RONDA open frame CPX trailer - Certification in accordance with ISO/CD 11819-2

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ABSTRACT
RONDA (ROad Noise Data Acquirer) is a CPX trailer conforming to ISO Standard ISO/CD 11819-2 intended for measuring road surface noise. The trailer is of the open frame construction without an enclosure. The results of certification testing in accordance with the ISO Standard is described in particular a) Annex A.2 sound reflections against an enclosure (if any) and other objects close to the microphones and b) Section 8.1 the effect of wind on the microphones. These issues are particular relevant to open frame trailers which by their inherent design are potentially susceptible to wind noise. Whilst not considered in the ISO Standard, the contribution of noise from the tyre located on the far side of the trailer is also evaluated and an error correction term is derived. This correction is relevant to both enclosed and open framed trailers.

Keywords: CPX, OBSI, Tyre noise, Pavement noise I-INCE Classification of Subjects Number(s): 13.2

1. INTRODUCTION
ISO Standard ISO/CD 11819-2 (1) describes a method for evaluating different road surfaces with respect to their influence on traffic noise under conditions where the tyre/road noise predominates. At the time of writing, this ISO Standard is in final draft form and publication is imminent.

The ISO Standard contains guidelines for the construction of test vehicles (trailers) which may be of the closed or open type. Common test vehicles are constructed in the form of a trailer incorporating two wheels which are either covered by an acoustically lined enclosure (closed type) or uncovered (open type). Microphones are located close to the wheels to measure the emitted tyre/pavement road noise levels. The majority of such trailers (here-in referred to as CPX trailers) are of the closed type because it is argued that the enclosure a) reduces the effect of wind noise on the microphones, and b) reduces extraneous noise from the test vehicle and from other passing vehicles. In this context, the wind noise referred to is the turbulent wind stream presented at the microphone created by the action of moving a microphone in a complicated air stream behind a moving vehicle close to the road surface.

On the other hand, an open type CPX trailer has the technical advantage of a) minimizing acoustic reflections because it avoids use of an enclosure and b) avoids long term stability potentially associated with changes in the absorption properties of the acoustic absorbing material over time (such as due to clogging by road debris or deterioration).

In respect of the influence of acoustic reflections in an enclosure fitted to a closed trailer, the ISO Standard at Annex A.2 specifies a detailed test method for determination of a correction factor $C_{df}$ for each wheel which is intended to correct for the effects of sound reflections within the enclosure. The correction factor should also be determined for open type CPX trailers because there is no guarantee that all reflections are eliminated in that form of construction.

In respect of the effect of wind noise on the measurements in an open type CPX trailer, the ISO Standard is not so specific and refers to monitoring “the noise in the system away from the test tyre”. If this means to monitor wind noise levels far removed from the trailer, then the difficulty is that the wind speed and turbulence close to the tyre are not being replicated and therefore the results might not be relevant or applicable. Faced with this difficulty, the authors instead elected to temporarily convert RONDA from an open type CPX trailer to a closed type CPX trailer in order to evaluate any

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difference in the measured CPX noise levels. In addition, the wind speed and turbulence at the microphone are measured so as to provide additional information on precisely what is the effect of enclosing a trailer.

Finally, although not considered explicitly in the ISO Standard, the influence of noise from one tyre on the measurements at the other tyre is also considered as this issue does not appear to have been addressed in the literature.

Therefore, the focus of this paper is a) the quantification of the correction factor \( C_{d,f} \) for an open type trailer, b) the effect of noise from one tyre influencing the measurement at the opposite tyre, and b) the influence of wind noise on the microphone.

An alternative procedure for the measurement of tyre/pavement noise is the on-board sound intensity (OBSI) method which is the commonly used standard in the USA. The OBSI method is described in AASHTO TP 76-13 (2). According to the OBSI method, two intensity microphones are located close to the rear tyre of a driven vehicle. This method avoids the use of a trailer (however, fitting the microphones to a trailer is also permitted in the AASHTO Standard). Other than the use of normal 90mm diameter wind screens, the microphones are not protected from the wind stream.

