Is the 2.5 dB(A) Façade Correction for Road Traffic Noise Correct?

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ABSTRACT

Reference measurements for Australian road traffic noise criteria are currently made at a set distance of 1 m from a building façade. Before using the collected data, a façade correction is applied. A common industry view is that the usually-applied correction of 2.5 dB(A) is potentially overstated. Reported in this paper are results from a software suite developed to explore the parameters relating to façade amplification. Also described is the mathematical model upon which the software suite was built. The predictions made by the software have been validated experimentally. The 2.5 dB(A) correction was found to be a function of the angle of view, the dimensions of the façade, the distance from the carriageway and the frequency spectra of the passing traffic. Measured frequency spectra were found to vary with speed and road surface.

INTRODUCTION

Reported in this paper is an exploration, using a theoretical model, into the key parameters contributing to the validity of a façade correction from road traffic noise. This model was implemented in a MATLAB-encoded software suite. Field tests were carried out in order to validate the sound level amplification predictions within the model.

The standard 2.5 dB(A) façade correction currently in use for road traffic noise appears to originate from research collated during the development of CoRTN (Department of Transport Welsh Office, 1988). The CoRTN noise level prediction algorithm is used almost universally across the acoustics industries in Australia and the United Kingdom. Owing to strict noise level requirements, the accurate estimation of noise levels is required in all road-related constructions and upgrades. An additional 1 decibel of noise level difference in predictions can severely affect the cost of a construction project.

LITERATURE REVIEW

There has been previous research investigating the façade correction due to road traffic noise. Delaney *et al* (1976) detailed the development of CoRTN which included a summary of unpublished research on façade correction. The familiar value of 2.5 dB(A) appears to originate from this data which had a median value of 2.66 dB(A) and a range from 1.5 dB(A) to 3.8 dB(A). The median value was incorporated with theoretical predictions, rounded to 2.5 dB(A) before implementation in CoRTN.

Further work was undertaken by Saunders *et al* (1983) who validated CoRTN for Australian conditions. This was completed using the older $L_{A10,18hr}$ descriptor that has been superseded in many Australian States by L_{Aeq}. Corrections to overall $L_{A10,18hr}$ predicted noise levels of -1.7 dB(A) and -0.7 dB(A) were published for façade and free field conditions respectively ($\pm$5.0 dB(A) and $\pm$3.6 dB(A) respective errors with 95% confidence limit). This appears to suggest that -0.7 dB(A) should be applied as a source level correction for façade and free fields and that the remaining -1.0 dB(A) is due to façade effects. This would indicate that the façade correction should be +1.5 dB(A) and not +2.5 dB(A). Much of the data used obtained in this research (>80%) was for nominal speeds of close to 60 km/h, and no information was reported regarding angle of view to the road and façade width. The reported error between different receiver locations for the façade corrected values was greater than the free field values.

Tang and Li (2001) assessed the validity of the CoRTN façade correction, focusing on the effects due to source distance and microphone height, as well as the ground over which the sound was propagated. It was shown that for receiver heights of 4 m or less, a façade correction in the order of 2.5 dB(A) is reasonable.

The influence of the ratio between receiver-façade (d) and source-façade (D) distance was explored by Memoli *et al* (2007). The findings were that for a d/D < 0.1, interference effects are dominant in façade amplification. Another implication of the findings is that the source-façade distance is a parameter that affects façade amplification.

Finally, Hopkins and Lam (2008) used a source height of 0.5 m in their model which implemented a source-receiver path and three associated image paths. They found from experimentation that diffraction effects can be ignored for façade dimensions greater than 4 m.

MODEL DESCRIPTION

In developing the model used in the current work, consider a building with a perfectly flat façade orthogonal to the ground made of soft, short grass as shown in Figure 1.

The 3-dimensional coordinate system has an origin at the intersection of the building and the ground, halfway along the length (L) of the façade. All *xyz* coordinates are expressed in metres (m).

The position of the receiver (microphone or other measuring device) is 1 m in front of the building, 1.5 m above the ground and in the centre of the length of the façade. Let the receiver be denoted by $R(x = 0, y = 1, z = 1.5)$.

The road is parallel to the façade at fixed distance Sy.

A moving point source of height 0.5 m travels past the building along the predefined road.
The angle of view (α) is defined as the angle to the normal subtended by the moving source's initial and final positions, $S(x_i, y_i, z_i)$ and $S(x_f, y_f, z_f)$, as shown in Figure 2.

