New Orleans, Louisiana
NOISE-CON 2020
2020 June 29 – July 1

Gunshot suppressors and sound level meters dBZ Peak performance tests

Erich Thalheimer
WSP USA, Inc.
100 Summer Street
Boston, MA 02110
Erich.Thalheimer@WSP.com

ABSTRACT

The art and the science of manufacturing effective small-arm gunshot suppressors (i.e. silencers) has progressed rapidly in recent years due in large part to a national upsurge to legalize civilian ownership of silencers for recreational, hunting and competitive shooting applications. This paper will describe a unique study that was conducted in late-2018 in which several dozen production and prototype silencers were independently tested using four different sound level meters to simultaneously measure dBZ Peak in accordance with test standard MIL-STD 1474D. Fourteen large bore (.300 BLK) and twelve small bore (.22 LR) silencers were tested and rank-ordered for effectiveness using a Bruel & Kjaer 2209, a Larson Davis LxT, a Svantek 971 and a Casella CEL 593 sound level meter. The results demonstrated that the more effective silencers could reduce gunshot sound levels by as much as 35 dBZ Peak. The phenomenon referred to as "first shot pop", in which the silencer is typically not as effective for the first shot through it, was also explored and quantified in this study. Lastly, the results of the four sound meters were compared to one another to evaluate how similarly they were able to measure dB Peak levels.

1 INTRODUCTION

A series of controlled gunshot sound suppressor (silencer) tests were performed on 9/30/18 at the testing grounds of Discrete Ballistics in Plainfield, New Hampshire. The intent of the event was twofold, (1) to compare the noise reduction effectiveness of multiple small-arm silencers produced by various manufacturers, and (2) to compare various sound level meters and their abilities to measure dB Peak sound levels in accordance with MIL-STD 1474D.

The silencer manufacturer industry is a relatively small but tightknit group with a strong presence in the Northeast United States. While they are certainly competitive with one another for commercial success, they have a remarkable eagerness to come together to share notes and procedures of common interest. Such is the case with their desire to measure sound levels associated with their silencer products in a more consistent and repeatable manner making use of modern-day sound measurement instrumentation. The silencer industry currently follows the procedures defined in MIL-STD 1474D to test and evaluate their products, however that standard is over 23 years old. Thus, efforts are currently underway to develop a new test standard that will ideally be detailed enough to allow for meaningful comparison of results obtained by different silencer manufacturers.

2 MIL-STD 1474D

Military Standard (MIL-STD) 1474D[1], entitled *Department of Defense Design Criteria Standard: Noise Limits*, was released in 1997. Other than a generally recommended impulsive noise limit of 140 dBA Peak, the standard does not provide criteria limits for impulsive gunshot noise and the possible adverse health effects on those exposed to it. However, the standard does define the testing procedures and instrumentation recommended to evaluate small-arms gunshot sound levels.

The standard calls for mounting the firearm with the muzzle parallel with the ground, made of grass or other non-reflecting surface, at a height of 1.6 meters (63 inches) to simulate a person shooting a rifle in the offhand (standing) position. Sound levels are supposed to be measured with the microphone positioned at the same height perpendicular from the muzzle a horizontal distance of 1.0 meters (39 inches). Additional sound measurements can be made at a distance of 0.15 meters (6 inches) from the gun's action to simulate the potential sound exposure at the shooter's ear location. A picture of the equipment set up in this study in accordance with MIL-STD 1474D can be seen in **Photo 1**.

Photo 1: Equipment set up per MIL-STD 1474D

Being an impulsive noise source, the response time of the sound meter was specified in MIL-STD 1474D as "the rise time capability shall be less than 1/20 of the measured duration of the impulse and should be not more than **20 microseconds**". At the time of its writing, only two sound meters had Peak detectors fast enough to meet this standard, namely the analogue Bruel & Kjaer Model 2209 and the digital Larson Davis Model 800-B.

