International Journal of Mechanical, Industrial and Aerospace Sciences
ISSN: 2517-9950
Vol:6, No:6, 2012

FEM Simulation of HE Blast-Fragmentation Warhead and the Calculation of Lethal Range

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Abstract**—**This paper presents the simulation of fragmentation warhead using a hydrocode, Autodyn. The goal of this research is to determine the lethal range of such a warhead. This study investigates the lethal range of warheads with and without steel balls as preformed fragments. The results from the FE simulation, i.e. initial velocities and ejected spray angles of fragments, are further processed using an analytical approach so as to determine a fragment hit density and probability of kill of a modelled warhead. In order to simulate a plenty of preformed fragments inside a warhead, the model requires expensive computation resources. Therefore, this study attempts to model the problem in an alternative approach by considering an equivalent mass of preformed fragments to the mass of warhead casing. This approach yields approximately 7% and 20% difference of fragment velocities from the analytical results for one and two layers of preformed fragments, respectively. The lethal ranges of the simulated warheads are 42.6 m and 56.5 m for warheads with one and two layers of preformed fragments, respectively, compared to 13.85 m for a warhead without preformed fragment. These lethal ranges are based on the requirement of fragment hit density. The lethal ranges which are based on the probability of kill are 27.5 m, 61 m and 70 m for warheads with no preformed fragment, one and two layers of preformed fragments, respectively.

Keywords**—**Lethal Range, Natural Fragment, Preformed Fragment, Warhead.

I. INTRODUCTION

FOR a fragmentation warhead type, preformed fragments in the formed of sphere ball are filled between the explosive layer and warhead casing. Generally, the number of these preformed fragments is much higher than those of natural fragments resulted from breaking of warhead casing. Increasing the number of preformed fragments generally increases the lethality range. However, volume of explosive is decreased when more preformed fragments are filled. This would lead to lower initial velocities of both natural and preformed fragments as the C/M is decreased. Therefore, it is necessary to assess whether the mass and velocity of fragment are sufficient to damage a target.

A finite element (FE) approach can be employed to determine mass and velocity of natural fragments of warhead. However, it is not quite practical to model preformed fragments explicitly as this would require much computation resources. Therefore, this study attempts to model the problem in an alternative approach by considering an equivalent mass of preformed fragments to the mass of warhead casing. The results from FE simulation are compared to the results from analytical calculation performed in this study.

A well known Gurney's equation and Shapiro's formula are adopted for the calculation of initial velocities and spray angles of fragments, respectively.

II. LITERATURE REVIEW

In this study, the modified Gurney's equation was employed to calculate initial velocities of natural and preformed fragments resulted from the detonation of warhead. It can be seen from (1) that initial velocity of fragment depends on the values of $\sqrt{2E}$ (Gurney velocity coefficient) and C/M (charge weight per metal mass ratio).

$$V = \sqrt{\frac{2E}{\frac{M}{C} + \frac{1}{2}}} \tag{1}$$

It is noted that the difference in the initial velocity of natural and preformed fragments is resulted from the gas leakage between preformed fragments. Therefore, the initial velocity of preformed fragment is always lower than that of natural fragment since a reduction in blast pressure resulted from the gas leakage prohibits acceleration of preformed fragment. Reference [1] suggested reducing the C/M value to represent the greater energy loss until acceptable agreement between the calculation and the test data was achieved. This study adopts the gas reduction factor of 0.50 as suggested in [1].

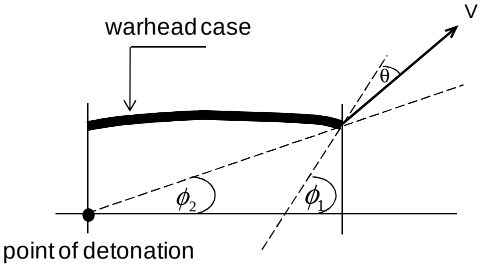

Fig. 1 Spray angle of fragment

Apart from the initial velocities of natural and preformed fragments, the spray angles of those fragments can be determined using Shapiro's formula [2] as presented in (2). It can be seen from (2) and Fig. 1 that the spray angle of fragment depends on the position of warhead case and its preformed fragment relatively to the detonation point of warhead. The initial velocity of fragment also affects spray angle.

$$\tan\theta = \frac{V}{2V_0}\cos\left(\frac{\pi}{2} + \phi_2 - \phi_1\right) \tag{2}$$

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In order to evaluate hit density and capability of killing of such a warhead, it is important to determine a fragment mass distribution produced from a detonation of the warhead. Reference [3] suggested an analytical formula to obtain the distribution of fragment mass as shown in (3) and (4).

