AD

AD-E402 901

Technical Report ARFSD-TR-99002

120-mm AMMUNITION FEASIBILITY ASSESSMENT FOR LIGHT ARTILLERY

Stephen G. Floroff
Project Engineer
ARDEC

Bryan L. Salatino
Project Engineer
General Dynamics Armament Systems
Burlington, VT

March 2000

US ARMY
TANK AUTOMOTIVE AND
ARMAMENTS COMMAND
ARMAMENT RDE CENTER

U.S. ARMY ARMAMENT RESEARCH, DEVELOPMENT AND ENGINEERING CENTER

Fire Support Armaments Center

Picatinny Arsenal, New Jersey

Approved for public release; distribution is unlimited.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 2000	

4. TITLE AND SUBTITLE
120-mm AMMUNITION FEASIBILITY ASSESSMENT FOR LIGHT ARTILLERY

5. FUNDING NUMBERS

6. AUTHOR(S)
Stephen G. Floroff – ARDEC, Project Engieer
Bryan L. Salatino – General Dynamics Armament Systems

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

ARDEC, FSAC
Artillery and Mortars Division
(AMSTA-AR-FSA-S)
Picatinny Arsenal, NJ 07806-5000

General Dynamics Armament Systems
Lakeside Ave
Burlington, VT 05401-4985

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

ARDEC, WECAC
Information Research Center (AMSTA-AR-WEL-T)
Picatinny Arsenal, NJ 07806-5000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

Technical Report
ARFSD-TR-99002

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT

A study was undertaken to determine the feasibility of a 120-mm solution for future light artillery systems using existing U.S. 120-mm ammunition. By combining existing U.S. 120-mm mortar and tank ammunition, a complete direct and indirect firing solution is created without significant ammunition development costs. Improvements in lethality over 105-mm artillery ammunition as well as a reduction in weight, size, and logistics burden over 155-mm ammunition are further rationale for this study.

This study concluded that the maximum range achievable with existing mortar rounds was 10.9 km. By imposing ballistic restrictions of mortar rounds to the M830A1 high explosive antitank (HEAT) round, the fuzing will not arm. The only other available tank round is the M829A2 armor piercing projectile, which does not rely on fuzing. By imposing the same ballistic restrictions of mortar rounds to the M829A2, an almost 65% decrease in muzzle velocity will occur; severely restricting or even negating its effectiveness in defeating heavy armor targets.

14. SUBJECT TERMS
Lightweight towed artillery, Breech loaded mortar, Towed artillery, 120-mm artillery ammunition, Direct support artillery, 120-mm mortar tank ammunition

15. NUMBER OF PAGES
25

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

NSN 7540-01-280-5500

Standard Form 298 (Rev 2-89)
Prescribed by ANSI Std Z39-18
298-102

ACKNOWLEDGMENTS

The authors wish to express their thanks to several U.S. Army Armament Research, Development and Engineering Center employees who contributed to this report.

John N. Gravina is acknowledged for his superior CAD skills; James Wejsa, Donald Huie, and Mathew Evangelisti for their assistance in clarifying mortar round design and operation; Gregory Kolasa for providing insight in tank round design and operation; and Edward Rudnicki for his constructive critique of this reports contents.

CONTENTS

FIGURES

FIGURES
(cont'd)

TABLES

EXECUTIVE SUMMARY

This study was undertaken at the request of the Director of Combat Developments (DCD), Ft. Sill, Oklahoma to determine the feasibility of a U.S. 120-mm solution for future light artillery systems. By combining existing U.S. 120-mm mortar and tank ammunition, a complete direct and indirect fire solution is created without significant ammunition development costs. Improvements in lethality over 105-mm artillery ammunition as well as a reduction in weight, size, and logistics burden over 155-mm ammunition are further rationale for this study.

Currently, a U.S. 120-mm breech loaded mortar system does not exist. Foreign mortar systems available would not be compatible with U.S. tank ammunition. Therefore, this study assumes use of a modified M1A2 tank cannon. These modifications include altering chamber volume and projectile travel to maximize mortar round range and minimize weight of the cannon. To achieve this, a new propellant formulation is required. Compatibility between the mortar round and the tank cannon breech is maintained by mating the mortar round to a stub case.

Mortar rounds are limited by the maximum launch acceleration they will tolerate. In addition, mortar rounds are aerodynamically unstable at supersonic velocities. This study concluded that the theoretical maximum range achievable with an existing conventional mortar round was 10.9 km. Ranges in excess of 12 km may be possible with mortar rounds which incorporate rocket assist mechanisms, but these rounds are currently in early development stages.

By imposing ballistic restrictions of mortar rounds to the M830A1 high explosive (HE) antitank round, the fuzing will not arm. Altering propellant formulation specifically to increase tank round muzzle velocity and ensure fuze arming may effect chamber volume and create incompatibility between mortar and tank rounds. It should also be noted that imparting a higher impulse specifically to arm the tank round imposes additional forces on the firing platform. Invariably, weight and cube of the platform must be increased to counteract this condition, which runs counter to the lightweight theme of this study. The only other available tank round is the M829A2 (an armor piercing projectile), which does not rely on fuzing. By imposing the same ballistic restrictions to the M829A2, an almost 65% decrease in muzzle velocity will occur. This may severely restrict or even negate the M829A2's effectiveness in defeating heavy armor targets.

INTRODUCTION

At the request of DCD, General Dynamics Armament Systems, Burlington, Vermont and the U.S. Army Armament, Research, Development and Engineering Center, Picatinny Arsenal, New Jersey jointly undertook this study to determine the feasibility of a 120-mm solution for future light artillery systems. The rationale for this choice was the obvious improvement in lethality over 105-mm artillery ammunition and a reduction in the weight, size, and logistics burden of 155-mm artillery ammunition. The 120-mm mortar and tank ammunition can theoretically be combined to create a complete 120-mm artillery ammunition suite at significantly lower cost than developing new ammunition from a clean sheet of paper. The existing 120-mm mortar ammunition suite includes HE, smoke, and illumination rounds. Developmental ammunition includes a rocket assisted dual purpose improved conventional munition (DPICM) as well as a laser guided round. While no direct fire mortar ammunition currently exists that can defeat armor targets, the 120-mm tank ammunition, specifically the high explosive antitank (HEAT) round and the armor piercing fin stabilized discarding sabot (APFSDS) round could be used for this purpose.

The intent of this document is to describe the engineering challenges associated with firing mortar and tank ammunition out of a single breech loaded cannon and determine the resulting performance characteristics.

TECHNICAL APPROACH

The use of tank and mortar rounds in the same cannon creates a dichotomy with respect to operating environments. Tank rounds are designed for extremely high muzzle velocities due to their flat trajectory, direct fire role. Mortar rounds are designed for relatively low muzzle velocities and rely on a ballistic trajectory for the indirect fire role. Firing mortar rounds at tank round muzzle velocities results in unstable flight and subsequently unacceptable large targeting errors. Firing tank rounds at mortar round velocities results in dud rounds due to failure of the fuzing to arm.

For purposes of this study, mortar round limitations were the most technically challenging. Therefore, the first task is to optimize the cannon chamber and length to achieve maximum range of the mortar round while minimizing overall cannon length. This will require a propellant formulation specifically tailored to this application. Furthermore, to minimize development costs, the envisioned breech loaded system will rely on the existing U.S. 120-mm tank breech assembly. This constraint necessitates encasing the mortar round in a stub case much like the current tank round is configured. A method to ensure proper ignition of the mortar round when firing an electrically actuated tank round stub case bayonet primer is presented. Finally, to maintain a multiple zone capability without resorting to disassembling the complete round, a single charge solution is investigated, which relies on high angle firing to achieve minimum range.

The next task becomes determining if cannon chamber length and propellant formulation optimized for a mortar round in the indirect fire role will be sufficient to arm the tank round in the direct fire role.

To minimize development costs, it will be assumed that internal dimensions of the cannon envisioned for this feasibility study will be identical to the standard M256 smooth bore tank cannon. This constraint necessitates a compatibility study of the mortar round in the tank bore and an assessment of the effectiveness of obturation and in-bore flight dynamics. This is addressed later in this report. In addition, to minimize weight and optimize the tube for the mortar round, its length will be shortened. It is also anticipated that the cannon wall thickness would be reduced to save weight due to reduced internal pressures; however, no analysis of this phenomenon was undertaken in this study. A risk assessment in chart format was also created to summarize issues associated with firing 120-mm mortar and tank ammunition out of a single cannon.

TECHNICAL ANALYSIS

Mortar Round Velocity Limitations

Maximum velocity of a mortar round can be obtained by determining its pitching moment coefficient. The pitching moment coefficient is the aerodynamic overturning coefficient, which indicates whether the projectile is stable or not for a given velocity. A negative coefficient indicates stability, and a positive coefficient indicates instability. As shown in figure 1, the M934 120-mm mortar round can achieve stable flight up to approximately Mach 2 (680 m/s).

