INFLUENCING PARAMETERS ON HE PROJECTILES WITH NATURAL FRAGMENTATION

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Abstract:

Design of the HE warhead is process confronted with series of contradictory requirements. Influence of warhead design on lethal efficiency is very complex. Lethal efficiency of HE warhead depends on the form and dimension of the warhead, quantity and type of explosive, warhead case material, warhead case thickness, fuse type, explosive train etc. At warheads natural fragmentation, fragments geometry, their mass and spatial distribution are functions of designed shape of the warhead case (shell), mechanical properties of case material (tensile strength and yield strength) and performances of explosive (physical and energetic). It is essential to have a capability to make warhead performance predictions in the earliest phases of ammunition or warheads preliminary design.

Keywords: *warhead, natural fragmentation, fragment velocity, fragment size, geometry of fragments, case material, design, lethality, explosive charge, fragments spatial distribution.*

1. INTRODUCTION

Artillery projectiles or rocket warheads are usually considered two-dimensional axial symmetric. Natural fragmentation of projectiles or warheads results in wide range of random distributions of fragment sizes (masses and geometries). Expansion of warhead case caused by detonation products of explosive charge brings about a warhead structure being split into various sized fragments [4].

HE warhead performances depend on its geometrical shape and dimensions, mass of explosive charge and explosive type, material of warhead case, initiation way and initiation point position, fuse type, round-to-round variations, etc. Lethal efficiency of HE warhead is a function of fragments velocity, geometrical shape and mass of natural fragments and their spatial distribution.

Fragment velocity depends on the explosive mass and warhead metal case mass ratio, detonation velocity and explosive density.

Fragments spatial distribution around detonated cylindrical warhead is not uniform. Naturally fragmented cylindrical warhead typically splits into long axially oriented strings. Splitting effect of warhead case radial fracture depends on toughness, brittleness and material structure grain size, explosive power (magnitude of the detonation impulse). Further, these strings are broken up into ultimate fragments in both ways, radial and longitudinal, during subsequent detonation products expansion, whose fragments mass distribution can be described approximately by the Mott formula. Detonation products solicit expansion of the warhead case greater than twice the warhead initial radius. For cylindrical steel warhead cases, initial elastic-plastic expansion of the case occurs when it is extended from the original volume to about 1,44 times. When the current case volume being risen to about 2,56 to 3,24 times of the initial warhead volume, the detonation products are released through cracks and subsequently an expanding detonation products cloud is developed beyond the fractured warhead case [9].

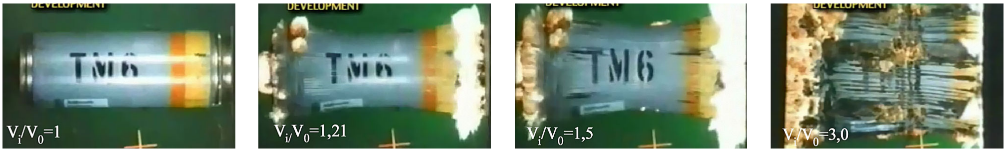

Fig 1. Sequences of a HE warhead natural fragmentation (www.nawcwpns.navy.mil/mov/energet/seg/WB.mov)

Natural fragments spatial distribution (including their geometrical shapes and masses) is a complex function depending on internal and external geometry of the warhead case surface, warhead case mechanical properties (tensile strength and yield strength) and energetic characteristics of the explosive.

Geometrical shape of natural fragments, their mass and spatial distribution are functions of geometrical forms of internal and external warhead case surfaces, mechanical properties of warhead case material (tensile strength and yield strength) and performances of explosive (physical and energetic).

It is essential to have a capability to make warhead performance prediction in the earliest phases of HE ammunition or warheads preliminary design. Ability for warhead performances prediction depends on comprehensive data base of warheads natural fragmentation features, including data on fragment numbers, initial fragment velocities, warhead case material performances, fragment shape features and spatial fragment distributions, etc.

Measurements of warhead performances require very complex measuring equipment and measuring process itself is expensive as well.

Capability of warheads performances and efficiency assessment is based on complexity of our database of natural fragmentation parameters which should encompass data on number, mass, initial velocity, fragments shape factor and spatial distribution, material characteristics of warhead case and explosive charge, etc.

Researches performed in USA were aimed on development of simulation methods for prediction of fragmentation characteristics of HE ammunition [5]. The recent attainment is development of CALE computer simulation program, which is able to simulate fragmentation performances of two and three - dimensional axial symmetric warheads and HE ammunition.

2. TEST METHODS FOR HE PROJECTILES NATURAL FRAGMENTATION ASSESSMENT

Parameters of natural fragmentation process are determined with analytical methods, experimental researches and numerical modeling methods. Number of fragments, their mass, geometrical shapes and spatial distribution are determined experimentally, with Pit test method and Arena test method.

2.1 Pit test

In Pit test, warhead is detonated in closed space (pitfall), filled with sand (Fig.2.). After the fragmentation of warhead, fragments are obtained from the sand. Mass and shape of fragments are determined, and fragments are classified by their mass groups.

Experimental researches performed by authors were undertaken in order to estimate all relevant performances of warhead natural fragmentation (number, mass and fragments shape) when the material of the warhead case is changed (three types of steel with different mechanical properties). Number, mass and fragments shape of each mass group are determined using the Pit test, and relative estimation of spatial fragments efficiency was done by Arena test.

Prediction of fragments mass distribution is usually performed by application of Mott formula, or Held formula. Each of mentioned formulas has certain limitations. These empirical formulas are based on experimental data gained from many fragmentations in Pit and Arena facilities.

