12th INTERNATIONAL SCIENTIFIC CONFERENCE ON DEFENSIVE TECHNOLOGIES
OTEH 2026
Serbia, Tara, 21 - 24 October 2026

PERFORMANCE ANALYSIS OF SPECIAL SUBSONIC SMALL CALIBER WEAPONS FOR URBAN CONDITIONS

NEBOJŠA HRISTOV
Military Academy, University of Defence, Belgrade, nebojsahristov@gmail.com

DAMIR JERKOVIĆ
Military Academy, University of Defence, Belgrade, damir.jerkovic@va.mod.gov.rs

ALEKSA ANIČIĆ
Agency for Testing, Stamping and Marking of Weapons, Devices and Ammunition, Kragujevac, aleksa34@live.com

MILJKO PAVLOVIĆ
Company Milan Blagojevic – Namenska AD, Lucani, mpavlovic.mbn@gmail.com

IGOR EPLER
Military Academy, University of Defence, Belgrade, igorepler@gmail.com

Abstract: *The paper presents a comparative analysis of the ballistic performance of subsonic weapons of small caliber, which are suitable for use in urban conditions. The use of small-caliber subsonic weapons with shot suppressors is very effective for close range of 50 to 150 meters. The weapon suppressors enable operations that take place with reduced gunfire noise level and reduce the detection of the position of the shooters. Proper selection of ammunition systems is important for the effectiveness of subsonic weapons at close range. Automatic pistols, submachine guns and special subsonic rifles are used for such operations. The paper presents an analysis of significant ballistic parameters during the use of small-caliber firearms with silencers. The analysis includes a comparison of gunfire noise level, muzzle velocity and statistical indicators of precision and accuracy. The paper shows the experimental measurement of the gunfire noise level and the muzzle velocity. In addition to the reduction of gunfire noise level, the energy of the projectile that interacts with the target is also important. Based on the characteristics of the projectile, an estimate of the energy of the projectile during interaction with the target at different distances is presented.*

Keywords: *Muzzle Velocity, Sound Pressure Level, Energy of Projectile, Energy Density.*

1. INTRODUCTION

Special subsonic small caliber weapons for use in urban conditions are silenced personal weapons of small dimensions and mass intended primarily for tactical units. Standard rifle ammunition creates a localized gunshot noise during firing because of breaking the sound wall with the supersonic flight of the projectile on the trajectory, which easily detects the position of the shooter. By using subsonic projectiles with a weapon silencer, the sound of the gunshot is eliminated, which optimizes stealth and tactical advantage for operations at short distances in urban conditions. Among other things, weapons that use subsonic ammunition have lower recoil forces, which allows for more accurate hits, even in multiple bursts of fire. Weapon silencers (mounted or integrated) on this type of small arms, in addition to reducing sound, eliminate flash during firing, which increases the camouflage characteristics of tactical units. Among other things, short-barreled rifles (SBR) with folding stocks allow users to move freely in urban and difficult-to-access conditions, as well as facilitate the transportation of units during operations. Typical special subsonic ammunition is .300 Blackout (Figure 1a for SIG MCX Rattler Figure 2a), 9x19 mm (Figure 1b for Daewoo K7 Figure 2b), 9x39mm (Figure 1c for AS Val Figure 2c) and others similar. The mass of the projectile of the listed ammunition is generally in the range of 8 to 16 grams.



a) b) c)

Figure 1. Special subsonic ammunition: a) .300 Blackout, b) 9x19 mm, c) 9x39mm SP5

Generally, this type of special subsonic small caliber weapon is intended for effective action at distances of up to 200 meters, or rather, it provides the best results at distances of 50 to 100 meters.

Corresponding author: N. Hristov;
E-mail: nebojsahristov@gmail.com
DOI: 10.5937/OTEH26020H



a)



b)



c)

Figure 2. Special subsonic small caliber weapons: a) SIG MCX Rattler, b) Daewoo K7, c) VS VAL

The paper analyzes the performance efficiency of four representatives of weapons and ammunitions. The analysis considers the mass of the projectile, the muzzle velocity and the kinetic energy of the projectile in interaction with the obstacle at distances of 50 and 100 meters. The intensity of the gunshot sound is also analyzed as an important characteristic.

