Colonial Era Firearm Bullet Performance: A Live-Fire Experimental Study for Archaeological Interpretation©

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With contributions by Daniel M. Sivilich and Daniel T. Elliott

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Acknowledgements

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Introduction

Firearms were a central feature of combat for the past millennium and a significant vector of political, ecological, and cultural change. Guns entered the Americas as a refined technology that became a causal factor in post-Columbian developments. Guns, gunpowder, and projectiles affected interethnic, colonial, and political relations and were a major point of commerce and trade. They also deeply impacted the ecology of the Americas. To address these kinds of issues, archaeologists need analytical tools to understand why gun parts failed, what types of firearms fired discovered projectiles, and the meaning of projectile distribution found on archaeological sites created by colonists, soldiers, traders and hunters, and Native Americans. A systematic archaeological study of guns is, however, only beginning.

In recent years, battlefield and conflict studies have emerged as a significant focus of archaeology internationally. This study intends to enhance archaeological research on these topics by using multidisciplinary experimentation to reveal residue patterns associated with pre-modern gun use. Attempts to interpret battlefield evidence indicate the need for specialist expertise to explain the origins of firepower. This information is scattered across various disciplines, with respective researchers not adequately sharing information with one another. Forensic scientists, firearm examiners, and engineers have developed techniques for the study of firearms, but these are rarely addressed by archaeologists.

Experimental archaeology has emerged as a rigorous approach to the study of material reflections of human behavior. This is an increasingly refined field that allows archaeologists to develop insights and methods for making behavioral interpretations of things in the archeological record. To study firearms, archaeologists need to design and conduct appropriate experiments and draw on technical methods developed by firearm examiners, engineers, and physicists. Recent battlefield archaeological investigations have given new impetuous to identifying the rifling characteristics of historic rifled firearms, the external ballistic capability of such firearms, and the combat efficiency of such arms. The goal of this study was to collect information on the ballistic capability of late eighteenth-century smoothbore firearms.

With some modern exceptions (see External Ballistics section), there have been few controlled studies of flintlock and percussion ignition systems small arms combat efficiency since a government sponsored external ballistic study done by the British in 1840 (Hughes 1983; 1969; 1974). This study is a byproduct and outgrowth of conversations and personal interest associated with the recovery of fired and dropped colonial and British musket balls from the Parker's Revenge site, a part of the April 19, 1775, battles that began the Revolutionary War. The Parker's Revenge project at Minute Man National Historical Park directed by Margaret Watters Wilkes (2016) was responsible for bringing the team together that eventually conducted the live-fire research effort.

The results of this live-fire experiment with colonial and Revolutionary War-era firearms are a beginning for the investigation of late pre-modern gun use. To determine what happens when large-caliber lead balls were used in combat or hunting we observed impacts of experimentally fired balls into ballistic gelatin, an accepted tissue simulant with end coverings to simulate clothing of the era, and into a sand backstop. We also used a wooden palisade made up of dry loblolly pine, green loblolly pine, live oak, and maple palings to obtain bullet impact information. Projectile deformation associated with varied ranges were catalogued. The results of these experiments will permit archaeologists to better interpret recovered projectiles.

The study goals were to collect data and conduct live-fire experiments with high-quality faithful reproductions of typical and common colonial and other Revolutionary War weapons. The study activities were designed to benefit several audiences:

1) Those interested in the history of firearms.

2) Re-enactors who will use the information in creating more authentic presentations.

3) Professional historians, archaeologists, and interpreters who either deal with firearms or how firearms were used; and

4) Firearm examiners who can use the information to exclude historic bullets and cartridges that are sometimes found on crime scenes from consideration and/or correctly assess black powder and reproduction firearms that are sometimes used in shooting incidents today.

The live-fire experiments were designed to capture information on flintlock firearm performance and capabilities that will benefit the goal audiences in their understanding and interpretation of archaeologically recovered spherical lead balls. To achieve these objectives, we designed the experiments to collect data on:

1) The velocity, range, and ballistic performance of common spherical lead balls of the type used in the colonial-era.

2) Factors that could cause variation in ball impact, and

3) How deformation of lead balls can be linked to velocity, impact range, and target media.

This report is well illustrated for the simple purpose of providing the reader with illustrations of weapon types, bullets, bullet deformation, etc. The extensive use of figures is, we believe, important to visualize and make clear the complex elements of firearms external and terminal ballistics that would result in a far wordier presentation otherwise.

Components of the Live-Fire Experiment

The live-fire experiment used common types of French & Indian War and Revolutionary War flintlock firearms. Other components of the experiment included the firing range, consideration of the black gunpowder used as a propellant, standardization of the lead balls, the construction of authentic-style cartridges, and the methods of data collection.

Firearms Used in the Experiment

Seven flintlock shoulder-fired firearms were used in the live-fire experiment. The seven are a reasonable representation of guns commonly used in the French & Indian War as well as the Revolution. They are all custom-made replicas of actual Revolutionary War flintlock firearms. One colonial fowling piece, a copy of a .62-caliber Thomas Earle fowling piece, represents a common type of weapon used by many colonial minute and militiamen. Two British Long Land Brown Bess guns, the Pattern 1742 and Pattern 1756 in .76-caliber, represent the standard British infantry firearm used in the French & Indian War as well as the American Revolution. Another common British gun of the era is a British Royal Artillery carbine in .65-caliber, which also represents the British officers' fusil and the British sergeants' carbine in our study. Two French models, 1728/41 and 1763/66 were also fired. The French 1728/41 musket has a .71-inch bore and was also commonly used in the French & Indian Wars as well as by Revolutionary War minute and militiamen. The Model 1763/66 has a .68-caliber bore and was used for single ball as well as buck and ball shots. The seventh gun was a reproduction Model 1740 Potsdam musket, .73-caliber, and is of the type often carried by Hessian units recruited by the British during the Revolution.

The experimental firing was conducted over a three-day period, November 14-16, 2016, near La Grange, Georgia.

Firing Range

For this study, a 100-yard range was constructed to contain or concentrate the fired projectiles in a safe and manageable way. At 100 yards a 7.5-foot-high palisade wall was constructed from freshly cut oak and pine logs. Directly in front of the palisade wall a sand backstop 5.5-foot high by 10-foot wide was mechanically piled using fine clean sands. These media were chosen to replicate soil impacts and wood impacts of diverse types to add to the data of the study. In addition to the palisade and sand backstop a shooting bench was constructed to provide a stable base for consistent shooting. While demonstrating accuracy was not the goal of the live-fire experiment, the bench and target provided a stable aiming point for all shots.

The range was established with safety as the priority. A large hill provided a natural backstop at 200 yards and a safe zone extended another 1500 yards. The range, located on private lands with limited access, thereby provided access control for personnel and equipment.


Figure 1. The firearms used in the live-fire experiment. Top to bottom, British Royal Artillery Carbine, British Pattern 1742 Long Land musket, British Pattern 1756 Long Land musket, French Model 1728/41 musket, French Model 1763/66 musket, Thomas Earle fowling piece, and a Model 1740 Potsdam musket.

One team member was designated as range safety officer, with all other shooting team participants also remaining vigilant. Prior to all firing, the safety officer, William Rose, announced ready and proclaimed the range hot. After firing the weapon was cleared and deemed safe a recovery team proceeded down range to recover the projectile. When a hang fire or flash in the pan occurred, the weapon was held in place for a count of 30 seconds, the pan cleaned and re-primed, then an attempt to fire the weapon again. The range was declared clear only when the weapon was successfully discharged.

The palisade wall was constructed to provide additional data on impacts of projectiles on selected wood species. The trees selected; live oak (Quercus virginiana), loblolly pine (Pinus taeda), and red maple (Acer rubrum) were all about four inches in diameter. Each is a common species found along the east coast, which allowed for a reasonably accurate recreation of a colonial block house palisade wall. Constructed with two 25-foot long 6-inch truss supports screwed in place with 10-inch screws, the log palings were placed between two living oaks that were 20-feet apart. These functioned as additional support for the palisade line. Each 4-inch post was placed in a 12-inch-deep post hole and backfilled after wood post placed. After placement, baling wire was utilized as lashing to secure the post in place. After all posts were in place they were trimmed to the same length. It was not the intention for the palisade to function as a backstop but rather to add data on bullet impact and deformation. Because of the chance of projectiles passing though the gaps or wood post, a tarpaulin was placed on the backside of the palisade to track projectile trajectory.

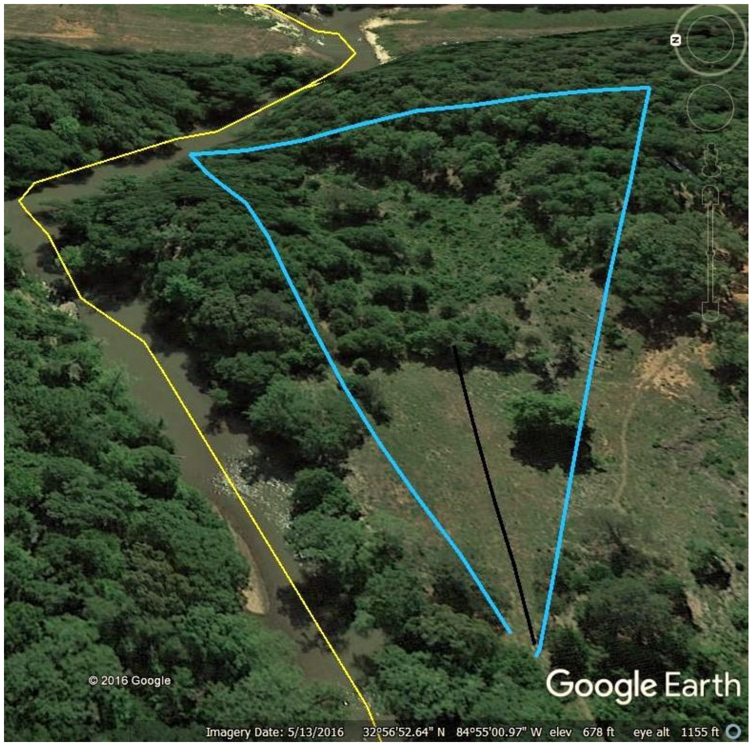

Figure 2. The area of the firing range. The blue line is the safety zone, black line is the 100-yard range, and the yellow line delineates the western property boundary along a stream.


Figure 3. Patrick Severts seated at the shooting bench and taking aim at the 100-yard range.

The sand backstop in front of the palisade wall not only provided a backstop for projectiles but also offered soil impact data. For this, clean loose sands were chosen to minimize escapement or deflection. After each firing a metal detector sweep of the backstop was conducted to expedite the locating of the fired projectile and to keep the sand free of potential hazards. Just to the front of the sand backstop a target stand with a silhouette target provided a defined aiming point. The target frame was constructed of 4x4 inch treated pine lumber with a sheet of fiberboard as a target backing. A man-sized head and torso standard paper silhouette target was affixed to the fiberboard.

Figure 5. Charles Haecker and Corinne Rose standing on either side of the target frame. Note the sand backstop behind the target and the palisade wall behind the backstop. The stake in front of the target is at 94 yards from the shooting bench, with the palisade at 100 yards from the bench location.

Black Gunpowder Propellant

In this study, we used Swiss FFg black gunpowder as the priming and propellant charge in all weapons. Only the charge weight was varied among the guns fired and for purposes of achieving lower velocities for shooting into tissue simulant. Dodd (2006:31) defines black powder as:

> "Black powder, by its very nature, is a true explosive. The smallest of sparks is sufficient to effect ignition. On ignition, a large quantity of bluish-grey smoke is generated, and a characteristic sulfurous residue is deposited on both the weapon and the shooting hand. The Chinese are credited with its discovery and the discovery of the explosive properties of the mixture of substances we know as traditional gun powder — sulfur, charcoal, and saltpeter (potassium nitrate). It is suggested that gun powder may have been used in the manufacture of fireworks well before its application to firearms and warfare. Only the manufacturing process has been refined over time."

The origin of black gunpowder is still debated in academic circles, but it is largely agreed to have originated in China in the eleventh century and spread to Europe by the late thirteenth or early fourteenth centuries (Buchanan 1996). The first black powder was hand mixed and is referred to as serpentine powder (Hall 1996:87-88). The black gunpowder used in this study is much more refined and is referred to as corned gunpowder. Corning, the wetting of the dry mixture, stamping, and glazing, as well as other manufacturing processes, began in the mid-1400s and largely supplanted serpentine powders by about 1550. The corning process was refined over time, but for all practical purposes corned black gunpowder was the only type used in the Americas after the mid-1500s (Hall 1996; Tascón et al. 1996; Howard 1996). The Swiss® brand corned black gunpowder used in our experiments is considered to be among the best at producing reliable and replicable results in comparisons with other black gun powders and black powder substitutes manufactured today for sporting purposes (Haag 2001; 2012).

Historically, the amount of black gunpowder used in various weapons in the eighteenth and early nineteenth centuries varied substantially. One source (Force 1846:667-68) list powder charges for muskets as:

> *"In Committee of Safety, May 29, 1776...The Committee appointed to consider of a proper mode of providing Cartridges for the different bores of Fire-Locks in the hands of the Associators report, that the practice of our Commissary, upon the authority of Books, is, two-fifths of the weight of each Ball to a charge of Powder, which proportion has been ascertained by actual experiment, as lately reported by a Committee appointed out of the Battalions in this City, as published in the publick prints, adopted by this Board and entered on our Minutes."*

The Committee of Safety then listed several bore sizes in gauge or balls to the pound with their respective pennyweight and grain weight powder charges. The list, with a conversion to standard caliber measurements and powder charge by grains is:

Balls to the pound	Caliber in inch	Powder charge in grains
13	.777	236
15	.695	204
17	.665	180
19	.637	160
21	.618	146
24	.588	128
30	.533	102

Ayde (1800:60) lists a series of gunpowder charges for common European muskets of the late eighteenth century, but does not list the calibers, although they were all in the .69 - .75-caliber range for known muskets of the time.

English - 7 Drams = 192.5 grains

Hessian - 6 Drams = 165 grains

Austrian -5 Drams = 137.5 grains

Dutch - 4 Drams = 110 grains

French - 3 Drams = 82.5 grains

Another source (de Marolles and Cleator 1789:200-201) suggests: *"Some determine the charge of a fowling piece, by the weight of the ball of the exact size of the caliber; estimating the weight of the powder at one-third of that of the ball, whether it is proposed to shoot with ball or with shot..."*

Spearman (1828) in his British Gunner treatise states the following charges were standard since 1775:

Musket:
Proof charge: 23.334 drams (642 grains)
Service charge: 6 drams (165 grains)
Exercise charge (for blanks): 5 drams (138 grains)

Carbine (Rifle Bore)
Proof charge: 15 drams (413 grains)
Service charge: 4 drams (110 grains)
Exercise charge: 4 drams (110 grains)

Carbine (Musket Bore)
Service charge: 5.5 drams (151 grains)
Exercise charge: 4.5 drams (124 grains)

Spearman also stated: *"The service charges given in this table, although established by authority, are too great, and might be reduced by about one-fourth. They have not been altered since 1775, while the strength of the powder has been increased in nearly a two-fold ratio since that period."*

Klatt (1999) reported on two surviving Revolutionary War era cartridge packets, containing buck and ball loads. Both packets are dated 1777 and had powder charges of around 115 grains (7.45 grams). This charge is consistent with Spearman's observation of reducing the approved British powder charge by one-fourth to account for the availability of better-quality gun powders.

The range of black powder charge sizes for any given caliber is varied as these and other sources cited later demonstrate. We choose to use a 110 grain black powder charge in .69-caliber to .75-caliber guns including the priming charge as it most closely approximates the Spearman recommendation and is consistent with the known charges in surviving Revolutionary War cartridges. For smaller caliber firearms we choose to use an 85 grain powder charge including the priming charge. We also used reduced charges to lower the muzzle velocity when firing at ballistic gelatin to try and capture the bullet in the gelatin. Powder measures showed only .1-gram variation in weight among any given charge size.

Lead Spherical Balls Used in the Experiment

Information on the diameter and weight of Revolutionary War musket and fowling piece balls comes primarily from the archaeological record. There are a few surviving Revolutionary War spherical balls from non-archaeological contexts that are available or have been studied. Klatt (1999) reported on two surviving Revolutionary War-era cartridge packets, all of which are buck and ball loads. Both packets are dated 1777 and each contain 10 buck and ball cartridges. One packet was still sealed, but the second was open. The cartridges in the open packet were removed and examined. The bullet caliber is noted only as .69-inch (17.5mm), although it appears no formal measurements were taken. The buckshot is reported to be .32-inch (8.1mm). The average weight of the balls is reported to be 490 grains (31.75 grams), for the buckshot 150 grains (9.72 grams), and the powder charge 115 grains (7.45 grams).

Thomas (1997:106-108) illustrates and provides measured diameters and weights for fifteen pre-Civil War .69-inch (17.5mm) spherical balls. The balls vary .64-inch (16.2mm) to .715-inch (18.1mm) in diameter and vary in weight from 423 to 700 grains (27.5 to 45.3 grams). Thomas' observations are based on source material from a variety of origins, but the ranges in weight and diameter are far greater than the bullets used for this study. The same is also true for the range of variation in the Brown Bess caliber bullets reported from several French & Indian War sites as well as Revolutionary War sites (Thomas 1997:105) with a range in diameter of .625-inch (15.9mm) to .695-inch (17.7mm) and a weight range of 343 to 472 grains (22.2 to 30.65 grams).

Wilkes (2016:315) provides weights and diameters on fifteen British and nine colonial fowling piece balls that were fired on the first day of the American Revolution, April 19, 1775, at the Parker's Revenge site in Minute Man National Historical Park. The British spherical range in weight from 364.2 to 483 grains (23.6 to 31.3 grams) and the calculated diameters range between .639 to .702-inch (16.23 to 17.8mm). The colonial fowling piece spherical balls ranged in weight from 126.5 to 381.1 grains (8.2 to 24.7 grams) and in diameter from .449 to .649-inch (11.4 to 16.5mm). Similar findings are reported by Sivilich (2016) in his spherical ball study and by Harding (2012) in his study of lead shot from the seventeenth-century English Civil War.

One of the earliest known studies of bullet performance and penetrations was conducted by a U.S. medical officer on behalf of the U.S. Army Ordnance Department in the early 1900s. La Garde (1991:36) in his pre-World War I study of gunshot injuries complied a table of 'early' small arms ammunition, which included the pre-1851 round ball. He reported the round ball to have ranged in diameter from .7559-inch to .6929-inch in diameter and with a weight range of

484 to 584 grains. He also noted the initial muzzle velocity of these early balls to range from 590 to 754 feet per second. La Garde does not provide a source for his data, and it seems in part inaccurate, but it likely reflects the loss of accurate information on bullet diameter and weight for spherical balls that occurred after the mid-nineteenth century shift to conical or cylindro-conical bullets.

Dr. Lawrence Babits conducted a series of live-fire experiments to determine the accuracy of buck and ball loads at different ranges. He conducted the experiments over several years with French and U.S. regulation muskets (Babits 2002). His report used documentary sources and compared them to his live-fire experiments. He found that the ball was reasonably accurate out to 100 yards, but the buckshot rarely hit the target at that range. Buckshot would hit an intended target at 25 to 30 yards, but beyond that range it was largely a matter of conincidence if a buckshot hit its intended target.

The spherical balls used in the live-fire experiment are commercially cast soft lead bullets (see Appendix C for pXRF trace element information). The experimental spherical ball weights show a minimum of 1.5 grain (.1-gram) to a maximum of 4.6 grain (.3-gram) weight variation in the 20% sample weighed. The measured ball diameter also showed extraordinarily little variation, being about .001 to .003-inch among all the balls measured. They have far less variation in weight and diameter than any of the published historical ball diameters or archaeological specimens reported. The balls are less than bore size. Typically, balls were less than bore sized to allow ease of loading, especially after multiple rounds were fired which caused black powder fouling in the bore. The common term for this is windage.

Figure 6. Unfired cast-lead balls used in the experimental firing. L to R, .282-inch buckshot, .315-inch buckshot, .520-inch ball, .580-inch ball, .626-inch ball, .663-inch ball, and .69-inch ball.

Cartridges and Cartridge Paper

Prior to the live-fire experiments Corinne and William Rose rolled a series of cartridges in each of the calibers to be used following eighteenth century guides on cartridge construction. Proper weight laid paper in a trapezoid shape was rolled around a wood former. A ball or a ball and three buckshot were placed in one end, the top twisted closed and the former removed. The appropriate powder charge for the caliber was then poured into the other end of the cartridge, twisted closed and the excess laid paper folded over to form a tail. Linen twine was then wetted and tied below the ball or ball and buck to hold the bullet in place. Finally, a ballpoint pen was used to mark the completed cartridge with the gun it was to be fired from and ball diameter.

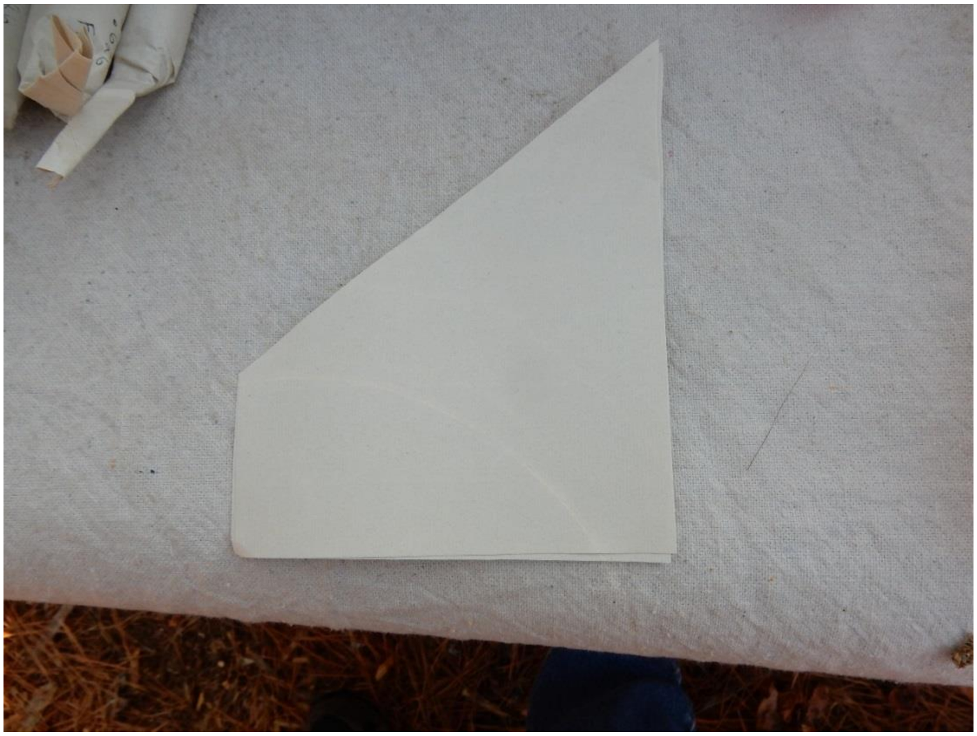

Figure 7. Laid cartridge paper cut to standard form and ready for rolling cartridges.

Figure 8. Corinne and William Rose rolling cartridges in preparation for the experimental firing.

Figure 9. Completed cartridges with notes on the laid paper body denoting ball size and intended firearm.

Live-Fire Experiment Methods

The live-fire experiments were conducted on November 14-16, 2016. Each firearm was loaded for the experimental firings by a single individual. Each firearm was fired in either a 10 shot or 5 shot string by the same individual. Shooters were changed for each gun. The guns were fired from a bench rest, not to achieve accuracy for each shot, but to enable the use of high-speed videography to capture the ball as it emerged from the muzzle as well as record initial muzzle velocity.

Nathan Boor of Aimed Research® provided and operated a Phantom V611® high-speed camera that was calibrated for each shot string. The camera recorded imagery at approximately 6,900 frames per second in raw format. For each shot string, the gun was placed on the bench, the height from muzzle to ground surface was recorded. Each shot had the ball diameter and weight noted. Also recorded were the weight of the propellant charge, the calculated muzzle velocity, temperature, wind speed, and humidity. Barometric pressure was obtained from the local weather service daily records.

Figure 10. High-speed camera setup in progress with personnel measuring muzzle height above ground surface and preparing to calibrate the camera.

A LabRadar® unit, which is a Doppler radar tracking device, was set up to acquire initial muzzle velocity data. The unit was unable to acquire any data due to the amount of gas, flame, and smoke emanating from the muzzles of the flintlock muskets. The radar unit was moved down range in several increments until it reached 20 feet from the muzzle. It was unable to acquire any data and was then retired from the project.

Figure 11. LabRadar® Doppler radar unit. Due to the extensive downrange gas flare and smoke from firing the unit was not capable of acquiring downrange velocity data and was withdrawn from service.

Most shots were fired at a range of 94 yards using a man-sized head and torso silhouette target mounted on a 4x4 treated pine frame. Buck and ball loads were fired at ranges of 25 and 30 yards with the target frame moved to each of those distances from the firing bench. On November 16 shooting was confined to firing three guns at blocks of Clear Ballistic® gelatin as well as some offhand shooting done to record the flintlock function and the nature of the recoil.

After each shot was fired two to three team members moved down range with metal detectors to search for and recover the fired ball. Metal detectors employed included a Minelab CTX 3030®, a Minelab E-TRAC®, and a Fisher F75®. Recovered bullets were bagged separately and labeled with the gun type, shot number, ball diameter, muzzle velocity, date, and any other relevant information.

The Thomas Earle Fowling Piece, .62-caliber, was fired on each of the three days of shooting. No brushing or cleaning between shots was done on the first day. Twelve shots were fired with one misfire on shot eleven on the first day. The load was 85 grains of FFg Swiss Black powder with a .520-inch ball rolled in cartridge paper. Five shots were fired on the second day using 85 grains of powder and an unpatched .580-inch ball. No misfires occurred. On the third day four shots were fired using the unpatched .580-inch ball. Two shots were fired with 85 grains of powder and two with 75 grains of powder. No misfires occurred. The fowling piece was later fired, after resting several hours, using six buckshot. Two misfires occurred and the flint was replaced. A total of 23 shots were fired from the fowling piece with one misfire on the eleventh shot, and two misfires after 19 shots when the flint was replaced, and two additional shots were made with no misfires. The fowling piece was cleaned each evening.

Figure 12. Man-sized torso paper target and target frame used as an aiming device during the firing. Hits were patched with duct tape and the shot noted. The uncovered holes in the target show a buckshot and ball hit from a buck and ball load.


Figure 13. Metal detecting underway to recover a ball after a shot at the 94-yard range.

Figure 14. British and French blade-style gunflints used in the experimental firing. The top left is a British unused flint, and the top right flint is expended. The bottom flint is a French-style unused flint.

The British Royal Artillery carbine, .65-caliber, was fired ten times on the first day with three misfires occurring, two on shot 7 and one on shot 9. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The British Pattern 1742 Long Land musket, .76-caliber, was fired five times on the second day with two misfires on shots 1 and 5. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The British Pattern 1756 Long Land musket, .76-caliber, failed to fire and after four misfires was withdrawn from use until the touchhole was cleaned using a vent pick and the loaded charge could be safely fired. The gun was not thoroughly cleaned after its last use and carbon fouling at the breech prevented the powder charge from reaching the touchhole. Working with a vent pick helped clear the hole and fouling to the point where sufficient powder grains worked into the chamber via the touchhole allowed the gun to be safely discharged. The gun was given a thorough cleaning that evening. The Pattern 1756 Long Land musket was fired twelve times on the third day. Ten shots were fired at the Clear Ballistic® gelatin and two additional live-fire shots were made in the offhand position to film details of the working of the flintlock mechanism and observed the full firing sequence as well as recoil. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The French Model 1763/66 musket, .68-caliber, was fired fifteen times on the second day with buckshot and ball loads. The range was decreased to 25 yards for the first 10 shots. Shot 1 had a spread of 12 inches for the buckshot and ball. Shot 2 had a spread of 8 and 9 inches from the ball to the two buckshot that struck the target and target frame post. Shot 3 had a spread of 9 and 15 inches. Shot 4 had a spread of 8 and 9 inches with one buckshot nicking the target frame post. Shot 5 had a spread of 9 and 15 inches.

Shot 6 did not strike the target. Shot 7 had a 9-inch spread between the ball and one buckshot. Shot 8 had only a single buckshot hitting the target. Shot 9 did not strike the target. Shot 10 had a 6-inch spread between the ball and a buckshot.