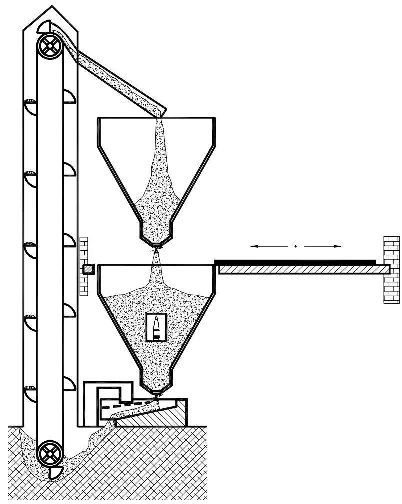

Fig 2. Pit test facility

2.1.1 Mott formula

The Mott equation has been used for many years for prediction of fragments mass distribution in naturally fragmented warheads and ammunition, and this method is only one used in U.S.A. [10]:

$$N(m) = \left[M_0 / \left(2 \cdot M_k^2\right)\right] \cdot e^{-\left(m^{0,5}/M_k\right)} \qquad \textbf{(1)}$$

where: N*(m)* is fragments number with a mass greater than *m*, M_0 is the total fragments mass and M_k is parameter which characterizes fragments mass distribution. Parameter M_k is a function of warhead case thickness t_i, internal diameter of the warhead d_i and explosive charge. In the parameter M_k, constant *B* depends on the explosive charge and casing material.

$$M_k = B \cdot t_i^{\frac{5}{6}} \cdot d_i^{\frac{1}{3}} \cdot \left(1 + t_i / d_i\right) \qquad \textbf{(2)}$$

For a mild steel case, the constant B obviously decreases with increasing of detonation pressure (yielding smaller fragments); but it also decreases with increasing case hardness [8].

2.1.2 Held formula

For prediction of mass distribution of natural fragmented warhead, Held formula with two parameters and the total mass M_0 or the best fit of total mass M_{0Best} as inputs, gives an excellent description of the experimentally found mass distributions of a natural fragmented warhead [6]. An improved fit to natural-fragmentation data can be obtained using equation:

$$M(n) = M_0 \cdot \left(1 - e^{-B \cdot n^{\lambda}}\right) \qquad \textbf{(3)}$$

where; B and λ are both empirically determined constants, with $B = const. \cdot \sqrt{d/t}$ and of order 10^{-2} and λ of order 2/3. In Held equation M_0 is the total mass of all fragments, $M(n)$ and n are cumulative fragments mass and cumulative fragments number beginning with the heaviest fragment. Held found that it was necessary to discard a few of the heaviest fragments in order to obtain a curve fit to data over the rest of the range. The constants B and λ are determined from above equation by mathematical transformation:

$$[M_0 - M(n)]/M_0 = e^{-B \cdot n^\lambda} \quad \textbf{(4)}$$

and the natural logarithm of the above equation is:

$$\ln[(M_0 - M(n))/M_0] = -B \cdot n^\lambda \quad \textbf{(5)}$$

If the logarithm of above equation is performed again, it is possible to determine the constants B and in the log-log plot. By differentiating of the equation, Held $M(n)$ gave the approximate mass of the n-th fragment:

$$m(n) = dM(n)/dn = M_0 \cdot B \cdot \lambda \cdot n^{\lambda-1} \cdot e^{-B \cdot n^\lambda} \quad \textbf{(6)}$$

From the fragment mass distribution (FMD) log-log diagram, constant B and exponent λ with correlation coefficient r^2 are obtained. If in the log-log diagram, the straight line does not fit the measuring data very well, given total mass M_0 is not an optimum mass for such fragments mass distribution. Now, an optimum mass (or best mass) M_{0Best} is calculated:

$$M_{0_{Best}} = M(n)/\left(1 - e^{-B \cdot n^\lambda}\right) \quad \textbf{(7)}$$

The constants B and λ are determined based on original mass of projectile metal body. The new constants B_B *and* λ_B are determined with the total mass M_{0Best}

$$M(n) = M_{0_{Best}} \cdot \left(1 - e^{-B_B \cdot n^{\lambda_B}}\right) \quad \textbf{(8)}$$

This procedure is repeated until a satisfactory correlation coefficient is obtained ($r^2 \geq 0{,}99$).

2.2 Arena tests

Spatial fragments distributions were determined through Arena tests. At the arena fragmentation test, fragments concentration density per steradian is measured when projectile or warhead are put in horizontal position at a certain distance from the ground (Fig.3).

Fig 3. Arena fragmentation test (measurement of the fragments concentration density per steradian)

After the warhead detonation, number of hits and perforations at wooden sectors are counted and then hits number and perforations number per m^2 are calculated for each sector.

From such obtained data, dependency of fragments concentration density per m^2 as a function of sector distance is established. Further, a characteristic distance, at which fragments concentration density of 1 perforation per m^2 is obtained, is determined from the above function. This distance is called warhead efficiency radius, which means that warhead with greater efficiency radius has corresponding greater lethal zone.

When it is necessary to compare lethal efficiencies for similar warheads, then a projectile or a warhead is put on the ground in the vertical nose-down position (Fig.4).

Fig 4. Arena fragmentation test (measurement the fragments concentration density per m^2)

2.2.1 Spatial distribution fragments

Fragments concentration density per arena sector's area at certain distance from the warhead detonation center is given with formula:

$$d(R_i) = N_{pen}(R_i) / A(R_i) \qquad \textbf{(9)}$$

where N_{pen} is number of perforations at arena sector made of wooden panels, A is the sector's area and R is radial distance between the warhead explosion center and a certain sector.

Spatial distribution and density of effective fragments is determined experimentally, with fragmentation of HE projectiles in Arena facility.

