Firearm Sound Suppression

Nature and Measuring of Firearm Sounds

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Nature of Sound

- Air in motion
- Pressure variation the human ear can detect
- Pressures measured in Pascals*
- Threshold of human hearing:

  20 μPascals (0 dB)
- Sound is a form of overpressure

*NOTE: 1 PSI = 6895 Pascal

Decibels (Db)

- Pressures in Pascals are unwieldy numbers
- Decibels are a ratio of pressures

(named after Alexander Graham Bell)

$$dB = 10(\log_{10}(P_1/P_0))$$

where P_0 is the reference pressure (20 μPa) and P_1 is the measured pressure

Example: doubling (or halving) of the pressure is a 3 dB change, changing the pressure by a factor of 10 is a 10 dB change or a factor of 100 a 20 dB change

If 1 PSI = 6895 Pascal. How many PSI overpressure is a 170 dB gunshot?

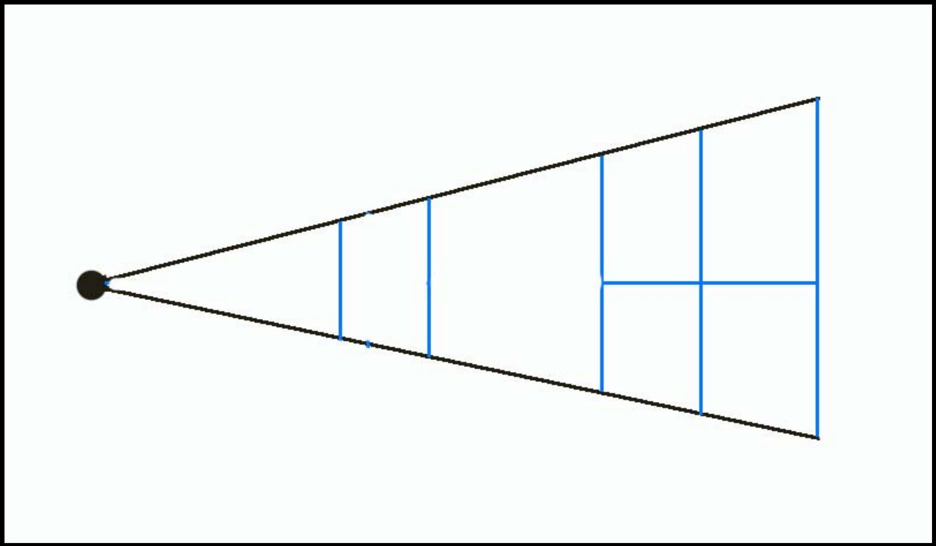
Firearm Sound Sources

Firearm sound generated by

1. Sudden release of hot, high pressure propelling gases in bore, and
2. Sound of bullet in flight (ballistic crack/sonic boom) which is generated outside the weapon system and cannot be addressed by a suppressor

Firearm Sound Character

Sound diminishes by inverse square law as observer moves away from source. Each doubling of distance reduces sound level by 6 dB.



How Loud are the Weapons?

P229	.357 SIG	162-163 dB
P229	.40 S&W	161-162 dB
P228	9mm	159-162 dB
AR15	.223	162-163 dB (164 db M4)

(All measured 1 meter to the left of the muzzle)

Maximum Safe Sound Levels

Maximum permissible sound exposure before hearing protection is required:

- Steady Sound (OSHA) : 85 dB work environment (40 hr/week, 52 wk/year)
- Peak Firearm sound (MIL-STD-1474D) : 140 dB

(Assuming no other excessive exposure)

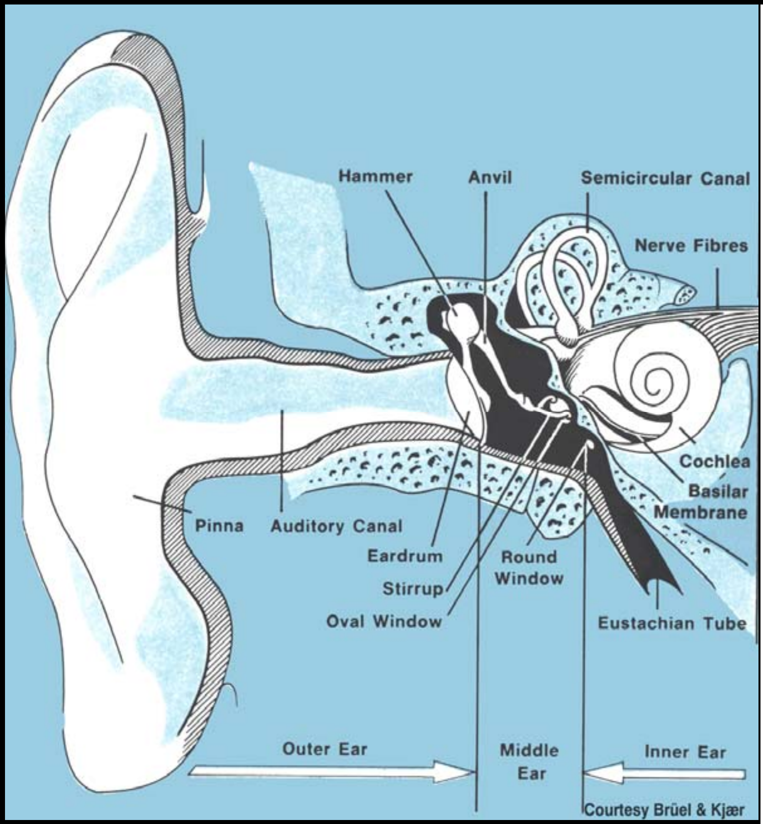
Firearms and Hearing Damage

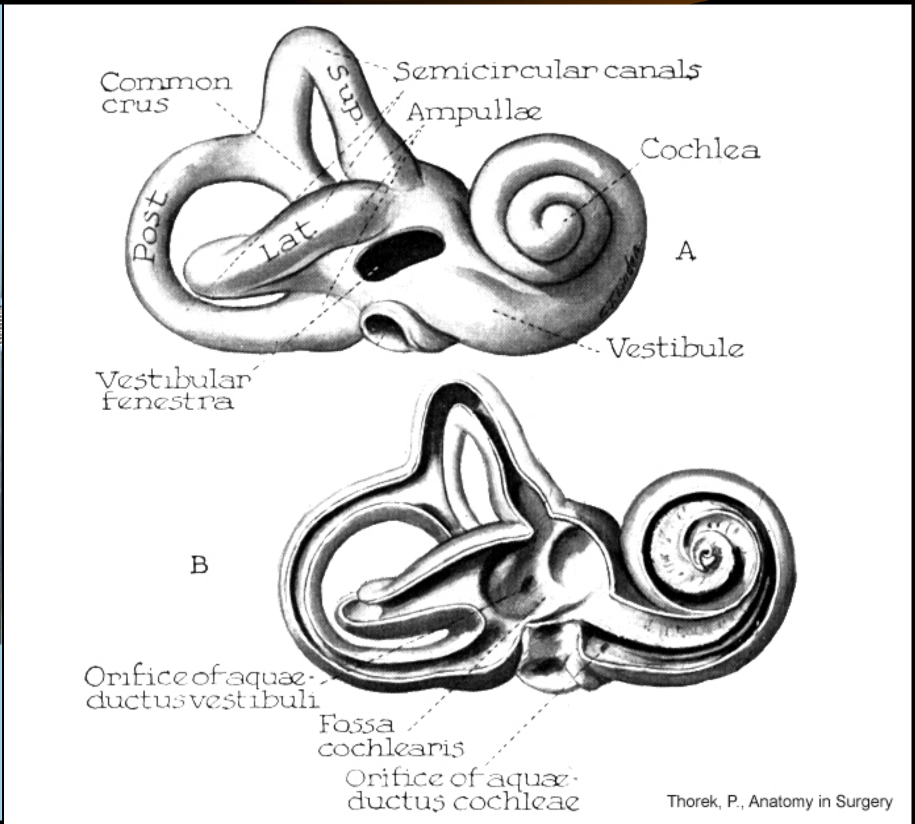
- Hearing damage is dose related and cumulative.
- Damage also relates to the total sound energy exposure.
- Firearm sounds are of short duration, so shorter time exposure permits higher energies.

