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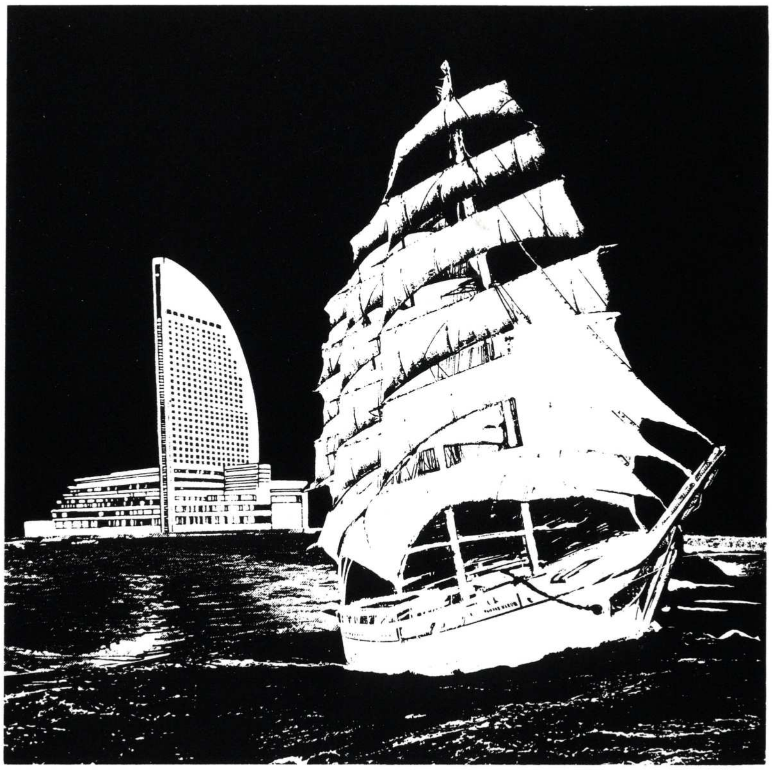

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SHALL WE MEASURE L_{MAX} OR L_{EQ} OF ROAD VEHICLES?

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INTRODUCTION

Due to limited capabilities of sound level meters, road vehicle noise emission has traditionally been measured as the maximum A-weighted sound level, L_{max}, during a vehicle pass-by. It means that the vehicle is assumed to be only a point source and that any possible directionality of the sound is not taken into consideration. Firstly, it is obvious that some vehicles are far from just a point source. Secondly, it is well known from experiments that directionality influences the sound level time history of a pass-by to a great extent, and one can imagine several cases where highly different time histories resulting from different directionalities could give the same maximum level.

There are discussions in some international standardization groups whether one can just use the traditional maximum levels or if one should switch to levels averaged over an entire pass-by, i.e. a single-event equivalent level (L_{seq}), now that many instruments and software packages offer such capabilities.

REVIEW OF THE RELATION BETWEEN THE L_{EQ} AND L_{MAX} MEASURES

The commonly used measure for individual vehicle noise characterization is the maximum sound pressure level (L_{max}) occurring during a vehicle pass-by. In almost all cases, this is based on a level measurement with a detector circuit (or corresponding software procedure) using a time constant "fast" as standardized by the IEC. The time constant rise time is 0.125 s and the decay time such that the meter indicator shall decay by 10 dB in $\leq$ 0.5 s. According to Brüel & Kjœr, this is approximately equivalent to using a rectangular time window of 0.25 s ("linear averaging").

The equivalent level, L_{eq}, is defined as follows:

$$L_{eq} = 10 \cdot \log \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} \frac{p^2(t)}{p_{ref}^2} \cdot dt \right] \qquad \text{(unit = dB)}$$

where t_1 is the start time, t_2 is the stop time of the integration, p(t) is the sound pressure and p_{ref} is the reference sound pressure (20μPa). The integration can be based on a distance of the vehicle in relation to a point opposite to the microphone in the road lane in question instead of time, i.e. from a start distance d_1 to a stop distance d_2. When applied to single passes of vehicles, there are often position detectors which trigger on and off of the measurement at positions well before and after the passage, in order that virtually all the noise energy is encompassed in the integrated level. Alternatively, the measurement is triggered manually or automatically at corresponding, appropriate times. In this way one obtains a single-event L_{eq}; here denoted L_{seq}.

