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The ballistics of 17th Century musket balls

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Abstract

This paper investigates the firing of 17th Century musket balls. Prior to this research the main concerns with making such predictions were associated with the deformed shape of the musket balls affecting their drag coefficient and therefore their distance to ground impact. However, the distance due to bounce and roll after initial impact has been unknown. In this work, the distance travelled after the first ground impact greatly exceeded expectations, with the musket balls approximately doubling the distance to their final resting positions. From these findings the initial factors thought to have had high relevance to the final resting position of the musket ball (velocity variation and drag co-efficient) become less significant and factors such as ground hardness become more prominent. The knowledge gained during this investigation will allow more accurate information to be obtained on the firing positions of opposing forces during conflicts in the English Civil War.

Keywords

black powder, wad, pressure, accuracy, range

Introduction

17th Century muskets

Inspection of the 52 weapons in the Littlecote Collection (The Royal Armouries, Leeds, UK) suggested that the main weapon used in the English Civil War was typically a 10 bore matchlock musket with a 48 "(1.22 m) long barrel; the internal diameters of the barrels actually varied from 18.87 mm to 22.35 mm (mean diameter = 19.87 mm) (Eyers, 2006). The true calibre of 10 bore equates to 19.70 mm (i.e. the diameter from a sphere of lead weighing 1/10th of a pound) (Eyers, 2006).

There are many references to the calibre of 17th Century muskets in the literature e.g. *"The bore of the barrel was standardised at 10, and this was designed to provide an easy-fit for a 12-bore bullet"* (Rogers, 1968). With regards to the barrel length, again there are many references to be found e.g. *"c.1640 commonest of all infantry arms in the seventeenth Century was the matchlock musket. The regulation 48 inches long"*. (Bull, 1991). As well as variations in individual musket calibre it is likely that most barrels would not have been perfectly straight. According to Greener (1910) *"Previous to 1795 there was no reliable method of ascertaining when a barrel was or was not perfectly straight. The barrels of the finest ancient guns were usually far from straight".*

The 17th Century musket would not have been capable of withstanding the pressures that a modern weapon could, as modern steels and manufacturing processes were not available. Greener (1910), states *"The method of making barrels prior to the introduction of Damascus iron (1820) from the east was to forge them from plates or strips of iron-this iron manufactured from old horse shoe nails".* This could be one of the limiting factors affecting the maximum velocity of the 17th Century musket.

17th Century musket balls

Musket ball were cast using a split mould of two halves; the sprue was usually removed (Foard, 2009). Several articles provide information on 17th Century musket balls recovered from archaeological sites (e.g. Harkins, 2006; Foard, 2009). A musket ball recovered from the site of the Battle of Marston Moor in 1664 had a Vickers hardness of 6.32 and was 99.7

% lead (Harkins, 2006). Musket balls recovered from the Battle of Edgehill (1642) were 12 bore with a mean diameter of 18.51 mm and had a typical mass of 37.9 g (Harkins, 2006). Foard (2009) also studied musket balls recovered from Edgehill and reported that 12 bore was the most common calibre represented.

Musket balls recovered from archaeological sites are usually banded; this is a distinctive firing mark where the bullet is flattened in a band around the circumference of the bullet (Foard, 2009). Other features visible on fired musket balls include pitting and evidence of melting; usually affecting the hemisphere of the musket ball adjacent to the powder (Foard, 2009).

A 17th Century musket that was 10 bore (19.68 mm) internal diameter and fired a 12 bore (18.51 mm)musket ball had a large amount a windage i.e. the space between the musket ball and the inside of the barrel. Windage ensured that the musket ball would easily slide to the bottom of the musket barrel even when the barrel had become fouled from black powder residue after several firings. The disadvantage of such a large amount of windage is that it results in a reduction in muzzle velocity due to gases escaping past the musket ball and quite possibly a reduced accuracy.