Firearms and Hearing Damage

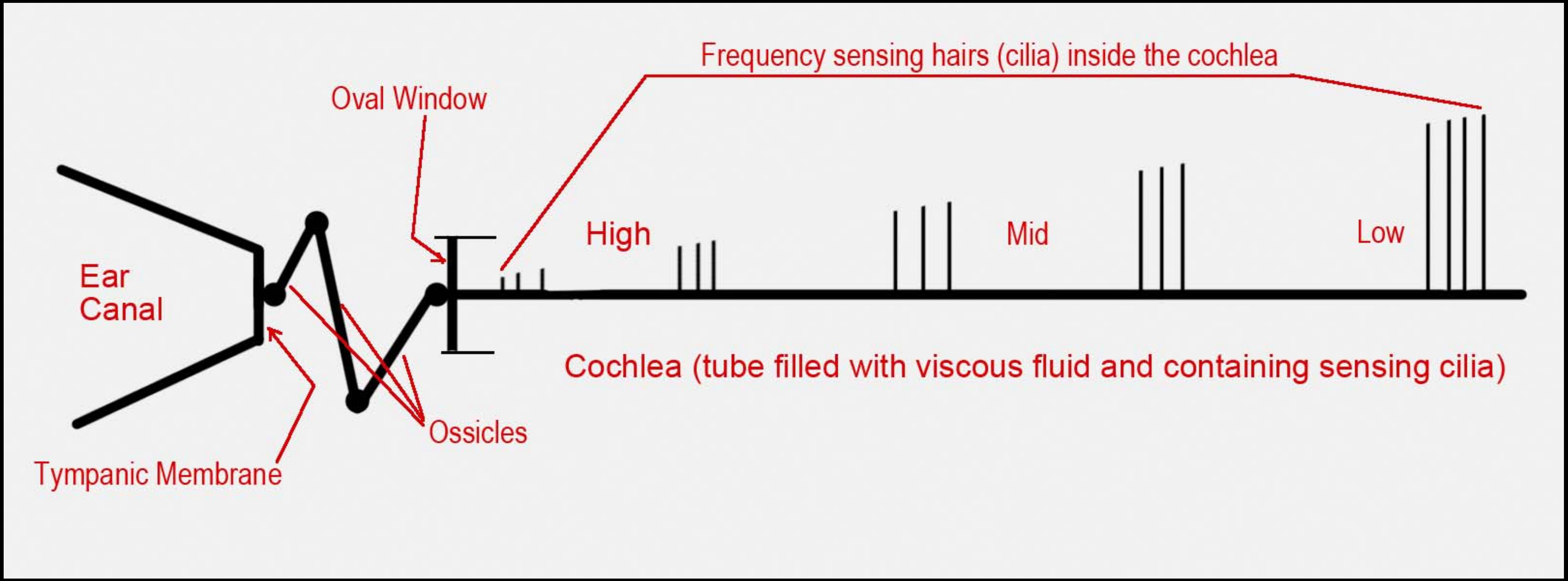
Because of the short duration, gunshots are not perceived as being as loud as a lower intensity continuous sound source.

Hearing Mechanism





Hearing Damage Mechanisms



Hearing Damage Mechanisms

- Continuous high sound levels cause inflammation of the cilia (sensing hairs) in the cochlea resulting in eventual loss of the sensory hair.
- High intensity peaks can shear the cilia
- High frequency sensing hairs, closer to the oval window, are more susceptible to damage than low frequency sensors.

Action type & Effects on SPL

Locked breech weapons do not vent gases

Direct Impingement gas operated weapons vent unlocking gases into the bolt/bolt-carrier.

Piston systems vent gases directly from the barrel port before the muzzle and suppressor. *These will be loudest at the shooter's ear and cannot be addressed by a suppressor.*

Action type & Effects on SPL

Suppressed sound levels referenced to an M4 Carbine
(M855 ball ammunition, 14.5” barrel, same suppressor)

HK 416	5 dB louder
SIG 551	14 dB louder
Steyr AUG	9 dB louder
Bolt action	Same (however, barrel was 20”)
AR-15	2 dB quieter (20” barrel)

Measurements 1 meter let of muzzle

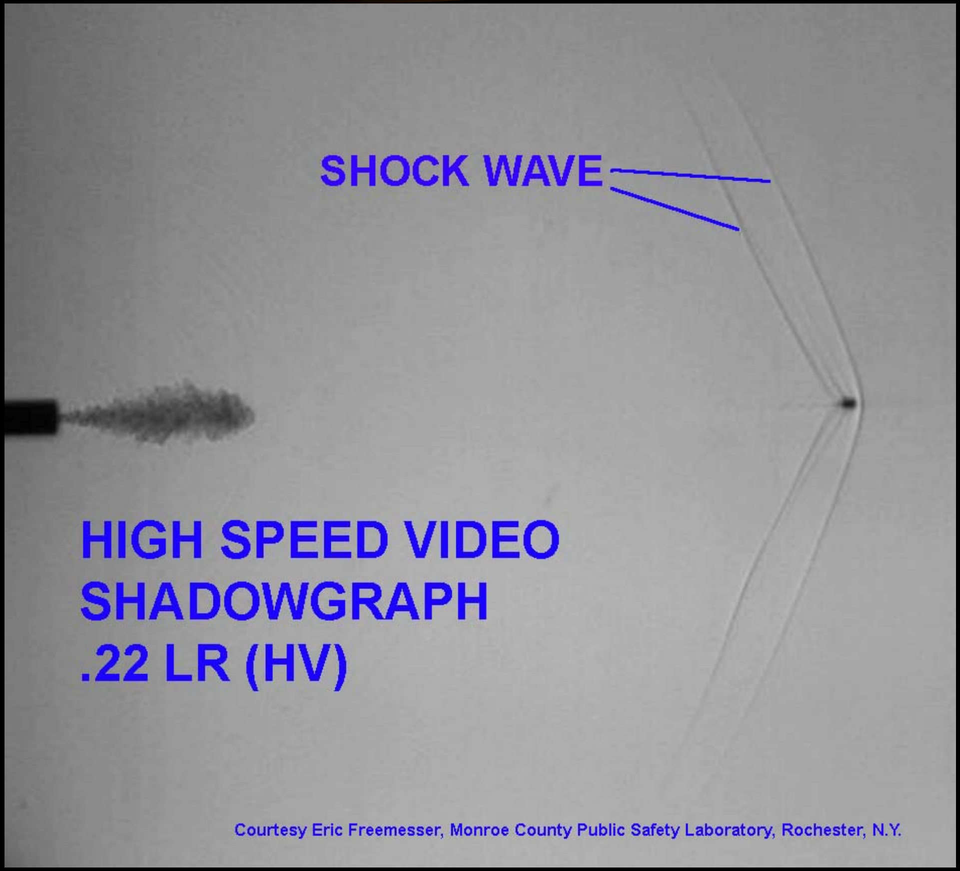
Ballistic Crack

- Shock wave generated by anything in flight traveling over the speed of sound (Mach 1) and cannot be reduced by a silencer.
- Not a source of hearing damage as it is generated downrange and follows the projectile.

Ballistic Crack:

Supersonic shock wave can be perceived only when it reflects off of a surface (such as a post). A subsonic object does not generate this shock wave.

It is also called a “sonic boom.”



Bullet Flight Noise:

We did some bullet flight sound measurements 55 yards downrange from the muzzle and 1 meter to the side of the bullet flight path with and without the suppressor:

	Suppressed	Non-Suppressed
.308	152.6	151.9
.223 (M855)	148.5	148.1
.22LR HV	143.5	144.1

There was no measurable or perceived sound with subsonic or standard velocity .22LR

Speed of Sound

The formula for calculating the speed of sound for the English system of units is:

$$\lambda = 49.06 * (T + 459)^{-2}$$

Where:

λ = speed of sound in ft/sec

T = Temperature in degreed Fahrenheit

Speed of Sound

Temperature (°F)	Speed of Sound (ft/sec)
0	1,051
32	1,087
60	1,118
80	1,139
100	1,160

In the metric system, the formula is:

$\lambda = 20.05 * (T+273)^{-2}$

Where:

λ = speed of sound in meters/sec

T = Temperature in degrees Celsius

Basic Suppressor Principles

- The sound is caused by the sudden release of high pressure propelling gases at the moment of bullet exit (uncorking).
- The suppressor significantly reduces the pressure of these gases before they are released into the atmosphere.

