PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

ISSN 2081-5891

12, 3(45), 2021, 97-110

PROBLEMS OF MECHATRONICS
ARMAMENT, AVIATION, SAFETY ENGINEERING

Comparative Analysis of the Trajectories of Projectiles Fired from Polish Small Arms Systems: MSBS-5.56 and BERYL

Łukasz SZMIT*, Mirosław ZAHOR

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:
lukasz.szmit@wat.edu.pl; https://orcid.org/0000-0001-5243-2903

Received: November 4, 2020 / Revised: January 26, 2021 / Accepted: March 6, 2021 / Published: September 30, 2021

DOI 10.5604/01.3001.0015.2430

Abstract. This paper presents the results of the theoretical external ballistic calculations for projectiles fired from barrels which correspond to the barrels used in two Polish small arms systems: MSBS-5.56 system (MSBS GROT standard rifle and MSBS GROT carbine) and BERYL system (BERYL standard rifle and MINI BERYL carbine). The results obtained allowed the analyse of the effects of barrel length and the associated initial projectile velocity on the nature of projectile trajectory, particularly the over height and projectile range obtained along the trajectories. The analysis of the results facilitated an assessment of the scope of proposed changes in the settings of the firearm sights, resulting from the use of barrels of different lengths and the consequential changes in projectile trajectory.
Keywords: mechanical engineering, ammunition, ballistics, firearms, assault rifle

1. INTRODUCTION

The subject of this analysis were the trajectories of projectiles fired from small arms systems: MSBS-5.56 system (MSBS GROT standard rifle and MSBS GROT carbine) and from BERYL system (BERYL standard rifle and he MINI BERYL carbine), as used by the Polish Armed Forces. Among other differences, the rifles vary in the length of the barrel and the design of the iron sights. It is also likely that further versions of the MSBS GROT rifle, which vary in barrel length from the standard carbine, will enter military service. These conditions prompted an analysis of the trajectories of projectiles fired from barrels of different lengths. A detailed analysis of this problem would facilitate an indication of the optimum solutions in the discipline of the iron sights used for firearms, especially the settings of sights, and to evaluate whether the optoelectronic sights designed for the BERYL rifle will require modification of the reticle to achieve compatibility of the sights with the GROT rifle system.

External ballistic calculations [1, 2], relevant to the characteristics of the trajectories of projectiles fired from the analysed firearm types, were performed with the PRODAS 3.5 software from Arrow Tech. The aerodynamic model of the 5.56 mm calibre SS-109 projectile was developed from its physical model [3]. The locations of the projectile's centre of gravity, CG and centre of pressure, CP and the aerodynamic characteristics of the projectile were then determined. These inputs facilitated stabilisation analyses to be performed for the projectile and ballistic curves to be plotted for the examined barrel lengths and sight settings [4]. The initial velocities of the SS-109 projectile corresponding to the tested barrel lengths were assumed from the specifications of the respective firearm manufacturers. They also show that the initial velocities of the RS projectile (manufactured by MESKO S.A., Poland), which is the domestic equivalent of the SS-109 projectile, were comparable.

2. ANALYSIS OF THE TRAJECTORIES OF PROJECTILES FIRED FROM THE BERYL RIFLE AND MINI BERYL CARBINE

The BERYL standard rifle has an 18 inch (0.457 m) long barrel, which provides the RS projectile (manufactured by MESKO S.A.) with an initial velocity of V_0 = 920 m/s. The carbine is provided with open iron sights, comprising a fixed foresight (Photo 1), and a rear sight notch on a sliding tangent (Photo 2). The rear sight element consists of a base, a spring, a sliding tangent, and a slider. The sight base has two cams to set the elevation of the sliding tangent.

On the sliding tangent is a scale with graduations from “1” to “10” and the letter “S”; the graduation mark digits indicate the firing distances in hundreds of metres while the “S” indicates a fixed sight setting corresponding to graduation mark “4”.

According to the manufacturer’s specifications provided, the maximum point-blank range to a “Torso Silhouette” target is 350 m [5]. The rifle’s line of sight is 0.048 m above the axis of the barrel bore.

