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Fragment Impact Testing of the XM25

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The developmental XM25 Counter Defilade Target Engagement (CDTE) is a shoulder-fired weapon designed to provide U.S. Soldiers with the capability of engaging targets under cover. Current cartridges include the XM1083 High Explosive Airburst (HEAB) and XM1081 Target Practice (TP) rounds. Baseline IM tests were conducted against the packaged configuration and showed that HEAB cartridges react violently when subjected to fragment impact (FI). This is consistent with modeling predictions that the first impacted round will likely react violently as the induced shock strength for small caliber items is particularly sensitive to fragment attitude and hit location error even though the fragment likely breaks up on perforation. Continuum modeling also suggest significant mechanical insult to adjacent rounds should only a single round detonate, both in FI and Sympathetic Reaction (SR) scenarios. This is consistent with engineering level SR tests performed for packaged rounds which indicate violent reactions for adjacent and diagonally adjacent acceptor rounds. Several FI mitigation strategies are discussed and modeled to predict their effectiveness. FI testing of the TP cartridges (inert warhead with live propellant) were conducted to determine how much of the reaction was due to the propulsion vice how much was the result of the warhead. While these responses were generally benign, in all these tests the lid was repeatedly thrown a significant distance from the initial test location. FI tests against containers with inert simulants were conducted to determine how far debris was expected to be thrown as a function of fragment momentum alone. These results were compared with those determined via high-rate continuum modeling. It was determined, both experimentally and computationally, that the propellant alone was sufficient to project hazardous debris.

Introduction

As part of an ongoing, developmental 25mm program, a host of complete rounds are under development. Efforts to improve the Insensitive Munition (IM) response of these all up rounds (AUR) are currently under way and include the XM1081 target practice (TP) and XM1083 High Explosive Air Burst (HEAB) AUR (Figure 1). The XM1083 HEAB is a next generation of medium caliber technology with fore and aft, air bursting warheads. The propulsion for both the XM1083 HEAB and XM1081 TP cartridges features a standard percussion primer and a small amount of small caliber gun propellant. Both warheads in the XM1083 projectile are loaded with PBXN-5. The XM1081 TP fires a projectile with ballistically similar performance to the HEAB cartridge, but without any energetic filler.

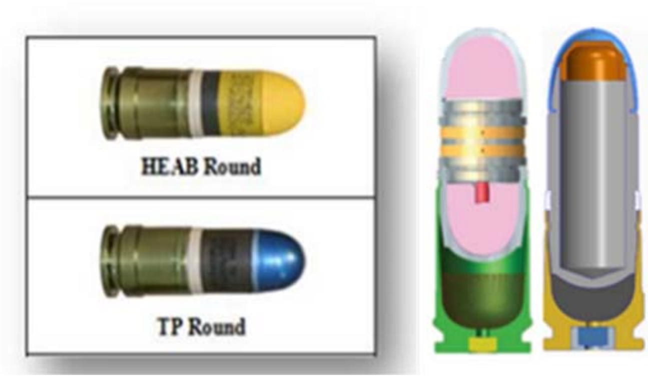

Figure 1. HEAB and TP Cartridges.

HEAB AUR FI Testing

Fragment Impact (FI) tests were conducted as per MIL-STD-2105D and NATO STANAG 4496 [1]. For these experiments, test articles were placed less than 15m from the muzzle in order to reduce impact variability [2, 3], including pitch, yaw, hit location, and velocity. An example of the setup can be seen below in Figure 2. Fragment impact velocity of 2530±90 m/s, with an alternate velocity of 1830±60 m/s, are specified in the STANAG. The 14.3mm mild, steel fragment has an aspect ratio (L/D) of approximately 1 with a conical ogive possessing a 160˚ included angle.

Figure 2. Typical fragment impact test setup

HEAB Packaged Configurations

FI tests were conducted in both the tactical, that is operational, and logistical configurations. In the tactical configuration, the 40 XM25 AURs are loaded in a single PA108 metal ammunition can containing two fiberboard boxes. These boxes are stacked one on top of the other with all of the noses of the AUR pointed down with each round separated from its neighbor with fiberboard dividers. The two boxes are subsequently offset, so that the primers do not line up with the cartridges above or below. The PA108 container is roughly 20 cm long, 32 cm high and 32 cm wide. The logistical configuration consists of two full PA108 ammunition containers packed in a wire-bound, wooden crate. Both configurations are shown below in Figure 3.

