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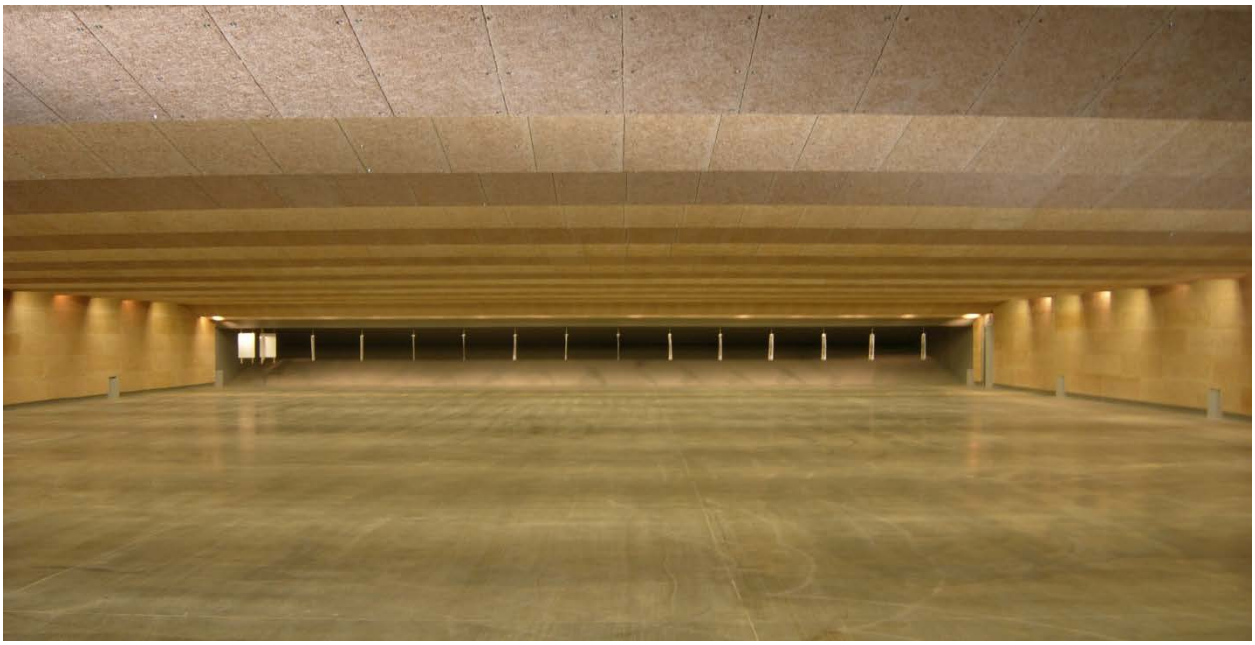
A Primer on Indoor Shooting Range Acoustics

By Stephen Katz, Vice President, Research and Technology, Troy Acoustics



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Executive Summary

Loud noise is hazardous to your health! Intensely loud noise as found on indoor shooting ranges is extremely hazardous to the health of anyone who trains, instructs, or is just a recreational shooter.

Hearing protection is not enough, even double protection. Exposure to intense sound fields, besides leading to hearing loss and tinnitus, impacts the whole body with the most common indications being fatigue and headaches. Longer exposure may lead to hypertension, heart disease, anxiety, headaches, judgment impairment, sleep disturbance, and other conditions that can lead to disability claims and lawsuits.

The only way to protect the "whole" person is through engineering noise controls. OSHA's noise standards specify that feasible engineering controls must be used to reduce noise to acceptable levels and that personal protective equipment, such as ear plugs and ear muffs, must be used only as supplements. It's only a matter of time before OSHA enforces this standard.

There are benefits beyond protection of the health and well-being of persons that work on and use indoor shooting ranges. Safe sound levels mean you can train and work harder, shoot longer and create an environment that is healthy for the whole family.

What are engineering noise controls for indoor shooting ranges? It can be summed up with one word, **acoustics**.

Caveat emptor, "buyer beware". There are many acoustical products and treatments being marketed and sold that claim to be effective on indoor shooting ranges but clearly are not.

Not all acoustical products are created equal. There are many issues that need to be addressed when choosing the right products for shooting ranges; sound absorption, absorption in intense sound fields, sound reflection, sound transmission, material density, porosity, tortuosity, bullet absorption, ricochet, splash back, combustibility, flame spread, smoke developed, mold and mildew resistance, ease of cleaning and maintenance, durability, and the manufacturers warranties and guaranties.

You want to treat your range just once, and get it right.

Indoor shooting range noise can effectively be controlled through proper engineering and the right choice of products and their placement.

Troy Acoustics, the worldwide leader in shooting range acoustics, offers the world's highest acoustic rating and the shooting range industry's only guaranteed solution. Only Troy is able to meet all the issues defined above. The benefits and impact of proper acoustic treatment will be felt and appreciated for years and years to come.

What is Sound?

Sound *is a mechanical wave that is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing and of a level sufficiently strong to be heard, or the sensation stimulated in organs of hearing by such vibrations*[1].

Sound can also impact the whole body, especially low frequency sound. Have you ever been to a movie in Dolby 5.1? The theater shakes. How about at a dance club or a rock concert, or a symphony orchestra? All those can be fun, invigorating uses of sound. They can also become uncomfortable, even painful. That's when sound becomes **noise!**

What is Noise?

Noise is a sound that disturbs or harms. Noise is one of the most common occupational and recreational health hazards. "The government paid out approximately $1.1 billion in VA disability compensation for tinnitus in 2010. At the current rate of increase, service-connected disability payments to veterans with tinnitus will cost $2.26 billion annually by 2014.[2]" Nonmilitary ranges pay the price in increased workers' compensation and insurance payments, and then there are the lawsuits.

Hearing protection, even double protection can offer only so much personal defense. While hearing protection covers the ears, the rest of the body, particularly the skeleton transmits the sound to the ear canal through bone conduction. That is why the highest rating for the best double hearing protection is barely over 30 dB.

[1] http://en.wikipedia.org/wiki/Sound

[2] Testimony before a March 2012 joint session of the House and Senate Committees on Veterans Affairs

Physiological effects of noise on the human body are not part of the OSHA/NIOSH standards. However, these effects can and will cause illness to personnel using the range if acoustically untreated. The symptoms range from cardiovascular effects such as myocardial infarction. This is brought on by elevated levels of cortisol production. Cortisol production within the human body is brought on by heightened stress levels which are directly related to long exposure to high sound levels. Increased blood pressure levels are brought on by the elevated heart rate, which is another reaction as the muscular walls contract to the high intensity of sound waves.

Our chest is a natural resonator that amplifies low frequency noise. The resonant gain for the chest vibrations is about 25dB occurring in the frequency range from about 30Hz to 80Hz, depending on stature and gender. There is current research that has shown links between traumatic brain injury and ballistic pressure waves originating in the thoracic cavity and extremities.

Other effects of exposure to high intensity noise are increased frequency of headaches, fatigue, irritability, anxiety, judgment impairment, sleep disturbance, stomach ulcers and vertigo.

Types of Noise

Noise is categorized in two ways; continuous/steady state, and impulsive. Shooting range noise comes under impulsive noise, as the actual noise generated by small arms fire is of very short duration, on the order of a few milliseconds. Experience has shown that impulse noise may be more harmful to hearing than continuous, steady state noise.[3]

Table 1 below shows the range of human hearing relative to various sound sources as expressed in Sound Pressure Level (SPL) in decibels (dB). The range is from the soft sound of leaves rustling in the distance to the crack of a 5.56 rifle as heard by a shooter.

[3] Schwetz F, Hloch Th, Schewczik R. "*Experimental exposure to impulse noise in the especially pathogenic impact frequency range.*" Acta Otolaryngol 1979;87:264-6

Table 1

dB SPL	Sound Sources
165	5.56 Rifle as heard by the shooter
140	Jet on carrier deck
130	Threshold of pain
120	Threshold of discomfort
110	Chainsaw, 1 m distance
100	Disco, 1 m from speaker
90	Diesel truck, 10 m away
80	Busy traffic
70	Vacuum cleaner, distance 1 m
60	Normal conversation
50	Average home
40	Mosquito buzzing
30	Quiet bedroom at night
20	Whisper (at 1 m)
10	Rustling leaves in the distance
0	Threshold of hearing

What Makes Up The Sound of Small Arms Fire?

The speed of sound at sea level, in dry air at 68 °F is 1,126 feet per second. This works out to 768 miles per hour (mph), or approximately one mile in five seconds. The muzzle velocity of just about every caliber rifle and shotgun will exceed the speed of sound as well as some handguns.

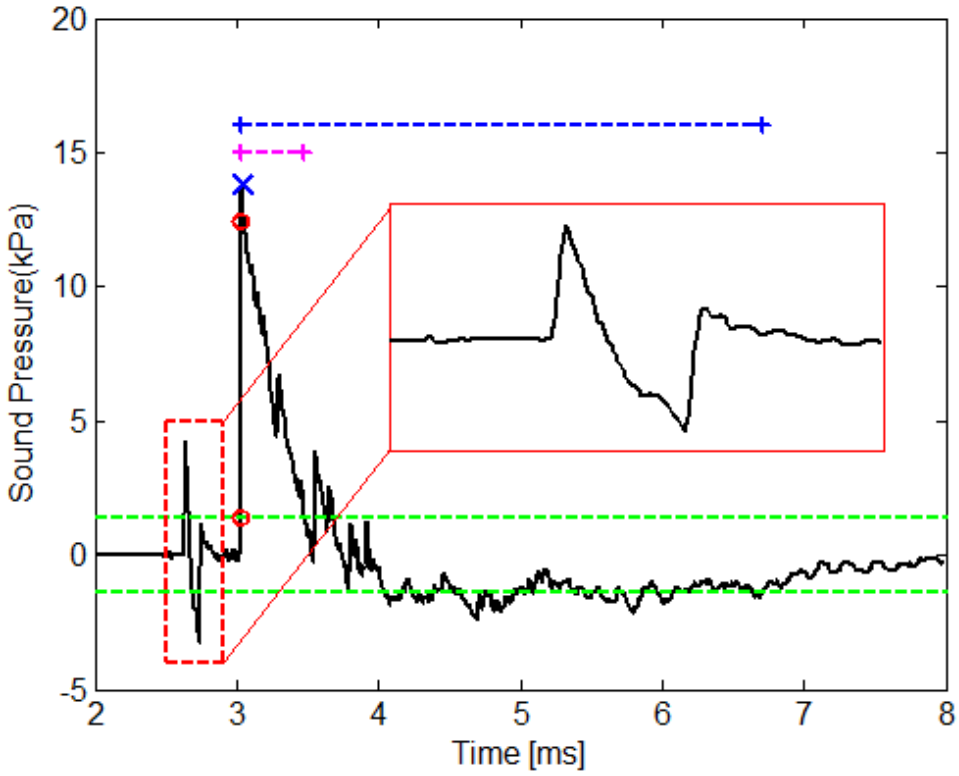
Table 2 below shows some common ammunition and their muzzle velocity. All but the 38 and 45 caliber break the sound barrier (supersonic), with the Ruger 204 hitting a blistering Mach 3.5. It stands to reason that the faster the round the louder the sound.

