

ARMY RESEARCH LABORATORY



Development of a 40-mm Nonlethal Cartridge

by David H. Lyon

ARL-TR-1465

August 1997

DTIC QUALITY INSPECTED 3

Approved for public release; distribution is unlimited.

19970825 024

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-TR-1465**August 1997**

Development of a 40-mm Nonlethal Cartridge

David H. Lyon

Weapons and Materials Research Directorate, ARL

DTIC QUALITY INSPECTED 3

Approved for public release; distribution is unlimited.

Abstract

As U.S. soldiers are increasingly employed in humanitarian roles, as opposed to traditional mission, new equipment requirements are being generated. One such requirement included a nonlethal, or deterrent, munition for use in riot control. In response to this requirement, the U.S. Army Research Laboratory (ARL) has developed a nonlethal cartridge that is compatible with both the M203 and M79 40-mm grenade launchers. This cartridge contains a spin-stabilized projectile that is launched using a "high-low" propulsion technique. The projectile consists of a hollow plastic body fitted with a stiff foam nose, while the high-low propulsion system permits the use of smokeless propellant. The munition is designed to engage specific point targets out to 70 m.

This cartridge has been evaluated for lethality using several experimental techniques in addition to an analytical model. From the results, it appears as though an acceptable compromise between effectiveness and lethality has been achieved with a projectile mass of 58 g launched with a muzzle velocity of 56.4 m/s. Transitioned to the U.S. Army Armament Research, Development, and Engineering Center (ARDEC), this item is currently undergoing type classification as the XM1006.

Acknowledgments

The author wishes to express his appreciation to those who provided assistance to this program. This includes MAJ Jack Supplee, John Cline, and Frank Dindle from the U.S. Army Armament Research, Development, and Engineering Center (ARDEC); George Niewenhous from the Aberdeen Test Center (ATC); and Russell Prather from the U.S. Army Research Laboratory (ARL). In addition, thanks also goes to Donald McClellan and Brendon Patton from the ARL Aerodynamics Range for their support and hard work, and also to Dave Webb for his assistance with data analysis.

A special thanks goes to LTC Mike Harris of the U.S. Special Operations Command (SOCOM) for initiating this project and to MSG Bud Schiff of the Military Police (MP) School for providing a wealth of user-oriented guidance.

INTENTIONALLY LEFT BLANK.

Table of Contents

	<u>Page</u>
Acknowledgments	iii
List of Figures	vii
List of Tables	ix
1. Introduction	1
2. Background	2
2.1 Chemical	2
2.2 Kinetic Energy	3
3. User Requirements	4
3.1 Weapon Platform	4
3.2 Performance Requirements	5
4. Cartridge Design	5
4.1 Projectile Geometry	5
4.2 Ballistic Performance	5
4.3 Propulsion System	14
5. Lethality Assessment	17
6. Summary	20
7. References	21
Distribution List	23
Report Documentation Page	27

INTENTIONALLY LEFT BLANK.

List of Figures

<u>Figure</u>	<u>Page</u>
1. Cross Section of Prototype Design	7
2. Total Yaw, or Angle-of-Attack, vs. Range Plot for Prototype Design	8
3. Complex Yaw Plot (Theta vs. Psi) Plot for Prototype Design	8
4. Swerve and Drift Motion (Lateral Distance vs. Range) Plot for Prototype Design	9
5. Cross Section of Improved Design	10
6. Total Yaw, or Angle-of-Attack, vs. Range Plot for Improved Design	11
7. Complex Yaw Plot (Theta vs. Psi) Plot for Improved Design	11
8. Swerve and Drift Motion (Lateral Distance vs. Range) Plot for Improved Design	12
9. Sparkshadowgraph of Improved Design at $M = 0.16$ and $\alpha = 3.0^\circ$	12
10. Velocity vs. Range Plot of Improved Design	13
11. Various Trajectory vs. Range Plots for Improved Design	13
12. Cross Section of Cartridge Adaptor Assembly	15
13. Pressure vs. Time Plot for Interior of Cartridge Adaptor "High Side"	16
14. Pressure vs. Time Plot for Weapon Chamber "Low Side"	16
15. Probability of Lethality vs. Range, According to Sturdivan Model	19

INTENTIONALLY LEFT BLANK.

List of Tables

<u>Table</u>	<u>Page</u>
1. Projectile Physical Properties for Initial and Final Configurations	7
2. Selected Aerodynamic and Stability Parameters for Initial and Final Configurations	9
3. Results From Ballistic Firings at Clay Target	18

INTENTIONALLY LEFT BLANK.

1. Introduction

As U.S. soldiers are increasingly employed in humanitarian roles, as opposed to traditional missions, new equipment requirements are being generated. One such requirement includes a nonlethal, or deterrent, munition for use in riot control and pilfering situations. The rules of engagement under such circumstances often disallow the use of deadly force unless soldiers encounter a lethal threat.

Recent U.S. involvement in low-level conflicts, such as Somalia and Haiti, have produced specific scenarios where nonlethal munitions were needed. One such situation entails providing escort security to a convoy of relief trucks. If confronted by a mob of unarmed citizens, often surrounding the vehicles and blocking the roadway, soldiers are left with few options. Without nonlethal munitions, they could defend the cargo and themselves with bullets, bayonets, or rifle butts. Another option is to simply abandon the cargo and retrograde from the area (Harris 1993). In these situations, the soldiers are usually not in grave danger; the mob is interested in the cargo, not in harming the escorts. However, should the mob reveal weapons or attack the escort force, the situation could quickly degrade, and lethal force would be not only be justified, but warranted.

A second scenario involves crowd control. It has long been recognized that if the person(s) instigating and leading a mob can be rendered ineffective, the balance of the crowd will not only lose focus, but also much of its motivation. Usually, these individuals are easily recognized as the persons shouting taunts and giving orders; however, these persons typically are not located in the front row, but hang back several layers deep in the crowd (Schiff 1994).

A final scenario consists of maintaining perimeter security. Brazen locals have been known to cut holes in fences surrounding military compounds, even mocking the troops on guard duty, once they realized that the soldiers would not fire upon them. These same individuals would often return after dark, slip through the holes they had previously cut, and attempt to pilfer supplies and equipment (Harris 1993).

If troops involved in scenarios, such as those previously described, were equipped and trained with nonlethal munitions, they would be better equipped to diffuse the situations and regain control. By providing the soldier with a midlevel force response, appropriate to the level of threat, the chance of an escalation can be reduced. In addition, if this nonlethal response can be employed at a standoff distance, the troops can maintain a buffer zone between themselves and the crowd, another major advantage. Finally, the capability to target a specific individual, as opposed to spraying the crowd, will significantly reduce the chance of collateral injury.

2. Background

The U.S. Army has been involved in the development of nonlethal weapons for several decades. Interest peaked during the Vietnam era, when troops were regularly called upon to control civilian crowds of war protesters. Although various techniques were investigated, some quite diverse in nature, the majority of work focused on either the use of lachrymatory agents or the delivery of kinetic energy munitions.

2.1 Chemical. The class of compounds called lachrymatory agents, commonly referred to as "tear gas," has gained wide acceptance in both military and law enforcement communities. These chemicals can affect individuals in different ways, but generally produce tearing and burning of the eyes, coughing, irritation of the skin and sinuses, as well as respiratory distress (Campbell and Egner 1976). Most often, these agents are delivered by one of three dispensing methods: projectors, grenades, or projectiles.

At close ranges (less than 10 m), powdered agent can be dispensed using pressurized gas as the propellant, similar to an aerosol spray. Called projectors, such devices often resemble a fire extinguisher, consisting of a pressure vessel and a nozzle with a control valve. The grenade-type dispenser can be used on outdoor crowds or within a building. These items are typically thrown by hand and utilize a pyrotechnic charge to dispense a cloud of agent after a short delay. Several types of grenades are also designed to be gun launched, from either a 37-mm gas gun, 40-mm M203, or

modified shotgun. Lastly, a projectile-type dispenser is designed to penetrate an obstacle, such as a window, door, or vehicle windshield, and deliver agent behind the obstruction (AAI 1990). This delivery method is best suited to barricade and/or hostage situations, where access to the immediate area involves substantial risk.

The previously mentioned devices almost exclusively contain one of three compounds; O-Chlorobenzylidene Malononitrile (CS), α -Chloroacetophenone (CN), or 1-Methoxy-1,3,5-Cycloheptatriene (CR). These agents have been effectively employed in nonlethal roles for many years. There also exists a rather large database on these chemicals regarding their safe employment. However, in recent years, another lachrymatory, Oleoresin Capsicum (OC), has quickly attained almost universal endorsement. Commonly refereed to as "pepper spray," this chemical is available to the public, typically in aerosol form, for self-defense. It is thought to possess several advantages over the other compounds. These include an extremely fast action time combined with severe effects and reduced contamination. Due to its increasing popularity, manufacturers are now offering all dispenser types filled with OC as well.

2.2 Kinetic Energy. In contrast, the delivery of kinetic energy is by far the oldest and most often used form of a nonlethal weapon. The concept is simply to transfer adequate striking energy to produce enough pain to force retreat and/or the cessation of hostilities. A familiar example is the nightstick carried by police officers, although many ballistic delivery systems have also been developed. The U.S. Army pursued several developmental programs involving kinetic energy weapons during the Vietnam era as well. The most notable was the XM743, commonly referred to as the Sting RAG (DEVA 1976). This device employed a ring airfoil grenade, which consisted of a doughnut-shaped projectile with an airfoil cross section. This shape resulted in a low drag-to-lift ratio and provided a fairly flat trajectory for such a low velocity. The disadvantage to this design is its inherent sensitivity to cross wind, making it difficult to hit an intended target in cross wind conditions. In operation, the launcher (XM234) was attached to the muzzle of an M16A1 rifle and required the firing of a 5.56-mm blank cartridge. This procedure would, of course, severely compromise a soldier's lethal capability, should the need arise.

