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Venting of Anti-Armor Warheads to Mitigate Cook-Off Threats

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Technology to allow the shaped charge liner of anti-armor warheads (AAW) to release from the rest of the warhead has been demonstrated on small-caliber items as a way to prevent violent response during cook-off (CO) events. Several methods of accomplishing this goal have been applied to the 40mm M430A1 grenade with success. The purpose of this paper is to analyze the viability of applying similar techniques to a large-caliber warhead, specifically the 120mm gun-launched anti-armor munition. ARDEC scientists used their expertise in high-rate continuum hydrocodes to model the jet collapse and used jet tip velocity and profile before and after IM modifications to verify the warhead performance. In addition, structural analysis of selected venting designs was conducted to ensure the munition survives launch and set-forward forces. The IM features for mitigating violent response were designed using the multiphysics ALE3D hydrocode software. The venting features allow the gaseous byproducts of the heated explosive charge to exit the munition without pressurizing the compartment and accelerating the reaction.

INTRODUCTION

The U.S. Army Armament Research, Development and Engineering Center (ARDEC), the Program Executive Office for Ammunition (PEO Ammo) and the Joint Insensitive Munitions Technology Program (JIMTP) Office are developing and applying Insensitive Munitions (IM) technology in order to survive unplanned stimuli produced by fires (slow & fast cook-off - SCO & FCO threats). The technology development is concentrating on warhead venting and release of the Shaped Charge (SC) or Explosively Formed Penetrator (EFP) liner in Anti-Armor Warheads (AAW) to release explosive gaseous products, while maintaining required structural body characteristics and high warhead performance. Warhead venting for mitigating the violent response to unplanned thermal stimuli caused by fires or other heating sources is not a new concept [1,2,3,4,5,6].

AAWs are characterized as warheads with an EFP or SC liner. Mitigation of AAW munitions response to cook-off threats is often difficult as they use the highest energy/metal accelerating explosives with high dP/dt. Furthermore, explosive venting requirements, characterization and quantification for different explosives, sizes and heating rates is generally lacking [7]. AAW provide a unique opportunity unlike other convention ammunition, whereby the interface between the liner and the warhead body maybe released during a thermal event. Coupled with meltable materials release of the shaped charge or EFP liner allows to provide for maximum depressurization of the explosive billet. The technology involves use of melting pins, adapters, ionomer base plates, etc for releasing the liners during cook-off events. Modification of the body and/or ogive may be required to allow for the use of melting pins, adapters, baseplates etc. Material and concept design performance under system requirements would limit the choice of material that can be utilized. Liner release concepts must not impact EFP or

SCJ performance. In addition, some AAW must penetrate walls before they arm and function. Here, the liner release design must not interfere with the penetration requirement and warhead performance after wall penetration.

MEDIUM CALIBER LINER RELEASE VENTING

Liner Release technology has been investigated under the PEO Ammunition Insensitive Munitions IM Warhead Venting Thrust area in a 40mm medium caliber munition. The munition in this study is a 40mm medium caliber round with an copper anti-armor shaped charge. The main charge is Comp A-5. The external steel body is pre-scored which is a single piece. Specifically, baseline and proof of concept engineering tests of the medium caliber round have been conducted. The heating rate for these tests was 50F/h.

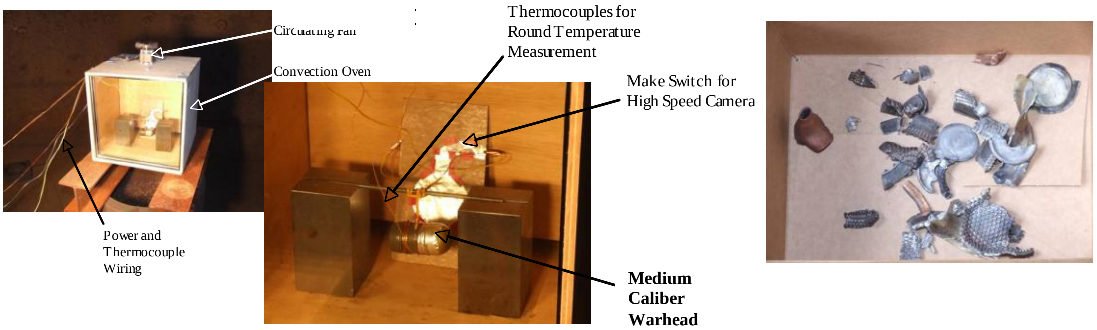


Figure 1. Medium Caliber AAW–Baseline SCO Testing (Setup and Post Test)