The *angle to source* (θ) is defined as the angle relative to the normal subtended by the source at a given position $S(x_0, y_0, z_0)$ relative to the origin. In Figure 2, the *angle to source* is shown as subtended from the position $S(x_f, y_f, z_f)$.

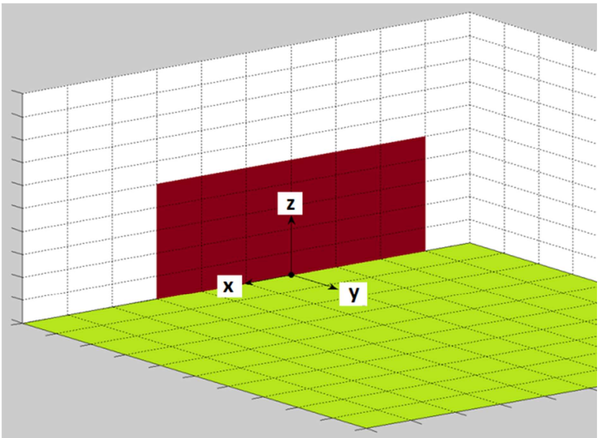


Figure 1 – Origin of the coordinate system.

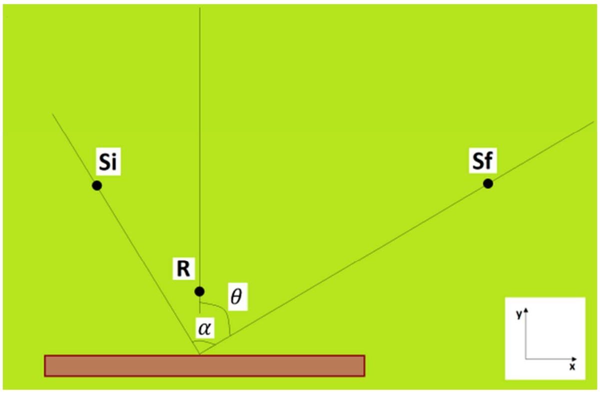


Figure 2 – Top view of the scenario shown in Figure 1, showing the position of the receiver with *angle of view* and *angle to source.*

Sound that travels from the source to the receiver can follow four distinct paths;

– Path 1, which follows a straight line (direct);
– Path 2, which reflects from the façade (reflected);
– Path 3, which reflects from the ground (direct ground) and
– Path 4, which reflects from both the ground and the façade (ground reflected).

The lengths of the four propagation paths are defined as $r1$, $r2$, $r3$ and $r4$ respectively.

The three source-receiver propagation paths (paths 2-4) that involve one or more reflections, have virtual sources associated with them, as pictured in Figure 3. These virtual sources are denoted $M2(x, y, z)$, $M3(x, y, z)$, and $M4(x, y, z)$ respectively.

Path $r1$ follows a direct line between the source $S(x, y, z)$ and receiver $R(x, y, z)$ and will be denoted as $\overrightarrow{SR}$ (vector notation) for the remainder of this work. The three remaining paths ($r2$, $r3$ and $r4$) are identical in length to their corresponding virtual paths and they will henceforth be denoted respectively as vectors $\overrightarrow{M_2R}$, $\overrightarrow{M_3R}$ and $\overrightarrow{M_4R}$ respectively.

In addition, the subscripts when referring to the associated properties of these paths will be d, r, dg and rg; respectively referring to *direct*, *reflected*, *direct ground* and *reflected ground.*

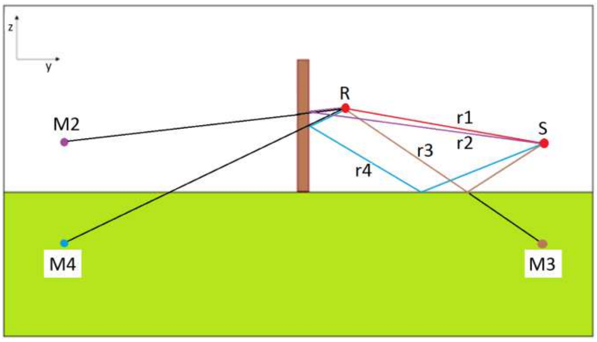


Figure 3 – Source-receiver geometry with virtual sources and propagation paths (side view).