Table 2

Rifle Ammunition	Velocity f/s	Mach
17 HMR 17 gr. V-MAX	2250	2.00
204 Ruger 40 gr. V-MAX	3900	3.46
22 Hornet 35 gr. V-MAX	3100	2.75
223 Rem 75 gr. TAP-FPD	2790	2.48
22-250 Rem 60 gr. SP	3600	3.20
243 Win 100 gr. BTSP InterLock	2960	2.63
257 Roberts 117 gr. BTSP InterLock	2780	2.47
25-06 Rem 117 gr. BTSP LM InterLock	3110	2.76
270 Win 150 gr. SP InterLock	2840	2.52
7MM Rem Mag 154 gr. SST InterLock	3035	2.70
30-30 Win 160 gr. Evolution	2400	2.13
308 Win 168 gr. TAP-FPD	2700	2.40
30-06 Sprg 165 gr. BTSP LM InterLock	3015	2.68
300 Win Mag 180 gr. SP HM InterLock	3100	2.75
5.56x45mm NATO 55 gr FMJ	3240	2.88
7.62x51mm NATO147 gr FMJ	2800	2.49
12GA 00 buckshot 53 gr .32"	1325	1.18
12GA 480 gr rifled lead HP slug	1600	1.42
Handgun Ammunition		
9MM Luger 115 gr. JHP/XTP	1155	1.03
38 Special 125 gr. JHP/XTP	900	0.80
40 S&W 155 gr. JHP/XTP	1180	1.05
45 Auto 185 gr. JHP/XTP	970	0.86
45 Colt 255 gr. Cowboy	725	0.64
500 S&W 300 gr. EVOLUTION	2075	1.84

Figure 1 below is a representative of a centerfire rifle, sound-pressure time series. The measurement was made outdoors in a non-reverberant environment. First is the bullet supersonic shock wave (red outline and inset plot), muzzle blast rise time (red circles), peak overpressure (blue X), A-duration (magenta dashed line), and B-duration (blue dashed line) are illustrated. (The green dashed lines are the 20 dB down points, in absolute value, from the peak overpressure and are used to calculate the A- and B-durations.) [4] Typical rise times for center small arms are typically from four (4) to seven (7) microseconds (us). The fast rise times dictates the need for special equipment to accurately measure shooting range sound.

Figure 1[5]

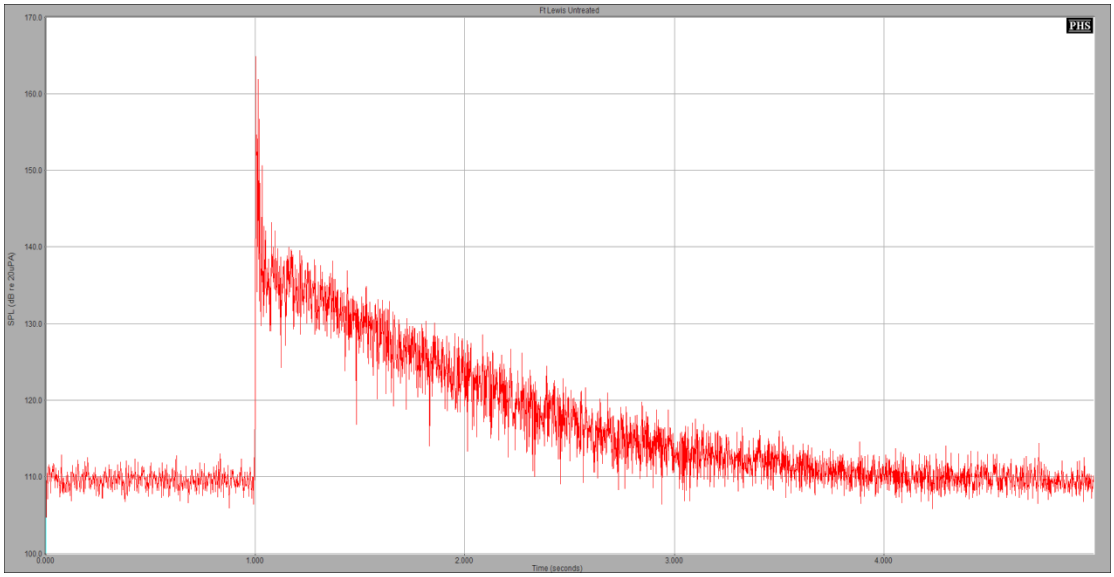


From the time series above we see the basic elements that make up small arms fire. The first component is the supersonic shock wave closely followed by muzzle blast rise time, peak overpressure, then the sound ring out, known as reverberation time. In this case, as the weapon was measured outdoors in a non-reverberant environment the reverberation time was on the order of a few hundred milliseconds.

[4] "Investigating the source characteristics of gunshot noise Investigating the source characteristics of gunshot noise," Andrew R. Barnard, H. John Camin, David M. Kiger, Penn State University / Applied Research Laboratory
[5] *Ibid*

Figure 2 below shows a time series of a M4 5.56 firing a single round as measured on a non-acoustically treated indoor shooting range. You can see the long ring-out. The Reverberation Time (RT60) was measured at 5.64 seconds. That means that everyone on the range was subjected to the overblast pressure of the single round fired for over five-seconds (5 sec).

Figure 2



Reverberation, Nature's Amplifier

Reverberation is nature's amplifier. Think of clapping your hands in the middle of nowhere versus clapping your hands in a parking garage. The clap is the same; the reverberation makes the sound many, many times louder. The problem is compounded when there are multiple shooters present.

How Is The Sound Of An Indoor Shooting Range Measured?

Conventional sound level meters are not fast enough to fully capture the sound of a gunshot. When you use a meter slower than the event a lower sound pressure will be recorded. In tests comparing a conventional sound level meter to a high speed digital recording, the errors noted were from three (3) to six (6) dB SPL. A 6 dB difference represents underreporting of the actual sound pressure by half, a significant error.

The microphone selected is also very critical to measuring a shooting range. As most small arms produce an instantaneous over pressure of 160 dB SPL or more, a microphone with a dynamic range of 170 dB or greater should be used. Typically these microphones will have a 1/4" or 1/8" capsule with a high-level preamplifier. If the microphone/preamp used does not have enough dynamic range it will clip the impulse, again underreporting of the actual sound pressure.

In order to accurately capture impulse overpressure wave of small arms fire, a meter or recording device should have a response time on the order of eight-microseconds (8 us). Today, two-channel high-speed analog to digital converters can be purchased for less than three-hundred dollars ($300). They sample up to 192 thousand samples per-second which equates to a sample every 5.2 microseconds, enough to accurately capture the sound of small arms fire.

There are easy to use two-channel digital sound recording and complete post analysis software packages that will run on your laptop currently available for under $1,500. They can report any current measurement standard and will upgrade as new standards are developed.

Picture 1 below shows a portable 16 channel high-speed (192k) recording rig developed by Troy Acoustics. The upper unit in the rack is a Lynx Studio Technology: Aurora 16, 16 channel AD/DA converter with Lynx LT-MADI[6]. The LT-MADI provides digital input and output in MADI (Multichannel Audio Digital Interface) format. The MADI is sent via optical fiber to the laptop to where it is recorded.

The lower unit in the rack is a PCB Model 483C05 8-channel, line-powered, ICP® sensor signal conditioner. There are currently two of these units in the rack pictured for 16 microphones and/or sensors.[7]

[6] http://www.lynxstudio.com/product_detail.asp?i=1
[7] http://www.pcb.com/spec_sheet.asp?model=483C05&item_id=14291

Picture 1

Picture 2

Picture 2 on the right shows a shooter wearing a Personal Mounted Microphone (PMM) designed and built by Troy Acoustics. The placement of the microphone is always a difficult decision especially as consistency and repeatability is a major concern in shooting range measurement. When microphones are placed on a stand next to the shooter the issue is that every shooters stance is different so their position relative to the microphone will vary. The PMM offers a consistency relative to the shooters ears. This is very useful in evaluation of a range pre and post acoustic treatment where the same shooters may not be available.

Picture 3 below shows multiple shooters firing at the same time. The microphone on the stand on the left is for measuring RT60 and stays in place as the shooters move to various positions in the range. The shooter on the left in addition to having a Personal Mounted Microphone mounted to his hard hearing protection there is also a pressure sensor mounted to the temple region. The concept of using pressure sensors was pioneered by Troy Acoustics. The purpose of the pressure sensor is to gauge the effect on the shooter from the shooter in the adjacent lane. Pressure sensors are used for this purpose; as a microphone cannot be directed at a high-level source as its diaphragm will be bottomed out by the impulse overblast pressure wave where a piezoelectric pressure sensor will not. This author currently utilizes four (4) Personal Mounted Microphones for range testing, three shooters and an instructor, plus four (4) fixed microphone positions, and three (3) piezoelectric pressure sensors on the shooter in the center lane, one on each temple, and one on the sternum.

