

Study on the effects of training round caliber and propellant type on the ballistic characteristics of a dynamic-reaction training device

Bui Xuan Son, Bui Minh Tuan, Nguyen Van Huong*

Le Quy Don Technical University, 236 Hoang Quoc Viet, Nghia Do, Hanoi, Vietnam.

*Corresponding author: nguyenvanhuong@lqdtu.edu.vn

Received 8 Apr. 2026; Revised 22 May 2026; Accepted 1 Jun. 2026; Published 25 Jun. 2026.

DOI: <https://doi.org/10.54939/1859-1043.j.mst.112.2026.192-198>

ABSTRACT

This study proposes the structural and ballistic design for an 82 mm PUI-type training device based on the dynamic-reaction principle. Using a MATLAB-based program to ensure the training projectile's trajectory matches that of the combat projectile, the authors analyzed the influence of two main parameters: the caliber of the training projectile (d) and the propellant type. The results show that NBL-62 propellant significantly reduces maximum pressure and stabilizes ballistic characteristics compared to NBL-34. The study identifies $d = 23$ mm with NBL-62 as the optimal configuration, ensuring a compact, low-pressure, and stable device. These findings provide an important scientific basis for designing and manufacturing an 82 mm training device based on the dynamic-reaction principle

Keywords: PUI-type training device; Dynamic-reaction; Internal ballistics; External ballistics.

1. INTRODUCTION

The training of the armed forces is always closely linked to the use of weapons and technical equipment. However, organizing live-fire exercises often faces many difficulties due to high costs, strict safety requirements, and limited training ground conditions. Therefore, research into and the manufacture of training equipment that simulates real-life situations while ensuring safety, economy, and effectiveness are extremely necessary.

The 82 mm combat ammunition based on the dynamic-reaction principle is a highly powerful anti-tank weapon that plays an important role in infantry operations [1]. In countries around the world, training procedures often employ shooting practice equipment based on various principles, helping soldiers train under conditions that increasingly resemble real-life firing. These procedures enable shooters to achieve the optimal shooting practice with minimal ammunition consumption and cost. Some typical types of shooting practice equipment are as follows: laser-based shooting practice equipment (IS); shooting practice equipment using gun ammunition (PUS); shooting practice equipment using smaller-caliber ammunition (PUI); and shooting practice ammunition (ammunition with an inert-filled warhead) [2-4].

Research and analysis of the types of shooting practice equipment for anti-tank guns worldwide reveal that equipment based on the PUI principle offers many outstanding advantages in both technical aspects and training effectiveness. This type of device is designed to almost completely replicate the combat operations of live firing, from preparation, loading, and aiming to firing, while ensuring high safety and significantly reducing costs.

Domestically, the development of training equipment is also receiving attention; however, it still has many limitations compared to the rest of the world. Currently, training with 82 mm dynamic-reaction ammunition primarily involves live firing, while PUI and PUS - type training equipment are not yet available. Some units use a makeshift solution by attaching an AK rifle to the outside of the barrel, which does not closely follow the principles of practical training. Based on an understanding of the advantages and disadvantages of each training device, this paper selects the design of a training device using a smaller-caliber projectile (PUI) for training with 82 mm dynamic-reaction ammunition.

The device's launching tube is essentially a gun barrel based on the dynamic-reaction principle, a smooth tube used to fire training rounds, with an outer casing similar to that of combat rounds.

82 mm dynamic-reaction combat rounds are recoilless. Therefore, the training rounds are selected similarly to those for the combat round; the round is stabilized by fins, ensuring consistency in operating principles and, in particular, producing trajectories similar to those of the combat round.

Based on the analysis and selection of the PUI principle for the training device, this paper establishes a program to calculate the ballistics and investigate the influence of two main parameters - projectile caliber and propellant type - on the ballistic characteristics. The resulting data serve as the basis for defining structural specifications that guarantee realistic simulation of the firing process, trainee safety, and suitability for actual operating conditions.