It should also be noted that MIL-STD 1474D is somewhat ambiguous with respect to specifying the use of A-weighted (dBA) or Z-weighted (dBZ) Peak sound pressure levels when impulsive gunshots are involved. Consequently, this study made use of unweighted dBZ Peak sound levels because it would contain all the sound energy and all of the sound meters were able to measure it for direct comparison.

3 SOUND MEASUREMENT INSTRUMENTATION

All the sound measurement instrumentation used in the study complied with ANSI Standard S1.4[2] for Type 1 (precision-grade) accuracy and quality as summarized in **Table 1**. As shown in **Photos 2 and 3**, two sound meters were positioned at a distance of 1.0 meters (39 inches) lateral to the rifle's muzzle, and two sound meters were positioned at a lateral distance of 4.0 meters (156 inches). In this manner, the two closer sound meters were set up according to MIL-STD 1474D and the other two farther sound meters were at a convenient distance to normalize/adjust their results to that of the closer meters.

More importantly, the microphones of the two closer sound meters were 1/4-inch diameter to withstand the very high sound pressure levels (possibly 170 dBZ Peak), while the two on the farther sound meters were regular 1/2-inch diameter microphones positioned far enough away from the muzzle to avoid damaging them. All the microphones were oriented directly upwards for a 90 degree sound gracing angle, and all the sound meters were calibrated before and after use with the same Bruel & Kjaer Model 4231 acoustical calibrator to a level of 94.0 dBZ at 1,000 Hz.

Table 1: Sound Measurement Instrumentation

Sound Meter	Microphone	Lateral Position
Bruel & Kjaer Model 2209	Bruel & Kjaer Model 4939 (1/4-inch)	1.0 meters (39 inches)
Larson Davis Model LxT	PCB Model 377C10 (1/4-inch)	1.0 meters (39 inches)
CEL Casella Model 593	Bruel & Kjaer Model 4189 (1/2-inch)	4.0 meters (156 inches)
Svantek Model 971	Svantek Model 7052E (1/2-inch)	4.0 meters (156 inches)

Photo 2: Sound level meter positions

Photo 3: Sound level meter positions

All the sound level meters were programmed to measure and display the Peak sound level in unweighted (dBZ) decibels which were manually read for each shot and transcribed into a master spreadsheet before the sound meters were reset for the subsequent shot. Five separately recorded shots were fired through each silencer, as well as a five shot string through the unmuffled rifles. All the participants could follow along with the results being displayed for all to see (**Photo 4**).

All the sound level meters were mounted on tripods and their microphones were extended to the proper height of 1.6 meters (63 inches) above the ground. The microphones were oriented upwards for a 90 degree sound gracing incident angle with the noise source, with the exception of the Larson Davis LxT which was slightly tilted to get its microphone as close as possible to the Bruel & Kjaer 2209 microphone at the critical position of 1.0 meters (39 inches) lateral from the muzzle. The weather conditions on 9/30/18 were ideal for the sound tests; 15^{o} C (60^{o} F), partly cloudy, calm winds and no rain.

4 FIREARMS AND SILENCERS

Silencers were tested in two general sizes, .30 caliber and .22 caliber. Hence, only two rifles were used for all of the silencer tests in order to eliminate the firearm as a variable. A Ruger American Ranch bolt action rifle chambered in centerfire .300 BLK was used to test the .30 caliber silencers, and a Cricket KSA PT bolt action rifle chambered in rimfire .22 LR was used to test the .22 caliber silencers. Both rifles had 0.4 meters (16 inches) long barrels. The same subsonic ammunition, in .300 BLK and .22 LR, respectively, was also used for all tests to eliminate the ammunition as a variable to the extent possible. Note – subsonic ammunition, where the bullet velocity is less than the speed of sound, is commonly used with silencers in order to eliminate the supersonic crack of the bullet in flight.

Fourteen different .30 caliber silencers and twelve different .22 caliber silencers were tested. Some of the silencers were production products already available to the public while others were prototype designs. A list of all the silencers can be seen in **Table 2** in alphabetical order, and a picture of the .30 caliber silencers can be seen in **Photo 5**.

