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ANALYSIS OF THE PISTOL BULLET PENETRATION THROUGH A WOODEN BARRIER

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Abstract

Effects of handgun (pistol) bullets on wooden barriers, and the ballistic gelatine placed behind these barriers, are compared. In one comprehensive analysis, the penetration of three frequently used handgun bullets through wooden barriers of different hardness and thickness is compared, and at the same time, the effect on the replacement biological tissue behind such barriers is analysed. The ballistic gelatine is prepared according to the NATO standard and therefore results are directly comparable with results of earlier tests for other bullet calibres. A significant difference in the efficiency of the tested bullets is discovered, based on which recommendations can be made on the most effective calibre for use in police and military for urban operations.

Keywords: terminal ballistics; ballistic gelatine penetration; pistol bullets; wooden barrier penetration.

1. Problem Statement and Overview of Previous Works

By reviewing previous works, it is clear that primary focus is maintained on rifle bullets where [1] and [2] analyse the effect on ballistic gelatine, whereas [3] and [4] analyse the effect of rifle bullet when hitting barriers made of stronger materials (respectively shock-absorbing concrete and ceramic composite armour).

On the other side, pistol bullets and their ability of penetration is less examined, and if so it is mainly focuses on penetration and terminal capabilities on actual or replacement biological tissue [5], [6]. This is understandable since the mentioned analyses aim for the military purposes, and the primary infantry weapon is the rifle. Handguns are mainly used for police forces but also have purpose in military environment (secondary weapon, special operations, close-quarters combat).

Capabilities of wooden barriers penetration become more and more interesting for police and armed forces lately mainly due to increased number of combat operations in urban environment (Military Operations in Urban Terrain – MOUT). Because of this it is very important to know penetration capabilities of wooden barriers with individual cartridge, enabling soldier or policeman to survive in urban environment. Wooden barriers can be frequently seen in urban environment (doors, furniture, walls).

In this paper, testing of multiple pistol cartridges on different types of wood will be presented. Wood is the second most common material in the household so it can be expected that it will be necessary to penetrate wooden barrier which protects the opponent. Two most common types of furniture wood were examined in this test – fir and oak. Aside from wooden barriers, pistol cartridges which would be tested are 9mm Luger, .40 S&W and .45 ACP. These cartridges are the three most used calibres today in military and police worldwide. From recent research on this topic, papers that should be singled out are [7] and [8] although they analyse the effectiveness of only one calibre. The paper will demonstrate the advantages of individual calibres when penetrating through wooden obstacles. It will also be proven how effective such obstacles can be as a protection against the analysed calibres.

2. Wood as a Building Material

Wood has been used as construction material since ancient times. Nowadays materials like polymers, alloys or composites have found greater application thus reduced the share of wood in construction and everyday application. Despite this revolution of new materials wood is still the second most used material in construction and therefore there is still a good chance of enemy taking cover behind wooden barrier during the close-quarter combat.

Anisotropy is the greatest problem when performing examination connected with wood behaviour. Namely, physical properties of wood are different in all directions (longitudinal, radial and tangential) [9]. During the experiment in this work penetration of bullet was examined on the radial axis, i.e. perpendicular to tree rings. Mechanical properties which may be of interest for this test are toughness, torsional, compressive, tensile and shear strength, Poisson's ratio, wear resistance and more.

Hardness and density of wood are the most important parameters for determining projectile penetration. These two characteristics are in strong mutual correlation, which means that denser wood usually also has a higher hardness. Hardness is usually tested by Brinell test by pressing the steel ball into the wood surface. Diameter of cavity is measured after the application of force, and according to that diameter hardness of material can be detected. Hardness according to Brinell is then:

$$HB_D = \frac{2F_B}{\pi D_B \sqrt{D_B^{\,2} - d_B^{\,2}}} \tag{1}$$

where F_B presents applied force [N], D_B diameter of test ball [mm] and d_B diameter of imprinted trace in the wood [mm].

In our analysis two most common types of European construction wood were used: fir and oak. Except for being two most used wood types in construction applications, these wood types were also used due to different characteristics. Fir is very soft and according to Brinell $HB_D = 1{,}81 \pm 0{,}12$ (depending on dryness), while on the other hand oak is pretty hard with hardness $HB_D = 3{,}56 \pm 0{,}2$ [10].

3. Pistol Cartridges

For the penetration analysis, three most popular pistol calibres were used: 9x19 Parabellum, .40 S&W and .45 ACP. All three are presented od Figure 1.