2. EXPERIMENTAL PERFORMANCE TESTING

Experimental tests were carried out on the automatic pistol M84 in 7.65x17 mm caliber, the HK MP5SD in 9x19 mm caliber, the VSS Vintorez in 9x39 mm caliber, and on the modified modular platform AM 20 in caliber 7.62/6.5x39 mm, for which a 9x39 mm caliber barrel was manufactured. During the experimental tests, the muzzle velocity of the projectile and the sound pressure level on the corresponding sample were recorded.

The sound level test of a firearm shot is complex due to the very short duration of the peak of the sound pressure level (SPL) function. The Bruel & Kjaer model 2250 shown in Figure 3 was used to register the SPL according to the MIL-STD-1474D testing standard. The device is equipped with software for sound level measurement, frequency analysis, and appropriate filters for measured signals (FFT analysis and vibration and frequency analysis). The sound level meter sensor is a 1/2" condenser microphone 4189, with a sensitivity of 50mV/Pa (corresponding to: 26dB equivalent to 1V/Pa) ± 1.5dB, a capacitance of 14pF (at 250Hz), which is connected to a ZC-0032 preamplifier with a nominal attenuation of 0.25dB [22].



Figure 3. Bruel & Kjaer model 2250 [22]

The MIL-STD-1474D specifies the position of the sound level meter, which is placed at a 90-degree angle, 100 centimeters to the left of the silencer tube outlet. Both the silencer and the sound level meter should be 160 centimeters above the short-cut grass. The SPL of the gunshot is recorded at this position, as shown in Figure 4. [20].

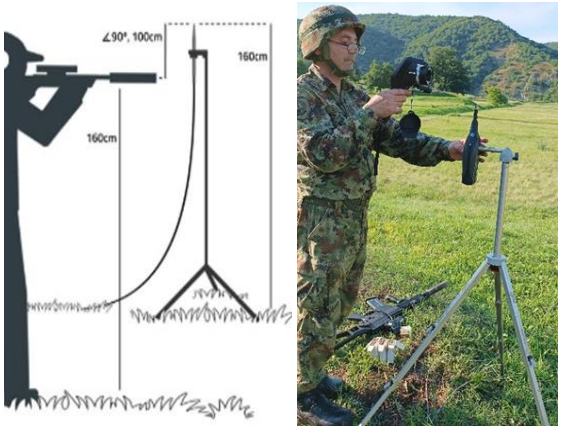


Figure 4. The noise meter position for measuring SPL [22]

To measure the muzzle velocity of the projectile, the GARMIN Xero C1 Pro Doppler ballistic chronograph shown in Figure 5, with the characteristics in Table 1, was used.



Figure 5. Chronograph GARMIN Xero C1 Pro

Table 1. Characteristics of Chronograph GARMIN Xero C1 Pro

Period	Production per period (pcs)
Measuring range	30 to 1600 m/s
Dimension	77 mm x 60.5 mm x 34.44 mm
Weight	105.6 g
Water rating	IPX7
Display type	Sunlight-visible, monochrome
Display size	133 mm x 44 mm, diagonal 55 mm
Battery type	Internal rechargeable lithium-ion battery; non replaceable
Battery life	Up to 2,000 shots or up to 6 hours
Operating range	-10° C to 55° C (14° F to 131° F)
Memory/history	50 sessions at max 100 shots per round before a Xero Core app sync is required to save data to phone
Interface	USB-C

During noise level measurements, for a detailed analysis of efficiency, in addition to *LCpeak* (the absolute maximum sound pressure level currently achieved, with a flatter frequency response that includes more low-frequency sounds), *LAeq* (the average sound level over the period, weighted to reflect typical human hearing) was also recorded.

As the first sample, the performance of the M84 automatic pistol, caliber 7.65x17 mm, with a silencer was measured (Figure 6).