The first two baseline tests were conducted with warhead bodies which had the shaped charge liner confined by the fuze assembly (Figure 1). There was no cartridge case on the test items. The 40mm medium caliber munition responded violently. It was noted that the liner was deformed in one of these tests.

A third, proof-of-concept, test was conducted with no confinement of the liner (simulating release of the SC liner) and the resulting reaction was a Type V. Figure 2 shows the SCO test setup and result of the third test. There was no deformation of the liner and the thin aluminum sheet that seals the apex of the liner was still intact. Results indicated that liner release would provide sufficient venting under slow cook-off conditions resulting in a low order reaction of the warhead in a SCO event.

Figure 2 . Medium Caliber AAW Liner Release –Proof of Concept SCO Testing (Setup and Post Test: liner and body intact)

Further testing of the medium caliber AAW has been conducted which evaluated various initial concepts. The resulting non-violent type V responses were achieved under slow cook-off conditions as sufficient venting was provided by releasing the warhead body from the fuze using plastic threaded o-give, pinned o-give and reduced thread o-give (see Figure 3 below). These engineering IM SCO tests were conducted at 6F/h per the Joint IM requirements.

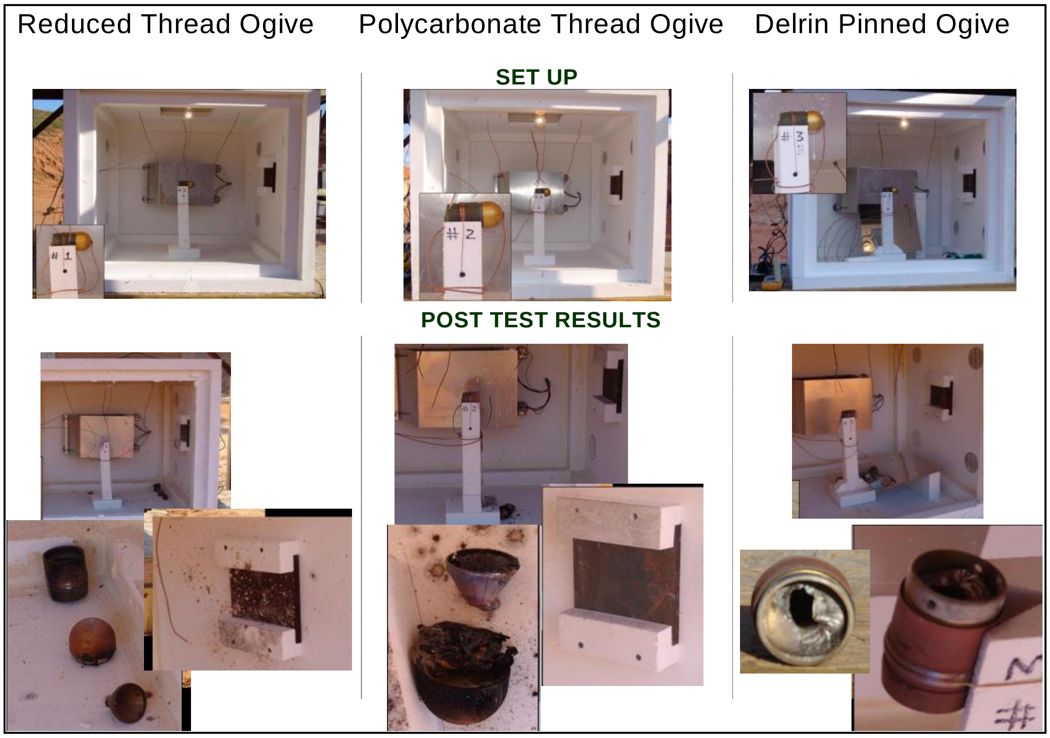


Figure 3. Medium Caliber liner release concept SCO testing: Type V

Plastic and reduced thread designs were subjected to a second set of SCO tests to show repeatability of the warhead response (Figure 4). Delrin was selected as the plastic for the second set of tests as the material has been used in other munitions. The delrin thread design resulted in a burn response and the reduced thread design was more violent. The reduced thread design was down-selected out and further analysis was conducted with plastic threads.

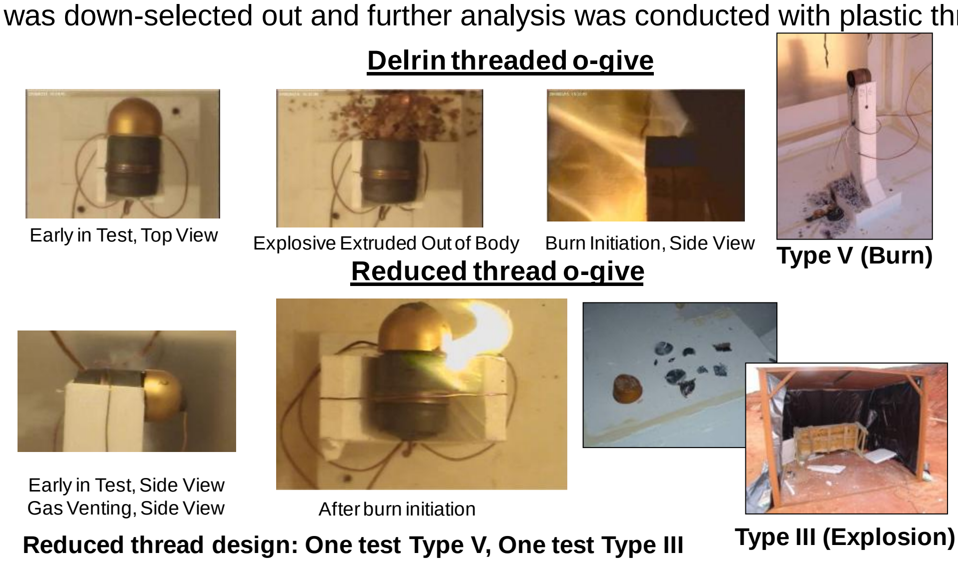


