Acoustic noise units

A pathway through the decibel jungle

by James Moir, F.I.E.E.

The proliferation in recent years of Acts and Statutes setting limits to the level of acoustic noise inside and outside the home, in public places and in workshops, has resulted in an almost equal proliferation of units in which the noise level may be measured. It is very difficult indeed to duplicate by objective measurements the brain's analysis of its pleasure or annoyance. Thus we now have a large number of units in which the "loudness" (using the word in its widest sense) of a noise may be measured, all of them attempting to achieve agreement between objective measurements and subjective impressions. This article is an attempt to present a coherent picture of the problem.

The first sound level meter was merely a microphone, amplifier and indicating meter, the whole system having a repsonse that was substantially independent of frequency. The readings obtained were the mean (average) value of the input waveform, oxide-type rectifiers being used to convert the amplifier output to d.c. to operate the moving-coil meters. The parameter measured was the average value of the sound pressure at the microphone diaphragm and, within the limitations of the microphones available at that time, the reading was independent of the acoustic frequency.

To deal with the vast range of sound pressures met in nature, the system had to read over a sound pressure range of roughly 10^6:1 so a logarithmic unit, the decibel, was adopted from the telephone industry. Any logarithmic scale requires an empirically chosen zero point and this was fixed at a sound pressure level of 0.0002 dynes/cm^2 (now 20μ newton/m^2, 20μ pascal.) At the time this was thought to be the minimum audible sound level but it is now known to be about 5dB higher. Using this base, sound pressure levels in dB are then expressed as:

$$\text{s.p.l. (dB)} = 20 \log_{10} P/P_0$$

where P_0 is the reference pressure of 0.0002 dynes/cm^2, and P is the measured sound pressure.

Early experience indicated that there was only moderate agreement between the objective readings taken with the meter and a subjective judgement of the loudness of the noise by a group of observers. It was soon appreciated that the discrepancies were in part due to the sensitivity/frequency relation of the hearing system. Experiment indicated that not only did the sensitivity of the hearing system vary with frequency but that it also varied with the absolute intensity of the noise, particularly at the low-frequency end of the spectrum. Thus the hearing system has a substantially uniform frequency response to sound at high intensity but it is relatively bass deficient at low sound intensities. Fletcher and Munson, and later Robinson and Dadson, found that the frequency response of the hearing system to pure tones was as shown in Fig. 1. The Robinson and Dadson data is now an international standard.

Decibels A, B, and C

This change in frequency response with intensity was dealt with by adding a switch to the metering system to change the amplifier frequency response in the three steps shown in Fig. 2. The response labelled 'A' was to be used when making measurements at sound levels below about 40dB, response 'B' when the sound level was between about 40 and 70 dB and the flat response, labelled 'C' used for all levels above about 70dB. The weighting used was indicated by adding the appropriate suffix to give, for example, dBA or dB(A). In practice the only safe course was to record the A. B, and C readings for every noise, for it was rarely clear which switch position should be preferred. A noise with much of its energy in the low frequency range might well measure 35dBA or 60dBC and the correct switch position was then rather indeterminate.

The use of a three-position switch was a logical decision in the light of the data then available, because it matches