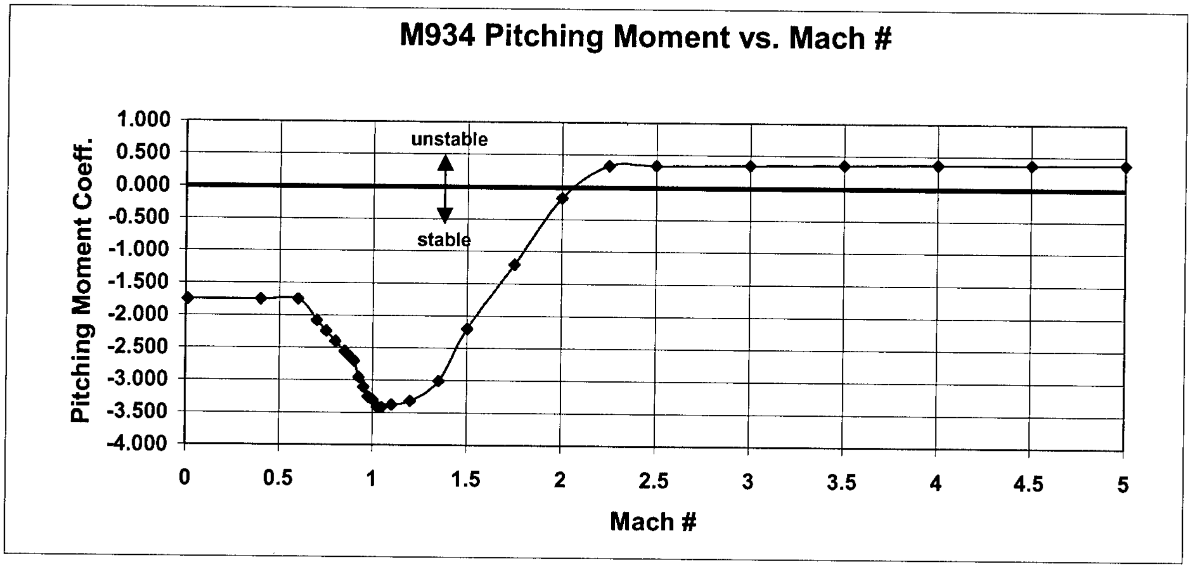


Figure 1
Pitching moment versus Mach number of M934 mortar round

While maximum velocity for the M934 round is roughly Mach 2, a lower threshold velocity limit exists during launch. All rounds exhibit off-axis motion as they leave the muzzle, which contributes to dispersion at target. A measure of the flight sensitivity to this dispersion is jump sensitivity. As shown in figure 2, jump sensitivity for the M934 increases rapidly when launch velocity exceeds 600 m/s, indicating a limitation for accurate projectile flight. Launch velocities at Mach 2 yields exceptionally poor dispersion, about 2 mils/rad/sec at maximum range. At 600 m/s, the dispersion is reduced to about 0.381 mils/rad/sec.

Stability and dispersion are technical limits, which may be overcome with a new fin arrangement. Modification to the mortar tail boom to add deployable (pop-out) fins that extend beyond the projectile body diameter will yield improved aerodynamics. The result will be an increase in maximum velocity with improved stability; thus slightly more range is theoretically possible. As a minimum, since the mortar round tail boom will have to be modified to integrate with a breech loaded-electrically primed tank cannon (discussed later), fin configuration should be optimized to reduce jump sensitivity at high launch velocities.

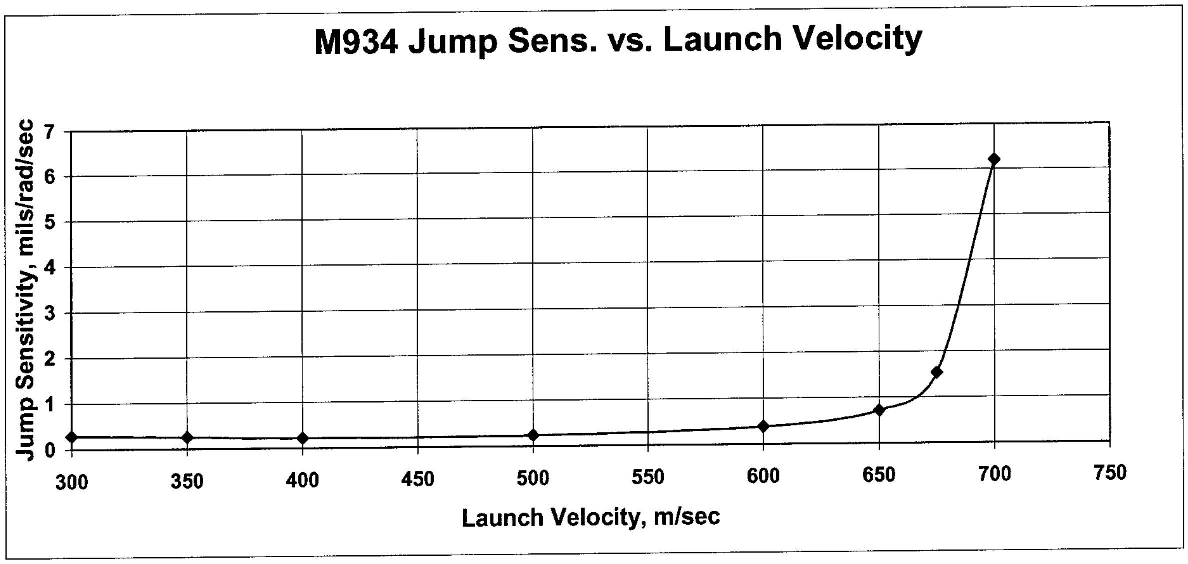


Figure 2
Jump sensitivity versus launch velocity of M934 mortar round

It should be noted that the developmental XM984 DPICM extended range mortar round offers a radical approach to maintain maximum velocity during flight. The round incorporates a post-launch tractor type (pull) rocket motor in addition to deployable fins, which create a mortar round with a theoretical maximum range of 12 km from a standard mortar tube (fig. 3). Assuming this round is fired from a longer tube at maximum mortar round muzzle velocity, range will theoretically increase beyond 12 km. This round is currently scheduled to begin engineering development in FY07; however, if user interest and financial commitment is increased, this round could be available in an earlier timeframe. It is this type of technology that will be required to obtain significant range increases from mortar type rounds.

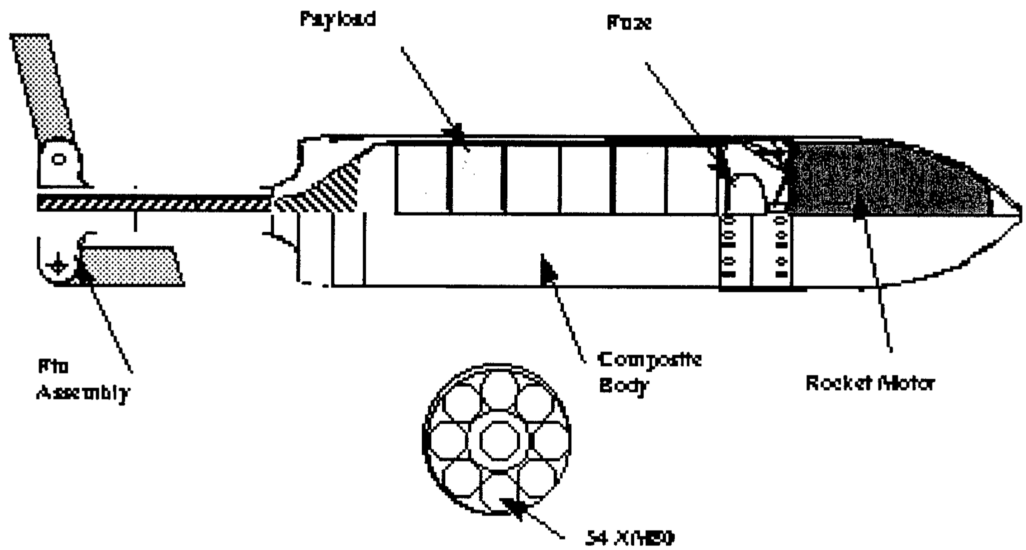


Figure 3
Developmental XM984 extended range DPICM mortar round

Standard Mortar Round Maximum Range

By limiting the mortar round to peak pressures and accelerations generated in the current U.S. M298 120-mm mortar tube and operating with standard mortar propellant, muzzle velocities of 600 m/s and higher will be difficult to achieve, requiring an unreasonably long tube to substantially increase muzzle velocity. This is due to the fact that in a standard mortar system, propellant masses are intentionally kept small to reduce muzzle blast and minimize health hazards to the gun crew. A low muzzle pressure from a short tube indicates there isn't much energy to take advantage of with a lengthened tube. Figure 4 illustrates this point. Assuming a 111 MPa (16,100 psi) peak chamber pressure and 7,500 to 8,000 g peak acceleration, a muzzle velocity of 500 m/s is achieved from a 300 cm (118 in.) long tube, while an 800 cm (315 in.) tube is required to achieve 600 m/s. Converting muzzle velocity to theoretical maximum range yields a range versus in-bore travel relationship (fig. 5). It should be noted that the tube length required to achieve 600 m/s using standard mortar propellant increments is over 127 cm (50 in.) greater than the cannon length of the M198 towed howitzer.

