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A NUMERICAL INVESTIGATION OF TOP-ATTACK SUBMUNITION IMPACT ON STEEL TARGET

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The normal and oblique impacts of top-attack submunition on steel target are analyzed with a 3D explicit finite element method. A bilinear material constitutive behavior with isotropic hardening is assumed. The impact to detonation time lag is estimated and structural deformations of the submunition are monitored. The detonation time lag is found to increase exponentially with the obliquity of impact and large structural deformations are predicted to occure before onset of detonation. The reduced stand-off distance as well as improper jet formation due to the large asymmetric structural deformation result in the reduced terminal performance of the submunition.

1 INTRODUCTION

Top-attack submunitions are being increasingly used these days in a large variety of cargo ammunitions starting from the mortar bombs and gun shells to the artillery rocket warheads. While the primary kill mechanism of the submunition is the hyper velocity jet produced by the lined hollow charge, the blast and fragmentation generated by explosion cause the anti-personnel and antimaterial secondary effects. These submunitions are primarily used against the tanks, armored personnel carriers, infantry combat vehicles, mechanized infantry formation and land troop concentrations. A large number of submunitions are carried in the bomb, shell or warhead and they are dispensed in air over the target. The submunition has a mechanical fuze, which gets armed after ejection of submunition from the carrier shell and functions on impact of the submunition with the ground or the target. A great deal of research work has gone into improving the efficiency of top-attack submunition and a nearly optimized design of submunition has been evolved under the name Dual Purpose Improved Conventional Munitions (DPICM). While the DPICM exhibits excellent terminal performance in static tests, its performance is considerably reduced under dynamic conditions. The dynamic performance of top-attack submunition can be assessed experimentally for oblique as well as normal impact by launching the submunition from a gun against the target plate kept at desired orientation; but, the above experimental study can not monitor the striker movement and the exact state of submuni-

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tion before detonation. Hence, knowing reason for degraded dynamic performance of the submunition remains osbcure. Another possible alternative for developing useful insight into the problem is the numerical simulation of the event. Numerical methods are capable of attacking the entire set of field equations and can accurately model transient phenomena. But, they are still approximate in nature; mostly due to errors associated with uncertainties in the material constitutive description. It is important to add here that despite limitations of modeling sophisticated constitutive equations to characterize material behavior, numerical results for deformation fields often bear close resemblance to those found experimentally.

In this work, a three dimensional numerical analysis of submunition impact on a steel target has been carried out. The study is aimed at investigating the impact induced structural deformation of the submunition and finding the possible reasons for reduced terminal performance under dynamic conditions. Numerical simulations of submunition impact have been performed with the help of LS-DYNA3D [1]. It is a Lagrangian non-linear explicit finite element code that is widely used for modeling lower to hyper velocity impacts. A frictional surface-to-surface contact and isotropic hardening bilinear elastic-plastic material model have been used in the analysis. Normal and oblique impacts, each with an impact velocity of 150 m/s have been considered for computational study.

2 THE COMPUTATIONAL MODEL

A section model of the top-attack submunition depicting internal details is shown in Fig. 1(a). As shown in Fig. 1(a), fuze of the submunition is a complex assembly of several tiny parts, which need not be modeled for finite element analysis. As such, a stepped hollow cylinder with a striker replaces the fuze in the finite element model. The size and mass of the cylinder has been kept similar to that of the actual fuze. A discretized half-finite element model of the submunition is shown in Fig. 1(b). The discretization of continuum is performed with 99732 8-node brick elements.

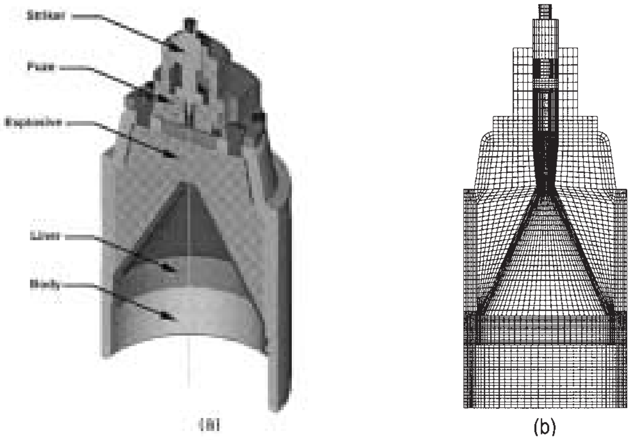

Figure 1: (a) Section model of BAT38. (b) Finite element model.

