Acoustical Characterization of Gunshots

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Outline

- Applications
- Gunshot acoustical properties
  - Mechanical action
  - Muzzle blast
  - Shock wave (supersonic projectiles)
- Range effects
  - Propagation and Attenuation
  - Reflections
  - Limitations
- Conclusions

Gunshot Analysis Applications

- Real Time Tactical Information
  - Gunshot Detection
  - Sniper Localization
- Forensic Reconstruction
  - Timeline Assessment
  - Shooter Location and Orientation
  - Firearm Classification

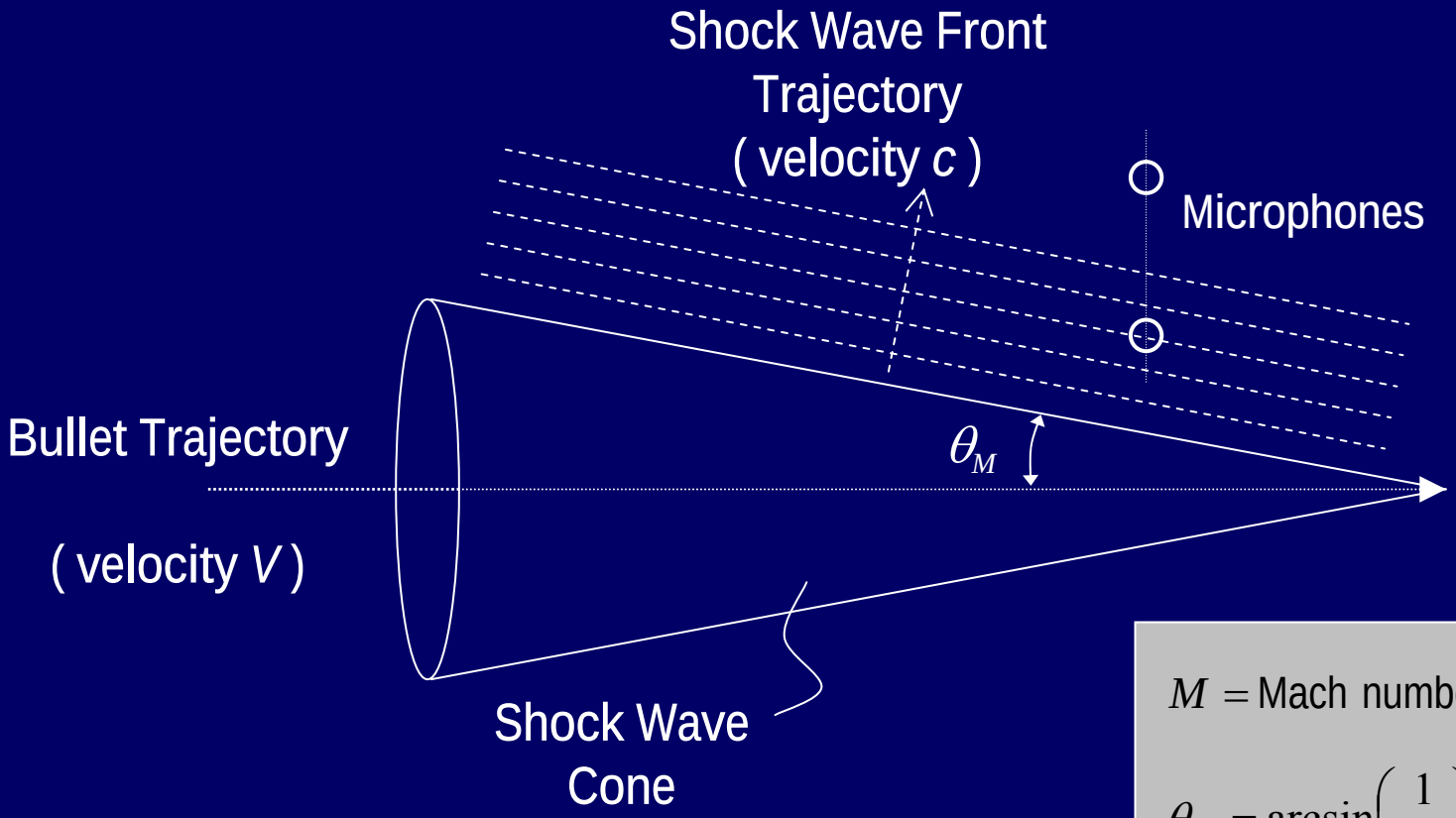
Sound Characteristics

- Acoustic behavior depends upon:
  - Firearm type
  - Projectile parameters
  - Explosive load
  - Distance
  - Meteorology
  - Obstacles

Acoustical Gunshot Evidence

- Mechanical Action
- Muzzle Blast
- Supersonic Projectile (shock wave)
- Surface Vibration
- Reflections, Refraction, Reverberation
- Microphone Type and Location
- Audio Coding Issues (e.g., cell phone)