Basic Suppressor Principles

Pressure is reduced by:

1. Increasing volume and decreasing temperature (general gas law)

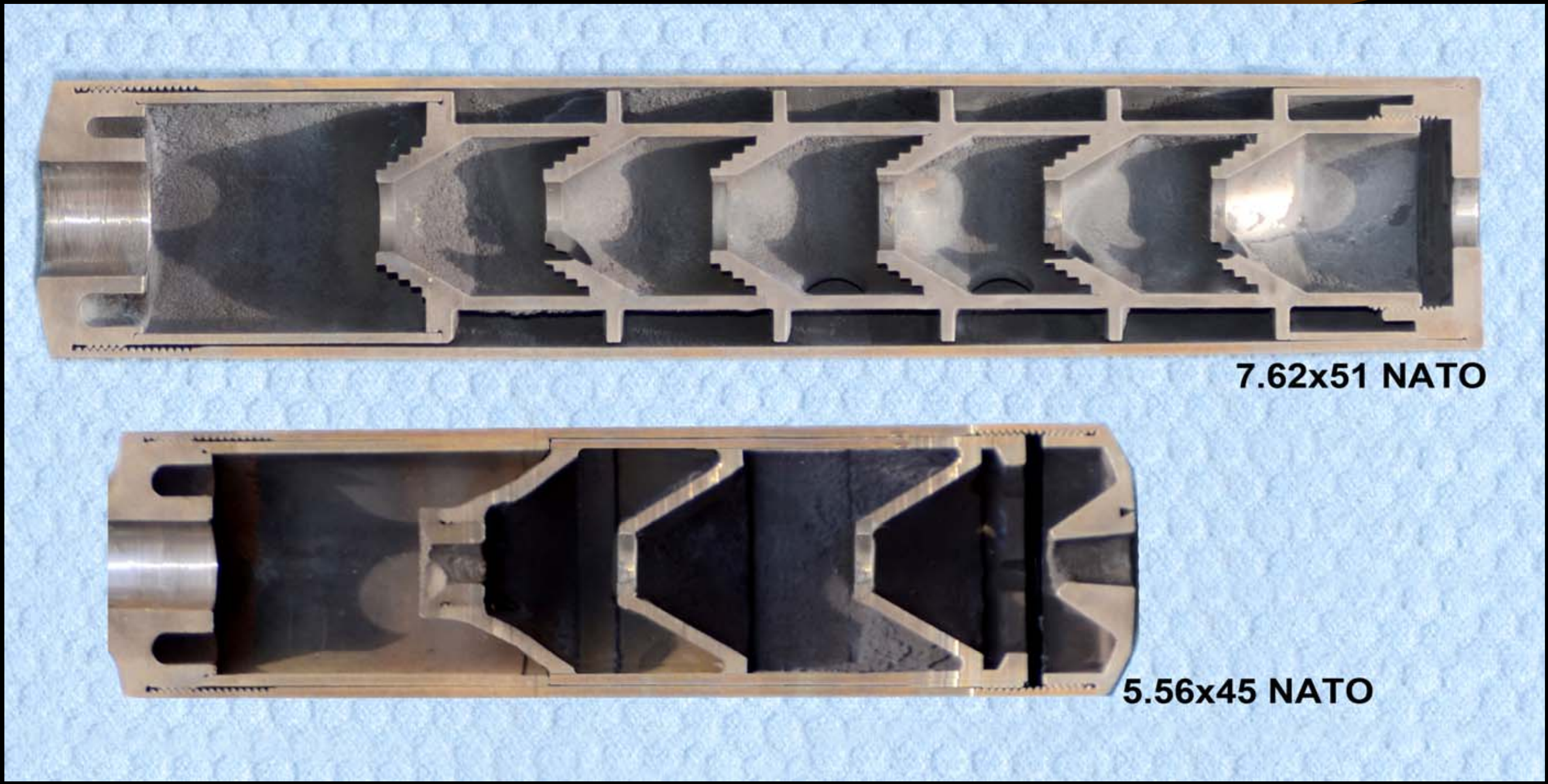
$$P_1V_1/T_1 = P_2V_2/T_2$$

2. Time curve extended: dissipate energy over a longer time interval through gas trapping or turbulence

Integral Suppressors: VSS

The Soviet VSS suppressed carbine (caliber M9x39) is simple and highly effective. Barrel twist is 1:210 mm (1:8.3 inches)

RIFLE SUPPRESSORS



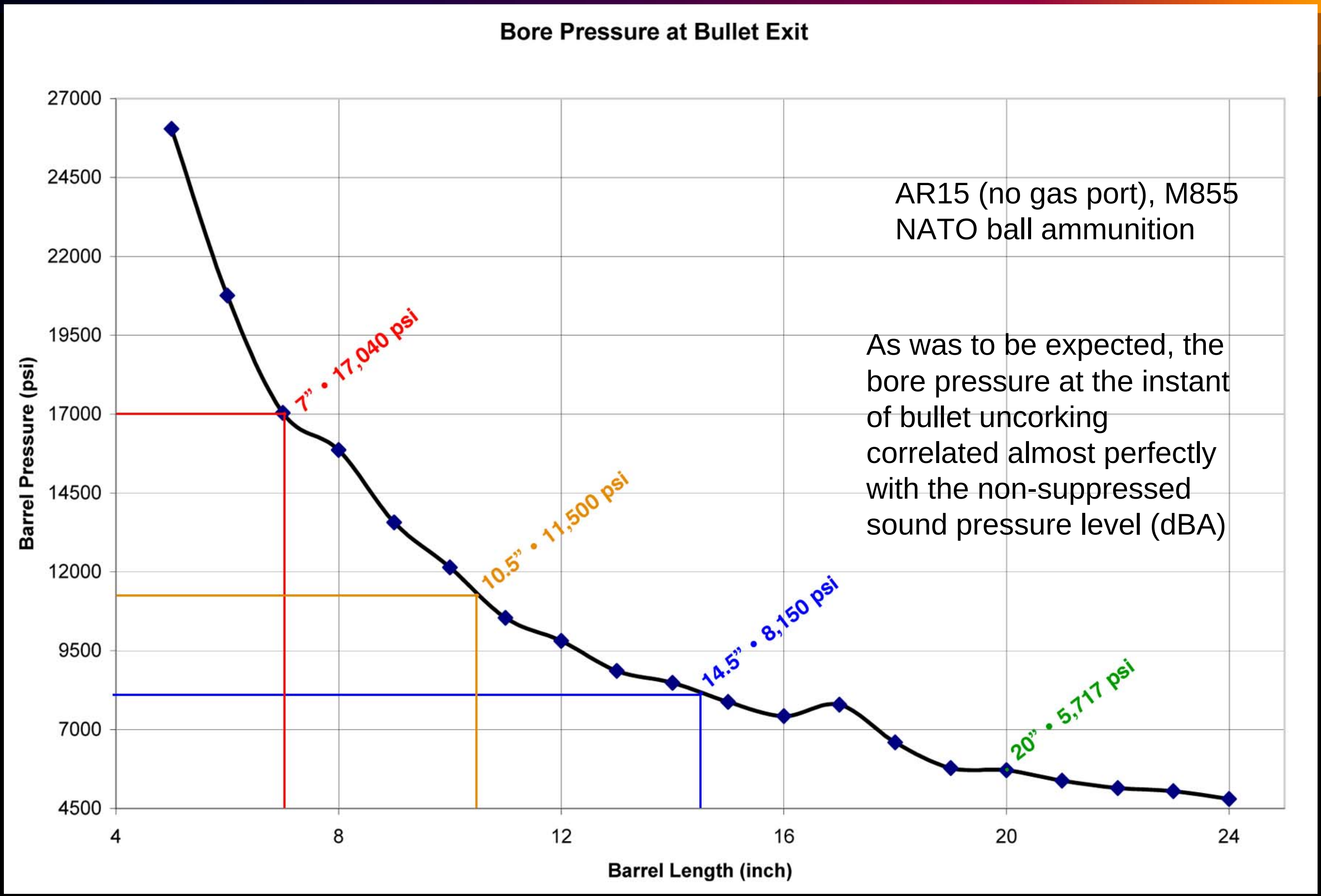
Pressure Issues: Barrel length

We were curious about the pressure in the weapon's bore at the instant of bullet exit.

