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Original Research

PROJECTILE SEATING DEPTH INFLUENCE ON A SMALL ARMS CARTRIDGE PERFORMANCE

WPŁYW GŁĘBOKOŚCI OSADZENIA POCISKU NA CHARAKTERYSTYKI BALISTYCZNE NABOJU BRONI STRZELECKIEJ

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Abstract

In the world of small-arms ammunition, precision reigns supreme. The most significant feature of ammunition for shooters is undoubtedly the repeatability from one shot to the next. This study explores the detailed assembly process of small arms cartridges, leveraging modern machinery and innovative designs employed by cartridge manufacturers. It emphasizes how these tools ensure the fundamental repeatability and precision necessary for the quality of each batch of rounds. Establishing standards for the highest possible quality requires assessing the impact of imprecise cartridge assembly on ballistic performance.

Utilizing a free-flight ballistic tunnel, a high-speed camera, light- and target-screen systems, the authors analyzed the effects of varying projectile seating depths thus affecting cartridge overall lengths (COAL) and cartridge base to ogive distance (CBTO) on the initial velocity and shot dispersion at 50 meters. The study was conducted for two types of projectiles, differing in their ogive profiles: secant and tangent ogive. The performance differences between these profiles provided valuable insights for future projectile designs, highlighting that low-drag projectiles are slightly more sensitive to the seating depth than tangent profile bullets, and the importance of it should be considered in mass, military production as well. It is a valuable resource for analyzing the trade-off between producing bullets with a low drag coefficient and ensuring high precision. The research enhances the understanding of internal and external ballistics but most importantly draws attention to the importance of the standards of assembly processes to ensure optimal performance and safety in the field.

Keywords: mechanical engineering, ballistics, ammunition design, cartridge assembly, projectile

Streszczenie

Zapewnienie powtarzalności między kolejnymi strzałami jest niewątpliwie najistotniejszą cechą nabojów dla każdego strzelca. Autorzy poddali analizie proces montażu nabojów do broni strzeleckiej, wykorzystujący nowoczesne maszyny i innowacyjne rozwiązania konstrukcyjne stosowane przez światowych producentów amunicji. Biorąc pod uwagę jakość wykonanej amunicji, te narzędzia są wykorzystywane do zapewnienia jak największej dokładności i powtarzalności, które są fundamentalne w kwestii kontroli jakości partii nabojów. W celu wypracowania odpowiedniego standardu zapewniającego wymaganą jakość amunicji, istotne jest oszacowanie wpływu nieprecyzyjnego montażu nabojów na ich charakterystyki balistyczne.

Przeprowadzając badania w tunelu balistycznym z wykorzystaniem kamery szybkiej oraz bramek prędkościowych i współrzędnościowych, przeanalizowano wpływ zmiennej głębokości osadzenia pocisku, a więc również całkowitej długości nabojów (COAL) oraz odległości od dna łuski do części ostrołukowej (CBTO) na prędkość wylotową rozrzut pocisków na odległości 50 metrów. Analizy przeprowadzono dla różnych typów pocisków, różniących się kształtem części ostrołukowej. Wpływ różnic w ich konstrukcji na charakterystyki balistyczne jest istotny pod względem przyszłościowych nabojów, ponieważ pociski o mniejszym współczynniku oporu czołowego – większym promieniu profilu części ostrołukowej, są wrażliwsze na głębokość osadzenia, niż pociski o profilu ostrołuku stycznym do części cylindrycznej, które charakteryzują się większym współczynnikiem oporu czołowego. Analizowane różnice okazują się istotne również w masowej produkcji amunicji wojskowej. Wyniki stanowią cenne źródło informacji w poszukiwaniu kompromisu między produkcją pocisków o niskim współczynniku oporu aerodynamicznego, a zapewnieniem wysokiej precyzji. Praca pogłębia zrozumienie balistyki wewnętrznej i zewnętrznej, ale przede wszystkim zwraca uwagę na znaczenie jakości procesu montażu amunicji w kwestii zapewnienia optymalnej skuteczności zastosowania i bezpieczeństwa na polu walki.

