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Efficiency Analysis of a Fragmentation Warhead Against Soft Targets

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The efficiency of the weapon system has been usually studied by altering the guidance and control or aerodynamics of the missile. This research investigated methods of enhancing the efficiency of the weapon system against soft targets based on the fragmentation warhead design. Different warhead geometric configurations, initiation points, as well as premade fragment material and shapes have been studied to enhance overall weapon efficiency against soft target. The study considered the static fragment distribution and velocity as the base for the analysis. A new vulnerability code has been developed based on the mean area of effectiveness to prove the study using both simulations and field tests. There were significant improvements on the weapon efficiency by altering the warhead parameters. The simulated results showed good correspondence with the test results. The newly developed vulnerability code can be considered as an additional system engineering analysis tool for the calculations of weapon efficiency

Key words: **Fragmentation warhead; Efficiency; Vulnerability; Soft Targets.**

Introduction

NOWADAYS there are different warhead due to the variation of targets that the weapon is built to attack. The usual targets that weapon designers look for are personnel, light armored vehicles, tanks, bunkers, aircrafts, fortifications, magazines, radars, missiles, ships, etc. Based on the selected target, the warhead can be with preformed fragments, controlled fragmentation, natural fragmentation, shaped charge, EFP, penetrator, incendiary, blast, thermobaric or a multipurpose warhead with combined effect [1-3].

Personnel are one of the main targets that a weapon designer is looking for. Personnel are either unprotected or behind protecting shield.

There are different software that are used to analyze fragmentation warhead. The premade fragmentation warhead was investigated using the finite element method as well as an analytical method. The software used are ANSYS Autodyn and Matlab.

The purpose of the paper is to study the efficiency of a weapon based on fragmentation warhead design parameters. ANSYS Autodyn and a developed vulnerability code were used to study the efficiency of a weapon based on its integrated warhead and fuze and selected target. The aim of this paper is to develop a tool that a warhead designer can use to analyze different interception scenarios between the weapon and the soft targets. The results of the fragment and velocity distribution are inputted into the developed code for mean area of effectiveness determination, which allows the warhead designer to design the warhead based on the weapon impact angle, weapon impact velocity, and target.

Algorithm

The mean area of effectiveness defines that for a density of a target in an element of area it will be incapacitated once the warhead is detonated. It is calculated using input derived from either finite element software Autodyn or arena test. For the analysis on this paper, Autodyn was used, as well as the test data from one of the warhead configurations used in the simulations. The algorithm that is used to derive the mean are of effectiveness values is shown in Fig.1.

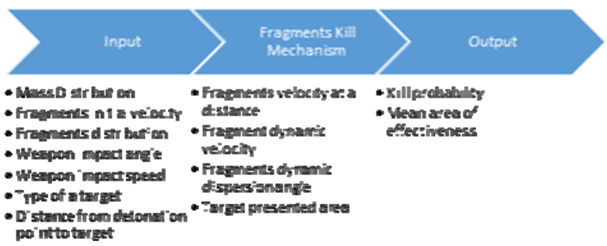

Figure 1. Mean area of effectiveness calculation algorithm.

As shown in Fig.1, to get the mean area of effectiveness, fragments mass distribution, fragments initial velocity, fragments distribution in each polar zone, weapon impact angle and speed, type of target and distance from detonation point to target must be inputted. These inputs will lead to calculations of fragments velocity at a distance, fragments dynamic velocity, fragments dynamic dispersion angle as well as the target presented area. These calculations lead to the calculations of the kill probability and the mean area of effectiveness. The vulnerability software was verified by continuous testing at Halcon. The weapon target interaction is shown in Fig.2.

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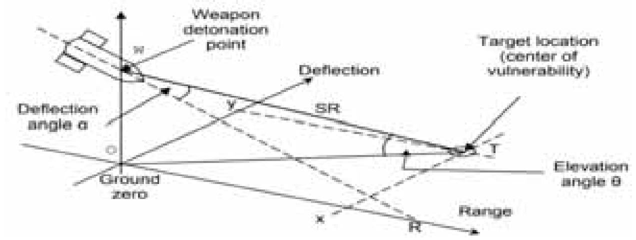

Figure 2. Weapon and target interaction geometry [4].