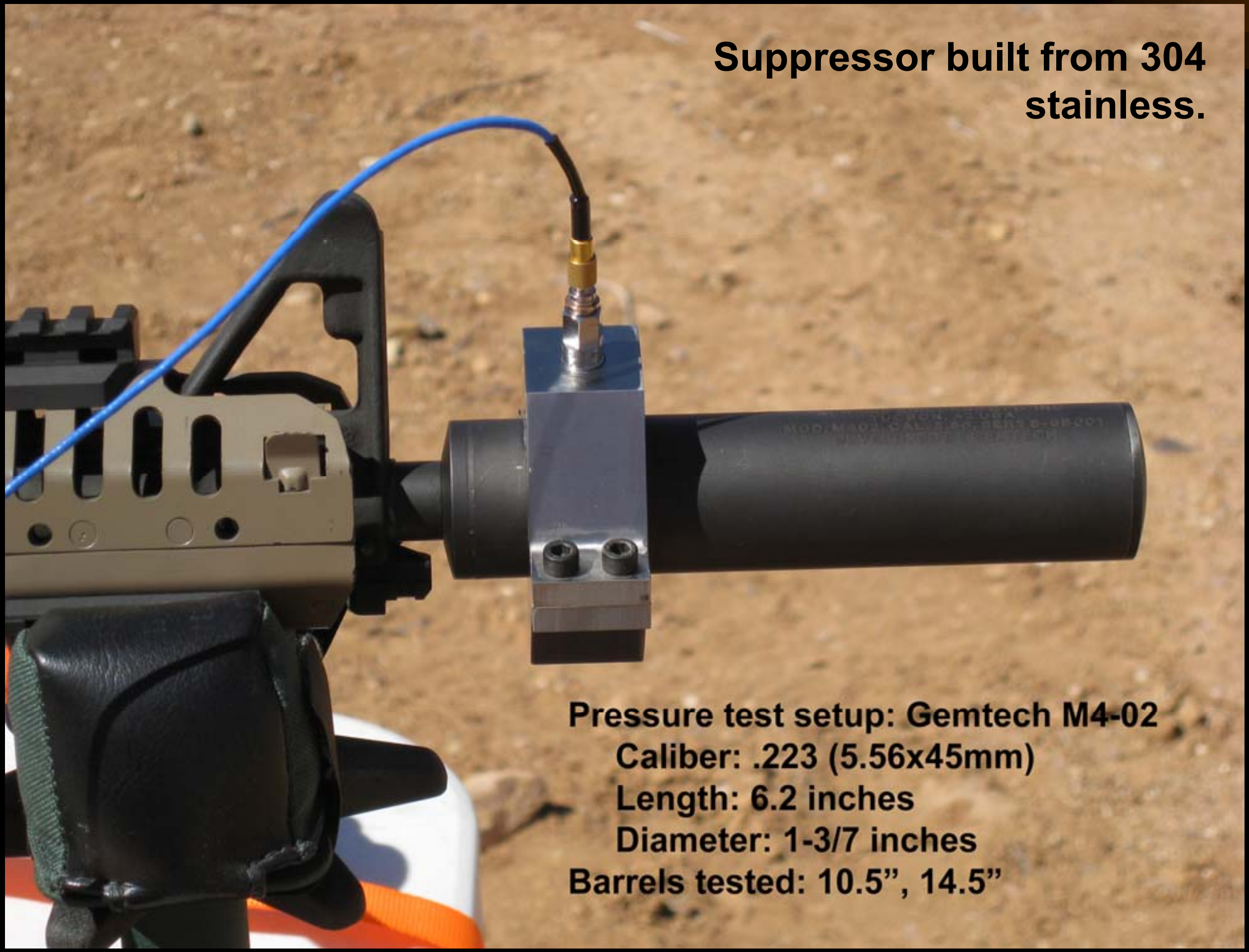
We started with a 24" AR15 barrel (no gas port), and measured pressure at uncorking, projectile velocity, and non-suppressed sound level.

We then cut the barrel 1" at a time and repeated the measurements down to a 5" barrel.

Pressure Issues: Barrel length



Pressure Issues



14.5 inch barrel:
- Pressure: 2,000 psi
- Hoop Stress: 10,458 psi
- Yield Strength: 30 kpsi
- Safety factor: 2.87

10.5 inch Barrel:
- Pressure: 3,000 psi
- Hoop Stress: 15,688 psi
- Yield Strength: 30 kpsi
- Safety factor: 1.91

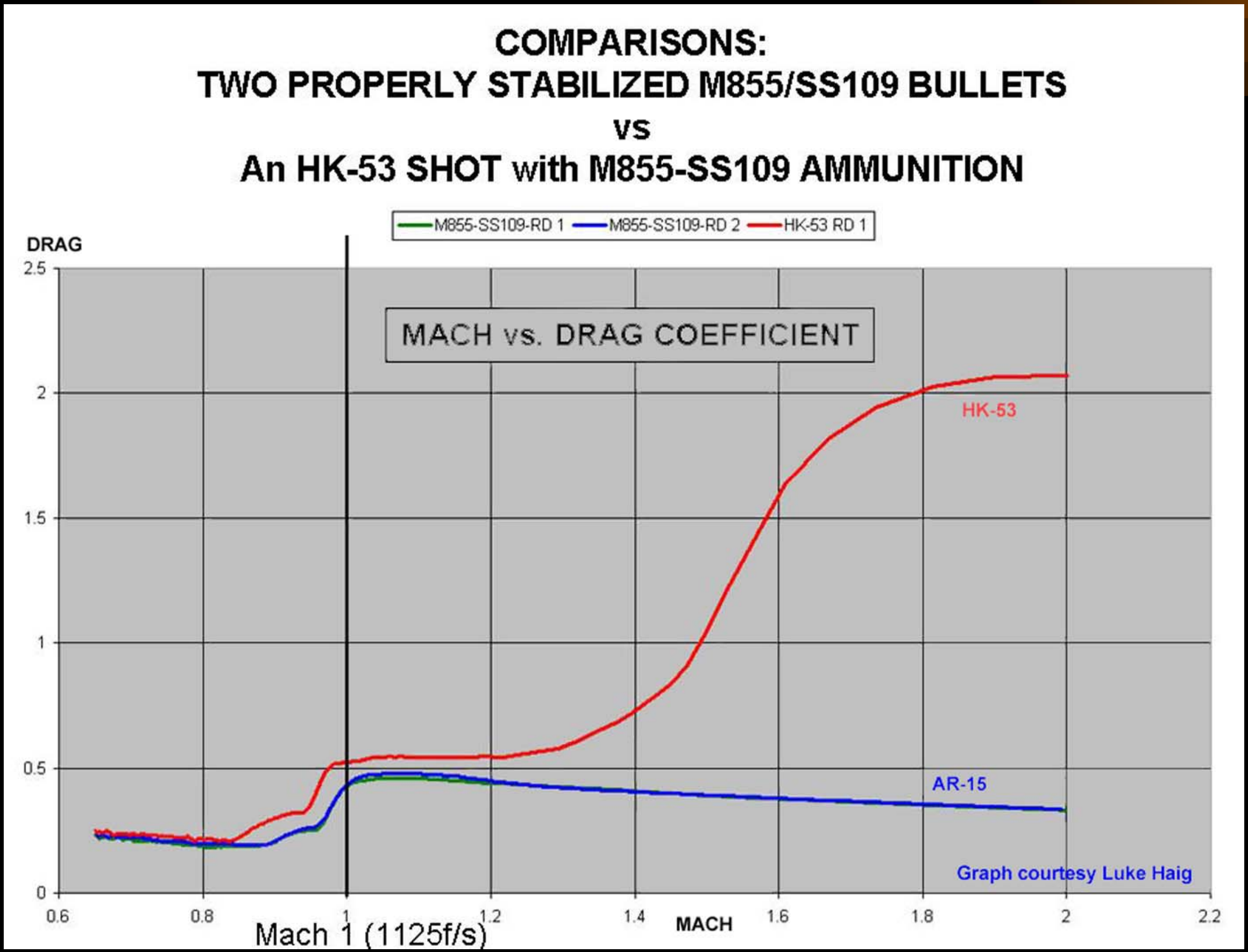
7 inch barrel not yet measured, but estimates are safety factor ≦1

After 100 rounds with temp increasing to 800°F, yield drops to 18 kpsi and safety factors drop to 1.72 (14.5”) and 1.10 (10.5”)