2. BALLISTIC CALCULATION METHODS FOR THE TRAINING DEVICE

2.1. External ballistics calculation

The trajectory of an 82 mm projectile depends on the following factors [5]:

- Initial velocity of projectile, v_0 ;

- Launch angle, θ_0 ;

- Launch coefficient, $C_0 = \frac{id^2}{q} 10^3$, where: i is the projectile shape coefficient; d is the projectile caliber (m); and q is the projectile mass (kg).

Changing only one of the three factors above yields a different projectile trajectory.

To achieve a simulated projectile trajectory similar to that of a combat projectile, the training projectile must be designed so that: $X_{CD} = X(v_0, \theta_0, C_0) \equiv X_{DBT} = X(v_{0bt}, \theta_{0bt}, C_{0bt})$. Thus, to ensure matching trajectories between the training and combat rounds, the following conditions must hold: $v_0 = v_{0bt}$; $\theta_0 = \theta_{0bt}$; $C_0 = C_{0bt}$.

Where: v_0 and v_{0bt} are the initial velocities of the combat and training rounds, respectively; θ_0 and θ_{0bt} are the launch angles of the combat and training rounds, respectively; C_0 and C_{0bt} are the launch coefficients of the combat and training rounds, respectively.

During the design process, the preliminary shape of the training round is selected using the shape coefficient of the 82 mm combat round, i.e., $i = i_{bt}$. From this, the relationship between the caliber of the training round (d_{bt}) and the mass of the training round (q_{bt}) is established using the caliber (d) and mass (q) of the combat round as follows:

$$C_{0bt} = C_0 \Rightarrow i_{bt} \frac{d_{bt}^2}{q_{bt}} = i \frac{d^2}{q} \Rightarrow \frac{d_{bt}^2}{q_{bt}} = \frac{d^2}{q} = \frac{82^2}{3.89} = 1728.5 \quad (1)$$

Based on the structure of the 82 mm combat ammunition and the structural diagram of the selected training device, the training ammunition must satisfy the condition $d_{bt} \leq 30$ mm, since the smallest diameter Φ of the stabilizer tube of the combat ammunition is 30 mm. This paper will perform calculations and surveys using several training ammunition calibers, as shown in Table 1.

Table 1. Relationship between diameter d_{bt} and mass of the flying portion q_{bt} of a training projectile.

d_{bt} , mm	20	23	25	27	29
q_{bt} , kg	0.231	0.306	0.362	0.422	0.487

2.2. Internal ballistics calculation experiment preparation

The general problem of internal ballistic design aims to determine the structural parameters of the barrel and the filling conditions given the caliber d , the mass q , and the initial velocity v_0 [6].

Solving this problem involves comparing and evaluating a series of options obtained by solving the fundamental internal ballistic problem with different input data. An option is considered optimal if it yields a maximum propellant gas pressure P_{max} and a barrel travel length l_d that are sufficiently small, ensuring that the system has minimal weight and size while remaining safe and reliable for use.

The problem of designing the internal ballistics for training rounds involves determining multiple parameters of the launching tube and the training projectile. Determining these parameters depends heavily on the dimensions of the combat projectile and the structural principle chosen for the training equipment.

To simplify the design process, the launching mechanism's structural parameters were determined through a preliminary survey of dynamic-reaction systems, aiming for minimal recoil and compatibility with domestic technology, and the type of propellant selected for the training projectile is NBL, specifically as follows:

+ Based on the dimensions of the combat projectile (the total length of the combat projectile is 585 mm), this paper preliminarily selects the travel length of the training projectile as $l_d = 500$ mm.

+ According to [7], to ensure stability (no recoil) of the dynamic-reaction artillery system, the critical cross-sectional area should be approximately 2/3 of the cross-sectional area of the barrel bore. The caliber of the launching mechanism is surveyed based on the data in Table 1.

+ Training projectiles using NBL propellant. The characteristics of NBL propellant are as follows: Propellant force $f = (97000...1250000)$ (J/kg); Total mass (covalume) $\alpha = (0,6...1,2)$ (dm³/kg); Burning velocity coefficient $u_1 = (0,75...1,25) \cdot 10^{-2}$ (mm.s⁻¹/MPa).

