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LOUDNESS OF IMPULSIVE WEAPON NOISE AND DYNAMIC CHARACTERISTICS OF HEARING

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1. INTRODUCTION - SUMMARY

The dynamic characteristics of hearing explain presumably the high annoyance of gun noise and the penalty for small arms noise. They may contribute as well to the loudness of sonic bangs from large-bore projectiles, a somewhat neglected topic.

Discarding the physical and psychoacoustical properties of weapon bangs leads to bias in rating weapon impulsive noise and to penalties as corrections. Using only a few penalties as in the amendments to ISO 1996 Part 2 proposed in [14] causes bias in assessing weapon impulsive noise.

Some available investigations on hearing of short sounds [1,3,7,9,11,12] point to a field of research which may lead to essential improvements in assessing weapon impulsive noise.

2. DYNAMIC CHARACTERISTICS OF HEARING AND PENALTIES

Outline

As shown in [7,11], exposure level measurements (SEL) underestimate the loudness of decaying impulsive sounds of less than 60 ms in duration. Overshoot at the onset of the stimulus, subsequent suppression and after-effect seem to add a physiological energy to the sound energy. These dynamic characteristics of hearing become more important for shorter impulse durations and are more pronounced for decaying stimuli than for rectangular pulses [7,11]. Presumably, decaying stimuli are more appropriate to investigate the loudness of impulsive weapon noise than rectangular pulses.

During an experiment reported in [7,11], subjects had to set the exposure level of comparison stimuli until they reached the PSE with decaying standard stimuli specified as follows:

decay time varying from 2 to 999 ms
constant peak level of 80 dB(A)
rise time of 2 ms
carrier frequency of 1 kHz sin.

The (practically) rectangular comparison stimuli exhibit a steady state of 20, 100 or 500 ms in duration. According to investigations of Ibukuro mentioned in [7,11], their loudness depends on the duration. The subjects hear the 20 and 500 ms comparison stimuli 2.5 dB louder and 2.5 dB less loud respectively than the loudness corresponding to the equal energy line (fig. 1).

If we assume that the auditory temporal integration is completed after about 100 ms, the loudness of the 100 ms comparison stimuli and the equal energy line correspond both approximately to the loudness of 1000 Hz continuous sounds. This also defines a relation between the loudness of the 20 and 500 ms comparison stimuli with the loudness of continuous sounds. Hence, fig. 1 provides a useful link between the loudness of the comparison stimuli and the loudness of continuous sounds. It will be needed in fig. 2. Fig. 2 below reproduces *fig. 2* from [7,11] with modifications. In both figures, the ASEL of the standard stimuli vary proportionally to their duration because of their constant peak level (80 dB(A)).

In the original *fig. 2* from [7,11], the ordinate would represent the exposure levels of the comparison stimuli at PSE with the loudness of the standard stimuli. These exposure levels are labeled by dots, squares and triangles, corresponding to 20, 100 and 500 ms respectively. The offset between the labels mentioned above and the equal energy line would show that the auditory temporal integration is more efficient for decaying standard stimuli than for comparison stimuli with steady state.

In fig. 2 below, the dots and triangles were shifted by +2.5 dB and -2.5 dB respectively according to fig. 1. The modification substitutes 100 ms comparison stimuli, corresponding to continuous sounds, for 20 and 500 ms comparison stimuli. Hence, the ordinate represents the exposure level of continuous 1000 Hz sounds at PSE with the loudness of the standard stimuli. It aimed to compare fig. 2 with studies on penalties for impulsive noise which use continuous noise sources as reference, e.g. traffic noise.

A Possible Explanation for the Penalties

ASEL measurements of the standard stimuli clearly underestimate the loudness perceived by the subjects, especially for durations less than 60 ms (fig. 2). For bullet bow waves of 1 to 2 ms in duration, the offset is about 10 dB. This explains the considerable annoyance of sharp sonic bangs from rifle bullet bow waves of which loudness was enhanced by the dynamic characteristics of hearing [4]. Moreover, this may account for the outdoors penalties for small arms impulsive noise and for their dependence on the weapon [2,13,15,16].

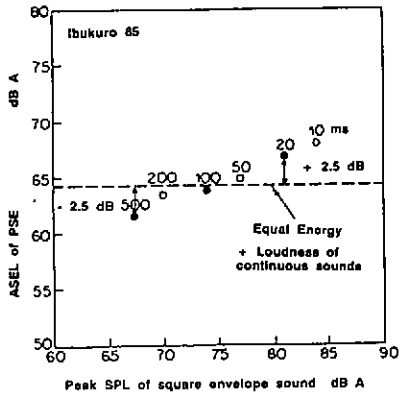

Fig. 1. Loudness of short stimuli with steady state such as the comparison stimuli. (Reproduced from [7,11]).

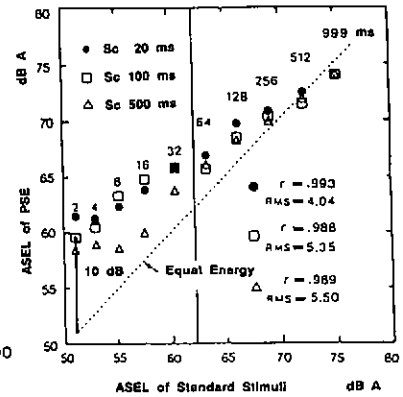

Fig. 2. Loudness of decaying stimuli compared with that of continuous sounds at PSE. (Adapted from fig. 2 of [7,11], see text).

The offset of the PSE from the equal energy line increases towards lower exposure levels. This effect is due to the shortness of the sounds [7,11] and may not be related to the level-dependent penalties as reported in [2,6,15,16].

Large-bore Weapon Noise: see [4,5].

