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A Practical Approach for Estimating Sound Propagation of Artillery Projectile Noise

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Abstract. Generally, a supersonic projectile generates an acoustical shock wave along its trajectory. This projectile sound is only audible in the Mach region area. The geometry of this area depends on the projectile speed relative to the speed of sound. At some distance from the projectile, the shape of the waveform is the typical N-wave shape. Projectile noise is one component of firing noise, which can be an important factor in environmental noise. The pressure prediction depends on the diameter, length and shape of the projectile and on the local Mach number. Due to non-linearity, the spectral energy content is not constant but depends on distance. Based on these principles, a practical approach for estimating projectile noise has been modeled. The approach takes into account the dimensions of the projectile, the projectile speed, weather and terrain conditions. In this paper the model has been described and compared with the open source available experimental data for large caliber artillery field gun system.

1. Introduction

Artillery projectile is a class of projectiles around which much of aeroballistics physical theory was originally developed. Large caliber firing noise consists in general of three components: muzzle noise, detonation noise, and projectile noise. A projectile with a supersonic speed generates projectile noise. For a projectile path of finite length, the projectile sound levels are high in a restricted area, the Mach area. Outside this area, only diffracted projectile sound is received, with considerably lower levels than in the Mach area. The boundaries of the Mach area are described with the angles θ_0 and θ_e shown in Figure 1. These angles are given by

$$\theta_0 = \cos^{-1}\left(\frac{c}{v_0}\right) \text{ and } \theta_e = \cos^{-1}\left(\frac{c}{v_e}\right) \tag{1}$$

where v_0 is the initial speed of the projectile and v_e is the projectile speed at the end of the trajectory. The numerical methods for the estimation of projectile sound in the Mach area are discussed in [1][2]. In this approach, Huygen's principle is used to handle the projectile path as number of point sources. This approach is very flexible, but it can only be applied by using a numerical procedure and is very time consuming.

The reason is that at each receiver point, the sound contribution of all points along the projectile path has to be estimated and combined. According to field users, a more practical approach has therefore been developed. This approach is based on theoretical knowledge of non-linear wave propagation and estimations with the numerical approach. With this practical approach, the sound exposure level is estimated from the geometric properties and the speed of the projectile, the geometrical attenuation, atmospheric absorption, and the excess attenuation due to ground reflections and atmospheric refraction.[3]

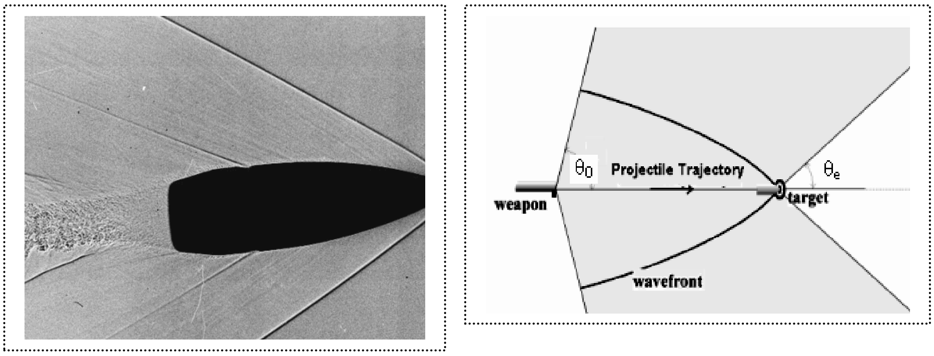


Figure1: Schematic of Shock Wave and its Mach Area

2. Practical Model For Projectile Noise

Projectile noise is described as originating from a certain point on the projectile trajectory, the source point. This point is located at the interaction of the projectile trajectory and the line from receiver perpendicular to the Mach wave. According to the 1/3-octane band sound exposure level L_E at the receiver is estimated as:

$$L_E(f_n) = L_{E,s}(f_n) - A_{geo} - A_{abs} - A_{ground} \tag{2}$$

where $L_{E,s}$ is the 1/3-octane band sound exposure level of the source, A_{geo} is the geometrical attenuation, A_{abs} is the atmospheric absorption from the source point to the receiver, and A_{ground} is the excess attenuation due to ground reflections and atmospheric refraction. A_{abs} is estimated by using the ISO standard, estimated on the basis of the immission spectrum. A_{ground} can be estimated by means of a method for prediction of outdoor sound propagation (for different ground types of profiles of wind and temperature), for example the parabolic equation method [4]. The computation of $L_{E,s}$ and A_{pro} is described below. The (broadband) source level $L_{E,s}$ is given by the geometric properties and the speed of the projectile at the source point:

$$L_{E,s} = 161.5 + 10\log\left(\frac{d_b^3}{l_b^{3/4}}\right) + 10\log\left(\frac{M^{9/4}}{(M^2-1)^{3/4}}\right) \tag{3}$$

where d_b is the maximal diameter of the projectile, l_b is the effective length of the projectile, Figure 2 and $M=v/c$, is the Mach number of the projectile at the source point, Figure 3. When the Mach approaches unity, these expressions diverge. Therefore, a lower limit of M =1.01 is used in these expressions.[5]

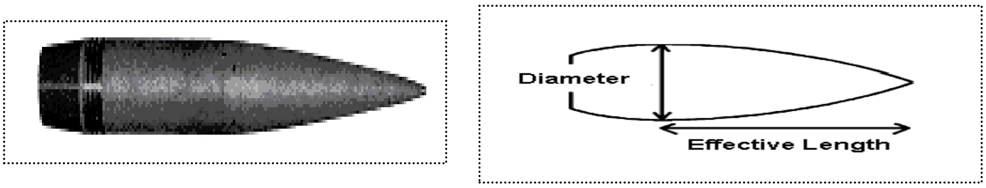


Figure 2: Schematic of Artillery Projectile and its Effective Length

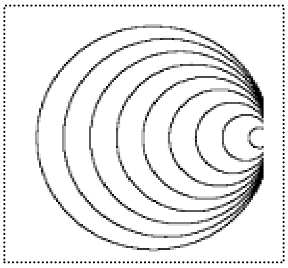


Figure 3: Schematic of Mach Profile at Source

To convert this source level into a 1/3-octave band spectrum using Fourier transformation of N-wave, a characteristics frequency f_c of the pressure waveform (N-wave) is defined:

$$f_c = 175.9\frac{(M^2-1)^{1/4}}{M^{3/4}}\frac{l_b^{1/4}}{d_b}\frac{1}{r^{1/4}} \qquad \text{for } r < R_{trans} \tag{4}$$

where r is the distance from the source point to the receiver and R_{trans} is 1 km. This equation shows that the characteristics frequency f_c decreases with increasing distance *r*. This is a consequence of pulse broadening due to nonlinear effects. For $r \geq R_{trans}$, $f_c(r) = f_c(R_{trans})$. The 1/3-octave band sound exposure level of the source is given by

$$L_{E,s}(f_n) = L_{E,s} + C_n - 10\log\sum_{i=1}^{9} 10^{C_i/10} \quad \text{for n} = 1\ldots27, \tag{5}$$

where

$$C_n = \begin{cases} 2.5 + 28\log\left(\dfrac{f_n}{f_c}\right) & if\ f_n < 0.65 f_c \\ -5.0 - 12\log\left(\dfrac{f_n}{f_n}\right) & if\ f_n \geq 0.65 f_c \end{cases} \tag{6}$$

Where f_n is the center frequency of the 1/3-octave band (16 Hz to 4 kHz).