Equation 1 shows the mean area of effectiveness for a target that is uniformly distributed over the ground plane. Double integration is used to obtain the mean area of effectiveness.

$$\frac{E_c}{\sigma} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} P_K(x,y)\,dxdy \tag{1}$$

where,

E_c - Expected number of causalities.

σ - Density of the targets.

$P_K(x,y)$ - Probability that the target will be killed.

$\frac{E_c}{\sigma}$ - Mean area of effectiveness $\left[\mathrm{m}^2\right]$.

The mean area of effectiveness is a weighted area that is determined for each element of area that has a probability to be killed. Figure 3 shows the geometry of weapon and target interaction for mean area of effectiveness calculations in equation 1.

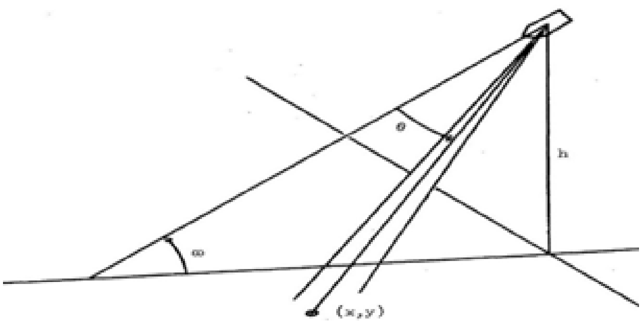

Figure 3. Geometry used for mean area of effectiveness calculations [5].

In Fig.3 it is assumed that the warhead is getting closer to the ground with impact angle ω and impact velocity V_h. The height of warhead burst from the ground is *h*. From mentioned geometry, the probability that the target will be killed by the accelerated fragments shall be calculated. The fragments are ejected from the projectile at an angle ϕ from the projectile main axis. In order to have a complete analysis on the probability that the target will be killed, fragments mass, fragments distribution, fragments initial velocity, fragments velocity at a distance from point of detonation, impact angle, impact velocity, and target presented area and probability of hit must be calculated.

Kokinakis and Sperrazza [6] developed a model to calculate the probability of kill or incapacitation of the target if the target is hit by a projectile or fragment. Different scenarios were considered in which personnel is protected or unprotected. According to the model, the probability of target kill/incapacitation is defined by:

$$P_{hk} = 1 - e^{-a\cdot\left(m\cdot V_r^{\frac{3}{2}} - b\right)^n} \tag{2}$$

where,

m - Fragment mass (g)

V_r - Fragment velocity at a distance *r* (m/s)

a,b,n - Sperazza criteria parameters found in [6].

The values of *a*, *b* and *n* are related to the tactical role and post wounding time defined in [6].

Once that the conditional kill probability is calculated using presented method the probability of kill can be calculated as in eq. 3. Poisson distribution is used for kill probability calculation [5]. The sum is for the weight fraction multiplied by the probability of kill.

$$P_k = 1 - e^{-\frac{\eta\cdot A_t}{R^2}} \sum_{i=1}^{n} q_i P_{hk_i} \tag{3}$$

where,

P_k - Probability of kill.

η - The ratio between total number of fragments in the polar zone (N) per the polar zone number that the fragments are at (Ω), $\eta = \frac{N}{\Omega}$.

R - Fragment traveling distance (m)

q - The fraction of the fragments in the spray or specified polar zone.

A_t - Target presented area (m^2)

In order to calculate the mean area of effectiveness the double integral shown in equation 1 shall be transformed to polar coordinates as in equation 4.

$$MAE = \int_{r_0}^{r_i}\int_{\phi_0}^{\phi_i} rP_k(r,\phi)\,drd\phi \tag{4}$$

where,

r - Distance from the burst point to a point on the ground.

ϕ - Angle in the ground plane measured from the projection of the projectile trajectory to the line connecting the origin to the point in the ground plane.

