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SNIPER RIFLE CARTRIDGE

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Abstract

The paper proposes a modification of the 7.62 mm NATO rifle cartridge. The design and the results of a computer simulation were presented. The projectile's flight behavior under different weather conditions was simulated. A figure diagram and a digital model of the projectile were presented. Ballistic calculations were performed, and an animation showing the projectile's behavior under various weather conditions was developed. The results were patented.

Introduction

This study describes a sniper rifle **cartridge**. The design was patented (SYROKA, SKŁODOWSKA 2020). A cartridge has two definitions in military terminology. In the basic definition, a cartridge is a unit of ammunition for a single shot – a gun cartridge (handgun, shotgun or rifle) or an artillery cartridge. A cartridge consists of:

– a projectile,
– propellant (such as gunpowder),
– and in fixed ammunition, also:
– primer,
– casing, such as a brass shell, that houses all projectile components.

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In the second definition, a cartridge is a propellant charge (such as a gunpowder cartridge) that is located behind the projectile in the firing chamber and leads to the explosion of gas in the barrel.

The designed cartridge has several advantages. It contains a lead core and penetrates hard targets at longer ranges. The projectile has an elongated shape, which increases its mass, reduces air resistance, and increases travel velocity, thus enabling the projectile to reach the intended target faster. The use of nitrocellulose powder as propellant slows down and stabilizes the burn rate in all types of weather, and it increases and stabilizes internal pressure which is always consistent with the specification.

Ammunition can be defined as cartridges that are intended for use in firearms. The main aim of sniper rifle ammunition is to neutralize a live enemy target.

Existing ammunition designs for sniper rifles

7.62×51 mm NATO cartridge

The cartridge was developed by the Institute of Armament Technology at the Faculty of Mechatronics and Aviation of the Military University of Technology in Warsaw and MESKO S.A. Metal Factory (presently MESKO S.A.) in Skarżysko--Kamienna. The cartridge contains a standard projectile with a lead core. Projectile tips are color-coded to indicate their type and designation. For example, projectiles with red tips are intended for live targets, whereas projectiles with black tips are light armor penetrators with a range of up to 500 m. Differently colored projectiles do not differ in size, but they contain different propellants or powders.

.300 Winchester Magnum

.300 Winchester Magnum measures 7.62×67 mm, and it was developed by the US Army. It was initially used by hunters, and it is currently deployed in police sniper rifles. Similarly to the 7.62×51 mm NATO cartridge, .300 Win Mag has differently colored tips to identify various projectile types.

.338 Lapua Magnum

.338 Lapua Magnum measures 8.6×70 mm or 8.58×70 mm. It has been designed for sniper rifles, but it is also used in hunting rifles. The cartridge was produced by the Finnish ammunition manufacturer Lapua, and it combines the features of 7.62 mm and 12.7 mm NATO cartridges. .338 Lap Mag has a maximum effective range of 1,000 m, and it is not much heavier than NATO cartridges.

Structural design of a patented cartridge for sniper rifles

The cartridge is presented in Figure 1, and the projectile is shown in Figure 2. The sniper rifle cartridge was designed as a long-range cartridge for penetrating hard targets. The cartridge (*1*) contains a lead projectile (*2*) in a brass jacket. The cartridge has a sharp tip (*3*), and the tungsten carbide core (*4*) weighs 1.62 g. Core height is equal to 2/3 of projectile length, and core width is equal to 1/3 of projectile width. The shell (*5*) was crimped to a length of 69.00 mm, and it contains N140 nitrocellulose powder (68.8%) (*6*). The shell is connected to a Large Rifle Magnum primer.

Projectile seating depth is 7.60 mm. The core material is protected against excess gas and friction by a solid brass jacket with a bridge. The cartridge has a boat tail base. Shell length is 69.00 mm. Shell volume is typical for projectiles of the type. The shell is filled with N140 nitrocellulose powder (*6*) with a weight of 4.760 g. A Large Rifle Magnum primer (*5*) is integrated into the base of the cartridge. This primer is characterized by higher explosive energy which facilitates the ignition of spherical powder propellant. Cartridge length is 81.42 mm.

