ANALYSIS OF THE FACTORS AFFECTING THE STABILITY OF THE BULLET WHEN IT MOVES IN ENVIRONMENTS WITH DIFFERENT DENSITY

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***Abstract**: After being shot, the bullet has to pass through environments with different density and the ricochet phenomenon is often observed. It changes the energy of the bullet, its trajectory, and its integrity. By limiting the ricochet, both shooting efficiency and shooter safety are improved.*

***Keywords**: ballistics, bullet ricochet.*

АНАЛИЗ НА ФАКТОРИТЕ, ОКАЗВАЩИ ВЛИЯНИЕ ВЪРХУ СТАБИЛНОСТТА НА КУРШУМА ПРИ ДВИЖЕНИЕ В СРЕДА С РАЗЛИЧНА ПЛЪТНОСТ

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In many cases, the ricochet phenomenon is used and controlled to achieve the expected results, but in certain situations it may be dangerous and even deadly. The bullet loses some of its energy, its trajectory is changed, and its integrity is eventually impaired. For these reasons, it is advisable to limit the occurrence of unwanted ricochets. To do this, it is necessary to study the ricochet conditions from different types of surfaces and the emergence of dependencies that determine the conditions of its occurrence, the way the ricochet is controlled or its exclusion.

In the artillery shooting, ricochet shooting is used to achieve air explosion after the projectile has reached the ground (water) barrier. The ricochet explosions on people and outdoor ricochet in open trenches are much more effective than the ground, as the area, affected by the splinters, is bigger.

Ricochet shooting is used in combat aviation to cause significant damage to surface ships in ricochet bombardment.

Despite the long-standing practice of using ricochet, its use in shooting on water is not well-studied and there are no mathematical models that clarify the process. Partial research and experimental results have been published in some specialized publications.

The problem that should be analyzed is the factors that affect the stability of the bullet when moving in different environments. Factor analysis can be used to define the requirements of the bullet shape, which would improve its movement in different density environments and minimize ricochets. Obtaining a bullet with an optimal shape that meets the requirements for the necessary striking action in environments of different density is a problem of exceptional theoretical complexity. It requires simultaneous solving of three tasks - the task of the external ballistics, the movement in the air environment, the task of the strike of the bullet with water, which determines its shape for limiting the ricochet and the task of its stable movement in the water in the conditions of cavitation.

Conditions for bullet resistance in the air

Stability means the bullet's ability to resist the external forces that divert its longitudinal geometric axis from the tangent to the trajectory. If the angle formed by the longitudinal axis of the bullet and the tangent to the trajectory of the center of gravity (c.g.) increases as a result of the action of the external forces, the bullet is considered to be unstable when flying. If the specified angle which is due to these reasons is reduced, the bullet is considered to be steady.

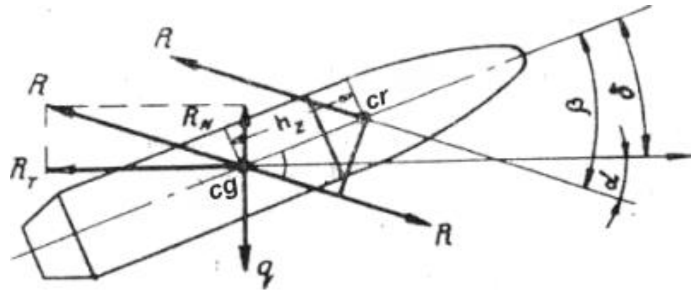


Fig. 1. Forces affecting the bullet when flying in the air.

The force of the air resistance *R* and the force of the bullet gravity *q* (Figure 1) refer to the external forces acting on the bullet in the air. The point of application of the force of air resistance is equal to surface forces, and it is called the center of resistance (c.r.).

The force of the air resistance is directed at a certain angle α relative to the tangent to the trajectory. The effect of this force becomes clearer if it is brought to the center of gravity of the bullet. By applying to the center of gravity two forces equal in value to the force *R* and directed to opposite sides and decomposing one of them into two components, we get a system of forces R_T, R_N and *q*, applied to the center of gravity, and also a pair of RR forces turning the bullet into the plane of the figure.

