An introduction to forensic gunshot acoustics

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An Introduction to Forensic Gunshot Acoustics

November 3, 2011

Steven D. Beck
steve.beck@baesystems.com

BAE Systems
6500 Tracor Ln. MS 27-16
Austin, TX 78725

Hirotaka Nakasone
Hirotaka.Nakasone@ic.fbi.gov

Kenneth W. Marr
Kenneth.Marr@ic.fbi.gov

FBI
ERF-E Bldg 27958A
Quantico, VA 22135

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The primary reference is our JASA paper:

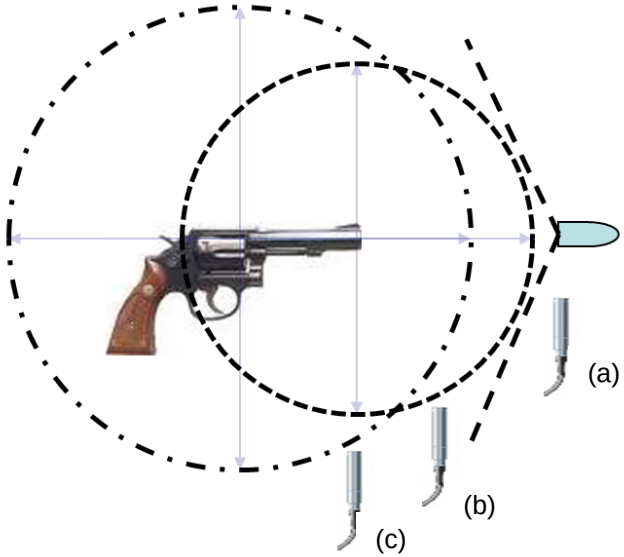
S. Beck, H. Nakasone, and K. Marr, “Variations in recorded acoustic gunshot waveforms generated by small firearms,” J. Acoust. Soc. Am. **129**, 1748-1759 (2011)

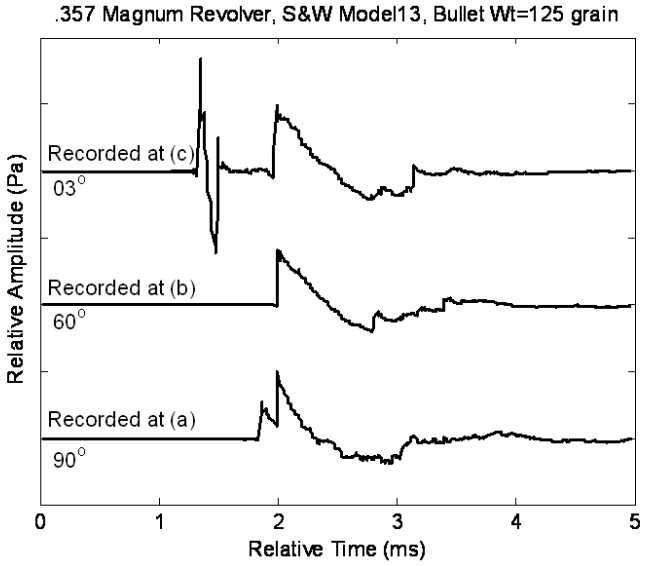
The Forensic Gunshot Problem

- Gunshot sounds are made up of one or more discrete acoustic events
- The waveform characteristics of any event depend on many different variables
  - ➢source, channel, and receiver
- Most gunshots recorded in forensic conditions do not match standard theoretical models

Typical

MB Only





Experimental Data Collection

Firearm Variables Under Investigation Include:

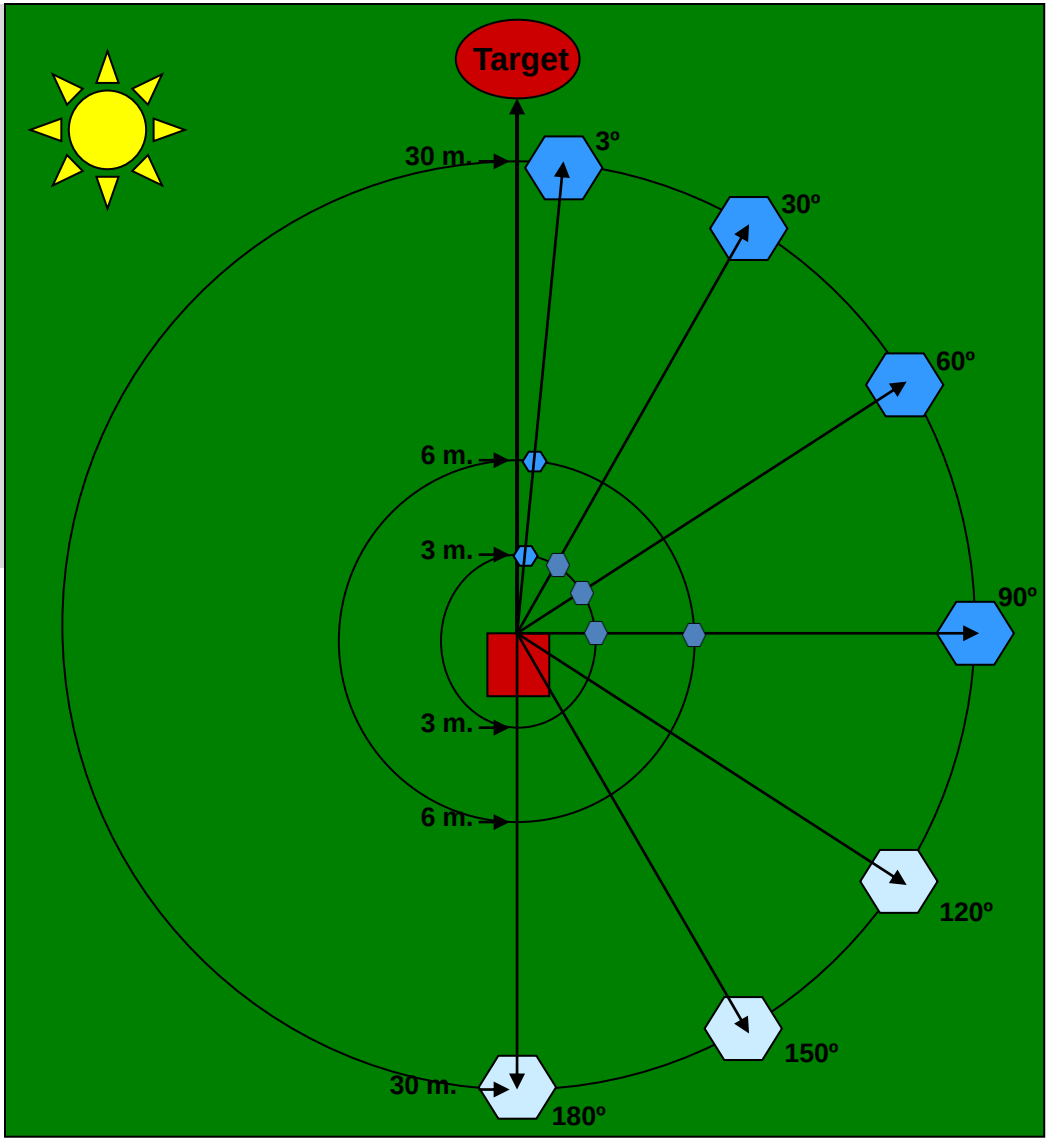
- Different firearm types, makes and models
- Different barrel lengths
- Different ammunition types and weights

