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POSSIBILITIES OF DETERMINING THE FRAGMENTS SPEED AFTER DETONATION BY CALCULATION

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Abstract:

The article describes methods for determining the speeds of fragments, which arise from the division of the body of the projectile or the payload by detonation of the working charge. The article summarizes the calculation methods for individual types of shells and charges. At the end of the article, the calculation of speed of the fragments, which arises during the shattering of the steel body of a 20 mm caliber projectile using a TNT filling, is given. The article also describes ways to verify the calculated values.

1 Introduction

At present, the demand for new types of ammunition, the task of which is to destroy special targets, is gaining ground in advanced armies. Increasing attention is being paid to the elimination of armored vehicles. On the other side, there is ammunition, the effect of which in the target should be such that it allows the elimination of only the target and does not cause unnecessary material damage. This type of ammunition can include, for example, "payloads" of unmanned aerial vehicles. These types of loads are transported to the place of use either by a kamikaze UAV means or by a means capable of providing repeated transport.

On the modern battlefield, UAVs in the field of observation have become an indispensable part in the conduct of modern combat. They provide a realistic picture of the situation on the battlefield and thus allow operational decisions to be made to eliminate potential dangers and minimize losses.

In real conditions, we encounter terrorism, which uses available conventional manufactured aircraft on which conventionally produced ammunition is placed - e.g. 40 mm grenades, which are adjusted with plastic tubes and badminton baskets, which provide stabilization when falling on target.

Fig. 1 Conventopnal UAV with improvised ammunition

Fig. 2 Detail view on improvised ammunition

In this paper, we will deal with the acceleration of metals by the detonation of explosives. This process is widely used in military as well as civilian practice. In military practice, it is most often used to determine the take-off speed of fragments, which arise after the initiation of an explosive charge placed in the projectile. These theoretical calculations will provide information on what take-off speed can be achieved and thus ensure the required kinetic energy of the shard, which has the task of disabling not only the technology but also the manpower of the enemy.

During fragmentation process, projectiles should have large number of fragments to increase probability of hit on target.

Fragments density enabling multiple hit on a target with enough kinetic energy for target penetration. Lethal fragment range depends on initial velocity, fragment ejection angle, mass and shape of fragment.

Projectiles with natural fragmentation technology are characterized by low cost of manufacturing, wasted mass/energy, and least mass efficient at target.

Embossed fragmentation projectiles or ammunition technology is characterized by less wasted mass/energy, improved lethality, and low cost of manufacturing. This kind of technology is not applicable in artillery projectiles since there is high axial acceleration during the launching phase and this could jeopardize structural strength of the projectile body. This kind of fragmentation has been in use for a long time with guided and unguided rocket warheads. Inside of the warhead there are integrated segments which have partially formed fragments.

Preformed fragmentation projectiles or warheads technology characterizes efficient mass/energy, optimized lethality and more cost of manufacturing and most mass coefficient. Modern artillery projectiles with preformed fragments are usually equipped with large amount of pre formed fragments which are formed as a sphere or a cube made of steel or tungsten and positioned in front and in the middle of projectile built in cured polymer matrix.

2 Take-off speed calculation models

When calculating the take-off speed, we assume that the take-off speed has the same value for all weight categories of shrapnel. Fully formed shrapnels have a 10 to 25% lower take-off speed than shrapnel made randomly from a homogeneous grenade body. Special type is projectile body with pre fragmetation. When calculating the take-off speed, we often encounter a filling coefficient - Kω, which indicates the ratio between the weight of the used explosive and the total weight of the grenade without the initiation device.

Fig. 3 Projectile with homogenous body

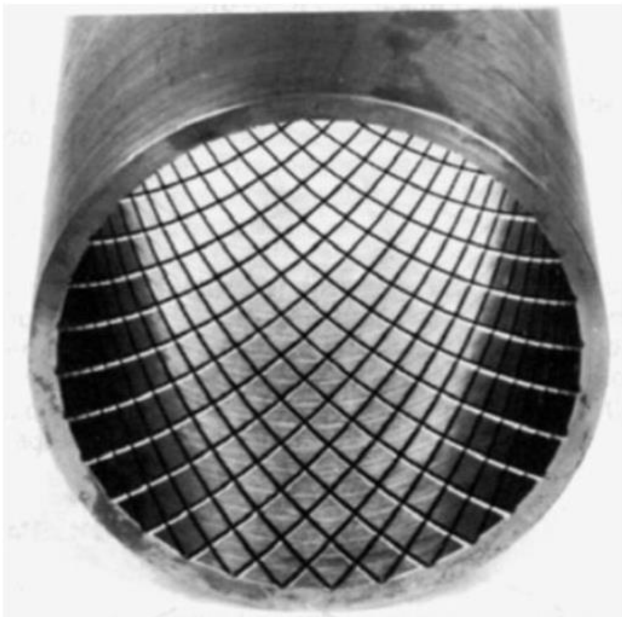

Fig. 4 Steel body with pre formed fragments

Fig. 5 Matrix with fully formed shrapnels

2.1 Formulas for determining the take-off speed of shards without the author

In the literature, we can find formulas that provide quick and easy information about the take-off speed of shards. The following formulas can be included among such formulas [5].