$$N(m) = \frac{M_0}{2M_k^2} e^{-\left(\frac{m^{1/2}}{M_k}\right)} \tag{3}$$

$$M_k = Bt^{5/16} d^{1/3} \left(1 + \frac{t}{d}\right) \tag{4}$$

III. FEM SIMULATION

This section presents the FEM set up and simulation results of warhead with and without preformed fragments. Three simulation cases were modelled to validate the modelling technique proposed in this study. As it is not rather practical to model a large number of small preformed fragments in the warhead explicitly, this study modelled preformed fragments as a layer of steel with equivalent weight to those of steel ball fragments. It is noted that this study adopted 6 mm diameter of preformed fragments.

The model was set up in 2D-axisymetric and is illustrated in Fig. 2. The warhead filled with TNT is surrounded by air. Air and explosive were modelled using Euler formulation whilst the casing of warhead was modelled using Lagrange formulation. The interaction between casing, explosive blast and air is activated through Lagrange-Euler interaction in Autodyn interface. Location of detonation point is assumed at a position of booster as shown in Fig. 2.

TABLE I
EQUIVALENT DENSITY AND NUMBER OF PREFORMED FRAGMENTS FOR 1 AND 2 LAYERS OF PREFORMED FRAGMENTS

Model	Total number of preformed fragments	Equivalent density of a layer of preformed fragments (g/cm^3)
One layer of preformed fragments	11,705	4.40
Two layers of preformed fragments	22,721	4.40

Fig. 3 presents three FE models analyzed in this study. First, the FE results of warhead with no preformed fragment were compared with those obtained from analytical calculation ((1)-(4)). The comparison was performed so as to confirm the accuracy of the model. The FE models of warheads with one and two layers of preformed fragments were analyzed sequentially.

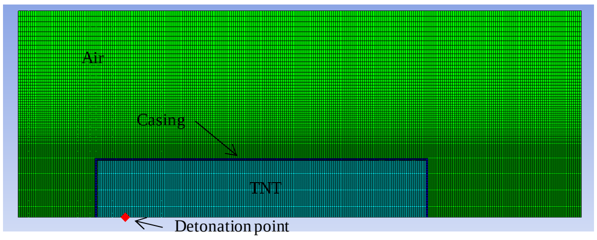

Fig. 2 Composition of the FE model

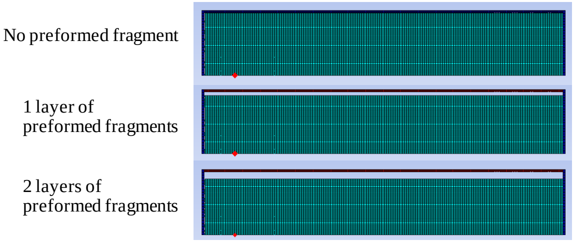

Fig. 3 Decrease in TNT volume for the warhead with preformed fragments

IV. FE RESULTS

The warhead explosion processes are presented in Fig. 4. The warhead casing starts to expand from the initiated end and propagates to the opposite end. The breaking of simulated warhead along time is also illustrated in Fig. 4. The velocity vectors of natural fragments at each stage are presented in Fig. 5. The velocity vectors of natural fragments obtained from numerical simulation are compared with those obtained from analytical calculation and presented in Fig. 6. The magnitude of velocity vectors of natural fragments produced from warhead without preformed fragment reported from the FE simulation agrees well with the analytical results.

The comparison of magnitude of velocity vectors resulted from numerical and analytical approaches of one layer of preformed fragments warhead is also in a good agreement. The average difference in velocity is approximately 7 % for both analysis cases. However, it was found that the method of equivalent density of preformed fragment does not appropriate for the two layers of preformed fragments as the magnitude of velocity vectors of natural fragments obtained from the numerical simulation differ from those obtained from analytical calculation by almost 20%. However, spray angles or eject angles of natural fragments obtained from the numerical simulation agree well with those obtained from analytical calculation for all analysis cases. The plots of velocity vectors for all analysis cases are presented in Fig. 6.