3. ASSESSEMENT OF WEAPON IMPULSIVE NOISE

ASEL (or CSEL) and Penalties as Descriptor?

The A-weighted exposure level neglecting the dynamic characteristics of hearing, a 10 dB penalty is needed for assessing small arms impulsive noise. More generally, penalties are required for impulsive noise because the descriptors usually measured are not fully appropriate to this purpose. These descriptors do not take sufficiently into account the frequency spectrum of weapon impulsive noise ranging from infra-sound to several kHz. Neglecting the pressure- or power-time history and the dynamic characteristics of hearing is critical, especially in the range of duration considered of 1 to 100 ms. The imperfections of the descriptors usually measured lead to deviations in assessing weapon impulsive noise; correcting them would require a *directory of penalties*, depending on all physical impulse properties, such as temporal pattern and frequency spectrum. Furthermore, the penalties would not only depend on the weapon, but also on the distance to the weapon because of the propagation effects.

These considerations raise the question whether present knowledge is sufficient for issuing international standards.

Remarks Concerning International Standards on Impulsive Noise

The way of assessing impulsive noise outlined in the section above is cumbersome. Simplifying and taking into consideration only a few impulsive noise sources with their corresponding penalties as in [14] would lead to bias in rating impulsive noise.

In fig. 3 below, the 4 parallel lines correspond to the generally admitted proportionality between annoyance and ASEL. The horizontal distances between the 4 lines are 5, 10 and 20 dB according to the penalties proposed in [14], for impulsive noise, highly impulsive noise (gun) and large amplitude impulsive noise (artillery), respectively.

The comparison of the bang A with bang B in fig. 3 shows that a greater bang energy (ASEL) could be related to less annoyance. In this case, the result of the comparison - i.e. a decrease in annoyance - is not given by a change of the measured parameter ASEL, but mainly by the penalty, thereby calling in question the usefulness of descriptors such as ASEL requiring too large penalties. This contradicts the fact generally admitted that the annoyance increases monotonously with the exposure level, but yet corresponds to the presumption that annoyance from low frequency impulsive noise may be underestimated by A-weighted exposure level measurements. Furthermore, we can see in fig. 3 that an energy (ASEL) increment yields either a greater annoyance along the lines or, comparing bang A with bang B, less annoyance. The internal

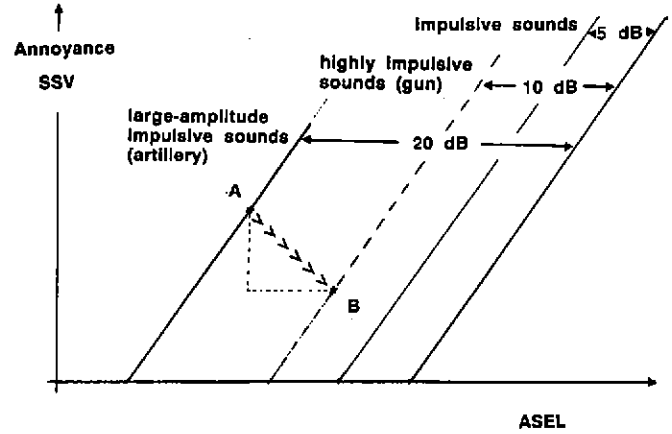

Fig. 3. Schematic representation of the penalties according to [14].

incoherencies shown above are due to the penalties which lump all unknown facts on annoyance from impulsive noise.

Prescribing only one penalty of 5 dB for impulsive noise, the original ISO/R 1996 did not exhibit the imperfections mentioned above. This magnitude is in agreement with investigations reported in [2] and [13] yielding a penalty of 4 to 7 dB for outdoors weapon impulsive noise and with laboratory experiments using a 2500 W impulsive noise simulator [10]: according to the latter, the penalty for outdoors weapon impulsive noise may not depend on the weapon. Hence, as provisional standard, ISO/R 1996 may be better than the amendment proposed in [14].

Another Descriptor for Assessing Weapon Impulsive Noise?

Another way of assessing weapon impulsive noise consists in researching refined knowledge on hearing of short sounds and in improving the sound level meters correspondingly. The calculation model of Namba et al., expressing the dynamic characteristics of hearing, could be used in sound level meters as improved time-weighting. However, data on the dynamic characteristics of hearing encompassing the entire frequency range of weapon noise are still needed. Attempting to take the dynamic characteristics of hearing into account, Krahé and Buchta [9] have been partly successful. In several studies, the Zwicker's frequency weighting is mentioned either as better than the A-weighting for impulsive noise [3,9], or even as the best [12].

4. CONCLUSION

The penalties increase with the inadequacy of the used descriptors for assessing impulsive noise. As seen above, the annoyance from impulsive noise may in some cases not be determined by the measured parameter, but mainly by the penalty.

Determining the penalties experimentally for all different impulsive noise sources would require considerable work which would be better invested in research on the primary question of an appropriate descriptor for impulsive noise.

Several previous investigations [7,9,11,12] allow to define a first step in this direction: the time-weightings currently in use (standard IEC 651) should be replaced by a time-integration of the acoustical power which takes the dynamic characteristics of hearing into account. It would yield higher levels for impulsive sounds containing very fast level variations of less than 60 ms in duration, without changing the assessement of practically continuous noise sources varying slowly.

Because the best descriptor found will not be perfect, deviations in assessing weapon impulsive noise are still to be

expected. They will correspond to the penalties mentioned above, but will be considerably smaller than their present magnitude if the improved descriptor is adequate for weapon impulsive noise. Penalties of less than 3 dB would be within the audibility threshold of loudness increments, would be of minor importance compared for instance with the fluctuations due to the atmospheric conditions and would meet the requirements for practical use.

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