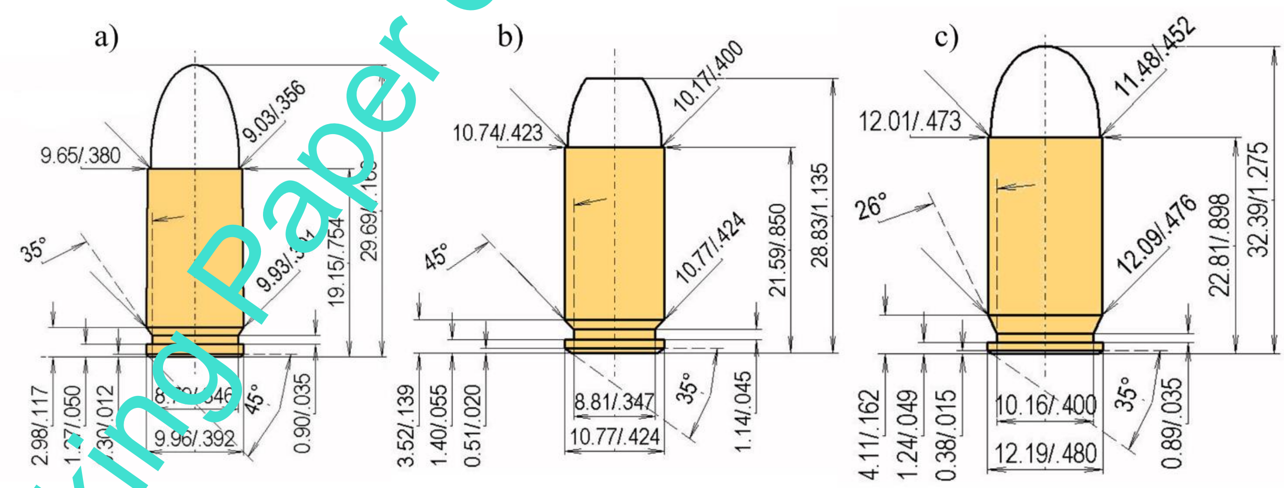

Fig. 1. Analysed cartridges: a) 9x19 PARA, b) .40 S&W, c) .45 ACP [14]

According to STANAG 4090 9x19 Parabellum characteristics are: calibre 9 mm, case length 19 mm, bullet mass between 7 g and 8,3 g. The bullet should inflict deadly wound on a target which stands at a distance of 23 meters, even when the target has basic level of head and body protection. According to NATO STANAG 4090 from 1982 group on a target should be less than 3 inches wide with standard barrel length.

This experiment was performed with Sellier&Bellot's 9x19 Nontox TFMJ with cartridge mass of 12.7 g, and bullet mass of 8 g. According to manufacturer this bullet achieves average velocity of 360 m/s from 150 mm long barrel which comes to 518 J of kinetic energy on the muzzle exit. This part of the test was executed with HS Produkt's SF19 4.5" with barrel length of 116,5 mm which gives a slightly lower muzzle velocity and energy compared to the manufacturer's statement. 9x19 Parabellum is appreciated due to its low mass and recoil during firing process, even though there were some speculations about low efficiency of this cartridge in the past. That was the reason for a constant improvement of this cartridge during the past and today there is a wide variety of 9 mm ammunition. At 25 meters from the muzzle bullet velocity decreases to 326 m/s providing 425 J of energy and on 50 m from muzzle velocity decreases to 301 m/s with 362 J of energy which is enough for instantaneous neutralization of target [11].

Bullet trajectory keeps flat trajectory for the first 30 m, and on 50 m from the weapon there is a slight bullet drop that amounts only 37 mm. Manufacturer's data are used for the purposes of this paper, however if higher data accuracy is required it is possible to calculate the bullet trajectory with flight models like MMPM (*Modified Mass Point Model*) or 6DOF (*Six Degrees of Freedom*) model [12], [13]. Figure 2 shows bullet velocity decrease with distance and Figure 3 presents decrease in kinetic energy up to a distance of 100 m for all cartridges used in the experiment.