More recent advancements in this type of munition have primarily taken place overseas. Ballistically delivered nonpenetrating projectiles, dubbed "rubber bullets," are used against civilians on a regular basis in countries such as Great Britain, Israel, and South Africa. Various police and prison guard forces within the United States employ a variation of this device, the shot-filled bean bag (Cuadros 1995).

3. User Requirements

As a first step in any successful design process, the user requirements must be fully understood. This requires direct interaction with the ultimate user—U.S. soldiers. Much of this information was provided by several user representatives to include LTC Mike Harris of the U.S. Special Operations Command (SOCOM), MAJ Jack Supplee of the U.S. Armament Research, Development, and Engineering Center (ARDEC), MSG Bud Schiff of the Military Police (MP) School, and CPT Scott O'Neil of the Dismounted Battlespace Battle Lab.

Typically, the light forces, such as special operation units, are flown in by aircraft, be it helicopter or fixed wing. Therefore, they are severely restricted in terms of their equipment weight and bulk, as everything must be either carried or stowed in a backpack. This constraint dictates that any nonlethal device these troops might carry must be man-portable. In addition, any soldier carrying a dedicated nonlethal device has presumably compromised a capability by sacrificing other equipment.

3.1 Weapon Platform. Considering this, the most attractive approach calls for the design of a nonlethal munition compatible with a currently issued weapon platform. This strategy would minimize the impact on unit performance, and greatly reduce the associated purchase costs, as well as training. Focusing on the weapons typically carried by infantry soldiers, the 40-mm M203 grenade launcher is the most appealing when considering performance characteristics. The cartridge envelope allows for a large projectile volume, while the single-shot breech-loading design does not require a specific recoil impulse to function the weapon. Therefore, a lightweight projectile could be launched at a reduced velocity with no deviation from normal weapon function.

3.2 Performance Requirements. The maximum effective range, as perceived by user consciences, is on the order of 50 m. Such a standoff would allow troops to engage a crowd at a relatively safe distance, or engage persons attempting to cut or climb fencing from the security of fortified positions. A minimum engagement range of 10 m was considered appropriate from a tactics standpoint. However, for an additional margin of safety, the cartridge should be designed to ensure relative safety at zero range, impacting with full muzzle velocity. These parameters served to bound the design problem. In addition, this cartridge is expected to function under the extremes adopted for standard ammunition types. This includes temperature, humidity, rough handling, etc. Furthermore, the cartridge must comply with applicable ammunition safety standards. Lastly, the design should conform to the established 40-mm cartridge envelope to satisfy any packaging, transport, and chambering concerns.

4. Cartridge Design

4.1 Projectile Geometry. The design of the flight body itself entailed a series of tradeoff analysis between aerodynamic properties and favorable impact characteristics. Often, parameters that produce superior ballistic performance are undesirable in terms of impact injury and lethality. Therefore, the resultant design was considered a reasonable compromise between these opposing elements.

The barrel of the M203 grenade launcher is rifled, containing six lands with a twist rate of one turn in 48 in of travel. This rifling imparts the spin necessary to stabilize conventional ammunition types with relatively low length-to-diameter (L/D) ratios. This method of stabilization allows for maximum warhead volume in combination with an easily producible design. The advantages of adopting spin stabilization far outweigh alternative methods of aerodynamic stabilization, such as lifting surfaces (i.e., fins). Therefore, spin stabilization should be considered the primary stability method for any nonlethal projectile launched from the M203.

4.2 Ballistic Performance. Due to a severe time constraint, prototype projectile designs were simultaneously fabricated for range testing and analyzed using predictive tools, as this method

provided the timeliest results. Once a prototype geometry had been established, aerodynamic performance was determined utilizing a combination of numerical and experimental techniques. A projectile analysis program (PC Prodas) was utilized to calculate mass properties and aerodynamic coefficients. The predicted mass values were then compared against static measurements and found to be in close agreement. In addition, the computed aerodynamic coefficients were correlated with experimental range firings and adjusted accordingly. The first prototype design consisted of a solid projectile body with a hemispherical nose, as illustrated in Figure 1. Nylon 6/6 was selected as the body material, while the nose was shaped from a cylindrical blank of natural foam rubber. Table 1 contains the physical properties associated with this configuration, which represented a very simple, low-cost design. Although it survived gun launch and possessed acceptable impact characteristics, its marginal stability resulted in poor flight performance. A low gyroscopic stability factor (S_g) of 1.1, combined with an undamped slow arm caused this configuration to fly with a high-limit-cycle yaw, as indicated in the total yaw plot of Figure 2, as well as the complex yaw plot of Figure 3. Illustrated in Figure 4 is the lateral movement (swerve and drift) as a function of range, which is a result of these characteristics. This poor flight performance was confirmed by outdoor range firings where a clearly visible swerve motion was observed with the naked eye. Table 2 summarizes several aerodynamic and stability criterion, which remain nearly constant over the narrow Mach number range experienced during a typical flight.

In addition to projectile geometry, material selection proved to be a nontrivial task. The Nylon 6/6 originally used is susceptible to moisture absorption, which results in swelling. As an alternative, Polypropylux was substituted as the body material for following prototype designs. This material possessed the mechanical properties necessary to survive launch; however, it left a thick melt layer behind on the rifling lands. It was felt that the firing of numerous rounds could result in buildup on the lands, adversely affecting weapon performance. Several other materials, such as Teflon (polytetrafluoroethylene) and Ultem (polyetherimide), were also investigated and test fired. However, due to factors such as cost, density, coefficient of thermal expansion, water absorption, and dimensional stability, they were not considered optimum. Following consultation with a plastics application engineer, polyethylene terephthalate (PET) was recommended (Knotts 1993). This material possesses high strength, good machinability, excellent dimensional stability, and a wide

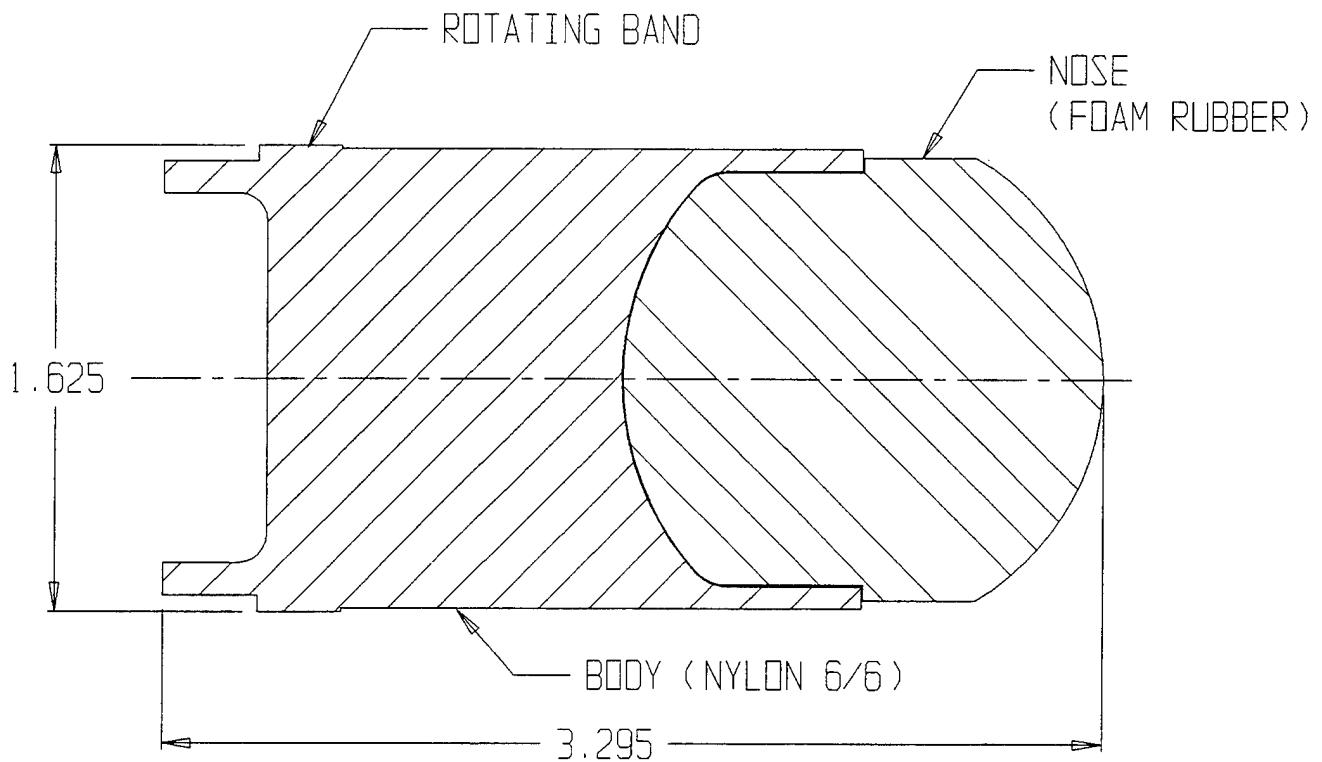


Figure 1. Cross Section of Prototype Design.

