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ANNOYANCE CAUSED BY SHOOTING NOISE - DETERMINATION OF THE PENALTY FOR VARIOUS WEAPON CALIBERS.

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1. INTRODUCTION

The annoyance caused by shooting noise produced by small firearms is usually quantified by adding a correction (penalty) to the A-weighted sound exposure level (ASEL) of the shooting noise, yielding ASEL of equally annoying road-traffic noise. For shooting noise produced by large firearms, however, the noise rating is based in several countries on the C-weighted sound exposure level (CSEL) without applying additional penalties. At present there is no universal model to assess shooting noise produced by various weapon calibers (from rifles up to howitzers). As a result, it is difficult to predict the annoyance caused by impulses from large weapon calibers or to quantify the annoyance in conditions in which a mixture of different weapon calibers is used. With the help of a statistical model, the required penalty is derived from the results obtained in psycho-acoustical experiments.

Fig. 1 shows the results obtained in experiments in which the annoyance caused by various shooting sounds was compared with the annoyance caused by vehicle passby sounds [1,2].

The shooting sounds were produced by rifles (G3), medium-large caliber cannons (20-35 mm), and by detonations (various charge sizes). The detonations were used to simulate the sounds from firearms with calibers greater than 100 mm.

For each weapon type, outdoor CSEL of the shooting sounds is highly correlated with outdoor ASEL of equally annoying vehicle sounds, as rated by the subjects for indoor listening conditions with the windows closed.

Fig. 1 also shows that there were considerable differences in the annoyance among weapon calibers. For the simulated large-caliber bangs presented at a CSEL of about 85 dB, the ASEL of equally annoying vehicle sound was 75 dB (bonus equal to 10 dB). For a comparable CSEL of the sounds from the 20-35 mm cannons the ASEL of the equally annoying vehicle sounds was 85 dB (penalty equal to 0 dB), for the rifles (G3) the ASEL of equally annoying vehicle sounds was 95 dB (penalty equal to 10 dB). Apparently, each weapon caliber needs a separate model.

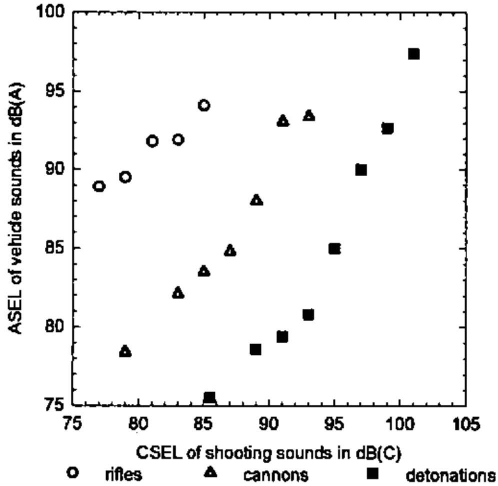

Fig. 1. Outdoor ASEL of vehicle sounds as a function of outdoor CSEL of equally annoying shooting sounds, as rated indoors with closed windows, for three weapon calibers

2. A- OR C-WEIGHTING

For the assessment of rifle shots ASEL is usually applied. Recent studies [3,4] suggest that ASEL should be one of the basic measures also for the sounds from large-caliber firearms. For technical reasons, however, the use of CSEL is preferred in the present paper. The model should be applicable to the entire range of shooting sounds, including those with most energy in the lower frequency bands, as was the case for the detonations that simulated large caliber firearms [1]. The spectral contents of these latter sounds are dominated by frequencies lower than 100 Hz, in extreme cases even lower than 20 Hz. Especially for such sounds, low signal-to-background noise ratios limit the accuracy at which A-weighted levels can be determined.

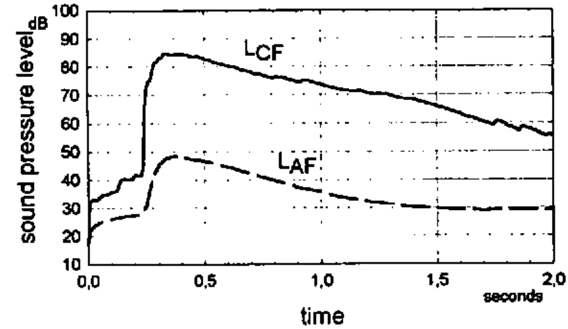

Fig. 2. C- and A-weighted sound pressure levels as a function of time for a bang with relatively much low-frequency energy.

From Fig. 2, in which the sound pressure level is plotted as a function of time for C-weighted and A-weighted levels, separately, it can be concluded that with C-weighting, the signal-to-background noise ratio is much higher. Since for small and medium-large caliber weapons the accuracy of CSEL measurements is not seriously restricted, the use of CSEL as the basic parameter in the model is preferred.

3. THE RELEVANCE OF SPECTRAL DISTRIBUTION

The annoyance caused by the various impulses might be related to the spectral content of the sounds. The higher frequency components become increasingly more relevant with decreasing weapon calibers. It is proposed here to express the spectral differences between the various impulses as the difference between C-weighted and A-weighted sound levels. This difference should decrease with decreasing weapon caliber.

It was already noted that this difference should not be based on CSEL and ASEL. Higher signal-to-background noise ratios can be obtained with the help of fast-weighted maximum sound levels. Temporally, the higher-frequency components are located in the rise portion of the impulses. As a result, the A-weighted and fast-weighted sound level, L_{AF}, is significantly higher than the background noise level to just that extent that reliable measurements can be achieved. In the model proposed, the penalty will therefore be based on the difference between L_{CF} and L_{AF}.