Figure 3. Closed tactical (left), open tactical (center) and logistical configurations (right).

FI testing is performed against both the warhead and the propellant to determine the participation of each in the overall reaction. For the logistical and tactical configurations, the shot line is determined by the longest line-of-site of the cartridges. In the tactical case with only a single container, the fragment is fired into the end. In the logistical configuration, with two ammo containers packed side-by-side, the fragment is fired into the side of the container. Aim point heights and shot line are shown in Figure 4.

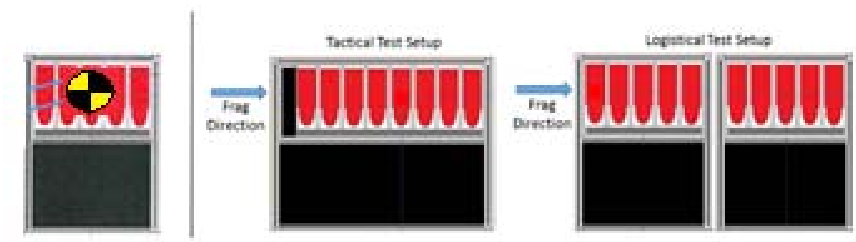

Figure 4. Fragment impact aim points and firing direction

HEAB AUR Engineering Tests

Two engineering tests were conducted against the explosive and propellant in the tactical configuration. Figure 5 shows the results of both tests. The state of the test arena after both tests was very similar. Some XM1083 cartridges traveled more than 30m and landed outside of the arena. The fragment velocities for both tests were measure by high speed video (HSV) and determined to be within the allowable velocity tolerance: 2448m/s for the propellant test and 2527m/s for the explosive. In both tests, the packaged cartridges did not mass detonate and most of the individual cartridges survived intact but were strewn around at various distances in and around the arena. The witness plate from Test 2 (along the explosive shot line) shows more scarring and slight bowing. The witness plate for the propellant shot line exhibited minimal damage. Based on this data, the results from the fragment impacting the explosive were found to be more violent than those achieved from propellant impact.

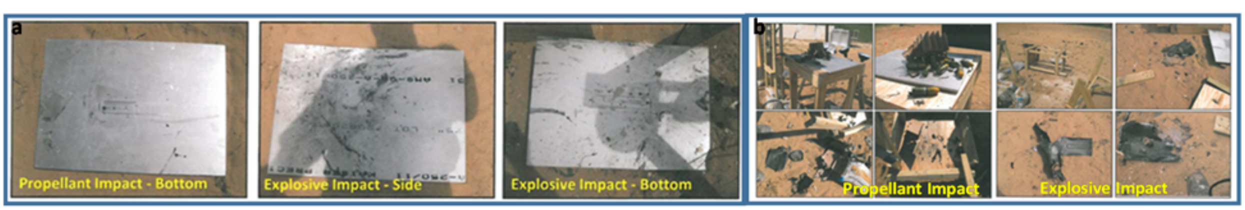

Figure 5. Engineering Tests: (a) Recovered witness plates; (b) Post Test Images

Formal HEAB Testing

Formal FI testing was conducted against both the HE and propellant of the HEAB AUR. The first test, fired against the HE as shown below in Figure 6 a., was in the logistical configuration. The fragment impacted at a velocity of 2461 m/s. The lid of the first container was thrown a significant distance from the test stand and cartridge and container fragments were scattered throughout the arena. The second container exhibited a very different response. It survived intact and none of the cartridges contributed to the response. The farthest fragment recovered was 27m from the test stand with no visible damage to the witness plate.

The second single container FI test was conducted in the tactical configuration against the propellant. This time the fragment achieved a slightly higher velocity of 2517m/s. The container was torn to pieces, with only a few large portions recovered (Figure 6b.). The witness plate showed damage from both the container and cartridges and the farthest fragment recovered was a cartridge case with fuzed projectile found over 46m from the test stand.