Index	Firearm Caliber and Type	Firearm Make[1] and Model	Barrel (in / cm)	Bullet Type[2]	Bullet Wt (grains / gram)	Bullet Speed (m/s at 2 m)	SPL[3] (dB re 20 µPa)
1	.357 Magnum Revolver	S&W Model 13	3.0 / 7.7	Win. STHP	145 / 9.4	362.4	155.4
2	.357 Magnum Revolver	S&W Model 13	3.0 / 7.7	Rem. JHP	125 / 8.1	427.0	158.5
3	.38 Revolver	S&W Model 10	2.5 / 6.4	Win. STHP	110 / 7.1	269.7	153.0
4	.38 Revolver	S&W Model 10	4.0 / 10.3	Win. STHP	110 / 7.1	287.1	151.4
5	.38 Revolver	S&W Model 60	2.5 / 6.4	Win. STHP	110 / 7.1	250.2	155.4
6	9 mm Pistol	Sig Sauer P-226	4.5 / 11.5	Win. FMJ	115 / 7.5	333.8	153.7
7	9 mm Pistol	Colt Model 2000	4.5 / 11.5	Win. FMJ	115 / 7.5	345.0	153.7
8	9 mm Pistol	Sig Sauer P-226	4.5 / 11.5	Win. STHP	115 / 7.5	344.7	152.5
9	9 mm Pistol	Colt Model 2000	4.5 / 11.5	Win. STHP	115 / 7.5	357.5	153.1
10	9 mm Pistol	Sig Sauer P-226	4.5 / 11.5	Win. FMJ	147 / 9.6	280.7	152.4
11	9mm Pistol	Colt Model 2000	4.5 / 11.5	Win. FMJ	147 / 9.5	288.3	151.9
12	.30-06 Rifle	Winchester 70	22.0 / 56.4	Win. Soft Pt.	125 / 8.1	889.1	160.8
13	.30-06 Rifle	Winchester70	22.0 / 56.4	Win. Soft Pt.	165 / 10.7	827.5	160.1
14	.223 Rifle	Colt M16A1	21.0/ 53.8	Win. Hollow Pt.	64 / 4.1	803.8	156.0

[1] S&W=Smith&Wesson
[2] Win.=Winchester, Rem.=Remington, STHP = Silver Tip Hollow Pt; FMJ = Full Metal Jacket; JHP = Jacketed Hollow Pt
[3]Estimated values at 1 m and at an angle of 90^{o}

Experimental Data Collection

- High quality recording equipment
- Cross firing angle recordings at multiple distances
- Cross range recordings at multiple firing angles
- Ground truth measurements:
  - Barrel length, SPL, temperature, reflections, distance, azimuth angle



Muzzle Blast Theory

Friedlander Model

$$p(t) = P_0 + P_s\left(1 - \frac{t}{T_0}\right)e^{\frac{-bt}{T_0}}$$

Let T_0=0.5 ms and b=1,
Ps = 200 Pa.
SPL = 140 dB re 20 μPa.