Figure 4. Medium Caliber liner release concept SCO testing: Delrin and Reduced Threads

LARGE CALIBER LINER RELEASE VENTING

Following successful liner release technology demonstrated on the 40mm medium caliber warhead, the JIMTP has funded a project titled Anti-Armor Warhead (AAW) Liner Release Venting, Task 08-3-02. This paper provides the latest information in the development of IM warhead design as conducted under this project. The effort is to adapt proven concepts demonstrated on 40mm ammunition to large caliber (120mm) anti-armor warheads (AAW). The concepts allow gasses from a heated warhead to exit the munition without building up pressure and accelerating the reaction to the point of explosion or worse. Since the designs have been demonstrated on smaller caliber warheads there is more confidence that similar techniques can be made to work on larger munitions.

There are several challenges that are unique to the large caliber items. First, the explosive billet tends to insulate itself, causing the ignition to happen in the middle where vents are unable to provide relief at a heating rate of 6F/h [7]. This might be mitigated by providing maximum vent area available and venting the gasses early in the cook-off event. Second, the vent design must not cause the munition to fail during launch; i.e. vents on the outside of the body must not allow incursion of propellant gasses, it must survive high-G launch, etc. Third, there are frequently other pieces of the projectile both fore and aft of the warhead such as electronics and rocket motors that may block the gas escape path and the vent feature must be designed appropriately.Several concepts for aft or forward venting of the 120mm MRM munition were developed. The forward venting concepts dealt with moving the shaped charge liner out of the way with wedge-shaped or flat melt-able retaining rings, or melting supports on the aft end, or even putting holes in the liner itself (Figure 5).

