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# An Outline Guide to Criteria for the Limitation of Urban Noise

*by*

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# An Outline Guide to Criteria for the Limitation of Urban Noise

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## Summary

A review is given of the steps involved in relating noise emitted in urban areas to the disturbance caused to the community, with special reference to transportation noise. An outline of existing methods of rating individual noises and of successions of noises is presented. From the latter a common measure, termed noise pollution level, emerges which is derived in a simple manner from physical quantities and which summarizes the disturbing character of a complex noise environment. Suggestions for noise limits are included.

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# Contents

## 1. Introduction and scope

This paper deals with various quantitative aspects of noise nuisance, in the general setting of people living or working indoors and disturbed by noises originating out of doors. Whilst fixed installations and construction sites are thus within the scope, it is more convenient to discuss certain general considerations by reference to transportation noise, since additional considerations enter in with moving noise sources, especially aircraft.

The chain of events with which we are concerned may be represented in the following syllogism:-

a) operations of the vehicles in service
b) sound propagation
c) noise stimulus received by the listener
d) direct effects on the individual
e) indirect effects on the individual
f) community reactions.

Into this scheme there intervene other factors. Thus, between b) and c) one may add noise stimuli from other sources, including the pre-existing ambient noise; and between d) and e) a multitude of socio-psychological considerations operate to modify the individual's overt response. Finally, the output of f), as expressed through media of public communication, may in its turn modify still further the response of an individual at e), by a feedback loop.

In contrast to this, the chain of events required to effectuate a limitation of the noise is, in essence, reducible to the following relatively simple scheme:

a') specified vehicle manoeuvre
b') sound propagation, normalized to reference conditions
c') physical measurement of received noise level.

The overall problem may thus be described as the matching of c') to c), subject to some declared criterion at the level f) or to criteria at the levels d), e) and f) in combination.

The following general points must be kept constantly in mind:

(i) the criterion of acceptable community reaction ultimately rests on arbitrary decisions of a socio-political nature, and therefore cannot be arrived at by dead-reckoning

(ii) an apparently reasonable decision at (i) is no necessary guarantee that certain individuals may not be affected to an intolerable degree at the levels d) or e), due to the wide variations of individual toleration

(iii) some factors in the chain c)-d)-e)-f) may be unstable with time, so that up-dating must be reckoned with. All these factors are, moreover, difficult to assess with precision. The determination of acceptable levels at c) is therefore subject to considerable latitude when approached "scientifically", that is, through present experimental evidence concerning the relationships between the various links in the chain

(iv) a definite attitude has accordingly to be taken up with regard to the uncertainties in (iii). The author's viewpoint is that the correct attitude is one that inclines towards conservative interpretations in the interests of public hygiene and general well-being. Where this leads to conclusions in conflict with the continued operation of existing vehicles of various types, or with the introduction into service of new forms of transport, other considerations, such as economics, may have to be accepted as overriding in the short-term, but this could not be accepted as legitimate for long-term planning

(v) the noise stimulus at c) cannot, in general, be directly equated with the noise as measured at c'), for at least two reasons. First, the noise specification at c') is necessarily tied to one, or to a finite series, of positions on the ground, whereas c) is meaningful only in inhabited places, and in the aggregate. Secondly c) implies a whole sequence of operations, not necessarily of the same kind. It follows that c') cannot be logically derived from c), even if the latter can be derived from a basis of community reaction by logical steps f)-e)-d)-c), without taking into account the forecasts of traffic and of the paths of the vehicles.

The scope of this paper is confined to estimating c), that is to say, expressing in physical terms the magnitude and nature of the total noise stimulus that should not be exceeded in the neighbourhood of built-up areas in order to guard against excessive degrees of probable public unacceptability. However, in order to do this in a way which is compatible with other studies, for example those that take a) and a') as their starting points, one modification is made. Namely, that part of the sound propagation pathway from the exterior to the interior of buildings is also taken into consideration where appropriate. This means, working backwards, that unacceptability is expressed basically in terms of the outdoor noise environment.

The various noise measures described later can be stated in terms of, or computed from, frequency analysis of the noise in one-third octave bands plus time histories of the instantaneous level expressed in some simpler terms, for example a weighted sound level. It may well be, and often is, argued that less detailed specifications are all that can be justified in view of the uncertainties of subjective predictions, and the author would certainly caution against the false attribution of greater precision to a unit merely because it looks more sophisticated and thus generates a mystique about it. That there are some advantages of more complicated units over simple ones may be demonstrable in carefully-staged comparison tests with many factors held constant. In the real, multi-factor situation, it is not so sure that such advantages are maintained; in any case the discrimination afforded is largely irrelevant at the broad planning stages. Nevertheless, reference will be made below to some of the more complicated, as well as to the simpler, units, and where this is done it is intended for the purpose of facilitating comparisons with present practice. Unfortunately, there are many units in current use - far too many - and quite unnecessary confusion has been imported into the already difficult problems of noise rating. In the Conclusions to this paper, a proposal is offered which, at one stroke, accomplishes both a simplification and a generalization of several systems.

## 2. Measuring scales and criteria

Examining first the link between c) and d), one is faced immediately with deciding which of the direct effects, and hence which algebraic function of the physical properties of the noise, to consider. Different effects are not governed by the same combination of properties. The available data provide information, of varying degrees of reliability, on the following effects, which are considered in turn in Chapter 3:

(i) loudness
(ii) perceived noisiness
(iii) speech interference
(iv) duration and number of occurrences
(v) auditory fatigue and permanent hearing damage

Turning to the indirect effects, e), and their various manifestations, such as expressions of annoyance, loss of working efficiency, error rate at tasks, effects detrimental to general health, loss of or difficulty with sleep, interruption of leisure activities and so on, little can be stated with quantitative assurance as to their relation to the direct effects listed. A considerable body of experimental work is, however, available for relating some of these effects, or of the total effect as evidenced by judgements of overall acceptability or unacceptability of living in particular noise climates, to direct - if somewhat inexact - measurements of the noise stimulus causing them. This evidence comes from opinion surveys, some of which provide scale numbers which can be interpreted broadly as a scale of percentage community annoyance. Furthermore, particular points on these scales can often be identified with known percentage occurrences of specific incidents, for example a known proportion of people being awoken so many times per month on average. Some studies have been specifically related to aircraft noise; others to general environmental noise, in practice mainly traffic noise; yet others have dealt with office noise. The various measures derived from these studies are as follows, and they are further discussed in Chapter 4. The list is almost certainly not exhaustive.

(i) Noise and number index, NNI
(ii) Composite noise rating, CNR
(iii) Störindex, $\bar{Q}$
(iv) Indice de classification, R
(v) Aircraft noise exposure index, $L_{exp}$
(vi) Noisiness index, NI
(vii) Aircraft exposure level, $L_E$
(viii) Annoyance index, AI
(ix) Traffic noise index, TNI
(x) Equivalent disturbance level, $L_q$
(xi) Office noise acceptability scale, $L_A$/TPI
(xii) Noise immission level, NIL.

In addition to this list may be mentioned a scale of "intrusiveness", originated by the author and also used by investigators in U.S.A. and Switzerland, which is designed to rate individual noisy events rather than the total impression of a sequence of occurrences. It is arguable that this measure belongs neither to the class described under "direct" effects nor to that of the "indirect" effects, but intermediately, as it attempts to abstract from a noise event a property involving more than that which is governed by the auditory mechanism but less than that which corresponds to real situations wherein the indirect effects are the product of a whole series of events covering a span of time. To some extent, the same may be said of "perceived noisiness" but this has been classed with "direct effects" due to its close association with the dimension of subjective loudness. It may help in distinguishing between what are here termed "direct" and "indirect" effects to note that the element of specific awareness of the noise in question is generally implicit in the former. This does not hold, however, for the case of hearing damage which can be occurring without the person's being aware of it.

Considering next the final link in the chain, that is the link e) to f), one finds no data directly connecting community response measures with the effects on individuals, but once again there are several established procedures for assessing community reaction from physical data on the noise stimulus with allowances of a rather crude kind for some of the socio-psychological influences alluded to in Chapter 1. These allowances concern such factors as the time of day, the intermittency (thus overlapping to some degree the direct effect iv)), the type of district, whether the noise is new or of long standing, whether it is in character with the environment, whether there is an economic tie between the population and the noise source, and the kind of environment being assessed, i.e. home, office, concert hall etc. The various systems have been evolved from case histories with subsequent modifications to obviate failing cases, on the basis of overt complaints ranging from the sporadic to the threat of concerted vigorous legal action. The principal systems of this kind are those based on:

(i) Noise criterion curves, NC
(ii) Noise rating curves, NR
(iii) British Standard BS 4142:1967.

Of these, (i) can be applied to noises either of internal or external origin in buildings affecting interior spaces of various functions. (ii) has been the intended basis of an international recommendation under ISO, but after 10 years discussion agreement on the final form of the document is still wanting. (iii) is an elaboration of the proposals submitted to the Wilson Committee by the Building Research Station; it is confined to industrial noise affecting residential premises. Attempts to generalize the scope of these systems to embrace vehicular noise have not been fully successful, due to certain psychological factors as yet imperfectly understood. Since these factors raise important principles it is worthwhile to digress at this point, and to return to further discussion of the application of the noise rating schemes in Chapter 5.

The first of the psychological factors referred to above concerns the relation of the intruding noise to the pre-existing noise climate. The latter may range from rural, or dormitory suburban, quiet to any of a range of more or less noisy backgrounds. These in turn may have different characters, from the fairly steady, as in offices with mechanized equipment, through the fluctuating, as in premises adjacent to a thoroughfare, to the highly intermittent, as in dwellings abutting a railway. The role of the novel intruding noise in this diversity of circumstances is not well documented, but the following general principles may be stated:

a) when the intruding noise is very much louder than any existing noise, its absolute level is likely to be the decisive factor

b) when it is comparable with, or not much greater than, the level of an existing steady background, the excess over the background is likely to determine the reaction.

In conformity with b), it has been asserted, and is even claimed to be experimentally demonstrated, that the intruding noise is judged more acceptable if the background is raised. That, however, presupposes that opinion is concentrated upon the intruding noise. Commonsense tells one that, other things being equal, there is a point at which the greater the total amount of noise the worse things must be. Nevertheless, the paradox is important in drawing attention to the fact that a fairly small margin between intruding and background noise may permit the former to be introduced without much protest. The reason for diminished reaction in the experiment where the background noise is raised is attributed by some workers to masking, but a more likely explanation is that the diminished level gap results in a corresponding diminution of the attention-arresting capacity of the intruding noise. Everyday experience confirms that where this capacity exists, the problem with the intruding noise is as much psychological as acoustical: dripping taps, nextdoor conversation, untraceable squeaks in the car are examples of this. Cases are authenticated in which vigorous complaints are traceable to man-made noises so feeble as to be barely perceptible and almost impossible to measure physically. A serious objection to availing oneself of the margin by which a new noise may intrude upon an existing climate without immediately exacerbating the reaction is that it opens the way to the "creeping background", rendering nugatory any long-term amelioration which those concerned with the hygienic aspects are striving to attain. These working rules should therefore be firmly adhered to:

(i) where unacceptable levels of nuisance already exist, no significant addition of noise shall be permitted

(ii) where the existing level is acceptable, it shall not be permitted to rise to a level that is unacceptable.

The first of these rules can be expressed quantitatively, by requiring no new noise to contribute more than the equivalent of 10 dB below the exposure level already occurring. This does not necessarily rule out loud noises, but they would have to be counterbalanced by adequate brevity or infrequency of occurrence.

The second of the psychological factors is related to the phenomenon known as "constancy of the object". For example, the image of a human figure in a person's retina is interpreted as a human being of normal stature whether the image be small or large, depending on the distance of the viewer. In terms of noise perception, the phenomenon takes on the aspect of magnifying the apparent noisiness of a source when the latter is separated from the listener by large distances or by intervening sound attenuation to which he is conditioned, for example closed windows. These phenomena have been demonstrated by the author (1) but more research is needed before the conditions in which they occur and the noise level penalties they imply can be stated with assurance. The evidence permits one to conjecture that the "constancy phenomenon":

a) does not apply when the intruding noise has no meaning to the auditor (has no "semantic content" in current jargon), or is composed of numerous items prohibiting individual identifications, as in a continuous traffic stream,

b) does not apply when the intruding noise fails to reach the level of attention-arrest (this will depend on the person's preoccupation and may be quite high if he is heavily engaged in mental work),

c) does not apply to activities governed by purely acoustical and auditory considerations, for example interference with the perception of speech, and

d) does apply in generally quiet surroundings or the absence of preoccupations. Thus it is likely to affect leisure pursuits; the effect probably depends on the character of the noise.

The extent to which these psychological factors will come into play in particular cases depends on many unknowns and environmental extrapolations. The best that can be done is to adopt a cautious line, erring on the side of setting lower limits.

To conclude this Chapter, mention should be made of a number of the socio-psychological factors that complicate the assessment of effects at the levels e) and f) of Chapter 1, which are additional to those listed above in connection with the "package deal" noise rating methods. Those on which some data of a more or less scientific or systematic kind are known include the following, and are discussed in Chapter 6:

(i) differences of national attitude
(ii) possibilities of "attitude control"
(iii) adaptation
(iv) cash value equivalence of environmental improvement
(v) differential attitudes to different classes of noise.

Beyond vague generalizations, the author is not aware of anything that can be firmly stated about long-term trends in environmental control, nor on the effects which such improvements may have upon the lowering of the threshold of public unacceptability, nor upon propositions such as the one that general association with the source of a nuisance tends to lessen annoyance. On the last point there seem to be contradictory viewpoints. If it is a fact that popular participation in motoring creates relative toleration of traffic noise, compared say with aircraft or factory noise, the prognosis for the operation of future types of transport vehicle, for example VTOL aircraft, would obviously depend on the rapidity with which that form of transport came to be regarded as common, as road or rail transport is today. Again, it seems prudent to make no allowance for this possibly beneficial factor.

