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Simulation Method of Assessing the Destructive Effect of Fragmentation

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Abstract. The paper presents an outline of a simulation method for assessing the fragmentation effectiveness of ammunition equipped with proximity fuses. The method, developed at the Military University of Technology (MUT – Warsaw, Poland) is based on an unambiguous fragmentation action model with a defined and justified degree of simplification. It is a versatile method suitable for all weapons, designed to test the effects of individual parameters describing shells decomposition on the effectiveness of their fragmentation.
Keywords: fragmentation effectiveness, simulation of destruction efficiency

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1. INTRODUCTION

The destructive effect of fragmentation of projectiles with high explosive shells can be assessed through experimental tests or calculations using computer simulation methods. Experimental tests of the destructive effect of fragmentation of 122 mm and 152 mm artillery projectiles and 120 mm mortar grenades were conducted, i.a., in Bulgaria [1]. Up to a tenfold increase in the destructive effect of fragmentation was achieved when initiating detonation at selected heights $H_w \in$ <4;14> m and fall angles $\theta_p \in$ <20;70> °. Similar tests were also conducted in FPS Bolechowo (Poland), where during work on the prototype of the FENIKS missile, the destructive effect of fragmentation of SPALL warheads was assessed.

A more effective, less work-intensive and expensive way of assessing the destructive effect of fragmentation are computer simulation methods. They provide the ability to obtain reliable results (provided that correct input data are established) in a short amount of time. They can serve as the basis for assessing the effects of:

- conditions of projectile attack against the target;
- characteristics of the projectile's high explosive payload;
- characteristics defining the group target;

on effectiveness of target destruction. It is a basis for formulating the requirements for the activation altitude of the proximity fuse designed for the given projectile.

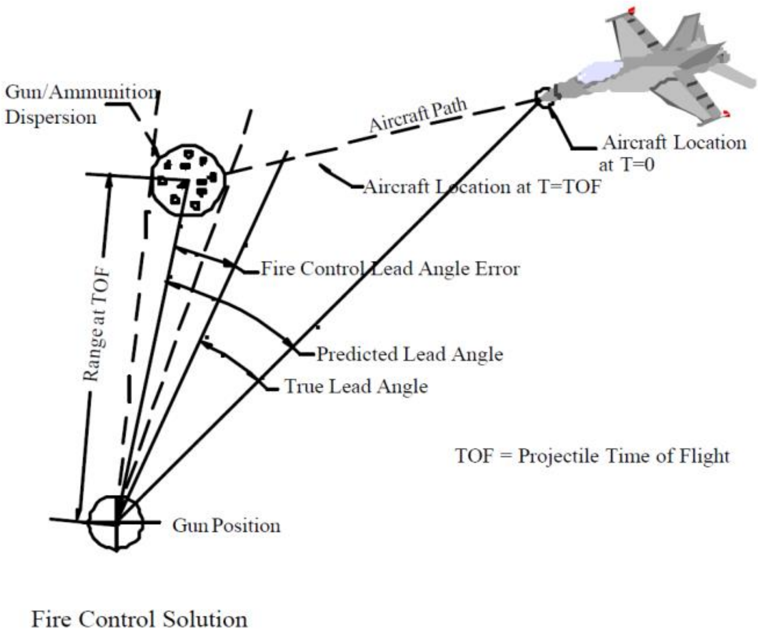


Fig. 1. Illustration of the issue of aerial target destruction in the PRODAS software [3]

An example of such a simulation package is the commercial software PRODAS V3 [2] by ARROW TECH ASSOCIATES, which is available with an optional analytical module for precise assessment of the end effectiveness of projectiles. These modules were designed to assess various cases:

- air defence (surface to air) - module AT665A;
- ground combat (surface to surface) - module AT666A;
- air combat (air to air) - module AT663A;
- air support (air to ground) - module AT664A;