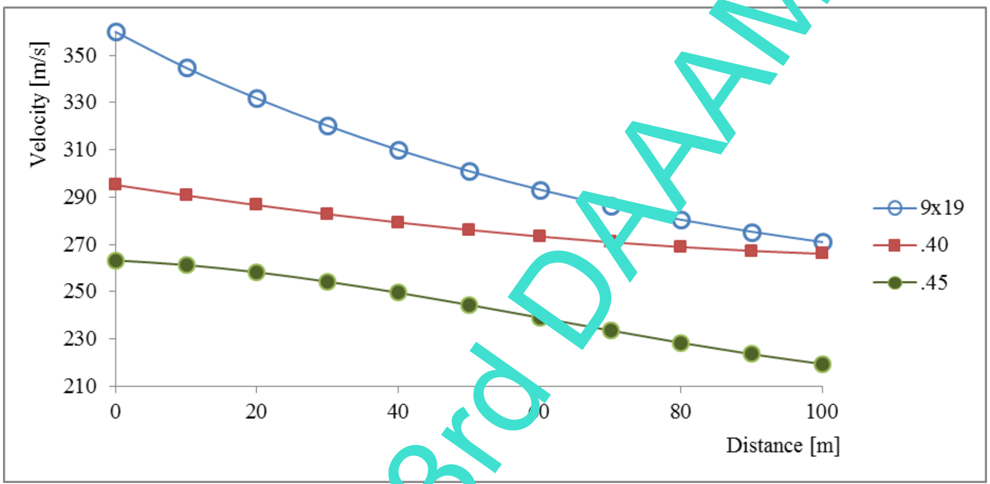

Fig. 2. Bullet velocity decrease for 9x19 mm, .40 S&W and .45 ACP; according to [11]

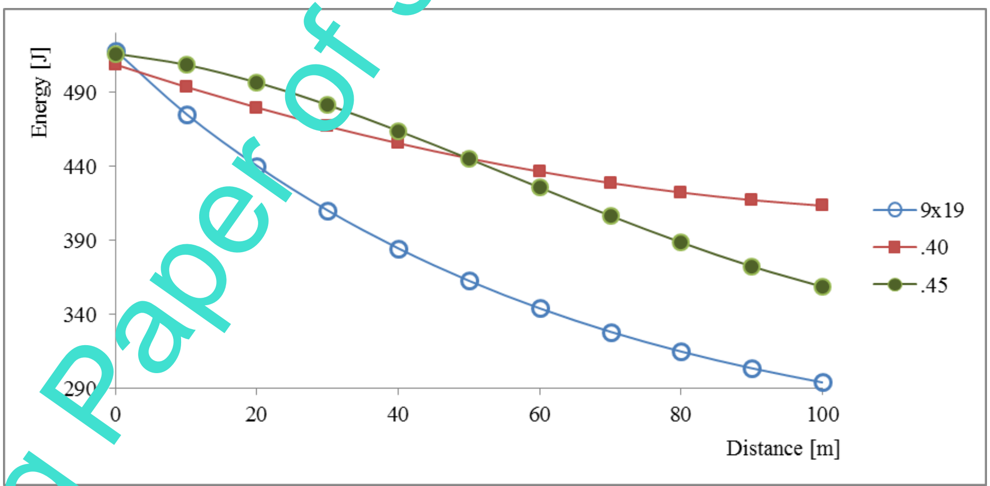

Fig. 3. Kinetic energy decrease for cartridges 9x19 mm, .40 S&W and .45 ACP; according to [11]

Cartridge .40 S&W (Smith&Wesson) is the second most used option for police and armed forces around the globe. It was introduced in 1990 as a replacement for 9x19 which was considered as to be of inadequate mass and stopping power. Weight of the cartridge (S&B TFMJ Nontox) was 16.7 g, and bullet mass was 11.7 g. HS Product's XDM 40 4.5" was used for the experiment, giving the bullet 295 m/s and 509 J of energy at the barrel muzzle. Although the bullet is heavier compared to the 9x19, due to the lower initial velocity it has less kinetic energy (509 J), which is why it failed to replace the 9x19 calibre. Quite the opposite, in the last several years more and more agencies and armies leave .40 S&W and return to the 9x19 Parabellum.

The velocity decrease due to the aerodynamic force is not so dramatic for .40 S&W compared to 9x19 Parabellum, meaning that the .40 S&W bullet keeps its kinetic energy better (Figures 2 and 3). However, since in the real battle conditions pistol cartridges are mostly used at a distances from 10 to 20 meters, the velocity preservation is not of great importance. On the other hand, due to its higher mass, the recoil is stronger, and the trajectory drop is more accentuated (55 mm at the 50 m distance) than one of the 9x19 bullets.