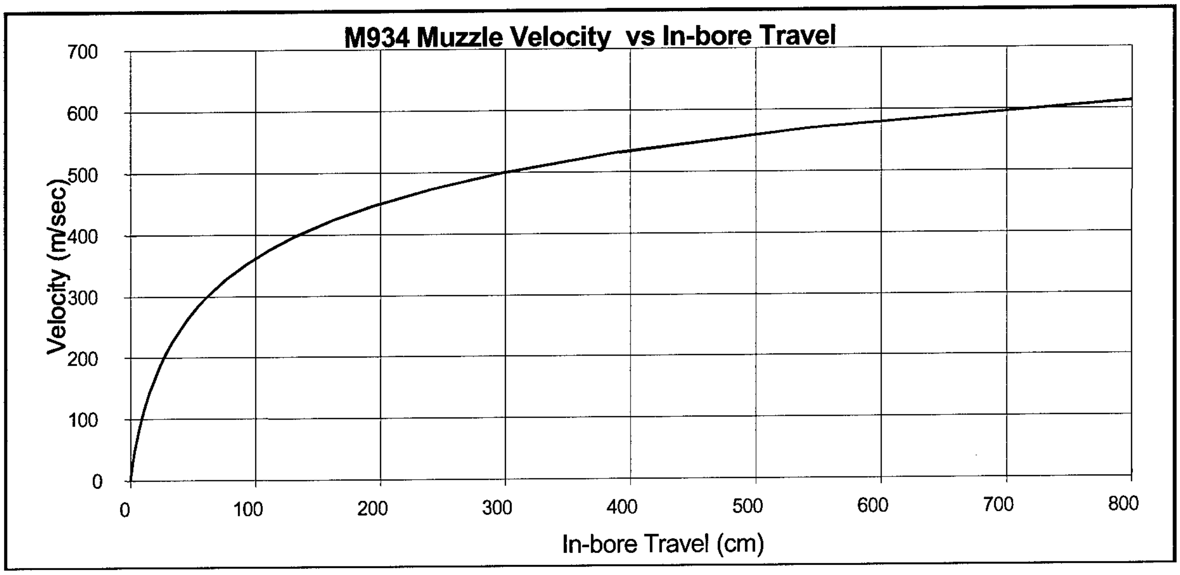


Figure 4
M934 mortar round muzzle velocity versus in-bore travel

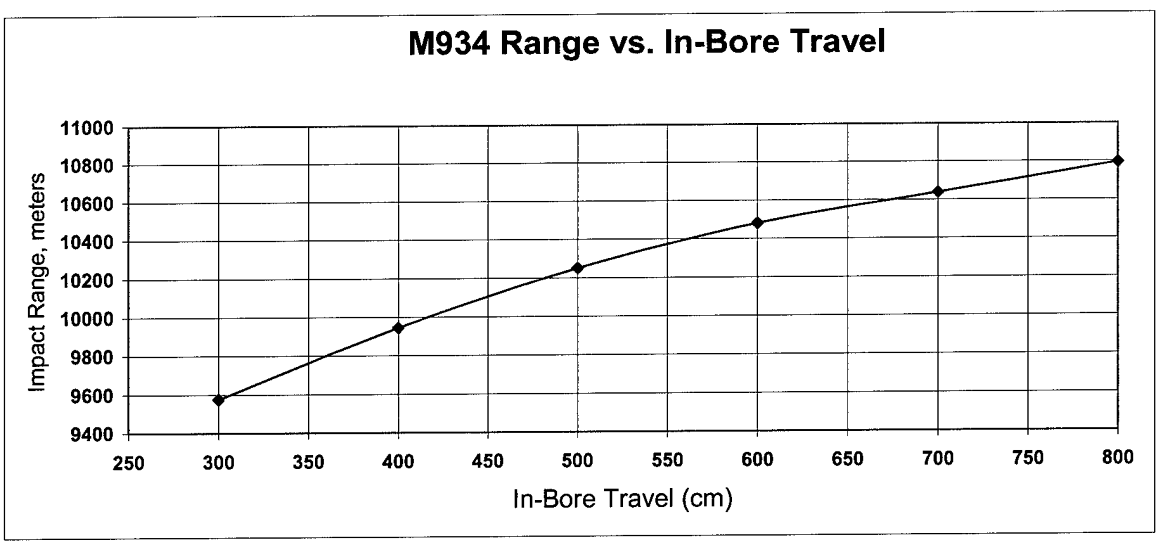


Figure 5
Maximum impact range versus in-bore travel of M934 mortar round

Figure 6 validates the aerodynamic limitations inherent in a mortar round. Neglecting accuracy, figure 6 indicates only a negligible increase in range for a large increase in muzzle velocity when velocities are above Mach 2 (680 m/s). This is due to a rapid increase in drag coefficient, since mortar rounds are designed for subsonic flight. It is interesting to note that at approximately 700 m/s, the actual range falls off from the idealized case. This is due to a large yaw that develops shortly after launch due to jump sensitivity as described previously.

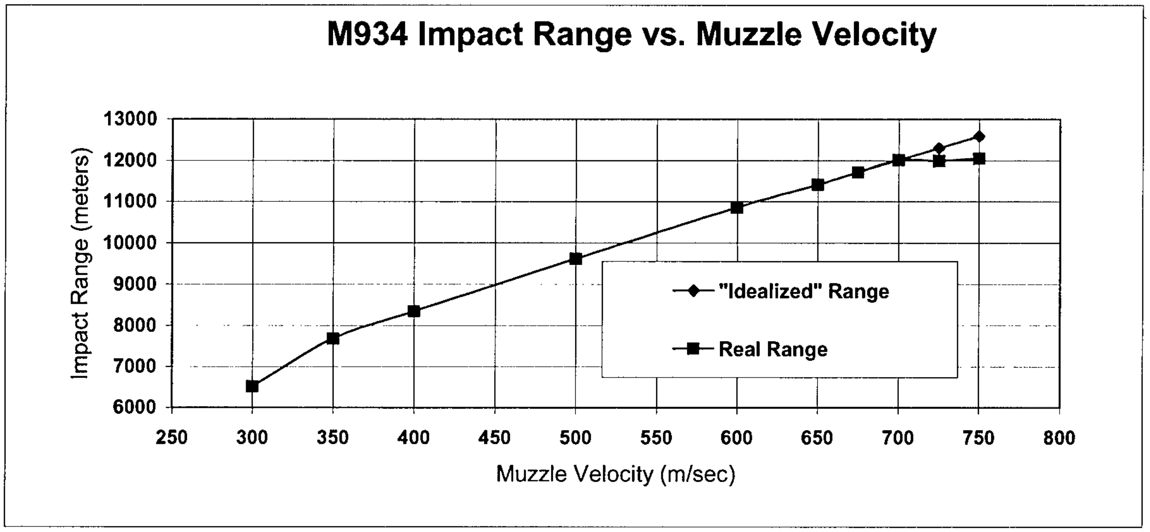


Figure 6
Maximum impact range versus muzzle velocity of M934 mortar round

It has been demonstrated that by limiting the mortar rounds to peak pressures and accelerations generated in the M298 mortar tube and operating with standard mortar propellant, significant range restraints are unavoidable. For example, to achieve a 10-km range, a reasonable length 425-cm (167-in.) tube will suffice. If more range is required, in-bore travel can be increased to realize a small improvement.

The approach taken for the remainder of this study is to use the basic mortar round as is and incorporate a tank-like propellant charge with a 120-mm combustible case derivative. Traditionally, tank cannons incorporate a large chamber volume to accommodate the propellant energy needed for high muzzle velocities. It is possible to develop a slower burning propellant charge that would allow the use of a larger propellant mass while maintaining the same maximum peak pressure limitations imposed on the mortar projectile. A large charge and chamber volume can also be used to optimize (reduce) cannon length.

An interior ballistics model (ref. 1) was used to simulate firing an M934 mortar round from cannons with a 3,300-cm^3 (201-c.i.) chamber volume/425-cm (167-in.) in-bore travel and a 7,000-cm^3 (427-c.i.) chamber volume/270-cm (106-in.) in-bore travel. The propellant used for this simulation was the modified M30, 7-perf with a web of 0.84 mm. The ballistic simulation was run with known burn rate characteristics until all the propellant was consumed in the desired travel without exceeding the 110 MPa (15,958 psi) peak chamber pressure. Exit pressure is slightly less than 53 MPa (7,650 psi), and the total impulse from firing is about 11,000 n-sec (2,500 lb-sec). The propellant characteristics are listed next:

Weight (kg)	2.4131
Impetus (MJ/kg)	1.0910
Gamma	1.2410
Co-volume (m^3/kg)	0.0011
Flame temperature (K)	3040.01
Density (gm/cm^3)	1.6608
Burn rate exponent	0.7500
Initial burn rate (cm/sec/bar)	0.07366
Final burn rate (cm/sec/bar)	0.07366

The pressure time histories for each cannon configuration are shown in figure 7. Note the larger area, i.e., impulse available under the curve with the larger chamber, shorter barrel. This is the configuration considered optimal for a mortar round to achieve maximum range in a reasonably sized ordnance package.