Table 1. Projectile Physical Properties for Initial and Final Configurations

Configuration	Mass (gm)	CG ^a from Nose (calibers)	Axial Moment (gm - cm ²)	Transverse Moment (gm - cm ²)
Nylon Body (solid)	65	1.33	149.4	231.0
PET ^b Body (hollow)	58.0	1.04	132.3	157.3

^a CG - center of gravity

^b PET - polyethylene terephthalate

range of chemical resistance. A further advantage of the PET was its relatively high density (specific gravity of 1.41). These mechanical properties allowed a design with a hollow projectile body, which served to increase gyroscopic stability. In order to shift the center of gravity (CG) forward and further contribute to enhanced flight stability, a material substitution was made for the closure disk

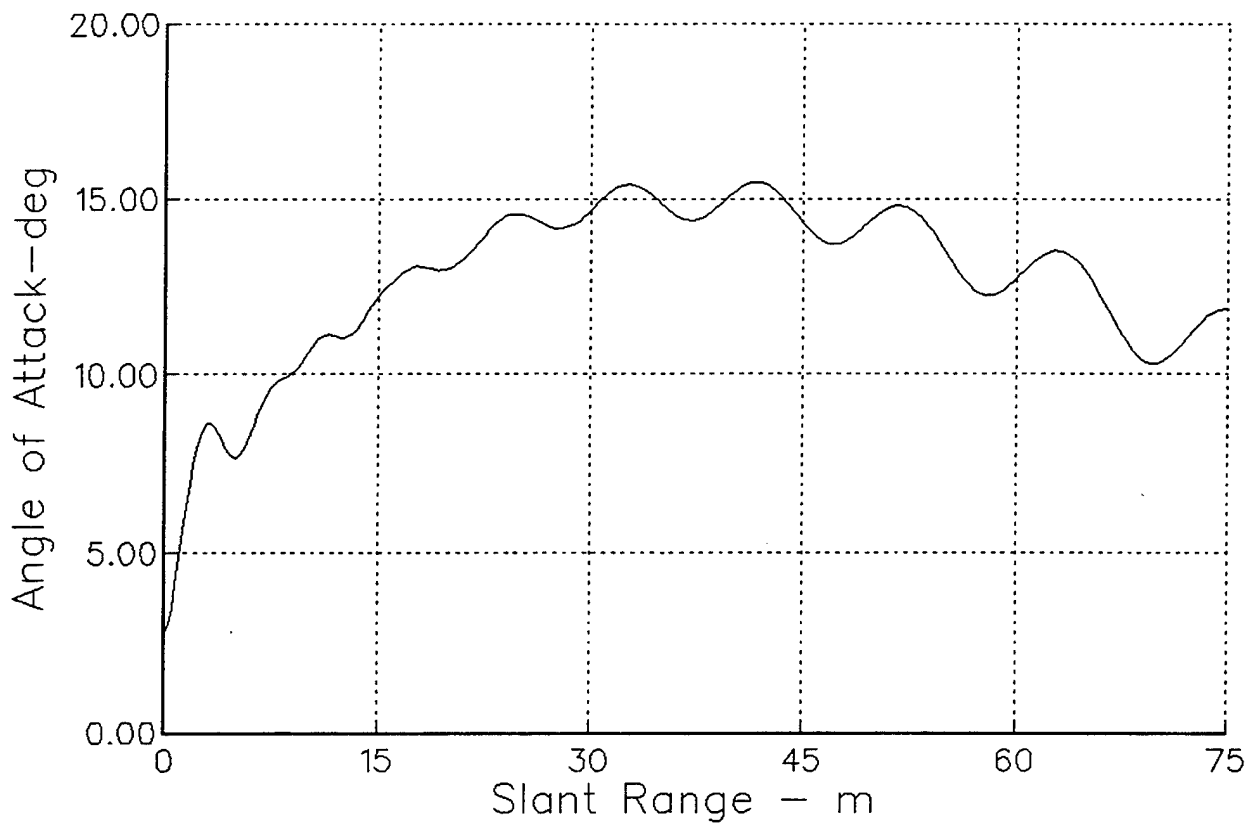
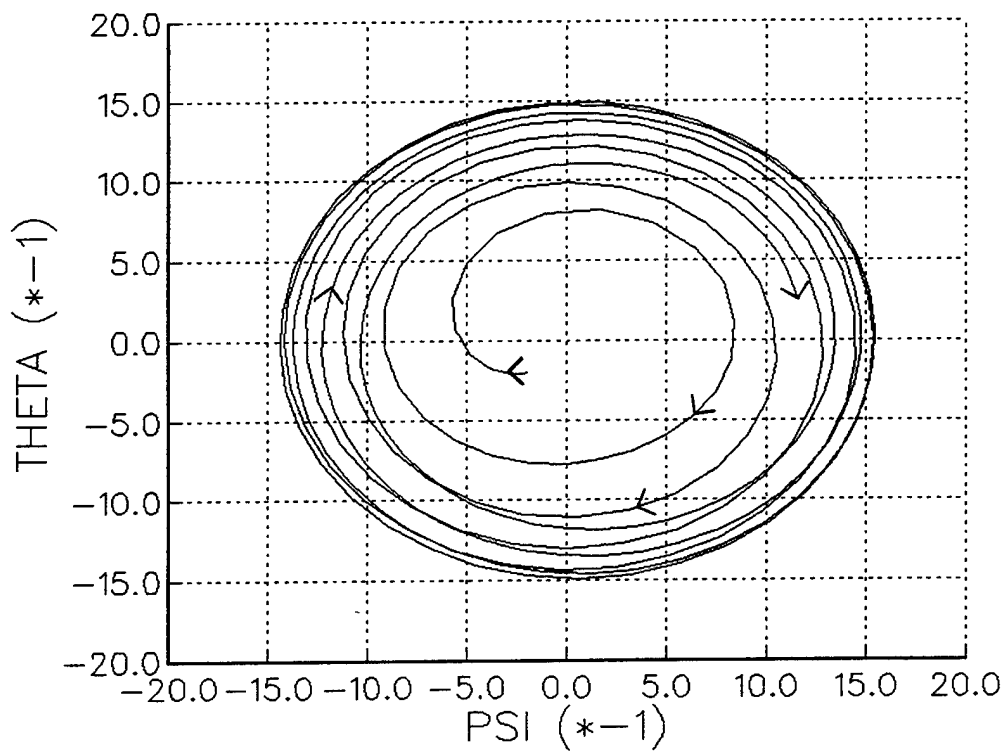


Figure 2. Total Yaw, or Angle-of-Attack, vs. Range Plot for Prototype Design.



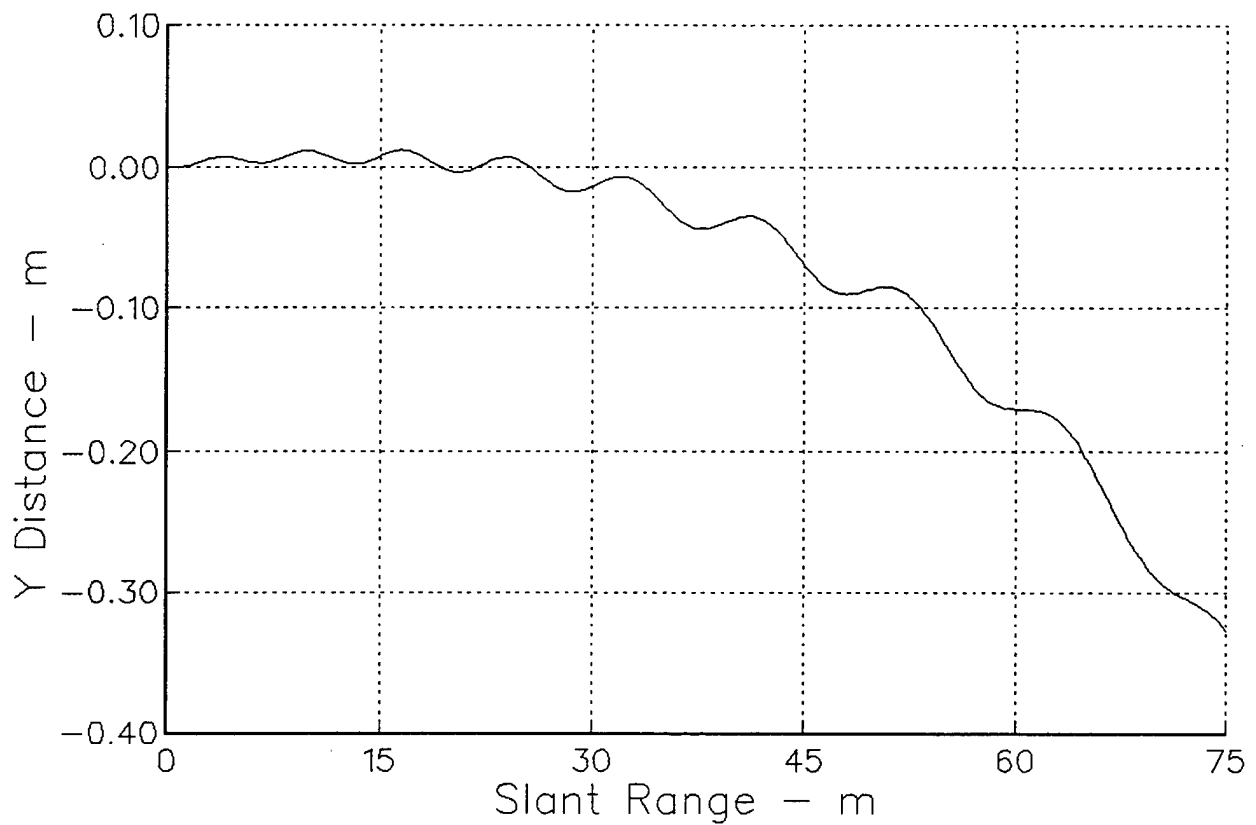


Figure 4. Swerve and Drift Motion (Lateral Distance vs. Range) Plot for Prototype Design.