17th Century powder and wadding

The propellant used in 17th Century firearms was black powder (often called gunpowder) which consisted of a mixture of saltpetre (potassium nitrate), sulphur and charcoal (Brown, 2005). A modern black powder consists of 75% potassium nitrate, 15% wood charcoal (carbon) and 10% sulphur; earlier mixtures contained much smaller amounts of saltpetre

(Brown, 2005). The three components must be well mixed and finely powdered for efficient burning.

When black powder is ignited, the oxygen from the nitrate allows the sulphur and the carbon to burn rapidly producing a mixture of hot gases including sulphur dioxide and carbon dioxide, this in turn causes a rapid increase in volume (Brown, 2005). If the black powder is lit in a confined space such as inside a barrel, this rapid increase in gas volume will lead to an increase in pressure propelling the musket ball along the barrel.

Little archaeological evidence is available regarding gunpowder manufactured during the Civil War. It is known that powder mills were made from local converted water mills (Cocroft, 2000). With the limited amount of historical data available and small amounts of research previously conducted, it is difficult to accurately establish how the 17th Century powders would compare to those of today.

Nathaniel Nye (1647) a master gunner from Worcester gave a detailed description of black powder production during the Civil War ... "*four parts petre, one part Brimstone and one part Cole*." (Nye, 1647). It is hard to establish the exact purity of the saltpetre or the grain size of powder used in the musket and it is not until much later in history that grain sizes are mentioned. Modern military black powders are classified according to British INT DEF STAN 13-166/1 and INT DEF STAN 13-167/1. An example is G12, dark glazed, uniform granulation and free from foreign matter, granulation 1 - 2 mm. Other classifications can carry a U.N. number and a designation for example type 3A (Fine) U.N. number 0027 grain size 0.25-0.50 mm. Otherwise, black powder is simply classed as fine or course grain.

Reported muzzle velocities include i) between 1425 fps (434 m/s) – 1700 fps (518 m/s) with a ¾ " (19.05 mm) diameter ball and 45 " (1.143 m) long barrel (Benjamin Robins in 1742) and ii) an average muzzle velocity of 1561 fps (476 m/s) for an English musket

(Captain Alfred Mordecai in 1840) (Roberts, 2008). Other data in the literature states that 16th, 17th and 18th Century muskets (17 mm calibre, 15 g of powder) produced muzzle velocities of between 450 m/s and 500 m/s (Harding, 1997).

Deposits left inside the barrel of the musket after firing (fouling) will alter the amount of windage, especially if there is a cumulative effect. Over 50 % of constituents produced by black powders are non-gaseous. This material either takes the state of a liquid during the combustion cycle, or as a powder found either escaping as smoke at the end of the barrel or as particles left inside the barrel (Greener, 1910).

It was suggested by Roger Boyle (the first Earl of Orrery from Grose) in 1801 that wadding was sometimes used during the Civil War; he stated that *"... such softe haire as they stuff saddles with... this soldier must use when time permits"*(Eyers, 2006). Other researchers have also suggested wadding was not used to shorten the time to load and fire the weapon (e.g. Foard, 2009; Rogers, 1968).

The aim of the research summarised in this paper was to investigate the ballistics of 17th Century musket balls through a combination of experimental firings conducted in i) an indoor range which considered the effect of the type of black powder used, windage and elevation and ii) outdoor firings which investigated range, accuracy and bounce and roll of musket balls.

Methods

Manufacture of reproduction musket balls

Reproduction 12 bore lead musket balls (18.51 mm diameter) were cast using a split mould. After cooling, the mould was opened and the sprue removed. Flash was visible where the two halves of the mould joined as are observed on 17th Century musket balls (Figure 1).