DESCRIPTION OF MODEL CALCULATION

The pressure is evaluated for the four separate paths based on the following equation (Kinsler, 2000):

$$P = \frac{A}{r} e^{(\omega t - kr + \varphi)}$$

$$P = \frac{A}{r} cos(\omega t - kr + \varphi) + i \frac{A}{r} sin(\omega t - kr + \varphi)$$

Where:

– P (Pa), is the pressure;
– A, is the amplitude of the sound wave;
– k (m^{-1}), refers to the wave number, $k = \frac{1}{\lambda} = \frac{2\pi f}{c}$;
– ω $(radians)$, the angular frequency, $\omega = 2\pi f$;
– r (m) denotes propagation path length;
– t (s), refers to time; and
– φ $(radians)$ and f (Hz) refer to phase and frequency.

The pressure for each wave will be a complex array with one element for each frequency. Amplitude is a frequency specific value calculated as a combination of ground and air effects, which is then A-weighted. The pressure contribution at the receiver point is evaluated for combinations of waves.

As the function is operating in the frequency domain, the time can be set to t=0. This is because time is not a variable in the frequency domain – all time would do is rotate the phase vector. It is not required to propagate geometrically in the frequency domain. The relative phase between the sound paths is handled by the 3-d spatial vector and the different distances in reflected noise paths. The resulting pressure-squared component for a single propagation path can be calculated by taking the square of the complex amplitude for each frequency and then simply adding the complex pressure components:

$$P_{d,final}{}^2 = \sum_{frequency} \left(\frac{A}{r}\right)^2$$

Note that the frequency and phase information is effectively lost in this process for a single propagation path. So, in order to model interference, each of the waves from the respective propagation paths must be superposed in their complex form before the magnitude of the combined waveform is found. For example, the $\overrightarrow{SR}$ and $\overrightarrow{M_3R}$ propagation paths (direct and direct ground) can be combined as follows:

$$P_{d+dg,final}{}^2 = \sum_{frequency} (P_d + P_{dg})^2$$

Hence, the interference between wave components is modelled before the magnitude of the waveform is evaluated. In a similar manner, the total of all four propagation paths $\overrightarrow{SR}$, $\overrightarrow{M_2R}$, $\overrightarrow{M_3R}$, and $\overrightarrow{M_4R}$ can be found from:

$$P_{total,final}{}^2 = \sum_{frequency} (P_d + P_{dg} + P_r + P_{rg})^2$$

The amplification can be calculated, as stated above, by comparing multiple paths. Comparing $P_{d+dg,final}$ with $P_{total,final}$ is the main interest of this work, as it will provide the amplification of pressure due to the façade presence, with ground effects included. Hence:

$$Amplification\ [dB(A)] = 10 \cdot \log_{10}\left(\frac{P_{total,final}{}^2}{P_{d+dg,final}{}^2}\right)$$

Which may be plotted against the *angle to the source*. This may also be integrated to find the average correction for a road traffic line source for a given angle of view.

The influence of air absorption on propagating sound waves has been modelled using ISO 9613-1 (ISO, 1993).

Ground absorption is relatively difficult to model, as a sound ray impacting grass- will not reflect in a perfectly uniform and specular manner. The local geometry of tufts and blades of grass will cause the sound to propagate in a complex and chaotic manner, requiring various numerical approximations.

The method reported by Attenborough (1988) has been used with flow resistivity of 386 000 Rayls/m. The result of calculations is a correction coefficient in complex form, from which amplitude and phase can be extracted.

RESULTS

CoRTN Soft Ground Validation

Figure 4 shows a comparison of the relative attenuation of the models over various distances. The models are adjusted so that the same approximate attenuation occurs for the 13.5 m case (where the façade-source distance is 10 m plus half the width of the road). It appears that the values from the software suite closely match those from typical soft ground predictions under CoRTN. Within the acoustics industry, most consultants use values for CoRTN soft ground between 50-100%, and the values from the software suite lie close to this range for the façade-carriageway distances of interest.

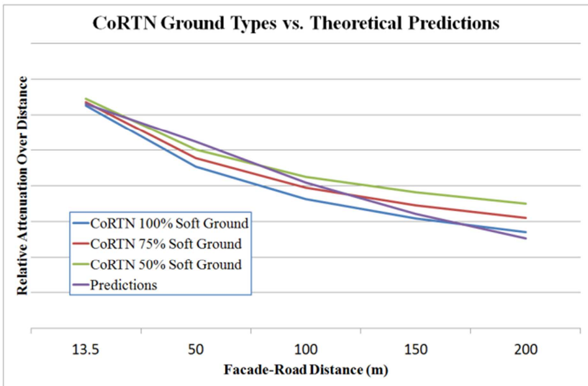


Figure 4 – CoRTN vs theoretical predictions.

