VENTING TECHNOLOGY FOR LARGE CALIBER GUN PROPULSION SYSTEMS – METAL CARTRIDGE CASE AND PACKAGING CONTAINER VENTING

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ABSTRACT

During its life cycle, the large caliber gun propulsion charge spends most of its time in some form of confinement – metal cartridge case and/or metal storage/shipping container. When ammunition is subjected to unplanned stimuli such as heat, impact, and shock, the confinement of propulsion charge leads to unfavorable violent reactions. There have been multiple past projects that have included venting development work, but almost all of them have been 'item specific' in efforts to meet IM (insensitive munitions) compliance and have used 'trial-and-error' approach. However, no research work has been conducted to investigate the fundamentals of venting by taking more of a scientific approach. The objectives of this program are: 1) to better understand the underlying design principles of venting mechanisms which can be transitioned and applied to variety of items in both container and cartridge case systems; and 2) to develop a methodology of venting technology development, given a charge system, with the help of available tools, including a propulsion charge simulator and interior ballistic and structural models. Thus far the generic container, propulsion charge, and a simulator were designed, and the baseline test was conducted. In addition, the modeling effort is underway in which interior ballistic code and structural code will be applied iteratively to predict the maximum pressure of a vented container. The generic container's dimensions were similar to that of MACS (Modular Artillery Charge System) packaging container. The propellant charge consisted of M31A2 triple base propellant, used in MACS, and M47 double base propellant which was situated at the center longitudinally. For the modeling purposes, the propulsion charge was simplified by eliminating the combustible cartridge case and replacing the 'dual-bagged' igniter system with M47. The pressure, temperature, and flamespread speed were captured at various locations of the generic containers during the baseline fragment impact (FI) tests.

INTRODUCTION

This program is funded by the Joint Insensitive Munitions Technology Program (JIMTP) in efforts to develop venting technology that is applicable and can be transitioned to various packaging containers and cartridge cases of large caliber gun systems. In addition, via employing and implementing available modeling and simulation tools such as interior ballistics

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(IB) code, structural model, and ballistic simulation to develop a process or methodology of venting technology development. By following this methodology, given a charge system, optimal venting schemes mitigating fragment impact (FI) and slow cook-off (SCO) stimuli can be designed relatively quickly and easily. The Large Caliber Gun (LCG) Munitions Area Technology Group (MATG) in the Joint Insensitive Munitions Technology Program (JIMTP) has goals in mitigating the following three types of threats: fragment impact, shape charge jet (SCJ), and slow cook-off. The objective of this program is to improve the FI response to a Type IV reaction (+10 year LCG MATG goal) and to improve SCO response to a Type V reaction (+10 year LCG MATG goal).

To effectively address IM threats, especially cook-off threats, the venting technology is often necessary. Venting technology has been successfully developed, demonstrated, and fielded for munitions systems, such as warheads and rockets motors, as a valuable means to mitigate the effects of impact and cook-off threats. While these examples are encouraging and show a level of technology maturity, they suffer from being applicable only to specific systems and were often designed using a “cut-and-try” engineering approach. As a result, the examples cited above may not be applicable to the gun propulsion systems of interest under this proposal and are not directly transferable because of a lack of fundamental understanding and underlying design principles for the venting mechanism. Many of the past and current venting research efforts involve the implementation of memory alloy, eutectic metal, and plastic plugs that melts/softens. These ‘pre-opened’ venting methods require certain periods of exposure to heat before they become effective and are mainly addressing cook-off threats.

To address these shortcomings in the proposed program, venting mechanism types will be carefully selected such that they can mitigate multiple types of threats (e.g. FI, SCO) and can be utilized on a wide variety of storage containers, cartridge cases, and other ammunition systems (e.g. rocket motor cases). The independent variables that control the function of the selected venting mechanisms will be identified and quantified for the selected materials of construction. Design of experiments (DOE) variable matrices will be developed to identify trends. The DOE will also identify which variables are more influential than others for vent function and which can tolerate variability in the manufacturing process. In addition, for a motor, it is imperative to facilitate vents before the propellant could react under the SCO scenario. Thus, ‘pre-opened’ vents of various dimensions, locations, and sizes will be selected as independent variables for addressing cook-off threat; however, how these ‘pre-opened’ vents will open up during the initial heating cycle will not be investigated in this program.

In an attempt to clearly depict different classifications of gun propulsion venting problems, and to tie these problems with system requirements and enabling technologies, the diagram titled “Tree of Venting Technology Development for the Large Caliber Gun Propulsions Systems” is constructed and can be seen below (Figure 1).

