CORE
CENTER FOR OPEN RESEARCH AND EDUCATION

Applied Research Advances

Journal homepage: www.ara-journal.org
ISSN: 3104-2643

# Experimental Validation of Internal Ballistic Mathematical Model for a Small Caliber Weapon

Aleksa Aničić 1*, Vučko Vučković 2, Luka Đorđević 3, Lazar Blagojević 4, David Tošić 5

1 University of Novi Sad, Technical Faculty „Mihajlo Pupin“, Zrenjanin, Serbia
2 Technical Overhaul Works, Kragujevac, Republic of Serbia
3 University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
4 Agency for Testing, Stamping and Marking of Weapons, Devices and Ammunition, Kragujevac, Serbia
5 University of Kragujevac, Faculty of Engineering, Kragujevac, Serbia

**ARTICLE INFO**

***Article history:***
Received 19 October 2025
Received in revised form 2 December 2025
Accepted 15 January 2026
Available online 25 January 2026

***Keywords:***
Initial velocity; Barrel pressure; Small weapon calibers; Internal ballistic; Experimental measurement

**ABSTRACT**

This paper examines the influence of barrel length on pressure and the initial velocity of the projectile. The theoretical analysis is conducted using the Drozdov analytical solution. An experimental method is used to investigate the ballistic characteristics of different barrel lengths from 720 mm to 600 mm, and also to validate the analytical results. The obtained deviations between analytical and measured values are less than 3.5%, 2%, and 6% for barrel maximum pressure, initial velocity, and firing time, respectively. The study findings show the reliability of the used model in determining internal ballistic characteristics for small-caliber weapons.

## 1. Introduction

A critical aspect of ammunition investigations is measuring pressures and projectile velocity during flight. Achieving accurate results necessitates reliable analytical methods and ballistic measurement systems. Over the past few decades, many researchers have concentrated on the ballistic characteristics of different caliber weapons. Goździk *et al.* [1] compared projectile velocity and gas pressure in barrels made according to two different standards (CIP and NATO EPVAT). They found that projectile velocities remain nearly constant, while barrel pressure discrepancies between the two standards are about 5% due to design differences. Purwanto *et al.* [2] examined how air pressure and projectile mass influence the velocity of projectiles fired from a compressed air gun. It has been revealed that although increased pressure helps boost velocity, the mass of the projectile plays a more critical role in both velocity and its ability to penetrate armor. Additionally, when comparing projectiles of identical mass, variations in shape do not significantly alter performance. Jedlicka *et al.* [3] studied the ballistic characteristics of a standard 9 mm Luger pistol cartridge by focusing on how variations in projectile mass influence the overall weapon-cartridge

---

[*] *Corresponding author.*
*E-mail address: tehnika@aiz.rs*

https://doi.org/10.65069/ara2120268

system. They discussed the implications of altering projectile mass for developing new projectile types and optimizing cartridge performance. The study also outlines how this approach can be applied to tailor parameters such as impact energy and muzzle velocity in small arms design. Boukera Abaci *et al.* [4] used both analytical and numerical models to calculate internal ballistics parameters, focusing on gunpowder gas pressure and projectile muzzle velocity. Experimental tests on a 12.7 mm rifle showed excellent agreement between calculated and measured values. The findings confirmed that both models reliably predict pressure and velocity, providing key insights for optimizing weapon performance. Ma *et al.* [5] introduced a rapid method for measuring bullet velocity using high-speed sequential images. A synchronized camera network was employed to capture images before and after impact, allowing 3D reconstruction of the bullet's trajectory. Velocity parameters were accurately determined in accordance with deceleration laws, and valuable data was also provided. Allouche *et al.* [6] conducted a contact-based measurement method for the counter-recoil movement of a D30J 122 mm howitzer was. Displacement and acceleration sensors were employed to derive velocity, acceleration, and displacement, with the results being compared for validation. Advantages and limitations of the sensor types were discussed, and the approach was proposed for further testing on actual firing ranges.