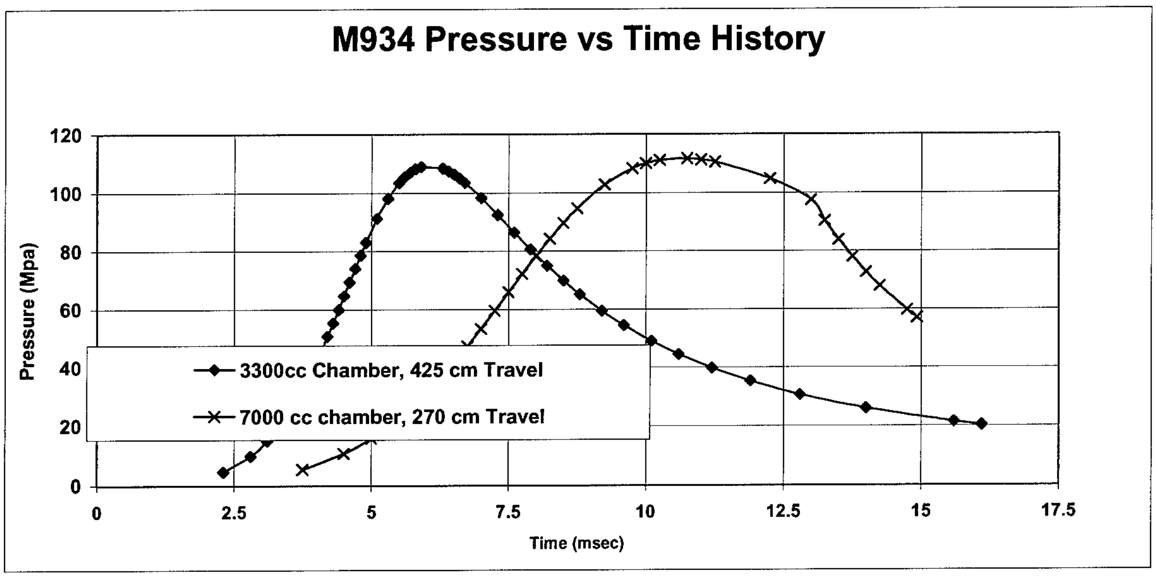


Figure 7
Pressure versus time history for optimized 120-mm cannons

Muzzle velocity versus in-bore travel for the optimized cannon (fig. 8) demonstrates that 270 cm (106 in.) of in-bore travel of the M934 mortar round generates a maximum muzzle velocity of 600 m/s. This results in the previously established 10.9 km maximum range (fig. 6). Of note is the previously mentioned projectile exit pressure of slightly less than 53 MPa (7,650 psi) and its effect on crew safety. Overpressure effects are significantly less than the current M198 155-mm towed howitzer, which produces 75 MPa (11,000 psi) of muzzle pressure (ref. 2).

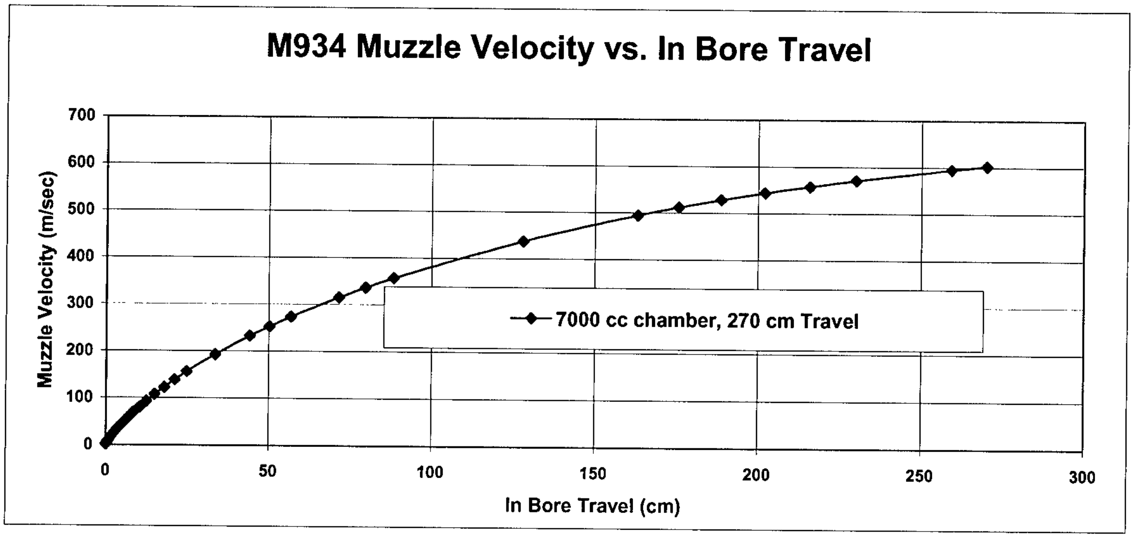


Figure 8
M934 mortar round muzzle velocity in optimized 120-mm cannon

To realize another incremental improvement, the mortar round can be modified to allow higher launch accelerations. This would allow a larger charge, smaller chamber, and most importantly shorter tube solution to drive down weight and cubic volume of the armament system. This approach, however, requires a mortar round development program, which defeats the original intent of this study.

Mortar Round Setback Acceleration Limitations

The peak in-bore pressure during maximum impulse firing in a standard 120-mm mortar system is about 110 MPa (15,958 psi). This results in approximately 7,500 to 8,000 g's applied to the round. The 120-mm mortar round has very little margin on setback acceleration. It is not a structural issue, but the amount of setback the explosive fill can tolerate. In a traditional artillery HE projectile, the base of the HE cavity inside the projectile is very nearly flat, so that the compressive loading on the explosive during setback is not concentrated towards any single spot. In the 120-mm mortar round, the base of the HE cavity is hemispherical. Modeling of the dynamics of the explosive during firing (ref. 3) shows analytically that it shifts during firing, potentially causing two problems: (1) adiabatic compression of any bubbles or gaps in the explosive, which generates heat and can potentially cause an in-bore initiation and (2) friction between the explosive and the shell body as the explosive sets back into the hemispherical cavity seat, which may cause an in-bore initiation.

These issues could be addressed by compartmentalizing the fill volume into two separate chambers. This approach minimizes compressive effects by reducing propellant stacking effects. These compartments may also be further modified so that they are almost cone shaped in the direction of force to further minimize the compressive load effect. These modifications will yield a mortar round that can tolerate significantly higher launch accelerations, albeit with less explosive per round. This approach will require essentially a new round development program, which again defeats the original intent of this study.

Propelling Charge Zoning Solutions

While maximum range has been the focus of this report, minimum range requirements must be established. For purposes of this report, a 2.7 km minimum range is chosen. It has previously been established that a greater volume of propellant would be required than a standard mortar system to maximize range and that the mortar round must somehow be fitted to the 120-mm tank round stub case for breech loading. With these assumptions in place, it is further assumed that the mortar round will consist of a fixed propellant fill and be crimped to the case, which will preclude traditional zoning. Therefore, the issue of minimum range is merely one of selecting the correct elevation.

Several zoning options are identified (ref. 4), which would normally be established by the Qualitative Materiel Requirement (QMR) written by the Combat Developer. The QMR typically establishes four parameters:

- Either a maximum range or muzzle velocity
- Minimum range
- Either a high or low elevation criterion or mask criteria
- Amount of range overlay

For purposes of this study, a maximum range was pre-established given technical limitations of a standard mortar round. Therefore, using 10.9 km as a reasonable maximum range for the M934 mortar round in its current configuration, and a minimum range of 2.7 km, the range overlap requirement can be determined. A low elevation criteria is usually selected for direct fire weapons, while a high elevation or mask criterion is usually selected for indirect fire weapons. A mask criterion is selected if a particular barrier (telephone poles, trees, etc.) has to be safely cleared by artillery projectiles. For range overlap, 10% is a typical number. Reference 4 establishes zoning using a graphical method, which is shown in figure 9 for a 120-mm M984 mortar round. Figure 9 establishes 1,245 mils (70 deg) as the maximum elevation angle for the optimized (7,000 cm^3 chamber/270 cm projectile travel) cannon. For this example, at least four zones are required. However, if the maximum elevation is increased, the minimum range for each zone is decreased, allowing the overlap requirement to be met with fewer zones.

