ACOUSTIC CHARACTERIZATION OF RICOCHETS

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1. Abstract

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This presentation describes the activities which have been carried out within the scope of a task appointed by the Ministery of Defence, Dienst Gebouwen Werken & Terreinen. Projectiles fired at a firing range will sometimes undesirably fly over the present bulletstop after hitting the ground surface. The task was to identify these stray bullets at a specific firing range. First the most suitable method has been determined. A pre-investigation showed that determination of different characteristics, related to the projectile's trajectory, might be feasible by analysis of the acoustic signals. Therefore it was decided to install an array of microphones at the end of the firing range and to record the data during shooting exercises. The data collection campaigns have been carried out on various days. This presentation gives more details about the acoustic model used and examples are shown which compares the model with real data.

2. Background

To keep soldiers well experienced they have to practice in shooting exercises. For this purpose there are a number of firing ranges in the Netherlands. For reasons well understood, these areas are kept as far as possible from the urban areas. One of these ranges is in a part of Holland where it borders on an ecologically sensitive area, the so called Dutch Shallows. These shallows fall dry with the tides and are very rich on food (snails etc). A huge number of birds are foraging here during their migration. Stray bullets which might fall into these shallows, might cause chemical pollution in this area. To prevent this to happen as good as possible, a number of measures was already taken.

In figure 1 (not on scale) the problem has been illustrated. The elevation angle (of the gun) and the angle of incidence are very small so there is a reasonable chance that projectiles will glance off and will follow a new and unpredictable trajectory. Some of these projectiles might pass the bulletstop and the sea dike which is pretty close behind the bullet stop.

Illustration:

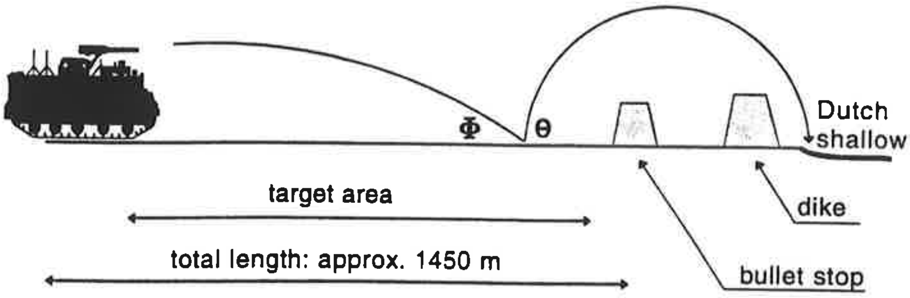


Figure 1 *Illustration of the problem.*

To get a better information about the real number of projectiles falling into the area, the Ministery of Defence, Dienst Gebouwen Werken & Terreinen, asked to develop tools to measure it.
Most currently 25 mm calibre ammunition is being used which has a muzzle velocity of approximately 1300 m/s. If the target is missed and the projectile is not stopped (e.g. by hitting the bullet stop) the velocity at the end of the shooting range is in the order of 500 m/s (after roughly 1.5 sec).

To determine whether or not the projectile is crossing the dike, various options were considered, such as the application of radar, cameras perpendicular to the vertical plane of fire, all having their specific advantages and disadvantages. Finally it was decided to find a way to solve the problem acoustically.

3. The acoustic approach

Close to the dike an array of 10 microphones has been deployed, all microphones separated 200 meter from each other. In figure 2 the sensor-configuration has been shown.