$$v_r = (0{,}75 \div 0{,}90) \cdot v_d \cdot \frac{m_\omega}{m_0} \quad (1)$$

$$v_r = \frac{v_d}{2} \cdot \sqrt{\frac{0{,}9 \cdot m_\omega}{2 \cdot m_0 + m_\omega}} \quad (2)$$

$$v_r = \frac{v_d}{2} \cdot \sqrt{\frac{K_2 \cdot m_\omega}{2 \cdot m_0 + m_\omega}} \quad (3)$$

v_d – detonation velocity of the explosive [m.s^{-1}],
m_ω – explosive mass [kg],
m_c – total projectile weight [kg] $m_c = m_0 + m_\omega$,
m_0 – projectile body weight [kg].

Tab. 1 Coefficient K_2

explosive	m_ω/m_c					
	0,10	0,11	0,12	0,13	0,14	0,15
TNT	0,81	0,82	0,82	0,83	0,84	0,84
TNT/HMX	0,76	0,77	0,77	0,78	0,79	0,79

2.2 Gueney's model for determining the take-off speed

During World War II, American physicist R.W. Gurney designed and implemented a simple model based on which he derived the speed of explosion-accelerated shards. The calculation model was based on two assumptions:

a) Detonation of a given explosive releases a certain amount of energy per unit mass of the explosive and this energy is distributed to accelerate the inert material - in the form of kinetic energy and to the energy transferred by the gaseous product of combustion.

b) These gaseous products have a spatially uniform density and a linear 1D velocity profile in the spatial dimensions of the system.

Primarily, the energy that is of the total energy usable for accelerating inert matter, expressed in terms of velocity (km.s^{-1}), is characteristic of each type of explosive and its specific density. It is called $(2E)^{1/2}$ – Gurney's speed. The exact determination of this speed is performed experimentally [3, 4].

Gurney's formula I.

$$v_{r(i)} = \sqrt{2 \cdot E} \sqrt{\frac{G_{(i)}}{1 + 0{,}5 \cdot G_{(i)}}} \quad (4)$$

$$G_{(i)} = R \cdot F_{(i)} \cdot \frac{m_\omega(i)}{m_{(t)}(i)} \quad (5)$$

i - i-th section - distance from the front of the filling (place of initiation),

$\sqrt{2 * E}$ – explosive characteristics,

R – a constant expressing the influence of the design. Preformed shrapnel R = 0.75, random decomposition R = 1.00, F(i) – correction function depending on the shape of the filling and the place of initiation.

Tab. 2 Characteristic parameters of explosives

Explosives	Explosive density [kg.m^{-3}]	Detonation speed [m.s^{-1}]	$\sqrt{2*E}$ [m.s^{-1}]
TNT	1630	6940	2370
Pentrit	1760	8260	2930
Hexogen	1770	8640	2830
Octogen	1890	9110	2970

Gurney's formula II.

It allows you to determine the take-off speed with respect to different body thickness of the grenade wall or. different diameter of explosive in a given section. The formula is suitable for calculating the flying speed of fragments formed from a long tube.

$$v_r = \frac{\sqrt{2 \cdot E}}{\left[\frac{M}{C} + \frac{1}{2}\right]^{\frac{1}{2}}} \tag{6}$$

$$\frac{M}{C} = \frac{\rho_k (D_v^2 - d_0^2)}{\rho_k \cdot D_v^2} \tag{7}$$

√(2*E) – explosive characteristics,
M/C – ballistic ratio,
ρ_k – projectile body density,
ρ_ω – explosive density,
d_0 – inner diameter of the projectile body,
D_v – outer diameter of the projectile body.

2.3 Bakar's formula

Bakar's formula uses the mechanical properties of the projectile body and the explosive constant to determine the take-off speed. This formula has the disadvantage that each explosive is assigned an explosive constant At and this must be determined experimentally [3].

$$v_r = A_t \cdot \frac{\sqrt{K_\omega}}{\sqrt[27]{R_m}} \cdot \sqrt[50]{Z} \tag{8}$$

A_t – constant according to the type of explosive (for TNT = 2736),
K_ω – filling factor,
R_m – the strength limit of the projectile body material,
Z – relative narrowing (contraction) usually 0.2 to 0.5.

2.4 Pokrokov´s formula II [5]

$$v_r = 2500 \cdot \sqrt{(K_\omega - a_m)} \tag{9}$$

K_ω – filling factor,
a_m – the material constant of the projectile body, for steel it is equal to 0.05 and for steel for castings 0.02.