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A high strength hardened alloy steel has been considered for the submunition body as well as for the target. The elastic-plastic responses of the steel and copper liner are modeled by using a bilinear isotropic hardening constitutive behavior within the framework of infinitesimal displacement gradient J_2-flow theory. Thus, the yield surface in the stress space is given by,

$$\phi = \frac{1}{2} s_{ij} s_{ij} - \frac{\sigma_y^2}{3} \tag{1}$$

In eqn.(l), the deviatoric stress tensor s_{ij} is obtained from the Cauchy stress tensor σ_{ij} by:

$$s_{ij} = \sigma_{ij} - \frac{1}{3}\sigma_{kk} \tag{2}$$

The current yield stress σ_y is a function of plastic strain and obeys the relation:

$$\sigma_y = \sigma_o + E_p \bar{\varepsilon}^p \tag{3}$$

where σ_o is the initial yield strength, $\bar{\varepsilon}^p$ is the effective plastic strain

$$\bar{\varepsilon}^p = \int_0^t \left(\frac{2}{3} \dot{\varepsilon}^p_{ij} \dot{\varepsilon}^p_{ij} \right)^{1/2} dt \tag{4}$$

Part	$\rho (kg/m^3)$	E (GPa)	ν	σ_o(MPa)	E_t(MPa)	μ_s	μ_d
Target and body	7820	207	0.29	1235	7730	0.15	0.1
Copper liner	8820	247	0.29	200	00.00	-	-
Explosive	1700	28	0.4	Elastic	-	-	-
Fuze	5207	207	0.29	Elastic	-	-	-
Striker	13603	207	0.29	Elastic	-	-	-

Table 1: Material properties.

and E_p is the plastic hardening modulus in terms of elasticity modulus E and tangent modulus E_t

$$E_p = \frac{E E_t}{E - E_t} \tag{5}$$

The total strain rate follows the elastic-plastic decomposition:

$$\dot{\varepsilon}_{ij} = \dot{\varepsilon}^e_{ij} + \dot{\varepsilon}^p_{ij} \tag{6}$$

Kreig and Key [2] formulated this model and the implementation in LS-DYNA3D is based on their paper. As the material is very moderately strain rate sensitive, the strain rate effects are not considered in the analysis. All balance equations have been integrated with

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a time step $\Delta t = 7.616 \times 10^{-9}$s, which was decided by the code. The materials for explosive and fuze are considered to be linear elastic. Results presented in this paper are for the material properties given in Tab. 1.

3 RESULTS

The BAT38 DPICM top-attack submunition has been considered for analysis in this work. The submunition weighs 220 grams and is aerodynamically stabilized by means of a clip-ribbon system attached to the fuze striker. The fuze gets armed when the submunition is ejected from the carrier structure and the aerodynamic pull exerted on the ribbon stabilizer keeps the striker away from the detonator. On impact, the striker moves forward in the fuze cavity due to its inertia and pricks the detonator. The impact to detonation time primarily depends on the impact velocity and the orientation of the submunition at the time of impact. The prime concerns of this study are the estimation of impact to detonation time lag and the structural deformation of the submunition during this lag period. The numerical experiments were conducted on 25 mm thick steel target that simulates the top of a tank. Four impact orientations of the submunition, namely 0°, 10°, 20° and 30° with the target plate normal, each with an impact velocity of 150 m/s were considered for computational study. As the gun launched cargo ammunitions have usually very high spin rates, the submunition was assumed to be spinning with a rate of 1250 rad/s.