Picture 3

What Metrics Are Used To Measure A Shooting Range?

Sound pressure level (SPL) is a logarithmic measure of the effective sound pressure of a sound relative to a reference value measured in decibels (dB). The commonly used "zero" reference sound pressure in air is 20 µPa RMS, which is considered the threshold of human hearing. When looking at a time series such as in *Figure 1* or *Figure 2* the peak sound pressure level is the highest point. In figure 2 the peak level was 164.9 dB.

The peak sound pressure level can be used to calculate other metrics such as Equivalent Continuous Level (Leq). Leq represents the average energy over a period of time. Typically OSHA will look at sound averaged over 8 hours, Leq8. While it is possible to average a single impulse over 8 hours it is questionable as to its value as who only fires one shot.

A-Weighting - There are those who use "A-weighting" to analyze peak sound pressure levels and calculate Leq (LAeq). A-weighting refers to the high and low-frequency filtering of a signal with a low-frequency roll off that starts at 1 kHz and is down 10 dB at 125 Hz. A-weighting is commonly used to emphasize frequencies around 3–6 kHz where the human ear is most sensitive, while attenuating very high and very low frequencies to which the ear is insensitive. The issue is the most significant energy generated by small arms fire is between 100 Hz and 400 Hz.

There are those who question the use of A-weighting. While it is in common use for assessing potential hearing damage caused by loud noise, this seems to be based on the widespread availability of sound level meters incorporating A-Weighting rather than on any good experimental evidence to suggest that such use is valid[8].

Reverberation Time (RT60) Reverberation is the persistence of sound in a particular space after the original sound is produced. It is created when a sound is produced in an enclosed space and a large number of repeats of the same sound build up and then slowly decay as the sound is absorbed by the walls and air. Reverberation Time, RT60 is the time required for the reflections of a direct sound to decay by 60 dB below the level of the originating sound. The more shooters there are the more sound that is produced on the range as the repeats build it to higher and higher levels.

[8] http://en.wikipedia.org/wiki/Weighting_filter

B-duration, for impact noise, the two principal descriptors are the highest peak in a series of successive peaks (reverberations) and the so-called B-duration, the duration from the highest peak level to a point in time when the reverberations have decayed either 10 or 20 dB. B-durations range from 50 to 300+ milliseconds (ms). The distinction between impulse and impact noise becomes blurred in many real-life situations because impulse noise can reflect off the ground, or other surfaces, and the reflections add to the initial impulse noise, creating a large, more complicated waveform that is best described using the B-duration.[9] An example of B-duration can be seen in *Figure 1*.

Allowable Number of Rounds (ANOR) as defined in Department of Defense Design Criteria Standard, Noise Limits, MIL-STD-1474D uses the peak pressure level in dB SPL, and the B-duration to calculate an allowable number of rounds (ANOR) that can be fired in a 24-hour period without a significant risk of hearing loss. These formulas assume that a certain level of hearing protection will be used by personnel exposed to the weapons noise.[10]

Pressure Time

Pressure Time (PSI(t) is a metric advocated by Troy Acoustics to compare shooting range acoustics before and after acoustic treatment. MIL-STD-1474D only refers to a hearing conservation criterion. To better understand the impact on the whole body the metrics **Pound-Force per Square Inch (psi)** and **Pound-Force per Square Inch Time (psi(t))**[11] **can be used** to evaluate shooting ranges and gauge the amount of improvement from sound absorption/noise abatement treatment. Pressure Time measurement advantages include:

- Psi(t) gives an actual representation of the total energy generated within the range
- Psi(t) gives an accurate representation of the effect of multiple shooters firing multiple rounds
- Psi(t) gives an accurate representation of automatic and semiautomatic fire, single or multiple shooters
- Psi(t) can be used to compare any range whether acoustically treated or not

[9] Hamernik and Hsueh, 1991

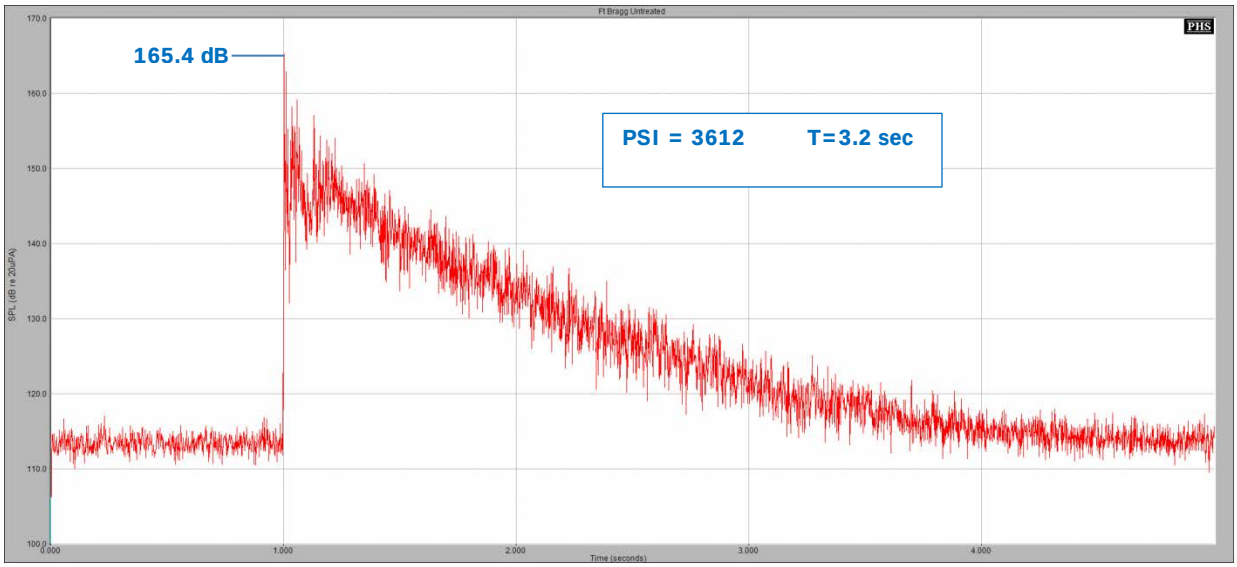
[10] Jokel, "Criteria and Procedures for Auditory Health Hazard Assessment of Impulse Noise (Blast Over Pressure)," U.S. Army Public Health Command Technical Guide No. 338, Feb 2012

[11] psi(t) is the integer of the area under the peak pressure curve (in Pa) times the total event duration in seconds with the formula (psi (t) = Zn (∫ ƒ (x) dx (sec)))

- Psi(t) is an excellent way to compare an indoor or outdoor acoustically untreated range to an acoustically treated range to gauge performance and improvement
- Psi(t) clearly expresses the effect on the total human physiology not just hearing

Figure 3 below is a time series of seven shooters (7) each firing one-round on an M4 5.56 on an untreated fifty-meter (50m) indoor shooting range. The peak level is 165.4 dB SPL. The total pressure is 3612 PSI for 3.2 seconds for a PSI(t) of 11433 equating to 175.1 dB.

Figure 3



How Acoustically To Treat an Indoor Shooting Range

There are several goals that must be achieved to meet all standards and protect the whole person when acoustically treating an indoor shooting range:

- Use products with significant density that offer the maximum amount of sound absorption at all frequencies and that are capable of maintaining their absorption coefficient at high-intensity sound levels
- Do not use a product that absorbs some frequencies and reflects back others
- Use products that are capable of absorbing low-frequencies
- Treat 75% or more of all exposed surfaces
- Reduce the Reverberation Time (RT60) to 1.3 seconds or less
- Keep the sound of the range from getting into adjoining spaces and leaving the building

- Materials used must allow bullets to penetrate or pass without ricochet or splash back, and without noticeable deformation of system
- Products must be highly rated as to combustibility, flame spread, smoke developed, mold and mildew resistance, ease of cleaning and maintenance, durability
- All acoustic materials should warrantied and guaranteed by the manufacturer as to their specific performance on a shooting range

Material Specifications

Noise Reduction Coefficient (NRC) is a scalar representation of the amount of sound energy absorbed upon striking a particular surface. An NRC of 0 indicates perfect reflection; an NRC of 1 indicates perfect absorption.[12] The acoustical material selected should have a NRC of 0.85 or higher based on tests at 16 third-octave band frequencies from 125 to 4,000 hertz (Hz). NRC is being replaced by the Sound Absorption Average (SAA), which is described in the current ASTM C423-09a. The SAA is a single-number rating of sound absorption properties of a material similar to NRC, except that the sound absorption values employed in the averaging are taken at the twelve one-third octave bands from 200 Hz to 2500 Hz, inclusive, and rounding is to the nearest multiple of 0.01.[13]

Material Density: sound absorption and noise abatement material shall be of significant density and porosity to mitigate blast overpressure (BOP) from single and multiple weapon fire with peak amplitudes in excess of 165 dB (SPL) and Pressure Time (PSI(t)) exceeding 10,000 (PSI(t)). Sound boards should have a minimum density of two (2) pounds per square-foot per each inch of thickness. All batt-type sound absorption materials should be mineral based and have a nominal density of no less than two and one-half pounds per cubic foot (2.5 pcf) per inch.

[12] http://www.acoustical.com/documentation/acoustical-education/32-what-is-nrc-stc-and-saa-acoustical-material-distributors-inc
[13] http://www.astm.org/Standards/C423.htm

Sound Transmission Class (STC) is an integer rating of how well a building partition attenuates airborne sound. STC for a shooting range needs to be determined on a case-by-case basis. Particular care and attention needs to be paid to the wall, window, and door design separating the range control room, classrooms, show room, etc. It is paramount that the sound level reaching these areas be below 85 dB else persons in those areas will be required to wear hearing protection and or be enrolled in a hearing conservation program. Regarding sound leaving the building it is dependent as to where the range is located. It is critical if the range is located in a building with offices and/or other business or in or near residences. If an indoor shooting range is located in the middle of nowhere, not so much.