2. ASSUMPTIONS FOR THE METHOD OF ASSESSING THE DESTRUCTIVE EFFECT OF FRAGMENTATION

Studies on fuses for ammunition of various calibres have been conducted at the Military University of Technology (MUT) for many years, which led to the need for a simulation method of assessing the destructive effect of fragmentation. This method, presented in [4, 5, 6], assumes the criteria of the expected effective affected area μ_s effectiveness increase index q_s. Furthermore, it was assumed that the principle of the method would involve:

- simulating an explosion of a fragmentation warhead above target for specific projectile flight parameters;
- dividing the fragment scatter area into sectors around the projectile fragmentation point, and the target location area into elementary fields s_z;
- calculating (as a result of numerical integration) the field size s_z and determining the number n_{sz} of effective fragments falling to individual fields s_z;
- calculating the hit probability p_z of individual fields s_z;
- calculating the μ_s and q_s indexes.

Multiple fragmentation simulations and calculating destruction effectiveness each time provides the ability to quickly obtain information on the effects of projectile flight parameters, fragmentation warhead characteristics, and the target's nature on the projectile's destruction effectiveness. Warhead fragmentation is simulated numerically for each consecutively selected combination of values:

$$H_w \in \langle H_{wmin};H_{wmax}\rangle;\ v_p \in \langle v_{pmin};v_{pmax}\rangle;\ \text{and}\ \theta_p \in \langle \theta_{pmin};\ \theta_{pmax}\rangle$$

with the selection made at an appropriate step.

The calculation algorithm contains the mathematical model of the projectile, to be elaborated with the following assumptions:

— the projectile's centre of gravity is also the centre of its fragmentation, and the projectile's velocity vector v_p is applied at the fragmentation centre and has a direction identical to the projectile's axis of symmetry;
— at the moment of shell fragmentation, a fragment set $\boldsymbol{A}$ numbering n fragments forms, which contains a subset of effective fragments $\boldsymbol{A_s}$ and a subset of ineffective fragments $\boldsymbol{A_n}$; the numbers of fragments n_s and n_n in these subsets change with the distance from the point of fragmentation, with their total number n remaining constant;
— fragment trajectories along their effective path d_s are straight lines and originate from the fragmentation centre;
— velocity vectors v_{max} are applied at the fragmentation centre, while their directions and senses are random;
— the area affected by the fragments is a sphere with its centre at the projectile detonation centre and with a radius r_s equal to distance d_{smax}, reached by the most effective fragment;
— the effective fragment dispersion space is defined based on the quantitative distribution $n(i)$, weight distribution q_j and percentage weight distribution $\varepsilon(j)$ of fragments.

Using the destructive effect assessment simulation method developed at the MUT [7] involves feeding the following data to the software:

— number of sectors into which the post-explosion fragment dispersion area is divided - I;
— number of weight classes into which the fragment set is divided - J;
— angular step of division into sectors - α [°];
— initial fragment velocity, obtained on detonation - v_d [m/s];
— velocity of the fragmentation casing at the moment of explosion - v_p [m/s];
— explosion altitude - H_w [m];
— inclination angle of the fragmentation casing axis of symmetry at the moment of explosion - θ_p [°];
— mean head resistance coefficient for the entire fragment set - C_x;
— radius of a sphere with its centre at the point of explosion and with a known density of fragment distribution on its surface - r_o [m];
— effective energy - in_s [KGm/cm^2];
— target characteristic surface - s_c [m^2];
— table of fragment weight distribution - g_j [gr];
— table of effective fragment distribution - $\varepsilon(j)$;
— table of quantitative fragment distribution - $n(i)$;

- number of inclination angles of the fragmentation casing axis of symmetry at the moment of explosion - N1;
- number of declared altitudes of explosion H_w - N2.

The calculation results are displayed on the screen and saved to a calculation sheet with an .XLS extension. Based on the results received, the destructive effect of fragmentation can be presented in a graphical form, for example.