Table 2: Silencers Included in Sound Tests
(Alphabetical Order)

.30 Caliber Silencers	.22 Caliber Silencers
Deadair Sandman K	Bowers Bitty
Deadair Sandman L	CGS Hydra SS
E.E. Vox S With Wipe	DA Mask
E.E. Vox S Without Wipe	EA Nyx
Full Nelson	EA Nyx Mod2 (Full)
Half Nelson	EA Nyx Mod2 (Short)
Huntertown Doomsday	Huntertown Guardian 22
Liberty Goliath	Q El Camino
NextGen Max Flo	Q Erector (Full 10)
OSS HX762	Ruger Silent-SR
SiCo Omega	SiCo Sparrow
Sig SRD 7.62	Torrent
Sig SRD 7.62 Ti	---
Tornado F-3	---

Photo 4: Silencer sound testing facility

Photo 5: Silencers (.30 caliber) included in tests

5 NOISE REDUCTION TEST RESULTS

Again, the intent of the firearm silencer sound tests were twofold, (1) to compare the noise reduction effectiveness of competitive silencers, and (2) to compare various sound level meters and their abilities to measure dBZ Peak sound levels. Excel spreadsheets were used to try to isolate and rank-order the results for each goal.

5.1 Silencer noise reduction results

Gunshot sound levels with and without each candidate silencer were measured by the four sound level meters for strings of five shots each. The noise reduction measured at each position was then averaged over the four sound level meters used in this study and then rank-ordered to determine the most effective gunshot silencer. The results are shown in **Table 3** and **Figure 1** for the .30 caliber silencers and the .22 caliber silencers, respectively. The names of the top three performing silencers are revealed.

Table 3: Rank-Order of Gunshot Silencers Noise Reduction Effectiveness

.30 Caliber Silencers	Noise Reduction (dBNR)	.22 Caliber Silencers	Noise Reduction (dBNR)
1st - Tornado F-3	35.2	1st - Torrent	24.5
2nd - Full Nelson	35.1	2nd - SiCo Sparrow	24.1
3rd - Sig SRD 7.62 Ti	34.7	3rd - DA Mask	24.1
4th	32.0	4th	23.0
5th	31.9	5th	22.9
6th	30.5	6th	22.1
7th	30.4	7th	21.6
8th	30.2	8th	21.2
9th	28.2	9th	21.1
10th	27.7	10th	20.0
11th	20.5	11th	19.6
12th	18.0	12th	16.6
13th	17.4	---	---
14th	11.7	---	---