The results of the parameter measurements are shown in Table 2.

Table 2. Measured performance for the automatic pistol M84, caliber 7.65x17 mm.

Group (10 shots)	Muzzle velocity (m/s)	*LAeq* (dB)	*LCpeak* (dB)
1	306,4	88	133,7
2	306,2	88,9	133,7
3	304,6	89,6	138,9
4	306	86,4	127,6
5	311,1	86,8	129,2
6	309,6	85,7	134,7
7	316,5	91,2	138
8	316,2	88,4	135
9	308	85,1	130,9
10	319,9	88,1	130,4
average	310,45	87,8	133,2
Min	304,6	85,1	127,6
max	319,9	91,2	138,9
Spread	15,3	6,1	11,3
Standard deviation	5,32	1,86	3,68



Figure 6. Automatic pistol 7.65 mm M84 with a silencer

In the second case, the characteristics measured for the submachine gun (SMG) HK MP5 SD, caliber 9x19 mm (Figure 7) are shown in Table 3.



Figure 7. SMG 9 mm HK MP5 SD

Table 3. Measured performance for the SMG 9×19 mm HK MP5 SD.

Group (10 shots)	Muzzle velocity (m/s)	*LAeq* (dB)	*LCpeak* (dB)
1	294,4	82,3	121,6
2	305,1	82,4	121,8
3	308,2	80,7	119,4
4	299,3	82,3	121,1
5	303,5	83,7	120
6	303,5	83,4	121,3
7	294,2	85,2	121,6
8	272,4	85,9	127,3
9	281,5	88,3	123,1
10	280,5	83,4	123,3
average	294,26	83,76	122,05
min	272,4	80,7	119,4
max	308,2	88,3	127,3
Spread	35,8	7,6	7,9
Standard deviation	12,19	2,19	2,20

As the third representative, the VSS Vintorez special sniper rifle in 9x39 mm caliber was tested (Figure 8) with the results in Table 4.



Figure 8. VSS Vintorez rifle

Table 4. Measured performance for the VSS Vintorez rifle, caliber 9x39 mm.

Group (10 shots)	Muzzle velocity (m/s)	*LAeq* (dB)	*LCpeak* (dB)
1	283,26	89,20	132,20
2	282,5	90,60	133,30
3	280,26	90,40	132,20
4	283,74	90,40	130,90
5	280,68	90,80	132,70
6	281,91	89,80	131,70
7	283,85	89,50	131,30
8	282,21	90,70	130,50
9	283,44	89,30	131,70
10	282,78	89,20	130,70
average	282,46	89,99	131,72
Min	280,26	90,80	133,30
max	283,85	89,20	130,50
Spread	3,59	1,60	2,80
Standard deviation	1,23	0,66	0,90

For this research, in the fourth case, the AM 20 modular assault rifle platform was used, for which a 9x39 mm caliber barrel was made (Figure 9). Given that the rear cross-section of the case is identical for the 7.62x39 mm, 6.5x39 mm and 9x39 mm calibers, no additional changes to the locking and firing mechanism are required. The idea of the research itself was to examine the possibility of improving the existing AM 20 platform with minimal changes.

The recoil spring was replaced, which is less powerful, but is long enough to safely return and lock the bolt. The powder chamber was modified, which was reduced to fully utilize the pressure of the borrowed powder gunpowder gases, and the percussion spring was replaced. These changes did not affect the functions of the other mechanisms of the rifle.

The existing gunpowder is unknown, so the energy characteristics and dimensions were examined. It was determined that the energy potential is about 3900 J/g and that the shape is a seven-channel cylinder, with a thickness of about 0.176 mm.

Based on the experimental results obtained, it can be concluded that the gunpowder is probably double base. To improve the function of the test rifle, thicker gunpowder with similar energy characteristics was used. Optimal results were achieved using the double-base plate gunpowder NGB-09.

For smooth functional operation, in addition to structural changes to the rifle, the propellant was also replaced, which resulted in higher muzzle velocities, but the maximum pressure is lower than with the original ammunition. The test results are shown in Table 5.