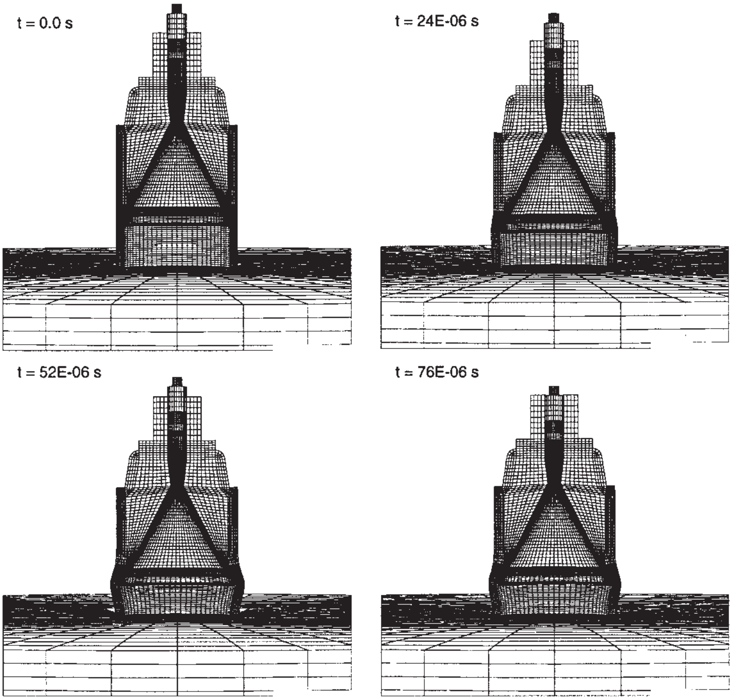

Figure 2: Deformed shapes of the submunition in normal impact.

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The snap shots of structural deformations of the submunition at three different time intervals during normal impact are shown in Fig. 2. Large deformation resulting in bulging of the body is predicted at the interface location of the body and liner. The above structural instability is caused by the presence of grooves in the body, which are required for peening of the liner into the body. However the submunition maintains a symmetric structure, the effective stand-off for the submunition is considerably reduced. Approximately 20% reduction in stand-off distance has been predicted for the normal impact. Thus the jet penetration of the lined charge will be less in dynamic case as compared to that in the static.

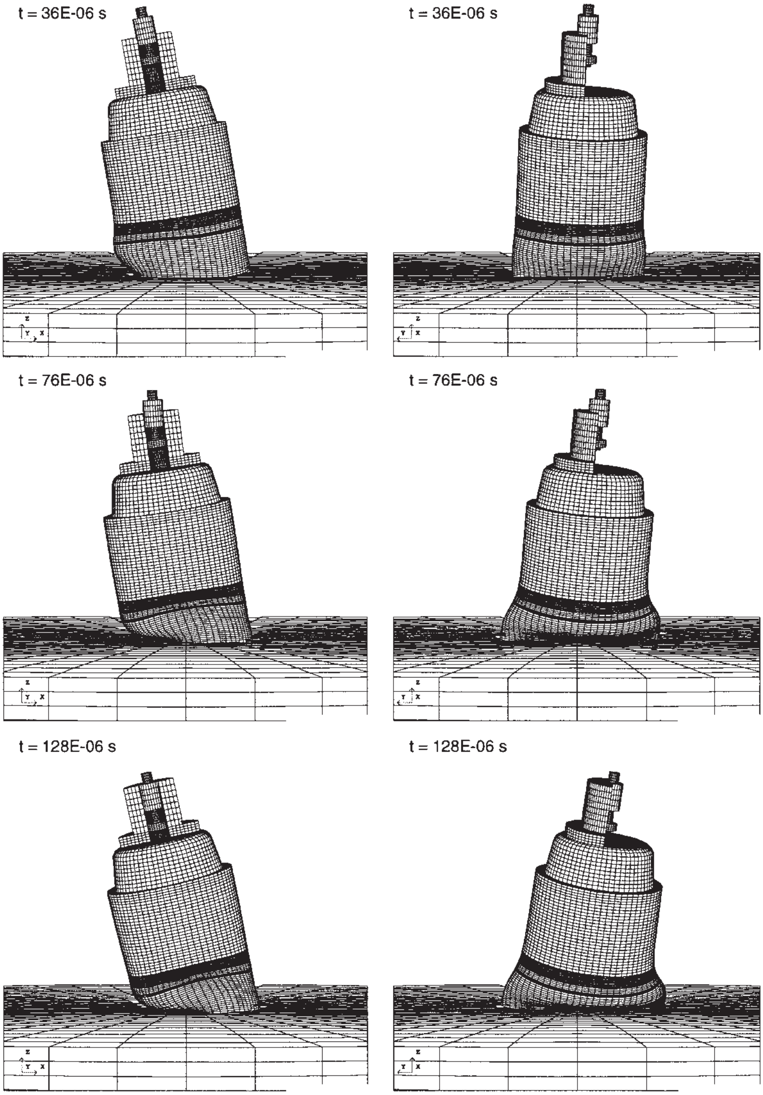

Figure 3: Deformed shapes of the submunition in 10° oblique impact.

