Internoise 98, Christchurch, Newzealand

SOURCE DATA FOR SHOOTING NOISE

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Introduction

Rating levels for noise assessment often base on clearly defined physical measures at the receiver. Some of these levels are only good for single events, for example peak or maximum levels, others are good for long-term averages or accumulations, for example ASEL. They all have in common that they are measurable at the receiver. At the source these measures are not clearly defined. However, in order to keep things simple, many noise prediction models for shooting noise use the same measures to describe the source and the propagation. From a physical point of view, this way is not simple because it involves weightings made with respect to human hearing at the source. This paper will point out a way of how to archive physical source data for muzzle blast and the blast of explosions that meets the requirements of all noise prediction models.

Characteristics of shooting sounds

The sources of blast sound differ widely from other noise sources: Blasts are high energy single events yielding reproducible coherent sound impulses. Any analysis of emission data must take care for superposition effects in the measured sound pressure signals. These effects will not average out. Neglecting these effects will lead to unreliable or wrong data. In addition, the directivity pattern is very important. Muzzle blasts can yield more than 20 dB higher intensity levels in the direction of fire then to the rear. The emission data are sensible to slight changes of the propagation direction. Eventually, there is a great variety of weapons and ammunition. For example, a reloading guide enumerates 52 different ammunitions for the caliber .308 Winchester with charge weights ranging from 2.2 g to 3.2 g. That means it is not rather likely to find a weapon/ammunition combination on the file of measured emission data.

The concept of source data

Emission data must provide direction-dependent spectral information about the energy flow from the blast source. Due to the reproducible coherence of the source, spectral information means amplitude and phase. For an explosion in air which yields a spherical directivity pattern, a simple formula, eq. 1, can describe the blast spectrum. This formula, firstly published by Weber [1], provides only one parameter to determine the Fourier spectrum p(ω) for the sound pressure. This parameter R_W is called Weber-radius because this formula was derived for an exploding sphere radiating a blast wave at the very moment when the expansion speed equals the speed of sound. Today, this formula is validated for explosions of different size. Therefore, it is sufficient to know the Weber-Radius to determine the emission data for such sources.

$$p(w) = \frac{P_W}{p}\left[\frac{a}{a^2+w^2} + j\frac{w}{a^2+w^2}\right] \quad \text{with} \quad a = \frac{3c}{R_W}\left[1+\left(\frac{c}{w \quad R_W}\right)^2\right]^{\frac{1}{2}} \qquad \text{eq. 1}$$

$$P_W = 14.4\ kPa, \quad w \rightarrow circle\ frequency,\ R_W \rightarrow Weber-radius,\ c \rightarrow speed\ of\ sound$$

The source of the muzzle blast from a firing gun is by no means a simple spherical volume. However, tests with some blasts from different guns (small arms including 4 pistols and 8 rifles, and a 20 mm and 120 mm gun) show eq. 1 can also describe the signal in each measured direction. In particular to the rear of the weapon, the signals are looking very similar to Weber-spectra. Therefore, one way of defining emission data also for muzzle blast is to use eq. 1 as engineering formula to describe the source spectra.