Spectrum

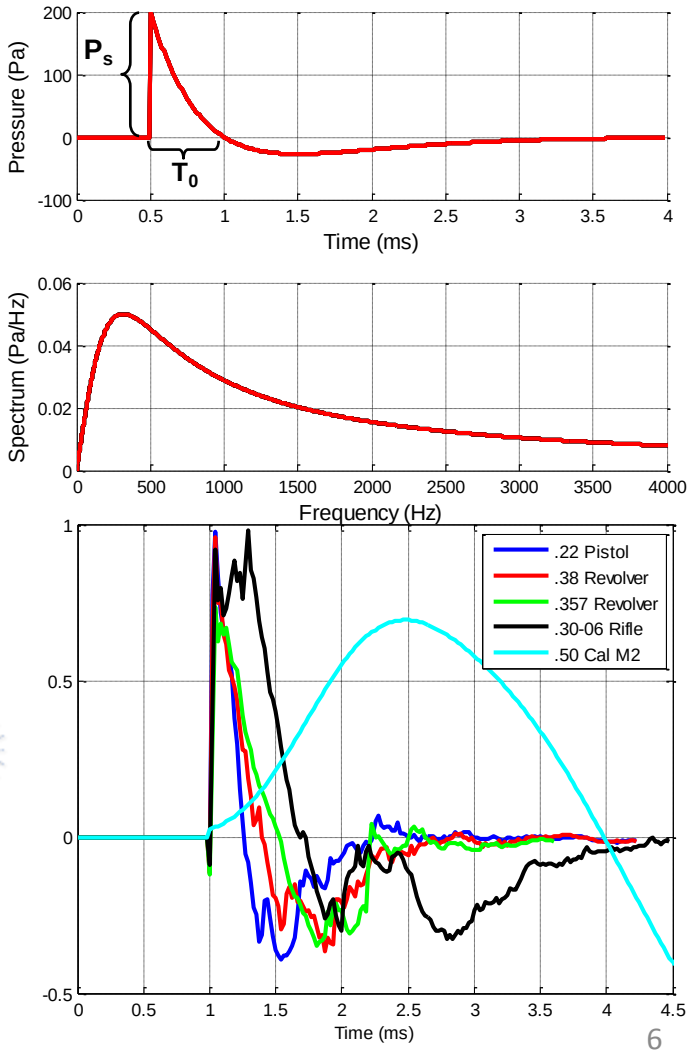
$$\|F(w)\| = \frac{P_s}{T_0}\frac{\sqrt{(b-1)^2 + T_0{}^2 w^2}}{(b/T_0)^2 + w^2}$$

$$w_{peak} = \frac{1}{T_0}\sqrt{-b^2 + 4b - 2}$$

Let T_0=0.5 ms and b=1.
f_{peak} = 2000/(2π) = 318 Hz.

Firearm Caliber & Type (Typical)	SPL @ 1m Re 20 μPa	Peak Freq (FFT)
.22 Pistol	146 dB	750 Hz
.38 Revolver	151 dB	500 Hz
.357 Magnum	155 dB	400 Hz
.30-06 Rifle	160 dB	250 Hz
.50 Cal Sniper	170 dB	75 Hz

Muzzle Blast Waveform and Spectrum



Ballistic Shockwave Theory

N-Wave Model

$$f(t) = P_N\left(1 - \frac{2(t-\tau)}{T_N}\right) \qquad \tau \le t \le \tau + T_N$$

$$\sin\alpha = \frac{v}{u}$$

Magnitude

$$P_N = P_P - P_0 = \frac{0.53P_0 d\left(M_a{}^2 - 1\right)^{\frac{1}{8}}}{y^{\frac{3}{4}} l^{\frac{1}{4}}}$$

- Dominant factors are Mach speed, bullet diameter, and miss distance

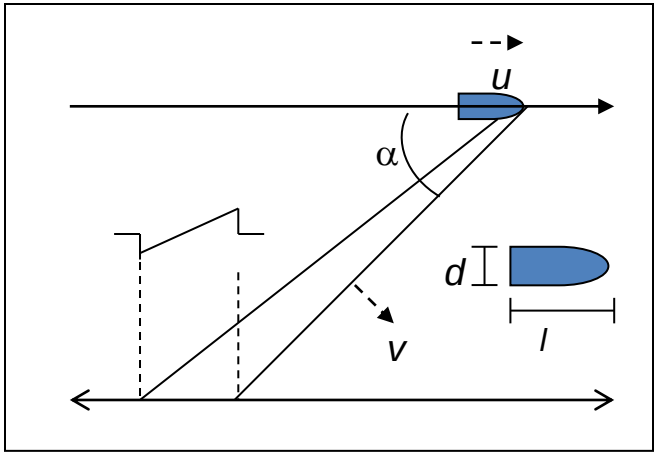
Duration

$$T_N = \frac{1.82M_a d}{v_0\left(M_a{}^2 - 1\right)^{\frac{3}{8}}}\left(\frac{y}{l}\right)^{\frac{1}{4}}$$

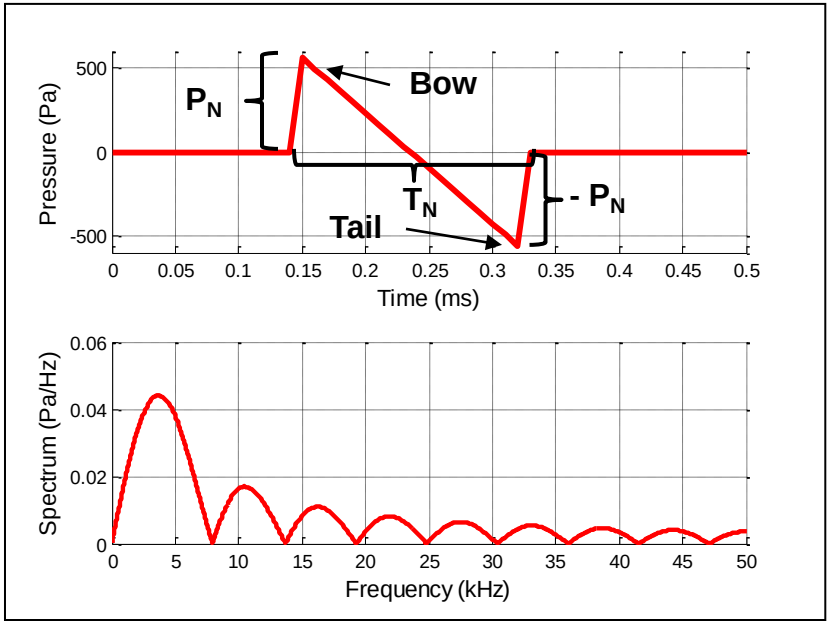
- Dominant factors are Mach speed and bullet diameter

Spectrum

$$F(w) = \frac{2P_N}{w}\left|\cos\left(\frac{wT_N}{2}\right) - \frac{2}{wT_N}\sin\left(\frac{wT_N}{2}\right)\right|$$