The final product of calculations for a single data set is the size of the calculation area of fragmentation effect S_r. At the same time, during the same calculation cycle, without additional actions needed, other supplementary indicators are calculated, which provide a complete overview of the fragmentation effect. These include:

- n_s - number of effective fragments falling to the surface of the affected area;
- $n_s(i, k)$ - table of quantitative distribution of effective fragments on fields S_{ik}, into which the affected area was divided;;
- $p(i, k)$ - table of probability of target hit with a fragment at individual fields S_{ik};
- $l(i, k)$ - table of effective fragment distances, for the complete range of weights and initial velocities of fragments formed from a single fragmentation casing;
- $s(i, k)$ - table of field sizes into which the affected area was divided.

3. SAMPLE SIMULATION RESULTS

The presented numerical example is intended to demonstrate the correctness of the calculation method, according to the assumptions made and the program prepared, for a complete range of possible inclination angles of axis of symmetry of the shell fragmentation, at the moment of explosion at any altitude. As the method is proposed for practical applications, it was attempted to select such input data for the purpose of the example so that the simulated fragmentation had every attribute of realism. A fragment weight distribution was taken from actual statistics developed for a 105 mm fragmentation shell. The quantitative distribution of fragments in arbitrary angular sectors was adopted for a steel shell, based on data presented in [4]. The other data were adopted on the basis of shell fragmentation analysis, and tabular data for typical fragmentation shells.

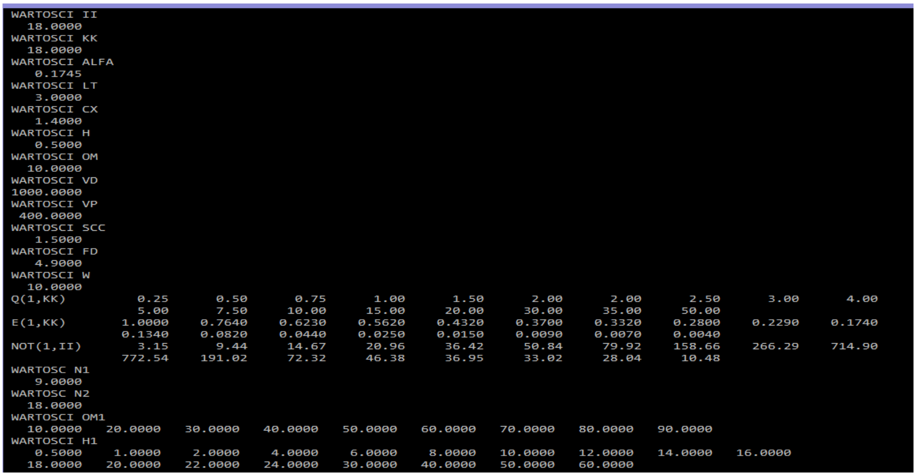
This way, a theoretical data set was obtained that defined a fictional fragmentation projectile with parameters possible to be achieved in reality, and based on actual, statistical tests of shells fragmentation.

The numerical values provided can be assumed as representative for fragmentation shells used by gun artillery. Numerical data, software input (symbols used in the software given in brackets):

- number of sectors into which the post-fragmentation fragment dispersion area is divided I (II) = 18;
- number of weight classes into which the fragment set is divided K (KK) = 18;
- angular step of division into sectors α (ALFA) = 10;
- initial fragment velocity gained from detonation V_d (VD) = 1000;
- remaining fragmentation casing velocity at the moment of detonation V_p (VP) = 400;
- fragmentation altitude h (H) = 0.5, 1, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 30, 40, 50, 60;
- inclination angle of casing axis of symmetry at the moment of fragmentation θ_p (OM) = 10, 20, 30, 40, 50, 60, 70, 80, 90;
- mean head resistance coefficient for the entire fragment set C_x (CX) = 1.40;
- radius of a sphere with its centre at the point of fragmentation and with a known density of fragment distribution on its surface r_o (LT) = 3.0;
- effective energy w_s (W) = 10.0;
- function implementation coefficient $S = u\mathrm{f}(m) - u$ (FD) = 4.9;
- target characteristic area S_c (SCC) = 1,5;
- fragment weight distribution table g_j (Q (1.KK)) = 0.25 0.50 0.75 1.00 1.50 2.00 2.00 2.50 3.00. 4.00 5.00 7.50 10.0 15.0 20.0 30.0 35.0 50.0;
- effective fragment weight distribution table $\varepsilon(j)$ (E(1,KK)) = 1.000 0.764 0.623 0.562 0.432 0.370 0.332 0.280 0.229 0.174 0.134 0.082 0.044 0.025 0.015 0.009 0.007 0.004;
- fragment quantitative distribution table $n(i)$ - (NOT (1,II))= 3.15 9.44 14.67 20.96 36.42 50.84 79.92 158.66 266.29 714.90 772.54 191.02 72.32 46.38 36.95 33.02 28.04 10.48
- number of inclination angles of the casing axis of symmetry at the moment of fragmentation N1 = 9;
- number of declared fragmentation altitudes N2 = 18.

