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PREDICTION OF THE SHIELDING EFFECT FOR BULLET SOUND

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ABSTRACT
In prediction models for bullet noise it is normally assumed that the sound stems from a single point along the projectile trajectory. This assumption can lead to an overestimate of a possible shielding effect. To predict the shielding effect more accurately, the bullet noise may be simulated as a coherent line source, employing a series of point sources along the trajectory. It turns out that the sound pressure is determined mainly by signals that arrive within a half period after the first signal. The region of the projectile path responsible for the bullet noise is thus located to both sides of the original, single "source point" and corresponds to the first Fresnel zone. If this region is shielded by a barrier, two new Fresnel zones become important at each end of the barrier. The shielding effect may be estimated based on the length of these two additional zones compared to the length of the original zone. This calculation method was confirmed by measurements carried out with varying barrier lengths.

1 - INTRODUCTION
When a weapon is fired with a bullet speed exceeding the speed of sound the bullet generates a shock wave along its path. In contrast to the muzzle blast, the bullet noise is significant only in certain regions in front of the weapon. Most models to calculate the bullet noise are based on the simplifying assumption that the sound stems from a single point along the bullet trajectory, namely the point representing the earliest time of arrival of the bullet noise [1], [2], [3]. Although this simplification allows a rapid calculation of the sound propagation it sometimes leads to inaccuracies, particularly concerning the shielding effect of short barriers. This paper describes an improved calculation method employing Fresnel zones. The method was developed based on a simulation model and verified by field measurements.

2 - SIMULATION MODEL
The shock wave generated by the bullet may be considered as a continuous line of point sources related to one another by a fixed phase relationship, i.e., a coherent line source. The sound pressure observed at any given receiver location is calculated by superimposing the contributions from all of these sources, maintaining the proper phase relationship between them. In the simulation, the signal from each point source consists of a single period of a sine wave with a given frequency. Only geometric attenuation is considered. For investigating the shielding effect, selected portions of the trajectory are reduced in strength in accordance with Maekawa [4] and delayed according to the increased path length over the barrier.

3 - FRESNEL ZONES
From the simulation model it became apparent that only a small portion of the trajectory is responsible for the sound pressure at the receiver. Destructive interference neutralizes the larger portion of the incoming impulses. Constructive interference occurs only for those impulses arriving at the receiver within the first half period following the earliest impulse. These impulses correspond to the first Fresnel zone [5] and are located to both sides of the "source point".
At first glance one might imagine that the shielding of the first Fresnel zone would lead to the complete elimination of the bullet noise. However, this is not the case, as this original, first zone is then replaced by a new "first" zone located just to the sides of the barrier. This effect is illustrated in Figure 1.

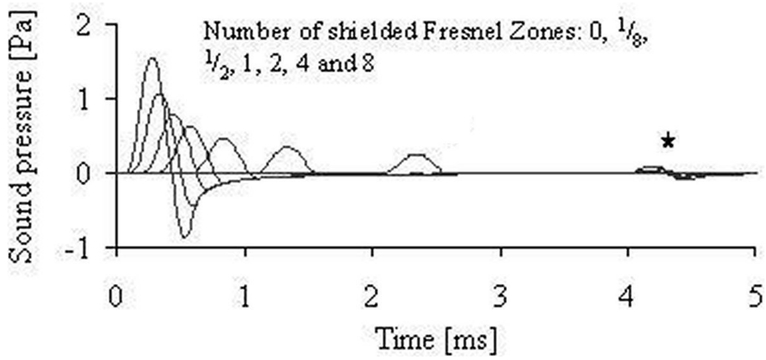

Figure 1: Sound pressure vs. time for various degrees of shielding.

This example considers a high barrier (attenuation over the barrier = 25 dB) shielding various numbers of Fresnel zones to each side of the source point. With an increasing number of shielded Fresnel zones the sound pressure decreases. This is mainly because the successive Fresnel zones are correspondingly smaller in size. For example when one Fresnel zone is shielded the sound pressure is reduced by a factor of approximately 3 (respectively 10 dB).

The figure also shows the contribution of the path over the barrier, marked with a ★. Since the attenuation of this path is 25 dB, it may be ignored here. However, in the case of lower barrier heights, this path may dominate.

4 - DEVELOPMENT OF SIMPLIFIED MODEL

By using the concept of Fresnel zones, the tedious calculation as a coherent line source may be avoided. The simplified method then consists of a series of closed formulas. In situations where the original "source point" is shielded by a barrier, three sources are calculated. The first of these stems from the first Fresnel zone (including the source point). Here the propagation path is over the barrier and therefore reduced in amplitude and delayed in time. The other two sources stem from the first unshielded Fresnel zones to each side of the barrier. Each of the three sources is characterized by its pressure maximum, minimum and time of arrival at the receiver. Considering phase relationships, the respective sound pressures are added, squared and integrated. Finally the shielding effect is determined by comparing the energies with and without the barrier. Figure 2 illustrates typical results achieved with the simplified model, compared with those of the simulation model.