In cases where the noise is emitted from a point source, with equal emission in all directions, there is full correlation between L_{max} and L_{seq} and it is unnecessary to measure both. In practice, this may be the case for vehicles where noise is dominating from one rather small source or for incoherent sources quite close together. This may be the case for a small car even today, and may have been a fair approximation in earlier days also for trucks when most noise came from the vehicle engine or exhaust. However, for modern vehicles, not the least trucks running at speeds higher than 50 km/h, the common case is that noise is dominated by tire/road noise coming from a row of tires, in some cases distributed over a 20 m distance. Furthermore, tire/road noise is often directional with higher emission to the front and rear than to the side.

REVIEW OF EARLIER DATA

Firstly, we will review experimental data in the literature as well as data collected earlier by this institute.

A comparison between L_{max} values and sound power levels (i.e. sound measured in several microphones around the vehicle and integrated over a half-sphere) appearing in [Hamet, 1988], showed that the simple L_{max} approximated the power levels well, with a slight overestimation of around 1 dB. The same author [Hamet, 1993] later, in a detailed discussion comparing L_{seq} and L_{max}, arrived at the conclusion that L_{seq} can be determined from L_{max} with very little error (around 0 dB for porous surfaces and less than 1.5 dBA for dense asphaltic concrete). He then based the conclusion on tests with three car tires and four road surfaces.

Measurements of light and heavy vehicles showed that sound power levels could be accurately determined from L_{max} with errors < 1 dBA, according to [Lucquiaud, 1993]. A similar study by [Yoshihisa et al, 1991] showed similar results but the authors concluded that the sound power level determination was more accurate and efficient. They, however, included also octave band analysis.

Measurements presented in [Kragh, 1991] showed normal differences for light and heavy vehicles within 1 dB between L_{max} and L_{seq} levels (taking into account theoretical differences) over the speed range 15-100 km/h. Maximum differences were 2 dB.

According to [Ullrich, 1991], L_{max}-L_{seq} differences are generally within ±0.5 dB for cars and it was concluded that L_{seq} did not offer any advantage relative to L_{max}.

In the Netherlands, correlation coefficients between L_{max} and L_{seq} measurements of 0.98 for light and 0.96 for heavy vehicles have been recorded [van Houdt, 1992]. This indicates that there is not much variation to explain with L_{seq} which is not contained in L_{max}. However, there may be some systematic differences by up to 1 dB between porous and non-porous surfaces.

Measurements made already 15-20 years ago at our institute, for 3 car tires, 19 road surfaces and 2 speeds, showed the relation between L_{max} and L_{seq} presented in Fig. 1. The residual standard deviation is 0.5 dBA there. L_{seq} was measured over a 75 m distance. For trucks, we prefer to enclose much more recent data (1991) covering four trucks (two 2-axle trucks and two 5-axle tractor-semitrailer combinations), three road surfaces (one wet and two dry), three driving conditions, three tire types and four speeds. The relation L_{max}-L_{seq} is shown in Fig. 2. The maximum devation there from the ideal is 2 dBA; residual st. dev. is 0.4 dBA. The integration covered a total of 40 m.

It may be worth noting that sound power ideally should be integrated over a half-sphere around the vehicle, while single-event L_{eq} is only measured at one microphone height. Depending on vertical directivity, such values need not therefore coincide.

RESULTS OF SIMULATIONS

The review above is supplemented with simulations, using a vehicle noise time history program made by P. Mioduszewski and J. Ejsmont (see Acknowledgements).

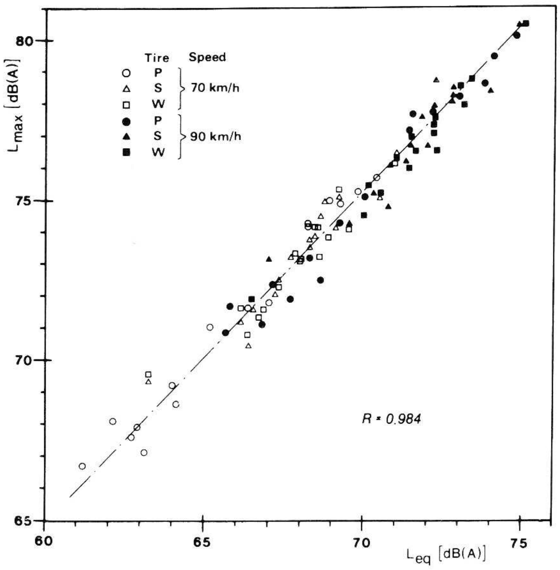

Fig.1 Relation L_{max}-L_{seq}(75m) from measurements in the late 70's on 3 car tires, 2 speeds and 19 surfaces