The munition in this study is a variant of the Medium Range Munition (MRM), a 120mm tank round with an anti-armor shaped charge made of molybdenum. The main charge is PBXN-9, a 92% HMX composition. Several aft and forward venting concepts were investigated, Fig. 5., to depressurize the warhead during a cook-off event.

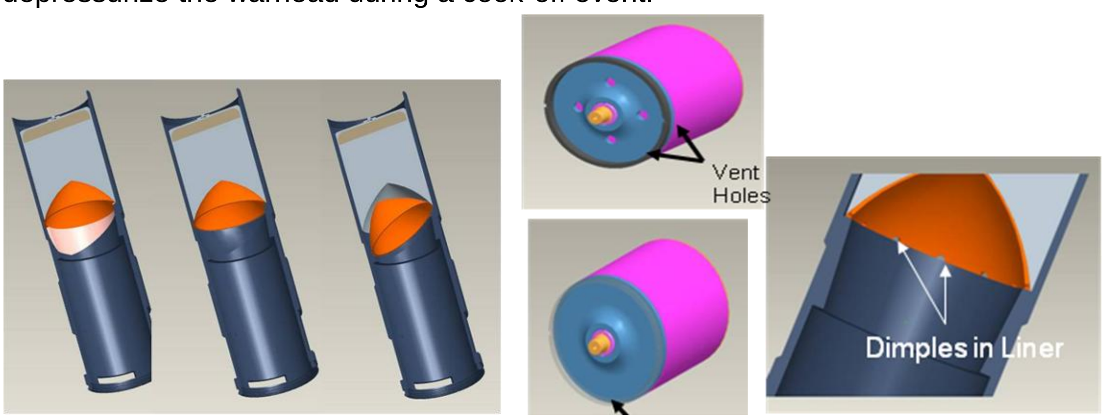


Figure 5: AAW Venting Concepts (Left to Right – Wedge, Vent Holes in Base Plate, Melt-able retaining ring, Dimpled Liner)

After analyzing the candidate venting methods in the structural code, ABAQUS, it was found that only the forward venting melt ring as well as a thicker wedge ring design would survive launch. For the dimpled liner concept, stresses in the liner vents/dimples exceeded 18500 psi upon impacting the lip during set forward and the concept was dropped.

Additionally, the joint between the warhead and the base section (to the rear) provided no path to the atmosphere so the aft venting concepts were eliminated, leaving the only remaining choice to place the melt ring ahead of the liner, as seen in Figure 6. Multiple variants of this concept were selected: wedge ring, uniform melt ring and snap ring.

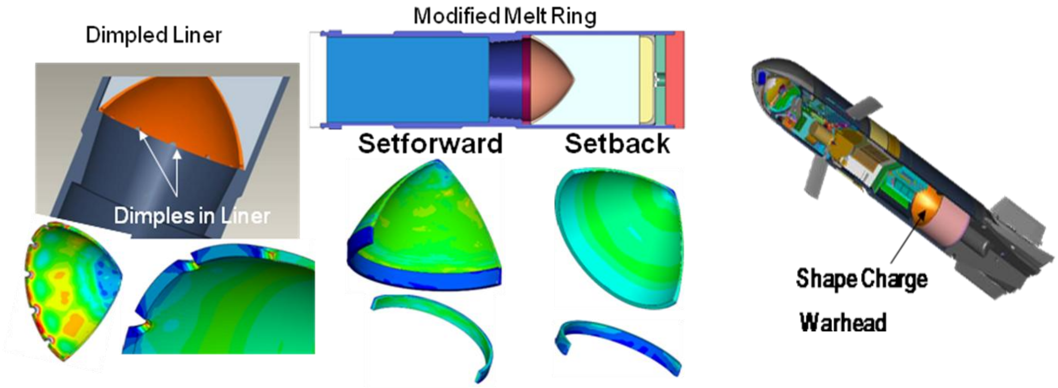
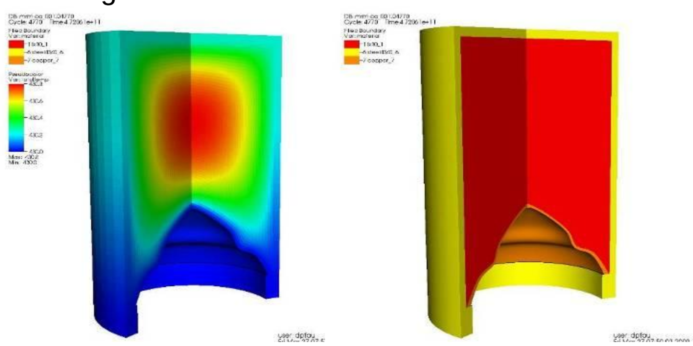


