

# Using Sound of Target Impact for Acoustic Reconstructions of Shooting Events

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## Abstract

**The sound of a bullet hitting a target is sometimes discernable in an audio recording of a shooting event and can be used to determine the distance from shooter to target. This paper provides an example where the microphone is adjacent to the shooter and presents the simple math needed in cases where the microphone is adjacent to the target.**

## **Introduction**

With surveillance systems becoming more ubiquitous in society, the number of shooting events being captured on audio is rapidly increasing. The sound of a bullet hitting a living target is very loud, almost as loud as the muzzle blast. This allows determination of the distance between the shooter and target if the time of the muzzle blast and target strike can be determined from an audio recording. If the location of the target is known, this greatly narrows possible locations of the shooter.

## **Method**

Deer were shot with a muzzleloader shooting sabot .40 caliber pistol bullets impacting at velocities typical of the .40 S&W cartridge (1350 fps for a 135 grain bullet). A microphone was placed near the muzzle to record both the muzzle blast and the sound of the bullet hitting the deer. The time recorded between the muzzle blast and bullet striking the target represents the sum of the bullet time of flight ( $t_b$ ) and the time for the sound to return to the microphone from the target ( $t_s$ ),

$$t = t_s + t_b = \frac{d}{V_s} + \frac{d}{V_b},$$

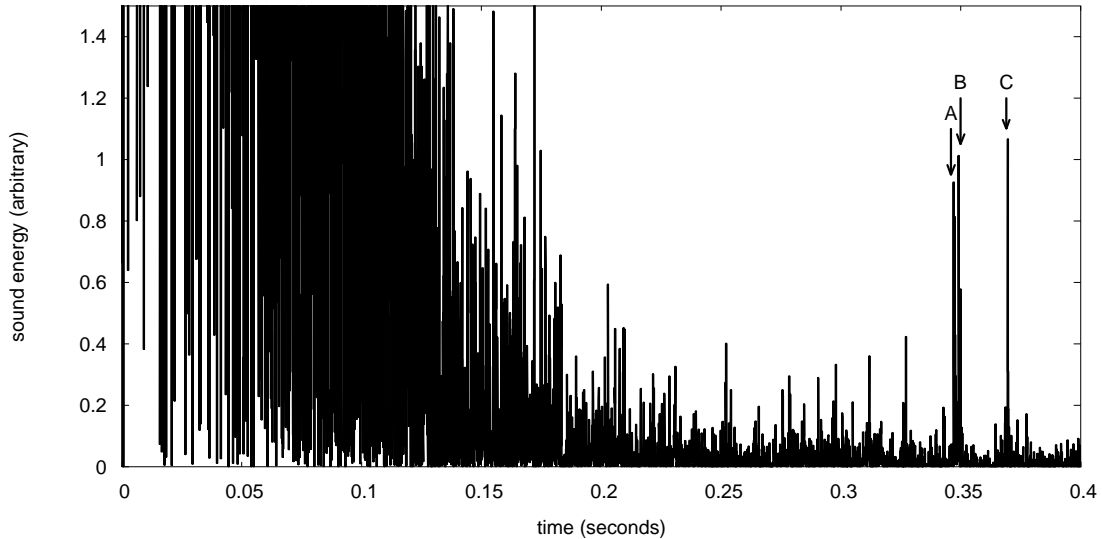
where  $d$  is the target distance,  $V_s$  is the velocity of sound, and  $V_b$  is the average bullet velocity over the distance.

$V_b$  depends on the distance, because the bullet is slowing in flight due to air resistance. Consequently, this equation must be solved using a ballistic calculator [1] and an iterative technique where one guesses different distances and computes the resulting  $t_s$  and  $t_b$  until there is agreement with the observed total time. The ballistic calculator requires knowing the muzzle velocity, ballistic coefficient of the bullet, air temperature, relative humidity, barometric pressure, and altitude. Converging on a distance is not hard since the total time is a monotonic and nearly linear function of the distance.

## **Results**

Figure 1 shows the sound waveform of a bullet hitting a deer. Sampling is triggered by the muzzle blast ( $t = 0$ ). The microphone is saturated by the muzzle blast until  $t = 0.15$  s. Peaks from  $t = 0.15$  s until the peak at A represent reverberating echoes of the muzzle blast. The peak at A records the bullet breaking the near shoulder ( $t_A = 0.34705$  s) followed by the sound of the bullet breaking the far shoulder at B. The peak at C can be tentatively identified as the sound of the temporary cavitation of the lungs striking the rib cage [2]. Since the near shoulder is close to the surface, the time of initial impact can be approximated by  $t_A = 0.34705$  s.

Figure 1: Sound Waveform of Bullet Hitting Deer



Treating the distance as an unknown in the shooting reconstruction, one can use the muzzle velocity (1884 fps), the ballistic coefficient (0.093), the speed of sound (1117.2 fps), the relative humidity (50%), the air temperature (61° F), the barometric pressure (29.98 in Hg), the altitude (1100 ft), and the measured time to impact ( $t_A = 0.34705$ ) to compute a target distance of 228 feet. The actual measured distance was 231 feet. The error (1.5%) arises from shot-to-shot variations in the muzzle velocity (about 1%) and uncertainties in the ballistic coefficient and atmospheric conditions. This procedure was repeated for the recorded shootings of five separate deer, and in each case, the acoustic distance determination was accurate to within 2%.

### Discussion

We have shown that it is possible to use an audio recording of a shooting event to accurately determine the distance between the target and shooter. In cases where the location of the microphone is different, the mathematical details are different, but the ideas are the same. For example, if the microphone is adjacent to the victim (such as a 911 recording might be), the equation for determining the distance becomes:

$$t = t_b - t_s = \frac{d}{V_b} - \frac{d}{V_s}$$

If the muzzle blast duration obscures the sound of the bullet hitting the target, simple inspection of the sound waveform is insufficient. Filtering techniques or spectrogram generation might recover the time of the target hit, or determination of the target hit might not be possible. However, in cases where the microphone is adjacent to the target and the bullet is supersonic, the sound of the bullet hitting the target occurs first, so it cannot be obscured by the muzzle blast.

The observation that a bullet hitting a living target makes a very loud sound [3] also suggests the possibility of locating the target by triangulation in cases where there are three or more microphones present. This is the case in municipalities employing gunshot detection systems such as the Shot Spotter system [4] may be possible for gunshot detection systems to quickly distinguish between random gunfire into the air, and shots that strike a target.

## Footnotes and References

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[1] <http://www.eskimo.com/~jbm/>

[2] The assignment of features in the audio waveform with specific physiological structures is not obvious and depends upon detailed physics and acoustical analysis which is beyond the scope of the current paper. For the current purpose, it is sufficient to assign the initial peak (labeled A) of the bullet hit as the time of the target strike.

[3] In Figure 1, the muzzle blast appears louder, but this is only because the microphone is adjacent to the muzzle and the target is over 231 feet away. Sound falls off with distance, so the source closer to the microphone appears larger. In cases where the microphone is adjacent to the target, the target strike appears louder. In cases where the target and gun are roughly the same distance the microphone, the two signals are of comparable magnitude.

[4] [www.shotspotter.com](http://www.shotspotter.com)