The geometrical attenuation A_{geo} for receiver positions in the Mach area is given by

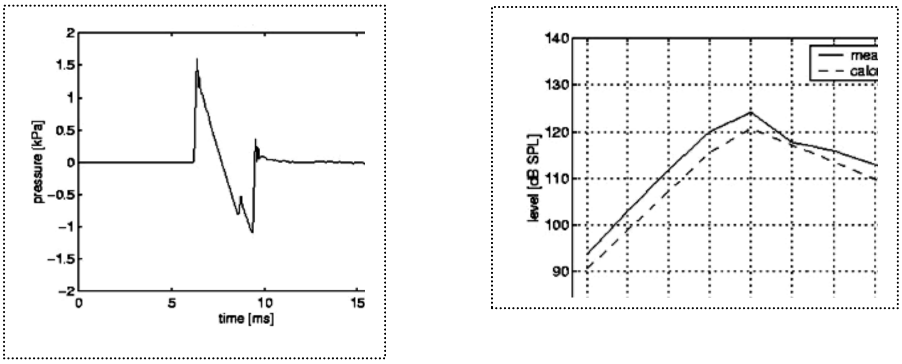
$$A_{geo} = 12.5\log\left(\frac{r^2 k + r(M^2 - 1)}{r_0^2 k + r_0(M^2 - 1)}\right) \quad \text{for } r < R_{trans} \tag{7}$$

where $k = -v_1/c$, v_1 is the reduction of the projectile speed per length unit, and r_0=1 m. At large distance ($r > R_{trans}$), the coherence of the wave front is reduced as a result of atmospheric turbulence [6]. Therefore, the sound level is expected to decrease as 20log(r) beyond the transition distance. Thus

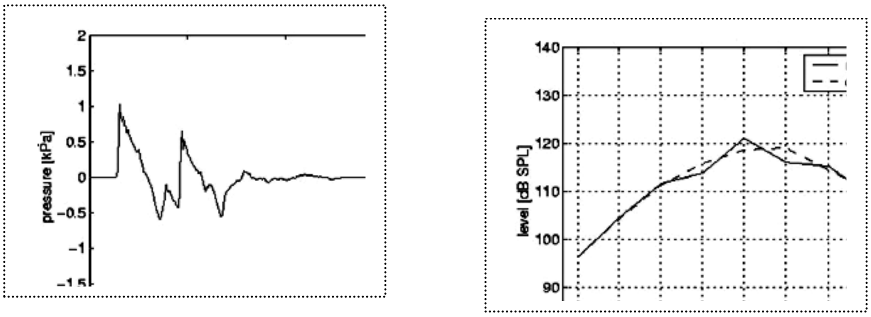
$$A_{geo} = 12.5\log\left(\frac{R_{trans}^2 k + R_{trans}(M^2 - 1)}{r_0^2 k + r_0(M^2 - 1)}\right) + 20\log\left(\frac{r}{R_{trans}}\right) \quad \text{for } r \geq R_{trans} \tag{8}$$

3. Comparison with Experimental Data

Figures 4a and 4c show measured waveforms of the sound of large caliber artillery projectile. The receivers are located at approximately 32 m from the sources point on the projectile trajectory. The projectile speed at the source points is estimated at 560 m/s. The height of the projectile is roughly 7 m. The heights of the receivers are 10 m (Figure 4a.) and 1.5 m (Figure 4c). For the receiver at 10 m high, the difference in path length between the direct sound and the ground reflection is large enough to be able to separate the direct sound from the ground reflection.



(a) Measured waveform at 10 m high (b) Measured and computed spectrum at 10 m high



(c): Measured waveform at 1.5 m high (d): Measured and computed spectrum at 1.5 m high

Figure 4: Sound Profile of an Artillery Projectile

The direct sound is shown in Figure 4a. The characteristics N-wave is clearly recognizable in the signal. Figure 4c shows the direct sound and the ground reflection. The corresponding measured spectra are shown by the solid lines in figures 4b and 4d, together with the spectrum estimated with the practical approach discussed above (dashed line). For the receiver at 10 m high, the measured broadband sound exposure level is 121.6 dB(A) and the estimated sound exposure level is 119.2 dB(A). For the receiver at 1.5 m high, the measured broadband sound exposure level is 119.4 dB(A) and the estimated sound exposure level is 119.8 dB(A). There, a good correspondence is observed between the measured and estimated data.

4. Conclusions

A practical approach to estimate projectile noise discussed in the paper. Comparisons to measurements of projectile noise show that the measured data correspond very well agreement with the data estimated with this practical approach.

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