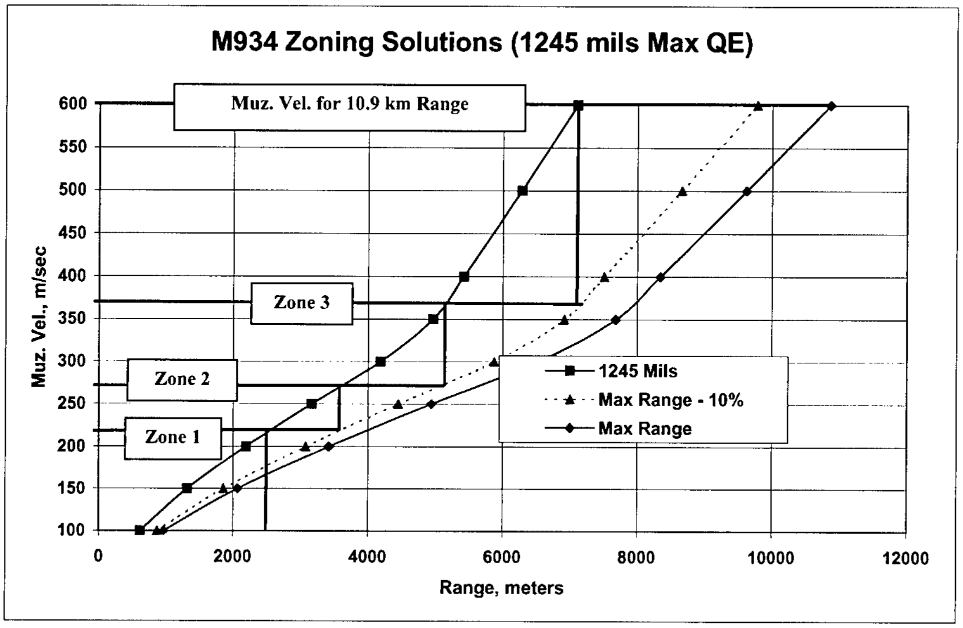


Figure 9
Indirect fire zoning solutions with 1,245 mil maximum QE

For the same cannon configuration, if the maximum quadrant elevation (QE) is increased to 1,500 mils (84 deg) and the overlap is increased to 1 km, only one zoning solution is required (fig. 10). A constant 1-km overlap instead of the standard 10% appears practical, particularly at shorter ranges where a 10% overlap becomes very small. It can be seen that for this configuration overlap requirements are exceeded with a single charge zone, whether the requirement is for 10% or 1 km overlap.

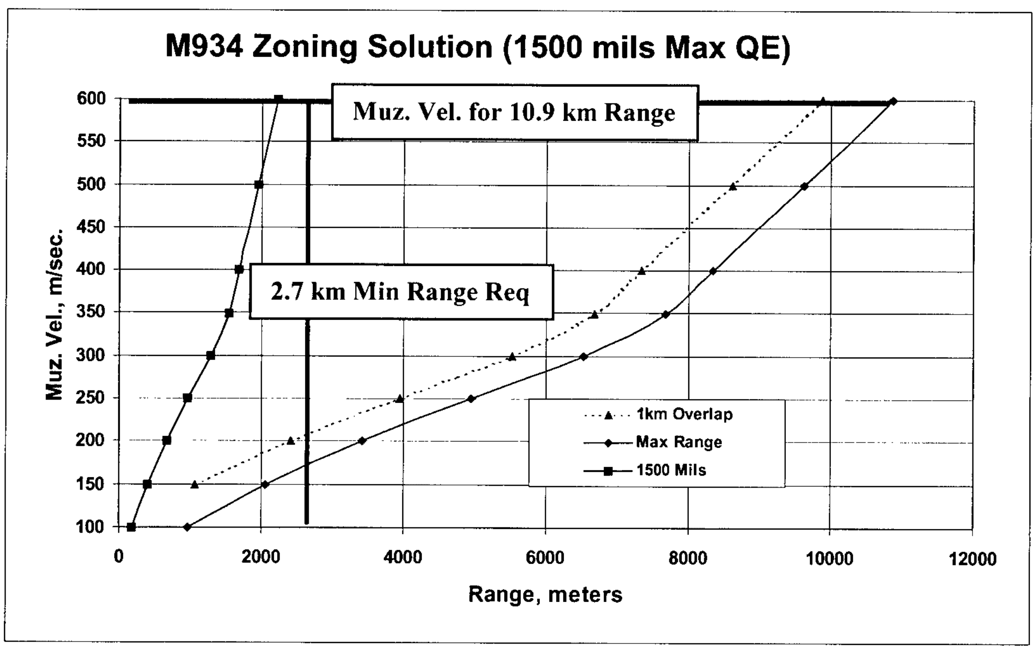


Figure 10
Indirect fire zoning solutions with 1,500 mil maximum QE

Tank Round Fuze Arming

The M830A1 tank projectile operates in both a ground mode (point detonating) and air (proximity) mode. The air mode is advantageous in direct fire to defeat helicopters and soft targets. To achieve this dual mode capability, the M830A1 incorporates a proximity sensor in the nose spike as well as a base fuze (M774), which ultimately detonates the warhead. Four events must occur during launch to make full use of this round. Outside stimulus (acceleration/deceleration) is required to initiate each event. Power for the proximity sensor is provided by a thermal battery, which is setback initiated. To activate the thermal battery, 30,000 g's are required (ref. 5). The firing train on the M774 base fuze is also setback activated, which is the first safety for this round. To activate the mechanism, 7,000 g's are required (ref. 5). The second safety is initiated by sensing deceleration at exit from the cannon. A minimum of –10 g's is required to activate the second safety (ref. 5). Power to detonate the warhead is generated within the fuze by moving a magnet through a coil and storing the energy in a capacitor. A shear disk must be broken to initiate movement of the magnet. An absolute minimum of 13,000 to 14,000 g's is required to shear the disk and initiate magnet movement (ref. 5).

Tank Round Ballistic Performance

The M830A1 projectile has no minimum stable flight velocity. Aeroballistic spark range tests show positive static margin to very low Mach numbers. With the charge, chamber, and shot travel calculated in the Standard Mortar Round Maximum Range section, a comparison of the interior ballistics performance of the M934 mortar round and the M830A1 tank round is shown in figure 11. Since the M830A1 is lighter than the M934, lower pressures result from the same propelling charge, but muzzle velocities are closely matched (fig. 12).

