The Effects of Igniter Design
on the Interior Ballistic Performance of Deterrent Coated Propellants

T.G. Manning, C.P. Adam, D. Park, E. Rozumov, S. M. Gilbert and M. Ellis
U.S. Army RDECOM-ARDEC Picatinny Arsenal
Picatinny, NJ 07806-5000

J. Colburn and B.E. Homan
Propulsion Systems Branch, Ballistics and Weapons Concepts Division
Weapons and Materials Research Directorate, Army Research Laboratory
Aberdeen Proving Ground, MD 21005-5066

C.R. McMurray, K.B. Moran, and S.J. Ritchie
ATK/Radford Army Ammunition Plant
Radford, VA 24060

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The US Army RDECOM ARDEC has developed a new environmentally friendly, insensitive propellant, designated PAP-8386 for medium caliber applications. Preliminary tests of the material in the M793 cartridge at ambient temperatures were very promising. Subsequent extreme temperature testing identified an unacceptable pressure rise as the temperature decreased. This pressure increase was assumed to be caused by the break-up of the propellant due to the mechanical properties of the propellant combined with a base-pad type ignition event. To mitigate this problem, further work was done to better understand the influence on interior ballistics of the igniter design, location, and strength, and the consequent interaction with the propellant bed. Tests were conducted utilizing rounds built with modified igniters. The influence of the igniter system on the overall ballistic performance proved to be significant across all temperatures. Optimizing the ignition system to achieve the desired performance requires balancing the need for a strong igniter, necessitated by the deterrent coating, and the mechanical limits of the propellant.

INTRODUCTION

In an effort to supply an environmentally friendly propellant for medium caliber ammunition applications that also improves the insensitive munitions characteristics, the US Army RDECOM ARDEC teamed with ATK to design and produce small quantities of a solventless propellant for the 25mm M793 round.

The M793 TP-T is a low cost target practice cartridge ballistically matched to the M792 HEI-T (High Explosive Incendiary with Tracer) and the MK210 HEI-T rounds. The cartridge can be fired from any platform that uses the M242 Bushmaster, KBA, M811 or GAU-12 weapons. It was chosen as a good candidate that would be representative of the 25mm ammunition family.

During the course of the initial development work, some unexpected issues arose which led to the need for a more complete understanding of the ignition system employed and its interaction with the propellant.

PAP-8386 PROPELLANT

Propellant Formulation

To achieve the desired goals of meeting existing performance levels for the M793 round, eliminating environmental problems, and improving the insensitive munitions characteristics, a propellant manufactured using the solventless process was considered essential.

The solventless propellant manufacturing process relies on energetic plasticizing agents mixed with nitrocellulose to create the appropriate material properties that allow for extrusion of the propellant grains through a heated press. The plasticizers in the propellant formulation give the final product more ductile material properties relative to propellants that are manufactured using a solvent process. This ductility gives the material more desirable response to impact related IM threat scenarios such as bullet impact, fragment impact and shaped charge jet impact.

The final formulation that was settled upon was given the identifier, PAP-8386. Cheetah 4 [1] was used to determine the thermochemical constants needed for performance modeling and closed bomb burn rate determination. The initial development and testing of PAP-8386 is detailed in “Environmentally Friendly ‘Green’ Propellant for the Medium Caliber Training Rounds” [2].
Preliminary Performance Assessment

The choice of a solventless process coupled with more environmentally friendly ingredients fulfilled one element of the overall design objectives. The remaining requirements were to meet performance and improve IM characteristics. The performance requirements for the round are shown in Table 1.

An initial assessment of the PAP-8386 in the M793 round was carried out using the CONPRESS model [3]. The CONPRESS evaluation showed the PAP-8386 formulation to have sufficient chemical energy to meet the M793 performance needs. The next step was determination of an appropriate grain design to effectively release the propellant’s chemical energy and convert it to projectile kinetic energy. The US Army RDECOM ARDEC and Army Research Laboratory supported this effort by modeling the round using the IBHVG2 (Interior Ballistics for High Velocity Guns) computer model [4].

From the available information on the propellant, the predicted web size (burn distance between the outer and inner diameters) for the M793 was 0.61 mm (0.024”). To ensure ballistic success, Radford Army Ammunition Plant (RAAP) chose to process three web sizes, the target of 0.61 mm (0.024”), a smaller web 0.51 mm (0.020”) and a larger web 0.70 mm (0.0275”). These samples are referred to as Yellow, Red, and Blue respectively.