Photo 1. Foresight of the BERYL rifle

Photo 2. Open iron sight of the BERYL rifle

The sight allows precise adjustment over a very wide range; however, given the way the rifle is zeroed, which if necessitated by the dimensions of the standard zeroing target (Fig. 1), then the sight settings do not coincide with the distances to which they are assigned.

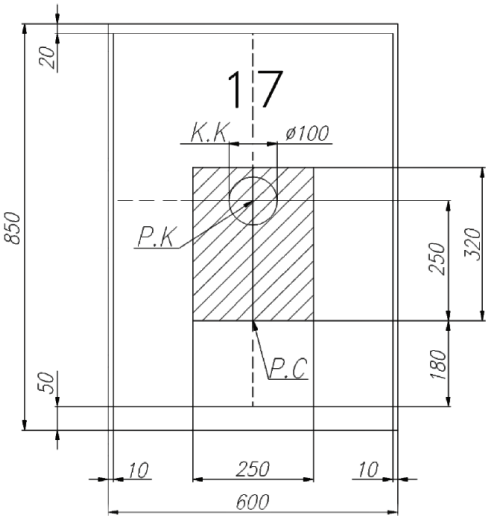

Fig. 1. Rifle zeroing target: PK – strike point; PC – point of aim; K.K – circle of 5 cm radius [5]

According to the information contained in the operating manual, the BERYL rifle is zeroed in a way that with the sight set to "4", the trajectory of the projectile reaches 0.25 m of overheight above the line of sight 100 m from the barrel muzzle. A trajectory like this, plotted in PRODAS, is shown in Fig. 2.

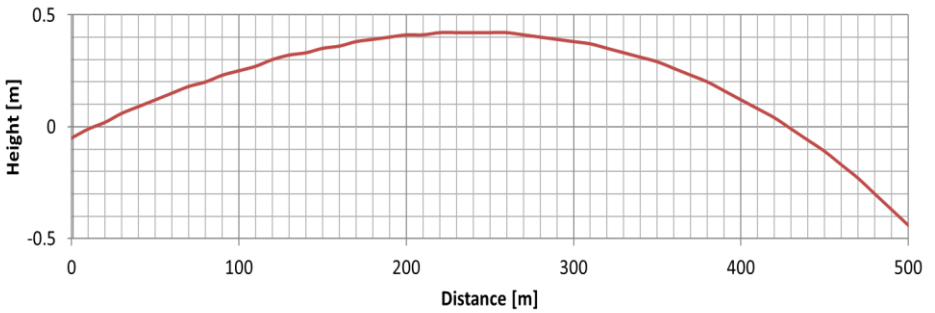

Fig. 2. Trajectory of a projectile fired from a BERYL rifle with the sight set to "4"

It is easy to see that with this zeroing of the rifle, the sight setting "4" does not correspond to a range of 400 m but to a range of approximately 428 m. The peak of the trajectory in this case was 0.42 m and did not exceed 0.5 m. Therefore, this sight setting corresponds to the maximum point-blank range [5], which, in contrary to what the operating manual of the rifle, is approximately 450 m. A consequence of this zeroing method of the firearm is that other sight settings do not match the suggested distances.

The operating manual specifies that "(...) the rifle is most effective at a firing distance of up to 400 m". The sight setting "4" is therefore the universal setting for combat firing.

A projectile fired from the BERYL rifle with velocity V_o = 920 m/s maintains supersonic speed up to a range of 740 m. Due to the phenomena associated with the transition of the projectile to subsonic speeds, it should be considered that this is the maximum distance for which it is possible to maintain satisfactory accuracy of the weapon. Consequently, any sight setting above 700 m is unnecessary from a practical point of view. The highest sight setting in combat firing should also not be greater than the maximum point-blank range to a target 1.5 m high. In the case of the BERYL rifle sight, this would be setting "6". Therefore, two sight settings would be sufficient for the BERYL rifle; one for the maximum point-blank range to a 0.5 m target and the other for the maximum point-blank range to a 1.5 m target.

The MINI BERYL carbine has an 9,5 inch (0.235 m) long barrel, which provides the RS projectile (manufactured by MESKO S.A.) with an initial velocity of 770 m/s. The iron sight consists of a fixed foresight and a flip-up rear sight (Photo 3) with a aperture sight for daytime shooting (settings "0-3"), and a sight notch for night-time shooting (setting "N").