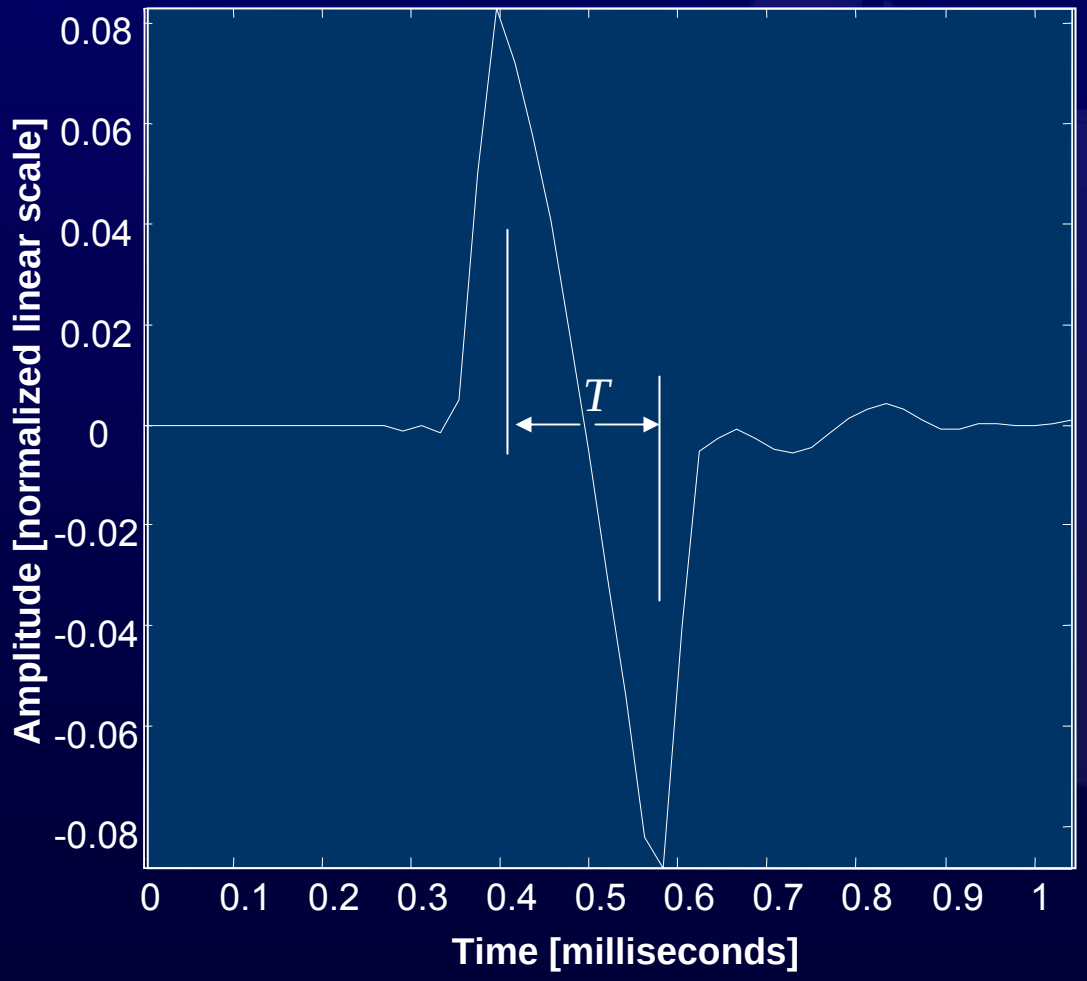
Supersonic Projectile



$$M = \text{Mach number} = \frac{V}{c}$$

$$\theta_M = \arcsin\left(\frac{1}{M}\right)$$

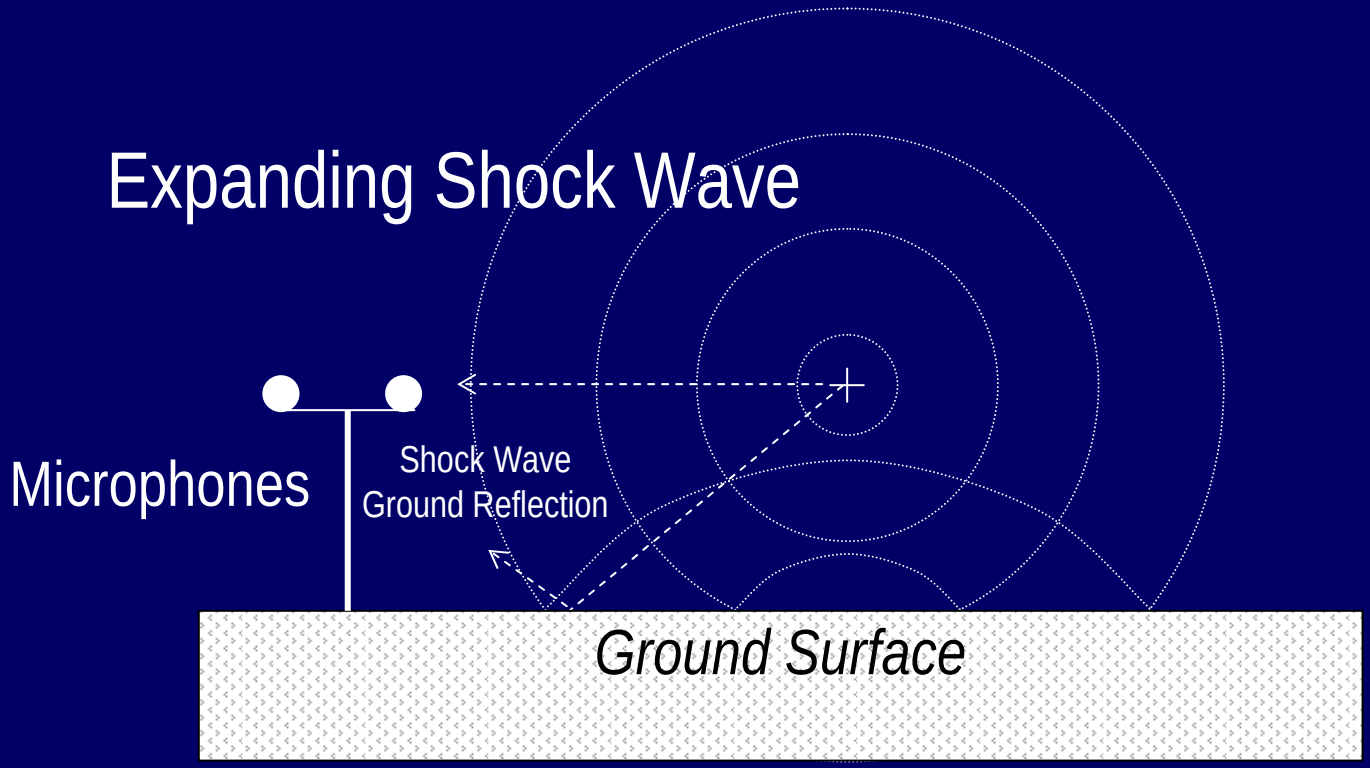
‘N’ Shaped Shock Wave



$$T \approx 1.82\left(\frac{d}{c}\right)\left(\frac{Mx}{l}\right)^{\frac{1}{4}}$$

d = bullet diameter
c = speed of sound
M = Mach number
x = path to microphone distance
l = bullet length

