ANALYSIS OF LOW-FREQUENCY PROJECTILE NOISE SIGNALS MEASURED CLOSE TO THE GROUND

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INTRODUCTION

Shooting noise in the vicinity of small arms ranges and military training facilities can have three major blast sources: the muzzle blast from the propellant, the sonic boom from the supersonic flying projectile and the demolition blast from the exploding shell at the target. At the receiver, the blasts from these sources will typically arrive at different times and from different directions and each are heard as a single event depending on the relative location of the receiver point to the firing position and the trajectory of the projectile. Muzzle blast and the demolition blast at the target can be described in the same way; their sources are explosions in air radiating a blast signature to be described as a point source with strong directivity. In contrast, sonic boom is generated along the trajectory of the projectile; the radiation direction strongly correlates to the local speed of the projectile relative to the local sound speed.

The area directly affected by the sonic boom is the projection of cones at the ground surface in firing direction. Each cone is established by the wave vectors from a certain point at the trajectory. Normally there are no residential areas in those affected areas or if they are far away. Therefore, in the context of shooting noise prediction and assessment, the projectile noise is normally not considered. However, due to reflections at safety baffles on German small arms ranges there is sonic boom also in the rear of the ranges. In addition, for long distance, high elevation trajectories of howitzer shots sonic boom is spreading across a large area including residential areas. In both situations noise prediction and assessment should include sonic boom.

For howitzer shots, the German rules for shooting noise prediction in the vicinity of military training facilities describe an useful empirical model for CSEL levels, /1/. However, this model needs projectile-specific measurements to determine the basic source data and is only validated for high elevation howitzer shots. In order to include sonic boom for small arms and flat shots of arbitrary projectiles, a more general model is needed.

A SOURCE MODEL FOR SONIC BOOM

In 1949 /2/ and 1952 /3/, Witham published an appropriate theory for sonic boom from arbitrary projectiles. These papers are obviously the sources of many recent approaches in this field. Due to the military background not everything is published. Measurements conducted by Brinkmann /4/ support the view that formulae (1) and (2) sufficiently describe – sufficient with respect to noise predictions – the source data for sonic boom for projectiles of battle tanks with complicated shape.

$$P_c(O) = 0{,}53 P_{atm} \frac{\left(M^2-1\right)^{1/8}}{O^{3/4}} \left[\frac{d}{l^{1/4}}\right] \qquad (1)$$

$$t_c(O) = \frac{1.82}{c_0} \frac{M}{\left(M^2 - 1\right)^{3/8}} O^{1/4} \left[\frac{d}{l^{1/4}} \right] \tag{2}$$

These formulas introduce the maximum diameter d of the projectile, the total length l, and the MACH-number M, i.e. the ratio of projectile speed to sound speed. The formulae yield the peak overpressure P_c and the duration t_c of the N-shaped signature of the sonic boom as a function of the distance O to the trajectory. Let P_{atm} denote the ambient pressure and let c_0 denote the speed of sound. In terms of exposure level L_E, formulae (1) and (2) yield for free field conditions

$$L_E(r) = 161{,}4 + 10\lg\left(\frac{d^3}{l^{3/4}} \right) + 10\lg\left(\frac{M^{9/4}}{\left(M^2 - 1\right)^{3/4}} \right) - 12.5\lg\left(\frac{r}{r_0} \right) \text{ [dB]} \tag{3}$$

$$f_c(r) = 176 \frac{\left(M^2 - 1\right)^{1/4}}{M^{3/4}} \frac{l^{1/4}}{d} \frac{1}{r^{1/4}} \tag{4}$$

In formulae (3) and (4), the length of the propagation path r substitutes the distance from the trajectory O in formulae (1) and (2). The appropriate one-third-octave spectrum of the N-signature can be easily calculated by numerical procedures.

VALIDATION

In order to validate this source model for sonic booms from howitzer shells, experiments were conducted at the Bergen training area for flat howitzer shots. The test plan of these experiments is published elsewhere /5/. The signals were recorded simultaneously at different heights and distances. The following discussion will point out the way how these measurements have to be analysed to yield reliable results for P_c and t_c.

