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The A-weighted decibel – are rumours of its imminent demise greatly exaggerated?

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1. ABSTRACT

Over the past 80 years, the A-weighted decibel (dBA) has become the predominant measurement used in environmental noise assessment. Over this period many studies have demonstrated that the A-weighted decibel is reasonably correlated with overall community subjective responses to noise from a wide range of sources. However, some studies have also shown that the A-weighted decibel may not correlate as well with the subjective response to certain noises, and that other measures may be better suited. This paper appraises the history of weighting curves, as well as research showing the positive and negative benefits of the A-weighted decibel. The paper concludes that whilst in specific circumstances the A-weighted decibel may not be the best means of measuring certain noises, its ease of measurement and prediction; and the wealth of established research in regard to the subjective response to noise based on the A-weighted decibel, means it is generally adequate for assessment of many environmental noises in most circumstances. Additionally, the paper highlights that the relative complexity of alternative means of loudness measurements that may have only marginally better correlation with subjective response and the lack of social survey based studies of the correlation with subjective response of these measures, the often significant influence of wind noise in confounding use of other weightings for measurement of environmental noise and the limited history of use of other methods; counts against supplanting the A-weighted decibel with alternative measures, until these gaps are closed by more common use of alternative measures.

2. Introduction

The hearing system does not perceive sounds of different frequency but the same intensity as being equally loud. Additionally the rate of change in perceived loudness is not uniform with increasing or decreasing intensity. Consequently, the objective measurement of loudness is complicated by the need to consider not only the sound pressure level, but also the frequency spectrum of the sound, and the shape of the sound spectrum. This means that typically methods of loudness measurement divide sound energy into octave or 1/3 octave bands, and a loudness value for each band is then determined and the total loudness is then calculated from the individual band values using a summation formula¹. Historically such methods have been time consuming and difficult to automate and incorporate into equipment easily used in real world conditions. As a result, in order to describe perceived loudness in a readily and quickly understood manner, since the 1930's weighting networks have been developed which take account of the variable sensitivity of the hearing system and produce single figure estimates of sound pressure levels that can be regarded as proxies of approximate equivalent loudness.

However, Since the 1930's there have been rapid advances in the ability to measure sound and understand its effects on humans; and development of modern computational techniques that allow enormous amounts of data to be processed quickly. Despite this making direct measurement of "loudness" practicable^{1A}, today the vast majority of acoustical measurements still use weighting networks originally developed 70 years ago. Consequently, the use of A-weighted sound pressure level measurement is ubiquitous and is rarely questioned.

3. Equal Loudness Contours and Weighting of Sound Pressure Levels

One of the primary reasons for measuring noise is to establish an objective estimate of its subjective loudness in order to assess its potential impacts. The perception of the loudness of a sound is influenced by many factors, some of which are acoustic, but many of which are non-acoustic and can significantly influence the perceived loudness and impact of noise. The influence of less tangible factors such as "annoyance" on the assessment of the loudness can be reduced by using equal-loudness judgements, which provide a more robust basis for the consistent measurement of loudness. Typically measurement of equal loudness uses a 1000 Hz tone as a reference frequency, for comparison by a listener with sounds of different tones and varying sound pressure level. This is the basis for the measurement of loudness in phons i.e. if a given sound is perceived to be as loud as a 60 dB sound at 1000 Hz, then it is said to have a loudness of 60 phons. The earliest measurements of equal loudness were those by Kingsbury² for telephone listening conditions, as shown below.

