheric and ground absorption. Calculation of slant distance from knowledge of the flight path is illustrated in Fig 4.2.1. It should be noted that in some contexts the term slant distance refers to the time-dependent distance from aircraft to observer. In this Guide it refers to the distance from aircraft to observer at the time when the ground track is closest to the observer. Use of this particular slant distance is generally preferred, being readily calculable from aircraft altitude and closest distance to ground track. To allow for the influence of ground absorption, k is varied with the angle of elevation ϕ (see Fig 4.2.1). A tentative form for k, based on limited empirical data, is given in Fig 4.2.2. As well as the guidance on the measurement of L_{AX}, given in Chapter 3 of this Guide, and in current standards[5], a detailed guide to the acquisition of L_{AX} values for aircraft (both fixed wing and helicopters) has been published by Bishop and Galloway[6]. Values of L_{AXO} for future aircraft may be estimated from the likely performance and noise output, making allowances for future technology. This is a very complex task which requires special expertise and a knowledge of the state of the art in aircraft engine technology; details are beyond the scope of this Guide.

Another approach is to use published curves or tables relating L_{AX} to slant distance. Information in this form for all aircraft types using United States airports has recently been published[7] and is used in a guide prepared for the Environmental Protection Agency[8], the term "sound exposure level" being used there with the same meaning as single event noise exposure level in this Guide.

Yet another, less direct, approach is to use published values of L_{Amax} as a function of slant distance, such as those resulting from the "Aircraft Noise Definition" project[9, 10, 11], together with estimates of τ, the 10 dB down time (see Section 2.4). L_{AX} is then estimated from:

$$L_{AX} = L_{Amax} + 10 \log(\tau/2) \qquad \text{Eq (25)}$$

An estimate of τ can be obtained if the airspeed is known using the approximation[12]

$$\tau = 3.66\ (d/v) \qquad \text{Eq (26)}$$

where d is slant distance and v is airspeed, in metres per second if d is expressed in metres.

Operational factors affecting the noise environment
A number of aircraft operational factors have to be taken into account in the calculation of L_{eq}. Every airport is unique in its pattern of operations and the particular information must be gleaned from a number of sources.

(i) Type of aircraft
Depending upon the scale of the problem it may be necessary to identify specific aircraft types, but it may suffice to categorize jet aircraft by broad groups according to noise output, number of engines, operating range, etc. An example of the latter is the grouping used in a recent consultation document[13], where there was a broad sub-division into short range, medium range and long range types followed by a finer classification according to passenger-carrying capacity.

(ii) Number of each type
Information on total traffic, classified by aircraft type, might be obtained from statistics of the kind compiled by British Airports Authority in their annual reports or from other airport operators. For studies of future situations numbers will depend on predictions of such factors as total passenger demand, aircraft capacity and operational load factors.

(iii) Runway usage/flight routeing
These factors, which affect the ground track followed by an aircraft, are dependent upon such considerations as local wind conditions, ultimate destination of aircraft, minimum noise routes, navigational aids, pilot behaviour and Air Traffic Control (ATC) constraints. Furthermore allowance should be made for a dispersion of aircraft around a nominal path.

(iv) Take-off/approach profiles
The profiles combine information on aircraft altitude and distance along the ground track (the projection of the flight path vertically downwards to the ground) with information on engine power and airspeed, if appropriate, at various phases of each operation. In a number of accounts of noise estimation methods, idealized profiles for various aircraft classes have been published[14]. The results of studies in the United States[15] allow profiles to be determined from information given on aircraft performance. In practice the profile flown will depend on factors other than aircraft performance, in particular ATC constraints and individual piloting procedures. For various reasons therefore, it is not practicable to give "standard" profiles in this document. One approach which is applicable to existing operations is the use of observation by photographic or radar tracking techniques to allow accumulation of "average" profiles for typical operations.

Prediction of L_{eq}
In principle the prediction of L_{eq} for the noise environment due to air traffic operating from an airport follows the equations given in Chapter 2. It must be recognized, however, that the estimation may be needed for one or more of a variety of purposes and that the technique to be adopted must be tailored to suit. Thus for an existing airport it may be required to establish zones for the purpose of planning policy or for assessing eligibility for sound insulation. It may be required to evaluate the effects of changes in operational factors such as runway usage or take-off/approach procedure. In other situations the noise impact of a hypothetical new airport may need to be assessed. The actual estimation procedure to be used will depend on the particular problem posed and on the information available. The Department of Trade, Branch CAP5, The Adelphi, John Adam Street, WC2—or, for military airfields, the Ministry of Defence, Division S4 (Air), Main Building, Whitehall, SW1—will be ready to advise on request.

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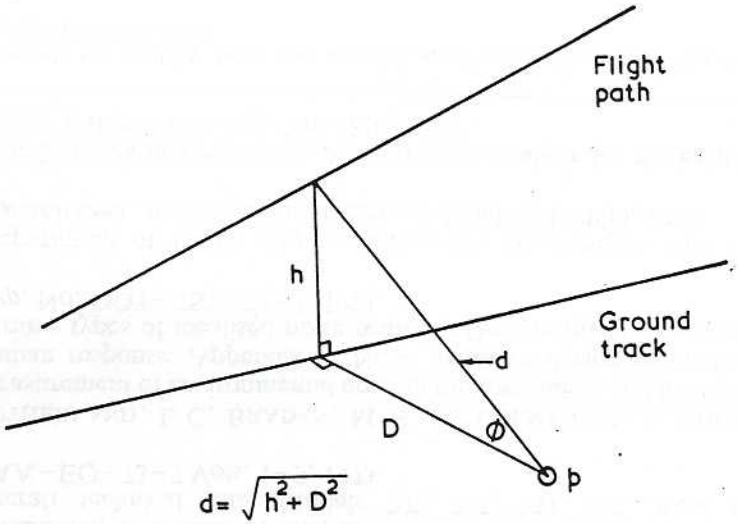

FIG. 4.2.1. CALCULATION OF SLANT DISTANCE d BETWEEN POINT p AND FLIGHT PATH

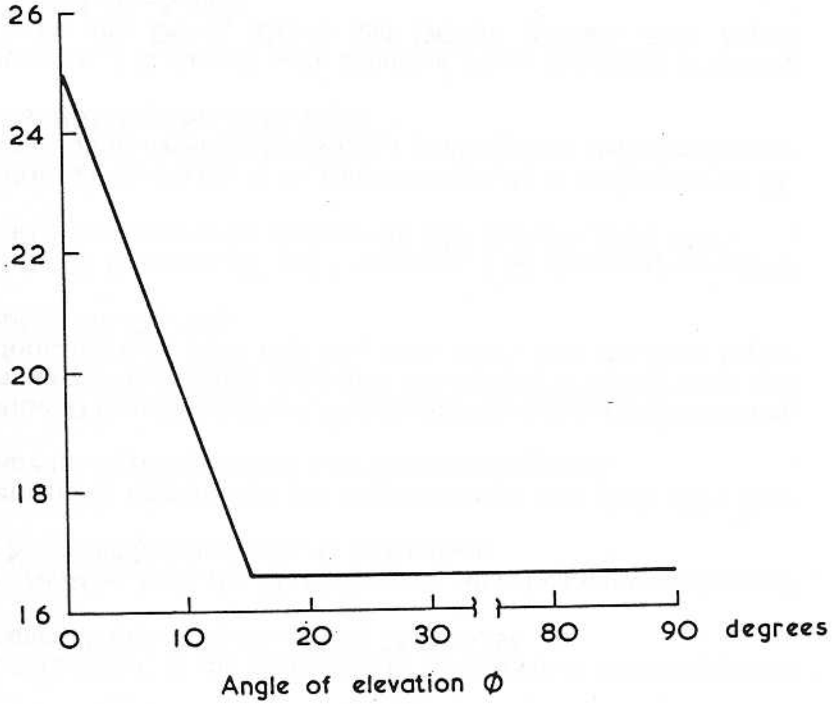

FIG. 4.2.2. VARIATION OF ATTENUATION CONSTANT k WITH ANGLE OF ELEVATION Ø

4.3 Railway noise

Introduction

This section of the Guide is concerned only with estimating noise from trains in motion. Various fixed or temporary installations, eg track maintenance equipment, stationary locomotives etc, involved in railway operations are sources of noise but these are best dealt with by the methods of section 4.4. British Rail has undertaken surveys of a wide range of such equipment and a large body of information has been collected[1].