Numerical Simulation analysis

Ansys Autodyn was used for numerical simulation using hydrocode models [7]. Explicit Coupled Euler-Lagrange approach was used in the analysis. Warheads with premade fragments were analyzed in variant with a simple cylindrical warhead, as well as warheads with explosive shaped inside it. The purpose of the analysis is to compare the fragment distribution difference and the mean area of effectiveness between varieties of warheads. The Euler domain was used for the explosive, liner, casing and the bulkheads, since the part deform within a fixed space. The Lagrangian domain was used for the fragments, which allows the mesh to move with the deformed parts. A flow out boundary condition was used to allow flow of the explosive without reflection at the end of the Euler space. Euler 3D multi material part was used in order to apply part fill for the parts that were in Lagrange domain and transformed them to the Eulerian domain. The Euler 3D material was air and the Lagrangian material transformed to Euler were explosive, epoxy, case and bulkheads. A plane symmetry boundary condition in the y-axis was used to allow for half symmetry analysis. A geometric strain erosion model was used with a value of 1.5.

The models used for the efficiency study were a cylindrical, cylindrical with liner, non-uniform barrel, barrel and half barrel shape warheads. The cylindrical and half barrel warheads were analyzed with varying the initiation point. The materials and dimensions used for the analysis are the same for all warheads and the mass varied. The warhead caliber used was 100 mm and the length was 190 mm. The case thickness used was 2 mm. The fragment shape was sphere for all warheads with diameter of 5 mm. The material used for the fragment was high carbon steel, while the case, liner and the bulkheads material were Acrylic Styrene Acrylonitrile (ASA) using additive manufacturing. In the simulation polycarbonate was used instead of ASA due to availability of material data. The explosive material used was composition B and the material that was used to hold the fragments was epoxy resin. The medium surrounding the warhead was air. The element size on the fragment was 1 mm while the Euler element size was 0.25 mm. The mesh type for the fragment was multizone, while for the Euler part it was box. The simulations were run using 8 CPU, which gave the final results faster than using either lower or higher number of CPU. The simulation has been stopped once the air leaked from the other side of initiation and the fragment velocity started to converge. Figures 4 to 7 show the models used for the simulation.

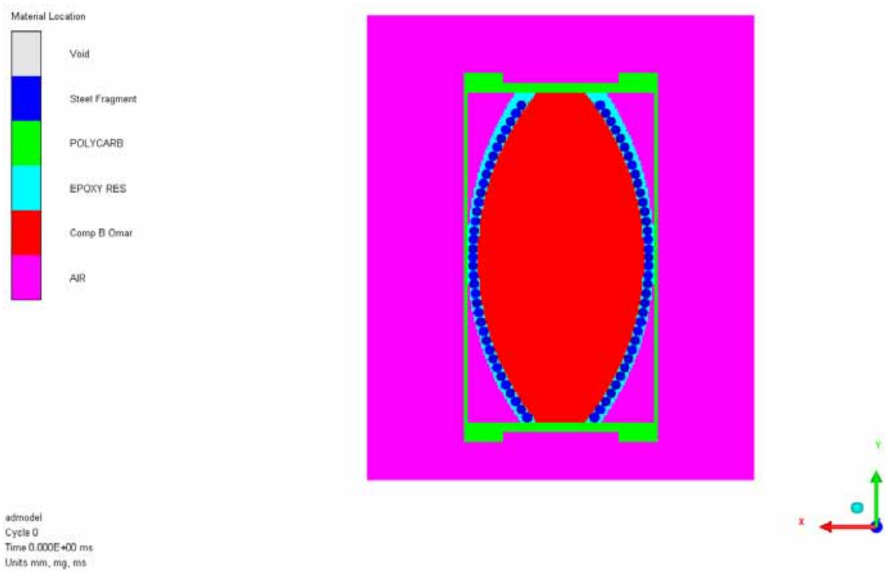

Figure 4. The Barrel Shape Used in the Simulation.

