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CONTENT
SADRŽAJ

TEMPERATURE CONDITIONS INFLUENCE ON THE CHANGE IN THE INITIAL VELOCITY OF THE 6.5 MM GRENDEL PROJECTILE

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ABSTRACT: *In this paper, the experimental method and mathematical procedure of measuring the 6.5 mm Grendel projectile's initial velocity at different temperatures, were analyzed. A mathematical model of external ballistics has been defined, that is, a mathematical calculation of the projectile's initial velocity has been made for the given conditions. The aim was to perform a comparative analysis at different temperatures based on the obtained results (analysis of the experiment and the mathematical model of external ballistics). The goal of this paper was to determine, based on experimental testing and mathematical calculations, whether the gunpowder for the Grendel 6.5 mm projectile is thermostable.*

Keywords: *initial velocity, 6.5 mm Grendel projectile, experiment*

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1. INTRODUCTION

Small-caliber bullets are intended for the destruction and incapacitation of unshielded and poorly shielded manpower, lightly armored and unarmored motor vehicles, and other technical material assets, especially at distances up to 100 m. It is crucial to shield the troops within motor vehicles from the effects of projectiles since the troops transported by such vehicles are an extremely easy group target. Paper [1] investigates with FEM (Finite element method) the minimum thickness of ballistic plates in order to protect the troops and military equipment. Small-caliber projectiles do not contain any destructive charges, instead, they operate by transmitting their kinetic energy to the target. Small-caliber projectiles present an object of interest and research, beginning with testing the resistance of the ballistic plate made of steel 1.3964 to the penetration of a 7.62 mm bullet [2]. In papers [3,4] optimal design and optimization of the head shape of a small-caliber supercavitating projectile were developed. Modern small-caliber bullets generally have a jacket and a core. The jacket is most often made of tombac (a brass alloy with high copper content and 5–20% zinc content). Paper [5] deals with the mechanical characterization of rings directly extracted from the jackets of small-caliber ammunition. In addition to tombac, the jacket is also made of mild steel coated with a thin layer of copper or some copper alloy. The core is made of lead with 10% antimony to increase strength. Given that weapons, as well as ammunition, are used in different weather conditions, it is very important to determine the thermostability of gunpowder. In paper [6], a TES (thermal energy storage) system is developed to examine the stability of expanded graphite and solar salts (KNO_3/$NaNO_3$) at high temperatures. This thermal reaction accelerates the start of the exothermic reaction of the TES system while being substantially comparable to the thermal responses of the gunpowder.

The aim of this paper is to determine the influence of atmospheric temperature change on the 6.5 mm Grendel projectile initial velocity change. All the experimental data will be presented in the paper.

A 6.5 mm Grendel bullet was used for the experiments and it is shown in Fig. 1.

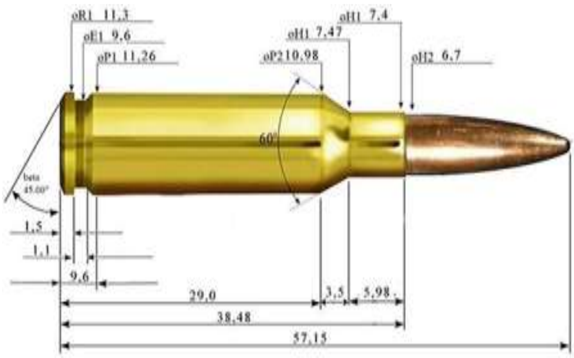

Fig.1. 6.5 mm Grendel bullet

2. EXPERIMENT

The aim of the experiment is to examine the effect of changing temperature conditions on the initial velocity of a 6.5 mm ammunition projectile. Based on the results, a comparative analysis will be performed with the mathematical model of external ballistics and experimental testing.

In this paper, a method based on measuring the time it takes for a projectile to travel between two points whose distance is known is used to determine the initial velocity of the projectile. The procedure is as follows: in two points of the path (Fig.2), detectors are placed and connected to the stopwatch (H). The detector at point A is starting the stopwatch, and the detector at point B is turning it off. Thus, the stopwatch registers the time required for the bullet to travel from point A to point B.