Figure 6. Formal Tests: (a) Explosive Impact- test setup, Post-test, Recovered debris; (b) Propellant Impact- Post-test stand/witness plate and recovered debris

These were officially scored packaged tests, in contrast to engineering or component tests conducted previously. The FI test against the propellant was determined to have resulted in a Type II reaction and against the explosive, it was scored as a Type III. Both engineering level tactical configuration and formal logistical configuration FI tests of packaged HEAB cartridges showed that impacting the explosive resulted in an explosion reaction. Tactical configuration tests of the packaged HEAB cartridge, including both engineering level and formal impacts conducted against the propellant resulted in mixed scores. There are a number of variables that can affect the response of munitions subjected to FI testing [3, 4]. These include fragment attitude, both pitch and yaw, velocity variation and aim point errors. Given that the fragment size is on the order of the explosive and propellant cross sectional diameter, it is possible that only slight variations in aim point result in greater violence when the shot line is through the propellant than when it is through the explosive.

Formal TP Testing

In addition to the formal testing conducted against the HEAB AURs as discussed in the previous section, five additional FI tests were conducted against packaged TP AURs. Since the TP cartridges contained only propellant, these tests were conducted with the goal of isolating the contribution of the propellant to the reaction of the HEAB AUR when impacted through the propellant shot line. Four of these tests were conducted at the standard velocity of 2530±90 m/s with two each conducted in the tactical configuration, and the remaining two conducted in the logistical configuration. One tactical test was conducted at a velocity of approximately 2000m/s. Although all responses were generally benign, the lid was repeatedly thrown over 30m in each test. Figure 7a are HSV images that clearly show the lid being launched as a result of the system response. At the lowest impact velocity, the lid bowed but was not perforated. In all the other tests that achieved a satisfactory mean velocity, the lid was perforated between the first and second cartridges. Generally the lids were thrown farther when tested in the tactical configuration than in the logistical configuration, owing their different response, at least in part, to the additional confinement offered by the wooden packaging. It is important to note however, that the lowest velocity tactical test resulted in the lid being thrown the farthest. This is in contrast to the high velocity tests, potentially due to the uninhibited pressure build-up of the burning propellant as the lid was not perforated by fragmentation as it was in the higher velocity tests. Figures 7b and 7c show the container and lid for these tests.

Figure 7. TP FI Test Results: (a) HSV images; (b) logistical configuration; (c) tactical configuration

Modeling Inert Cartridges

FI modeling utilizing inert cartridges was conducted using the Lawrence Livermore National Laboratories (LLNL) developed code ALE3D. This was done in an attempt to understand the interaction between the fragment and the container, independent of any contribution from an energetic reaction. Modeling results, shown below in Figure 8, suggest that the holes in the lid are caused by debris thrown when the fragment impacts the cartridge, and that the lid is likely thrown due to a hydraulic effect as suggested above.

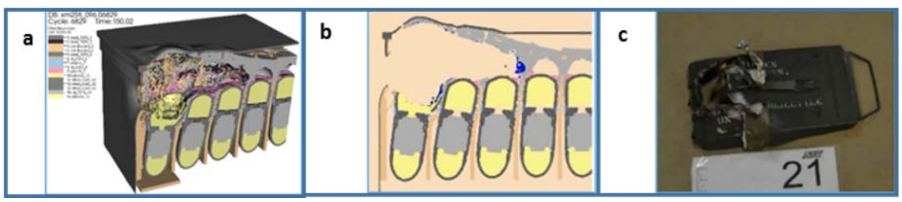

Figure 8. Inert propellant model compared to live propellant TP response.

Inert Simulant Modeling and Testing

Tests were conducted against PA108 containers with inert simulants to evaluate debris thrown exclusively as a function of fragment momentum. Solid aluminum cylinders were used as projectile simulants. Two tests were conducted at the mean velocity of 2530±90m/s, and in both tests the lids were thrown from the test stand but not as far as in the previous TP tests. In addition, there were also no holes in the lids as a result of these tests. This also suggests that the holes are caused by the debris field from the cartridge case fragments. Figure 9a shows the output from modeling conducted using the Elastic Plastic Impact Code (EPIC) [4] with pictures of the inert simulants from each test. These results do not indicate that the lids would likely be launched. HSV was also used to record the event and selected frames are shown in Figure 9c. These frames show the event and again, the lid appears to have been very violently separated and thrown from its original location.