Table 2. Selected Aerodynamic and Stability Parameters for Initial and Final Configurations

Configuration	Zero-Yaw Drag Coefficient CD_0	Overtuning Moment C_{ma}	Gyroscopic Stability Factor S_g	Normal Force Coefficient Derivative C_{Na}
Nylon (solid)	0.24	1.8	1.10	2.39
PET ^a (hollow)	0.22	0.91	2.52	2.38
Configuration	Magnus Moment Coefficient Derivative C_{npa} at 2°	Dynamic Stability Factor S_d at 1°	Fast Arm Damping Rate L_F at 2°	Slow Arm Damping Rate L_S at 2°
Nylon (solid)	-0.149	0.076	-0.362	0.140
PET ^a (hollow)	-0.116	0.394	-0.057	-0.023

^a PET - polyethylene terephthalate

(refer to Figure 5). The PET was replaced with an unfilled polytetrafluoroethylene (PTFE). Also known as Teflon, this material has an even greater density than PET, with a much reduced hardness. This would allow the closure to absorb more impact energy, through deformation, and further diminish the chance of projectile breakup. The design code predicted that this configuration possessed more than adequate gyroscopic stability with an S_g of 2.52. Projectile physical properties are included in Table 1. Both the total and complex yaw plots of Figures 6 and 7, as well as the tabular data of Table 2, indicate good flight behavior. In addition, the swerve motion plotted in Figure 8 is much reduced when compared to the previous design. These predictions were confirmed through experimental firings, via a shadowgraph technique, such as that shown in Figure 9. However, the natural foam nose, used for the early prototypes, proved to be unacceptable as a fieldable item. First, the material quickly degrades with exposure to sunlight, producing a hard, crumbling surface. Second, the fabrication process used to produce these noses was quite labor intensive. As part of an investigation into alternative materials, a product line of Polyolefin closed-cell foams was evaluated (Voltek 1994). This material possessed attractive characteristics to include a wide range of chemical resistance, a very fine cell structure, and simple fabrication techniques. A grade of this foam was chosen, which closely matched the stiffness of the original natural rubber. The foam manufacturer was then able to supply finished parts that met all performance criterion.

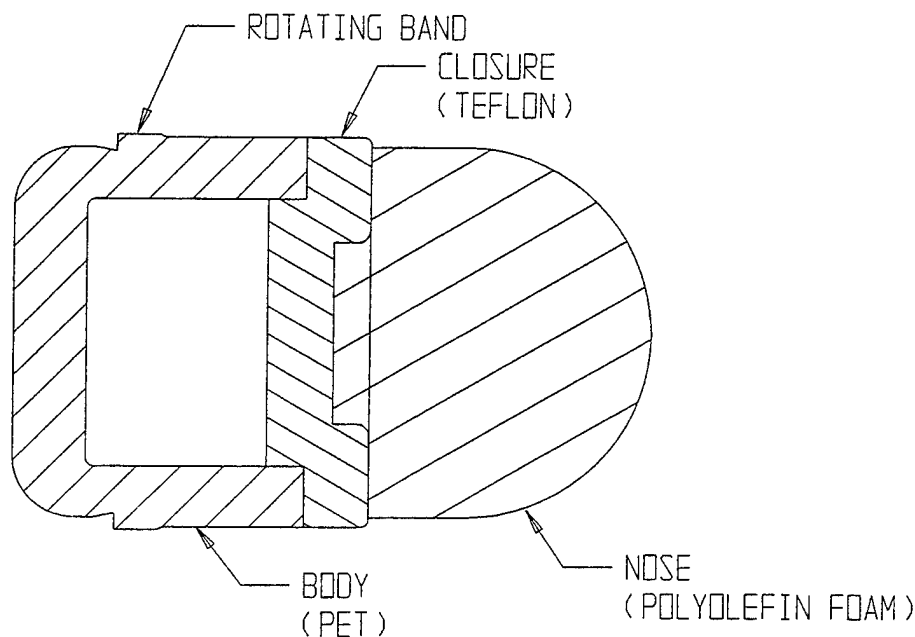


Figure 5. Cross Section of Improved Design.

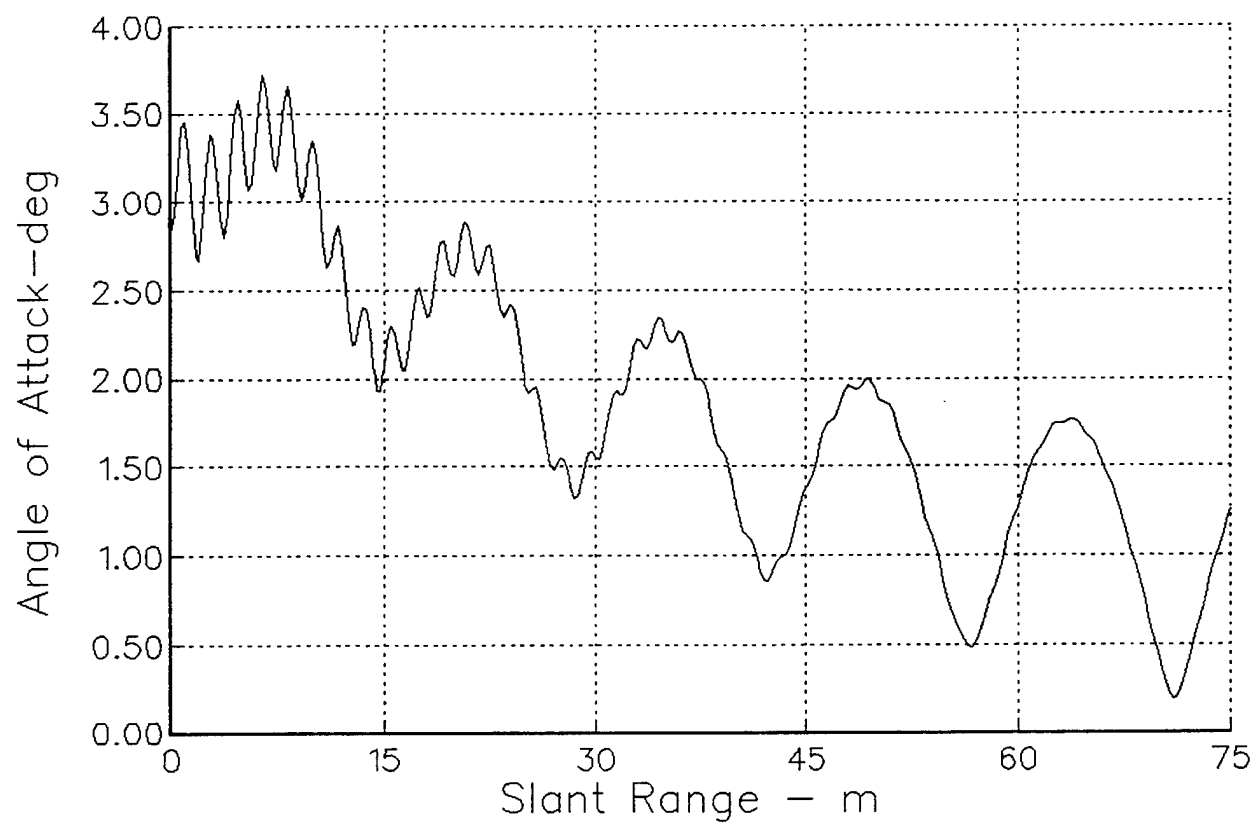


Figure 6. Total Yaw, or Angle-of-Attack, vs. Range Plot for Improved Design.

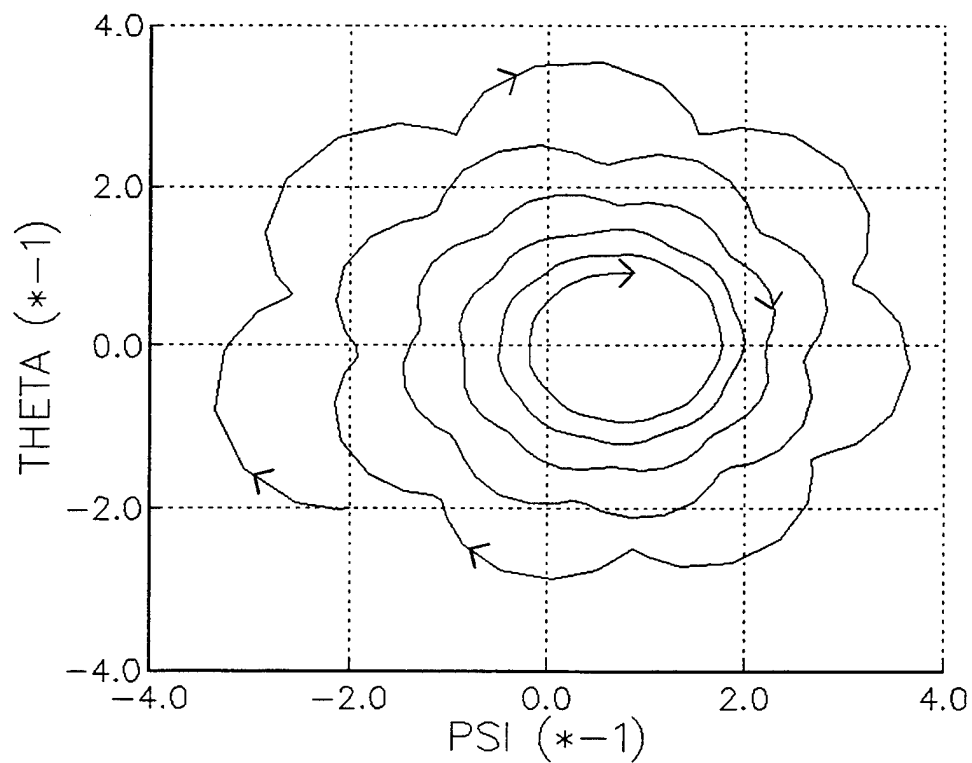


Figure 7. Complex Yaw Plot (Theta vs. Psi) Plot for Improved Design.