This research paper analyzes the impact of barrel length on the initial velocity of the projectile and the pressure within the barrel. A barrel with an initial length of 720 mm is shortened in increments of 20 mm, six times, down to 600 mm. After each shortening, an experimental examination is conducted, during which the ballistic characteristics of the projectile are monitored and recorded. The experiment and barrel shortening are carried out at the proof house in Kragujevac. A theoretical investigation is also conducted using the Drozdov analytical method. The obtained results are compared, and deviations between experimental and theoretical values are analyzed.

## 2. Methodology

### *2.1 Internal Ballistics*

Internal ballistics is a fundamental scientific discipline in the field of weaponry [7,8]. It serves as the foundation for all other related disciplines, with the primary objective of analyzing the operation of existing weapons or designing new ones. Ballistics is one of the essential military-technical disciplines that studies the principles of projectile motion and provides the scientific basis for designing the system: barrel – projectile – propellant charge – weapon/artillery. It defines the pressure of propellant gases within the barrel and the initial velocity of the projectile upon exiting the muzzle [9–11].

The main objectives of internal ballistics as a science are:

i. The primary objective of internal ballistics is to determine the laws governing projectile motion and the development of gas-dynamic characteristics for a known weapon system. A known weapon system refers to a manufactured system for which all design parameters, ammunition data, and propellant properties are known. For such a weapon, it is necessary to establish equation systems, solve them, perform calculations, and present results in the form of diagrams or tables.

ii. The second fundamental objective is the internal ballistic design of weapons. During the development of a new weapon system, internal ballistics must define the propellant to be used in the ammunition and determine certain structural characteristics of the barrel based on given tactical and technical specifications. Solving this problem requires determining more parameters than the number of available equations, making it an optimization problem. This means that from a multitude of possible mathematical solutions, the optimal one must be selected based on specific criteria.

Additional objectives of internal ballistics include:

i. Studying and analyzing the conditions and parameters influencing the ignition process of the cartridge within the barrel,
ii. Defining general and specific theoretical and experimental dependencies that characterize the ignition process,
iii. Developing methods for solving problems encountered in the study of the ignition process, and
iv. Advancing internal ballistics as a science that provides scientific and technical foundations for the improvement of weapon systems.

Phases of the firing process in a closed-barrel system:

i. Preliminary phase – from the start of propellant combustion to the beginning of projectile movement (pp in the Figure 1),
ii. First (Main) phase – from the start of projectile movement to the completion of propellant combustion (I in the Figure 1),
iii. Second phase – from the completion of propellant combustion to the projectile's exit from the barrel (II in the Figure 1),
iv. Third phase – the post-effect period of gases on the projectile after it exits the barrel (III in the Figure 1).

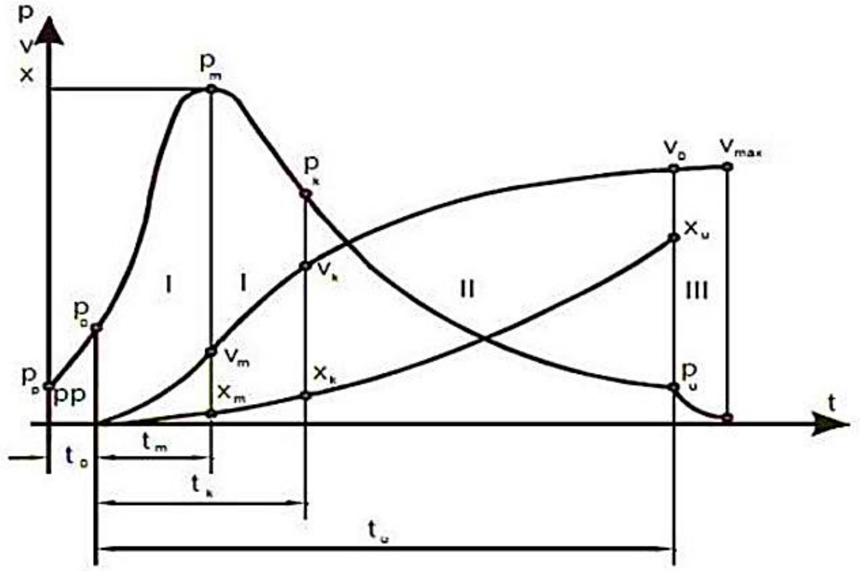

**Fig. 1.**Diagram of the change in propellant gas pressure - P, projectile velocity - V, and distance traveled - X as a function of time: $t_0$ - preliminary phase, $t_k$ - first phase, $t_u$ – time of the start of projectile movement to the projectile's exit from the barrel.