Fig . 1a exemplary shows the pressure signature at r = 88 m distance from an 8 m high trajectory (M = 1.64). The microphone lay directly on the grassy ground. Obviously, this is not an N-wave. The characteristic numbers P_c and t_c cannot be directly read from this signature because the ground effect will cancel most of the higher frequencies due to the flat angle of incidence.

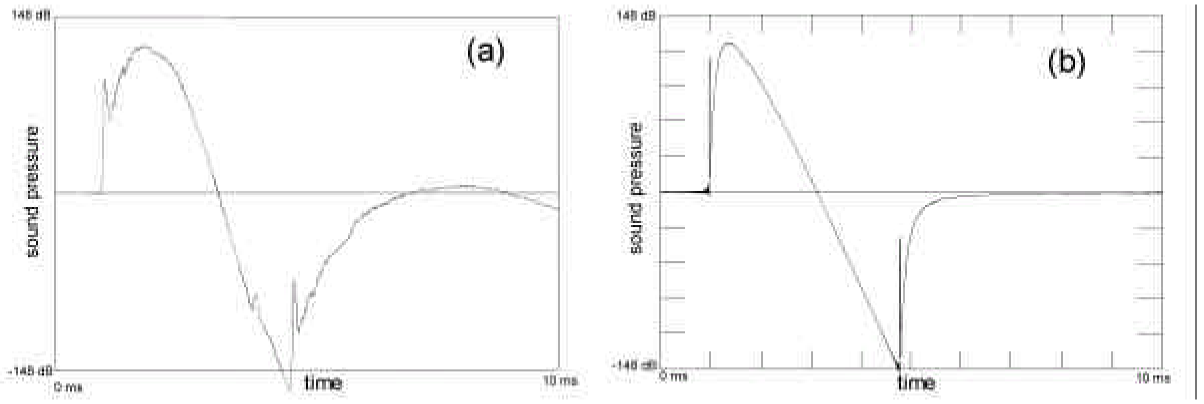

Fig. 1: Measured (a) and calculated (b) sound pressure versus time for sonic boom from a howitzer shot at r = 88 m distance and 0 m height

However the superposition of two N-waves, the direct wave and the reflected wave should explain the signature in fig. 1a. This superposition approach is not strictly true because it needs linear acoustics. In reality N-waves interact with other waves along the whole path.

Fig. 2a shows the time history of a superposition for two N-waves having $P_c = 330$ Pa (396 Pa) and $t_c = 3.95$ ms (3.5 ms) each. The numbers in parenthesis are the results of formulae (1) and (2), respectively. The relative frequency depending admittance A(f) of the ground was estimated to be

$$A(f) = 0.027e^{-j\frac{22}{180}p} + \frac{0.1s\ f}{1000}e^{-j\frac{77}{180}p} \tag{5}$$

The shape of the superimposed time history is rather sensitive to all parameters of the admittance, but also to the geometric quantities. The calculation directly at the ground is not yielding an appropriate shape. The calculation shows the same first sharp peak if the effective height above the ground was assumed to be 2 cm. This height of 2 cm causes a short delay for the reflected wave and explains this peak in both signatures. In general, measured and calculated time history agree to some extend.