The target was moved back to 30 yards and five more shots were fired with buckshot and ball using three different shooters. Shot 1 had no hits, but the ball and one buckshot were recovered at 100 yards in the soil backstop. Shot 2 had a spread of 9 inches between the ball and a single buckshot. Shot 3 had only a single buckshot hit the target, but the ball and a buckshot were recovered from the backstop at 100 yards. Shot 4 did not strike the target. Shot 5 had a 5-inch spread between the ball and one buckshot. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day’s shooting.

Figure 15. A buck and ball load hit on the paper target at 25 yards fired from the French Model 1763/66 musket. The ball struck the center mass with the three-buckshot striking, two at the lower 9 ring and one lower and left in the 8 ring.

The French Model 1728/41 musket, .71-caliber, was fired five times on the first day with three misfires occurring on shots three and four. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

The Model 1740 Potsdam musket, .73-caliber, was fired five times on the second day with one misfire occurring on the fourth shot. The bore was dry brushed for safety after each shot, but not thoroughly cleaned until completion of the day's shooting.

Figure 16. Charles Haecker firing the Model 1740 Potsdam musket. The musket misfired with only a flash in the pan.

The live-fire experiment resulted in the firing of 74 spherical balls and 63 buckshot. The breakdown for each caliber fired by number of shots fired with recoveries noted, and total number of balls recovered per caliber.

12 - .520-inch balls were fired – 6 known shot sequence recoveries – 2 unknown attribution – total 8=75%

19 - .580-inch balls were fired – 9 known shot sequence recoveries – 1 unknown attribution – total 10=52%

23 - .626-inch balls were fired – 10 known shot sequence recoveries – 9 with unknown attributions – total 19=82%

20 - .69-inch balls were fired – 5 known shot sequence recoveries - 6 unknown attribution – total 11=55%

63 .282-inch and .315-caliber buckshot were fired in 18 separate shots – 2 known shot sequence recoveries - 8 with unknown attribution- total 10=16%

Total ball and buck fired 137 - Total known recoveries 32=23% - Total unknown recoveries 26=19%. Total recovered 58=42.3%

Principles of Firearms Exterior Ballistics; Background to the Study

Exterior ballistics is the study of the performance of a bullet after it leaves the gun. As Lucien Haag (2006:214-215) observes there is a difference in what a ballistician and a forensic scientist, or for our purposes an archaeologist, is seeking in studying bullet performance. The forensic scientist or conflict archaeologist is seeking to reconstruct a shooting incident or event based on residual physical evidence, the artifact, and knowledge of one or more types of firearm ammunitions' ballistic properties and performance.

All firearms send a projectile toward a target in a like manner (Garrison 1993; Hueske 2006). The target is determined to be at a certain range, and there is a line of sight between the shooter and the target. When the bullet is fired from the firearm it has a line of departure, a bullet flight path, and an angle of fall which are affected by various physical forces, initial velocity, gravity, air resistance, wind direction, elevation, temperature, barometric pressure, and relative humidity. Each of these factors can be accounted for in one or more ballistic formulae that are used to calculate, with reasonable accuracy, how far the bullet will go before reaching a terminal velocity and return to earth. Likewise, formulae exist to calculate how much energy as foot pounds or joules, or kinetic energy a bullet will have at various ranges (Warlow 2005:130-134). These data become important to understanding bullets' ability to incapacitate or kill, or what may happen to a bullet that is an under or overshot. Knowing this basic information allows the archaeologist to better understand the pattern of bullet deformation observed on a battle site, the patterns in which bullets are found, and better interpret an artifact assemblage.

External ballistics for post-1900 firearms and bullets are well known and are the continuing subject of analysis as new smokeless gun powders and conical bullets are developed. Datasets on external ballistics and bullet performance are limited for the soft lead spherical balls and cylindro-concodial bullets of the preceding centuries, especially the spherical lead ball. A great deal of lore and apocryphal information exists on the ranges and performance of these historical bullets. There are good summaries of test shooting, largely at pine boards and thick catalogs or telephone books (Mattoo 1969; Cayton 1984; Fadala 1988; Osborne 1777a, b; Herring 1971; 1972a, b, c), to determine bullet penetration at various ranges that were conducted in the nineteenth century and well into the twentieth century. This data is of limited value to modern researchers. Thus, it becomes necessary to conduct firsthand live-fire research with a variety of weapons under controlled experimental conditions to ascertain the behavior of spherical bullets and other projectiles that will enhance our understanding of lead bullet behavior of the pre-1900-era.

The background for twentieth century studies of pre-nineteenth century bullet performance is summarized for comparative purposes. An anecdotal study of a live-fire experiment using a circa 1600 German-made combination matchlock and wheellock .75-caliber (19mm) musket was done in the early 1950s (Grancsay 1954). The experiment used a 430 grain (27.9 grams) lead ball with 80 grains (5.1 grams) of black powder which is approximately one-fifth the weight of the ball as prescribed in historical narratives. The experimenters fired the weapon at 10 feet (3 meters) at several pieces of original armor plate. A thin mild-steel Italian shoulder defense plate dating to about 1575 was easily penetrated by the bullet. Another experiment employed a German circa 1620 buttock defense armor. The ball struck the armor near the top edge and the metal was shot away, while an experimental firing against an early 1600s German heavy armor backplate resulted in only a slight dent to the armor. The author noted the ball disintegrated on impact with the heavy armor.

Late-twentieth century well-controlled live-fire experiments with historic and reproduction firearms are limited. One such live-fire study is reported by Krenn et al. (1995) employing original matchlock, wheellock, and flintlock muskets and pistols held in the provincial arsenal at Graz, Austria. The test involved fourteen firearms dating from 1571 to about 1800. The experiment used modern rifle grade black powder with the powder charge calculated to be one-third the weight of the lead ball used in the specific weapon. The calibers range from .539-inch (13.7mm) to .811-inch (20.6mm). The bullet diameters and weights allowed for windage, but bullets were specifically cast for each barrel diameter, ranging from .531-inch (13.5mm) to .795-inch (20.2mm) in diameter and 147.5 grains (9.56 grams) to 758.3 grains (49.14 grams) in weight.

The powder charges ranged from 77 grains (5 grams) to 309 grains (20 grams) of black gunpowder. For safety reasons the guns were fired electrically thus no loss of pressure occurred through the touchhole. The authors do not report if the gunpowder charges were reduced by 10 to 15 grains to account for priming in the pan. Every bullet fired achieved supersonic speeds ranging from 1263 f/s (385 m/s) to 1748 f/s (533 m/s) suggesting they used a full charge without consideration of reducing the main charge to account for priming. This coupled with the loss of pressure at the touchhole due to the electrical firing probably artificially inflated the recorded muzzle velocities.

Krenn et al. (1995) do not report recovering or examining any bullets except those fired at a modern steel plate and historic mild-steel breastplate armor as well as test fires into ballistic soap (10%). The study concluded that while the bullets had lethal capacity the arms themselves were inaccurate at ranges above 25 meters.

In 1998, the Royal Armouries in Leeds, England conducted a live-fire test of a fifteenth century matchlock musket and a handgun of the same century for the filming of a documentary (Richardson 1999:50-52). The description of the experiments is limited with no information presented on the type of gunpowder used, how the weapons were fired, if the priming amount was subtracted and a host of other details. The handgun was fired with a 50 grain (3.24 grams) black powder charge of unspecified size and a .615-inch (15.6mm) diameter lead ball with an average muzzle velocity of 590.7 f/s (180.05 m/s). The matchlock, or arquebus, was fired with 50 grain (3.24 grams), 65 grain (4.2 grams), and 90 grain (5.83 grams) black powder charges of unspecified size. These resulted in muzzle velocities of 1242.3 f/s (378.65 m/s), 1443.7 f/s (440.05 m/s), and 1706.4 f/s (520.10 m/s) respectively. Penetration tests were conducted against 2mm, 4mm, and 6mm thick mild-steel plates with the arquebus. The arquebus bullets pierced the 2 and 4mm plates but just failed to penetrate the 6mm mild-steel plate.

A well-controlled experiment using a modern .75-caliber (19mm) diameter barrel to replicate the caliber of an eighteenth century Brown Bess musket was conducted by Roberts et al. (2008). They (Roberts et al. 2008:4) summarize eighteenth and nineteenth century experiments that suggest the Brown Bess achieved muzzle velocities of 1500 f/s (457.2 m/s) on a regular basis. They did note that gunpowder of the era could be variable in quality and the resulting burn rates and gas pressures were likely to result in muzzle velocities different from the ideal.

Roberts et al. (2008:7-10) fired the barrel using an electrical matchhead placed in the flash pan. They used a replica rolled paper cartridge with various powder charges ranging from 116 grains (7.5 grams), 154 grains (10 grams), and 231 grains (15 grams) and a .691-inch (17.4mm) lead ball. The experiment's purpose was to reach a muzzle velocity of 1500 f/s (457.2 m/s). The gun powders used were a 3A fine which is a military designation for special purpose black gunpowder and is roughly the equivalent of the U.S. FFFg black gunpowder, G12 which is roughly equivalent to U.S. Fg gunpowder, and coarse blasting powder. Each has a different burn rate resulting in different internal pressures.

The loading and firing process did account for priming the pan. They deducted 10 grains (0.65 grams) from each charge for priming. The experiment fired 21 shots using three different gunpowder granulations. The firings resulted in a range of velocities based on powder charges of 427 f/s (130.2 m/s) to 1685 f/s (513.9 m/s). The range of velocities achieved using a 154 grain (10 gram) powder charge is of more direct interest and value to our experiment as it is the closest to the 110 grain charge used in our experiments. The 3A fine gunpowder 154 grain charge resulted in firings producing 1032.5 f/s (314.7 m/s), 925.8 f/s (282.2 m/s), and 672.2 f/s (204.9 m/s). The G12 gunpowder charge of 154 grains resulted in muzzle velocities of 427.16 f/s (130.2 m/s), 691.3 f/s (210.7 m/s), and 1080.4 f/s (329.3 m/s). The Blasting grade powder at a 154 grain charge achieved muzzle velocities of 363.2 f/s (110.7 m/s), 454 f/s (138.4 m/s), and 612.2 f/s (186.6 m/s).

Roberts et al. (2008:20) concluded that at 1500 f/s (427.2 m/s) a bullet fired at an elevation of 35 degrees would travel 3937 feet (1200 meters) or if fired horizontally would travel 663 feet (202 meters). Their work also included calculating wound effects using ballistic gelatin and penetration studies of replica eighteenth century armor. They found the 1500 f/s bullet penetrated the armor and simulated human arm tissue and bone at 150 yards (137 meters). They observed that a shot would drag fragments of clothing into the wound as well as shatter human bone. They concluded that the Brown Bess ball would most certainly have significant wounding and lethal effect at traditional combat ranges of 100 yards (91 meters) and 75 yards (69 meters) if it was traveling at 1500 f/s (457.2 m/s).

Lucien Haag (personal communication March 28, 2015) did more recent controlled replica Brown Bess experimental firings. In these tests, Haag used a .72-caliber (18.29mm) Brown Bess with a .718-inch (18.23mm) diameter lead ball with a cotton patch. He used 100 grains (6.4 grams) of Goex FFg black powder. The firings resulted in a muzzle velocity of 951 f/s with 1108.3 ft-lbs. (337.8m) of energy at the muzzle. At 200 yards (183m) the muzzle velocity dropped to 668.4 f/s (203.7m) and the energy to 547.6 ft-lbs. (167m/). The bullet is calculated to have dropped 100.55 inches (2.55m) over 200 yards (183m). The highest muzzle velocity reported was 1168 f/s (356m/s) with 1671 ft-lbs. (509m/s) of energy at the muzzle. At 200 yards (183m) the bullet had slowed to 747.8 f/s (228m/s) and the energy dropped to 685.3 ft-lbs. (209m/s). The bullet drop was calculated at 75.64 inches (1.921m) at 200 yards (183m).

Haag (personal communication March 27, 2015) also fired a high-quality replica of a British Ferguson rifle. His test firings used a .650-inch (16.5mm) lead ball weighing 402 grains (26 grams). The powder was Goex brand of 60 grains (3.88 grams) mixed from FFg and FFFg in equal proportions. The firing produced several shots that exceeded the speed of sound, with one reaching 1237.9 f/s (377.3m/s). He also fired .610-inch balls (16.4mm) with FFFg Swiss black powder with muzzle velocities at 1000 f/s (304m/s) and below.

Mike Willegal in his 1999 online Brown Bess accuracy analysis reports the British Brown Bess cartridge contained 6 to 8 drams of black powder which is equivalent to 165 (10.69 grams) to 220 grains (14.25 grams). He recognizes that some of that load is required to prime the flash pan. He evaluated two different granulations of black powder using an American Civil War Minié ball, presumably a .58-inch (14.7mm). He found that in one case that 20 grains (6.1 grams) of powder produced a muzzle velocity of slightly less than 400 f/s (122m/s) and by increasing the charge up to 140 grains (9 grams) of powder he achieved a muzzle velocity of 1200 f/s (366m/s). His second black powder of a different size using a 50 grain (3.2 grams) charge up to a 130 grains (8.4 grams) charge resulted in muzzle velocities of just over 600 f/s (182.8m/s) to nearly 1400 f/s (476.7m/s). He does not specify which grade or size of black powder he used in his experiments.

Willegal’s primary goal was to model musket accuracy and range. He calculated how the .75-caliber (19mm) Brown Bess using a .69-inch (17.5mm) ball would drop at 1000 f/s (304.8m/s), 900 f/s (274.3m/s), 800 f/s (243.8m/s), and 700 f/s (213.3m/s). He determined the drop to be from an average of 20 feet (6m) if fired at 1000 f/s (304.8m/s). His point is that for a shot to hit a target at 300 yards (274.3m) the gun would have to be aimed at a point 20 feet (6m) and 7.2 inches (18.2cm) above the target. Conversely at 75 yards (68.5m) the bullet is expected to drop only 22 inches (55.9cm) with a muzzle velocity of 1000 f/s (304.8m/s). The slower the muzzle velocity the greater the drop over distance. He cites Gibbon (1860) in describing the variation in drop of .69-caliber (17.5mm) musket shots at 200 yards (182.8m) being from 36 inches (91.4cm) to 54 inches (1.37m). Willegal concludes his analysis by stating the Brown Bess musket was unlikely to be effective beyond 150 yards (114m) given the reality of field conditions and general lack of target practice by armies of the eighteen and early nineteenth centuries.

Results of Live-Fire Experiment and General Observations

The live-fire experiment collected a significant amount of controlled data on muzzle velocity, bullet penetration, and bullet deformation from seven different flintlock firearms that represent the common colonial and Revolutionary War firearms. The data is presented in both quantified and qualitative forms. Additional observations are presented that are relevant to shooting incident reconstruction. Archaeologists often recover impact deformed lead balls from colonial-era sites. The live-fire experiment data enhances the capability to understand archaeological lead ball finds as well as the distribution pattern and context in which they found. An appreciation of how a bullet found its way into the ground as determined by this and other studies allows for better archaeological interpretation of the site or event being investigated.

Laid Cartridge Paper Observations

The laid paper cartridges were nearly fully combusted during the firing. The high-speed video confirms that cartridge paper did not fully combust in the barrel during firing, but numerous fragments were expelled with the gases, and most combust before reaching the ground. Fragments of laid cartridge paper are clearly seen in the videos being expelled down range from the barrels. Incompletely consumed cartridge paper pieces were found 15 feet to 30 feet down range from the shooting bench. In one case, about 30 feet from the bench, a piece of smoldering cartridge paper caused a grass fire that was quickly extinguished. The burn area was about 12 inches in diameter. Historically, the same phenomena were observed after shooting events. Lines of shooters have been interpreted from the discarded cartridge ends and fires are known to have been started by gun fire. Archaeologically the evidence for fires, cartridge paper, and cartridge tails or ends is not likely to survive. However, a careful vetting of oral history and historical documentation may reveal similar phenomena and coupled with surviving artifact patterns may allow for identification of potential firing lines.

Figure 17. French Model 1763/66 musket being fired. Note the laid cartridge paper debris and the buck and ball in the center right of the debris field.

Figure 18. Bits of unburned laid cartridge paper in the duff.

Figure 19. Tails of laid paper cartridges lay strewn on the ground at the site where the muskets were loaded.

Lead Ball Ranges as a Function of Velocity and Energy Loss

When a bullet is fired, it achieves an initial maximum velocity then begins to deaccelerate due to energy loss as a function of drag or resistance, and of course, gravity. Bullets have a maximum range they can travel before all energy and forward momentum is lost. However, bullets often fail to reach that maximum range due to hitting a target or another media. They also fail to reach maximum range as a function of the angle at which the shot was fired, was the barrel level to the ground or elevated? An elevated barrel will send the bullet further down range than a horizontally aimed barrel simply due to physics. The less velocity a bullet has when it drops to the ground the less deformation is likely to occur. This information is important to shooting event reconstruction such as determining if the recovered bullets are on or near a firing line or simply under or over shots. The live-fire experiment data helps to address these questions in several ways.

During the live-fire experiments, shooting ranges were 94 yards for the first series and then reduced to 25 and 30 yards for buck and ball firing. Shooting into ballistic gel was done at 25 yards.

In dry air at 20 °C (68 °F), the speed of sound is 343 meters per second (1,125 ft/s; 1,235 km/h; 767 mph). The speed of sound is a function of air density at the local site and will vary with location. The range site weather conditions during the live-fire experiment are consistent with the speed of sound being 1125 f/s (343 m/s).

The live-fire experiment used seven flintlock firearms. The black powder charges were either 110 grains for the British and French muskets, British Royal Artillery Carbine, and the Model 1740 Potsdam musket or 85 grains for the Thomas Earle fowling piece. Reduced charges were also used during the ballistic gelatin experimental firing to capture the bullet in the gelatin.

The Thomas Earle fowling piece, .62-caliber, using a rolled cartridge with a .520-inch ball, achieved a muzzle velocity range of 1160 to 1345 f/s with average initial muzzle velocity of 1259.3 f/s. The fowling piece was also fired using a .580-inch unpatched (loose) ball which resulted in a muzzle velocity range of 1415 to 1480 f/s with an average muzzle velocity of 1444 f/s. A three shot string using buckshot was also fired with 85 grains of black powder. The first shot used a .58-inch ball and three .282-inch buckshot that had an initial muzzle velocity of 655 f/s. The second buckshot firing used 6 - loose .282-inch buckshot also resulted in a muzzle velocity of 655 f/s. The third shot used 6 - loose .282-inch buckshot. On this shot the muzzle velocity varied for the buckshot. The first three buckshot exited the muzzle as a group and achieved 495 f/s, the second two buckshot were closely spaced but achieved only 240 f/s, and the third buckshot was slower yet at 230 f/s. Except for the buck and ball shot and the two buckshot all single ball shots exceeded the speed of sound.

The external ballistic calculations indicate the .520-inch, and .580-inch balls would travel the farthest and have greater penetration capability at greater ranges than the larger caliber bullets used in this experiment. See the graphs for the bullet drop calculations that emphasize this point.

The British Royal Artillery carbine, .65-caliber, firing a .580-inch ball also exceeded the speed of sound for eight of its ten shots. The initial muzzle velocity ranged from 960 f/s to 1335 f/s with an average of 1018 f/s, which is below the speed of sound. It is notable that the two shots that were well below the speed of sound resulted in dropping the average muzzle velocity for all shots to less than the speed of sound. Like the fowling piece, the carbine balls would go further and have greater penetration capability than the larger caliber muskets. This can be observed in the bullet drop graphs.

The British Pattern 1742 Long Land musket, .76-caliber, was fired five times using a 110 grain charge with a paper patched .69-inch ball. The muzzle velocity ranged from 780 to 870 f/s with an average velocity of 822 f/s. All shots were less than the speed of sound and had far less range as can be observed in the drop graphs.

Figure 20. The British Pattern 1742 Long Land musket during the live-fire with flame and smoke being discharged from the muzzle, cartridge paper and the ball shown right of the smoke column.

The French Model 1728/41 musket, .70-.71, has a slightly oval bore and was fired 5 times with a 110 grain charge with a paper-patched .626-inch ball. This shot string ranged in muzzle velocity from 775 to 960 f/s with an average muzzle velocity of 870 f/s. Like the British Pattern 1742 Long Land the French Model 1728/41 did not reach the speed of sound. One reason for not reaching the speed of sound may be the oval bore at the muzzle. This shape may not have allowed the balls to fully conform to the bore which, including windage, allowed more gas to escape around the balls during firing. Such an event would lower the gas pressure and the bullet velocity.

The French Model 1763/66 musket, .68-caliber, using a 110 grain charge with a .626-inch ball. It was fired 15 times with paper patched buck and ball loads. The three buckshot were .282-inch and the ball .626-inch. The 15 shots had a muzzle velocity range of 865 to 1215 f/s. Eight of the fifteen shots were sub-sonic with an average muzzle velocity below Mach 1 at 1009 f/s. The muzzle velocity range is wide for this gun and is probably due to the amount of windage between the .68-caliber bore firing a .626-inch ball. Since 7 shots did exceed the speed of sound, and all variables were held constant between the Model 1728/41 and the Model 1763/66 French muskets, this helps support the contention that the earlier style musket with the oval bore shape influenced the lower muzzle velocities seen in that shot string.

The Hessian style Model 1740 Potsdam musket is .73-caliber. It was fired five times with a 110 grain charge and a .662-inch ball. Like the British Pattern 1742 and the French Model 1728/41 muskets the muzzle velocity did not achieve Mach 1. It ranged from 712 to 858 f/s with an average of 817 f/s.

Ball Velocity and Calculated Bullet Drop Ranges

The initial muzzle height above ground, muzzle velocity, along with ambient air temperature, wind speed, site elevation, and humidity were then used to calculate external ballistics data using the Round Ball Ballistics Calculator found online (http://www.ctmuzzleloaders.com/ctml_experiments/rbballistics/rbballistics.html) and downloaded to a hard drive. Comparison with other ballistic calculators including the Sierra Infinity-6 and Shooters Calculator.com indicates the ball velocity, energy, and time calculation are within 1% (usually 1% less) of the various programs.

Using the Round Ball Ballistic Calculator the data were entered for each shot using muzzle height above ground as a dependent variable. The amount of bullet rise and/or drop was then calculated for each round at 25 yards, 35 yards, and 100 yards to simulate known combat ranges. Graphs were output through the calculator for minimum and maximum velocity for each gun type. The following graphs provide a visual summary of when a ball is likely to hit the ground given the powder charge, its weight or mass, and initial muzzle velocity. For each graph the Velocity is expressed as feet per second (f/s), Energy loss is expressed as foot pounds of energy (fpe), the X axis is range in yards, and the Y axis is velocity as f/s and energy as fpe.

It is important to note when fpe drops below the 300 to 200 fpe range the potential for lethal wounding is unlikely. Assuming the intended target is a human, the fpe needed to incapacitate is dependent on the age of the individual and the type of clothing being worn as well as the type of media the bullet strikes.

Each graph has a textual summary to aid in explanation of the data presentation.

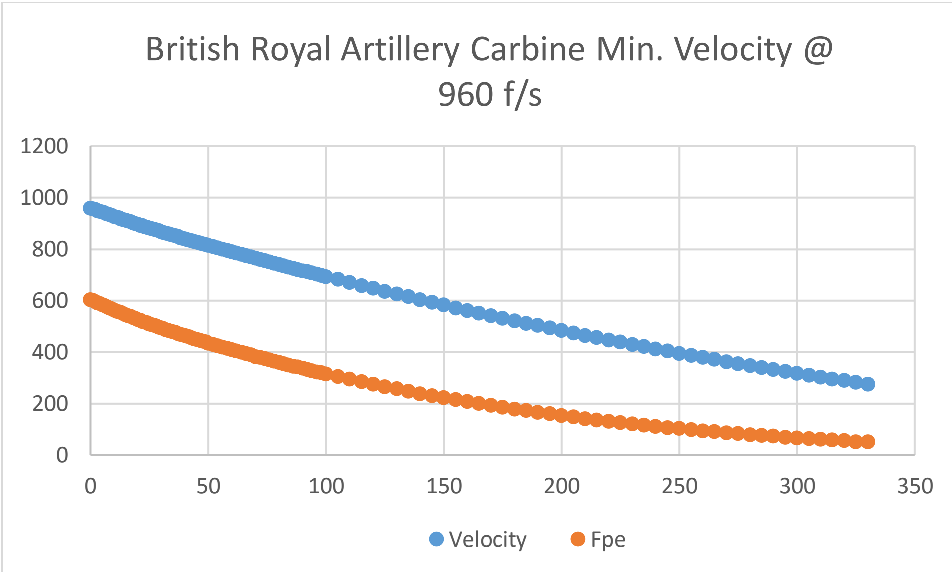

Figure 21. **British Royal Artillery Carbine -** .580-inch ball and 110 grain powder charge at 960 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.3 inches at 25 yards, 1.2 inches at 35 yards, and drop 14.6 inches at 100 yards then it is calculated to strike the ground at 150 yards.

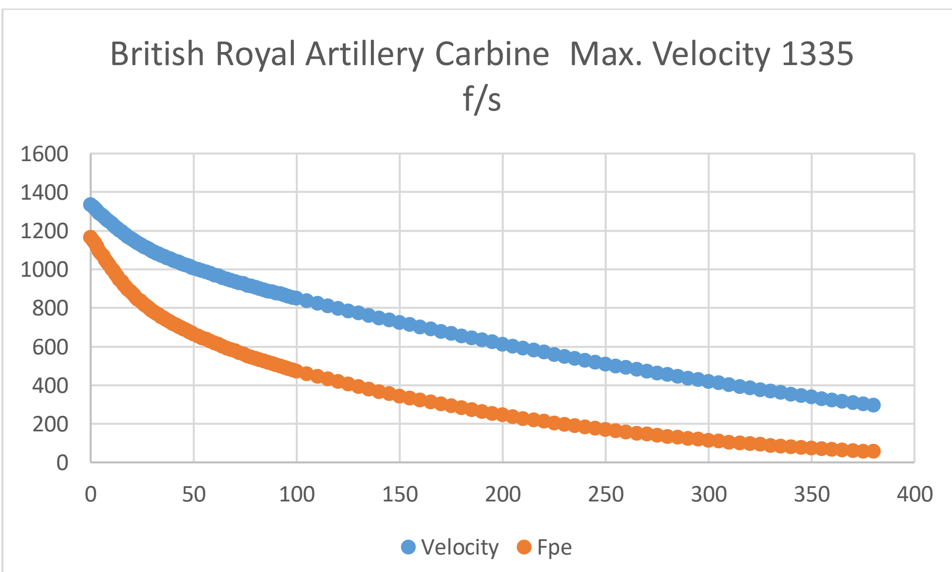

Figure 22. **British Royal Artillery Carbine** – .580-inch ball and 110 grain powder charge at 1335 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .7 inch at 25 yards, .7 inch at 35 yards, and drop 9.5 inches at 100 yards then it is calculated to strike the ground at 170 yards.

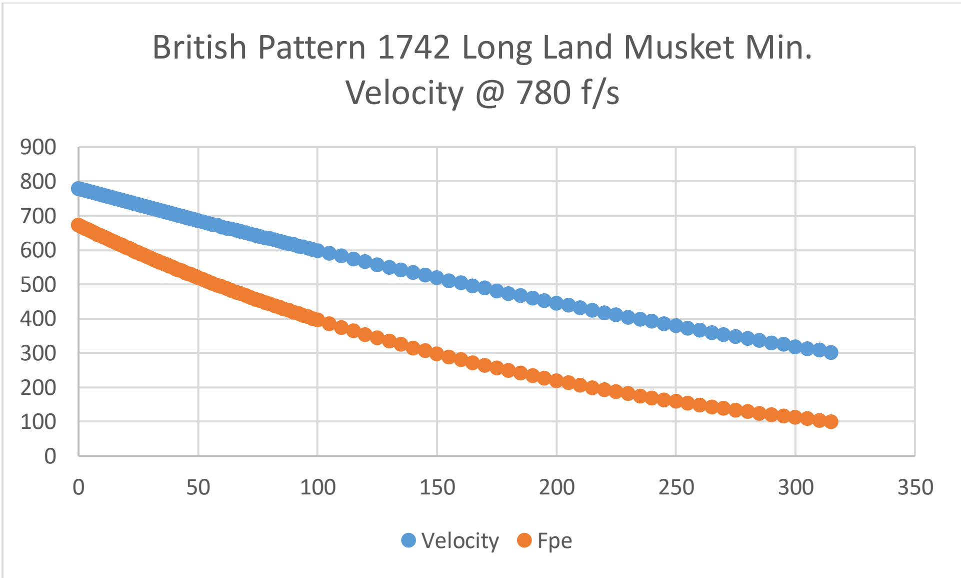

Figure 23. **British Pattern 1742 Long Land Musket -** .69-inch ball and 110 grain powder charge at 780 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.6 inches at 25 yards, 1.7 inches at 35 yards, and drop 20.2 inches at 100 yards then it is calculated to strike the ground at 135 yards.