4. MODEL ON THE BASIS OF CSEL AND L_{CF} - L_{AF}

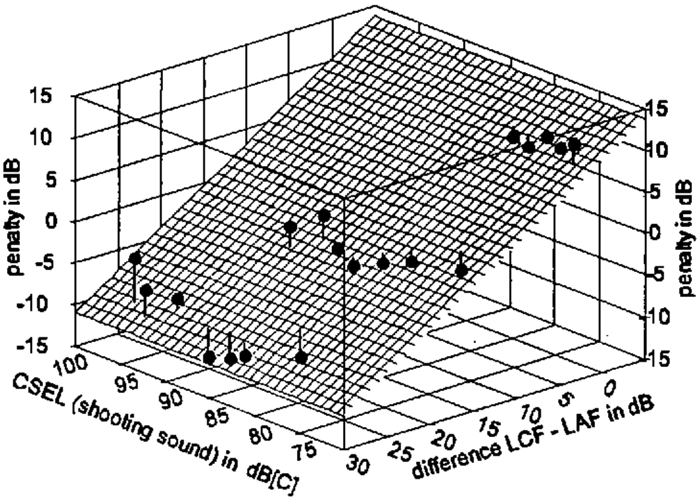

Fig. 3. Penalty (solid dots) as a function of CSEL and L_{CF} - L_{AF}

Fig. 3 shows the penalty (solid dots) as a function of both CSEL and the difference between L_{CF} and L_{AF} of the impulse sounds. The position of the plane inserted in Fig. 3 was determined by linear regression analysis on the basis of the penalty and L_{CF}-L_{AF} only. In the experiment L_{CF}-L_{AF} ranged between about 0 dB and 30 dB and clearly discriminated among the penalties for the three weapon types.

For the impulses produced by the rifle, L_{CF}-L_{AF} was about 0 dB and the penalty was slightly higher than 10 dB. For the medium-large caliber (20/35mm) weapons L_{CF}-L_{AF} was about 15 dB which caused a penalty of 0 dB.

For the detonations that simulated large caliber firearms, L_{CF}-L_{AF} ranged between 20 and 30 dB and the penalty ranged between -5 dB and -15 dB. The penalty could be surprisingly well predicted from L_{CF}-L_{AF}, the explained variance, r^2, in the data was as high as 0.91.

It can be seen in Fig. 3 that especially for the heavy bangs the penalty is underestimated by L_{CF}-L_{AF} at high CSELs and overestimated at low CSELs. This means that the penalty is dependent on both L_{CF}-L_{AF} and CSEL.

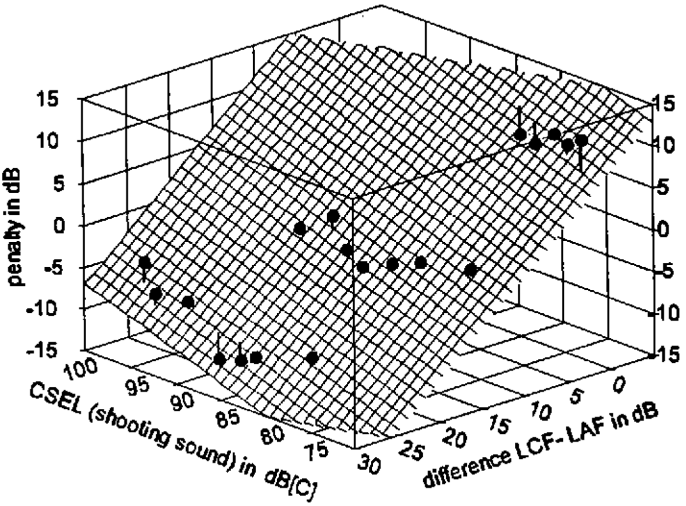

Fig. 4. Penalty (solid dots) as a function of CSEL and L_{CF}-L_{AF}

The position of the plane in Fig. 4 was determined by multiple linear regression analysis with these two predictors. With CSEL as the second predictor, r^2 increased from 0.91 to 0.95.
The penalty, P, is given by

$$P = 0.40 * L_{CE,impulse} - 0.92 * (L_{CF,impulse} - L_{AF,impulse}) - 21.9 \text{ dB}.$$

ASEL of equally annoying vehicle passby sound, $L_{AE,vehicle}$, is given by

$$L_{AE,vehicle} = 1.40 * L_{CE,impulse} - 0.92 * (L_{CF,impulse} - L_{AF,impulse}) -21.9 \text{ dB}.$$

A further increase in the explained variance might be expected by assuming curvi-linear relationships between the predictors and the penalty. For such a test, however, more data points are needed.

5. DISCUSSION AND CONCLUSIONS

The present model allows the prediction of ASEL of equally annoying vehicle sounds for shooting sounds produced by a great variety of weapon calibers. In the model this prediction is based on CSEL and, to greater extent, on the difference between L_{CF} and L_{AF} of the shooting sounds. Due to the predictive power of L_{CF}-L_{AF}, the effect of spectral content of the impulses, either as a result of weapon caliber, or as a result of changes in the distance between source and receiver, can be easily determined. With a universal model it is even possible to predict the annoyance without knowledge of the weapon caliber used. This would be an advantage in the case of noise monitoring.

The present model suggests a promising procedure for the rating of shooting sounds produced by any weapon caliber. With respect to both the selected predictors and the selected functional relations, alternative solutions are conceivable. If the difficulties noted with the determination of ASEL of heavy bangs at large source-receiver distances are taken into the bargain, the alternative universal model presented in a related paper [4] may be of interest as well. In that paper the penalty was found to depend on the product of ASEL and (CSEL-ASEL).

Detailed tests on the validity of the model are forthcoming. For the time being, however, it must be concluded that the present model is simple and effective. Since most sound level meters allow the determination of the A- and fast-weighted and the C- and fast-weighted levels in parallel, the proposed procedure is also highly applicable to practical situations.

ACKNOWLEDGMENTS

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