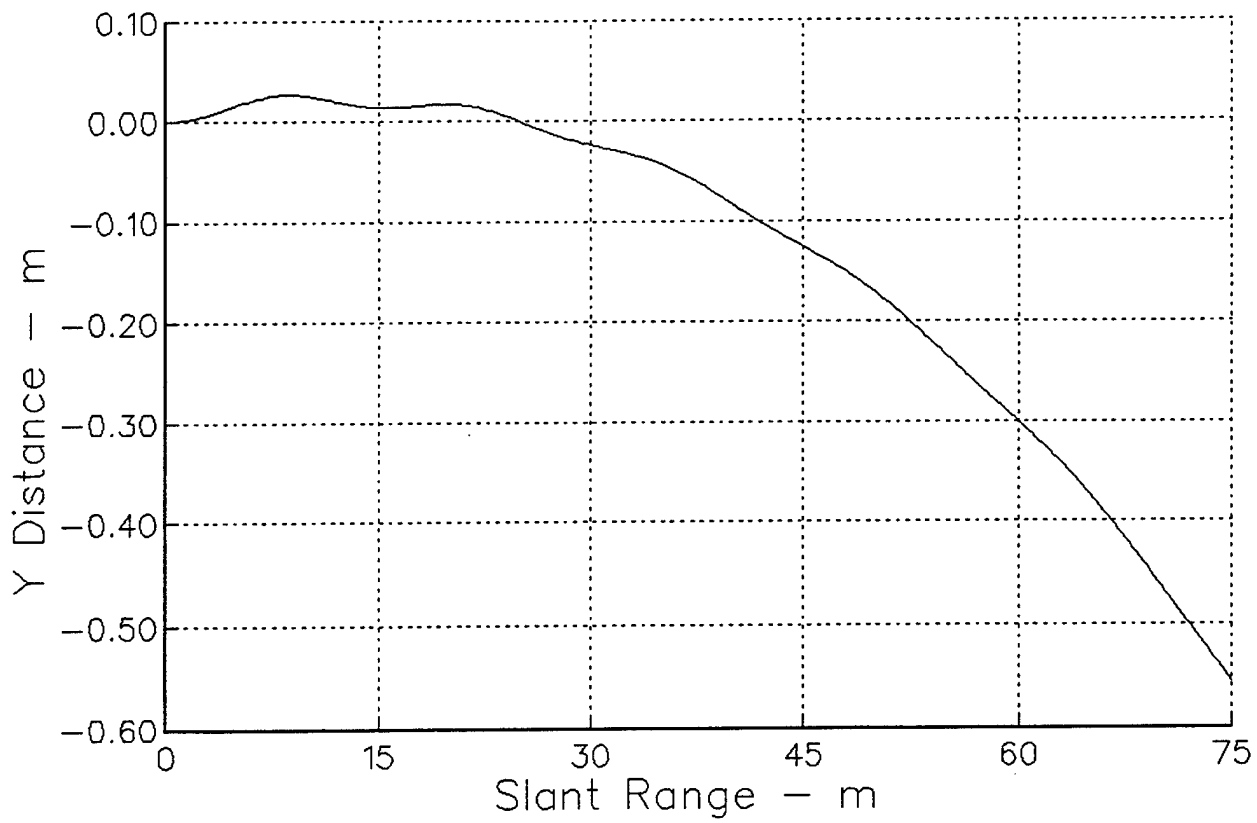


Figure 8. Swerve and Drift Motion (Lateral Distance vs. Range) Plot for Improved Design.

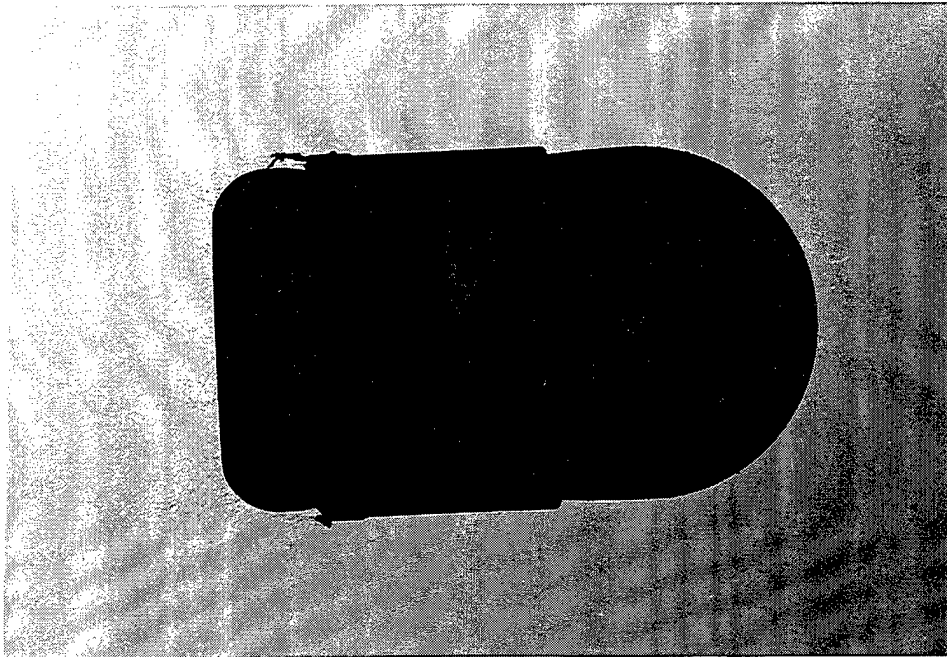


Figure 9. Sparkshadowgraph of Improved Design at $M = 0.16$ and $\alpha = 3.0^\circ$.

The velocity vs. range curve of Figure 10 was obtained using a zero-yaw drag coefficient (CD_0) of 0.22, which was extracted from range data. Utilizing this CD_0 , in combination with a muzzle velocity of 56.4 m/s, a series of simulated trajectories was computed. Figure 11 includes these curves, for various ranges, and serves to illustrate the height of apogee for each range.

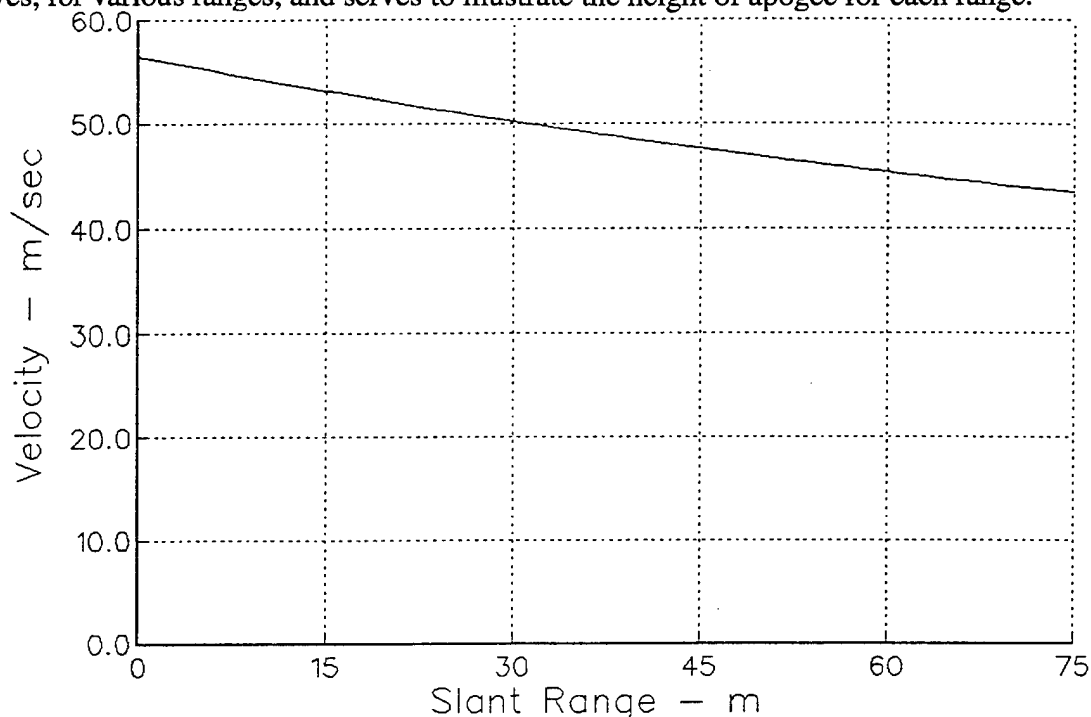


Figure 10. Velocity vs. Range Plot of Improved Design.

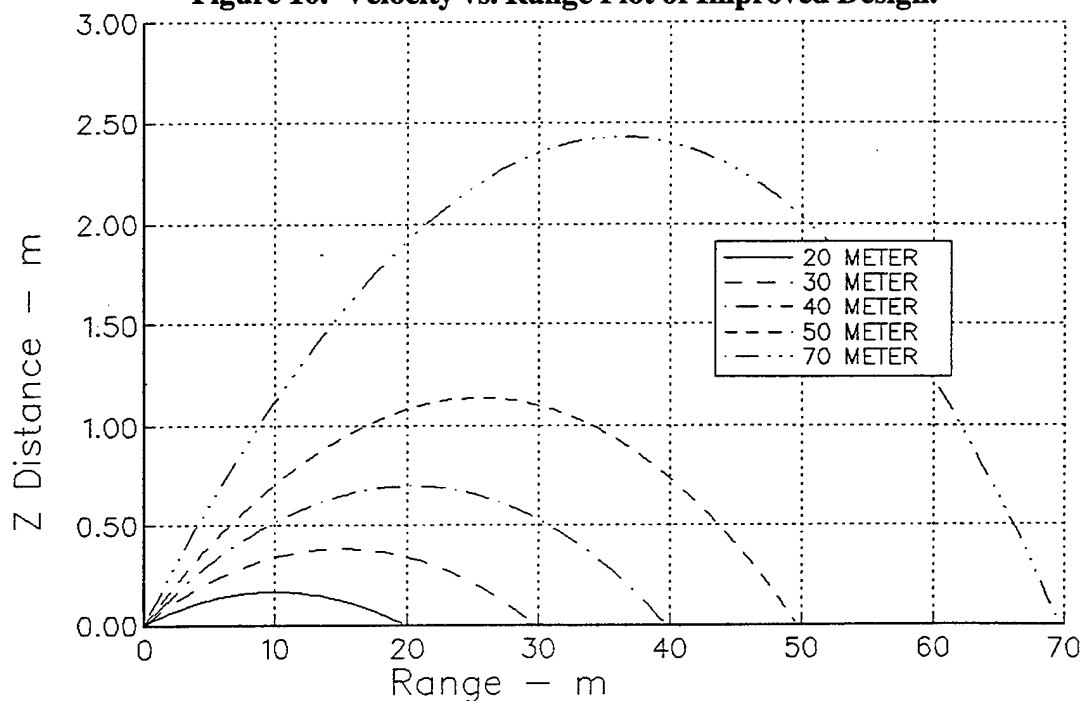


Figure 11. Various Trajectory vs. Range Plots for Improved Design.