Stability: Barrel length issues

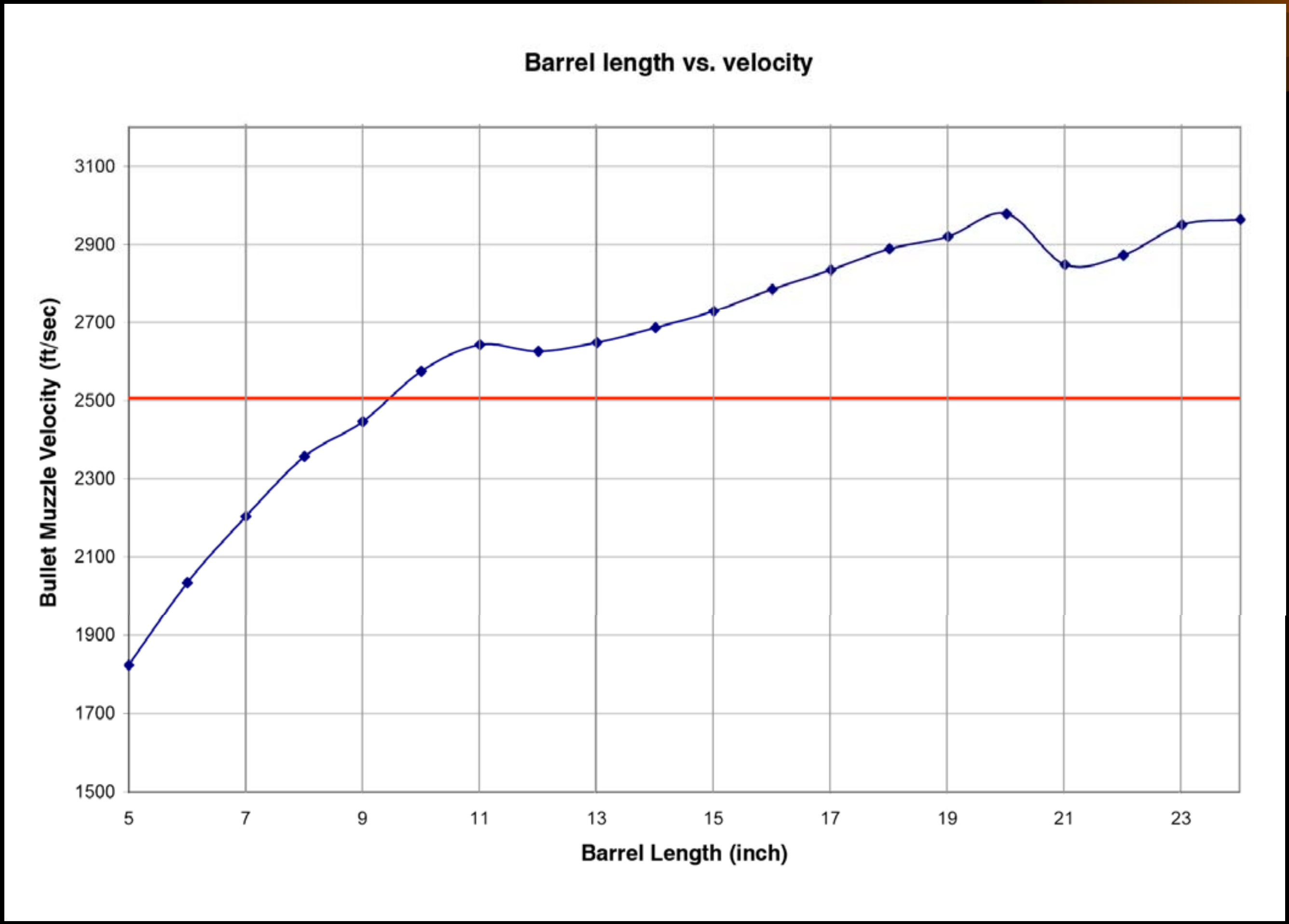
In .223, we have always had concerns of suppressor damage on short barrels. We tested an HK-53 (8.3" barrel) and tracked the projectile using Doppler radar.

Stability: Barrel length issues



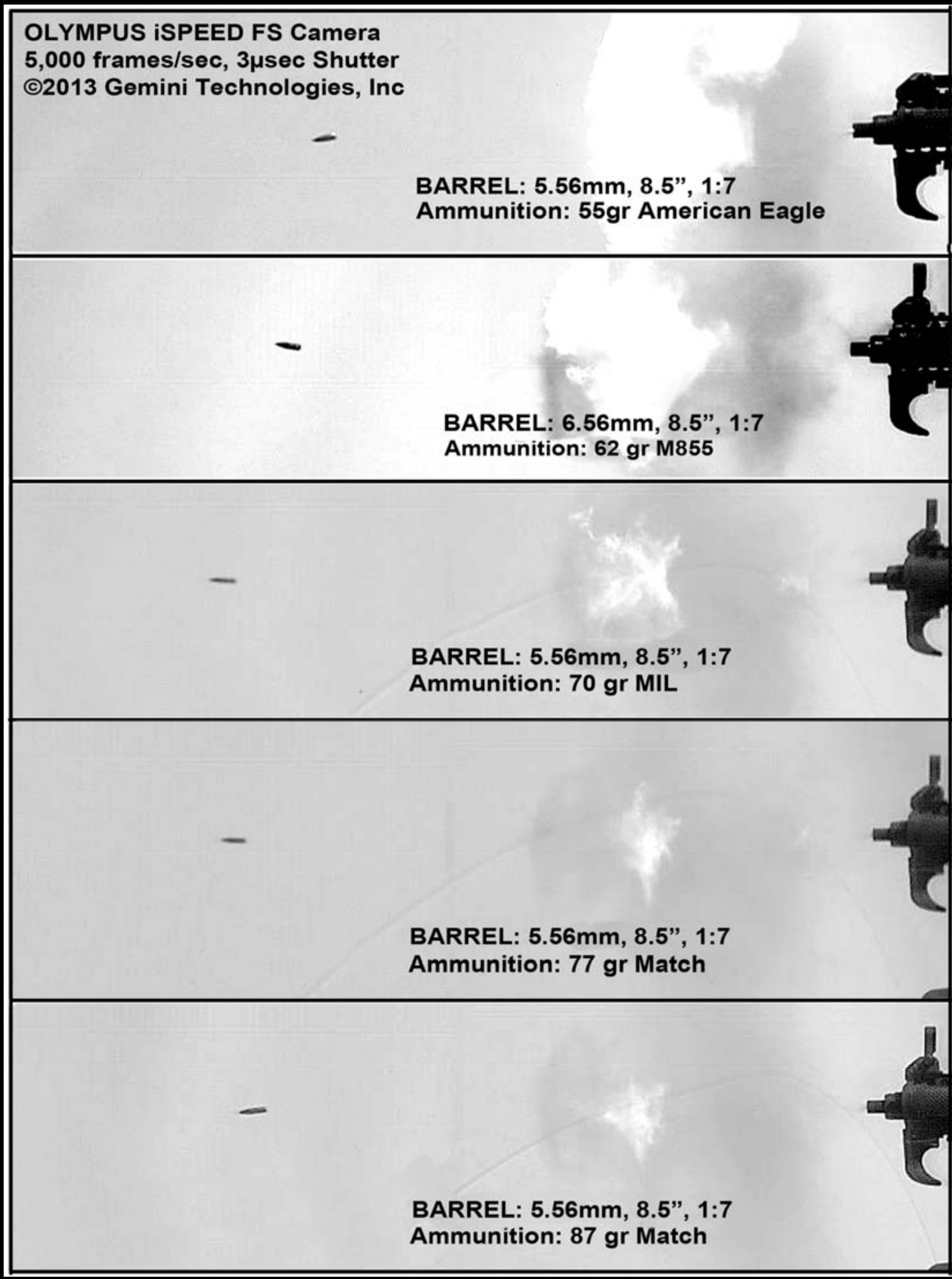
Drag of a round from the HK-53 compared to two from an AR-15 (16" barrel). High drag indicates bullet instability.

Velocity Issues: Barrel length



For those curious about velocity and barrel length (5.56mm, M855 ammunition)

Stability, Twist, & Barrel Length



Not all projectiles were stable in this barrel.

Stability depends on velocity, twist, pressure at bullet exit, and barrel length.

MIL-STD-1474D

Department of Defense
Design Criteria Standard

Noise Limits

12 FEB 1997

A Little History…

In the 1970s, Don Walsh, Reed Knight, and Charles (“Mickey”) Finn working loosely with NSWC (Crane) developed some protocols for measuring suppressed firearm sound levels.

These, along with studies at Human Engineering Laboratories, eventually evolved in to the current MIL-STD-1474.

The use of weighting networks, while not correct, evolved from other military noise sources and have been incorrectly applied to firearm sound levels.

A Little History…

The use of A-weighting for measurements was the result of the early pioneers (primarily Finn) deciding the “numbers” looked better than when using no weighting network.

MIL-STD-1474D

While not perfect and needing some updating (primarily for clarification), this is the current military standard.

It is also the standard used by the major manufacturers with a minor modification.

MIL-STD-1474D

This standard, which encompasses a number of noise measurements, including shipboard, cannon, etc., addresses small arms fire in Requirement 4.

MIL-STD-1474D

5.3.1.1.5 Rise-time.

Rise time capability shall be less than 1/20 of the measured A-duration of the impulse and should be not more than 20 microseconds. Cables that cause an increase in measured rise time shall not be used.