As RONDA is also fitted with OBSI sound intensity measuring equipment, it is instructive to also investigate the effect of the wind stream on the intensity microphones in a closed and open type trailer.

2. PREVIOUS STUDIES

2.1 Trailer Correction Factor

The results of a round robin test on open and closed trailers concluded that the difference between open and a closed trailer design does not lead to significantly different results, as long as the closed trailer is equipped with an absorbent lining in the hood and as long as the influence of reflections under the hood is corrected for with a trailer correction factor (3).

2.2 Effect of Wind Noise on CPX Measurements

Ledee et al (4) examined the influence of wind noise on an open trailer designed by Jos Reubsaet known as DeciBellA (5). The experiment involved two parts: first, an assessment of wind noise on the microphones in the open trailer and second, an assessment of wind noise on microphones fitted to the rear tyre of a vehicle (i.e. without a trailer). In the first part, the wind speed at the microphone location was measured using a rotating cup anemometer. The wind speed at the microphone was shown to vary between 50-72% of trailer speed. Presumably this is the result of screening by the towing vehicle. Next, data for the wind induced noise contribution was taken from measurements conducted by Bruel & Kjaer on a microphone with a 90mm windscreen rotating on a boom in an anechoic chamber. It was concluded that in the 315Hz 1-3 octave band, the wind noise sound level contribution was about 23dB below the 315Hz sound level generated by tyre/road for a reference dense asphalt concrete pavement. Similarly, the overall A-weighted sound level generated by wind noise was about 36dB below that generated by the reference pavement.

In the second part of the experiment relating to microphones fitted to the rear tyre of a vehicle, tests were conducted in a wind tunnel. It was first established by site tests that the wind speed at the rear tyre was approximately equal to the driven speed. This, it was postulated, was due to the limited screening by the vehicle on wind. Next, the wind noise was measured in the wind tunnel for the designated wind flow corresponding to vehicular speed from which it was concluded that there was no influence on the overall levels but that there was some influence at low and at high frequencies for test vehicle speeds above 90kph.

An important observation was that wind induced noise levels measured on the test vehicle were higher than the noise levels measured by Bruel & Kjaer (with a rotating boom), by 8 dB(A) on overall level at 80 km/h (22 m/s) and 12 dB at 315 Hz. Whilst such differences remained unexplained by the authors, it was postulated that the different measuring methods and conditions are probably the reason for this large difference. The rotation of the microphone on the boom at high speed, it was said, may produce a rotational air flow in the anechoic room that lowers the relative speed of the microphone. In the case of the test vehicle, although the air flow around the microphones was expected to be mostly laminar, it may contain some turbulence that could increase the wind-induced noise level. In actual fact, the degree of turbulence was unknown for all systems: the rotating boom, the open trailer and the test vehicle because it was never measured.

The importance of upstream turbulence on wind noise was postulated by Strasberg (6). In
considering data from a variety of sources, Strasburg concluded that the one-third octave band wind noise level could be expressed as follows:

\[
L_{1/3} = 61 + 63\log V - 23\log f - 23\log D
\]  

(1)

where \(L_{1/3}\) is the one-third octave band sound pressure level (dB re 20\(\mu\)Pa), \(V\) is the wind speed (m/s), \(f\) is frequency (Hz) and \(D\) is the diameter of the spherical screen (cm). Strasberg noted that this formula related to measurements made in the laboratory by moving the microphone through substantially quiet air. In this situation, the noise is associated with turbulence generated by motion of the microphone (i.e. self-generated noise). Strasberg stated that in naturally occurring winds, where the upstream wind turbulence is strong, noise from the upstream wind turbulence may exceed the self-generated noise.