Not All Acoustic Materials Are Created Equal

Just because a manufacturer tells you that their product will work on an indoor shooting range doesn't make it so. Some products are very good at not allowing bullets to penetrate or pass without ricochet or splash back but acoustically can reflect back as much or more noise then they absorb. Some products offer some sound absorption at low-levels but literally are torn to shreds if hit by a bullet.

Noise Reduction Coefficient (NRC) is a very nebulous standard. To test for NRC you use a known reverberant room. The reverberation time (RT60) is measured in the room without and with a sample of absorptive material being tested. From the differences in the reverberation time (RT60) the NRC is calculated. Even though the reverberation time (RT60) is measured typically from 20 Hz to 20,000 Hz only four-frequencies are averaged to derive the material's NRC, 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz. These frequencies were chosen in the 1930's based on speech intelligibility in an auditorium. They have nothing to do with the complex impulse overblast pressure wave we know as gunfire.

The computation of NRC by averaging the four-speech frequencies by itself is flawed. The standard for NRC is a one-square foot open window which is considered to have an NRC of "one." If the NRC at each of the four-frequencies is equal to .5 the NRC is called .5. If the NRC at 1000 Hz and 2000 Hz is 1 and the NRC at 250 Hz and 500 Hz is 0 the NRC would still be .5. By way of example a thick ham sandwich could have an NRC of 1 at 1000 Hz and 2000 Hz. Is that what you want protecting you in a gun range?

When NRC is measured the sound level put into the reverberant test room is around 85 dB. The sound of gunfire on a range can be over 165 dB! NRC fails to tell you how much you are protected from the high-intensity sound of gun fire.[14]

Chart 1 below compares the Noise Reduction Coefficient (NRC) of acoustic products that have been used on shooting ranges. Most of these products exhibit a low NRC in the critical frequency bands below 500 Hz. The Troy System™ shows an NRC of 1.20, significantly higher the next highest NRC 0.60 of acoustic tile. For years acoustic tile has been installed in shooting ranges with very little to no benefit. The benefit of acoustic foam products is also suspect as little is known on how they perform under the influence of intense sound fields found on shooting ranges. Ballistic rubber products are not represented as-to-date, as no ballistic rubber manufacturer has published NRC ratings from an accredited laboratory. It is felt by some that ballistic rubber products actually heighten the noise and pressure in a shooting range. There is also measurement and comparison data that also points to that supposition.

[14] Public Safety Newsletter, June 2010, SHOOTING RANGE NOISE, Higher Absorptive Value provides safer environment for the shooter, S Katz

Chart 1

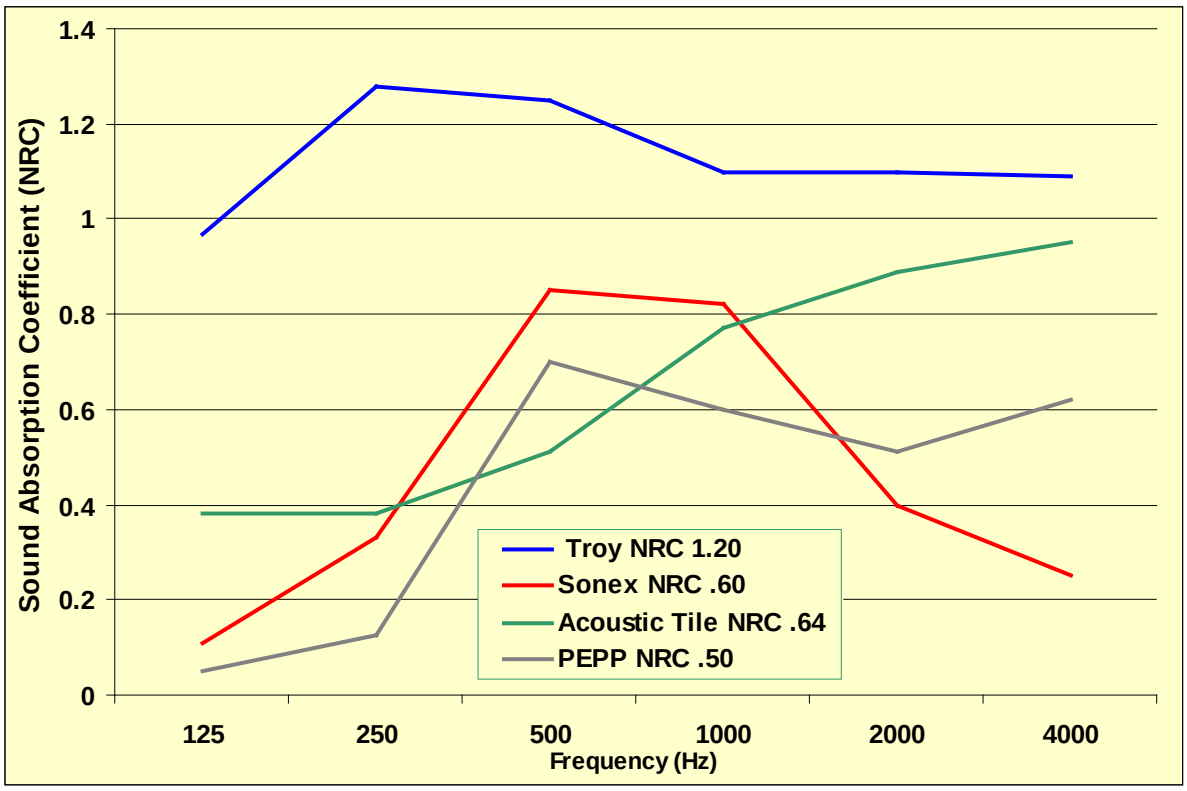


Chart 2 below shows a generic comparison of the reverb time (RT60) in an indoor small arms range that is; treated with wedge foam, PEPP, 2" Rubber, and the Troy System. It can be seen that effectiveness of the PEPP, and 2" Rubber is moderate at mid and frequencies, a steep rise at high frequencies, and almost nonexistent at the critical lower frequencies. The Troy treated range shows an RT60 of less than one-second (1 sec). As Reverberation Time (RT60) is a natural amplifier, if you think of the sound of your car alarm turning on or off in an underground parking versus outdoors, it is easy to see how important reducing the reverberation time in a shooting range is.

"Bang! Bang! Bang! Bang! Bang! Bang!" versus... "Bang! Bang!"

Chart 2

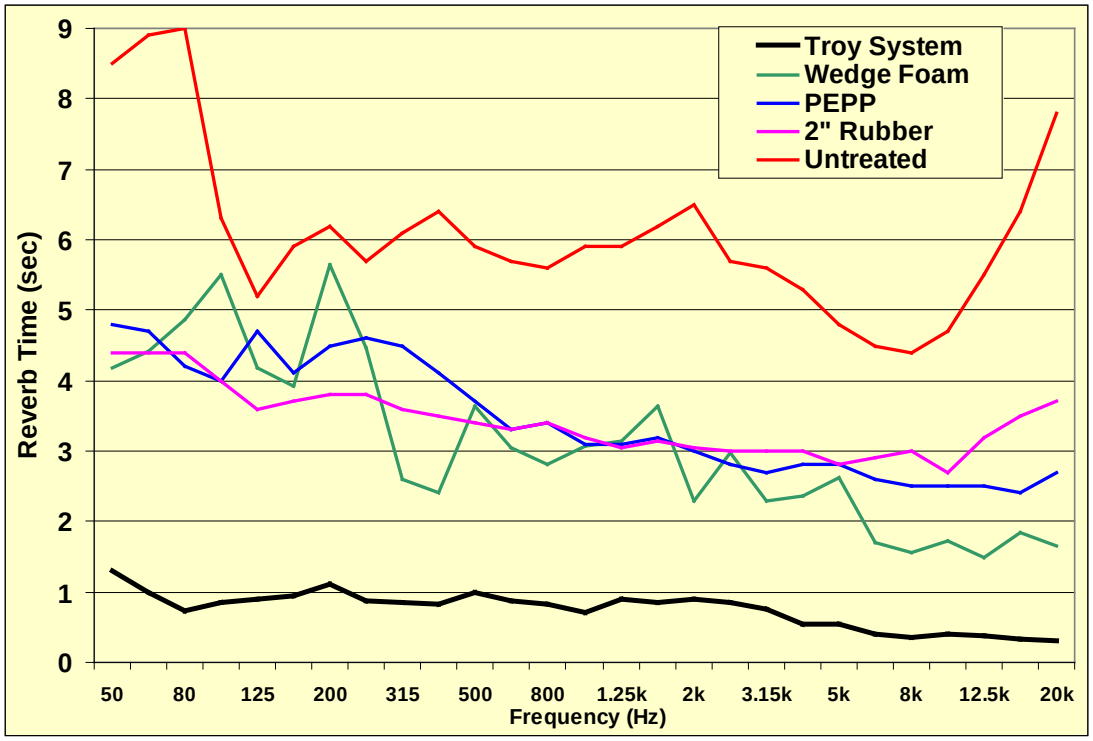


Figure 4 below shows a comparison between the relative pressure in PSI on an untreated (concrete sidewalls, steel baffles) fifty-meter, fourteen-lane indoor shooting range and a ten-lane, twenty-five yard indoor range treated with ballistic rubber, for a single shooter firing a single round of an M4 5.56 rifle.

In each case the shooter was firing from the furthermost firing-line from the target and nearest to the rearmost wall. We can see that even as the time period is 3.0 seconds for the larger range, the pressure on the shooter is greater on the range treated with ballistic rubber range by 25 psi. It is apparent from this that ballistic rubber is not an ideal acoustic treatment for a shooting range.