RISE TIME:

Rise time refers to the lag between the start of an event and the beginning of recording. A somewhat older term, it is synonymous with “response time.”

$$T = 1/(2*F)$$

T: is the rise (response) time in microseconds

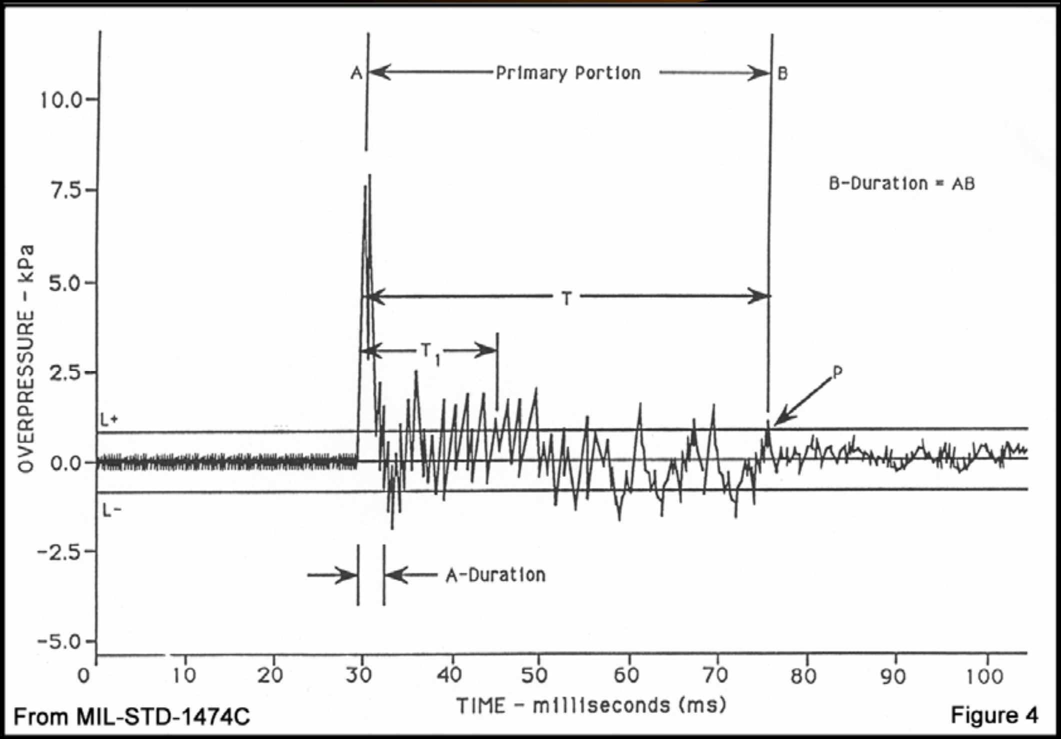
F: is the frequency where the microphone (or system) first deviates more than 3 dB from the baseline

RISE TIME

The rise (response) time specified by MIL-STD-1474D for firearms is:

1/20 the A-duration but not more than 20 microseconds.

(A-duration is time from beginning of pulse until pressure has dropped 20 dB below peak)



MIL-STD-1474D

5.4.5 Transducer locations.

For shoulder-fired and hand-held weapons, transducers shall be located at the center of each operator or crewmember's probable head location. For other weapons the transducer shall be positioned 1.60 m above the ground surface; for sitting locations it shall be 80 cm above the seat. When the operator must be present, the measurement shall be made 15 cm from the ear closest to the noise source (i.e., muzzle or breech, as the case may be) on a line between the operator's ear and the noise source.

MIL-STD-1474D

5.4.5.1 <u>Reference Transducer</u>

a. If required, a transducer shall be placed 200 cm to the side of the major noise source of the weapon (e.g., perpendicular to the muzzle for closed breech systems and perpendicular to the rear for rocket launchers), with the weapon and the sensor 160 cm above the ground.

MIL-STD-1474D

5.4.5.1 Reference Transducer

b. If required, a reference transducer shall be located on the 135-degree or 225-degree radial (taking the line-of-fire as 0 degrees). … For weapons of smaller [less than 20mm] bore diameter, the transducer shall be located at the same elevation as the muzzle, at a distance of 100 cm.

MIL-STD-1474D

5.4.6 Transducer orientation.

Blunt cylinder shaped transducers shall be positioned with the sensing surface facing up … This orientation is defined as grazing incidence (90 degrees). ... This technique will tend to minimize the arrival of shock waves at transducer incidence angles between 0 and 90 degrees, which may cause ringing and overshoot.

MIL-STD-1474D

Reference Location:

- 2 meters to the left of the muzzle, 90° to the bore axis
- 1.6 meters above non-reflective surface (standing) or
- 80 cm above seat if sitting
- No reflecting surfaces within 10 meters

"Ear" Location: *Not exactly defined!*

- Estimate of the center of the shooter's head, or
- 15 cm out from the ear closest to the sound source
- Sound source muzzle or breech?

MIL-STD-1474D

5.4.10.2 Weighting networks.

If used, weighting networks shall meet the requirements of ANSI Sl.4.

[This is a hold-over from general environmental noise measurements addressed elsewhere in MIL-STD-1474 and is not correct for firearm sounds.]

METERING

There are 3 general categories of meters:

Type 0: Laboratory reference meter

Type 1: High Precision (usually has peak detector)

Type 2: General Purpose (usually does not have peak detector)

The Type 1 is best suited for firearms

DETECTORS

Type 1 Sound meters generally have 4 detectors:

1. Slow: For average continuous ambient sounds
2. Fast: For rapidly repeating industrial sounds
3. Impulse: For impulse sounds of <1 second duration
4. Peak: For recording the highest peak of an impulse sound.

PEAK DETECTOR: Analog

The peak detector in an analog sound meter (such as the LD 800B or the B&K 2209) will have a short rise time (well under 20 μ-sec) before the weighting network.

Most meters with analog peak detectors have digital signal processing after the detector.

PEAK DETECTOR: Digital

Digital: Because of the physical constraints of digital electronics, the shortest possible rise time of a purely digital peak detector is 28 µ-sec and most are worse.

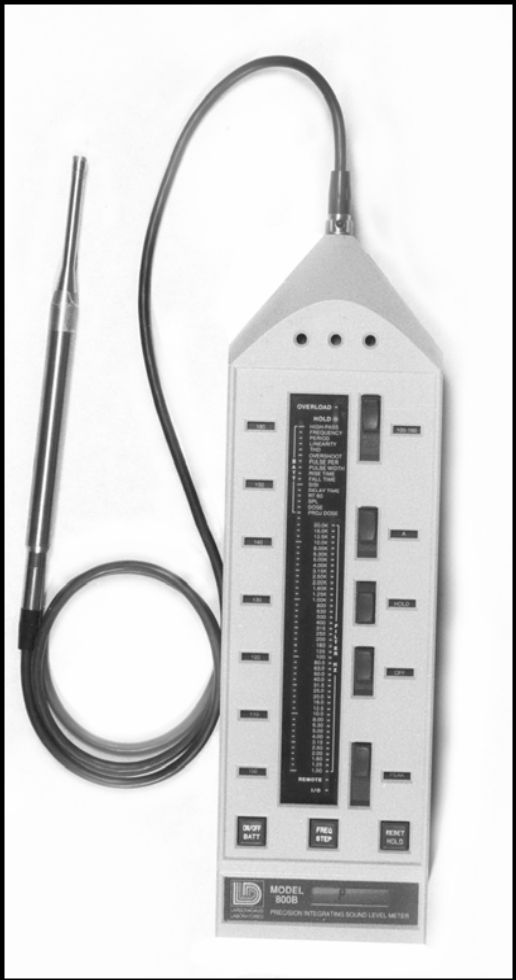
Source: David Ahlstrom, Larson-Davis Technical Support

Rise Time? Meter Limitations

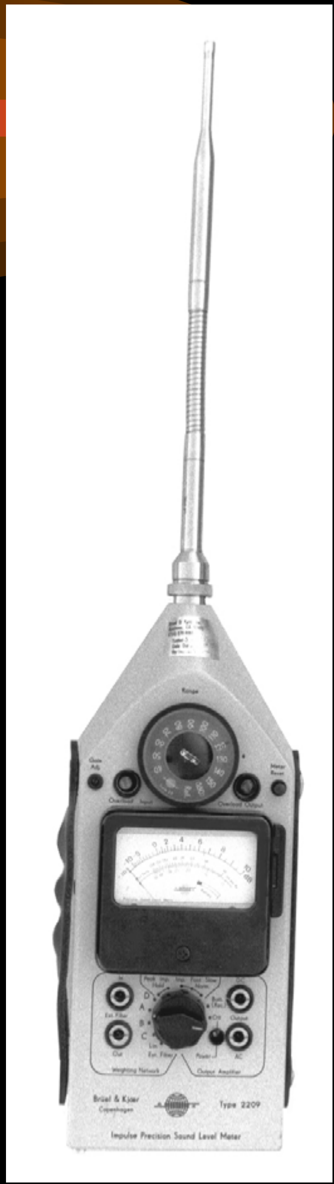
Analog field-portable meters with peak detectors are no longer manufactured, and the only meters available today are digital.