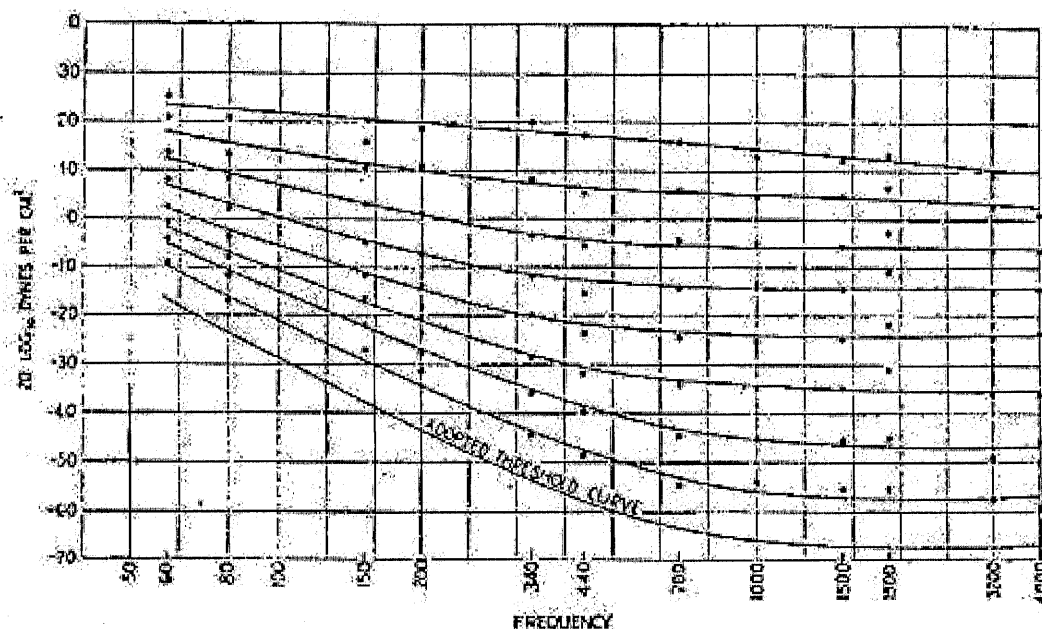


Figure 1 Kingsbury's Equal Loudness Contours (from ref 2)

Kingsbury's work was followed by research relevant to a broader range of listening conditions carried out by Fletcher and Munson³ to determine loudness level contours for various sound levels. This research is widely regarded as one of the major works in defining loudness and was instrumental in the development of the A-weighting network. Figure 2 below shows the Fletcher and Munson loudness curves from their 1933 paper.

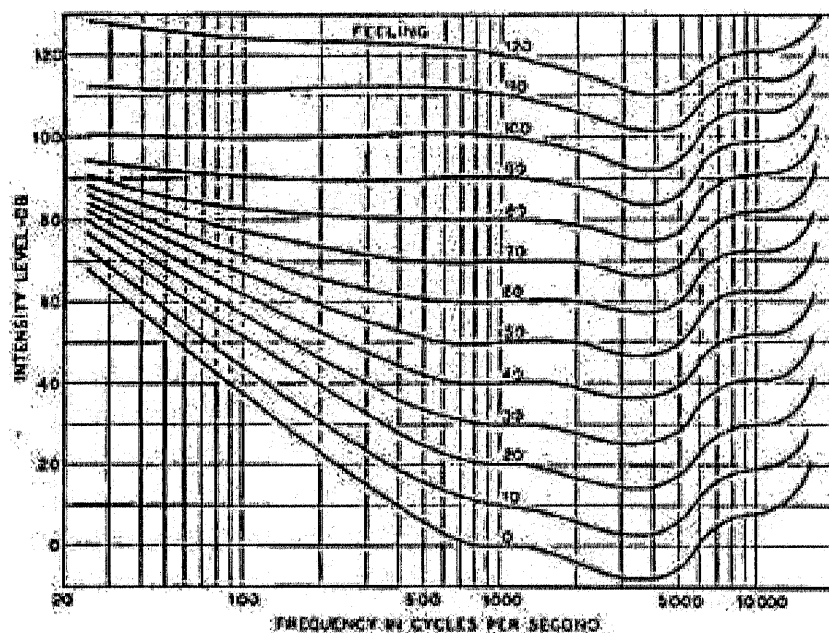
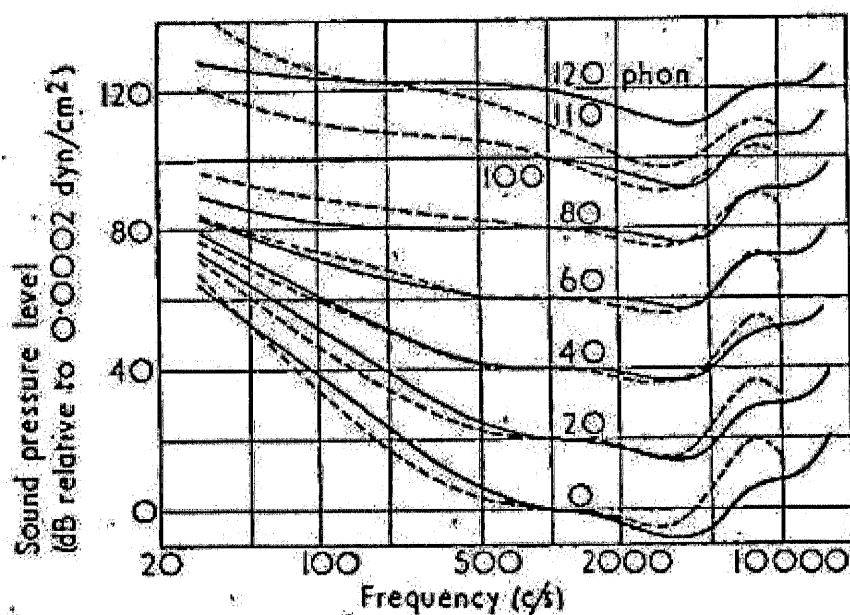