Figure 1 Reproduction musket ball

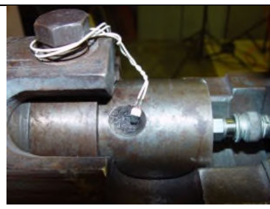
Firings in the indoor ballistic range

<u>Firing system</u>

A firing system was developed for the indoor range work (Figure 2). A muzzle loading barrel was used; 48 " 10 bore (19.69 mm internal diameter), which had a screw thread on one end to attach it to a breech block with a counter-sunk touch hole to allow priming gunpowder to used. A tapping for a pressure transducer was located in the end of the breech which was inserted into a Number 3 proof housing and secured with a back nut. The pressure transducer was connected to a charge amplifier and the signal was then transferred to a pc via a data capture card. The proof housing was bolted to a stand which allowed movement of the gun horizontally and vertically. A laser pointer was attached to the rear of the proof housing for accurate aiming. A Weibel Doppler radar type W700 was used to record the velocities of the musket balls.

For each firing, a small wooden dowel was inserted into the touch hole to ensure that the powder did not leak out when it was being poured into the barrel. For wadding, nine sheets of rolled tissue paper were lightly rammed in with a ram rod. The musket ball was then inserted into the barrel and very gently rammed in. Two sheets of tissue paper were inserted into the barrel and gently rammed in on top of the musket ball. The barrel and the proof housing were then lifted onto the stand and secured. The dowel was removed and a small amount of priming powder (Swiss no.1) poured into the touch hole and allowed to spread around the counter-sink. An electrical igniter consisting of two wires joined by a match head was taped over the priming powder. The match was initiated with a 20 V electrical supply completing the circuit to the match head.

Figure 2 Firing system

			
Pressure housing with barrel	Powder	Ball	Electrical ignition

A soft capture system consisting of multiple sheets of Plastozote foam located 10 m from the end of the barrel was used to determine the depth of penetration (DoP) of the musket balls and to examine the musket balls post-firing.

<u>Effect of type of black powder</u>

Three black powders were compared i) Swiss No.1 a fine grained and fast burning black powder (grain size = 0.23-0.51 mm), ii) 3A which is a fine grained powder (grain size = 0.25-0.50 mm) and iii) G12 which is a coarse grained powder (grain size = 1-2 mm). As it is possible that wadding may have been used during the Civil War, tests were conducted with and without a wad. The criteria for establishing the most appropriate powder was determined by the quantity required to obtain correct velocities without overpressure, but be able to generate enough pressure to produce the banding effects seen on musket balls retrieved from the battle field. A charge mass of 12.5 g was used.

Effect of bore diameter

Two additional barrels, each 48 " long, were manufactured; one barrel had a bore diameter of 18.7 mm to recreate a very tight fitting musket ball, while the other barrel had a bore diameter of 20.4 mm for a loose fitting musket ball. Trials were carried out firing a 12 bore lead musket ball (diameter = 18.51 mm) to investigate the effect of barrel bore diameter on musket ball ballistics and damage.

Effect of elevation

A Figure 11 target (a type of military target used on firing ranges) was placed 5 m from the end of the barrel and the effect of altering the elevation of the barrel from 0° to 10° was determined.

Long range trials

Location and apparatus

Long range outdoor trials were conducted along the main grass ride at Ashdown Wood (Ashdown House, Ashbury, Oxfordshire, UK) (Figure 3). The ride is 18 m wide and 1500 m long; the first 300 m is almost flat and largely free of metallic debris, a requirement for finding the musket balls post-firing using a metal detector. Ground hardness was measured with a cone penetrometer.

The apparatus used in the indoor trials was transported to the outdoor venue. The barrel was 1.39 m above the ground; this distance was the mean shoulder height for volunteers from The Battlefields Trust (Pollard, 2008). Witness screens were placed down the ride. The horizontal position was sighted to the first witness screen by looking along the barrel. An optical level was used to mark the witness screens with a 0, 0 coordinate at 1.39 m high and centred to enable drop and sideways movement to be measured. A Weibel Doppler radar model W700 (powered by a portable generator) was used to record the velocities. A metal detector was used to find the musket balls after firing.

Figure 3 Outdoor firing location

<u>Test day 1</u>

The grass length was approximately 30 mm and the soil damp, wind conditions were calm. To measure impact positions, cartridge paper witness screens (1.2 m (w) x 2.0 m (h)) mounted in custom made steel tubing frames were used at 20 m intervals from the gun to a total of 200 m. Four musket balls were fired used a 48 " 12 bore barrel with 0° elevation; the barrel was loaded with 18 g of G12 black powder.