The propellant shape characteristics χ, γ, μ are calculated based on the burning thickness, length, and width of the propellant, as shown in Table 2.

Table 2. Characteristic parameters of NBL propellant types.

Propellant types	Burn thickness, $2e_1$	Length c, mm	Width b, mm
NBL-34	0.34	100	1.7
NBL-38	0.38	115	3
NBL-42	0.42	115	3
NBL-50	0.50	120	2.5
NBL-62	0.62	137.5	3.75

For non-recoil dynamic-reaction systems, the propellant loading density is selected empirically as: $\Delta = 0,2 \div 0,25$ (kG/dm³) [6]. Therefore, to find a reasonable set of loading parameters, a survey will be conducted with different values of Δ within the range of $0,2 \div 0,25$ (kG/dm³).

The propellant mass is preliminarily determined according to the following formula [7]:

$$\omega_{bt} = q_{bt} \frac{2v_{0bt}}{2\eta_{dt}gJ_{1bt} - v_{0bt}} \quad (2)$$

Where: g is the gravitational acceleration, $g = 9,81$ (m/s²); η_d is the relative gas consumption at the moment the projectile leaves the barrel. According to [7], for long - barreled cannons, $\eta_d = 0,68 \div 0,8$. In the calculation, the average value is taken as $\eta_d = 0,75$; J_1 is the impulse of the unit thrust force, $J_1 = 225$ kG.s/kG; v_0 is the initial velocity of the training projectile, $v_{0bt} = 322$ m/s; q_{bt} is the projectile mass, kg.

Based on the selected preliminary values, this study solves the internal ballistic algorithm for the dynamic-reaction system to select a suitable set of loading conditions for the designed training device, ensuring trajectory consistency between the training and the 82 mm combat projectiles. The internal ballistic algorithm flowchart is shown in Figure 1.

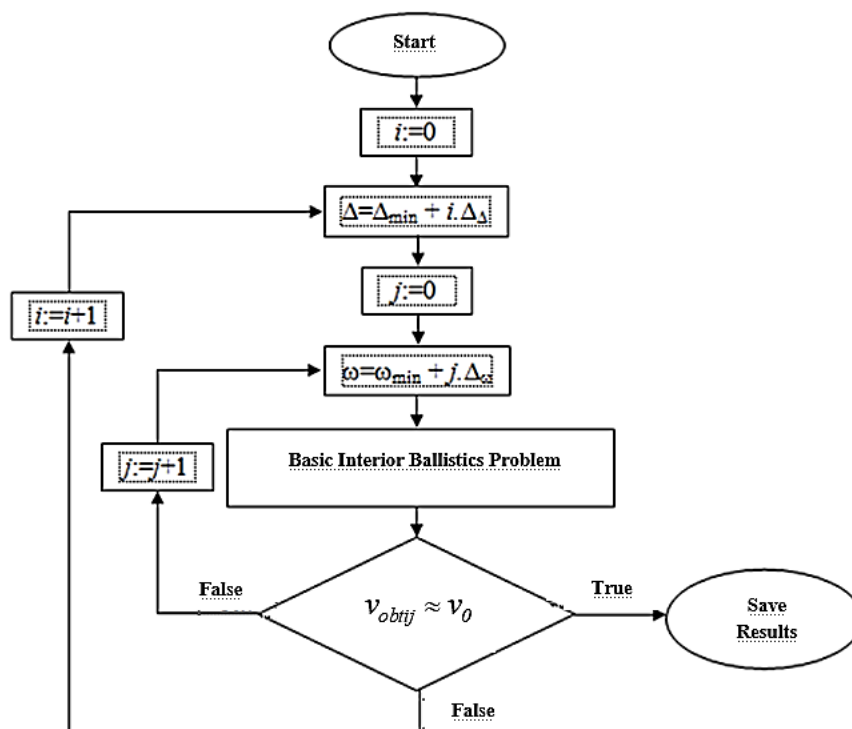


Figure 1. Algorithm flowchart.