Experimental Validation

Various items of acoustical equipment was borrowed from Wilkinson Murray Pty Ltd and used in the validation of the refelction model. The set-up is shown in Figure 5 and included:

- An RCF ART 310A speaker with IEC C13 speaker power cable;
- A Brüel & Kjær 2231 Sound Pressure Level meter (Hereafter referred to as the SPL meter);
- An anti-aliasing filter, as part of the SPL meter;
- A tripod for SPL meter;
- A laptop with power adapter and
- A Creative *Soundblaster 24-bit Advanced HD* duplex USB sound card.

The frequencies tested are shown in Table 1. As the software suite predicts for a high frequency resolution (10 per 1/3 octave band for the 70km/h conditions), these theoretical amplification predictions are plotted as a blue continuous line in the following figures. The 17 frequency amplifications from the experimental analysis are superimposed as black circles on the same figure.

Table 1 – Frequencies used in the experiments.

250 Hz	315 Hz	400 Hz	500 Hz	630 Hz
800 Hz	1250 Hz	1600 Hz	2000 Hz	2500 Hz
3150 Hz	4000 Hz	6300 Hz	8000 Hz	10 kHz
12.5 kHz	16 kHz			

Figure 5 – The set-up for the experiments. The façade amplifications were compared at a number of frequencies at four distances.

Besides a few outliers, the experimental values appear to fit very closely with those predicted by the software suite.

Figure 6 shows how the 10 m façade-source distance experimental values appear to have the most deviation from the predicted values. There are noticeable outliers at 250 Hz, 400 Hz, 1250 Hz, and 8000 Hz. The remaining 14 frequencies, however appear to match predictions quite uniformly.

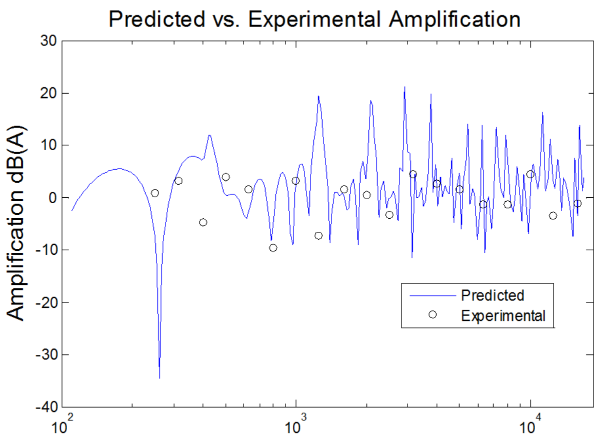


Figure 6 – 10 m façade-source distance.

The 50 m case illustrates again the seemingly typical outlier at 250 Hz, as can be seen Figure 7. The middle frequencies appear to be an extremely close fit again; much like in the $10m$ case, the majority of values between 315-4,000 Hz are lying directly on the theoretical blue line. There are three distinct outliers in the high frequencies; 5,000 Hz, 8,000 Hz and 10,000 Hz.

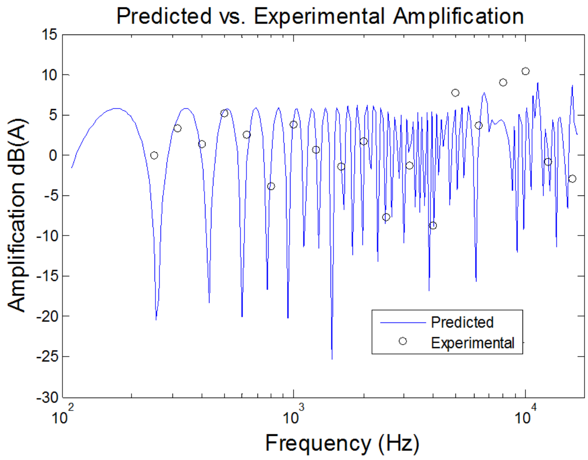


Figure 7 – 50 m façade-source distance.

The 10m and 50m façade incident configurations appear, on the whole, to have data which matches predictions within reasonable bounds of error. Many of the experimental values around the mid to high frequencies appear to lie directly on, or very close to, the theoretical blue line.