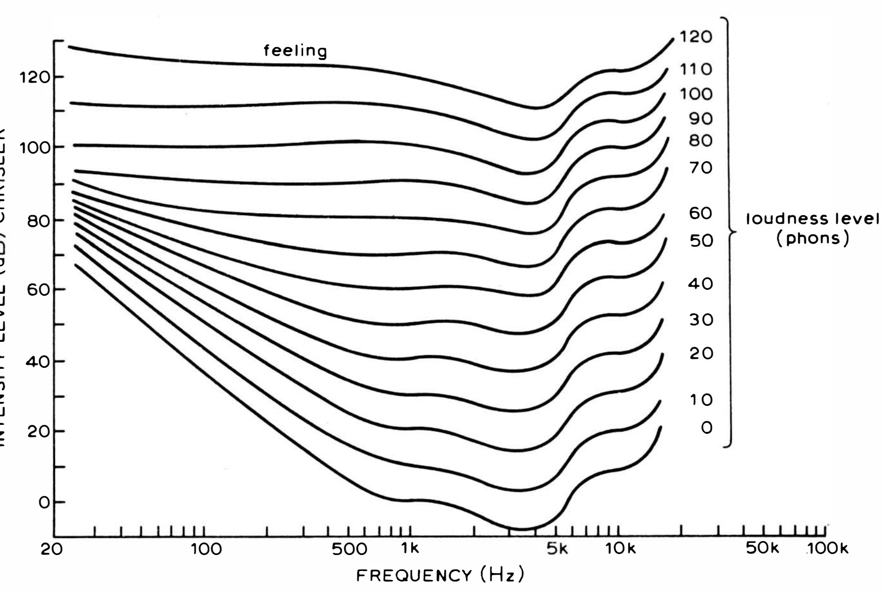


Fig. 1. Fletcher and Munson equal loudness contours. (Note that the loudness level of a sound is defined as n phons when it is judged to be equal in loudness to a pure 1000Hz tone with a sound pressure level of n dB above the standard reference pressure.)

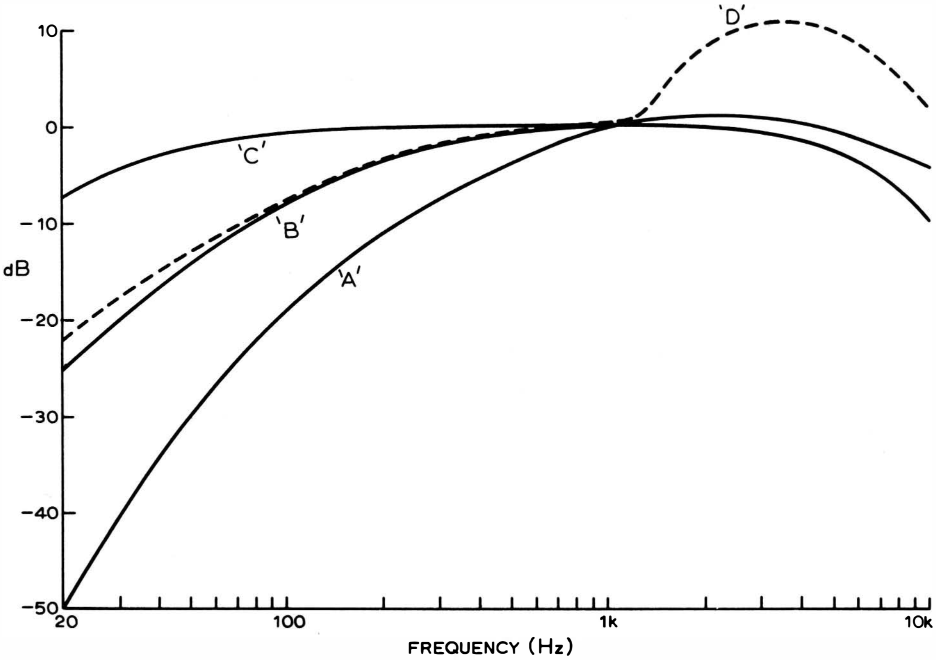


Fig. 2. Weighting curves showing the significance of dBA, dBB, dBC and dBD.

the frequency response of the meter to that of the ear at the sound level being encountered, but increasing experience began to suggest that the best agreement between meter readings and a subjective judgement of the "loudness" or "noisiness" of a sound was obtained by using the A weighting, quite irrespective of the intensity of the noise. This has now been substantiated for many kinds of noise and in consequence noise level readings relating to annoyance are now almost always quoted in dBA. Indeed, many later versions of the standard sound level meter only include the A-weighting network. This apparent contradiction of the earlier data has been shown to be due to the assumption that the ear's reaction to a wide-band noise would be indicated by its reaction to pure tones. It is now known that the hearing system does not sum the energy in bands of noise in the way suggested by the Fletcher-Munson curves for pure tones, the summation/frequency response being more accurately indicated by the A-weighting curve at all intensity levels.