Figure 2 The Fletcher and Munson Equal loudness contours (from Ref 3)

Soon after, a second set of equal loudness contours were also produced by Churcher and King⁴, which Robinson and Dadson⁵, who also established how the age of the listener may influence the perceived loudness of a sound, compared with contours in their seminal work in the 1950's, as shown in the figure below.



---, Churcher and King; —, Fletcher and Munson.

Figure 3 Comparison of the Fletcher & Munson with the Churcher and King Equal Loudness Contours (from ref 5)

New standards of equal loudness contours with revised and marginally different equal loudness contours were published relatively recently in ISO 226:2003⁶, as shown in figure 4 below.

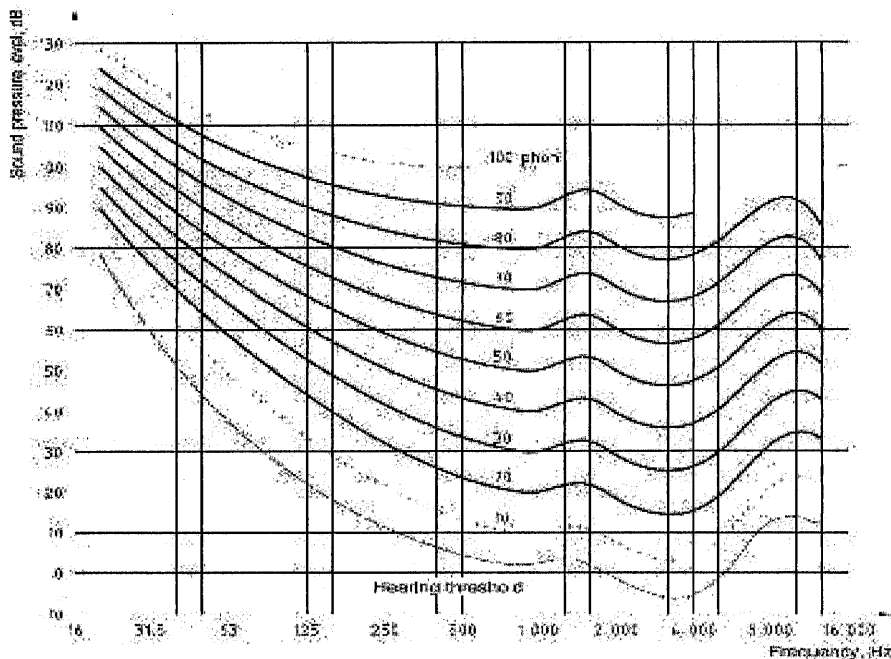


Figure 4 ISO 226:2003 Equal loudness Contours (from ref 6)

It is important to note that equal loudness contours represent statistical averages. Moreover, they are the results of experiments using headphones or in a reflection-free environment, so the equivalent loudness level perceived in any other listening environment may vary.