Figure 4

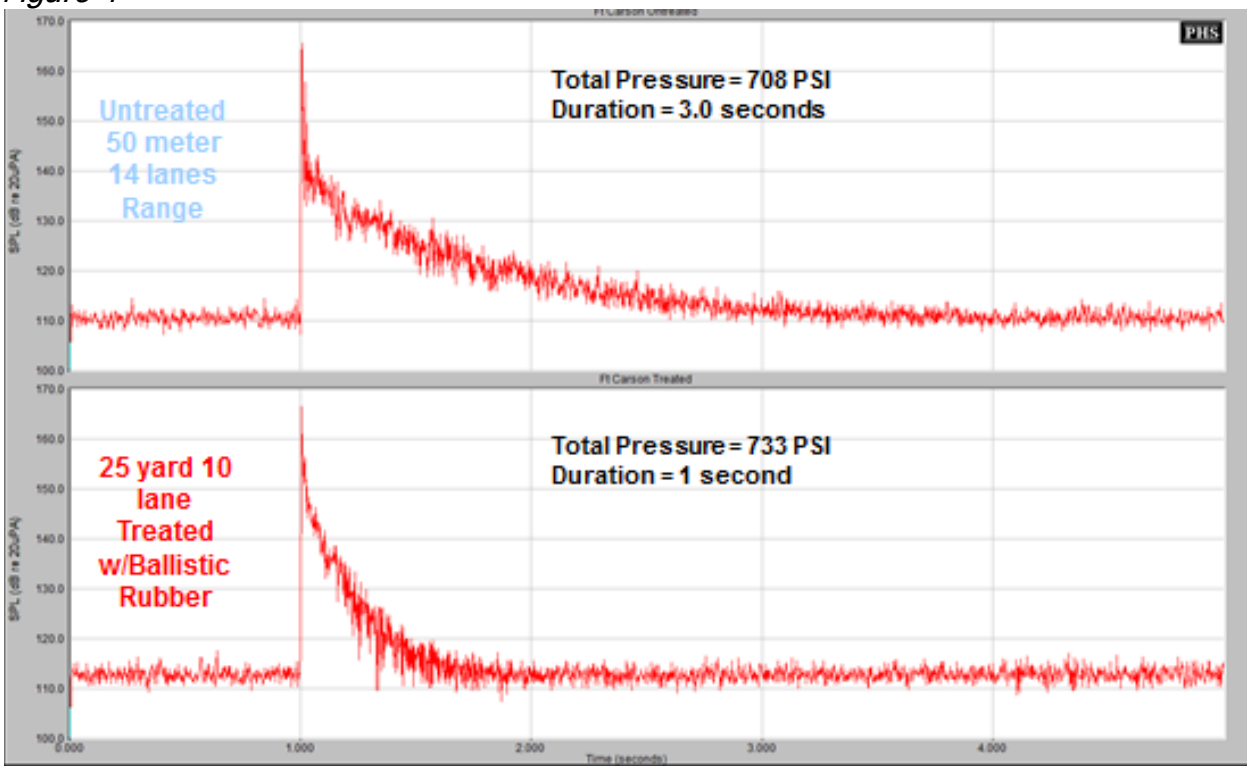


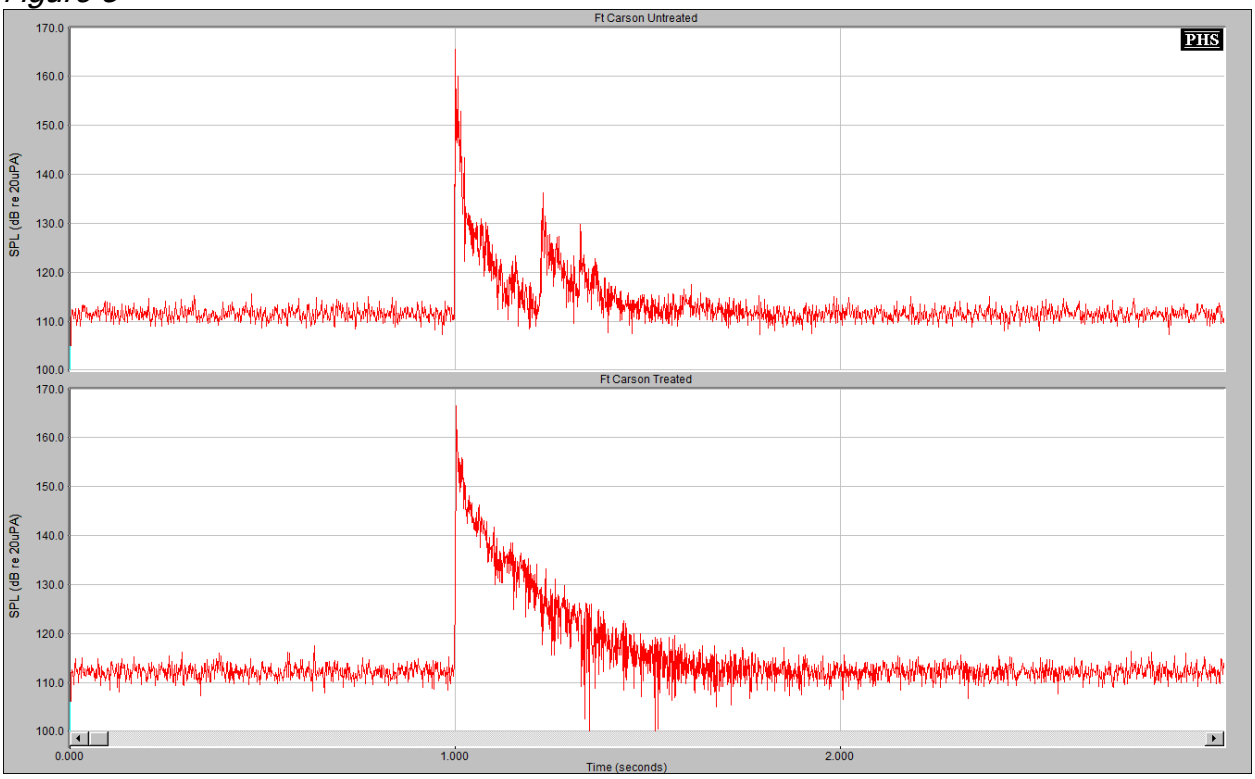
Figure 5 below shows a comparison between the relative pressure in PSI on the same range as above (fifty-meter, fourteen-lane) that has been acoustically treated with the Troy System™ and the same ten-lane, twenty-five yard indoor range treated with ballistic rubber, for a single shooter firing a single round of an M4 5.56 rifle.

The Troy acoustically treated 50-yard range shows a total pressure of 196 psi over one-half of a seconds verses 733 psi over a one-second time period on the 25-yard range that is treated with ballistic rubber, for one shooter firing one round on a M4, 5.56.

The variance of pressure on the shooters' hearing and body in the ballistic rubber treated 25-yard range is 537 psi greater the Troy Treated 50-meter, 14-lane range. This equates to a difference of 374% greater pressure on the shooter which equates to the extreme "loudness" shooters experience on this range.[15]

[15] Sgt Lou Salseda formerly Range Master for the Los Angeles Police Department was acting as Range Master when this range was measured and commented that this was the loudest range he had ever heard

Figure 5



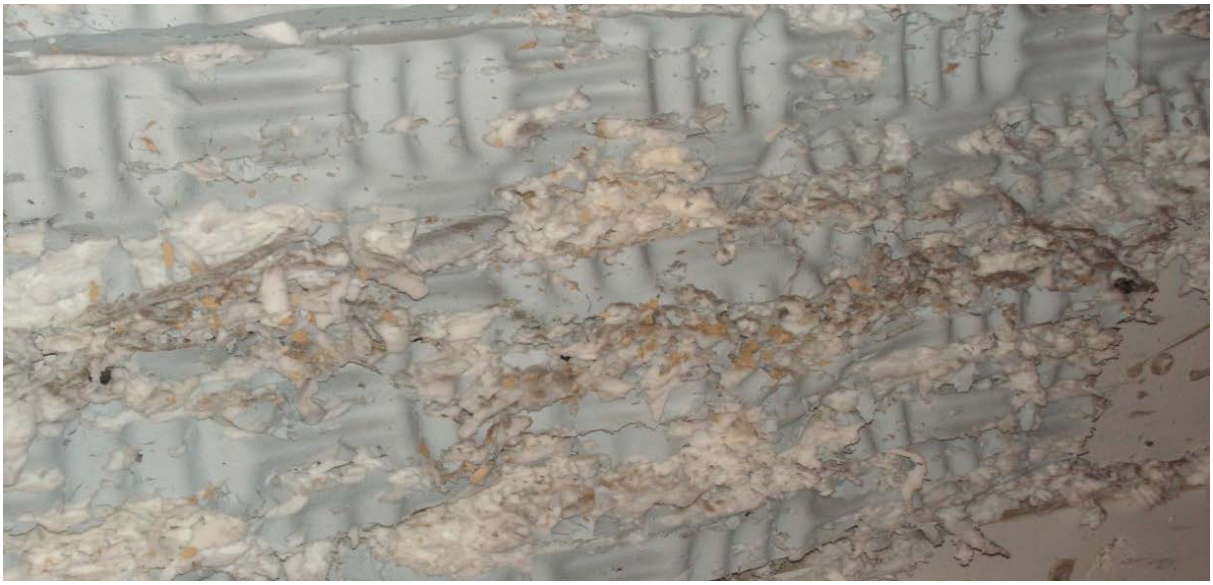
How Do You Acoustically Treat an Indoor Shooting Range?

Acoustically treating an indoor shooting range is not something that should be taken lightly. "*Primum non nocere*," do no harm. There are products that claim to have acoustic proprieties but can actually make the sound of an indoor shooting range worse. They achieve their noise reduction rating mainly because their product diffuses the sound rather than absorbs it. Rubber products are extremely prone to this. Rather than reduce the sound overpressure pressure on the range they can actually amplify it. There are multiple instances where rubber type products had to be removed because they exacerbated a range's noise problem.

There are products that might slightly change the range acoustics but create dangerous conditions in regards to ricochet and splash back. Foam type products are especially prone to this. The cell structures of foam products are generally not continuous. This discontinuity, low porosity and low tortuosity reduce foam products' ability to fully absorb sound at all frequencies. At extremely high sound pressure levels, as found on shooting ranges, the foam cells become blocked by the impulse overblast pressure wave turning the foam more into a reflector then an absorber. There are also issues with cleaning and lead remediation in ranges with acoustic foam. There are also multiple instances where acoustic foam type products had to be removed because they exacerbated a range's noise problem as well as ballistic, cleaning and lead issues.