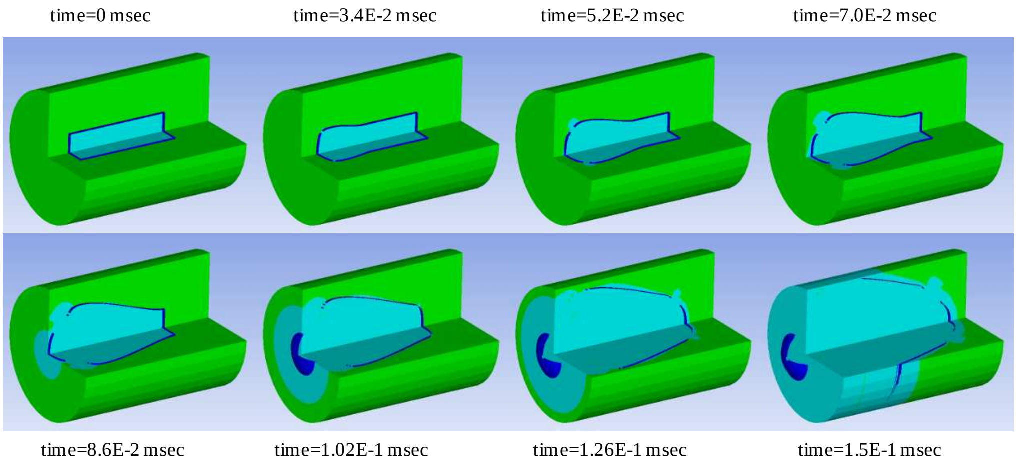

Fig. 4 Warhead explosion processes

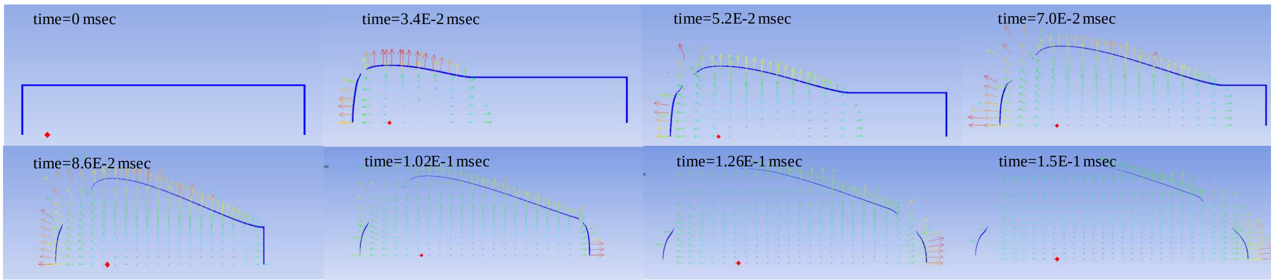

Fig. 5 Velocity vectors of warhead casing and TNT

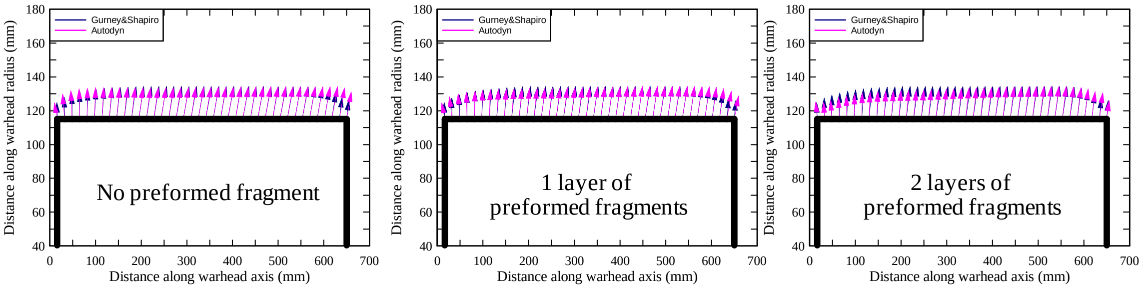

Fig. 6 Comparison of velocity vectors of casing obtained from analytical calculation and FE simulation

V. LETHAL RADIUS OF WARHEAD

The methodology employed to determine lethal radius of such a warhead is presented in this section. The input parameters for the assessment of lethal radius are velocity vectors of natural and preformed fragments and the total number and average natural fragment mass. These are obtained from calculation presented in Sections III and IV.