## 3. Scales for assessing direct effects of noise on individuals

### 3.1 Loudness scales

A self-evident factor in the degree of nuisance caused by a noise is its intensity: other things being equal, an increase in the latter will result in an increase in the former. Different sounds of the same physical intensity, however, do not necessarily evoke equal sensations of loudness. But it is possible to compensate for this fact, by measuring the sound along another scale, that of loudness level, which is related in a definite way to physical intensity. In the nature of things, magnitudes in this scale are, within wide limits, independent of the duration of the sounds so that, whilst the loudness level can correctly portray one aspect of nuisance value, it cannot possibly convey the whole.

The subjective property of sound known technically as loudness, "the observer's auditory impression of the strength of the sound", is fundamentally to be measured only by subjective means, by aural comparison with an arbitrary reference sound of adjustable intensity. Conventionally this is a tone of 1000 Hz heard binaurally at frontal incidence. The loudness level in phon is then declared to be numerically equal to the sound pressure level of the reference tone in decibels relative to $2 \times 10^{-5}$ N/m$^2$. The loudness may also be expressed in sone, this scale being uniquely related to the phon scale. The relation, though rather complicated in reality due to the nature of the human auditory apparatus, has been conventionally standardized (2) in the simple formula:

$$S = 2^{(L_P - 40)/10}$$

where $S$ is the loudness in sone and $L_P$ the loudness level in phon. This relation embodies the approximate fact that it takes an increment of 10 phon, that is roughly a 10-fold increase in intensity, to produce twice the auditory impression. Conversely, to achieve a halving of loudness, a reduction of no less than ten times is needed in terms of intensity. This explains why noise sources that are already rather loud at a considerable distance, such as jet aircraft, are not easily abated by increasing the distance. For instance, in the case cited, the distance of nearest approach would have to nearly treble, since sound attenuates in the air at about 7 decibels per doubling of distance. For someone under the flight path, this example means trebling the height; for anyone well to side it means a still larger factor and so becomes practically impossible without changing the ground track.

Phon values for certain basic sounds have been systematically determined. Those for pure tones, obtained by Dadson and the author (3), are now standardized internationally (4). Values for octave bands of random noise are also well-established (5), as are the modifying adjustments required to express results in "diffuse field" conditions, appropriate to indoor assessments (6).

Such direct determinations demand large groups of test listeners, and are quite impractical for everyday application to noises. Methods of calculating loudness level have therefore been evolved and standardized (7), which, using the spectral content of a noise as the input, give values in fair agreement with results of actual subjective measurements. For all practical purposes loudness levels are of the calculated type. Logically there can only be one loudness level for a given noise but alternative methods are in fact employed. Method A of reference (7) is due to S.S. Stevens (8) and applies to broad-band noises that can be sufficiently described by their octave band spectra, that is, by eight values of sound pressure level embracing the audio-frequency range. It assumes diffuse-field conditions, and values so calculated are known as calculated loudness levels in phon (OD). Method B is based upon work by Zwicker (9); it is much more complicated and entails description of the noise in one-third octave bands (27 values); it is available in both free-field and diffuse-field variants, and it will work for much less regular spectra than Method A. The results of calculations are known as calculated loudness levels in phon (GF) and phon (GD) respectively. If more than a handful of such calculations are to be done, a computer is essential, but the programming is very complicated. An analogue computer is now available commercially, but is also rather complicated in construction.

To compare two or more different noises, the same calculation procedure must be used. The choice depends partly on the context, partly on the nature of the noise spectra to be evaluated, and partly on the amount of labour justified for the comparison. Phon (OD) and phon (GD) purport to estimate the same thing, but differences of 5 units or more are not uncommon. Relative inversions, however, are unlikely to occur; that is, either method will rank a series of noises similarly from low to high in order of true loudness level unless violent differences of spectra exist between the items compared.

### 3.2 Perceived noisiness

Until about 1950, the phon, as calculated by a precursor to the Method A just mentioned, was normally used to characterize the nuisance value of aircraft sounds. With the introduction of jet transports it became apparent that this procedure underestimated the nuisance of jets in comparison to the then conventional aircraft. Latterly this has been seen to be the consequence of shortcomings of the calculation procedure in certain of its details. Historically, it led directly to the work of Kryter and his associates at Bolt, Beranek and Newman Inc. (10), and to the formulation of a different scale of measurement. This was the scale of perceived noise level, based on subjective experiments in which the qualities of "noisiness" and "unacceptability" were introduced as the criteria for comparing the test sounds, in place of "loudness". In view of the subsequent history of the "PNdB", and the way in which it has permeated the aircraft world, it is only of academic interest to point out that the author, in 1962, and other workers at Bolt, Beranek and Newman Inc., in 1967, have remarked that the difference between perceived noise level and properly-calculated loudness level is at most marginal. In the intervening years, a series of titivations, and even one major change, have been made to the calculation procedure for perceived noise level, though the basis of principle has remained the same. Perceived noise level (PNL) is analogous to loudness level calculated by Method A: an intermediate parameter (noy) is used that is analogous to sone (or, strictly, to the parameter "loudness index" occurring in the description of Method A); the algebra in the two processes is identical. The differences reside simply in the relative weight given to parts of the spectrum, and to the fact that one refers basically to the "noisiness of a band of random noise between one-third and one octave wide centered on 1000 Hz", and the other to the 1000 Hz pure tone, as the respective reference sounds. Due to the broad-band restriction on the scope of the Method A loudness calculation and to its close analogy with the calculation of PNL, it is really not surprising that PNL values (designated $L_{PN}$) have, in their turn, been found wanting. This is the case with noise spectra having marked irregularities, such as the discrete tones emitted by fans. To overcome this limitation, a version of PNL designated $L_{TPN}$ (tone-corrected perceived noise level) has been proposed as a makeshift extension of the original concept. Recognition of the need to make some allowance for tonal components was given at the London Conference of 1966 (11).

At the time of writing, the last word has not been written on the calculation of $L_{TPN}$, nor probably even of $L_{PN}$, but for the purpose of definiteness, the particular formulations in ISO Draft Recommendation 1760 (itself a revision of ISO R-507) will be assumed here (12). Thus, $L_{PN}$ is henceforth to be computed from the one-third octave band spectrum at intervals of some half-second, each value being corrected for spectrum irregularities (when present) by adding a term C. C is a fixed fraction (1/3 or 1/6) of a parameter F; the fraction depends on the frequency range wherein the essential irregularity lies. F is determined for each band by logarithmically subtracting from the observed one-third octave band sound pressure level the notional value which would be present in that band in the form of random noise if the discrete spectral line could be eliminated. Tabular methods are given for estimating F. The final correction applied, C, is the highest of the C-values in any band, and it runs from zero to an artificial upper limit of 6.7 dB for a noise with an extremely prominent tone. The form of this correction was arrived at "on the back of an envelope" by Little and the author, neither of whom would claim it to be elegant. Experimental data from numerous subjective tests in U.K. and U.S.A. are unanimous in showing that a positive correction is required but they are very divergent as to its magnitude. It is recognized that further modifications will be needed to embrace noise spectra with a plurality of tones ("comb spectra") and perhaps other peculiarities. Present discussions on the noise certification of subsonic jet aircraft are based on tone-corrected PNL obtained in the same manner, that is, in accordance with ISO DR 1760.

### 3.3 Numerical relations between loudness, perceived noise and weighted sound pressure levels

Descriptions of, and some account of the reasons underlying, the various measures of subjective intensity have just been given. To these measures should be added two others. These are the sound level A, designated $L_A$ and stated in dB(A), and the sound level D, designated $L_D$ and stated in dB(D). Although these are purely physical measures, they are in wide use, especially $L_A$, as simple means of direct objective measurement, yet still providing a reasonable degree of correlation with subjective qualities of annoyance or noisiness. Values of $L_A$ and of $L_D$ are obtained by means of a sound level meter with distinctive frequency responses known as the A- and D-weighting respectively. A considerable advantage of these measures is that all the relevant acoustical and electrical performance requirements of the measuring instrument are standardized (13) or (in the case of D-weighting) are in the process of standardization. This ensures uniform measuring characteristics even in relatively inexperienced hands. A secondary advantage is that they are direct-reading, requiring neither frequency analysis nor computation. This is sometimes represented to be a handicap: for example, there is no simple rule for correcting $L_A$ for distance, for transmission of sound through structures, or indeed in any circumstances where the change of sound pressure level is frequency-dependent. However, it is possible to erect a compatible and comprehensive rating system based on either $L_A$ or $L_D$. One uses direct measurements when possible; when it is not, one calculates the values with frequency dependence taken into account, from a knowledge of the noise spectrum and of the A- or D-weightings. Such calculations require exactly the same input data as loudness or perceived noise level calculations, but they are algebraically simpler. Moreover, their direct relation to the physical quantity sound intensity confers on them certain theoretical advantages. This point is further discussed in relation to indices of total noise exposure, in Chapter 4.

In this situation, it will easily be appreciated that the advantage lies with the simplest measure, $L_A$, except in circumstances where the numerical magnitudes of the various measures differ amongst themselves by amounts large compared with the uncertainties in the overall assessment of the problem, whatever that may be. Considering community annoyance, these uncertainties are without doubt very large, so that $L_A$ becomes the measure of choice. In more discriminating circumstances, for example assessing marginal subjective advantages between alternative machine designs, the converse argument leads to a preference for one of the calculated types of measure, such as $L_{PN}$. Actually, the distinction has been stated in terms that are unnecessarily severe: the same conclusions are justified if the various measures differ by numbers that, if not on average zero, are essentially constants contaminated by fluctuations which are small compared to the overall uncertainty. This is the actual situation.

Much effort has been expended in the literature (14, 15, 16 and others) on determining orders of merit of these and many other measures. The results of such labours would be the more convincing if they all arrived at the same conclusions, but this is not the case. Orders of merit are found by testing the calculations against the results of different subjective measurements, usually those of the respective authors. The present writer has also engaged in these pursuits and, in common with others, has used his results to proclaim the superiority of this or that variant of procedure (17). The real distinction that should be made has been stated above: it depends on the purpose of the evaluations. In the present context, it will suffice to concur with this quotation from Young and Peterson (16):

> "The minor differences among A-weighted sound level, calculated loudness level, (and) calculated perceived noise level, in their correlation with judged noisiness, are not statistically significant. Only the B and C levels are clearly inferior as predictors of noisiness".

Tables I and II have been constructed to give the reader some grasp of the typical magnitudes of the "minor differences". Three hypothetical and radically different broad-band noise spectra are assumed. <u>a</u> rises at the rate of 3 dB/octave over the whole spectrum, 50 to 10 000 Hz; <u>b</u> falls at this same rate; <u>c</u> falls at 9 dB/octave. All are arbitrarily assigned the same level in the 1000 Hz band, namely 80 dB.

Table I

Loudness, perceived noise, and weighted sound levels
of three hypothetical noises a, b and c.

| Noise | Loudness level phon (OD) | Perceived noise level dB(PN) | Weighted sound level | | | |
|---|---|---|---|---|---|---|
| | | | dB(A) | dB(D) | dB(B) | dB(C) |
| a | 110.8 | 109.6 | 96.8 | 104.9 | 95.4 | 97.0 |
| b | 101.6 | 104.3 | 90.5 | 96.9 | 95.9 | 100.0 |
| c | 117.3 | 117.1 | 100.5 | 111.9 | 113.9 | 121.6 |
| Mean | 109.9 | 110.3 | 95.9 | 104.6 | 101.7 | 106.2 |

Table II

Loudness, perceived noise, and weighted sound levels
relative to mean value of three noises

| Noise | Loudness level phon (OD) | Perceived noise level dB(PN) | Weighted sound level | | | |
|---|---|---|---|---|---|---|
| | | | dB(A) | dB(D) | dB(B) | dB(C) |
| a | 0.9 | -0.7 | 0.9 | 0.3 | -6.3 | -9.2 |
| b | -8.3 | -6.0 | -5.4 | -7.7 | -5.8 | -6.2 |
| c | 7.4 | 6.8 | 4.6 | 7.3 | 12.2 | 15.4 |

Inspection of Table II instantly supports the view of Young, with regard to the quite different relative ratings given by $L_B$ and $L_C$, and the comparative similarity amongst the remaining measures. Thus, ignoring the B- and C-weighted levels, any of the other four measures listed agree that noise *a* is within -0.7 and 0.9 dB of the (artificial) mean, *b* lies between -5.4 and -8.3 dB, and *c* between 4.6 and 7.4 dB. Each measure ranks the noises similarly and in approximately the same degree. In this hypothetical example there is, of course, no subjective measurement to provide a yardstick of relative merit. But it is obvious that if one set about such an experiment, the results could not settle the matter one way or the other unless their accuracy were an order of magnitude better than the discrepancies. Since the latter only amount to 1.6, 2.9 and 2.8 dB on the three noises respectively, the subjective tests would need to achieve an absolute discrimination better than, say, 0.3 dB, a tall order indeed.

The mean values at the foot of Table I differ, and although the hypothetical noises resemble no particular ensemble of actual noises, these differences are fairly typical of those found in practice. The relation $L_{PN} \sim L_D + 7$ is specifically recommended in reference (12); the difference between $L_{PN}$ and $L_A$ is also stated to lie generally between 9 and 14. The author has found the mean difference of 13 to be effective for the majority of aircraft sounds (18) and this value is also given by American workers. $L_{P(OD)}$ is generally one or two units less than $L_{PN}$.