3. RESULTS AND DISCUSSION

Based on the established algorithmic model, the authors calculated the ballistic design for the training device using different calibers and propellant types, ensuring that the initial velocity of the training projectile equals that of the combat projectile. The calculation program was developed numerically in MATLAB. The optimal results for each propellant type and each studied ammunition caliber are shown in Table 3. The results obtained enable the construction of graphs illustrating the influence of caliber and propellant type on the ballistic characteristics of the training device (Figure 2).

The results from Figure 2a show that the maximum pressure decreases as the training projectile diameter increases from 20 mm to 23 mm, then increases rapidly from 23 mm to 25 mm. When the diameter of the training projectile is greater than 25 mm, the maximum pressure value becomes less dependent on the diameter, as indicated by the significant decrease in the steepness of the curve. When the propellant type is changed from NBL-34 to NBL-62, the pressure curve shifts almost parallel downward (gradually decreasing).

Figure 2b shows that as the projectile diameter increases, the muzzle pressure increases sharply and almost linearly for $20 \text{ mm} \leq d < 23 \text{ mm}$, and tends to decrease when $23 \text{ mm} \leq d \leq 25 \text{ mm}$, approaching a stable region when $d > 25 \text{ mm}$. Meanwhile, the trend in muzzle pressure when changing from NBL-34 to NBL-62 is the opposite of that for the maximum pressure.

Figure 2c shows that as the caliber increases, the propellant burnout point tends to shift toward the breech, although the effect is not significant. Conversely, when the propellant type is changed from NBL-34 to NBL-62, the burnout point shifts significantly toward the muzzle. Specifically, for NBL-34 propellant, the burnout point (*Netak*) is located near the breech and fluctuates within a narrow range from 0.160 to 0.169 for all calibers tested. Meanwhile, for NBL-62 propellant, the burnout point is located approximately midway between the breech and the muzzle ($Netak = 0.533$) for all tested calibers.

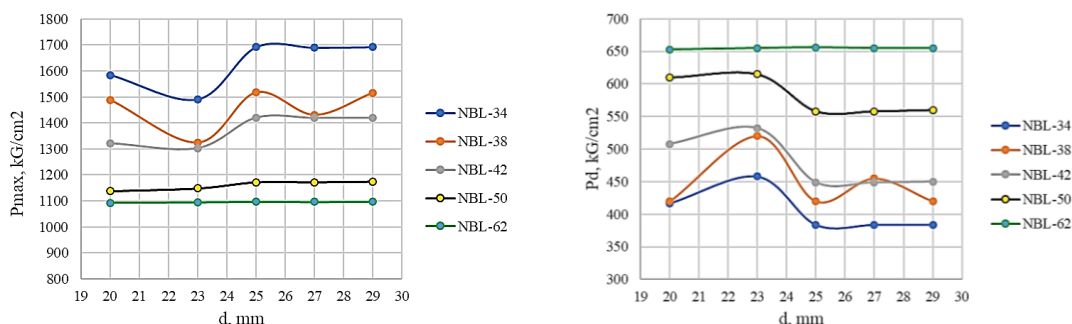
The results in Figures 2d and 2e show that the general trend is an almost linear increase in propellant mass and chamber volume with increasing test firing caliber. As the caliber increases, both propellant mass and initial chamber volume increase when switching from NBL-34 to NBL-62 propellant.

Table 3. Internal ballistic calculation results for different propellant types and projectile calibers Propellant NBL-34.