The noise sources on moving trains which have to be considered are the locomotive for low speed operation, particularly with diesel traction, and the rail/wheel interaction (for all operations). Information is therefore presented for both these sources.

Determination of L_{AX} values

We consider first the basic case of propagation over unobstructed ground where the track is of continuously welded rail, on ballast, at ground level. The influence of variations from this condition and of additional factors, eg cuttings, are described later.

Fig 4.3.1 shows a typical sound pressure level/time history of the noise of a moving train. The level can be seen to comprise an initial rise to a maximum emanating from the locomotive (this maximum has been exaggerated in the diagram for clarity) followed by a plateau which is due to the rail/wheel source. For multiple unit stock there may be more than one power unit noise maximum. For multiple unit stock there may be more than one power unit noise maximum. The absolute and relative levels of the noise peak and the plateau depend on many factors. Rail/wheel noise is dependent upon train speed and for speeds in excess of 80 km/h it is usually the dominant source. Locomotive noise is more clearly linked with engine power setting, which is not solely a function of speed.

At present it is not possible to present either analytical or empirical data which would allow prediction of sound pressure level/time histories for all types of locomotive and rolling stock and for all situations. Mathematical models have been developed to predict L_{AX} for both rail/wheel noise and locomotive noise and some data will be given allowing prediction in certain cases, eg high speed passenger trains. In some cases, however, in the present state of knowledge, the models will need to be supplemented by resort to measurements of maximum sound pressure level. It should be noted that the separate values of L_{AX} for rail/wheel noise and locomotive noise should be combined to give a single value of L_{AX} for a given train pass-by.

(i) Locomotive noise

An analytical form for the sound pressure level/time history of locomotive noise has been given elsewhere[1]. This derives from a mathematical model in which locomotive noise is treated as a point source of sound with a cosine directivity pattern.

An expression for L_{AX1} for the locomotive noise alone, derived by integration from the model, is as follows:

$$L_{AX1} = L_{Amax1} + 10\log_{10}(d/V) + 8.6 \quad \text{dB} \qquad \text{Eq (27)}$$

where d is the perpendicular distance between the track and the receiver position, in metres, V is the train speed, in km/h, and L_{Amax1} is the maximum A-weighted sound pressure level at the reception point.

($L_{AX1}-L_{Amax1}$) from equation (27) is given in Fig 4.3.2 as a function of d and V. Thus, knowing these quantities and L_{Amax1}, L_{AX1} can be obtained. In many cases measurement of L_{Amax1} will be necessary but a limited amount of information on sound pressure levels L_{Amax1} at d = 25m for various British Rail diesel electric locomotives has been obtained[1] and is reproduced in Fig 4.3.3. The values given relate to maximum power output and predictions using these values are likely to be overestimates. These values of L_{Amax1} are not speed-dependent.

(ii) Rail/wheel noise

It has been shown[2, 3] that the sound pressure level/time history and hence L_{AX2} for the rail/wheel source can be predicted adequately from a mathematical model in which the sources are treated as a line of incoherent dipoles. Using this model the following expression for L_{AX2} has been derived:

$$L_{AX2} = L_{Amax2} + 10\log_{10}(L_t/V) - 10\log_{10}\left[\frac{4D}{4D^2+1} + 2\tan^{-2}\frac{1}{2D}\right] + 10.5 \quad \text{dB} \qquad \text{Eq (28)}$$

where L_{Amax2} is the maximum A-weighted sound pressure level at a distance d metres from the track, L_t is train length in metres, V is train speed in km/h and and $D = d/L_t$. This can be rewritten as

$$L_{AX2} - L_{Amax2} = 10\log_{10}(L_t/V) + C \qquad \text{Eq (29)}$$

The quantity C is plotted in Fig 4.3.4 as a function of $D = d/L_t$ and thus, provided the length and speed of train and the value of L_{Amax2} at distance d are known, L_{AX2} can be calculated.

In many cases measurements of L_{Amax2} will be necessary but data are available for British Rail Mk. II and Mk. III coaching stock used on high speed passenger trains. Fig 4.3.5 shows, for such stock, expected sound pressure levels (L_{Amax2}) as a function of speed, at d = 25 m. L_{Amax2} at other distances can be found from Fig 4.3.6. It should be noted that the latter curve is empirical, based on measurements over grassland. Depending on the type of ground cover and other factors the uncertainty in estimating L_{Amax2} at distant points may be large (± 10 dB) even where the uncertainty at the 25 m distance for the same trains is small (± 1.5 dB). The length of high speed passenger trains is typically 250 m and, using Fig 4.3.4, ($L_{AX2}-L_{Amax2}$) has been derived as a function of d and V and is given in Fig 4.3.7.

Example

As an example of the use of these curves for high speed trains consider a train of length 250 m using Mk II stock travelling at 160 km/h. We wish to know L_{AX2} at 100 m from the track. From Fig 4.3.5 we obtain L_{Amax2} = 96 dB(A) at 25 m and Fig 4.3.6 gives a correction of −10 dB, hence L_{Amax2} at 100 m is 83 dB(A). Fig 4.3.7 gives for V = 160 km/h and d = 100 m $L_{AX2}-L_{Amax2}$ = 8 dB. Hence L_{AX2} at 100 m is 91 dB.

(iii) Effect of track type/condition

The basic rail/wheel noise already discussed will be modified by various factors relating to the track and route, eg rail corrugations. These may need to be taken into account when using the data on high speed trains or in interpreting measurements made on one type of track for use in predicting the other situations. An indication of the magnitude of these modifications is given elsewhere[1].

(iv) Additional factors influencing propagation of the noise

(a) Housing development. The results of research on the propagation of railway noise in residential areas[4, 5] are summarised in Table 4.3.1. This indicates the likely reduction in maximum sound pressure level due to screening by various forms of housing development.

Table 4.3.1 Screening effects of houses on noise propagation

Type	Detached/ semi-detached	Terrace 150 m long	Terrace 300 m long	
No. of rows	1	⩾2	1	⩾2
Excess attenuation dB	8	12	15	17

(b) Cuttings. An indication of the effect of a track being in a cutting can be obtained from the work of Manning and Kurzweil[6] in which a correction factor is derived, ranging from 0 to 15 dB depending on the depth of cut and distance of receiver position from the cut. This particular treatment applies only to rail/wheel noise but similar theoretical treatments using image sources could be used for locomotive noise.