Figure 6: Left: Dimpled and Melt Ring - Setforward and Setback M&S
Right: MRM CE projectile, with AAW section indicated, near the rear

COOK OFF MODELING

The first step was to model the warhead alone in a cook-off environment. The simulation was conducted in ALE3D, a hydrocode published by Lawrence Livermore National Laboratory. Using the implicit hydrodynamics routines, analysts were able to simulate the 6F/hr cook-off rate. The PBXN-9 main charge was modeled as LX-10 which is a similar, high-HMX content explosive. The LX-10 model uses a Prout-Tompkins kinetics model. Modeling shows that a fully confined billet (baseline configuration) will ignite in the middle of the charge, as expected (Figure 5). Additionally, large pressures generated inside the warhead actually deforms the SC liner, buckling the liner in the middle.



(U) Figure 8: Cook-off of de-featured warhead - Ignition occurs in the center of the billet

The warhead was modeled a second time with no confinement at all at the liner end, and the liner can be seen being pushed out by the main charge (Figure 9). This unconfined liner was viewed as the “best case” scenario where the melt ring was completely melted and provided no resistance at all.

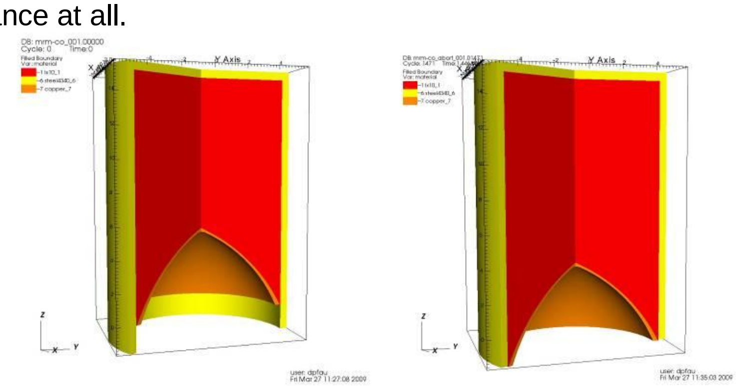


Figure 9: Unconfined Liner moves out to the bottom of the warhead.

BASELINE AND CONCEPT PROVE-OUT TESTING

Initial baseline and Concept prove-out SCO and FCO tests were conducted on the warhead section only, without system level confinement. The baseline SCO test resulted in a Type V response and baseline FCO test resulted in a Type IV response (Fig. 10). The concept prove-out test hardware consisted of the warhead without any retaining ring, similar to the “best-case” scenario as seen in the second simulation, Fig. 9. These tests results were ed in a Type V (burning) reaction (Fig. 11.)

