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# Perspective Armour-Piercing Intermediate Cartridge Projectile

Krzysztof PIASTA[*], Przemysław KUPIDURA

*Military University of Technology,*
*Faculty of Mechatronics, Armament and Aerospace*
*2 Sylwestra Kaliskiego Str., 00-908 Warsaw, Poland*
*[*]Corresponding author's e-mail address and ORCID:*
*krzysztof.piasta@wat.edu.pl; https://orcid.org/0000-0002-6331-5590*

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**Abstract.** Ongoing military conflicts, along with a constant evolution of individual protection devices, have shown an urgent need of development in terms of the armour piercing capability of standard infantry small arms ammunition. The following paper includes a brief overview of the existing armour-piercing intermediate rounds, in an effort to define the most reasonable design of a perspective armour-piercing projectile. Therefore, various projectiles were designed and evaluated in terms of their external ballistic performance for chosen initial conditions, followed by preliminary internal and terminal ballistic calculations that were performed in order to assess the most reasonable outcome.

**Keywords:** mechanical engineering, armour-piercing rounds, small arms, ballistics, projectile

# 1. INTRODUCTION

Individual body armour has been developed significantly in recent years. Advances in the material of armour systems have led to modern solutions capable of stopping even armour-piercing rounds. They are classified as type III and IV protection devices in the NIJ Standard 0101.04 [1]. Therefore, along with the armour, natural effect is a development of small arms ammunition to provide the infantry with abilities to penetrate aforementioned individual armours.

During the last decade, various development programs seeking new intermediate cartridges could be observed around the world. One of the most important and therefore one that would influence NATO armies, is the Next Generation Squad Weapon program (NGSW), which has chosen Sig Sauer with a design of a new rifle, carbine, and a 6.8 × 51mm hybrid ammunition.

The vital aspect of a new cartridge is understandably the diameter of a projectile. Recent studies have stated, that required stopping power along with maintaining reasonable peak chamber pressure could be achieved with a projectile of a diameter between 6 and 7 mm. However, equally important as an estimation of the diameter, is the construction of a perspective projectile. Therefore, there is a necessity to establish a design of an intermediate cartridge projectile which would acquire the best target penetration with satisfactory external ballistic performance, while maintaining reasonable internal ballistic parameters, which is a main aim of the paper.

# 2. OVERVIEW OF CHOSEN ARMOUR PIERCING INTERMEDIATE CARTRIDGES

Achieving armour piercing (AP) abilities with an intermediate cartridge requires the use of a different than standard full metal jacket design of a projectile. Analysing the most used AP cartridges, there were various attempts to improve the considered feature, both by modifying existing rounds, like with the 5.56 × 45 mm M855 and its Extended Performance version – M855A1, or designing a new projectile, usually utilising a higher density material as an armour-piercing penetrator.

In order to outline advantages and disadvantages of the chosen armour-piercing intermediate projectiles, the following cartridges were analysed:

- 5.56 × 45 mm M855A1 Enhanced Performance Round;
- 5.56 × 45 mm M995 Armour Piercing 3;
- 5.56 × 45 mm Armour Piercing 45.

## 2.1. 5.56 × 45 mm M855A1 EPR

M855A1 Enhanced Performance Round (EPR) was introduced in the US Army in 2010 to replace the M855. It was designed to provide better and more consistent performance compared to the M855, including improved hard-target penetration, better accuracy, and reduced muzzle flash.

The projectile in M855A1 round consists of a copper alloy core, copper jacket, and a hardened steel penetrator, exposed from the rest of the projectile. It is 3.2 mm longer than the M855, however, because of different densities of used materials, weights of both projectiles are equal – to provide interchangeability. In terms of penetration, the projectile is supposed to penetrate 9.5 mm of a steel plate at 350 m, compared to 160 m of M855 [2].

Construction of a M855A1 round is shown in Fig. 1 and the basic technical data is presented in Table 1.

Fig. 1. 5.56 × 45 mm M855A1 round
Below - cross section of the round (www.forum.cartridgecollectors.org)

## 2.2. 5.56 × 45 mm M995 Armour Piercing 3 / Armour Piercing 45

5.56 × 45 mm Armour Piercing 3 (AP3) round (Fig. 2) is an intermediate cartridge designed in 1996 by Nammo AS, adopted by the US Army as M995. The main purpose of the new design was to provide better armour piercing capability for the M4 carbine and M249 SAW, especially considering an improved penetration of lightly armoured vehicles at longer distances [3].