Decibel 'D'

Though general experience and many investigations have shown that noise levels measured in dBA are in good agreement with subjective opinion of the loudness of most intruding noises, it appears probable that the agreement could be improved in a specific situation by the adoption of a special weighting curve for each type of noise. Kryter has shown, for example, that the noisiness of jet aircraft can be more accurately assessed by the adoption of a weighting curve that places greater emphasis on the higher frequencies and the relation shown in Fig. 2, the D-weighting curve, also known as the N curve in (ISO) Draft Recommendation 1761, has been internationally standardized for this purpose. However ISO Recommendation No. 507 requires the noise level in the vicinity of an airport to be expressed in still another unit, the Perceived Noise Level (PNdB). This is to be obtained from measurements of the sound pressure level in octave bands and the perceived noise level determined from these readings by a summation process detailed in the Recommendation.

In general, use of D weighting results in readings some 13dB higher than a measurement of the same noise using the A-weighting curve. The increased accuracy of agreement between objective measurement and the subjective opinion of the "noisiness" of the noise from jet aircraft is not thought to justify the confusion that has resulted from the introduction of D weighting. The environmentalists in particular have often reached alarming conclusions by comparing aircraft noise measured using D weighting, or the deduced level in PNdB, with road traffic or similar noise measured using A weighting. Similarly alarming conclusions can be reached if the A-weighting noise level of an existing type of aircraft is compared with the D-weighted noise produced by Concorde. It is reasonably certain that agreement with subjective judgement could always be improved by adoption of a weighted curve appropriate to each type of noise source but the overall result would be mild chaos, for the noise levels of different sources could not be compared.

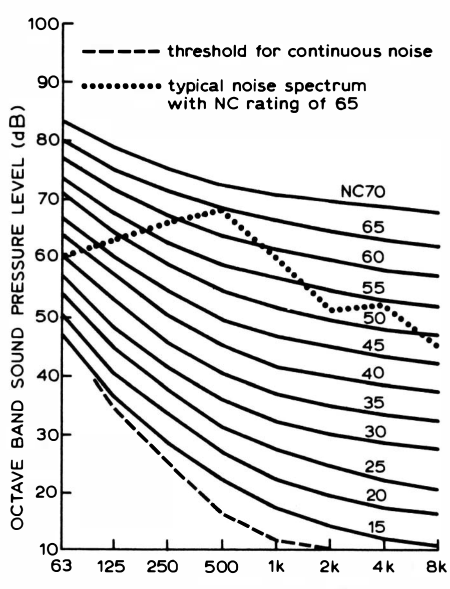


Fig. 3. Noise criteria curves of Beranek for obtaining better agreement between measured values and subjective loudness of a complex noise.

Noise Criteria system

In an attempt to obtain better agreement between measured values and subjective opinion of the loudness (noisiness) of a complex noise, Beranek introduced the Noise Criteria system, still widely used in the heating and ventilation field. Instead of taking one reading of the weighted average value of the sound pressure of a wide band noise (i.e. dBA), he proposed to take readings with a frequency selective meter at each of eight octave band frequencies and to plot these on special graph paper (see Fig 3). An NC (Noise Criteria) rating was obtained by quoting the NC reading on the right hand scale immediately above the highest octave band sound pressure level. Thus a noise having the frequency spectrum shown in Fig. 3 would be given a Noise Criteria rating of NC65, the curve immediately above the highest sound pressure reading in any octave band. This appears to be good common sense and the system is widely used.

In Europe a slightly different set of contours was produced following the same basic approach but these were quoted as Noise Rating curves, the number obtained being quoted as NR 65. Except for special noise spectra there is no significant difference between the NC and NR numbers and in retrospect there appears to be no good reason for the existence of two sets of Noise Rating and Noise Criteria curves. In practice the situation was further confused by the appearance of a third set of Noise Rating curves in the 1967 issue of British Standard 4142. Experience suggests that they have no real advantage over either of the earlier NR or NC curves. Indeed many users believe that they are not as useful as the earlier curves and that they have only served to add further confusion to an already confused situation.

