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Projectile for a New Intermediate Cartridge

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Abstract. Evolution of contemporary military conflicts has revealed some shortcomings of existing individual small arms ammunition. The first attempts to undertake research and development works on new weapons and ammunition were made in the USA, however, some projects are also being launched in other countries. This paper presents a short review of the newly developed rounds for perspective small arms' systems as well as an attempt to determine a caliber of perspective individual weapon. For this purpose, some preliminary external and terminal ballistic analyses were conducted for various diameter projectiles of the same design.

Keywords: mechanical engineering, ballistics, small arms, intermediate cartridge, projectile

1. INTRODUCTION

An increasing interest in new types of small arms ammunition development can be observed recently. The most commonly used small arms cartridges were designed over 60 years ago and their construction and design process are not significantly different than the technology that was available almost 100 years ago [1]. Since then, science, as well as the technological resources, have developed considerably. Therefore, various kinds of tools that were unavailable at the time are now commonly used in the design process, including ballistic programs, CAD, and CAE systems that significantly improve the quality and shorten the time required for creating and analyzing new designs.

Another reason for such interest is modern battlefield evolution. Nowadays, typical live target is protected by body armour what demands higher penetration ability of the projectile. Moreover, new tactics of using troops need higher hit probability. Due to the abovementioned and following a new approach to the criteria for a small arms ammunition, which is considering the weight of a cartridge and higher required effective range, there is an understandable need for a new small arms cartridge design, that could benefit from the technologies available currently in that field of science [2]. The main aim of the paper is to evaluate the most reasonable and promising diameter of a perspective projectile.

2. OVERVIEW OF THE NEXT GENERATION SQUAD WEAPON PROGRAM CARTRIDGES

In order to understand the requirements for a new cartridge, ammunition designs that took part in the Next Generation Squad Weapon program (NGSW) were analyzed. The NGSW was initiated in the U.S. in 2017 with the aim to find a replacement for the M4 carbine, M249 LMG, and M240 MG, including the new weapons, ammunition, and a fire control system. Initially, three main competitors were involved in the program:

- SIG Sauer Inc: SIG MCX SPEAR rifle, SIG MG 6.8 machine gun – using 6.8 × 51 mm hybrid cartridges;
- LoneStar Future Weapons and Beretta USA: Genesis RM-277R bullpup rifle and Genesis RM-277AR machine gun – using 6.8 × 51 mm True Velocity Composite-Cased Munition (TVCM) polymer cased ammunition designed by True Velocity;
- Textron Systems: 6.8 mm Textron CT rifle, LSAT LMG – using 6.8 mm Cased-Telescoped cartridge.

Throughout the program, Textron Defense Systems design was withdrawn, and the first two competitors remained in the competition. In January 2022, fire control system for the NGSW was chosen, as Vortex Optics XM157 NGSW-FC (Next Generation Squad Weapon – Fire Control) system won the competition with L3Harris Technologies.

In April 2022 the U.S. Army announced Sig Sauer as a winner of the competition for a rifle (XM5), automatic rifle (XM250) and the 6.8 mm ammunition [3].

2.1. 6.8 × 51 mm Sig Sauer Hybrid Cartridge

6.8 × 51 mm Hybrid Cartridge is a centrefire rimless bottlenecked rifle cartridge designed by SIG Sauer in 2019. The cartridge was initially designed with a case which consisted of stainless-steel base, brass body, and a locking washer connecting them, however, during the program its design has developed, and currently the locking washer is omitted by a change in the shape of a steel base and brass case body.

Steel base of the cartridge case allows it to withstand over 550 MPa of chamber pressure, which provides much higher muzzle velocities than it was possible with a standard brass case, therefore achieving better external ballistic performance and higher bullet energy at a target. The overall data of 6.8 mm Hybrid Cartridge is presented in Table 1. Specific construction of the projectiles is yet unknown (since its design is imposed by US Armed Forces), however, from the information available, it can be concluded that the bullet is characterized by a boat-tail, relatively long with hybrid ogive shape. The cartridge is shown in Fig. 1 [4,5].