Test day 2

The grass was approximately 30 mm long, the ground dry; wind conditions were calm. Due to difficulties encountered with impacting the witness screens during Day 1 trials, a slightly different witness screen arrangement was used on Day 2. The first witness screen was placed 50 m from the muzzle, seven further witness screens were then placed at intervals of 30 m to a total of 260 m and a further two sets of screens were placed at 20 m intervals to a total of 300 m.

A total of nine musket balls were fired on Day 2 with 0° elevation, each used 18 g of G12 black powder. Shots 1 to 5 used a 48 " 10 bore barrel (internal diameter = 19.49 mm), shots 6 and 7 used a 48 " barrel with an internal diameter of 18.7 mm and shots 8 and 9 used a 48 " barrel with an internal diameter 20.4 mm. The musket balls were painted with a thin coat of white paint to aid location post-firing.

Test day 3

The ground was damp and the grass approximately 30 mm long; there was a light wind. A total of ten musket balls were fired used a 48 " 12 bore barrel with 0° elevation; the barrel was loaded with 18 g of G12 black powder with no wads used. The musket balls were painted with a thin coat of bright orange paint to aid location post-firing. A single witness sheet of paper was positioned 100 m from the barrel and a cross marked on it as a point of aim by bore sighting. A telescopic sight was then positioned on the barrel and adjusted to the cross so each shot would have the same aiming mark. Due to limited time, the Doppler radar was not used and the muzzle velocity predicted from previous data.

Results and discussion

Indoor firings

Effect of black powder

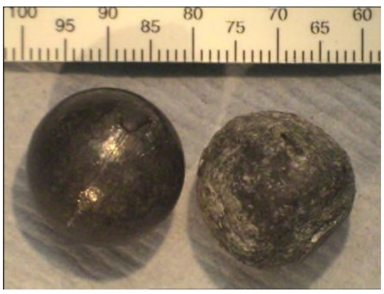
The effect of the type of black powder and whether or not a wad was used on the peak pressure measured by the pressure transducer is summarised in Table 1. Swiss no. 1 black powder resulted in an unacceptable peak pressure and was excluded from the trials after the first shot. The 3A and G12 black powders resulted in velocities in the order of those for 17th Century muskets. However, the pressure vs. time curve for G12 identified it as a slower burning black powder compared to 3A; 17th Century propellant was likely to be slower burning as it would have been less refined than a modern powder.

Table 1 Effect of type of black powder and whether or not a wad was used on peak pressure

powder	wad used?	muzzle velocity (m/s)	peak pressure (bar)	time after trigger
3A	yes	417	228	2.65 μs
G12	yes	341	176	2.32 μs
Swiss no. 1	yes	453	779	7.62 μs
3A	no	388	268	1.86 ms
G12	no	334	174	1.70 ms

The musket balls were retrieved from the soft-capture system post-firing, examined and compared to the reported appearance of 17th Century musket balls recovered from archaeological sites. All musket balls fired with wadding showed visible banding irrespective of black powder type. The musket ball fired using Swiss No.1 showed signs of melting around the banding circumference. The musket balls fired without a wad showed similar characteristics to those found on the Edgehill battlefield musket ball (Foard, 2009). Non-wadded balls showed evidence of pit marks produced from the burning propellant on the base of the projectile where as the wadded musket balls showed no sign of powder pitting (**e.g. Figure 4**). These results suggested that the Edgehill musket ball was fired without a wad.

Figure 4 Examples of fired musket balls



The remainder of the experiments were conducted using G12 black powder.

Effect of bore diameter

The effect of bore diameter on the peak pressure measured by the transducer mounted on the breech block is summarised in Table 2. Velocity and peak pressure increased with decreasing bore diameter and with the use of wads; the bore diameter had the greatest effect on both velocity and peak pressure.