Following the AP3, Nammo company has manufactured a heavier version of the 5.56 mm projectile, Armour Piercing 45 (AP45) (Fig. 3), which provided improved performance at longer ranges in comparison with its lighter counterpart, however, it was never introduced to use by the US Army, nor in any other country. The M995 projectile consists of a copper jacket, a 1.1 g tungsten carbide penetrator, and an aluminum sleeve that centers the tungsten core inside the bullet. A shape of the AP45 penetrator is slightly different than this of AP3 penetrator. Except being longer, it has an ogival shape of the front part with two different radiuses, and a chamfered base, to avoid rotation of the core relatively to the rest of the projectile [4].

Fig. 2. 5.56 × 45 mm M995 AP3 cartridge,
Below - cross section of the round (www.forum.cartridgecollectors.org)

Fig. 3. 5.56 × 45 mm AP45 cartridge,
Below – cross section of the round (www.forum.cartridgecollectors.org)

Table 1. Technical data of the analysed armour piercing rounds (based on [2,3,4])

| **No.** | **Parameter** | **Value** | |
|---|---|---|---|
| | | M855A1 | M995 AP3 |
| 1. | Projectile diameter (mm) | 5.56 | 5.56 |
| 2. | Projectile mass (g) | 4.18 | 3.3 |
| 3. | Penetrator mass (g) | 1.2 | 1.1 |
| 4. | Penetrator material | Steel | Tungsten |
| 5. | Muzzle velocity (m/s) | 961 | 1030 |
| 6. | Muzzle energy (J) | 1859.0 | 1750.4 |
| 7. | Penetration ability | 9.5 mm of steel at 350 m | 12 mm of RHA at 100 m |

## 3. DESIGN OF A PERSPECTIVE PROJECTILE

One of the vital aspects of designing a new projectile, is the diameter itself. Following the results of previous analysis and preliminary estimation, the designed perspective projectiles are characterised by 6.8 mm diameter.

Having chosen a diameter of a projectile, the next aspect is its construction. Concluding the overview of the commonly used armour-piercing projectiles, four different approaches to the problem were proposed, therefore four following designs were analysed:

- 6.8 mm Steel Penetrator projectile (6.8 mm SP);
- 6.8 mm Jacketed Tungsten Penetrator projectile (6.8 mm JTP);
- 6.8 mm Tungsten Penetrator projectile (6.8 mm TP);
- 6.8 mm Light Tungsten Penetrator projectile (6.8 mm LTP).

## 3.1. 6.8 mm Steel Penetrator projectile

The first designed projectile exploits the idea of a M855A1 round, with a change of the projectile diameter. 6.8 mm SP consists of a 2.29 g hardened steel penetrator, a copper slug and a reverse-drawn copper jacket enclosing the components together. Steel penetrator affects the overall weight of a projectile insignificantly, thus a higher muzzle velocity with reasonable peak chamber pressure should be achievable. Scheme of the designed 6.8 mm SP construction is shown in Fig. 4.

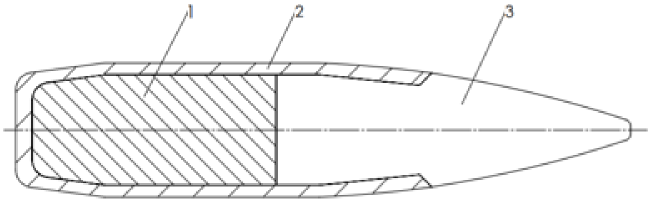

Fig. 4. Cross section of 6.8 mm SP projectile
1 – copper slug, 2 – copper jacket, 3 – steel penetrator

## 3.2. 6.8 mm Jacketed Tungsten Penetrator projectile

The 28.22 mm long 6.8 mm JTP consists of a 4.59 g tungsten penetrator centered in an aluminum sleeve, fully jacketed in a copper jacket. Construction of a 6.8 mm JTP projectile is shown in Fig. 5.

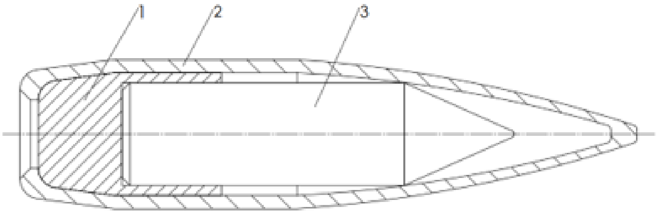

Fig. 5. Cross section of 6.8 mm JTP projectile
1 – aluminum sleeve, 2 – copper jacket, 3 – tungsten penetrator

In an afford to reduce weight of the projectile, overall length was shortened when compared to the 6.8 mm SP, thus achieving a reasonable weight of 7.29 g for the 6.8 mm projectile. Furthermore, the design is characterised by a larger ogive radius, aiming to improve its external ballistics performance at supersonic velocities.