Arena consists of k semicircular sectors, divided on n_k segments, where increment of polar angle $(\Delta\theta_k)$ is constant. As a result of conducted experiments, number of penetrations is determined in every segment, and for every sector of Arena. Based on given results it is possible to determine total number of fragments in j-th polar zone and for every distance (radius of sector). After the experiment, number of fragments that penetrated the target is obtained (n_j, for j = 1-22). As the surface of every segment (target) is equal, we can determine the number of fragments penetrating particular polar zone, with following equation:

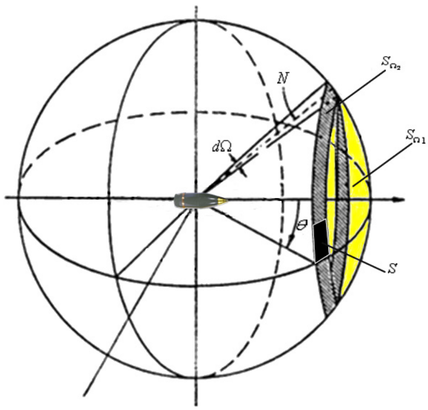

Fig 5. Spatial distribution of fragments

$$N_{jk} = n_{jk} \frac{S_{\Omega jk}}{S_k} \quad \textbf{(10)}$$

where:

N_{jk} - Scaled fragment density or total number of fragments in j-th polar zone of k-th sector

n_{jk} - Number of fragments (penetrating the targets) in j-th segment of k-th sector

S_k - Total surface of segment (target)

$S_{\Omega jk}$ - Total surface of j-th polar zone in k-th sector, and it is determined by formula

If we introduce spatial angle (steradian) of j-th polar zone:

$$\Omega_j = 2\pi(\cos\theta_j - \cos\theta_{j+1}) \quad \textbf{(11)}$$

Total surface of j-th polar zone in k-th sector is determined by formula

$$S_{\Omega jk} = \Omega_j \cdot R_k^{\,2} = 2\pi R_k^{\,2}(\cos\theta_j - \cos\theta_{j+1}) \quad \textbf{(12)}$$

2.3 Fragment velocities

Fragment velocities are measured using different techniques as electronic, optical or x-ray. If these techniques are not available, initial velocity of fragments released from explosion of a warhead is approximated by the Gurney formula. The simplest expression of the Gurney formula for symmetrical configurations is:

$$v_{Gurney} = \sqrt{2 \cdot E} \cdot \sqrt{1/(0{,}5 + M / C)} \quad \textbf{(13)}$$

where $\sqrt{2 \cdot E}$ is Gurney constant, M-metal mass of warhead case and C - mass of explosive charge [7].

The Gurney constant can be approximated by the simple expression $\sqrt{2 \cdot E} = 0{,}338 \cdot D$, where D is the detonation velocity (depending on explosive type and its density).

3. EXPERIMENTAL RESEARCH

3.1 Influence of warhead case material on natural fragmentation performances

Experimental researches performed by authors were undertaken in order to estimate all relevant performances of warhead natural fragmentation for 120mm W1 and 120mm W2 (three types of steel with different mechanical properties).

Author also analyzed experimental data for projectiles 155 mm HE M107 of U.S. type and Bofors 155 mm HE M54 in order to determine the fragmentation effect for two different types of projectile body material [2]. Both projectiles are practically identical geometrically.

Number, mass and fragments shape of each mass group are determined using the Pit test, and relative estimation of spatial fragments efficiency was done in Arena test.

The main point of first research was directed to an influence of warhead metal case material properties on warhead natural fragmentation performances (number, mass and fragments geometrical shape). Dimensionless thickness of the warhead shell W1 was *t/d=0,0707*, and ratio of metal warhead shell and explosive charge mass was C_{TNT}/m =

0,565. Dimensionless thickness of the warhead shell W2 was $t/d=0{,}0629$, and ratio of metal warhead shell and explosive charge mass was $C_{TNT}/m = 0{,}653$ [12].

Tested warheads cases were made of following steels 45Cr2 (ratio of tensile strength and yield strength $R_m/R_v=1{,}09$), C70D ($R_m/R_v=1{,}59$) and steel AB or 9180VP ($R_m/R_v=1{,}41$) marked according to Army standard, former SFRJ.

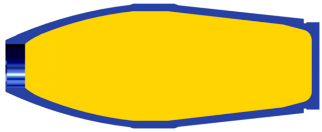

Fig 6. Warhead 120 mm W1

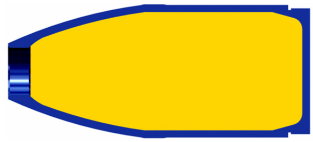

Fig 7. Warhead 120 mm W2

Four warheads fragmentation tests were performed for each casing material of the warhead and obtained data were processed according to Mott methodology (Fig.8).

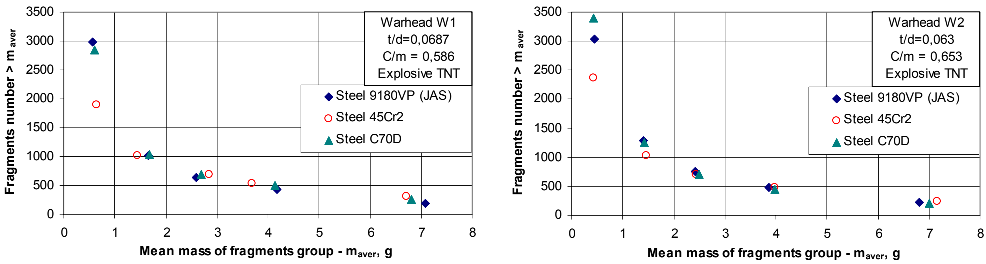

Fig 8. Dependency of fragments number variation greater than m from the mean fragments mass for warheads W1 and W2

Comparing the two warheads W1 and W2, greatest number of fragment has warhead W2, made of steel C70D. Warhead W1 with case made of the steel 9180 has greatest fragments number and minimal fragments number with case stell 45Cr2. Warhead W2 has minimal number of fragments for case made of steel 45Cr2. Between steels C70D and 9180 there are slightly differences in number of fragments for warhead W2.

Authors noted a strong dependency of fragments number and their mass from the ratio R_m/R_v. Steels with higher ratios R_m/R_v generated considerable higher fragments number (steels C70D and 9180). However, it was not possible to conclude from Fig.8 which material would be the most favorable. Because of that, authors presented their results in a different way (fig. 9). The mean fragments mass of each particular group was taken as a variable. Relationship between fragments mass groups number, whose mean masses are less than the mean mass of the total fragments number, or between fragments mass of each group and the total warhead fragments mass were established [12].