Though this curve fitting procedure should take into account the shape of the frequency spectrum of a complex noise, experience has shown that there is a substantially constant numerical difference between the NC or NR value and an instrumental reading in dBA of the same noise, the NC or NR level being 5 units lower than the measured level in dBA. A determination of either the NC or NR level requires an octave band analyser to produce separate readings of the noise level in the eight octave bands and plotting of the data on special graph paper. Thus the technique can only be justified if experience shows it to have some considerable advantage over the single measurement of noise level in dBA, for this only requires a relatively simple sound level meter. Surprisingly, perhaps, experience appears to show that NR or NC numbers do not have any real advantage over the use of dBA to express noise levels, but the curves have considerable advantage when analysing noise data to obtain guidance on which part of the noise spectrum is responsible for criticism.

The phon

There are obvious advantages in having a unit that is an indication of the "loudness" of the noise and for this purpose the phon was originally proposed. British Standard 661 defines the phon as:

"The loudness of a noise in phons is numerically equal to the sound pressure level of the 1000Hz tone that is judged to be equally loud."

This apparently simple definition is the real reason for the failure of the phon to achieve widespread use. It requires a group of people to judge the level at which a locally-generated 1000 Hz tone is considered to be as loud as the unknown noise being assessed. This is a subjective judgement and it is one that is extremely difficult to make even by a skilled observer. Thus as phons cannot be measured directly by a meter the phon has died.

The sone

Though the decibel scale is almost universally used for the measurement of sound intensity, its logarithmic structure makes it difficult for the non-technical to use or even understand. A unit so fashioned that a noise level of two units is twice as loud as a noise of one unit should have advantages in such situations. This requires units that express loudness on a simple arithmetic scale. Such a unit is the sone, defined by British Standard 661 as:

"The unit of loudness on a scale designed to give scale numbers proportional to the loudness."

The reference loudness of one sone is that of a 1000Hz note having an intensity of 40dB, the relation adopted being shown in Fig. 4. Thus a sound intensity of 2 sones corresponds to an intensity of 50dB and 10 sones to 73dB. Surprisingly perhaps the sone scale is not widely used, though the reasons for its neglect are not very obvious. There are no simple meters available that read in sones directly and as it is easy to remember that an increase in sound intensity of 10dB generally corresponds to a doubling of the subjectively judged loudness, the sone, if not dead, is not prospering.

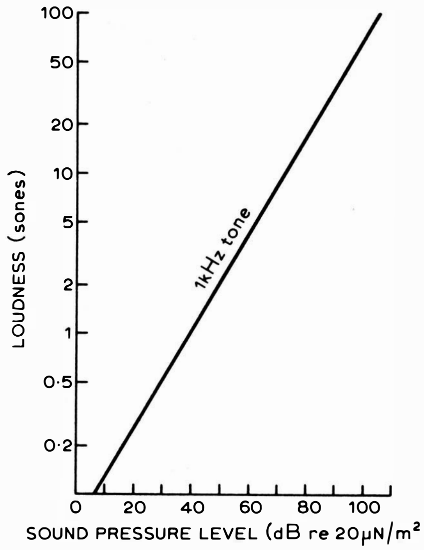
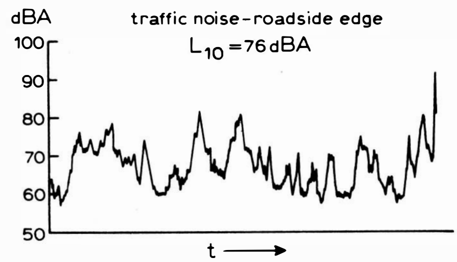


Fig. 4. Relation between loudness in sones and sound pressure levels in decibels. Scale numbers on the sone scale are proportional to loudness.



Fg. 5. Recorded chart of typical traffic noise.

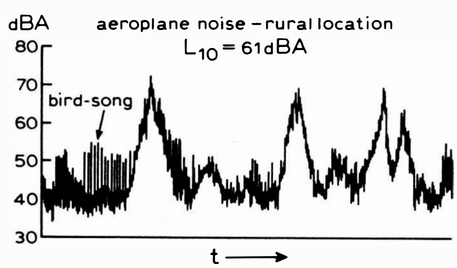


Fig. 6. Recorded chart of typical aircraft noise.