Multipath: Ground Reflection



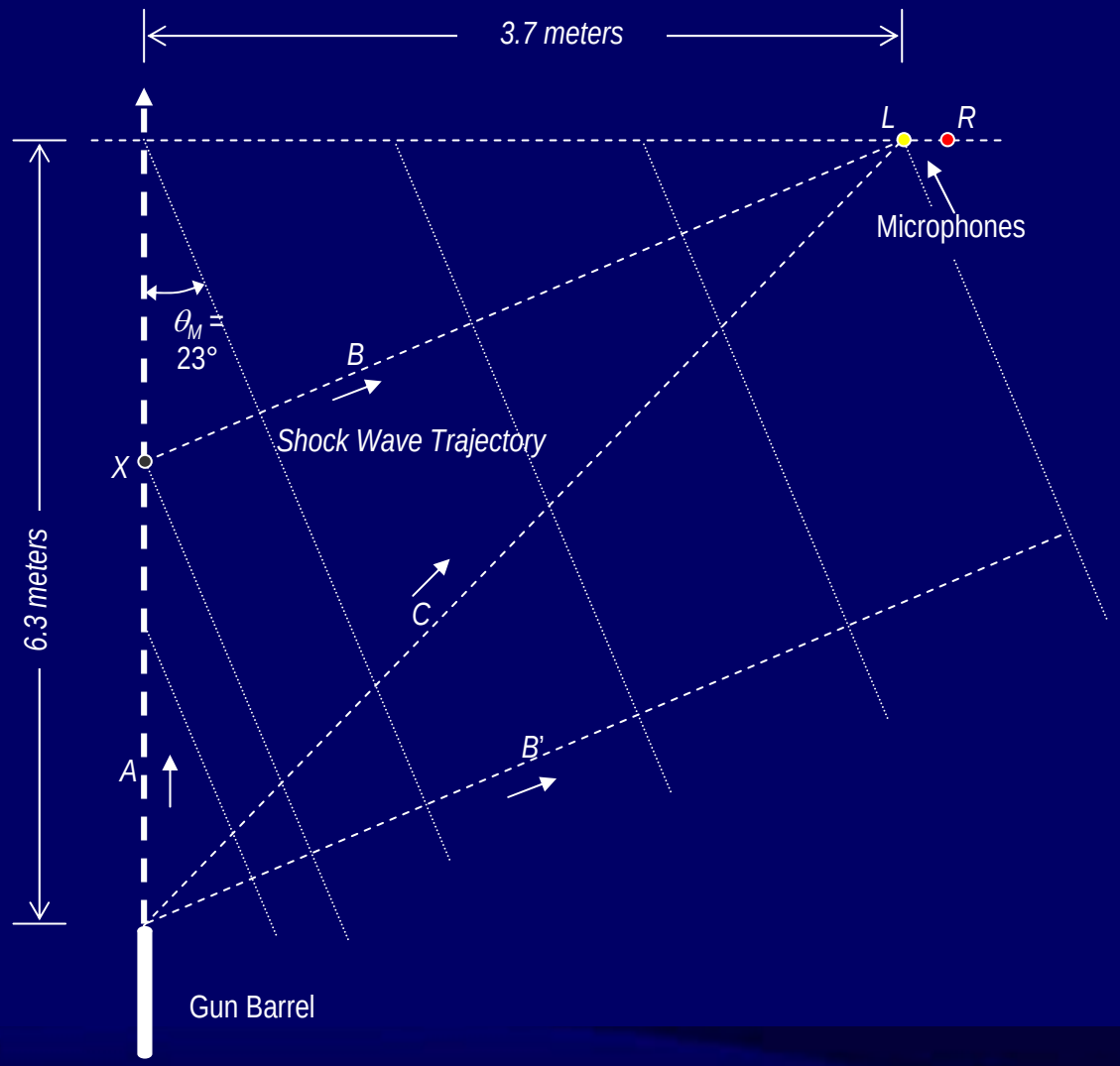
Shock Wave Timing Example

Bullet speed at muzzle:
2728 ft/sec (831.5 m/sec)

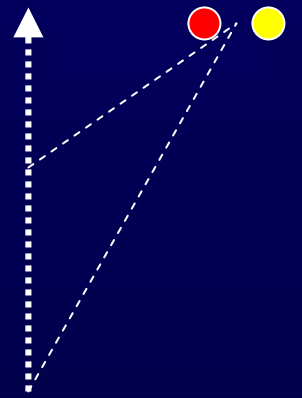
Speed of sound (c):
1075 ft/sec (328 m/sec)