Photo 3. Rear sight of the MINI BERYL carbine

According to the specifications in the operating manual [6], the daytime sight setting corresponds to a distance of 300 m, and the night sight setting corresponds to 100 m. The firearm's operating manual states that "(...) the carbine is most effective at a firing distance of up to 400 m", the same as for the BERYL rifle. The carbines line of sight is 0.056 m above the axis of the barrel bore. The operating manual also specifies that the MINI BERYL carbine is zeroed fired in a way that with the sight set to daytime ("0-3"), the trajectory of the projectile reaches 0.25 m of overheight above the line of sight 100 m from the barrel muzzle. A trajectory like this, plotted in PRODAS, is shown in Fig. 3.

At any of the "0-3" settings, the projectile achieves a range of 340 m and a peak trajectory of 0.34 m. This does not coincide either with the operating manual specifications or with the maximum point-blank range to a target 0.5 m high, which in this case would be about 380 m. Furthermore, the operating manual does not specify the maximum point-blank range of this firearm.

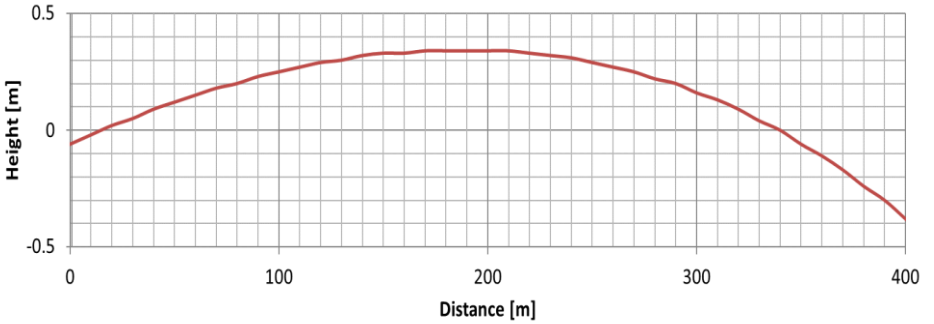

Fig. 3. Trajectory of a projectile fired from a MINI BERYL carbine with the sight set to "0-3"

A projectile fired from the MINI BERYL carbine maintains supersonic speed up to a distance of 570 m, while the peak trajectory exceeds 1.5 m at distances beyond 550 m. A potential additional setting of the iron sight should correspond to a range of 500 m; however, firing the carbine at this distance has never been planned.

3. ANALYSIS OF THE TRAJECTORIES OF PROJECTILES FIRED FROM MSBS-5.56 SYSTEM RIFLES

The MSBS-5.56 system rifle has a modular design that allows the configuration of an entire family of weapons based on a common receiver pattern. One of the basic modules of this firearm is the barrel module. The firearm system standard rifle has a barrel length of 0.406 m (16 inches), the carbine has a barrel length of 0.265 m (10.5 inches), and the sniper rifle and the light machine gun configurations have a 0.406 m or 0.508 m barrel (20 inches). There are 14.5 and 12 inch long barrels planned for implementation. The standard rifle should allow effective firing at distances of up to 500 m, while the carbine should provide effective firing at distances of up to 350 m.

So far, the Polish Armed Forces have adopted the standard rifle of the system, codename MSBS GROT, with a barrel length of 0.406 m, while work on the service implementation of a carbine with a barrel length of 0.265 m is nearing completion.

The standard length (0.406 m) of the barrel of the MSBS GROT rifle provides the RS projectile (manufactured by MESKO S.A.) with an initial velocity of 890 m/s. The standard rifle is provided with a iron sight on the mounting rail atop of the receiver (Fig. 4).

This is an aperture (closed) folding sight and intended as a backup for the primary sight (which is usually an optoelectronic sight). Given the temporary unavailability of optoelectronic sights, the standard aperture sight is the primary aiming device. The line of sight is 0.073 m above the axis of the barrel bore. The rear sight has a sight plate with two apertures: the main aperture – for precision shooting (including zeroing), and the enlarged aperture for firing at minimum distances. Note that the centres of the apertures used for sighting targets are not at a uniform distance from the axis of rotation of the target. This means that switching the sight from one aperture to the other resets the sight setting in an uncontrollable manner, which is not mentioned in the operating manual for this firearm. However, due to the very large diameter of the minimum-distance sight aperture, it is of no practical significance.