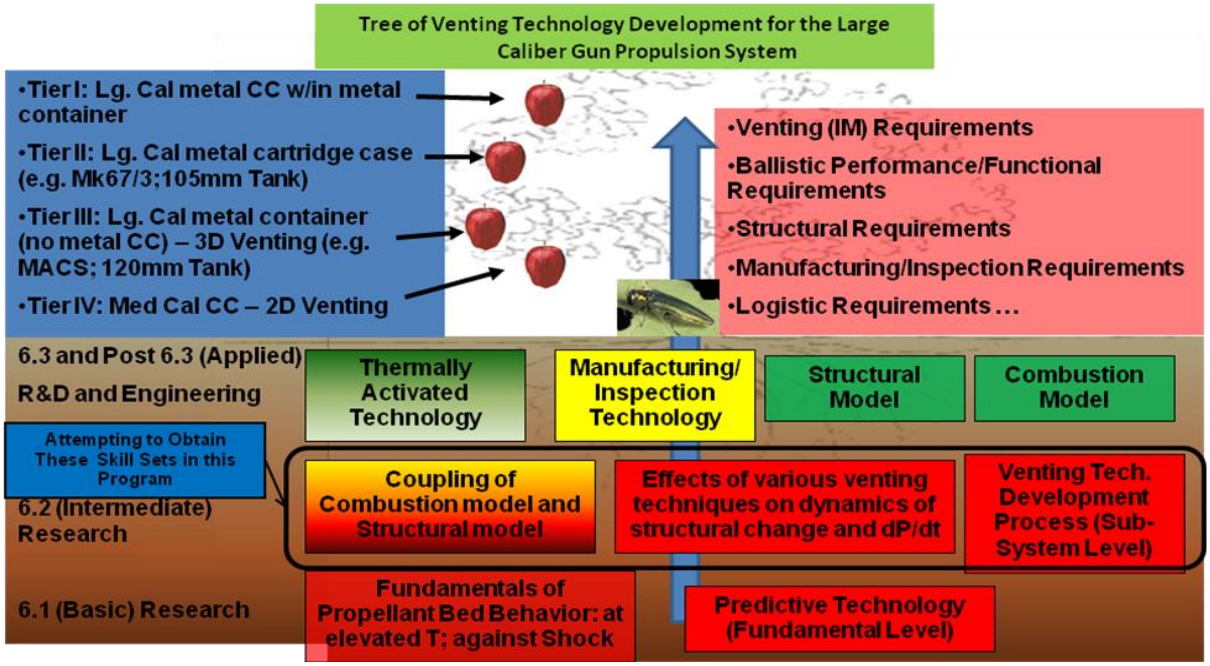

Figure 1. Tree of Venting Technology Development for the large Caliber Gun Propulsion Systems

In the top left corner of Figure 1, different tiers of venting challenges are shown. The lowest hanging fruit is venting a medium caliber cartridge case, because most medium caliber cartridge cases can be vented through the base. The product gas of initiated propellants can escape through pre-drilled and plugged vents holes through the base. This technology is being optimized and implemented over several medium caliber munitions that are funded by PEO Ammo IM Thrusts Area. The next higher hanging fruit is venting a large caliber metal packaging container that contains combustible cartridge cases such as MACS or 120mm tank munitions. Because the combustible cartridge cases rapidly combust upon initiation of propulsion system, the only confinement of the system is imparted by the packaging container. The next more difficult challenge in the gun propulsion system is venting a metal cartridge case such as Mk67/3 or 105mm tank munitions. They are more difficult to solve than the packaging container due to its operational requirements. The cartridge case has to withstand the large pressure and high temperature in the gun chamber during the operation as well as the structural strength requirements. The most difficult challenge is a system containing dual layers of confinement – metal cartridge case in a metal packaging container. Prior programs in efforts to develop the vented packaging container for MACS showed that it is difficult to address both IM requirements and functional (rough handling) requirements simultaneously.[1, 2] The margin of error in the thickness of scored wall was so small (less than 0.010”) that the program could not transition the venting technology. In this current program, a more scientific approach will be taken focusing primarily on the IM requirements and secondarily on end items’ functional requirements. Upon the completion of this 6.2 research program, the final deliverables will be transitioned to follow-on 6.3 programs solving Tier II and III problems in which other functional requirements will be addressed.