For a projectile to possess low dispersion, consistent muzzle velocity is essential. This is especially critical for a projectile with a low velocity and lobbing trajectory. To examine this performance parameter, a 20-round test was conducted, during which, muzzle velocity and target impacts were recorded. The launcher was rigidly held within a fixed mount to eliminate any shooter induced errors and the target distance was set at 25 m. This group produced a 1.8-m/s standard deviation (one sigma) in muzzle velocity. It should be noted that deviations on this order are capable of significantly increasing the dispersion in the vertical direction, due to differences in time of flight and the resulting gravity drop. The target impacts at 25 m resulted in one sigma dispersions of 5.29 mil in the vertical and 1.67 mil in the horizontal directions. Although not on the order of typical small-arms fire, performance of this nature was deemed acceptable, since this munition is only intended for engagements of 70 m or less.

4.3 Propulsion System. Launching a projectile with such a low sectional density (0.046 gm/mm^2) at a reduced velocity becomes a nontrivial problem in itself. Typically, smokeless propellants burn erratically at pressures below several thousand pounds per square inch (psi). One alternative is to use black powder, which burns very consistently at low pressure. However, black powder is susceptible to the absorption of moisture in addition to producing a heavy, dirty residue. This residue can accumulate after a limited number of firings to a thickness that will begin to affect ballistic performance. Furthermore, this residue contains corrosive products; if not thoroughly cleaned after each use, these products will corrosively attack the metallic components of the launcher. Therefore, the most attractive solution would combine the ballistic performance of black powder with the low-residue, noncorrosive effects of smokeless powder.

Such a technique has been developed and is currently used in standard 40-mm grenade munitions. This method utilizes a high-pressure vessel to burn the powder with vents to communicate the gas products to the breech side of the weapon, where they act upon the projectile base. Referred to as a "high-low" system, this approach can allow smokeless propellant to mimic the low-pressure performance of black powder. For this particular configuration, a stainless steel cylinder is used as the high-pressure vessel (shown in Figure 12). This cylinder contains a relatively small amount of a standard military small-arms propellant (M9 Flake, Type I). Referred to as the

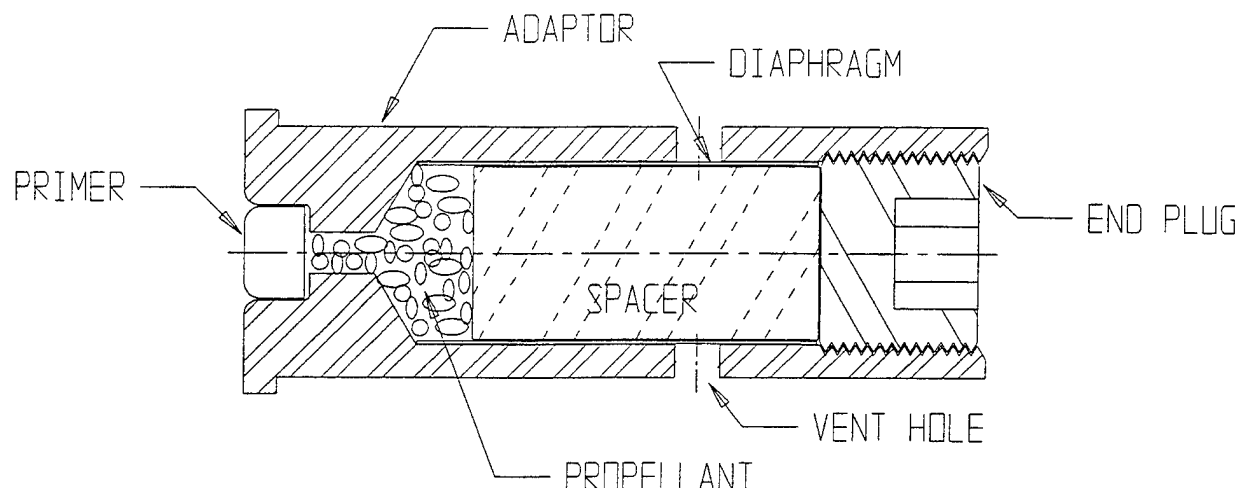


Figure 12. Cross Section of Cartridge Adaptor Assembly.

cartridge adaptor, this component also houses a standard percussion primer (M42C1) for ignition. Two holes, 2.06 mm (0.081 in) in diameter, communicate the propellant gases from within the adaptor (high side) to the weapon breech area (low side). These holes are initially covered by a thin brass diaphragm that allows the pressure to build before venting occurs. A polystyrene wad serves to hold the powder charge in close proximity to the primer for proper ignition. Finally, a threaded end plug seals the adaptor end after it is loaded.

Using this configuration, loaded with a charge weight of 1.8 grains, results in the pressure vs. time curve of Figure 13. A sharp initial spike, early in the trace, indicates the ignition of the primer material. The leading edge of this spike serves as the zero time base. Following this event is a fairly smooth rise in pressure produced by the propellant ignition and consumption phases. A peak pressure of 9,705 psi is achieved just prior to 0.5 ms into the trace. As the pressure decays, following this peak, it is assumed that the powder is nearly consumed and the venting process exceeds the rate of gas generation. Although not clearly delineated in this trace, the brass diaphragm bursts at approximately 5,000 psi.

Occurring immediately following rupture of the diaphragm is the venting process into the weapon chamber. This event is captured in the pressure vs. time curve of Figure 14, which does not share a common time base with the previous trace. Several sharp spikes are noted early in the plot

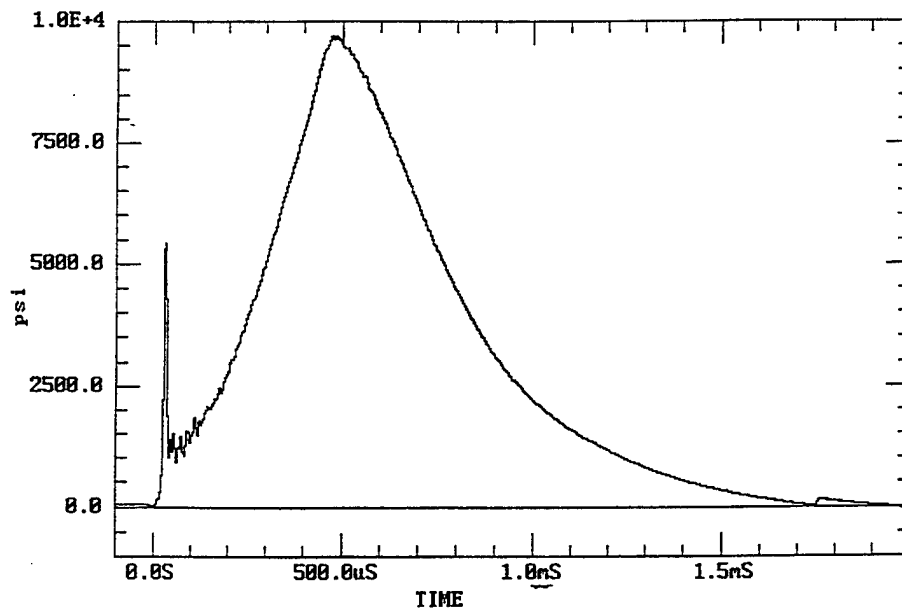


Figure 13. Pressure vs. Time Plot for Interior of Cartridge Adaptor "High Side."

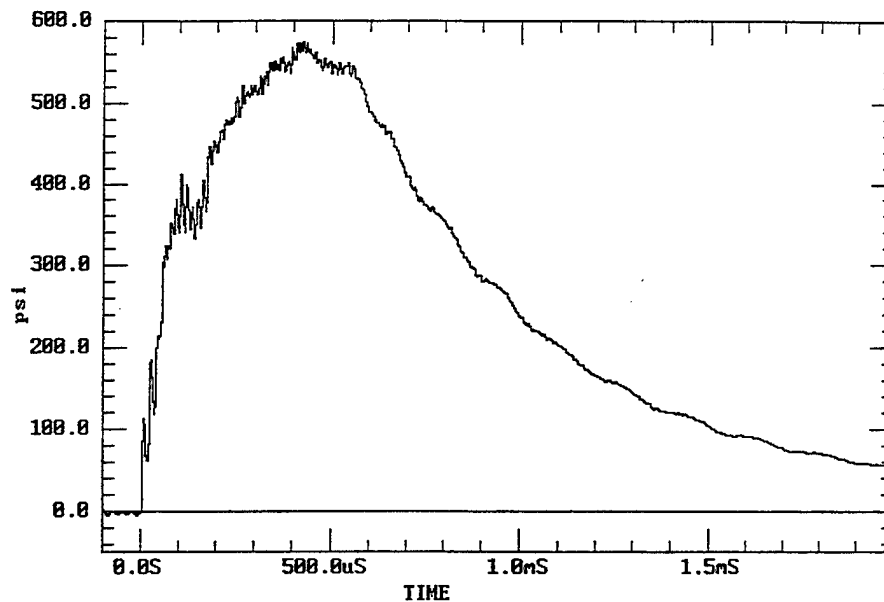


Figure 14. Pressure vs. Time Plot for Weapon Chamber "Low Side."

as the pressure rises quite rapidly. Most likely these are due to the bursting of the diaphragm, covering the two vent holes, and subsequent filling of the chamber volume behind the projectile. Immediately following is a fairly flat response dithering at about 360 psi and lasting approximately 0.1 ms. This is thought to be produced as the projectile unseats from the cartridge case and moves forward into the forcing cone to engage the bore rifling. A following increase in pressure denotes the higher resistance, due to rifling, as the projectile begins to accelerate down the launch tube. This

trace reaches a maximum pressure of 583 psi occurring approximately 0.4 ms into the trace, then gradually decays after the projectile uncorks.