### 3.4 Interference with speech

Interference with speech communication - direct, by telephone, radio or TV - is possibly the most widespread contributory factor in producing annoyance in the daytime or evening; in the case of schools, conference rooms and offices it may well be the decisive factor. Like loudness and perceived noisiness, interference with speech is related to the intensity and spectral distribution of noise, but in a different way. As a nuisance factor, it may work in two ways: first, by blotting out current speech; second, by demanding raised voices, strained listening and promoting a general atmosphere of discomfort. The first of these effects can be assessed quite accurately; the second clearly not so, though considering the total activity within an urban population it is probably the more significant in terms of incidence.

The classical work of French and Steinberg (19) showed that the frequency range 200 to 6000 Hz could be divided into 20 unequal bands each contributing equally to the intelligibility of speech. If the spectrum level* of normal connected speech is plotted on a distorted frequency scale derived from the limits of these bands, together with the spectrum level of the noise, the noise does not interfere at all with the speech if the curves are everywhere 18 dB or more apart. Intelligibility is totally lost when the noise curve exceeds the speech curve everywhere by 12 or more dB. Intelligibility was measured in these experiments by the articulation index, that is, the fraction of meaningless, but phonetically-balanced, syllables correctly interpreted by the listener. Over the 30 dB range from complete interference (articulation index 0) to no interference (articulation index 1), the relationship is nearly linear, so that the articulation index is calculated as the fraction of the area between curves parallel to the speech spectrum curve lying 18 dB below and 12 dB above it, that is not covered by the curve of noise spectrum level. The intelligibility of connected speech, due to the redundancies in language and to the perceptual processes, is much higher than that of meaningless syllables; it is still higher in face-to-face communication where the listener can see the face and lips of the speaker, the increase being equivalent to about 0.1 in the articulation index. The relations obviously depend on the speech material, cliches being more readily comprehended in the presence of interfering noise than information-bearing words or messages. Sentence intelligibility better than 95% represents, generally, acceptable conditions and corresponds to an articulation index of about 0.4. For good conditions, or for stringent material such as calling over lists of names, 0.6 should be the aim.

The procedure of French and Steinberg has been adapted for use with conventional one-third octave or octave band analysis of the noise by Fleming (20), Kryter (21) and others. In its simplest form, due to Fleming, the calculation follows the pattern of the example in Table III below. The case represents a typical indoor (open window) noise from a landing turbofan aircraft at a height of some 800 m, with speech levels for normal voice at about 2 m, or raised voice at about 4 m, with adjustment for semi-reverberant indoor conditions, i.e. at a long-term average speech level of 60 dB. These conditions approximate to those in a school classroom. Referring to the Table, the intelligibility of sentences would be little impaired in this example. It is, perhaps, instructive to note the loudness and other levels corresponding to these conditions. As the example is hypothetical, even if realistic, the tabulated values should be taken only as a guide (see Table IV).

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* Spectrum level is the spectral density (i.e. intensity per unit band width) expressed in decibels; not to be confused with the spectrum expressed in band pressure levels as is conventional in the acoustics of noise. They differ by 10 log $\Delta f/\Delta f_0$ where $\Delta f$ is the band width and $\Delta f_0$ is the unit of bandwidth i.e. 1 Hz.

Table III

Example of calculation of articulation index

| Octave band centre frequency (Hz) | Band pressure level of speech, plus 12 dB | Band pressure level of noise | Speech level minus noise level (a) | Weighting factor | Contribution to articulation index |
|---|---|---|---|---|---|
| 250 | 62 | 56 | 6 | .0018 | .0108 |
| 500 | 67 | 54 | 13 | .0050 | .0650 |
| 1000 | 67 | 50 | 17 | .0075 | .1275 |
| 2000 | 62 | 47 | 15 | .0107 | .1605 |
| 4000 | 54 | 40 | 14 | .0075 | .1050 |
| 8000 | 44 | 29 | 15 | .0006 | .0090 |
| | | | | Total | .4778 |

(a) If the difference in this column is negative, one enters zero; if it is greater than 30, one enters 30.

Table IV

Loudness, perceived noise, and weighted sound levels, corresponding to the example in Table III

| | phon (OD) | dB(PN) | dB(A) | dB(D) |
|---|---|---|---|---|
| Indoors | 66.5 | 65.5 | 55.6 | 60.2 |
| Outdoors | 74.9 | 75.1 | 65.6 | 70.2 |

At a level of the aircraft noise 5 dB higher than that assumed in the example, the articulation index would be reduced to 0.31, and sentence intelligibility would be correspondingly reduced to about 92%; at a level 5 dB higher still, the values become 0.15 and 50% and very serious interference would be caused. Classroom work would effectively be halted. Notice that at this stage, the outdoor perceived noise level is in the order of 85 dB(PN), but that windows are open. Assuming normal single glazing, shutting the windows will drop the indoor level by about 5 dB, and the intermediate conditions will obtain, that is a noticeable but not incapacitating interference. Generalizations from these examples are inadvisable; in each case the calculations should be worked through since the result is rather sensitive to some of the many variables involved.

A number of refinements to the calculation of articulation index are recommended in the literature. These take more precisely into account than does the simplified procedure such considerations as the upward and downward spread of masking due to the noise (important when the noise spectrum is humped or peaked), reverberant or dead conditions, the level of the speech (relevant at higher levels as in public address systems), the influence of sending-end and receiving-end room noise (in communication systems, notably the telephone), and so on. Furthermore, it is probably unrealistic for general purposes to assume that the "normal voice level" of laboratory tests applies: one is only too aware that some people fall short in this respect, and do not adapt readily to difficult conditions, or soon relapse after a prompt to "speak up". Mention is also due of work by Williams et al (22) showing that the effective speech interference during an aircraft flyover is less than would be inferred from the articulation index even though the latter is calculated instant by instant as the noise rises and falls. Using a particular form of test speech material (MRT, or modified rhyme test), they showed that for an articulation index of 0.4 the intelligibility was 80% for steady (simulated) jet noise, but rose to 90% for a flyover. Evidently some effects work one way, some the other, but as before the author recommends not to count on doubtful bonuses.

For general planning purposes, it is inconvenient and sometimes impracticable to calculate the articulation index, though this should be done in critical cases where reasonable assumptions of a sufficiently accurate nature can be made about the spectra involved. A broader assessment is provided by any of three other methods, all much simpler to use. The first of these, known as the "tangent-to-curve" procedure, requires the octave band spectrum of the noise to be plotted on a chart with a set of prepared numbered contours. The number attached to the highest contour to which the spectrum is just tangent then characterizes the speech interfering value of the noise. The contours used nowadays for this procedure run from 500 to 2000 Hz only, and the method is equivalent to determining the greatest of the three weighted sound pressure levels in the octave bands centred on 500, 1000 and 2000 Hz. One such set of contours is that known as NCA (noise criterion alternate) of Beranek (23); latterly the noise rating curves NR have come into use (24) for the same purpose. The difference is trivial and the tangent-to-curve method may be approximated as follows:

1. measure the band pressure level in the octave at 500 Hz and subtract 3 dB

2. measure the 1000 Hz octave band pressure level

3. measure the 2000 Hz octave band pressure level and add 3 dB

4. select the greatest of these three quantities.

The second type of method is the "averaging procedure". Now out of vogue due to the introduction of modern preferred frequencies, this method was formerly used to determine speech interference level, SIL; the value being simply the average of the band pressure levels in the octaves centred on 425, 850 and 1700 Hz, with an allowance for the 212 Hz band if this level was high. The third procedure uses a sound level meter with an appropriate weighting network. In a study using 16 equally interfering noises, that is, having the same articulation index, it has been shown (25) that there is not much difference between any of the methods, sound level A included. A new contour, described as SI, was devised to optimize the correlation but, to the author's knowledge, this has not gained any wide acceptance.

The interpretation of the simplified speech interference rating procedures is done in terms of the greatest distance at which conversation can be carried on in the presence of the noise or, in the case of telephone communication, in descriptive terms. Table V is taken from a draft ISO paper which, though as yet unpublished, has not been challenged technically since it was tabled in 1961.

Table V

Speech interference in terms of Noise Rating NR

| $\mathrm{NR}_{.5,1,2}$ | Distance at which everyday speech is considered intelligible (m) | | Quality of telephone communication |
|---|---|---|---|
| | Conversational voice level | Raised voice level | |
| 40 | 7 | 14 | |
| 45 | 4 | 8 | |
| 50 | 2.2 | 4.5 | Satisfactory |
| 55 | 1.3 | 2.5 | |
| 60 | 0.7 | 1.4 | Slightly difficult |
| 65 | 0.4 | 0.8 | |
| 70 | 0.22 | 0.45 | |
| 75 | 0.13 | 0.25 | Difficult |
| 80 | 0.07 | 0.14 | Unsatisfactory |
| 85 | - | 0.08 | |

In the author's experience, the distances quoted are perhaps on the low side considering the terms in which are described, namely intelligibility. On the other hand, they are realistic, if not on the high side, if they are interpreted to mean distances at which conversation can proceed for any length of time without noticeable discomfort.

## 3.5 Effects related to noise duration

In a general way it is obvious that a loud sound lasting a long time, or occurring repeatedly, produces more annoyance than a short single occurrence. It is equally self-evident that time and intensity are different entities, whether in the physical or subjective realms. In forming a judgement about the annoyance of a noise, one is therefore making some kind of combined estimate of its extensions along two psychological dimensions. It is convenient for practical purposes, however, to represent the extension along the dimension of "duration" in terms of its equivalent extent along the dimension of "loudness", a process which is often spoken of as a "trade-off". Experiments (26) show that stable judgements can be obtained in a given environmental situation by having subjects match the total impression of noises of variable level and duration against a reference sound of fixed duration and adjustable level, as in loudness testing. This is a special case of cross-modality matching which, in a more general way, permits matches to be made between any two, or any two combinations of, sensory experiences. The author has, for example, used cash value, in the form of estimates of the compensation judged equitable to sustain the given environment regularly, as a common scale linking assessments of the overall nuisance produced by aircraft and traffic noise respectively. The results are remarkably consistent with more conventional procedures, see Chapter 6.

In the case of duration, or recurrence rate, and noise level, the combination of the sensory experiences yields estimates of the trade-off ranging from 6 to 2 dB per double duration, the value falling as the absolute duration increases (27). This behaviour can be predicted theoretically from a model evolved by the author (28) which links a number of experimental observations concerning the formation of annoyance. In recent experiments, Little (29) has found a somewhat smaller influence of duration, but what is more significant about his experiments is that the result depended on the "set" of the subjects. A larger duration trade-off resulted when their attention was called to the fact that duration was one of the experimental variables than when this fact was not disclosed. In tests where the spectrum as well as the duration were both varied within a test sequence, the subjects virtually ignored the second factor and matched the sounds more or less purely in terms of their peak perceived noisiness. Little regarded these tests as pilot studies only, setting the scene for more extensive work on the influences of methodology.

It is intuitive that loudness and subjective duration are independent psychological dimensions, that is, they can be visualized as orthogonal axes in a space of, perhaps, many dimensions. In such a space each physical event can be mapped as a point of n coordinates. Contours in n - 1 dimensions can be traced out, which connect all points representing events with a given annoyance potential. In two dimensions, such contours might be quadrants of circles; this would be the case if loudness were quite independent of duration and vice versa. But in the general theory of multi-dimensional subjective scaling no such limiting assumptions are made, and the trade-off, which is equivalent to tracing out the course of such a contour from one axis round to the next, may well be a non-constant relation between the physical correlates of the subjective axes. The sophistication of this kind of conceptual model-making obviously does not harmonize with practical engineering, and approximate simple rules are needed. The practical question, as yet unresolved to everyone's satisfaction, is what constant to choose for the loudness/duration trade-off, given that it is going to be force-fitted to the experimental facts. There is also the problem of coping with arbitrary time-histories where the two dimensions are confounded and a definition of duration becomes somewhat indeterminate. It will suffice here to quote two current usages, each in its own domain. The first concerns the over-flight of aircraft from the point of view of characterizing its effective perceived noise level, considered as a separate event; the second concerns interference with speech caused by a stream of interfering noises, with special reference to aircraft noise in schools.

For adjusting peak perceived noise level, $L_{PNmax}$, to obtain effective perceived noise level, $L_{EPN}$, the draft ISO Recommendation 1760 specifies the addition of a duration allowance, defined, in principle, by the equation:

$$\Delta = 10 \log (1/T_o) \int_{-\infty}^{\infty} 10^{L_{PN}/10} . dt - L_{PNmax}$$

where $L_{PN}$ is the "running value" of perceived noise level, or of tone-corrected perceived noise level as appropriate, and $T_o$ is an arbitrary constant having the dimensions of time. Since the event cannot, in practice, be known over all time, a working definition is also given which is the same except that the limits of integration are $t_1$ to $t_2$ where $(t_2 - t_1)$ is the time interval over which $L_{PN}$ is within a specified distance of its peak value. For "20 dB down", the definitions are practically identical, but background noise may make this quantity difficult to measure so that "10 dB down" is preferred in some quarters. It is permitted to use $L_D$ and $L_{Dmax}$ in place of $L_{PN}$ and $L_{PNmax}$ which facilitates instrumentation without introducing appreciable error. $T_o$ has been set at 10 seconds, merely to make the value of the duration allowance about zero for present-day heavy jet take-offs.

The leading factor 10, and the third "10", namely the one in the denominator of the exponent of the integrand, are empirical values which imply the trade-off of 3 dB per double duration. It has been argued that both 10's might equally well, or better, be 13.3 or 15, implying trade-offs of 4 and 4.5 respectively. The value 10 is certainly within the range obtained experimentally, and it has the very great advantage that the integral is effectively a measure of the total weighted sound energy. This point is elaborated in Chapter 4 in connection with indices of total noise exposure.