### *2.2 Results Obtained Using the Drozdov Program Solution*

This program analytically solves the system of internal ballistics equations based on energy balance by phases [4]. The computational solution used for calculations was developed in Octave [12].

Figure 2 presents a graphical representation of pressure as a function of distance traveled within the barrel, displaying all theoretical results for different barrel lengths. From this graph, it can be concluded that there is no significant difference in the change of maximum pressure; the only noticeable variation occurs at the muzzle, where the pressure is slightly higher when the barrel is shortened.

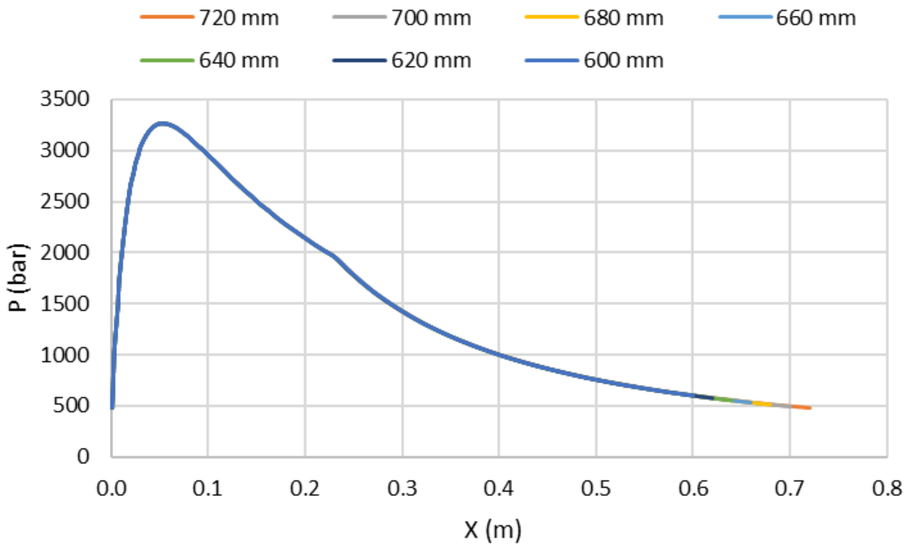

**Fig. 2.**Comparative analysis of pressure as a function of distance traveled for different barrel lengths (720 mm to 600 mm)

Figure 3 illustrates the projectile velocity as a function of distance traveled within the barrel, showing all theoretical results for barrel lengths ranging from 720 mm to 600 mm. This figure clearly indicates a decrease in the projectile's initial velocity at the muzzle as the barrel length is reduced. The velocity drop occurs because, with a shorter barrel, less energy from the propellant gases is transferred to the projectile's propulsion.