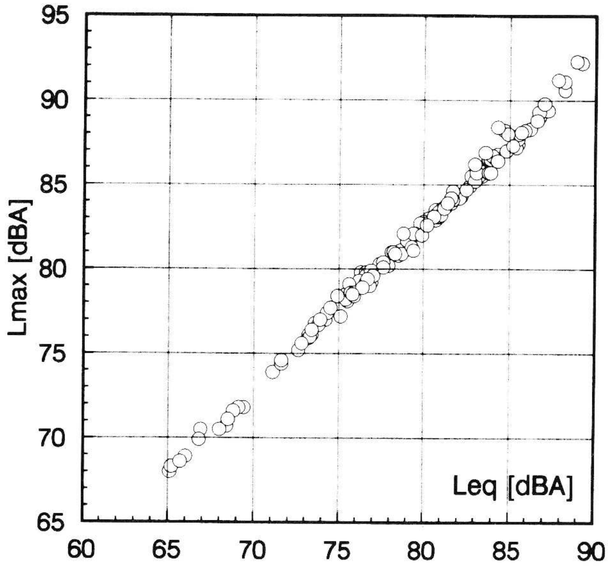

Fig. 2 Relation L_{max}-L_{seq}(40m) from measurements 1991 on a number of heavy vehicle combinations

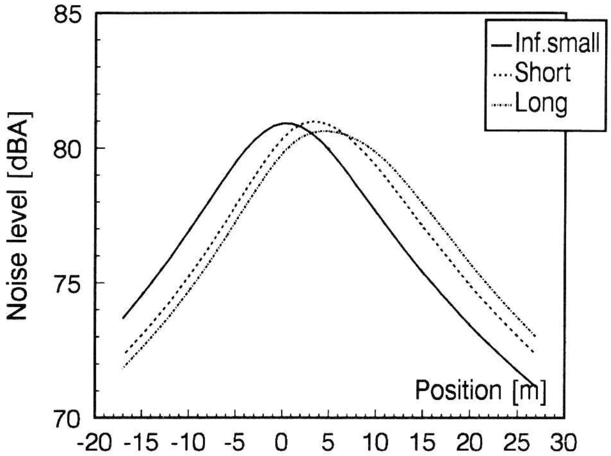

Fig. 3 Simulated time history of vehicle pass-by. Three 2-axle trucks. Omnidirectional

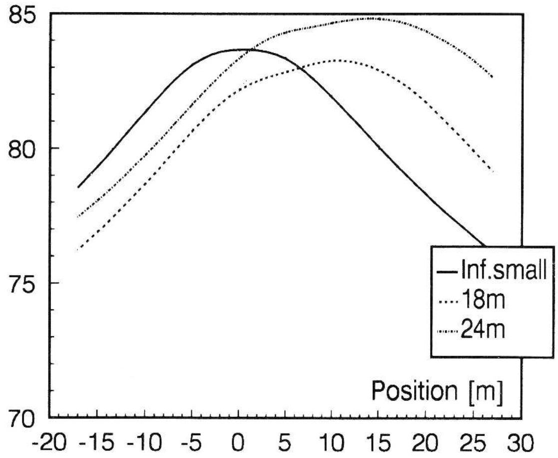

Fig. 4 Same as in Fig. 3, but for three articulated truck sizes. Directional +3dB

