Uncertain about uncertainty… A practical approach?

By Tony Higgins

Great, an environmental noise job! In the past we would rush out and deploy meters, secure them in position, and watch over them like mother hens in case it rained or the wind blew. Then the industry provided all weather microphones, and we were saved, we could leave them out in their fancy all weather boxes safe in the knowledge that there were no more blown mics or blanked out screens and we could relax. Indeed, we could go and get a coffee and leave the meter happily ticking away.

That is, until we got back to the office, and downloaded the data and tried to make sense of it. Something was wrong. Something didn't look right, and you'd squint at the data, and try to work out what had happened during the period of unattended monitoring. In short, we were uncertain of our results, and maybe just a little ignorant of the potential uncertainties that could (and probably did) affect our measurements. Fortunately, we all now have a much greater understanding of the possible uncertainties and new standards like the recently re-issued BS 4142:2014 make evaluating and *minimising* uncertainty a critical part of the any assessment. Whilst this article focuses on BS 4142 the discussion is probably applicable to most environmental measurement. I realise in writing this that the Measurement and Instrumentation (M&I) Group has dealt with uncertainty in several recent *Instrumentation Corners*, however, anecdotally, uncertainty and reporting of uncertainty remains the single biggest concern for acousticians as both consultants and regulators. This article aims to provide some practical observations on identifying and reporting of uncertainty.

So, what are those uncertainties? And how can we best deal with the issue of uncertainty when reporting? The principal uncertainties in environmental measurement are:

- Weather
- Reflections and interference
- Absorption (both ground absorption and air absorption).

The magnitude of the various uncertainties will depend on the conditions encountered when monitoring, the location and other site specific factors.

Nick Craven and Geoff Kerry have published a number of papers that evaluate uncertainties in environmental noise measurement and help to provide a method for quantifying uncertainty that will allow acousticians to validate their work (ref: *A Good Practice Guide on the Sources and Magnitude of Uncertainty Arising in the Practical Measurement of Environmental Noise*). http://usir.salford.ac.uk/20640/1/Good_Practice_Guide_May_2007.pdf). Good though that research is, it still doesn't replace proper consideration of the potential uncertainties by the acoustician in a site specific manner. It is not always necessary to consider uncertainties that may be small and unlikely to significantly affect the result, and it is probably worth summarising and making some practical observations on those that have the potential for greatest impact.

Weather

That weather conditions have an impact on measurement is well understood, wind direction and wind speed in particular can significantly affect results to the extent that a noise which is audible in favourable conditions, becoming inaudible in adverse conditions. The M&I Group (Mark Dowie, Brüel & Kjær) held an event in October 2016 entitled *When shall we three measure again — in thunder lightning or in rain…* which helped identify some issues around uncertainty due to weather. Rather typically when they were looking for adverse conditions, the weather was fine, however, Mark, David Waddington and Jon Tofts did produce some data on the effects of wind speed and direction (see fig.1) and the effect of wind speed change on LA90 measurements (see fig.2)

It is clear that distance from source upwind reduces the sound levels record comparative to those measured downwind. David reported that wind speeds above 4m/s seem to show an increase upwind probably because of noise generated by the wind itself. In practice, this means that higher winds will result in wind generated noise that will tend to mask the source under evaluation. More importantly, if the wind is blowing hard, most receptors will be (a) indoors, and (b) have windows closed, and any adverse perception they have of the source will therefore be mitigated.

The LA90 data (fig.2) collected shows the effect of wind speed on short term LA90 results. In general, the results for >5m/s wind speed are as expected, higher than those for <5m/s. The difference between the two visually appears obvious, e.g. around 42dB with wind, 32dB without. BS 4142 requires that we consider a modal average and that would present a problem in the above dataset, where the difference between the two conditions is much less e.g. 41dB for <5m/s. So, which dataset should be believed, and how should we deal with this in practice?

For the data in fig.2; Jon concluded of wind speed that "When it is windier, it is noisier; when it is calm, it <u>can</u> be quieter".

BS 4142 notes that we should:

"*Monitor wind speed at the measurement location, using an anemometer, and record the wind speed together with the wind direction. Exercise caution when making measurements in poor weather conditions such as wind speeds greater than 5 m/s*".

It goes on to suggest that recording data on cloud cover, and temperature at the measurement location are also appropriate. And that, for longer term measurements, a weather station might be required.

From a practical point of view, recording weather conditions whilst monitoring helps provide context to the measurements, by describing the conditions within which the sound is propagating. Weather conditions affect the transmission path of sound through the air, with wind direction being the most obvious concern. Changes in temperature and humidity, and the presence or absence of precipitation will also play a part, but the most significant effects are from wind speed (see fig.1).