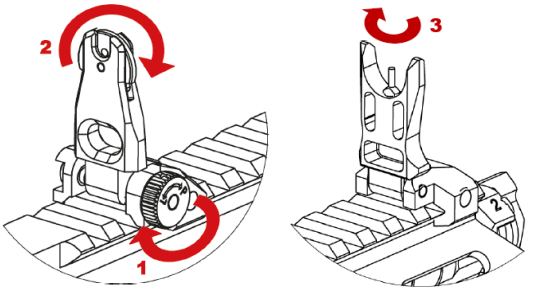

Fig. 4. Rear sight and foresight of the MSBS GROT rifle with the adjustment direction marks shown: 1 – Sight plate base adjustment; 2 – Sight plate aperture selection, 3 – front post height adjustment [7]

The rifle is zeroed with the precision firing setting of the sights and a standard zeroing target, not unlike for the BERYL rifle and the MINI BERYL carbine [7]. The trajectory of a projectile fired from the rifle, plotted in PRODAS, is shown in Fig. 5.

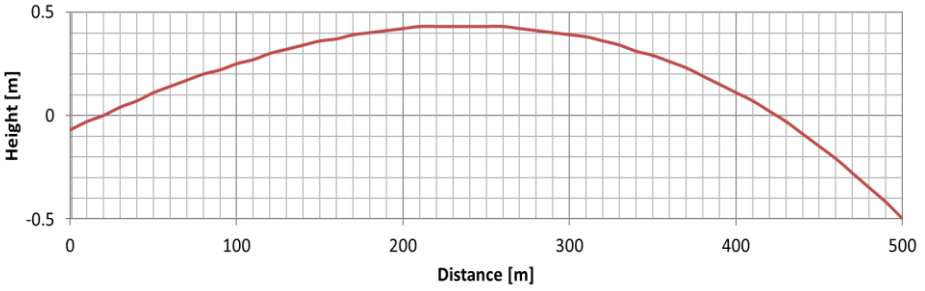

Fig. 5. Trajectory of a projectile fired from the 0.406 m long barrel MSBS GROT rifle

The projectile achieves a range of 425 m and a peak trajectory of 0.43 m. This sight setting therefore corresponds to the maximum point-blank range to a 0.5 m high target and is the universal setting for combat firing.

A projectile fired from the MSBS GROT rifle with a 0.406 m long barrel maintains supersonic speed at distances of up to 700 m, while the peak of the projectile trajectory exceeds 1.5 m at distances above 640 m. An additional setting of the iron sight should therefore correspond to a range of 600 m.

For the MSBS-5.56 system rifle with a barrel length of 0.508 m (the prototypes of the sniper rifle and the machine gun configurations), the initial velocity of the RS projectile (manufactured by MESKO S.A.) is 945 m/s. If rifles in these configurations receive the same sight and zeroing method, the projectile trajectory will match the graph shown in Fig. 6. Here the projectile achieves a range of 460 m and a peak trajectory of 0.47 m. This sight setting therefore corresponds to the maximum point-blank range to a 0.5 m high target and is the universal setting for combat firing.

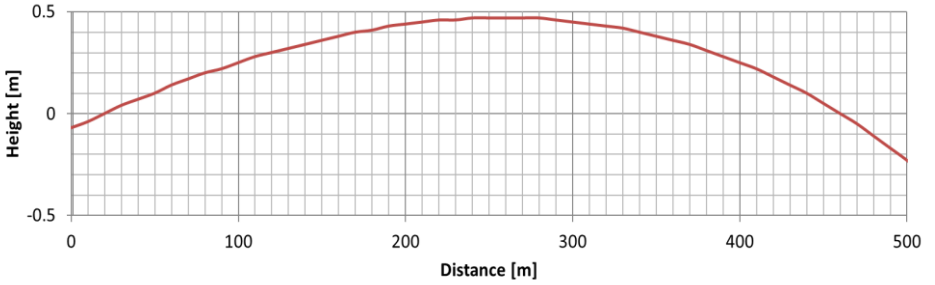

Fig. 6. Trajectory of a projectile fired from the 0.508 m long barrel MSBS GROT rifle

A projectile fired from the MSBS GROT rifle with a 0.508 m long barrel maintains supersonic speed at distances of up to 760 m, while the peak of the projectile trajectory exceeds 1.5 m at distances above 680 m. An additional setting of the iron sight should therefore correspond to a range of 700 m.