5. Lethality Assessment

Although various blunt trauma models have been developed over the past 30 yr, no single method is capable of evaluating a wide variety of projectile types impacting various locations on the body. The simpler models include only the most basic parameters, while more complex models tend to limit themselves to very specific projectile types. Therefore, for the purpose of evaluating this munition, several experimental methods in addition to an analytical model were employed.

The first method involved shooting at a block of ballistic gelatin, covered with skin simulant, and recording the impact using a high-speed framing camera. Several critical data items are then extracted to include the maximum depth of temporary deformation, as well as an evaluation of the gelatin for surface damage such as penetration or laceration. Assessment criterion suggest a depth of 44 mm (1.73 in) or greater is considered adequate to produce injury such as liver fracture in an adult male. For experimental impacts at full muzzle velocity with skin simulant, the maximum temporary cavity depth measured approximately 33 mm (1.3 in). Neither the skin simulant nor the gelatin behind it showed any sign of damage. As a worst-case scenario, a second series of shots was performed against gelatin with no skin simulant, again at full muzzle velocity. The maximum depth observed was 38.1 mm (1.5 in) with no damage to the gelatin surface. Although these results were considered favorable, it is strongly recommended that no target be engaged at a range of less than 10 m.

The second evaluation technique was established by the National Institute of Justice (NIJ) and used to evaluate the blunt trauma that can occur as a result of nonpenetrating projectile impact, into the torso, when protected by soft body armor. This is referred to as NIJ Standard 0101.03 (National Institute of Justice 1987). The test procedure involves placing a block of oil-based modeling clay (Roma Plastilina No.1) in contact with the rear face of the body armor sample. Projectiles are then

fired at the arrangement, and the signature in the clay is measured for maximum cavity depth. If this depth is greater than 44 mm (1.73 in) the test is considered a failure, equating to a potentially lethal injury. The following rationale was used to allow evaluation of the XM1006 projectile using this technique. A bare block of Roma Plastilina No.1 would be impacted at full muzzle velocity and the cavity measured. If this cavity depth was less than 44 mm, it would indicate a nonlethal impact to the torso. Also of interest to users was the impact mitigation provided by soft body armor. To investigate these effects, a series of firings was conducted at both bare clay and clay covered by a personal armor system for ground troops (PASGT) vest. Table 3 contains these results. With the maximum cavity in the bare clay shots measuring only 22.1 mm, all impacts were considered nonlethal by this method. Furthermore, the shots into vest-covered clay show a significant reduction in the energy transmitted to the target, as verified by the maximum cavity depth of 8.9 mm.

Table 3. Results From Ballistic Firings at Clay Target

Projectile Configuration	Impact Velocity (m/s)	Target	Cavity Depth (mm)
Polyolefin Foam Nose	52	Bare Clay	18.0
Polyolefin Foam Nose	53	Bare Clay	19.9
Natural Foam Rubber Nose	54	Bare Clay	19.0
Polyolefin Foam Nose	55	Bare Clay	22.1
Polyolefin Foam Nose	54	Vest-Covered Clay	8.9
Polyolefin Foam Nose	52	Vest-Covered Clay	7.2

One analytical model in particular has been employed as the nonlethal baseline, since its development in the late 1970s. Based upon a compilation of empirical databases derived from live-animal tests, the Sturdivan model estimates the probability of lethality associated with thoracic blunt trauma (Mayorga 1995). This type of injury is consistent with the impact of nonlethal kinetic energy munitions. The Sturdivan equation is

$$P(L) = 1/[1 + 6.645 \times 10^{14}/(MV^2/DW^{1/3} T)^{3.597}] ,$$

in which

- M = mass of the projectile in grams,
V = impact velocity of the projectile in meters per second,
D = diameter of the projectile in centimeters,
W = mass of the victim in kilograms,
T = thickness of the victim's body wall at impact point, in centimeters, and
 $1/2 MV^2$ = kinetic energy.

Substituting the appropriate XM1006 characteristics into this model produced the probability of lethality $P(L)$ vs. range plot (included as Figure 15). This reveals a probability of 0.0032 at the muzzle, 0.0026 at 10 m, 0.0010 at 50 m, and finally 0.0006 at 70 m.

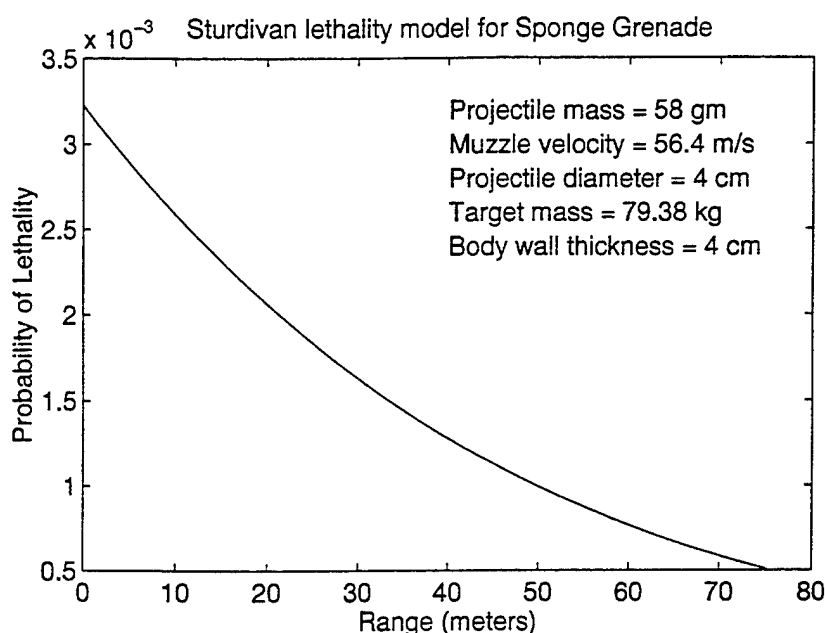


Figure 15. Probability of Lethality vs. Range According to Sturdivan Model.

No suitable model was available to allow evaluation of impacts to the head, in particular, the eye area. Generally, impacts to this area require a lower threshold for serious damage than other organs. Therefore, an impact in the head area could cause a potentially fatal injury. For this reason, it is strongly recommended against impacting the head or throat areas.

6. Summary

A nonlethal 40-mm cartridge, designated XM1006, was designed for U.S. soldiers involved in operations other than war. This cartridge is compatible with both the M203 and M79 grenade launchers. The projectile itself consists of a two-piece hollow plastic body fitted with a stiff foam nose. This allows a relatively lightweight projectile of 58 g. The propulsion system utilizes a high-low technique that permits the use of a modern smokeless propellant while providing acceptable ballistic performance. This system is designed around a stainless steel adaptor that retains a percussion primer, as well as the powder charge. In operation, the adaptor vents propellant gases through two holes after a brass diaphragm has been ruptured. By venting the combustion products in a controlled manner, a consistent muzzle velocity is achieved.

The projectile has been evaluated for lethality using several experimental techniques and one analytical model. Although these methods are no substitute for a complete Health Hazard Assessment, they provide an indication as to the degree of projectile lethality. An acceptable compromise between effectiveness and lethality has been reached with a projectile mass of 58 g launched with a muzzle velocity of 56.4 m/s (185 ft/s).

This munition has since been accepted as an item in the Soldier Enhancement Program, and transitioned to ARDEC's Product Manager (PM) Small Arms, where it is undergoing type classification as the XM1006.

7. References

- AAI Corporation. "Law Enforcement Products." Hunt Valley, MD, 1990.
- Campbell, D., and D. Egner. "Modeling for Less-Lethal Chemical Devices." TM-2-76, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, MD, January 1976.
- Cuadros, J. Private communication. Arts and Engineering, March 1995.
- DEVA Corporation. "Projectile, 64 mm, Riot Control, Kinetic Energy, XM743." Chemical Laboratory, Edgewood Arsenal, Aberdeen Proving Ground, MD, July 1976.
- Harris, LTC M. Private communication. U.S. Special Operations Command, November, 1993.
- Knotts, W. Private communication. Bronze and Plastic Specialists, June 1993.
- Mayorga, LTC M. "Initial Health Hazard Assessment Report (IHHAR) for the Non-Lethal Cartridge, 40 mm." Walter Reed Army Institute of Research, Walter Reed Army Medical Center, August, 1995.
- National Institute of Justice. "Ballistic Resistance of Police Body Armor - NIJ Standard 0101.03." U.S. Department of Justice, Washington D.C., April 1987.
- Schiff, MSG I. Private communication. U.S. Army Military Police School, March 1994.
- Voltek, Division of Sekisui America Corporation. "Minicel Samples and Properties Chart." 1994.

INTENTIONALLY LEFT BLANK.