Morgan et al explained that the dominant source of wind noise in outdoor microphones is the pressure fluctuations caused by the velocity fluctuations of the incoming flow (7). According to Bernoulli’s principle:

\[
p = 0.5\rho(u + V)^2 = 0.5\rho V^2 + 0.5\rho u^2 + \rho u V
\]  

(2)

where \(p\) is the total pressure at the microphone (Pa), \(\rho\) is the density of air (kg/m\(^3\)), \(V\) is the average wind speed (m/s) and \(u\) is the rms fluctuation in the wind speed (m/s). The value \(u/V\) is known as the Turbulence Intensity. Ignoring the second term in the equation above, the rms pressure fluctuation due to in-flow turbulence is approximately \(P = \rho u V\) which, it is stated, dominates over the two other sources of wind noise, being boundary-layer noise produced by the flow around the wind screen and wake shedding (Van den Berg (8), Zheng et al (9)).

Therefore, it is important, when assessing the wind noise level in CPX trailers, to have an understanding of not only the average wind speed at the microphone but also the rms fluctuation of wind speed i.e. the turbulence intensity. In short, it is inappropriate to equate the wind noise produced in a wind tunnel or by a rotating microphone on a boom with that which occurs in the real situation in a CPX test where a microphone is moved through air with a complicated flow and turbulence character.

2.3 Effect of Wind Noise on OBSI Measurements

In the OBSI method, two sound intensity microphones are normally located adjacent to the rear tyre of a vehicle. As previously noted, at this location the wind speed at the microphone is approximately equal to the vehicle speed. However, it is also permitted in the AASHTO standard to use a trailer to which the microphones are attached. As previously noted, the wind speed presented at the microphone location fitted to a trailer is less than the vehicle speed because of the shielding effect of the vehicle.

In Donavan (10) an assessment was made of the effect of wind noise on the microphones using measured data obtained in a wind tunnel with turbulent free wind conditions. It was concluded that above 2kHz flow noise contaminates the tyre noise data.

In Donavan & Lodico (11) wind noise levels were measured in a wind tunnel with a very low inflow turbulence intensity (~0.6%). An “average” road surface was first selected from five of the quietest pavements measured using the SRTT tyre. Detailed tests were conducted at 60mph (96kph) with a dual intensity probe setup (as described in the AASHTO standard) fitted to a GM Impala situated inside the wind tunnel. It was found that sound intensity measurements were unaffected by wind at the vehicle test speed for zero degrees yaw (i.e. with the vehicle oriented in the direction of the wind) or for negative angles of yaw (i.e. with the vehicle angled so as to shield the intensity probe from the wind). For positive angles of yaw, the overall A-weighted OBSI level was affected by less than 0.3dB. In the 500Hz band, there was an increase of up to 2dB. It was therefore recommended that the PI index be scrutinized for all tests in respect of influence of wind induced noise with particular attention paid to the 400, 500 and 5kHz frequency bands.

As noted in the previous section, these tests involved very low levels of inflow turbulence intensity and, as stated by Donavan, are unlikely to be representative of real test conditions.

3. EXPERIMENTAL PROCEDURE AND RESULTS

The experiments are conducted on an open frame trailer known as RONDA as depicted in Figure 1 below. RONDA comprises a solid steel upper frame supported on air bags attached to two articulated arms on which two test tyres are attached. This configuration is intended to replicate the dynamic characteristics of a motor vehicle.
3.1 Sound Reflection Coefficient

The measurement of the trailer sound reflection correction $C_{d,f}$ is described in section A.2 of ISO 11819-2. This involves the use of an artificial noise source in the shape of a tyre with a loudspeaker fitted to the underside as shown in the figure below.