Following manufacture, the base grain was characterized both chemically and physically. This provided verification that the process was capable of matching the target levels for the formulation and physical dimensions within a reasonable tolerance. Additionally, absolute density measurements were made and at 1.6 g/cc fell within the typical double base propellant range.

### TABLE I. PERFORMANCE SPECIFICATIONS FOR THE M793 CARTRIDGE

<table>
<thead>
<tr>
<th>Performance Measure</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Muzzle Velocity</td>
<td>1100 m/s</td>
</tr>
<tr>
<td>Max. Pressure (All Temps)</td>
<td>496 MPa</td>
</tr>
<tr>
<td>Max Amb. Pressure</td>
<td>402 MPa</td>
</tr>
</tbody>
</table>

Closed Bomb Characterization

The best way to assess propellant performance is through combustion testing. The closed bomb test is a standard device used to measure gasification rates for energetic materials. Knowledge of propellant chemical formulation and geometry allows for calculation of a linear burn rate from the measured pressure versus time data.

Even more conveniently, the closed bomb can be used to directly measure the relative performance of two propellants (MIL-STD-286C, Section 801.1). The performance comparison is in terms of relative quickness (RQ) and relative force (RF). Relative quickness applies to the speed with which the material burns and is a comparison of the pressurization rates (dP/dt). Relative force is a comparison of the total energy; observed in the bomb as peak pressure (Pmax). This test demonstrated that all of the candidate PAP-8386 propellants burned slightly slower than the standard propellant and provided roughly equal pressure levels in the closed bomb.

To provide a visual comparison of the relative performance, a variable called dynamic vivacity [5] has been reviewed. A typical comparison is shown in Figure 1. In these plots, the
dynamic vivacity has been calculated and plotted against the normalized pressure \( (P/P_{\text{max}}) \) in the closed bomb. The dynamic vivacity is calculated at each time step. It is determined by the following equation:

\[
Vivacity = \frac{dP/dt}{P * P_{\text{MAX}}}
\]

(1)

Higher vivacity values are an indicator of higher gasification rates. The vivacity comparison provided a strong indication that PAP-8386 would be appropriate for the M793 Round.

![Average Vivacity Comparisons of RP-36 unc vs. PAP-8386 0.024" Web](image)

**Figure 1.** PAP-8386 vivacity results for the target web (0.61mm)

**Deterrent Coating**

To further improve the interior ballistic efficiency, deterrent coatings are applied to the exposed propellant surfaces as part of the finishing process. This serves to reduce the propellant burn rate during the very early part of the ballistic cycle. As the projectile moves down bore, the burn rate increases as the outer layer burns away. By optimizing this coating process to match the movement of the projectile, the gasification rate can be increased as the volume behind the projectile increases.

Deterrent coating at Radford Army Ammunition Plant for this project was accomplished on a small scale using a proprietary system. A combination of penetrant and inhibitor deterrents was applied to the grains as part of a coating optimization investigation. Multiple deterrents were implemented based on previous work involving highly plasticized propellants.

Once again, the closed bomb was used to provide a comparative evaluation against standard 25mm M793 propellant (RP-36). These graphical comparisons provided a strong indication that the proper blend of coated and uncoated material would be able to achieve the performance requirements of the M793 cartridge.

**BALLISTIC TESTING**
Initial Ballistic Test Results

The final proof of performance for any propellant system is gun testing in the final configuration. These initial firings were carried out in the M793 cartridge using uncoated base grain PAP-8386 at ambient conditions (21°C). Charge weights were varied to determine optimal load conditions.

As shown previously, the performance requirements for ambient conditions are a muzzle velocity of 1100 m/s and a mean pressure below 402 MPa. For all three dies, the pressure levels were too high indicating a need to slow the burning down early in the ballistic cycle.

To slow the initial pressurization rate down early in the ballistic cycle, deterrents were applied to the propellant. After the deterrent coating process was completed, additional ballistic tests were conducted. A blend of uncoated and coated propellants was shot in an effort to meet the ballistic targets. Once again, all testing was carried out at ambient temperatures (21°C) in the M793 cartridge.

From the intermediate tests, a final blend configuration was chosen for a final set of ballistic tests. The Blue Web (0.70 mm) final propellant blend and the Yellow Web (0.61 mm) blend. Both of these blends were able to meet the ambient performance requirement of the M793 cartridge.

Additional ballistic testing was conducted across the operating temperature. While hot propellant performance was well within specification, both candidate propellants had increased ballistic pressure at cold. The increased pressure at cold was attributed to thin walled propellants and grain fracture under extreme cold conditions coupled with base-pad ignition.