The force *q* causes the bullet to drop when flying, resulting in a distortion of the trajectory in the firing plane. The R_T force, called drag, causes delays in the bullet flight, resulting in descending branch of the trajectory being shorter than the ascending. The force R_N, called normal (lateral) force, causes the center of gravity to shift from the tangent to the trajectory. As the scheme of forces, which are shown in Fig. 1, revolves around the tangent to the trajectory (except the force q which retains its direction and magnitude), so the center of gravity resulting from the action of force R_N makes a helical line around the same tangent line. The torque of the pair of forces is:

(1) $$M = R.h_Z.sin\beta \approx R.h_Z.\ \beta$$

As it was pointed out, these forces try to rotate the bullet in the plane of the figure around the center of gravity, to divert its geometric axis from the tangent to the trajectory, increase the angle of the δ and impede the stability of the flying bullet. This torque is called reverse.

Two methods have been used in practice to ensure the bullets’ stability during their flight in the air.

The first method is to force a strong displacement of the center of the resistance back behind the center of gravity. In this case, the torque M, defined in formula (1), ceases to be reverse and becomes stabilizing. It occurs every time the projectile's axis deviates from the tangent to the trajectory. The strong displacement of the center of gravity is possible with the help of stabilizers. This ensures stability of mines, aviation bombs and non-rotating reactive projectiles.

The second method of providing stability is to render a great angular velocity of rotation to the bullet (projectile) around the longitudinal geometric axis. In this case, the effect of the turning torque does not cause an increase in the angle of the nutation β and rotation of the bullet when flying, but leads to a precession, i.e. the rotation of the bullet axis around the tangent to the trajectory.

The rotating movement of the bullet (projectile) is achieved by imparting the necessary tilt (curvature) to the rifling of the barrel.

The tilt angle of the rifling may be constant along the barrel (constant curvature rifling) and variable, increasing depending on the channel travel of the barrel from the breechblock to the muzzle (progressive curvature rifling).

Progressive rifling is made to reduce the pressure from the casing on the barrel and thus reduce the wear of the groove part of the barrel. [3]

Interaction of the bullet with water barrier

It is necessary to consider the cases of interaction of the bullet with the water barrier. Water has a significantly higher density than air (800 times). Practically at a bullet speed of 100 m/s, water is to the bullet like a solid barrier.

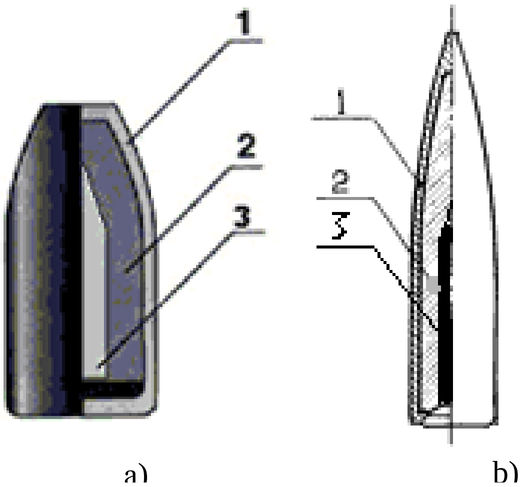


Fig. 2 Types of bullets and their elements
a) a bullet with long-range form; (b) a bullet with short-range form.
1 – shell (steel, brass, tompac); 2-lead; 3 – hard-alloy core.

Long-distance form bullets have a pointed front (Figure 2, b), and these with short-range form have a rounded front part (Figure 2, b). Bullets are produced also with a flat cut at the front.

In Russia, the Center for Independent Expertise on Automotive Transport has conducted an experiment on the interaction of a bullet with an aquatic environment. For the experiment, a mount was used to allow a firm fixation of the weapon, firing the bullet into a small pool with fresh water, and measuring the angle α with accuracy of one minute (Figure 3). A shot is produced, using an electro-trigger with pre-launch of high-speed camera that fixes the results of the experiment: the bullet's entry into the water, the movement, and the exit.