Figure 10: Baseline MRM FCO test, Type IV response

Figure 11: Concept prove-out – SCO & FCO tests, Type V response

PERFORMANCE MODELING AND TESTING

Anti-armor performance was modeled in ALE3D to ensure that the IM designs do not significantly degrade performance. The analysis of the melt ring design was also conducted in ALE3D. The model was set up with ALE mesh, initially rectilinear, and subcycled within the first timestep to allow the mesh to conform to the geometry. Analysts used the MRECTANGLE function to allow higher zoning along the axis to better show the shaped charge (Figure 118). The explosive is modeled with a JWL equation of state representing PBXN-9 and detonated with a Lund burn, which is a programmed burn that can take into account corner-turning to handle the waveshaper. The problem was approximately 62,000 elements in 2D-axisymmetric.

For this simulation, the jet tip velocity and jet profile were observed since these were quantitative and qualitative measurements that could easily be compared side by side. The first run was a 120mm warhead with a metal rim for the shaped charge to bottom out against. The metal lip against which the shaped charge liner rests was replaced with a plastic ring, and finally no ring at all to compare the effects on the resulting shaped charge jet (Figure 12, 13).

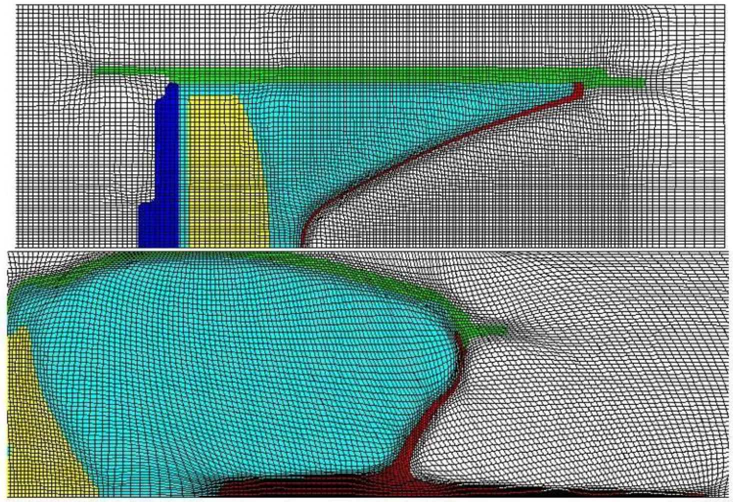


Figure 11: Shaped charge in ALE3D at t=0µs and t=31µs

The jet tip velocities of the traditional shaped charge and the melt ring version were identical, with the unrestrained liner trailing by only 0.01 km/s. All of the collapsing liner profiles were almost identical, the only visible differences occurring at the very aft end, near the mouth of the warhead body. The explosive by-products appear to break through the liner earlier with the melt ring and without any ring at all, but the jet is well-formed at this point of the simulation.

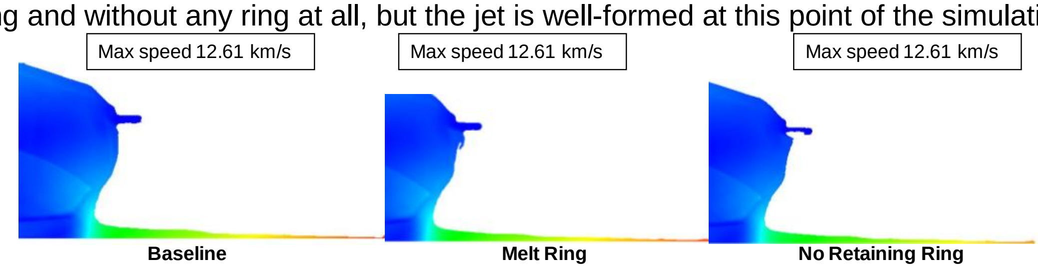


Figure 12: Jet velocity of various configurations of the MRM warhead at 34µs.

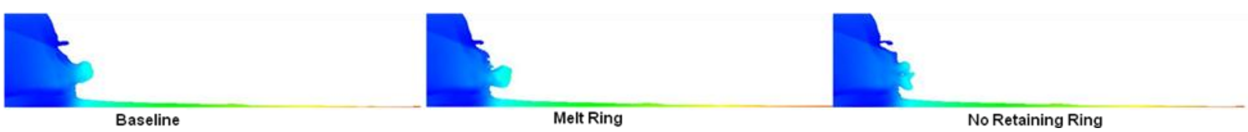


Figure 13: Velocity profiles of at 49µs, just prior to target impact.

