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A PRACTICAL METHOD FOR CALCULATING THE LONG-RANGE SOUND PROPAGATION OF PROJECTILE NOISE

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ABSTRACT

Due to the supersonic flight of a projectile, a shock wave is generated (sonic boom). Projectile noise is one component of shooting noise, which can be an important factor in environmental noise. In a former paper, the basic physical principles were given for a computational model for long-range sound propagation of projectile noise. Based on these principles, a practical method for calculating projectile noise has been formulated. The method takes into account the dimensions of the projectile, the projectile speed, weather and terrain conditions. In this paper, the model will be described and it will be compared with experimental data for large artillery ammunition.

1 - INTRODUCTION

Large calibre shooting noise consists in general of three components: muzzle noise, detonation noise, and projectile noise. Projectile noise is generated by a projectile with a supersonic speed. 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 ξ_0 and ξ_e shown in figure 1. These angles are given by

$$\xi_0 = \arccos\left(\frac{c}{v_0}\right) \qquad \text{and} \qquad \xi_e = \arccos\left(\frac{c}{v_e}\right) \tag{1}$$

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 method for the calculation of projectile sound in the Mach area is given in a former paper [1]. In this method, Huygen's principle is used to handle the projectile path as a number of point sources. This method 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 calculated and combined. By order of the Dutch Ministry of Defence, a more practical method has therefore been developed for consideration in ISO working group 51 under TC43. This method is based on theoretical knowledge of non-linear wave propagation and calculations with the numerical method. With this practical method, the sound exposure level is calculated 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.

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 intersection of the projectile trajectory and the line from the receiver perpendicular to the Mach wave.

The 1/3-octave band sound exposure level L_E at the receiver is calculated as

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

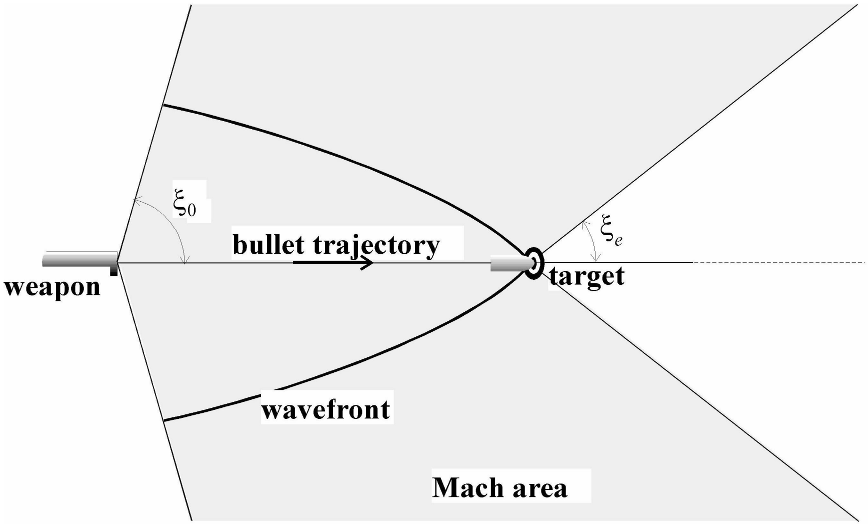

Figure 1: Definition of the Mach area.

where $L_{E,s}(f_n)$ is the 1/3-octave 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 calculated by using the ISO standard 9613-1, estimated on the base of the immission spectrum. A_{ground} can be calculated by means of a method for prediction of outdoor sound propagation (for different ground types and profiles of wind and temperature), for example the parabolic equation method [2]. The computation of $L_{E,s}$ and A_{geo} 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:

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

where d_b is the maximal diameter of the projectile, l_b is the effective length of the projectile, and M=v/c, is the Mach number of the projectile at the source point.

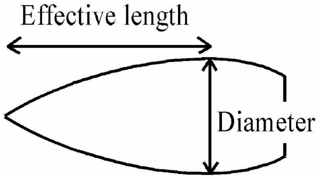

Figure 2: Illustration of the effective length of a projectile.