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The computed structural deformations of the submunition at three different time intervals during a 10-degree oblique impact are shown in Fig. 3. The front views of the submunition are shown in the left column while left-hand side views are shown in the right column. Only half part of the fuze has been shown in order to depict the striker movement clearly. The snapshot at t=128 microseconds corresponds to that just before the detonation. Considerable structural deformation is predicted before the detonation of the explosive charge. As expected, the deformation of the body is highly asymmetric and also larger compared to that in the normal impact. Thus, not only the effective stand-off distance for the jet is reduced but also the symmetry of liner is disturbed by oblique impact. Both, the liner asymmetry and reduced stand-off, contribute towards the reduced terminal performance of submunition.

The computed time histories of the striker positions with respect to the detonator are plotted in Fig. 4(a) for three impact orientations. We notice in Fig. 4(a) that the fuze moves as a rigid body for about 20 microseconds and remains unaware of the impact event. As can be easily inferred from the average slope of the curves, the sliding velocity of the striker gets considerably affected by the orientation of the submunition at impact and reduces with increasing obliquity of impact. The time lag between the impact and detonation is obtained as the time corresponding to the zero striker distance. The impact to detonation time lag for different angles of oblique impact is shown graphically in Fig. 4(b). We find that the impact to detonation time increases exponentially for oblique impacts. Hence, the striker hits the detonator with less relative velocity in oblique impact and energy imparted to the detonator may not be sufficient to initiate detonation. Large numbers of duds reported in the literature for top-attack submunitions may be attributed to the above reason.

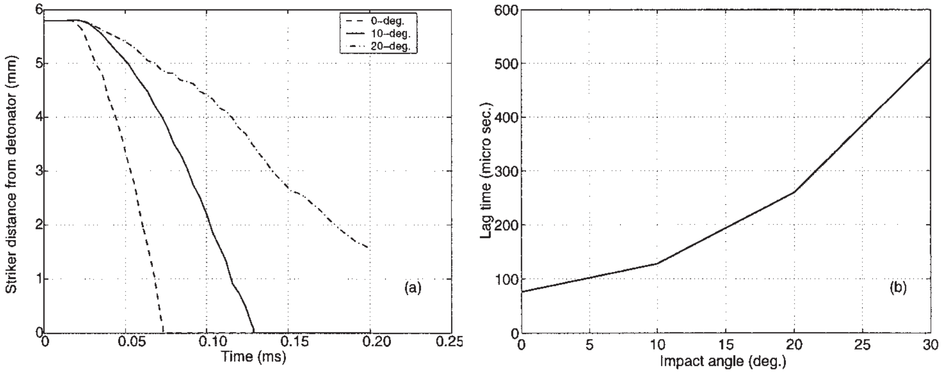

Figure 4: (a) Striker position. (b) Impact to detonation time lag.

4 CONCLUSIONS

The normal and oblique impacts of top-attack submunition on steel target are analyzed numerically with the help of LS-DYNA, a 3D explicit finite element code. A bilinear elastoplastic material constitutive behavior with isotropic hardening has been used. The impact to detonation time lag is estimated for four impact angles. In all cases, the structural deformations of the submunition are monitored till onset of detonation. The detonation time lag is found to increase exponentially with increasing angle of impact and larger structural deformations are predicted to preceed detonation for oblique impacts. The large asymmetric structural deformation results in the reduced stand-off distance as well as improper jet formation. The effects on the terminal performance parameters, such as stand-off distance and symmetry, are found to be the minimum for the normal impact and increases substantially for the oblique impacts. The results of simulation suggest that a fuze with the minimum impact to detonation time lag should be used for achieving the maximum terminal performance.

REFERENCES

1. LS-DYNA3D, Livermore Software Technology corporation, Livermore, CA
2. Kreig, R.D. and Key, S.W., “Implementation of a time dependent plasticity theory into structural computer programs.” *Constitutive Equations in Viscoplasticity: Computational and engineering aspects* (ASME), Vol. 20, 125–137, 1976

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