Słowa kluczowe: inżynieria mechaniczna, balistyka, amunicja, montaż nabojów pośrednich, pocisk

1. Introduction

In the domain of small-arms ammunition manufacturing and elements production, precision plays a key role. Consideration of the geometric restrictions and accurate dimensions was a subject of various analyses and is thoroughly understood in the long-range shooting community. However, the aspect of precision with which a bullet is seated into its cartridge case is still of utmost importance, specifically in case of military use, where the ammunition is produced and assembled on a mass scale. Especially in the case of long-range precision shooting, the small differences in the performance of cartridges in an ammunition batch play a vital role.

The process of bullet seating is influenced by several factors, including the design of the cartridge elements itself. Small-arms cartridges are manufactured in a variety of designs, from the widely used centerfire and rimfire cartridges to specialized configurations like ammunition with semi-jacketed, boattailed projectiles and hybrid steel-brass cases. Each design presents its own set of challenges in achieving consistent dimensions due to differences in the mechanical interaction between the bullet, case, and seating machinery (Frost, 1990).

The main parameters used for specifying how deep the bullet should be placed inside the cartridge case, are the cartridge's overall length (COAL) and cartridge base to ogive distance (CBTO). COAL is the distance between the base of the cartridge case and the bullet's tip – méplat. On the other hand, CBTO is the distance between the cartridge case base to the point where the bullet's ogive starts (Fig. 1). CBTO is specifically a critical measurement directly related to the precision of the cartridge. It can be used to characterize the distance that a bullet moves when fired, before its surface engages the barrel rifling.

Considering the projectile's geometry, the most difficult part to manufacture repetitively is its méplat. Moreover, it is problematic to measure the diameter of a méplat, therefore the biggest differences in a batch of cartridges can be noticed in the COAL measurements, which correspond not only to the seating depth, but to the differences in projectile geometry as well. This aspect indicates that to accurately estimate the seating depth influence on ballistic performance, it is necessary to measure the CBTO instead of COAL when sorting the cartridges, to avoid variances in the projectile lengths itself.

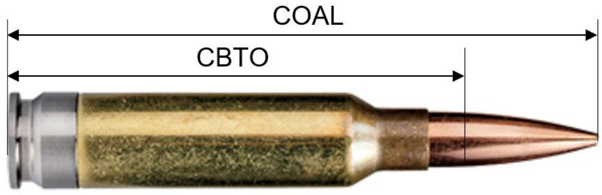

Fig. 1. COAL and CBTO of a small arms cartridge

In terms of ballistic performance, it is established that the bigger COAL/CBTO, the more volume inside the case, and therefore more propellant can be used, which provides higher muzzle velocity at lower pressures. Nevertheless, there are some restrictions in the maximum COAL, which are specifically important in the military solutions:

- bolt carrier group travel length – the maximum length of a cartridge is constrained by the distance that the bolt carrier group travels after each shot to extract the spent cartridge case from the chamber. If a cartridge exceeds this maximum COAL, it may interfere with the proper cycling of the weapon, potentially leading to failures in extracting and ejecting spent casings,
- magazine length – when considering a weapon system with magazine feeding, the maximum COAL will be restricted by the length of the magazine utilized. Assembling longer cartridges may cause malfunctions or even inability to use the rounds. In the case of different feeding methods, that issue is not a concern,
- elevated pressure – long cartridge assembly with a bullet positioned in direct contact with the barrel rifling while chambered, results in heightened resistance opposing the initial bullets movement. This leads to immediate opposition to the bullet's forward motion upon ignition due to the engraving force, thereby elevating chamber pressures to potentially hazardous levels. Seating the projectile a slight distance away (often referred to as a *bullet jump*) from the lands effectively mitigates this concern.

Due to the abovementioned, for user safety, the maximum COALs for each cartridge type are specified in the SAAMI and C.I.P regulations (CIP, 2024; SAAMI, 2015), as well as in separate military standards for military ammunition, for instance the 5.56x45 M193 (U.S. DoD, 1999).