Spectra Comparison

Data collected from a number of sources on roads with dense-grade asphalt (DGA) surfacing and a 100 km/h speed limit were obtained from the NSW Roads and Maritime Services Authority (RMS). Additionally, the authors used data from Wilkinson Murray Pty Ltd of measurements taken along Campbelltown Road (DGA) with traffic flowing at 70 km/h. The former data was represented in 1/12 octave band spacing. The latter data was analysed in MATLAB and represented with a spacing of 10 intervals per 1/3 octave band.

The two spectra (shown A-weighted in Figure 8) appear to have quite different shapes across the frequency range of interest. The slower vehicle speed appears to have a spectrum which is flatter, and dominant in the low frequencies. This is hypothesised to be due to a lower contribution of noise from the tyre-road interface, compared with noise from the engine, at the lower vehicle speed. The noise generated at the tyre/road interface appears to be more significant in the high-speed cases for DGA road surface conditions, where the frequency dominance is around 1,000 Hz.

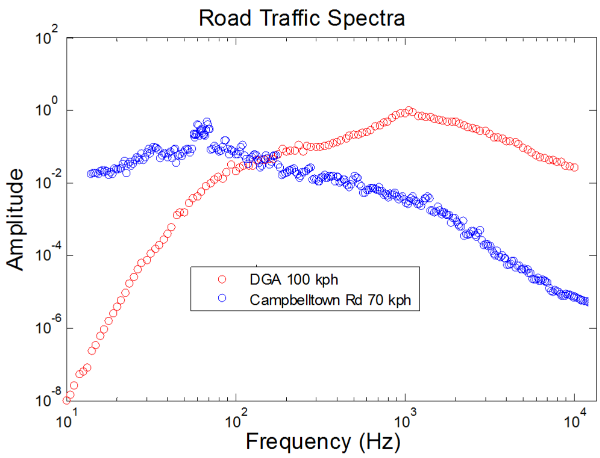


Figure 8 – Comparison of traffic spectra, 100 km/h vs. 70 km/h.

Standard Conditions

Figure 9 illustrates the angle specific amplification predictions by road distance and *angle to source*. The predictions lie between 2-3 dB(A) until the *angle to source* becomes quite large. This is because at large angles, the distance from the source to the receiver will be so large that there is no effective difference between the various propagation path lengths. This means that the model will predict near-perfect reinforcement at large *angle to source* values as the two signals reinforce.

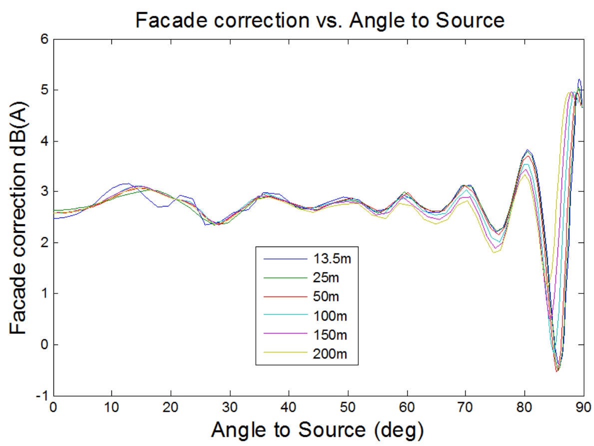


Figure 9 – Façade correction vs. *angle to source* (100 km/h).

Data collected for *angle to source* is not directly useful for road traffic analysis. This is because a passing noise source will be loudest when closest to the receiver. The amplification is therefore most relevant near this point, and becomes less relevant as the noise source is further away from the receiver. The cumulative integrated average over the a*ngle of view* of the noise passing is illustrated in Figure 10. As expected, the integrated amplifications at large *angle of view* values do not greatly increase even though the more distant amplifications tend to 5-6 dB(A) for the corresponding *angle to source* in Figure 9.

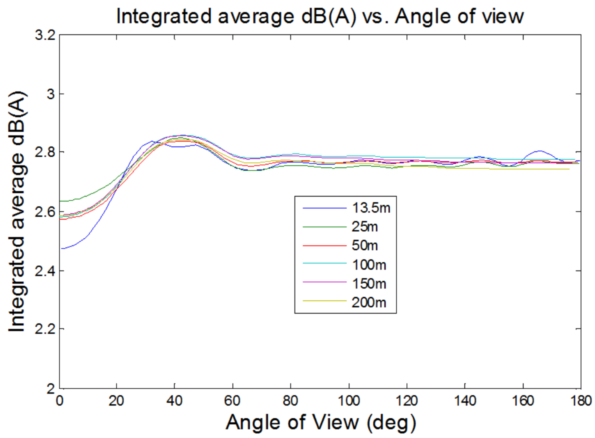


Figure 10 – Façade correction vs. angle of view (100 km/h).