One-third octave spectrum of a blast source with directivity

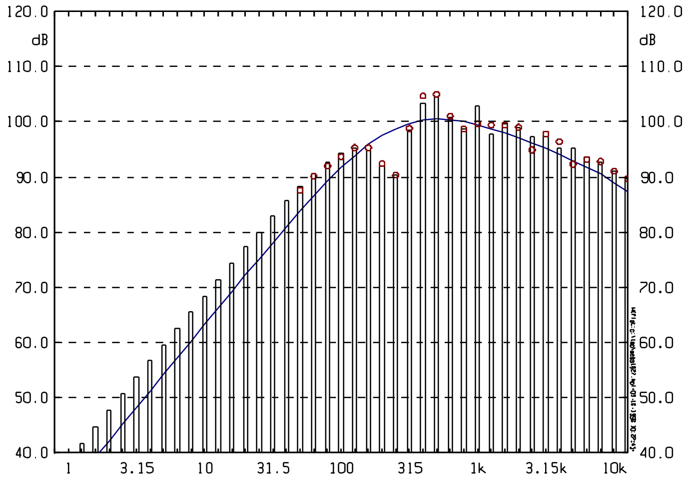


Fig 1: One-third octave spectra at 120°

Fig. 1 shows the measurement and analysis in terms of one-third octave spectra for a .300 Winchester muzzle blast at 120°. There are three spectra. The spectrum denoted by the circles is the spectral p^2 measured at a distance of 8 m; source and receiver height are 1.5 m. The continuous line gives the Weber-spectrum representing the energy flow from the source. The spectrum shown as bars indicates the predicted spectrum at the receiver for p^2 using the Weber-spectrum as source spectrum. The predicted spectrum is calculated with respect to the ground reflection because the measured p^2 is the superposition of the direct and reflected source signal. The calculation considers the reflection of a spherical wave at a plane surface with complex impedance. If the bars exceed the line by 6 dB then the pressure doubles in that frequency range. If the bars are clearly lower then the line, the sound velocity doubles. However, the spectral energy output of the source has no such dips but follows a smooth Weber-spectrum. The Weber-radii now are different in different directions. However, the correlation between measured data and Weber-data is still good enough to use eq. 1 as an engineering formula to describe the spectrum. This conclusion means that there is still only one parameter needed to determine the source spectrum.

Spectral directivity

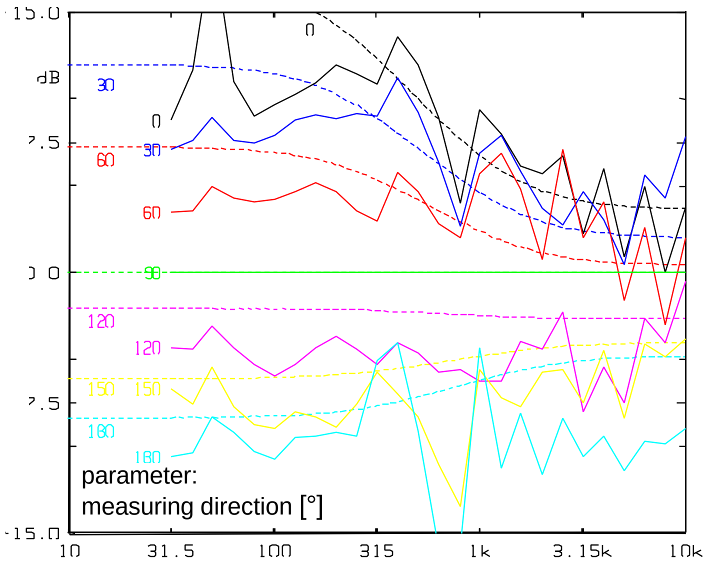


Fig. 2: Spectral directivity relative to 90°

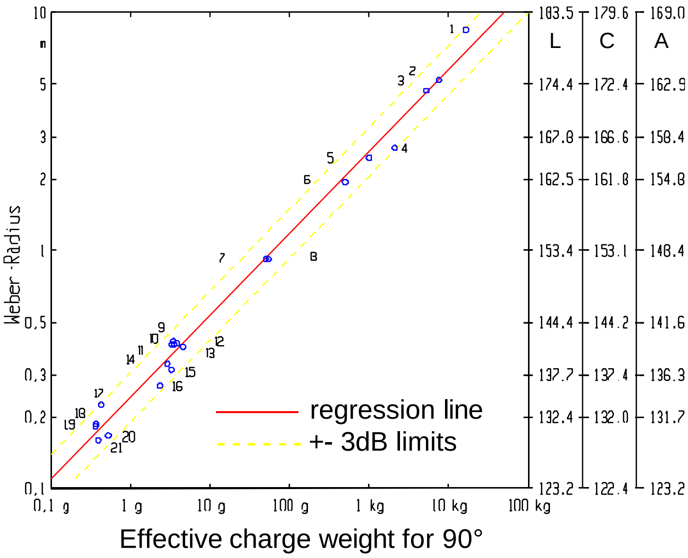
Fig. 2 shows the spectral directivity pattern for the same blast. Each line represent a relative spectrum to the measurement at the 90° position. There are two sets of lines. One set (solid) represents the measured p^2-spectrum without any correction. The second set (dotted) is the prediction on the basis of the Weber-spectra at each direction.
A spherical source is normally expected to have a weaker directivity to lower frequencies. In contrast, the directivity here is stronger in the region of low frequencies and tends to less significant differences for higher frequencies. This is typical for muzzle blasts under consideration. It is encouraging that the analysis according to a Weber-spectrum supports this result. This set of lines roughly indicates the average of the measured data.