Fig. 7 illustrated the diagram used to describe the concept to determine the lethality area under warhead. In addition to the fragment characteristics of warhead, impact velocity, impact angle of warhead and height of detonation all affect to the lethality area as shown in Fig. 7

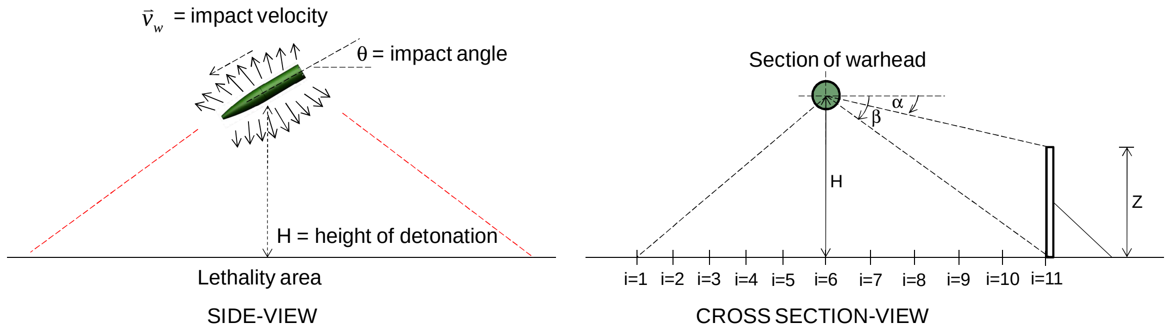

Fig. 7 Lethality area below warhead and location of fragment distribution

Two criteria used to assess lethal radius in this research are fragment hit density and probability of kill required to damage each type of target. Reference [4] stated that the presented area of a standing man is 0.50 m^2 so that the required minimum fragment hit density is two fragments/m^2.

By performing a series of calculation varying the distances from warhead, hit densities can be calculated for warheads with and without preformed fragments. Fig. 8 presents the charts of hit density versus distance from warhead.

The hit densities presented in Fig. 8 were calculated based on the number of preformed fragments (see Table I) and the number of natural fragments (see TABLE II).

The distance in which the hit density equals to two fragments/m^2 is considered to be lethal radius. Therefore, hit densities of warheads without perform fragment, with one and two layers of preformed fragments can be determined directly from the charts shown in Fig. 8.

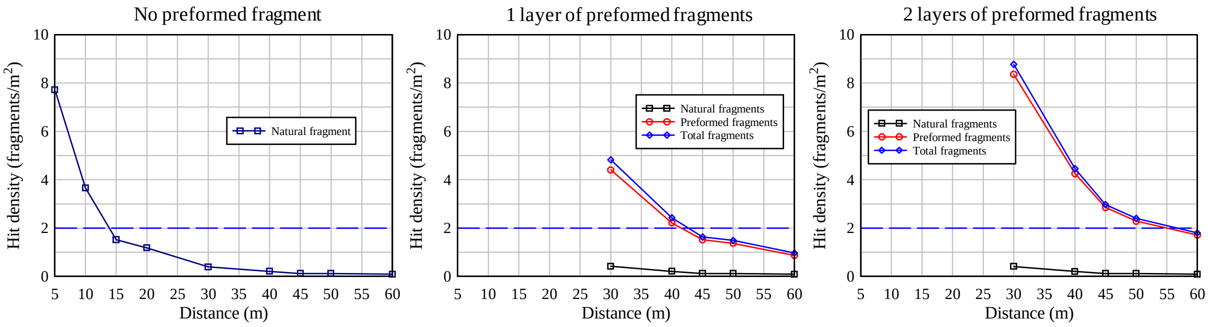

Fig. 8 Hit densities of warheads without preformed fragment, with one and two layers of preformed fragments

TABLE II

NUMBER OF NATURAL FRAGMENTS PRODUCED FROM WARHEAD WITH AND WITHOUT PREFORMED FRAGMENTS

	Number of natural fragments	
	Mott's distribution	Autodyn
No preformed fragment	1,323	1,043
1 layer of preformed fragments		1,062
2 layers of preformed fragments		110

However, the lethal radius can be assessed based on the probability of kill (P_k) in which the range within which there will be a 50% probability of kill is called a lethal range of a warhead [5]. The probability of kill can be determined from (5).

$$P_k = 1 - \left(1 - P_{k|hit}\right)^{N_{hits}} \quad \text{, if } N_{hits} > 1$$
$$P_k = N_{hits} P_{k|hit} \quad \text{, if } N_{hits} < 1 \qquad (5)$$

where $P_{k|hit}$ can be obtained from Table III where the value of $P_{k|hit}$ relates to kinetic energy of fragment and type of target.

TABLE III

VALUES OF $P_{k|hit}$ FOR DIFFERENT DAMAGE LEVELS ON THREE TYPES OF TARGETS

	Fragment energy (kJ)		
Target type	Light damage (Pk=0.1)	Moderate damage (Pk=0.5)	Heavy damage (Pk=0.9)
Personnel	0.1	1	4
Aircraft	4	10	20
Armoured vehicle	10	500	1000

From the hit densities at various distances presented in Fig. 8 and the fragment characteristics, i.e. average fragment mass and average residual velocity of fragment, probabilities of kill for each warhead at various distances can be plotted as shown in Fig. 9.It is noted that the average natural fragment mass is 2.2 grams determined using a Mott's distribution (see (3) and (4)).