## 3.3. 6.8 mm Tungsten Penetrator projectile

6.8 mm TP (Fig. 6) is characterised by much greater overall weight when compared to the rest of the designs, due to the use of a significantly heavier tungsten penetrator. It consists of a copper plug and a 5.01 g core, partially covered in a copper, reverse-drawn jacket. The arrow-shaped penetrator is utilised to significantly improve projectile capacity of armour-piercing. However, it affects the weight considerably, increasing the overall weight of a projectile to 9.24 g, which must be considered when evaluating the peak chamber pressure required for achieving the assumed muzzle velocity.

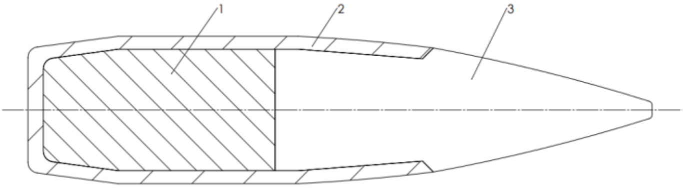

Fig. 6. Cross section of 6.8 mm TP projectile
1 – copper slug, 2 – copper jacket, 3 – tungsten penetrator

## 3.4. 6.8 mm Light Tungsten Penetrator projectile

To maintain the overall weight of a projectile at an acceptable level, the last proposed design is a midway between all the previously designed projectiles.

6.8 mm LTP projectile consists of a tungsten penetrator whose front part is exposed from the reverse-drawn copper jacket, inside filled with a copper slug, and an aluminum sleeve which positions the 2.24 g penetrator. Following design is characterised by a relatively low weight – 6.86 g, while still utilising the high-density tungsten core on the front of a projectile. Those characteristics are vital for achieving much higher muzzle velocity while maintaining reasonable chamber pressure, thus significantly improving both the external ballistics performance and the armour piercing abilities. Design of the projectile is shown in Fig. 7.

Summary of the technical data of designed projectiles is presented in Table 2.

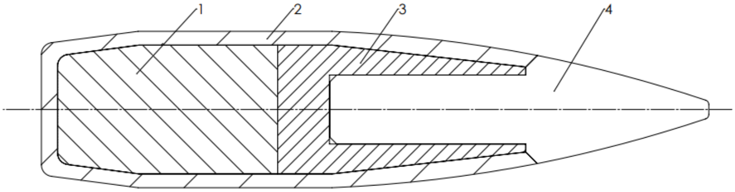

Fig. 7. Cross section of 6.8 mm LTP projectile
1 – copper slug, 2 – copper jacket, 3 – aluminum sleeve, 4 – tungsten penetrator

Table 2. Technical data of the designed projectiles

| **Parameter** | **6.8 mm SP** | **6.8 mm JTP** | **6.8 mm TP** | **6.8 mm LTP** |
|---|---|---|---|---|
| Projectile length (mm) | 31.37 | 28.22 | 28.98 | 29.20 |
| Projectile mass (g) | 7.09 | 7.29 | 9.24 | 6.86 |
| Penetrator mass (g) | 2.29 | 4.59 | 5.01 | 2.24 |
| Ogive radius (mm) | 60.0 | 62.2 | 83.6 | 60.0 |

## 4. PERFORMANCE of the DESIGNED PROJECTILES

### 4.1. External Ballistics

In order to assess the most perspective construction, the designed projectiles were analysed in terms of their external ballistics, using Arrow Tech PRODAS V3.5 software. Initially, parameters like the drag curves, ballistic coefficients, sectional densities, and projectiles stability were estimated.