CONFIGURATION & INSTRUMENTATION

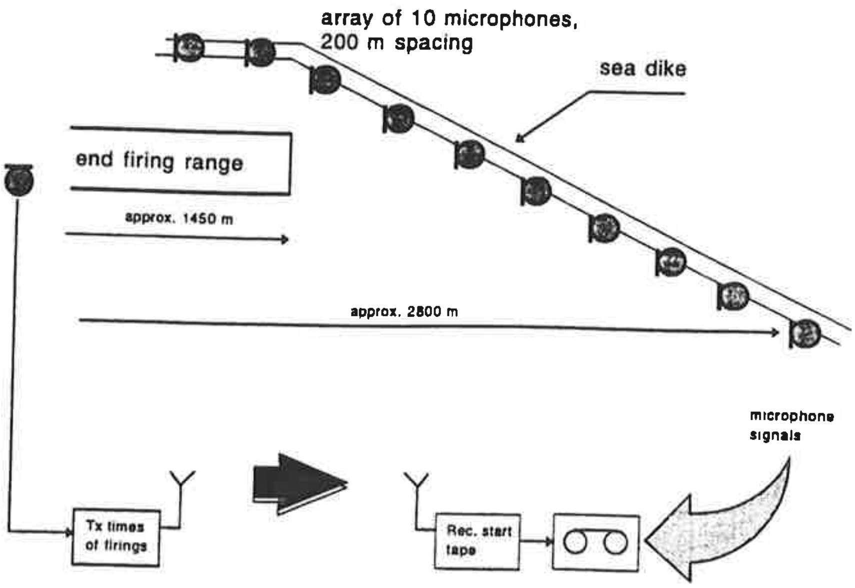


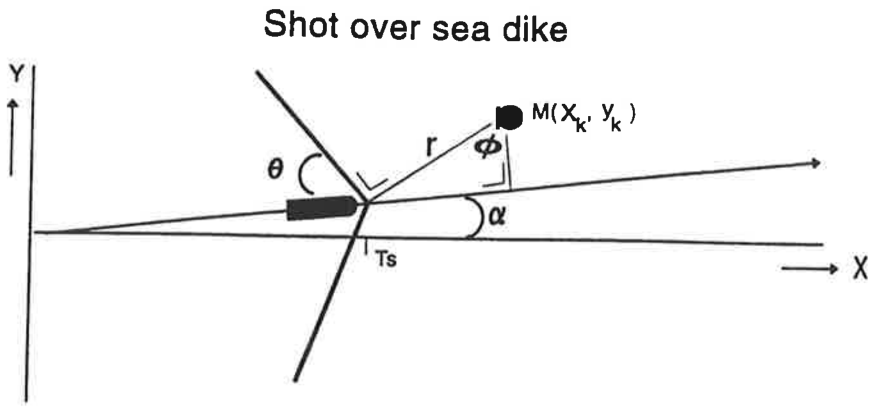
Figure 2 *Sensor configuration for acoustic data acquisition.*

All microphone signals were stored on analoge tape. Because during the exercises nobody was allowed to remain in the area, the taperecorder had to be started remotely. This starting was initiated automatically by an impulse derived from the muzzle blast at the moment the gun went off; a trigger signal was then transmitted radiographically to start the tape recorder. As there were 4 guns, there were 4 muzzle blast sensors. In addition information about the shots was logged, such as the target number the gunner is shooting at, etc. (there are targets all over the terrain). The data collected at the firing range were then analysed at the office afterwards. The main classes of trajectories to be recognized, were those of projectiles which:

(1): slightly touch the soil and then cross the sea dike (with hardly loss of projectile's speed)
(2): hit the target or bullet stop and clearly remain at the firing range
(3): clearly touch the soil and then cross the sea dike (with significant loss of projectile's speed)

4. Acoustic characterization

Let us first assume a projectile slightly touching the ground, glancing off and then crossing the sea dike with only a small loss of its kinetic energy. This kind of a trajectory is almost equivalent with the trajectory the projectile would follow if the shot would have been fired intentionally directly over the sea dike (with no loss of kinetic energy due to the ground touch). As the shockwave propagates perpendicularly to the shockwave front, the shockwave a microphone will receive, comes from a point at the trajectory where the wave front is perpendicular to the microphone direction, or where φ equals θ , see figure 3.



For M>1:

- shockwave propagates perpendicular to shockwave front
- microphone receives the shockwave from a source point, attained after Ts sec.
- Ts can be calculated from the condition: $\theta(Ts) = \phi(Ts)$

$$\tan\theta = 1/\sqrt{M(t)^2 - 1}$$

$$\tan\phi = [X_k/\cos\alpha + (Y_k - X_k\tan\alpha)\sin\alpha - s(t)]/(Y_k\cos\alpha - X_k\sin\alpha)$$

Figure 3 *Geometry for calculations.*

This point is called the source point and the projectile has reached that point after Ts seconds. The angle θ is a function of time due to the diminishing speed, the angle φ can be expressed as a function of the projectile position s(t), the trajectory azimuth a and the microphone coordinates (X_k, Y_k).
If the projectile is not stopped by the target or by the bullet stop, it will somewhere get a speed lower than the speed of sound (M<1). In that case Toa is given by "Toa = time the projectile need to reach the point where M=1, plus the time the wave needs to hit the microphone with the normal speed of sound".
The times of arrival of the shockwave have been calculated for these type of firings, using a simple model and assuming no loss of kinetic energy due to the ground touch. First the source point was calculated, the times of arrival then simply were obtained by "Toa=Ts + r/c".
The picture in figure 4 shows the 10 microphone signals, recorded for a shot as discussed in this paragraph. The signal at the end of each trace represents the muzzle blast of the gun. A few small spikes in the signal are due to cross talk components which sometimes occurred if the signal amplitude was very large. To verify the model, the measured times of arrival were compared with the calculated ones.