2.5 Gabeaud's formula for calculating the take-off speed [5]

$$v_r = 1{,}4185 \cdot \sqrt{p_m} \cdot \tag{10}$$

$$\cdot \sqrt{\frac{1}{\rho} \cdot \left(1 - \frac{A}{100}\right) \cdot \left(1 + \frac{A \cdot d}{200 \cdot t}\right) \cdot \left(1 - \frac{200}{100 - A} \cdot \frac{t}{d}\right)}$$

d – projectile caliber [m],
t – wall thickness [m],
A – ductility of the projectile body material [%],
P – projectile body material density [kg.m^{-3}],
P_m – maximum pressure developed by the explosive in a closed container (for TNT = p_m=5*10^9 Pa).

2.6 Baum's formula for calculating the take-off speed

$$v_r = \frac{C_a}{4} \cdot \sqrt{\frac{v_d^2}{4} \cdot \frac{m_\omega}{2 \cdot m_0 + m_\omega} \cdot} \tag{11}$$

$$\cdot \left[1 - \left(\frac{r_0}{r}\right)^4\right] \cdot \frac{2 \cdot R_{ED} \cdot m_\omega}{r_0^2 \cdot \rho_\omega \cdot m_0} \cdot$$

$$\cdot h_0^x \cdot (2 \cdot r_{0x} + h_{0x}) \cdot \ln\left(\frac{r}{r_0}\right)$$

v_d – detonation velocity of the explosive [$m.s^{-1}$],
m_ω – explosive mass [kg],
m_c – total projectile weight [kg] $m_c=m_0+m_\omega$,
m_0 – projectile body weight [kg],
r_{0x} – inner radius of the projectile cavity in section x,
h_{0x} – wall thickness in section x ($h=-r+\sqrt{(r^2+a)}$),
r_0 – initial inner radius of the projectile cavity,
ρ_ω - explosive density,
C_α – correction function depending on the distance from the initiation point and the initiation position.

3 Example of take-off speed calculation

Determine the take-off speed of shrapnel for a 20 mm projectile with a wall thickness of 3 mm. The body of the projectile is made from steel with a density of 7800 kg.m^{-3} and an elongation of 15%. TNT is used as the explosive charge.

We used Gabeaud's formula to determine the take-off speed.

$$v_r = 1{,}4185 \cdot \sqrt{p_m} \cdot \sqrt{\frac{1}{\rho}} \cdot \left(1 - \frac{A}{100}\right) \cdot \left(1 + \frac{A \cdot d}{200 \cdot t}\right) \cdot \left(1 - \frac{200}{100 - A} \cdot \frac{t}{d}\right) =$$
$$= 1{,}4185 \cdot \sqrt{5 \cdot 10^9} \cdot \sqrt{\frac{1}{7800}} \cdot \left(1 - \frac{15}{100}\right) \cdot \left(1 + \frac{15 \cdot 0{,}02}{200 \cdot 0{,}003}\right) \cdot \left(1 - \frac{200}{100 - 15} \cdot \frac{0{,}003}{0{,}02}\right) = 1031{,}6\,\frac{m}{s} \tag{12}$$

4 Conclusion

Needs for cost reduction of military operations at low intensity battles, which are often taking place in urban areas, have caused development of new types of projectiles with longer range, more accuracy, preciseness at target and greater lethal efficiency at the target.

Inside the lethal area of natural fragmentation projectile, fragments, all different in shape and mass, are moving mostly at the supersonic velocity. Fragments formed by natural fragmentation process have irregular shape. While flying through the space, multiple shockwaves are formed on their surface which results in sudden drag increase and rapid decrease in its velocity.

Application of natural fragmentation technologies in modern HE artillery projectiles means possession of high fragmentation steel production technology and thermal procession control of the steel,applying high performance explosives and IM characteristics. Realistically, very few developed countries have this knowledge and technologies. New trend in application of preformed fragments in modern projectiles requires even more specific knowledge and technologies, thereby reducing the number of countries capable of manufacturing modern artillery projectiles with significantly higher lethal efficiency.

In practice, we can encounter six ways to calculate the take-off speed. An appropriate methodology must be selected to calculate the take-off speed. Most calculations are based on practical experiments.

Verification of these calculations is complicated. It can be performed using a Doppler radar, which must, however, be suitably positioned to prevent it from being destroyed by flying fragments. Another method for verifying these calculations is to measure the speed using frames. At a specified distance, we set the frames, which are woven with lacquered copper wire of minimum diameter. These frames are connected to an oscilloscope capable of detecting an open circuit. After detonation, the moment of detonation becomes the start signal. When the wire breaks on the frame, a stop signal occurs. Since we know how far the frame is from the place of detonation and we know the time from the beginning of the initiation to the stop signal, we can determine the take-off speed at that distance.

These methods of verification or even determination of the take-off speed are demanding, but often required. This is one of the evaluation parameters of function and work ability when designing payloads. Knowledge of the take-off speed at pre-fragmented payloads will allow the determination of the kinetic energy of the fragments and thus the wound potential.

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