Type of vehicle or vehicle combination	No. of axles/tires	Lseq(1s)-Lmax(fast) 7.5m micr. dist. Omnidirectional	Lseq(1s)-Lmax(fast) Directional +3 dB front&rear	Lseq(1s)-Lmax(fast) Directional +6 dB front&rear
Car: Infinit. small (point source)	1/4	(0.2) dB	(1.4) dB	(2.5) dB
Car: Sub-compact (w.b. 2.3 m)	2/4	**0.3**	**1.4**	**2.5**
Car: Large (wheel base 2.8 m)	2/4	0.3	1.4	2.5
Two-axle truck: Infinitely small	1/6	(0.1)	(1.3)	(2.5)
Two-axle truck: Short (wb 3.5m)	2/6	0.6	1.8	2.7
Two-axle truck: Long (wb 6.1m)	2/6	1.0	1.8	2.8
Truck+semitrailer: Infinit. small	1/10	(0.1)	(1.4)	(2.6)
Truck+semitrailer: Tot 18m long	4/10	1.7	2.1	2.8
Truck with trailer: Tot. 24 m long	6/14	**2.0**	**2.4**	**3.0**

Table 1. Results of simulated time histories of vehicle pass-by (only tire/road noise) for various vehicle types/sizes. Pure theoretical cases in ( ). Min. and max. values in **bold**.

All the L_{seq} integrations have been made over a distance of 54 m. The results appear in Table 1 above. Figs. 3 and 4 illustrate the results (however, these printouts cover only 44 of the 54 m utilized). The calculations have been made only for tire/road noise. The reason is that this is the case which most of all deviates from an omnidirectional point source and no "worse" cases should be expected.

In Table 1, the vertical differences represent the influence of source size and the horizontal differences the influence of directivity. It appears that classification of vehicles can underestimate the largest vehicles with approx. 1.5 dBA in relation to the smallest if they are only characterized by L_{max}. Directivity effects may give approx. 2 dBA of underestimations with L_{max} (assuming unusually directional tires, however). In combination, a 24 m truck+trailer with extremely directional tires may be 2.5 dBA underestimated in relation to a car or to a small 2-axle truck with omnidirectional tires.

Simulations using 15 m microphone distance have indicated that the influences of vehicle size and noise directivity then reduces to approximately half that at 7.5 m.

CONCLUSIONS

The results indicate that, given a microphone distance of 7.5 m, L_{max} and L_{seq} levels are so closely related that the two measures describe almost the same thing. Under normal circumstances in Europe, estimation errors would be within 1.5 dB when using L_{max} instead of L_{seq}. It is concluded from the simulations, that the L_{max} gives an "average" over such an important part of the time history that what happens outside the L_{max} "window" is of relatively little importance. The case which would deviate the most from the simple point source, is an articulated heavy vehicle, perhaps 24 m long and with tire noise emitted most prominently to the front and rear. However, at the time when the maximum level occurs, the contributions from closely located tires add together and "far away" located tires actually influence also the L_{max} value to a significant degree.

Consequently, there is little to win by using L_{seq} measurements during a vehicle pass-by instead of L_{max}. Similarly, there is a very small advantage with 15 m microphone distance instead of the common 7.5 m to compensate for its many disadvantages. The L_{max}, which is somewhat simpler to measure and to explain to non-experts, is therefore preferred also for future characterization of vehicle noise, as is the 7.5 m microphone distance. However, when exceptional accuracy is required, e.g. when comparing tire/road noise with power unit noise, it may be motivated to use the L_{seq}.

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REFERENCES

Hamet, J. F. (1988): "Measurement of Power and Directivity of Tyre/Road Surface Noise". Proc. of INTER-NOISE 88, Avignon, France (1988).

Hamet, J. F. (1993): "Niveau de bruit d'un véhicule au passage: L_{eq} ou L_{pmax}. Utilisation de la signature acoustique pour valider........". Les Actes INRETS No. 36, INRETS, Lyon, France.

van Houdt, J.J. (1992): "Noise measurements on road surfaces - A comparison between SEL and maximum noise levels obtained from heavy traffic". PDWW 92-704, DWW, Delft, NL.

Kragh, Jørgen; Pedersen, Jan; Carlsen, Ole (1991): "Nordisk beregningsmetode for vejtrafikstøj". Report LI 972/91, DELTA Acoustics and Vibration, Lyngby, Denmark (in Danish).

Lucquiaud, R. (1993): "Sound power levels of road vehicles: Determination by peak or single event levels". Proc. of INTER-NOISE 93, Leuven, Belgium.

Yoshihisa, K.; Tatsuda, K.; Tachibana, H. (1991): "Sound power levels of road vehicles measured by the square-integrating technique". Proc. of INTER-NOISE 91, Sydney, Australia.

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