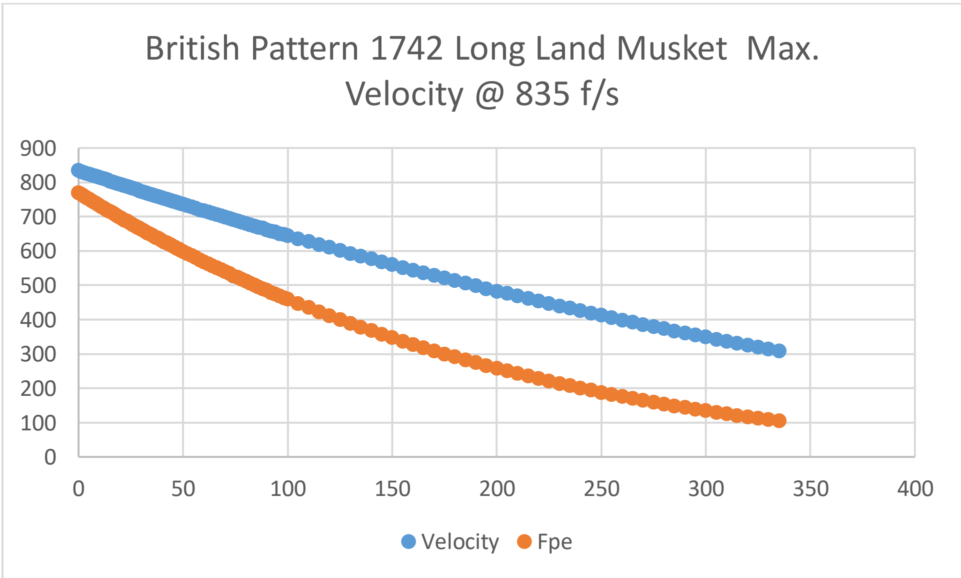

Figure 24. **British Pattern 1742 Long Land Musket -** .69-inch ball and 110 grain powder charge at 835 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.6 inches at 25 yards, 1.4 inches at 35 yards, and drop 17.5 inches at 100 yards then it is calculated to strike the ground at 140 yards.

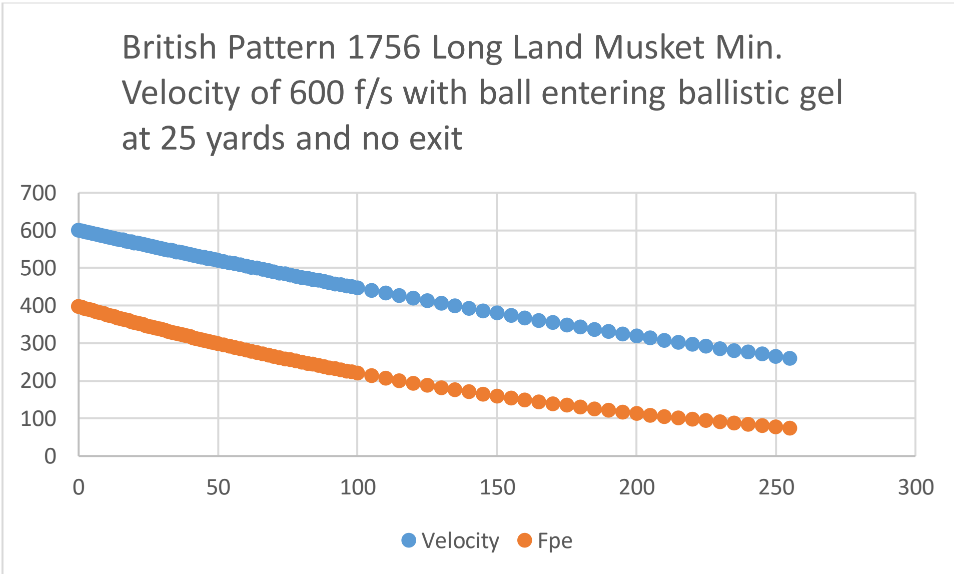

Figure 25. **British Pattern 1756 Long Land Musket -** .69-inch ball with 75 grain powder charge with a velocity of 600 f/s fired at 25 yards into Clear Ballistic gel with ball being retained in the gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 3.2 inches at 25 yards, 3.1 inches at 35 yards, and drop 36.4 inches at 100 yards then it is calculated to strike the ground at 110 yards.

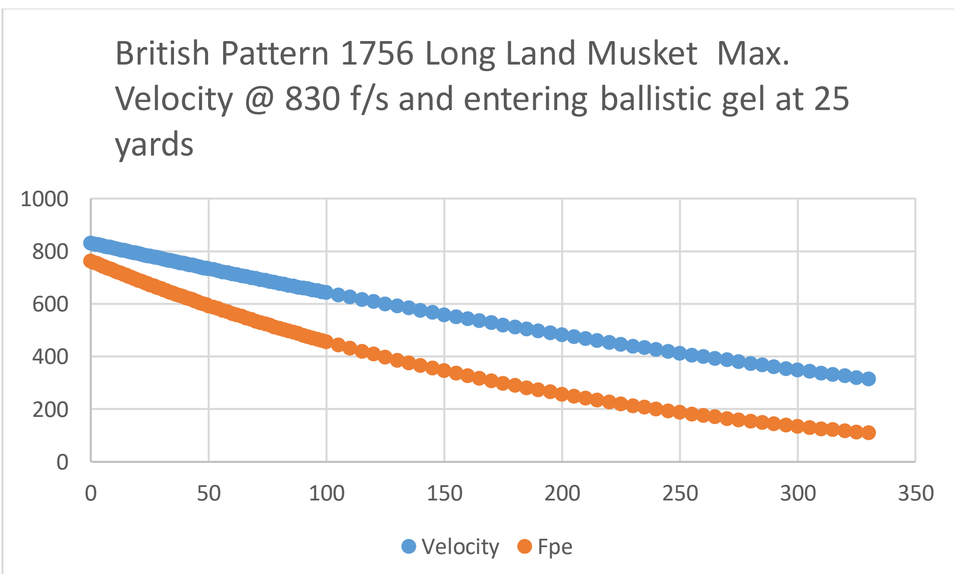

Figure 26. **British Pattern 1756 Long Land Musket -** .69-inch ball with 110 grain powder charge with a velocity of 830 f/s fired at 25 yards into Clear Ballistic gel with ball passing through 32 inches of gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.6 inches at 25 yards, 1.6 inches at 35 yards, and drop 17.8 inches at 100 yards then it is calculated to strike the ground at 140 yards.

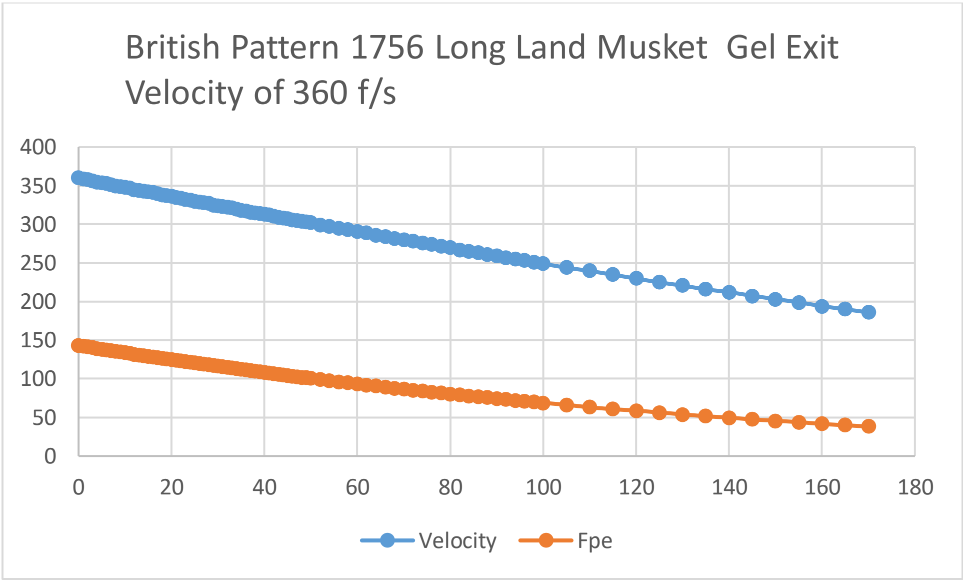

Figure 27. **British Pattern 1756 Long Land Musket -** .69-inch ball with 110 grain powder charge fired at 25 yards into Clear Ballistic gel with ball passing through 32 inches of gel. Ball exited gel at 360 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 10.6 inches at 35 yards, and it is calculated to strike the ground at 80 yards.

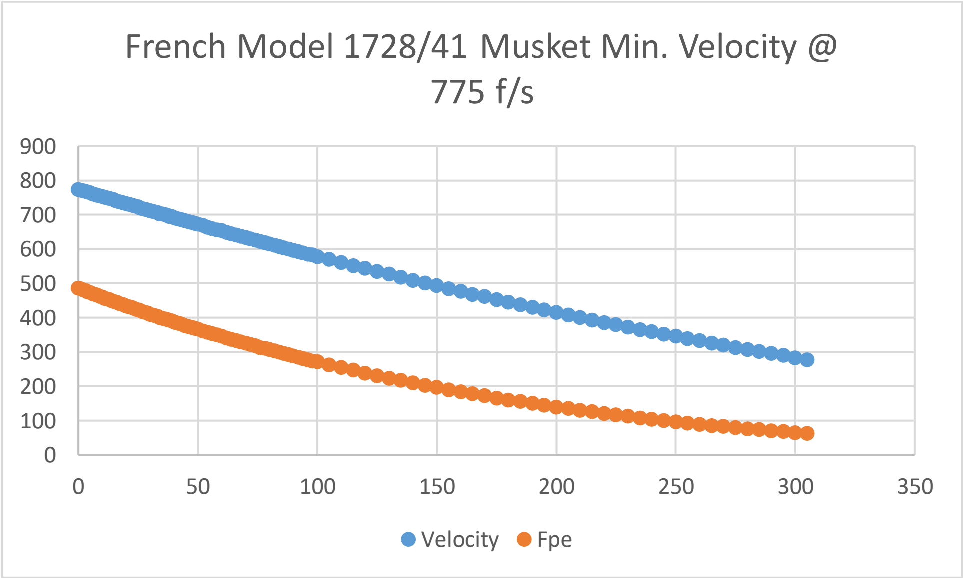

Figure 28. **French Model 1728/41 Musket -** .626-inch ball with 110 grain powder charge with a velocity of 775 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the calculated drop over distance indicates the ball is calculated to rise 2 inches at 25 yards, 1.7 inches at 35 yards, and drop 21.7 inches at 100 yards then it is calculated to strike the ground at 130 yards.

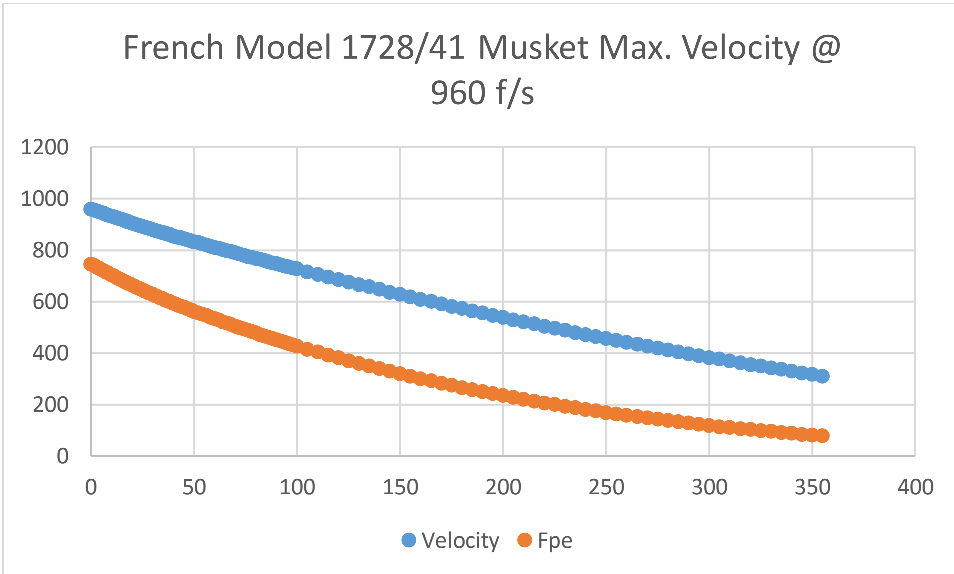

Figure 29. **French Model 1728/41 Musket -** .626-inch ball with 110 grain powder charge with a velocity of 960 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.2 inches at 25 yards, 1.1 inches at 35 yards, and drop 13.6 inches at 100 yards then it is calculated to strike the ground at 150 yards.

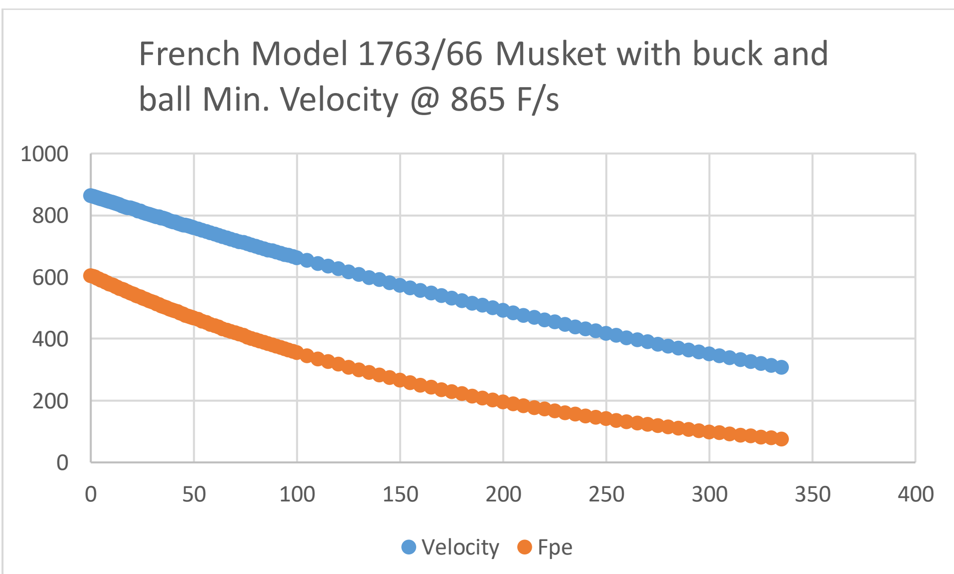

Figure 30. **French Model 1763/66 Musket -** .626-inch and 3 - .282-inch buckshot with 110 grain powder charge with a velocity of 865 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.5 inches at 25 yards, 1.4 inches at 35 yards, and drop 16.4 inches at 100 yards then it is calculated to strike the ground at 140 yards.

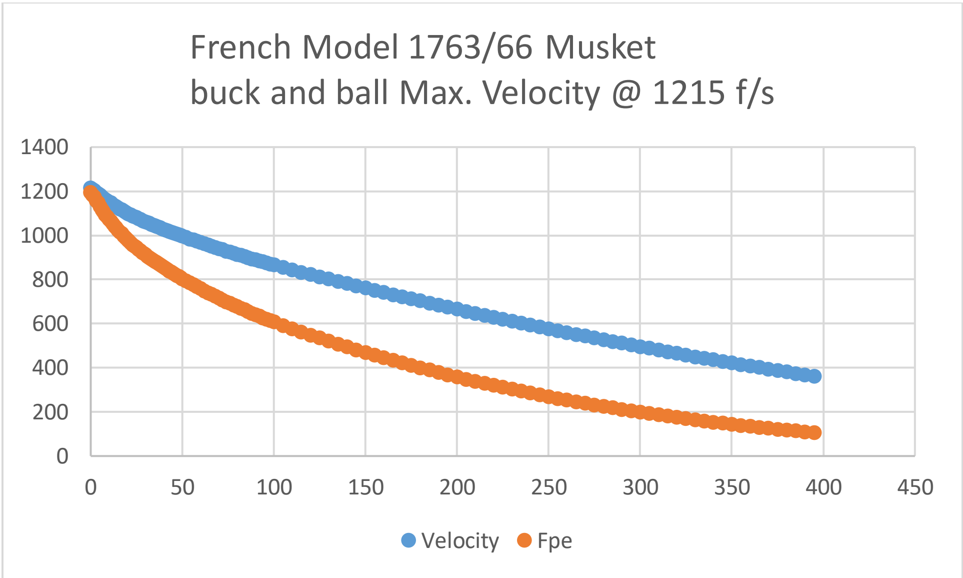

Figure 31. **French Model 1763/66 Musket -** .626-inch ball and 3 - .282-inch buckshot with 110 grain powder charge with a velocity of 1215 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .7 inch at 25 yards, .7 inch at 35 yards, and drop 9.4 inches at 100 yards then it is calculated to strike the ground at 175 yards.

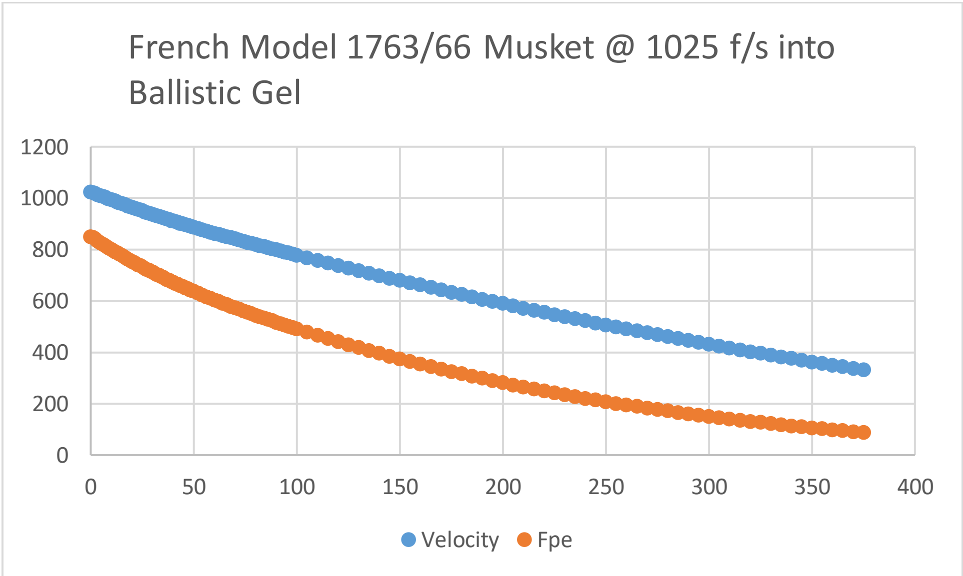

Figure 32. **French Model 1763/66 Musket -** .626-inch ball with 110 grain powder charge with a velocity of 1025 f/s fired into Clear Ballistic gel and passing through 32 inches of gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1 inch at 25 yards, .9 inch at 35 yards, and drop 11.9 inches at 100 yards then it is calculated to strike the ground at 160 yards.

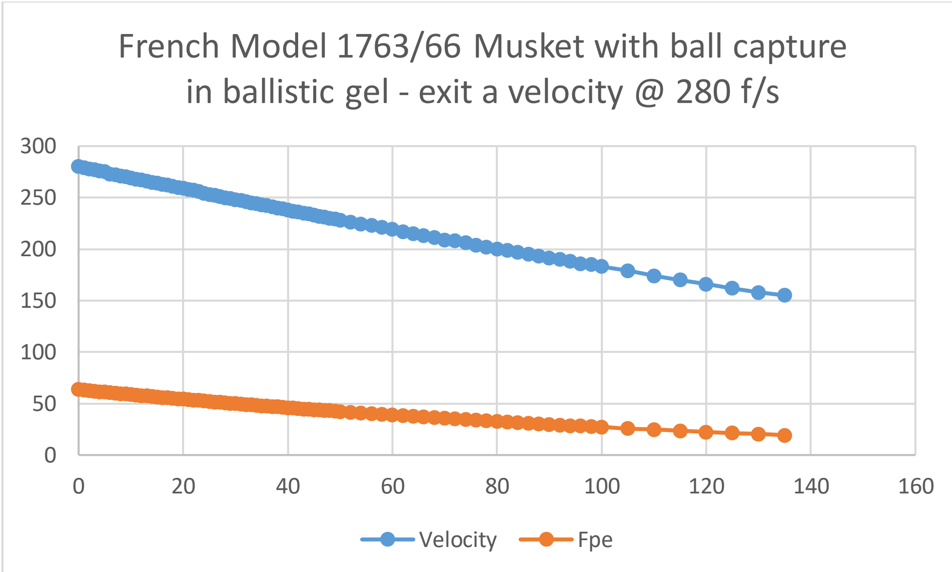

Figure 33. **French Model 1763/66 Musket -** .626-inch ball with 110 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with an exit velocity of 280 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 16.1 inches at 35 yards and drop 11.9 inches at 100 yards then the ball will strike the ground at 70 yards.

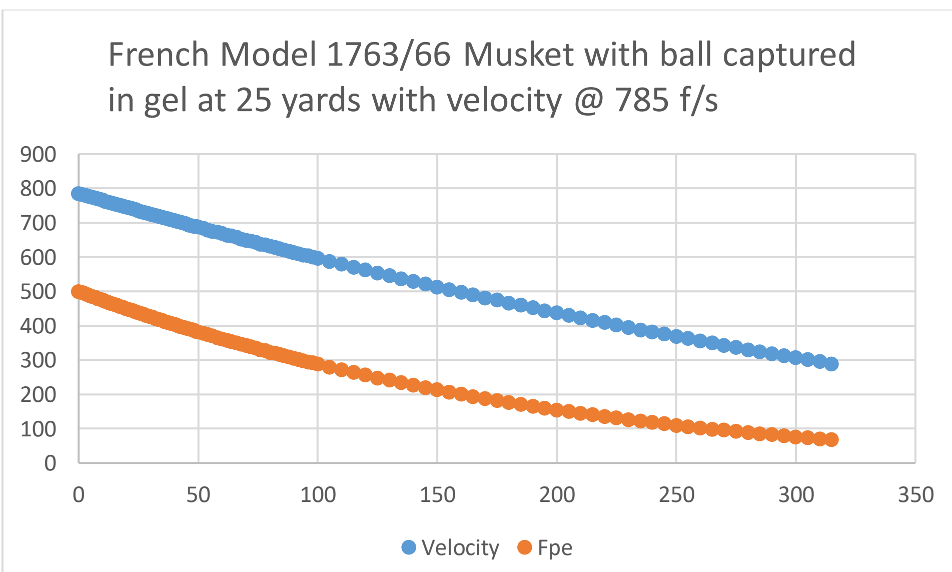

Figure 34. **French Model 1763/66 Musket -** .626-inch ball with 75 grain powder charge with a velocity of 785 f/s fired into Clear Ballistic gel at 25 yards, with ball retained in gel. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the calculated drop over distance indicates the ball would have struck the ground at 135 yards.

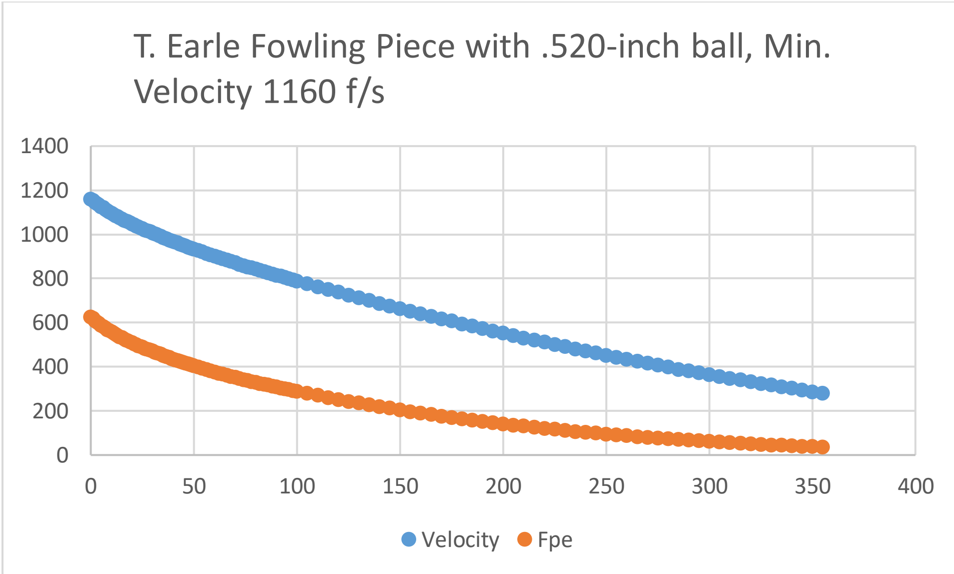

Figure 35. **Thomas Earle Fowling Piece -** .520-inch ball with 85 grain powder charge with a velocity of 1160 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .8 inch at 25 yards, .9 inch at 35 yards, and drop 11.4 inches at 100 yards then it is calculated to strike the ground at 160 yards.

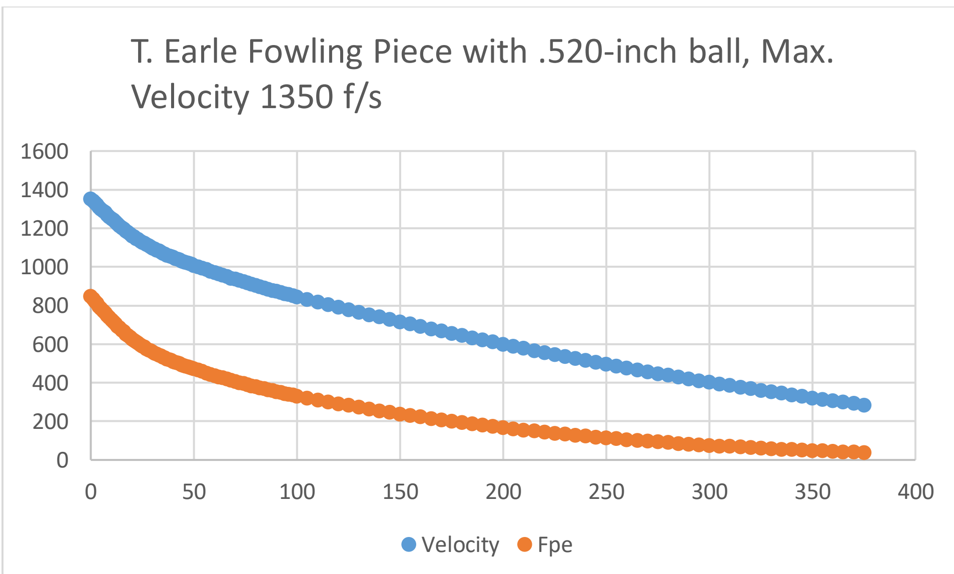

Figure 36. **Thomas Earle Fowling Piece -** .520-inch ball with 85 grain powder charge with a velocity of 1350 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .7 inch at 25 yards, .7 inch at 35 yards, and drop 9.8 inches at 100 yards then it is calculated to strike the ground at 170 yards.