Figure 9. Inert Surrogate: (s) EPIC model; (b) FI test debris; (c) High Speed Video frames of lid projection.

Based on these results, the hypothesis is that as the fragment entered the confined container volume, it generated a significant hydraulic effect that subsequently propelled the lid. A scored or vented container might function to minimize this. Modeling the non-detonative response of a shocked granular propellant bed was impossible within the confines of time and funding afforded this project, so no attempt was made to model this complexity. Due to the lid being thrown five times farther in the TP tests than in the inert tests, the propellant reaction is believed to be the single most important contributing factor as to why the lid was thrown so far.

FI/Sympathetic Reaction (SR) Spacing Designs and Modeling

The chemical energy of an individual aft warhead is roughly half the kinetic energy of the incoming fragment, so it is conceivable that shock initiation of the first warhead under fragment attack, in conjunction with the residual fragment energy, is a more severe threat to adjacent cartridges than that which would result from SR alone. Assuming that the first warhead in the shot line always promptly detonates upon impact, SR test data can be used to help provide a lower bound for the reaction violence in adjacent cartridges.
Two SR tests were conducted, one with HEAB AURs, and another with TP AURs. Each test utilized a total of six live cartridges (one donor and five acceptors) per test, utilizing two layers of packaging. The acceptors were placed in the following positions: adjacent-1, diagonal-1, below-2, adjacent-2, and diagonal-2 (the numbers denote the top (1) or bottom (2) of the packaging). All of the cartridges were painted in order to determine the severity of reaction for each acceptor placement (Figure 10a.).

Figure 10. SR Test: (a) HEAB Engineering SR Test Cartridge Configuration; (b) HEAB Results

A detonator was used to initiate a donor HEAB round. The acceptor test items in the HEAB SR test reacted with a Type III explosion level of violence. Figure 10b shows the blast chamber and the collected debris. In particular, the adjacent and diagonal acceptor cartridges appeared to have deflagrated, and the bottom row warheads appeared not to have reacted. In light of these results, it was determined to be necessary to measure exactly how much more severe the FI threat was than that posed by SR. In addition, this information is desirable from the perspective of considering potential mitigation schemes. Within the model, an augmented CJ volume burn was used to light the explosive region in the first grenade warhead at the point of impact, and a Jones-Wilkins-Lee (JWL) equation of state (EOS) was used to describe the adiabatic expansion of the detonation products. Modeling predictions are shown in Figures 11 and 12.
These results indicate a directionality to the shock input to the adjacent cartridges, as would be expected for a completely inert target. The peak pressure in the second cartridge in the shot line is calculated to be substantially greater than the LSGT pressure threshold for this explosive. Although this criterion is not sufficient in and of itself, it is a qualitative benchmark useful for the purpose of making comparisons. The results also show that a reduction in the induced peak pressure of adjacent cartridges can be achieved by using a higher density separator material than corrugated fiberboard, such as a common polymer. Other efforts are ongoing in order to reduce sympathetic reaction violence in the event that prompt detonation of the first cartridge cannot reasonably be prevented. These include evaluation of different round to round spacing and packaging configurations.

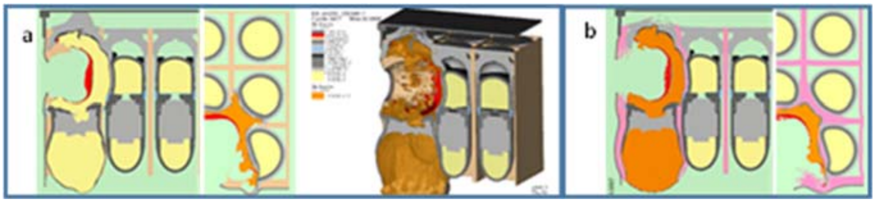

Figure 11. Material plots for first live cartridge subjected to FI: (a) baseline; (b) plastic separator configuration (right)