Fig. 3 shows a sample screenshot with the simulation parameters entered. The calculation results obtained from the program simulation are shown in Fig. 4 and Fig. 5 as the values of fragmentation effect parameters:

- calculation area of fragmentation effect S_r (θ_p, h);
- number of effective fragments $n_s(\theta_p, h)$.



```
WARTOSCI II
  18.0000
WARTOSCI KK
  18.0000
WARTOSCI ALFA
   0.1745
WARTOSCI LT
   3.0000
WARTOSCI CX
   1.4000
WARTOSCI H
   0.5000
WARTOSCI OM
  10.0000
WARTOSCI VD
1000.0000
WARTOSCI VP
 400.0000
WARTOSCI SCC
   1.5000
WARTOSCI FD
   4.9000
WARTOSCI W
  10.0000
Q(1,KK)          0.25      0.50      0.75      1.00      1.50      2.00      2.00      2.50      3.00      4.00
                 5.00      7.50     10.00     15.00     20.00     30.00     35.00     50.00
E(1,KK)        1.0000    0.7640    0.6230    0.5620    0.4320    0.3700    0.3320    0.2800    0.2290    0.1740
               0.1340    0.0820    0.0440    0.0250    0.0150    0.0090    0.0070    0.0040
NOT(1,II)        3.15      9.44     14.67     20.96     36.42     50.84     79.92    158.66    266.29    714.90
               772.54    191.02     72.32     46.38     36.95     33.02     28.04     10.48
WARTOSC N1
   9.0000
WARTOSC N2
  18.0000
WARTOSCI OM1
  10.0000   20.0000   30.0000   40.0000   50.0000   60.0000   70.0000   80.0000   90.0000
WARTOSCI H1
   0.5000    1.0000    2.0000    4.0000    6.0000    8.0000   10.0000   12.0000   14.0000   16.0000
  18.0000   20.0000   22.0000   24.0000   30.0000   40.0000   50.0000   60.0000
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Fig. 3. Sample screenshot with the simulation parameters entered

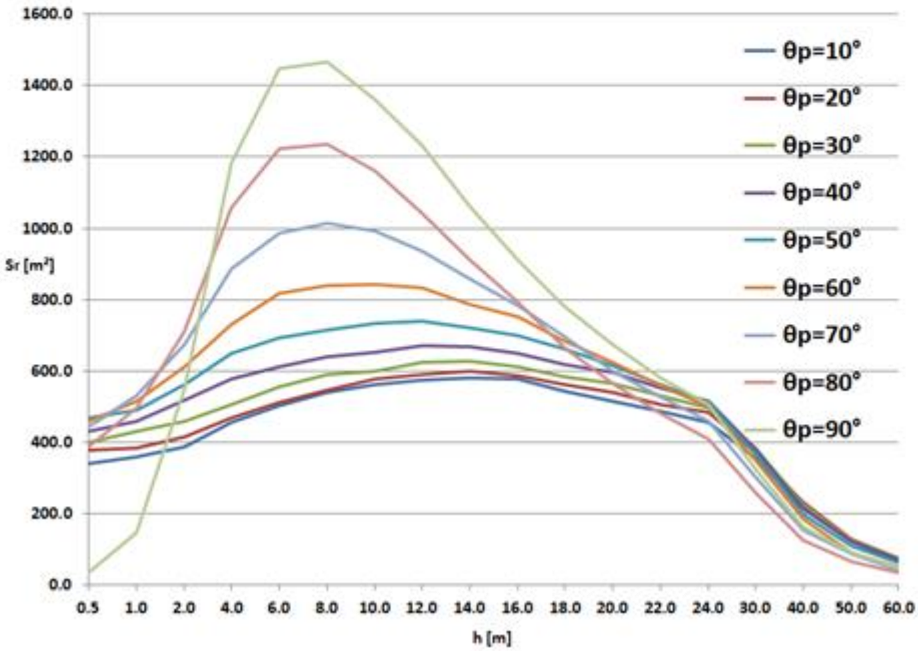

Fig. 4. Calculation area of fragmentation effect S_r (θ_p, h)