Time-varying noise levels

Except in some industrial situations, noise is rarely constant, the more usual situation being one in which the noise level is varying continuously rather as shown in Figs. 5 and 6, charts of typical road traffic and aircraft traffic noise. In such a situation there is a real problem in deciding on the objective level of the noise that is related to the level of subjective criticism. This is likely to depend not only on the noise in dBA but also on the fraction of the relevant time that the noise reaches or exceeds this acoustically effective level.

There have been many attempts to define a single-number parameter that includes both the noise level in dBA and the length of time that the noise reaches or exceeds this level. The simplest is merely to specify the noise level that is exceeded for 10% of the length of time that is significant in the particular situation. Thus when dealing with the noise from road traffic it has been found from social surveys that the extent of criticism is related to the level that is exceeded for 10% of the 18 hours between 6 a.m. and midnight. In traffic planners' parlance, the significance noise level is the "18-hour L_{10}".

Other aspects of a time-variable noise that are significant are the level exceeded for 90% of the 18 hours, effectively the minimum level, denoted by L_{90}, and the "average" level L_{50}, the value exceeded for 50% of the 18 hours. Note that all these levels are measured in dBA. A statistical analysis of the time-varying noise level data is required to obtain L_{10}, L_{50}, L_{90} etc., but analysers are now available that provide a continuous display of the required parameter over the period up to the time of display.

Noise and Number Index

Robinson has shown that the subjective annoyance aroused by an intruding noise is a function not only of the noise level but also of the extent of the excursions above the mean average level and the frequency with which these excursions occur. Much personal experience in other applications supports this view: A client's bedroom having an ambient noise level of 20dBA with occasional peaks up to 40dBA was pronounced as "noisier" than another room in which the ambient level was around 38dBA, but with excursions of only about ±2dBA. To evaluate the noise climate around airports, Robinson first proposed the use of a "Noise and Number Index" (NNI) that takes into account both the average noise level in dBA, the extent to which the noise level rises on peaks and the number of times in twenty four hours that the peaks appear. This is the unit used in the Report on Noise by the Wilson Committee. The Noise and Number Index can be calculated from:

$$NNI = \text{Average peak noise level} + 15 \log N - 80$$

where N is the number of aircraft per day.

On this basis a reasonable Noise and Number Index for the areas adjacent to an airport is around 50 during the day, but probably around 35 during the night.

Noise pollution level

At a later date, Robinson suggested another unit, the "Noise Pollution Level", that also takes into account the effect of the variability in level on the nuisance rating of typical noises. This parameter can be computed from:

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

where σ is the standard deviation of the instantaneous noise level and L_{eq} is the equivalent noise level. There is sound justification for the use of this unit for it would appear to be applicable to all forms of nuisance noise and to allow the "noisiness" of different forms of noise to be compared. At present it is really waiting large scale confirmation of its value, for though noise experts are almost unanimous in approval, it has not been specified in any legislation.

Traffic noise index

The Building Research Station have also suggested a unit that is directly applicable to the specification of the "noisiness" of a noise of variable intensity, though it is primarily intended for dealing with traffic noise. It has been shown by social surveys that there is a high degree of correlation between this Traffic Noise Index and the degree of dissatisfaction expressed by residents exposed to high levels of road traffic noise. The Traffic Noise Index is defined as:

$$TNI = L_{90} + 4(L_{10} - L_{90}) - 30$$

and as this is likely to be used in legislation both here and in America it will presumably displace the other units suggested, although it does not appear to have such a sound theoretical base as L_{NP}. Note that the noise levels used in all these units that combine level and variability are expressed in dBA.

Hearing damage and L_{eq}

High levels of noise, 90dBA and above, are known to result in eventual damage to the hearing, the damage being approximately proportional to the product of noise level in dBA and duration of the exposure. In the simplest case where the noise level is constant, the damage to the hearing system is directly proportional to the length of exposure. However, this is not the usual condition, for in an industrial situation the noise level is fairly constant at one value for a few seconds (or minutes) and then changes to a higher or lower level which is only maintained for a short period.

In such a situation an equivalent noise level can be defined that would, if held constant for the whole 8-hour working day, result in the same damage to the hearing system as would have resulted from the noise of variable level. This is known as the equivalent noise level, L_{eq}, and again is expressed in dBA. The Department of the Environment Code of Practice specifies 90dBA as the maximum permissible value for L_{eq} in an industrial situation.