Prediction of emission data

Due to the variety of weapon/ammunition combinations, it is necessary to predict emission data from non-acoustical data of the source. The most important parameter is the total energy involved in the process. This conclusion is the consequence of the good correlation between a Weber-spectrum and the available test data because the Weber-radius is a measure for that energy. Basically, the Weber-radius determines the size of an expanding sphere filled with ideal gas at that moment when the expansion speed equals the speed of sound. This size is only determined by the mass of gas and therefore a measure of energy. The more energy is involved the bigger is the sphere and the more area radiates. Therefore, the total energy should strongly correlate to the R_W^3. For sources with directivity this basic assumption is no longer true. However, the energy radiated in a certain direction should still correlate to the Weber-radius measured in this direction. An available measure for the total energy is the charge weight. Using the relative directivity pattern for the acoustical energy to calculate the part of the total energy involved in the radiation into a certain direction yield a measure which should correlate to the Weber-Radius in that direction. (The energy directivity is not the directivity of p^2 measured on a circle around the weapon. With respect to the rotational symmetry of the source, the measuring positions on such a circle represent areas of different size. The evaluation of total acoustical energy or power must take this into account. See [2] for more information about energy, intensity and power of a blast source.)

Fig. 3 shows this correlation for 21 blasts. The effective charge weight in fig. 3 ranges from 0.5 g to 16 kg and covers simple demolitions and muzzle blasts from small arms up to 120 mm canons. The overall agreement is better then 3 dB in each case. Fig. 3 provides three more scales indicating the LSEL(L), ASEL(A) and CSEL(C) at 1 m distance calculated from the Weber-radius. For very small charge weights all levels yield the same values. However, with increasing weight the scales are reading different values because with increasing radii the spectrum is shifted to lower frequencies and the A-weighting is missing more and more energy. Consequently, frequency-weighted levels cannot correlate to charge weight.

Fig 3 is a tool to predict the Weber-radius, if the directivity and the charge weight are available. Up to now, there are not enough data available to determine the directivity from weapon characteristics. However, for the group of rifles in fig. 3, the Weber-radius in the direction of fire is twice that high compared to the radius to the rear of the weapon. This seems to be a good rule of thumb for guns without muzzle brake. There might be a chance to classify directivity pattern with respect to muzzle brake, tube length or other available weapon characteristics.



1 16,5 kg TNT demolition
2 120 mm gun
3 105 mm gun
4 155 mm howitzer 5GB
5 1 kg TNT demolition
6 500 g PETN demolition
7 50 g demolition
8 20 mm gun
9 .300 Winch. Hohlspitz
10 .300 Winch. Vollmantel
11 Mauser SR93 rifle
12 .300 Magnum rifle
13 6,5x68 rifle
14 PSG 1 Pistol
15 .243 Winch. rifle
16 5,6x50 rifle
17 Pistol SIG
18 Pistol P1
19 9 mm Signalpistol
20 Machine pistol MP5
21 .22 Hornett rifle

Fig 3: Weber-radius versus effective charge weight for the 90° direction relative to the line of fore for 21 blast sources

Conclusion

Using the charge weight and classes of directivity patterns is a promising way of defining emission data for blast noise predictions. The major advantage is that these emission data covers the prediction of the Fourier-spectrum of the blast sound, providing access to all time and/or frequency weighted acoustical levels.

[1] W. Weber: „Das Schallspektrum von Knallfunken und Knallpistolen mit einem Beitrag über die Anwendungsmöglichkeiten in der elektro-akustischen Meßtechnik“; *Akustische Zeitschrift* 4(1939), 377-391.

[2] K.-W. Hirsch: „Messung der Emissionsdaten von Mündungsknallen“, VDI Report 1386, p. 159-174.