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A Successful Systems Approach to Insensitive Munitions Requirements Compliance

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Insensitive Munitions (IM) requirements have been mandated for new munitions since about 1980. A new munition, the XM155 Spider, was developed in response to the requirement to replace traditional passive minefields with more selective munitions, avoiding the cost of collateral damage to unintended targets. The IM threats facing this munition include, Sympathetic Detonation (SD), Slow Cook-Off, Fast Cook-Off, Bullet Impact, Fragment Impact, and Shaped Charge Jet Impact. To mitigate the violence of response to these threats, a systems approach was implemented to ensure that IM response was carefully considered as a key performance requirement during development. For this purpose novel design approaches in energetics, packaging and venting were leveraged to ensure success. The result is a munition that passes four of the five applicable Insensitive Munitions threats, with shaped charge jet impact resistance still to be demonstrated.

INTRODUCTION

Applying a systems approach to Insensitive Munitions (IM), the XM7 (formerly designated XM155) Spider Integrated Product Team (IPT) was able to mitigate most IM threats by leveraging novel design approaches in energetics, packaging and venting to ensure success. Limitations in one IM area were handed off to another IM area for mitigation with a careful balance of characteristics. The resultant munition is scheduled to be type classified in March 2006, and demonstrates IM compliance for Sympathetic Detonation (SD), Slow Cook-Off (SCO), Fast Cook-Off (FCO), Bullet Impact (BI), and Fragment Impact (FI). Shaped Charge Jet Impact, originally assessed to fail by the system threat hazard assessment (THA), has yet to be tested due to the limited amount of development hardware and cost of the testing. Shaped Charge Jet Spall impact has also yet to be addressed.

SYSTEMS APPROACH

The success of the Spider program in meeting lethality and other requirements while achieving IM compliance is entirely due to adoption of the systems approach. The approach analyzed all aspects and characteristics of the munition during its lifecycle. The threats to the munition were initially defined through a THA. The results of the THA indicated that the munition would be subjected to all MIL-STD-2105C threats including shaped charge jet spall impact, and that the most probable threat configuration would be the palletized munition. Once this effort was completed, the Integrated Product Team was able to develop an IM mitigation plan, employing an integrated suite of techniques involving reduced sensitivity energetics, venting technology, and a robust packaging architecture. In general the goal of the program was to limit the response of the munition to no greater than a Type 5 (burn only) reaction, except for sympathetic detonation and shaped charge jet impact which requires no greater than a Type 3 (explosion) reaction.

THE SPIDER SYSTEM

The Spider System (Figure 1) is comprised of three main hardware components: a Remote Control System (RCS), a Repeater and Munition Control Units (MCUs – Figure 2). The RCS is utilized by the operator during hand-emplacement of the MCU's. The Repeater is a relay device that is optionally used to extend the range of control of the RCS over the munitions or to maintain communications in difficult terrain. The MCUs allow a control capability that provides notification to the operator (via a radio frequency link to the RCS) of intrusion, tampering and system status, and receives commands from the operator for control of the functioning of the munition. The baseline MCU includes 6 miniature grenades that provide the lethal capability of the Spider System.