Fig. 1. 6.8 × 51 mm Sig Sauer Hybrid Cartridge (www.gunsandammo.com)

2.2. 6.8 × 51 mm TVCM True Velocity Cartridge

6.8 × 51 mm TVCM is a composite-cased cartridge designed by True Velocity as a part of the Next Generation Squad Weapon program. The cartridge is created for a new Amicus 6.8 × 51 mm rifle, that operates on gas & short recoil patented automatic system. The case of the new cartridge consists of two parts – a composite case body and a steel base. A bullet used is a boat tail, hybrid ogive projectile with a relatively small diameter meplat. The cartridge is equipped with a standard, large rifle primer. Due to the ongoing program, ballistic data and specifications are currently confidential, thus the maximum peak pressure to achieve a muzzle velocity of 920 m/s is unknown. Table 1 shows the technical data of 6.8 mm TVCM Cartridge.

What can be noticed from the information available, is that the polymer case is shaped without a characteristic neck, to simplify the structure, increase shear strength, ammunition durability and moreover, to provide more volume for the propellant. On the other hand, the steel base had to be used in order to achieve safe extraction of the spent case.

The most important feature of a polymer cartridge case is that while its external profile is dictated by the chamber, the internal shape of a case can be designed freely. It provides constructors the possibility of achieving the volume and shape of a cartridge optimal for the propellant with required ballistic parameters. Moreover, the use of plastic case provides not only cartridge weight reduction, but also due to the insulating properties of polymer, it reduces heat transfer therefore improving weapon’s efficiency. The TVCM cartridge is shown in Fig. 2 below [6,7,8].

Fig. 2. 6.8 × 51 mm TVCM True Velocity Cartridge (www.modernfirearms.net)

2.3. 6.8 mm CT Textron cartridge

NGSW Cased-Telescoped ammunition was designed by Textron Systems and Winchester. The cartridge consists of a primer, a projectile fully seated within a cylindrical, polymer case surrounded by the propellant. The biggest advantage of that solution is reduction of the cartridge’s weight, which reaches around 37% when compared to similar brass-cased cartridges. Moreover, this specific design allows us the use of longer projectile (better ballistic coefficient), due to the ability to use more propellant with shorter overall length of the cartridge. Currently, available technical data of 6.8 mm Hybrid Cartridge is shown in Table 1. The projectile used in 6.8 mm CT cartridge is a long, boattail bullet, with a visible front part made of a different material – probably hardened steel, in order to improve the terminal ballistic performance – penetration of a target. Cross section of the 6.8 mm CT cartridge is shown in Fig. 3 [9, 10].

Fig. 3. Cross section of 6.8 mm CT cartridge (www.gatdaily.com)

Table 1. Technical data of the NGSW program rounds (based on [4, 5, 6, 8, 9, 10])

No.	**Parameter**	**Value**		
		6.8 × 51 mm Sig Sauer	6.8 × 51 mm TVCM	6.8 mm CT Textron
1.	Projectile diameter [mm]	7.06	7.06	~7.0
2.	Cartridge length [mm]	71.8	71.0	51.0
3.	Projectile length [mm]	51.2	49.48	~36.0
4.	Projectile mass [g]	8.75	8.75	8.8
5.	Muzzle velocity [m/s]	915.0	920.0	915.0
6.	Muzzle energy [J]	3662.8	3703.0	3683.9
7.	Max. chamber pressure [MPa]	550	448.16*	-