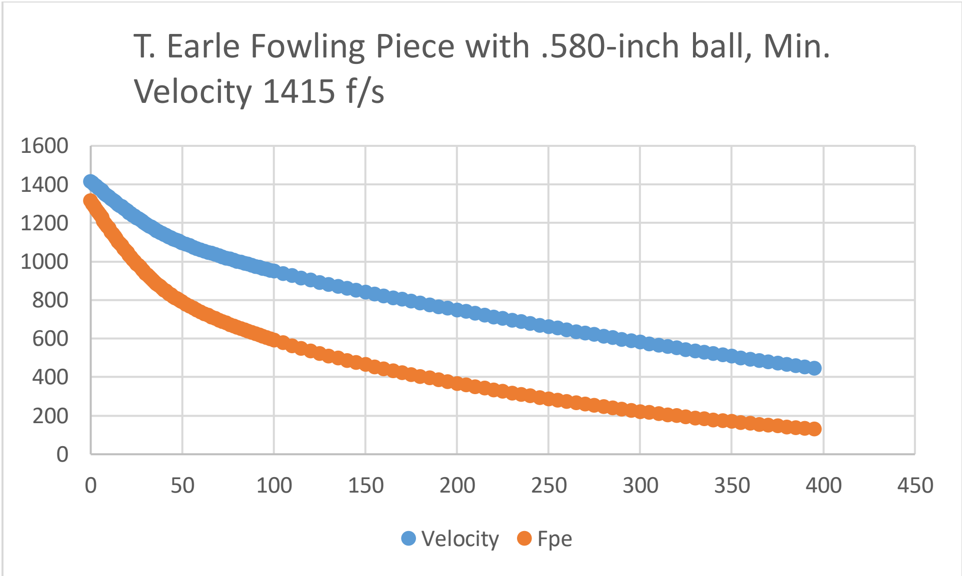

Figure 37. **Thomas Earle Fowling Piece -** .580-inch ball with 85 grain powder charge with a velocity of 1415 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .6 inch at 25 yards, .6 inch at 35 yards, and drop 7.9 inches at 100 yards then it is calculated to strike the ground at 185 yards.

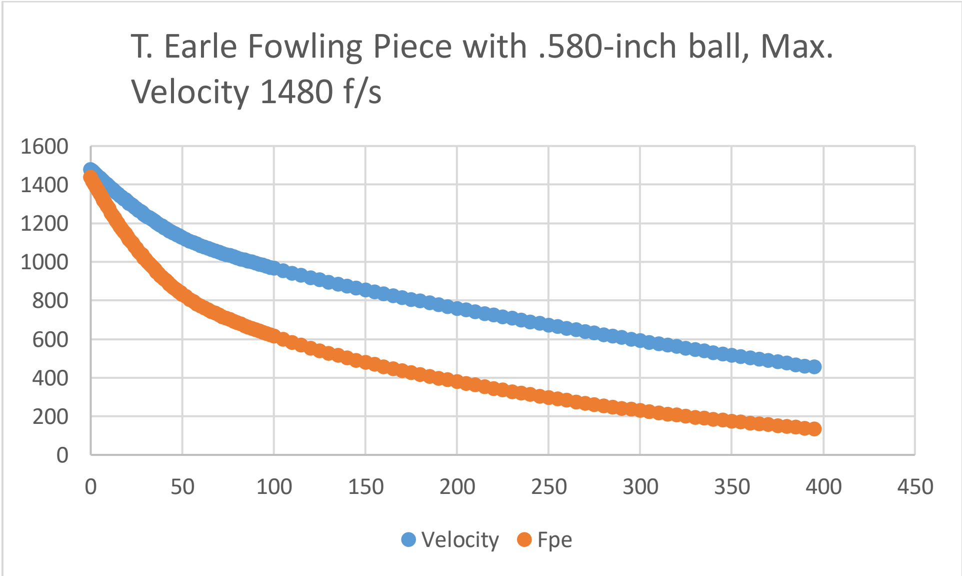

Figure 38. **Thomas Earle Fowling Piece -** .580-inch ball with 85 grain powder charge with a velocity of 1480 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .6 inch at 25 yards, .6 inch at 35 yards, and drop 7.5 inches at 100 yards then it is calculated to strike the ground at 185 yards.

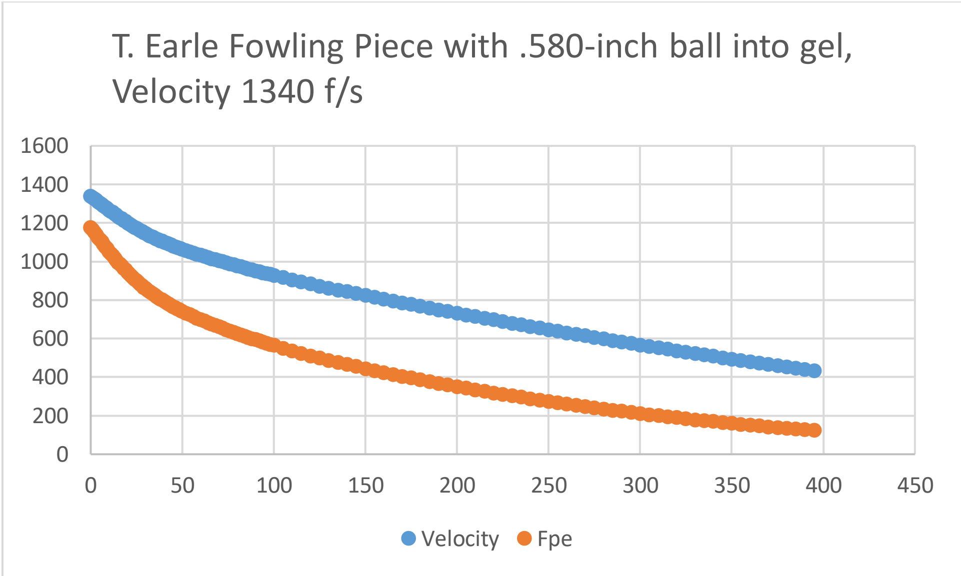

Figure 39. **Thomas Earle Fowling Piece -** .580-inch ball with 85 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with at a velocity of 1340 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .7 inch at 35 yards and drop 8.3 inches at 100 yards then the ball will strike the ground at 180 yards.

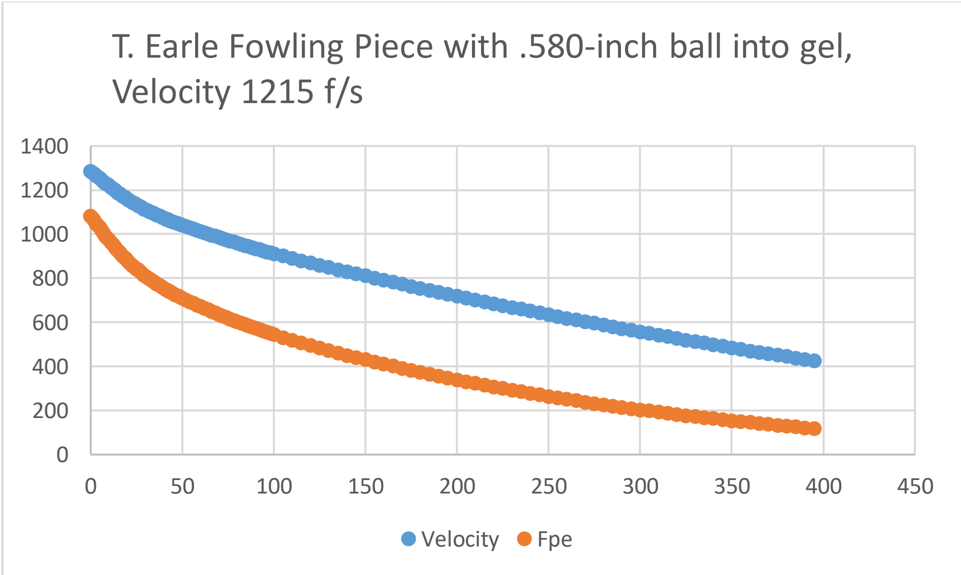

Figure 40. **Thomas Earle Fowling Piece -** .580-inch ball with 85 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with at a velocity of 1285 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .7 inch at 35 yards and drop 8.8 inches at 100 yards then the ball will strike the ground at 175 yards. Note: The graph legend incorrectly states the velocity as 1215 f/s, but it is correct in the caption at 1280 f/s.

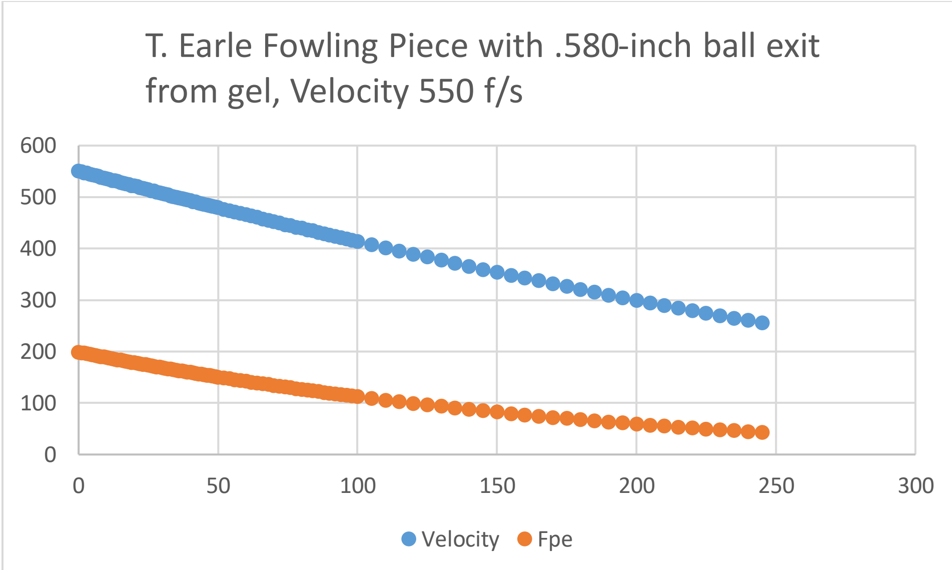

Figure 41. **Thomas Earle Fowling Piece -** .580-inch ball with 85 grain powder charge fired into Clear Ballistic gel at 25 yards, and passing through 32 inches of gel with an exit velocity of 550 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 3.7 inches at 35 yards and drop 43.1 inches at 100 yards then the ball will strike the ground at 105 yards.

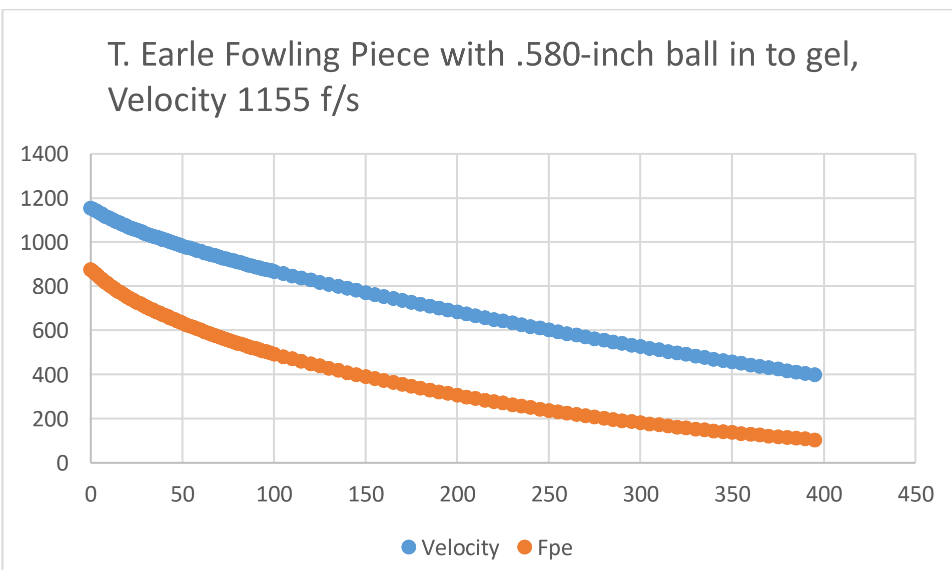

Figure 42. **Thomas Earle Fowling Piece -** .580-inch ball with 75 grain powder charge fired into Clear Ballistic gel at 25 yards at a velocity of 1155 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise .8 inch at 25 yards, .8 inch at 35 yards, and drop 9.8 inches at 100 yards then the ball will strike the ground at 170 yards.

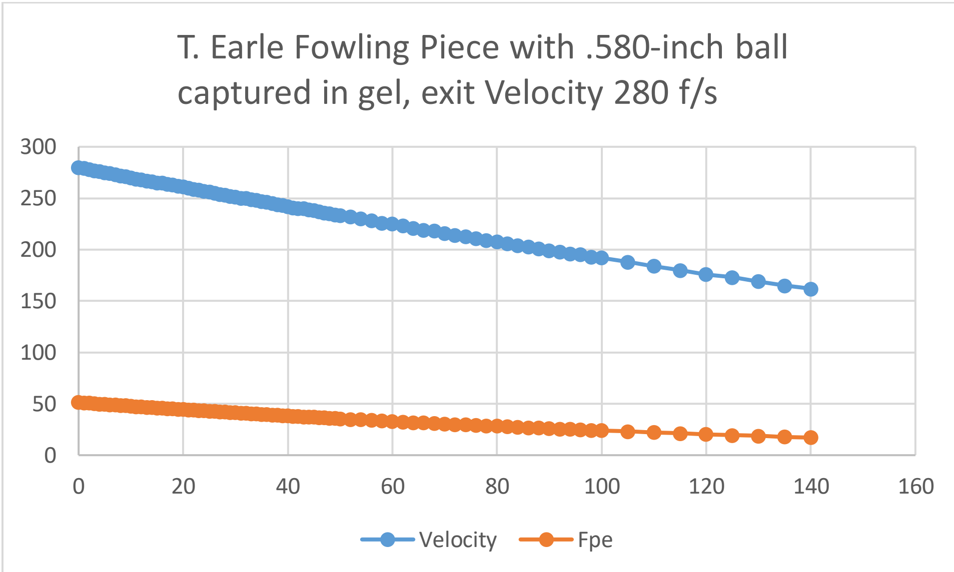

Figure 43. **Thomas Earle Fowling Piece -** .580-inch ball with 75 grain powder charge fired into Clear Ballistic gel at 25 yards with an exit velocity of 280 f/s, however the ball rebounded and was captured in the gel. Hypothetically with the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 15.7 inches at 35 yards then the ball will strike the ground at 70 yards.

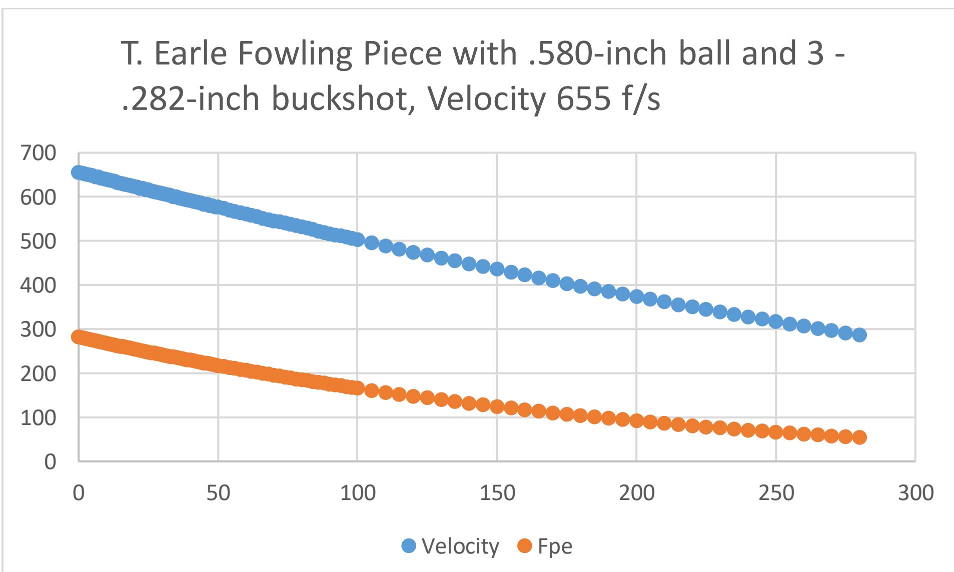

Figure 44. **Thomas Earle Fowling Piece** – .580-inch ball and 3 **-** .282-inch buckshot with 85 grain powder charge with a velocity of 655 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 2.9 inches at 25 yards, 2.5 inches at 35 yards, and drop 2.4 inches at 100 yards then the shot will strike the ground at 115 yards.

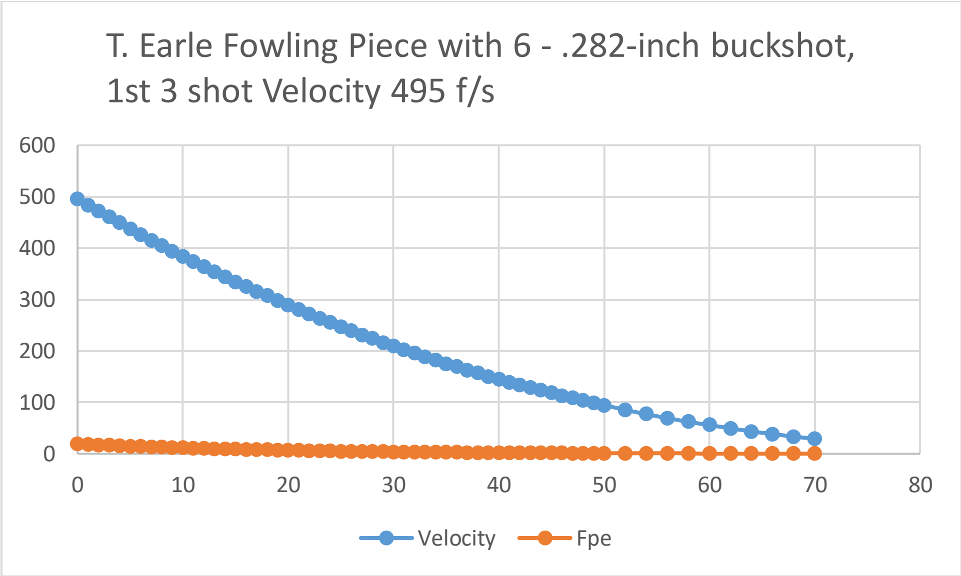

Figure 45. **Thomas Earle Fowling Piece** – 6 - .282-inch buckshot with 85 grain powder charge. The first 3 shots had a velocity of 495 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the shot is calculated to rise 39.7 inches at 25 yards, 43.7 inches at 35 yards, and the shot will strike the ground at 55 yards.

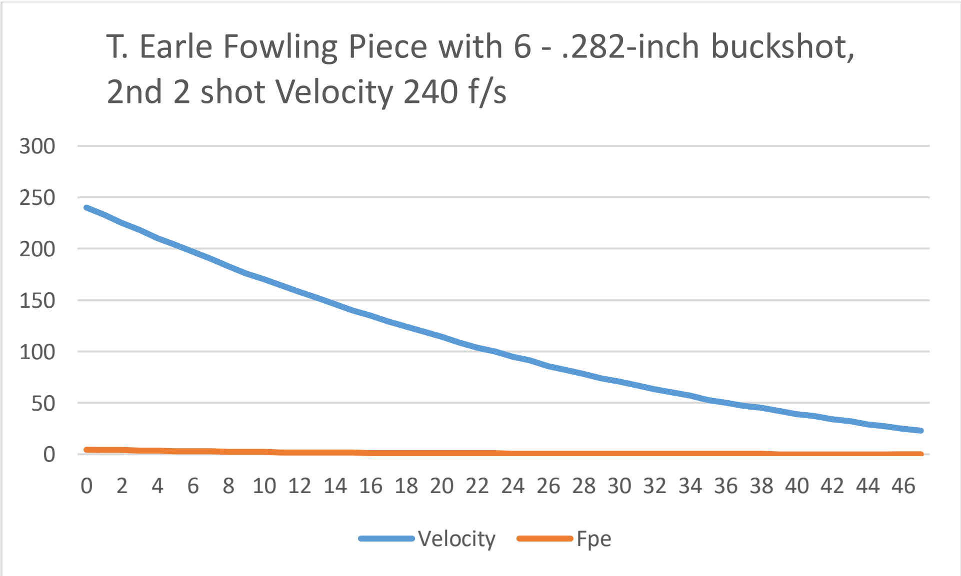

Figure 46. **Thomas Earle Fowling Piece** – 6 - .282-inch buckshot with 85 grain powder charge. The second 2 shots had a velocity of 240 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the shot is calculated to drop 43.6 inches at 25 yards and the shot will strike the ground at 26 yards.

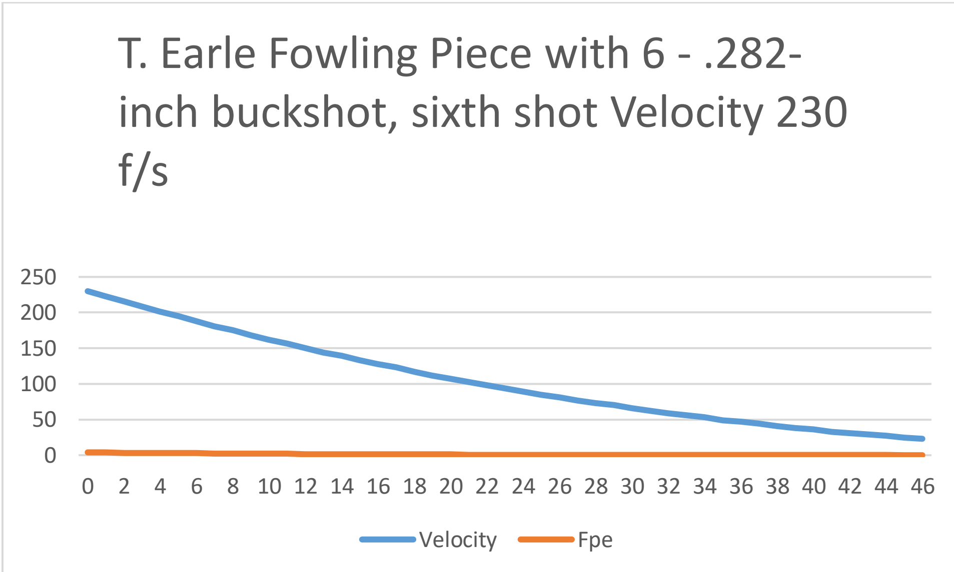

Figure 47. **Thomas Earle Fowling Piece** – 6 - .282-inch buckshot with 85 grain powder charge. The sixth shot had a velocity of 230 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the shot is calculated to drop 7.5 inches at 25 yards and the shot will strike the ground at 30 yards.

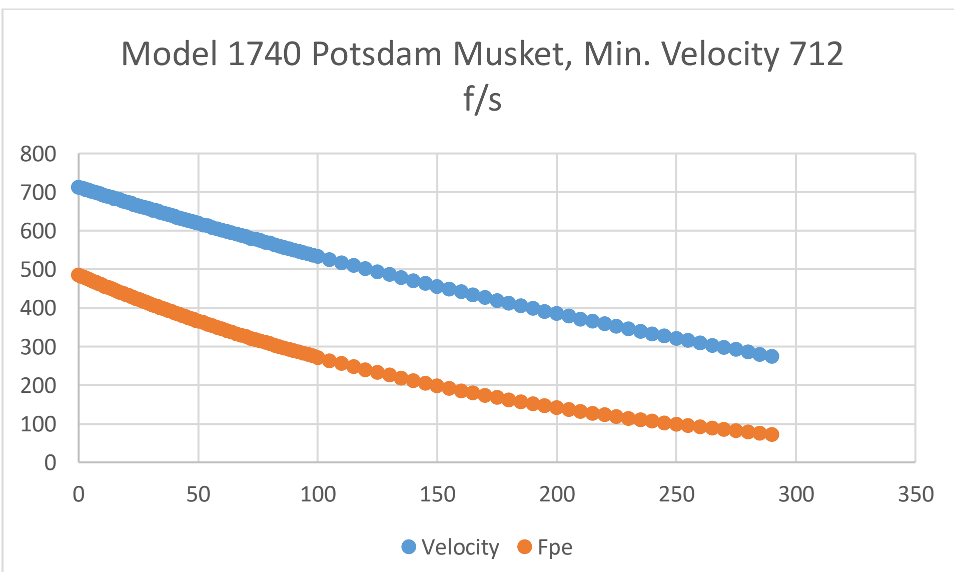

Figure 48. **Model 1740 Potsdam Musket -** .662-inch ball with 110 grain powder charge with a velocity of 712 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 2.2 inches at 25 yards, 2 inches at 35 yards, and drop 25.5 inches at 100 yards then it is calculated to strike the ground at 125 yards.

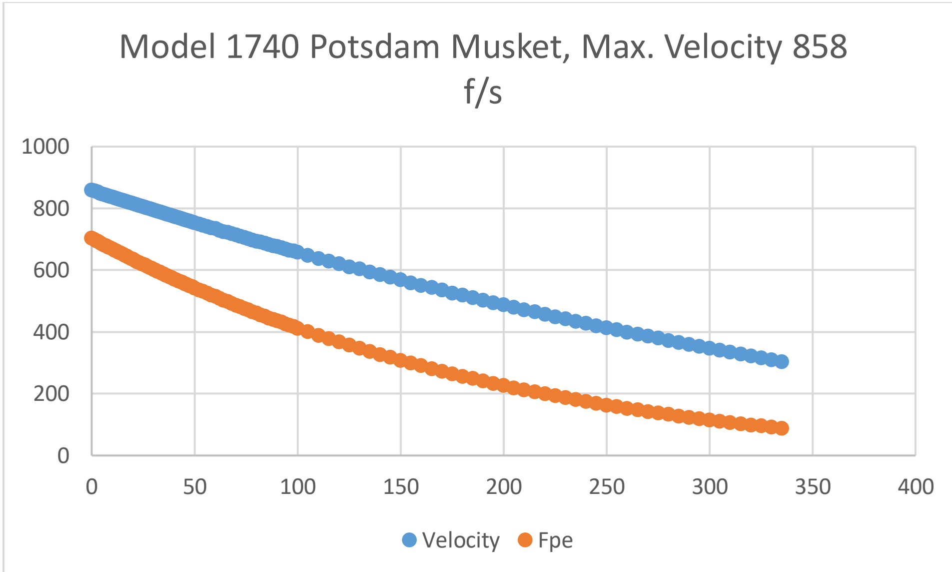

Figure 49. **Model 1740 Potsdam Musket -** .662-inch ball with 110 grain powder charge with a velocity of 858 f/s. With the barrel level (0 degree of elevation) and at an average of 49 inches above the ground the ball is calculated to rise 1.4 inches at 25 yards, 1.3 inches at 35 yards, and drop 16.6 inches at 100 yards then it is calculated to strike the ground at 140 yards.

Most recovered balls and buckshot struck some type of media before coming to rest. Most balls hit the sand backstop at the 94-yard range, a few struck and passed through the target frame, others struck and embedded in or passed through the wooden palisade behind the earth berm. Those bullets are discussed in the bullet penetration and deformation section. The few bullets that did not strike media and were recovered down range at or near ground surface represent those that dropped at the end of their flight path. The landform where the firing range was established slopes, very slightly, down, and away from the shooting bench. Past the palisade line the ground drops a bit more noticeably. That ground slope allowed bullets to travel farther than the predicted model suggested. While there is no one-to-one correlation with the caliber and muzzle velocity or where they dropped, bullets were recovered within a one or two standard error deviation of the predicted drop range.

Tissue Simulate Live Firing Results

Tissue simulants are materials that approximate the density of human tissue and approximate the penetration resistance of soft tissue (Boackle 2011). Bullets fired into tissue simulants create a temporary and a permanent wound cavity that mimics actual wound trauma reasonably well (MacPherson 1994:63-78). The temporary cavity can be observed using high-speed videography. The permanent cavity is what remains after the bullet passes through or is captured in the tissue simulant. A variety of studies demonstrate that tissue simulants meeting the standard BB penetration test (MacPherson 199:74-75) achieve dynamic equivalence which can then be used to model wound trauma. When a spherical ball enters the tissue simulant at a given velocity the gelatin begins to deform as a response to strain forces acting upon it. The gelatin deforms elastically until it reaches a critical point where it ruptures and then rebounds to near its original position. The strain forces caused by the bullet diameter, mass, and velocity create an elastic response in the gelatin that creates a wound track or cavity that expands with the initial strain and then contracts leaving a visible but small wound track.