(v) Total L_{AX} for a train pass-by

It is necessary to add the component L_{AX}-values from the locomotive and the rail/wheel sources, adjusted as necessary for track type and condition and for propagation effects, in order to derive a single total value to represent the passage of each train. The expression for the total L_{AX} to represent the train pass-by is:

$$L_{AX} = 10\log_{10}\left[10^{L_{AX1}/10} + 10^{L_{AX2}/10}\right] \quad \text{dB} \qquad \text{Eq (30)}$$

Prediction of L_{eq}

L_{eq} for the noise at a receiver position due to railway operations over a period of time is determined from the equations in Chapter 2. The L_{AX} values used for this purpose are the total ones for the different types of train in operation. Adequate source noise data from different types of train may not be readily available—if they are not it will be necessary to make measurements.

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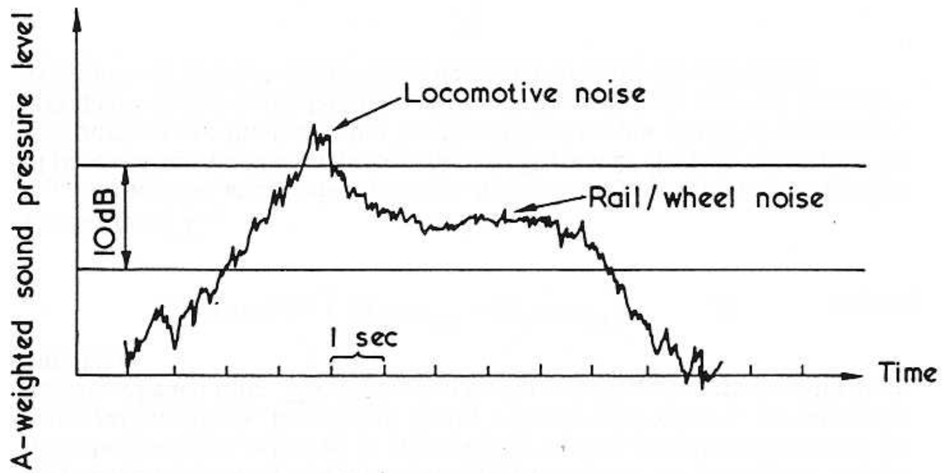

FIG. 4.3.1. TIME HISTORY FOR NOISE OF DIESEL-HAULED TRAIN

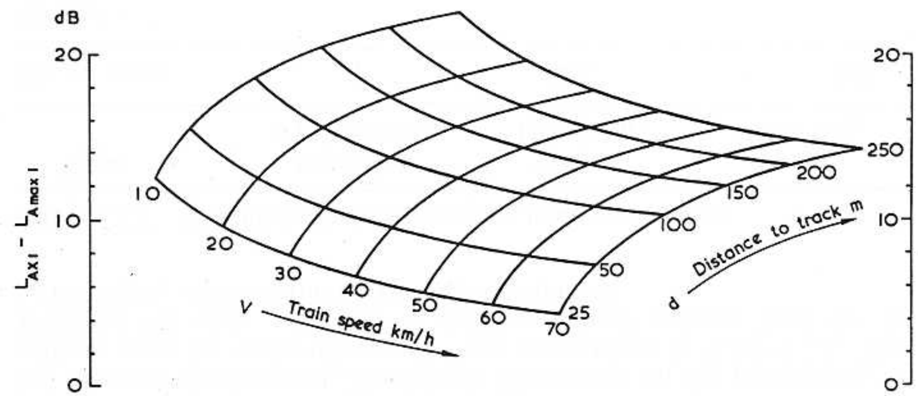

FIG. 4.3.2. $L_{AXI} - L_{Amax\,I}$ FOR LOCOMOTIVE NOISE

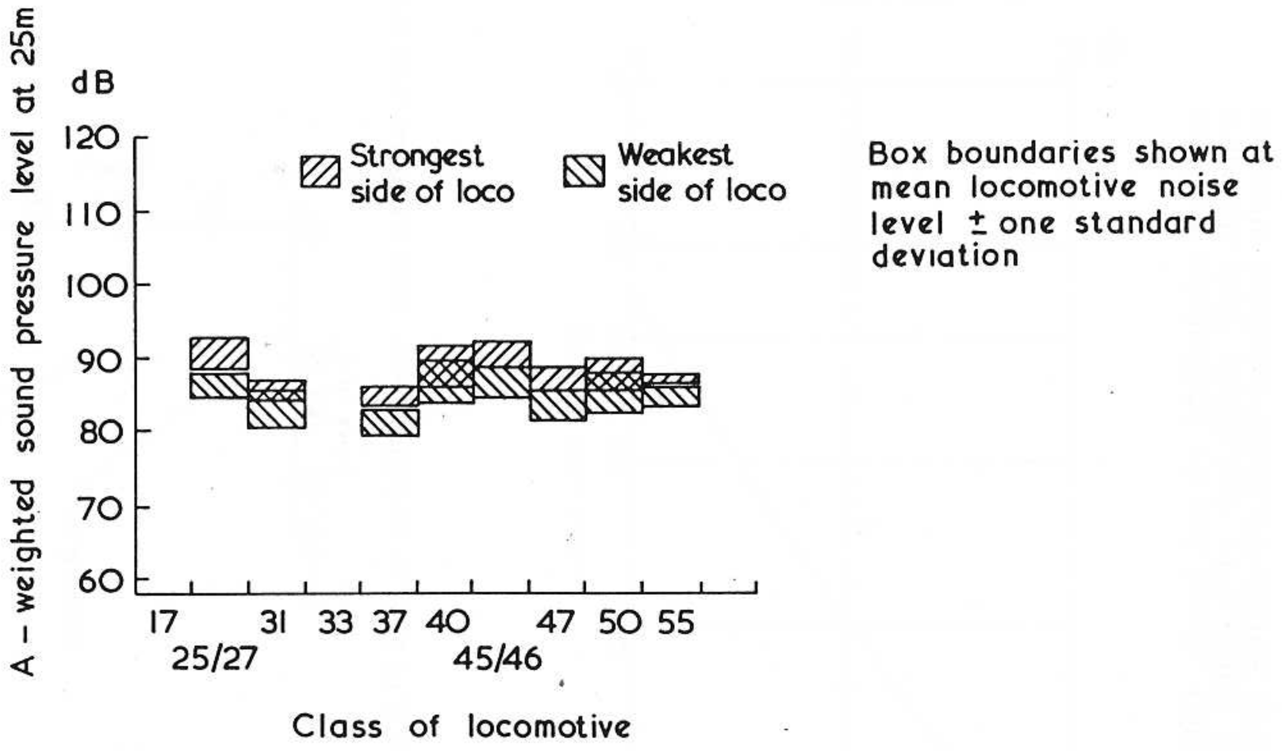

FIG. 4.3.3. MAXIMUM SOUND PRESSURE LEVELS FOR VARIOUS BRITISH RAIL LOCOMOTIVE TYPES. (DIESEL ELECTRICS.)