The artificial noise source (in our case a Bose loudspeaker) is attached to the trailer in place of each tyre in sequence and the sound level measured with random noise emitted by the loudspeaker (SPL\textsubscript{trailer}). The artificial noise source is then moved away from the trailer and the measurement is repeated (SPL\textsubscript{free-field}). The difference $C_{d,f}$ is then equal to SPL\textsubscript{free-field} − SPL\textsubscript{trailer}. As recommended
in the ISO Standard, it is imperative that the microphone locations are preserved with respect to the artificial noise source and therefore, a thin frame was used, as shown in the figure above, to ensure the microphone locations are maintained when moving the artificial noise source. Also shown is the use of 1mm thick aluminium sheets covering the area under the trailer to make the ground plane totally reflective. The results for the forward left microphone are shown in the upper graph of the figure below for the case of “CPX+OBSI” meaning that both the CPX and OBSI microphones were in place during the test (the results of the other microphones are similar). Importantly, the standard deviation (SD) is shown for repeated measurements verifying that confidence level of the determination of $C_{d,f}$ is high. The results are shown in comparison with the allowable limit of ±3dB specified in the ISO Standard.

![Figure 3 - $C_{d,f}$ sound reflection coefficient for the forward CPX and the leading edge OBSI microphones](image)

Shown in the lower graph above is the equivalent result for the OBSI leading microphone. Whilst this is not a requirement of the AASHTO Standard it is informative to note that the standard deviation SD of sound intensity levels is much higher than for the equivalent sound pressure levels. Because the SD levels are so high, a much larger set of measurements will need to be taken in order to have confidence in the means. The reason for this is unknown and should be investigated.

### 3.2 Effect of the Adjacent Tyre

Whilst not considered in the ISO Standard, it is instructive to determine the effect of the sound level correction for contributing noise from the adjacent tyre. As shown in the figure below, the sound level at microphone M1 is the contribution of the direct tyre sound level L1 and L2C from the adjacent tyre. What is ideally required are L1 and L2 instead of M1 and M2.
During the test for the sound reflection coefficient described above, it is relatively simple to
measure the sound level at the other tyre as well as the sound level at the subject tyre. The difference
in sound level between the microphone closest to the artificial noise source and the corresponding
microphone on the other side of the trailer is denoted as follows:

$$\Delta 1 = L1C - L1$$  \hspace{1cm} (3) 

$$\Delta 2 = L2C - L2$$  \hspace{1cm} (4) 

The measured difference in sound levels is shown in the figure below (where 1-3 is the difference
between the right and left fore microphones and 2-4 is the difference between the aft microphones)

It can be shown that the tyre noise level at the microphone uncontaminated with the contribution
from the adjacent tyre is as follows:

$$L2 = 10 \log \left[ \frac{10^{M2/10} - 10^{(M1+\Delta 1)/10}}{(1-10^{(\Delta 1+\Delta 2)/10})/10} \right]$$  \hspace{1cm} (5) 

$$L1 = 10 \log \left[ \frac{10^{M1/10} - 10^{(M2+\Delta 2)/10}}{(1-10^{(\Delta 1+\Delta 2)/10})/10} \right]$$  \hspace{1cm} (6) 

Where the difference between the left and right microphones is greater than 10dB then the
correction for the cross-influence can be neglected. However, for the worst case frequency at 1kHz,
where the difference is about 6dB, the error is 0.97dB which is significant.
3.3 Experimental Procedure

For the reasons previously described, the effect of wind noise on the microphones should not be determined in a wind tunnel or with a rotating boom but should be performed in-situ. However, this is impossible because the tyres cannot be replaced with completely silent tyres. The authors have therefore elected to temporarily cover RONDA with a shroud so as to effectively convert it into a covered trailer. On the assumption that a covered trailer represents the ideal standard, then a comparison can be validly made.

The acoustic shroud is shown in the figure below and is constructed from a number of interconnecting CSR Martini Omega panels made from 50mm thick fine grade polyester acoustic insulation density 60kg/m³ faced on the outside with an acoustically transparent woven PVC fabric known as Flamex FR. The sound absorption coefficient of the inside face of the material exceeds 0.6 at 315Hz and 400Hz and exceeds 0.9 for frequencies 500Hz and above as recommended in the ISO Standard.