*Maximum Average Pressure value for SAAMI method

3. INTERMEDIATE ROUNDS PROJECTILE EVOLUTION

Analyzing the most commonly used cartridges, the M855 projectile is known for its lack of rebuttal capacity, being yaw-dependent – the terminal effect is dependent on the angle of the projectile while hitting the target, and having poor effectiveness at the ranges over 300 m, due to fast drop of its kinetic energy. To avoid the drawbacks mentioned above, the M855A1 Enhanced Performance Round (EPR) was designed. Instead of covering the steel penetrator over with a copper jacked and filling the bullet with lead slug like in the M855, M855A1 EPR consists of a copper core, copper jacket, and a heavier steel penetrator, that is fully exposed from the rest of the projectile. The projectile is longer than its predecessor, thus it maintains better external ballistic performance, and by moving the center of gravity rearward, the yaw-dependence problem was solved [11]. However, the kinetic energy of a 5.56 mm projectile achieved at a target is still reported to be too low to effectively affect it. At the same time, the use of 7.62 × 51 mm cartridge with M80 bullet involves the higher weight, more visible muzzle flash, and worse controllability while automatic firing [12].

Another attempt to improve the abilities of small arms ammunition was a design by the US Company Advanced Armament - .300 Blackout cartridge, which achieved 16% higher muzzle energy with 8.1 g projectile, than the 5.56x45 mm NATO. However, that approach to improve the performance of intermediate cartridge turned out to be a failure, due to unsatisfactory improvement over 5.56 mm and 7.62 mm rounds [13].

Those aspects lead to the conclusion, that a new projectile should be a mid-way between the 5.56 mm and 7.62 mm caliber, having a better external ballistic performance and higher terminal effect on a target, while maintaining lower muzzle flash and recoil small enough to allow a controlled automatic fire.

The following desired characteristics of a new projectile were specified:

- improved terminal ballistics – defeating live target protected by class 4 body armour (PN-V-87000 and NIJ 0101.04) at 100 m distance. Due to the problems with penetration tests of typical materials used for individual protection, appropriate simplification is a 10 mm steel plate. Since this work has a preliminary analysis character, such an assumption is acceptable;
- the projectile has to be lead-free due to the UN regulations – therefore another material than lead has to be used in the core of a projectile.

4. BULLET DIAMETER ESTIMATION

In order to choose the most perspective diameter of a new bullet, five projectiles of different diameters between 5.56 mm to 7 mm were taken into consideration. Projectile design was based on M855A1 (Fig. 4) while dimensions were scaled to appropriate diameters. Afterwards, using ballistic calculation program – PRODAS V3, the terminal effect of each bullet at a specific distance was compared.

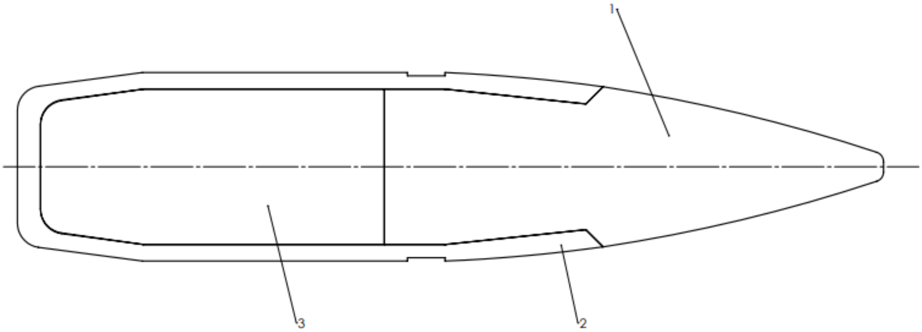

Fig. 4. Cross section of the projectile's design
1 – steel penetrator, 2 – copper jacket, 3 – copper core

The designed shape of a projectile was evaluated in terms of its external ballistic performance, specifically by estimation of the drag curve (Fig. 5), while the basic dimensions, calculated ballistic coefficients (BC), and sectional densities (SD) are presented in Table 2. A ballistic coefficient can be understood as an ability of the projectile to penetrate the air, therefore the higher BC, the better external ballistics performance of the designed projectile. PRODAS V3 estimates the BC for a bullet according to the Ingalls Ballistic Tables, which means it is similar to the G1 standard. It is an appropriate use for the purpose of comparison of the new designed projectiles.