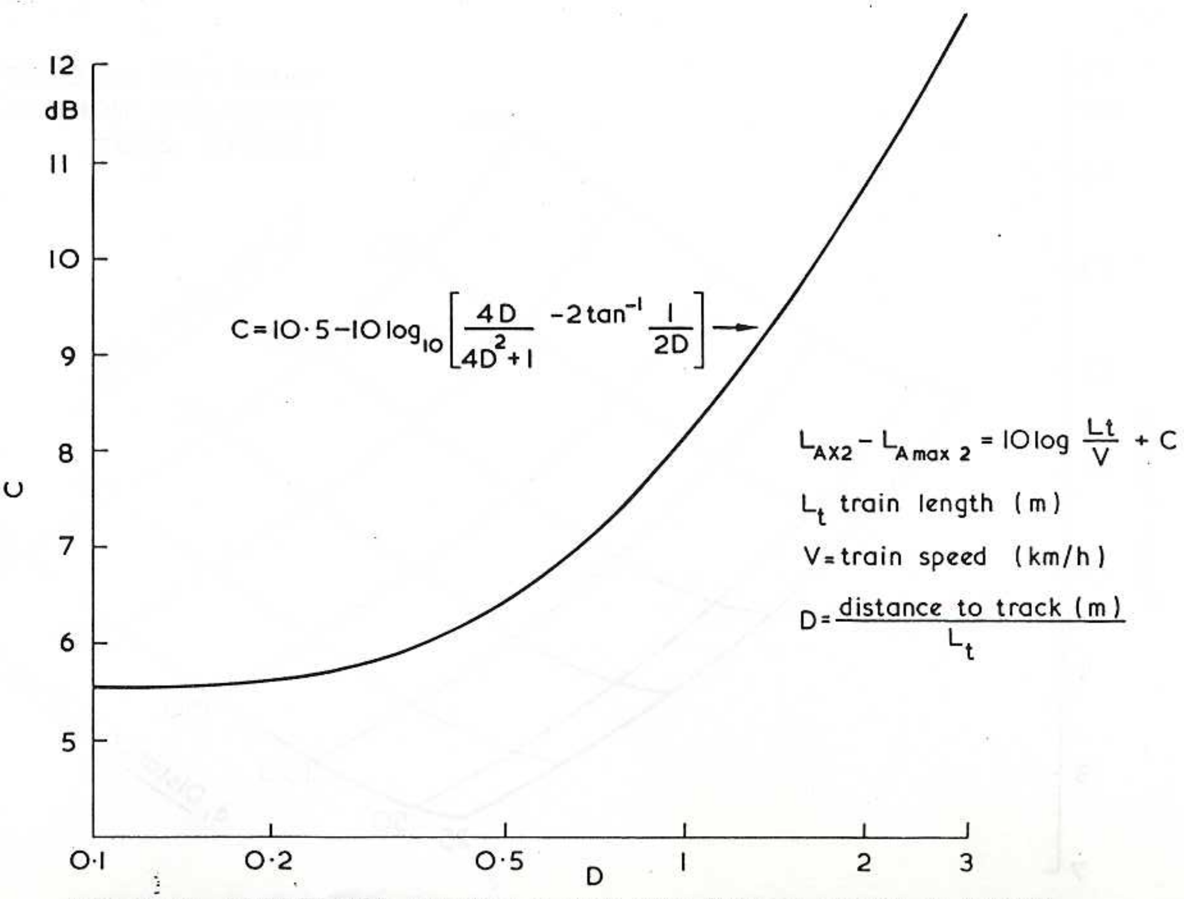

FIG. 4.3.4. CORRECTION FACTOR C FOR RAIL/WHEEL NOISE, IN TERMS OF DISTANCE FROM TRACK AND TRAIN LENGTH

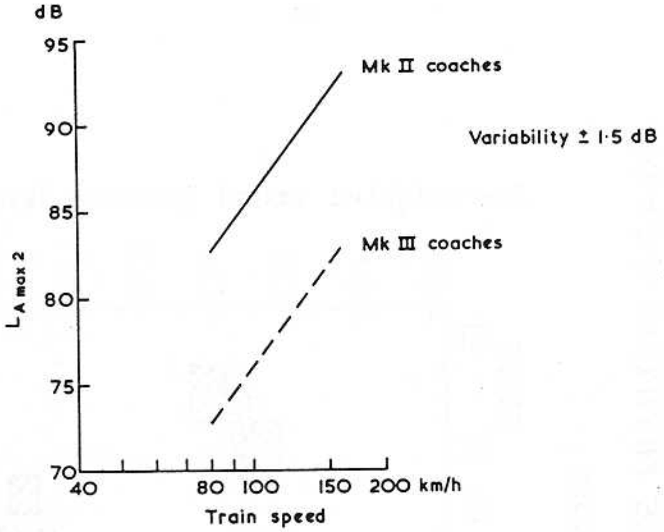

FIG. 4.3.5. RAIL/WHEEL NOISE FROM BRITISH RAIL MK.II AND MK.III COACHING STOCK

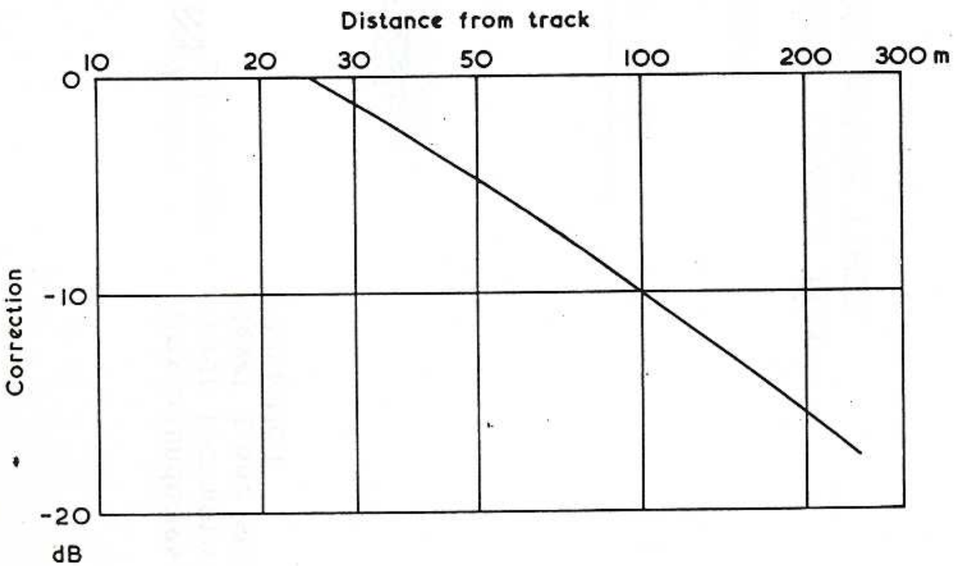

FIG. 4.3.6. CORRECTION TO RAIL / WHEEL NOISE WITH DISTANCE OVER GRASSLAND (APPLICABLE ONLY TO INTER-CITY PASSENGER TRAINS, APPROXIMATE LENGTH 250 m)

