inter•noise 96
25th Anniversary Congress – Liverpool

INCE: 24

A COMPUTATIONAL MODEL FOR LONG-RANGE PROPAGATION OF BULLET NOISE

N A Kinneging & F H A Van den Berg

TNO Institute of Applied Physics, Stieltjesweg 1, PO Box 155, 2600 AD Delft, The Netherlands

1. INTRODUCTION

Shooting noise can often be heard at large distances from the shooting ranges. In order to predict the immission levels of shooting noise there is a need for reliable long-range propagation models. Shooting noise may have three components: muzzle noise, due to the explosion of the propulsive powder; bullet noise for supersonic bullets and detonation noise in case of a detonating charge. In an accompanying paper [1] an overview is given of a method, that is being developed for the Dutch Ministry of Defence, to predict average propagation of shooting noise around shooting ranges. This paper will concentrate in more detail on the propagation model for bullet noise.

Due to the supersonic flight of the bullet a shock wave is generated (sonic boom). The form of the wave front is conical, where the cone is centered on the bullet path. The top angle α of the cone depends on the bullet speed v and the sound speed c by,

$$\alpha = 2 \arcsin\left(\frac{c}{v}\right)$$

For a bullet path of finite length the bullet noise is just audible in a restricted area, the Mach area. In figure 1 the Mach area is illustrated relative to the bullet path. Outside this area the level of the bullet noise is much lower than inside the Mach area.

The wave propagation of bullet noise is non-linear. There exist analytical solutions for bullet noise [2], but these are restricted to idealised situations with bullet paths of infinite length and bullets of constant speed.

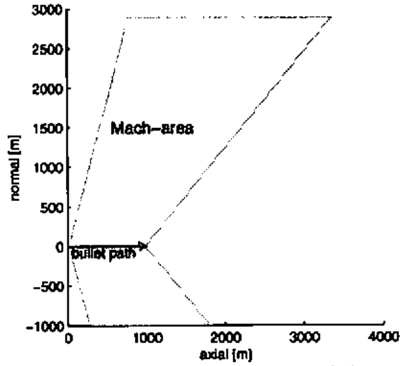

Fig. 1: Illustration of the Mach area relative to the bullet path

In this paper we present a method to compute the propagation of bullet noise, which can also be used for bullet paths of finite length with decreasing bullet speed. The method can also correct for atmospheric absorption, meteorological effects and ground effects.

2. COMPUTATION SCHEME

The pulse of the bullet noise has the form of an N (an N-wave). The propagation of N-waves can be described by the weak shock theory. Using this theory the amplitude and pulse length of the N-waves can be calculated as a correction to amplitude and pulse length derived from linear acoustics. The atmospheric, meteorological and ground effects are incorporated as an excess attenuation to the non-linear free field parameters.

Therefore the global scheme consists of three steps:

1. computation of the linear wave propagation
2. non-linear correction of the amplitude and pulse length of the N-wave
3. application of atmospheric, meteorological and ground effects

Linear Modelling

For the modelling of the linear wave propagation we use Huygen's Principle. This principle states that a wave front can be seen as a number of point sources. The propagation of the total wave front is the sum of the contributions of all (secondary) point sources. For bullet noise the bullet path can be considered as a line source. Using Huygen's Principle this line source can be handled as a number of point sources. Each point source has a delay that corresponds to the time that the bullet passes that point. The strength of the sources is based on the bullet dimensions

and the local bullet speed.
In this way it is possible to calculate the response of bullet paths of finite length with a decreasing bullet speed. In figure 2 an example is given of the wave fronts that are calculated for a decreasing bullet speed. The initial speed of the bullet was 650 m/s and after 150 m it has decreased to below the sound speed. The ray paths are indicated, which are normal to the wave fronts.

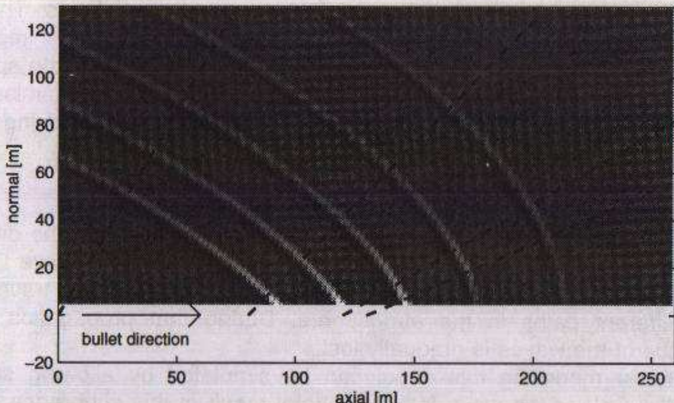

Fig. 2 Wave fronts and rays calculated using linear modelling

Non-Linear Corrections

For large sound pressures the propagation velocity of sound depends on the sound pressure itself. In the first order this can be described as,

$$c(p) = c_0 + \beta \frac{p}{\rho c_0}$$

where c_0 is the linear sound speed, p the sound pressure, β a non-linearity constant (=1.2 for air) and ρ the density of air.
The normalised amplitude factor $B(\ell)$ gives the linear amplitude at a distance ℓ along the ray. At a reference point ℓ=0 the amplitude factor equals 1. Using the weak shock theory the amplitude (P) and pulse length (T) of the N-wave can be calculated by,

$$P(\ell) = B(\ell)P(0)\left[1 + \frac{P(0)}{T(0)}\mathrm{Age}(\ell)\right]^{-1/2}$$

$$T(\ell) = T(0)\left[1 + \frac{P(0)}{T(0)}\mathrm{Age}(\ell)\right]^{1/2}$$

where the Age-function is defined as,

$$\mathrm{Age}(\ell) = \frac{\beta}{\rho c_0^3}\int_0^{l} B(\ell^*)\,d\ell^*$$

From the linear wave field these non-linear parameters can be determined numerically. A description of the weak shock theory can be found at [2].