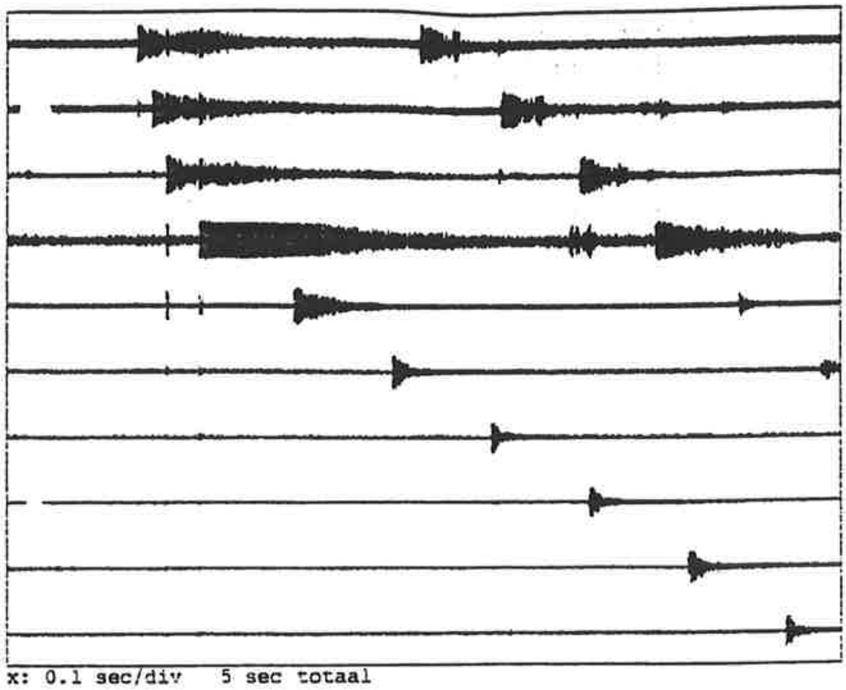


Figure 4 *Example of the acoustic response of a shot.*

In figure 5 the measured times of arrival of figure 4 have been plotted while in addition the calculated times for this shot are shown: the similarity is reasonable.
Choosing small changes in the azimuth angle may give even a better fit.