The MSBS GROT carbine has a 0.265 m long barrel, which provides the RS projectile (manufactured by MESKO S.A.) with an initial velocity of 790 m/s. If the carbine is provided with standard sights for this firearm system and zeroed with the standard method, the PRODAS-plotted trajectory of the projectile corresponds to the graph shown in Fig. 7. Here the projectile achieves a range of 360 m and a peak trajectory of 0.37 m.

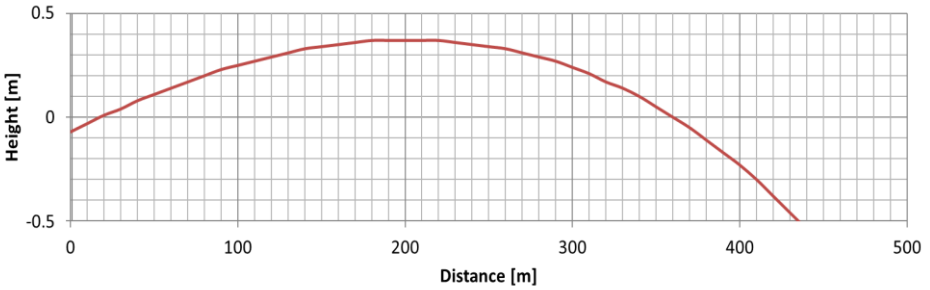

Fig. 7. Trajectory of a projectile fired from the 0.265 m long barrel MSBS GROT carbine

A projectile fired from the MSBS GROT carbine with a 0.265 m long barrel maintains supersonic speed at distances of up to 590 m, while the peak of the projectile trajectory exceeds 1.5 m at distances above 570 m. An additional setting of the iron sight should therefore correspond to a range of 550 m. Not unlike with the MINI BERYL carbine, this greatly exceeds the specification requirements for the firearm.

4. COMPARISON OF THE TRAJECTORIES OF PROJECTILES FIRED FROM BARRELS OF DIFFERENT LENGTHS

A comparison of the trajectories of projectiles fired from barrels of different lengths is shown in the form of graphs. Fig. 8 shows a comparison of the trajectories of projectiles fired from the BERYL rifle and the MSBS GROT rifle with barrels 0.406 m and 0.508 m long.

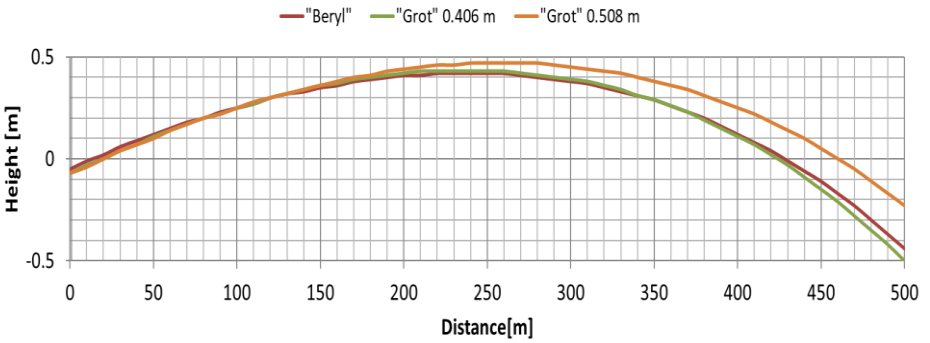

Fig. 8. Trajectories of projectiles fired from the BERYL rifle and the MSBS GROT rifle with 0.406 m and 0.508 m long barrels

Despite the difference in barrel lengths, and thus in the initial projectile velocities, the trajectories of the projectiles fired from the BERYL rifle and the MSBS GROT rifle with the 0.406 m barrel were similar.

This is due to the different height of the line of sight above the barrel bore axis between the two rifles. As a result, in order for the MSBS GROT rifle to achieve an overheight of 0.25 m at a distance of 100 m from the barrel muzzle, it was necessary to increase the barrel elevation angle. This made it possible to achieve a projectile trajectory almost identical to that of the BERYL rifle at distances of up to 420 m. In practice, this means that if the reticle of an optoelectronic sight does not feature sight marks for firing at distances greater than 400 m, it may be used interchangeably with the sights designed for both rifles in question.