Just as noisiness and time conspire to augment annoyance, so must the speech disturbance of a noise increase the longer the noise persists. Meister (30) has studied this question, as well as annoyance and auditory fatigue, and determined appropriate trade-off relations. His procedure for speech disturbance rating starts with the noise level measured indoors in dB(A). The duration of each intruding noise occurrence, $t_i$, is reckoned on the "10 dB down" basis. A sample period, such as a school lesson of duration T, is considered. The total intrusion time $\Sigma t_i$ is then entered into a formula to determine the parameter $L_t$ thus:

$$L_t = m \log (T/\Sigma t_i)$$

m in this formula has the same kind of connotation as the "10"s in the $L_{EPN}$ formula. Meister considers that the value of m is variable, running from 15 at low background noise levels below 40 dB(A), downwards. At levels of around 60 dB, that is, where the "background" is speech, he takes the value of m to be 13.4. Next, $L_{Amax}$ is calculated as the average of the peaks of the intruding noise levels, and finally one derives the equivalent disturbance level $L_q$ from the formula:

$$L_q = L_{Amax} - L_t$$

A set of curves is then entered on which the abscissa is the mean speech level, the parameter is $L_q$, and the ordinate is the percentage loss of intelligibility for meaningless syllables. From the last-mentioned one may deduce loss of sentence intelligibility as from the articulation index. A simpler rule applies for comparatively small ratios of lost time to total time, according to Meister, whereby the loss of sentence intelligibility can be expressed directly in terms of the ratio, independent of the noise level, as follows:

$$V = 0.2 (\Sigma t_i/T) \times 100\%$$

He considers that, for schools, V should not exceed 2%; a further loss of some 2% is to be assumed due to imperfect perception even in ideal conditions, and these two losses operating together are as much as should be tolerated. This means that the lost time fraction should not exceed 10%, but Meister points out that in reckoning T one ought to take the time during which verbal communication actually takes place rather than gross classroom time.

Turning to the question of recurrence rate, the experimental evidence is less plentiful or, at any rate, less direct. Perret, Grandjean and Lauber (31), using a German translation of the author's rating scale of intrusiveness, attempted to obtain judgements from students, in the course of normal physiology lectures, designed to compare the annoyingness of 1, 5 (or 6), and 10 (or 11) recorded aircraft noise intrusions respectively. The rating scale was shown to be quite sensitive to factors of intensity, duration and noise spectrum, but practically no difference was found in respect of the occurrence rate. The explanation of this null result is unclear. On the other hand, various social surveys have yielded by rather indirect means some positive evidence of annoyance increasing with numbers of occurrences. McKennell (32) found a correlation of 0.43 between "annoyance score" and the number of aircraft heard. The same correlation, 0.43, was found when the logarithm of the number was substituted for the cardinal number, but in the light of other considerations it was the logarithmic form that was adopted in the formula for NNI (see Chapter 5), with the coefficient 15. A Dutch survey (33) near Schiphol Airport also yielded a value close to 15. French surveys at Orly, le Bourget, Lyon and Marseille airports suggested the value 10, which is incorporated in the "indice de classification"; the value 10 is also widely used in U.S.A. (34). The estimates are derived from experiments unavoidably involving rather low correlation coefficients; in other words, the confidence limits on the coefficients thrown up by the correlation technique are rather wide. The results of the 1967 Heathrow survey by the Board of Trade, and of those being carried out around 8 major American airports by Tracor Inc., are not yet available but may well settle this issue soon. Meanwhile, the draft ISO Recommendation 1760 adopts the coefficient 10. This has, of course, the same advantage as mentioned in connection with the duration allowance; inasmuch as the general question of noise nuisance, not specifically due to aircraft, entails the case where duration and recurrence rate begin to blur and merge into a semi-continuous pattern, it is obviously desirable to have a rating system that is compatible along this continuum. In its simplest form, that is, the energy principle, this goal appeared until recently to be unattainable or illusory, due to contradictory evidence from traffic noise studies (see under Traffic Noise Index, Chapter 5). The author has succeeded, however, in showing how a quite simple modification to the principle will harmonize the results (28).

### 3.6 Effects on hearing

The effects of prolonged exposure to noise in industrial and military situations have been the object of extensive research in recent times. It is possible to state with conviction (35) that, save for minor symptoms of auditory fatigue (TTS) in a small proportion of people from which recovery is rapid and which in itself is not harmful, there is negligible effect on the hearing of people in communities living near present-day airports.

As a guide, a level of 85 dB(A) may be sustained for 8 hours daily over a period of 20 years before 2% of the most noise-susceptible ears attain a level at which there is slight difficulty with the perception of speech; this assumes ear pathology from other causes to be absent. This level of noise immission is several orders of magnitude greater than anything that would be deemed acceptable on grounds of community annoyance and interference with living. For information on the prediction of hearing loss due to noise, see reference (36).

## 4. Indices of total noise exposure

As has been seen, different characteristics of the stimulus are associated with different reactions; the way in which the time factor is involved, however, seems to be in some measure common to all. The need for a number of different indices representing the exposure to an ensemble of noises e.g. on the basis of 1 day or 1 year, has to be recognized though such indices may have an underlying similarity. There is also some evidence (1) that reactions depend partly on the nature of the noise source, possibly due to such psycho-sociological factors as fear, familiarity, participation and prestige. Such factors are stated (35) "to play at least as prominent a role as the physical or acoustical variables in determining the responses of individuals". For this reason, then, it is necessary to keep an open mind on the possible need to count exposures from different classes of noise separately, though in the limit such procedures should converge to describe the case of mixed noises where individual identity is lost in the general uproar.

Within this framework, the various indices in current use, listed in Chapter 2, can be classified as follows:

a) indices summarizing a succession of aircraft noises

b) indices summarizing the "noise climate" of road traffic

c) an index for rating office noise

d) an index for rating disturbance to speech communication

e) an index for assessing the risk to hearing.

These will be considered in turn.

### 4.1 Aircraft noise exposure indices

These indices are shown in Table VI.

/Table VI

Table VI

Aircraft noise exposure indices

| Title | Abbreviation | Country of origin | Definition | Note |
|---|---|---|---|---|
| Noise and number index | NNI | U.K. | $\bar{L}_{PNmax} + 15 \log N - 80$ | |
| Composite noise rating | CNR | U.S.A. | See text | |
| Störindex | $\bar{Q}$ | Germany | $(1/a) \log (1/T) \int_0^T 10^{a\, Q(t)} . dt$ | 1. |
| Indice de classification | R | France | $\bar{L}_{PNmax} - 16 + 10 \log (N/960) + 5 \log \xi$ | 2. |
| Annoyance index | AI | Australia | $10 \log \Sigma\ 10^{L_{PNmax}/10}$ | |
| Noisiness index | $\overline{NI}$ | South Africa | $10 \log \Sigma \{k^2 (t/T)\ 10^{L_A/10}\}$ | 3. |
| Noise exposure index | $L_{exp}$ | Netherlands | $20 \log \Sigma (k . 10^{L_A/15}) - 106$ | 4. |
| Aircraft exposure level | $L_E$ | ISO | $10 \log \Sigma\ 10^{L_{EPN}/10} + 10$ | |

Notes:

1. The value of $a$ and the choice of the measure $Q(t)$ are left free, but in practice the former is taken to be 1/13.3 and the latter to be $L_{PN}$ or $L_A$ .
2. $\xi$ is the annual average runway utilization factor.
3. $k^2$ is a time-of-day factor, 1 from 08.00 to 18.00 .
4. k is a time-of-day factor, the same as $k^2$ in the South African formula.

Composite noise rating is obtained by adding to the value of $L_{PN}$, for a given class of flight operation, a correction taken from a table which distinguishes between night and day, percentage runway utilization and the number of movements. The last-mentioned rises in coarse steps which approximate to the rule 3 dB per doubling of number.

The quite unnecessary confusion of symbolism conceals a remarkable similarity between all these concepts. Save for additive and multiplicative factors applied to the actual index number, which are scientifically meaningless accretions, all conform to the canon $\bar{L} + A \log N$, $\bar{L}$ being the mean of the peak levels in dB(A), (PN) or (EPN), N the number of occurrences, and A a coefficient in the range 10 to 15. South Africa and Netherlands would embody, within the formula, a time-of-day factor whilst the remainder prefer differential limits; South Africa would attribute different durations to overflights according to the formula:

$$t = (W/W_o)^{\frac{1}{2}}.(s/v)$$

where W is the aircraft weight and $W_o$ a reference weight, s is the length of the normal to the flight path from the measurement point, and v is the aircraft speed. The British and American formulae exclude the duration as an independent variable, on the basis of experimental data; whereas the ISO formula includes it, by the use of the measure $L_{EPN}$. Germany offers a practical simplification of the Störindex, namely

$$13.3 \log \Sigma \{(t/T).10^{Q/13.3}\}$$

where t is 3.4(s/v), independent of weight, but they claim for the integral formula that its use is not confined to aircraft noise. One is driven to the conclusion that there is as much mythology as science in this area, and it is much to be hoped that the ISO formula will come to be accepted by everyone.

### 4.2 Traffic noise

The Wilson Report (37), without actually defining an index, implies one, by stating certain indoor levels in dB(A) that should not be exceeded for more than 10% of the time. Recent work in Sweden (38) has cast doubt on the appropriateness of this measure, which is designated $L_{A10}$; it was found to correlate less well with the opinions of respondents in a survey than some other measures. The best correlation, in fact, was found with the 24-hour energy mean level in dB(A). This measure is, save for the use of $L_A$ in place of $L_{PN}$, the same as the ISO specification for aircraft noise, though for reasons already mentioned this does not necessarily mean that corresponding values of the two indices would represent equal degrees of toleration to the two classes of noise.

Griffiths and Langdon (39), however, having conducted a survey of opinion in 11 neighbourhoods of Greater London, reach a conclusion contradictory to that of the Swedes. They postulate a <u>traffic noise index</u>, TNI, defined as $4L_{A10} - 3L_{A90} - 30$, the sound levels being measured outside the dwellings. Following the authors, the formula can be written in the form $L_{A90} + 4\ (L_{A10} - L_{A90})$, dropping the irrelevant constant, and it embodies the fact, amply supported by their evidence, that the annoyance is composed of contributions from the prevailing level and from the scale of the level fluctuations. The large coefficient attached to the latter term, 4, causes difficulties if the TNI is applied outside the immediate domain of validity, which is stated to be urban planning in the vicinity of motorways, that is, in the region of TNI 70 to 90 for the hourly average over a period of 24 hours. It is easily shown, however, that TNI is not the only formula which accommodates the data of Griffiths and Langdon, nor is it even the optimum in terms of best fit. An alternative form of index, devised by the author (28) and entitled <u>noise pollution level</u>, $L_{NP}$, is less sensitive to the vagaries of statistical fluctuations of the level than is TNI, the latter depending rather precariously on only two points selected from the cumulative distribution. This formula also reconciles the British and Swedish work, since it turns out that in the latter the variations in the statistics between one survey site and another were less than in the Greater London sites. The basic term in the noise pollution level is the "energy mean level", found to be optimum by the Swedes; however, it also contains a second term which renders it closely in accordance with Griffiths and Langdon's finding regarding the annoying role of the fluctuations.

### 4.3 Office noise

From the results of 1204 self-administered questionnaires in diverse types of office, Keighley (40) has devised a tentative acceptability scale, any point along which can be identified with a contour in a two-dimensional display. The coordinates of the diagram are respectively the mean noise level inside the office in dB(A), and a quantity termed transient peak index, TPI. Any pair of these quantities connected by the said contour represents conditions of equal acceptability. The TPI expresses the fluctuating character of the noise, but unlike the corresponding term in TNI it is not assumed to be arithmetically additive to the mean level, but rather in the manner described earlier in connection with multi-dimensional scaling. However, the terms are such that an increase in either increases the unacceptability. The value of TPI is defined as the average peak count in a 60 second period; a peak is defined as an excursion above the modal level as recorded on an instrument of specified ballistic response; peaks between 5 and 10 dB(A) score 1, those between 10 and 15 score 2, and so on. The following combinations are stated to be equivalent on a basis of acceptability, at the level where 6 persons out of 7 declared themselves to be satisfied with the conditions:

| | | | | | |
|---|---|---|---|---|---|
| modal value of $L_A$ | 60 | 62 | 64 | 66 | 68 |
| value of TPI | 28-34 | 16-27 | 9-15 | 6-8 | 4-5 |

This method of rating is almost totally insensitive to intruding noises unless their duration is such as to make an appreciable difference to the modal value of $L_A$. Its domain of application would appear to be office noise predominantly of internal origin.

### 4.4 Speech disturbance

This case has already been covered by the description of equivalent disturbance level $L_q$ in Chapter 3.5. For completeness and consistency with the aircraft and traffic noise annoyance indices, an index of total speech disturbance could be defined simply as $L_q + 13.4 \log T$, T being the total time under consideration. This index does not appear explicitly in the literature.

### 4.5 Hearing loss

As already stated, hearing loss is not considered to be a normal hazard to communities at present-day neighbourhood noise levels. If it should be desired to assess a noise environment from this standpoint, however, it may be done by calculating an index known as noise immission level, NIL (36). It corresponds exactly in formulation to the Störindex with $(1/a)$ equal to 10 and with Q taken as $L_A$, also to the ISO exposure level (save for the use of $L_A$ in place of $L_{PN}$) and to the Swedish rating proposal for traffic noise, all with the exception that the dimension of time is retained in the numerator (i.e. no normalization to a reference time with a factor $T_o$ in the denominator is used). The integration over time is reckoned over working hours, or for such time as the ear is exposed to the noise hazard. Thus it measures total sound energy.