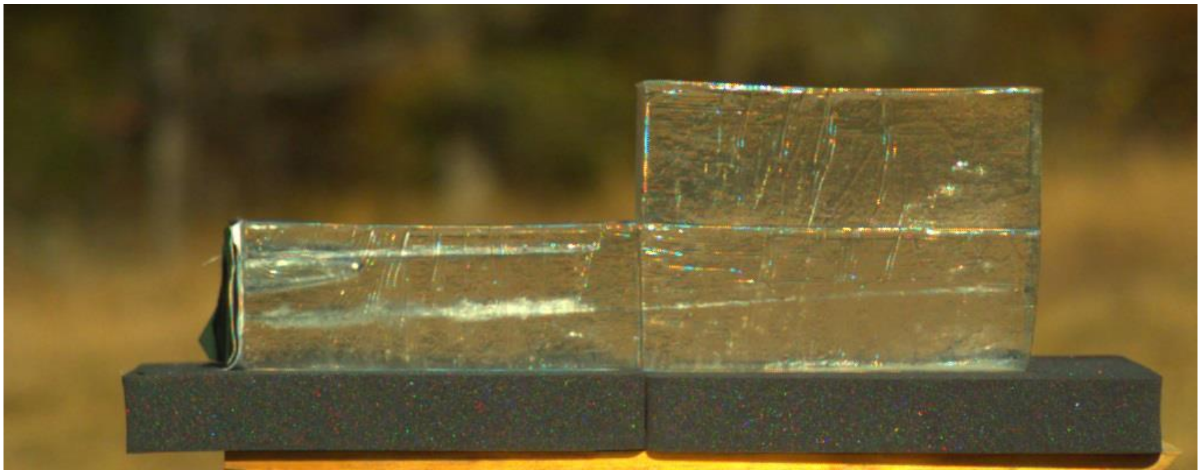

Figure 50. Ballistic gelatin block firing test set-up. Two blocks placed end to end create 32 inches of length. Note the wound tracks from previous shots in the two lower blocks. The large cavity on the left side is a .626-inch ball entering the block and creating an initial wound cavity.

The live-fire experiment used Clear Ballistic® gelatin obtained from Clear Ballistics®. Clear Ballistic gelatin meets the FBI and NATO protocols for testing terminal ballistics of human tissue simulants. The protocol standard states that an acceptable calibrated gelatin must have a steel BB (.177 inch or 4.5mm in diameter) shot at 590 f/s (180 m/s) at 10 feet (3.04m) come to rest between 1.73 and 1.8 inches (4.4 and 4.6cm) into the gelatin.

The Clear Ballistics' blocks are 6x6 inches square and 16 inches long. The blocks were placed on a specially constructed wooden table covered with 2 ½ inch thick foam pads. Two blocks were placed end to end and aligned creating a 32-inch-long area of gelatin. A 6x6 inch square of cloth, meant to simulate the thickness and weight of average colonial era clothing, was placed on the front and rear of the lower blocks.

The cloth squares were made up of broadcloth followed by a piece of serge to represent a coat and lining. Behind these was another piece of broadcloth and a piece serge to represent a waistcoat and lining. The final piece of cloth was a square of linen representing a shirt. The cloth was replica fabric that is the same weight and weave of known historic cloth constructed of similar materials (Potter and Hanson 2014; Moore and Haynes 2003; Brown 1999; Kidwell and Christman 1974).

The British Pattern 1756 Long Land musket, .76-caliber, was fired nine times in the ballistic gelatin shot series. The paper patched ball was .69-inch in diameter. The first four shots used a 110 grain charge that resulted in muzzle velocities of 760, 790, 815, and 830 f/s. For one shot the entrance and exit velocity for the gelatin was recorded. The entrance velocity was 830 f/s with the ball passing through 32 inches of gelatin and exiting at 360 f/s, with a loss of 470 f/s.

Figure 51. One of the cloth squares, 6x6 inch used to simulate a colonial era uniform clothing thickness. Two shots have passed through the cloth, and a recovered .626-inch ball is shown next to the hole it created. Note: Entry holes in cloth or tissue are often smaller than the bullet that created it due to the elasticity of the media.

The black powder charge was reduced to 75 grains to capture the ball in the gelatin. Five shots were fired, reaching 600 f/s, 605 f/s, 615 f/s, and two at 630 f/s. Four balls missed or passed through the gelatin. One, 600 f/s, passed through the side of the blocks and exited at 22 inches into the gelatin. One shot reaching 630 f/s was captured at 24 inches into the gelatin.

The French Model 1763/66 musket was fired twice into the gelatin. The first round was fired with a 110 grain charge and a .626-inch ball. The muzzle velocity achieved 1025 f/s, which is just above Mach 1. The ball passed through 32 inches of gelatin and exited the block at 280 f/s.

The second shot used the .626-inch ball but with a 75 grain charge to reduce the velocity enough to capture the ball in the gelatin. The muzzle velocity was 785 f/s and the ball passed through the gelatin along with a piece of the cloth but did not break the plane of the block and the ball rebounded back into the block. It was recovered at 29 inches into the gelatin block (see ball penetration and deformation section).

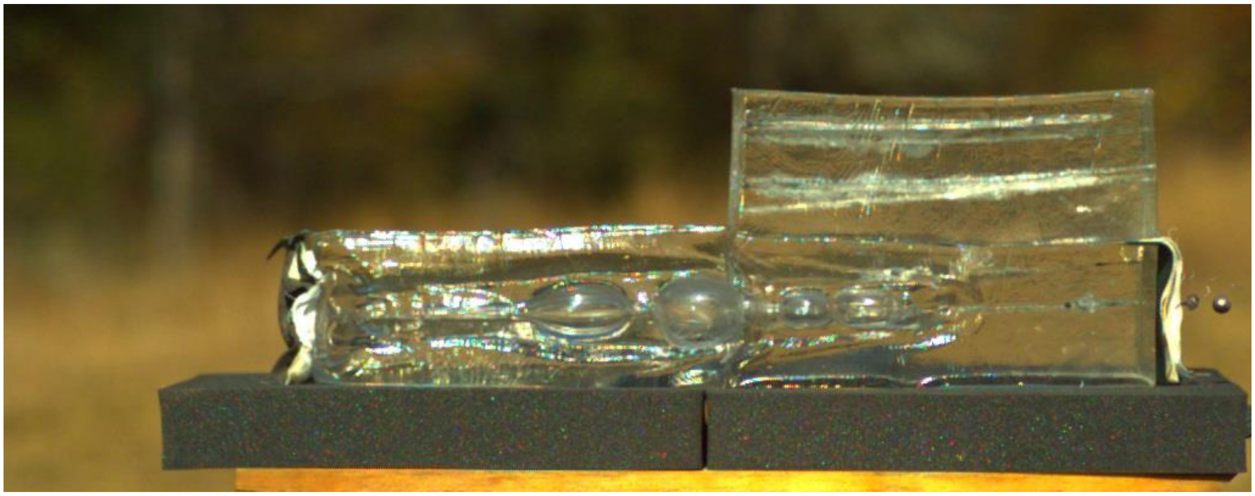

Figure 52. A .69-inch ball fired from a British Pattern 1756 Long Land musket exiting 32 inches of gelatin. Note the initial wound cavity, bits of cloth in the wound cavity on the right and a larger piece of cloth exiting the block behind the ball.

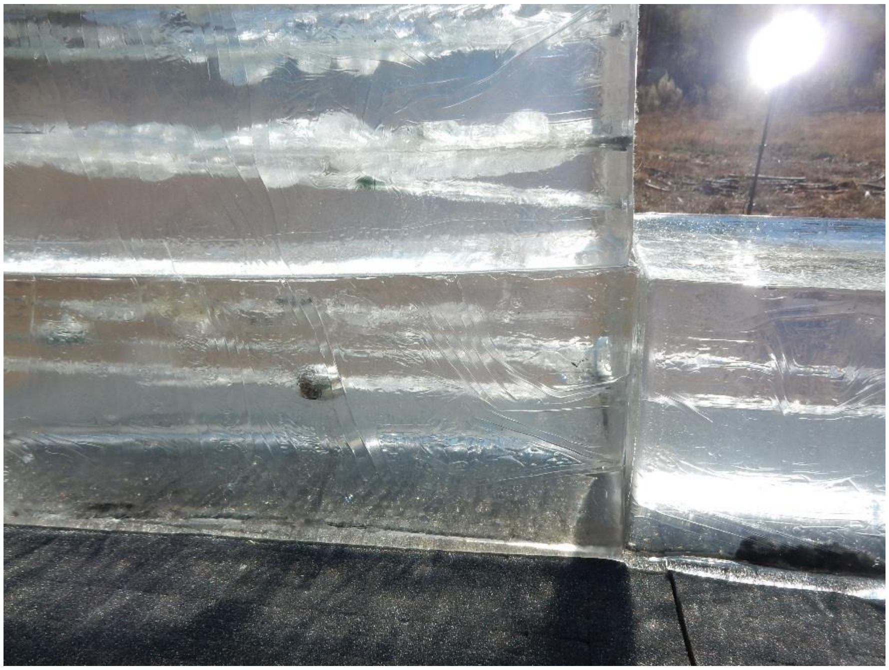

Figure 53. A .69-inch ball fired from the British Pattern 1756 Long Land musket with 75 grains of powder at 25 yards. The ball traveling at 630 f/s traveled 24 inches into the gelatin blocks.

Figure 54. A fabric impressed .69-inch ball fired from the British Pattern 1756 Long Land musket with 75 grains of powder at 25 yards. The fabric impressions resulted from passing through the simulated uniform clothing.

The ball that rebounded back into the gelatin is a known effect in the study of wound trauma. The rebounding effect seen with the French Model 1763/66 musket fired at 785 f/s into gelatin is consistent with the MacPherson's (1994:156) experimental work. It reflects the static strain, kinetic energy dispersion, and gelatin excitation of the bullet as it passed through the tissue simulant. MacPherson (1994:224-227) concluded that bullets that rebound have lost enough velocity to fall below the minimum velocity to either penetrate or exit the media. In cases involving human skin that minimum velocity is somewhat variable but generally falls into the range of 200 to 350 f/s. In part that is dependent on age, health, and body part involved.

The high-speed video shows the uniform fabric being pushed into the wound track and then the ball, given its greater velocity and aerodynamic capability, passing ahead of the cloth. The cloth often left debris in the wound channel that is easily observable as small fragments of thread embedded in the wound track. In some cases, the larger piece of cloth will exit the gelatin behind the ball, but in some cases the cloth lost momentum and remained in the wound channel.

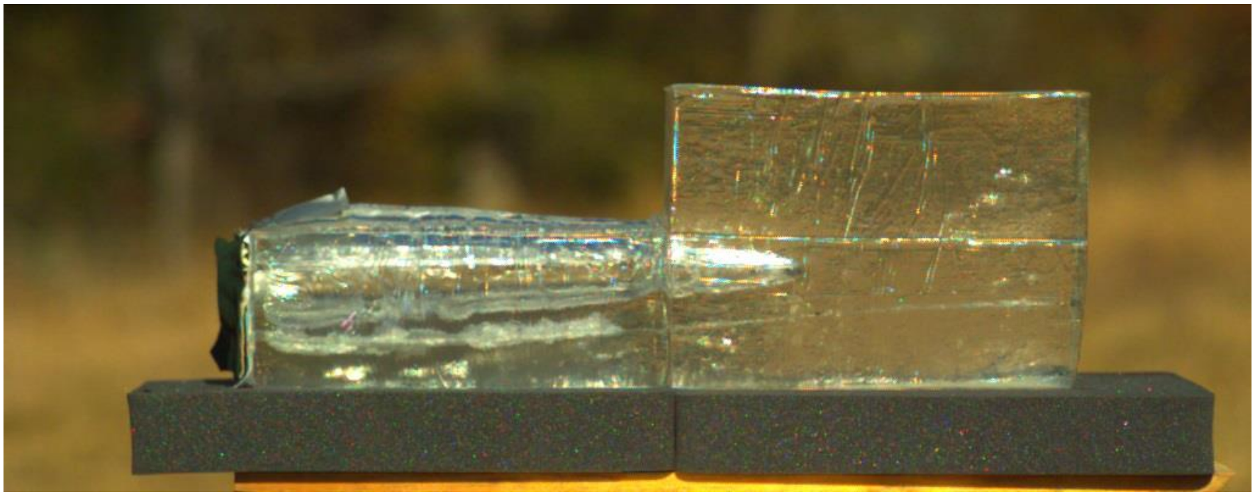

Figure 55. A .626-inch ball fired from a French Model 1763/66 musket creating an initial wound cavity in gelatin. The ball entered the block at 1155 f/s, passed through one 16-inch-long block, and is moving through the second block.

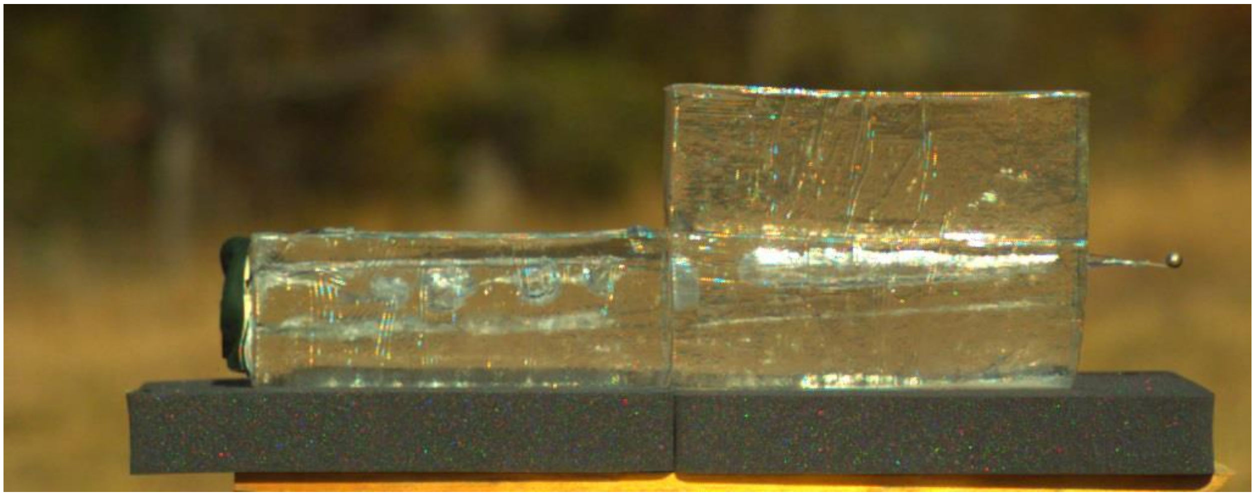

Figure 56. The .626-inch ball fired from the French Model 1763/66 musket as it exits the second gelatin block at a velocity of 280 f/s. The ball has passed through 32 inches of gelatin and lost 745 f/s of velocity passing through the tissue simulant.

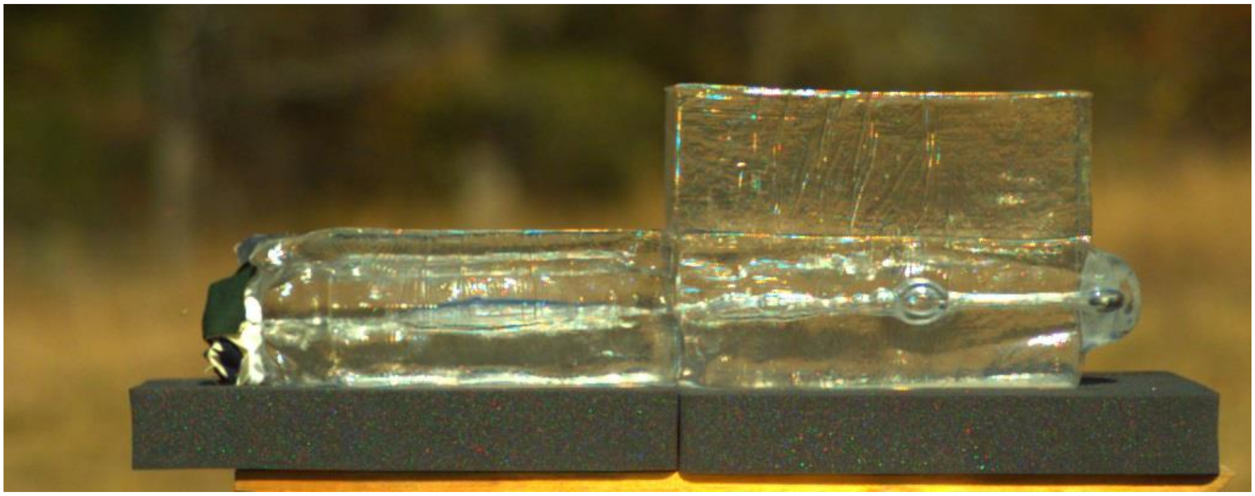

Figure 57. A .626-inch ball fired from the French Model 1763/66 musket at 785 f/s passes through 32 inches of gelatin but does not break the plane of the tissue simulant.

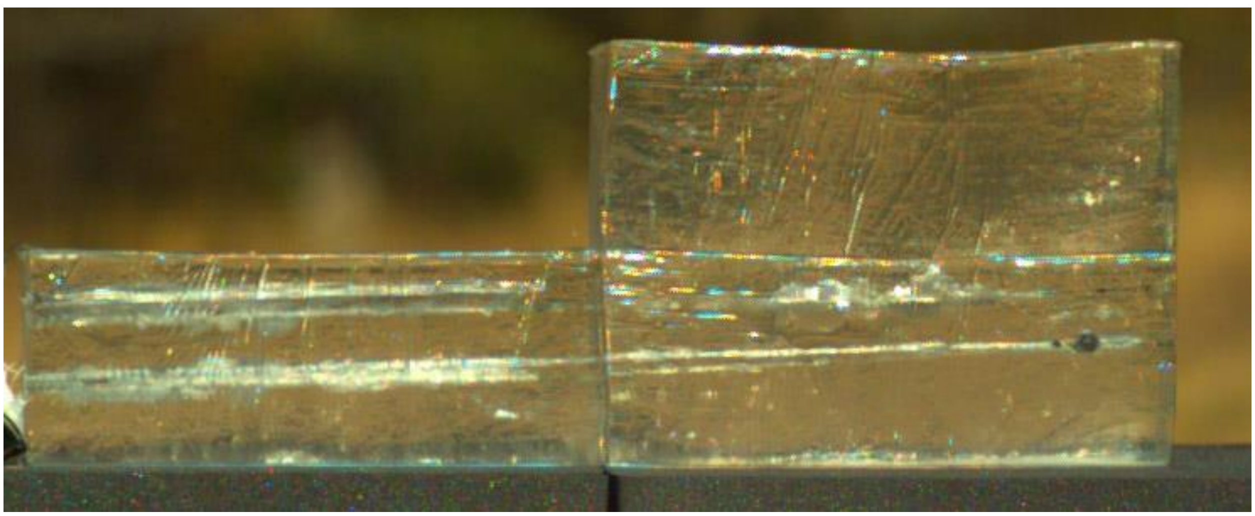

Figure 58. A .626-inch ball fired from the French Model 1763/66 musket at 785 f/s that rebounded or was pulled back into the tissue simulant coming to rest about 30 inches from the entry point. Note the dark spot to the left of the ball, which is a piece of fabric carried into the wound channel.

Figure 59. Fragments of fabric recovered from gelatin wound tracks. L to R. recovered from entry site 4 inch in, 12 inches in, 12 to 14 inches in, 14 to 16 inches in, 15 to 16 inches in and 30 inches in. In a real wound track the fabric would be sources for infection and sepsis, a known issue in eighteenth century medicine.

The Thomas Earle fowling piece was fired four times at the gelatin blocks. The first two shots used the .58-inch ball without patch and with an 85 grain charge. The first shot achieved a muzzle velocity of 1285 f/s, passed through 32 inches of gelatin, and exited the blocks at 550 f/s. The second shot entered the blocks at 1340 f/s and passed through 32 inches of gelatin. The third shot had the powder charge reduced to 75 grains. It entered the block at 1140 f/s and exited the block. The fourth shot, also using the 75 grain powder charge, entered the block at 1155 f/s and exited the block after passing through 32 inches of gelatin at 280 f/s. The ball was recovered on the ground surface at 100 yards from the shooting bench and 75 yards beyond the gelatin block position.

Ball Penetration and Deformation

The dynamics of bullet penetration in any media are complex and dependent on velocity at the time of impact, the density of the media it strikes, and drag or resistance on the bullet during flight. Miller and Bailey’s (1979:449-463) study of drag drawn from eighteenth and nineteenth cannon firing sources demonstrated that with the development of the 1868 Bashforth chronographic instrument, reasonably accurate velocity and drag measurements were attainable. They also found the earlier ballistic pendulums (ca. 1787 and ca. 1839) were less accurate than the Bashforth chronograph, but still produced reasonable data. Using modern data and mathematical formulae they created drag models for spheres ranging in velocity from Mach 0.3 to Mach 2.0. Their basic research is incorporated into the ballistic models employed in this study.

Likewise, bullet deformation is dependent on the same issues. MacPherson (1994) studied and modeled bullet penetration as related to incapacitation from wound trauma. Bullet penetration in any substance, be it soil, wet or dry wood, or human tissue, is dependent on several factors including the energy it has when it strikes a substance. This is kinetic energy, and here we express it as foot/pounds (ft-lbs.). A soft lead bullet traveling at a velocity has mass (weight), speed, and stored but dissipating energy as it fights resistance or drag. The object or media the bullet strikes, if soft, transfers the kinetic energy of the bullet in the form of heat, if hard the bullet is deformed to some degree or another as a function of the laws of thermodynamics. The force that results in bullet deformation is simply Newton's Third Law of Motion, for every action there is an equal and opposite reaction. There is not an absolute direct correlation to bullet deformation since kinetic energy and damage is not due directly to energy absorption, but to the amount of force per area on the bullet and media. Bullets behave according to physical laws, and by knowing the velocity, mass (weight), and other variables bullet deformation and penetration can be mathematically modelled (MacPherson 194:11-14). Modern ballistic calculators take these variables into account when calculating muzzle velocity, changes in velocity over time, air resistance (drag), and gravity, to determine bullet speed loss over distance and drop from the angle of the firearm muzzle relative to the ground surface.

In penetration studies the terms low and high velocity have specific definitions. Low velocity is considered to be a bullet traveling at 300 f/s or less, while high velocity is considered to be a bullet traveling at 600 f/s or more (MacPherson 1994:74-77). For practical purposes, all charges fired in the arms in this experiment achieved high velocity as used in penetration and wound trauma studies.

Bullet penetration and expansion or deformation is modelled using the principles of fluid dynamics. Bullets expand more in higher density fluids and less in lower density fluids. Lower density fluids include water, tissue, tissue simulants, and experiments have shown that bullets penetrate and expand or deform in consistent ways in these lower density situations (MacPherson 1994:122-125; Fackler 1988:555-557).

Bullets yield or deform in response to the force applied on it. A ball striking a hard, strong solid (e.g., rock, hard woods, etc.) will deform at relatively low velocities because the hard and rigid surfaces produce large forces on the bullet (Kerkhoff et al. 2015; Mattijssen et al. 2016). The diameter of the bullet and its mass (weight, usually expressed as sectional density) is another factor in the amount of deformation that occurs when a ball strikes a hard or rigid surface. Pure or dead soft lead (not pure in the chemical sense, but with impurities present as such low levels as to not be significant) is very ductile and deforms significantly based on static loading as confirmed in experiments (MacPherson 1994:127) using spherical balls and black powder loads.

The experiments show that lead spherical balls show slight deformation at about 690 f/s velocity and increase accordingly at higher velocities when fired into soft fluids like tissue or water.

Lucien Haag (personal communication December 15, 2004) conducted an experiment firing lead spherical balls from modern cartridge pistols and rifles using controlled black powder charges. He fired each shot into a water tank at velocities ranging from 360 f/s to 1026 f/s for .45-inch balls in a pistol and ranging from 1049 f/s to 1529 f/s for .45-inch balls fired from a rifle. His investigation found the higher the velocity the greater the deformation. His lower velocity impacts ranging from 630 f/s to 1026 f/s had virtually no deformation while rounds fired above 1049 f/s to 1138 f/s showed some slight flattening. Recovered balls fired between 1281 and 1336 f/s were flattened to almost half the diameter, while the round fired at 1529 f/s was nearly flattened. Haag's experiments largely confirm the work of MacPherson (1994).

Bullet Deformation Correlated with Velocity

Deformation seen in the lead balls fired by the various guns in the current experiment largely mimics the results reported by MacPherson (1994:126-130). Balls fired into tissue simulant, the loose sand backstop, dry soft woods, and wet pine, exhibited the least deformation. The smaller balls, .520-inch and .580-inch showed the least deformation and the larger balls, .69-inch, showed the largest deformation at any given velocity, which is consistent with metal yielding functions correlated to the bullet's sectional density (MacPherson 1994:142-143). These phenomena are clearly illustrated in the following images and graphic representations.

Figure 60. Unfired buckshot and bullet examples as used in the live fire experiments. l to r – .282-inch buckshot, .315-inch buckshot, .520-inch ball, .580-inch ball, .626-inch ball, .662-inch ball, and .69-inch ball.

Figure 61. Unfired .69-inch ball, .69-inch ball fired at 600 f/s that struck ground surface at 100 yards, .69-inch ball fired at 630 f/s that struck a wood table, foam, and ballistic gel at 25 yards and was collected laying on the foam at the back of 32 inches of ballistic gel, and a .69-inch ball fired at 630 f/s that was captured in the ballistic gel at 25 yards after passing through 28 inches of gel. Note fabric impression on second and fourth balls.

Figure 62. Unfired .626-inch ball, .626-inch ball fired at 775 f/s recovered from a soil and sand backstop at 100 yards and a .626-inch ball fired at 785 f/s and captured in ballistic gel at 25 yards after passing through 30 inches of gel. Note ramrod mark on second ball and fabric impressions on third ball.

Figure 63. Top row: Unfired .282-inch buckshot and fired .282-inch buckshot at 865 f/s. Second row: Unfired .626-inch ball and fired .626-inch ball at 865 f/s. Third row: Unfired .69-inch ball and fired .69-inch ball at 870 f/s. Note each fired buckshot was recovered in the sand and soil backstop at 100 yards.

Figure 64. Unfired .626-inch ball, fired balls l to r fired at 905 f/s, 960 f/s, 960 f/s, and 1090 f/s. All balls recovered at 100 yards in sand and soil backstop. Note third ball from the left passed through a pine 4x4 target frame upright and the fourth ball from left also struck the edge of the pine target frame before embedding in the backstop.

Figure 65. Left column, unfired .626-inch ball, fired .626-inch balls at 1110 f/s and 1175 f/s, both found in sand and soil backstop. Second column, unfired .282-inch buckshot and fired .282-inch buckshot at 1110 f/s found in sand and soil backstop. Third column, unfired .580-inch ball and fired .580-inch ball at 1135 f/s found in sand and soil backstop. Fourth column, .580-inch ball fired at 1155 f/s, and Fifth column, .580-inch ball fired at 1170 f/s and found in soil and sand backstop. All balls recovered at 100 yards.

Figure 66. Top row, Unfired .626-inch ball, fired .626-inch ball at 1205 f/s and found in sand and soil backstop, fired .626-inch ball at 1215 f/s which nicked the target frame post and was found in the sand and soil backstop. Bottom row, Unfired .520-inch ball, fired .520-inch ball at 1215 f/s that hit oak palisade paling and ricocheted back into sand and soil backstop, fired .520-inch ball at 1250 f/s which hit a pine palisade paling and ricocheted back into sand and soil backstop, .520-inch ball at 1240 f/s that struck an oak palisade paling and fell to the ground below the fence, and .520-inch ball fired at 1285 f/s that went through a 4x4 pine target frame upright and was recovered in the sand and soil backstop. All balls found at 100 yards.