The .45 ACP (*Automatic Colt Pistol*) is the largest and heaviest of all three cartridges included in this experiment. Weight of the cartridge (S&B TFMJ Nontox) is 20.9 g, and the bullet weight is 14.9 g. For the experiment purposes HS Product's XDM 45 4.5“ was used. With the bullet velocity 263 m/s at the muzzle it gives 516 J of kinetic energy. Figures 2 and 3 show a decrease in bullet velocity and kinetic energy; it loses both faster than the .40 bullet (due, among other things, to a higher coefficient of resistance), but not as drastic as the 9x19 bullet. As for the trajectory curvature, the .45 bullet drop is the largest of the three calibres analysed (76 mm at a distance of 50 m).

The large mass potentially suggests that the penetrability of this bullet will be the highest, but since the aeroballistic coefficient is very low it could cause a large negative acceleration and difficult pass through the surrounding medium (including both the air and the set barrier). The aeroballistic coefficient is calculated according to the following expression:

$$C_b = \frac{m_p}{C_D A} = \frac{\rho l}{C_D} \tag{2}$$

where C_b presents aeroballistic coefficient, m_p bullet mass, A is cross-sectional area of the bullet, ρ is surrounding media density, while l presents characteristic bullet length. C_D is drag coefficient which directly determines the value of aeroballistic drag according to expression:

$$D = \frac{\rho v^2}{2} A C_D \tag{3}$$

where the velocity of the bullet v is also introduced. Equation (2) shows inversely proportional relationship between aeroballistic coefficient and drag coefficient, meaning that the bullet with higher drag coefficient C_D will also have lower aeroballistic coefficient C_b. The second part of (2) indicates that a shorter bullet (and therefore of shorter characteristic length l) would have a lower coefficient C_b.

Ammunition manufacturer (Sellier&Bellot (2022)) indicates that the .45 ACP has the lowest aeroballistic coefficient $(C_b = 0{,}068)$, 9x19 Parabellum has slightly higher coefficient $(C_b = 0{,}09)$ while the most favourable aeroballistic coefficient has the .40 S&W bullet $(C_b = 0{,}157)$.

4. Anticipated Bullet Penetration

Penetration of the bullet is affected by its kinetic energy at the point of impact, construction of the bullet, and material properties for both the bullet and the target.

Kinetic energy depends on mass and velocity of the bullet ($E_k = m_p v^2 / 2$). Kinetic energy grows linearly with increasing mass of the bullet m_p and with a square of increasing bullet velocity v. During the flight heavier bullets lose their velocity more slowly. Deceleration is also affected by the drag coefficient. Handgun bullets usually have a higher drag coefficient due to construction limitations of the weapon itself: bullet and cartridge should not be too long because the magazine should fit into the handgun grip, and the only way to increase the kinetic energy of a short bullet is to increase its calibre. Therefore, pistol bullets are more spherical than protruded (Figure 1) which leads to a higher drag coefficient compared to rifle bullets.

When it comes to construction, the tip of the bullet is the primary factor determining bullet penetrability and other terminal ballistics aspects. Some bullets are intended for fragmentation upon impact (e.g. 5.56x45 NATO) with less penetration into the target. Our experiment was performed with lead core bullets coated with CuZn30 alloy. This alloy (69-71% copper, small shares of iron, aluminium and nickel, and the rest of alloy makes of zinc) is characterized by great tensile strength which prevents fragmentation upon impact. Therefore, the bullet penetrates into the target, and if there is enough kinetic energy left, the bullet makes a complete breakthrough. But this is not a necessary condition for pistol bullets with rounded tips (Figure 1); they primarily aim for enemy neutralization by transferring as much energy as possible, wherein the bullet stays in the target. This suggests that pistol bullets could have problems with penetrating wooden barriers – which will be verified during the experiment.

For preliminary calculating of bullet penetration capabilities, two expressions were used. The first one is Journee's equation:

$$X = c_p d\, v_C^2 \tag{4}$$

where X is depth of bullet penetration [mm], c_p is penetrability coefficient, d bullet calibre [mm], while v_C embraces bullet velocity upon impact in wooden barrier [m/s] [15]. The penetrability coefficient for fir is $c_{pJ} = 0{,}000093$ while for oak the coefficient is $c_{pH} = 0{,}000076$. Journee's expression takes into account calibre and velocity of the bullet. Poncelet's expression is better because it is more complex and takes more elements in consideration [5]:

$$m_p \frac{dv}{dt} = -\beta - \alpha v^2 \tag{5}$$

where β presents material resistance-dependent parameter while α is contribution of inertial stress. By integrating (5) follows the expression for penetration depth X in a function of bullet velocity upon impact v_c.