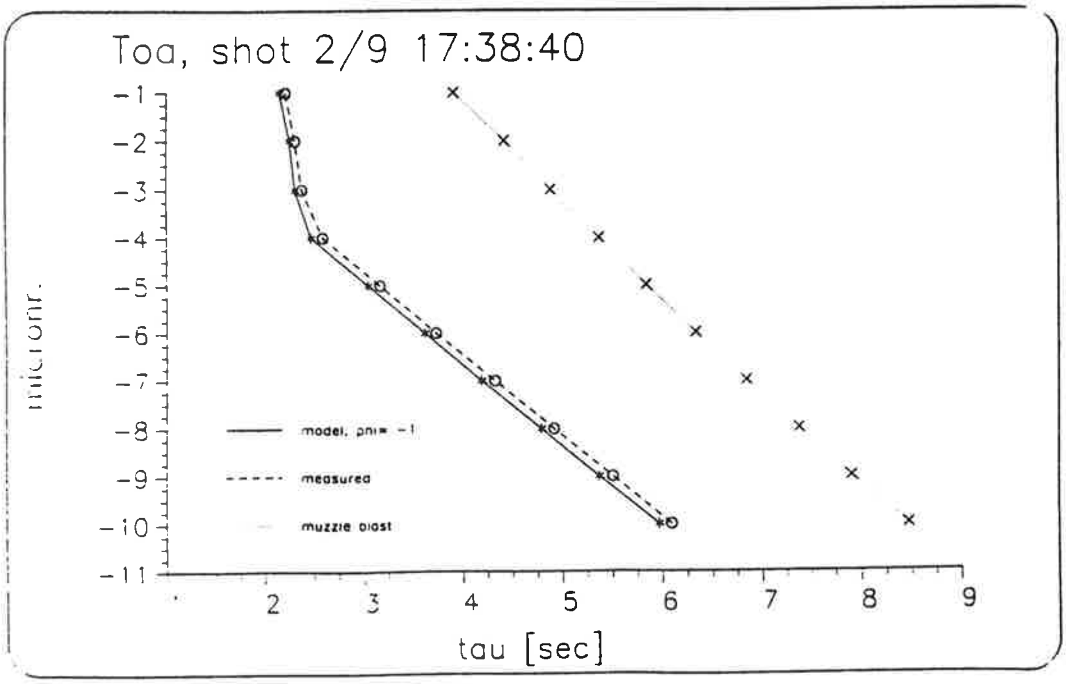


Figure 5 *Measured and calculated times of arrival.*

Figure 6 shows the results for another shot. In most cases a reasonable fit between measured data and the model is very well possible. The steep gradient of the curve up to the first 3 or 4 microphones is a very characteristic feature that all those shots have in common; this feature could be used for the identification of this type of projectile trajectories.

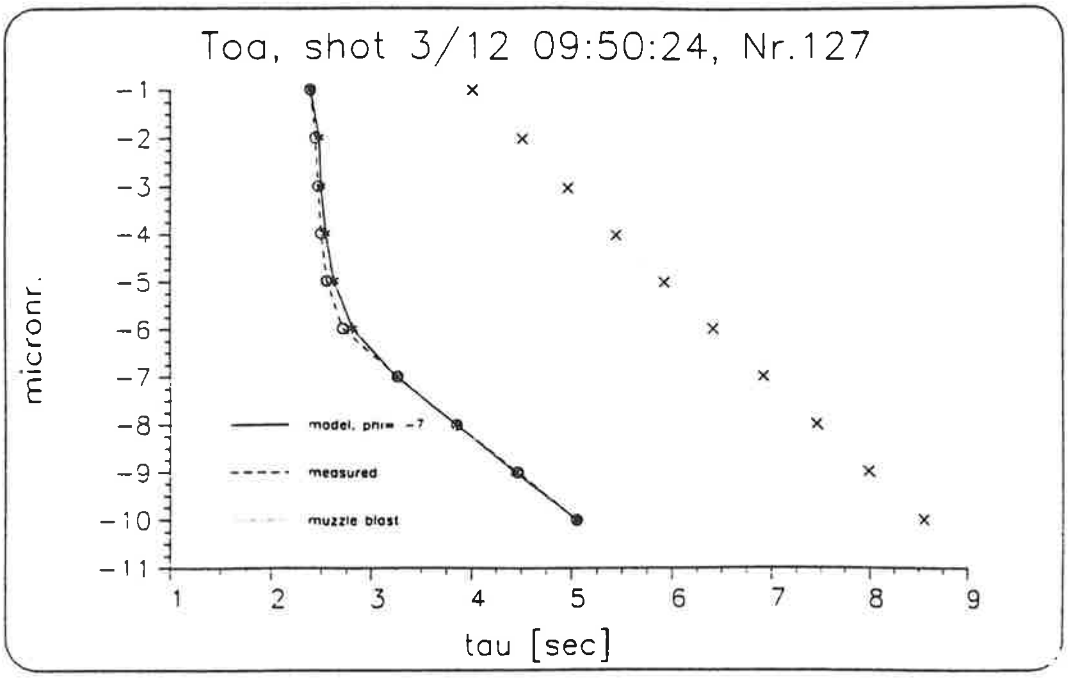


Figure 6 *Another example of measured and calculated times of arrival.*

Now what happens if the projectile hits the target or ends in the soil or the bullet stop ? In that case it can easily be calculated that only the first 2 or 3 microphones will detect the shockwave because all other microphones will remain out of the Mach area, which is illustrated in figure 7.