Atmospheric, Meteorological and Ground Effects

From the first two steps in the scheme the non-linear wave field is calculated without the influence of absorption, meteorological (wind and temperature profile) and ground effects. Ideally these effects should be incorporated in the previous steps, because of the non-linear effects. These steps however prove to be of second order and can therefore be treated separately. The atmospheric absorption is calculated based on the spectrum, that is derived from the amplitude and pulse length at the immission location. The meteorological and ground effects are calculated using the Parabolic Equation (PE) method described by [3].

Coherence Loss

In the computation scheme described above we assumed that the different parts of the bullet path contributed coherently to the total wave field. However the noise from the different secondary sources has travelled along different paths in the atmosphere. During that propagation the coherence of the waves is gradually lost.

In the linear modelling this effect can be simulated by allowing small pertubations along the wave front. The total result of this coherence loss is a decrease of the amplitude of the wave front and therefore the non-linear effects on the wave propagation will be smaller. The amount of coherence loss will depend on the turbulence of the atmosphere.

3. RESULTS

Figure 3 shows the contours of equal sound exposure level around a certain bullet path with a length of 1000 m. Clearly the Mach area can be recognized. In the forward direction also bullet noise (at a much lower level) can be observed, due to the truncation of the bullet path at 1000 m. The bullet noise in the backward direction will usually coincide with the muzzle noise and cannot be observed in practice.

In figure 4 the spectrum of the bullet noise is displayed for a point at about 2 km from the bullet path. The solid line is the measured bullet noise. Below 125 Hz the measurements are dominated by wind noise.

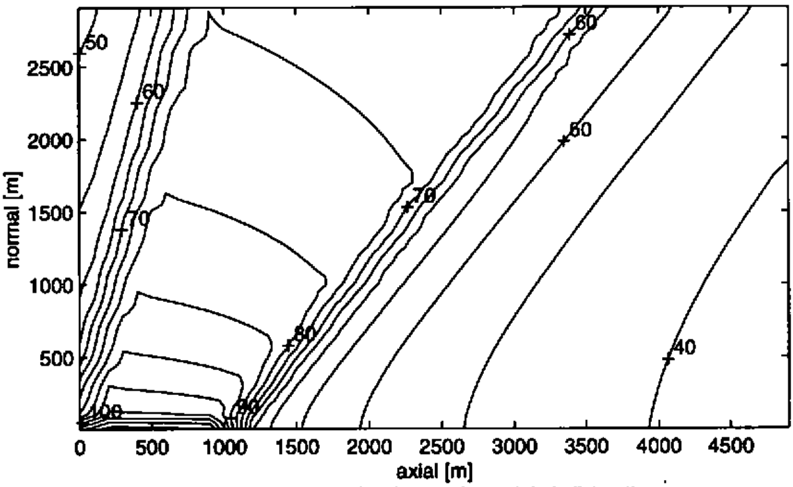

Fig. 3 Contours of equal sound exposure level around a certain bullet path

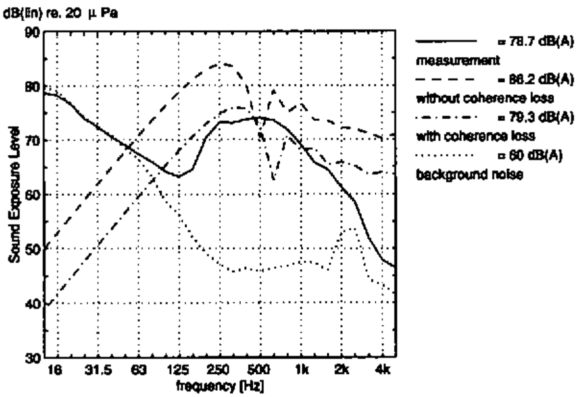

Fig. 4 1/3 octave band spectrum of measured data (solid line), computed without coherence loss (dashed line) and with coherence loss (dash-dotted line) and the background noise on the measurements (dotted line).

The dashed line is the computed result when no coherence loss is introduced. The level is clearly too high and the central frequency too low. Including coherence loss gives the dash-dotted line, that corresponds very well with the measurements. For this case it proves that about 50 m of the bullet path contributes coherently to the wave front at 2 km distance.

4. CONCLUSIONS

In this paper we have introduced a method to calculate the immission level of bullet noise around shooting ranges. With this method the noise can be calculated for finite bullet paths and decreasing bullet speeds. Also effects caused by the propagation through the atmosphere, like wind, turbulence and absorption, can be incorporated.
Comparison to measurements of bullet noise at large distances from the shooting range show that the model corresponds very well with the measurements.

Acknowledgement
The research has been supported by the Dutch Ministry of Defence.

5. REFERENCES

[1] FHA Van den Berg, NA Kinneging, EM Salomons, InterNoise96 (1996)
[2] AD Pierce, Acoustics (Acoust. Soc. Am., New York, 1989)
[3] EM Salomons, J. Acoust.Soc.Am., 95, 3109 (1994)