Situated in the top right corner of Figure 1 are the requirements to be met by the venting technology developers. The developer not only has to address IM issues but also multiple arrays of operational, functional, manufacturing, and logistic requirements. The venting technology developers are faced with an immensely difficult challenge in which conflicting

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requirements must be met simultaneously. The case or container has to be weakened to the point so that it can open up to provide venting in the event of unwanted initiation, yet it has to be strong enough so that it can withstand the rough handling and normal operational pressure of gun.

Symbolized as the root of a tree are the enabling technologies or the skill sets that can aid in successful implementations of venting technologies in various items. There are a few matured enabling technologies that can be utilized as tools including thermally activated venting technologies, structural models/codes, and interior ballistics (combustion) model/code. However, there is a lack of fundamental understanding on the behavior of the propellant bed when it is subjected to IM threats such as cook-off or fragment impact. The predictive technology is being developed and refined for the monolithic rocket propellant and the high explosive warhead.[3-5] None exists for the large caliber gun propulsion system, because it is very difficult to model a bed of propellant that consists of numerous randomly situated perforated propellant grains.

RESULTS AND DISCUSSION

There are several facets of this program including, but not limited to, simulation, coupling of IB and structural models, conducting DOE to quantify and determine influential factors of venting, conducting baseline tests, and validating models via experimentations, etc. However, only the design of the baseline test fixture and the baseline FI tests will be discussed in this paper.

Baseline Test Fixture (Generic Container)

Before the baseline test fixture (generic container) was designed and fabricated, the dimensions of many fielded packaging/storage containers and cartridge cases for large caliber gun systems were surveyed. Because the MACS packaging container is easier than other systems to model due to having a single layer of confinement with a cylindrical wall of uniform thickness, the dimensions of the baseline test fixture were chosen to closely follow those of MACS packaging container. Also, the dimensions of the MACS packaging container, namely the diameter, length, wall thickness, and L/D ratio, fall in the middle of many of surveyed fielded items. The propulsion charge system was chosen to be M31A2 triple base propellant, which is currently being used for the MACS. This program is leveraged with the PM-CAS MACS program and has a good chance to be transitioned to the follow-on program targeting the MACS packaging container. Therefore, designing the test fixture close to the MACS packaging container and uploading it with M31A2 propellants used in MACS made most sense.

Once the dimensions of the test fixture were considered, several instrumentation ports were designed and placed on the cylindrical wall and on the end plates to measure the pressure, temperature, and flame spread within the container. No report was found on the measurements of pressure, temperature, and flame spread rate of a propulsion system when subjected to fragment impact. These data are valuable in two ways: 1) one can better understand the dynamic behavior of a propulsion system during the FI event; and 2) various quantifiable data can be fed into IB and structural codes to in an attempt to build a high fidelity model. The types and locations of instrumentation ports are depicted in Figures 2 and 3 below.