### 4.6 Energy summation : fundamental principle or illusion?

As will be clear from the foregoing chapters, the concept of noise exposure as the sum of a noise level and 10 times the logarithm of a time, or the equivalent integral formulae for non-steady noises, is a rather pervasive one. There is solid experimental evidence that it reflects a fact of nature in the case of permanent noise-induced hearing loss (41). This does not prove that it operates for annoyance, but there is also good experimental evidence that something like it, coefficient ranging from 6 to 15 according to Meister, applies to annoyance in various circumstances. Pearson's results on the duration trade-off (27) can also be adduced, implying a coefficient between 6.7 and 20. Finally, the evidence from recurrence rate suggests values between 10 and 15, and recurrence is only another manifestation of the time variable. Recognizing this tendency, and conscious of the fact that where the exact numbers cannot be reconciled refuge must be sought in an appeal to general principles, the ISO Acoustics Committee TC43 has introduced the energy principle into several current documents, in various guises. The draft Recommendation relative to aircraft noise has already received mention; in addition, the concept appears in the Secretariat Proposals now circulating that concern the annoyance aspects of residential noise (primarily in the context of industrial noise emission), and the conservation of hearing within the factories. There is one discordant note : the experimental work of Griffiths and Langdon, whose measure TNI is incompatible with energy summation. One must also take cognizance of Keighley's work and its incompatibility with the energy principle due to the same cause, that is, neglect of the fluctuating character as a source of additional annoyance in itself.

On the side of energy summation, one must bear in mind that this principle alone carries with it the principle of arithmetical additivity. In the limit, it is easy to see that the energy principle must be correct. Imagine, for example, a noise A producing exposure level $A + 10 \log T_A$ and therewith a certain annoyance; then a noise B producing exposure level $B + 10 \log T_B$ and such that the annoyance is the same as that due to A. Now let noises A - 3 dB and B - 3 dB coexist, in the first instance with $T_A = T_B$. The energy (strictly, weighted energy) is the same as before. Moreover, provided the noises are measured in a scale related to annoyance such as dB(A) or dB(PN), the combined noise has the same numerical value as before and therefore the annoyance remains as it was. The restriction on the respective durations unfortunately hampers generalizations from this example.

In an attempt to make a synthesis of the experimental results which, in part, appear to present incompatibilities, the author discovered that the basic principle of energy summation together with an allowance for fluctuating character accounts for a great deal of the data and a single formula would act as a bridge spanning the various gaps between the domains of individual studies. It is believed that this is the first time such a synthesis has been accomplished and it is, no doubt, possible that the concept can be refined in the light of further study. The formula for the noise pollution level is as follows:

$$L_{NP} = L_{eq} + 2.56\sigma$$

where $L_{eq}$ is the energy mean noise level over the period in question. The choice of the basic measure L can be left free, but as in the case of the Störindex there are strong reasons to limit the choice to $L_A$ or $L_{PN}$, and as between these the author would recommend to follow the line of reasoning in Chapter 3.3. $\sigma$ is the standard deviation of the level fluctuations calculated, or measured, over the same period. The coefficient 2.56 sets the right hand term in the equation almost exactly equal to $L_{10} - L_{90}$ when the statistical distribution of the noise level across time is Gaussian, as it often is. The coefficient derives, however, not from this fortuitous coincidence but from consideration of the data of Griffiths and Langdon, Pearsons and others.

There is a useful corollary to the definition of $L_{NP}$ as given above, which facilitates the instrumental measurement of the index in many practical cases. For a Gaussian distribution of levels, it can be shown rigorously that the equivalent continuous level $L_{eq}$ is related to the median level $L_{50}$ by the equation:

$$L_{eq} = L_{50} + \sigma^2/20 \log_{10} e = L_{50} + \sigma^2/8.68$$

(57)

This expression remains nearly correct for distributions well removed from Gaussian provided that the standard deviation is not too large. For example, triangular and rectangular distributions obey the above formula within a decibel for $\sigma$ up to about 7 dB. The experimental determination of $L_{50}$ is particularly simple with the conventional level recorder/statistical counter equipment in current use. With the same equipment it is straightforward, but a little more trouble arithmetically, to derive $L_{eq}$ directly and then with no limitation on the statistics of the fluctuations.

## 5. Community reaction criteria

Three examples of these rating systems have been mentioned in Chapter 2. That using the noise rating curves, NR, evolved historically out of the American noise criterion, NC, system, taking account of parallel work in other countries around 1960, notably Austria and the Netherlands. The later history of the NR proposals within ISO has been chequered, the discussion mainly centring around the relative merits of the NR "tangent to curve" application as against simple sound level A. The issue is not finally resolved but sound level A is at the moment strongly in the ascendant due to its immediate compatibility with the methods of calculating indices of total exposure. The noise measure, however, is only one part of the system: the remainder, which is of principal relevance in this Chapter, applies to both measures, and concerns the environmental corrections.

Meanwhile in this country the Wilson Report, which embodied a similar system based from the outset on dB(A), led to the publication of an elaborated version by the British Standards Institution in 1967, entitled BS 4142:1967, Method of rating Industrial Noise affecting mixed Residential and Industrial Areas (42). This Standard takes the time factor into account in a different way from any other proposal and has a number of other features which will be mentioned in outline here, but it is liable to be amended when the ISO Recommendation has been published.

The noise level is measured out of doors near the affected premises and provides for three cases, the "typical low value or mean minimum" of the background noise $L_0$, the general steady level of the intruding noise $L_1$, and - in the case of intermittent bursts of higher level - the mean high noise level $L_2$. Experience with industrial noise situations seems to show that this somewhat arbitrary method of description is a practicable simplification. $L_1$ and $L_2$ are treated separately to corrections to obtain corrected noise levels $L'_1$ and $L'_2$. The corrections are +5 for noise of definite tonal character, +5 for impulsive character, and duration and intermittency corrections which are specified differently for day (07.00 to 22.00) and night (22.00 to 07.00). The first two adjustments recognize the attention-arresting quality of tonal and impulsive noises, so that either the first or second or both qualities penalize the noise by 5 dB(A). The duration is represented by the percentage on-time, $100\,\Sigma\, t/T$, where T is the total period (day or night) under consideration, and t an on-time of the noise $L_1$ or $L_2$. One then enters a diagram having percentage on-time as abscissa, noise level allowance in dB(A) as ordinate, and "typical on-time duration" as the parameter of a set of curves. Thus, by day, for a noise persisting 10% of the time, the allowance is only 2 dB(A) if it occurs all in one go but rises to 7 dB(A) if the 60 minutes on-time is broken up into separate bursts of half a minute each. The night-time allowance follows a similar pattern but with diminished values. In an extreme case, a single night-time occurrence of 2 seconds duration is awarded an allowance of 21 dB(A). These intermittency allowances were invented by a small committee consisting of Purkis, Delany and the present author; they have no foundation in direct experiment but were arrived at by studying case histories. The relative innocuity of split exposures presumed in this system clearly has limitations at the extremes of the range, but seems not to have caused difficulties in practice. It is, of course, quite incompatible with energy summation although some of its features are generated by the new concept of noise pollution level.

The second part of the Standard specifies a basic criterion of 50 dB(A) to which various environmental corrections are applied in order to arrive at the corrected criterion. These corrections concern novelty, type of district, time of day, day of the week, season of the year, in steps of 5 dB(A). The datum case is a new noise, quiet suburban area, evening or week-end, summer (implying open windows). Examples of the corrections are as follows:

| | |
|---|---|
| for old-established factories completely in character with the area in which they are situated | +10 dB(A) |
| residential urban area with some light industry or main roads | +10 dB(A) |
| weekdays, 08.00 to 18.00 | + 5 dB(A) |
| nights, 22.00 to 07.00 | - 5 dB(A) |
| noise occurring in winter time only | + 5 dB(A) |

The third part of the Standard assesses the liability of the noise to cause complaints by comparing the magnitude of the corrected noise levels, $L'_1$ and $L'_2$ whichever is the greater, with the corrected criterion or - when such is practicable - directly with the uncorrected background noise level $L_o$. Excesses of 10 dB(A) or more can be expected to lead to complaints; 5 dB(A) is marginal but indicative of the need for remedial measures to prevent a "creeping background". Refinements of the rules are given for cases where the actual background is out of line with the corrected criterion; in principle they should be the same on average, since that is how the values were derived in the first place.

It is instructive to work through an example, strictly speaking outside the scope of BS 4142 but within the subject matter of this paper, namely traffic noise. As source material one may take the London Noise Survey (43) which quotes the following noise climates:

residential roads, local traffic only (approximately equal to BS 4142 "urban residential") .......................... $L_{A90} = 57$

...... $L_{A10} = 65$

minor roads or gardens of houses with traffic routes more than 90 m distant (approximately BS 4142 "suburban, little road traffic")................................... $L_{A90} = 52$

...... $L_{A10} = 60$

Taking the second case, one may equate $L_1$ with 52; tonal and impulsive character will not apply and the duration correction is negligible so that $L_1'$ is equal to 52. $L_2$ may be taken as 60 dB(A) and the duration correction for 10% on-time may be assessed at 5, since the peak levels, when they occur, are likely to last for periods of 15 to 30 seconds. Therefore $L_2'$ is about 55. The corrected criterion will be 65, the corrections to the basic criterion being 10, in respect of the noise source being completely in character, and 5 because the data refer to noise in the day time. $L_2'$ thus falls short of the corrected criterion by 10 dB(A) and, as certainly appears right in this case, the noise is predicted to be well below the complaint level. Taking the first set of data instead of the second adds 5 dB(A) to the noise levels, but it also adds 5 to the corrected criterion in respect of the type of district, and therefore leads to the same reasonable conclusion.

One may ask what is the expectation on this system of a noise climate between 50 and 60 NNI, the range above which, according to the Wilson Report, the annoyance from aircraft noise becomes intolerable. For an example, an average peak perceived noise level of 100 dB(PN) and 200 movements may be taken; these provide an NNI of 55. In an area where such levels might occur their duration, assuming aircraft of current types, may be assessed at 30 seconds between "10 dB down points". Each event is thus approximated by a "rectangular" time pattern with an on-time of 30 seconds and a level 3.5 dB below the actual peak, that is 96.5 dB(PN) or 83.5 dB(A). This is the value of $L_2$. Intermittency and duration corrections work out at 5, so that $L_2'$ is equal to 78.5. Whether "tonal character" correction should be applied is debatable, but adding half a penalty brings $L_2'$ to 81. The affected area may well be of the "suburban, little road traffic" or "urban residential" types and the former will be assumed. The corrected criterion then becomes 55, on the basis that the aircraft noise "has been established for a few years but is not typical of the area in which it occurs", slightly to paraphrase BS 4142. There is no correction for time of day in this case, since evening operations are included in the NNI. The corrected noise level thus exceeds the corrected criterion by the handsome margin of 26 dB(A), and the reasonable expectation of vigorous complaints in this scenario is well predicted.

Pursuing the last example a little further, an abatement of some 20 dB would reduce the aircraft noise to the marginal level for complaint, and a further 5 dB should reduce it to a level of acceptability; going back to the data assumed, this means perceived noise levels measured outside the dwellings of 80 and 75 dB(PN) respectively. For residential urban areas conditioned to main road traffic, the Standard suggests that the levels could be 10 dB higher, say 85 dB(PN) to be acceptable. This conclusion assumes, of course, that the aircraft noise is substituted for the noise to which the people are conditioned, not added to it. Otherwise the rule of the 10 dB margin would have to be invoked, in order not to make unacceptable that which is initially just acceptable; thus the introduction of aircraft noise into the urban residential area ought to be done so that $\bar{L}_{PNmax}$ is no higher than 75. One can present this conclusion in terms of any of the exposure indices, but since the starting point was NNI it may be convenient to keep in these terms, and the results can then be summed up thus:

Table VII

Aircraft noise limits derived from BS 4142 to preserve existing amenity

| Type of district | Maximum NNI | Maximum of the mean peak value of $L_{PN}$ given N movements<br>N = 200 | 100 | 50 |
|---|---|---|---|---|
| Suburban, little road traffic | 19.5 | 65 | 69.5 | 74 |
| Urban (residential) | 24.5 | 70 | 74.5 | 79 |
| Predominantly residential urban but with some light industry or main roads | 29.5 | 75 | 79.5 | 84 |

Although the application of BS 4142 to these motor vehicle and aircraft noise examples goes beyond the stated scope of the Standard, the results are seen to be concordant with experience. However, it is possible that additional adjustments ought to be made to the rating system according to the class of noise, for reasons already mentioned. The evidence from reference (1) suggests that aircraft noise, particularly at high levels, is actually not as annoying as motor vehicle noise of the same high level. The relative difference at the levels cited in the examples, however, would be quite small, at most 1 or 2 dB in favour of the aircraft noise. This clearly makes no significant difference to the conclusions.

The BS 4142 system is unsuited to rating noise other than that in residential premises; for other environments one must turn to the NC or draft ISO methods. Curiously enough, these rating procedures for functional buildings are devoid of all complexity, being expressed simply in terms of maximum suggested noise levels. For broadcasting and recording studios, or for concert halls and theatres, it is no doubt right to ignore the duration element, since any interruption may be artistically disastrous. It is not so evident whether a single-figure rating is adequate for the other cases listed in Table VIII below. This Table is an amalgam of suggested levels taken from various draft ISO papers, including the one now current, ISO/TC43/SC1(Secretariat-4)4. The numbers in the Table are not everywhere quite consistent, reflecting shifts of opinion in the deliberating committee. The ratings relate to noise entering from outside and in no case to noise generated within the room, but the values refer to the noise as measured indoors. A rough-and-ready rule for the interpretation of NR values for broad-band noises is $NR = L_A - 5$. For buildings of normal construction and for rooms of moderate size, say 30 to 150 $m^3$ (1000 to 5000 cubic feet), the following insulation values may be taken as a guide:

windows open ............ 10 dB(A), single windows shut ...... 15 dB(A)
double windows shut ..... 20 dB(A), non-openable windows ..... 20 dB(A)

Table VIII

Suggested maximum noise levels for indoor spaces

| Examples of type of room | Suggested maximum level | |
|---|---|---|
| | $NR_{63..8000}$ | dB(A) |
| Bedroom, hospital ward, TV studio, living room, theatre, church, cinema, concert hall, small office, reading room, conference room, lecture room | 20 - 30 | "Not usually to be set lower than 20" |
| Larger office, business store, department store, meeting room, quiet restaurant | 35 | 30 - 40 |
| Larger restaurant, secretarial office | 45 | 40 - 50 |
| Larger typing halls | 55 | 50 - 60 |
| Workshops, according to function | 45 - 75 | 60 - 70 |

## 6. Socio-psychological factors

### 6.1 National differences

Sociologists would probably maintain that intranational differences of community reaction should be taken into account before embarking on the bolder question of international comparisons, introducing as they do additional complications such as that of language.