Picture 3 below shows foam based acoustic product used on an indoor shooting range after being hit by gunfire.

Picture 3



There are acoustic products that pose fire and smoke hazards. There is a classic story of a brand new three-million dollar ($3m) military indoor shooting range that was treated with rubber products. As the story goes they were warned not to shoot any tracer type rounds. Not everyone got the message. The range was fully destroyed. The good news was no one was hurt.

There are acoustical products that are prone to mold and mildew and can literally melt in high humidity conditions or if hit by water. Some gypsum based soundboards are especially prone to this. A leak or someone trying to clean it by hosing it down can be catastrophic. High humidity exposure over time can have the same effect. Most manufacturers will put a warning in their literature. Gypsum based soundboards also have an issue with density. If the product is not dense enough its ability to absorb the sound of gunfire, especially multiple shooters will be considerably compromised.

Fiberglass insulation products are not designed for use on shooting ranges, either as a backing or exposed. It is prone to moisture build-up causing mold, mildew and decay. Moisture buildup diminishes fiberglass's acoustical and thermal properties. Exposed fiberglass has potential health risks such as lung damage and bronchial and skin irritation. Fiberglass insulation does not burn but does melt at fairly low temperatures emitting potentially harmful carcinogens.

Additionally, there are acoustical products that can't be cleaned after lead exposure from gunfire. These products may have to be fully remediated and replaced, a very costly proposition.

Yes, cost is always a factor but nothing is as costly as having to do it twice. For reasons of health and safety and yes, cost, get it right the first time.

Types of Indoor Shooting Ranges

Tactical Shooting Ranges are where shooting is permitted from every point on the range (multiple firing lines). These are also known as fully baffled ranges as baffles are continuously placed, in a sawtooth pattern from the end of the safety ceiling to the trap. For a tactical range, as shooters will move both transversely and laterally all performance specifications must be met at any possible firing point within the range.

Fixed Point Shooting Ranges have a single firing line and usually but not always have shooting stalls.

Acoustic Treatment Basics

How Much Acoustic Treatment Do You Need?

Ever shoot outdoors under perfect acoustic conditions, e.g. where there is deep brush and foliage to absorb the sound or in the middle of nowhere with no reflective surfaces for miles and miles.

You can never have too much sound absorption. To fully absorb the sound of gunfire it is imperative that at least 75% of all exposed surfaces be acoustically treated. This is because if you allow reverberation to build up in any area of the range it will increase the overall sound pressure on the entire range.

For a tactical range this means all the baffles, except for the one nearest to the trap, the rear wall, safety ceiling, any area between the safety ceiling and the rear wall, the side walls behind the firing line, and at least fifteen feet in front of the target line nearest to the trap.

You treat a fixed point range the same as a tactical range. The main difference is that there are fewer baffles which are spaced widely apart. Because of that, an isolation ceiling is recommended from the rear wall behind the shooter down to the trap. If there are shooting stalls, they can create their own set of problems as they tend to enclose the shooter. It is possible to design shooting stalls with excellent acoustic and ballistic properties. In any case the ceiling above the stalls should always be covered with high absorbing acoustic materials across ALL frequencies.

Recommended Acoustical Treatment

Rear Wall – it is recommended that the range rear wall be treated with a two-inch (2”) soundboard with a density of no less than four-pounds (4lbs) per square foot. The soundboard in order to be effective needs to be backed by a two-inch (2”) mineral wool based insulation product with a nominal density of no less than two and one-half pounds per cubic foot (2.5 pcf). All materials need to be UL approved as to fire, flame spread and smoke developed. If for some reason you have a laminar flow back wall, you introduce other factors. If you are isolating noise you may want to consider placing acoustic material behind the wall if allowable. A clear laminar flow wall, like a glass wall, should have varying thicknesses of glass or Lexan to help mitigate the noise.

If the rear wall backs up to a control room and/or class rooms it is recommended that before applying acoustic material the wall be covered with one layer of a gypsum board material (drywall) nominal dimension 5/8" thick. This must be installed directly onto the concrete CMU block or AR Steel with NO air space.

All doors should be ballistic and acoustically rated. If there are windows they should be comprised of a single pane ballistic or a duel pane acoustically rated laminated glass.

Side Walls - it is recommended that the side walls be treated with a two-inch (2") soundboard with a density of no less than four-pounds (4lbs) per square foot. The side walls need to be treated from the rear wall to at least seventy-five percent (75%) from the furthermost firing line to the bullet trap. The soundboard in order to be effective needs to be backed by a minimum of two inches (2") of inorganic mineral wool based insulation product with a nominal density of no less than two and one-half pounds per cubic foot (2.5 pcf). All materials need to be UL approved as to fire, flame spread and smoke developed.

Safety Ceiling – the safety ceiling should be treated with one-inch (1") soundboard with a density of no less than two-pounds (2lbs) per square foot. The soundboard needs to be backed by two inches (2") of inorganic mineral wool based insulation product with a nominal density of no less than two and one-half pounds per cubic foot (2.5 pcf). All materials need to be UL approved as to fire, flame spread and smoke developed.

Baffles – all baffles except to the one nearest to the bullet trap should be treated with one-inch (1") soundboard with a density of no less than two-pounds (2lbs) per square foot. The soundboard needs to be backed by two inches (2") of inorganic mineral wool based insulation product with a nominal density of no less than two and one-half pounds per cubic foot (2.5 pcf). All materials need to be UL approved as to fire, flame spread and smoke developed.

Isolation Ceiling - the factors governing the need for a range isolation ceiling are if there is a noise containment issue in the case of a tactical range, or if the range has a fixed firing line and not-complete down range baffle coverage. An isolation ceiling can be attached to the roof deck or hung. It should consist of one-inch (1") soundboard with a density of no less than two-pounds (2lbs) per square foot. The soundboard needs to backed by six inches (6") of inorganic mineral wool based insulation product with a nominal density of no less than two and one-half pounds per cubic foot (2.5 pcf). All materials need to be UL approved as to fire, flame spread and smoke developed.

The Troy Solution

Troy Acoustics' patented solution to treat a shooting range is to use high density soundboard that is a mixture Portland cement and woven wood fibers, bonded together, and that have a material density of equal or greater than two-pounds per square foot (2lbs/sq. ft.) for a one-inch (1") board, and a density of equal or greater than four-pounds per square foot (4lbs/sq. ft.) for a two-inch (2") board.

Troy treats the sidewalls, from the rear wall to the target line with their two-inch (2") Troy Board™ mounted over their two-inch (2") Troy Wool™. Troy Wool™ is a basalt based mineral wool with a nominal density of two-and-one-half pounds per cubic foot (2.5 pcf). The safety ceiling and baffles are treated with one-inch (1") Troy Board™ mounted over two-inches (2") of Troy Wool™. In the case of a fixed-point firing line Troy installs a hung, isolation ceiling that runs from the end of the safety ceiling to the trap that consists of one-inch (1") Troy Board™ topped with six-inches (6") of Troy Wool™.

The key to the Troy design is the full coverage of the range surface areas and high density materials that are proven capable of maintaining their acoustical properties when exposed to intense sound pressures found on a shooting range.

Troy custom engineers every installation to be cost effective while delivering optimum sound absorption and noise abatement.

Comparisons of Acoustically Treated and Un-treated Shooting Ranges

Chart 3 below shows a Reverberation Time (RT60) of 5.39 seconds in all octave bands from 50 Hz to 20,000 Hz before treatment of the Ft Lewis, WA shooting range with the Troy System™, and a Reverb Time (RT60) of 1.08 seconds in all octave bands from 50 Hz to 20,000 Hz after treatment of the Ft Lewis, WA shooting range. The Reverberation Time (RT60) was arrived at by averaging shooter positions in lane 7 firing a single shot M4, at the 7, 25, and 50 meter lines, respectively along with fixed positions in the center of the range at the 25 meter point.