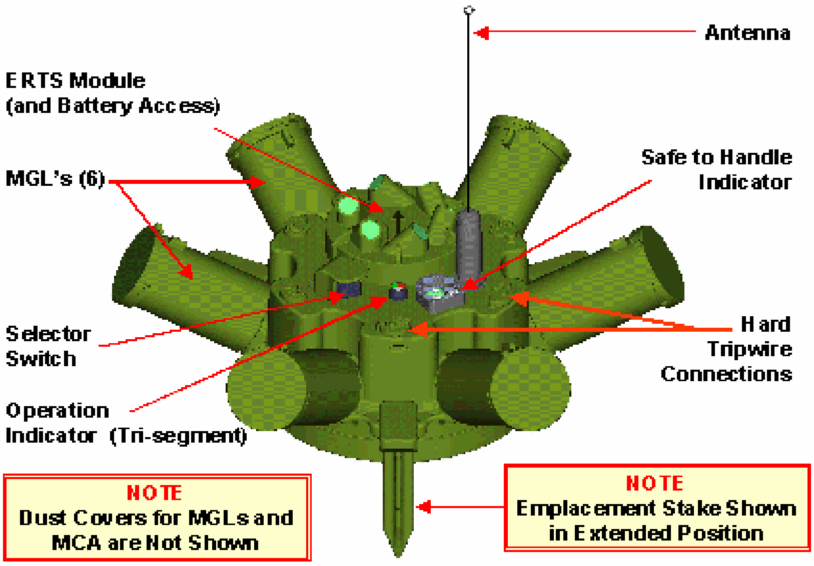

Figure 1: Spider Munition Control Unit (MCU)

ENERGETICS

A key component in the approach to IM compliance is the selection of energetics. The Miniature Grenade Launcher (MGL – Figure 2) is very small, requiring an energetic with a small critical diameter to fully ramp up the grenade to detonation. The shape of the munition is spherical, leading to a pourable type energetic over a pressed explosive which would require a more costly and complex design. This leads to a choice between a cast cure type explosive and a melt pour explosive since a pressed explosive would require a two piece design, significantly raising loading and assembly costs. For reduced overall lifecycle costs, a fully recoverable and recyclable melt pour explosive was developed for the system, designated PAX-41. PAX-41 is a simple derivative of PAX-21, a main charge fill developed for the M720A1 60mm mortar cartridge. It is a combination of 2,4-dinitroanisole and 1,3,5-tetranitrazacyclohexane (RDX). It was designed with a small critical diameter tailored for optimum performance in the Spider munition. After an extensive process, PAX-41 received interim qualification in December 2005. The explosive demonstrates a combination of reduced sensitivity and excellent performance. It is very low in cost and exhibits good thermal properties when used in combination with a venting mechanism. The shock sensitivity is lower than many legacy explosives. The Integrated Product Team (IPT) decided to handle the limitations of the explosive by design for venting and the use of barriers integrated into the packaging design.

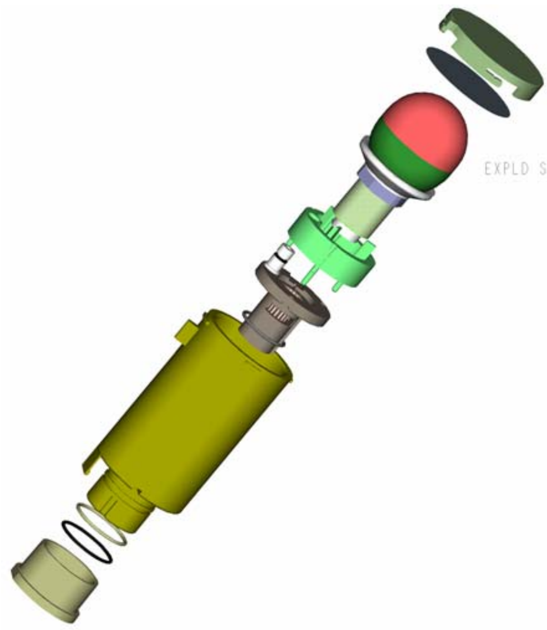

Figure 2: Miniature Grenade Launcher (MGL)

Another key energetic aspect of the system requiring attention was the fuze and booster mechanism. The Spider grenade houses a Grenade Initiation Module (GIM – Figure 3). The GIM contains a Low Energy Exploding Foil Initiator (LEEFI) with RSI 007 explosive, a hexanitrohexaazaisowurtzitane (CL-20) based explosive configuration. The selected GIM design has twice the output and half the cost of a traditional fuze and booster design. It also has superior aging characteristics and good environmental performance and can be reliably initiated at the same energy level as legacy explosives in these devices. This use represents the first or one of the first applications of a CL-20 based explosive in a US Army munition.