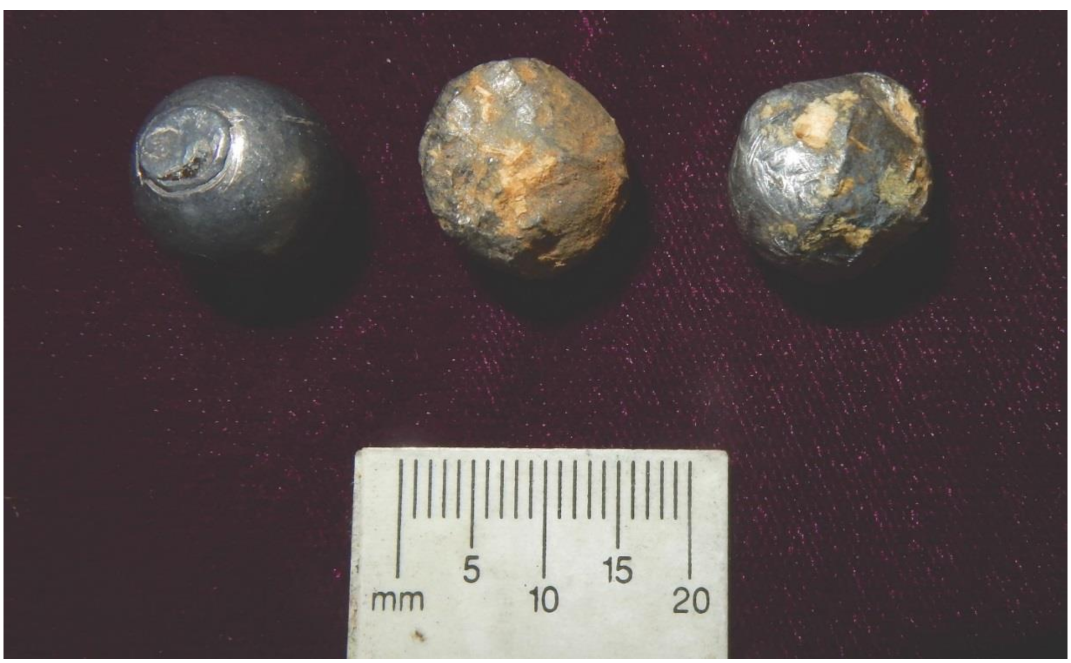

Figure 67. Unfired .520-inch ball and two fired .520-inch balls, center fired at 1345 f/s and hit pine target frame and right fired at 1350 f/s and hit pine target frame. Both found in sand and soil backstop at 100 yards. Note banding on last ball from being upset in firing from the musket.

Figure 68. Unfired .580-inch ball and fired balls, second – fired at 1415 f/s and struck oak palisade paling and found in sand and soil backstop below fence, third – fired at 1435 f/s and found in sand and soil backstop, fourth – fired at 1480 f/s and found in sand and soil backstop. All balls recovered at 100 yards.

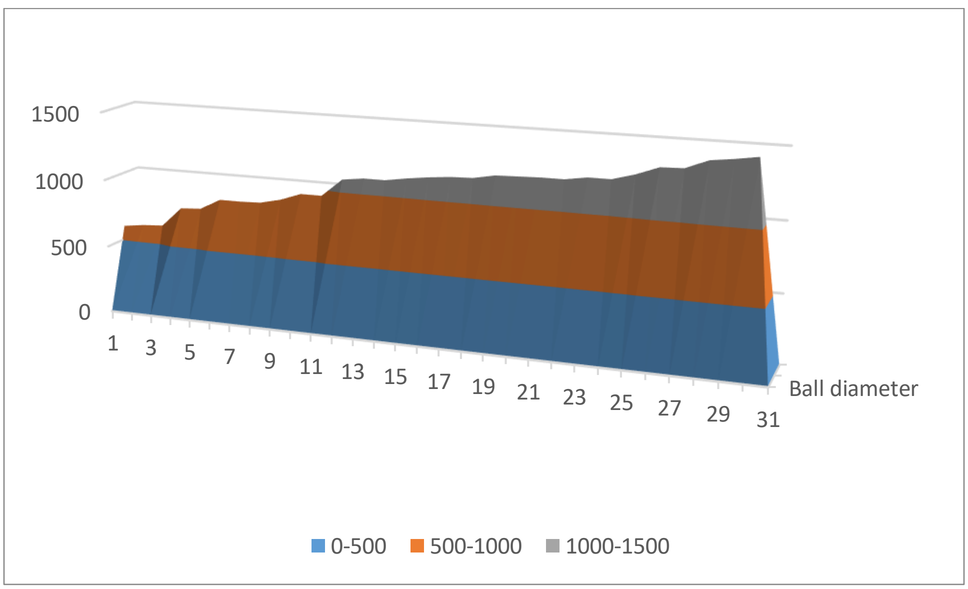

Figure 69. Flattening is observed on balls as velocity increases regardless of ball diameter. The greater the muzzle velocity the larger the degree of flattening observed.

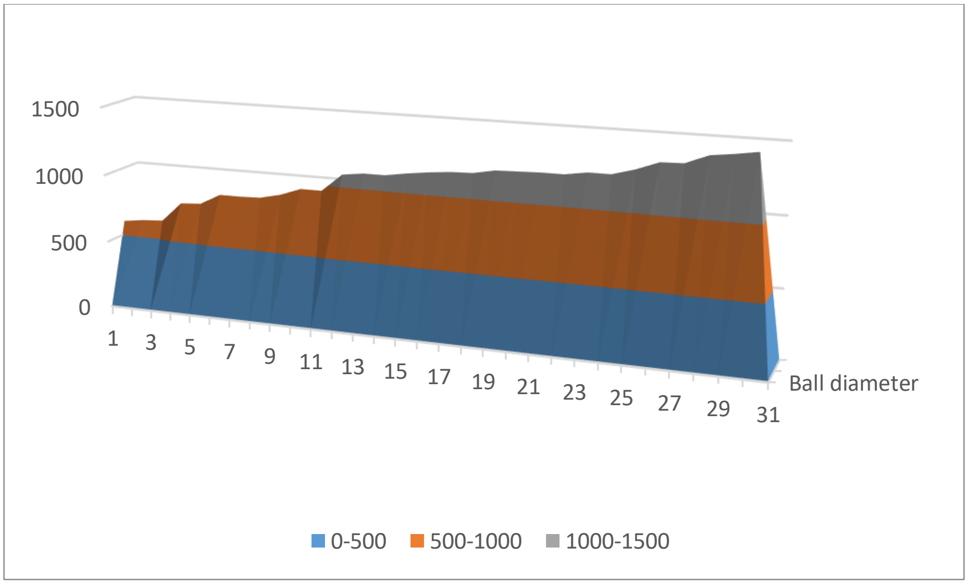

Figure 70. Change in diameter, A, observed on balls as velocity increases regardless of ball diameter. The greater the muzzle velocity the larger the degree of diameter A change observed.

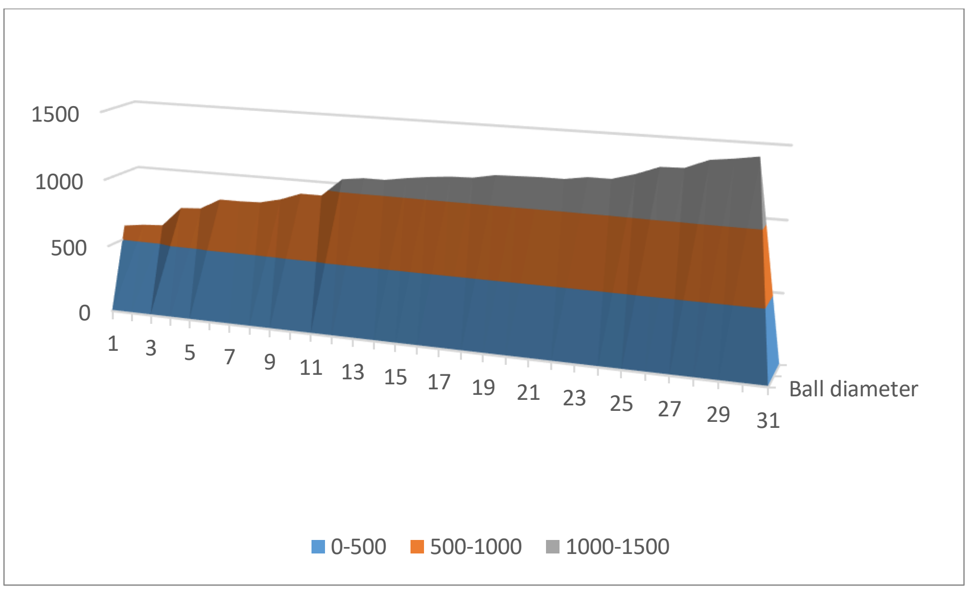

Figure 71. Change in diameter, C, observed on balls as velocity increases regardless of ball diameter. The greater the muzzle velocity the larger the degree of diameter C change observed.

The graphs showing the relationship of ball deformation to velocity clearly show a general linear trend, in that that the greater the velocity the greater the deformation. A scatter plot with a linear regression trend line confirms this relationship. However, the relationship can only be considered as a general trend, as the variable of the media which a bullet strikes is not likely to be found in the archaeological record.

Lead Bullet Deformation Index

For more than 30 years an intuitive scale based on personal experience with shooting muzzle loading weapons has been used to assign value to impact deformed bullets. The scale is descriptive using Low, Medium, and High Velocity Impact terms as a means of defining impact deformation (e.g., Scott et al. 1989). The current live-fire experiments where bullets fired at known velocities were recovered allows a new more quantitative-base index scale to be suggested. While this scale has recognized weaknesses, it does refine and replace the even less precise Low, Medium, and High Velocity Impact scale that is in common use (e.g., Scott et al. 1989).

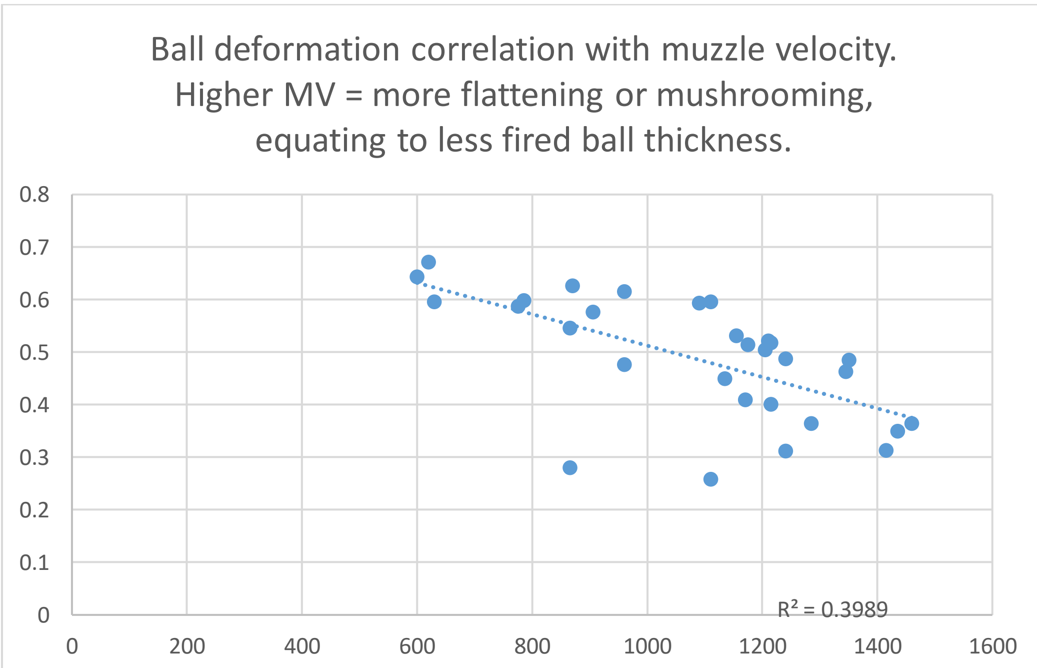

Figure 72. Muzzle velocity compared to thickness or flattening of fired balls. The fired ball thickness is in tenths of inches on the left and muzzle velocity is shown on the bottom as feet per second. There is general agreement that balls flatten at higher velocities, but the linear regression trendline indicates the relationship is only about 40%. This further reinforces the fact that the nature of the medium the ball strikes at the end of its flight as well as remaining velocity and kinetic energy are significant factors in deformation.

Using the ball deformation data acquired during the live-fire experiment we present an ordinal or nominal bullet deformation rating scale to equate to an approximate velocity range. We emphasize that the **Lead Bullet Deformation Index** scale we propose cannot be used as a one-to-one correlate to absolute velocity and the amount of deformation, rather it is intended to give the user an approximation of the relationship between velocity and deformation. Using the ordinal rating scale model results in a number that can be tested using ANOVA, Regression, or Chi-square tests.

We define the **Lead Bullet Deformation Index** to be:

Based on a mixed qualitative and quantitative set of observations of the fired bullet a rating scale number can be determined. Measurements should include the maximum diameter (diameter A), the thickness or amount of flattening (diameter B), and the minimum diameter that is not in the plane of deformation (diameter C). These data can be plotted and trendlines applied through scatter plots and various statistical regression procedures to observe and refine trends. Qualitative observations range from the amount of impact scarring present from minimal to extreme as to the degree of impact flattening (commonly called mushrooming) the bullet exhibits.

The ordinal scale is:

> 1. Likely velocity is less than 800 f/s based on little or no visible scarring or flattening. Diameter measurements are essentially consistent for the three measured points on the ball.
>
> 2. Likely velocity is between 800 and 1100 f/s based on slight to moderate visible impact scarring, possibly imbedded residue, or negative impressions (sand or rock inclusions or impressions), and some impact flattening that is less than half the diameter of the ball. Diameter measurements show flattening to less than one half the ball's original diameter or caliber.
>
> 3. Likely velocity is greater than 1100 f/s based on significant impact scarring and flattening of ball to becoming totally mushroomed. Measurements should reflect the thickness of the flattening relative to the measured diameter as extreme.

We suggest when there is a question of whether a ball falls in one ordinal range or another that it is appropriate to use a .5 number. An example is that a ball shows minimal impact scarring, and moderate flattening would be assigned a 1. However, the measurements in the A and C axes are essentially the same, but the thickness or flattening measurement is notable and was assigned a 2. We suggest assigning it a 1.5 rating. That data can be used to refine any statistical analysis. We do not endorse any finer intermediate resolution between the numbers as this will only be pure speculation and confuse any statistical analysis.

Figure 73. Fired ball that struck wood showing little to no impact deformation. This would score as a 1 on the Bullet Deformation Index indicating a likely velocity of less than 800 f/s.

Figure 74. Fired ball with moderate impact scarring and deformation that is consistent with a Bullet Deformation Index of 2 indicating a likely velocity of 800-1100 f/s.

Figure 75. Fired ball that hit a palisade post with a wire tie. The impact scarring is moderate, but the impact deformation is more than moderate but not extreme. It scores a 2.5 on the Bullet Deformation Index.

Figure 76. Two fired balls with significant impact scarring as well as impact deformation. The left ball shows significant flattening, and the right ball also shows significant deformation. The left ball is scored at 3 and the right ball could be scored a 2.5 on the Bullet Deformation Index.

Figure 77. A .580-inch ball fired from the fowling piece hit on a live oak palisade paling with inset images showing the complete flattening or mushrooming effect of a high velocity hit on a hard media. The muzzle velocity was 1240 f/s. The ball scores a 3 on the Bullet Deformation Index.

Other Observations

Sometimes balls fired from muzzle loading firearms exhibit a variety of characteristics that can be mistaken for impact deformation. These can be identified and interpreted with careful observation and analysis. Sivilich (2016), Foard (2012), Foard and Morris (2012) and Harding (2012) have observed, described, and interpreted these and other non-impact characteristics on spherical lead bullets from a variety of archaeological contexts. Sivilich was one of the first to use live-fire data to validate interpretations of impact and non-impact marks on fired balls. The current live-fire empirical evidence further verifies and validates the archaeological based descriptions and interpretations as well as those of Sivilich (2016).

The live-fire recovered bullet data confirm characteristics found on balls relate to the loading or the type of load. These characteristics, like ramrod marks from loading the round, or faceting or multiple dimples on one surface likely indicate a buck and ball round. Another characteristic is a smooth band completely or partially around the ball. The banding effect occurs when a ball is upset in the bore during loading, slightly compressing the bullet. When fired the propellant gases further force the ball against the bore creating the band. It is a tell-tale indication of a ball being fired from a smooth bore gun. The following figures illustrate several of these observed non-impact related characteristics.

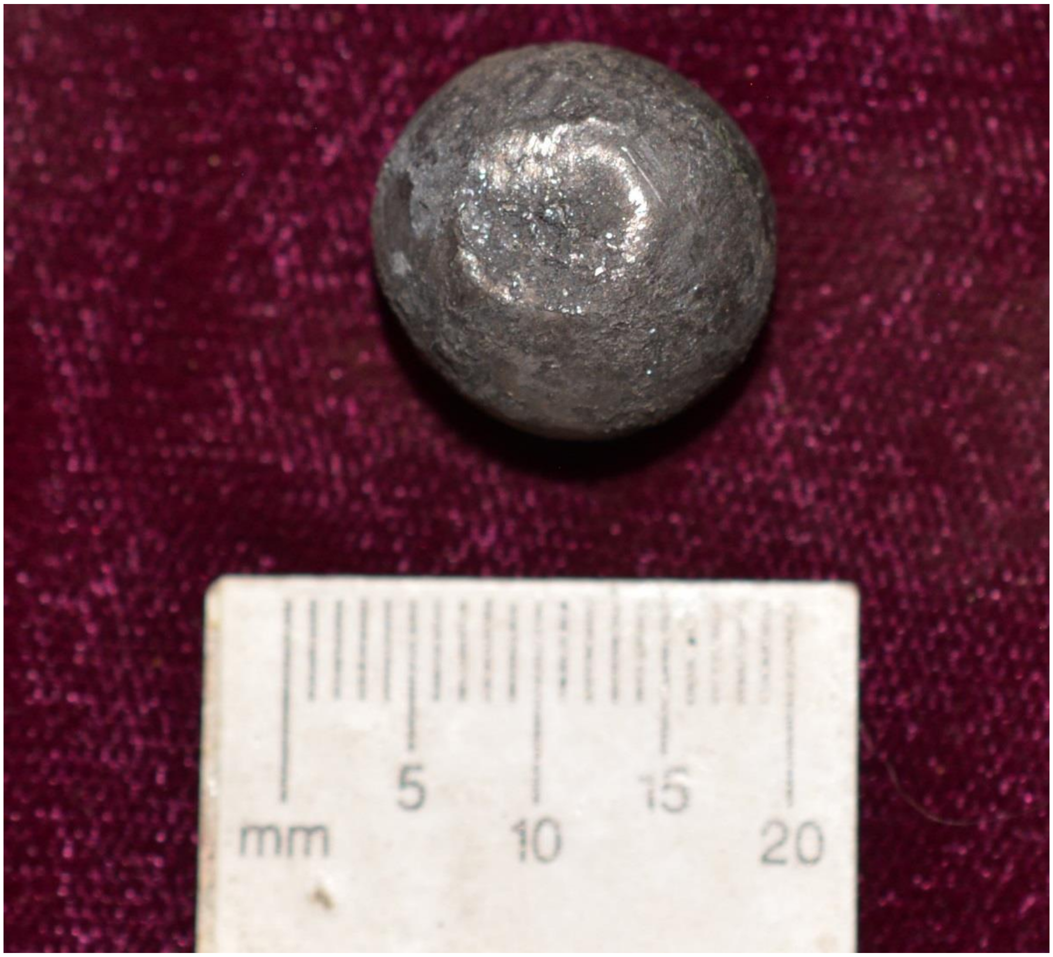

Figure 78. Typical denting and slight flattening caused by a ramrod head being forced against the ball during the loading of a muzzle loading firearm. There are different ramrod shapes for different firearm types and that data can be used to aid in identification of the type of gun in which the ball was fired.

Figure 79. A fired ball with three dimples or small facets adjacent to one another. This dimple pattern is typical of firing deformation when three buckshot are placed on a larger ball, known as a buck and ball round. The flattening observed on the left side of the ball is impact deformation.

Figure 80. The slight to moderate faceting seen on the two buckshot are typical of buckshot that were in proximity to one another when loaded and fired. The soft lead is compressed in loading and firing causing the buckshot to press against and deform one another. The flat area on the left side of the right buckshot is a ramrod impression.

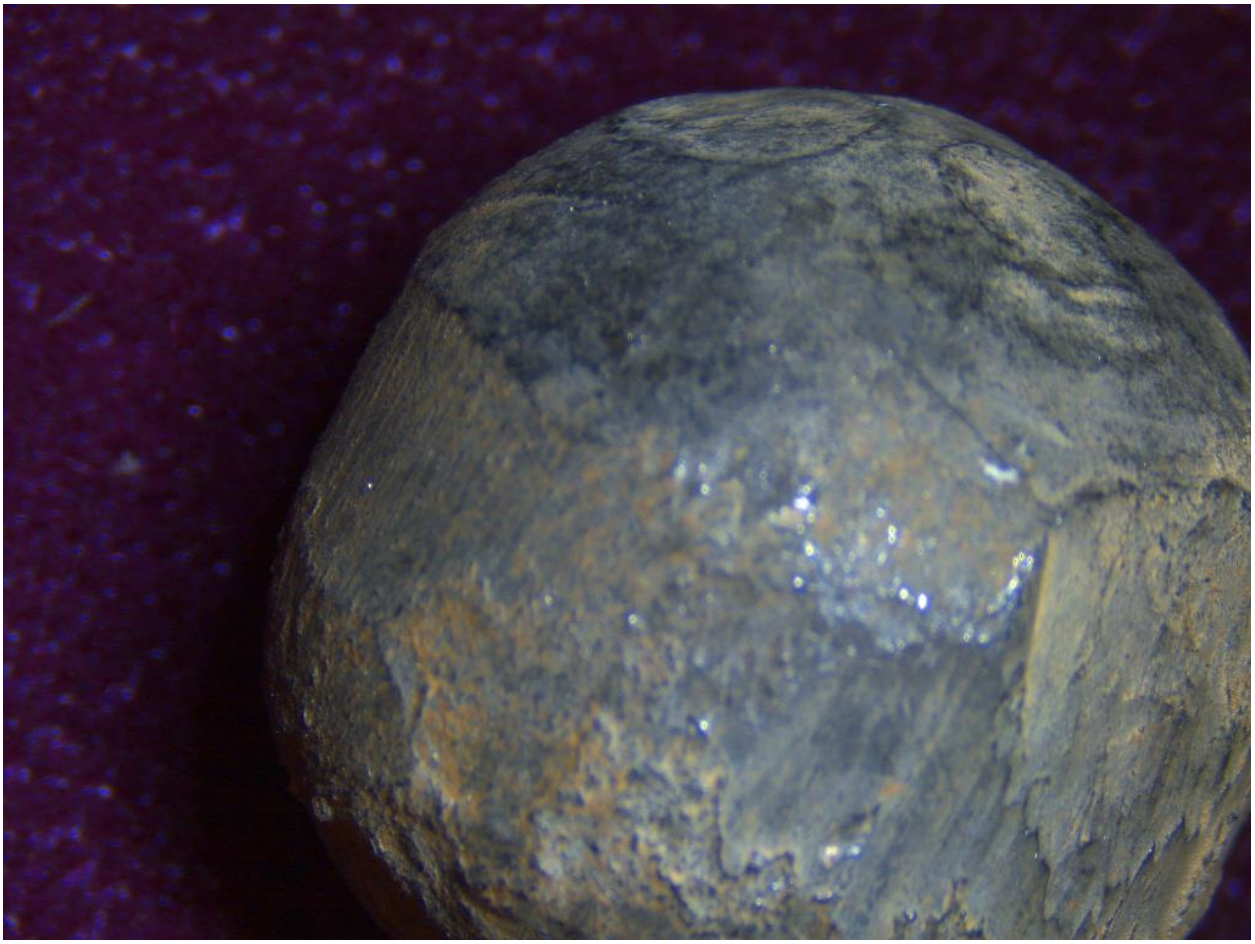

Figure 81. A 40x magnification of the bore band seen on balls fired in smoothbore guns. Note the micro striations run parallel to the line of the bore. This ball also has buckshot dimpling on the upper right surface.

Microscopic examination of fired balls can often reveal a number of other micro characteristics that may aid in identifying the media in which the ball imbedded or passed through. Traces or impressions of wood, soil (e.g. sand or gravel), fabric impressions or fabric adhering to the ball surface, or even bone embedded in the ball aid in the interpretation of the shooting incident under investigation.

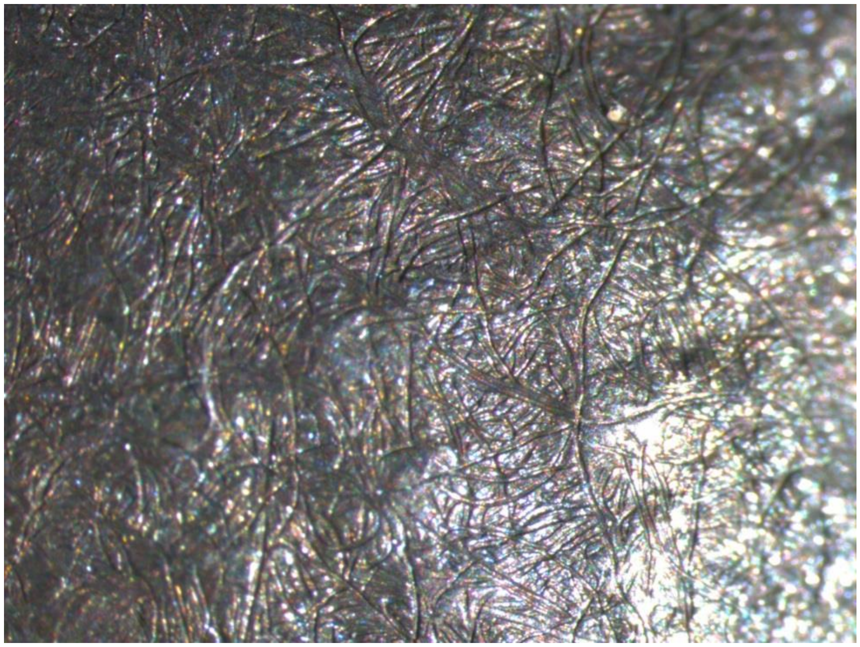

Figure 82. A 75x magnification of the surface of an unfired lead ball. The lines are a result of the differential cooling at a micro scale of the lead ball when it was cast in a mold. Mold lines and these microscopic cooling lines are indicative of a cast ball. These microscopic cooling lines are largely obscured when a ball is fired.

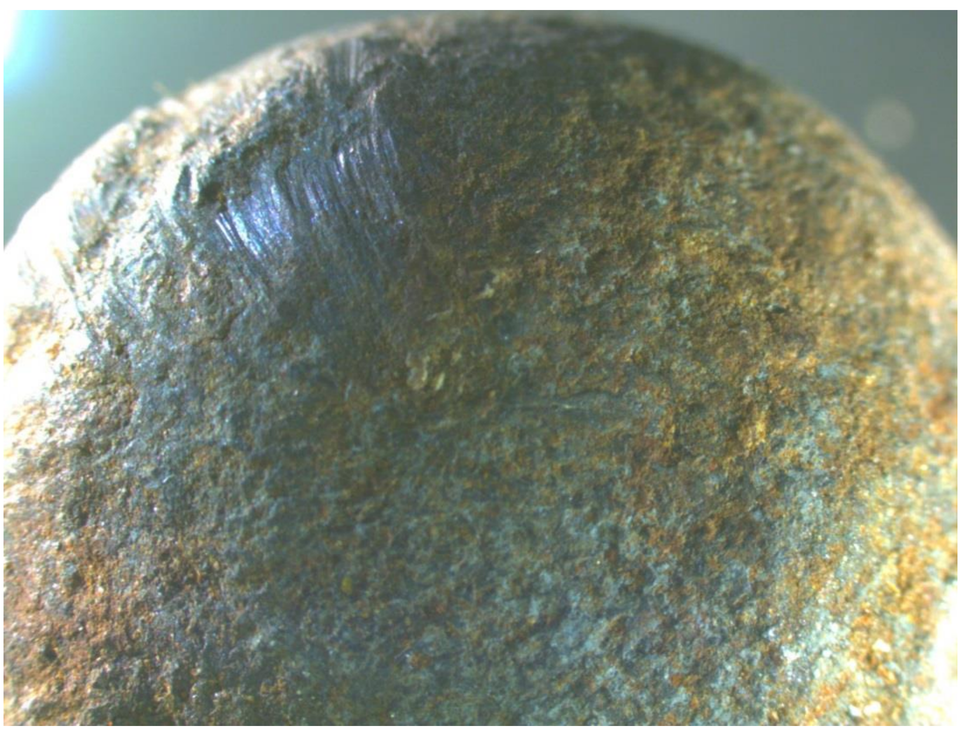

Figure 83. A 60x magnification of a ball fired in the French Model 1728/41 musket at 870 f/s that hit the sand backstop. Slight impact scarring is seen in the upper portion of the image and the fine sand particles impressed on the ball as it struck the backstop.