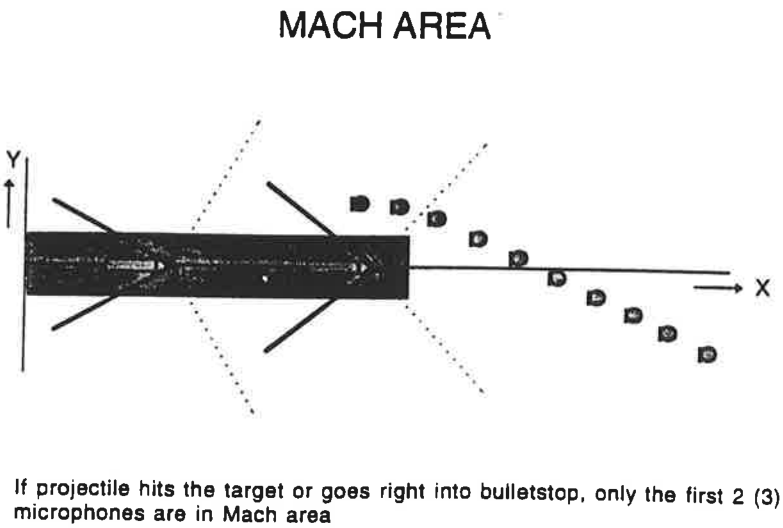


Figure 7 *Only 2 sensors in the Mach area.*

Figure 8 illustrates the signals recorded for such a shot; only the first two channels show a response.

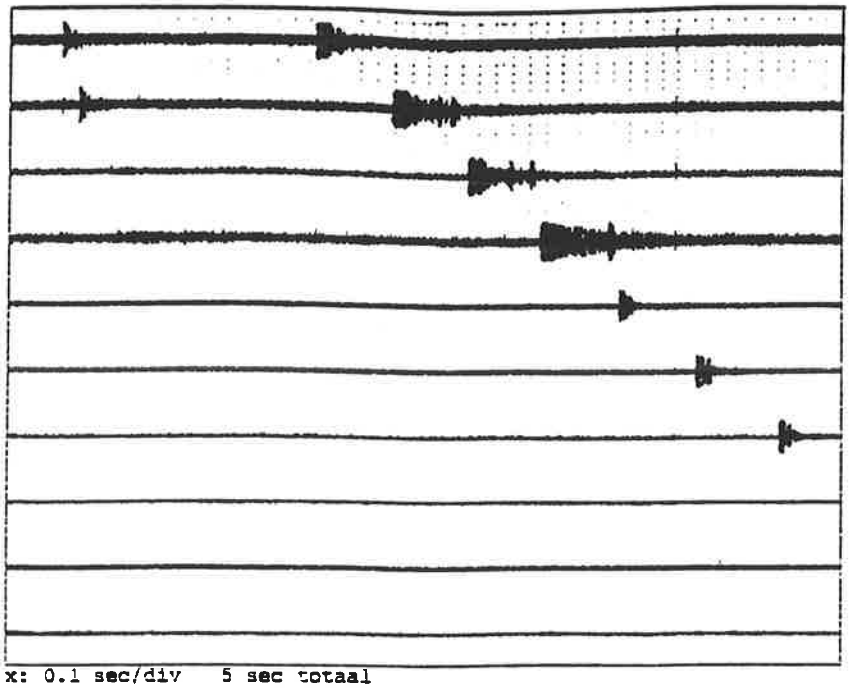


Figure 8 *Acoustic response of a shot where the projectile hits the bullet stop.*

How do the signals look like if the projectile behaves as a ricochet ? Figure 9 shows the signals, of a ricochet.