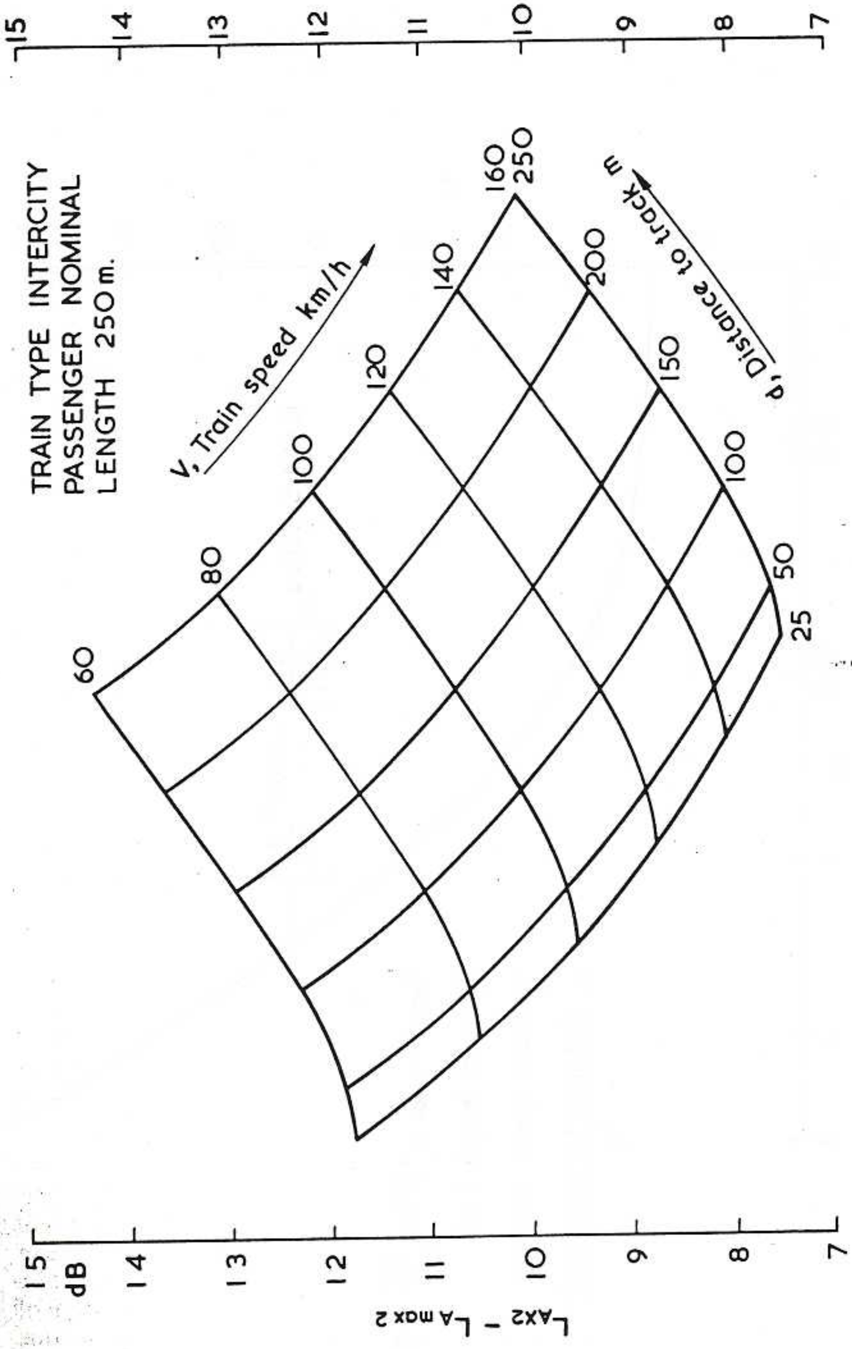

FIG. 4.3.7. $L_{AX2} - L_{A\,max2}$ FOR RAIL / WHEEL NOISE

4.4 Noise from industrial premises, fixed installations and construction sites

Introduction

The noise sources with which this section of the Guide is concerned are sometimes referred to collectively as "fixed" sources. This is misleading in some instances, where, as is often the case on construction sites, the machinery and plant are mobile and can operate over distances of up to several hundred metres. However the local neighbourhood tends to regard the site rather than the machinery as the source of noise and even though construction sites are of temporary duration they are considered here for purposes of noise prediction along with other installations which are permanent and where the machinery itself is also stationary. This distinction being understood, prediction of the noise from such fixed sources poses a number of problems which are not common to the types of source dealt with in the other sections of this Chapter:

(i) The number of different sources concerned is very large and their acoustic characteristics vary widely. There are relatively few published data on source noise, but again where there are data they take different forms: sometimes sound power level is quoted, sometimes a range of sound pressure levels is given and sometimes there is only a single sound pressure level at a reference distance. This all means that the noise of fixed sources is statistically not nearly so well-defined as is, say, the noise of road traffic; nor, apart from the Code of Practice on noise from construction and demolition sites[1], are there any "official" publications for reference to compare with the DoE Memorandum on road traffic noise.

(ii) In addition to the variety of sources their situations and modes of operation vary widely also. Sometimes it is a single machine which is of interest, sometimes it is a conglomeration of machines, sometimes the machines are inside a building and sometimes they operate out in the open. The directional characteristics of the radiated sound also differ. Thus the size of source and the pattern of radiation vary greatly as from one noise problem to another.

(iii) The distributions of noise level with time generally differ. Some machines work for a short time and then stop; some machines work continuously but move about; the load or throttle-setting on a machine changes from time to time, and often it is continually changing; other machines are static and work steadily and continuously. Hence there may not be a single noise event which can be characterized by L_{AX} for use in the determination of L_{eq} over a period.

(iv) No general rules can be established regarding propagation of the noise of fixed sources. The spectral distribution of the noise emitted varies greatly as between different sources and a number of the mechanisms of sound attenuation over distance are frequency-dependent. The degree of attenuation therefore varies according to the spectrum of the source noise output. Some of these mechanisms depend for their effect on the height of the source above ground level. Thus again each noise problem is unique and prediction of the noise levels must be approached from general principles.

There are a number of published descriptions of prediction methods, some specific to a particular fixed source[2, 3], some to an industry[1, 4] and some of more general applicability[5, 6, 7, 8]. In addition there is an extensive literature on various aspects of estimating propagation effects[9, 10, 11, 12]. The approach taken here is to outline the major steps in dealing with the problem, to refer the reader to the most up to date information on the various propagation effects and, where possible, to give approximate estimation methods.

General approach to noise prediction

The prediction of the noise environment resulting from the operation of fixed noise sources comprises in general three main steps:

(1) Quantify the noise output of sources by sound power levels in frequency bands (usually octaves) and directivity factors.

(2) Calculate the sound pressure level at the receiver position, in each band due to each source, making allowance for a variety of factors affecting propagation.

(3) Convert the frequency band sound pressure levels at the receiver position, for each source, to A-weighted values and add these logarithmically with reference to the operating times for each source, to give L_{eq} for the period in question.

Source noise output

Data on the sound power spectrum and on directivity may be obtained by a variety of means. Measurements on the proposed sources, or their equivalents may be made according to the appropriate International Standard[13]. Use may be made of manufacturers' data or other published information[14]. For large complex sources it may be necessary to devise ad-hoc measurement methods. One example of such a method is that developed by the Oil Companies Materials Association[4] to deal with plant and equipment used in the petroleum industry. The measurement method, and its associated calculation procedure, have been shown to give reasonably accurate predictions and it is claimed that the procedure has wider applications outside the petroleum industry[15]. For some specific sources, eg cooling towers, sound power has been related to the basic physical characteristics of the source[2]. This approach can be applied to other sources.