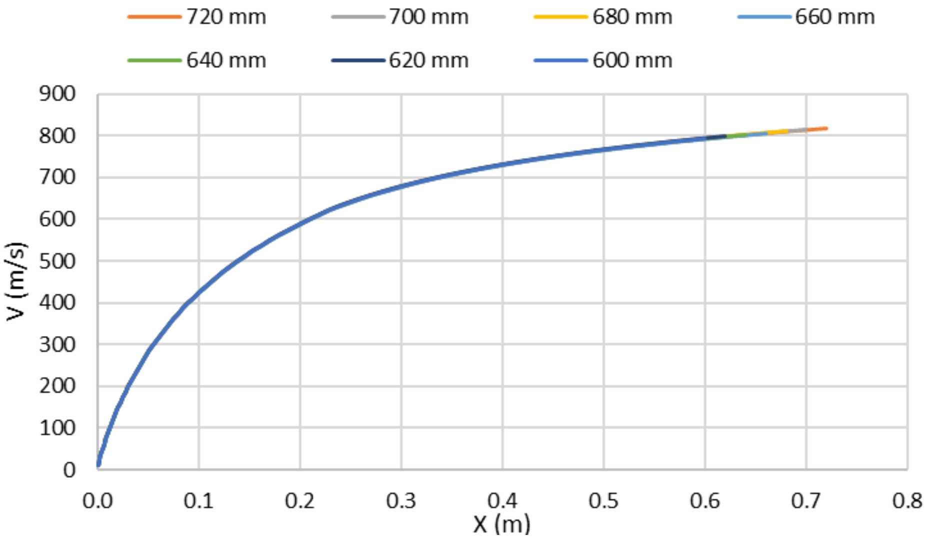

**Fig. 3.**Comparative analysis of velocity as a function of distance traveled for different barrel lengths (720 mm to 600 mm)

### *2.3 Experimental Method for Measuring Ballistic Characteristics*

The experiment is conducted using a mechanical system for cocking, triggering, and firing with electronic ignition. The primer in the cartridge case is activated, providing an initial heat impulse that ignites the propellant charge inside the case. As the propellant burns, the pressure inside the barrel increases. Measurement equipment monitors the pressure at a point located 25 mm from the rim of the cartridge case and at the muzzle of the barrel. The pressure of the propellant gases imparts the initial velocity to the projectile, which is then measured using a ballistic chronograph [13].

First, the experiment is conducted using an unmodified barrel (720 mm in length). Then, the barrel is shortened by 20 mm, and the experiment is repeated with a 700 mm barrel. This procedure is repeated a total of six times until the barrel is reduced to 600 mm in length.

The ballistic tunnel, 100 m in length, allows for this type of testing. To ensure safety for operators and the surrounding environment, the mounting system holding of the barrel must be inspected before each firing sequence, and the alignment and elevation of the barrel must be verified. The optimal barrel position is with an elevation of 0°, aimed at the end of the tunnel, where a sand trap is located to capture the fired projectile. An infrared barrier inside the tunnel must be adjusted to a standard pre-defined distance before each test series.

The position of the projectile catcher (target) during the experiment is shown in Figure 4.

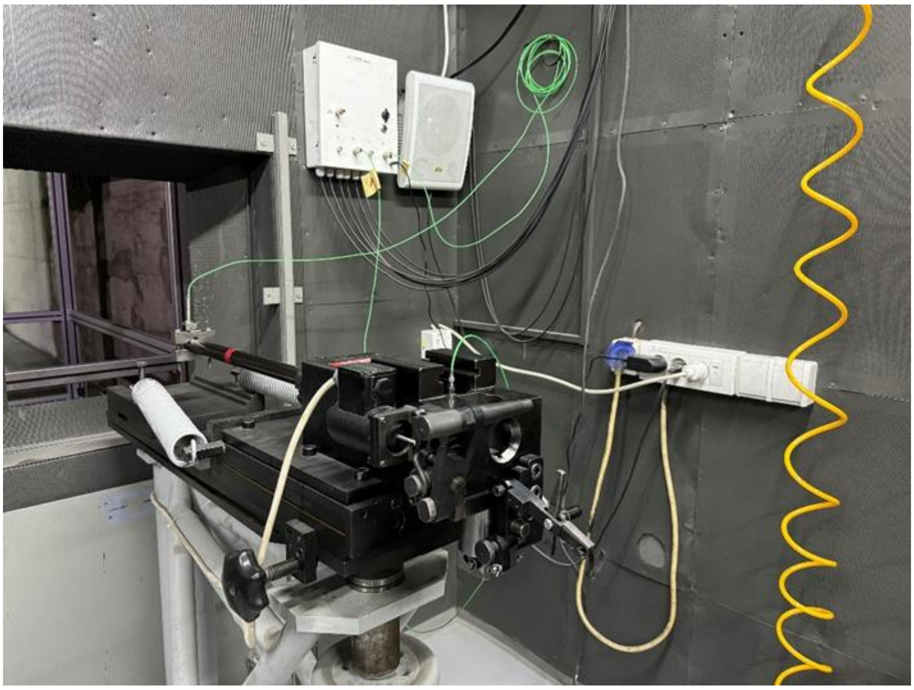

**Fig. 4.**Ballistic barrel holder for testing with measurement system

The barrel shortening process (Figure 5) and experiment arecarried out at the proof house in Kragujevac.