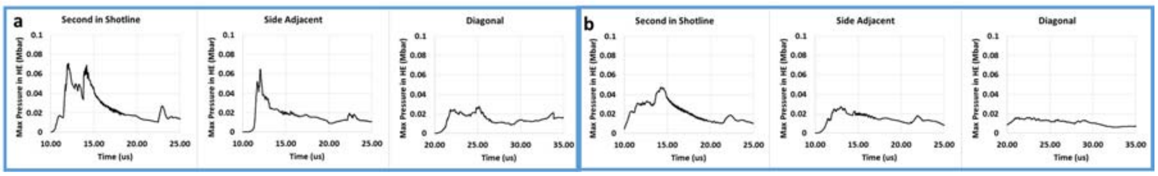

Figure 12. Maximum pressure in HE region (Mbar) vs. time (us) plots for cartridges, (a) baseline and (b) plastic barrier configurations

Barrier Designs and Hydrocode Modeling

Particle Impact Mitigation Sleeves (PIMS) are one technique that has been successfully used in the past to mitigate violent response of ordnance subjected to FI [5]. PIMS may be used on the outside of the packaging, on the inside of the packaging but on the outside of the munition, internally between the munition case and energetic material, or in any combination of these scenarios. For a variety of reasons, not the least of which includes cost minimization, a PIMS liner is planned to be integrated within the PA108 container external to the rounds. The PA108 ammunition container is lined with corrugated fiberboard with the two boxes stacked one on top of another with some space to incorporate PIMS in lieu of the corrugated fiberboard dunnage currently used.

High-rate continuum modeling, using ALE3D, was utilized to identify barrier configurations that would reduce the initial shock within the weight and volume constraints [6]. Two dimensional axisymmetric modeling was used as it allowed appropriate resolution of the shock fronts. Several combinations of materials of varying thicknesses occupying this space were modeled, including the baseline corrugated fiberboard packaging, wood, plastic, aluminum, porous aluminum, and 4340 steel. These were modeled using standard Mie-Gruneisen equations of state [7] and Steinberg-Guinan strength models. Spall failure was modeled with a tensile hydrostatic stress criterion, and void seeding was used to remove excessively strained, and subsequently failed material, from the calculation.

Several shock initiation criteria were considered in evaluating the merit of various protection schemes. These included wedge test data, critical energy fluence, the NOL LSGT pressure, as well as several variants of the James criterion [10]. The usefulness of any of these models is dependent upon the availability of experimental data with which to parameterize them. Wedge test data, from a similar explosive to PBXN-5 at a roughly equivalent density, was used as a tentative criterion [8]. This data is shown below in Table 1. Since the critical diameter of this explosive is equivalently small [9], it is assumed that the pressures are essentially planar for pass/fail determinations even though the shock is diverging and the pressure field behind it is non-uniform.

Table 1. Wedge test data

Pressure (kbar)	Run to Detonation (mm)
48	4.6
68	2.9
101	1.7
164	_ _

The LSGT pressure threshold criterion was also considered. The go/no-go threshold pressure transmitted to the acceptor explosive was obtained via a shock impedance matching calculation. Exceeding this pressure over is often used as a qualitative benchmark in the absence of better data. However, rational use of this criterion requires discerning between pressure spikes due to shock and isentropic compression. A secondary goal is to reduce the overall mechanical insult to the warhead to the greatest extent practical so as to avoid shear initiation and reduce any subdetonative response [11-13]. A reasonable strategy would be to model the scenario in an attempt to keep the shock pressure low, and experimentally test progressively heavier barrier designs until the desired reduction in reaction violence is achieved. Figure 13 shows typical centerline pressure profiles (in blue) compared to experimental data (in red). By comparison with the wedge test data, improvements over the baseline are hypothesized to occur using various PIMS configurations. Figure 14 shows material and pressure plots for several of these.

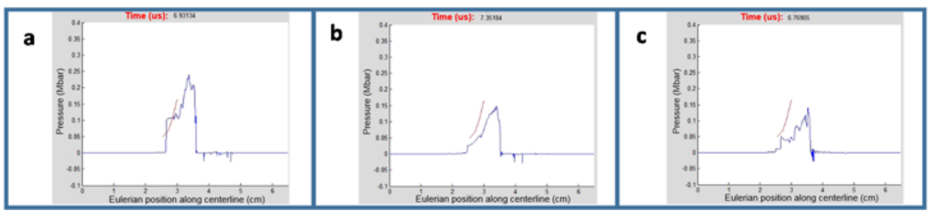

Figure 13. Shock run distance compared to wedge test data (a) baseline configuration; (b) Polymer PIMS; (c) Metal/polymer PIMS.