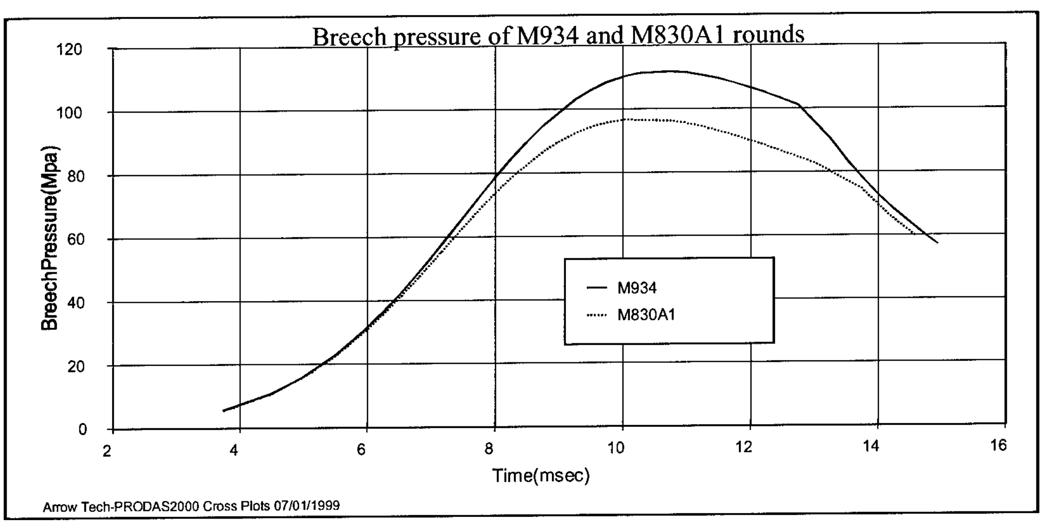


Figure 11
Breech pressure versus time for M934 and M830A1 rounds

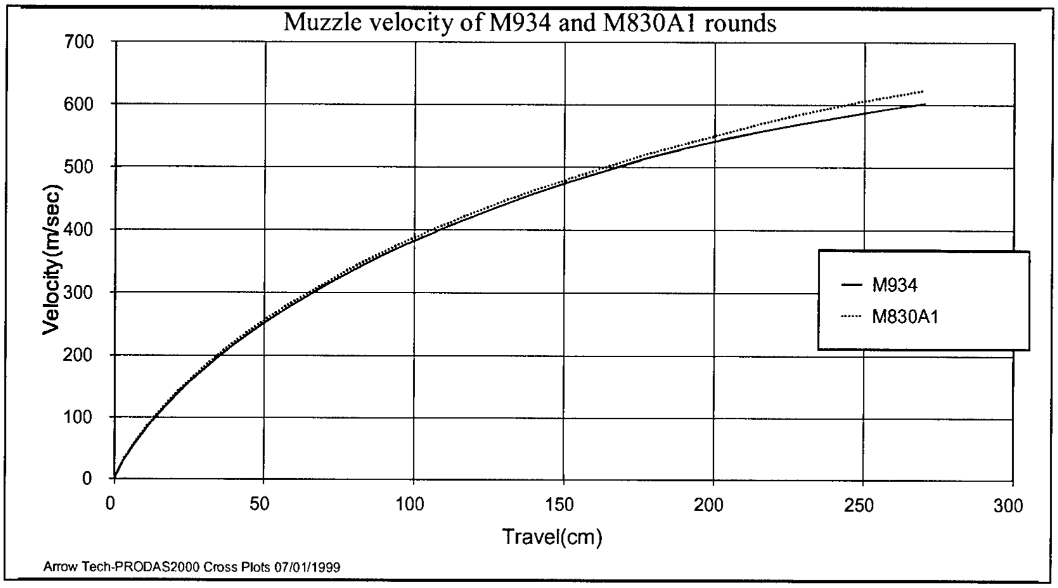


Figure 12
Muzzle velocity of M934 and M830A1 rounds

The expected muzzle velocity of the M830A1 from this optimized cannon is approximately 625 m/s at 21°C. The expected impulse is just under 10,000 n-sec (2,250 lb-sec). While the M830A1 is capable of stable flight at these relatively low velocities, it is designed for muzzle velocities of approximately 1,400 m/s at 21°C. Realistically, the sabot will likely require redesign so that it will strip at the lower combustion pressure, acceleration, and muzzle velocity.

Mortar and Tank Round Fuze Incompatibility

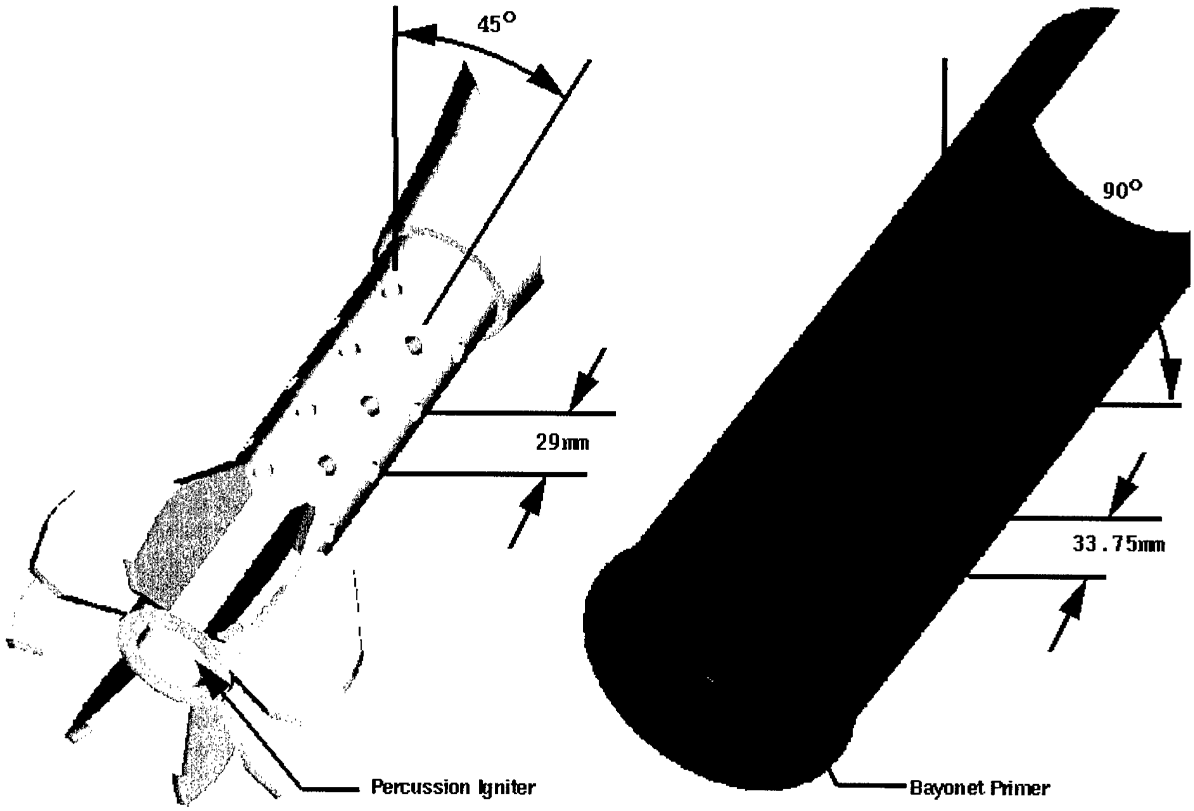
The M734A1 multi-option mortar fuze's first safety initiates at roughly 400 g's setback (ref. 6). The M734A1's second safety occurs after 1,056 turns of a turbine alternator being spun in the air stream (ref. 6). This feasibility analysis thus far has built a charge/cannon system specifically tailored to limitations of the mortar round. As a result, the operating environment for the tank round is much less severe. For example, applying the interior ballistic conditions described previously, a setback acceleration is 8,751 g's for the M830A1 tank round is expected (ref. 1). This is insufficient to activate the proximity sensors' thermal battery (30,000 g's required). It is also an insufficient g level to fail the shear disk, which is required to generate power to detonate the warhead (13,000 to 14,000 g's required). The interior ballistic conditions also result in a barrel exit deceleration of 10.4 g's for the M830A1, giving little margin on the 10 g secondary safety fuze arming requirement. Increasing barrel length by 30 cm to 300 cm results in a maximum muzzle velocity of 650 m/s for the M830A1 round and 625 m/s for the M934 projectile (refs. 1 and 3). This alteration increases barrel exit deceleration of the M830A1 to 11 g's, providing a 10% margin over the 10 g arming requirement while minimally increasing jump sensitivity of the M934 mortar round. However, it is insufficient to fail the shear disk or activate the proximity sensors' thermal battery.

Three additional options are possible to force the M830A1 tank round to function without resorting to increased cannon length. First, a higher impulse charge could be applied only to the tank round to assure an all arm condition. This would have the benefit of reducing time of flight and aid in obtaining a flatter trajectory to target. Conversely, this course of action will negatively impact weapon stability. The high direct fire impulse will cause the recoil, spade, and carriage design to be altered to manage the increased energy. This in turn will ultimately drive the weight and cube of the weapon system upward, which is undesirable. A compromise condition may exist for this option. By eliminating the proximity or air mode of this round, maximum setback g levels could be reduced from 30,000 g's to 13,000 to 14,000 g's, reducing direct fire impulse. This would assist in reducing weight and cube penalties. A second alternative would be to design a new fuze for the mortar projectile for use in direct fire applications, eliminating the need for the tank round. Third, the tank round fuze could be redesigned to reduce the setback acceleration and flight deceleration required for arming. Either a new fuze or redesigned fuze would require significant development funding and incur costs associated with re-qualifying the round.

The only alternative from a cost and schedule perspective may be to eliminate the requirement for firing the M830A1 tank round entirely and instead rely on the M829A2, APFSDS round for the direct fire mode, since this round has no fuzing requirement. Firing this round at almost 65% less than its intended muzzle velocity of 1,680 m/s (ref. 7) may severely restrict or even negate its effectiveness in defeating heavy armor targets.

Integrating Mortar Projectile with Cased Charge

Ignition of a mortar round is based on percussion ignition (firing pin) while the tank round is electrically ignited. Currently, a U.S. 120-mm breech loaded mortar does not exist. A foreign breech loaded 120-mm mortar (Royal Ordnance) relies on a percussion-type ignition system and screw block breech, which is not compatible with the tank round. Therefore, in the interest of minimizing cost and risk it would be expedient to adapt the mortar round to operate with the tank breech/ignition system. The mortar round's primer and benite booster is integral with the tail boom (fig. 13). Since it is anticipated that a new tail boom assembly will probably be required (discussed previously) to minimize jump sensitivity and maximize range, this tail boom could be modified to adapt to the bayonet primer arrangement found on the tank round stub case.



M934 Tail Assembly **M830A1 Stub Case**

Figure 13
M934 tail assembly and M830A1 bayonet primer

One approach to achieve compatibility between the mortar round and bayonet primer would be to slide the mortar trail assembly (minus primer and booster components) over the bayonet primer. A review of this approach was undertaken using representative tank and mortar rounds (the M829A2 APFSDS-tracer primer body drawings and M933 120-mm HE mortar projectile fin tube drawings). It was determined that axial spacing of the bayonet primer holes is 90 deg, while spacing of the mortar round flash holes is 45 deg. In addition, axial spacing of the tank and mortar round flash holes are different (fig. 13). Conceivably, misalignment of the respective hole patterns could create an overpressure condition within the bayonet primer. To ensure proper ignition some form of timing and re-indexing of hole patterns would be required to ensure initial alignment of the holes. Depending on duration of primer burnout either short or long slots could be used on one of the aforementioned components to relieve a potential overpressure condition. One possible approach is shown in figure 14.