The lethal range for each analysed warhead can be assessed from charts shown in Fig. 9 where the lethal range is at the distance corresponded to a probability of kill of 0.5. TABLE summarizes lethal ranges for each warhead based on the criterion of fragment hit density and probability of kill. It can be seen that the lethal range determined using a criterion of fragment hit density is smaller than those determined using a criterion of probability of kill.

Therefore, this study suggests that the criterion of fragment hit density should be considered when the conservative design is required.

This study also reveals that the lethal range of fragmentation warhead can be significantly enhanced when preformed fragments are included in the design. However, double the number of preformed fragment layer does not significantly improve the lethal range.

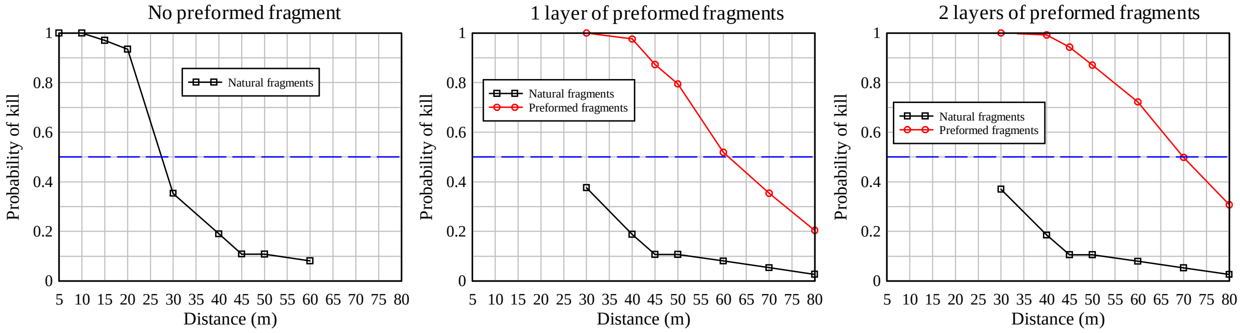

Fig. 9 Probability of kill of warheads without preformed fragment, with one and two layers of preformed fragments

TABLE IV
LETHAL RANGE OF WARHEAD WITH AND WITHOUT PREFORMED FRAGMENTS

Configuration of warhead	Lethal range (m)	
	Based on fragment hit density	Based on probability of kill
No preformed fragment	13.85	27.5
1 layer of preformed fragments	42.6	61
2 layer of preformed fragments	56.5	70

VI. SUMMARY

This paper presents an approach employed to determine lethal ranges for fragmentation warheads with and without preformed fragments. This study also compares the lethal range for the warheads with one and two layers of preformed fragments. A high computation resource in modelling a large number of preformed fragments is avoided by modelling spherical preformed fragments as another layer of casing with equivalent density so as to obtain the same weight of preformed fragments. It is found that this approach can be employed to model warhead with one layer of preformed fragments whilst this approach does not appropriate for the two layers of preformed fragments as the magnitude of velocity vectors of natural fragments obtained from the numerical simulation differ from those obtained from analytical calculation by almost 20%. Apart from the determination of velocity vectors of fragments, average fragment mass and a total number of fragments were calculated, a lethal range of warhead can be assessed based on fragment hit density and probability of kill. This study shows that a lethal range of warhead is determined conservatively based on a criterion of fragment hit density. A one layer of preformed fragments can significantly enhance the lethal range of warhead compared to that of warhead without preformed fragment. However, two layers of preformed fragments do not significantly increase the lethal range of warhead over that of one layer of preformed fragments warhead.

REFERENCES

[1] Y. Charron, "Estimation of velocity distribution of fragmenting warheads using a modified Gurney method," Air Force Institute of Technology, 1979.
[2] "Elements of terminal Ballistics, Part One, Introduction, Kill Mechenics and Vulnerability," in Washington, D.C., 1962, pp. 4-175.
[3] N. F. Mott, "Fragmentation of high explosive shells, A theoretical formula for the distribution of weights of fragments," 1943.
[4] "AAAV 30 mm HE lethality testing, Test procedures and casualty models," NAVSEA, Dahlgren.
[5] Federation of American Scientists (FAS). “Introduction to Naval Weapons Engineering, Damage Criterion”, http://www.fas.org/man/dod-101/navy/docs/es310/dam_crit/dam_crit.htm.