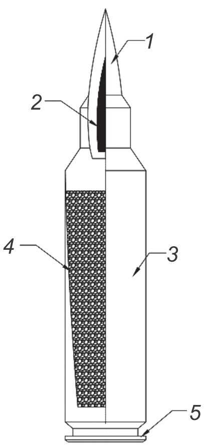

Fig. 1. Cartridge for a sniper rifle; description in the text

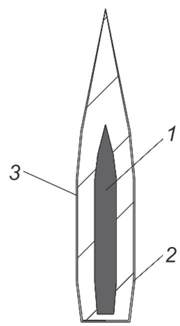

Fig. 2. Projectile in the sniper rifle cartridge; description in the text

Projectile design and model

The trajectory of the designed projectile was calculated with Gordons Reloading Tool software. The program supports the selection of materials, primers and powders. All values are calculated automatically, the results are presented graphically in diagrams, and the optimal values are suggested. Trajectory calculations are presented in a diagram in Figure 3.

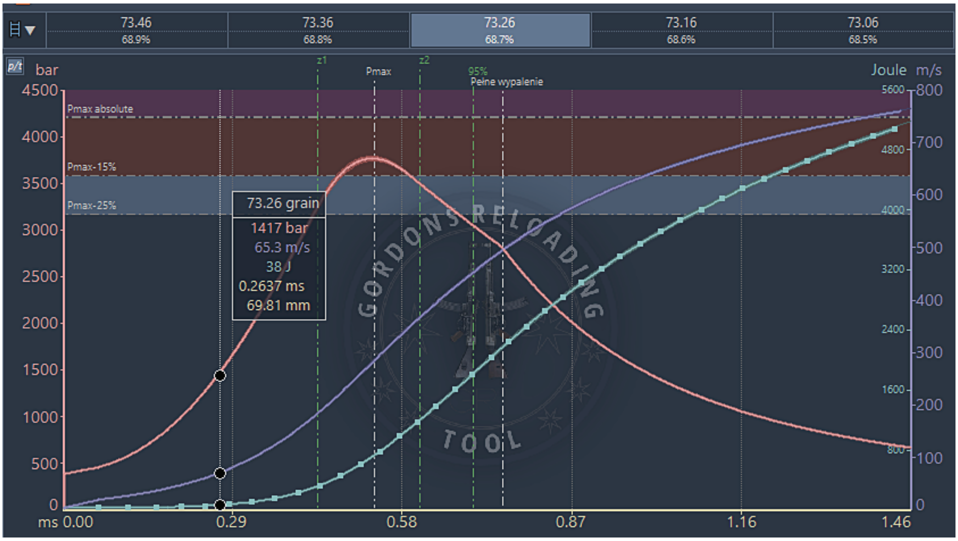

Fig. 3. Calculations of a projectile's trajectory parameters

Cartridge model

The cartridge was modeled in Blender 2.8 software. The modeling process was divided into several stages. The projectile and its tip were modeled in the first stage. The carbide core was modeled in the second stage, and the shell and primer were modeled in the third stage.

Model of the projectile and the projectile tip

In the first step, the projectile was modeled with the Circle tool. Cell layers were extruded and transformed to generate a grid object. The projectile tip was modeled separately because projectiles designed for various purposes have differently colored tops. The Subdivision Surface modifier was added to smooth the edges of the modeled object. A model of a projectile without a tip is presented in Figure 4, and a model of the projectile tip is shown in Figure 5. The entire projectile is presented in Figure 6.