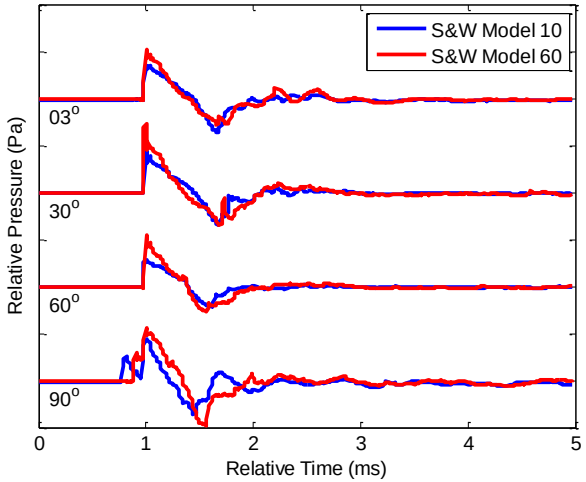
Ballistic Shockwave and Spectrum



Source Variations

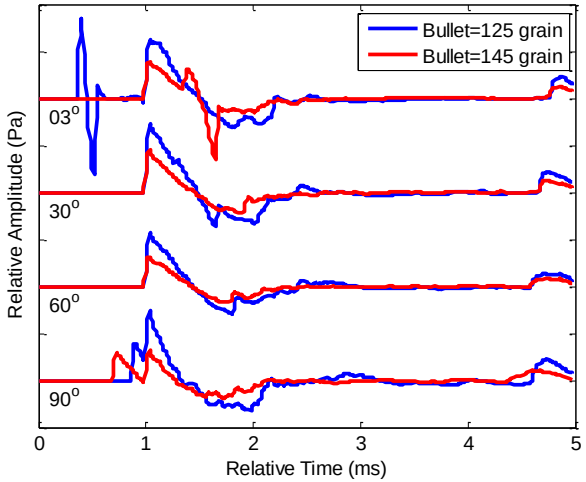
Different Revolver Models

Barrel Len=4.0 in, 110 Gr



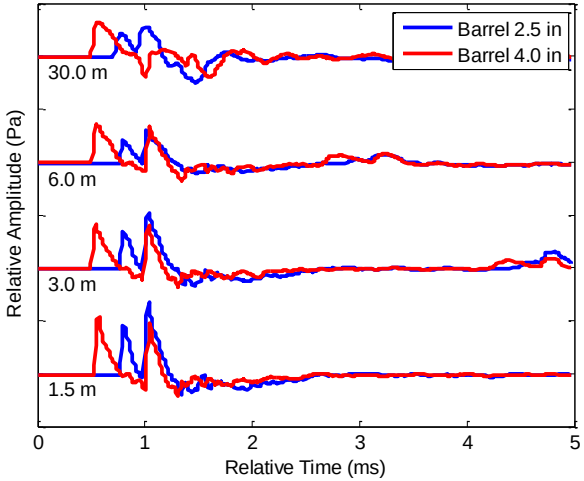
Different Bullets

.357 Magnum Revolver, S&W Model 13

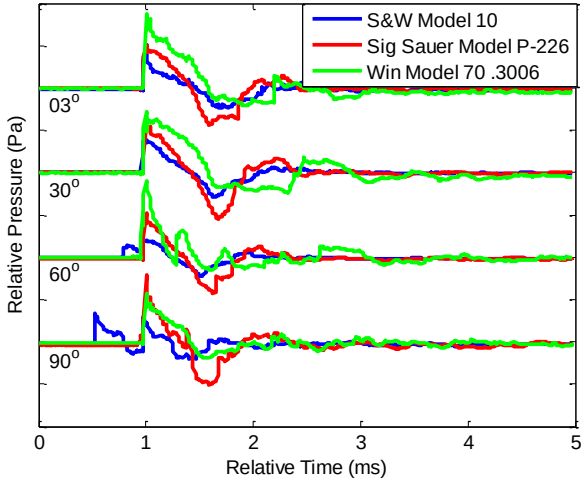


Different Barrel Lengths

.38 Revolver, S&W Model 10, 110 Gr



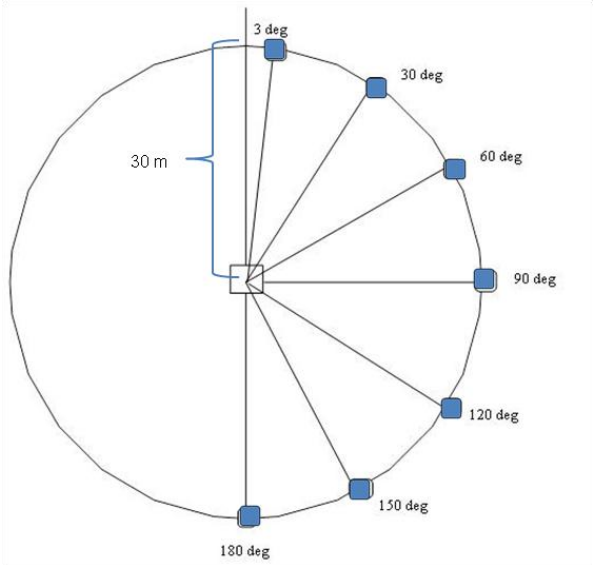
Revolver, Semi-Auto, Rifle



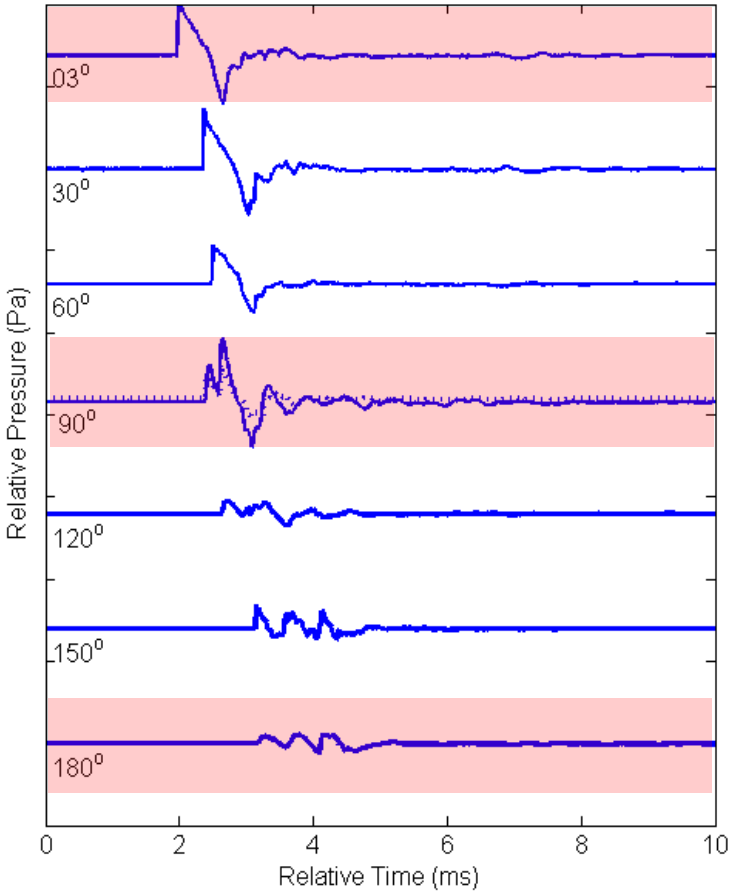
Channel (Azimuth) Variations

Recordings at Multiple Angles

- The muzzle blast is highly directional
- Waveforms at 3, 90, 180 deg are significantly different



Recordings of a .38 caliber revolver
Smith&Wesson Model 10 with 2.5 in. barrel