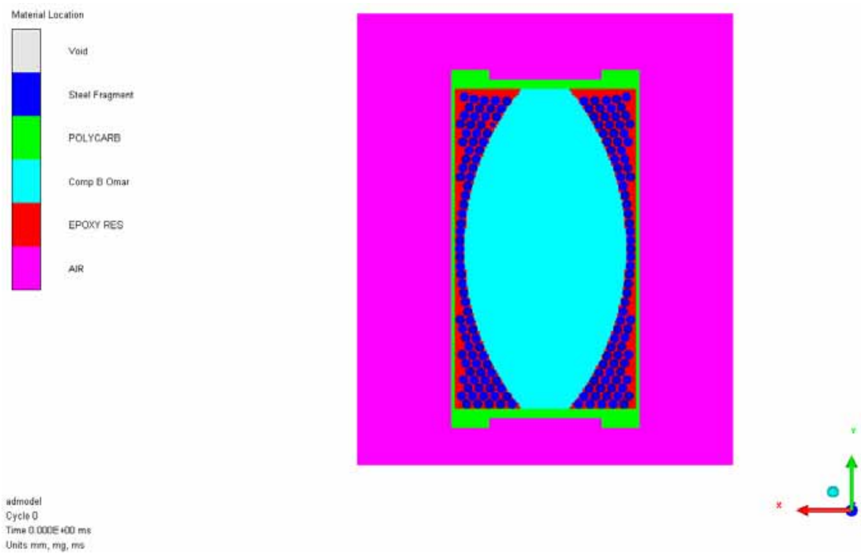

Figure 5. Non Uniform Barrel Shape Used in the Simulation.

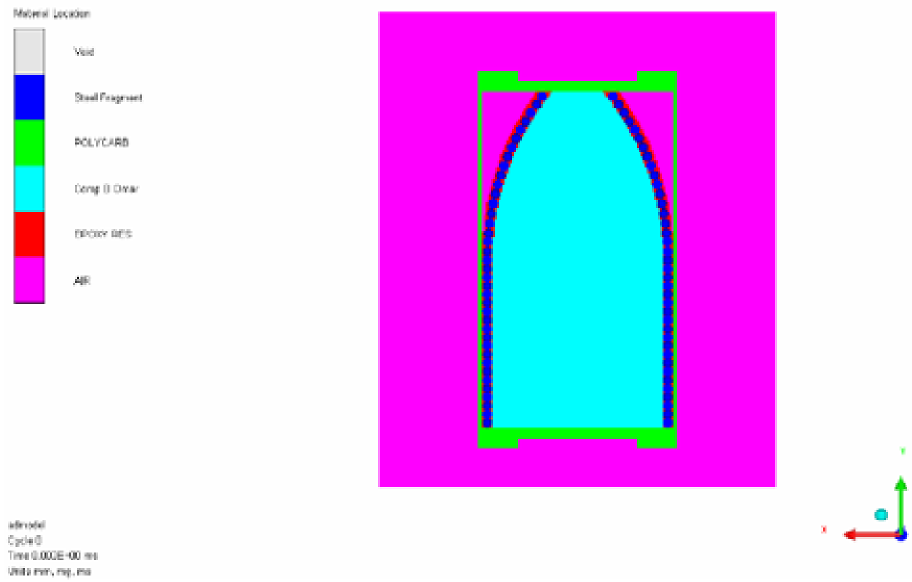

Figure 6. Half Barrel Shape Used in the Simulation.

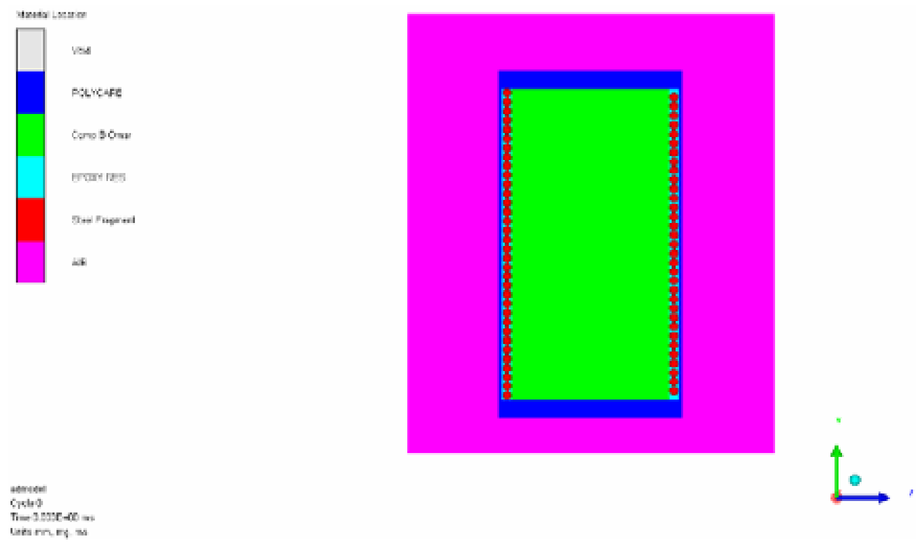

Figure 7. Cylindrical Shape Used in the Simulation.