Figure 9. Test Rifle 9×39mm based at the AM 20 modular assault rifle platform

The weapon's silencer is designed by modifying the silencer for the M76 sniper rifle by changing the chambers. In terms of dimensions and volume, it corresponds to the silencer for the VSS Vintorez.

Silencer type 1 is standard silencer for sniper rifle M76 adapted to test rifle caliber. Silencer type 2 is new design of silencer consisting of standard casing (cylinder of M76 silencer) and inner parts that compose four chambers.

Table 5. Measured performance for the Test rifle, caliber 9x39 mm, silencer type1.

Group (10 shots)	Muzzle velocity (m/s)	*LAeq* (dB)	*LCpeak* (dB)
1	309,90	93,60	136,40
2	310,10	94,50	135,00
3	306,80	93,70	130,80
4	312,20	93,40	137,10
5	310,40	93,70	135,70
6	306,70	94,20	136,90
7	308,60	93,40	137,20
8	308,40	95,30	137,30
9	310,00	94,80	136,60
10	307,60	94,00	137,10
average	309,07	94,06	136,01
min	312,20	95,30	137,30
max	306,70	93,40	130,80
Spread	5,50	1,90	6,50
Standard deviation	1,76	0,64	1,97

Table 6. Measured performance for the Test rifle, caliber 9x39 mm, silencer type 2.

Group (10 shots)	Muzzle velocity (m/s)	*LAeq* (dB)	*LCpeak* (dB)
1	305,60	90,20	134,20
2	303,10	91,60	135,30
3	306,50	91,40	134,20
4	306,20	90,40	132,90
5	307,80	90,80	133,70
6	306,30	89,80	132,70
7	303,60	92,50	134,30
8	306,70	91,70	132,50
9	307,00	91,30	134,70
10	303,50	91,20	133,70
average	305,63	91,09	133,82
min	307,80	92,50	135,30
max	303,10	89,80	132,50
Spread	4,70	2,70	2,80
Standard deviation	1,64	0,80	0,91

3. MODEL OF PROJECTILE FLIGHT

Based on the measured results of muzzle velocities, projectile velocities were calculated for all shot cases at distances of 50 and 100 meters. The calculation of the velocities of the projectile was realized according to the modified material point flight model. The governing equations of the model are,

$$m\frac{d\vec{V}_k}{dt} = m\vec{g} + \vec{D} + \vec{L} \quad (1)$$

and,

$$\frac{d\vec{K}}{dt} = I_x\frac{dp}{dt}\vec{x}_0 + I_x p\dot{\vec{x}}_0 + I_y(\vec{x}_0 \times \ddot{\vec{x}}_0) \quad (2)$$

where are aerodynamic forces are,

$$D = \frac{\rho V^2}{2}SC_D(Ma) \quad (3)$$

$$L = \frac{\rho V^2}{2}SC_L(\sigma, Ma) \quad (4)$$

Velocity is defined as,

$$\vec{V}_k = \vec{V}_w + \vec{V} \quad (5)$$

$$V = \sqrt{(u_k - u_w)^2 + {v_k}^2 + (w_k - w_w)^2} \quad (6)$$

where are,

u_k, v_k, w_k components of velocities and

u_w, w_w horizontal components of wind velocities,

$\vec{g}$ gravitational acceleration,

S projectile cross-section surface and,

C_D, C_L aerodynamic coefficients of drag and lift forces.

Angular momentum is defined as,

$$\vec{K} = I_x p\vec{x}_0 + I_y(\vec{x}_0 \times \dot{\vec{x}}_0) \quad (7)$$

where are

I_x, I_y are projectile's moment of inertia,

$\vec{x}_0$ is axial axis of projectile,

$\dot{\vec{x}}_0$ is axial spin of projectile and,

p spin rate of projectile.

Calculated values of the velocities are initial data to determine the terminal parameters (energy and energy density) of the different projectiles at distances of 50 and 100 meters.