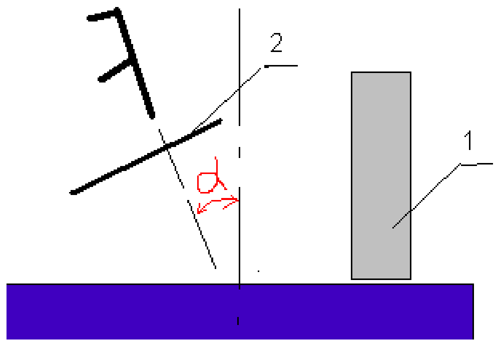


Fig. 3 Scheme for conducting an experiment on the interaction of a bullet with water barrier.
1-bullet catcher. 2-light barrier for stopping gunpowder gasses

The shooting was carried out with various ammunition and kinds of weapons. The experiment used both ordinary for the system cartridges and also cartridges with a flat cut, made with a file, resembling the expanding bullets of the hunting cartridges. About 100 shots have been produced. As a result of the experiment, it has been found that the angle of the bullet ricochet with water barrier with a pointed and rounded front has practically the same value and does not depend on the shape of the front part of the bullet.

Angle α, which has and does not have a 50/50 ricochet is for example 11 degrees and 40 minutes – the transition angle.

100% ricochet is absent at an angle α equal to 11 degrees and 15 minutes.

100% there is a ricochet at an angle α equal to 12 degrees and 00 minutes.

Expanding bullets (with a flattened front) often broke down when they encountered the water surface, and ricochet could not be seen. Also, the flat front of the bullet forms a cavitation cavity that prevents the bullet from exiting the water at an angle greater than 12 degrees. The experiment conducted allows us to conclude that a separate case study should be carried out with bullets with a flat front to determine the angle of the ricochet's occurrence.

It is also necessary to consider the case when the shot from the weapon is produced in close proximity to the water surface. In this case, there is an effect of breaking the water surface from the gunpowder gases, which overtake the bullet in the after-action phase, forming a cavity in which the bullet falls and a ricochet is not observed.

In the course of the experiment, it was found that the depth at which the bullet penetrates at the ricochet from a water surface is about 10-20 cm, and largely depends on the angle of encounter with the water surface. [2]

Combat tasks which are performed by the crew of the battleships include shooting at mines on the surface, high-speed small surface ships and boats, boarding operations, shooting at underwater enemy divers, etc. The position of the weapon against the water surface determines "advantageous" ricochet conditions (Figure 4).

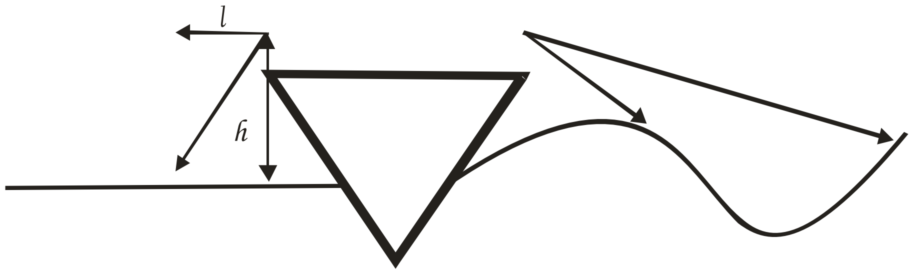


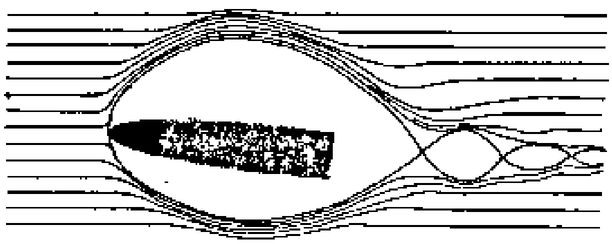
Fig. 4. Graph of ricochet conditions depending on the position of the weapon against the water surface. h - shooting height (board and shooter height); l - critical distance which has 100% ricochet; l / h - tan 300.