$$X = \frac{m_p}{2\alpha} \ln\left(1 + \frac{\alpha v_c^2}{\beta}\right) \tag{6}$$

For the case of uniform deceleration $\alpha = 0$, (6) transfers into:

$$X = \frac{m_p v_c^2}{2\alpha} \tag{7}$$

which is actually the Robins-Euler's model. Bullet penetration into living tissue can be calculated according to:

$$-m_p \frac{dv}{dt} = \frac{1}{2}\rho v^2 A C_D + \frac{1}{2}\rho (aU)^2 A C_D \tag{8}$$

or as a function of the travelled distance x:

$$-m_p v \frac{dv}{dx} = \frac{1}{2}\rho A C_D \left[v^2 + (aU)^2\right] \tag{9}$$

where a present modification of C_D due to tissue tearing, while U presents characteristic tissue velocity [16]. Due to the small number of wood and bullet samples, the penetration calculation was not done in advance, and the experimental results were subsequently analysed.

5. Description and Course of Experiments

Two main variables were combined in experiments, pistol calibre and selection of wooden barrier. Twelve separate experiments were analysed:

- Experiments No. 1-3: shooting into the ballistic gelatine with each pistol calibre (3 bullets per calibre) with a 50 mm thick barrier of fir wood
- Experiments No. 4-6: shooting into the ballistic gelatine with each pistol calibre (3 bullets per calibre) with a 50 mm thick barrier of oak wood
- Experiments No. 7-9: shooting into a 100 mm thick barrier made of fir wood
- Experiments No. 10-12: shooting into a 100 mm thick barrier made of oak wood

The shooting was performed at the HS Produkt's closed shooting range which eliminated the influence of other variables (including atmospheric conditions). Wooden barriers were at a distance of 10 m and the ballistic gelatine was placed on a stand right behind those barriers. The shooting range was equipped with a laser system that measures the velocity of the bullets. Due to high-tech equipment at the shooting range impact velocity v_c was measured and not approximated according to ballistic charts.

The ballistic gelatine can be 10-percent or 20-percent. The percentage indicates the proportion of beef gelatine in the water. 10 kg heavy block of 20% ballistic gelatine is made of 8 litters of water and 2 kg of beef gelatine while the 10 kg heavy block of 10% ballistic gelatine is made of 9 litters of water and 1 kg of beef gelatine. According to available online sources, the FBI uses the 10% ballistic gelatine while the 20% ballistic gelatine is in experiments performed by NATO. However, this is not so important as long as the ballistic gelatine is properly validated, and the results can be extrapolated onto living tissue. On the other hand, the same type of ballistic gelatine can be used while examining the effects of different calibres, and these results can be directly compared. Demonstrations of the ballistic gelatine use and gelatin preparation techniques can be seen in [17], while in [18] is analysed how different concentrations, temperatures, and curing times affect calibration results affect the experiment results.

Four steps are required to make a ballistic gel. The first step involves the preparation of a hand and electric mixer as well as beef gelatine. In the first step, 56 litters of water are poured into the caldron and heated to the appropriate temperature. This procedure required a water dosimeter as well as a thermometer sensor. The second step started with adding 14 kg of beef gelatine (20% ballistic gel) into the caldron. Mixing of the mixture immediately followed and a hand mixer was used. Using the hand mixer eliminates the creation of foam which can be caused by an electric mixer. The execution of the second step can be seen in Figure 4.

Fig. 4. Water and beef gelatine mixing procedure

An electric mixer was used at the end of this step to crush greater clumps of beef gelatine. This procedure created a small amount of foam which was subsequently removed. Pouring the ballistic gelatine mixture into moulds (with dimensions of 150x150 mm and 400 mm in length) was the third step of the procedure. The last step is cooling. The moulds were left at room temperature for half an hour. After the initial cooling process, they were placed in the refrigerator. This cooling process lasted for 38 hours thus achieving the required level of gelatine strength.

The main part of this experiment was executed in HS Produkt's indoor shooting range in the town of Karlovac. The shooting was performed by HS Produkt's authorized handgun shooter under the supervision of an engineer. As already mentioned, shooting range was equipped with HPI's laser system for measuring bullet velocity. At the distances of 10 m (ballistic gelatine and wooden barriers were placed at that distance during the experiment) following bullet velocities were measured:

1) 9 x 19 mm Nontox TFMJ with a bullet weight of 8 g achieved an average speed of 331,27 m/s;
2) .40 S&W Nontox TFMJ with a bullet weight of 11,7 g achieved an average speed of 290 m/s;
3) .45 ACP Nontox TFMJ with a bullet weight of 14,9 g achieved an average speed of 240,7 m/s.