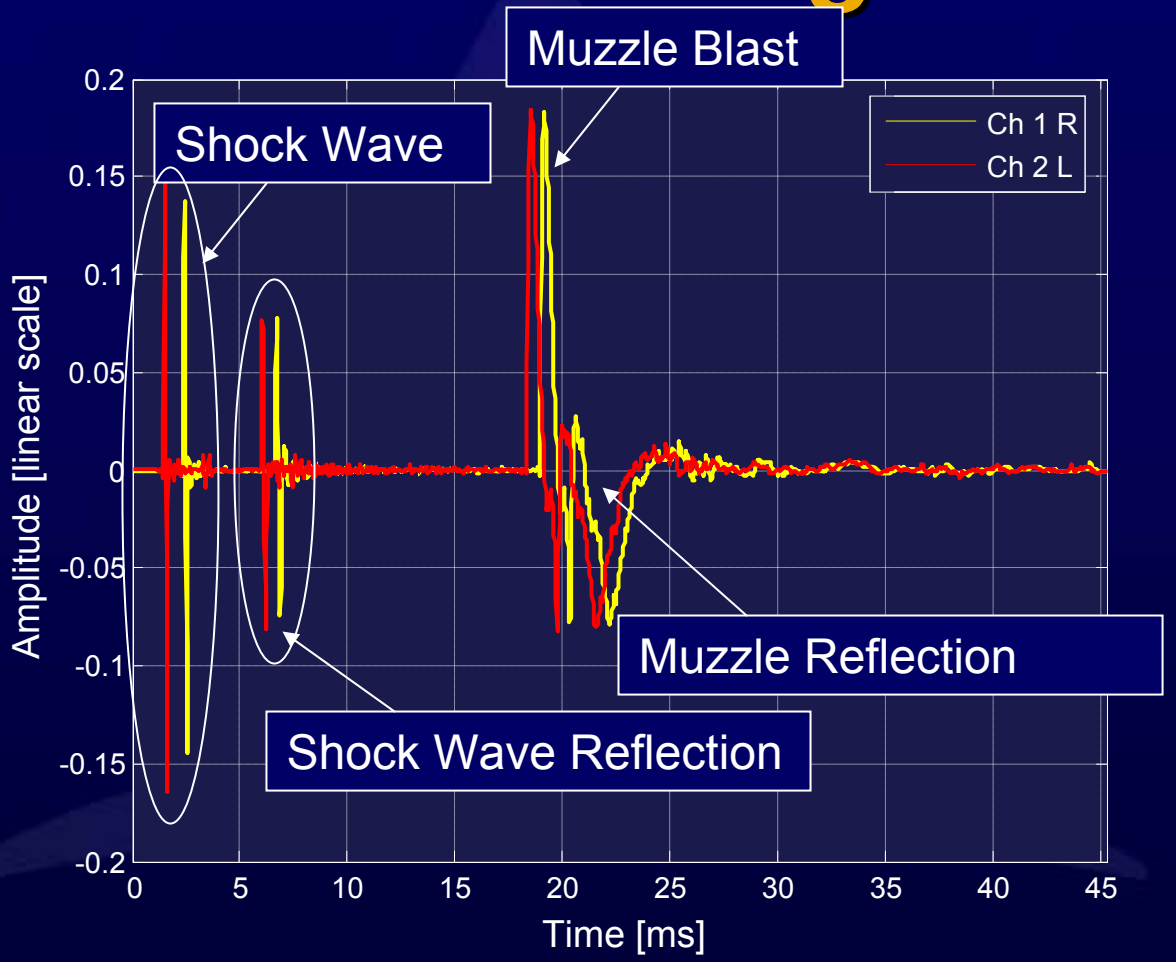
Mach Number (V/c):
2.54

Mach Angle (θ_M):
23.2°

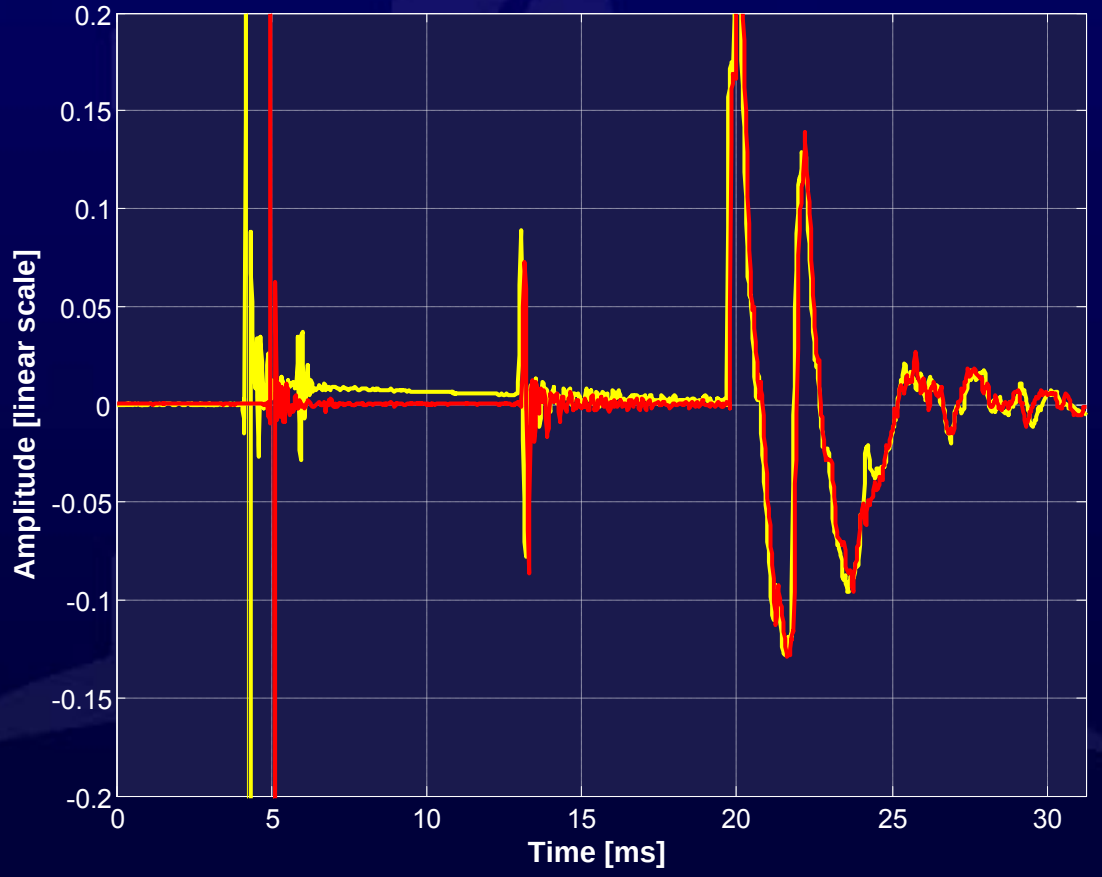


Gunshot Recording: Path 1

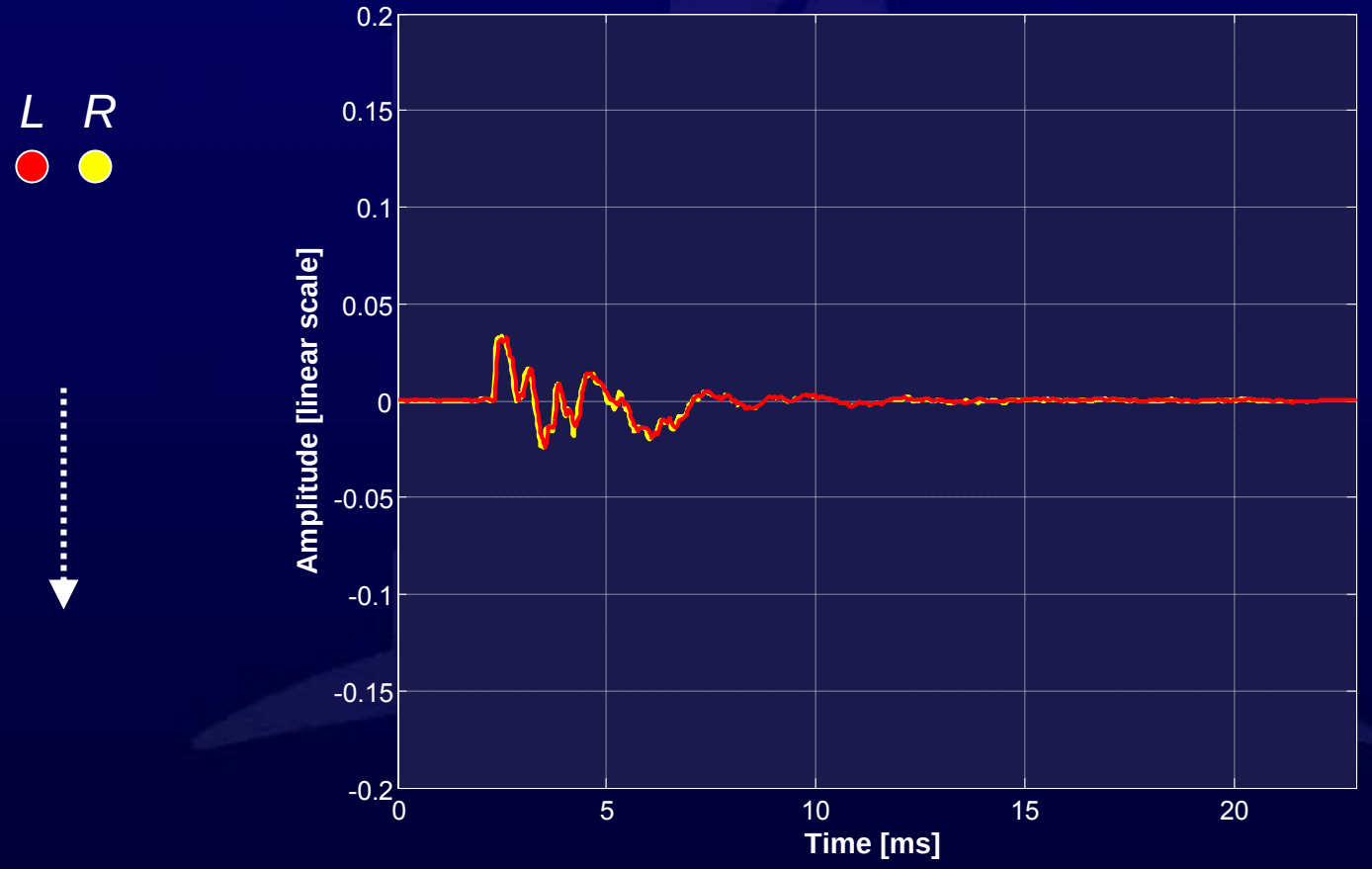




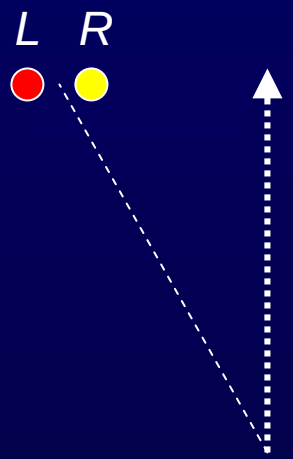
Gunshot Recording: Path 2

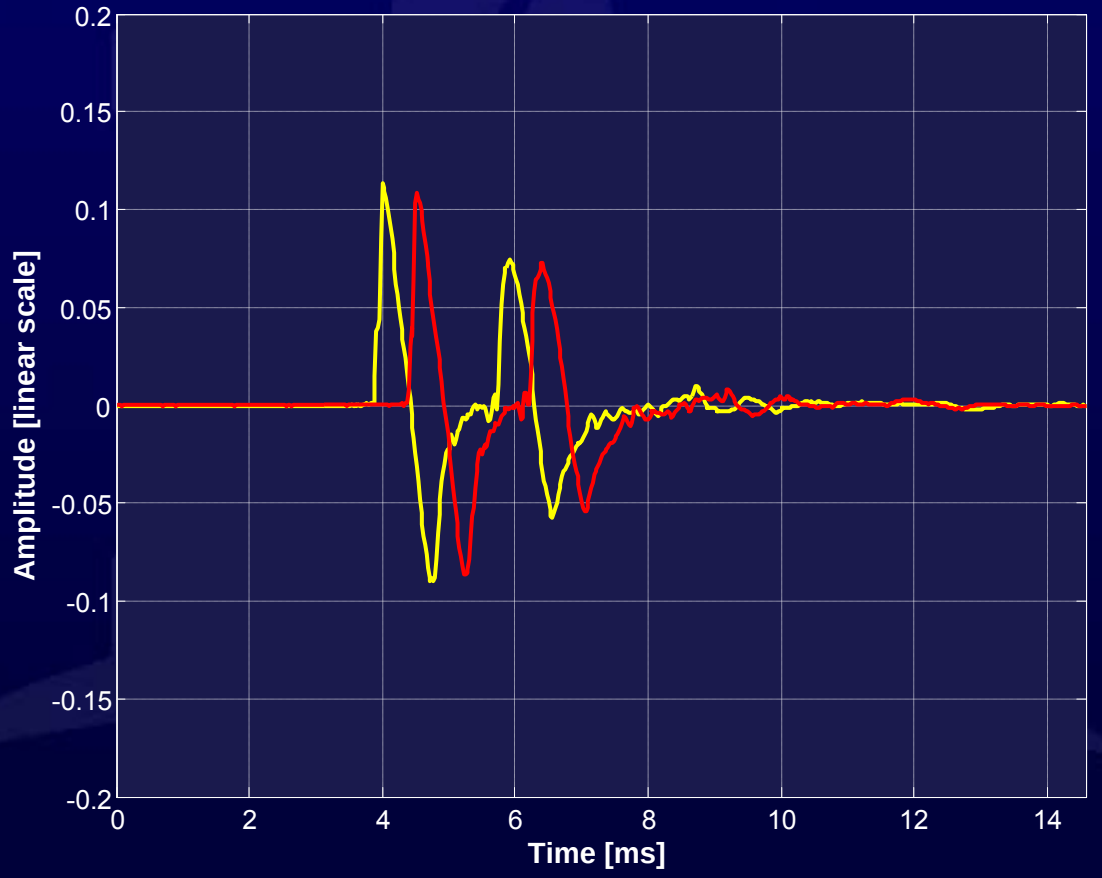