As can be gleaned from Figure 6 above, the acoustic panels are semi-rigid and taped together with gaffer tape. The air gap at the bottom of the shroud is approximately 50mm all around. A set of orthogonally oriented Dwyer pitot tubes fitted with pressure sensing electronics was located next to the microphones as shown in Figure 7 above. Also shown is the microphone arrangement conforming to the CPX (the two pressure microphones furthest from the tyre) and OBSI Standards (the two intensity microphones are closest to the tyre).

The roadway selected for study was a section of Sydney’s M5 South Western Motorway between The River Road and Fairford Road in Padstow NSW. This road is a 6 lane divided highway (3 lanes
in each direction) with a sign posted speed of 100kph. The left hand lane traveling Eastwards was used. The roadway surface was newly laid in 2014 and comprises 10mm open graded asphalt with a polymer modified binder (OGAC). The procedure involved travelling over the identical 400m section of road from Mackenzie St bridge to Gibson Ave bridge at 60/80/100kph with and without the shroud fitted. Care was taken to ensure that heavy trucks were not close to the trailer during the measurements. Weather conditions were fine with nil wind.

Measuring instrumentation consisted of a SINUS Soundbook 2 analyser and GRAS 40AE microphones for the CPX method. The pitot tube output signals were connected to the Soundbook so that contemporaneous sound level and wind speed levels could be obtained at 100ms intervals. The pitot tubes were calibrated in the WINDTECH wind tunnel laboratory (12). A SoftdB Alto-6i OBSI analyser and two GRAS 40GI/26CB microphone/ preamplifier sets were used for sound intensity measurements. The SoftdB software determines sound intensity, pressure, PI index and Coherence at 125ms intervals. All microphones were calibrated before and after measurements using a GRAS 42AA pistonphone. Both CPX and OBSI instruments were fitted with Garmin GPS 16x/18x receivers which enabled the noise measurement data to be position located. The analysed data was grouped into 20m road segment intervals and 1-3 octave band and overall noise levels calculated in accordance with the standards.

3.4 Wind Speed and Turbulence Measurements

The following results were obtained for the in-flow pitot tube.

![Figure 8 – Detailed Wind Results With and Without Shroud Fitted](image)

Table 1 below shows the numeric values at 60 and 100kph. The effect on wind speed of fitting the shroud is to reduce the wind speed at the microphone to about half, from 38.9kph to 21.3kph at a trailer speed of 100kph (see also Figure 8(a)). Figure 8(d) shows the ratio of wind speed at the wheels to trailer speed can be said to be approximately speed independent with an average of about 36% without the shroud and 18% with the shroud. In other words, the shroud halves the wind speed at the microphone. However, as shown in Table 1, the effect of the shroud is to increase the SD of wind turbulence by a factor of 1.5-1.8, not quite double. In other words, whilst the shroud halves the average wind speed at the microphones, the standard deviation SD of the turbulence increases by almost the same factor.

On the assumption that the product of the mean wind speed and SD is related to wind noise level, one almost offsets the other. Therefore, if the sound level increases between 6 and 8 times for a doubling of speed (representative of dipole and quadrupole noise sources respectively), say an average of 7 times, then the increase in sound level due to removing the shroud should be approximately
70\log(2/1.8)=3.2\text{dB} \text{ at } 100\text{kph} \text{ and } 70\log(2/1.5)=8.7\text{dB} \text{ at } 60\text{kph} \text{ and not } 70\log(2)=21\text{dB}.