### *2.4 Barrel Shortening*

The barrel examined in this study is of 7.62x54R caliber, with an initial length of 720 mm. According to the required specifications of the C.I.P. (Commission Internationale Permanente)[14], the barrel must be shortened to a final length of 600 mm. In this study, the barrel was shortened in six steps, with interval of 20 mm, with experimental measurements conducted between each shortening. These measurements included chamber pressure of propellant gases and projectile velocity. The primary objective was to establish the dependence of the observed parameters on barrel length.

Due to the complexity of the barrel shortening operation, the process was conducted using the necessary tools for the procedure. The shortening was performed using a universal lathe, after which the barrel's muzzle had to be reworked to restore the rifling grooves, which were deformed during the cutting process. Throughout the shortening process, strict adherence to operator safety protocols and preservation of the barrel's initial ballistic characteristics was required.

(a) Unmodified barrel (720 mm) (b) Shortened barrel (600 mm)

**Fig. 5.** 7.62x54R Ballistic Barrel (a) Unmodified barrel (b) Shortened barrel

### *2.5 Measurement Equipment*

To obtain a complete physical representation of the processes inside the barrel during firing - an inherently impulsive and non-homogeneous phenomenon - it is necessary to use multiple piezoelectric sensors simultaneously. Modern technology fully supports this approach. The electric charge generated by the piezo sensors is transmitted via a coaxial cable to an intermediate amplification unit and subsequently to a data acquisition and processing system.

Measurement equipment used:

i. Kistler 6215 - Piezoelectric pressure sensor
ii. Kistler 5015A - Signal amplifier
iii. Top Trend V2.205 - Ballistic chronograph
iv. Kistler 603CAB - Cable set
v. WEISS SB1 500 - Climatic chamber
vi. 7.62x54R ballistic barrel
vii. 7.62x54R ammunition

### *2.6 Results of the Experimental Method*

For each barrel length, ten (10) consecutive firings were conducted. The system automatically calculates and records the average maximum pressure, initial velocity, and firing time. Table 1 presents the experimental results, displaying the mean values of pressure, velocity, and combustion duration for each tested barrel length.

**Table 1**
Experimental Results

| Length (mm) | Pressure (bar) | Velocity (m/s) | Firingtime (s) |
|---|---|---|---|
| 720 | 3382.6 | 805.1 | 0.00199 |
| 700 | 3387 | 799.33 | 0.00151 |
| 680 | 3327 | 797.52 | 0.00152 |
| 660 | 3389 | 795.44 | 0.00147 |
| 640 | 3385 | 794.42 | 0.00144 |
| 620 | 3326 | 793.55 | 0.00143 |
| 600 | 3378 | 786.76 | 0.0014 |

## 3. Comparative Analysis of Theoretical and Experimental Testing Results

Comparative analysis enables the evaluation of results obtained from both experimental and theoretical approaches, allowing for further analysis and the formulation of conclusions.

Table 2 presents a comparative overview of theoretically and experimentally obtained chamber pressure values. It can be observed that in theoretical investigations, the maximum pressure remains constant, while experimental measurements yield varying values. The discrepancy between theoretical and experimental results arises because theoretical models assume ideal conditions, whereas experimental conditions involve variable factors that influence the final outcome. The maximum deviation observed is 3.63%, which remains within acceptable tolerance limits.