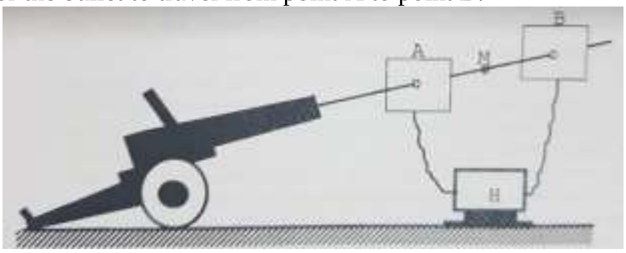

Fig. 2. Method for measuring the projectile's initial velocity [7]

Photocells or square frames (velocity barriers) through which current flows are used as detectors so that when a magnetized projectile passes, an electromagnetic field is induced and the possibility of receiving an impulse to start or stop the stopwatch is created. The average projectile velocity between points A and B is determined as [8]:

$$v = \frac{\overline{AB}}{t} \tag{1}$$

If points A and B are close, the projectile velocity corresponds to point M, which is in the middle of AB. If the length of the base is x, and the measured time is t, then, given the length of the base, the projectile velocity at the point in the middle of the base M is [8]:

$$v_M = \frac{x}{t} \tag{2}$$

The decrease in projectile velocity from the muzzle of the barrel to point M is determined by the path calculation method in external ballistics and is defined as [8]:

$$\Delta v_0 = \frac{id^2\delta}{m\delta_0} D(v)\, x_M \tag{3}$$

where are: i - the projectile shape coefficient, d - caliber, m - projectile mass, δ - air density in shooting conditions, δ_0 - air density at standard conditions, $D(v)$ - function of dependence on the adopted resistance law, and x_M - the distance from the muzzle of the barrel to point M.

Accordingly, the projectile's initial velocity is [8]:

$$v_0 = v_M + \Delta v_0 \tag{4}$$

If the experiment is conducted at a certain angle of elevation, then the loss of projectile initial velocity due to the action of the earth's gravity is also calculated [8]:

$$\Delta v_q = \frac{qtg\theta_0}{V_M} x_h \tag{5}$$

where are: g - the acceleration of the Earth's gravity, and x_h - horizontal distance of the center of the base from the muzzle of the barrel.

In that case, the projectile initial velocity is [8]:

$$v_0 = v_M + \Delta v_0 + \Delta v_q \tag{6}$$

In practice, the projectile initial velocity is measured for the entire group of bullets, and then the average value of the initial projectile velocity for the entire group is determined. The accuracy of the measurement depends on the accuracy with which the base length $\overline{AB}$ and projectile flight time are measured. The base measurement error is 0.05%, so the projectile's initial velocity is obtained with an accuracy of 0.05%. To rule out possible measurement mistakes, the initial velocity is measured with two stopwatches. The average value is taken from the two values obtained if they do not differ from each other by more than: $3\ \frac{\mathrm{m}}{\mathrm{s}}$ for the projectile's initial velocity up to $600\ \frac{\mathrm{m}}{\mathrm{s}}$ and 0.5% for the velocity over $600\ \frac{\mathrm{m}}{\mathrm{s}}$ [8].

2.1. Measuring equipment used in the experiment

Measuring equipment used in the experiment is: **velocity barriers A and B,** in which detectors are placed and connected to the stopwatch; **"VÖTSCH" cooling and heating chamber** which is used for cooling and heating the ammunition with frames and rifle, which can operate in the temperature range from -42 to +100 ˚C (Fig.3), and **device for measuring projectile initial velocity "EPVAT"**. The tasks of this system are to provide: Graph and maximum pressure value in the chamber, graph and maximum port pressure value, velocity (any combination, from the muzzle barrel, two optical gates, and target), action time (and generally all time intervals), X and Y coordinates of the shot in the target system, terminal projectile velocity and projectile energy.

Fig. 3. "VÖTSCH" chamber

2.2 Procedure of experimental testing

During the experimental testing, the ammunition and the rifle itself will be exposed to different ambient temperatures. Heating and cooling are done in the "VÖTSCH" chamber (shown in Fig.3). Ammunition and the rifle are inserted into the chamber, and when they reach the appropriate temperature, they are removed from the chamber and assembly of the ammunition frame and the rifle that is used during experimental testing is carried out. The temperatures at which the experimental testing was performed are: -30 ˚C, normal conditions 20 - 24 ˚C, and +50 ˚C. The firing is carried out in the tunnel, and with the "EPVAT" system projectile initial velocity is measured. For all three temperature cases, 10 bullets were fired.