In the case of the 70 km/h data from Campbelltown Road, it appears that the low frequency dominance leads to much more uniform results.
As seen in Figure 11, the trends of intergrated façade correction all show attenuation at low *angle of view*. The predictions all tend smoothly up to a maximum of 2.5 dB(A) at the full *angle of view*. For angles of view around 150^{o} close to the road the façade correction is approximately 1.5 dB(A) which is consistent with the suggested interpretation of the data by Saunders *et al* and also with the lower range reported by Delany *et al*.

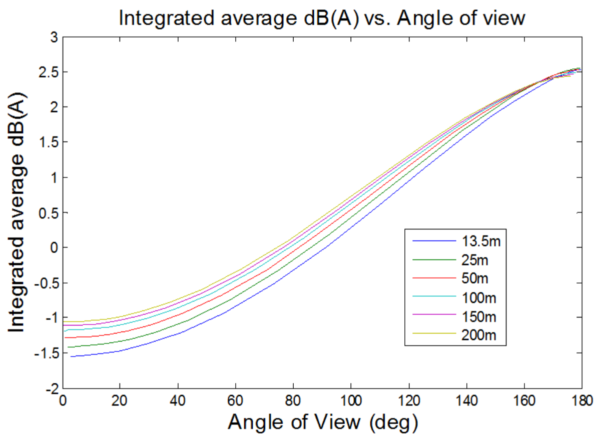


Figure 11 – Façade correction vs. angle of view (70 km/h).

Variation of Façade Width

Limitation of the façade dimensions will reduce the amplification beyond a certain *angle to source*. This is inherent in the geometry of a source-receiver system adjacent to a façade as illustrated in Figure 12.

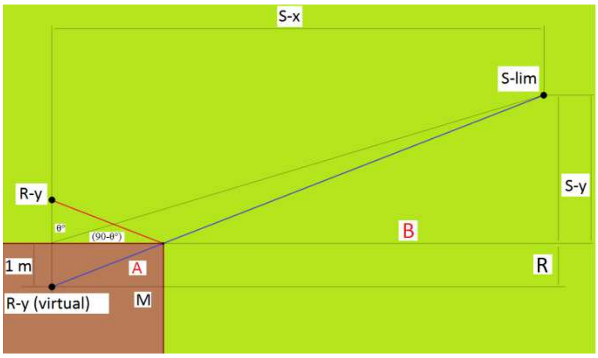


Figure 12 – Limiting case of façade reflection.

The *angle to source* at which amplification will no longer occur has a simple derivation and can be expressed in terms of the surrounding geometry as:

$$\theta = \tan^{-1}\left(\frac{M(Sy + Ry)}{Sy}\right)$$

It is evident in Figure 12 that for a façade width of 4 m, the integrated amplification will dip close to $\theta = 130°$ and then tend to greatly reduce the amplification for a full 180° angle of view. The reduction in overall amplification when compared to an infinite façade width is between 0.1-0.6 dB(A) depending on road distance. Similar trends were observed in the 70 km/h Campbelltown Rd data.

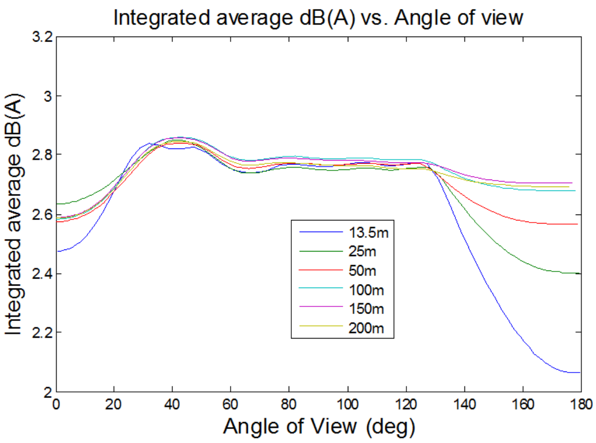
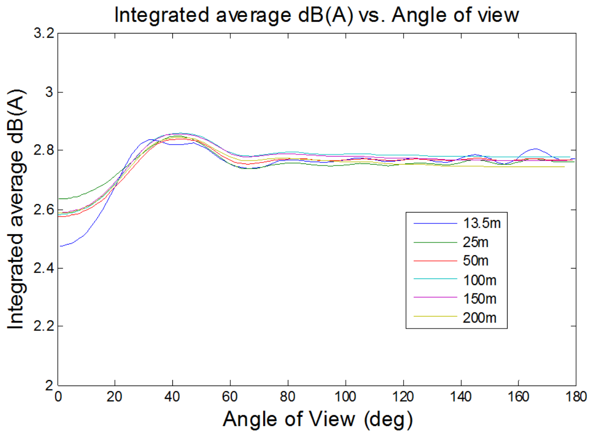