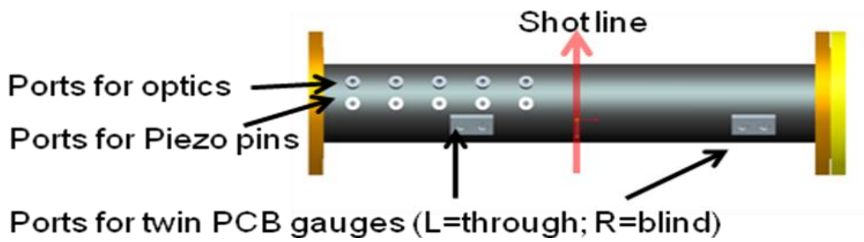

Figure 2. Top View of Baseline Test Fixture Showing Instrumentation Ports

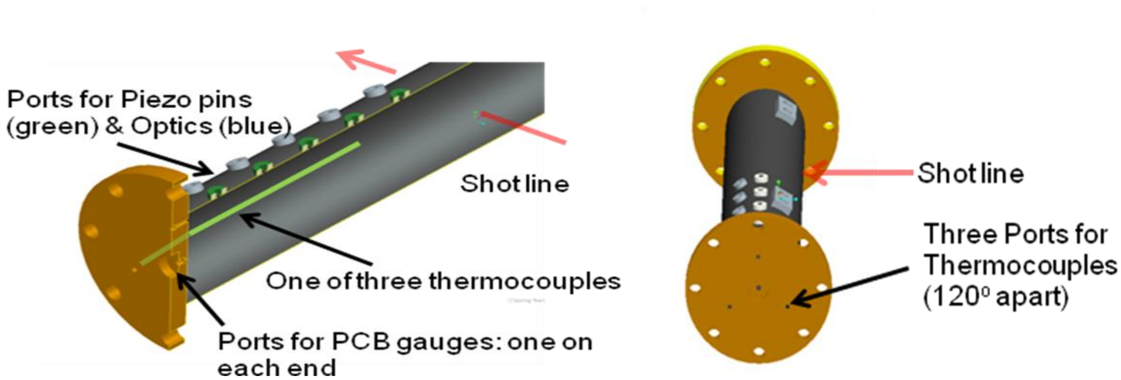

Figure 3. Alternate Views of Baseline Test Fixture Showing Instrumentation Ports

Two rows of five (5) ports were situated on the left side of the test fixture, one row of which was for the piezo pins while the other row was for the fiber optics. For each row, five ports were located 3, 6, 9, 12, and 15 inches (or 76, 152, 229, 305, and 381mm) away from the shot line. These ports facilitated the instrumentation of Piezo pins and fiber optics, which in turn enabled the acquisition of pressure-time and flame spread rate data along the length of baseline test fixture. The details on its significance and the results of FI tests will be discussed in the subsequent section. As seen in Figures 2 and 3, in addition to two rows of five ports, several PCB gauge ports were implemented on the cylindrical wall as well as on both end plates of the baseline test fixture. Lastly, three holes were drilled on one end plate to accommodate three thermocouples. These holes were 120 degrees apart, and three different lengths of thermocouples were utilized to acquire temperature information at 3 points along the length of the baseline test fixture. The lengths of thermocouples were chosen to be 4.33in, 8.46in, and 12.9in (110mm, 215mm, and 328mm). The diagram on the left in Figure 3 above depicts how one of the three thermocouples is situated inside the baseline test fixture.

Baseline FI Tests

As discussed in previous sections, the instrumented baseline test fixtures were filled with M31A2 triple base propellants and were subjected to fragment impact. The original plan was to test two shots under the same test configuration. However, as the authors discovered unexpected findings, the test configurations were adjusted to better meet the program/test objective – establish a baseline in which Type IV or worst reaction level is observed. For all three tests, the instrumentation and the uploading of propellant grains were identical; however the configuration of igniter/igniter-tube assembly was slightly varied. Three different pre-test configurations as well as the results from the FI tests will be explained and discussed in this section.

In all three tests, all of the gauges were mounted on the ports depicted in Figures 2 and 3, M31A2 propellants were loaded, and the fragment was aimed through the center of the baseline test fixture. In Test 1, unlike other two tests, no igniter material was loaded into the baseline test fixture. The idea was to keep the propulsion system as simple as possible to increase the probability of success in modeling. The velocity of the fragment in Test 1 was unexpectedly low measured at 7081 ft/s (2158 m/s). It was later found that the gun tube was worn, and when it was replaced, the desired fragment velocity of 8300 ft/s (2530 m/s) was easily reached in the subsequent tests. The reaction time was measured to be about 2.25 ms, which was found to be relatively slow when compared to the results from subsequent tests. The baseline test fixture was split into two pieces, and each piece traveled about 5 to 6 ft (about 1.5 to 2 m) away from the center. The level of reaction was relatively very benign, and the IM score of Type V reaction was assessed. The post-test photo can be seen below in Figure 4.

Figure 4. Post-Test Photo of FI Test 1

Learning about the potential significance of the igniter, a makeshift igniter/igniter-tube assembly was designed and inserted as a part of the propulsion charge in Tests 2 and 3. The MACS has WC864, a double base propellant and one of the two igniter materials, encased in the combustible tube. Neither WC864 nor combustible tube was available. Hence M47 (double base propellant similar to WC864) was loaded in a paper tube, and this igniter-tube assembly was inserted through the center of the baseline test fixture. The result of implementing this makeshift igniter-tube assembly was rather successful. In Test 2, the fragment velocity was measured to be 8323 ft/s (2537 m/s), the internal reaction was measured to be less than 1 ms in duration, two large end pieces were thrown 12 ft and 19 ft (3.7 m and 5.8 m) away from the center, and a few smaller pieces of the cylindrical wall were scattered within the 50 ft (15 m) circle. Considering the heavy mass of the end pieces, the reaction was much more violent than the first. It was calculated that if the end pieces weighed about 3 lbs (6.6 Kg) or less, the same force that was generated in Test 2 would have thrown the lighter end pieces beyond 50 ft (15m). Another interesting point is that the igniter tube split asymmetrically into three pieces. The uneven splitting pattern of the igniter tube and the uneven splitting of the baseline test fixture indicate that: 1) the pressure within the paper tube was built, and the tube was split in an uncontrolled manner; 2) the pattern of localized reaction stemming from the reaction of igniter material contributes significantly to the pattern of the splitting of metal container. The post-photos of Test 2 can be seen below in Figure 5.