A ballistic coefficient (BC) is a value expressing projectile's external ballistics performance, showing its ability to 'penetrate the air', thus it is one of crucial parameters. The higher BC, the better external ballistics results. Chosen software calculates BC using the Ingalls Ballistic Tables. Ingalls tables use rather outdated standard projectile model similar to the G1 standard, however, the purpose of this paper is to compare all newly designed projectiles with themselves, not with actual projectiles in use, thus it is of an appropriate use [5]. Sectional densities (SD) of the projectiles were calculated using Eq. (1) [6]. The value of SD expresses external performance of the projectile, but also terminal ballistics performance, and it can be understood as the bullet ability to penetrate the target.

$$SD = \frac{4m}{\pi d^2}\left[\frac{g}{mm^2}\right] \tag{1}$$

where:
*m* – projectile mass;
*d* – projectile diameter, in this case: $d = 6.8$ mm.

Figure 8 shows the calculated drag curves for all analysed projectiles, as a value of the drag coefficient (CD) in accordance with the Mach number of a projectile during its flight. Table 3 presents the calculated external ballistic parameters.

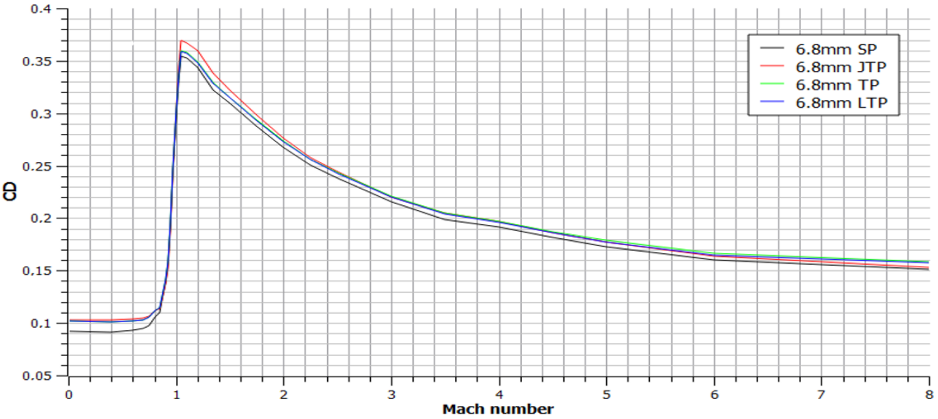

Fig. 8. Drag curves of the projectiles

Table 3. External ballistics parameters of the designed projectiles

| Parameter | 6.8 mm SP | 6.8 mm JTP | 6.8 mm TP | 6.8 mm LTP |
|---|---|---|---|---|
| Ballistic coefficient [-] | 0.492 | 0.494 | 0.628 | 0.466 |
| Sectional density [g/mm$^2$] | 0.195 | 0.201 | 0.255 | 0.189 |
| Average drag coefficient [-] | 0.261 | 0.269 | 0.267 | 0.266 |
| Gyroscopic factor [-] | 4.07 | 6.83 | 7.97 | 4.12 |
| Muzzle Jump Factor [rad/s] | 0.007 | 0.006 | 0.011 | 0.012 |

As shown in Fig. 8, it can be observed that for all velocities analysed in the paper during the bullets flight (1 ±3 Mach), the curves coincide each other. An average drag coefficient, calculated for the corresponding velocities, is the lowest for 6.8 mm SP equaling 0.261, and the highest for 6.8 mm JTP, reaching 0.269. These values are relatively low and they can be compared to the experimental value of 0.283 of a steel core projectile in 5.56 × 45 mm RS cartridge, which is very promising in terms of external ballistic performance [7].

Understandably, the heaviest projectile is characterised by the highest sectional density, therefore increasing its ballistic coefficient.

The 6.8 mm TP projectile, weighting 9.25 g has a SD equal to 0.255 and BC at 0.628, while the sectional density of the lightest projectile, 6.8 mm LTP, is equal to 0.189, and its BC equals 0.466. However, as mentioned before, the growth in weight of the projectile affects other vital aspects of its overall performance, which will be stated followingly. Ballistic coefficients of the 6.8 mm SP and 6.8 mm JTP are almost equal, with a difference of 0.002, which will most probably lead to matching trajectories of those projectiles.

In order to achieve satisfactory external ballistics performance, designed rounds need stabilisation. Since the projectiles are statically unstable, they require gyroscopic stability achieved by the rotary movement. It is measured with a factor, which is a ratio between the rigidity of a spinning mass of the projectile, and the overturning torque applied to the centre of pressure. The projectile is stable if its gyroscopic stability factor (GF) is higher than 1.1, however, to maintain a safety margin for uncertainties of the muzzle velocity, mass distribution of a bullet and atmospheric conditions, required GF should be over 1.5 [8]. As shown in Table 3, all analysed projectiles are characterised by the required gyroscopic factor, while the smallest muzzle jump is achieved while using 6.8 mm JTP.