Propellant NBL-34						
d_{bb}, mm	$p_{max}, kG/cm^2$	$Pd, kG/cm^2$	$NetaK$	$Omega, kg$	W_0, dm^3	$Dental, kg/dm^3$
20	1585	417	0.169	0.0548	0.239	0.23
23	1490	458	0.18	0.077	0.37	0.21
25	1692	384	0.16	0.083	0.33	0.25
27	1690	384	0.163	0.0951	0.38	0.25
29	1692	384	0.162	0.1102	0.4408	0.25
Propellant NBL-38						
20	1489	420	0.224	0.04631	0.185	0.25
23	1325	520	0.246	0.072	0.36	0.20
25	1517	420	0.206	0.0762	0.304	0.25
27	1431	455	0.222	0.0909	0.395	0.23
29	1516	420	0.207	0.1012	0.4048	0.25
Propellant NBL-42						
20	1322	508	0.303	0.0592	0.269	0.22
23	1303	532	0.31	0.082	0.39	0.21
25	1421	449	0.281	0.0871	0.3484	0.25
27	1420	449	0.281	0.101	0.404	0.25
29	1420	450	0.281	0.1164	0.466	0.25
Propellant NBL-50						
20	1137	610	0.456	0.06026	0.262	0.23
23	1148	615	0.48	0.076	0.32	0.24
25	1172	558	0.422	0.091	0.3644	0.25
27	1172	558	0.422	0.1057	0.4228	0.25
29	1175	560	0.421	0.122	0.488	0.25
Propellant NBL-62						
20	1093	653	0.533	0.0606	0.242	0.25
23	1095	655	0.533	0.0803	0.3212	0.25
25	1097	656	0.533	0.096	0.382	0.25
27	1096	655	0.533	0.1108	0.4432	0.25
29	1097	655	0.533	0.1277	0.5108	0.25

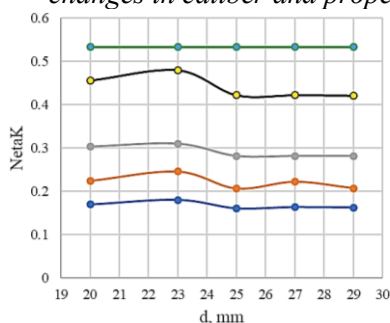
The results demonstrate that NBL-62 propellant minimizes the maximum pressure for training rounds, though this choice requires accepting a relatively high muzzle pressure. Accordingly, when using NBL-62 propellant, the sensitivity of the training round diameter to firing characteristics such as muzzle pressure, maximum pressure, propellant burnout point, and optimal loading density is low. In this case, only propellant mass and initial chamber volume exhibit high sensitivity to the round diameter. To avoid equipment becoming too bulky, the training round diameter should satisfy $d \leq 25$ mm. Within the limits of technological feasibility, the preferred value is $d = 23$ mm.

Furthermore, for projectile calibers ranging from 23 mm to 25 mm, relatively complex variations are observed depending on the propellant type. Specifically, with NBL-34, NBL-38, and NBL-42 propellants, muzzle pressure and initial chamber volume tend to decrease as the projectile diameter increases.

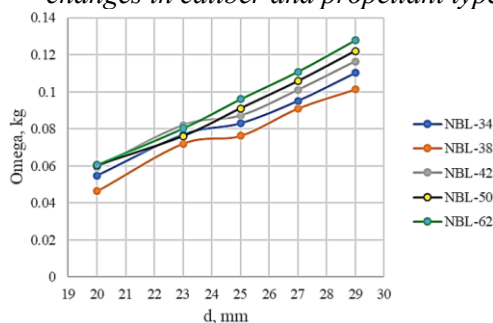


a) Variation of maximum pressure (P_{max}) with changes in caliber and propellant type.

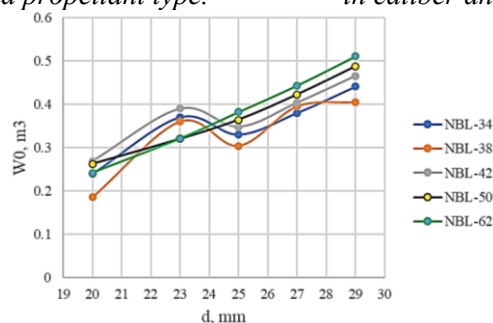
b) Variation of muzzle pressure (P_d) with changes in caliber and propellant type.



c) Variation of the propellant burnout point with changes in caliber and propellant type.



d) Variation of propellant mass with changes in caliber and propellant type.



e) Variation of chamber volume with changes in caliber and propellant type.

Figure 2. Variation of ballistic characteristics in the training device with changes in caliber and propellant type.