Chart 4

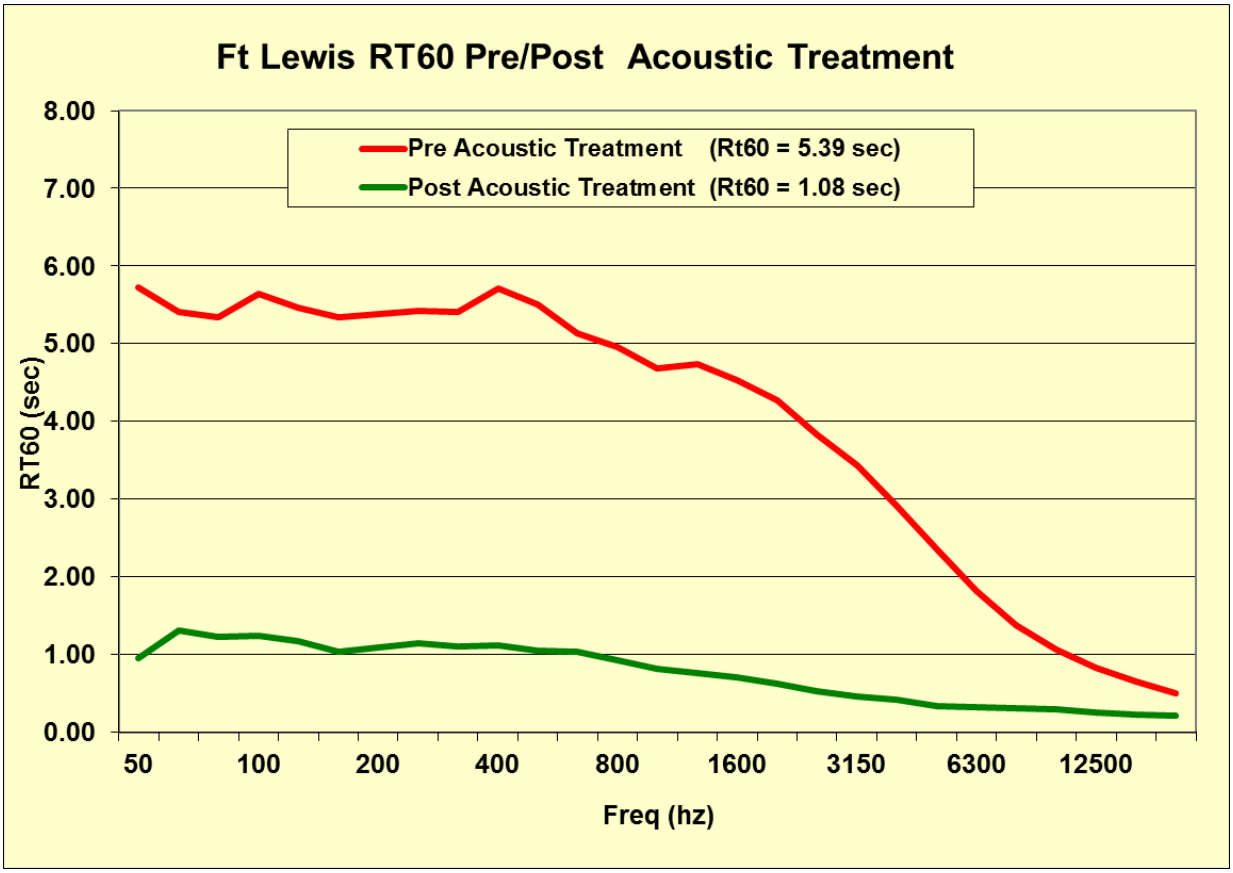
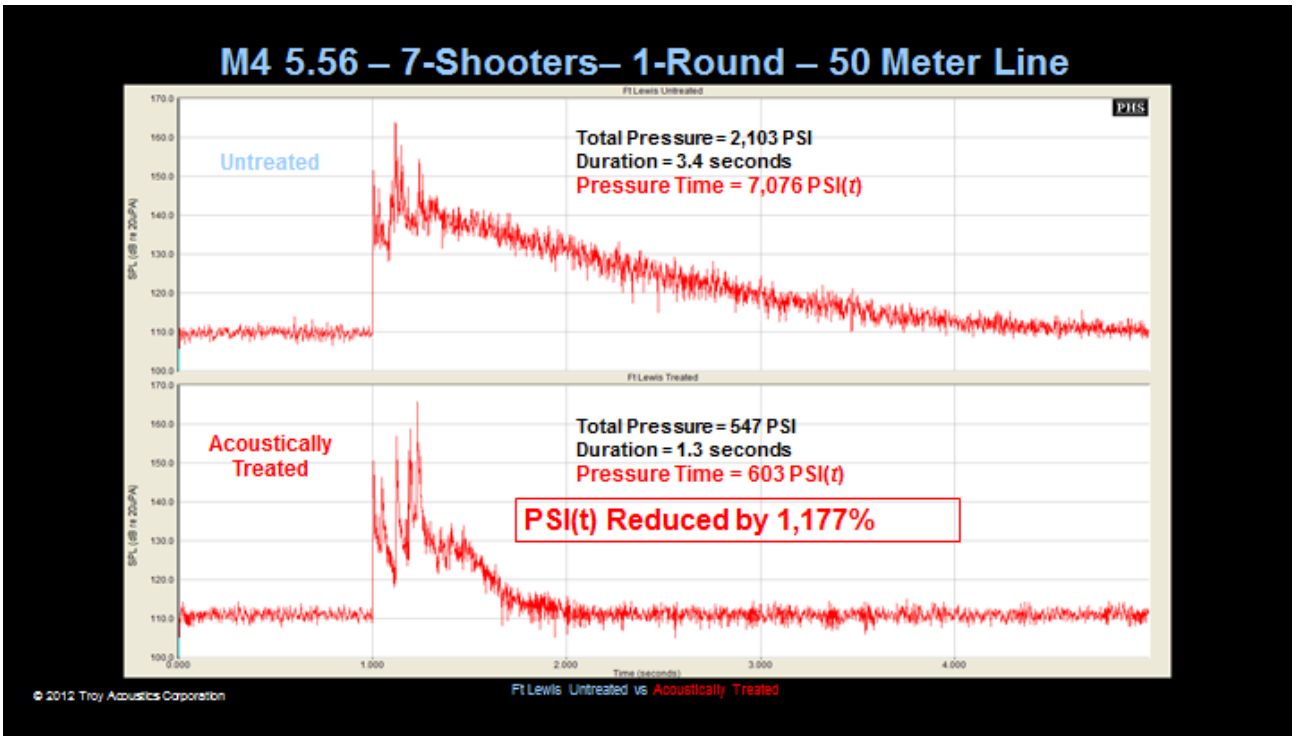


Figure 6 below shows seven (7) shooters, standing in lanes, 1, 3, 5, 7, 9, 11, 13 firing a single round on a M4 – 5.56 from the 50 meter line at Ft Lewis, WA. Psi(t) was reduced from 7,076 psi(t) to 603 psi(t), an improvement of 1,177 percent (%). The total pressure in psi was reduced from 2,103 psi to 543 psi. The shooters exposure time was reduced from 3.4 seconds to 1.3 seconds. The reduction in total pressure is demonstrably apparent and follows the reduction in reverberation (RT60).

Figure 6



Small Ranges Are Particularly Susceptible To Noise Issues

Chart 4 - below shows a Reverberation Time (RT60) of 2.54 seconds in all octave bands from 50 Hz to 20,000 Hz before acoustic treatment of the San Diego Sheriff's Department Vista Range, Vista, CA shooting range, and a **Reverb Time (RT60) of 0.69** seconds in all octave bands from 50 Hz to 20,000 Hz after treatment.

The range is located in the basement of a court house. The range dimensions are 25 feet wide and 100 feet deep.

Chart 4

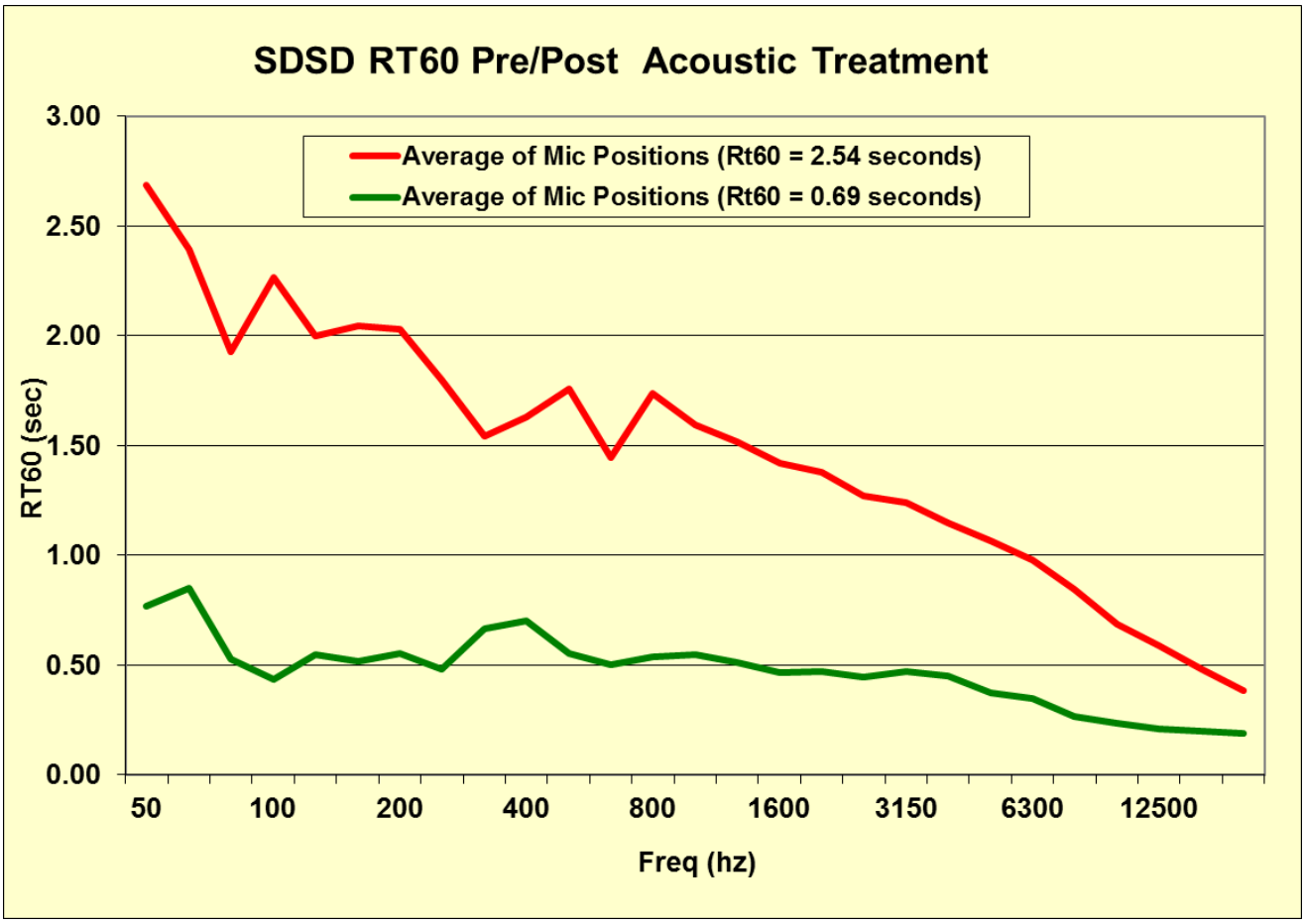


Figure 7 below shows one (1) shooter, standing in lane 3 firing a single round on a M4 – 5.56 from the 25 yard line of the San Diego Sheriff's Department Vista Range, Vista, CA. Psi(t) was reduced from 733 psi(t) to 28 psi(t), an improvement of 2,623 percent (%) after acoustic treatment. The total pressure in psi was reduced from 690 psi to 93 psi. The shooters exposure time was reduced from 1.06 seconds to 0.3 seconds.