To compare external ballistic performance of all designed projectiles, three simulations of point-blank shooting (for 0.5 m target height) were performed for each projectile, with the following initial conditions:

- muzzle velocity: 850 m/s, 900 m/s, 950 m/s;
- barrel length: 406 mm;
- barrel twist: 178 mm, 6 grooves;
- standard meteorological data used in PRODAS V3.5 software (pressure: 1013.2 hPa, temperature: 15°C, air density: 1.225 kg/m$^3$, speed of sound: 340.2 m/s).

The calculated trajectories are shown in Figs. 9-11 below.

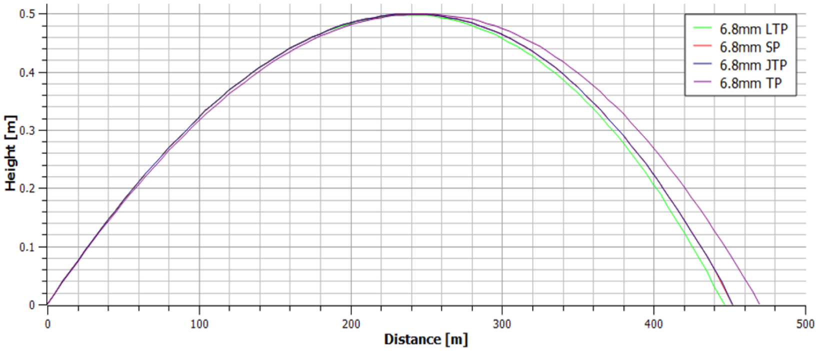

Fig. 9. Trajectories of the projectiles at $v_0 = 850$ m/s

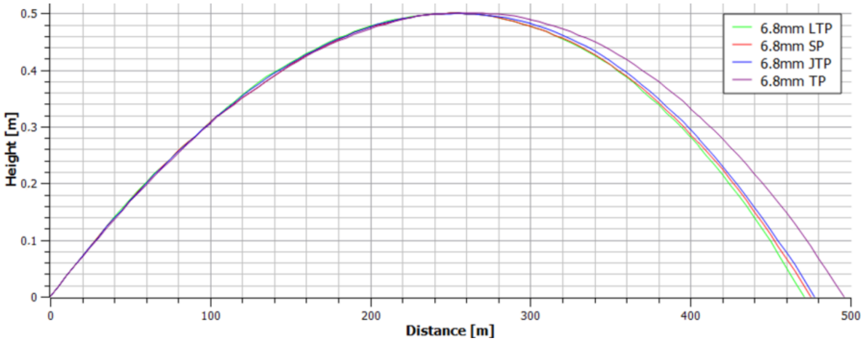

Fig. 10. Trajectories of the projectiles at $v_0 = 900$ m/s

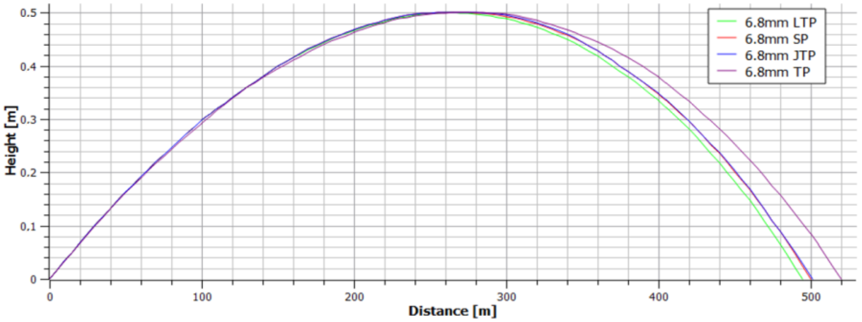

Fig. 11. Trajectories of the projectiles at $v_0 = 950$ m/s

It can be concluded that the 6.8 mm TP projectile is characterised by the ‘flattest’ trajectory, while the 6.8 mm LTP has the lowest point-blank range for all assumed muzzle velocities, however, the differences do not exceed 5%. Moreover, due to the highest gas pressure limit, in real shooting the 6.8 mm TP projectile is supposed to achieve lower muzzle velocity, therefore its trajectory would be recalculated and should be compared with the rest of the projectiles fired with the higher $v_0$.

As anticipated, due to almost equal BCs, SP and JTP projectiles trajectories are matching perfectly for 850 m/s and 950 m/s, and they are strongly coinciding for the 900 m/s muzzle velocity.