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Figure 5. Post-Test Photos of FI Test 2

In Test 3, the paper tube was modified by drilling four evenly spaced rows of evenly spaced holes. The rest of the test configuration was identical to that of Test 2. The fragment velocity was estimated to be about 8200 ft/s (2499 m/s), the internal reaction was measured to be less than 1 ms in duration, two large end pieces were thrown lesser distances away from the center than it did in Test 2, and the metal container was split symmetrically into two. The reaction level was still more violent than the first but was less violent than the second test. The major difference between Test 2 and 3 are the splitting pattern and the reaction level contributed by the igniter/igniter-tube assembly. Unlike Test 2, the igniter tube split in half symmetrically with evidence of an even and controlled combustion. The pattern of holes indicated that the hot product gas from the combustion of igniter escaped the tube in a controlled and in a symmetric way. Also, the charring on the outside of igniter tube indicates that the flame spread from igniter propagated to the bed of propellant in a controlled fashion as one would observe in a typical ammunition. Similarly, the metal container split symmetrically in half, which supports the idea that the initial combustion characteristics of the igniter heavily influences the combustion and rupturing pattern of the metal container. In addition, controlled out-flow of hot gases prevented any uncontrolled pressure build-up within the igniter tube, therefore the overall reaction level of Test 3 was lower than that of Test 2. The post-photos of Test 3 can be seen below in Figure 6.

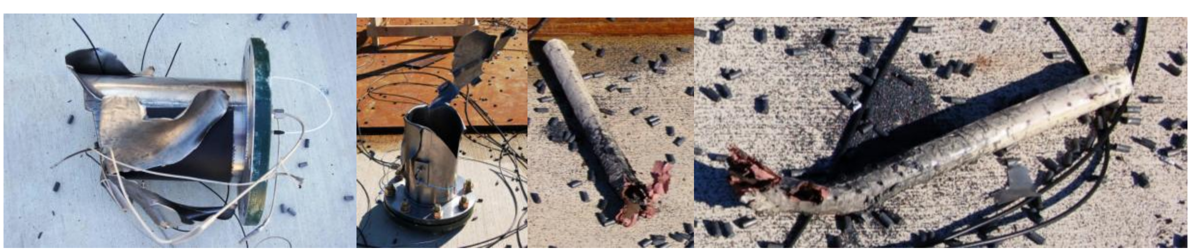

Figure 6. Post-Test Photos of FI Test 3

SUMMARY AND CONCLUSIONS

To address the fragment impact and cook-off threats in the large caliber gun propulsion area, venting technology is being developed fully utilizing the available tools such as a ballistic simulator, NGEN interior ballistic model (3-dimensional computational fluid dynamics model), structural model, and Minitab (statistical analysis software – for design of experiments). The gun propulsion community is lacking the fundamental understanding in the behavior of propellant bed under unplanned stimuli (e.g. impact, cook-off) and the underlying principles of venting highly confined propulsion systems. Due to this fact, it was and continues to be extremely difficult to fully solve IM problems using the 'trial-and-error' method. In this program, a more scientific approach is taken and attempts to better understand the fundamentals will be made.

Although a broad overview of the program was covered in a recent JANNAF paper[7], this paper covered and focused only on the design of the baseline test fixture and the baseline FI tests. The baseline test fixture was designed to acquire various data including pressure, temperature, rate of flame spread, etc. Three test fixtures were instrumented with gauges, filled with M31A2 triple base propellant, and were subjected to baseline FI tests. The authors were able to gain new insights on the combustion characteristics of the propulsion charge that was subjected to fragment impact. Several key findings from the baseline FI tests include:

- Igniter in the propulsion charge affects the level of reaction greatly
- Igniter tube provides a level of confinement for the igniter, which in turn influences the reaction level of the overall propulsion charge
- Localized reactions within several inches of the fragment impact point were occurred
- The reaction pattern of igniter-tube assembly influences the reaction and rupturing pattern of the propulsion charge and the metal container, respectively

The above findings and new insights could aid in current and future venting technology development programs.

ACKNOWLEDGEMENTS

Authors would like to acknowledge the OSD and JIMTP Office for funding support.

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