Bullet velocity variations are acceptable for both 9x19 Parabellum and .40 S&W while for .45 ACP it was to high: a difference between the maximum and minimum velocity was almost 19 m/s, while for the test group of 10 bullets a very large velocity dispersion was recorded (standard deviation was 7,7 m/s).

After evaluating bullet velocities, the main part of the experiment started consisting of 12 separate experiments. In all experiments, the gelatine was situated 6 to 8 cm behind a wooden barrier which can be compared with a real situation when someone takes cover behind an object.

The experiment No. 1 consisted of shooting 9x19 mm Parabellum through a 50 mm thick barrier made of fir. Considering high bullet velocity and lower drag due to the small impact area, good penetration capabilities were presupposed. This assumption proved to be correct because the bullet made a complete breakthrough in the wooden barrier, and after that made a deep penetration into the gel. The average gelatine penetration depth was 36 cm. One of the bullets hit the table on which the gelatine was situated and lost a part of its kinetic energy; it is therefore possible that the gelatine penetration could be even higher (Figure 5).

According to the FBI protocol, bullet penetration of 25 to 30 cm into the ballistic gelatine is enough to neutralize the opponent. Hit into vital organs leads to instant neutralization and a fatal outcome. Therefore, a barrier made of 50 mm thick fir is insufficient to be used as a cover.

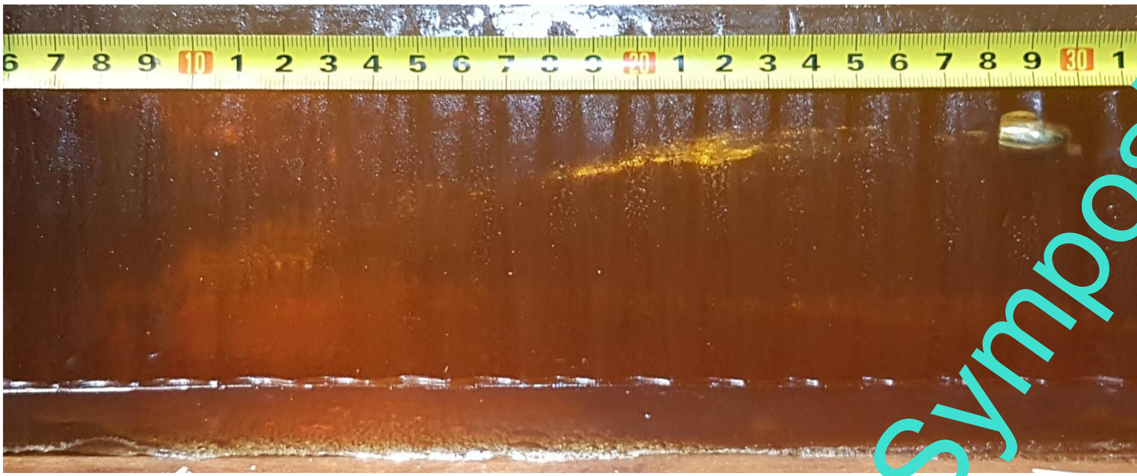

Fig. 5. Bullet 9x19 Parabellum, penetration of one bullet into the ballistic gelatine behind a fir barrier

The experiment No. 2 involved shooting at a ballistic gelatine with a .40 S&W projectile behind a 50 mm fir wooden barrier. The assumption was that this projectile would have a similar effect as 9 mm because of similar kinetic energy, although having a slightly larger cross-section. The assumption proved to be correct, and an average penetration of 36.5 cm was recorded. Similar to the 9x19 bullet, the barrier made of fir proved to be inadequate. As for the permanent cavity in the gel, it is substantial and it can be assumed that such a hit in the body would result in heavy internal bleeding.

The experiment No. 3 involved shooting with a .45 calibre ACP bullet, again through 50 mm of fir. Preliminary measurements have shown that this bullet, despite its large mass, has a lot of problems when trying to break through rigid wooden barriers. During the experiments, a mean penetration of only 29 cm was recorded. This still means that the opponent will be neutralized. Interestingly, the .45 ACP calibre does not create a larger permanent cavity (as the .40 bullet S&W does), despite the larger calibre and higher mass. One example of permanent cavity is clearly visible in Figure 6.