It can be seen from the figure that at height of the board h = 6 m, the critical distance for the ricochet is 3.46 m, i.e. when firing at distances greater than the one described above, the probability of a ricochet is 100%. The situation is even more complex in wave conditions, because the angle of incidence will be determined by the directrix of the shooting and the tangent at the point of encounter with the water surface, and they are unpredictable. Theoretically, there may be a shot from the deck of the ship towards an approaching wave that causes ricochet and return of the bullet to its own ship or a neighboring one in the group of ships. This presents a new perspective on the type of ammunition used in our navy. [1]

Principle of bullet movement in water

Water contains dissolved air, which is released from it when heated and the pressure increases. The effect of separating air from the water can be observed with the phenomenon "Cavitation". This effect is also used in this case. The APS machinegun bullet is a steel rod 120 mm long and 5,6 mm in diameter, which becomes thinner towards the front and ends with a flat cut with a diameter of about 2 mm. The bullet has considerable mass and with great force, coming from the kinetic energy, effects the water on the area of the flat cut (with a diameter of about 2 mm). Under the pressure from the water, air is released which forms an elongated cavity (cavern) and the air pressure in it is in the range of 0.01 - 0.1 atmospheres.

a)



b

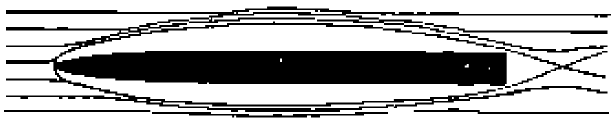


Fig. 5. The principle of bullet movement in an aquatic environment.
(a) the movement of a normal bullet; (b) the movement of a bullet designed
for shooting in an aquatic environment.

Stabilization in the direction of the bullet movement (preservation of the direction) occurs at the expense of the constant oscillation in the back side of the bullet in the walls of the cavity. After the bullet passes, the cavity collapses, leaving behind small air bubbles. The bullet will continue to maintain enough speed until the speed drops below the critical value. Then the cavity decreases its size at the rear, where friction on the bullet in the water increases greatly, resulting in slowing and stopping. The reduction of the range of fire with the depth of immersion is due to different water pressure at different depths and the consequent changes in the conditions for the formation of cavities.

The stability of the bullet and its movement are controlled by the laws of hydrodynamics (cavitation, etc.), which differ significantly from the principles of bullet flight stability in the air. In this connection, it is practically impossible to create a universal bullet for air and water. A rotating bullet or bullet with stabilizers will break the cavern, etc. All versions of the bullet for smoothbore weapons can only be simplified versions of projectiles for smoothbore artillery and hunting rifles. One of the versions may be the one, shown on Fig. 5 or its modifications, although developers are limited in the versions the cartridges.

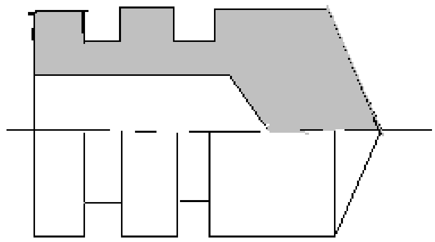


Fig. 6. A bullet variant for a smoothbore weapon, including a 12 and 16 caliber hunting weapon.

CONCLUSIONS:

1. The analysis of the stability requirements a single bullet has to meet when firing in different environments indicates that they are completely opposite when the bullet moves in air and water.
2. On the basis of this analysis, it can be concluded that it is more efficient to develop a model of the bullet shape in which its ballistic properties are preserved in air motion without ricochets from the water surface.

References:

1. Давидов К. С., Цонев Ц. Г., Маринов М. Г., “Минимизиране на вероятността от появата на нежелан рикошет при стрелба към водна повърхност”., НВУ „В. Левски“ Факултет “Артилерия, ПВО и КИС Научна сесия 2012. Сборник научни трудове – част I., Ш., 2013 (110 – 117 стр.) ISSN 1313-7433.
2. Взаимодействие пули с водной преградой, Исследование Центра независимой експертизой на автомобильном транспорте, РФ, 443098, С. https://www.cneat.ru/bullet.htm
3. Кирилов В.М., „Основи на устройството и проектирането на стрелковото оръжие“ стр. 139-141, София, 1975.