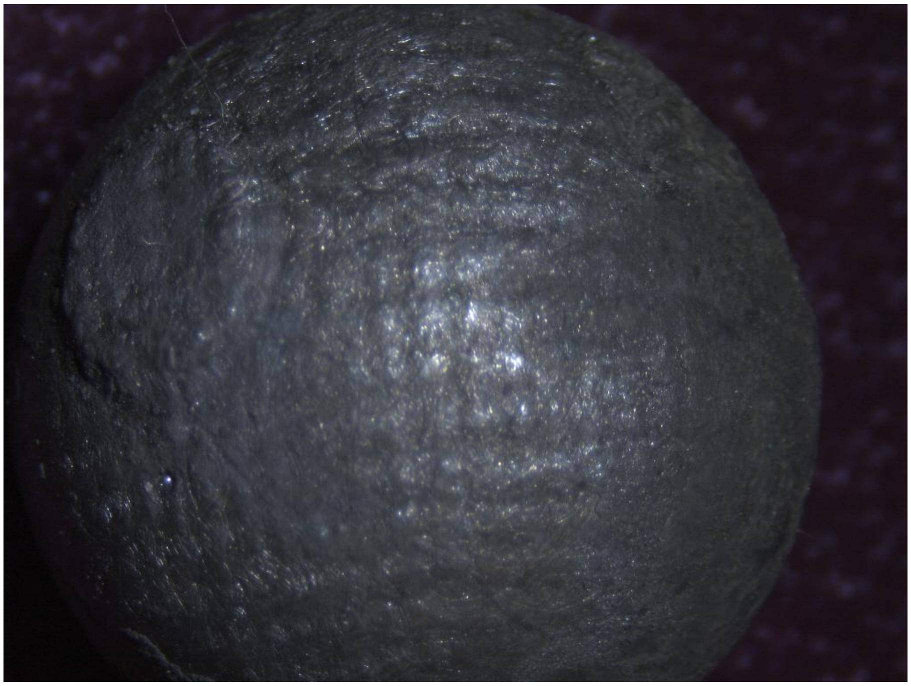

Figure 84. A 40x magnification of a ball fired from the British Pattern 1756 Long Land musket that passed through the simulated uniform cloth and gelatin blocks. The fabric impressed its weave on the ball providing a textile analyst data for interpretation. The raised circular area on the left of the ball is a sprue from casting the bullet in a mold.

Figure 85. A 20x magnification of a ball fired from the French Model 1763/66 musket with fabric still adhering to its surface after passing through the simulated uniform cloth and gelatin blocks.

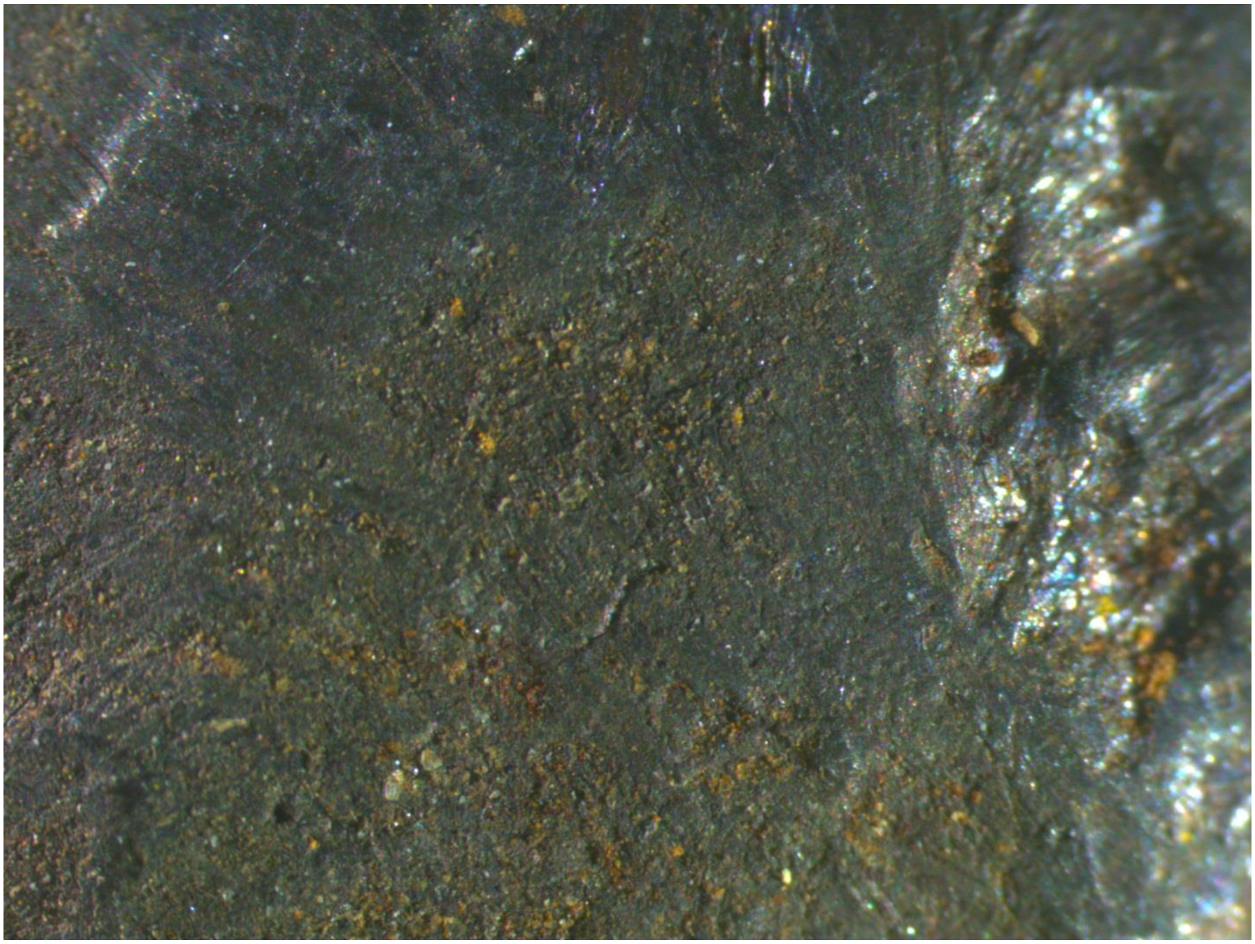

Figure 86. A 75x magnification of a ball's surface that shows small fabric threads and impression of soil from passing through the simulated uniform cloth, gelatin blocks, and landing in the soil in front of the target backstop.

Bullets, regardless of form or composition, deform on impact depending on the velocity and the media which it strikes. We observed this on the balls recovered during the live-fire experiment, some of which are illustrated here. Balls also embedded in the wood palisade and provided further examples of deformation that couples velocity and media.

Figure 87. A .626-inch ball embedded ¾ inch in a dry loblolly pine post. Note the deformation to the ball is moderate and would fall on the Bullet Deformation Scale as a 2.

Figure 88. A .580-inch ball embedded in dry green oak.

Figure 89. The .580-inch ball removed from the dry green oak. The ball is significantly deformed having hit at a higher velocity into a dense wood media. The bullet deformation is a 3 on the Bullet Deformation Scale.

Ball Deformation and Determination of Original Caliber

The deformed pure or soft lead spherical ball is particularly noted for being difficult to determine its original nominal caliber in archaeological contexts due to impact. Several formulae have been advanced that use the weight of the deformed spherical ball to calculate its approximate original diameter. Arrowood and Berglund (1980) developed one formula that gave a 99.5% level of confidence when at ± three standard deviations. Daniel Sivilich devised a similar formula (1996; 2009) with only one standard degree of error which has proved quite dependable and replicable. Branstner (2006) attempted to improve the Sivilich formula by recalculating the density of lead and reformulating the Sivilich formula. Branstner devised a table of lead ball diameters based on weights that range from .228-inch in diameter to 1.67-inch in diameter. Sivilich (2016:25-27) revised his formula and included new data on lead density to determine an original caliber more accurately, with only one degree of standard error.

We evaluated the revised Sivilich formula against the recovered fired balls from the live-fire experiment. We knew the original ball diameter weight before firing and we weighed the fired balls as well as calculated the fired ball weight loss by caliber and average weight loss for each ball diameter. The weight of the recovered balls was used to evaluate the 2016 Sivilich formula (See Appendix B for a blind study of the known velocity balls and their deformation).

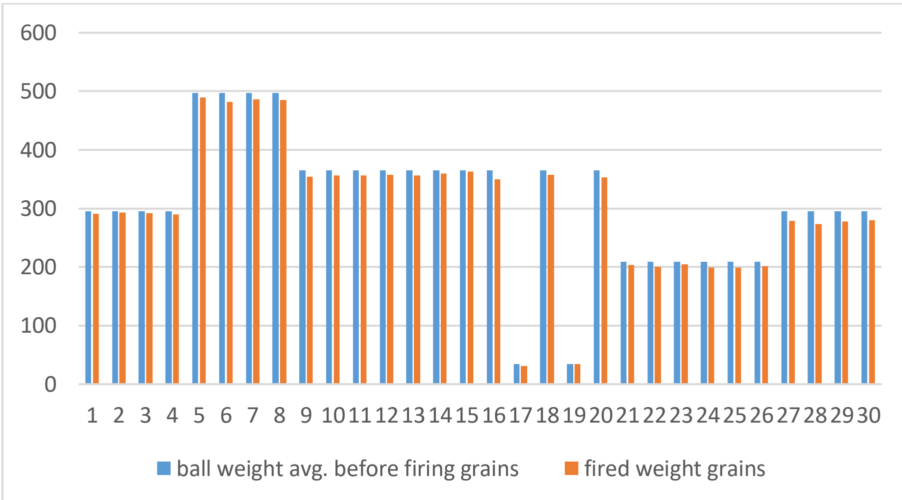

Figure 90. Ball weight before firing compared to weight loss with recovered balls. Note that items 1-4 are .580-inch balls, 5-8 are .69-inch balls, 9-16, 18, and 20 are .626-inch balls, 17 and 19 represent .282-inch buckshot balls, 21-26 are .520-inch balls, and 27-30 are .580-inch balls. The overall average weight loss of fired balls is 2.4%, although this generally increases as velocity increases ranging from 0.4 to 7.5%.

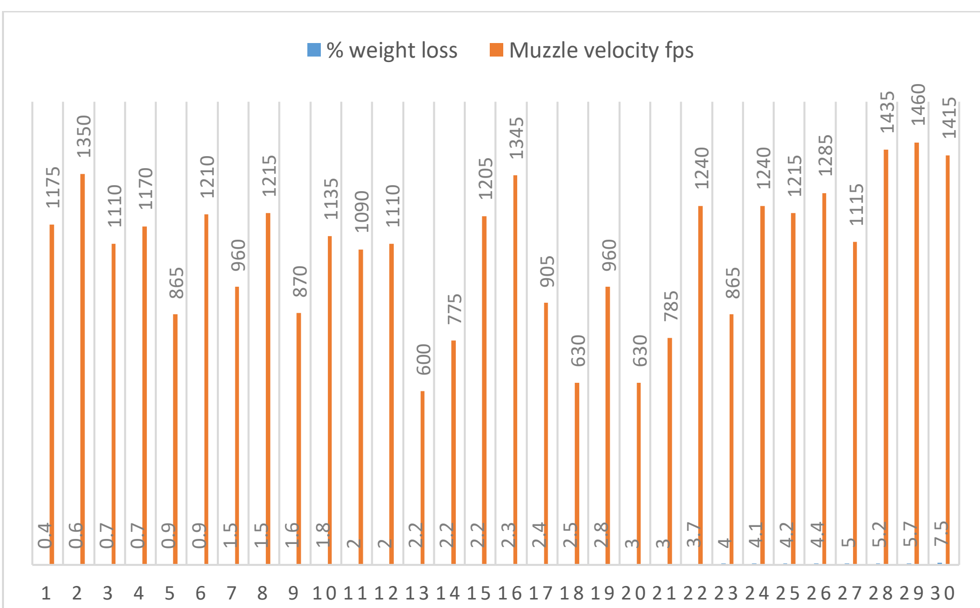

Figure 91. The percentage of fired ball weight loss compared to muzzle velocity. The weight loss range is from 0.4 to 7.5%. To some degree the fired ball weight loss is partially dependent on the hardness of the media it struck when the ball's flight terminated.

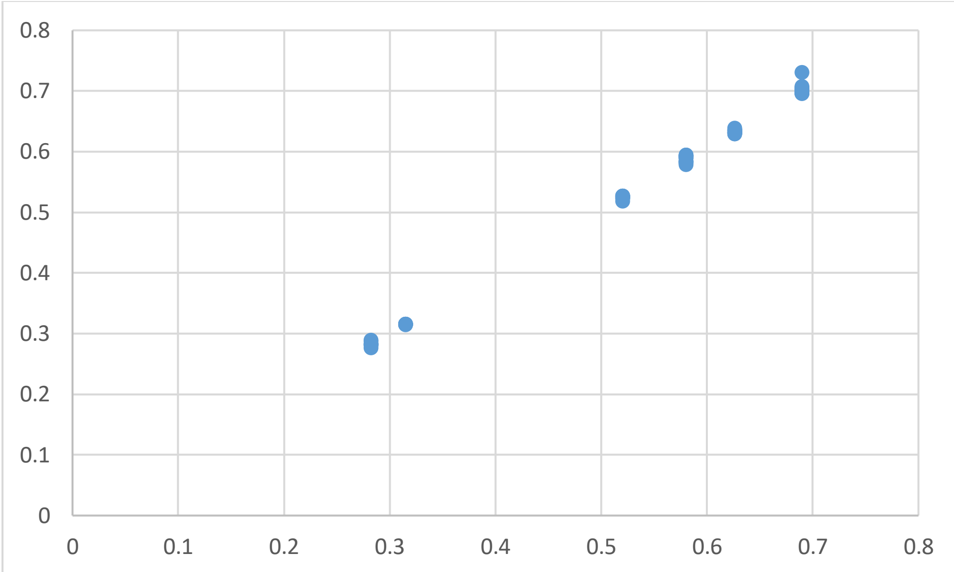

Figure 92. The measured ball diameter compared to the calculated ball diameter using the Sivilich Formula (2016). The differences are well within one standard deviation with an R value of .998.

The revised Sivilich Formula proved exceptionally reliable and accurate. A regression correlation was run comparing the two data sets. Sivilich's Formula tends to overestimate the ball diameter from a few thousandths of an inch to about one-hundredth of an inch. The R value was calculated to be .998 with less than one standard error of deviation. The R value is near ideal and proves the Sivilich Formula to be accurate and reliable for calculating the original ball diameter using weight or mass from recovered archaeological specimens.

Summary and Conclusions

The colonial firearms live-fire experiment can be characterized as an unqualified success. The intent behind the investigation was to determine the external ballistic bullet performance of a series of smoothbore shoulder-fired guns of the type commonly used during the American Revolution. The general premise or research design that drove the experimental investigation was to document the fired ball performance in terms of muzzle velocity, penetration capability, and bullet deformation as it terminated its flight. Prior to this controlled experimental work there are only a limited number of controlled shooting studies using colonial-era or replica weapons. This study not only recovered bullets fired at different media; tissue simulant, sand, and wood; it also used high-speed videography to determine initial muzzle velocity for each shot. The collected information was analyzed and compared to models of lead sphere external ballistic performance.

Our data exhibits excellent correspondence with ballistic performance models, further validating those models and allowing us to compare our data findings with various data sets. A particularly valuable finding is that the approximate original caliber of fired and deformed lead balls can be accurately determined using the Sivilich Revised Formula. This validation of the Sivilich Formula is of real value to archaeological investigations.

Our live-fire experiments were designed to determine colonial-era musket and fowling piece bullet performance. Accuracy was not a major component of the study; however, general shot accuracy was noted. The least accurate firearms were the British Long Land pattern muskets. Regardless of range the shots did hit the man-size torso target or were near misses, but had a very wide spread, often exceeding 30 inches. The Model 1740 Potsdam musket never struck the target at 100 yards. In part this may have been a function of the shooter's experience level but given the range of shooter experience in the eighteenth century this is not unrealistic. The British Royal Artillery carbine and the French model muskets achieved good target hits at all ranges at about 75% of the shots fired. The Thomas Earle fowling piece had an exceptional record for accuracy. Regardless of shooter experience, and nearly every shooter fired the fowling piece at least once, over 85% of the shots hit the target at all ranges. This led some of the shooters to observe they would rather have been colonial minute men or militia than British or Hessian troops being fired at by the fowling piece during the Revolutionary War.

Another valuable lesson derived from the live-fire experiments is the validation of bullet deformation and a general correlation with velocity. We present a Lead Bullet Deformation Index that we believe archaeologists will find useful. The LBDI we present needs additional testing and validation, but we believe that it has utility as an independent ordinal scale to assess impact deformation on conflict sites. The LBDI assessment can be of use in determining possible firing line distances on battlefields which will expand the archaeological interpretative potential of bullet datasets.

The microscopic examination of unfired and fired lead balls revealed changes in the microstructure of the balls' surface that are observable and clear. We have not yet examined the effect of patination on the observability of those surface changes in archaeological samples, but knowing they do and did exist on fresh lead bullets offers another line of investigation and interpretation to determine if a ball has been fired or not.

The work we undertook was designed to aid archaeologists in better understanding of the potential information yields that can be gained from bullet analysis from archaeological sites. We have focused on conflict sites specifically and the role bullet analysis has in yielding information that expands and enhances their interpretive value. An additional intent in conducting the live-fire experiments is to provide well controlled and defined data to forensic firearm examiners so they may use the information to identity historic firearm types involved in law enforcement cases either by inclusion or exclusion. We believe the data presented here will aid firearms examiners with case work when it involves shooting incidents with smoothbore muzzle loading black powder firearms.

The goals and objectives of this project were to collect data and conduct live-fire experiments with appropriate replica colonial firearms. The goals also included recording that information and disseminating it to battlefield archaeologists, interpreters, reenactment groups, and others to enhance various aspects of public interpretation regarding of the effectiveness of selected firearms used in combat in the past. Firearms had an enormous impact on the European settlement and conquest of the western hemisphere.

We see this report as the first step in creating a wide-ranging database on effectiveness and external ballistic performance of firearms in general, and in this specific study of colonial-era muskets and fowling pieces specifically. We also see this report as the first step in creating a database on bullet performance of firearms that were used in the Americas after 1492.

This study demonstrates the need to conduct additional live-fire experiments of with a variety weapons and firearms of the types used in the prior to the American Revolution, during the War of 1812, Mexican War, Civil War, and Indian Wars. Live-fire experiments with bows and arrows, lances, crossbows, matchlocks, and other common black powder weapons should be undertaken. Using this or similar data collection models to acquire muzzle and downrange velocities will result in better comparative observations of bullet velocity for a given weapon type as well as ascertaining when the projectile falls below a velocity and kinetic energy threshold that could cause death or a serious wound. Continued controlled live firing of weapons into ballistic gelatin will further assess wounding and lethality effects of various ammunition types in simulated tissue. Firearms functioned as tools throughout their history, evolving in concert with the cultures and technologies in which they were used. Firearms deserve serious study as points of industrial development and evolution and as factors in affecting cultural change across the globe.

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Appendix A
Experiments with 3-D Microscopy in Modeling Bullet Surfaces

A Leica DVM 5000 3-D microscope was used to capture images of some bullet surfaces as an experiment in the applicability of 3-D imaging to bullet analysis. The DVM 5000 microscope complements traditional microscopic inspection and analysis. The microscopic image is displayed directly on a high-resolution monitor and can reach extremely difficult-to-access surfaces. This allows for nondestructive inspection of elements which are difficult to examine using traditional microscope techniques. As an advanced digital microscope, it also offers a variety of quantitative analysis options. Among those are shade relief models of surfaces, colored wire frame models, and calibration functions.

The DVM 5000 has a large array of magnification capabilities. In the case of the lead balls the surface area that could be modeled is limited to a 6x6-millimeter area for any given ball tangent. In this experiment balls with fabric impressions were imaged at low magnification to achieve the 6x6-millimeter area, then modeled as surfaces to show fabric impressions and impact scarring. Relief models, profiles, and graphic profiles, and wire frame models were collected. The 3-D experiment demonstrates analytical potential, but time constraints prevented detailed comparisons and full analytical capability. More studies are needed to fully explore 3-D modeling potential.

Figure 93. The Leica DVM 5000 3-D microscope setup.

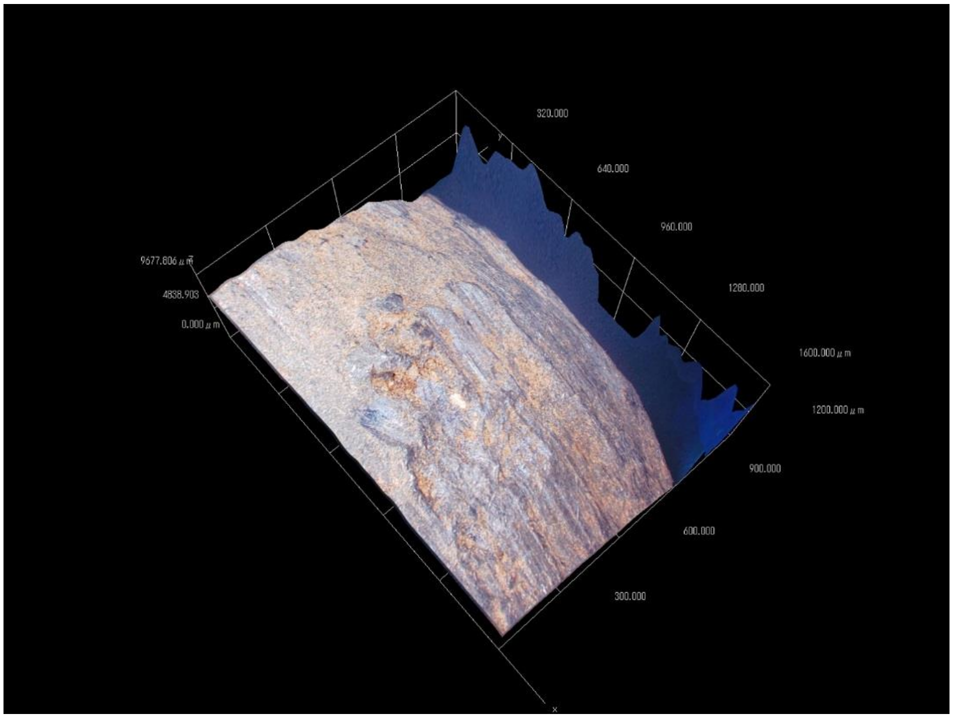

Figure 94. Ball segment, .69-inch, showing detail of wood impact scarring.

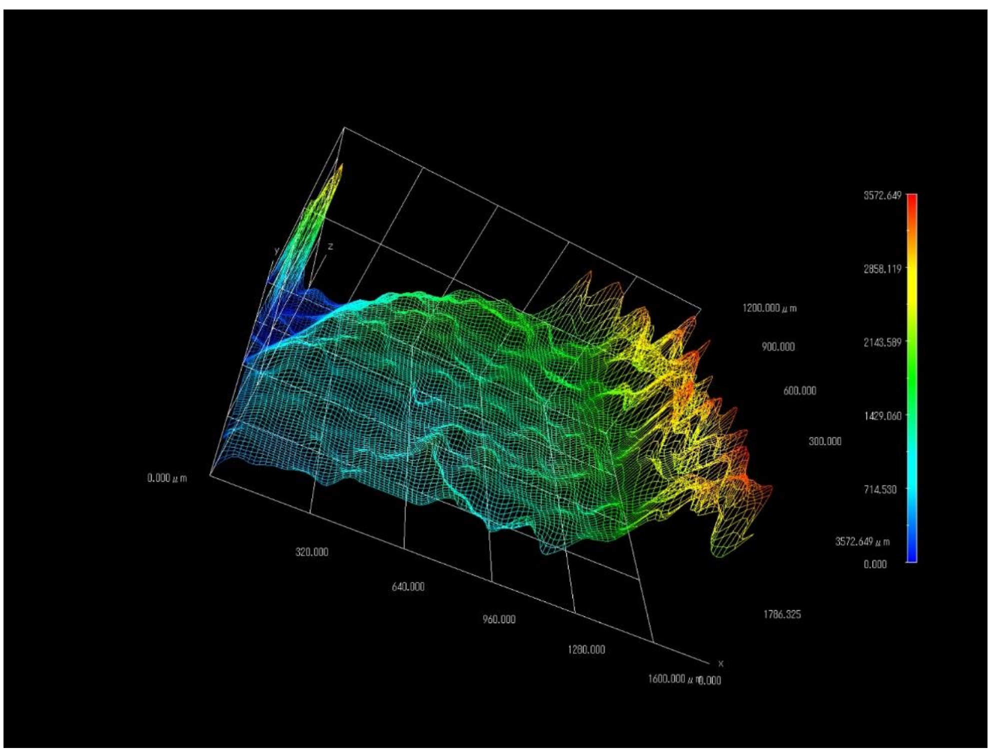

Figure 95. Wire frame model of the ball segment, .69-inch, showing detail of wood impact scarring.

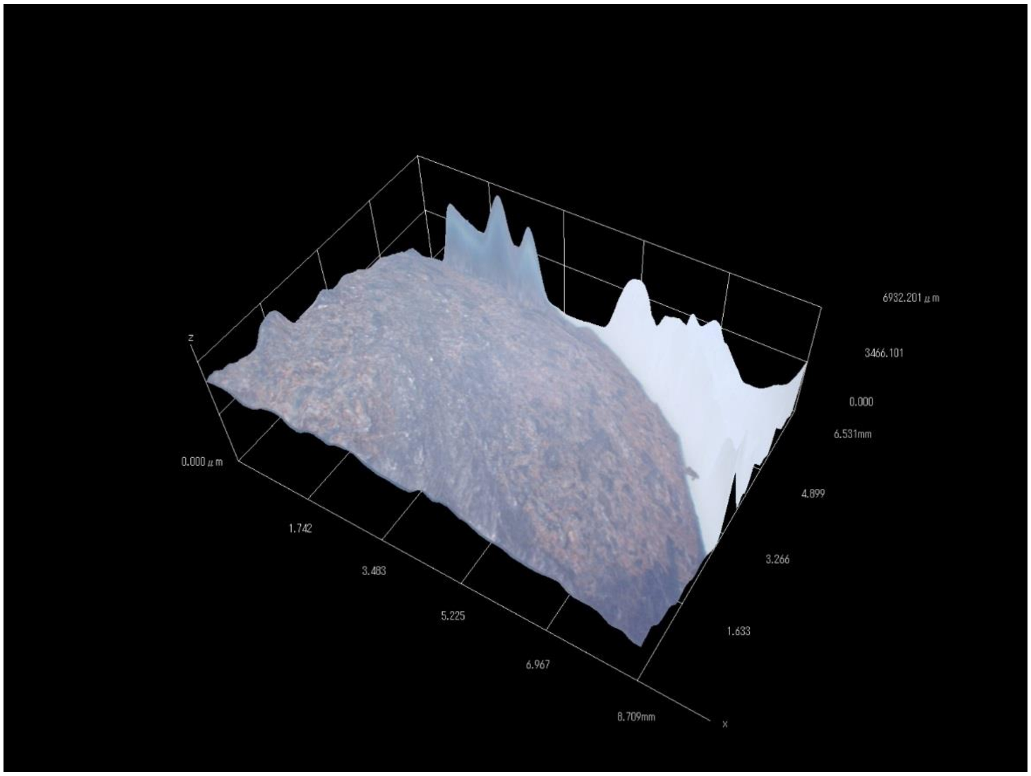

Figure 96. Fabric impressions on a .69-inch ball segment.