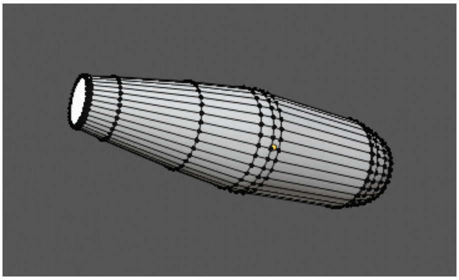

Fig. 4. Model of a projectile without a tip

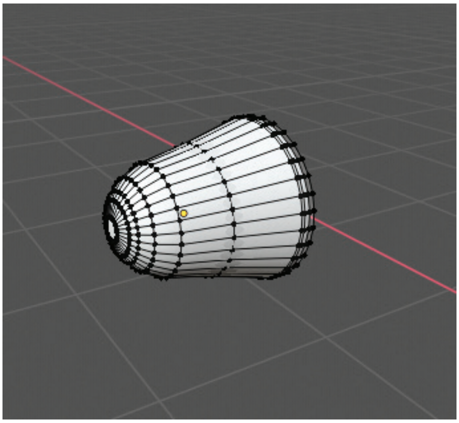

Fig. 5. Model of the projectile tip

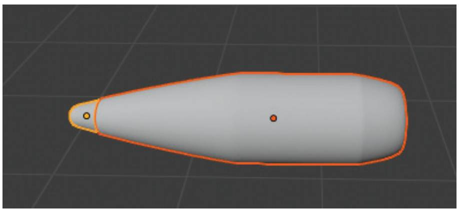

Fig. 6. Model of the entire projectile

Core model

In the first step, the projectile core was modeled with the Circle tool. The resulting object was rescaled, and a modifier was added to smooth the edges. In the last step, the core was connected to the projectile based on the location and characteristics described in the patent. The core model is presented in Figure 7, and the model of the projectile with the core is shown in Figure 8.

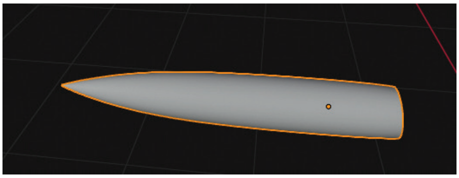

Fig. 7. Core model

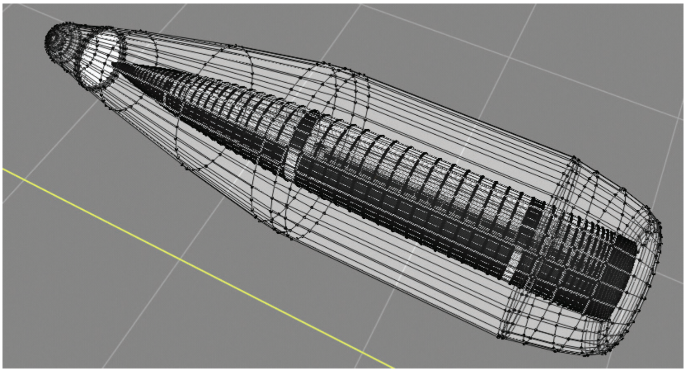

Fig. 8. Model of the projectile with the core

Shell model

The projectile, the projectile tip and the core were modeled with the Circle tool, whereas the shell was modeled with the Cylinder tool. The object was opened, and several commands were used to model the shell. Wall thickness was modeled with the Solidify modifier. The same method was applied to model the primer and the shell. The front view of the shell model is presented in Figure 9, and the rear view is presented in Figure 10.

The materials for all cartridge components were selected. Nodes were not used. The selection of color was most problematic. Surface color and texture were modeled by the selecting the appropriate values of Specular and Roughness.

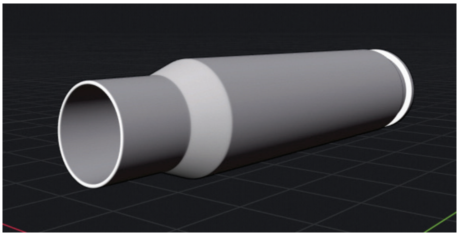

Fig. 9. Front view of the shell model

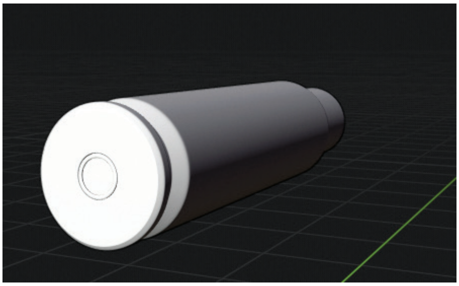

Fig. 10. Rear view of the shell model

Basic calculations

Ballistic resistance of armor against the designed projectile

Ballistic resistance is the protection offered by armor against projectiles that do not contain explosive materials. The ballistic resistance of armor is influenced by the projectile's kinetic energy which is calculated with the use of the following equation (SPERSKI 2009):

$$\frac{\left(m \cdot v_p^2\right)}{2} = k \cdot \pi \cdot d \cdot h \cdot h \tag{1}$$

where:

m – projectile's mass [kg],
v_p – projectile's velocity upon impact with target [m/s],
d – caliber [m],
h – shield thickness [m],
k – average shear stress on the lateral surface of a cylindrical shaft with base diameter d and height h (FLIS, SPERSKI 2012).