4. Weighting Networks

However, due to the complexities in measuring loudness, as alluded to above, a simpler “short-hand” method of measuring sound pressure level and applying a correction to approximately mimic the hearing systems differential frequency responses was required. This led to the direct extrapolation of the A, B, and C weighting curves, that can be regarded as crude approximate inversions of the 40, 70 and 100 phon equal loudness contours⁷. These weighting curves are shown in figure 5 below, and represent a series of corrections that can be applied to discrete frequency bands so that the total summed broadband noise level is weighted to reflect the non-linear frequency response of the human hearing system.

The A-weighting curve was calculated based on the fact that the A-weighting is 0dB at 1000Hz and the 40 phon curve is 40dB at 1000Hz, therefore, these two points coincide. In addition different weighting curves were developed to take into account that the degree of differential frequency response varies with intensity, with the A-weighting curve intended for noise levels below approximately 55 dB, B-weighting between 55 and 85 dB, and C-weighting applying at noise levels above approximately 85 dB.

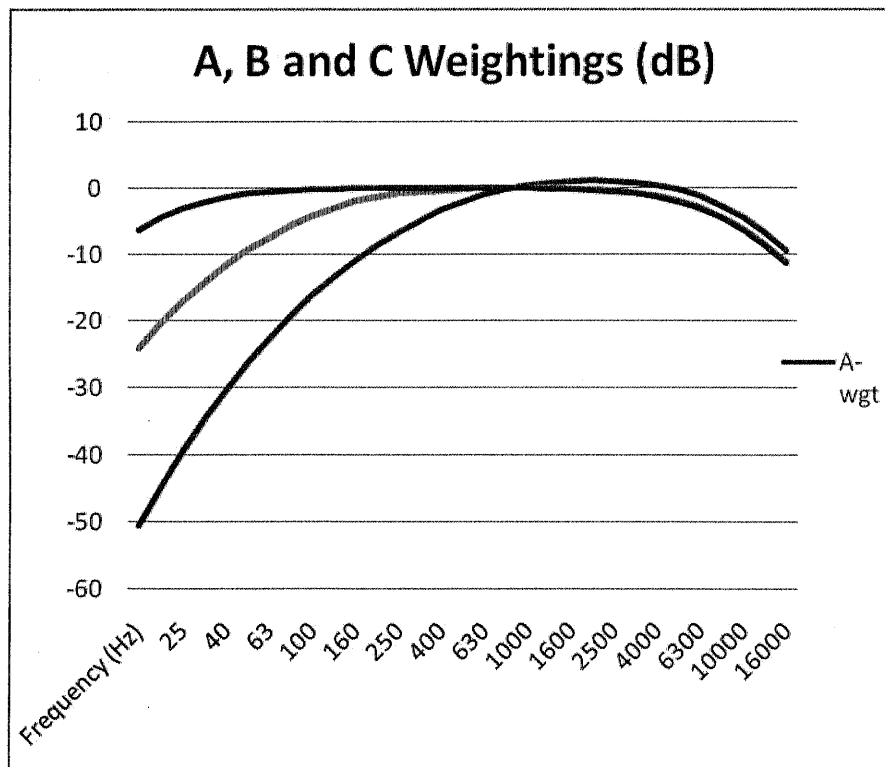


Figure 5

A, B and C Weighting Curves

There are other weighting networks, such as D weighting which was developed specifically for early jet aircraft which tended to have a distinct compressor “whine” at relatively high frequency, and the more recent Z and G weightings which have been developed for linear un-weighted and very low frequency noises respectively.

Since the 1950's international and national standards for sound level meters have required the incorporation of at least the A-weighted network into noise measuring equipment

5. The advantages and dis-advantages of A-weighting sound level measurements

Advantages

- Simple;
- Quick;
- Copes well with measurement variability due to the intrusion of extraneous low frequency noise due to wind and long distance sources⁸ during environmental noise assessment;
- A long history of use across the world and a very substantive body of research based on the A - weighted measure. Means that despite the difference in sensitivity and absolute values of for example A and C weighted decibel measurements of the same noise, or when using measures of loudness such as sones and phons; reasonable correlations with subjective response to many noise types have been established using the A-weighted decibel^{9, a,b,c,d & e}. Based on these studies a wide range of guidelines, limits and assessment advice has been developed using the A-

weighted decibel. Consequently, where a noise level guideline, limit or assessment value is stipulated using the A-weighted decibel, even though it may be possible to change to using another measure, in order to maintain a correlation with subjective response at least as efficient as the A-weighted equivalent; any new guideline, limit or assessment advice would need to be substantially different to make the change worthwhile. However, there is little or no research into the correlation between the subjective response and noise levels using measures other than the A-weighted decibel. Thus, adopting a sound level standard with an alternative measure would require years of research, possibly similar to the time it has taken to amass the body of data supporting A-weighted decibel based guidelines.