Propagation of noise

The sound pressure level at a receiver position in the acoustic far field of a noise source depends on the distance from the source, owing to wave divergence, and on extra attenuation due to environmental conditions. For the general case of a source located very close to a hard, flat ground surface the expression for the sound pressure level (either within a given frequency band or over a range of frequencies) is:

$$L_{p\psi} = L_W + DI_\psi - 20 \log_{10} r - 11 - A \quad \text{dB} \qquad \text{Eq (31)}$$

where $L_{p\psi}$ is the sound pressure level (in dB re 20 micropascals) at a receiver position located in the direction ψ at a distance r (in m) from the source, L_W is the sound power level (in dB re 1 picowatt) of the source over the same frequency range as that of the sound pressure level, DI_ψ is the directivity index (in dB) of the source in direction ψ and A is the excess attenuation (in dB) in propagation due to one or more of various factors listed below. It should be noted that even if the source is non-directive, DI = 3 dB for hemispherical radiation; the constant of 11 dB corresponds to $10 \log_{10} 4\pi$.

Excess attenuation in propagation
The attenuation of sound pressure levels over and above that due to wave divergence in propagation from noise source to receiver might be caused by one or more of a number of effects. The processes involved are complex and a full treatment is beyond the scope of this Guide. Some guidance is given below on how to decide in a particular case whether or not the different effects are likely to occur and some calculation procedures for their approximate magnitudes are set out. The various factors can each be considered independently and their combined effect can be taken as the arithmetic sum of their individual contributions. It should be noted, however, that if there is a barrier the ground effect should be ignored. If there are a number of barriers in the line of sight only the one presenting the maximum calculated attenuation is to be counted.

(i) Barriers
Two comprehensive reviews of the state of knowledge on barriers, encompassing rigid and absorbing barriers, barriers on hard and absorbing ground and barriers of various shapes, have recently been published by Kurze[16] and Maekawa[17]. Other useful treatments are given by Kurze and Beranek[10] and Tatge[18]. As an approximation, the received level in each frequency band can be corrected for the effects of a rigid, thin barrier, using the equation:

$$A_b = 10 \log_{10} (3 \pm 20 N) \quad \text{dB} \qquad \text{Eq (32)}$$

where the quantity N is defined by

$$N = \frac{2}{\lambda}(a + b - R) \qquad \text{Eq (33)}$$

where, in turn, λ is the acoustic wavelength (in m) based upon the band centre frequency (bandwidth not exceeding an octave), a is the distance from source to edge of barrier (in m), b is the distance from receiver to edge of barrier (in m) and R is the straight line distance from source to receiver (in m). Normally the + sign is to be observed within the brackets in Eq (32) but the − sign is to be assumed if there is a direct sight-line from the source to the receiver (ie if the receiver is above the shadow zone of the barrier).

The above approximation is used by Judd and Dryden[8] and derives from Maekawa[19]. In practice the maximum barrier attenuation is 25 dB. Delany[9] ascribes this to the scattering of sound into the barrier shadow-zone by atmospheric turbulence.

It should be noted that the above approximation to barrier effect applies to barriers whose thickness is less than λ, the wavelength. For thicker barriers, eg buildings, there are various solutions (see Kurze[16] and Maekawa[17] for details). Here again an approximation can be made by deriving the effective height and position of the equivalent barrier which is defined by the intersection of two straight lines both just grazing the top edges of the building, one drawn from the receiver and one drawn from the source. Equation (32) is then applied to the equivalent barrier.

(ii) Ground effect
Excess attenuation is caused by interference between the direct sound from source to receiver and the sound reflected from the ground between source and receiver. The attenuation is most marked in the frequency range 200–600 Hz. Delany and Bazley[20] have successfully explained the effect by theoretical methods and have outlined a method whereby the effect can be evaluated quantitatively in terms of the acoustical properties of the ground, the heights of source and receiver above the ground and their horizontal separation. Kurze and Beranek[10] have given a design chart for estimating the effect for a limited range of conditions.

The empirical data of Parkin and Scholes[21] can be explained by the detailed method of Delany and Bazley[20]. Keast[5] has shown that the same data can be represented by an approximation:

For hard ground, water, frozen earth, rock, concrete, etc the effect is ignored.

For soft ground the frequency of maximum effect, f_{max}, is first determined from the equation

$$f_{max} = \frac{1500}{h \log_{10} (r/0.3)} \qquad \text{Eq (34)}$$

where h is the mean height of the source-to-receiver path (in m) and r is the distance from source to receiver (in m). The attenuation in the octave band containing f_{max} is then calculated from

$$A_g = 15 \log_{10}(0.065\, r/h) \quad \text{dB} \qquad \text{Eq (35)}$$

If 0.065 r/h is less than unity, A_g is taken as zero. In the two octave bands adjacent to that of maximum attenuation, the attenuation is half the maximum value; in all others it is zero.

It must again be pointed out that where the path from source to receiver is obstructed by barriers there should be no allowance for ground effect.

(iii) Atmospheric absorption
Atmospheric absorption involves two types of process, the so-called "classical absorption" due to viscous and thermal losses, and "molecular absorption" due to rotational and vibration relaxation of the oxygen molecules in the air. As Delany[9] has pointed out, the effects of the first type of process can be ignored for practical purposes in the audio frequency range. The most up-to-date information on atmospheric absorption is that given by Bazley[22].

Kurze and Beranek[10] give equations from which useful engineering estimates of atmospheric absorption effects can be obtained provided propagation takes place in isotropic, quiet (non-turbulent) air. The attenuation at a temperature of 20 °C and 50% relative humidity is calculated from:

$$A_a = 0.148\, f^2 r \times 10^{-8} \quad \text{dB} \qquad \text{Eq (36)}$$

where f is the band centre frequency (Hz) and r is the distance from source to receiver (in m). For other temperatures within ± 10 ° of 20 °C the attenuation may be found from:

$$A_a = \frac{0.148\ f^2 r \times 10^{-8}}{1 + \beta\ \Delta t\ f} \quad dB \qquad Eq\ (37)$$

where Δt is the temperature difference from 20 °C and $\beta = 4 \times 10^{-6}$ for t in °C.

(iv) Wind and temperature gradients
Kurze and Beranek[10] describe the formation, by such gradients, of shadow zones into which direct sound cannot penetrate and Ingard[23] describes converse circumstances in which sound can be propagated over unusually long distances. The influence of these gradients can be considerable and, despite the difficulties involved, should not be ignored. The effects do not lend themselves easily to approximations but a quantitative treatment has been described by Delany[9].

(v) Other propagation factors
The presence of thick grass or shrubbery has the effect of increasing the excess attenuation due to ground effect but there is little quantitative information. The influence of trees is only significant where planting and foliage are dense and even then, as Kurze and Beranek[10] observe, there are large differences between reported results. Delany[9] took a figure of 0.06 dB/m at 400 Hz as typical of dense forest and this agrees with the curve given by Kurze and Beranek[10] as average for all types of forest. An analytical approximation to this curve is $0.01\ f^{1/3}$ dB/m where f is the band centre frequency. For bare deciduous trees values should be reduced to $(0.01\ f^{1/3} - 0.10)$ dB/m.

A number of meteorological effects (turbulence, fog, rain) can produce scattering and attenuation of acoustic waves, but according to several authors quoted by both Delany[9] and Kurze and Beranek[10] the influence on average levels is negligible.