Different ogive designs exhibit varying sensitivities to seating depth. Low-drag secant ogive projectiles, which offer the lowest drag coefficient and thus improved external performance, are considered more sensitive to seating depth than tangent ogive projectiles. A smooth juncture with the bearing surface facilitates self-alignment with the bore rifling, whereas an abrupt connection with the bearing surface leads to poor alignment with the rifling, and thus, greater sensitivity to seating depth. The combination of the aforementioned characteristics is found in hybrid ogives, where the bullet's nose profile is tangent up to the point of contact with the rifling and secant forward of that point.

Prior investigations (Thamna, 2018) have highlighted the importance of achieving uniform performance of cartridges, by improving the inspection process using an automatic visual inspection system to control the dimensions of each cartridge after assembly. The explained system provided an imperfections detection rate of 86.7% with a rate of 2 cartridges per second. Scientists (Li, 2022) utilized image processing to improve the assembly quality of the cartridge primer, which is a key part of the safety and reliability of ammunition. The general qualitative assessment of the influence of different COAL and CBTO in cartridge assembly was widely analyzed in the long-range shooting community, for instance by Berger Bullets (Litz, 2013), however, there is a need to quantify the effect of different seating depth on performance of diverse cartridge types, focusing on the different ogive profiles.

This study aims to assess the impact of the assembly variables within the context of different projectile designs, assessing their influence on ballistic performance, and focusing on the internal and external ballistics. By addressing those challenges the research seeks to enhance the understanding of the manufacturing process, aiming to assess the requirements of repeatability and precision of future small-arms ammunition production.

2. Material and methods

To systematically evaluate the impact of seating depth on ballistic performance – specifically focusing on muzzle velocity and shot dispersion at 50 meters, an extensive experimental framework was established. This section explains the methodological approach adopted to investigate these parameters, detailing the laboratory setup and the specific characteristics of the cartridges utilized.

2.1. Ammunition

The authors precisely handloaded 30-06 Springfield cartridges using two types of projectiles, with various seating depths. With the use of the 30-06 cartridge cases (Sellier&Bellot), each cartridge was filled with RS60 propellant (ReloadSwiss), and large-rifle primer (Fiocchi). To analyze the considered parameters, especially the seating depth and the projectile's sensitivity to it in various configurations, the following projectiles were chosen for the experiment (Fig. 2):

- .30 Lapua Open Tip Match Scenar (10.85 g / 167 gr) GB422 – tangent ogive profile, bullet length: 31.2 ± 0.1 mm, 3.74 g (57.7 gr) of RS60 propellant,
- .30 Lapua Open Tip Match Scenar-L (10.0 g / 155 gr) GB552 – secant ogive profile, bullet length: 32.8 ± 0.1 mm, 3.72 g (57.4 gr) of RS60 propellant.

Both projectiles used in the experiment are Open-Tip Boat-Tail designs. Due to the beforementioned larger differences in the distance between the base of the bullet and its tip, than the base and the ogive, they were sorted by measuring each bullet's base to ogive distance.

Fig. 2. Bullets used for the experiment:
Top: secant ogive profile Lapua Scenar-L,
Bottom: tangent ogive profile Lapua Scenar

Followingly, each cartridge type was assembled with 5 different CBTOs using a single-stage reloading press, followed by dimension and weight control of each element and the whole cartridge assembly. The cartridge cases were primarily resized, trimmed, and cleaned to avoid any excessive influence on the cartridge's performance. The maximum difference in the CBTO distance was maintained at 1 mm, with a 0.25 mm difference between each configuration.

2.2. Experimental setup

The experiment was conducted in a 50-meter-long ballistic free-flight tunnel. The setup consisted of the following elements (Fig. 3):

- mobile firing stand STZA13M2 with universal ballistic breech UZ-2002 and velocity ballistic test 30-06 Springfield barrel with 1:10 inches twist, manufactured according to C.I.P. standard (Prototypa, Czech Rep.),
- muzzle velocity head EMG-1 (Prototypa, Czech Rep.),
- Phantom V2012 Ultra High-speed camera (Phantom, USA),
- light screen type 2521A at 5 m (Kistler, Switzerland),
- target system type 2523A at 50 m (Kistler, Switzerland).