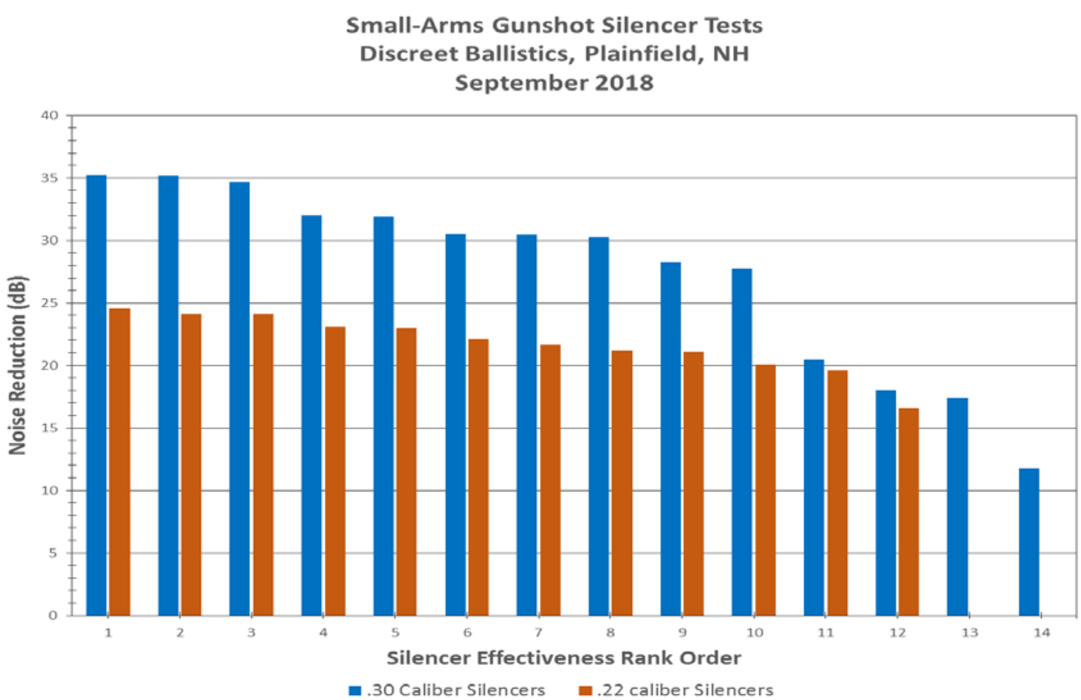

Figure 1: Rank-Order of Gunshot Silencers Noise Reduction Effectiveness

5.1.1 First shot pop

A well-known but undesirable performance trait of small-arm gunshot silencers is known as the "first shot pop" (FSP) in which the first shot through a silencer is notably louder than subsequent shots. The generally accepted reason for this louder pop is that regular air inside the silencer has a higher oxygen content for the first shot than for ensuing shots in which exhaust gas and smoke partially displace the oxygen, thus leading to quieter follow-up shots. In fact, a recently awarded silencer patent design injects nitrogen into the silencer to completely displace the oxygen and eliminate the first shot pop.

The FSP effect does not happen all the time and can be more pronounced with some silencers than with others. An attempt was made to quantify the FSP in this study by comparing the Peak sound level of the first shot through each silencer to those of the remaining four shots in each 5-shot string. **Table 4** summarizes the results for the loudest and average FSP results experienced through the .30 caliber and .22 caliber silencers in this study. Negative decibels indicates that the first shot was actually *quieter* than the average loudness of the remaining four shots. The results show that the FSP could vary significantly between silencers and that the .30 caliber silencers tended to exhibit a more pronounced FSP than did the .22 caliber silencers.

Table 4: Silencer First Shot Pop (FSP) Results

.30 Caliber Silencers	FSP Exceedance[1] (dB)	.22 Caliber Silencers	FSP Exceedance[1] (dB)
Deadair Sandman K	-1.3	SiCo Sparrow	-2.1
Sig SRD 7.62	-0.6	Bowers Bitty	-0.8
Sig SRD 7.62 Ti	0.1	Torrent	-0.7
4th	0.8	4th	-0.6
5th	1.0	5th	-0.2
6th	1.0	6th	0.0
7th	1.1	7th	0.1
8th	1.6	8th	0.4
9th	1.7	9th	0.5
10th	2.0	10th	0.6
11th	2.1	11th	0.7
12th	3.2	12th	1.1
13th	3.7	---	---
14th	5.9	---	---
Average	**1.6**	**Average**	**-0.1**

Note (1) Relative loudness of first shot compared to average of remaining four shots.

5.2 Sound level meter dBZ Peak results

As mentioned above, four different manufacturers' sound levels meters were used in these gunshot silencer tests, a Bruel & Kjaer 2209, a Larson Davis LxT, a Svantek 971 and a Casella CEL 593 sound level meter. The long-discontinued Bruel & Kjaer 2209, with its 20 microsecond Peak detector, was used because it was the standard sound level meter used for these kinds of tests when MIL-STD 1474D was written. The Larson Davis LxT, Svantek 971 and Casella CEL 593 are currently available, although the latter dates back some 25 years. All the sound levels meters complied with ANSI Standard S1.4 for Type 1 accuracy and quality.