The results of fragment number and velocity distribution are shown in Figures 8 and 9 below.

The static fragment distribution illustrated in Fig.8 shows that the non-uniform barrel shape warhead has the widest fragment distribution amongst all warheads and the cylindrical warhead has the least fragment distribution. Also, the barrel shape warhead showed wide fragment distribution but with smaller number of fragments compared to the non-uniform barrel shape warhead. Moreover, the cylindrical warheads with center and two point initiation from front and rear have almost the same distribution and better than the cylindrical warhead with one point initiation, as well as the two side initiation from the rear cylindrical warhead. The half barrel shape warhead with both small side initiation and big side initiation showed almost the same distribution. The half barrel shape warhead initiated from the small side showed slightly higher number of fragments to the rear than the one initiated from the big side. Also, more fragments to the front side in the half barrel warhead initiated from the big side than that of the half barrel warhead initiated from the small side. Finally, the non-uniform barrel warhead showed high fluctuations and various peaks between the polar zones, which are very interesting phenomena that will be studied in the future.

The fragment velocity distribution illustrated in Figure 9 shows that the highest velocity distribution is for the non-uniform barrel shape warhead followed by the barrel shape warhead. The half barrel with big side initiation shows higher velocity distribution up to 80 degrees polar zone and then the half barrel with small side initiation shows higher velocities than those of the big side initiation. The highest velocity is achieved by the cylinder shape warhead with two point initiation from the front and rear of the warhead. The rest of the cylindrical warheads showed almost same velocity distribution except for the center point initiation which showed higher velocities toward the rear.

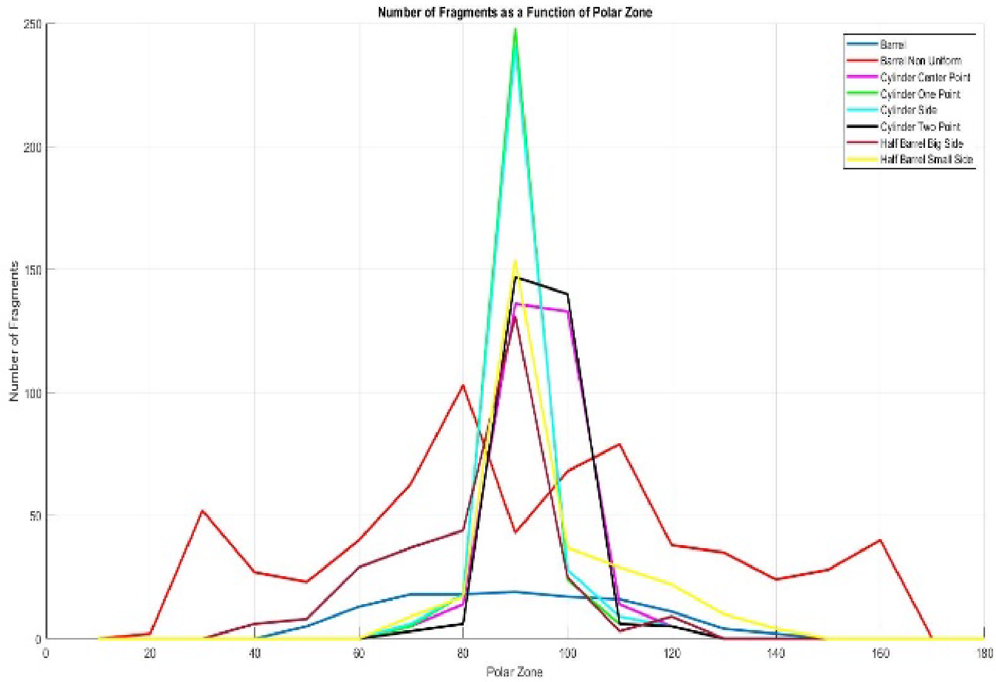

Figure 8. Comparison of Number of Fragments as a Function of Polar Zone for all Warheads.