To estimate the drop of kinetic energy during the flight of the projectile, which is a vital aspect for its stopping power, the kinetic energy changes for all considered muzzle velocities were calculated. The results for a muzzle velocity of 900 m/s are presented in Fig. 12 below.

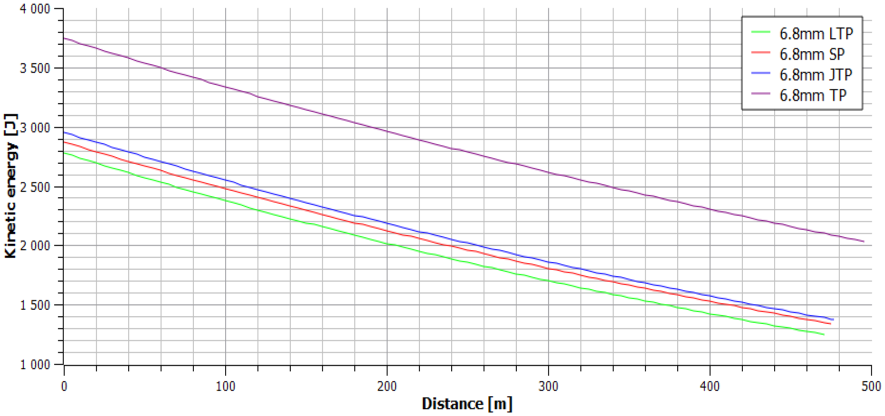

Fig. 12. Kinetic energy drop at $v_0 = 900$ m/s

The main conclusion from an analysis of a kinetic energy change of the projectiles during their flight is that the curves are shifted, the ratio of energy loss is equal for all analysed projectiles, therefore differences in the construction do not affect the rate of energy decrease during the flight. The character of kinetic energy changes in the projectiles is analogical for all analysed muzzle velocities. Summary of external ballistic performance of the designs for all three considered muzzle velocities is presented in Table 4.

Table 4. External ballistic parameters of the projectiles

| **Parameter** | **6.8 mm SP** | **6.8 mm JTP** | **6.8 mm TP** | **6.8 mm LTP** |
|---|---|---|---|---|
| **Results at $v_0 = 850$ m/s** | | | | |
| Point-blank range (m) | 452.2 | 452.3 | 469.8 | 447.0 |
| Muzzle energy (J) | 2561.3 | 2633.8 | 3340.5 | 2476.8 |
| Energy at 100 m (J) | 2198.1 | 2261.4 | 2964.4 | 2107.7 |
| Energy at 300 m (J) | 1587.4 | 1632.4 | 2308.5 | 1493.6 |
| **Results at $v_0 = 900$ m/s** | | | | |
| Point-blank range (m) | 475.1 | 477.1 | 495.6 | 471.1 |
| Muzzle energy (J) | 2871.5 | 2952.8 | 3745.0 | 2776.8 |
| Energy at 100 m (J) | 2475.4 | 2547.2 | 3334.5 | 2373.7 |
| Energy at 300 m (J) | 1806.6 | 1859.7 | 2616.6 | 1700.9 |
| **Results at $v_0 = 950$ m/s** | | | | |
| Point-blank range (m) | 500.9 | 501.3 | 520.8 | 494.7 |
| Muzzle energy (J) | 3199.4 | 3290.0 | 4172.7 | 3093.9 |
| Energy at 100 m (J) | 2769.6 | 2850.1 | 3727.1 | 2656.2 |
| Energy at 300 m (J) | 2040.6 | 2101.9 | 2944.1 | 1922.1 |

## 4.2. Terminal Ballistics assessment

In order to preliminarily assess the ability of the designed projectiles to penetrate a target, the kinetic energy required for penetration ($E_{\mathrm{kmin}}$) was calculated, using modified Jacob de Marre formula (2), assuming a direct hit at a right angle between the axis of a projectile and the plate [9].

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

where:

$C$ – constant dependent on the projectile type;

$s$ – thickness of the target; $s = 12$ mm;

$d$ – projectile diameter; $d = 6.8$ mm,

$n$ – constant dependent on the character of the projectile performance inside the target; $n = 1.3$.

As it was stated before, required characteristics of a modern armour-piercing projectile is to defeat a live target protected by a class IV body armour, at 100 m distance. Since the preliminary character of this assessment, a simplification of a class IV body armour by a 12 mm steel plate was made, therefore $s = 12$ mm.