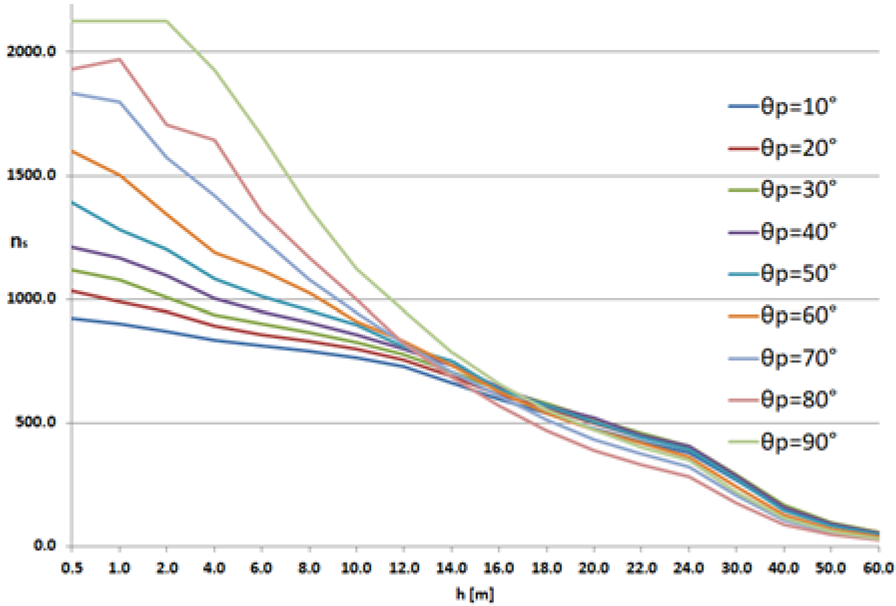

Fig. 5. Number of effective fragments falling on the affected area; $n_s(\theta_p, h)$.

4. CONCLUSION

The paper presented an outline of a simulation method for studying the effectiveness of ammunition equipped with proximity fuses. The method, developed at the Military University of Technology in Warsaw (Poland), is based on an unambiguous fragmentation action model with a defined and justified degree of simplification. It is a versatile method suitable for all weapons, designed to test the effects of individual parameters describing weapon casing fragmentation on the destructive effect of fragmentation, among others:

- explosion altitude;
- inclination angle of the fragmentation casing axis of symmetry at the moment of explosion;
- initial fragment velocity gained from detonation;
- fragmentation casing velocity at the moment of detonation;
- quantitative and weight distribution of fragments in the dispersion space after the explosion.

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Symulacyjna metoda oceny skuteczności rażenia odłamkowego

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Streszczenie. W artykule przedstawiono zarys symulacyjnej metody oceny skuteczności rażenia odłamkowego amunicji wyposażonej w zapalniki zbliżeniowe. Metoda, opracowana w Wojskowej Akademii Technicznej, oparta jest na jednoznacznym modelu działania odłamkowego o zdefiniowanym i uzasadnionym stopniu uproszczenia. Jest uniwersalną, przeznaczoną dla wszystkich środków rażących, metodą badań wpływu poszczególnych parametrów opisujących rozprysk skorupy odłamkowej na skuteczność rażenia odłamkowego.
Słowa kluczowe: skuteczność rażenia odłamkowego, symulacja skuteczności rażenia