Shield thickness is calculated with the use of the following equation:

$$h = v_p \sqrt{\left(\frac{m}{K \cdot d}\right)} \tag{2}$$

where:

$$K = 2 \cdot k \cdot \pi \tag{3}$$

Coefficient K is determined experimentally for various types of steel and projectiles. Parameter K has to be computed, but a method where shield thickness is calculated based on the available data delivers better results. In this approach, the mass m_1 of a cuboid that comes into contact with the shield is calculated. The volume of shield material that is displaced by the projectile upon impact is equal to the volume of a cylinder with diameter d and height h (SPERSKI 2009):

$$m_1 = \rho \cdot \left(\frac{(\pi \cdot d^2)}{4}\right) \cdot h \tag{3}$$

where:

ρ – density of a shield made of steel with a density of 7,860 kg/m^3 (FLIS, SPERSKI 2011).

Projectile and shield parameters are presented in Figure 11 (SPERSKI 2009).

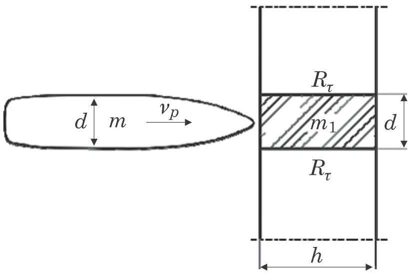

Fig. 11. Projectile upon impact with the shield

The initial velocity of the center of mass of a system composed of a projectile with mass m and a shield with mass m_1 is calculated with the use of the following equation:

$$v_0 = \frac{m}{m + m_1} \cdot v_p \tag{4}$$

where:

v_p – the projectile's velocity upon impact.

The distance that has to be traveled by the projectile to achieve a terminal velocity of 0 is referred to as the braking distance, and it is equivalent to the thickness of the penetrated shield. A projectile's braking distance is calculated with the use of the below formula (SPERSKI 2009):

$$s = \frac{(m + m_1)}{2 \cdot \pi \cdot d \cdot h \cdot R_\tau} \tag{5}$$

where:

R_τ – the shear strength of the shield material, which is calculated with Huber's equation:

$$R_\tau = 0.577 \cdot R_m \tag{6}$$

where:

R_m – the material's tensile strength which, in this case, equals 1,100 MPa.

The projectile's terminal velocity after shield penetration is calculated with the following equation (SPERSKI 2009):

$$v_k = \sqrt{v_0^2 - \frac{2 \cdot \pi \cdot d \cdot h^2}{m + m_1} \cdot R_\tau} \tag{7}$$

The following formula is applied to calculate shield penetration time (SPERSKI 2009):

$$t_k = \frac{m + m_1}{\pi \cdot d \cdot h \cdot R_\tau} \cdot (v_0 - v_k) \tag{8}$$

The above calculations were performed in Matlab.

The results of the calculations performed in Matlab for a projectile that travels in vacuum and does not penetrate the shield are presented in Table 1.

Table 1

Calculations for a projectile that does not penetrate the shield

Projectile's mass [kg]	0.019
Muzzle velocity [m/s]	736.2
Caliber [m]	0.00726
Shield thickness [m]	2.8
Shield density [kg/m^3]	7,860
Tensile strength [MPa]	1,100
Shear strength	634.7
Nose shape factor [°]	0.33
Acceleration of gravity	9.81
Height of the shooter [m]	1.72

cont. Table 1

Range [m]	2,532.5
Time of flight [s]	3.44
Velocity upon impact [m/s]	769.94
Volume of shield material displaced upon impact [m^3]	0.94
Initial velocity of the system's center of mass [m/s]	15.19
Distance traveled by projectile after impact [m]	2.64
Projectile's velocity after impact [m/s]	0
Shield penetration time [s]	0

The results of the calculations performed in Matlab for a projectile that travels in vacuum and penetrates the shield are presented in Table 2.