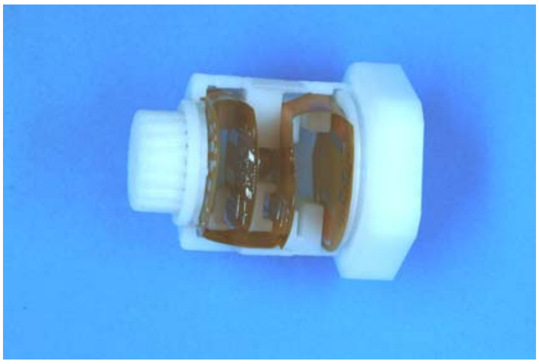

Figure 3: Grenade Initiation Module (GIM) in meltable plastic housing

These energetic design approaches provided sufficient margin for an integrated packaging solution to be applied which would complete the equation to yield IM compliance in the Spider munition.

PACKAGING AND VENTING

Packaging has played an integral part in the successful mitigation of IM threats to the munition. The intent of traditional packaging has been to provide environmental protection to munitions, such as from moisture and humidity and from shock due to rough handling and transportation. This role is often fulfilled through the use of robust structures that are capable of surviving these rigors. In addition, well-designed packaging has also contributed to the munitions logistical efficiency through low weight and small cube. Unfortunately, traditional packaging approaches can actually make matters worse from an IM perspective. A design tug-of-war thus exists that requires the packaging engineer to develop specialized container systems that are capable of doing both. The packaging must require little, if any maintenance and be affordable.

For Spider MGL, these conflicting design criteria presented a daunting challenge requiring packaging, energetic selection and munition design to be complimentary to each other. No independent variables could be tolerated. For the packaging, that meant first having a detailed understanding of the munitions design, functionality, and damage boundary. Characterization of how the munitions would be handled, by whom and in what quantity was essential. Only after having a full understanding of these key areas could the packaging solutions be developed.

As the Spider MGL became defined, and insight as to how the munitions would behave under the various operational and logistic environments was gained, a packaging system emerged. The M548 metal ammunition shipping and storage container was selected as a prime container candidate for this application (Figure 4). The container was developed as a means to efficiently ship and store small to medium caliber ammunition and was known to be very robust. While effective at maintaining the required three pounds per square inch (psig) seal integrity following exposure to transportation rough handling environments, the container design by virtue of its large sealing area and gasket design, is capable of venting around the gasket. This is due to thermal degradation of the gasket material, enabling the pressure resulting from combustion of contained energetics to breach the container. The Spider MGL's use of PAX-41 explosive enabled the container to vent in this manner, as the energetic characteristically does not transition beyond burning when exposed to fast heating. As seen in figure 5, the grenades were consumed in the fire, burning in a non-violent manner. The container remained intact and vented through the gasket as seen in figure 6. In addition, the plastic material surrounding the GIM melts at a lower temperature than the cook-off temperature of the energetic, creating a vent which allows the GIM to detach from the grenade allowing the explosive melt out without detonating (Figure 3).

This systems approach also proved effective when subjected to thermal threats. PAX-41's thermal stability and the rate of thermal transfer though the packaging medium allowed the MGLs to cook-off non-violently resulting in no debris projection outside the container. This is very significant since slow heating effects have typically resulted in mass combustion, causing overpressure conditions within the package.

Figure 4: M548 Shipping and Storage Container

This typically leads to a rapid transition from burning to detonation with most explosives. Figures 5 and 6 show clearly that the grenades remained intact and the container vented (bulged) as a result of combustion pressure when subjected to fast cookoff. This was only achieved through a pro-active design approach.