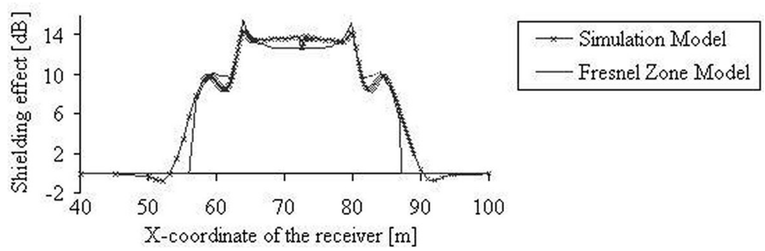

Figure 2: Shielding effect for a moving receiver 50 m from the trajectory.

In this example, a barrier 30 m long and yielding 15 dB attenuation (for the path over the barrier) was placed 1 m from the trajectory. At receiver positions until x = 55 m and following x = 87.5 m the source point was unshielded. Here, the simplified model was programmed to yield no shielding effect whereas the simulation model shows first a slight negative attenuation (enhancement) and then a gradually increasing attenuation. In the region of the barrier, both models predict almost the same attenuations (within 1 dB).

5 - COMPARISON WITH FIELD MEASUREMENTS

Field measurements were carried out to evaluate the two prediction methods. A barrier was placed at a distance of 1 m from the bullet trajectory. It consisted of 4 elements, each 2.5 m high and 2.5 m long. Depending on the measurement series, 0, 1, 2, 3 or all 4 barrier elements were used. Thus, the maximum

barrier length was 10 m. The measurement points were at 10 and 40 m from the trajectory at a height of 3 m above the ground.
Figure 3 shows a typical sound pressure diagram at a point behind the barrier. As predicted in the model, three separate signals are observed. For this example the order of time of arrival is from the left side (1), over the barrier (2), and from the right side (3). Additional signals stem from ground reflections.

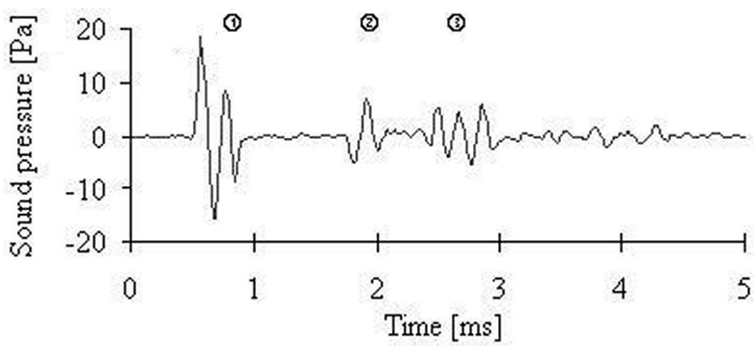

Figure 3: Sound pressure vs. time at a point behind a barrier.

Surprisingly, the presence of the barrier does not significantly influence the spectrum. In the case of a single point source it would be expected that the shielding decreases at the lower frequencies. The explanation lies primarily in the presence of sound energy from the sides. This is unshielded and hence has the same frequency spectrum as the original bullet noise.
Since the spectra with or without the barrier are similar, it is possible to perform the prediction calculations at one representative frequency. Due to non-linear effects (broadening of the N-wave) the duration of the N-wave increases with distance. Therefore, the representative frequency has to be selected at the receiver based on measurements or calculations [6].
Figure 4 summarizes the measurement results compared with the calculations using the simulation method and the simplified (Fresnel zone) model.

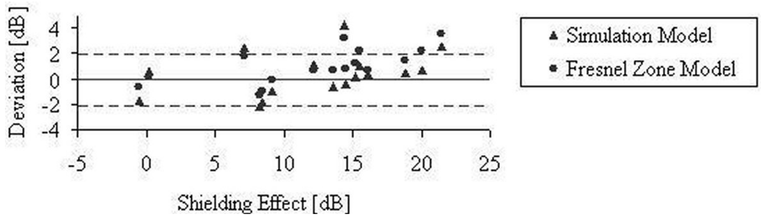

Figure 4: Comparison of measured and calculated shielding effects.

In general, the measured and calculated results agree quite well: 3/4 of all the calculated shielding values lie within 2 dB of the measured values. Furthermore the simplified method yields about the same accuracy as the simulation method. One cause for deviations may be the ground reflection which is not included in the models. Other reasons for discrepancies between measurement and calculation are attributable to inaccuracies in establishing the exact measurement positions and thus do not necessarily indicate actual calculation errors.

6 - CONCLUSIONS

The concept of regarding the bullet noise as a coherent line source provides good insight into the mechanism of the sound propagation, particularly in the case of shielding effects. Furthermore, by utilizing Fresnel zones instead of a series of point sources, a considerable simplification in the calculation model may be achieved with no significant loss of accuracy. In the future, the model may be improved by including ground reflections, non-linear effects and the influence of turbulence.

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