However, one notable attempt has been made to effect such a comparison (44), in relation to traffic noise annoyance, with the aid of expert linguists to draw up the parallel questionnaires. Sites were selected in Stockholm and Ferrara where the traffic counts were about 8000 per 24 hours. Road widths were similar, and in both towns surveys were carried out mainly in apartment blocks, selecting only the people living on the first floor (English meaning). The comparison was complicated by two things, namely substantial differences in the composition of the traffic (more motor cycles in Italy), and by some differences of sound insulation with open windows (naturally more so with the windows closed). Making allowance, so far as possible, for these factors the investigators drew these conclusions. First, reactions in Stockholm were somewhat stronger, in spite of an essentially lower degree of noise exposure. Second, the Ferrarese seem to have shorter steps on their scale of tolerance than the Swedes. From the detached vantage point of an Anglo-Saxon, the author would have guessed these results correctly without the aid of experiment! A selection of the significant findings is given in Table IX.

Table IX

Abstract of results of Stockholm-Ferrara tests

| Description | Stockholm | Ferrara |
|---|---|---|
| Source of highest noise levels, and value with standard deviation in dB(A), measured indoors with open windows | Bus 68; 5.0 | Truck 71; 4.2 |
| The same, with windows closed | Truck 51; 4.6 | Truck 58; 5.4 |
| Mean level difference due to closing windows | 15 | 13 |
| Most often reported source of annoyance | Heavy traffic | Motor cycles and mopeds |
| Relative mean noise level, open windows | Datum | -5.4 |
| The same, with windows closed | | -8.0 |
| Percentage of respondents who: | | |
| "notice" vehicle noise ......... | 92 | 63 |
| "are disturbed by" ............. | 61 | 49 |
| "are greatly disturbed by" ..... | 23 | 21 |
| "are disturbed at least once/ day ... | 52 | 46 |
| "are woken up several times/ week".. | 26 | 28 |
| "are woken up once/week" ....... | 40 | 34 |
| "have tried to get disturbance reduced"......... | 12 | 4 |
| Percentage of respondents who "notice": | | |
| noise from building projects.... | 11 | 2 |
| noise from public places of entertainment etc | 1 | 30 |

The Table shows only those factors that were found to give statistically significant national differences; many others were about the same but there is no physical information about the relative magnitude of them, for example aircraft noise.

Turning to social surveys on aircraft noise in different lands, the voluminous nature of the reporting puts it beyond the scope of this paper to give more than a cursory comparison of the findings. As seen in Chapter 4, the diversity of scales used to sum up the results obscures the attempt to compare them, but the U.K., Dutch and French results can be so treated in terms of NNI.

The material considered here comes from studies in U.K. (45), Germany (46), Netherlands (33), U.S.A. (34), France (47) and Australia (48).

The U.K. and Dutch results are so similar as to be barely distinguishable when compared on the overall basis of annoyance score ratings. Reference (33) shows that both can be represented by the equation:

$$A = 1.17 (NNI - 3).$$

At the level A = 45%, about 42 NNI, which the Dutch workers regard as the upper limit for acceptable habitation, the following collateral observations hold at Schiphol:

27% often disturbed in conversation
66% sometimes afraid
21% sometimes awakened
12% often awakened.

Comparing these findings with those of the Heathrow study (45), the Dutch investigators conclude that there is fair agreement. The Heathrow findings at 42 NNI are:

60% conversation interfered with
53% startled
55% woken up.

The author's reading from this comparison is that the Schiphol residents are appreciably more tolerant than those of West Middlesex, though apparently equal when it comes to reckoning their overall annoyance score on a Guttman scale.

The French study (47) combines the results of surveys at Orly, le Bourget, Lyon and Marseille, and presents them in a similar form except that the U.K. annoyance scale was of 6 points and the French of 5. This affects the factor used in expressing the relation of annoyance to NNI but, as near as the author can decipher, the corresponding equation is: $A = 1.36\ NNI - 15.7$ . For 42 NNI, this yields a value of A = 41%, in good agreement with the other studies. The higher coefficient, 1.36 compared with 1.17, is perhaps another manifestation of Latin temperament similar to that found in Ferrara. It is possible to express 42 NNI in terms of the "indice de classification" R from the regression lines given on Fig.39 and Annexe 14 of the French report, with the result R = 81. From this one can, in turn, deduce from Fig.23 the following collateral observations:

30% conversation interfered with
21% startled
27% woken up.

These reactions appear to be somewhat below the Heathrow levels.

The German experts commission report (46) presents a comparison of $\bar{Q}$, NNI, CNR and R scales annotated with verbal interpretations, which throws some indirect light on differences of national attitude. For a complete comparison the reader is referred to Fig.42 of the German report; here it will suffice to give a specimen at the level 42 NNI, as used in the previous comparisons. Based on the meanings assigned in the different countries to various points on the respective scales, the German investigators have attempted to align the scales at points of equal meaning, by shifting and stretching the scales as necessary. One can then read across and deduce equivalent scale numbers, thus:

| | | |
|---|---|---|
| NNI | 42 | |
| $\bar{Q}$ | 73 | (on the $L_{PN}$ basis, with $m = 13.3$) |
| CNR | 108 | |
| R | 67 | |

To appreciate the significance of these equivalences, they have to be set alongside the physical relationships between the scales. This, unfortunately, is a step at which yet more uncertainty is introduced, since assumptions have to be made. For concreteness, let it be assumed that 42 NNI is the result of a mean peak perceived noise level of 87.5 dB(PN) associated with 200 movements. Then one can calculate the following physical relations between the scales:

| | | |
|---|---|---|
| NNI | 42 | |
| $\bar{Q}$ | 75 | (taking each duration as 30 seconds and total time as 15 hours) |
| CNR | 97.5 | |
| R | 81 | |

On comparing these values with the equivalences above, it appears that the American guide (34) permits higher, and the French authorities lower, levels of noise exposure for approximately corresponding sets of circumstances. Whether this means that Frenchmen are less tolerant and Americans more tolerant than the British and Germans is conjectural; the result could just mean that the American authorities are willing to set higher limits and the French lower ones.

Piesse and the late N.E. Murray (48) studied complaints from the area around Sydney international airport and deduced a level of annoyance index AI of 120 to be the acceptable maximum. The area to which this study refers appears to correspond roughly to the 1961 65 NNI contour in the Wilson Report. The traffic consisted of 57 day-time take-offs, and using the tabulated data one computes NNI = 108.6 + 15 log 57 - 80 = 55, and AI = 134. This means that AI 120 corresponds approximately to NNI 41, by difference. Compared with the 65 NNI in the corresponding neighbourhood close to Heathrow, this figure looks small indeed. Probably no more can be read into this comparison than that a stricter view is taken of airport noise in Australia.

No useful summary of these rather slight facets of national attitude differences can be made beyond saying that they seem to exist.

### 6.2 Adaptation

This factor is, by its nature, not easily susceptible of study, and experimental evidence is meagre. The general principle that seems to operate is this : high levels tend to exacerbate, low levels to mollify reaction with the passage of time.

In the case of aircraft noise from military bases, Borsky (49) found that after a period of adjustment, people became on the whole less rather than more tolerant. Coblentz, Xydias and Alexandre (47) sum up their own experimental results thus:

(i) the number of people who become more tolerant exceeds the number who become less tolerant, but

(ii) the percentage more annoyed at a given time than they were in the past increases directly with their present annoyance score.

The French investigators interpret these findings in the following aphorisms:

- those who are not used to noise tend increasingly to resent it;
- the higher the noise level, the more difficult it is to get used to.

They add that aircraft noise, being intermittent, is more difficult to get used to than steady traffic noise even if the latter is fairly loud; also that this discontinuity is the more resented the more frequently the peaks occur. Without being able to say just how to do so, these investigators feel that a personal factor, "aptitude for getting used to noise" could with advantage be taken into account.

In the rating systems for industrial noise affecting residential premises, based on case histories, it is recognized that habituation to the noise environment diminishes the tendency to adverse reaction.

Thus, one seems to be able to conclude broadly speaking that high levels, especially if associated with intermittency, tend to exacerbate, whereas lower levels, especially if steady, can be adapted to. Where the dividing line comes is conjectural since the exacerbatory evidence comes aircraft studies where the intrinsic noise levels were high, whereas the industrial noise case histories are generally related to levels much lower down the scale, 50 - 60 dB(A).

### 6.3 Economic tie

It has often been assumed that involvement by people indirectly in the source of noise annoyance, for example by employment at an airport or in businesses on the periphery which exist by reason of the airport, lessens their tendency to adverse reaction. A 5 dB allowance was proposed for this factor at one stage of the ISO noise rating discussions but it has now been dropped. McKennell (32) dispels the idea firmly, and quotes similar views by Borsky. This factor is not the same as the "participation" factor mentioned earlier, on which, however, there appears to be only anecdotal evidence.

### 6.4 Attitude control

McKennell remarks that changes in certain personal factors, if these could be brought about, could be as effective in reducing the numbers annoyed by aircraft as reductions of the noise level itself. The most favourable factors for such an attack would be those most highly correlated with annoyance, and might include the following:

opinion about the effect of noise on health
fear of aircraft
views on the preventability of noise

Whether such control of attitudes is practicable has been explored on a small scale in Sweden, in an experimental study by Jonsson and Sörensen (50), and a follow-up field study by Cederlöf, Jonsson and Sörensen (51). The experimental situation was tape-recorded aircraft and motor vehicle noise, and a 3-point rating scale of disturbance. Three groups of listeners were employed, their respective "briefings" being negative, neutral and positive. For example, the positive briefing with respect to aircraft noise conjured up the vision of a local air command showing understanding and willingness to cooperate with residents; the negative briefing suggested a "couldn't care less" attitude and a concern only with the military training programme. The circumstances were imaginary, but remarkably different responses were recorded, the positive influence being more successful in inducing changed responses than the negative, as measured by percentage deviations from the neutral group. The hypothetical circumstances precluded drawing quantitative conclusions, but a real situation was found at Linköping, near a Swedish air force base, where positive influence was applied to one group of residents and none to another. The influence was applied through a questionnaire with leading questions on aircraft noise and the reward of a presentation booklet for a returned questionnaire. A summary of the results is given in Table X.

Table X

Results of positive attitude control test at Linköping

| Description | Percentage of persons | |
|---|---|---|
| | Influenced group | Control group |
| Greatly inconvenienced | 18 | 43 |
| Inconvenienced | 54 | 79 |
| Inconvenienced at least once a week | 37 | 64 |
| Woken up once a month or more | 12 | 24 |

The response rate was not high, about 60%, which might mean that attempts to influence the remainder were self-defeating. However, relatively large changes of reaction appear to have been brought about among the 60% who did respond. The Swedish workers conclude that "it seems perfectly clear that the results could be put to practical use".

## 6.5 Cash value of the environment

This factor deserves mention, not so much from the standpoint of being a sociological variable, but as a possible means of gauging overall reaction in terms that are less emotive than "annoyance".

In the experiments already referred to (52), subjects who were conditioned to generally quiet or moderate environments were subjected to adverse noise environments created by motor vehicle and aircraft noise, and their reactions to the prospect of working continually in the noise were scored by the compensation they considered to be equitable. The results were such that if the mean noise levels of the (three) environments were plotted against either the subjects' own noisiness ratings or against the logarithms of the money compensation, the two sets of data points practically coincided, by suitable choice of scale size. In the circumstances of this experiment, cash value was as good a means of comparing the three situations as was direct assessment of noisiness.

Waller and Thomas (53) have attempted a more elaborate comparison of amenity deprivations on the cash value basis. Of their 11 "annoyances", all but two concern noise of various kinds. By expressing the capital value, or in some cases the equivalent capitalized value, per household attaching to the amenity losses on a logarithmic scale and plotting it against the estimated percentage annoyance laid on an "arithmetic probability" scale, the data points lie along a straight line within a half-decade on the money scale. In view of the oblique and miscellaneous ways in which both the money and fractional annoyance assessments were arrived at, the result seems to offer promising prospects for a more homogeneous study on the same lines, and to support the contention of Waller and Thomas that the environment can be valued in monetary terms in spite of a certain natural repugnance at the idea. Using the results presented by these workers, a relationship between the nuisance of aircraft and motorway noise can be deduced. Whilst this treatment of the results may go beyond the intentions of their authors, it seems to be a legitimate pursuit particularly since after this work was done (1966) a direct basis of comparison has become available (32, 54, 55) against which to verify the cash comparison.