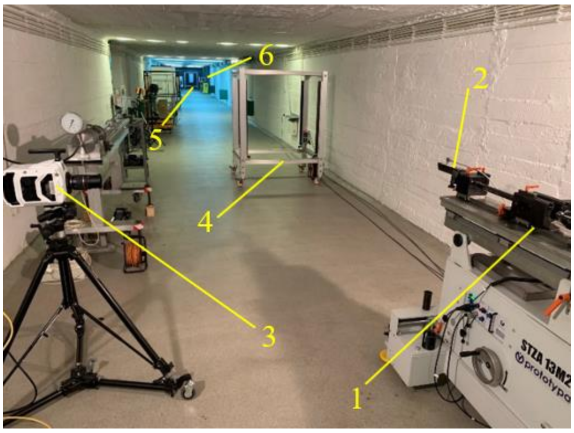

Fig. 3. Experimental setup
1 – STZA13M2, 2 – EMG-1, 3 – Phantom V2012,
4 – Kistler 2521A, 5 – Kistler 2523A, 6 – bullet trap

The measurements were performed with a series of shots for each specific CBTO of a given projectile type cartridge, measuring the muzzle velocity – V_0, velocity at 5 meters – V_5, coordinates, and velocity at the target at 50 meters – V_T. To analyze the bullet's stabilization and initial yaw movement, the high-speed camera was used to record the initial bullet movement.

3. Results

Experimental data were examined individually for the different CBTOs of each projectile, to evaluate their sensitivity to seating depth changes. Firstly, to begin the analysis of shot dispersion, the stabilization of the bullets was confirmed. If a projectile is stable upon exiting the barrel, it remains stable throughout its entire trajectory up to the bullet trap at 50 meters (McCoy, 2009), hence, its behavior at the muzzle exit was analyzed. Both types of projectiles tested were found to be gyroscopically stable, characterized by negligibly small yawing movement, therefore allowing the shot dispersion results to be considered reliable. An example of the bullet in motion at the muzzle exit is shown in Fig. 4.

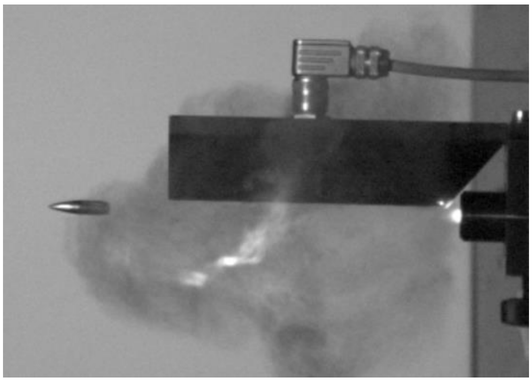

Fig. 4. Tangent projectile at the barrel muzzle

3.1. Tangent ogive projectile

The mean velocity at 5 m of shot groups of cartridges with tangent Lapua Scenar projectile varied from 933.2 m/s to 938.9 m/s with a maximum seating depth variation of 1.0 mm. The results are presented in Fig. 5 below.

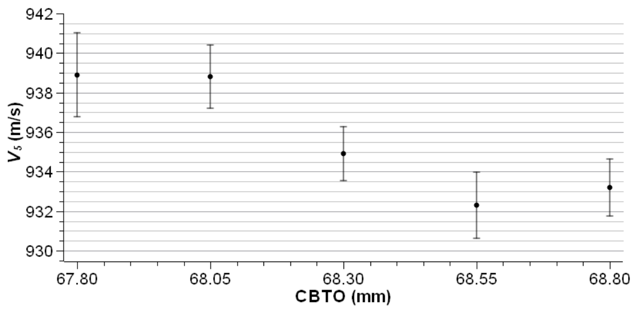

Fig. 5. Experimental results of velocity dependence on CBTO – tangent ogive profile

Following a procedure of 3 shots per each CBTO value, 5 groups of 3 shots were obtained with the same aiming point. To visually analyze the dispersion, the results are presented in Fig. 6.