For the MSBS GROT rifle with the 0.508 m long barrel, the projectile trajectory deviated from the others tested already at a distance of 200 m, with the deviation growing with the firing distance. This means that for a rifle with a barrel this long, it is necessary to modify the sight reticle dedicated to the BERYL rifle.

Figure 9 shows a comparison of the trajectories of projectiles fired from the MINI BERYL and MSBS GROT carbines. Due to the different initial velocities of the projectiles and the different designs of the sights for the two carbines, the projectile trajectories coincide only over the initial distance (up to 150 m from the barrel muzzle). This means that the sight reticle with marks for specific distances dedicated to the MINI BERYL carbine will require modification for adaptation to the MSBS GROT carbine. However, the differences are irrelevant for sights with a simpler, single reticle mark (like the HWS).

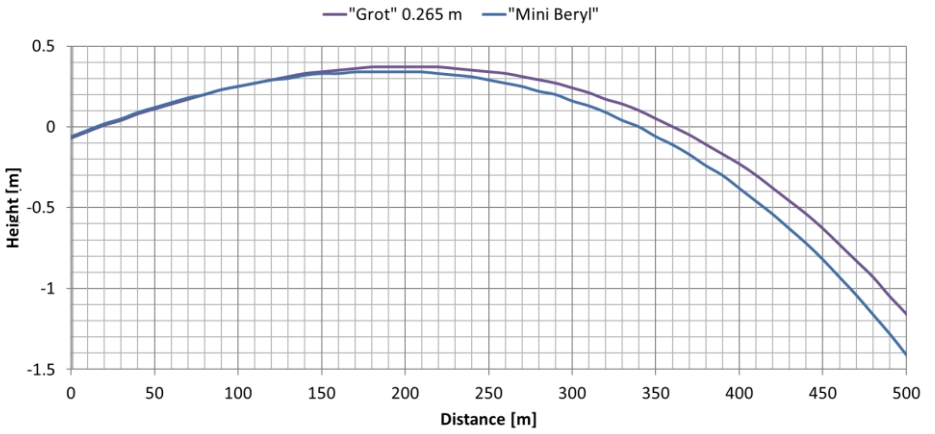

Fig. 9. Trajectories of projectiles fired from the MINI BERYL carbine and the MSBS GROT carbine with the 0.265 m long barrel

In comparing the trajectories of the projectiles fired from the BERYL rifle and the MINI BERYL carbine (Fig. 10), it can be seen that they coincide at distances of up to 150 m.

This means that a sight with the sighting marks assigned to the firing distances specific to the BERYL rifle will not be suitable for use with the MINI BERYL carbine without modifications to the sight reticle. This problem will not occur with simple single mark sights, which require zeroing at a single specific distance.

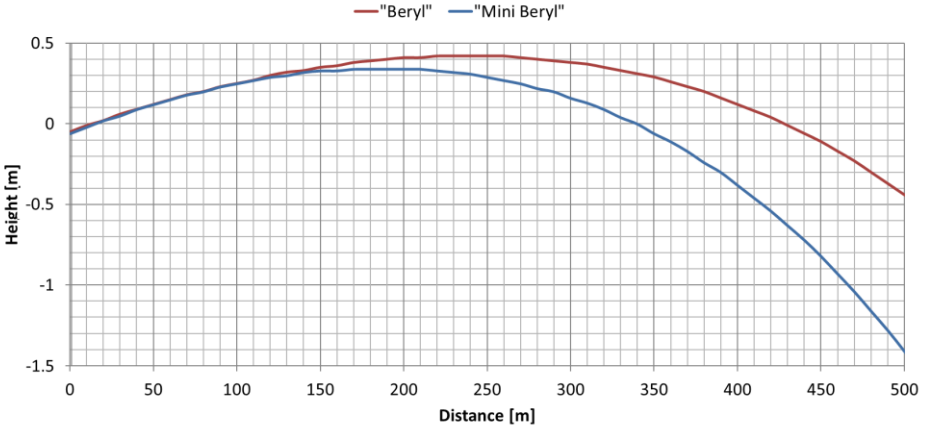

Fig. 10. Trajectories of projectiles fired from the BERYL rifle and the MINI BERYL carbine

A similar situation occurred for the MSBS GROT rifle and carbine with the 0.406 m and 0.265 m long barrels (Fig. 11). Here, the sight will require modification for use with a specific firearm.