Fig. 6. Bullet 9x19 Parabellum, penetration into the ballistic gelatine behind a fir barrier

Next three experiment (4-6) involved the same procedures as the first three, using a barrier of the same thickness (50 mm), but this time made of oak wood. Due to the higher density and hardness of the oak, the main assumption was that the penetration would be lower compared to the experiments in which fir wood was used.

The experiment No. 4 included the same procedures as the first experiment, but with a barrier made of oak. The 9x19mm bullet made its way through the wooden barrier, but the penetration into the gelatine was not so deep (23,5 cm, which is some 35% less compared to the first experiment). Because of the more shallow penetration, neutralization of the opponent would not be instant (depending on the hit position); instant neutralization may still occur if a vital organ is hit. In any case, the opponent would need urgent medical treatment.

The experiment No. 5 is best compared to the fourth one. The 40. S&W bullet proved similar terminal ballistic properties as a 9x19 Parabellum. A mean penetration was 24 cm, with one ejected sample - that was a bullet that achieved an unrealistically deep penetration of 34 cm because the bullet passed through the hole in the wooden barrier made by the previous bullet. The permanent cavity was greater compared to the one made by the 9 x 19 mm Parabellum bullet, leading to a higher probability of fast neutralization.

The experiment No. 6 included a test with the slowest bullet in the .45 ACP calibre. The lack of kinetic energy resulted in a mean penetration value of just 13 cm which is noticeably less compared to the other two calibres. During the experiment, bullets hit an area very close to the wooden knot, and that is exactly the place where anisotropy of wood can be present. According to that, these results cannot be taken with a sufficient level of confidence. What this experiment proved is that high calibre bullets with low velocity and high drag coefficients suddenly lose velocity upon impact. Due to the velocity loss, bullets tumble in and shortly after the barrier, causing them to hit the gelatin upside down. This increases drag and reduces the depth of penetration. But this is a desirable feature for this calibre, because it is not meant to break through the target but to stay trapped inside, consequently transferring the entire kinetic energy on the target. What lacked in this experiment was a tumble of a bullet in gel, because without tumbling it cannot make the large temporary cavity. As for the permanent cavity, it is not larger compared to the cavity made by the .40 S&W bullet - a conclusion that yet has to be confirmed by the additional experiments.

After conducting the first six experiments where the main focus was the depth of penetration into a gel, as well as the size of the permanent cavity, six more experiments were performed. These experiments were focused on the penetration through the wooden barriers (fir or oak) for each calibre. Two connected 50 mm thick wooden planks formed a single 100 mm wooden barrier. That thickness is chosen because it represents the upper limit for some practical barriers (a thick table, a door frame, or a multi-compartment closet).

In experiments No. 7-9, the possibility of penetration for each calibre through a 100 mm thick fir barrier was examined. Since fir is a wood of low density and low hardness, each calibre completely went through the barrier. A decisive conclusion can be drawn that the fir block (even when it is 100 mm thick) cannot be used as an adequate cover. Figure 7 shows the front of the wooden barrier (bullet inlet holes - left) and the rear side (exit holes - right).

Fig. 7. Bullet inlet holes (left) and exit holes (right) for the fir barrier

Experiments No. 10-12 provided information on the suitability of oak when used as a protection. Due to the high density of this wood, no calibre has achieved a complete breakthrough of the 100 mm thick oak barrier. The average penetration depth of 9x19 Parabellum was 6.85 cm, for .40 S&W it was 5.85 cm, and the lowest average penetration was achieved with a .45 ACP bullet (5.1 cm). This confirms that oak indeed can be used as protection during armed conflict in urban conditions.

The summary results for all experiments are shown in Table 1.

Experiment No.	Wooden Barrier		Bullet Calibre	Penetration	
	Type	Thickness [cm]		Through Wood [cm]	Into gelatine [cm]
1	Fir	5	9x19 mm	Breaks Through	36,0
2	Fir	5	.40 S&W	Breaks Through	36,5
3	Fir	5	.45 ACP	Breaks Through	29,0
4	Oak	5	9x19 mm	Breaks Through	23,5
5	Oak	5	.40 S&W	Breaks Through	24,0
6	Oak	5	.45 ACP	Breaks Through	13,0*
7	Fir	10	9x19 mm	Breaks Through	Not Measured
8	Fir	10	.40 S&W	Breaks Through	Not Measured
9	Fir	10	.45 ACP	Breaks Through	Not Measured
10	Oak	10	9x19 mm	6,85	-
11	Oak	10	.40 S&W	5,85	-
12	Oak	10	.45 ACP	5,10	-