Table 2

Calculations for a projectile that penetrates the shield

Projectile's mass [kg]	0.019
Muzzle velocity [m/s]	736.2
Caliber [m]	0.00726
Shield thickness [m]	2.8
Shield density [kg/m^3]	7,860
Tensile strength [MPa]	1,100
Shear strength	634.7
Nose shape factor [º]	0.33
Acceleration of gravity	9.81
Height of the shooter [m]	1.72
Range [m]	2,532.5
Time of flight [s]	3.44
Velocity upon impact [m/s]	769.94
Volume of shield material displaced upon impact [m^3]	0.94
Initial velocity of the system's center of mass [m/s]	15.72
Distance traveled by projectile after impact [m]	2.83
Projectile's velocity after impact [m/s]	14.89
Shield penetration time [s]	0.0192

Conclusions:

The results indicate that the projectile will not penetrate the shield if shield thickness exceeds the distance traveled by the projectile upon impact. The range and time of flight can be determined when the projectile penetrates the shield.

Ballistic coefficient

The ballistic coefficient (BC) of a projectile is its ability to overcome air resistance, such as wind, during flight. This parameter is largely influenced by a projectile's geometric dimensions that affect aerodynamic drag. Aerodynamic drag, such as wind force, slows down a moving projectile. The ballistic coefficient is calculated with the use of the following equation:

$$\mathrm{BC} = \frac{\mathrm{SD}}{i} \tag{9}$$

where:

SD – sectional density determined with the GR calculator,

i – form factor which, in this case, is given by the following formula:

$$i = \frac{2}{n} \cdot \sqrt{\frac{4 \cdot n - 1}{n}} \tag{10}$$

where:

n – caliber of an ogive-tipped projectile.

The closer the value of BC is to one, the lower the aerodynamic drag and the more stable the projectile's flight. The designed projectile has a BC of 0.7798.

Gyroscopic stability

A fired projectile is subjected to gyroscopic drift which is an interaction between the projectile's mass and aerodynamic forces. One of such forces is wind which exerts an adverse impact on a projectile's trajectory. A projectile has to be stabilized to ensure that it precisely hits the target. This is accomplished through gyroscopic stabilization. Projectiles for high-precision rifles are affected by gyroscopic precession when:

– a projectile rotates around its axis of symmetry with a certain speed – the higher the projectile's spin rate, the greater the gyroscopic motion,

– the direction of a projectile's rotation around its axis of symmetry does not change,

– the forces acting on a projectile can rotate the projectile by as much as 90°,

– a projectile is characterized by complex motion in three-dimensional space, which resembles that of a spinning top.

Gyroscopic stability is determined by the twist rate of the barrel. The twist rate should equal 1, and it should be higher than 1.2 for sporting projectiles and higher than 1.5 for military projectiles to guarantee stability (EJSMONT 2019).

This solution is not free of defects, and it can lead to the horizontal deflection of a projectile. The projectile can be stabilized or the twist rate can be decreased to minimize horizontal deflection. The gyroscopic spin of a projectile can be calculated with a formula developed by Bryan Litz (EJSMONT 2019):

$$Z = 1.25 \cdot \left(s_g + 1.2\right) \cdot t^{1.83} \tag{11}$$

where:

S_g – gyroscopic stability factor calculated based on the Miller's twist rule,
t – time of flight.

Influence of wind on a projectile's trajectory

The presented examples apply to ideal conditions that are very difficult to achieve. Wind often influences a projectile's territory. A projectile can be deflected by crosswind that blows from right to left or from left to right, as well as by headwind that blows in the opposite direction of a projectile's flight path. These influences are very difficult to eliminate. Wind phenomena have been extensively studied, but their effect on a projectile's path is difficult to model. To compensate for this path deviation, the sighting components have to be adjusted based on the direction and speed of wind. The elevation angle at which the projectile leaves the muzzle has to be calculated. The Minute of Angle (MOA) adjustments to compensate for bullet drop at different wind speeds is given in Table 3. Wind angle was set at 90° and range at 500 m.