The drag curve, presented in Fig. 5, shows the character of changes of Drag Coefficient (CD) value in accordance to the Mach number of a projectile during flight.

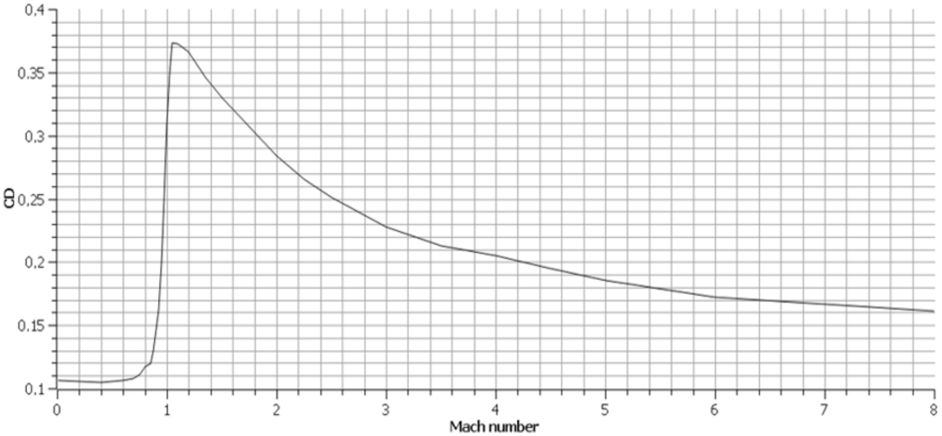

Fig. 5. Drag curve of the projectile

Table 2. External ballistic data of the designed projectiles

Parameter	**1**	**2**	**3**	**4**	**5**
Projectile diameter [mm]	5.56	6.0	6.5	6.8	7.0
Projectile length [mm]	26.25	27.68	29.99	31.37	32.29
Ballistic coefficient	0.402	0.424	0.460	0.482	0.496
Sectional density [g/mm^2]	0.165	0.174	0.189	0.198	0.203

As shown above, external ballistics performance of a bullet, expressed by its ballistic coefficient, increases with a projectile's mass. Therefore, the smallest projectile – 5.56 mm, has a BC equal to 0.402, while 7 mm bullet has the highest BC of 0.496.

Moreover, sectional density, which refers to the projectiles' external, but also terminal ballistic performance, is the highest for a 7 mm diameter as well and equals 0.203 g/mm^2, compared to 0.165 g/mm^2 for a 5.56 mm projectile.

In order to visually compare the external ballistic performance of the adopted bullets, simulation of a point-blank range shooting was performed, using the Trajectories module of PRODAS V3. Following initial conditions for simulations were set:

- muzzle velocity: 900 m/s and 1000 m/s;
- barrel length: 508 mm;
- barrel twist: 178 mm, 6 grooves.

The calculated trajectories for both muzzle velocities are shown in Fig. 6 and Fig. 7. In case of 900 m/s muzzle velocity, the 5.56 mm bullet was omitted, because that velocity is already achieved with the 5.56 × 45 mm NATO round (muzzle velocity of 920 m/s), so it was calculated only for the v_0 equal to 1000 m/s.