From above (fig. 9) diagrams, comparing number of fragments and mass participation it can be more precisely done by optimization of warhead type as function of warhead body material. In warhead W1 steel 9180 gives greater number of fragments and greater mass participation comparing to steel C70D for fragments with mean mass smaller than 5 gr, while for larger fragments mass more favorable steel is C70D. For warhead W2, for fragments mass smaller than 4 gr most favorable is steel C70D, while for larger fragments mass (greater from 4gr) most favorable is steel 9180. As a conclusion, steel C70D has better lethality performances in warheads which are used mainly against infantry, while steel 9180 would have better penetration capability against light armored vehicles.

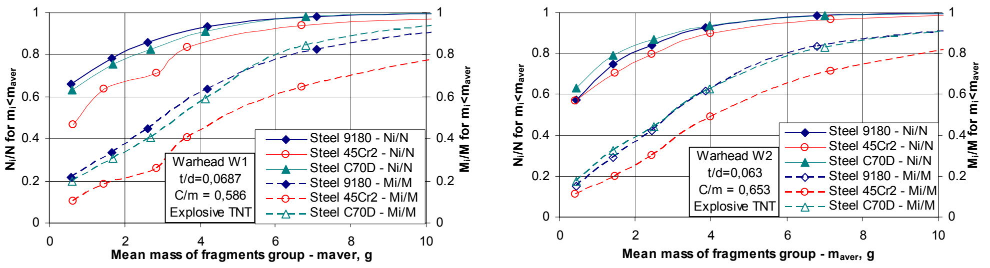

Fig 9. Fragments number or mass participation as a function of mean fragments mass for warheads W1 and W2

Warheads with case made of the steel with larger ratio of R_m/R_v generates greater number of fragments but with less mean mass and greater fragments mass participation. Authors explained this phenomenon as a consequence of warhead case ability to expand into more considerable volume with thinner case walls under detonation products pressure before fragmentation (warhead body mass conservation condition). Experimental researches have shown that initial volume of a warhead can be increased several times before fragmentation of warhead case material has been occurred (Fig. 1). Authors also found the relationship $t_i/t_0=(V_i/V_0)^{-0,5}$ between relative volume rise and relative wall thickness during the warhead case expansion [12]. At 4 times increase of warhead volume, new corresponding warhead case thickness decreases at 0,52 of initial case thickness. When the ratio of R_m/R_v rises, the ratio V_i/V_0 increases as well and t_i/t_0 decreases, what results in greater fragments number but with less mass.

Second analysis was analysis of natural fragmentation experimental data for projectiles 155 mm HE M107 (steel AISI 1045) and Bofors 155 mm HE M54 (High fragmentation steel), made in Bofors facilities. Projectiles were geometrically identical, with different types of projectile body material [2].

Before the tests, the ordinary bursting charges in the shells were removed, and the shells were filled with cast hexotol corresponding to "Composition B". The composition of this hexotol was RDX 59.5%, TNT 39.5% and wax 1%. The weight of the explosive was approx. 7 kg. The average weights of the complete shells (without fuzes used for the tests were: Bofors 155 mm HE shell M54 42.4 kg, US 155 mm HE shell M107 42.6 kg [2].

The shells were exploded statically, in target arrangements A and B of different designs. The shells were placed in horizontal and vertical positions.

The target arrangement type A (shell in horizontal position) was built up in the form of an enclosure. Three sides consisted of 2 mm mild steel plate, size 1 x 6 m. The fourth side was made of 7 mm steel plate, brand SIS 1411 (σ_S = 250 MPa, σ_B = 420 MPa) size 1 x 6 m. The distance at right angles from the pole on which the shell was placed to the sides was 3 m. The target arrangement type B (shell in vertical position) was made of steel plates with the dimensions 1 x 2 m, with thicknesses of 2 mm and 7 mm, respectively, and with the same mechanical properties as those used in target arrangement type A. The plates were placed on edge to a height of 3 m and a width of 2 m. For fragments efficiency assessment on unprotected personnel, 19mm chipboards with the dimensions 1,22 x 2,5m was used, at distances of 6m and 12 m [2].

The targets were placed so that the bottom edges of the lower parts were on the same horizontal plane. The height at which the shell was placed, in an upright position, was fixed at 1,50 m, and the line of sight to each target was drawn in [2].

In Bofors study, the general impression obtained from these comparative static bursting tests was that the Bofors shell gave considerably better fragmentation. Bofors 155 mm HE shell M54, gave twice as many perforations as the U.S. 155 mm HE shell M 107. The appearance of the holes also differed. The 155 mm HE shell M107, gave large, longish perforations, while the Bofors 155 mm HE shell M54, produced holes of more regular sizes. This was entirely due to the properties of the materials in the two types of shells.

Authors have determined, using the earlier explained method of fragments spatial distribution, following:

Target arrangement type A: In first polar zone (-45 to +45°) there is no significant difference in penetration density through targets (thickness 2mm). In polar zone of 45° to 135° (for 2mm target thickness) penetration density is 35% greater, and in polar zone of 225° to 315° (for 7mm target thickness), penetration density is 100% greater. Further more, in polar zone of 135° to 225° there is 92 % greater penetration density for Bofors 155mm M54 projectile. General conclusion is that Bofors warhead has about 35% better efficiency against infantry, and about 100% better efficiency against light armored and mechanized vehicles.

By analysis of experimental results of projectiles natural fragmentation in B arena (influence of lateral fragments), on different distances (3 m, 6 m and 12 m) and against targets of different thicknesses (2mm and 7mm steel plate) authors concluded that efficiency of Bofors 155mm M54 projectile against armored targets is 1,8 to 2,05 times better at distance from 3m to 12m, respectively, while efficiency of Bofors 155mm M54 projectile against infantry is from 2,1 to 1,42 times better at distances 6m and 12m, respectively.