**Table 2**

Comparative Analysis of Propellant Gas Pressures

| Theoretical Values | | Deviation (%) | Experimental Values | |
|---|---|---|---|---|
| Barrel Length (mm) | Maximum Pressure (bar) | | Maximum Pressure (bar) | Barrel Length (mm) |
| 720 | 3270.85 | 3.42 | 3382.60 | 720 |
| 700 | 3270.85 | 3.55 | 3387.00 | 700 |
| 680 | 3270.85 | 1.73 | 3327.40 | 680 |
| 660 | 3270.85 | 3.63 | 3389.50 | 660 |
| 640 | 3270.85 | 3.52 | 3385.90 | 640 |
| 620 | 3270.85 | 1.70 | 3326.50 | 620 |
| 600 | 3270.85 | 3.30 | 3378.90 | 600 |

Table 3 presents a comparative analysis of projectile initial velocity between theoretical and experimental values. The difference between theoretical and experimental velocity values remains within tolerance limits. The theoretical data indicates that for every 20 mm reduction in barrel length, velocity decreases by 0.44%, resulting in a 3.09% total velocity reduction for a 120 mm barrel shortening. In contrast, experimental results show a 2.3% velocity reduction for the same barrel shortening.

**Table 3**

Comparative Analysis of Projectile Velocities

| Theoretical Values | | Deviation (%) | Experimental Values | |
|---|---|---|---|---|
| Barrel Length (mm) | Initialvelocity (m/s) | | Initialvelocity (m/s) | Barrel Length (mm) |
| 720 | 818.20 | 1.60 | 805.10 | 720 |
| 700 | 814.60 | 1.87 | 799.33 | 700 |
| 680 | 810.80 | 1.64 | 797.52 | 680 |
| 660 | 806.70 | 1.40 | 795.44 | 660 |
| 640 | 802.60 | 1.02 | 794.42 | 640 |
| 620 | 798.20 | 0.58 | 793.55 | 620 |
| 600 | 793.60 | 0.86 | 786.76 | 600 |

Table 4 presents a comparative analysis of firing time between theoretical calculations and experimental measurements. The key observation from this table is that shortening the barrel results in a reduction in the total process duration.

**Table 4**

Comparative Analysis of firing time

| Computational Values (Drozdov Method) | | Deviation (%) | Mean Experimentally Measured Values | |
|---|---|---|---|---|
| Barrel Length (mm) | Firing time(s) | | Firing time(s) | Barrel Length (mm) |
| 720 | 0.00189 | 5.02 | 0.00199 | 720 |
| 700 | 0.00161 | 5.59 | 0.00152 | 700 |
| 680 | 0.00158 | 4.43 | 0.00151 | 680 |
| 660 | 0.00156 | 5.77 | 0.00147 | 660 |
| 640 | 0.00153 | 5.88 | 0.00144 | 640 |
| 620 | 0.00151 | 5.30 | 0.00143 | 620 |
| 600 | 0.00149 | 6.04 | 0.00140 | 600 |

## 4. Conclusions

The discrepancy in pressure values in the theoretical model does not occur in the region of maximum pressure, as the propellant chamber volume remains unchanged, and the initial input parameters related to the propellant properties are constant. Instead, variations appear toward the end of the cycle due to barrel shortening and the subsequent dissipation of propellant gases in shorter barrels. As a result, maximum pressure remains unchanged, but muzzle pressure increases in shorter barrels.

The projectile velocity at the muzzle follows a similar trend to chamber pressure, meaning that shortening the barrel leads to a velocity drop due to gas dissipation and incomplete energy transfer.

The experimental results confirm the theoretical predictions, as they exhibit a nearly equivalent velocity reduction trend with barrel shortening. However, minor deviations in maximum gas pressure values occur due to real-world factors, including:

i. Inconsistencies in the propellant charge,
ii. Variations in humidity and temperature during testing,
iii. Minimal human factor errors (e.g., slight misalignment of the cartridge in the test barrel), and
iv. Environmental deviations in temperature and humidity from standard conditions at the test site.

## Acknowledgement

This research was not funded by any grant.

## Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## References

[1] Goździk, D., Fikus, B., Kijewski J., et al. (2021). Comparative analysis of different types of ballistic barrels used in ammunition investigations. *Bulletin of the Military University of Technology, 70*(1), 31-42. https://doi.org/10.5604/01.3001.0015.6956

[2] Purwanto, H., Tauviqirrahman, M., Sugiarto, S., & Dzulfikar, M. (2022). Analysis projectile performance in ballistic tests using compressed air gun. *EUREKA: Physics and Engineering, (6)*, 120-127. https://doi.org/10.21303/2461-4262.2022.002418

[3] Jedlička, L., Komenda, J., & Beer, S. (2022). Analysis of Ballistic Characteristics of Pistol Cartridge. *Advances in Military Technology, 7*(1), 31-40. https://www.aimt.cz/index.php/aimt/article/view/1593

[4] Boukera, A. W., Hristov, N. P., Ziane, A. N., Jerkovic, D. D., & Savic, S. D. (2021). Analysis of thermal and gas-dynamic characteristics of different types of propellant in small weapons. *Thermal Science, 25*(6A), 4295-4306. https://doi.org/10.2298/TSCI200814138B

[5] Ma, H., Chen, P., Shi, H., & Zhao, J. (2021). Measurement of Bullet Velocity Parameter from High-speed Sequential Images. *Journal of Physics: Conference Series, 1827*(1), 012027. https://doi.org/10.1088/1742-6596/1827/1/012027

[6] Allouche, T., Ferfouri, A., Hristov, N., Jerković, D., Stalević, M., Benmeddah, A., & Bukvić, A. (2023). Measurement analysis of physical quantities for ballistic tests using different sensors. *Scientific Technical Review, 73*(1), 42–47. https://doi.org/10.5937/str2301042a

[7] Kriukov, O., Melnikov, R., Bilenko, O., Zozulia, A., Herasimov, S., Borysenko, M., Pavlii, V., Khmelevskiy, S., Abramov, D., & Sivak, V. (2019). Modeling of the process of the shot based on the numerical solution of the equations of internal ballistics. *Eastern-European Journal of Enterprise Technologies, 1*(5 (97)), 40–46. https://doi.org/10.15587/1729-4061.2019.155357

[8] Ongaro, F., Robbe, C., Papy, A., Stirbu, B., & Chabotier, A. (2024). Modelling of internal ballistics of gun systems: A review. *Defence Technology, 41*, 35–58. https://doi.org/10.1016/j.dt.2024.05.004

[9] Wang, Y., Zhu, W., Di, J., & Hu, X. (2018). Study on the analysis method on ballistic performance of deterred propellant with large web size in large caliber artillery. *Defence Technology, 14*(5), 522–526. https://doi.org/10.1016/j.dt.2018.07.027

[10] Ray, D., & Ramirez-Marquez, J. (2020). A framework for probabilistic model-based engineering and data synthesis. *Reliability Engineering & System Safety, 193*, 106679. https://doi.org/10.1016/j.ress.2019.106679

[11] Ferfouri, A., Allouche, T., Jerković, D., Hristov, N., Vučković, M., & Benmeddah, A. (2023). Prediction of drag aerodynamic coefficient of the 155mm projectile under axisymmetric flow using different approaches. *Journal of the Serbian Society for Computational Mechanics, 17*(2), 69–86. https://doi.org/10.24874/jsscm.2023.17.02.06

[12] Li, X., Mu, L., Zang, Y., & Qin, Q. (2020). Study on performance degradation and failure analysis of machine gun barrel. *Defence Technology, 16*(2), 362–373. https://doi.org/10.1016/j.dt.2019.05.008

[13] Korolev, S. A., & Mansurov, R. R. (2024). Development of Mathematical Support and Software for Ballistic Analysis and Optimization of Active-Missile Projectile Parameters. *Intellekt. Sist. Proizv., 22*(4), 98–107. https://doi.org/10.22213/2410-9304-2024-4-98-107

[14] The Permanent International Commission. (n.d.). Retrieved February 15, 2025, from https://www.cip-bobp.org/fr