4. RESULTS ANALYSIS

Based on the mass of the projectile and the cross-section, the values of kinetic energy and energy density during the interaction with the obstacle were calculated. The values of the quantities mentioned (velocity and energy) are shown in table 7.

Table 7. Performance of the projectiles during interaction

	Velocity [m/s]		Projectile energy [J]		Energy density [J/mm^2]	
	distance [m]					
	50	100	50	100	50	100
AP M84	290	276	193	175	4,03	3,65
HK MP5 SD	281	270	316	292	4,77	4,40
VSS Vinto-rez	273	265	578	544	8,70	8,19
Test rifle	309	299	740	673	11,14	10,43

Projectile energy and projectile's energy density during interaction with an obstacle at 50m and 100m are determined, in relation to velocities, mass and caliber. These parameters are key performances of the presented small arms weapon system.

Figure 10 shows the comparative values of projectile energy at 50m and 100m for the analyzed weapons.

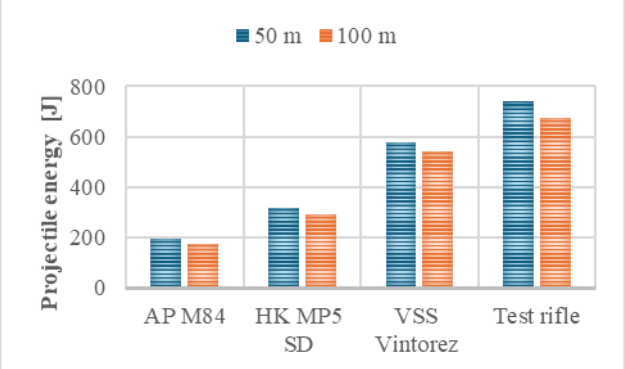


Figure 10. Comparative values of projectile energy at 50 and 100 m

Figure 11 shows the comparative values of the projectile's energy density during interaction with an obstacle at 50m and 100m.

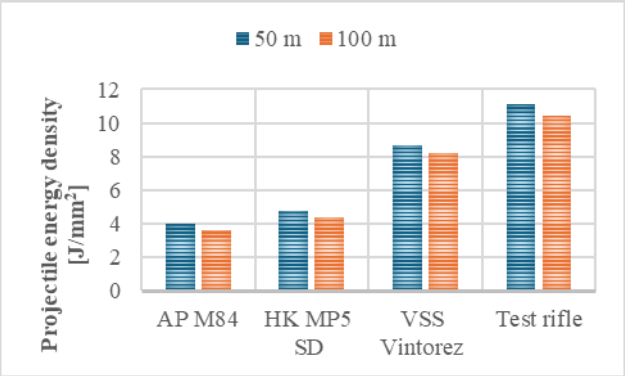


Figure 11. Comparative values of projectile energy density at 50 and 100 m.

Figure 12 shows the comparative values of sound pressure levels for different weapon systems.

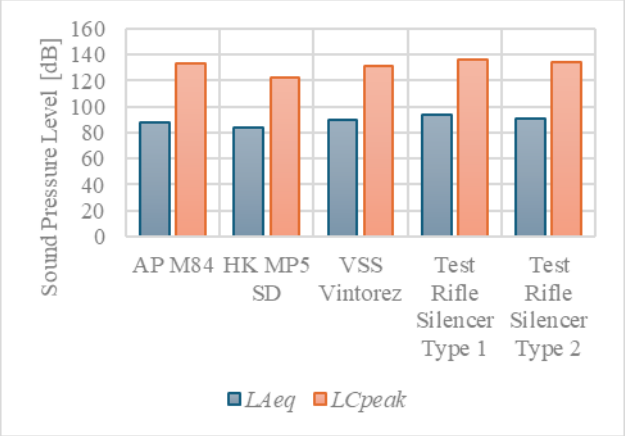


Figure 12. Comparative values of SPL.

The analysis is performed due to verification of the performances of the small arms weapon systems for tactical application in urban conditions and it's evaluating the quality of performance.