The results of these comparisons predict that a melt-ring will not significantly degrade the performance of the AAW. Penetration testing of the melt ring concept showed an increase of 14.6% and 12.38%. Penetration testing of the wedge ring concept showed a 10.26% increase in one test and a 2.75% decrease in another. This may be attributed to the non-symmetry of the design. Based on these results, no degradation is expected of the snap ring design since this design is symmetric in shape and similar results are expected. Penetration performance is expected to be the same.

LARGE CALIBER LINER RELEASE COOK-OFF TESTING

The initial baseline CO testing was conducted on only the warhead section. The results were benign (SCO-Type V, FCO-Type IV). Additional baseline CO testing was conducted with the front (seeker & CAS) stimulants and aft (rocket motor) stimulants. The system level confinement increased the SCO response to a more violent response of the warhead, Fig. 14, (Type III). Three pieces of the warhead were recovered. Fragments were thrown up to 118 yards. The baseline FCO response remained the same, Type IV, Fig 18.

Figure 14. MRM SCO Baseline Test With front and aft stimulants – Type III response

Melt, wedge and snap ring concepts, (Fig 15.), SCO testing was conducted with system level confinement. The melt ring and wedge ring concepts resulted in a violent (Type III) response, Fig 16. No exudation of the plastic material observed during these tests.

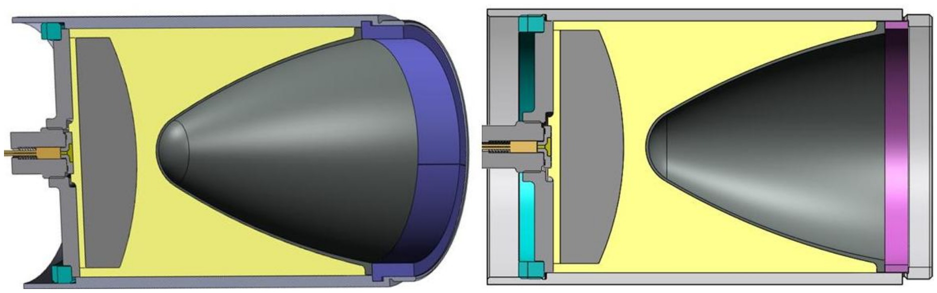


Figure 15. Snap Ring Concept (left), Melt Ring Concept (right)

Figure 16. MRM SCO Test Result – Melt Ring Concept With Seeker Simulant

During the snap ring SCO tests, there were beads of melted residue at the warhead/seeker stimulant interface prior to reaction. The snap ring SCO test result was less violent, Fig 17. The liner was found inverted and the warhead section was found intact.

Figure 17. MRM SCO Test Set-Up & Results – Snap Ring Concept With Seeker Simulant

The snap ring concept SCO testing was repeated and the result was benign (Type V). All fragments were recovered within 11 feet of the oven, Fig. 18. Successful demonstration of the snap ring vent feature depressurized the warhead even with system level confinement, resulting in a benign reaction.