Measuring impulsive sound levels with different sound level meters in a manner that can be directly compared can be a challenging and confusing matter. Accurate results are heavily influenced by the respond time of the sound meter's Peak detector, especially if the impulsive waveform is completed before the detector can come to full response. Moreover, the time it takes for gunshot Peak sound levels to occur is very close to the 20 microseconds response time specified in MIL-STD 1474D. Thus, if the waveform is shorter than 20 microseconds then the sound meter may under-measure the actual Peak sound level.

In this case, the Bruel & Kjaer 2209 had an analogue 20 microsecond Peak detector response time. However, the Larson Davis LxT, Svantek 971 and Casella CEL 593 are all digital instruments so their Peak detectors are based on the sample rate of their analogue to digital (A-to-D) converters. The Larson Davis LxT has a sampling rate of 51,200 Hz which translates to a sample just under every 20 microseconds. The current Svantek 971 has a sampling rate of 48,000 Hz or once every 21 microseconds, and remarkably the older Casella CEL 593 has a sampling rate of 67,200 Hz or a sample every 15 microseconds.

As mentioned above, MIL-STD 1474D calls for sound measurements to be performed at a distance of 1.0 meters (39 inches) lateral to the muzzle which is where the Bruel & Kjaer 2209 and the Larson Davis LxT were positioned. The Svantek 971 and the Casella CEL 593 were positioned at a lateral distance of 4.0 meters (156 inches); consequently their results were adjusted/normalized to the reference distance of 1.0 meters (39 inches) for comparison with the other sound meters. Because the only interest in this case was to measure Peak sound levels, the only adjustment made was for distance of 20 LOG (1/4) = -12.0 dB, thus assuming the direct sound path would be the loudest contribution with negligible effects from reflections off the ground.

Table 5 shows the results of comparing the dBZ Peak measurements between the four sound level meters. The results have been adjusted/normalized relative to the sound meter that measured the loudest average Peak levels, which in this case was the Larson Davis LxT.

Table 5: Comparison of Sound Level Meters dBZ Peak Measurements

Sound Level Meter	.30 Caliber Silencer Tests		.22 Caliber Silencer Tests	
	Average Gunshot dBZ Peak[1]	Relative Difference dB	Average Gunshot dBZ Peak[1]	Relative Difference dB
Larson Davis LxT	130.9	0.0	121.2	0.0
Bruel & Kjaer 2209	129.2	- 1.7	120.1	- 1.1
Casella CEL 593	127.8	- 3.1	117.1	- 4.1
Svantek 971	127.6	- 3.3	116.3	- 4.9

Note (1) All sound level results either measured at or adjusted to a reference lateral distance of 1.0 meters (39 inches).

6 DISCUSSION OF RESULTS

A technical discussion of the results obtained in this study are presented below. The findings and conclusions are the author's alone. Other physical factors and acoustical effects could certainly be relevant as well.

6.1 Gunshot silencer discussion

Inspection of **Table 3** reveals that the better performing silencers are capable of impressive quantities of noise reductions. The best of the .30 caliber silencers provided approximately 35 dBNR, while the best performing .22 caliber silencers were able to provide about 24 dBNR.

The reason the .30 caliber silencers could provide greater noise reduction than the .22 caliber silencers is most likely due to their larger physical size. The average size of the .30 caliber silencers was 0.00027 meters^3 (16.4 inches^3), while the average size of the .22 caliber silencers was only 0.00007 meters^3 (4.4 inches^3). The expansion chambers inside the .30 caliber silencers were able to reduce escaping air velocity and turbulence to a greater degree than the .22 caliber silencers. When expressed as a decibel difference, the .30 caliber silencers were about 12 dB larger than the .22 caliber silencers, thus accounting for the differences seen in **Table 5**.

Described subjectively, noise reductions of 24 dBNR and 35 dBNR, respectively, would be perceived to be about a quarter to an eighth as loud as the unmuffled gunshots. And to the author, who is a 35-year experienced competitive shooter, the results could be comparatively described as follows: A suppressed .30 caliber rifle sounds like an unmuffled .22 caliber rifle, and a suppressed .22 caliber rifle sounds like an air-powered BB gun.