Prediction of L_{eq}
Taking each source or characteristic operating phase of each source separately, the calculated band levels should be corrected according to the standardized A-weighting curve[24] and combined on an energy basis to give L_A. The value of L_{eq} may then be determined according to the equation:

$$L_{eq} = 10 \log_{10} \left\{ \frac{1}{T} \left[t_1\ 10^{L_{A1}/10} + t_2\ 10^{L_{A2}/10}\ .....\ + t_n\ 10^{L_{An}/10} \right] \right\} \qquad Eq\ (38)$$

whete T is the total time (in s) over which the noise is to be evaluated, L_{A1}, L_{A2} ..... L_{An} are the separate A-weighted levels at the receiver from each source or operating phase of each source and t_1, t_2 ..... t_n are the durations (in s) of operation of the respective sources or phases.

This method would be used whenever a new installation was to be introduced. It would also apply in cases where new plant was to be installed on an existing site. In cases where new plant replaced old, the old source could be used for control purposes to test the method. In view of the many uncertainities in the estimation procedure. such a validation would be valuable and could be used to estimate excess attenuation in difficult cases.

There may be cases in which the estimation of levels is required because of a planned change in the propagation path, eg a new barrier may be proposed. In such cases the actual source is, of course, available for detailed measurements from which the effects of the barrier on received levels can be estimated using the methods described. Another possible approach in such situations is to measure, where possible, octave band levels at the position corresponding to the top of the proposed barrier, to assume a source with this spectrum at the top and calculate received levels with the planned barrier from the formulae given. It should be noted that levels measured at the receiver position *without* the barrier do not form a good basis for estimating levels *with* the barrier since in the former case the ground effect is operating. Another case of a change associated with the source is a change in operating time with no change in level. In such a case the change in L_{eq} should be estimated, where possible, from measurements of L_A at the receiver position and use of Eq (38).

In other circumstances an estimation of L_{eq} may be required where some development takes place beyond the "boundaries" of the fixed source eg residential development on a previously open site, or infill development, or the erection of a wall. Barrier effects will then be required and the approach noted above may be used together with, where possible, measurements at the sources.

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5 CURRENT NOISE INDICES AND CORRESPONDING L_{eq} VALUES

5.1 Introduction

Noise nuisance from road traffic, aircraft and industrial premises has come to be assessed in the UK by means of L_{10} (18 hour), Noise and Number Index, and Corrected Noise Level respectively. The purpose of this chapter of the Guide is to indicate the values of L_{eq} to be expected in relation to values of these noise indices. It must be emphasized that the *conversions given are approximate* and are primarily intended to aid the process of familiarization with L_{eq}.

In all cases some estimate is given of the uncertainty in conversion. The accuracy with which direct conversions estimate the 'true' values of L_{eq} will also, of course, depend on the accuracy associated with the value of the original index.

Each of the current noise indices is associated with a particular day-time period. Thus L_{10} (18 hour) relates to the period 0600 to 2400 hours, whilst NNI values relate to a 12 hour day-time period, 0600 to 1800 hours. Daytime as considered in BS4142[1] is from 0800 to 1800. In the conversions discussed here the value of L_{eq} is that for the *same time period* as the one specified for the particular index.

5.2 Traffic noise

Values of L_{10} (18 hour) are defined as the arithmetic average of the values of L_{10} for each of the one-hour periods from 0600 to 2400 hours. The discussion which follows starts therefore with values of L_{10}, L_{eq} etc directly derived from a given distribution of sound levels over a given period of time, typically one hour. The question of averaging values of L_{eq} for comparison with the L_{10} (18 hour) index is taken up later.

In a particular case L_{10} may not be the only feature of the traffic noise distribution available. If the original distribution is available in histogram form then L_{eq} may of course be obtained directly using Eq (10) given in Chapter 3. Alternatively, if other parameters of the cumulative distribution, eg L_{10} and L_{90}, are known, then an estimate of L_{eq} may be obtained by assuming a Gaussian distribution of levels and using the equation[2]

$$L_{eq} = (L_{10} + L_{90})/2 + (L_{10} - L_{90})^2/57 \qquad \text{Eq (39)}$$

In an NPL study[3], involving traffic noise with widely varying characteristics, the mean difference between L_{eq} as calculated from the above equation and the true L_{eq} was 0.02 dB and the standard deviation of this difference 0.26 dB.

If only L_{10} is known it is possible to estimate L_{eq}, as may be demonstrated by reference to a number of studies. Berry[5] analysed results relating to traffic noise in a large scale noise survey[6] in which both L_{eq} and L_{10} were measured. The mean value of $L_{10} - L_{eq}$ was 2.7 dB, with standard deviation 1.4 dB. Driscoll[4], using 14 different distributions, found $L_{10} - L_{eq}$ = 3.6 dB with

standard deviation = 0.8 dB. Driscoll also presented a theoretical anaysis of the relationship between L_{10} and L_{eq} as a function of the variability of the noise. This shows that for a wide range of traffic conditions $L_{10} - L_{eq}$ is within 0.5 dB of 3 dB. In addition an indication is given of the value of $L_{10} - L_{eq}$ outside this range. Driscoll pointed out that of all the percentiles L_{10} had the highest correlation with L_{eq}. Similar high correlations were noted by Bishop and Simpson[7] in surveys involving 700 traffic noise samples taken in varying-flow conditions and for separate day, evening and night periods. In the NPL study already mentioned[3] a mean value of $L_{10} - L_{eq}$ of 2.9 dB, standard deviation 0.7 dB was found. All these studies lead to the conclusion that for the majority of situations of practical interest a value of L_{eq} over a specified period of time may be derived from a value of L_{10} *measured directly* over the same period by the numerical subtraction of 3 dB. In 95% of such conversions the estimated L_{eq} is likely to be within ± 2 dB of the 'true' value, provided the error in L_{10} is negligible.

Values on the L_{10} (18 hour) index are derived, as has already been pointed out, from the *arithmetic* average of the 'hourly' L_{10} values from 0600 to 2400 hours. If the individual hourly L_{10} values are known then the above conversion can be applied to produce a series of hourly L_{eq} estimates. These can then be combined, on a *logarithmic* basis to estimate L_{eq} for the 18 hour period or any sub-period. If, however, only the derived L_{10} (18 hour) value is available then the accuracy with which the suggested conversion estimates L_{eq} will depend on the hour-by-hour variations in L_{10}, which in turn depend on varying-traffic conditions throughout the period. For most busy traffic sites, where variations in traffic patterns, hour by hour, are not extreme, the arithmetic averaging of hourly L_{10} values will produce a value of L_{10} (18 hour) close to that which would be obtained from direct measurement of L_{10} over the total 18 hour period. Therefore a reasonable estimate of L_{eq} for the 18 hour period 0600 to 2400 hours could be obtained by subtracting 3 dB from the L_{10} (18 hour) index value.

5.3 Aircraft noise

Fig 5.3.1 depicts corresponding values of NNI and L_{eq} for a 12 hour day-time period, as obtained from a number of sources.

Berry[5] used a computer modelling technique in order to estimate NNI values corresponding to two particular values of L_{eq}. In the course of that work L_{eq} values were obtained from a range of 30 to 50 NNI resulting from a varied number of take off operations by 3 classes of aircraft in a constant mix—70% heavy jets (eg B707, DC8), 20% medium jets (eg B727, DC9), 10% "Jumbo" jets (B747). Each class of aircraft used a particular take-off profile and the flight paths were dispersed laterally about the observation point. Background levels (L_{50}) of 40, 50 and 60 dB(A) were assumed.