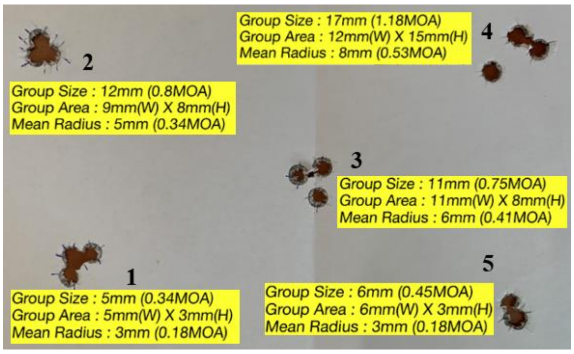

Fig. 6. Shot dispersion – tangent projectile

The shot dispersion differs significantly, depending on the CBTO, from a 3 mm mean radius in the case of group number 5, up to 8 mm for group number 4. In order to analyze the dispersion of shots regardless of the distance to the target, the mean radius was presented in minutes of angle – MOA. The average radius for the tangent projectile was estimated at 0.34 MOA, which equals 9.89, 19.78, and 29.67 mm at 100, 200, and 300 meters respectively. For each group, the dispersion analysis was performed, and the results are presented in Tab. 1.

Table 1. Experimental results of the tangent ogive projectile cartridges

No	CBTO (mm)	Mean V_5 (m/s)	Group size (mm)	Mean Radius (mm)	Mean Radius (MOA)
1	68.80	932.3	5	3	0.18
2	68.55	933.2	12	5	0.34
3	68.30	934.9	11	6	0.41
4	68.05	938.8	17	8	0.53
5	67.80	938.9	6	3	0.18
AVG			10.2	5.0	0.34

3.2. Secant ogive projectile

The mean muzzle velocity of shot groups of cartridges with secant Lapua Scenar-L projectile varied from 935.5 m/s to 949.7 m/s with a maximum seating depth variation of 1.0 mm. The results are presented in Fig. 7 below.

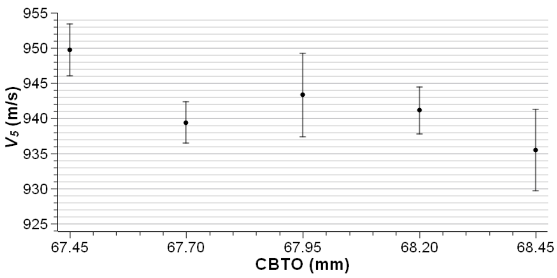

Fig. 7. Experimental results of muzzle velocity dependence on CBTO variance – secant ogive profile

The results of shot groupings indicate slightly stronger correlation between the seating depth and external ballistics of the bullets. The results are shown in Fig. 8.

In the case of the secant ogive projectile, the lowest mean radius of 4 mm was achieved with group number 3, and the highest – 6 mm for groups 4 and 5. The average mean radius estimated for the 5 groups equals 0.36 MOA, which gives 10.47, 20.94, and 31.41 mm for 100, 200, and 300 meters. The results of the shot dispersion analysis are presented in Tab. 2. The mean radius and group sizes are noticeably higher for the secant profile projectile cartridges.

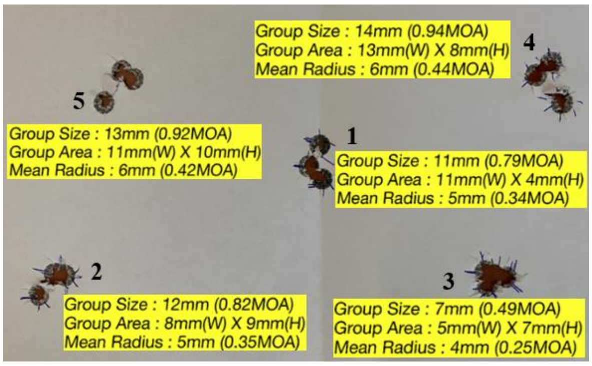

Fig. 8. Shot dispersion – secant projectile

Table 2. Experimental results of the secant ogive projectile cartridges

No	CBTO (mm)	Mean V_5 (m/s)	Group size (mm)	Mean Radius (mm)	Mean Radius (MOA)
1	68.45	935.5	11	5	0.34
2	68.20	941.1	12	5	0.35
3	67.95	943.3	7	4	0.25
4	67.70	939.4	14	6	0.44
5	67.45	949.7	13	6	0.42
AVG			11.4	5.2	0.36