Figure 5: Post FCO – Recovered MGLs

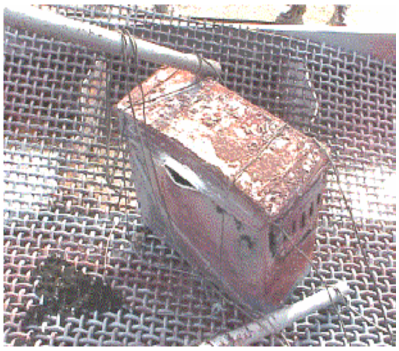

Figure 6: Post FCO – Container

Since Spider MGL is a component of the Spider, Non-Self Destruct – Alternative (NSD-A), it was essential that the container system facilitate efficient emplacement. Thus, the container had to be of a size that would allow for at least two (2) system loads. This meant that 12 MGLs had to be packaged with a single M548 container. The MGL, even with a reduced sensitivity explosive such as PAX-41 will cause sympathetic effects in a detonation and catastrophic loss if sufficient effort is not taken to adequately isolate the MGLs within the container. Thus, explosive shock mitigation was a primary objective in designing the Spider MGL cushioning. Shock mitigation effects through various packaging materials and configurations have been studied over the past decade. Research conducted by both ARDEC and the US Army Research Laboratory has shown that polyethylene foam is a good shock attenuator given the right geometry for a given munition application. The cushioning chosen for Spider MGL consisted of two (2) foam trays (Figure 7) each made from 6 pounds per cubic foot rated polyethylene foam, with 6 cutouts each to accommodate the packs 12 MGLs. The foam trays are designed to preclude the possibility of having more than 1 MGL in line vertically (within the container). This configuration insured that each MGL would have maximum separation necessary to achieve the desired shock mitigation from the surrounding foam. Test results proved that this arrangement was extremely effective in preventing SD effects. Adjacent MGLs, while damaged, did not function and all explosive material from the remaining packaged MGLs was recovered. This was the direct result of the proper explosive selection and the packaging design and choice of materials.

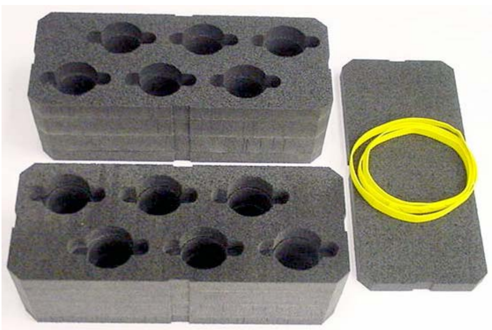

Figure 7: Polyethylene Foam Trays

Sympathetic effects were characterized using 6 live MGLs positioned in the most vulnerable locations within the package. This arrangement represented both horizontally positioned within each tray and vertically, i.e. the relative separation when stacked tray on tray within the container. As can be seen from Figure 8, significant damage to the container occurred, but only the donor grenade detonated (using a high output initiator attached to the MGL).

Figure 8: Post SD examination showing fragment perforations

Adjacent MGLs were crushed, yet the shock loads were below their detonation threshold. This was a significant finding as the blast instruments from the SD test showed that the output energy from detonating MGLs would be less than the input energy from the impact from the threat shaped charge (RPG-7 System PG-7 warhead), as identified through the threat hazard assessment process. Although the grenade is assessed to detonate upon SCJI, the lack of sympathetic reaction during the SD test indicates that a possible passing result may occur. However, the test issues involved with such a large threat stimulus into a small item are challenging and potentially costly. This issue is under review by the IPT. Also to be addressed when possible is shaped charge jet spall impact.

Additionally, fragments from the detonating MGL caused fragment perforations (see figure 9) in one of the acceptor grenades, which offered insight into how the MGL would respond to high velocity fragment impacts.

Figure 9: Post SD examination showing fragment perforations in acceptor grenade

Further testing, using the standard test protocol for fragment impact characterization proved this result. Although the container (Figure 10) was ripped by the exiting fragment, there was no reaction worse than Type 5. All MGLs were recovered as indicated in figure 11.

Figure 10: Post FI Container

Figure 11: Post FI MGL Fragments

Slow cookoff tests were conducted. Results in this test also demonstrated the required Type V reaction as shown in figures 12 and 13.

Figure 12: Post SCO M548 Container

Figure 13: Post SCO Grenade

All grenades were recovered and the container was bulged but essentially intact.

CONCLUSION

The Spider munition's outstanding response to external stimuli was only achieved by a dedicated team working to address insensitive munitions responses through a total systems approach. By incorporating a variety of techniques and technology, coupling the advantages and limitations of energetics, packaging and venting, near IM compliance was achieved with the balance yet to be tested. The careful selection of each of these innovations considered in the design of the total munition system was critical to the success of the program.