2.2.1 Projectile initial velocity measurement at a temperature of -30 ˚C

Testing begins with turning on the chamber and setting the thermostat to a temperature of - 30 ˚C. It takes 1 hour to reach the specified temperature.

When the chamber reaches temperature the ammunition frame and the rifle are inserted (Fig.4 – left). After 2 hours of cooling, the rifle with the frame reaches the set temperature (Fig. 4 – right).

Fig.4. Inserted ammunition frame and the rifle into the chamber – left, frame ammunition and rifle after reaching the temperature of -30 °C

The projectile's initial velocity is measured by shooting through the barrier as shown in Fig.5 – left. After firing, the barrel of the rifle is heated, and the ice begins to melt, as shown in Fig. 5 – right.

Fig.5. Shooting through the velocity barrier, set at 10m, after reaching -50 °C – left, heating of the rifle barrel and the ice melting – right

In the table 1 are presented measured projectile initial velocities at a temperature of -30 ˚C and the average projectile initial velocity v_{10} (10 bullets fired for each experiment) of $665.257\ \frac{\mathrm{m}}{\mathrm{s}}$.

Table 1. Projectile initial and average velocity measured at a temperature of -30 °C

Round	Time [ms]	Projectile initial velocity [m/s]
1	1.5219	657.087
2	1.4943	669.223
3	1.5008	666.315
4	1.5077	663.240
5	1.4942	669.250
6	1.5015	666.021
7	1.4899	671.189
8	1.5038	664.976
9	1.5040	664.888
10	1.5143	660.377
Avg.	1.5032	665.257

2.2.1.1 External ballistics mathematical model for a temperature of -30 ˚C

Based on the mathematical model projectile initial velocity can be calculated. v_0 represents projectile initial velocity and can be calculated as:

$$v_0 = v_{10} + \Delta v_0 \tag{7}$$

and Δv_0 can be calculated as:

$$\Delta v_0 = \frac{10Cx_{10}}{D\left(v_{10}\right)} = 6.147 \ \frac{\mathrm{m}}{\mathrm{s}} \tag{8}$$

where are: v_{10} - the measured average projectile initial velocity at the center of the base, x_{10} - the distance from the muzzle of the barrel to the center of the base, Δv_0 - the projectile initial velocity drop from the muzzle of the barrel to x_{10}, C - the ballistic coefficient for Siacci's law of resistance, $D\left(v_{10}\right)$ - the velocity function, whose values are given in table 2 (based on table 2 the value is 45.39).

Table 2. The velocity function [8]

v_{10} *[m/s]*	$D\left(v_{10}\right)$
400	77
450	65
500	57
550	53
600	49
650	46
700	44
750	44
800	41

$$C = \frac{id^2}{m} \cdot 10^3 = 2.79 \tag{9}$$

where are: C - the ballistic coefficient of the projectile, m - the projectile mass, d - bullet grain diameter – caliber, i - projectile shape coefficient.

Based on the previous calculation, the projectile initial velocity is:

$$v_0 = v_{10} + \Delta v_0 = 665.257 + 6.147 = 671.404 \ \frac{\mathrm{m}}{\mathrm{s}} \tag{10}$$

2.2.2 Projectile initial velocity measurement at normal conditions (20 ˚C - 24 ˚C)

In the table 3 are presented measured projectile initial velocities at a temperature of 20 ˚C - 24 ˚C and the average projectile initial velocity v_{10} (10 bullets fired for each experiment) of $696.77\ \frac{\mathrm{m}}{\mathrm{s}}$.

Based on the previous calculation presented in chapter 2.2.1.1 calculated projectile initial velocity is:

$$v_0 = v_{10} + \Delta v_0 = 702.917\ \frac{\mathrm{m}}{\mathrm{s}} \tag{11}$$

Table 3. Projectile initial and average velocity measured at a temperature of 20°C–24°C

Round	*Time [ms]*	*Projectile initial velocity [m/s]*
1	1.4217	703.401
2	1.4388	695.010
3	1.4421	693.447
4	1.4391	694.878
5	1.4333	697.668
6	1.4308	698.902
7	1.4297	699.445
8	1.4348	696.965
9	1.4375	695.665
10	1.4444	692.323
Avg.	1.4352	696.770

2.2.3 Projectile initial velocity measurement at a temperature of 50 ˚C

In the table 4 are presented measured projectile initial velocities at a temperature of 50 ˚C and the average projectile initial velocity v_{10} (10 bullets fired for each experiment) of $729.759\ \frac{\mathrm{m}}{\mathrm{s}}$.