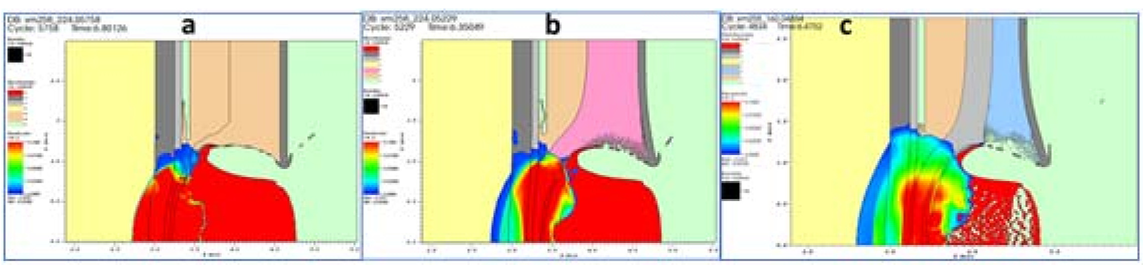

Figure 14. Pressure plots (a) baseline (b) Polymer PIMS (c) Metal/Polymer PIMS

The results of the modeling are summarized in Table 2. The wedge test criterion pass/fail rating indicates whether the centerline input shock was of sufficient pressure and duration to shock initiate based on experimental data, and the gap test criterion is based on whether the pressure ever exceeded the NOL LSGT go/no-go threshold.

Table 2. Modeling results.

Configuration	Wedge Test Criterion	Gap Test Criterion
Baseline CF	Fail	Fail
Wood	Marginal	Fail
Polymer	Marginal/Pass	Fail
Polymer/Metal 1	Pass	Fail
40% Porous Al	Pass	Fail
Solid Al	Fail	Fail
Polymer/Metal2	Marginal/Pass	Fail
Steel	Fail	Fail

As can be seen in the table above, there are several configurations that appear feasible for lowering the shock pressure enough for the initial input shock to pass the wedge test criterion, with several caveats. Primarily the pressure pulse generated by FI is likely more severe than the flat-top shocks generated via wedge test. Alternative techniques such as a volume-averaged pressure might be used to remedy this although they are not entirely free from other complications. Sufficiently refined, fully three-dimensional models need to be set up and run in order to predict a higher fidelity response. Another potential pitfall is response variability. Specifically, spall failure is an important feature of the response as this projectile has been experimentally verified to break up into several pieces upon impact with steel sheet used in ammo containers.

Conclusions

Both engineering level tactical configuration and official logistical configuration FI tests of packaged 25mm HEAB cartridges show that impacting the explosive results in a moderately violent reaction. Tactical configuration tests, engineering and formal, of the packaged cartridge where FI was conducted against the propellant resulted in mixed responses. Potential aim point variation related to challenges associated with the FI test methodology may have also contributed to the different reaction levels. FI tests of TP cartridges, in both packaging configurations, and inert simulants, in the tactical configuration, resulted in the container lid being launched over appreciable distances. The distance that the lid was thrown was greater for the tactical configuration than for the logistical when the TP cartridges were tested. In addition, in most of the TP tests the lids were also perforated. Modeling indicates that the holes in the lid may be caused by debris resulting from impact, and that the lid itself is likely thrown due to a hydraulic effect. Engineering SR testing shows that detonation of a single warhead causes adjacent cartridges in the same row to explode, but does not cause cartridges in the lower level to react violently. Modeling was used to evaluate various PIMS materials (wood, plastic and metal) as replacements for the existing corrugated cardboard dunnage. This modeling showed that a polymer and/or some combinations of polymer and metal has the potential (based on wedge test pass/fail criteria) to lower the shock pressure enough to prevent initiation of the explosive fill. Based on these results, there are several potential candidates for replacement dunnage that may provide a reduction in the level of reaction violence.

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