Figure 13 – Façade correction vs. angle of view (façade width 4m).

Variation of the Receiver Position

Although the façade corrections outlined in *CoRTN* explicitly state a receiver-façade distance of 1m, it is not always feasible to have the microphone at this exact distance from the receiver. Human error, as well as ambiguity over the exact distance to be measured for façades with features, can plausibly lead to a number of centimetres' deviation from 1 m. In addition, it has been heard anecdotally from some industry workers that if a measuring tape is not on hand, it is considered acceptable to make a visual estimate. Overall, this could mean positioning errors in the order of 30-40%.

Figure 14 illustrates the impact that changing the receiver-façade distance Ry will have on the overall amplification for the distances 1.1 m and 0.9 m, chosen as $\pm$10% of the standard model conditions distance of $Ry = 1.0\ m$.



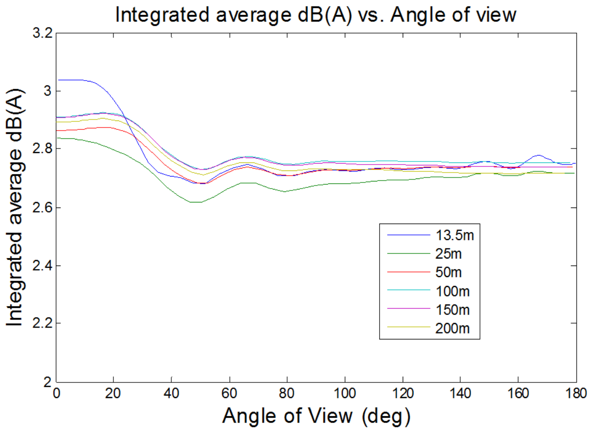


Figure 14 – Façade correction vs. angle of view; receiver position 0.9m and 1.1m (top to bottom).

The variation of receiver position does indeed have a substantial effect on the predicted amplification across the full angle of view. In the 0.9 m condition, the receiver position appears to have a different trend, dipping rather than peaking in the low angle of view values. In addition, the overall amplification appears to be more conservative; around 0.1-0.15 dB(A) lower than for the standard distance of 1.0 m. In the 1.1 m case, the trend is again rather different. Large amplifications are predicted for the very low angle of view values. Furthermore, the full angle of view predictions are around 0.5 dB(A) lower than those for the standard distance.

A similar degree of variation was noted using the 70 km/h Campbelltown Road spectrum.

Calculations during this investigation also indicated that the façade correction changes with:

- Angle of the façade relative to the road.
- Partial shielding of a receiver, particularly when an object such as a noise wall is directly in front of the residence.
- Road curvature and where a residence is located on a corner.

These three aspects all influence the degree by which the contributions from each *angle to source* component contribute to the overall integrated façade correction. Further work is being carried-out to validate these calculations.

CONCLUSION

The measurement of the noise levels at façades has the potential to introduce uncertainty into measurement and model calibration, as the value of 2.5 dB(A) used in standard practice is a sensitive variable.

An appropriate value of façade correction is strongly dependent on the frequency of the traffic noise, which in-turn changes with speed, surface correction and vehicle mix. It is also dependent on angle of view, façade width, distance from the road, the geometry of the road and barrier, the building orientation and error in microphone placement at the façade .

Propagation effects such as air and ground reflection absorption also have a minor influence on the significance of each *angle to source* component to the overall façade correction.

These effects cannot be modelled using current commercial software packages. The model developed during this work, based upon complex frequency domain propagation is an adequate model of the façade reflection mechanism.

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