Ammunition: Winchester STHP 110 grain



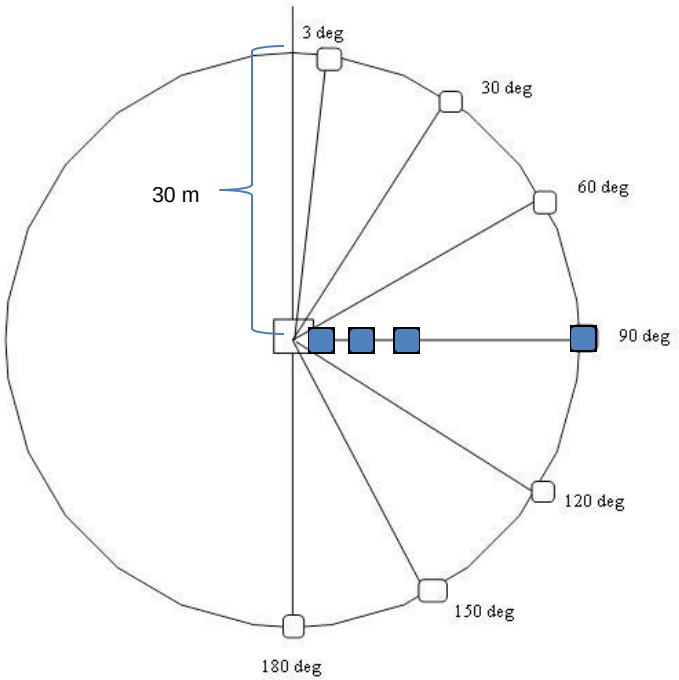
"…the difference in level and waveform details between on-axis and off-axis recordings of the same firearm are often significantly greater than the difference between two firearm types at the same azimuth."

R.C. Maher and S.R. Shaw, "Directional aspects of forensic gunshot recordings," Proc. Audio Engineering Society 39th Conference, Audio Forensics—Practices and Challenges, Hillerød, Denmark, June 2010.

Channel (Distance) Variations

Recordings at Multiple Distances

- High frequency loss at longer range
- Ground reflections “walk-in” at increasing distances
- At long distance, ground reflections can interfere with the main blast