Units and their application

It will be seen that there are a bewilderingly large number of units that can be used to indicate the "quantity" of noise present in a situation. A reasoned choice requires that we be sure that we know what we are trying to measure. If we are trying to measure sound intensity, i.e. power flow/unit area, then the sound pressure level in dBC is the appropriate unit. However, sound intensity is rarely the aspect that is really significant in a situation involving human exposure to noise. More usually we are trying to measure something that might be described as the "loudness", "noisiness", "annoyance" or "intrusiveness" of the noise.

Loudness, noisiness or the degree of intrusion are not always the same thing, though the noisiness or intrusiveness usually increases with increase of loudness, provided there is no change in the spectrum of the noise. If the noise is the subject of complaint and we wish to have a measure of the "noisiness" then the sound pressure level in dBA is the best of the current units, but this simple measurement of noise level in dBA fails as an indication of "intrusiveness or annoyance" if the noise being measured contains pure tones or is characteristically irregular. At the moment irregularity in occurrence or the presence of pure tones requires the measured noise level in dBA to be empirically corrected by the addition of 5 or 10 dBA to the measured levels (see British Standard 4142). This corrected level is then known as the "Corrected Noise Level" (CNL) and is expressed in dBA (CNL).

However, the degree of annoyance aroused by a noise is a function not only of the intensity of the noise, but also of the duration of the noise and of the "time on/time off" ratio in the period of time that is significant, usually the day of 18 hours. The level of the ambient noise is then best indicated by L_{90}, the level exceeded for 90% of the time, while the level of the intruding noise is indicated by a statement of L_{10}, both in dBA.

NC or NR ratings, though widely used at the moment, particularly in the heating and ventilating industry, do not appear to have any significant advantage over the simple measurement of sound pressure level in dBA when attempting to estimate annoyance and in consequence these units do not appear to have any future.

Where the noise levels of individual aircraft are being compared, dBD or PNdB is the correct unit, but the semi-empirical addition of 13dBA to the level measured in dBA gives a very good indication of the degree of annoyance or the intrusiveness of the noise from one aircraft. If it is required to have an indication of the overall level of annoyance due to aircraft activity at an airport, then NNI or L_{np} (Noise Pollution Level) are the proper units to employ, but L_{NP} values are not yet in widespread use in spite of their basic merits.

Where damage to hearing due to exposure to high noise levels is under consideration, there is in this country only one unit, L_{eq} to consider. Other countries use different rates of 'trade-off' between time and noise level although using dBA units in which to indicate the noise level, so this may lead to some further changes in the unit of noise exposure to obtain a greater degree of international agreement.

When assessing traffic noise, DBA is the appropriate indication of noise level, but it is now rarely that value read from a sound level meter directly. The quoted noise level is derived from a statistical analysis of the meter data, the quoted value being that exceeded for some specified percentage of the relevant time period, usually 18 hours in this country. Thus we have L_{10}, L_{50}, and L_{90} as the levels exceeded for the quoted fraction of the total time.

Traffic Noise Index (TNI) or the Noise & Number Index (NNI) or L_{NP} are met more infrequently and then chiefly in official publications, but this may change for they have real merit in indicating the nuisance value of a noise over an extended period.

This discussion covers the majority of units now in use in measuring the loudness of acoustic noise but there are many others waiting to make their appearance. Annoyance as subjectively judged, is a difficult reaction to quantify and, though many of the present units achieve this fairly well, there is need for a unit that will allow widely different types of noise to be rated on a common scale of annoyance.

Further reading

Sound level meters	British Standard 4197
Equal loudness contours for pure tones	British Standard 3383
Airport noise measurement	ISO Recommendation No. 1761
Noise rating curves	ISO Recommendation 1996
Method of rating industrial noise	British Standard 4142
Glossary of Acoustical terms	British Standard 661
Housing and road traffic noise	Dept. of Environment
The Noise and Number Index	Wilson Committee Report on Noise
Noise Pollution Index	NPL Report No. AC59
The Traffic Noise Index	BRS Report No. CP38/68
Hearing damage assessment	DOE Code of Practice