4. CONCLUSIONS

This paper analyzes the proposed structural principle of a PUI-type training device based on the dynamic-reaction principle. Based on the proposed structure, the paper establishes a program to calculate external and internal ballistics by varying the two main structural parameters, the caliber of the training projectile and the type of propellant, with the requirement that the training projectile's trajectory coincide with that of the combat projectile. From the obtained results, the following conclusions can be drawn:

- When the diameter of the training projectile changes within the range of $20 \text{ mm} \leq d < 23 \text{ mm}$, the maximum pressure value tends to decrease, while the muzzle pressure value tends to increase. Conversely, when $23 \text{ mm} \leq d \leq 25 \text{ mm}$, the maximum pressure value tends to increase, whereas the muzzle pressure value tends to decrease. When $d > 25 \text{ mm}$, both the maximum pressure and the muzzle pressure approach a stable region and become less dependent on the training projectile's diameter.

- As the diameter of the training projectile increases, the point of complete propellant combustion tends to shift toward the breech, while the propellant mass and the initial chamber volume increase linearly.

- When the propellant is changed from NBL-34 to NBL-62, the maximum pressure value tends to decrease sharply, whereas the muzzle pressure value tends to increase. With the NBL-62 propellant, the firing characteristics of the training projectile are less dependent on the projectile diameter.

- The calculation results indicate that selecting $d = 23$ mm with NBL-62 propellant achieves the lowest maximum pressure, and ensures ballistic characteristics remain less dependent on the training projectile's caliber. Additionally, this combination keeps the device from becoming bulky while providing a propellant burnout point appropriate for a dynamic-reaction system.

REFERENCES

- [1]. И. И. Грачев, А. А. Котосов, А. А. Плющ, “Физические основы устройства ракетно-артиллерийского вооружения,” Пензенский артиллерийский инженерный институт (филиал) федерального государственного казённого военного образовательного учреждения высшего профессионального образования, tr. 11-23, (2015).
- [2]. “Приспособление ПУС-7М для учебной стрельбы из РПГ-7: Техническое описание и инструкция по эксплуатации”, Москва, (2015).
- [3]. “Weapon training systems”, US Patent, (1990).
- [4]. “Training weapon system for recoilless antitank rifle weapons”, 2011/142695A1, US patent WO, (2011).
- [5]. N. Nasirov, “A Detailed Analysis of External Ballistics and a Study of Factors Affecting the Projectile Range,” vol. 7. Trans Tech Publications Ltd, pp. 29–35, doi: 10.4028/p-3p6fzl, (2024).
- [6]. Carlucci, Donald E and Jacobson, Sidney S, “Ballistics: theory and design of guns and ammunition,” CRC Press, (2025).
- [7]. Neves, Alexandre, *et al.*, “Recoilless gun: analysis of internal and external ballistics”, In 43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, p. 5160, (2013).

TÓM TẮT

Nghiên cứu ảnh hưởng cỡ đạn bắn tập và loại thuốc phóng sử dụng tới các đặc trưng thuật phóng của thiết bị bắn tập theo nguyên lý động - phản lực

Bài báo trình bày tính toán thuật phóng cho thiết bị bắn tập dạng PUI huấn luyện bắn đạn cỡ 82 mm theo nguyên lý động - phản lực. Xây dựng chương trình MATLAB tính toán thuật phóng để đảm bảo quỹ đạo của đạn huấn luyện phù hợp với đạn chiến đấu, các tác giả đã phân tích ảnh hưởng của hai thông số chính: cỡ đạn bắn tập (d) và loại thuốc phóng. Kết quả cho thấy thuốc phóng NBL-62 làm giảm đáng kể áp suất lớn nhất và ổn định đặc trưng thuật phóng so với NBL-34. Nghiên cứu xác định $d = 23$ mm với NBL-62 là cấu hình tối ưu, đảm bảo thiết bị nhỏ gọn, áp suất thấp và ổn định. Những phát hiện này cung cấp cơ sở khoa học quan trọng cho việc thiết kế và chế tạo thiết bị huấn luyện đạn chiến đấu cỡ 82 mm theo nguyên lý động - phản lực.

Từ khoá: Thiết bị bắn tập PUI; Động phản lực; Thuật phóng trong; Thuật phóng ngoài.