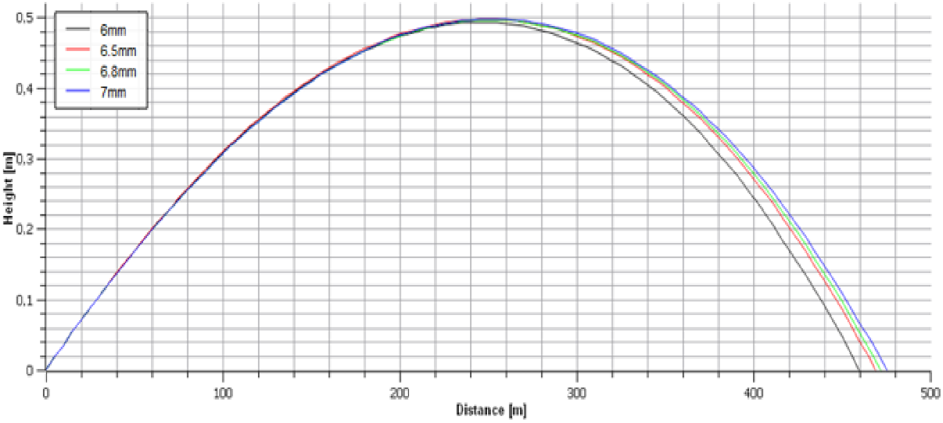

Fig. 6. Trajectories of the projectiles at $v_0 = 900$ m/s

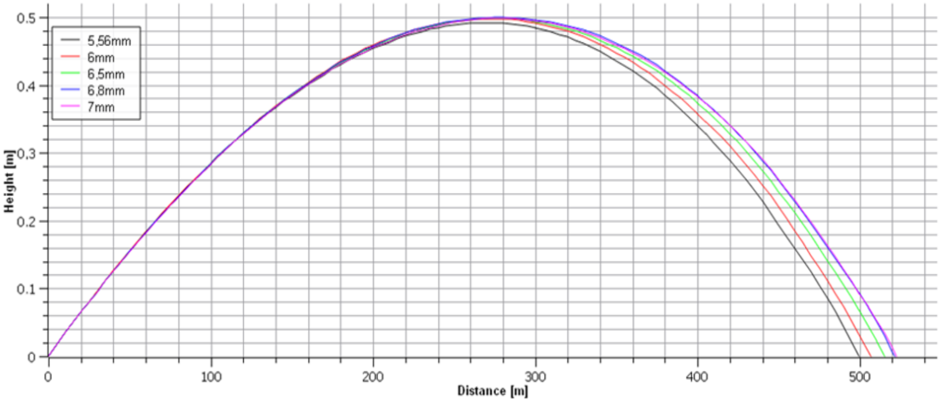

Fig. 7. Trajectories of the projectiles at $v_0 = 1000$ m/s

From the figures above, it can be concluded that as expected, the best performance was achieved by the heaviest projectile, due to the bullet's highest ballistic coefficient. The main parameter taken into consideration when comparing the projectile's performance, is its kinetic energy at a specific distance. The changes of kinetic energy of the designed bullets during the flight are shown in Fig. 8 and Fig. 9 below.