Table 3

Projectile's speed under different weather conditions

Wind speed [m/s]	Time of flight [s]	Velocity upon impact [m/s]	MOA
2	0.763	574	1.3
3	0.763	574	1.9
5	0.763	574	3.2

The time of flight and velocity upon impact with a target situated at a distance of 500 m are identical at different wind speeds, but the MOA ranges from 1.3 to 3.2. The MOA is critical for sighting the scope of a sniper rifle. The calculations were performed with the use of an online calculator, and they account for weather conditions such as temperature and barometric pressure. The parameters of a projectile influenced by a wind angle of 90° are presented in Table 4.

Table 4

Calculations for a projectile influenced by wind

Projectile's mass [kg]	0.019
Muzzle velocity [m/s]	736.2
Caliber [m]	0.00726
Shield thickness [m]	2.8
Shield density [kg/m^3]	7,860
Tensile strength [MPa]	1,100
Shear strength	634.7
Nose shape factor [º]	0.33
Acceleration of gravity	9.81
Height of the shooter [m]	1.72
Range [m]	2,532.5
Time of flight [s]	3.44
Velocity upon impact [m/s]	574
Volume of shield material displaced upon impact [m^3]	0.94
Initial velocity of the system's center of mass [m/s]	14.21
Distance traveled by projectile after impact [m]	2.32
Projectile's velocity after impact [m/s]	13.45
Shield penetration time [s]	0.0175

Conclusions:

The projectile's parameters are influenced by the direction of wind. When the direction of wind changes, the projectile's velocity upon impact also changes, and shield thickness that can be effectively penetrated by the projectile decreases. Therefore, the MOA has to be optimized to guarantee that the projectile precisely hits the target.

Animation of cartridge motion

When a round is fired, the cartridge is separated into two parts: the projectile and the shell. The spent shell is ejected from the chamber, and the projectile is fired from the muzzle (Fig. 12). The projectile travels towards the target and is flattened upon impact (Fig. 13). The projectile's trajectory was modeled in vacuum and under the influence of light wind with a speed of 2 m/s. The flattening of the projectile upon impact with the target was modeled in the animation. The tungsten carbide core is visible upon impact.

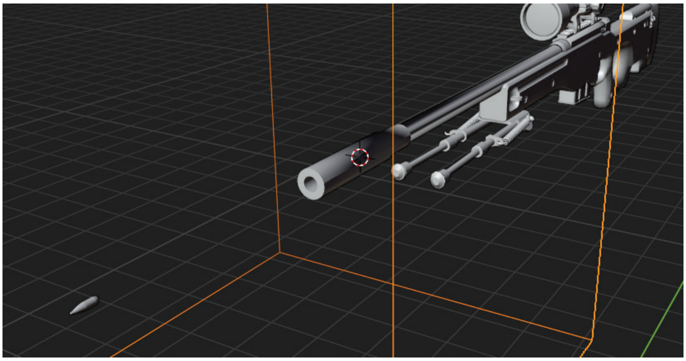

Fig. 12. Projectile leaving the muzzle

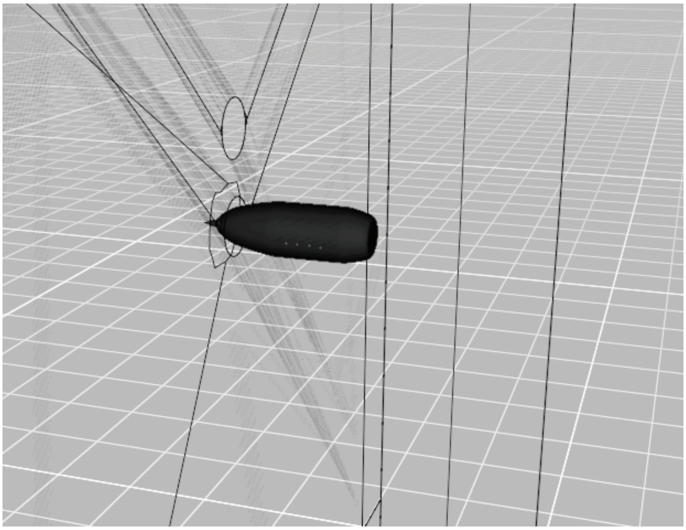

Fig. 13. Projectile upon impact with the target

Summary

The structure of a cartridge for a sniper rifle was described. The design process and basic calculations were presented. The projectile's behavior under different weather conditions was simulated. The designed cartridge was patented (Syroka, Skłodowska 2020).

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