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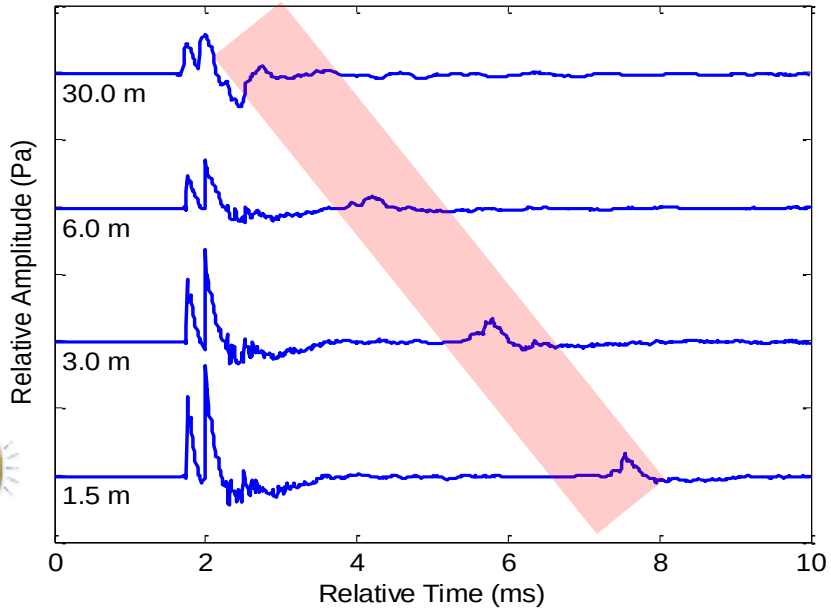
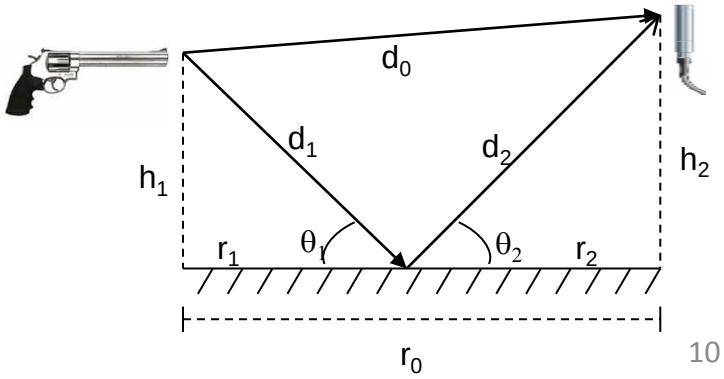
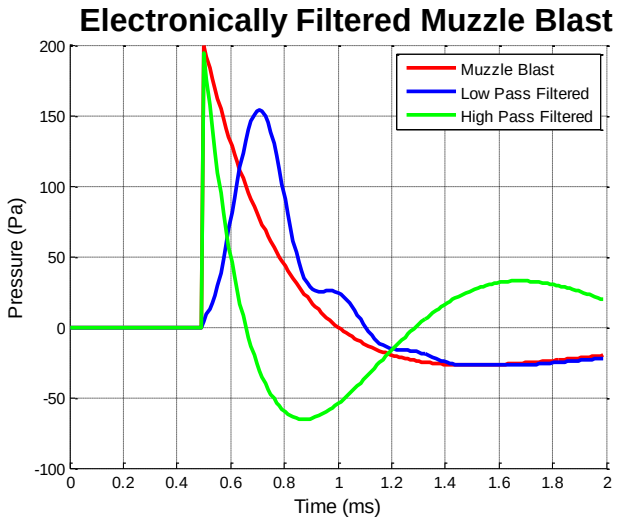
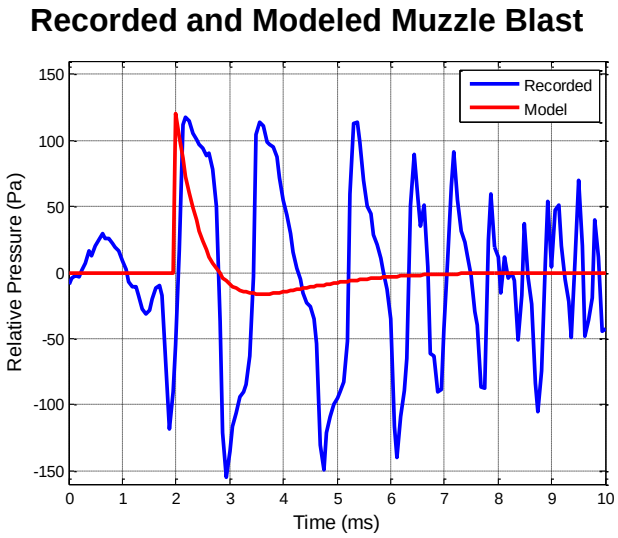


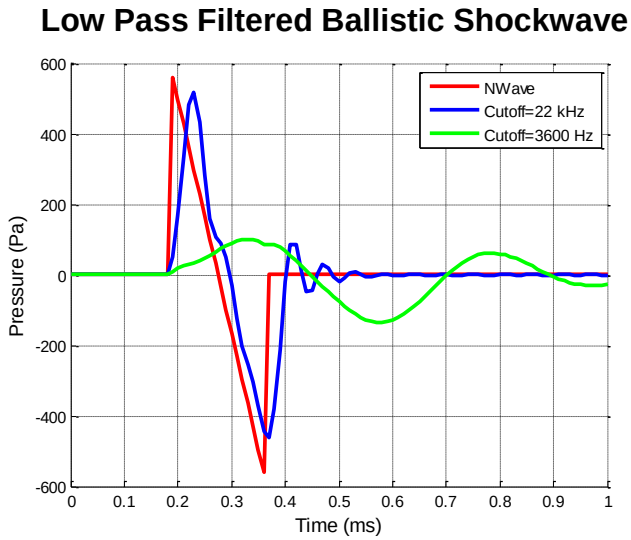


Channel and Receiver Variations

- High pass filtering significantly alters the Muzzle Blast waveform
- Low pass filtering significantly alters the Ballistic Shockwave waveform
- Audio waveforms recorded under forensic conditions are usually filtered and have reverberation.