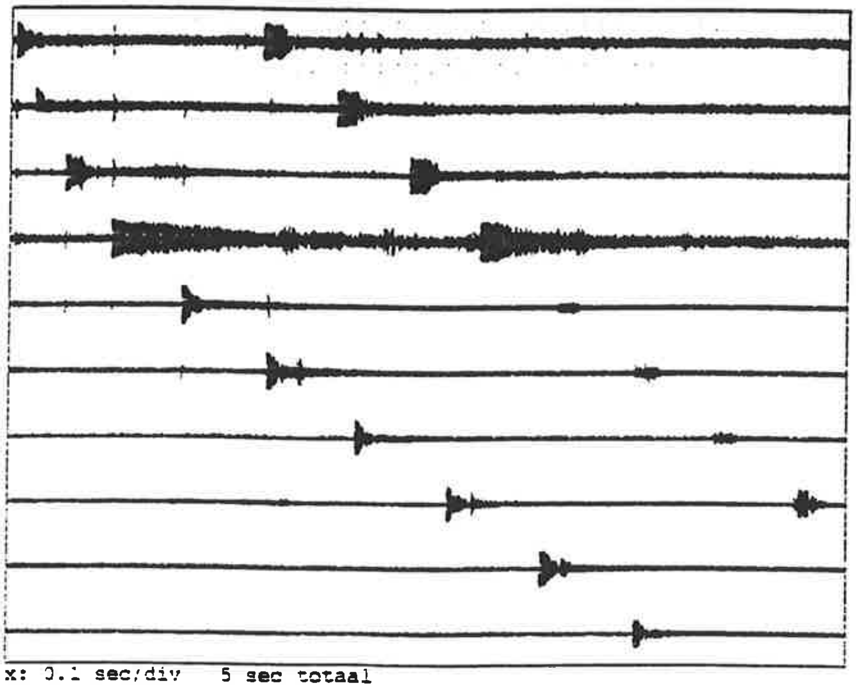


Figure 9 *Acoustic signals of a ricochet.*

Again the times of arrival have been plotted (figure 10).

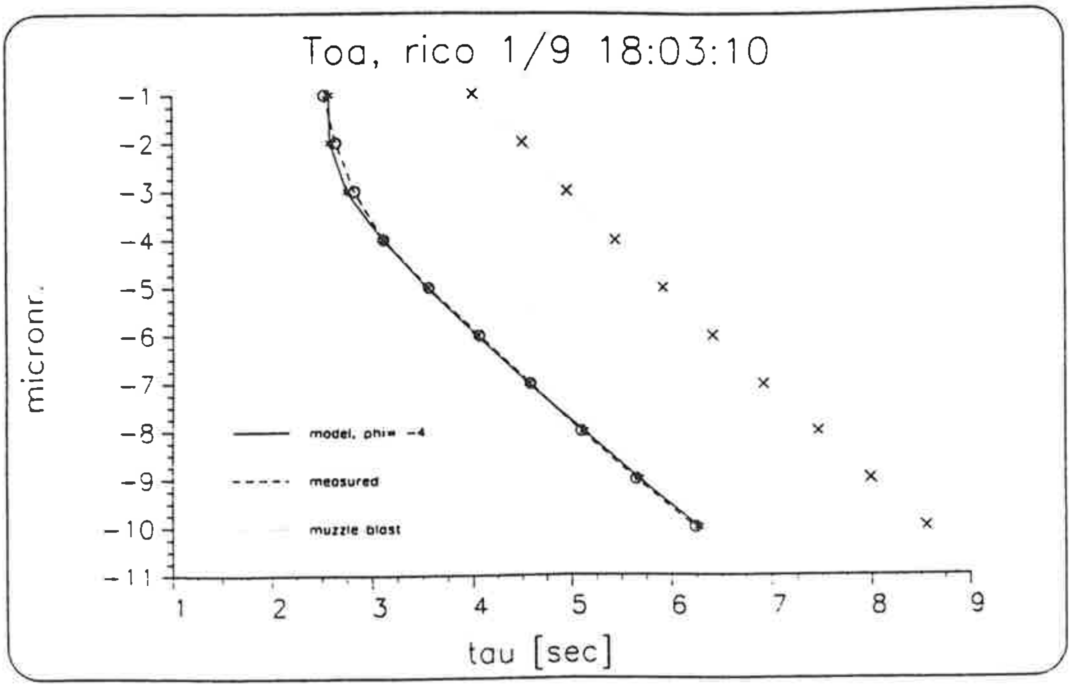


Figure 10 Measured and calculated times of arrival of the.

The plot of figure 10 gives the measured times of arrival of the signals, shown in fig. 9 and the calculated ones. The model, previously described, was changed a little bit for this purpose.
An arbitrary point of time at which the bullet is assumed to hit the ground surface, has been entered in the model. Secondly, a rather arbitrary factor, less than one, has been introduced which simulates the loss of the bullet's velocity from that point of time.
In figure 10, a time of 1.1 seconds was chosen as the moment the projectile touched the ground, and a factor of 0.6 to describe the decrease of velocity.
Also other evident ricochets could be fitted in this way.

5. Conclusions

The characterstic curves of the times of arrival could be used to discriminate between various trajectories of the projectiles. Comparison of the results of simple models with a number of controled firings (and which could clearly recorded on video) gave the evidence for a reliable discrimination.

References

[1] A.D. Pierce, Acoustics, An introduction to its Physical principles and Applications, Acoustical Society of America, Woodbury, New York, 1989.

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