Table 4. Projectile initial and average velocity measured at a temperature of 50 °C

Round	*Time [ms]*	*Projectile initial velocity [m/s]*
1	1.3765	726.499
2	1.3600	735.306
3	1.3677	731.140
4	1.3653	732.450
5	1.3605	735.015
6	1.3689	730.536
7	1.3752	727.145
8	1.3790	725.164
9	1.3794	724.947
10	1.3710	729.386
Avg.	1.3703	729.759

Based on the previous calculation presented in chapter 2.2.1.1 calculated projectile initial velocity is:

$$v_0 = v_{10} + \Delta v_0 = 729.759 + 6.147 = 735.905 \ \frac{\text{m}}{\text{s}} \tag{12}$$

From the diagram in the Fig. 6 it can be noticed that with an increase in temperature for the ammunition frame and a rifle, the time required for the projectile to travel from the velocity barrier A to velocity barrier B decreases.

The time required for the projectile to travel from velocity barrier A to velocity barrier B (Fig. 2 and Fig. 5 – left) for three experiments is shown in the diagram in Fig. 6. Each projectile velocity for three experiments is shown in the diagram in Fig. 7.

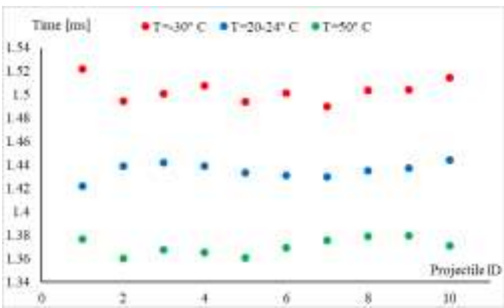

Fig. 6. Time required for the projectile to travel from velocity barrier A to velocity barrier B

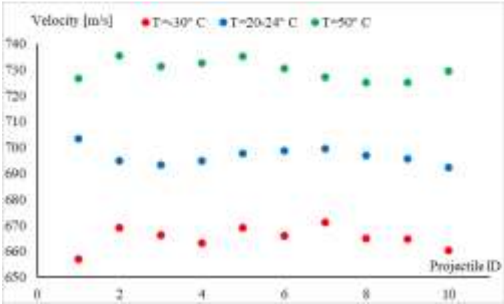

Fig. 7. Projectile velocity

It can be noticed that with an increase in temperature for the ammunition frame and a rifle, the velocity of the projectile increases.

3. CONCLUSION

Based on the obtained results, it can be concluded that the influence of the temperature change is significant because there is a greater oscillation of the projectile initial speed in the temperature range from -30 to 50 ˚C. Velocity change in relation to the average value of the measured projectile initial velocities values is $64.502\ \frac{\text{m}}{\text{s}}$, which represents a deviation of 9.26% from the average initial velocity in normal conditions ($T = 20 - 24°C$). Experimental testing showed that the initial speed of the projectile under normal conditions is $696.77\ \frac{\text{m}}{\text{s}}$. At a temperature of -30 ˚C, the projectile initial velocity decreases by 4.52%, while at a temperature of 50 ˚C, the projectile initial velocity increases by 4.73%. The conclusion is that the change in atmospheric temperature affects the firing process. These deviations lead to undershoots or misfires when shooting at the target. The temperature has the main influence on the combustion of gunpowder, which causes a change in the pressure of gunpowder gases, thus leading to a change in the projectile initial velocity.

Based on the experimental and theoretical testing, and comparative analysis it can be concluded that the gunpowder for the 6.5 mm Grendel bullet is not thermostable.

For the purpose of further research, the influence of the gas devices (flash suppressor and muzzle brake) on the change in the projectile's initial velocity should be tested. Also, an analysis of the change in the projectile's initial velocity on the shooting cadence can be performed.

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4. LITERATURE

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