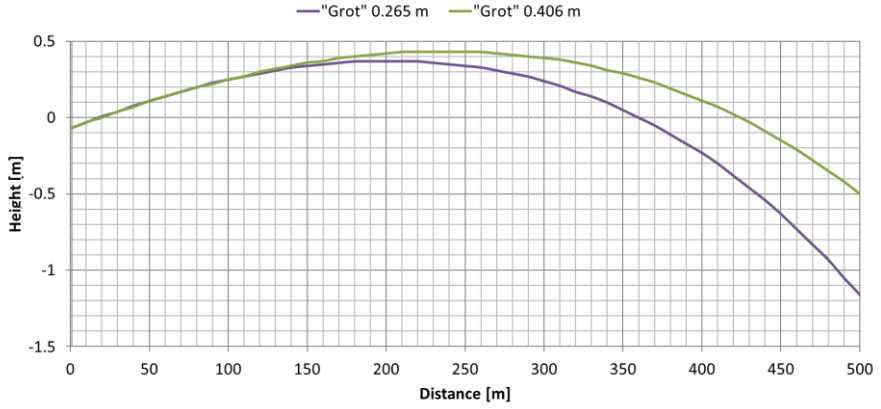

Fig. 11. Trajectories of projectiles fired from the MSBS GROT rifle and the MSBS GROT carbine with 0.265 m and 0.406 m long barrels

Some operators have expressed interest in a firearm configuration that features a 0.368 m (14.5 inch) long barrel. A comparison of the PRODAS-plotted trajectories of projectiles fired from the MSBS GROT rifles with 0.368 m and 0.406 m long barrels is shown in Fig. 12.

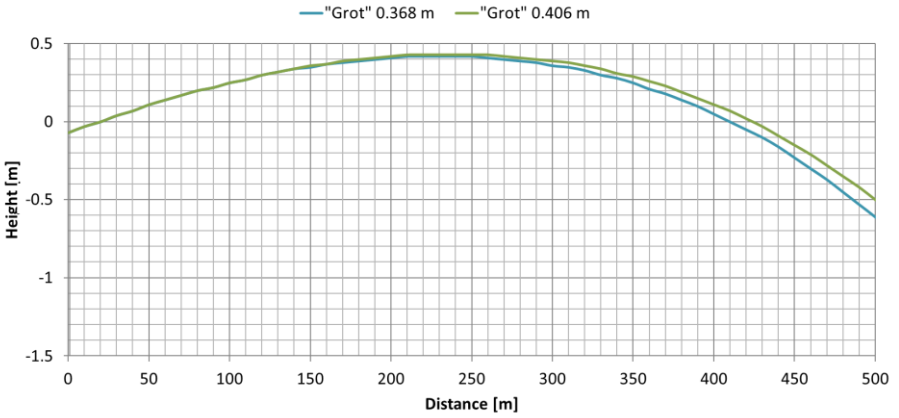

Fig. 12. Trajectories of projectiles fired from the MSBS GROT rifle and the MSBS GROT short rifle with 0.368 m and 0.406 m long barrels

The projectile trajectories coincide at distances of up to 300 m, but at longer distances the divergence becomes pronounced, reaching approximately 0.1 m at 500 m. In practical terms, this will need to be taken into account in the design of the sight reticle. When using a special-design sight with a complex sight reticle and sighting marks assigned for specific firing distances, it is recommended to use reticles set up for specific barrel lengths. It is unnecessary for simple single mark sights.

5. CONCLUSIONS

The results obtained through simulations allow the conclusion that the iron sight of a modern rifle fed with 5.56 × 45 mm cartridges does not require more than two settings. One sight setting would be for combat firing at an maximum point-blank range to a 0.5 m high target and another sight setting would be for shooting at a distance corresponding to the distance at which the projectile maintains supersonic speed. Note that given the development of optoelectronic sights and the backup nature of iron sights, the other setting is obsolete.