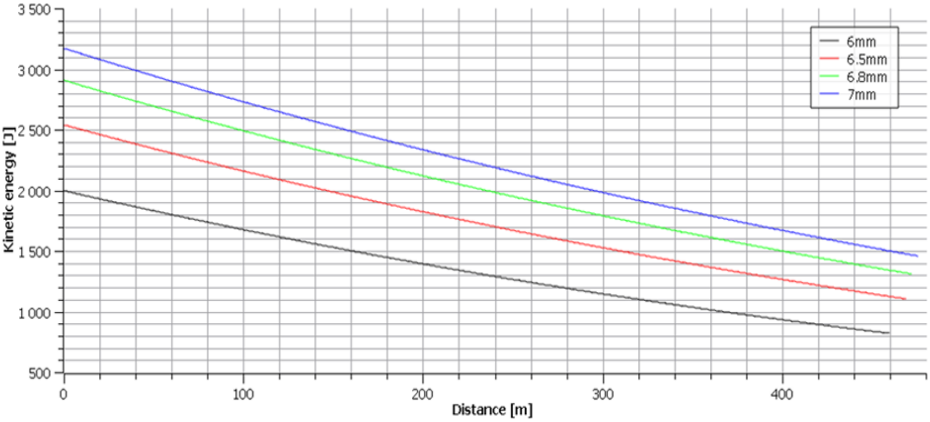

Fig. 8. Kinetic energy drop at $v_0 = 900$ m/s

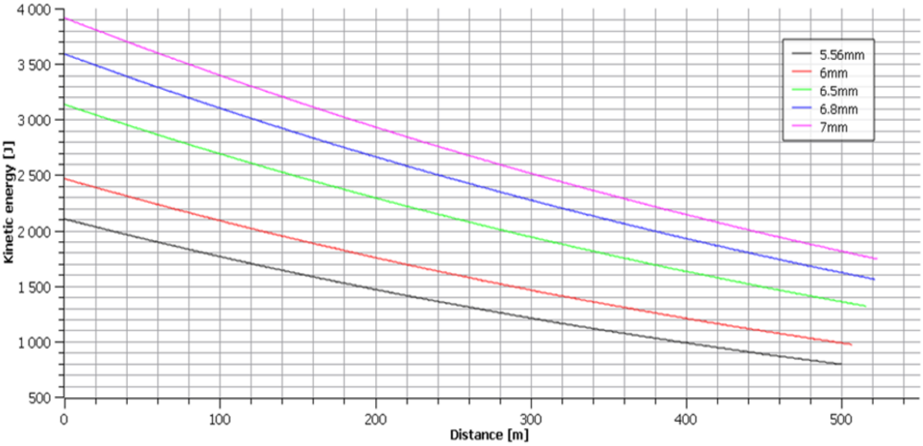

Fig. 9. Kinetic energy drop at $v_0 = 1000$ m/s

In order to compare all achieved data, the results from all charts above are presented in Table 3 for a muzzle velocity of 900 m/s and in Table 4 for a muzzle velocity of 1000 m/s.

Table 3. Performance of the designed projectiles at $v_0 = 900$ m/s

Projectile diameter [mm] **Parameter**	**6.0**	**6.5**	**6.8**	**7.0**
Mass [g]	4.93	6.27	7.18	7.83
Point-blank range [m]	459.4	468.6	472.0	475.2
Muzzle kinetic energy [J]	1997.9	2540.1	2908.4	3172.6
Kinetic energy at a distance:	-	-	-	-
100 m	1675.6	2160.0	2491.3	2729.9
150 m	1529.7	1986.6	2300.2	2526.5
200 m	1393.4	1823.7	2120.1	2334.5
250 m	1265.9	1670.5	1950.5	2153.4
300 m	1146.9	1526.7	1790.6	1982.4

Table 4. Performance of the designed projectiles at $v_0 = 1000$ m/s

Projectile diameter [mm] **Parameter**	**5.56**	**6.0**	**6.5**	**6.8**	**7.0**
Mass [g]	4.20	4.93	6.27	7.18	7.83
Point-blank range [m]	499.6	506.9	515.9	521.2	522.8
Muzzle kinetic energy [J]	2103.7	2466.5	3136.0	3590.6	3916.7
Kinetic energy at a distance:	-	-	-	-	-
100 m	1765.1	2088.9	2690.7	3102.1	3398.4
150 m	1611.7	1916.8	2486.3	2876.9	3158.8
200 m	1468.5	1755.5	2293.6	2664.1	2931.9
250 m	1334.8	1604.5	2112.3	2463.3	2717.6
300 m	1210.4	1463.2	1941.7	2273.8	2514.9

Assessment of terminal ballistics performance of the designed bullets in terms of a target penetration, according to the requirements mentioned before, was calculated using Jacob de Marre formula (1), in order to compare the results for different dimensions of the projectiles [14].

$$\frac{m{v_p}^2}{d^3} = C\left(\frac{s}{d}\right)^n \tag{1}$$

where:

m – projectile's mass,
v_p – projectile's velocity at the target,
d – projectile's diameter,
C – constant dependent on the projectile type; $C = 9.5$,
s – thickness of the target; according to this work assumptions: $s = 10$ mm,
n – constant dependent on the character of projectile's performance inside the target: $n = 1.3$.