NO. OF
COPIES ORGANIZATION

2 DEFENSE TECHNICAL
INFORMATION CENTER
DTIC DDA
8725 JOHN J KINGMAN RD
STE 0944
FT BELVOIR VA 22060-6218

1 HQDA
DAMO FDQ
DENNIS SCHMIDT
400 ARMY PENTAGON
WASHINGTON DC 20310-0460

1 CECOM
SP & TRRSTRRL COMMCTN DIV
AMSEL RD ST MC M
H SOICHER
FT MONMOUTH NJ 07703-5203

1 PRIN DPTY FOR TCHNLGY HQ
US ARMY MATCOM
AMCDCG T
M FISETTE
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

1 PRIN DPTY FOR ACQUSTN HQS
US ARMY MATCOM
AMCDCG A
D ADAMS
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

1 DPTY CG FOR RDE HQS
US ARMY MATCOM
AMCRD
BG BEAUCHAMP
5001 EISENHOWER AVE
ALEXANDRIA VA 22333-0001

1 DPTY ASSIST SCY FOR R&T
SARD TT T KILLION
THE PENTAGON
WASHINGTON DC 20310-0103

1 OSD
OUSD(A&T)/ODDDR&E(R)
J LUPO
THE PENTAGON
WASHINGTON DC 20301-7100

NO. OF
COPIES ORGANIZATION

1 INST FOR ADVNCD TCHNLGY
THE UNIV OF TEXAS AT AUSTIN
PO BOX 202797
AUSTIN TX 78720-2797

1 DUSD SPACE
1E765 J G MCNEFF
3900 DEFENSE PENTAGON
WASHINGTON DC 20301-3900

1 USAASA
MOAS AI W PARRON
9325 GUNSTON RD STE N319
FT BELVOIR VA 22060-5582

1 CECOM
PM GPS COL S YOUNG
FT MONMOUTH NJ 07703

1 GPS JOINT PROG OFC DIR
COL J CLAY
2435 VELA WAY STE 1613
LOS ANGELES AFB CA 90245-5500

1 ELECTRONIC SYS DIV DIR
CECOM RDEC
J NIEMELA
FT MONMOUTH NJ 07703

3 DARPA
L STOTTS
J PENNELLA
B KASPAR
3701 N FAIRFAX DR
ARLINGTON VA 22203-1714

1 SPCL ASST TO WING CMNDR
50SW/CCX
CAPT P H BERNSTEIN
300 O'MALLEY AVE STE 20
FALCON AFB CO 80912-3020

1 USAF SMC/CED
DMA/JPO
M ISON
2435 VELA WAY STE 1613
LOS ANGELES AFB CA 90245-5500

NO. OF
COPIES ORGANIZATION

1 US MILITARY ACADEMY
 MATH SCI CTR OF EXCELLENCE
 DEPT OF MATHEMATICAL SCI
 MDN A MAJ DON ENGEN
 THAYER HALL
 WEST POINT NY 10996-1786

1 DIRECTOR
 US ARMY RESEARCH LAB
 AMSRL CS AL TP
 2800 POWDER MILL RD
 ADELPHI MD 20783-1145

1 DIRECTOR
 US ARMY RESEARCH LAB
 AMSRL CS AL TA
 2800 POWDER MILL RD
 ADELPHI MD 20783-1145

3 DIRECTOR
 US ARMY RESEARCH LAB
 AMSRL CI LL
 2800 POWDER MILL RD
 ADELPHI MD 20783-1145

ABERDEEN PROVING GROUND

2 DIR USARL
 AMSRL CI LP (305)

NO OF
COPIES ORGANIZATION

5 CDR ARDEC
AMSTA AR CCL E
JOHN CLINE
PICATINNY ARSENAL NJ
07806-5000

1 CDR ARDEC
AMSTA AR CCL E
FRANK DINDL
PICATINNY ARSENAL NJ
07806-5000

1 CDR ARDEC
AMSTA AR CCH B
FRANK CHANG
PICATINNY ARSENAL NJ
07806-5000

1 CDR ARDEC
AMCPM SA
RAYMOND MAHTOOK
PICATINNY ARSENAL NJ
07806-5000

2 CDR
CHEMICAL SCHOOL AND
MILITARY POLICE CENTER
ATZN DLS S
MSG SCHIFF
FT MCCLELLAN AL 36205-0030

2 NONLETHAL WPNS DRCTRTE
SUSAN LEVINE
2033 BARNETT AVE STE 315
QUANTICO VA 22134-5080

2 CDR USAIC
ATZB WC DFD
MAJ PIELMEIER
FT BENNING GA 31905-5400

1 DIRECTOR
U S ARMY RESEARCH LAB
AMSRL SE DS
HENRY BRISKER
2800 POWDER MILL RD
ADELPHI MD 20783-1145

NO OF
COPIES ORGANIZATION

1 CDR
US ARMY NGIC
LARRY MABRY
220 SEVENTH STREET N E
CHARLOTTESVILLE VA 22902-5396

2 NATIONAL INST OF JUSTICE
OFC OF SCI AND TCHNLGY
RAYMOND DOWNS
GEORGE WAGNER
633 INDIANA AVE NW
WASHINGTON DC 20531

1 DEFENSE TECHNOLOGY
CORPORATION OF AMERICA
DAVID DUBAY
P O BOX 240
CASPER WY 82602

1 ST JOSEPH MERCY HOSPITAL
CLINICAL RESEARCH OFFICE
CYNTHIA BIR
5301 EAST HURON RIVER DR
ANN ARBOR MI 48106-0995

1 KNIGHT ARMAMENT COMPANY
C REED KNIGHT
7750 9TH ST S W
VERO BEACH FL 32968

1 SAN DIEGO COUNTY
SHERIFF'S DEPARTMENT
DEPUTY JOHN POKORNY
5255 MT ETNA DRIVE
SAN DIEGO CA 92117

1 ARTS AND ENGINEERING
JAMIE CUADROS
2742 FRANGANCIA AVE
HACIENDA HEIGHTS CA 91745

NO OF
COPIES ORGANIZATION

ABERDEEN PROVING GROUND

15	DIR USARL AMSRL WM PB DAVID LYON
2	CDR CBDCOM ERDEC SCBRD RTB LARRY BICKFORD
1	CDR CBDCOM ERDEC SCBRD ENM P JOSEPH DOMANICO
1	CDR U S ARMY ABERDEEN TEST CENTER STEAC AA LA ANDY ROSE
1	CDR ARDEC AMSTA AR FSF T ROBERT PUHALLA

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
<small>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.</small>				
1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE August 1997	3. REPORT TYPE AND DATES COVERED Final, January 1995 - October 1996		
4. TITLE AND SUBTITLE Development of a 40-mm Nonlethal Cartridge		5. FUNDING NUMBERS PR: 1L162618AH80		
6. AUTHOR(S) David H. Lyon				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory ATTN: AMSRL-WM-PB Aberdeen Proving Ground, MD 21005-5066		8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-1465		
9. SPONSORING/MONITORING AGENCY NAMES(S) AND ADDRESS(ES)		10. SPONSORING/MONITORING AGENCY REPORT NUMBER		
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.		12b. DISTRIBUTION CODE		
13. ABSTRACT (Maximum 200 words) <p>As U.S. soldiers are increasingly employed in humanitarian roles, as opposed to traditional mission, new equipment requirements are being generated. One such requirement included a nonlethal, or deterrent, munition for use in riot control. In response to this requirement, the U.S. Army Research Laboratory (ARL) has developed a nonlethal cartridge that is compatible with both the M203 and M79 40-mm grenade launchers. This cartridge contains a spin-stabilized projectile that is launched using a "high-low" propulsion technique. The projectile consists of a hollow plastic body fitted with a stiff foam nose, while the high-low propulsion system permits the use of smokeless propellant. The munition is designed to engage specific point targets out to 70 m.</p> <p>This cartridge has been evaluated for lethality using several experimental techniques in addition to an analytical model. From the results, it appears as though an acceptable compromise between effectiveness and lethality has been achieved with a projectile mass of 58 g launched with a muzzle velocity of 56.4 m/s. Transitioned to the U.S. Army Armament Research, Development, and Engineering Center (ARDEC), this item is currently undergoing type classification as the XM1006.</p>				
14. SUBJECT TERMS nonlethal, kinetic energy, small arms, munition		15. NUMBER OF PAGES 30		16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR	

INTENTIONALLY LEFT BLANK.

USER EVALUATION SHEET/CHANGE OF ADDRESS

This Laboratory undertakes a continuing effort to improve the quality of the reports it publishes. Your comments/answers to the items/questions below will aid us in our efforts.

1. ARL Report Number/Author ARL-TR-1465 (Lyon) Date of Report August 1997
2. Date Report Received _____
3. Does this report satisfy a need? (Comment on purpose, related project, or other area of interest for which the report will be used.) _____

4. Specifically, how is the report being used? (Information source, design data, procedure, source of ideas, etc.) _____

5. Has the information in this report led to any quantitative savings as far as man-hours or dollars saved, operating costs avoided, or efficiencies achieved, etc? If so, please elaborate. _____

6. General Comments. What do you think should be changed to improve future reports? (Indicate changes to organization, technical content, format, etc.) _____

CURRENT
ADDRESS

Organization

Name

E-mail Name

Street or P.O. Box No.

City, State, Zip Code

7. If indicating a Change of Address or Address Correction, please provide the Current or Correct address above and the Old or Incorrect address below.

OLD
ADDRESS

Organization

Name

Street or P.O. Box No.

City, State, Zip Code

(Remove this sheet, fold as indicated, tape closed, and mail.)
(DO NOT STAPLE)

DEPARTMENT OF THE ARMY

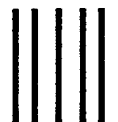
OFFICIAL BUSINESS

BUSINESS REPLY MAIL

FIRST CLASS PERMIT NO 0001,APG,MD

POSTAGE WILL BE PAID BY ADDRESSEE

DIRECTOR
US ARMY RESEARCH LABORATORY
ATTN AMSRL WM PB
ABERDEEN PROVING GROUND MD 21005-5066



NO POSTAGE
NECESSARY
IF MAILED
IN THE
UNITED STATES