Although the weighting networks degrade analog meters, analog meters are still more accurate than digital using the same weighting network.

METERS: MIL-STD-1474D COMPLIANT



- Field portable
- Type 1 sound pressure meter with 20 µsec or shorter rise time.
- Larson-Davis 800B (Left)
- B&k 2209 (Right)
- Both analog peak detectors



METERS: LD LxT1-QPR

We have tested the latest field-portable SPL meter from Larson-Davis, the LxT1-QPR marketed for firearm sound levels. As the LxT1-QPR, it comes standard with the ¼” pressure microphone. While it does not quite meet the current rise time requirements of MIL-STD-1474D (20 µSec), the LxT1-QPR has a rise time <30 µSec (typically 28 µSec). It is a Type 1 meter and has peak detector. Correlation with the LD-800B using the current A-weighting requirement is acceptable.

Of the available portable meters, it is the best candidate if the MIL-STD is amended.

The L-D 831 is an enhanced version of the LxT1-QPR

Measuring Firearm Sound

CCI (Sacramento, CA) 2009 Seminar: LD 800B compared to LD LxT1-QPR

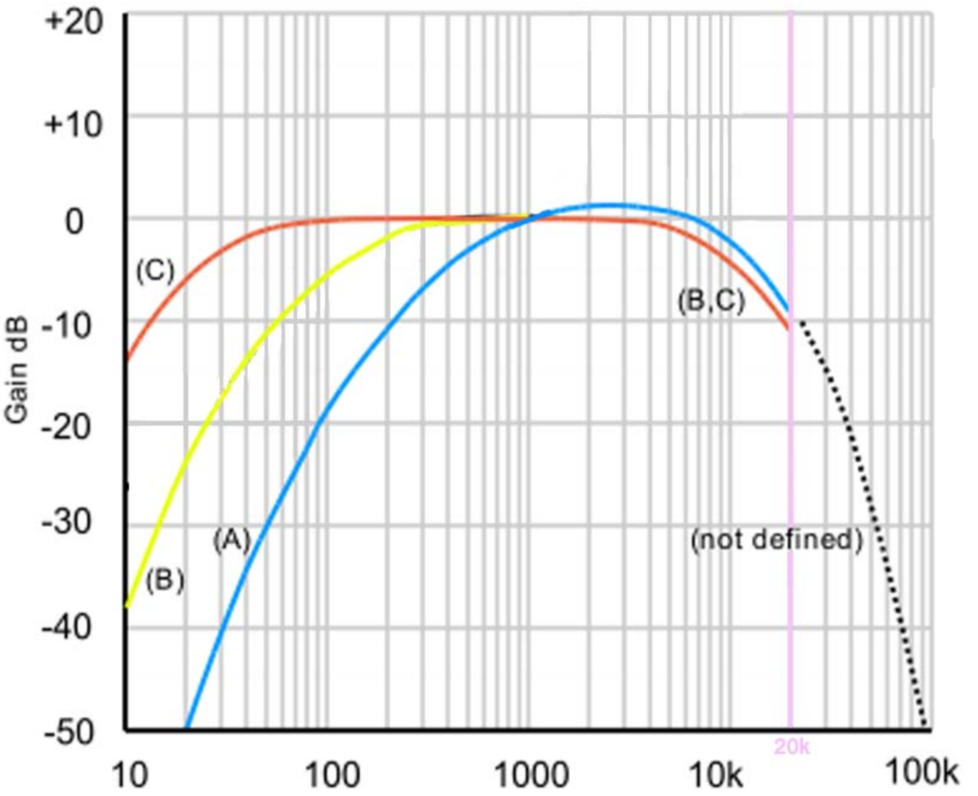
A-weighting	800B	LxT1-QPR
Knight M4QD M4 carbine, M855	132.5 dB	131.2 dB
GT Raptor MP5, 147 9mm Subsonic	129.5 dB	129.0 dB
MAXIM 1910 Ruger MK2, .22LR SV	128.3 dB	127.9 dB
GT Outback-II Ruger MK2, .22LR SV	118.1 dB	116.6 dB

With A-weighting, difference not statistically significant.

Weighting Networks

Weighting networks are electrical circuits that alter the sensitivity and frequency characteristic of a sound pressure level meter so as to improve the correlation of meter readings and the subjective judgment of noise by individual observers.

Weighting Networks



A-weighting (blue), B-weighting (yellow), and C-weighting (red)

A: For low-level sound pressure levels in the range of 20 to 55 dB

B: For mid-level sound pressure levels in the range of 55 to 85 dB

C: For higher sound pressure levels in the range of 85 to 130 dB

Z: Also referred to as Linear or un-weighted.

Weighting curves not defined or projected past 20 kHz (upper limits of human hearing)

All weighting adversely affects the rise time of the sound meter, meaning missing some of the shorter than 20 µsec suppressed pulse.

Weighting Networks: Unweighted

- Unweighted is a more accurate method of evaluating potential hearing damage and should be used for firearms.
- Weighting is inappropriate for sound levels over 130 dB
- Further, this setting does not adversely affect the rise time of the meter.

Weighting Networks

We did a test (same day) with a Ruger MK-II bull barrel pistol in a Ransom rest and an older silencer we had on the shelf. Ammunition was CCI .22LR standard velocity and recorded both suppressed and non-suppressed readings using A, C, and Z weighting (LD 800B).

All data average of 5 round groups.	Non Suppressed SPL (dB)	Suppressed SPL (dB)	Reduction (db)
A-weighting	152.4	122.2	30.3
C- weighting	151.5	118.8	32.7
Z-weighting (linear/unweighted)	155.8	126.0	29.8

Weighting Networks

A similar test was performed (non-suppressed only) with a Ruger 10/22 rifle using CCI Standard Velocity .22LR ammunition and an LD 800B SPL meter with the microphone at 3 ft.

All data average of 5 round groups.	Non Suppressed SPL (dB)
A-weighting	138.6
C- weighting	137.4
Z-weighting (linear/unweighted)	142.4

(courtesy Luke Haag)

DoD Instruction 6055.12

Hearing Conservation Program:

Applies primarily to general environmental sounds levels.

1. Specifies Type 2 (general purpose meter, not type 1 precision)
2. Specifies impulse detector, not peak
3. Specifies A-weighting

DoD Instruction 6055.12

Hearing Conservation Program:

4. Primary concern is daily/weekly environmental noise exposure
5. Specifies rise time of 35 µsec or better

International Industry Established Test Protocol

In the civilian marketplace, a variant of the Reference Location is used:

- 1 meter to the left of the muzzle, 90° to the bore axis
- 1.6 meters above grass
- No reflecting surfaces nearby

MEASURING: Protocol

Current Protocol

Meter settings for sound measurement:

- Detector: Peak (not impulse)
- Hold (not continuous)
- Weighting: A

NOTE: Un-weighted or linear would be more accurate and will probably be specifically addressed in future revisions of MIL-STD-1474. However, the standard of the industry calls for A weighting, probably related to reading other sections of 1474D. A-weighting reduces inaccuracies of digital metering and is what the marketplace is used to.

Commercial Protocol Location

Location: Specify microphone location with respect to the noise source.

Reference Location: Placing the microphone 1 meter to the left of the muzzle, 90° to bore axis, 1.6 meters above grass.

Other locations are acceptable, but must be specified (ie., shooter’s ear, downrange, etc.)

First round “POP”

Thought to be a secondary detonation from superheated, incompletely burned gases or powder particles entering an oxygen rich atmosphere. Analogous to a dust explosion in a silo or an afterburner in a jet plane.

(Pressure measured in suppressor entrance chamber proportionally increased.)