In order to calculate required kinetic energy of each of the designed bullets, the equation was modified (2).

$$E_{kmin} = \frac{C}{2}\left(\frac{s}{d}\right)^n d^3 \tag{2}$$

The results of calculations, using equation (2), are presented in Table 5. Maximum distance for a bullet, where the value of its kinetic energy is higher than the minimum value required for a penetration, is marked as E_{kmin} distance, successively for both simulated muzzle velocities.

Table 5. Terminal ballistics parameters

Projectile diameter	**5.56 mm**	**6 mm**	**6.5 mm**	**6.8 mm**	**7 mm**
Kinetic energy required for a 10 mm RHA target [J]	1826.76	1993.20	2283.74	2465.81	2590.36
E_{kmin} distance for $v_0 = 1000$ m/s [m]	80	125	200	245	280
E_{kmin} distance for $v_0 = 900$ m/s [m]	-	0	65	105	130

In case of the muzzle velocity $v_0 = 1000$ m/s, 6 mm diameter projectile has enough to fully penetrate the target at 100 m. However, achieving the same result at 200 m requires the use of a projectile of at least 6.5 mm diameter. A drop of 100 m/s in the muzzle velocity is significantly decreasing projectile's ability of penetration. With the muzzle velocity $v_0 = 900$ m/s, to achieve the required terminal effect, the use of at least 6.8 mm diameter projectile is needed. 6.8 mm bullet is able to achieve full target penetration at 105 m, whereas 7 mm bullet can achieve the same result at 130 m.

5. CONCLUSIONS

Due to the demands of a modern battlefield, the need to replace 5.56 × 45 mm round is obvious. Practically, there are no more possibilities of enhancing presently used round for basic small arms. However, new perspective round should be a compromised solution between 5.56 × 45 mm and 7.62 × 51 mm ammunition being in use. What is the most important, its ballistic parameters should be closer to the first of them. Such approach should allow us to maintain the weapon's weight and recoil energy at an acceptable level for individual small arms. The cartridges developed within the NGSW program seem to be too powerful. An analysis of these rounds has confirmed, that one of the vital aspects of the program is a type and design of a cartridge case and propellant, in order to achieve high muzzle velocities, even over 900 m/s for a 9 g projectile.

The results obtained by calculations have shown that a 6.0 mm diameter-steel-tipped projectile, shot with 1000 m/s muzzle velocity is powerful enough to achieve a full target penetration at 100 m. However, assuming a muzzle velocity of 900 m/s, a minimum diameter of the same round is 6.8 mm, which would provide full target penetration at 105 m, and at 245 m while fired with 1000 m/s muzzle velocity. Even better terminal ballistics performance could be achieved with a 7.0 mm projectile, nevertheless, every increase in the bullet's diameter equals increase in the weight of a projectile, thus affecting the peak pressure in a chamber during a shot with the same required muzzle velocity. Therefore, considering all abovementioned aspects, the projectile of 6.8 mm diameter was chosen as the most perspective between the analyzed diameters.

Further works should concentrate on external ballistics phenomena, analyzed with more sophisticated tools to improve the projectile's shape. Moreover, terminal ballistics' analyses are necessary in order to provide appropriate penetration of individual protection devices.

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Pocisk nowego naboju pośredniego

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Streszczenie. Rozwój współczesnych konfliktów zbrojnych ujawnił pewne wady istniejącej amunicji do broni strzeleckiej. Pierwsze próby podjęcia prac badawczo-rozwojowych nad nową bronią i amunicją podjęto w USA, jednak niektóre projekty są uruchamiane także w innych krajach. W artykule przedstawiono krótki przegląd nowo opracowanych pocisków do perspektywicznych systemów broni strzeleckiej oraz podjęto próbę określenia kalibru perspektywicznej broni strzeleckiej. W tym celu przeprowadzono wstępną analizę balistyki zewnętrznej i końcowej dla pocisków o tej samej konstrukcji, dla różnych średnic.

Słowa kluczowe: inżynieria mechaniczna, balistyka, broń strzelecka, amunicja pośrednia.