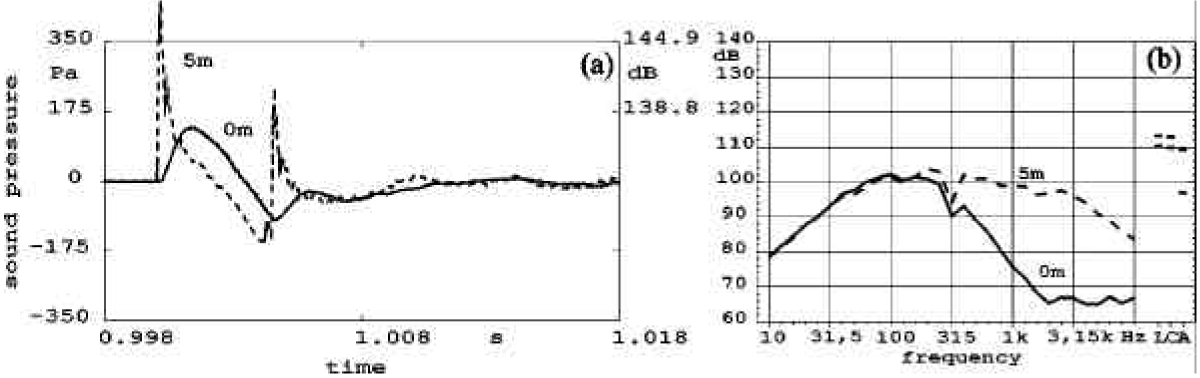

Fig. 2: Sonic boom from a howitzer shot measured at r = 122 m at 5 m (solid lines) and 0 m (dashed lines) height. (a) pressure versus time, (b) one-third octave spectra

The next example compares measurements at r= 122 m distance at 0 m and 5 m height. Again both signals are the sum of direct and reflected wave. Fig. 2a indicates the pressure time histories at both locations. Fig. 2b shows the one-third octave spectra. The result at the ground however shows a similar signature as in Fig. 1. Nevertheless, both signals are explained by the same original N-wave if the calculation described with Fig. 1 takes into account the different paths of direct and reflected wave in each case. In order to match the signatures of both time histories, the admittance was varied to find a good agreement between calculated and measured signatures. The calculation yields an N-wave having $P_c \approx 180$ Pa (316 Pa) and $t_c \approx 4.5$ ms (3.8 ms).

The main conclusion from Fig. 2b is that at 5 m height the spectrum looks like an N-wave spectrum up to a certain extend but for the measurement at the ground there is a broad ground dip. There are no high frequencies in the pressure signal; the particle velocity is storing the whole acoustical energy at this measurement point. Therefore, for any kind of A-weighted levels, the pressure measurement at the ground would strongly underestimate the present acoustical energy.

Considering all the results of the measurements in Bergen, the conclusion is that formula (1) tends to overestimate the pressure. For formula (2), the tests are not significant enough to find a clear statement. However, with respect to a noise prediction model, formulae (1) and (2) yield an appropriate source description.

CONCLUDING REMARKS

- Formulae (1) and (2) do not establish a sonic boom propagation model in terms of typical noise propagation models. The formulae are restricted to those areas where non-linear effects play an important rule. These effects cause additional absorption of acoustic energy and the change of the spectrum described in formula (2). The non-linear effects will decrease with pressure and distance, respectively. For large scale propagation, the geometric spreading, for example, is determined by cylindrical spreading in addition to the increasing sonic boom area due to the decrease of projectile speed along the trajectory /6/.
- Formulae (1) and (2) are promising to establish a source model for sonic boom at least for howitzer shots.
- Especially measurements close to the ground must be analysed carefully due to the always present superposition of direct and reflected wave.

ACKNOWLEDGEMENTS

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REFERENCES

/1/ Hirsch, K.-W.; Buchta, E.: „Zum Standardverfahren für die Berechnung der Schallimmisionen in der Umgebung von Truppenübungsplätzen“, *Fortschritte der Akustik - DAGA 93*, Bad Honnef: DPG GmbH 1994, S.656-659

/2/ Witham, G.B: „The behaviour o a supersonic flow past a body of revolution far from the axis“, *Proc. R. Soc. London*, Ser A261(1950) pp. 89-109 1950

/3/ Witham G.B.: „The flow pattern of a supersonic projectile“, *Commun. Pure Apl. Math.* V (1952) pp.301-348

/4/ Brinkmann H.: “Messungen für Lärmkataster WBVII, - Frequenzanalysen von Knallen des KPz Leopard 2“, Bericht der Erprobungsstelle 91 der Bundeswehr, Meppen, 1986

/5/ Buchta, E., Hirsch, K.-W.: „Low-Frequency Projectile Noise From Flat Howitzer Shots”, *Internoise 2000*, Nice, to be published

/6/ Hirsch, K.-W.; Buchta, E.: „Zur Berücksichtigung des Geschossknalles bei der Berechnung von Lärmkarten für die Umgebung von Truppenübungsplätzen“, *Fortschritte der Akustik - DAGA 91*, Bad Honnef: DPG GmbH 1991, S.393-396