We are seeking to monitor when conditions are optimum, and if we are carrying out a BS 4142 assessment, that means meeting the criteria within that standard. So if wind speed is above 5m/s, or temperature is below 5°C those non-conformances need to be reflected *and the effect on the results reported* or the source of uncertainty managed so that the effect is minimised. The most obvious answer is to only use data that complies with the weather data requirements of the standard. If you use data that falls outside of the standard parameter this would need to be reported and the impact on results assessed (see conclusion).

Reflections and interference

Reflections from surfaces in close proximity to a microphone will increase the measured sound levels. It is normal for acousticians to minimise these influences, by careful selection of monitoring position. The "accepted" method to minimise uncertainty stated in BS 4142, is to measure at least 3.5m from a reflecting surface and at least 1.2m above the ground. Where measurements are taken at 1m from the façade, a correction of 3dB is made to account from the reflections. This would need to be adjusted where the distance from the façade varies. Interference on the other hand could be more complex and might be overlooked.

Wind speed	Total	0-2 m/s	2-4 m/s	4-6 m/s	6-8 m/s	8-10 m/s
LAeq 100m Downwind(1)	62.4	62.9	62.3	62.2	62.6	63.5
LAeq 100m Upwind (1)	50,0	49.3	49.6	51.0	53.5	56.7

Fig.1 Upwind and downwind variability vs wind speed for a shooting range
Ref: David Waddington, University of Salford

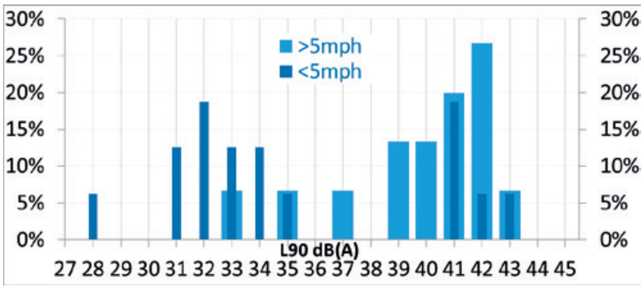

Fig.2 Effect of wind speed on LA90 measurements
Ref: Jon Tofts, Environment Agency

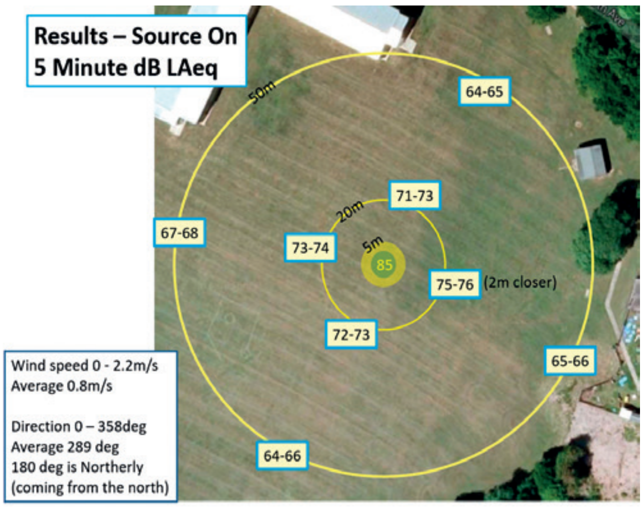

Fig.3 Variance in sound levels recorded during the “When shall we three measure again…” meeting
Ref: Mark Dowie, Brüel & Kjær

It is often the case that measurements at receptor locations are influenced by local residual sound levels, BS 4142 requires that residual sound should be deducted from ambient sound (with the source included) so that a specific level for the source can be determined. This acoustic correction can be misleading if the sound source is at the same level as the residual and the only way to establish a residual is to perform monitoring in similar location.

Results from the October 2016 meeting show a potential variation in levels even where monitoring is carried out at comparatively similar locations, fig.3 shows the variance found during the October meeting:

If we consider the potential differences in relatively static monitoring conditions, for similar locations of monitoring it is clear that variability in measured sound can occur, even more so where residual and specific sources vary over time. P28

◄ P27

Interestingly, the variation in the results noted in fig.3 was identified by the acousticians present to be mainly the rustling of clothes from the acousticians themselves with only a very slight wind effect. This raises another key issue around uncertainty, measured levels at the receptor can be heavily influenced by unexpected sources local to the microphone. This might be a particular problem where unattended measurements are carried out.

Uncertainty can be minimised by measurements taken closer to the source (ensuring that the specific noise is clearly dominant and residual impact limited) and then using calculation to estimate a level at the receptor location, this would also have the benefit of avoiding potential variation in residual noise measurements and may be more accurate and *reproducible* than measurement directly at the receptor. This form of "modelling" may also negate the influences of weather conditions on measured specific sound levels. Additionally, longer duration measurement might provide a more robust data set for evaluation that would "average out" any short-term anomalies.