As a general conclusion for both tests, Bofors 155mm M54 projectile with high fragmentation steel has significantly greater number of fragments, compared to US projectile 155mm M107. Bofors 155mm M54 projectile's efficiency is significantly better against light armored and mechanized vehicles and that penetration capability (min 80%) doesn't significantly change with increasing the distance, comparing to US projectile 155mm M107. Against infantry, that lethal efficiency is minimum 35% greater, comparing to 155mm M107 and what is important to mention, it decreases with increasing the distance. That penetration capability of fragments doesn't considerably change with increasing the distance, even though projectile 155mm M54 has considerably greater number of fragments, and smaller mean mass of fragments, with similar velocity of fragments; this points to fact that important role plays shape of fragments, during process of penetration through target, specific energy of fragment.

3.2 Experimental research on influence of explosive charge to natural fragment size distribution

The point of this research was an estimation of influence of detonation velocity on natural warhead fragmentation performances (number, mass, geometrical shape and velocity of fragments).

Experimental fragmentation tests were carried out with four types of HE warheads 120 mm W1 and W2, 128 mm M87 and 152 mm M84.

Warheads cases W1 and W2 were made of the steel C70D, and warhead masses were kept the same, but only types of explosive charge were varied (TNT and Composition B). Ratios of explosive charge mass and warhead metal case mass of the warhead W1 was $C_{TNT}/m = 0{,}565$ and $C_{Comp\ B}/m = 0{,}587$, and for warhead W2 was $C_{TNT}/m = 0{,}653$ and $C_{Comp\ B}/m = 0{,}667$. Dimensionless thickness of the warhead shell W1 was $t/d = 0{,}0707$, and for warhead W2 was *t/d = 0,0629*. Four fragmentation tests were carried out for each type of explosive charge.

For warheads W1 and W2 fragments were classified by mass groups and experimental data were processed using Held methodology (Fig.10).

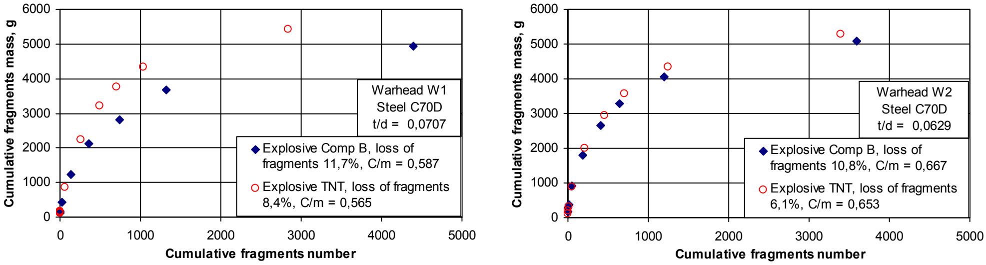

Fig 10. Cumulative fragments mass dependency on cumulative fragments number for warheads W1 and W2 [13]

Warheads W1 and W2 with the case made of steel C70D and Comp B produces larger number of fragments compared to the warheads with TNT explosive charge. At the same time, in these two warheads with Comp B greater loss of fragment mass has been noticed (metal part of warhead body has been converted to very small fragments), for W1 11,7 % (Comp B) and 8,7 % (TNT), comparing to W2 10,8% (Comp B) and 6,1% (TNT).

However, it is not possible to conclude from Fig.10 which warhead has better fragmentation performances. Because of that, authors presented their results in a different way (Fig. 11).

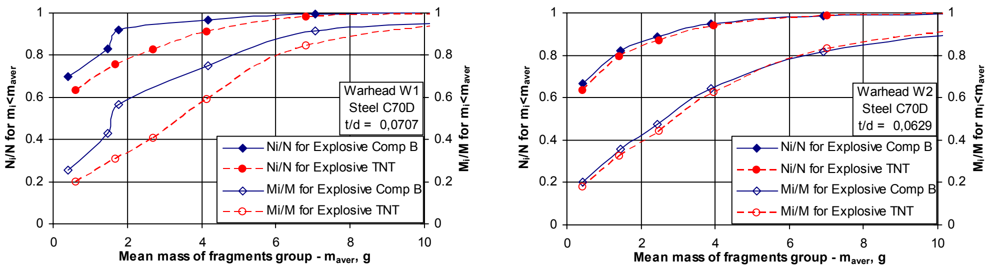

Fig 11. Fragments number contribution, or fragment mass contribution as a function of the mean fragments mass for warheads W1 and W2 [13]

The mean mass of particular groups was taken as a variable. Correlation between fragments number of mass groups, whose mean masses are less than mean fragments mass related to total fragments number, or between fragments mass of these mass groups and total fragments mass of the warhead were established. The warheads W1 and W2 with explosive charges of Comp. B generate more fragments but with less mean mass, compared to warheads W1 and W2 filled with TNT. Warhead W1, with Comp. B has in fragment groups, with mean mass smaller than 10gr, dominantly larger number of fragments and larger mass participation of these fragments, while in warhead W2 these differences aren't significantly greater.

Authors explained such results as consequence of more intensive influence of detonation products generated by more powerful explosive. When more powerful explosive is used, initial warhead volume is increased more intensive and warhead case thickness is decreased (condition of mass conservation).

Since the sophisticated measuring equipment for fragment velocity measurement was not available to authors, the Gurney's formula was used in order to predict initial fragments velocities [7]. Initial fragment velocity variation for warheads filled with TNT and Composition B explosives charge and for particular warhead segments was determined using methodology described in the Crull's report [3] (fig. 12 and fig. 13).

From these diagrams of velocity of fragments vs. relative distance of warhead case segments it can be seen that mean fragment velocity is about 300 m/s larger in warheads filled with Comp. B, fragments with less mass will have less energy and radius of lethality.