Taking as an example the mid-point along Waller and Thomas's annoyance scale, where the uncertainty is likely to be least, there is a stated cash equivalence between the 45 NNI aircraft noise environment and that existing at a distance of 180 m (600 feet) from the elevated section of the M4 motorway in West London. As in previous comparisons, some assumptions have to be made in order to render the measuring scales compatible, and in this case it is best to reduce the data in terms of dB(A). Considering first the aircraft noise, 45 NNI may be generated by such combinations as these:

| $\bar{L}_{PNmax}$ | N |
|---|---|
| 89 | 250 |
| 92 | 160 |
| 95 | 100 |

of which the intermediate case will be taken. Assuming durations of the order 15 seconds between "10 dB down" points and a mean difference between $L_{PN}$ and $L_A$ of 13, the equivalent continous level becomes:

$$L_{Aeq} = 79 + 10 \log (0.25 \times 160)/(15 \times 60) - 3.5$$

over the 15-hour period, say 07.00 to 22.00. The final term, 3.5, accommodates the rise-and-fall pattern, the integrated value being just under half that reckoned over the "10 dB down" time span at the peak level.* Thus one arrives at $L_{Aeq}$ = 62 dB(A). Turning to the motorway noise, one may reason as follows. Stephenson and Vulkan (54), give, for the average vehicle flow between 07.00 and 22.00 on the M4, a value of 2850 vehicles/hour, and the following mean noise levels over the same period: $L_{A10} = 80$, $L_{A90} = 71$, at 6 m (20 feet). The conversion of these data to the distance of 180 m can be performed with the aid of Johnson and Saunders' work (55), in two ways. Purely on a basis of distance correction, the cylindrical spreading law is indicated, leading to a value of $L_{A50}$ of about 75.5 - 10 log (180/6) = 61 dB(A), the first term being the mean of the 1st and 9th decile values from reference (54) at 6 m. The standard deviation of the fluctuations,

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*In the case of a monopole source in uniform rectilinear motion, the energy ratio is actually (1/3)arctan3, or 0.419.

from reference (55), would be about 2 dB(A), giving $L_{Aeq} = 61 + 2^2/20 \log_{10}e = 61.5$. Alternatively, one may take the noise levels direct from reference (55) for the appropriate distance of 180 m, the vehicle flow of 2850 v/h, and the mean speed of 65 km/h appropriate to the site in question; these data predict $L_{A50} = 58$ and $L_{Aeq} = 58.5$, but as the last result is for unobstructed propagation it is legitimate to add between 0 and 3 dB to compare it with Stephenson and Vulkan's measured results. The agreement is good, and the equivalent continuous level of about 61 dB(A) can be inferred. The difference between this and the value of 62 for the aircraft noise is remarkably little considering the number of steps involved.

The above comparison is in effect a test of cash assessment against physical meter readings. The comparison should also be possible on the basis of cash assessment versus annoyance rating, since Griffiths and Langdon (39) have provided the requisite data. Specifically, 50% of the respondents in these authors' survey scored less than or equal to 4.43 on their "scale of dissatisfaction", and this value corresponds to the following sound levels:

$$L_{A10} = 69, \quad L_{A50} = 60, \quad L_{A90} = 55 \text{ dB(A)},$$

as read from the regression lines in reference (39). Incidentally, the TNI calculated from these values is 81, compared with 82 read from the independent regression line, in good agreement. However, although the $L_{A50}$ value is sufficiently close to those derived by alternative routes above and therefore superficially in support of the cash comparison, regard has to be taken to the sound level distribution which Griffiths and Langdon find to be so important. Whereas Johnson and Saunders predict an interdecile range of only 5 - 6 dB(A) at 180 m from a roadway with vehicle flow rate in the order $10^3 - 10^4$ vehicles/hour, Stephenson and Vulkan's experimental data for the M4 show 9, and both are much less than the 14 implicit in the use of Griffiths and Langdon's data in the above manner. This value, 14, however, does not derive from measurements specific to motorways but from the ensemble of their data. Nevertheless, if one were to insert Johnson and Saunders' or Stephenson and Vulkan's noise climates into the formula for TNI, one would obtain values well below the 81 or 82 of Griffiths and Langdon, and therefore presumably expecting a weaker response than the median dissatisfaction score of 4.43. The implied discrepancy is considerably diminished if the climates are reckoned in terms of noise pollution level, according to the formula:

$$L_{NP(A)} = L_{A50} + d + d^2/60$$

where d is the interdecile range, $L_{A10} - L_{A90}$. In these terms, the level at which 50% of the people are just satisfied is as follows:

| Source of subjective data | Source of physical data | Value of $L_{NP(A)}$ |
|---|---|---|
| Waller and Thomas | Stephenson and Vulkan | 71.3 |
| Waller and Thomas | Johnson and Saunders | 67.6 |
| Griffiths and Langdon | Griffiths and Langdon | 77.3 |

To sum up, the reliability of the environmental cash value comparisons seems to be as good as the uncertainties in translating these, and the results of annoyance comparisons, into physical scales permit.

## 7. Summing-up and recommendations

The complexities of the noise rating problem have been reviewed. These lie partly in the nature of things subjective, psychological and sociological; they are compounded by the fragmentary scope of many of the experimental investigations and the diversity of formulations of the results even when the object of studies is essentially similar; finally there are additional uncertainties when considering situations which lie in the future. These difficulties have been sufficiently laboured in this paper, and it is now appropriate to take stock of the position. Since some choices and simplifications must be made in so doing, the personal judgement of the author cannot but obtrude, and to begin it is suggested that the requirements for predicting the daytime reactions of people can be reduced to four headings, as follows:

(i) a direct measure of sound intensity related to perceived subjective magnitude

(ii) a measure of speech interference

(iii) a composite measure of noise exposure to embrace a series of events, not necessarily of the same kind, magnitude or duration. This measure should be a compatible one, permitting the evaluation of environments, real or hypothetical, created by the successive, simultaneous or overlapping action of distinct noise streams, and thus capable of estimating the added effect of a new noise stream on an existing noise environment.

(iv) a broad rating system which permits the measure (iii), after appropriate adjustments for the nature of the environment, and possibly for the passage of time, to be interpreted in terms of overall acceptability, as a percentage of the population.

Night-time operations are excluded from consideration.

The four measures outlined will be briefly considered in turn, with the author's own suggestions for quantitative limits which should, however, be considered tentative and open to discussion.

### 7.1 Measure of subjective magnitude

Four measures of this type exist already with the sanction of international standardization. The method of calculating loudness level in phon (GF) or (GD) can, however, be discarded without regret in the context of noise planning though it undoubtedly has attractions for the research worker in audiology. This leaves phon (OD), which has a considerable following, dB(PN) which is endemic to the aeronautical world, and dB(A) which, it is recommended by ISO, should always be specified whether or not another measure is also used. In view of the likelihood that refinements, in the direction of tone-corrections and so on, will be pursued mainly amongst those "conditioned" to the dB(PN), and the absurdity of modifying the phon (OD) system to keep up with such developments, the field can be further narrowed by relinquishing the phon (OD). For comparisons with some existing noises which are conventionally measured in this way it may for a time still be necessary to employ this unit.

The recommendation is accordingly clear cut and simple. Levels should always be given in, or capable of calculation in terms of dB(A); when necessary (i.e. when questions of detail, refinement or critical comparison are involved) levels should be given in dB(PN) or dB(TPN). In practice it is desirable that a frequency analysis should be provided, as this is essential to accurate calculations.

### 7.2 Measure of speech interference

In Chapter 3 the question of rating noise with respect to its capacity for interfering with speech communication was examined, without regard to how long the interference persists. In Chapter 4 a method of defining an exposure index for speech disturbance was described, but this has no direct sequel in the sense that indices such as NNI have, that is to say, there is no experimental evidence of speech disturbance having been both measured subjectively and at the same time evaluated by the index of speech disturbance level. Evidence from the social surveys on aircraft noise, however, is clear that speech interference plays a leading part in the formation of annoyance.

The element of time in speech disturbance can therefore be assumed to be taken care of in an exposure index of some sort, which is the subject of the following sub-chapter. Here, therefore, it seems sufficient to recommend a measure, devoid of the time element, analogous to the measure of subjective magnitude $L_{PN}$ or $L_A$. Here the work of J.C. Webster seems to hold the key to the selection. In paper VII of the cited reference (26), one finds no marked disadvantage for the simple sound level A rating compared with any of the other reasonably simple ways of doing the job. There is also a strong correlation between them, so that when one of them errs the others tend to err by similar amounts in the same direction. The least satisfactory results occurred with the least likely noises, in particular those with rising spectra. Although such things cannot be ruled out in a context of future, and hence to some degree unknown, noises, it is very unlikely that rising spectral characteristics would be preserved after aerial propagation and sound transmission into buildings. Accordingly $L_A$ can be recommended as a measure of "first instance". Table V of Chapter 3.4 is readily converted for use in this way, by the empirical rule

$$NR_{.512} \sim L_A - 3.$$

As in the previous case, however, it is desirable to specify a more exact method for use in critical cases and for this purpose it is recommended to use the articulation index. For broad band noises the simplified procedure of Fleming given in Chapter 3.5 is appropriate. For less regular spectra the elaborated forms in Kryter's paper (21) are more appropriate. Fortunately, it will be found that they are compatible with Fleming's formula for broad band noise. For the translation of articulation index into terms of degree of difficulty with the communication of spoken messages there is a vast literature, but it seems sufficient for general planning to adopt the simple rule:

for normal conversational conditions, aim at 0.4
for difficult conditions, aim at 0.6

To assess the effects on communication systems, where additional complications of waveform distortion and system noise enter in, no simple rule can be set down.

### 7.3 Measure of total exposure

This question has been fully discussed in the body of this paper and, if the objective of a compatible rating index set out at the head of this Chapter is realizable, it seems perfectly clear that it will not be attained by shopping around amongst the prevailing indices. The nearest approach, and it may well be quite near, is the novel concept of noise pollution level. It has been, in fact, the task of preparing this paper that has spurred the author to attempting a synthesis of the many ideas with which the literature abounds, and it is a source of some satisfaction to discover that the problem is not as intractable as it seemed at the outset. The derivation of the noise pollution level concept is the subject of a companion report, in which it is shown that, starting from the "energy principle" with an allowance for fluctuating character of the noise in elementary algebraic terms, a number of experimental facts can be accounted for. Amongst these are the following:

(i) the results of Griffiths and Langdon's traffic noise survey are fitted by the index $L_{NP}$ as closely as by the authors' own Traffic Noise Index

(ii) Pearson's experiments showing that the trade-off between level and duration diminishes with the absolute duration over the range from some 6 to 2 dB per double time are closely predicted by the index $L_{NP}$

(iii) the index $L_{NP}$ generates a rate of increase of exposure level with number of occurrences that is steeper than the 3 dB per double number given by the simple concept of energy summation, and is thus more concordant with the social survey results used in the formulation of the indices NNI, $L_{exp}$ and $\bar{Q}$. Actually, the relationship is found to be a nonlinear one, growing more steeply in the middle range of occurrences, and in this respect it resembles some data in the report of the French airport surveys where this finding is presented only to be dismissed in favour of the index R.

It should be noted that when the noise pollution level is used to compare situations in which the statistical fluctuations are similar, the term embodying this factor is carried effectively as a constant, and the comparison then essentially depends on the mean energy level, thus possibly explaining why the measure $L_{Aeq}$ has sometimes been found effective, e.g. in the Swedish traffic noise survey.

To sum up, it is recommended that the expression of total noise exposure should be made in terms of noise pollution level, according to one of the equivalent formulae below. Undesirable as it is to announce a new formula and immediately to qualify it by saying that adjustments may be foreseen as experience with its use is gained, the author feels compelled to adopt this course in view of the length of time that may be involved in testing the concept by the results of past or new experiments.

The noise pollution level is provisionally defined by the formula:

$$L_{NP} = L_{eq} + 2.56\sigma$$

The choice of the basic measure L is governed by the same considerations as those in Chapter 7.2, accordingly it is to be taken as $L_A$ or $L_{PN}$, according to circumstances, with the understanding that, for general purposes, the relation between the two resulting measures is given by $L_{NP(A)} = L_{NP(PN)} - 13$.

The quantity $L_{eq}$ is defined basically as $10 \log (1/T) \int_0^T 10^{L/10}.dt$, but can be approximated in a great many practical cases by simpler formulae. When the distribution of the fluctuation of level L is Gaussian, $L_{eq} = L_{50} + \sigma^2/8.69$, and the equivalent level can be set in the convenient form: $L_{eq} = L_{50} + d^2/60$, where d is the interval between the upper and lower deciles, $L_{10} - L_{90}$. This expression, which is exact for the Gaussian distribution, is correct within 1 dB for other distributions ranging through triangular to rectangular if $\sigma$ does not exceed 7, that is if the absolute peak to trough level range does not exceed 26 dB. This accommodates many practical noise environments.

The advantage of the noise pollution level and the author's consequent recommendation may appear to cut across an expressed preference in Chapter 4.1 for the ISO index, aircraft exposure level. This preference was, however, stated in the context of a desire to abolish unnecessary divergencies of practice even within the bounds of one aspect of the nuisance problem, that of aircraft. What is the magnitude of the discrepancy between these two measures applied to a stream of aircraft noise alone has yet to be evaluated but the possibility of a translation from one scale into the other within a fairly small margin of tolerance seems likely. In any case, the concept of aircraft exposure level is not intended to be taken over into the realms of other noise problems except insofar as the use of the energy principle is gaining ground.

### 7.4 Broad rating system

For the assessment of the noise environment as it affects residential premises, the British Standard BS 4142 appears to provide the best basis. In spite of its stated scope, which is noise emanating from factories (though these are generously defined as including industrial premises and fixed installations in general), the recommendations seem reasonably well suited to rating vehicular noise provided due care is applied to the construing of certain clauses and to the definitions of the corrected noise levels, or rather the adaptation of these definitions to moving sources.

In one respect, however, the author would recommend a deviation from the provisions of the Standard. This concerns the duration and intermittency corrections. Instead of trying to identify two fictitious quasi-steady levels $L_1$ and $L_2$ and applying corrections to them in respect of the time factor, it would be better to determine $L_{Aeq}$ which automatically embodies this factor. The method of doing it is the same as just described in Chapter 7.3. The corrected noise level should then be determined by adding to $L_{Aeq}$ a correction for tonal or impulsive character of 5 dB(A) (but not 10 dB(A) if both characteristics are present) and a further 5 dB(A) if the noise is of a fluctuating character. In any coarse-step system it is impossible to say where the line should be drawn between one step and the next, and this will apply to fluctuating character as it at present applies to various other corrections. Such rough edges do not detract from the usefulness of the Standard which, by its nature, can only be a guide.