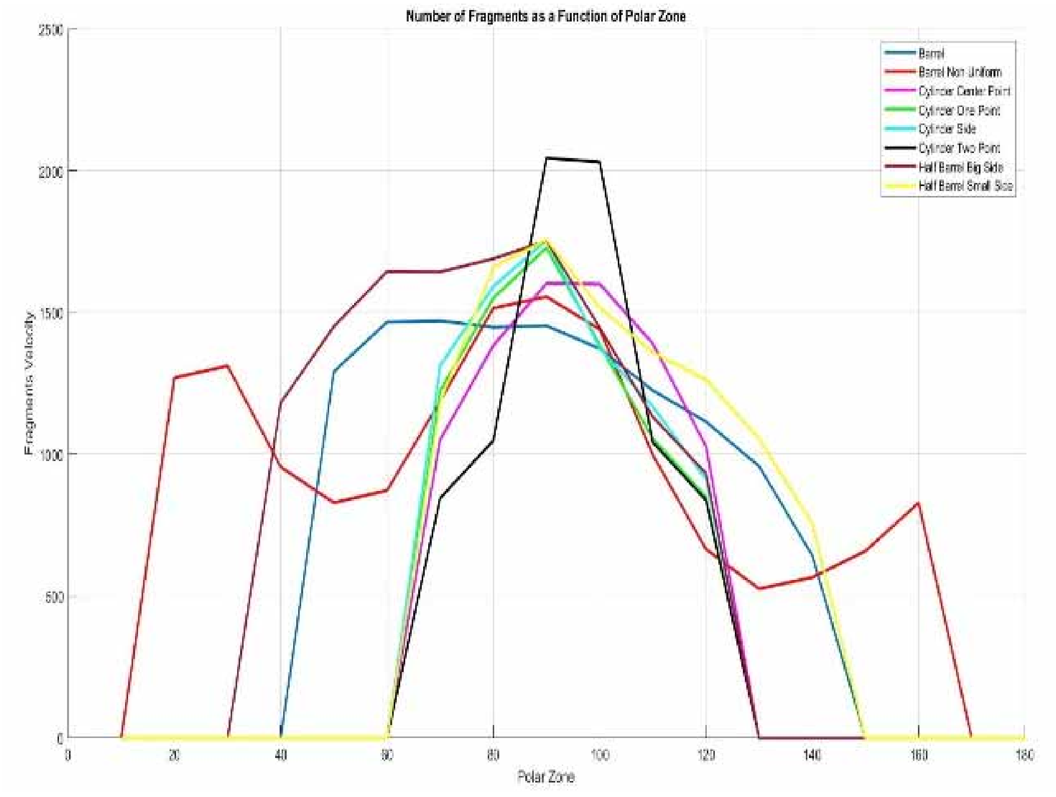

Figure 9. Comparison of Fragments Velocity Distribution as a Function of Polar Zone for All Warheads.

The mean area of effectiveness is calculated to illustrate the efficiency of the warhead when intercepting with the target. Fig.10 shows the visualization of the mean area of effectiveness using different colors where kill probability is calculated for non-uniform barrel shape warhead with 70° impact angle, 200 m/s impact velocity and 2 m height of burst. The kill probability is illustrated as PK in the Figure .