The most common representative of this weapon system in most of the world's armed forces is the SMG 9 mm HK MP5 SD, which was selected as a reference system for comparing characteristics.

The characteristics of different weapon models were compared in relation to the reference representative, namely: (a) sound pressure level (SPL) registered with two scales $LAeq$ and $LCpeak$, (b) muzzle velocity level and (c) energy of projectile interaction with an obstacle at the two stated distances.

Automatic pistol 7.65x17 mm M84 showed to have higher SPL on both scales (higher $LAeq$ by 4.82% and higher $LCpeak$ by 9.14%) with higher muzzle velocity by 5.5%. Although the muzzle velocity is higher, due to the significantly lower mass of the bullet (4.6 g vs. 8 g), the energy of the projectile at referential distances is about 40% lower.

The VSS 9x39mm Vintorez rifle was shown to have higher SPL on both scales (higher $LAeq$ by 7.44% and higher $LCpeak$ by 7.92%) with lower muzzle velocity by 4%. Although the muzzle velocity is lower, due to the significantly greater mass of the bullet (15.5 g vs. 8 g), the energy of the projectile at referential distances is about 85% higher.

The Test rifle 9x39 mm with Silencer Type 1 showed that having SPL on both scales (higher $LAeq$ by 12.3% and higher $LCpeak$ by 11.4%) with higher muzzle velocity by 5%. Due to the significantly greater mass of the bullet, the energy of the projectile at referential distances is about 132% higher.

The Test rifle 9x39 mm with Silencer Type 2 showed that it has higher SPL on both scales (higher $LAeq$ by 8.75% and higher $LCpeak$ by 9.64%) with higher muzzle velocity by 4%. Due to the significantly greater mass of the bullet, the energy of the projectile at referential distances is about 131% higher.

To evaluate the new weapon system Test rifles with two types of silencers, a comparison was made in relation to the special sniper rifle VSS of the same ammunition system. The results of the comparison in relation to the VSS rifle are given below.

The Test rifle 9x39 mm with Silencer Type 1 showed that it has higher SPL on both scales (higher $LAeq$ by 4.5% and higher $LCpeak$ by 3.3%) with higher muzzle velocity by 9.4%. The energy of the projectile at referential distances is about 26% higher.

The Test rifle 9x39 mm with Silencer Type 2 showed that it has higher SPL on both scales (higher $LAeq$ by 1.2% and higher $LCpeak$ by 1.6%) with higher muzzle velocity by 8.2%. The energy of the projectile at referential distances is about 25% higher.

To evaluate the performance of different types of silencers, the characteristics of the Test rifle with both silencers were compared. The comparison was made with the newly constructed silencer system Type 2 in relation to Type 1, which represents the existing modified silencer model.

The Test rifle with the new Type 2 silencer showed lower SPL values on both scales. Lower $LAeq$ values by 3.2% and lower $LCpeak$ values by 1.6%. The level of the muzzle velocity was lower by about 1%, as well as the energy of the projectile at referential distances by about 0.6%.

CONCLUSION

The paper presents an analysis of the performance of subsonic weapons for use in urban conditions. Comparisons were made of four types of weapons equipped with silencers. The aim of the research was to present the performance of the Test rifle with two types of silencers and to compare the performance in relation to existing systems. As a reference system, the SMG 9 mm HK MP5 SD was taken, which is the most common and is considered the standard for use in urban conditions.

Based on the presented results, it can be concluded that the weapon systems with the 9x39 mm ammunition system have significantly better performance compared to other representatives. The comparative analysis showed

significant improvements in the performance of the Test rifle in relation to the VSS Vintorez in relation to the muzzle velocity and the energy during the interaction.

If we compare the performance of the two silencer configurations for the Test rifle, it can be concluded that the concept with four chambers showed better results.

Selection of the optimal configuration demands additional tests and analysis of several possible structural solutions of the shot silencer.

Acknowledgment

The paper is a part of the research done within the project of the University of Defence in Belgrade, No. VA-TT/1/24-26.

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