For optical or optoelectronic sights with complex sight reticles which feature sighting marks for specific distances, the differences in trajectories necessitate modification for adaptation to specific firearm configurations.

Only for the BERYL rifle and the MSBS GROT rifle with the 0.406 m long barrel are the trajectory differences so small that, assuming firing at a distance below 450 m, modifications are not necessary.

Optical and optoelectronic sights with simple sight marks which correspond to the zeroing distance will work equally well on any rifle, regardless of the barrel length, with the only limitations being the zeroing method and ballistics (the projectile trajectory specific to a particular barrel length).

A barrel shorter than 0.406 m is sufficient to achieve the required effective firing range of 500 m for the standard rifle. Thus, the BERYL standard rifle has an unnecessarily long barrel and excessively complex iron sight, which is difficult to use at distances above 500 m. On the other hand, a barrel much shorter than in the MSBS GROT standard rifle will reduce the initial velocity of the projectile to a level which will negatively affect the penetrating capabilities of the projectile, especially when using special ammunition; it will also make hitting the target more difficult through a higher sensitivity of the projectile to side wind gusts and a steeper trajectory [2]. Despite the fact that the MSBS GROT standard rifle and the carbine configuration differ significantly in barrel length, their accuracy at a distance of 100 m is comparable. At longer distances a standard rifle will obviously be more effective, especially when used by a less well-trained operator.

A compromise seems to be the reduction of the barrel length to approximately 0.35 m, which on one hand significantly improves the manoeuvrability of the weapon, while on the other hand does not significantly reduce the projectile velocity and thus its striking effectiveness.

FUNDING

The paper contains the results of the R&D Project No. O ROB 0034 03 001 financed by the Polish National Centre of Research and Development (2014-2020).

REFERENCES

[1] Szapiro J. 1956. *Balistyka zewnętrzna*. Warszawa: Wydawnictwo Ministerstwa Obrony Narodowej.
[2] Gacek Józef. 1997-1998. *Balistyka zewnętrzna. Cz. I. i II*. Warszawa: Wydawnictwo Wojskowej Akademii Technicznej.
[3] PRODAS V3 Documentation.
[4] *Teoria strzału*. 1970. Warszawa: Wydawnictwo MON.
[5] *5,56 mm karabin szturmowy wz. 96 „Beryl”. Instrukcja obsługi i użytkowania Nr 1/2009*. 2009. Radom: Fabryka Broni Łucznik – Radom Sp. z o.o.

[6] *5,56 mm karabinek wz. 96 „Mini Beryl". Instrukcja obsługi i użytkowania Nr 1/2009*. 2009. Radom: Fabryka Broni Łucznik – Radom Sp. z o.o.
[7] *Instrukcja użytkowania 5,56 mm karabinka standardowego (podstawowego)*. 2017. Radom: Fabryka Broni Łucznik – Radom Sp. z o.o.

Analiza porównawcza torów pocisków wystrzelonych z karabinków systemu MSBS-5,56 i wz. 1996

Łukasz SZMIT, Mirosław ZAHOR

Wojskowa Akademia Techniczna,
Wydział Mechatroniki, Uzbrojenia i Lotnictwa, Instytut Techniki Uzbrojenia
ul. gen. Sylwestra kaliskiego 2, 00-908 Warszawa

Streszczenie. W pracy przedstawiono wyniki obliczeń teoretycznych z obszaru balistyki zewnętrznej pocisków wystrzelonych z luf o długościach odpowiadających lufom zastosowanym w karabinkach rodziny MSBS-5,56 (karabinek standardowy MSBS GROT i subkarabinek MSBS GROT) oraz wz. 1996 (karabinek standardowy BERYL i subkarabinek MINI BERYL). Uzyskane wyniki pozwoliły dokonać analizy wpływu długości lufy i związanej z nią prędkości początkowej pocisku na charakter toru pocisku, a zwłaszcza uzyskane na torze przewyższenia oraz donośność pocisków. Analiza wyników pozwoliła również ocenić zakres proponowanych zmian w nastawach przyrządów celowniczych broni, wynikających z zastosowania luf o różnych długościach i wynikających z tego zmian torów pocisku.
Słowa kluczowe: mechanika, amunicja, balistyka, broń strzelecka, karabinek