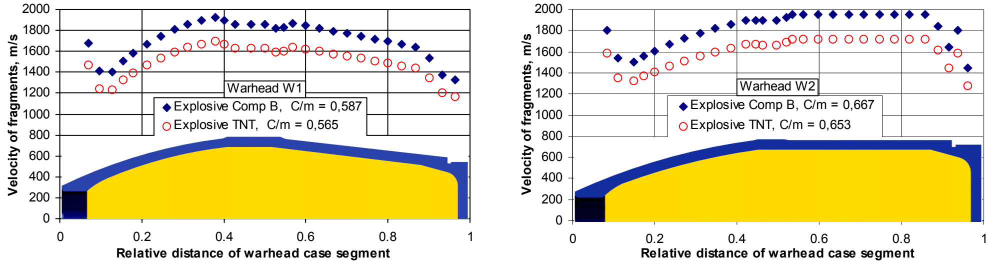

Fig 12. Variation of fragment velocity as a function of explosive type for warheads W1 and W2 [13]

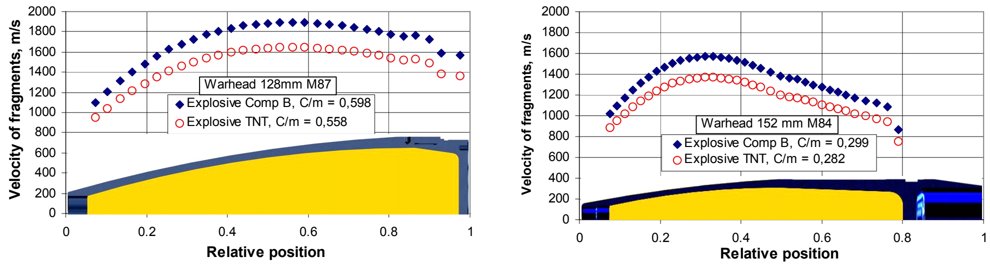

Fig 13. Variation of fragment velocity as a function of explosive type for warheads 128 mm M87 and 152 mm M84 with explosive Comp B and TNT

Fragments concentration density per steradian as a function of polar zone for warheads 128 mm M87 with explosive Comp B and TNT is presented in Fig. 14 [11]. Lethality zone for warheads 152 mm M84 with explosive Comp B and TNT is presented in Fig. 15.

For assessment of spatial fragments distribution and efficiency of warheads 128 mm M87 (steel C70D*)* and 152 mm M84 (steel 45Cr2*)*, experiments were conducted in two types of Arena facilities. In first Arena spatial distribution of fragments is determined, and in second one radius of lethality zones.

From diagram on fig. 14 it can be seen that greater fragment energy (with smaller mass, but larger velocity) have fragments from warhead filled with Comp. B, i.e. for fragment density of 400 frags/steradian width of polar zone for warhead with Comp. B is 35°, while for warhead with TNT it is 20°. Warhead filled with TNT had maximal fragment density of 930 frags/steradian, and for the same fragments density, warhead filled with Comp. B has width of polar zone of 15° and maximal fragment density of 1300 frags/steradian.

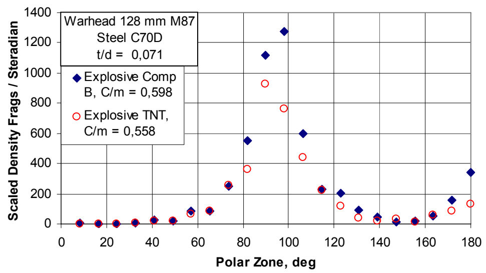

Fig 14. Fragments concentration density per steradian as a function of polar zone for warheads 128 mm M87 with explosive Comp B and TNT

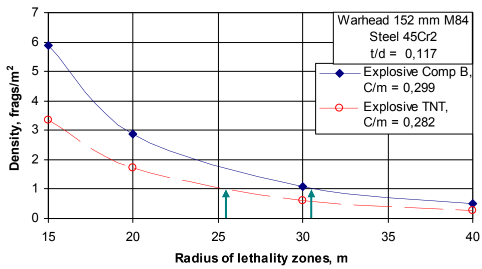

Fig 15. Lethality zone for warheads 152 mm M84 with explosive Comp B and TNT

Diagram on fig. 15 shows that projectile 155mm M84 filled with Comp. B has 33% larger lethality area.

3.3 Influence of warhead design on natural fragmentation performances

Experimental researches carried out by the authors were aimed on natural fragmentation performances estimation (number, mass and fragment form) of the warhead when the warhead or projectile design shape is changed [14]. Spatial fragments distributions were determined through arena tests.

Experimental fragmentation tests in order to determine the influence of projectile design on fragmentation characteristics were carried out with 11 types of HE warheads 105 mm M1 [1], 120 mm W2, 120 mm M62P3, 122 mm OF-462, 122 mm M76, 128 mm M63, 128 mm M87 [11], 152 mm OF-540, 152 mm M84, 155 mm M107 [1] and 155 mm ERFB.

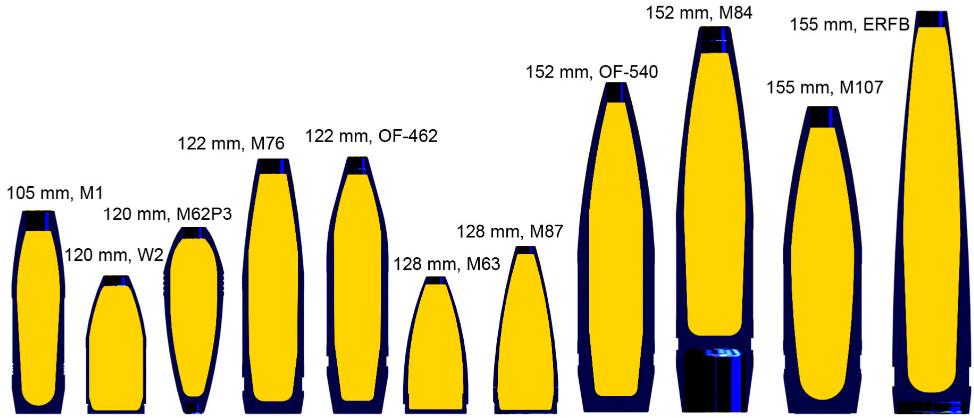

Fig 16. Warheads

Fragments concentration density per steradian (spatial fragments density) for each polar sector of the arena:

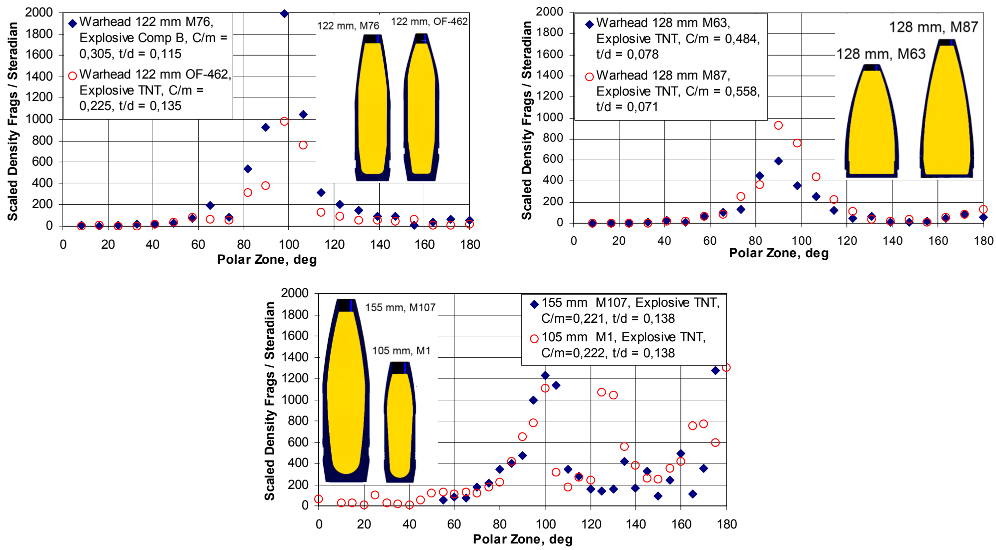

Fig 17. Fragments concentration density per steradian as a function of polar zone

Diagram (fig. 17) shows the complexity in determination of design influence on fragment distribution prediction for different polar zones. Beside outer design (slenderness of projectile ogive) significant role plays ratio of explosive mass to metal mass *C/m*, type and density of explosive charge and relative ratio *t/d* (equivalent thickness of projectile body wall). Projectiles with greater slenderness, greater ratio *C/m*, and smaller ratio *t/d* have larger density of fragments per steradian, for the same type of explosive. It is interesting to note that projectile 105 mm M1, 122mm OF-462 and 155 mm M107 have almost the same ratios *C/m* and *t/d*, and also approximately the same value of maximal density of about 1100 frags/steradian in polar angle of about 100°.

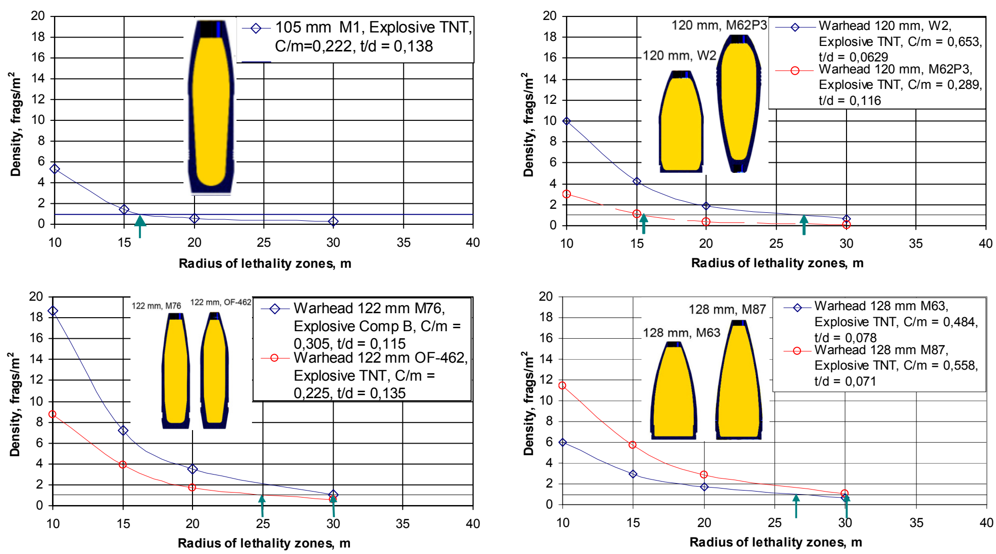

Fig 18. Warhead lethality zone

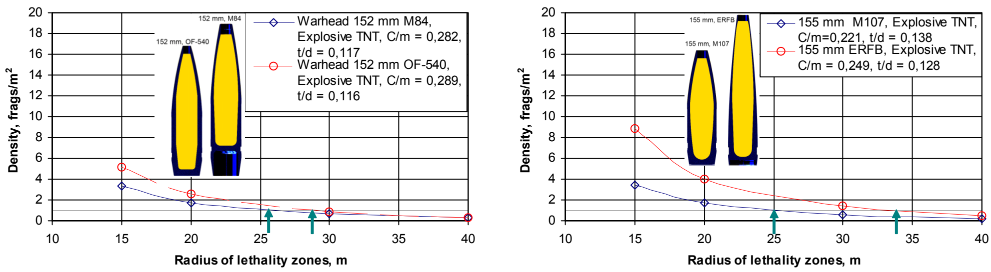

Fig 19. Warhead lethality zone

Comparative analysis of lethality radius for projectiles with the same caliber and different design confirm observations mentioned above. Projectile 120 mm W2 has considerably greater ratio *C/m* and smaller ratio of *t/d* comparing to projectile 120mm M62P3, so the lethality zone of this warhead is 2,8 time greater. Projectile 122 mm M76 (Comp. B) has 44% larger lethality area compared to projectile 122 mm OF-462 (TNT), because it has greater detonation velocity, greater *C/m* ratio, greater slenderness of ogive and smaller ratio of *t/d*. Warhead 128 mm M87 (TNT) has 50% larger lethality area or 80% larger lethality area when it is filled with RDX compared to projectile 128 mm M63 (TNT).