The propellant used in the initial trials above had a relatively small web to outer diameter ratio. Additional propellant was extruded with a slightly larger web (0.64 mm) and a smaller outer diameter. This should have resulted in propellant with better structural properties for resisting break-up at cold. However, extreme temperature testing of the propellant again revealed an unacceptable pressure rise as conditioning temperature was decreased. The results of the initial cold “walk-down” are shown in Table II. This testing was suspended at -25°C due to safety concerns.

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Velocity (m/sec)</th>
<th>Pressure (Mpa)</th>
<th>Action Time (msec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21</td>
<td>1125</td>
<td>434.7</td>
<td>3.136</td>
</tr>
<tr>
<td>62</td>
<td>1136</td>
<td>438.7</td>
<td>3.287</td>
</tr>
<tr>
<td>5</td>
<td>1136</td>
<td>**</td>
<td>2.959</td>
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<tr>
<td>-5</td>
<td>**</td>
<td>461.8</td>
<td>2.967</td>
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<td>2.842</td>
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<td>-25</td>
<td>1152</td>
<td>550.7</td>
<td>2.817</td>
</tr>
<tr>
<td>-35</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>-45</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
</tbody>
</table>

* Testing suspended.
** Data not captured due to instrumentation error.

The cause of the grain fracture was thought to be the initial shock delivered to the propellant by the ignition system and/or the action of the propellant being driven forward into the projectile by a “base-pad” type ignition. A similar scenario, described therein as a “solid phase wave”, is presented in “Theoretical Investigation of Flamespreading in a Small-Caliber Gun” [6]. A theoretical study by Horst and Conroy conducted on the large and small caliber problems...
associated with non-simultaneity of ignition. Based on their study, it was concluded that a localized ignition would likely lead to a strong longitudinal pressure gradients and ensuing pressure waves. Due to the tight packing of the propellant grains, large intergranular stresses can result during the flame spreading process. In particular, early bed stresses at the base of the projectile may actually be responsible for debulleting of the projectile from the cartridge case and early motion in some cartridges. If this occur before the complete ignition of the bed, a significant influence on performance (i.e., peak pressure and muzzle velocity) in terms of level and reproducibility could result. The use of uniform, instantaneous ignition eliminates such problems.

In order to further investigate this problem and to find solution, a study was initiated to better understand the influence on interior ballistics of the igniter design, the location of the point of ignition, and the strength of the ignition source, and the consequent interaction with the propellant bed.

IGNITION STUDY

The standard ignition system in the M793 used for this development program consists of a standard percussion primer (M115) and a 1.7 grain booster pellet. In an attempt to reduce the initial shock to the propellant, a number of alternate ignition systems were proposed. The majority of the proposed systems incorporated a flashtube normally used in a 30 mm round. Using this flashtube required that the 25 mm case of the M793 round be modified to accept the flashtube. The case, flashtube, and modification are illustrated in Figure 2.

The first configuration tested eliminated the booster pellet traditionally used in the 25mm round. The theory was that less initial energy might provide a more “gentle” ignition causing less break-up of the propellant at cold. The remaining configurations incorporated a flashtube, and varied the number of booster pellets. It was hypothesized that the flashtube would lower the initial shock on the propellant, and moving the ignition point into the propellant charge would improve flame spread throughout the propellant bed. The booster pellet used with the flashtube is smaller (1.5 grains) than the booster pellet normally used with the 25 mm round. Table III lists the ignition systems tested.

![Figure 2. Modified 25mm Case and Flashtube](image-url)
The propellant used in this study has a higher percentage of coated material compared to what had been previously tested, but provided very near the desired ballistics with the standard ignition scheme. Problems arose during testing of the modified case/flash tube assembly due to inaccurate flash tube pocket depths, and there were a number of misfires. These misfires were unrelated to the propellant and the ignition systems under consideration. Even with these misfires, enough data was collected to indicate which steps should be taken next. The results of the ignition study are shown in Table IV.

While the data was incomplete, some interesting trends were seen. Removing the booster pellet from the standard ignition configuration actually caused a significant increase in the pressure at ambient. Furthermore, the incorporation of a flashtube without a booster pellet increased the pressure further. As the number of booster pellets in the flashtube was increased, the pressure started to come back down.