Absorption

Air

Whilst not a significant concern for most urban locations (distances between source and receptor are short), in rural areas, ground, and sometimes air, absorption can be an issue that affects the propagation of sound. Distances over several hundred metres can reduce sound levels and change the perception of the sound at the receptor. Moderate and high frequency sounds tend to be absorbed better over distance, whilst low frequency sounds will propagate much greater distances, and diffract around barriers or other obstacles. The results of absorption over distance can therefore result in a significant change of perception of the sound, which in turn has implications for BS 4142 assessments. Numerically absorption through the air for a frequency of 1000Hz for reference conditions 101.3kPa, 20°C and 70% humidity is approximately 0.5dB/100m. Decrease in temperature to 5°C reduces this to 0.38dB/100m and 0°C shows absorption to be approximately 0.46dB. Similar variances occur where humidity changes, with 100% humidity increasing absorption to 0.54dB/100m and 50% humidity reducing absorption to 0.47dB/100m. Variance in atmosphere pressure has little effect.

(source NPL Acoustics: Calculation of absorption of sound by the atmosphere http://resource.npl.co.uk/acoustics/techguides/absorption)

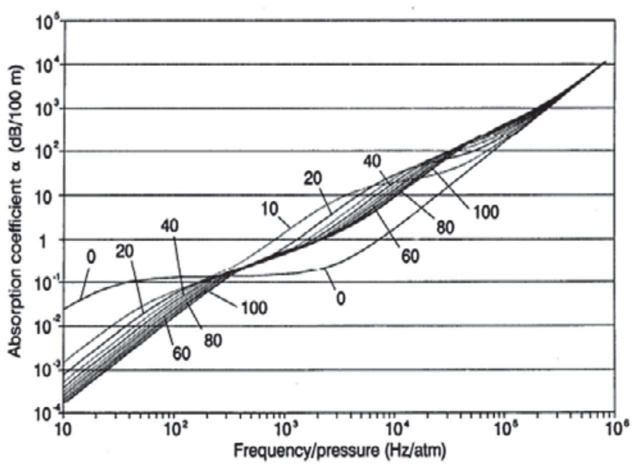

Fig. 4 Sound absorption coefficient in air (db/100) versus frequency for various relative humidities at 20°C
Ref: J. S. Lamancusa Penn State 7/20/2009 Noise Control, Chapter 10.3.1 Outdoor sound propagation

Ground

Absorption into the ground is potentially more significant than air absorption, but is dependent on the hardness and roughness of the ground, hard smooth reflecting surfaces (concrete, tarmac, bodies of water etc.) will not absorb significant sound, whilst grassland, woodland etc. will have a measurable effect. Ground absorption in favourable conditions can produce up to 10dB/100m attenuation, though 3-4dB/100m is more typical. Large barriers or topographical changes tend to negate ground absorption effects, but, like air absorption, the effect is frequency dependent with moderate and high frequency attenuating more quickly. NB: snow can significantly affect ground absorption and enhance the effects of trees and shrubs to reduce noise.

The effects of absorption are mainly of interest when calculating predicted levels. If ignored absorption can tend to overestimate the likely sound level for the source noise. The graph below shows typical absorption values based on research.

Conclusion

There are a large number of potential uncertainties to consider. For a BS 4142 assessment, the uncertainties need to be *managed*.

If compliant with those uncertainties listed in the standard, it should be sufficient to state (and evidence) that compliance.

If non-compliant, then it may be necessary to provide details of the uncertainty, in as far as that relates to the assessment. The details may be simple acknowledgement of the uncertainty and a qualification of the likely impact, e.g. "the monitoring period included light rain, the observed effect was that road increased sound levels by XdB".

More importantly, it is possible that there will be differences in LA90 measurements or a variance in LAEQ measurements. These variances as measured can produce a significant range of potential assessments values. It may be more appropriate to simply quote a range of assessment level results based on the variance in measured levels. E.g. if we have a rating level of 59dB and a background level varying between 42 – 49dB then quoting an assessment level of +10dB - +19dB might be appropriate. Alternatively quoting a "worst case" of +19dB might also be appropriate.

If we do need to quantify the uncertainty more accurately it is possible to by technical means (see Craven & Kerry 2007) and create an uncertainty budget. Such budgets would then be quoted alongside the assessment level, or measured values to show the degree of variance that is possible due to the uncertainties.

Whichever method is selected it is important to describe the effect of uncertainty in general terms in order that the recipient of the report can properly understand the implications and to provide the correct context. ◘

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Acknowledgement

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References

1. BS 4142:2014 Methods for rating and assessing industrial and commercial sound. British Standards Institute.
2. Craven, N.J. and Kerry, G 2007, A good practice guide on the sources and magnitude of uncertainty arising in the practical
3. *When shall we three measure again — In thunder, lightning or in rain…* IOA Meeting (see Acoustics Bulletin January-February 2017)
4. Ref: J. S. Lamancusa Penn State 7/20/2009 Noise Control, Chapter 10.3.1 Outdoor sound propagation