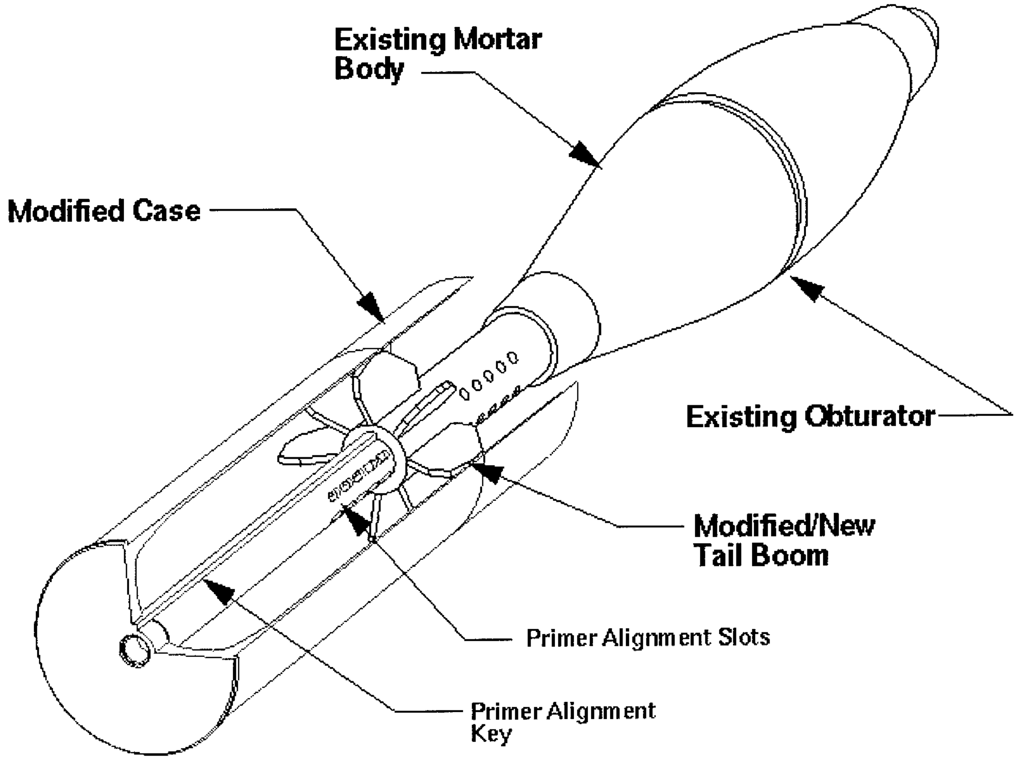


Figure 14
Integrated bayonet primer and mortar tail assembly

Compatibility of Mortar and Tank Rounds with Tank Cannon Bore

Table 1 is a compilation of selected interface dimensions obtained from various technical data packages. The table indicates that a mortar round can be fired from a tank cannon without interference. Therefore, no modifications to the ID of the existing M256 tank cannon are anticipated. This ensures the tank round will ride the bore as originally designed. It is further noted that the existing mortar obturator is a tighter fit in the tank cannon bore. Intrinsically, it could be surmised that dispersion due to jump sensitivity may be improved, and would result in a more accurate mortar round fired from this system. Actual live fire testing would need to be undertaken to validate this assumption.

Table 1
Mortar and tank ammunition and cannon tube compatibility data

	Body OD (mm)	Obturator OD (mm)	Front Bore Rider OD (mm)	Rear Bore Rider OD (mm)	Tube ID (mm)
M933 120mm Mortar Projectile	119.65 max	119.1 max	N/A	N/A	N/A
M829 APFSDS-T Tank Projectile	N/A	122.57	119.74 -.13	119.79 max	N/A
M865 TPCSDS-T Tank Projectile	N/A	121.1max	119.83 max	119.9 -.2	N/A
NATO STANAG 4385 Appendix C-2 for 120mm Tank Ammo	N/A	N/A	119.65 to 119.83	119.65 to 119.83	N/A
M120 120mm Mortar Tube	N/A	N/A	N/A	N/A	120.58 +.063
M256 120mm Tank Tube	N/A	N/A	N/A	N/A	119.95 +.1

Obturation and Bore Rider

As shown in table 1, the M120 mortar tube has a larger inside diameter than the M256 tank tube. This configuration permits air to escape when the mortar round is dropped into the mortar tube. As stated in the previous section, testing is required to determine if the mortar round requires an improved obturator. However, if the pressures increase greatly and/or it is required to alter the mortar projectile to allow rear and forward bore riders, the issue becomes more complicated. Without sufficient obturation in the longer tube, the mortar rounds are heavy enough that the shot start pressure may be affected by a wide range of elevation angles, impacting the repeatability of the round. Additional study of this condition should be undertaken.

In a tank round, the sabot (for the M829A2 APFSDS round as an example) has two bore riding surfaces, at the front and towards the rear of the sabot, in order to control in-bore balloting. The mortar round is supported in-bore by the obturator and the edges of the tail fins. This is sufficient for a mortar system since the round is fired at a high angle of attack. The mortar round may not have sufficient control in a low angle tube to get a good, repeatable launch and may move around in a tank bore. This can be solved with sabots, but then a larger diameter tube or a smaller projectile will be required. It is especially critical to have positive in-bore control if the round is to be flown at the limit of high jump sensitivity as described previously.

RISK ASSESSMENT

An assessment of the risk elements mitigation plan, and severity of risk and cost is shown in table 2.

Table 2
Mortar and tank round/cannon tube compatibility data

Description	Mitigation Plan	Risk	Cost	Comments
1) The mortar round muzzle velocity limitation of 600 m/s limits maximum unassisted range to approx. 10.9 km.	a. Design new tail boom with large deployable fins. b. Use XM984 extended range DPICM mortar round with larger fins and rocket motor for range in excess of 12 km.	a. Hi b. Hi	a. Hi b. Hi	a. Requires requalification. Small max range improvement. b. Reliance on new program funding, schedule, technical success.
2) The muzzle velocity required to arm the tank fuze and power supply is too high for the mortar round.	a. Redesign the tank fuze to arm with lower accelerations b. Create dedicated direct fire charge for tank round. c. Design a direct fire fuze and warhead for the mortar round to eliminate the need for the tank round. d. Redesign mortar explosive cavity and fuze to raise acceleration limit. e. Rely on M829A2 APFSDS tank round for direct fire.	a. Hi b. Me c. Hi d. Hi e. Low	a. Hi b. Me c. Hi d. Hi e. Low	a. Requires requalification. b. High direct fire impulse drives howitzer weight and cube. Logistics burden of additional charge. c. New fuze and warhead. Mortar round accuracy may not meet requirement. d. Development program, quaification required. e. Reduce effect due to low muzzle velocities.
3) U.S. 120-mm breech loaded mortar primer does not exist. New design must be integrated with the tank round and charge.	a. Use foreign screw block breech loaded mortar design and integrate with the direct fire tank round. b. Integrate tail assembly with tank primer.	a. Hi b. Me	a. Hi b. Me	a. Development program. Qualification required. Must integrate U.S. cased tank ammo to screw block breech. b. Low impact on tank round, mod. Impact on mortar round.
4) Mortar obturator may not be suitable for range/ accuracy. Bore rider may be required to stabilize low QE in-bore travel.	a. Modify mortar body to fit new oburator/forward bore rider, mod. Tail section to add rear bore rider. b. Leave mortar projectile as is.	a. Hi b. Me	a. Hi b. Low	a. Significant projectile mods, new tail assembly, and projectile requalification. b. Test bore wear and accuracy.

CONCLUSIONS

Mortar rounds become unstable at muzzle velocities in excess of Mach 2 (680 m/s) due to their aerodynamic shape. Additionally, at muzzle velocities in excess of 600 m/s, mortar rounds exhibit a sharp increase in jump sensitivity or tip off angle at muzzle exit. This characteristic causes unacceptably large dispersion at target. Therefore, maximum range and reliable ballistic flight with minimal dispersion will occur when muzzle velocities do not exceed 600 m/s. If existing mortar propellant is used for a given chamber volume, cannon length would be the only variable available to apply the requisite velocity. Theoretical projections indicate in excess of 800 cm (315 in.) of in-bore travel would be required to achieve 600 m/s. This is unrealistic and necessitates a different propellant formulation to reduce cannon length. This can be achieved with a modified M30, 7-perf propellant and results in 270 cm (106 in.) of in-bore travel. The predicted maximum range would then be 10.9 km. Slightly more range could be achieved using a revised tail boom with larger deployable fins, but the round would have to be re-qualified for use and is not considered for use and is not considered cost or risk effective. To achieve additional range (in excess of 12 km) the XM984 dual purpose improved conventional munition (DPICM) mortar round approach (post-launch rocket motor and deployable fins), could be considered, but this round is still in development and as such has high cost and technical risks. Realistically, existing 120-mm mortar ammunition can only achieve maximum ranges of 10.9 km.