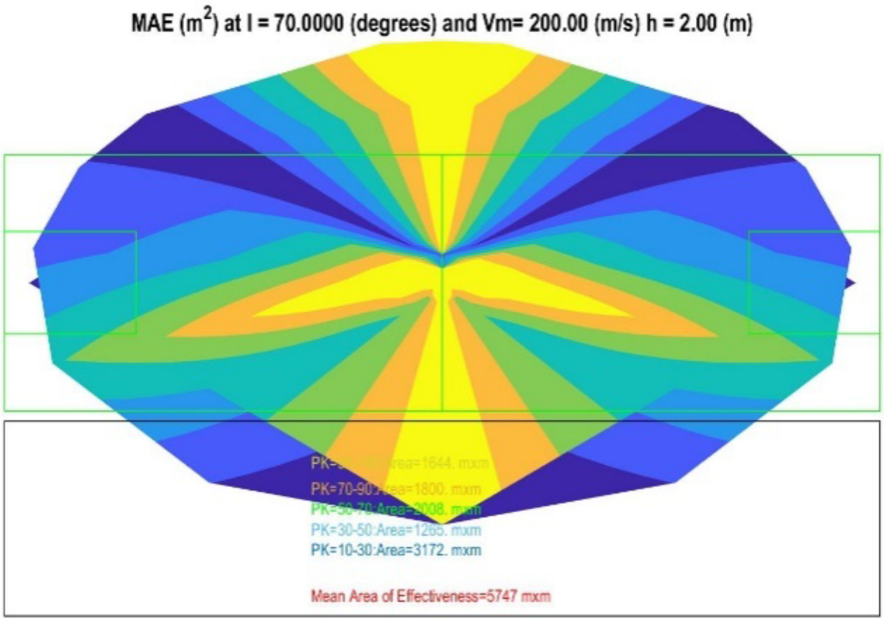

Figure 10. Mean Area of Effectiveness for 70 Degrees Impact Angle, 200 m/s Impact Velocity and 2 m Height of Burst.

Table 1 shows the mean area of effectiveness as well as the area for 90-100% kill probability for all warheads analyzed. The impact speed was the same for all scenarios with a value of 200 m/s. The impact angle and height of burst were varied. The abbreviations IA, HOB and PK represent the impact angle, height of burst and kill probability respectively.

Table 1: Total Mean area of effectiveness and 90-100% PK Mean Area of Effectiveness for All Warheads Simulated.

Warhead Type	Scenario		MAE (m^2)	
	IA (°)	HOB (m)	(90-100%) PK	Total
Non-Uniform Barrel	45	0	1635	5774
		2	2119	5347
	60	0	1540	6133
		2	1944	5164
	80	0	1404	5234
		2	1392	4785
Barrel	45	0	135	1265
		2	359	1914
	60	0	634	2672
		2	1521	5590
	80	0	1379	4963
		2	1343	4559
Cylinder One Point	45	0	544	2381
		2	731	2404
	60	0	248	2071
		2	726	2383
	80	0	628	2455
		2	1951	5260
Cylinder Two Points	45	0	558	2372
		2	727	2383
	60	0	333	2161
		2	744	2386
	80	0	652	3071
		2	1497	5306
Cylinder Side	45	0	544	2380
		2	731	2406
	60	0	247	2077
		2	726	2383
	80	0	641	2559
		2	1951	5260
Cylinder Center	45	0	299	2121
		2	750	2412
	60	0	158	1694
		2	737	2413
	80	0	648	2431
		2	1728	5014
Half Barrel Big Side	45	0	778	3949
		2	744	2486
	60	0	669	3601
		2	1222	4029
	80	0	574	2143
		2	1698	4864
Half Barrel Small Side	45	0	384	2334
		2	750	2514
	60	0	205	1939
		2	1510	5014
	80	0	1407	5146
		2	2015	5403

The non-uniform barrel shape warhead showed the highest values of the total and 90-100% PK mean area of effectiveness at 45° and 60° impact angle amongst all warheads. The values of the mean area of effectiveness were increasing as the height of burst increase for all warheads when the impact angle was 80° except for the barrel and non-uniform barrel shape warhead. For the cylindrical shape warheads it has been shown that their optimum scenario is when the weapon has impact angle of 80° with 2 m height of burst.

Comparison Between Test Results and simulation

The analyzed warheads are under testing and one of the models was tested successfully. Fig.11 shows setup for horizontal arena and Fig.12 shows the setup for vertical arena test.

Figure 11. Horizontal Arena Test Setup.

Figure 12. Vertical Arena Test Setup.