Due to different constructions and diverse types of all designed projectiles, a constant dependent of the type of the projectile – '*C*', was calculated separately for each projectile by comparison of the performance of existing armour-piercing rounds, like the AP3 and M855A1. Character of the projectiles performance inside the target – constant 'n', was assumed equal for all projectiles, since the main armour-piercing factor in all constructions is a core of a relatively harder material. Table 5 presents terminal ballistics parameters of the designed projectiles.

Table 5. Terminal ballistics parameters

| **Projectile type** | **6.8 mm SP** | **6.8 mm JTP** | **6.8 mm TP** | **6.8 mm LTP** |
|---|---|---|---|---|
| Energy required ($E_{\mathrm{kmin}}$) (J) | 2194.59 | 2112.17 | 1914.67 | 1917.96 |
| $E_{\mathrm{kmin}}$ distance for $v_0 = 850$ m/s (m) | 100 | 140 | 440 | 160 |
| $E_{\mathrm{kmin}}$ distance for $v_0 = 900$ m/s (m) | 175 | 220 | >495 | 230 |
| $E_{\mathrm{kmin}}$ distance for $v_0 = 950$ m/s (m) | 250 | 295 | >520 | 305 |

Analysing the results of penetration abilities, firstly, it can be concluded that understandably, with each muzzle velocity the heaviest projectile, 6.8 mm TP, is able to fully penetrate the target at the greatest distances, reaching over the point-blank range for both 900 m/s and 950 m/s.

The weakest terminal ballistic performance is achieved with the steel penetrator utilised in 6.8 mm SP, while the performances of 6.8 mm JTP and 6.8 mm LTP are reasonably similar, with the $E_{\mathrm{kmin}}$ distance varying just around 10 meters in favour of 6.8 mm LTP, depending on the muzzle velocity. What is more, penetration capabilities for the LTP projectile are expected to be even higher when compared to the JTP, due to higher kinetic energy density on the contact surface.

## 4.3. Internal Ballistics assessment

The main area of consideration, after obtaining the results of external and terminal ballistics, is to analyse if assumed initial conditions are achievable. Basic calculations of internal ballistics parameters were performed, to preliminarily assess if achieving assumed muzzle velocities is possible without increasing the peak chamber pressure excessively.

Interior Ballistics Simulation was performed in PRODAS V3.5 software, using the empirical method, thus implementing proposed values concerning the propellant and gun system from the system reference books. The achieved results indicate, that to achieve $v_0 = 900$ m/s, for a 6.8 mm SP (7.09 g) projectile, the maximum chamber pressure would reach 493 MPa, while for a 6.8 mm JTP projectile (7.29 g) the pressure value would exceed 540 MPa, which is a value exceeding the strength of commonly known rifle barrels, that would significantly reduce its life and increase the whole gun system weight. Moreover, theoretically, reaching that muzzle velocity while utilising a 9.25 g projectile (6.8 mm TP), would exceed 600 MPa, therefore it would be impossible to withstand by a rifle barrel.

Abovementioned brief aspects indicate the need of thorough weight consideration while designing a perspective intermediate projectile. It seems reasonable to maintain the projectile weight below 7.5 g. Moreover, to achieve muzzle velocities of over 900 m/s, while keeping an acceptable weight of the whole gun system, a projectile weighting less than 7 g is desirable.

# 5. CONCLUSIONS

In order to keep up with a constant and dynamic development of a modern individual body armour used in infantry battles, the need to improve armour-piercing abilities of intermediate cartridges is inevitable. A perspective round should utilise 6.8 mm diameter projectile, consisting of an armour-piercing element of a higher density, preferably tungsten. However, while using a tungsten core in a 6.8 mm diameter projectile, the overall weight of bullet increases rapidly, therefore a perspective design should be a compromise between the attempts to keep the highest weight of armour-piercing element while maintaining achievable muzzle velocity.

The obtained results indicate, that the external ballistics performance of 6.8 mm SP and 6.8 mm JTP projectiles is almost equal, while achieving respectively around 452, 475, and 501 meters of a point-blank range for 850, 900, and 950 m/s muzzle velocity. Slightly lower range would be achieved with a lighter 6.8 mm LTP projectile, while the heaviest, 6.8 mm TP bullet would exceed even 520 m of a point-blank range while shot with 950 m/s muzzle velocity. However, the range difference between 6.8 mm TP and 6.8 mm LTP equals 5.1% for $v_0 = 850$ m/s and $v_0 = 950$ m/s, and just 5% for $v_0 = 900$ m/s, while the difference in their weight reaches over 34%. Moreover, preliminarily assessed internal ballistics parameters show that the increase in a peak chamber pressure to achieve a 900 m/s of a muzzle velocity for the heaviest projectile, would exceed the strength of a rifle barrel.