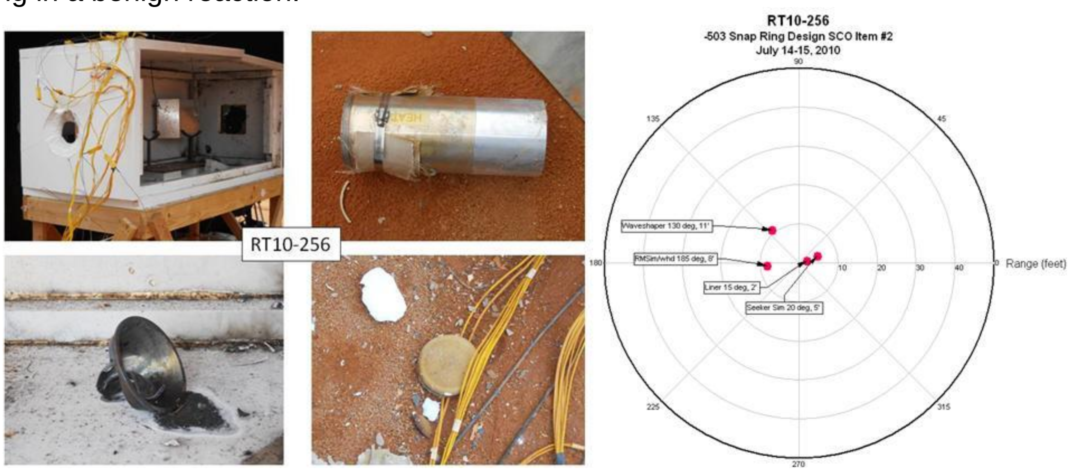


Figure 18. MRM SCO Test Results – Snap Ring Concept With Seeker Simulant

The FCO test results in the baseline configuration with system level confinement and with the snap ring design were similar, Type IV, Fig 19 and 20. The baseline confined FCO test was slightly more violent. The liner was cracked and explosive material was thrown in multiple directions to the aft of the munition. The rocket motor was thrown 100 ft. All of the debris exited the munition out of the aft end, including the liner.

Figure 19. MRM FCO Test Results – Baseline With Seeker Simulant

The fragment map for the snap ring design shows that the seeker stimulant was thrown forward of the munition and the warhead was thrown to the rear of the munition. This suggests that the pressure was released at the warhead and seeker stimulant interface. The gasses were able to push the liner forward and exit out through this interface, suggesting that the snap ring vent feature softened and allowed the liner to move forward, Fig 19. The liner was also found intact. Although the warhead was found at 55ft, it impacted the ground at 20ft and rolled downhill to its final destination. Video of this test shows that the reaction was less violent than that of the baseline confined configuration.

Figure 20. MRM FCO Test Results – Snap Ring Concept With Seeker Simulant

CONCLUSIONS

Baseline SCO and FCO testing of medium and large caliber AAWs resulted in a violent response. AAW venting concepts involve the use of melt-able ring in the interface between the warhead body and liner which allows the shaped charge (SC) liner of medium and large caliber AAWs to release from the warhead during cook-off events. The pressure that is generated inside the warhead, due to burning products of the explosive billet, then pushes the liner out of the way, providing a path for gases to vent to the atmosphere and prevent a violent reaction. Pressure rupture applications must provide sufficient venting area and respond at low enough pressures to prevent explosive high burning rates associated with violent response. These concepts outlined are considered passive venting techniques.

Liner Release Venting technology is a practical means of relieving pressures within medium and large caliber warheads to mitigate SCO threats. There is relatively low cost associated with implementing this design with a high pay-off of mitigating cook-off threats. Structural modeling of the venting design for the 120mm large caliber warhead was conducted to ensure the design meets launch requirements. Additionally, thermal modeling of the design was also conducted. Modeling and simulation aids in the design process and reduces cost when conducted prior to hardware fabrication, loading and testing. SCO testing of the snap ring vented design resulted in a benign response (Type V). SCO testing was successfully repeated and the results were similar. Additionally, FCO testing of the snap ring vented design showed slight improvement in the reaction violence.

Performance modeling of the melt and wedge vented designs was also conducted and shown to have minimal impact on the jet velocity and penetration. Penetration testing of the melt ring concept showed an increase of 14.6% and 12.38%. Penetration testing of the wedge ring concept showed a 10.26% increase in one test and a 2.75% decrease in another. This may be attributed to the non-symmetry of the design. Based on these results, no degradation is expected of the snap ring design since this design is symmetric in shape and similar results are expected. Penetration performance is expected to be the same. Liner Release technology has a high probability of success in the AAW munitions across all services.

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