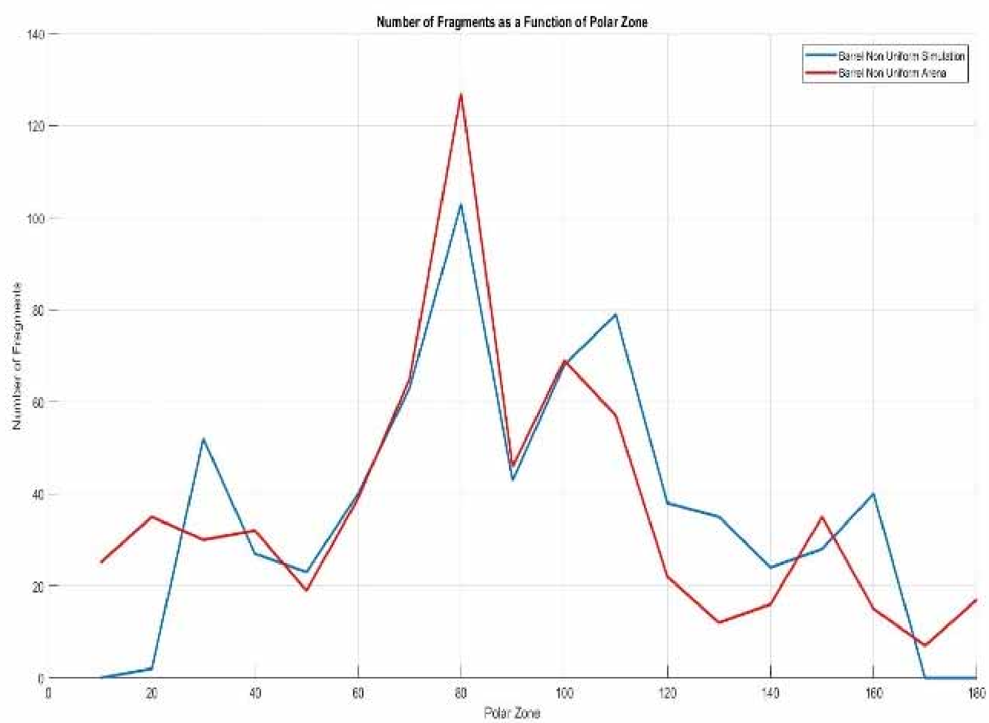

Figure 13. Number of fragments as a function of polar zone: comparison between the results of test and simulation for non-uniform barrel shape warhead.

The non-uniform barrel warhead shape was analyzed and the comparison between the test data and the simulation results are shown in Fig.13.

The fragment spatial distribution results for the non-uniform barrel shape warhead from the simulation and the arena test showed excellent correspondence. The pattern is almost the same except for the lower polar zones and higher polar zones. The lower polar zones from the simulation shows a value of zero while the arena test result shows small number of fragments present.

Conclusion

The paper considers improvement of numerical and analytical modeling techniques for evaluation of fragmentation warhead efficiency. The developed numerical models within Autodyn and code in MATLAB showed the usefulness and potential to assist designer to predict the warhead and soft target interaction.

Various scenarios in terms of warhead design configurations and initiation variants were considered and for each scenario the values for Mean area of effectiveness have been determined. Detailed analysis of the obtained results provides certain guidelines for choosing the optimal configuration of the warhead and its initiation. Specifically, a wider fragment distribution for the non-uniform barrel shape warhead showed significant improvement in weapon target interaction especially at lower impact angles.

Good agreement between the simulation results and the arena test result for the non-uniform barrel shape warhead was demonstrated.

The code will be enhanced in future work to include more targets as well as different interaction geometries.

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Analiza efikasnosti bojnih glava parčadnog dejstva protiv "mekih" ciljeva

Efikasnost sistema naoružanja se često razmatra sa aspekta unapređenja metoda vođenja i upravljanja, kao i aerodinamike projektila. U ovom radu reč je o istraživanju mogućnosti poboljšanja efikasnosti bojne glave parčadnog dejstva putem unapređenja njene konstrukcije. U cilju povećanja efikasnosti bojne glave protiv mekih ciljeva razmotrene su različite geometrijske konfiguracije bojne glave, različiti položaji tačaka iniciranja, kao i materijal i oblik unapred formiranih fragmenata. Osnovu studije predstavlja numeričko određivanje statičke raspodele vektora brzine generisanih fragmenata. Na osnovu ove raspodele razvijen je novi program koji omogućava određivanje efikasnosti bojne glave. Pokazano je da pomenute promene konstrukcionih parametara značajno utiču na efikasnost bojne glave. Rezultati simulacija se veoma dobro slažu sa rezultatima eksperimentalnog ispitivanja. Novi program za proračun efikasnosti bojnih glava, odnosno ranjivosti ciljeva, može se smatrati korisnim dopunskim alatom za sistemsku inženjersku analizu efikasnosti sistema naoružanja.

Ključne reči: **bojna glava parčadnog dejstva, efikasnost, ranjivost, meki ciljevi.**