Terminal ballistics evaluation indicated that a 6.8 mm TP projectile would be characterised by the highest armour-piercing abilities, completely outperforming the remaining designs. However, analysing the rest of projectiles, the highest penetration would be achieved with the use of 6.8 mm LTP, even though it is the lightest construction, which is a very valuable conclusion, due to the limitations concerning internal ballistics mentioned above. Supposing a muzzle velocity of 850 m/s, complete penetration of a specified target at 100 m would be achieved by all analysed projectiles, whereas with muzzle velocities of 900 m/s and 950 m/s the maximum distance would reach respectfully over 230 and 305 meters, using the lightest, 6.8 mm LTP projectile.

Considering the abovementioned differences, due to insignificant differences of point-blank range and satisfying terminal ballistics performance of the designed projectiles, a reasonable choice of the perspective projectile to maintain the chamber pressure at an acceptable level, would be a projectile of weight below 7 g. Therefore, a construction similar to the designed 6.8 mm Light Tungsten Penetrator projectile was chosen as the most perspective. 6.8 mm LTP could provide the infantry with the possibility of defeating the targets protected by a class IV individual armour, from the distances of over 200 and 300 meters, depending on the achieved muzzle velocity.

An important aspect of the presented designs is the environmental impact of the perspective ammunition. Due to the directives contained in regulations of the European Commission on the use of lead in ammunition, it is required to use a toxic-free projectile in the new cartridge. Therefore, however, currently tungsten is considered as a toxicologically relatively safe, the aspect of its effect on the environment should be furtherly analysed [10].

With the aim to design the best performing projectile, further analysis should focus on modifying its external shape and evaluating the external ballistics phenomena while using more sophisticated tools. An analysis of the weapon recoil is desirable, as well as a deeper consideration into a practical ability to produce the presented designs.

Furthermore, due to the main aim of the new design, thorough evaluation of terminal ballistics is necessary, with different attempts on the construction of the penetrator.

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# Perspektywiczny przeciwpancerny pocisk naboju pośredniego

Krzysztof PIASTA, Przemysław KUPIDURA

*Wojskowa Akademia Techniczna*
*ul. gen. Sylwestra Kaliskiego 2, 00-908 Warszawa*

**Streszczenie.** Trwającym konfliktom zbrojnym towarzyszy ciągła ewolucja środków ochrony indywidualnej, takich jak kamizelki kuloodporne. Nowoczesne płyty balistyczne, sklasyfikowane według normy NIJ 0101.04 na poziomie III i IV, powszechnie stosowane przez żołnierzy piechoty w kamizelkach typu „plate carrier" są w stanie bezpiecznie wytrzymać bezpośrednie trafienie z większości rodzajów broni strzeleckiej używanej na współczesnym polu walki, nie wykluczając trafionego żołnierza z walki. W artykule dokonano zwięzłego przeglądu istniejących nabojów pośrednich z pociskami przeciwpancernymi oraz porównano pociski analizowanych nabojów w zakresie ich konstrukcji. W zakresie balistyki zewnętrznej używając oprogramowania PRODAS przeprowadzono symulacje strzału bezwzględnego dla trzech różnych prędkości początkowych pocisków, sprawdzono stabilizację pocisków i wyznaczono pozostałe charakterystyki. W zakresie balistyki końcowej porównano zdolność przebicia płyty stalowej poprzez obliczenia analityczne, następnie przy wykorzystaniu modułu balistyki wewnętrznej programu PRODAS, wstępnie określono parametry ciśnienia maksymalnego w przestrzeni zapociskowej. Autorzy określili najbardziej perspektywiczną konstrukcję nowego pocisku przeciwpancernego do naboju pośredniego, przy czym stwierdzono jakie powinno być dalsze postępowanie, analizy i obliczenia, zwłaszcza w zakresie balistyki końcowej, mające na celu szczegółowe opracowanie konstrukcji perspektywicznego pocisku.

**Słowa kluczowe:** inżynieria mechaniczna, naboje przeciwpancerne, broń strzelecka, balistyka, pocisk