* During experiment No. 6 there was a hit in a wooden knot

Table 1. Summary results for all experiments

The graphical representation of results is shown in Figure 8:

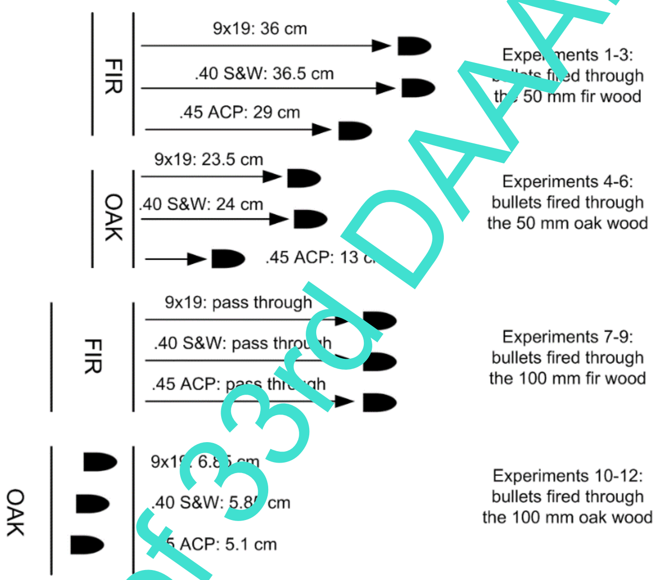

Fig. 8. Graphical representation of each calibre penetration capability, barriers of different wood and thickness

6. Results and Discussion

Experiments have shown that both the 9x19 Parabellum and the .40 S&W have good penetration capabilities, with the .40 S&W bulled showing slightly better terminal ballistic properties and creating a larger permanent cavity. This test showed why there is still no single decision by armies and police forces on the bullet to use. Both the 9x19 Parabellum and the .40 S&W have a number of strong arguments, both with their advantages and disadvantages. The analysis presented here, therefore, represents a contribution to the debate that is still ongoing. The 9 x 19 Parabellum bullet still seems to prevail over the .40 S&W bullet, and the main reason is the fact that the 9 x 19 Parabellum is standardized and widely accepted in NATO's defence systems. Other arguments in favour of this calibre are a long tradition, wider choice of pistols, easier supply of ammunition, and price. There is also a weaker recoil, factor important for improved control over the handgun.

Bullet.45 ACP, the largest of the three analysed, shows good characteristics when it comes to gelatine penetration, but due to its low flight speed and large cross-section, it is less successful in penetrating a wooden barrier. Therefore, this bullet relies primarily on its large mass, and then on the tumbling in the body of the opponent, which results in a large permanent cavity. As this bullet stops faster in the body, it is more likely to transfer complete kinetic energy to the target. The 9x19 mm and .40 S&W bullets can easily pierce the target if they hit a part of a small depth such as the extremities, after which the bullet continues its movement without transferring the remaining kinetic energy to the target. Significant drawbacks of the .45 ACP calibre are its low ballistic coefficient, low penetration ability, and a large bullet drop: in a collision with a hardwood barrier, this bullet gets completely stopped. As for the wooden barrier, the fir does not provide adequate protection - even a slow and cumbersome .45 ACP bullet will achieve a complete breakthrough. In contrast, dense and hard oak wood provides much better protection, so a barrier of sufficient thickness (> 50 mm) manages to stop all three bullets.

The surprisingly poor results shown by the largest analysed calibre (.45 ACP) show how important it is to properly test the behaviour of bullets in a particular scenario. Choosing the wrong calibre, even if it is widely accepted by the public as "the most powerful" (as is the case with the .45 ACP round), could have fatal consequences for soldiers and police officers. Perhaps such analyses will encourage improvements to the .45 bullet, just as the 9x19 mm bullet was improved after criticism for its poor efficiency. As for the limitations of the analysis, they were primarily related to the small number of samples. Therefore, the results should be confirmed in the future with an extended experiment. We also plan to examine the penetration of other pistol calibres, and the penetration of frequently used rifle bullets (for example 5.56 × 45 mm NATO, or 7.62x39 mm). In this way, an even wider range of potential scenarios related to military action in urban areas could be examined.

7. Acknowledgments

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