From the original data, values of L_{eq} corresponding to NNI = 30, 35, 40, 45 and 50 have been extracted for the various conditions tested. The variation with lateral dispersion is slight so results for the various flight paths may be combined. Similarly results for L_{50} = 40 and 50 dB(A) may be combined. For L_{50} = 60 dB(A) only values of L_{eq} for NNI = 45 and 50 are significant since for lower values, L_{eq} was determined by the background noise. By this process 7 pairs of related values of L_{eq} and NNI have been determined and plotted on Fig 5.3.1.

Information concerning higher NNI values has been derived from measurements made by the Surrey County Council Engineer's Department[8] at 3 monitoring points (2 for take-off, 1 for landing) at Heathrow Airport. At each site 80-minute recordings had been made at peak traffic periods (38 to 46 aircraft in the period). From these $\overline{L_{Amax}}$, the logarithmic average of peak levels in dB(A), L_{eq}, and the number of aircraft were obtained. For NNI computations $\overline{L_{Amax}}$ was then converted to $\overline{L_{PNmax}}$ by numerical adjustment of 13 units.

In order to relate a daytime (12 hour) L_{eq} to a daytime NNI on the basis of 80-minute-long recordings, it was necessary to make assumptions about the total number of aircraft and the distribution of peak levels over the whole day. Since the average peak level is determined by the noisier aircraft, whatever the total period, and since the sampled periods contained a good mix of typical aircraft, it seemed reasonable to assume that the average peak level was captured in the recordings. For each site, 5 daytime traffic levels were then assumed ranging from "saturation", in which the whole 12 hour day was filled, to a situation in which the only aircraft during the 12 hour day were those in the 80-minute period. Of the 15 pairs of NNI and L_{eq} values thus generated 11 fell in the range NNI < 65 and these have been plotted on Fig 5.3.1.

The straight line relation in Fig 5.3.1 has been produced from linear regression analysis of the 18 pairs of NNI and L_{eq} values from these two sources. The regression equation is

$$L_{eq}\ (12\ \text{hour}) = 0.88\ \text{NNI} + 26.5 \qquad \text{Eq (40)}$$

The correlation coefficient from Eq (40) is 0.981. The standard error of estimate of L_{eq}, given NNI, is 1.8 dB, so that 68% of estimates given by this relation would be within ± 2 dB and 95% of estimates would be with ± 4 dB.

Using Eq (40) and rounding to the nearest 1 dB it is possible to form a table relating significant values of NNI to L_{eq} (12 hour):

NNI	L_{eq} (12 hour)
35	57 ± 4
45	66 ± 4
55	75 ± 4
60	80 ± 4

The fact that the conversion is on a "sliding scale" results from the presence in the NNI formula of the 15 log N term, whereas L_{eq} effectively uses a 10 log N term since it involves energy summation.

In a recent European Communities report[9] a translation was used to allow annoyance data from the first Heathrow social survey to be related to L_{eq} rather than to NNI. The particular pairs of NNI/L_{eq} values used in that document have been plotted for comparison purposes on Fig 5.3.1 and they are a close fit with the other data.

5.4 Noise from industrial premises

If measurements of noise from industrial premises are reported in full conformity with the British Standard[1], giving explicit details of the various constituent elements of the Corrected Noise Level (CNL), eg the levels L_S and L_H and the percentage on-time p_2, L_{eq} can be obtained from the equation[5]

$$L_{eq} = L_S + 10 \log \left[p_2 . 10^{(L_H - L_S)/10} + 100 - p_2 \right] - 20 \qquad \text{Eq (41)}$$

If, on the other hand, the only information available is the value of CNL then the work of Berry[5] indicates that an estimate of L_{eq} can be obtained simply by subtracting 3 dB from the CNL value. There is, however, a larger uncertainty associated with this conversion than is the case with either L_{10} or NNI, the 95% confidence limits (± 2 standard deviations) being ± 6dB. Furthermore the conversion is only applicable to the particular daytime period stated in the British Standard, and even that may vary due to local circumstances. Also no account is taken, either in Eq (41) or the simple subtraction, of corrections for tonal or impulsive character. If it is known that the noise in question has such character and that the CNL allows for it, the 5 dB correction should also be substracted from the CNL in converting to the "uncorrected" value of L_{eq}.

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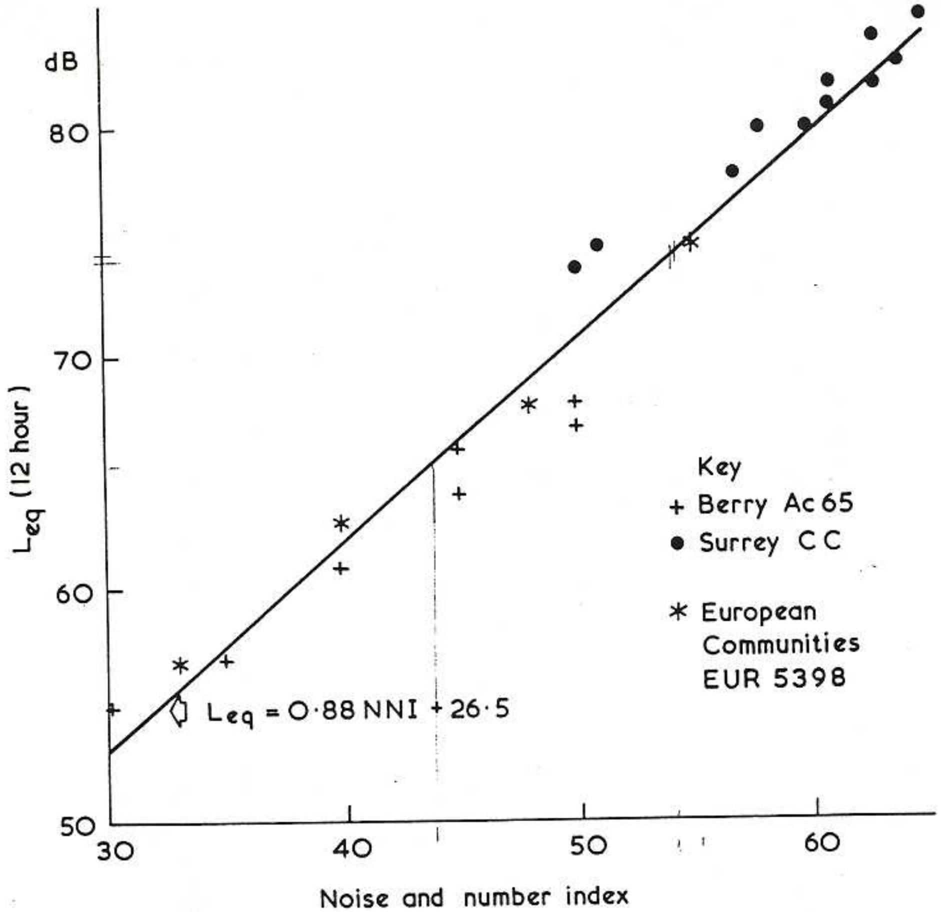

FIG. 5.3.1. Leq (12 HOUR DAY TIME) AND NNI

Other publications for the Noise Advisory Council

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Neighbourhood Noise	HMSO, 1971
Aircraft Noise: Should the Noise and Number Index be Revised?	HMSO, 1972
Traffic Noise: the Vehicle Regulations and their Enforcement	HMSO, 1972
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A Guide to Noise Units	Department of the Environment, 1974
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