Gunshot Recording: Path 3



Gunshot Recording: Subsonic

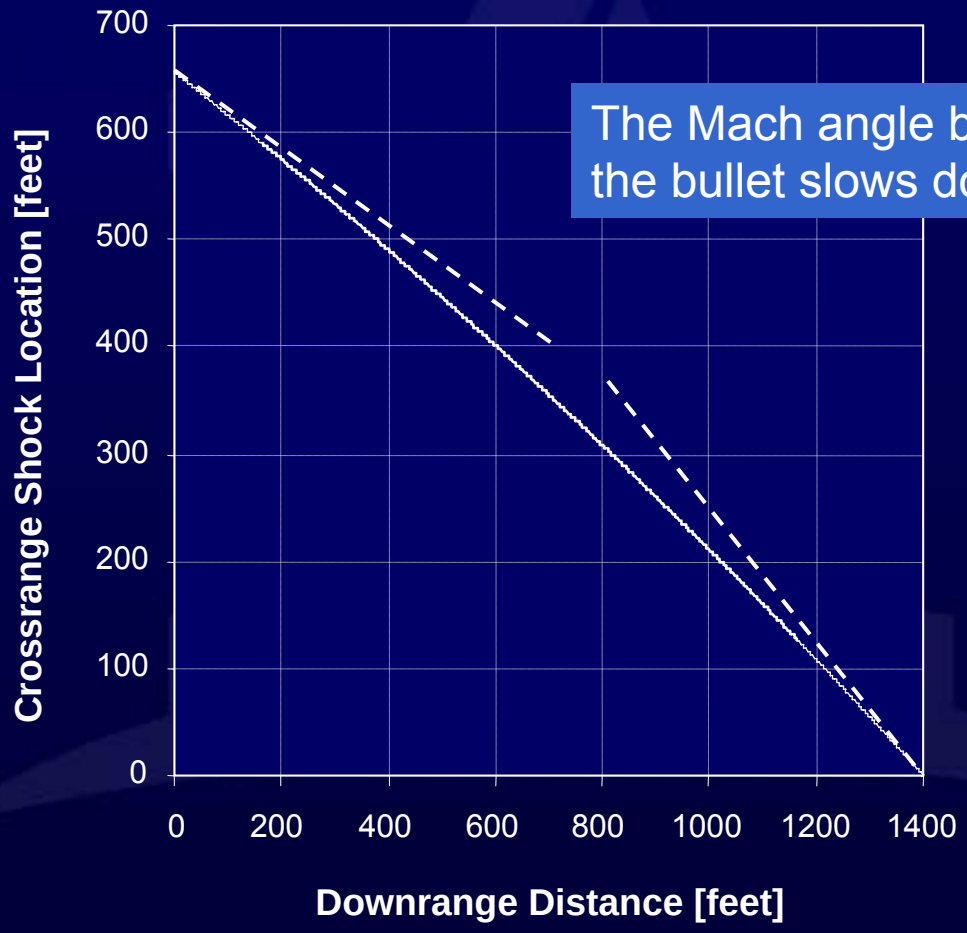




Propagation Effects

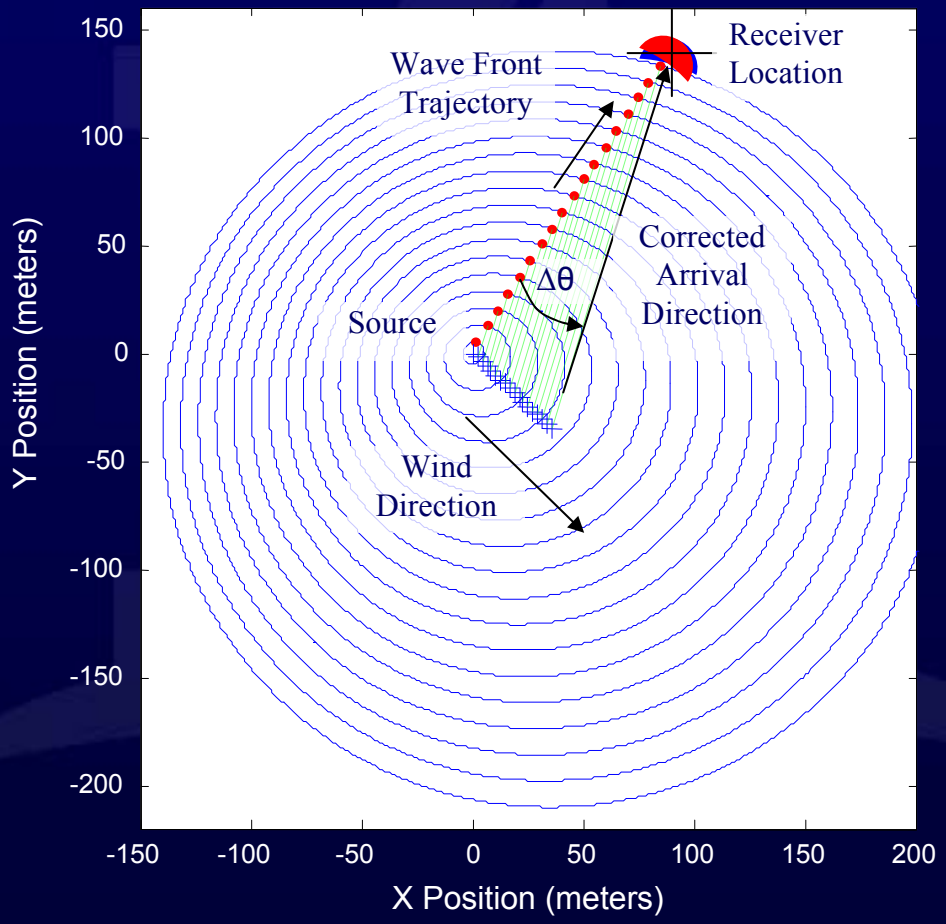
- Attenuation due to acoustical spreading
- Obstacles: reflection and diffraction
- Path elevation trajectory
- Projectile deceleration
- Temperature gradient
- Wind gradient

Projectile Deceleration



The Mach angle broadens as the bullet slows downrange

Effect of Wind



Effect of Temperature

- The speed of sound (c) in air increases with increasing temperature:

$$c = c_0\sqrt{1+\frac{T}{273}}$$

(T in ° C and c_0 = 331 m/s)

- Hotter air near ground: curves upward
- Cooler air near ground: curves downward

Conclusion

- Closely-miked gunshot recordings:
  - Geometric acoustics works well
- Distant recordings:
  - Propagation effects lead to greater uncertainty due to altered sound path
  - Reflections and reverberation dominate
- Verification is needed to assess the validity of acoustic analysis claims