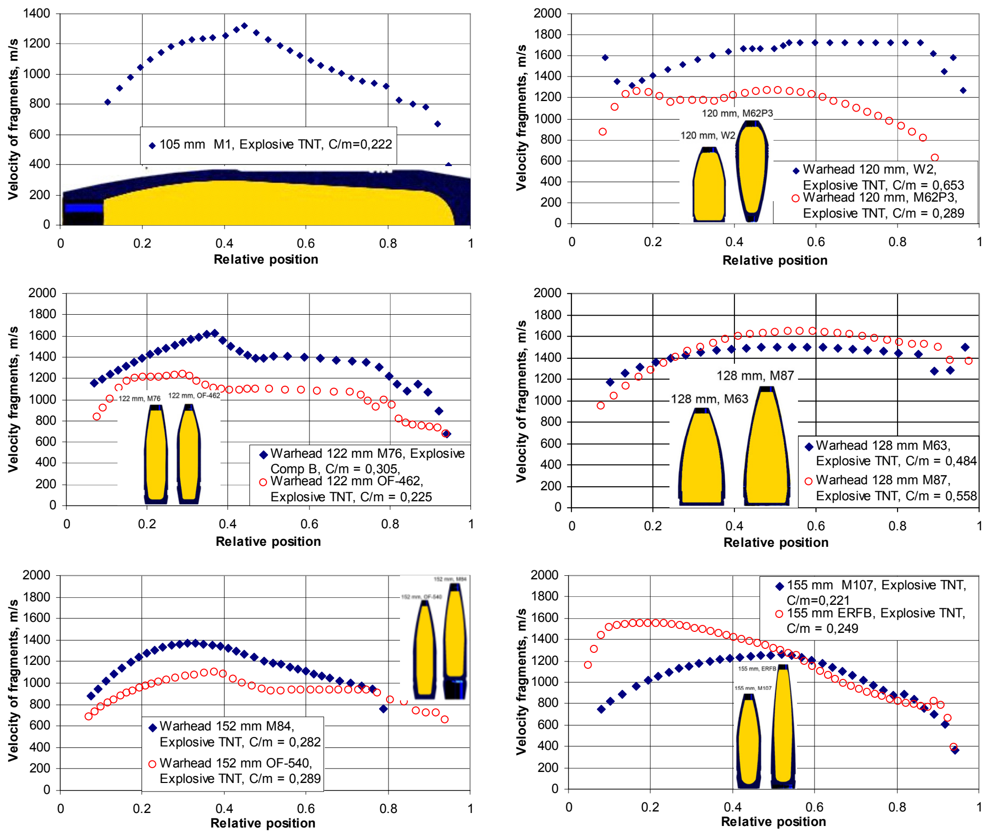

Fig 20. Fragment velocity as a function of relative position

Warhead 128 mm M87 has greater *C/m* ratio and slightly smaller ratio of *t/d* and greater slenderness of ogive. Comparing two projectiles 152 mm OF-540 and 152 mm M84 is interesting because of the influence of hollow base at the projectile (M84) bottom on fragmentation efficiency. This projectile has greater slenderness of ogive and similar ratios *C/m* and *t/d*, but the influence of hollow base reduces his lethality capabilities.

Projectile 155 mm ERFB has greater ratio *C/m* and smaller ratio *t/d* and significantly greater slenderness of ogive comparing to projectile 155 mm M107, so his lethality zone is 85% greater.

Significant influence on projectile efficiency is made by fragment velocity distribution along projectile symmetry axis. It is especially important for projectile ogive and his cylindrical part, because the fragments from these parts have highest influence on spatial distribution of lateral fragment spread.

Maximum fragment velocities are achieved at warheads having greater explosive charge mass and metal case mass ratio *C/m*, which are appeared within central fragments polar zone (fig. 20).

4. CONCLUSION

Influence of warhead design on lethal efficiency is very complex. Very important role play design factors as external and internal geometrical paths, relative warhead case thickness, explosive charge mass and warhead metal case ratio, type of explosive, etc.

Until recently, any prediction method, which is capable to quantify particular influence of above parameters on lethal efficiency radius, has not been developed yet.

It was not possible to clearly define the influence of explosive type on natural fragmentation performances by using Held method.

Mott formula cannot provide a clear influence of warhead metal case variation on natural fragmentation performances.

Authors proposed a new approach to presentation of experimental results, which enables selection of an optimal warhead explosive charge. Authors gave also different approach to presentation of fragmentation experimental data, which enables selection of an optimal warhead case material [12, 13].

Authors also established relationship between t_i/t_0 and V_i/V_0 and connected it with the ratio R_m/R_v in order to find how above parameters affect fragment number and their mass. Warhead with steel case, which has higher ratio R_m/R_v generates simultaneously greater fragments number but with less mean fragments mass and with greater fragments mass participation. Authors also concluded that it was necessary a further development of empirical relationship between R_m/R_v, and V_i/V_0 [12].

In attempt to introspect complexity of influence of design, material of body, types of explosive and methods of conducting the experimental testing, authors made comprehensive analysis of eleven types of projectiles and warheads. Authors observed significant influence of ratio *C/m* (mass of explosive to mass of metal body ratio), ratio *t/d* (equivalent thickness of projectile body wall to caliber ratio), projectile ogive slenderness, fragment velocity distributions along projectile symmetry axis and geometrical shapes of fragments.

Influence of geometrical shapes of fragments is not investigated in detail, and in following period numerical simulation (drag, center of pressure, center of mass, etc.) of behavior of fragment should be conducted during his flight through air and his behavior during the penetration through target, because of his influence on penetrating capabilities. Analysis of geometrical shape is conducted only for warhead 128 mm M87 [11], but it is insufficient for making scientific conclusions. Our activities are directed to creating expert base for natural fragmentation processes.

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