During this initial test, rounds were also tested at -5°C to indicate what effect the different ignition configurations might have on cold performance. As with the earlier tests the standard configuration saw a significant increase in pressure. The configuration with the booster pellet removed also saw an increase in pressure, but it was less of an increase than had been seen with the standard configuration. Unfortunately, there were enough problems with the rounds utilizing flash tubes, that a direct comparison of ambient and -5°C performance was impossible. However, enough data was collected to indicate that the flash tube configuration with two booster pellets was likely to give acceptable results. The data that was collected also indicated that the configuration using the flash tube would also require a different blend of coated and uncoated material. Again, the data collected in this test is shown in Table IV.

Based on the experiences of the first test, the way in which the cases were modified was changed slightly, and then additional cases were modified to accept flash tubes. A blend study using cases with the flash tube and two booster pellets was undertaken to determine what the blend of coated and uncoated material would be required to achieve ambient ballistics with this ignition configuration. Based on this study it was determined that the proper blend for this ignition system was a ratio of 3:2 coated material to uncoated. This is a considerably higher

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Pressure (21°C)</th>
<th>Velocity (21°C)</th>
<th>Pressure (-5°C)</th>
<th>Velocity (-5°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>384</td>
<td>1087</td>
<td>408</td>
<td>1097</td>
</tr>
<tr>
<td>1</td>
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<td>4</td>
<td>*</td>
<td>*</td>
<td>434</td>
<td>1115</td>
</tr>
</tbody>
</table>

*Data not captured.
percentage of coated material when compared with the blend that was tailored for the standard ignition system. That blend utilized only 1:3 coated to uncoated material. Charge weight for all rounds was 84g.

Once additional material had been blended, testing proceeded with the cold “walk-down”. This involved loading rounds as above (CW=84g, Blend Ratio = 3:2) and shooting at progressively colder temperatures until either the cold requirement for the M793 rounds was met (-46°C) or a pressure limit was reached. Because in the previous test the pressure had continued to decrease as more booster pellets were used in the flashtube, two different ignition configurations were to be tested. The first configuration utilized the M115 primer, a flashtube, and two booster pellets as had been tested previously. The second configuration was exactly the same except for utilizing additional booster pellets. The results of this test are shown in Table V.

The results of the cold walk-down were very encouraging. In the rounds utilizing two booster pellets, the pressure actually went down with temperature. The rounds with additional booster pellets showed a slight increase, but this increase was well within acceptable limits. Both configurations were able to reach the -46°C requirement from the performance specification for the M793 round without exceeding the allowable pressure.

Velocity for both configurations showed a slight decrease with temperature. However, the rounds with the additional pellet configuration exhibited less change over the range of temperatures tested. The additional pellet configuration also demonstrated shorter action times across all temperatures.

Although this test represents a limited amount of data (2 shots at each temperature), it is felt that future development of this propellant for the M793 round should be done with the flashtube and additional booster pellet configuration.

<table>
<thead>
<tr>
<th>Temperature</th>
<th>2 Booster Pellets</th>
<th>3 Booster Pellets</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Pressure (Mpa)</td>
<td>Velocity (m/sec)</td>
</tr>
<tr>
<td>62</td>
<td>426</td>
<td>1116</td>
</tr>
<tr>
<td>21</td>
<td>394</td>
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<td>1058</td>
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<tr>
<td>-46</td>
<td>359</td>
<td>1041</td>
</tr>
</tbody>
</table>
CONCLUSIONS

A new double base propellant, PAP-8386, manufactured using a solventless process shows great promise as a propellant for medium caliber applications such as the M793. The solventless process eliminates the use of VOC’s during manufacture and allows for a formulation that does not contain several environmentally hazardous ingredients such as diphenyl amine and dibutylphthalate.

Initially, acceptable ballistic performance in the M793 round was observed at ambient and hot temperature conditions. However, there were some problems meeting cold temperature requirements. Additional work was completed to ensure that the cold temperature performance requirements were met.

The key to meeting the cold performance requirements lay with the ignition system. During the course of this study, as expected, the influence of the igniter system on the overall ballistic performance proved to be very significant across all temperatures. Optimizing the ignition system requires balancing the need for a strong igniter, necessitated by the deterrent coating, and the mechanical limits of the propellant.

FUTURE WORK

Additional work has been funded by ARDEC to further explore production issues associated with this propellant formulation, and to complete ballistic testing. The next phase of this project will finalize the igniter design and conduct Insensitive Munitions (IM) testing on rounds loaded with this propellant. Ideally, a ballistic model would be constructed of this round so that the phenomena discovered during this work could be understood completely. Completion of this model will depend on funding and resource availability. Later, a seven perforated propellant configuration may be investigated for potential LW30 applications.

REFERENCES


