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Research on the change in ballistic characteristics of ammunition with a modified projectile shape during its movement in an air environment

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***Abstract*. When changing the shape of a projectile in order to reduce its ricochet effect when encountering a water environment, its ballistic characteristics during its movement in the air are also altered, such as projectile speed, range, ballistic coefficient, and shooting grouping. The present study aims to determine the influence on the projectile's speed and ballistic coefficient of the radial rings made on its ogive part.**

Keywords: external ballistics, form factor, ballistic coefficient, modified projectile.

I. INTRODUCTION

Changing the shape of the projectile causes changes in its ballistic characteristics: projectile velocity, ballistic coefficient, grouping of shots, and air resistance force. The impact of changing the projectile's shape on the average point of impact is presented in [1].

The ballistic coefficient (BC) allows for the determination of the trajectory and the analysis of other ballistic characteristics of the projectile. The value of BC is provided by ammunition manufacturers on the boxes and in the ammunition manuals, as well as on the company's website. Due to manufacturing deviations in the dimensions and mass of the projectiles, as well as differences in atmospheric conditions during experimental shootings, the value of BC is inaccurate. This inaccuracy turns into an error and makes any analysis based on the external ballistic characteristics of the projectile with this BC inaccurate. Having an accurately determined BC is extremely important for conducting a correct external ballistic analysis.

II. MATERIALS AND METHODS

The subject of the study is a standard projectile of ammunition with the nomenclature number 7.62x54mm, as well as five modified projectile models with radial-slotted channels on the ogive part, shown in Fig. 1, and with the number and setback of the channels from the tip indicated in Table 1.

The study is conducted following the methodology outlined in [2]

The required minimum number of experimental data in the series is determined according to the methodology from [3], [4] which was also used in [5].

TABLE 1 THE MODELS

№	**Name of the model**	**Distance of the channel from the tip of the projectile (mm)**	
		First	**Second**
1.	Model 1		
2.	Model 2	3	
3.	Model 3	3	6,4

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4.	Model 4	6,4	
5.	Model 5	12,7	
6.	Model 6	3	12,7

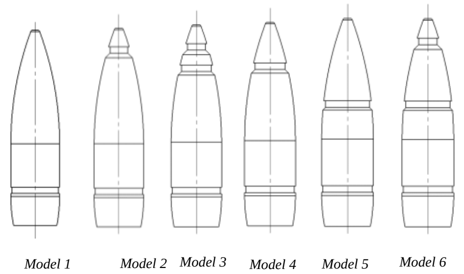

Fig. 1 The models of ammunition used in the experiment

1. Model 1 – Projectile with unchanged shape,
2. Model 2 – Projectile with one channel, located 3 mm from the tip,
3. Model 3 – Projectile with two channels, located 3 mm and 6.4 mm from the tip,
4. Model 4 – Projectile with one channel, located 6.4 mm from the tip,
5. Model 5 – Projectile with one channel, located 12.7 mm from the tip,
6. Model 6 – Projectile with two channels, located 3 mm and 12.7 mm from the tip.

For the conduct of the study, a ballistic barrel mounted on a stand (Fig. 2) and leveled with a precision level is used. Series of 20 shots from each model are fired. The velocity of the projectile is measured at 25 m from the muzzle end of the ballistic barrel using the Drello bal 4040 speed measuring device [2].

Fig. 2 A stand with a ballistic barrel mounted on it and secured to a foundation.

The ballistic coefficient is determined by the formula (1) [6], [7], [8]:

$$BC = \frac{id^2}{m} \quad (1)$$

where:

i – shape factor of the projectile;

d – caliber of the projectile (mm);

m – mass of the projectile (g).

The shape factor of the projectile allows for the calculation of the ballistic coefficient for each individual model and is determined by formula (2) [9]:

$$i = \frac{R}{R_{st}} \quad (2)$$

where:

R – resistance force of the projectile with a modified frontal part;

R_{st} - resistance force of a standard projectile.

The components of the air resistance force that affect the flight of the projectile are:

- Front part resistance.

When moving through the air, the projectile displaces air to the sides. A part of the kinetic energy of the bullet is used to displace the air. This loss of energy is due to air resistance and causes a constant decrease in the velocity of the bullet. The compression of the air created by the nose of the projectile spreads through space as a pressure wave and creates a disturbance that moves through space at the speed of sound. When the projectile moves at a speed less than the speed of sound (less than 340 m/s), the waves move ahead of the projectile and spread far from it (Fig. 3).

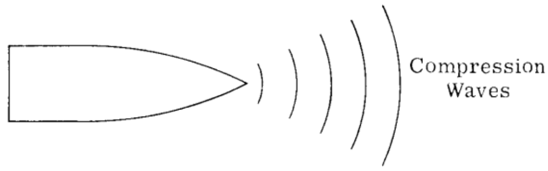

Fig. 3 Pressure waves created by the movement of a projectile in an air medium at subsonic speed [10].

The resistance of the front part increases significantly at projectile speeds above the speed of sound. Then, the compression waves cannot propagate far from the projectile, as it moves faster. They accumulate into a shock wave at the nose of the projectile (Fig. 4).