Figure 7

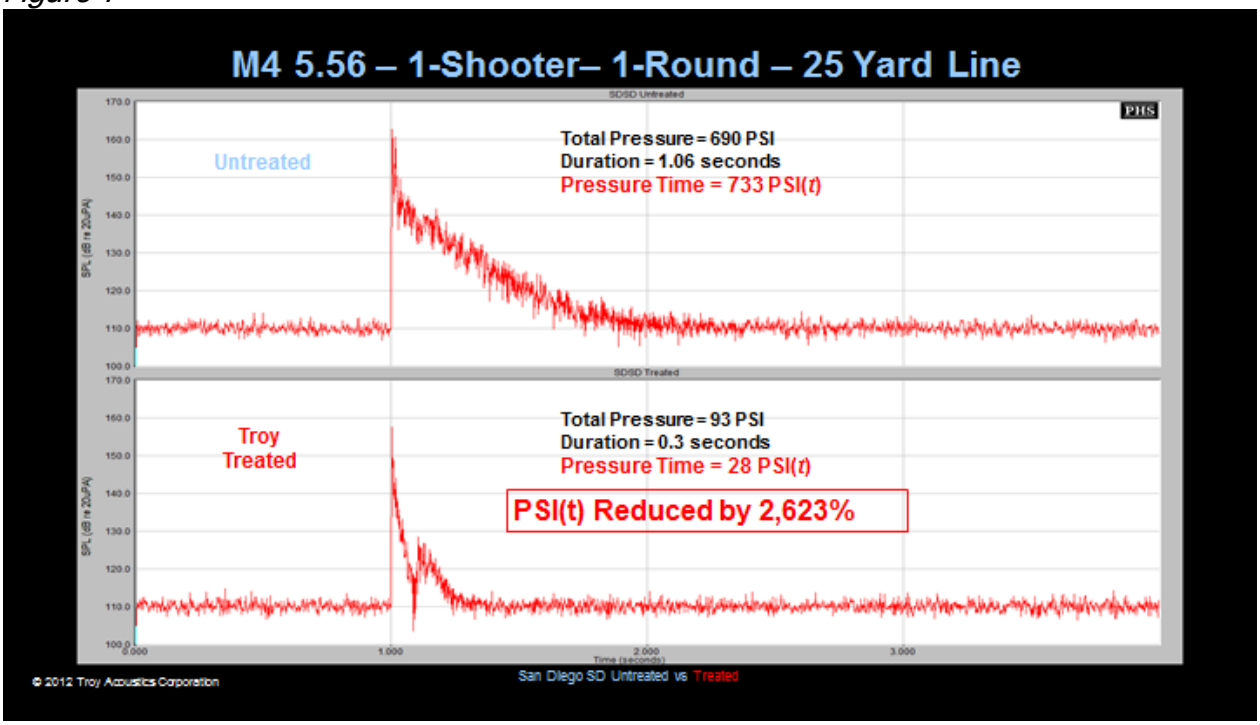
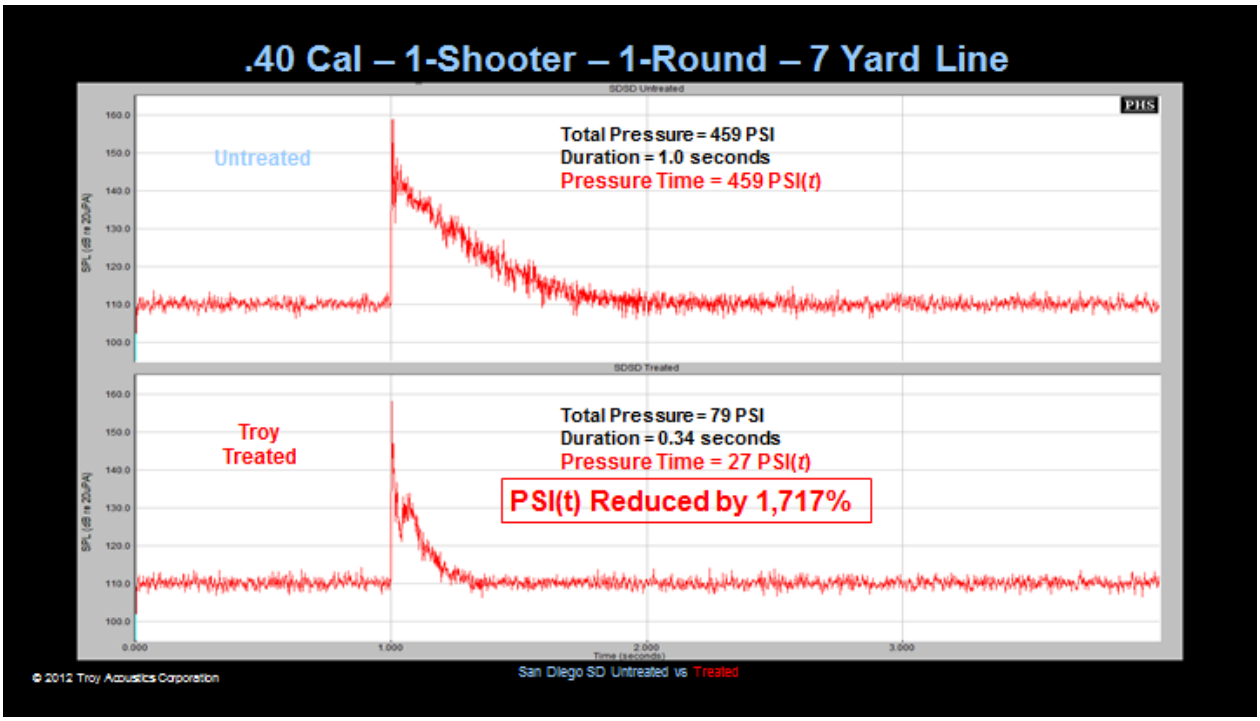


Figure 8 below shows one (1) shooter, standing in lane 3 firing a single round on a .40 caliber pistol from the 7 yard line. Psi(t) was reduced from 459 psi(t) to 27 psi(t), an improvement of 1,717 percent (%). The total pressure in psi was reduced from 459 psi to 79 psi. The shooters exposure time was reduced from 1.0 seconds to 0.34 seconds.

Figure 8



Conclusion

It is totally possible with the selection and proper use of acoustic materials capable of handling the intensely loud noise as found on indoor ranges to reduce the sound to safe levels that will insure full hours of range operation.

It is strongly recommended that you state acoustical performance and acoustical materials specifications in your design and on all bids.

At a minimum include:

- Must be tested to meet 1.3 seconds reverb or less at all positions within the range space, in all octave bands from 125 to 8000 Hz as measured with multiple microphones in multiple positions throughout the range
- That all acoustical products have NRC values of 0.85 or higher based on tests at third-octave band frequencies from 125 to 4,000 hertz (Hz)
- That all acoustic products used are guaranteed by the manufacturer to maintain their absorption values at sound intensities that exceed 160 dB
- That all soundboard used have a minimum density of not less than two-pounds (2 lbs.) per square-foot per one-inch (1”) of board.

- That all insulation products be of an inorganic mineral wool type with a nominal density of no less than 2.5 pcf (40 kg/m3)
- That the installed acoustic system be tested and guaranteed to allow bullets to penetrate or pass without ricochet or splash back, and without noticeable deformation of the system
- Must be tested upon completion to assure compliance with any local noise ordinance criteria (if applicable)
- That all materials selected are UL approved for fire to equal; Flame Spread-0, Smoke Developed-0.
- The final results be **warrantied** and **guaranteed** to meet all specifications

Your Next Step

Contact Troy Acoustics, the only company that specializes in engineering noise control for shooting ranges and that offers the industry's only guaranteed solution. Troy guarantees that Troy materials and the installed Troy System™ will meet all the specifications as listed above. Troy Acoustics engineers shooting range sound absorption, and noise abatement systems, to your exact requirements, and specifications, at a price you can afford. All our work is Guaranteed to meet all, OSHA, government, military, and civilian noise standards, regulations, and ordinances.

Summary

Properly treating an indoor and outdoor shooting range makes not only good health sense but good business sense. It allows the owner to get maxim utilization and return on the investment while protecting personnel from lifelong bodily harm.

The cost-to-benefits from avoiding potential lawsuits and disability claims will more than outweigh any initial investment.

For military and law enforcement ranges effective acoustic treatment means that your people can train longer and harder without fear of physiological effects.

For commercial and private ranges this can mean more customers that stay longer, buy more ammunition, and bring their whole family.

For all, proper acoustic treatment of indoor shooting ranges means good relations with all neighbors and being an integral and important part of the community.

Firearm's training in a safe, healthy environment is essential as to the protection of our country and communities, and to a recreational sport that is enjoyed by all.

Biographical Information

Stephen Katz

This primer was written by Stephen Katz, Vice President Applied Research & Technology, Troy Acoustics. Mr. Katz's experience and qualifications include:

Director, Research and Technology, Troy Acoustics

...Won an Academy Award for the co-development of Dolby Stereo. He has over thirty feature film credits including, *Star Wars, Close Encounters of the Third Kind,* and *Altered States.*

...He was a recording engineer for Jimi Hendrix, Chuck Berry, Ike and Tina Turner, Barry Manilow, the St. Louis Symphony, etc.

...Designed and built recording studios for Dolly Parton and Porter Wagner, Pete Drake, the original Cherokee Ranch (Steely Dan, *aja*), Tom T. Hall, Sea Saint Recording (Allen Toussaint), Grand Funk Railroad, etc.

...Founding partner Eventide Electronics, one of the first manufacturers of professional digital audio equipment including digital delay lines, auto-locators, and pitch changers. Eventides' first project was to design a 2.5 second digital delay line for NASA to be used for astronaut training in preparation for the first moon landing.

Mr. Katz is the Director of the Center for Entertainment Industry Data and Research (CEIDR).

Has authored, been featured, and published reports, papers and articles. His research has been covered by CNN, The New York Times, NPR, The Wall Street Journal to name a few. Mr. Katz was invited by the Harvard Club to debate a former Prime Minister of Canada.

Member: Acoustical Society of America (ASA), Audio Engineering Society (AES), Society of Motion Picture and Television Engineers (SMPTE).