Table 1 Wind Results With and Without Shroud Fitted at 60kph and 100kph

<table>
<thead>
<tr>
<th>Trailer Speed</th>
<th>60kph</th>
<th>100kph</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind speed at microphone kph</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shroud OFF</td>
<td>19.5</td>
<td>38.9</td>
</tr>
<tr>
<td>Shroud ON</td>
<td>8.9</td>
<td>21.3</td>
</tr>
<tr>
<td><strong>SD of Turbulence kph</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shroud OFF</td>
<td>4.0</td>
<td>4.8</td>
</tr>
<tr>
<td>Shroud ON</td>
<td>7.3</td>
<td>7.0</td>
</tr>
<tr>
<td><strong>Turbulence Intensity %</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shroud OFF</td>
<td>19.2</td>
<td>11.9</td>
</tr>
<tr>
<td>Shroud ON</td>
<td>79.2</td>
<td>30.7</td>
</tr>
<tr>
<td><strong>Ratio wind speed at mic / trailer speed</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shroud OFF</td>
<td>0.33</td>
<td>0.39</td>
</tr>
<tr>
<td>Shroud ON</td>
<td>0.15</td>
<td>0.22</td>
</tr>
</tbody>
</table>

3.5 Effect of Wind Noise on CPX Measurements

The results of the detailed Lcpx measurements with shroud ON and shroud OFF at the three reference speeds of 60/80/100kph are shown in the figure below.

![Figure 9 – 1-3 Octave Band Lcpx for Shroud ON and Shroud OFF at the reference speeds of 60/80/100kph](image)

The difference (Shroud OFF - Shroud ON), that is the effect of removing the shroud, is shown in the table below.
Table 2 Difference in Lcpx Shroud OFF - Shroud ON

<table>
<thead>
<tr>
<th>kph</th>
<th>315</th>
<th>400</th>
<th>500</th>
<th>630</th>
<th>800</th>
<th>1k</th>
<th>1.25k</th>
<th>1.6k</th>
<th>2k</th>
<th>2.5k</th>
<th>3.15k</th>
<th>4k</th>
<th>5k</th>
<th>Awt</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>0.5</td>
<td>-1.6</td>
<td>-0.4</td>
<td>-0.8</td>
<td>-0.8</td>
<td>-0.2</td>
<td>-0.4</td>
<td>-0.7</td>
<td>-0.8</td>
<td>-1.3</td>
<td>-1.6</td>
<td>-0.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>80</td>
<td>1.0</td>
<td>-1.5</td>
<td>-0.6</td>
<td>-0.6</td>
<td>-0.3</td>
<td>-0.3</td>
<td>-0.4</td>
<td>0.0</td>
<td>0.3</td>
<td>1.0</td>
<td>-0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1.3</td>
<td>-1.4</td>
<td>-1.1</td>
<td>-0.8</td>
<td>-0.5</td>
<td>-0.3</td>
<td>-0.2</td>
<td>-0.1</td>
<td>0.6</td>
<td>1.5</td>
<td>3.1</td>
<td>-0.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The following conclusions can be made:

1. With the exception of the result at 5kHz at 100kph, the effect of removing the shroud generally reduces noise at most frequencies, the level differences being less than 1.6dB in any frequency band.
2. With respect to the result at 5kHz, this is discussed further in the next section.
3. In respect of the overall level, there is a reduction of 0.8dB in the Lcpx.

The following figure shows 1-3 octave band sound levels extended to the low frequencies for a trailer speed of 100kph. It is at these low frequencies that wind noise levels predominate by the combined action of wind speed and wind turbulence as previously discussed.

A modified version of the Strasberg equation (1) above is proposed as follows:

\[ L_{1/3} = 84 + 63 \log u' - 23 \log f - 23 \log D \]  

(7)

where \( u \) is the standard deviation of turbulence (m/s) and \( V \) is the mean wind speed at the microphone (m/s) using the values in Table 1 above and with \( D=9 \text{cm} \). The predicted wind noise levels using this equation are shown as dashed lines in Figure 10 above. The increase in low frequency wind noise resulting from removal of the shroud is about 6.2dB. This results from an increase in average wind speed when the shroud is removed but a reduction in wind turbulence as postulated in section 3.4 above. The modified equation requires further examination at frequencies below 50Hz. It is possible that the standard deviation of wind \( u \) is not a constant but decreases with frequency.
3.6 Effect of Wind Noise on OBSI Measurements

The results on the final intensity level with shroud ON and shroud OFF are shown in the following table. It is evident that the final differences are small and insignificant. Again, there is a small decrease in the sound intensity level when the shroud is removed, however this is thought to be simply a reflection of measurement tolerance.