- Research¹⁴ has shown that the power law could be applied to the measurement of loudness by assuming the auditory perception system to have two essentially different stimuli: the intensity (sound pressure level) and pure pressure. These physically different quantities seem to be combined in the root of the power law, and these roots are determined from equal-loudness contours. A loudness function is derived on the basis of this finding. By adding a weighting, a method can be constructed for assessing loudness. After defining the weighting, the equal-loudness contours are constructed and are seen to be virtually identical to the contours in ISO 226. Finally, the weighting derived in this study was reasonably similar to the A-weighting. Therefore, because the weighting was not the main problem when assessing sounds in respect to loudness, the A-weighting can thus be chosen as a suitable for the study of environmental sounds.

Dis-advantages

Whilst the A - weighting network provides a simplified method to account for the differential frequency response of the hearing system, such an approach suffers from several disadvantages such as:

- Attempting to match the average frequency response of the ear as determined by equal-loudness methods does not account for all the other acoustic and non-acoustic factors that might affect the individual subjective response to the noise in question;
- For low frequency sounds or sounds with a prominent low frequency component, different frequency weightings are sometimes better correlated with the subjective response^{10, 11, 12 & 13;}
- Listening experiments¹⁵, have found Zwicker loudness to be superior to A-weighted measurements as an indicator of short-term loudness and annoyance of road-traffic sounds with wide variation in low-frequency content.

6. Discussion

The human response to noise is highly variable and volatile as indicated by Figure 6 below, which shows an indicative chart of the 'percentage highly annoyed' of samples of exposed populations plotted against noise level based on data from numerous social surveys of transportation noise carried out in different countries^{9a & b}. Each point in the figure represents the response of a sample of respondents exposed to a particular level of noise. The curves are a 'best fit' to the scattered data points, and the general shape of the curve has been re-confirmed more recently by further research^{9c,d & e} which shows similar scattering of data points.

The purpose of reproducing this chart here is to illustrate how a statistical estimate of the underlying trend between a subjective effect and an A-weighted noise index of a particular noise source can be developed for a population as a whole, even though the scatter of data i.e. the variability of individual sensitivity is high; as shown by the deviation of individual points from the trend line. This reflects the fact that environmental noise assessment cannot be sufficiently precise, primarily due to the substantial variation in sensitivity to noise across a population, to enable the subjective reaction of an individual to be confidently predicted, not least because non-acoustic factors¹⁶ have a strong influence on subjective response and these can be volatile for different noise sources, and at different times and locations. Consequently, objective noise level measures, independent of which weighting or type, can only provide indications of the likely extent and severity of the general effects of noise on communities; but due to the significant variability and volatility of individual subjective response to noise, and the significant influence of non-acoustic factors on these traits, they cannot indicate accurately how particular individuals will react. Substituting an alternative to the A-weighted decibel with a better correlation with individual sensitivity to a specific noise is therefore unlikely to significantly improve the overall correlation of measured noise with community response, as any increase in measurement efficiency is likely to be outweighed by the much greater variability in individual subjective response, due to the plethora of non-acoustic factors which influence the subjective response to noise.