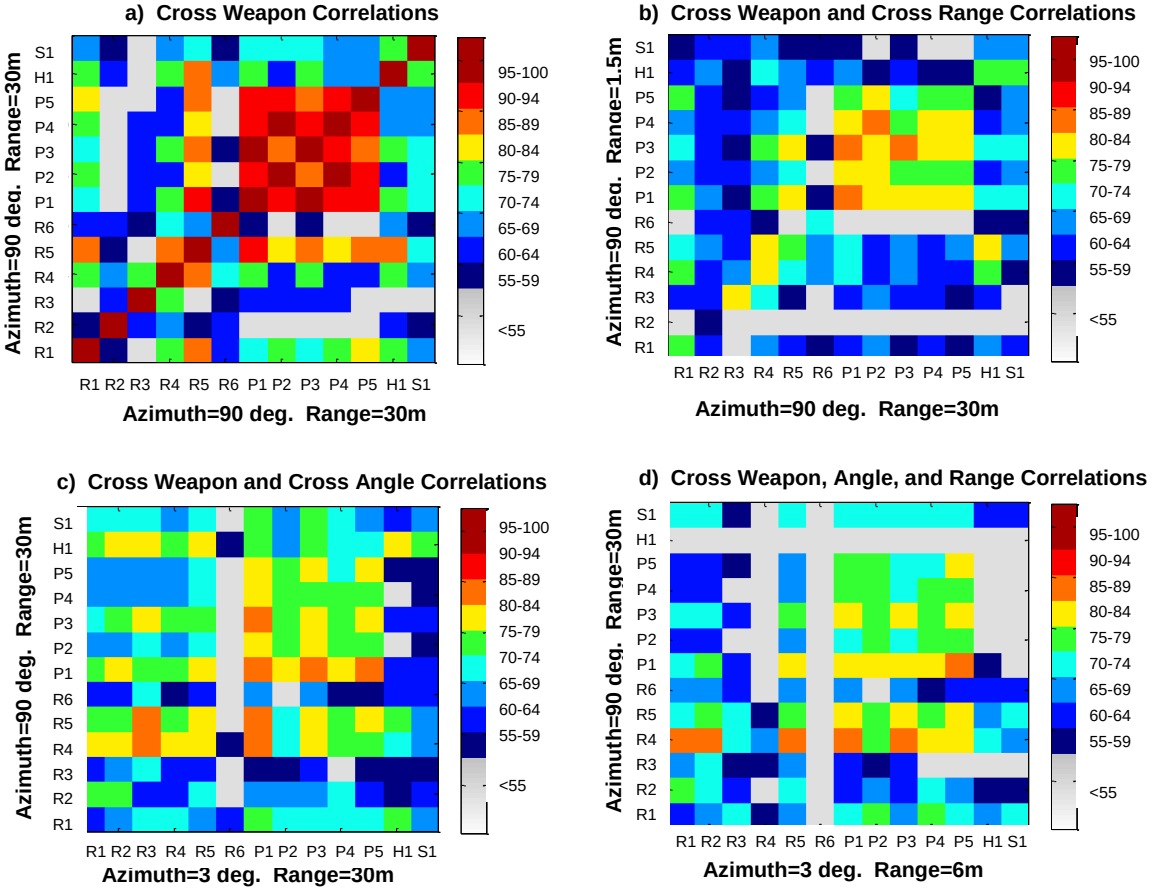






Correlation Analysis of Forensic Recordings

	Firearm Cal	Firearm Model	BLen (in)	Ammunition Desc
R1	.38 Revolver	S&W Model 10	2.5	Win. 110 gr., STHP
R2	.38 Revolver	S&W Model 10	4.0	Win. 110 gr., STHP
R3	.357 Mag Rev	S&W Model 13	3.0	Win. 145 gr., STHP
R4	.357 MagRev	S&W Model 13	3.0	Rem. 125 gr., JHP
R5	.38 Revolver	S&W Model 60	2.5	Win. 110 gr., STHP
R6	.44 MagRev	Ruger Black Hawk	7.5	Win. 210 gr., STHP
P1	9 mm Pistol	Sig Sauer P-226	4.5	Win. 115 gr., FMJ
P2	9 mm Pistol	Sig Sauer P-226	4.5	Win. 147 gr., FMJ
P3	9 mm Pistol	Colt Model 2000	4.5	Win. 115 gr., FMJ
P4	9mm Pistol	Colt Model 2000	4.5	Win. 147 gr., FMJ
P5	.380 Pistol	Walther PPKS	3.5	. 95 gr., FMJ
H1	.30-06 Rifle	Winchester70	22.0	Win. 125 gr., SP
S1	12 Shotgun	Remington 870	20.0	Win. #8 Birdshot

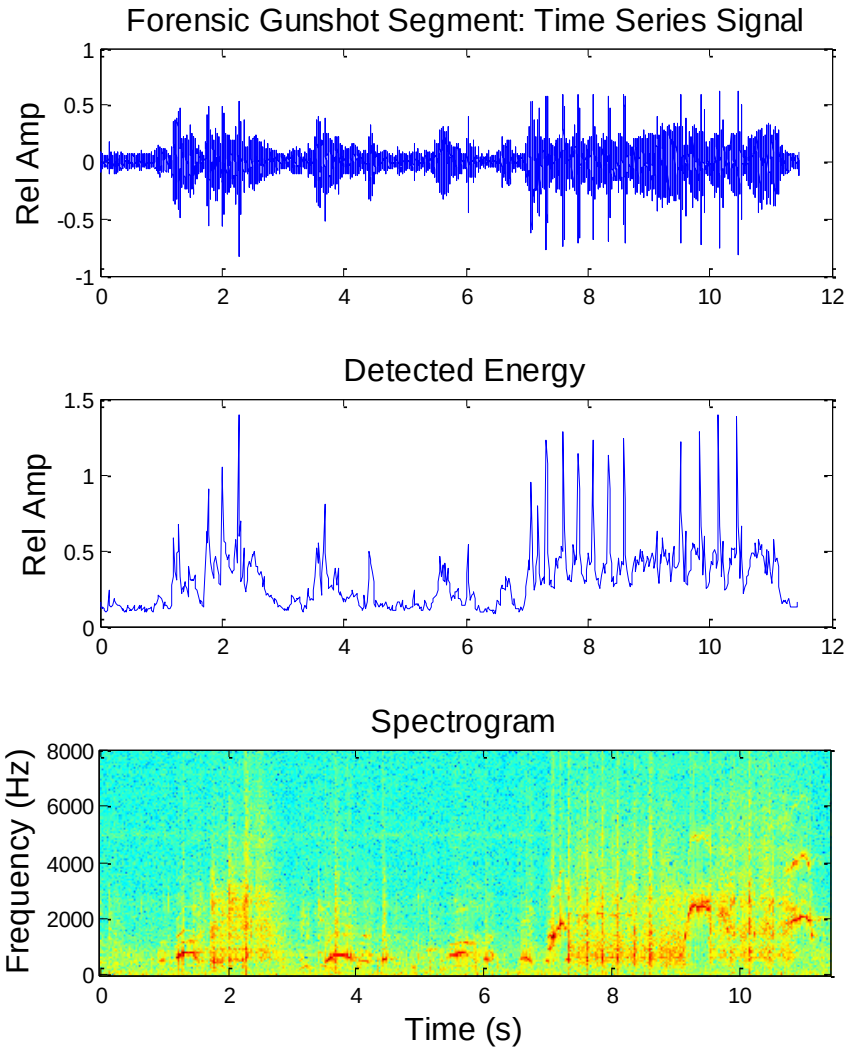


- Only very similar firearms have relatively high correlation
- Cross range and Cross firing angle result in lower correlations