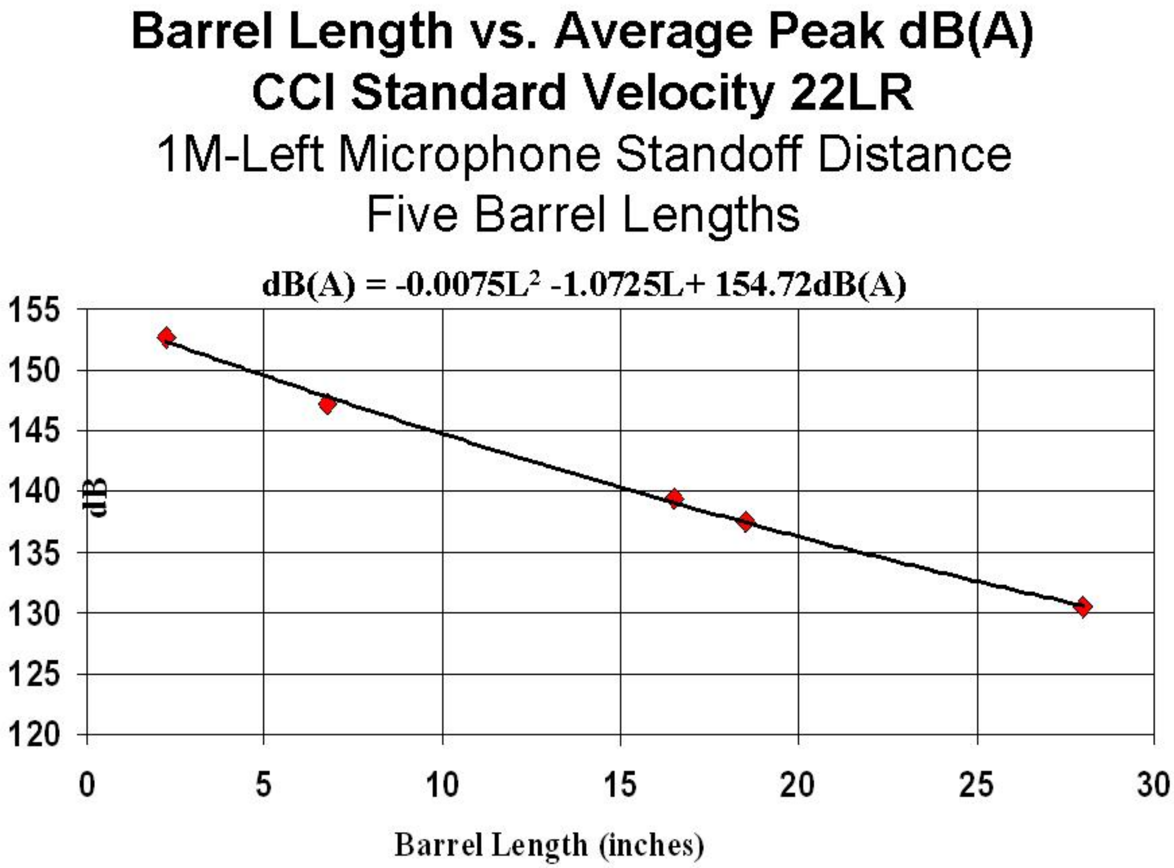
Measurement Locations

A series of measurements were taken using a non-suppressed Ruger 10/22 (CCI Std Velocity .22LR) spacing the microphone out from the muzzle…

Dist. Rt. of Muzzle	Ave. dB
1M (3.28-ft)	137.2
10-ft.	126.2
20-ft.	121.6
60-ft.	109.7
100-ft.	105.7
200-ft.	92.9

(Courtesy Luke Haag)

Pressure Issues: Barrel length



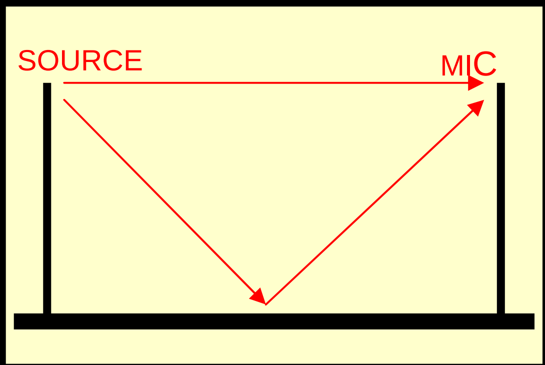
Measurements and graph courtesy Luke Haig

Barrel length has an effect on sound levels. .22LR is easy to model.

Environmental Factors

Ground Surface Effects:

1. Inverse square law theory suggests that a ground reflection of the sound wave will be attenuated more than the direct path from the muzzle to the microphone and theoretically *<u>should</u>* not affect the peak reading.



Environmental Factors

Ground Surface Effects:

2. Experiments in Finland measuring over concrete have shown a reading approximately 2+ dB greater than when measured over grass.
3. This suggests that the actual peak duration may well be under 20 μ-sec meter response time and part of the reflection is being measured also.

Usefulness of SPL measurements

- The prime values are in development and determination of hearing safety issues.
- Using measurement for advertising is deceitful, because the reader does not know the parameters used.
- Most suppressors for the same weapon, ammunition, and suppressor size will have similar sound levels.

MIL-STD 1474 Criticism:

From White Paper 300805 (Price, G.R., “Auditory Hazard Analysis,” 2005)

- Early noise standards (Garinther et al, 1968, 1975 H.E.L.) were empirical and had no theoretical foundation. Were also design standards, not hearing protection.
- Albuquerque Studies (1994, Patterson) and Chan (2003) found 10-20 dB errors in hearing damage assessment of current MIL-STD.

MIL-STD Wish List

Changes to Requirement 4:

- Eliminate option of weighting network usage,
- Change maximum rise time from 20 to 30 µSec to reflect equipmnt availability,
- Redefine “shooter’s ear” location to a reproducible mechanical location such as:

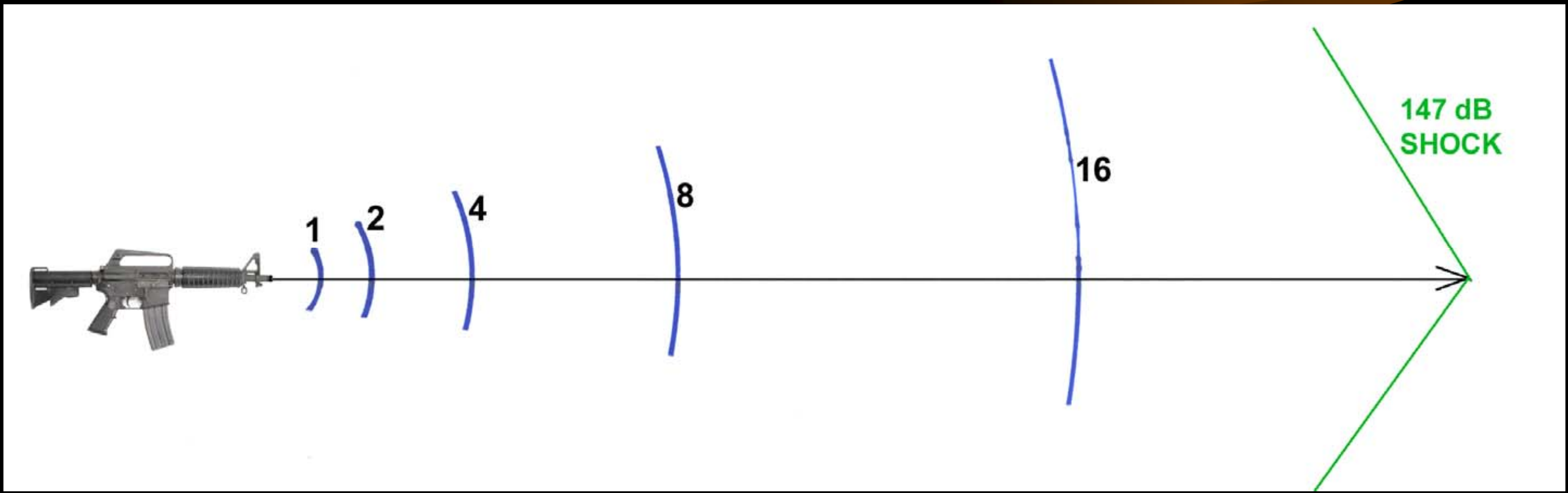
  80 cm rearward from muzzle,

  15 cm from bore axis on non-ejection side,

→ **Or totally new MIL-STD addressing hearing damage prevention.**

Point to Ponder…

Downrange observer, supersonic cartridge, and the Inverse Square Law



Distance	1 M	2 M	4 M	8 M	16 M
Non-Suppressed (dB)	164	158	152	146	140
Suppressed (dB)	136	130	124	118	112

Finis…