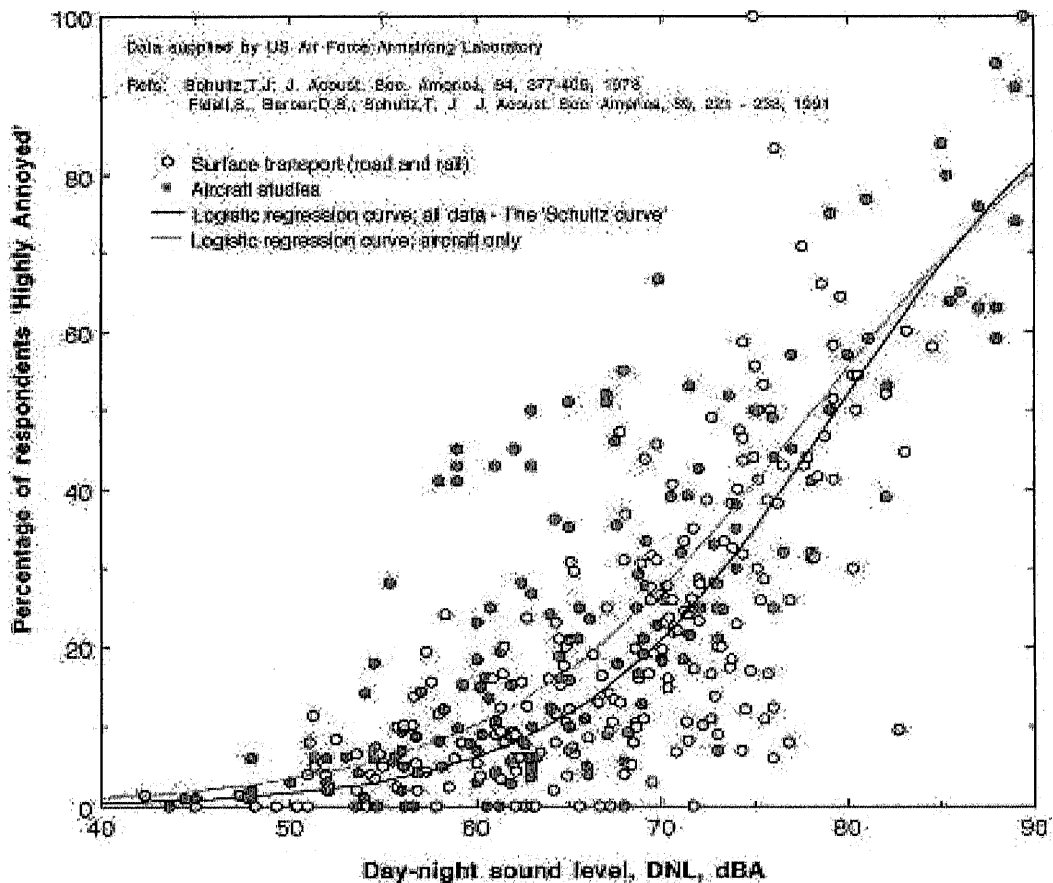


Figure 6: Incidence of Community Annoyance due to Transportation Noise from Social Survey Data

7. Conclusion

This paper has discussed the evolution of sound level measurement weighting networks from equal-loudness studies as a short-hand means of accounting for the non-linear frequency response of the human hearing system.

It is clear that for certain noises A-weighted sound pressure level measurements do not correlate as well with subjective response in specific circumstances as other weighting networks and objective measures of loudness.

However, it is equally clear from the substantial body of existing data and research using the A-weighted decibel that it does provide a useful measure with a reasonable correlation with subjective response to many noises in most circumstances.

Consequently, despite technology now being available to relatively easily use more complex methods and calculations in the measurement of the loudness of sound; and some studies have shown that these methods may be more useful, the A-weighted decibel continues in near ubiquitous use for noise measurement.

However, given the established and emerging limitations of the A-weighted decibel, the acoustic community would be prudent to always question the use of A-weighted measurements, and determine if more accurate measurements would be possible with alternative measures; although such an approach may be compromised by the relative paucity of studies and guidelines etc which utilise any alternative measures.

Given that modern measuring equipment and computational methods now make direct measurement of loudness much easier than before, it could be worthwhile researchers and those engaged in establishing guidelines and assessment advice; recording such parameters in tandem with A-weighted noise levels as a means of developing a suitable database from which to evaluate the benefits or dis-benefits of moving away from the A-weighted decibel.

So whilst rumours of the demise of the A-weighted decibel may be greatly exaggerated; it is starting to show its age and its ubiquitous use may not be justified in specific circumstances. However, until a substantive body of evidence exists to justify any change to any particular alternatives, its use will continue unabated.

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