When the Mach number approaches unity, these expressions diverge. Therefore, a lower limit of M = 1.01 is used in these expressions. To convert this source level into a 1/3-octave band spectrum, a characteristic frequency f_c of the pressure waveform (N-wave) is defined:

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

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

$$L_{E,s}\left(f_n\right) = L_{E,s} + C_n - 10\log\sum_{i=1}^{9}10^{C_i/10} \qquad \text{for } n = 1\ldots 27, \tag{5}$$

where

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

where f_n is the centre 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

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

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 will be reduced as a result of atmospheric turbulence [3]. Therefore, the sound level is expected to decrease as 20log(r) beyond the transition distance. Thus

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

3 - COMPARISON WITH EXPERIMENTAL DATA

Figures 3a and 3c show measured waveforms of the sound of a Howitzer projectile. The receivers were located at approximately 32 m from the source point on the projectile trajectory. The projectile speed at the source points was estimated as 560 m/s. The height of the projectile was roughly 7 m. The height of the receivers was 10 m (Fig. 3a) and 1.5 m (Fig. 3c). For the receiver at 10 m high, the difference in path length between the direct sound and the ground reflection was large enough to be able to separate the direct sound from the ground reflection. The direct sound is shown in Fig. 3a. The characteristic N-wave is clearly recognisable in the signal. Figure 3c shows the direct sound and the ground reflection. The corresponding measured spectra are shown by the solid lines in Figs. 3b and 3d, together with the spectrum calculated with the practical method described above (dashed line). For the receiver at 10 m high, the measured broadband sound exposure level is 121.6 dB(A) and the calculated 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 calculated sound exposure level is 119.8 dB(A). Thus, a good correspondence is observed between the measured and calculated data.

4 - CONCLUSION

In this paper, a practical method to calculate projectile noise is described. Comparisons to measurements of projectile noise show that the measured data correspond very well with the data calculated with this practical method.

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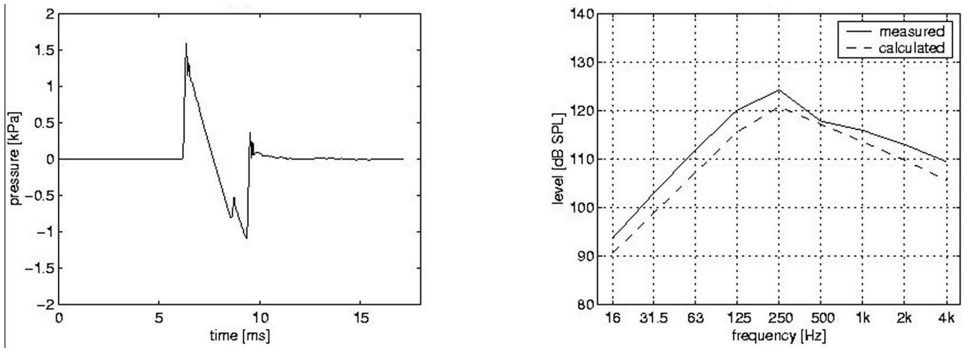
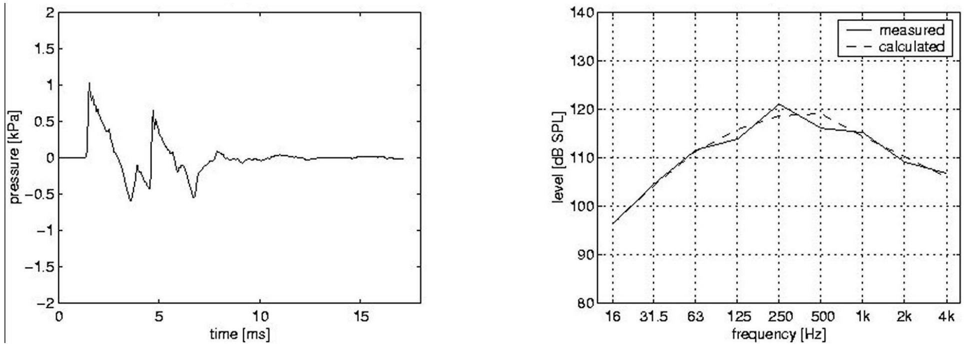


(a): Measured waveform at 10 m high.

(b): Measured and calculated spectrum at 10 m high.



(c): Measured waveform at 1.5 m high.

(d): Measured and calculated spectrum at 1.5 m high.

Figure 3: The sound of a Howitzer projectile.