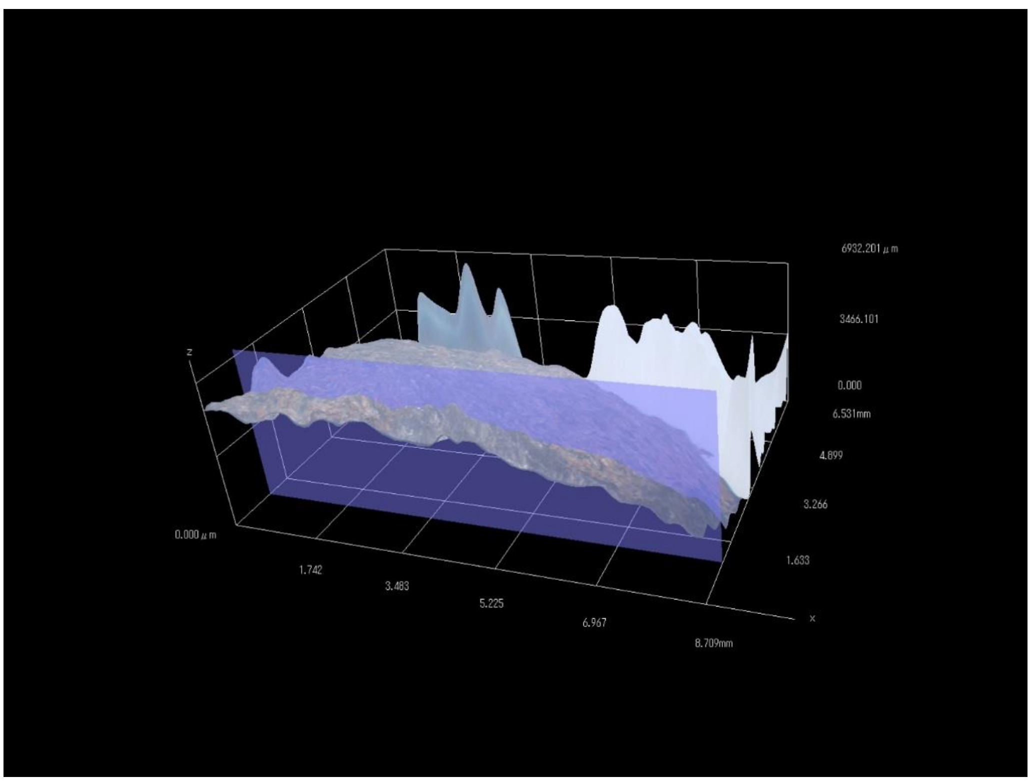

Figure 97. Profile location of the fabric impressions on the same .69-inch ball.

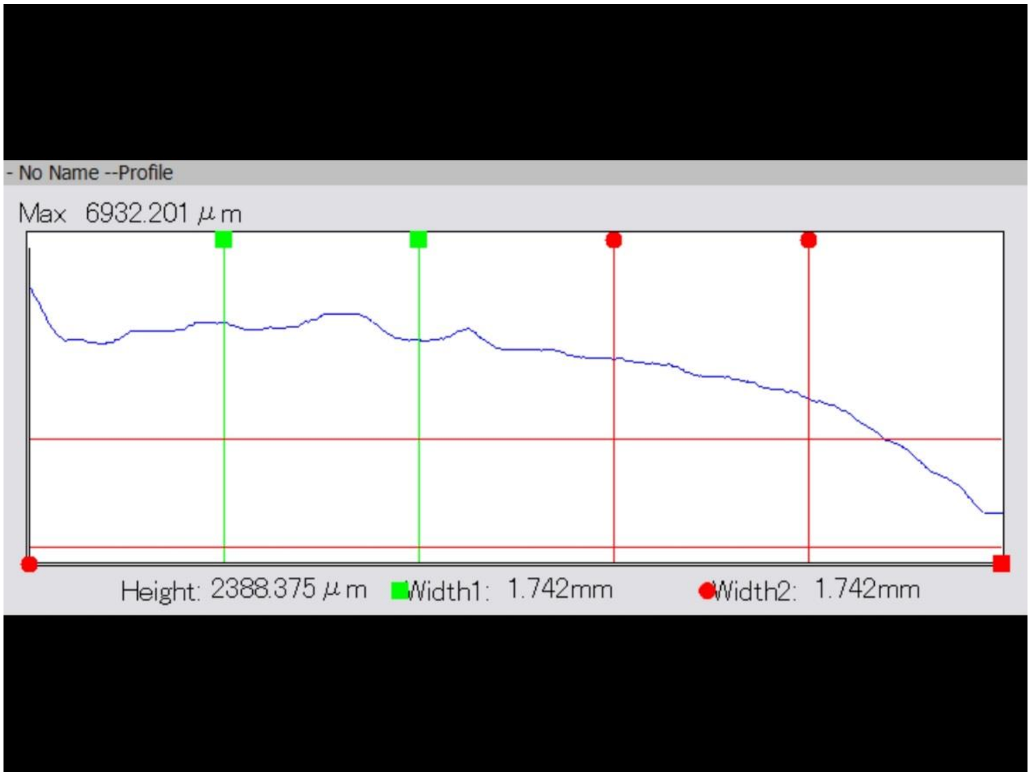

Figure 98. Graphic representation of the profile of the fabric impressions on the .69-inch ball.

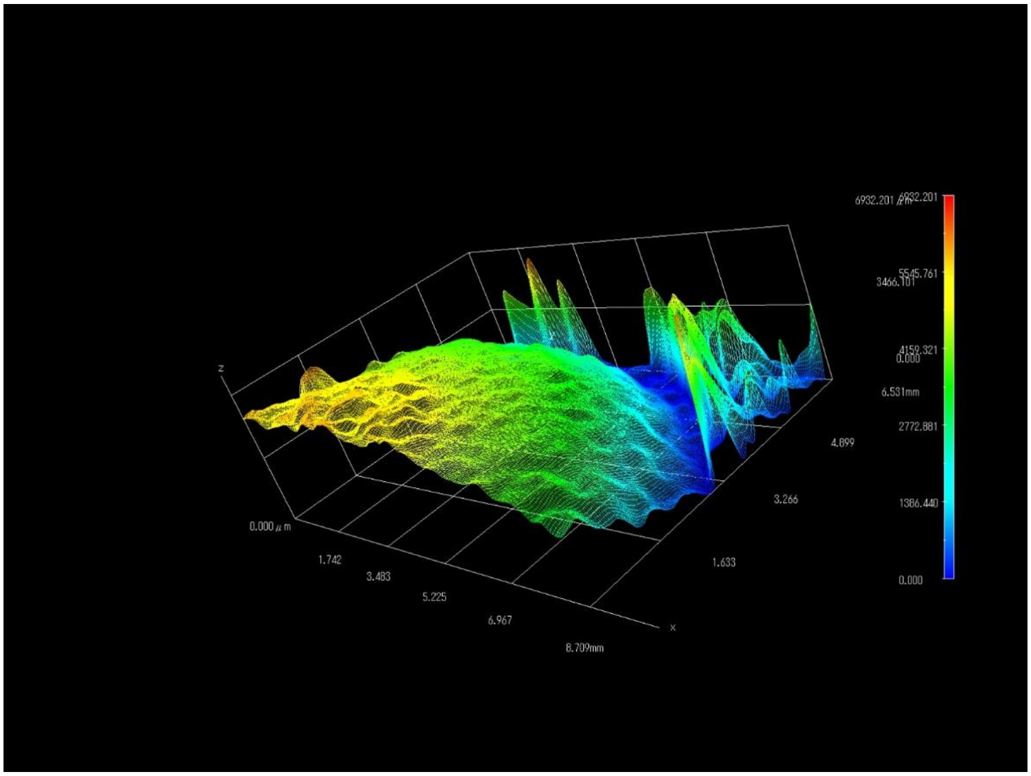

Figure 99. Wire frame model of the fabric impressed .69-inch ball.

Appendix B
Blind Lead Ball Analysis Study
by Daniel M. Sivilich

One component of the live-fire study identified the need to conduct a blind study of the known velocity and deformed lead balls recovered during the shooting event. Daniel Sivilich agreed to undertake the blind study as if the bullets were archaeological artifacts in need of analysis and interpretation. Mr. Sivilich is an acknowledged expert and published author (2016) on American Revolution and colonial-era bullets.

He examined the lead balls (n=31) that were:
1. Fired from a known firearm
2. Had a known velocity (3 exceptions)
3. Have a known recovery location
4. Deformation correlated with striking a known media
5. And were recovered immediately after firing by metal detecting

His analysis demonstrated that he correctly identified the bullet type, approximate caliber, and relative deformation at or above 90%. He suggested the submitted bullets were fired from at least four types of firearms based on caliber and bore characteristics engraved on the bullet during firing. In this he is essentially correct. He identified British Brown Bess caliber firearms, French caliber firearms, and two smaller bore-type firearms. In fact, the live-fire experiment fired seven different firearms. These can be grouped into two British Brown Bess caliber guns, two French caliber guns, and three other smaller bore firearms. These smaller bore firearms, Thomas Earle fowling piece, British Royal Artillery carbine, and Model 1740 Potsdam musket used similar sized lead balls as projectiles and do fall into two groups based on ball caliber. While the blind study could not, as expected, identify a ball as fired from a specific smoothbore musket, carbine, or fowling piece, the ball diameters used in the live-fire experiments do fall into four distinct groups.

Mr. Sivilich's analytical techniques are those commonly used by archaeologists who analyze and interpret lead projectiles recovered in colonial and post-colonial sites in the United States, as well as internationally. The blind study validates the commonly employed analytical techniques and interpretations used in the study of dropped and expended ordnance from archaeological contexts.

The table shows Mr. Sivilich's blind analysis. We have inserted in the first four columns information on the actual firearm, actual ball diameter, actual velocity, and actual range of the ball recovery for comparison purposes.

LIVE-FIRE MUSKET BALL EXPERIMENT - ANALYSIS BY DAN SIVILICH													
Actual gun	Actual ball dia.	Known Vel. f/s	Recovered at Range Yds.	**Study No.**	**Weight**	**Calc. Dia (in)**	**Caliber**	**Height (in)**	**% Compression**	**Fabric**	**Guesstimated Velocity at Impact**	**Guesstimated Distance (yd)**	
French 1766 musket - buckshot	0.282	1110	94	18A	2.0	0.2807	28						#1 Buck
French 1766 musket - buckshot	0.282	865	94	17A	2.2	0.2898	29						#1 Buck
						RIFLE or SMALL-BORE 1							
T. Earle Fowler - .62	0.52	1240	94	24	12.9	0.5225	52	0.504	3.5%		M	50-75	Hard target, deep scrape marks radiating out from center of impact.
T. Earle Fowler - .62	0.52	1350	94	20	13.2	0.5266	53	0.485	7.9%		M	50-75	Possibly hit hard wood or particle board, deep scrape marks radiating out from center of impact. Possible wood fragments (not very fibrous) on impact side.
T. Earle Fowler - .62	0.52	1345	94	22	13.2	0.5266	53	0.463	12.1%		M	50-75	Hit wood. Fibrous wood on impact side,
T. Earle Fowler - .62	0.52	1215	94	23	12.9	0.5225	52	0.410	21.5%		H	25-50	Deep scrape marks probably ricochet off a rock then hit hard dirt. Small embedded quartz crystals.
T. Earle Fowler - .62	0.52	1285	94	21	13.0	0.5239	52	0.381	27.3%		H	25-50	Badly scraped. Possibly hit a rock or hard target then dirt. Lead folded back on non-impact side.
T. Earle Fowler - .62	0.52	1240	94	25	13.0	0.5239	52	0.318	39.3%		H	25-50	Very flattened, lead slightly rolled back on non-impact side. Hit semi-hard target such as dry wood or hard dirt
						RIFLE or SMALL-BORE 2							
British Artillery Carbine - .65	0.58	1210	94	3	18.8	0.5924	59	0.563	5.0%		H	25-50	Possibly hit hard wood, deep scrape marks radiating out from center of impact. Small wood particle fragments on impact side.
T. Earle Fowler - .62	0.58	1155	25, captured in gel	31	18.1	0.5850	58	0.532	9.1%	Y	H	25-50	Fabric on impact side. Fired at target covered in fabric - fine weave impression. Ramrod mark.
British Artillery Carbine - .65	0.58	960	94	1	18.8	0.5924	59	0.475	19.8%		H	75-100	Hard target and/or clay/sand.
T. Earle Fowler - .62	0.58	no velocity data	94	26	18.0	0.5839	58	0.464	20.5%		H	50-75	Hard target, slight ricochet, sandy loam.
British Artillery Carbine - .65	0.58	1135	94	4	18.7	0.5914	59	0.453	23.4%		H	50-75	Hard target and/or clay/sand.
British Artillery Carbine - .65	0.58	1170	94	2	19.0	0.5945	59	0.425	28.5%		H	50-75	Hard target - slight ricochet off semi-hard target such as wood or tree then hit dirt.
T. Earle Fowler - .62	0.58	1460	94	30	18.0	0.5839	58	0.362	38.0%		H	25-50	Very flattened, hard dirt/compacted sand. Ricocheted off a sandbag?

T. Earle Fowler - .62	0.58	1435	94	28	18.1	0.5850	58	0.362	38.1%		H	25-50	Very flattened, hard dirt/compacted sand. Fired through a sandbag?
T. Earle Fowler - .62	0.58	1415	94	29	17.7	0.5806	58	0.325	44.0%		H	25-50	Hard target, deep scrapes radiating out from impact point. Lead rolled back, possible lead loss. Wood fibers trapped under rolled lead lip.
T. Earle Fowler - .62	0.58	no velocity data	94	27	18.0	0.5839	58	0.301	48.5%		H	25-50	Very flattened, hard dirt/compacted sand. Fired through a sandbag?

				SMOOTH BORE 1 - POSSIBLE CHARLEVILLE									
French 1728/41 musket - .70-.71	0.626	775	94	12	23.2	0.6354	64	0.624	1.8%		L	75-100	Possible ramrod mark. Hit dirt.
French 1766 musket -.68	0.26	1090	94	13	23.1	0.6345	63	0.620	2.3%		L	75-100	Non-Fibrous wood fragments on impact side. Concave indentation with scrape marks. Possible ricochet off a large pebble.
French 1728/41 musket - .70-.71	0.626	960	94	10	23.0	0.6336	63	0.612	3.4%		L	75-100	Wood fragments on impact side. Looks more like dried hardwood.
French 1766 musket -.68	0.626	785	25, captured in gel	19	22.9	0.6327	63	0.599	5.3%	Y	L	75-100	Patched, soft target (ballistic gel) or dirt. Possible ramrod mark.
French 1766 musket -.68	0.626	1110	94	18	22.7	0.6308	63	0.595	5.7%		L	75-100	Barrel band. Hit dirt. Ball and Buck.
French 1728/41 musket - .70-.71	0.626	905	94	11	23.1	0.6345	63	0.586	7.6%		L	75-100	Hit hard dirt. Concave indentation with scrape marks. Possible ricochet off a large pebble.
French 1766 musket -.68	0.626	865	94	17	23.1	0.6345	63	0.537	15.4%		H	25-50	Hit hard dirt. Embedded micro crystalline quartz. Concave depression with no scrape marks. Possible ramrod mark. Ball and Buck
Firearm not known - prob. French	0.626	no velocity data	94	32	22.5	0.6290	63	0.523	16.9%		H	25-50	Hit a tree or wood - much wood fiber still on ball,
French 1766 musket -.68	0.626	1215	94	15	23.2	0.6354	64	0.518	18.5%		H	25-50	Slight ricochet. Hit hard dirt. Concave indentation with scrape marks. Possible ricochet off a large pebble.
French 1766 musket -.68	0.626	1175	94	16	23.5	0.6382	64	0.513	19.6%		H	25-50	Hard target and/or clay/sand. Faint barrel band.
French 1766 musket -.68	0.626	1205	94	14	23.1	0.6345	63	0.499	21.4%		H	25-50	Hard target and/or clay/sand. Ricochet. Faint cut line across non-impact hemisphere
				SMOOTH BORE 2 - POSSIBLE BROWN BESS									
British 1756 Long Land musket - .76	0.69	630	25, captured in gel	9	31.3	0.7022	70	0.664	5.4%	Y	L	75-100	Patched, soft target or dirt.
British 1756 Long Land musket - .76	0.69	600	94	8	31.5	0.7036	70	0.651	7.5%	Y	L	75-100	Patched, light scrapes radiating out from impact point. Hard target and/or clay/sand. Barrel band.
British 1742 Long Land musket - .76	0.69	870	94	5	31.7	0.7051	71	0.619	12.2%		M	50-75	Hard target and/or clay/sand.
British 1756 Long Land musket - .76	0.69	1240	25	7	31.2	0.7014	70	0.591	15.7%		M	25-50	Hard target. Concave depression with rough cross hatch pattern, deep scrape marks radiating out from depression.

British 1756 Long Land musket - .76	0.69	no velocity data	94	6	32.0	0.7073	71	0.577	18.4%	WIRE	M	25-50	Concave depression and 0.050" (approx.) diameter wire impression on impact side. White particles suggest this hit a piece of wood.
				Diameter calculated with Sivilich Formula									
				"Caliber" is the calculated diameter * 100 and rounded up to a whole number									

Appendix C

Elemental Analysis of Modern Lead Shot

By Daniel T. Elliott, The LAMAR Institute, Savannah, Georgia 2017

Elemental analysis is a useful approach for the archaeological study of early ammunition. The present study examined modern examples of round lead balls, similar to those used in the ballistics study.

A sample of seven modern lead shot were analyzed. These shot measured .28, .31, .51, .58, .62, .66 and .67 calibers. This analysis was conducted at the Elliott's Archaeology Laboratory in Rincon, Georgia. Each sample was measured for 180 seconds using a Bruker Tracer. The methods employed were identical to those currently being used to analyze archaeological examples, following the advice of Bruce Kaiser. The composite spectrograms of these seven samples is shown in Figure 1. Results for individual samples are shown in Tables 2-8.

Figure 2 shows an enlargement of the composite spectrogram for the elements Cadmium, Tin and Antimony. Each of these elements is present in low quantities, but they are present. Previous study of archaeological examples from 18th century collections indicate that Tin and Antimony are sensitive indicators of possible cultural significance. The interpretation of these indications are currently under consideration by researchers.

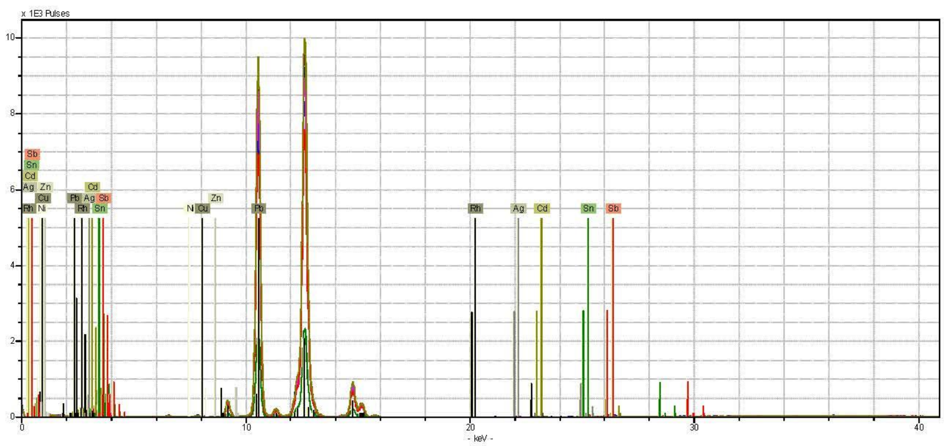

Figure 1. Composite of Seven Spectrograms.

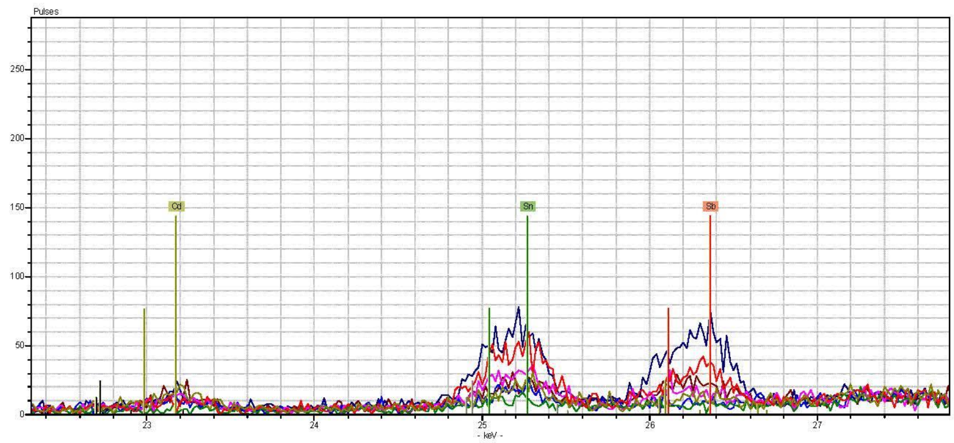

Figure 2. Enlargement of Composite Spectrograms, Showing Elements Cadmium, Tin and Antimony.

Table 1. Photon Energies from Seven Modern Balls.

Sample	Ag K12	Ag L1	Cd K12	Cd L1	Cu K12	Ni K12	Pb L1	Pb M1	Rb K12	Rh K12	Rh L1	Sb K12	Sb L1	Sn K12	Sn L1	Zn K12	Zr K12
28 cal	100	1	144	0	189	112	85542	788	108	75	6	483	64	927	3	2	249
31 cal	79	19	30	0	117	50	27076	228	1	30	0	5	14	121	9	9	89
51 cal	90	1	164	-5	249	116	105003	913	88	107	0	212	67	554	-4	21	351
58 cal	70	10	143	0	186	61	93385	722	102	38	0	26	26	262	18	26	298
62 cal	66	1	179	0	357	104	102789	871	1	23	0	1085	42	1106	35	53	268
66 cal	60	20	203	0	308	94	109591	961	235	15	0	276	41	318	25	0	328
69 cal	82	21	265	0	327	92	116861	970	140	84	0	93	40	307	2	59	358

ARTAX - ELEMENT ANALYSIS

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Optic:

Project:
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Live time: 162 s
Dead time: 0.1 %
Current: 20 µA
Filter: Ti/Al
Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	53	176
Fe	K12	0.00	154	191
Co	K12	0.00	52	224
Ni	K12	0.00	92	253
Cu	K12	0.00	327	269
Zn	K12	0.00	59	261
Ga	K12	0.00	768	436
Rb	K12	0.00	140	1494
Sr	K12	0.00	169	530
Y	K12	0.00	2234	1051
Zr	K12	0.00	358	400
Rh	K12	0.00	84	41
Rh	L1	0.00		397
Ag	K12	0.00	82	95
Ag	L1	0.00	21	349
Cd	K12	0.00	265	126
Cd	L1	0.00		321
Sn	K12	0.00	307	225
Sn	L1	0.00	2	267
Sb	K12	0.00	93	294
Sb	L1	0.00	40	263
Pb	L1	0.00	116861	1344
Pb	M1	0.00	970	454

BRUKER

ARTAX - ELEMENT ANALYSIS

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Optic:

Project:
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Fe	K12	0.00	117	178
Co	K12	0.00	12	207
Ni	K12	0.00	94	260
Cu	K12	0.00	308	292
Zn	K12	0.00		289
Ga	K12	0.00	676	457
Rb	K12	0.00	235	1416
Sr	K12	0.00	148	527
Y	K12	0.00	1911	994
Zr	K12	0.00	328	378
Rh	K12	0.00	15	65
Rh	L1	0.00		353
Ag	K12	0.00	60	126
Ag	L1	0.00	20	295
Cd	K12	0.00	203	156
Cd	L1	0.00		271
Sn	K12	0.00	318	309
Sn	L1	0.00	25	267
Sb	K12	0.00	276	407
Sb	L1	0.00	41	285
Pb	L1	0.00	109591	1233
Pb	M1	0.00	961	420

BRUKER

ARTAX - ELEMENT ANALYSIS

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Optic:

Project:
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Current: 20 μA
Filter: Ti/Al
Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	76	155
Fe	K12	0.00	173	169
Co	K12	0.00	14	198
Ni	K12	0.00	104	237
Cu	K12	0.00	357	282
Zn	K12	0.00	53	250
Ga	K12	0.00	562	377
Rb	K12	0.00	1	1327
Sr	K12	0.00	139	482
Y	K12	0.00	1817	975
Zr	K12	0.00	268	394
Rh	K12	0.00	23	56
Rh	L1	0.00		376
Ag	K12	0.00	66	121
Ag	L1	0.00	1	329
Cd	K12	0.00	179	168
Cd	L1	0.00		304
Sn	K12	0.00	1106	364
Sn	L1	0.00	35	284
Sb	K12	0.00	1085	426
Sb	L1	0.00	42	298
Pb	L1	0.00	102789	1191
Pb	M1	0.00	871	433

ARTAX - ELEMENT ANALYSIS

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Optic:

Project:
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Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	53	143
Fe	K12	0.00	135	160
Co	K12	0.00	1	188
Ni	K12	0.00	61	237
Cu	K12	0.00	186	273
Zn	K12	0.00	26	277
Ga	K12	0.00	679	400
Rb	K12	0.00	102	1120
Sr	K12	0.00	121	429
Y	K12	0.00	1591	913
Zr	K12	0.00	298	341
Rh	K12	0.00	38	41
Rh	L1	0.00		328
Ag	K12	0.00	70	94
Ag	L1	0.00	10	293
Cd	K12	0.00	143	128
Cd	L1	0.00		270
Sn	K12	0.00	262	212
Sn	L1	0.00	18	249
Sb	K12	0.00	26	307
Sb	L1	0.00	26	258
Pb	L1	0.00	93385	1043
Pb	M1	0.00	722	388

ARTAX - ELEMENT ANALYSIS

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Anode:
Optic:

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Current: 20 µA
Filter: Ti/Al
Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
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Fe	K12	0.00	112	160
Co	K12	0.00	53	175
Ni	K12	0.00	116	203
Cu	K12	0.00	249	262
Zn	K12	0.00	21	297
Ga	K12	0.00	783	448
Rb	K12	0.00	88	1267
Sr	K12	0.00	125	463
Y	K12	0.00	1790	979
Zr	K12	0.00	351	384
Rh	K12	0.00	107	21
Rh	L1	0.00		377
Ag	K12	0.00	90	104
Ag	L1	0.00	1	330
Cd	K12	0.00	164	149
Cd	L1	0.00		307
Sn	K12	0.00	554	230
Sn	L1	0.00		264
Sb	K12	0.00	212	307
Sb	L1	0.00	67	268
Pb	L1	0.00	105003	1153
Pb	M1	0.00	913	421

BRUKER

ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:48:57 PM

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Voltage: 45 kV
Anode:
Optic:

Project:
Meas.date: 4/7/2017 10:45:55 AM
Live time: 175 s
Dead time: 0.0 %
Current: 20 µA
Filter: Ti/Al
Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	43	68
Fe	K12	0.00	54	58
Co	K12	0.00	16	66
Ni	K12	0.00	50	79
Cu	K12	0.00	117	92
Zn	K12	0.00	9	92
Ga	K12	0.00	182	117
Rb	K12	0.00	1	377
Sr	K12	0.00	51	133
Y	K12	0.00	554	255
Zr	K12	0.00	89	114
Rh	K12	0.00	30	23
Rh	L1	0.00		232
Ag	K12	0.00	79	68
Ag	L1	0.00	19	219
Cd	K12	0.00	30	82
Cd	L1	0.00		207
Sn	K12	0.00	121	183
Sn	L1	0.00	9	181
Sb	K12	0.00	5	268
Sb	L1	0.00	14	182
Pb	L1	0.00	27076	331
Pb	M1	0.00	228	280

BRUKER

ARTAX - ELEMENT ANALYSIS

Listed at 4/12/2017 5:44:54 PM

Serial number:
Spectrum: Bohy7@070417_122539
Method: Lead2 (Bayes)
Count rate: 1580 cps
Voltage: 45 kV
Anode:
Optic:

Project:
Meas.date: 4/7/2017 10:58:39 AM
Live time: 166 s
Dead time: 0.1 %
Current: 20 µA
Filter: Ti/Al
Atmosphere: Air

Element	Line	Sigma/	Net area	Backgr.
Mn	K12	0.00	61	145
Fe	K12	0.00	72	138
Co	K12	0.00	29	134
Ni	K12	0.00	112	168
Cu	K12	0.00	189	229
Zn	K12	0.00	2	255
Ga	K12	0.00	585	350
Rb	K12	0.00	108	1079
Sr	K12	0.00	155	351
Y	K12	0.00	1428	764
Zr	K12	0.00	249	314
Rh	K12	0.00	75	36
Rh	L1	0.00	6	318
Ag	K12	0.00	100	74
Ag	L1	0.00	1	264
Cd	K12	0.00	144	118
Cd	L1	0.00		253
Sn	K12	0.00	927	284
Sn	L1	0.00	3	242
Sb	K12	0.00	483	386
Sb	L1	0.00	64	248
Pb	L1	0.00	85542	947
Pb	M1	0.00	788	392