3.3. Geometry analysis of military cartridges

To evaluate the impact of variations in CBTO within a batch on the performance of the rounds, an analysis was conducted on the geometry of military-use 7.62x51 mm Ball cartridges. The findings from 21 measurements suggest that the CBTO in a batch, and consequently the seating depth, can vary by as much as 0.48 mm. Given this variability, conducting an analysis with a CBTO difference of 1 mm for a .30 projectile is justified to determine the significance of precise seating depth inspections in the production of military ammunition.

4. Discussion

To analyze the results and formulate conclusions, it is necessary to consider the following aspects of the performed analysis:

- measurements of projectile geometries included verifying the COAL, CBTO, the diameter, and the weight of each projectile. Variations in ogive shape and méplat diameter are supposed to be negligible, therefore were not taken into account,
- variability in internal ballistics performance may occur from one cartridge to another due to inconsistent propellant powder filling, even

when the CBTO is consistent. These differences are expected to be significantly smaller than those caused by changes in CBTO,

- despite the thorough preparation of the cartridge cases before ammunition assembly, there is a certain influence noticeable on the performance of prepared cartridges. Variations in internal and external dimensions between each case led to differences in muzzle velocities among shots within the same CBTO groups,
- the tests were conducted on a small sample which is a simplification of the whole population, therefore the probability error must be considered while analyzing the results,
- the measurement system accuracy must be considered, especially concerning the measured velocities of the projectiles.

The findings indicate that the cartridges with secant ogive profile projectiles experienced greater muzzle velocity spread when the seating depth of the bullet varied, with a difference of mean velocities reaching up to 14.5 m/s, in contrast to 6.6 m/s observed in tangent profile projectiles.

Although muzzle velocity did not directly correlate with shot dispersion at the target, the mean radius equals 5.0 mm for the tangent projectile cartridge and it is slightly higher – 5.2 mm, for the secant bullet. The group size is also larger for the secant projectile configuration when compared to the tangent projectile – 11.4 mm versus 10.2 mm. While these differences in the mean radius are relatively minor at 50 meters, they increase with target distance, potentially exceeding 30 mm for secant projectiles at 300 meters due to inconsistencies in CBTO and thus seating depth.

The results indicate that a tangent ogive profile reduces the sensibility of a cartridge on seating depth variations, though it is characterized by a higher drag. The balance between drag and seating depth sensitivity should be thoroughly examined in further detail.

Dimensional analysis of a batch of 7.62x51 mm Ball military-use rounds indicated that the maximum CBTO variation within a batch could reach 0.48 mm. Given the analysis results, where the maximum CBTO differences were up to 1 mm, the impact of these variations in seating depth on cartridge performance should be considered.

5. Conclusions

Bearing in mind the abovementioned, the following conclusions can be drawn:

- seating depth has a noticeable influence on the ballistic performance of a cartridge, by increasing the muzzle velocity with the increase of the seating depth,
- cartridges with secant profile ogive projectiles are more sensitive to variations in the seating depth of the projectile compared to those with tangent profile projectiles,
- to achieve higher precision of small-arms ammunition, it is essential either to use higher drag, tangent profile projectiles or to ensure high repeatability in the seating depth of bullets in the cases,
- the effect of the seating depth may become imperceptible due to imperfections and variations in geometries of the cartridge cases, primers, and the associated differing characteristics of the process of propellant combustion,
- military ammunition may experience a high variation of the shot dispersion at the target due to seating depth inconsistencies.

The results have strong implications for future ammunition design by providing a resource in the analysis of the balance between manufacturing low drag coefficient bullets while maintaining high precision. Further works should focus on analyzing the hybrid ogive projectiles' external ballistics performance with the use of both CFD simulations and live firing, as well as on analyzing the bullet's performance dependence on minor damage caused during production and assembly, which may cause irregularities and asymmetries in the geometry.

Acknowledgments

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