6.2 Sound level meter dBZ Peak discussion

At the onset of this study it was hoped that a direct comparison of the dB Peak levels measured by each of the four sound level meters could be performed. And while this goal was accomplished for the pairs of sound meters, it was not accomplished when trying to reconcile the far pair of sound meters to the near pair. Inspection of **Table 5** shows that the near pair of sound meters (i.e. B&K 2209 and LD LxT) at 1 meter (39 inches) from the muzzle produced very similar average dB Peak values within 2 decibels of one another; and that the far pair of sound meters (i.e. CEL 593 and Svantek 971) at 4 meters (156 inches) produced very similar average dB Peak values within 1 decibel of one another. However, when adjusted for distance, the results for the far pair of sound meters was on average about *2.4 decibels lower* for the .30 caliber silencers and *4.0 decibels lower* for the .22 caliber silencers than when compared to the results for the near sound meters.

It should be noted that the noise reduction calculations presented in **Table 3** should be unaffected by this unexplained difference between the near and far sound meters because systematic errors would cancel out when subtraction is done to compute noise reduction. However, all efforts to date to explain the decibel differences between the near and far pairs of sound meters shown in **Table 5** have only served to raise more questions than they answered. The following possible explanations have all been considered:

- *Digital sampling rates?* Probably not – all the digital sound meters had acceptably fast A-to-D sampling rates approximating that of a Peak detector rise time of 20 microseconds.
- *Ground reflection?* Probably not – it was soft ground, and with the longer distance to the sound meters the reflected signal would have arrived too late after the direct signal to effect the Peak (**Photo 2**).
- *Muzzle directivity?* Probably not – all four sound meters were lined up in the same transverse straight line perpendicular to the muzzle (**Photo 3**).
- *Atmospheric loss?* Probably not – the far sound meters were only 4.0 meters (156 inches) away (**Photo 2**).
- *Freefield correction?* Probably not – the estimated freefield correction adjustment(3) would only be about 0.4 decibels for the freefield microphones used on the far sound meters.
- *Barrier effect?* Probably not – the near sound meters were not 'that' big and only the microphones were shadowing one another (**Photo 3**).
- *Nearfield anomaly?* Probably not – the near sound meters were a full 1.0 meter (39 inches) away from the muzzle per MIL-STD 1474D.

7 LESSONS LEARNED

It is very difficult to measure loud dBZ Peak levels with multiple sound meters and expect the results to come out exactly the same. Therefore, one must adhere as closely as possible to a published test standard in order to measure results that are comparable with other people's data. In doing so all of the above potential sources for systematic errors can be minimized.

The analogue rise time or digital sampling rate of the sound meter is very important when trying to compare impulsive Peak sound level measurements. In future standards it is suggested that both the rise time/sampling rate and the event duration be specified to ensure the entire impulsive waveform is being measured.

Lastly, it is also important to document all of one's sound test set up conditions, procedures, instrument configurations, and data reduction methods. In this manner, any differences between people's test results might be able to be reconciled.

8 ACKNOWLEDGEMENTS

The author would like to acknowledge and thank Mr. David Stark, founder and owner of Discreet Ballistics in Plainfield, NH for arranging, organizing and hosting this silencer testing event, and to the multiple silencer manufacturers who submitted samples of their products for testing.

9 REFERENCES

1. *MIL-STD 1474D Design Criteria Standard: Noise Limits,* Military Standard 1474D (United States Department of Defense, Washington, DC, 1997).
2. *American National Standard - Electroacoustics - Sound Level Meters - Part 1: Specifications,* American National Standards Institute ANSI S1.4-2019 (Acoustical Society of America, New York, 2019).
3. *Condenser Microphones and Preamplifiers for Acoustic Measurements Handbook,* Publication 033-0089, Bruel & Kjaer, Naerum, Denmark, 1982.