Applying ballistic constraints determined for the mortar round (charge, chamber, and projectile travel) to the M830A1 tank cartridge results in insufficient setback and deceleration to arm the fuze. Four options are possible. First, the tank fuze can be redesigned specifically for this application; i.e., to arm at lower decelerations. This would involve re-qualifying the round with attendant high cost and technical risk. Second, a dedicated charge for the tank round, which will arm it within the constraints of previously determined in-bore travel could be created. This requires a separate propellant solution than previously established for the mortar round. While this approach solves the arming issue of the tank round, it must be noted that high impulse applied in direct fire maximizes firing platform destabilizing moments. Increasing weight and cubic volume of the launch platform must occur to counteract these moments. While this is undesirable, technical risk and cost are considered to be medium. Third, a direct fire fuze can be designed for the mortar round to obviate the need for the tank round. While this is technically possible, mortar round accuracy and warhead performance in direct fire may not meet current artillery requirements. Regardless, the result will be re-qualification of the round with attendant high cost and technical risk. Fourth, the mortar round can be redesigned to accept larger setback accelerations than its current limitation of 8,000 g's. This solution also carries a high schedule and cost risk since the explosive cavity will have to be redesigned. Ultimately, this approach will result in less explosive delivered to the target which is undesirable.

The only alternative from a cost and schedule perspective may be to eliminate the requirement for firing the M830A1 tank round entirely and instead rely on the M829A2 armor piercing fin stabilized discarding sabot (APFSDS) round for the direct fire mode, since this round has no fuzing requirement. Firing this round at almost 65% less than its intended muzzle velocity of 1,680 m/s may severely restrict or even negate it effectiveness in defeating heavy targets, however.

The most expedient method to initiate combustion of the cased charge on the mortar round is to use the existing tank round's bayonet primer and electrical initiation approach, thereby eliminating the need for re-design and/or reconfiguration of the traditional tank breech mechanism. However, sliding the mortar round tail assembly onto the tank round bayonet primer will result in potential flame hole alignment mismatch. A redesign of the screw-on mortar tail assembly and tank round bayonet primer to assure consistent alignment and combustion initiation will be required. Traditionally, the mortar round functions with a loose fit between the obturator and the bore. It is expected that the smaller tank barrel bore diameter will improve in-bore travel characteristics of the round due to reduced combustion gas blow-by. This condition offers the potential for more consistent flight characteristics, particularly at low quadrant elevations. In addition, reduced in-bore balloting of the round may result in improved flight characteristics at all elevations due to the potential for less damage to the bore riding aluminum fins. Maintaining the mortar round geometry in its current state and performing testing to determine performance characteristics appears to be the lowest risk, lowest cost approach. A higher risk, higher cost back-up option would entail modification of the projectile body to accommodate an improved obturator and forward bore rider. Modification of the tail boom to include a rear bore rider may also be required, but only if range and accuracy are unacceptable.

REFERENCES

1. General Dynamics Internal Ballistics Modeling Code, Burlington, VT.

2. Personal notes – Bryan Salatino, General Dynamics, Burlington, VT.

3. General Dynamics Mortar Modeling Code, Burlington, VT.

4. Dickinson, Elizabeth R., "The Production of Firing Tables for Cannon Artillery," BRL Report 1371, Ballistic Research Laboratory, Aberdeen Proving Ground, MD, November 1967.

5. Internal correspondence, U.S. Army Armament Research, Development and Engineering Center, Picatinny Arsenal, NJ.

6. Military Handbook, MIL-HDBK-1452.

7. Firing Tables – FT120-d-2, Cannon 120-mm Gun M256.

DISTRIBUTION LIST

Commander
Armament Research, Development and Engineering Center
U.S. Army Tank-automotive and Armaments Command
ATTN: AMSTA-AR-WEL-T (2)
AMSTA-AR-GCL
AMSTA-AR-FSA-S (20)
AMSTA-AR-TD, M. Fisette
A. Warnash
C. Gagnon
J. Hedderich, III
AMSTA-AR-FS, J. Lehman
M. Cilli
J. Dyer
R. Pellen
M. Chiefa
W. Ryba
S. Pearcy
AMSTA-AR-FSA-M, J. Wejsa
M. Evangelisti
D. Huie
J. Feneck
AMSTA-AR-CCH, G. Kolasa
AMSTA-AR-FSA-T, E. Rudnicki
AMSTA-AR-WEE, S. Westley
S. Einstein
J. Rutkowski
Picatinny Arsenal, NJ 07806-5000

Defense Technical Information Center (DTIC)
ATTN: Accessions Division (12)
8725 John J. Kingman Road, Ste 0944
Fort Belvoir, VA 22060-6218

Director
U.S. Army Materiel Systems Analysis Activity
ATTN: AMXSY-EI
392 Hopkins Road
Aberdeen Proving Ground, MD 21005-5071

Commander
Chemical/Biological Defense Agency
U.S. Army Armament, Munitions and Chemical Command
ATTN: AMSCB-CII, Library
Aberdeen Proving Ground, MD 21010-5423

Director
U.S. Army Edgewood Research, Development and Engineering Center
ATTN: SCBRD-RTB (Aerodynamics Technology Team)
Aberdeen Proving Ground, MD 21010-5423

Director
U.S. Army Research Laboratory
ATTN: AMSRL-OP-CI-B, Technical Library
AMSRL-WM-MB, B. Burns
L. Burton
S. Bender
R. Dooley
C. Hoppel

Aberdeen Proving Ground, MD 21005-5066

Chief
Benet Weapons Laboratory, CCAC
Armament Research, Development and Engineering Center
U.S. Army Tank-automotive and Armaments Command
ATTN: AMSTA-AR-CCB-TL
Watervliet, NY 12189-5000

Director
U.S. Army TRADOC Analysis Command-WSMR
ATTN: ATRC-WSS-R
White Sands Missile Range, NM 88002

Commander
Naval Air Warfare Center Weapons Division
1 Administration Circle
ATTN: Code 473C1D, Carolyn Dettling (2)
China Lake, CA 93555-6001

GIDEP Operations Center
P.O. Box 8000
Corona, CA 91718-8000

HQDA
ATTN: SARDTT, F. Milton
J. Appel
LTC L. Thurman
Washington, DC 20310-0103

DARPA
ATTN: B. Kaspar
3701 N. Fairfax Drive
Arlington, VA 22203-1714

Expeditionary Warfare
Division N8S
ATTN: F. Shoup
200 Navy Pentagon
Washington, DC 20305-2000

Marine Corps Sys Cmd
PM Ground Weapons
2083 Barnett Ave, Suite 315
Quantico, VA 22134-5000

Naval Surface Warfare Center
ATTN: R. Hubbard, G33-C
R. Ellis, G32
Dahlgren, VA 22448-5100

Commandant
U.S. Army Field Artillery School
ATTN: DCD, COL Svitak
LTC Bumgarner
E. Lyles
Major W. Field
S. Johnson
Ft. Sill, OK 73503

Commander
Rock Island Arsenal
ATTN: SMCRI-XC, S. Robinson
SMCRI-SEE-C, K. Wynes
Rock Island, IL 61299-5000

Commander
XVIII ABN Corps Artillery
ATTN: BG Gottardi
Ft. Bragg, NC 28307-5000

U.S. Army Research Office
Engineering Sciences Division
ATTN: R. Singleton
G. Anderson
P.O. Box 12211
Research Triangle Park, NC 27709-2211

U.S. Military Academy
Math Science Center of Excellence
Department of Mathematical Sciences
Madn Math
Thayer Hall
West Point, NY 10996-1786

PEO Armaments
ATTN: PEO GCSS, F. Strong
Picatinny Arsenal, NJ 07806-5000

Project Manager, CRUSADER
ATTN: SFAE-GCSS-CR, LTC T. Hogan
S. Traendley
F. Ribe
J. Corsello
C. Kimker
Picatinny Arsenal, NJ 07806-5000

Project Manager, JLW155
ATTN: SFAE-GCSS-JLW, COL S. Ward
J. Shields
K. Gooding
J. Lipinski
Picatinny Arsenal, NJ 07806-5000

Project Manager, MORTARS
ATTN: AMSTA-DSA-MO, P. Felth
T. Greiner
A. Wood
Picatinny Arsenal, NJ 07806-5000

Project Manager, ARMS
ATTN: SFAE-GCSS-SD, R. Kiebler
Picatinny Arsenal, NJ 07806-5000

Project Manager for Tank Main Armament Systems
ATTN: SFAE-GCSS-TMA, R. Morris
Picatinny Arsenal, NJ 07806-5000

Commander
U.S. Army TACOM-ARDEC
Marine Corps Liason Officer
ATTN: MCLO
Picatinny Arsenal, NJ 07801-5000

Director
Benet Laboratories
ATTN: AMSTA-CCB, R. Hasenbein
L. Bennet
G. Friar
G. D'Andrea
E. Kathe
S. VanDyke-Restifo
Watervliet, NY 12189-4050

General Dynamics Armaments Systems
Lakeside Avenue
ATTN: B. Salatino (10)
Burlington, VT 05401-4985