Table 3 Sound Intensity Level Combined (IL combined) for Shroud OFF and Shroud ON

<table>
<thead>
<tr>
<th>Speed kph</th>
<th>Shroud OFF</th>
<th>Shroud ON</th>
<th>Difference OFF - ON</th>
</tr>
</thead>
<tbody>
<tr>
<td>60</td>
<td>97.0</td>
<td>97.3</td>
<td>-0.3</td>
</tr>
<tr>
<td>80</td>
<td>99.2</td>
<td>99.4</td>
<td>-0.3</td>
</tr>
<tr>
<td>100</td>
<td>100.9</td>
<td>101.1</td>
<td>-0.2</td>
</tr>
</tbody>
</table>

At the time of writing, the spectrum levels are not available. These will be presented in a subsequent paper.

4. DISCUSSION

The results presented here-in are applicable to the road surface under test, that is OGAC. Further investigations are required in respect of quieter road surfaces. In addition, the effect of increasing the turbulence intensity at the microphone when a shroud is fitted to the trailer is likely to depend upon the aerodynamic design of the shroud. In this experiment, the front of the shroud is a bluff body. Whilst there was no evidence of the front of the shroud being buffeted in the wind (which would have given an impression of high turbulence levels), this is not to say it had no effect on wind speeds and turbulence within the shroud.

In respect of the CPX method, the removal of the shroud does not increase the overall level $L_{cpx}$ at any of the wind speeds tested. The reduction of 0.8dB in $L_{cpx}$ at all speeds is not thought to be due to the effect of sound reflection in the shroud because preliminary measurements indicate the shroud has little effect on the measured levels other than at the lowest frequencies. In respect of the 1-3 octave band spectrum levels, with the exception of the 5kHz band at 100kph, the difference is less than 1.6dB in any band. These differences may simply be a result of measurement tolerance to be confirmed by repeated future measurements. In respect of the enhancement effect of 3.1dB at 5kHz, this needs to be investigated further. A prime suspect might be air flow within the open tubes supporting the microphones.

In respect of the OBSI method, the difference in the overall intensity level IL combined between the shroud on and off is insignificant, being less than 0.3dB. The results at 1-3 octave band spectrum level will be reported in a future paper.

5. CONCLUSION

The results of certification testing in accordance with the ISO Standard is described in particular a) Annex A.2 sound reflections against an enclosure (if any) and other objects close to the microphones and b) Section 8.1 the effect of wind on the microphones. Whilst not considered in the ISO Standard, the contribution of noise from the tyre located on the far side of the trailer is also evaluated and an error correction term is derived.

It is shown that whilst the average wind speed at the microphone is reduced by the trailer shroud used in this experiment, the turbulence level increases. On the assumption that both affect wind noise level, the overall increase in wind noise level due to removal of the shroud is not as great as one would expect from consideration of the change in the average wind speed alone. A modification to the classic Strasberg formula is presented to account for the effect of mean wind speed and turbulence which appears to predict the increase in wind noise level reasonably well at a vehicle speed of 100kph.

The measurements show that the overall $L_{cpx}$ and the IL combined levels are not increased at the tested wind speeds when the shroud is removed.

In respect of the CPX 1-3 octave bands, the differences in measured levels are less than 1.6dB at any frequency upon removal of the shroud with the exception of the 5kHz band at 100kph where the
increase is 3.1dB. The cause of this is thought to be trailer related and should be investigated.

ACKNOWLEDGEMENT

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