As regards noise ratings for functional buildings, there is nothing to add to the Table given in Chapter 5, except to say that it can be fairly assumed that authorities likely to be faced with difficult problems will examine their own requirements in detail, for example local authorities, broadcasting and hospital administrations. Where there is the reasonable possibility of specific measures being taken for noise protection, there is no real basis for determining maximum outdoor noise levels nor for prescribing a fixed system by which the requirements of specialist occupiers of premises should be stated. Sufficient protection against gross noise dosage of such premises is likely to be provided anyway, through considerations of limiting the nuisance to the general public.

### 7.5 Suggested limits

As regards the peak noise rating for individual noisy events, there are two ways of approaching the question of a limit. One is through the experimental data on judged noisiness, and the other through considerations of speech interference. The experiment referred to that used a rating scale of "intrusiveness" (52) contains both elements, since a task involving speech communication formed part of the set-up. For subjects indoors, the peak outdoor level which evoked the response of "intrusive" averaged 89 dB(A) or 102 dB(PN). The sounds were judged "noticeable" at the level 78.5 dB(A) or 91.5 dB(PN). Noisiness judgements made in the same tests, the subjects in this case having no preoccupying task, were found to depend strongly on the distance away from the noise source, even after allowance for the level difference, and in order to interpret the results for the purposes of the present paper it seems more reasonable to use the "church hall" rather than the "assembly hall" results of the Farnborough experiment. The typical distance here was 1 km (3300 ft), and for subjects indoors under these conditions the average results were:

| | | | |
|---|---|---|---|
| "quiet" | 71.5 dB(A) | or | 84.5 dB(PN) |
| "moderate" | 80 | | 93 |
| "noisy" | 88.5 | | 101.5 |

One should clearly not plan for noises to be either "noisy" or "intrusive", accordingly the values of 88.5 and 89 dB(A) are above the reasonable limit. The responses "noticeable" and "moderate" imply a degree of awareness that might be considered reasonable but is well above the "of no concern" threshold; thus a value around 78.5 or 80 dB(A) is somewhere near the mark. At 71.5 dB(A) the response is "quiet", meaning not quiet in an absolute sense but that the event was a quiet one of its type, namely aircraft, and at this level one has probably passed a little below the necessary level. This evidence therefore points to a limit in the neighbourhood of 75 ± 2 dB(A), or 88 ± 2 dB(PN). From similar experiments in the U.S.A. (56), one deduces that a level of 79 dB(PN) is "of no concern", 89 is "acceptable" and 99 "barely acceptable", if differences of sound insulation are taken into account. The sound insulation was 21 dB compared to 15 at Farnborough.

Considered purely as a hindrance to speech communication, an indoor level considerably below these is indicated. If one takes as a reasonable criterion the ability to continue conference or conversation uninterruptedly, the value $NR_{.512}$ of 45 or 50 (Table V) looks appropriate, and this can be translated into 48 - 53 dB(A) indoors, or 58 - 63 dB(A) outdoors assuming that the requirement holds for open windows. In any case not more than an extra 5 can safely be assumed for closing windows of normal single-glazed type. The suggestion is therefore a limit of 60 dB(A) or 73 dB(PN) on these grounds. As this is likely to be regarded as out of the question for vehicles of almost every kind operating in urban areas, the corollary is obvious: a certain degree of speech interference has to be regarded as an unavoidable concomitant of city life in buildings of present-day construction. It will be recalled that the more elaborate calculation of articulation index, Table III, confirms that an outdoor level of 80 dB(PN) with open windows (effective sound insulation 10 dB) begins to erode sentence intelligibility, using the turbofan aircraft example.

Turning to the question of a limit in terms of total noise exposure there is a widespread movement that considers the acceptable limit to lie in the neighbourhood of 40 NNI, and such a value accords with the example in Chapter 5 or is perhaps on the high side. From road traffic noise studies a noise climate somewhere below that at which only half the people are satisfied seems called for. It has already been shown in Chapter 6.5 that there is a fair measure of agreement between the annoyance of 45 NNI and at a level of $L_{Aeq} = 61$ from traffic noise, which is at the mid-point of Griffiths and Langdon's dissatisfaction scale. Thus 40 NNI is equivalent to a lower dissatisfaction rate, in fact about 35% using the data of reference (39). As this might still be regarded as rather a high rate, it tends to confirm the evidence from BS 4142 that 40 NNI is on the high side. The author accordingly suggests that the limit should be set in the region of 38 ± 2 NNI, or its equivalent in other measures. Since the noise pollution level seems the measure best adapted to expressing exposure when comparing data from different sources, we will conclude by stating the suggested limit in these terms: namely $L_{NP(A)max} = 72$, or $L_{NP(PN)max} = 85$.

These limits, applied to transportation systems, can be related to the limits suggested for $L_A$ (or $L_{PN}$) by taking into account the pattern of traffic and the nature and magnitude of the existing background noise into which the source of the noise for which the limit is being stated is introduced, or if need be by using forecasts of this information. In the author's view, the limits have both to be met, in a given situation, to provide an acceptable environment. Thus, it will not do to procure a tolerable $L_{NP}$ by packing vast numbers of passengers into few vehicles, if in so doing the individual noise level limit is exceeded. Likewise, it is intolerable to plan to the stated limit of individual noise level and then to allow the density of operations and hence the noise pollution level to increase insidiously. It is also of the highest importance to note that a reduction of noise will not necessarily reduce the noise pollution level; it can in some circumstances actually increase it (28).

## References

1. ROBINSON, D.W. J. Roy. Aero. Soc. (1967), 71, 396.
2. International Organization for Standardization, Geneva, 1959. ISO Recommendation R-131. Also British Standards Institution, BS 3045:1958.
3. ROBINSON, D.W. and DADSON, R.S. Brit. J. App. Phys. (1956), 7, 166.
4. International Organization for Standardization, Geneva, 1960, ISO Recommendation R-226. Also British Standards Institution, BS 3383:1961.
5. ROBINSON, D.W. and WHITTLE, L.S. Acustica (1964), 14, 24.
6. International Organization for Standardization, Geneva, 1965. ISO Recommendation R-454.
7. International Organization for Standardization, Geneva, 1966. ISO Recommendation R-532. Also British Standards Institution, BS 4198:1967.
8. STEVENS, S.S. J. Acoust. Soc. Amer. (1956), 28, 807.
9. ZWICKER, K.E. Acustica (1960), 10, 304.
10. KRYTER, K.D. J. Acoust. Soc. Amer. (1959), 31, 1415.
11. "Aircraft Noise"; Report of an international conference on the reduction of noise and disturbance caused by civil aircraft. London, H.M.S.O. 1967.
12. International Organization for Standardization, Geneva, 1968. Draft ISO Recommendation 1760.
13. International Electrotechnical Commission, Geneva, 1965. Recommendations for precision sound level meters, IEC Publication 179.
14. OLLERHEAD, J.B. FAA Report 68-35, April 1968.
15. HECKER, M.H.L. and KRYTER, K.D. FAA Report No-68-33, April 1968.
16. YOUNG, R.W. and PETERSON, A. J. Acoust. Soc. Amer. (1969), 45, 834.
17. ROBINSON, D.W. J. Sound and Vib. (1964), 1, 468.
18. ROBINSON, D.W., BOWSHER, J.M. and COPELAND, W.C.T. Acustica (1963), 13, 324.
19. FRENCH, N.R. and STEINBERG, J.C. J. Acoust. Soc. Amer. (1949), 19, 90.
20. FLEMING, N. 1968 (private communication).
21. KRYTER, K.D. J. Acoust. Soc. Amer. (1962), 34, 1689.
22. WILLIAMS, C.E., STEVENS, K.N., HECKER, M.H.L. and PEARSONS, K.S. FAA Report DS-67-19, September 1967.
23. BERANEK, L.L. Noise Control (1957), 3, 19.

24. KOSTEN, C.W. and van OS, G.J. The Control of Noise. NPL Symposium No.12, H.M.S.O. 1962, p.373.

25. WEBSTER, J.C. and KLUMPP, R.G. U.S. Navy Electronics Laboratory Report, NEL-1314, September 1965 (see Paper VII).

26. KRYTER, K.D. and PEARSONS, K.S. J. Acoust. Soc. Amer. (1963), 35, 866.

27. PEARSONS, K.S. FAA Report ADS-78, April 1966.

28. ROBINSON, D.W. The Concept of Noise Pollution Level. NPL Aero Report Ac 38, March 1968.

29. LITTLE, J.W. Boeing Company report, January 1968. Unpublished.

30. MEISTER, F.J. VDI Zeitschrift, Research report series 11, No.5, March 1968.

31. PERRET, E., GRANDJEAN, E. and LAUBER, A. Le Travail Humain (1964), 27, 53.

32. McKENNELL, A.C. Central Office of Information Report SS 337, April 1963 (see Appendix B).

33. van OS, G.J. International conference on the reduction of noise and disturbance caused by civil aircraft, London, November 1966. Paper INC/C4/P19.

34. Land Use Planning with respect to Aircraft Noise. Joint manual of the Departments of the Air Force (AFM 86-5), Army (TM5-365) and Navy (Navdocks P-98), Washington, D.C., October 1964.

35. Armed Forces/NRC Committee on Hearing and Bioacoustics (CHABA). Report of Working Group 34, Editor K.N. Stevens. Washington, D.C., October 1961.

36. BURNS, W. and ROBINSON, D.W. Hearing and Noise in Industry. H.M.S.O. London, 1970.

37. Noise - Final Report of the Committee on the Problem of Noise. H.M.S.O., 1963 (see para. 576).

38. FOG, H., JONSSON, E., KAJLAND, A., NILSSON, A. and SÖRENSEN, S. Statens Institut för Fölkhälsan, Stockholm. Trafikbullerutredningen 1966-67.

39. GRIFFITHS, I.D. and LANGDON, F.J. J. Sound and Vib. (1968), 8, 16.

40. KEIGHLEY, E.C. J. Sound and Vib. (1966), 4, 73.

41. ROBINSON, D.W. and COOK, Miss J.P. N.P.L. Aero Report Ac 31, June 1968.

42. British Standards Institution, BS 4142:1967.

43. PARKIN, P.H. PURKIS, H.J., STEPHENSON, R.J. and SCHLAFFENBERG, B. London Noise Survey. H.M.S.O. 1968.

44. JONSSON, E., KAJLAND, A., PACCAGNELLA, B. and SÖRENSEN, S. Arch. Environm. Health (1969), 19, 692.

45. Noise - Final Report of the Committee on the Problem of Noise. H.M.S.O., 1963 (see Appendix XI).

46. BÜRCK, W., GRÜTZMACHER, M., MEISTER, F.J. and MÜLLER, E.A. Fluglärm. Report to the Federal German Ministry of Health. Göttingen, May 1965.

47. COBLENTZ, A., XYDIAS, N. and ALEXANDRE, A. Anthrop. Appliquée. Doc. AA 16/67, Vol.5, June 1967.

48. MURRAY, N.E. and PIESSE, R.A. Commonwealth Acoustic Laboratories Report CAL No. 22, May 1964.

49. BORSKY, P.N. WADD Report TD-60-689, 1961.

50. JONSSON, E. and SÖRENSEN, S. Nordisk Hyg. Tidsk. (1967), 48, 35.

51. CEDERLÖF, R., JONSSON, E. and SÖRENSEN, S. Nordisk Hyg. Tidsk. (1967), 48, 46.

52. BOWSHER, J.M., JOHNSON, D.R. and ROBINSON, D.W. Acustica (1966), 17, 245.

53. WALLER, R.A. and THOMAS, R.J. Arena, December 1966.

54. STEPHENSON, R.J. and VULKAN, G.H. J. Sound and Vib. (1968), 7, 247.

55. JOHNSON, D.R. and SAUNDERS, E.G. J. Sound and Vib. (1968), 7, 207.

56. BISHOP, D.E. J. Acoust. Soc. Amer. (1966), 40, 108.

57. JOHNSON, D.R. N.P.L. Aero Report Ac 40, May 1969.

## Additional references consulted

NICKSON, A.F.B. Australian Building Science and Technology (1966), 4, 19.

KRYTER, K.D. Science (1966), 151, 1346.

HINTERKEUSER, E.G. and STERNFELD, H. NASA Report CR-1118.

Office of Science and Technology, Executive Office of the President. Alleviation of Jet Aircraft Noise near Airports. Report of the jet aircraft noise panel. Washington, D.C., March 1966.

EMBLETON, T.F.W., DAGG, I.R. and THIESSEN, G.J. Noise Control (1959), 6, 37.

BÜRCK, W. Rohde & Schwarz Mitteilungen (1965) No.19, p.199.

VAN NIEKERK, C.G. South African Mechanical Engineer (1967), 16, 187.

VAN NIEKERK, C.G., MULLER, J.L. and LIEBENBERG, J.J. South African CSIR Report MEG 585, August 1967.

NAGEL, D.C., PARNELL, J.E. and PARRY, H.J. FAA Report DS-67-22, December 1967.

PARNELL, J.E., NAGEL, D.C. and PARRY, H.J. FAA Report DS-67-21, December 1967.

SAE Research Project Committee R2.5. FAA Report DS-67-14, August 1967.

BISHOP, D.E. FAA Report DS-67-6, May 1967.

PEARSONS, K.S. FAA Report DS-67-1, January 1967.

KRYTER, K.D. J. Acoust. Soc. Amer. (1962), 34, 1698.

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DETACHABLE ABSTRACT CARDS

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