Forensic Gunshot Analysis Example

Typical Forensic Gunshot Recording

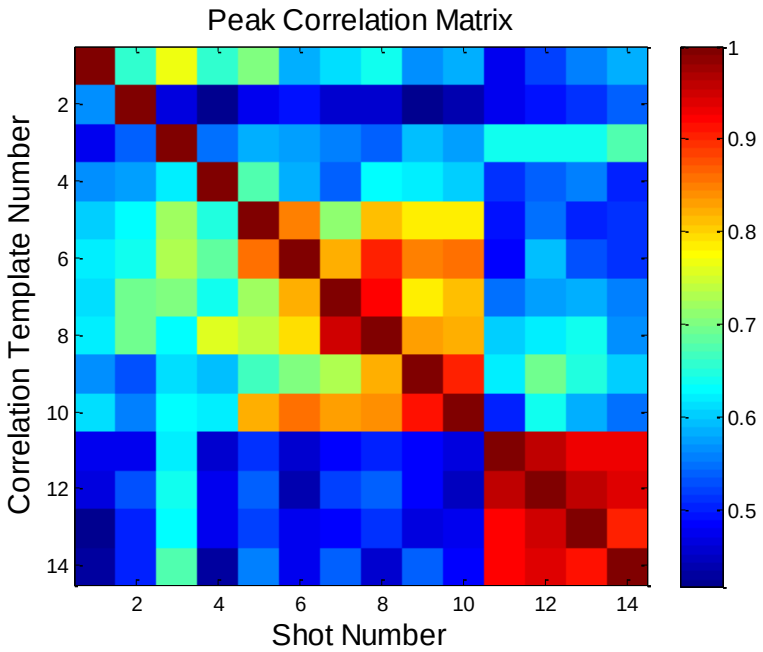
- Multiple firearm shots are recorded
- Firing orientation is unknown and possibly changes
- Significant interference due to voices
- Significant reverberation in unknown environment
- The recording system appears to have a HPF

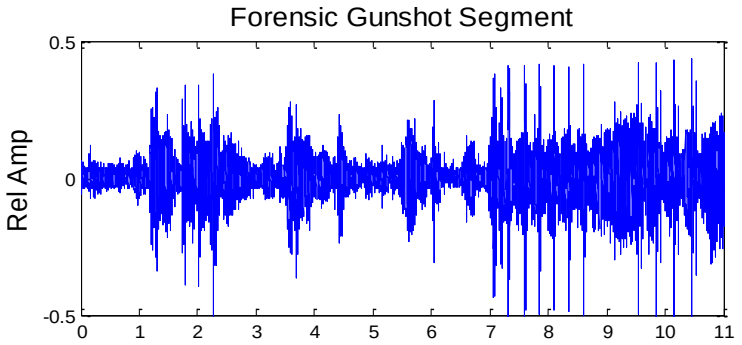


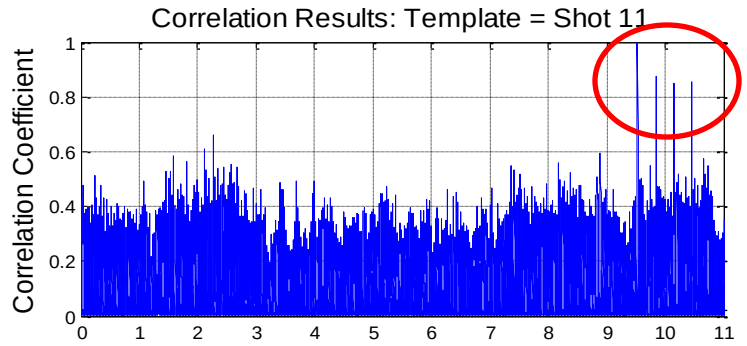
Forensic Gunshot Analysis Example

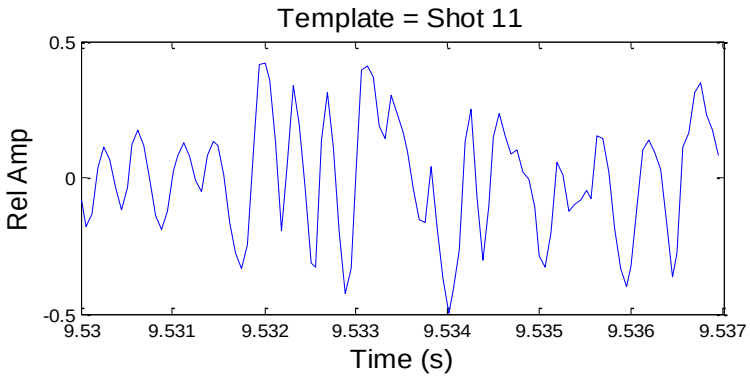
Correlation Analysis

- Every likely shot was extracted and used as a template
- Each template was correlated against the entire file
- The peak correlation values for each shot are shown
- At least two firearms, each firing multiple successive shots
- The first 4 shots do not correlate well – too many variations









Conclusions

- There are numerous acoustic source variations that can assist or limit discrimination among recorded gunshots
- Uncontrollable variations can significantly alter the waveform
  - Angle (turn and fire)
  - Propagation distance and reverberation
  - Recording system filters and/or saturation
- Shot-to-Shot Correlation is one of the few tools available to the analyst
  - but it breaks down if the firing conditions change
- **Forensic Need**:
  - Better forensic analysis tools
  - Better forensic models
  - Additional “real world” forensic testing
    - Can reverberation be modeled and accounted for?
    - How do new and different microphones affect gunshot signals?
    - How does compression affect gunshot signals?