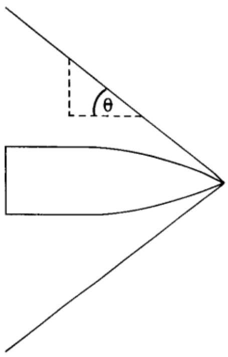

Fig. 4 Shock wave created by the movement of a projectile in an air medium at supersonic speed [10].

- Base resistance.

Turbulence is created behind the projectile, causing additional resistance. The reason is a low-pressure zone immediately behind the projectile, which occurs because the air cannot return quickly enough behind the projectile (Fig. 5). The result is a vacuum, which manifests as resistance to motion.

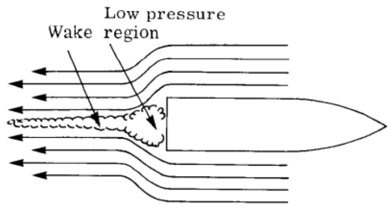

Fig. 5 Turbulence created behind the projectile [10].

• Surface resistance.

Additional resistance during motion is manifested by the air adjacent to the surface of the projectile. The air moves along the surface at the velocity of the projectile. Due to internal friction, the next layer of air particles also begins to move, but at a slower speed.

This layer imparts motion to the next, with each successive layer reducing its speed. Achieving a higher roughness class in the manufacturing of the projectile reduces surface resistance [10].

• Resistance of protuberances.

The resistance of protuberances is caused by the protrusions on the body of the projectile. This component of the air resistance force can be greatly reduced by removing the protrusions on the body of the projectile, and those that cannot be removed should be properly designed [10].

The air resistance force can be determined by the measured velocities with formula (3) [9]:

$$R_{cp} = \frac{q}{2g}\frac{v_1^2 - v_2^2}{L} \quad [N] \qquad (3)$$

where:

q – gravitational force on the projectile (N);

g – acceleration due to gravity (9,81 m/s^2);

L – distance between the velocity measurement points (m);

v_1 – initial velocity of the projectile (855 m/s) [11];

v_2 – velocity of the projectile, measured at a distance L (m/s) [12].

III. THE RESULTS

The velocities of the different projectile models, measured at a distance of 25 m, are indicated in Table 2 [12].

Table 2 THE VELOCITIES

Ammunition /type/, batch	7,62 x 54 mm ammunition Г 13-80-10					
Air temperature	15°C					
Charge temperature	18°C					
Number of the model	0	1	2	3	4	5
Measured velocity at 25 m V_{25} [m/s]	828	826	824	827	816	811

The values of the air resistance force for each individual model from the experiment are given in Table 3 based on calculations according to formula (3).

Table 3 THE VALUES OF THE AIR RESISTANCE FORCE

№	**The name of the model**	**Resistence force Rcp (N)**
1.	Model 1	8,724672
2.	Model 2	9,311437292
3.	Model 3	9,876144205
4.	Model 4	8,983057602
5.	Model 5	12,42824248
6.	Model 6	13,90691601

After substituting the values of the air resistance force into formula (2), we obtain the values for the shape factor of the projectile (i) for each model in the experiment. The results are presented in Table 4.

Table 4. THE VALUES OF THE SHAPE FACTOR OF THE PROJECTILE

№	**The name of the model**	**Shape factor of the projectile i**
1.	Model 1	1
2.	Model 2	1,067253565
3.	Model 3	1,131978853
4.	Model 4	1,029615509
5.	Model 5	1,42449395
6.	Model 6	1,593975797

When calculating the BC, the same mass value for the projectile cannot be used due to the material removed to create the channels in the ogive part. The mass of the standard projectile is 9.6 g [13], and for each model of modified projectiles, the mass will be reduced by the amount of material calculated to have been removed in the creation of the radial channels [10]. The mass of the projectile for the respective model is given in Table 5.

Table 5 THE MASS OF THE PROJECTILE

№	**The name of the model**	**Mass of the removed material (g)**	**Total mass of the projectile (g)**
1.	Model 1	0	9.6
2.	Model 2	0,049612	9,550388
3.	Model 3	0,1126475	9,4873525
4.	Model 4	0,0630355	9,5369645
5.	Model 5	0,0646055	9,5353945
6.	Model 6	0,1142175	9,4857825

After all the components necessary for determining the BC have been calculated, they are applied in formula (1). The results are presented in Table 6

Table 6 THE RESULTS OF THE BC

№	**The name of the model**	**Balistic coefficient (mm2/g)**
1.	Model 1	6,534
2.	Model 2	6,973435
3.	Model 3	7,39635
4.	Model 4	6,727508
5.	Model 5	9,307643
6.	Model 6	10,41504

IV THE CONCLUSION

The calculated ballistic coefficient for the modified ammunition is smallest for Model 4 (with one radial channel located 6.4 mm from the tip of the projectile) and is very close to that of the standard projectile. This indicates that, aerodynamically, this projectile has characteristics most similar to the standard projectile. On the other hand, a projectile with the same channel distance, made on the ogive part, showed the best angle for forming a cavitation cavity when encountering a water medium [14]. The creation of such a cavity leads to a reduction in the projectile's ricochets from a water medium. Thus, the projectile from Model 3 has both limited ricochet action and good aerodynamic qualities.

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