Table 2 Effect of bore diameter on peak pressure

internal diameter (mm)	wad used?	muzzle velocity (m/s)	peak pressure (bar)
18.70	yes	472	419
18.70	yes	459	393
18.70	no	452	319
18.70	no	465	403
19.49	yes	427	308
19.49	yes	431	331
19.49	no	410	270
19.49	no	420	314
19.49	no	410	240
20.40	yes	410	284
20.40	yes	403	283
20.40	no	346	182
20.40	no	351	203

More visible banding was evident on musket balls fired from the smallest bore diameter barrel compared to musket balls fired from the largest bore diameter barrel. Musket balls fired from larger bore diameter barrels deformed less than those fired from smaller bore diameter barrels. Musket ball mass lost was recorded for all conditions; the greatest amount of mass (1.729 g) was recorded for one of the musket balls shot without wadding using the largest bore diameter barrel.

Effect of elevation

Impact sites increased vertically with elevation angle; this vertical increase was 0.88 m when the elevation angle was increased from 0° to 10°.

Long range tests

Day 1

Mean ground hardness for musket ball rest locations was 110 CI. Ground impact distance varied from 115 m to 213 m (Table 3). Comparing shots 1 and 4 which had similar muzzle velocities (410 m/s and 438 m/s respectively), a large difference in ground impact distance was observed (213 m and 146 m respectively); this was due to the variation in trajectory identified by impact location on the witness screens. The final resting position distance varied less (288 m to 323 m) compared to the ground impact position (Table 3).

Table 3 Data from Day 1 firings

	shot 1 muzzle velocity = 410 m/s	**shot 2 muzzle velocity = 361 m/s**	**shot 3 muzzle velocity = 298 m/s**	**shot 4 muzzle velocity = 438 m/s**
ground impact	213 m	not known	115 m	146 m
final position	288m 2.3 m right	not found	323 m 5.7 m left	310 m 2.5 m right

<u>Day 2</u>

Mean ground hardness for musket ball rest locations was 195 CI. Ground impact distance varied from 140 m to 234 m (Table 4). Only three musket balls were recovered; the final resting position varied from 296 m to 402 m (Table 4). There appeared to be no relationship between bore size and muzzle velocity and between muzzle velocity and ground impact distance.

Table 4 Data from Day 2 firings

Shot number (muzzle velocity in m/s)	**distance from muzzle (m)**	
	ground impact	**final position**
1 (429)	170	-
2 (423)	166	402
3 (423)	203	330
4 (412)	153	296

5 (412)	170	-
6 (467)	140	-
7 (484)	182	-
8 (339)	-	-
9 (351)	234	-

Day 3

Mean ground hardness for musket ball rest locations was 85 CI. Muzzle velocity was assumed to be 413 m/s from previous firings. The results from the testing are summarised in Table 5. Six musket balls (out of ten firings) when recovered. Impact distance could not be determined as the Doppler radar has not been used. Final resting position varied from 230 m to 313 m (Table 5).

Table 5 Data from Day 3 firings (missing data due to musket balls missing witness screens or deviating beyond the 18 m wide of the ride; muzzle velocity assumed 413 m/s)

recovered musket ball	final position (m)	distance deviated from centre line	direction deviated
1	229.99	1.35	left
2	312.49	4.60	left
3	270.29	0.60	left
4	266.39	3.40	left
5	265.39	2.20	right
6	227.89	1.29	left

Conclusions

This research i) developed a method for firing 17th Century muskets, ii) reproduced the firing marks found on musket balls recovered from battlefields of the 17th Century and iii) investigated a number of important variables affecting ballistics of weapons from that period. The distance to the musket balls final resting position (after bounce and roll) was approximately 315 m; almost double the distance from the initial landing point. In reality, this value is likely to be greater because of the limitation of the width of the range which almost certainly resulted in the musket balls travelling the furthest being lost in the undergrowth so not being included in the results.

Wadding was originally thought to have been used by 17th Century musketeers. However, it was shown that the appearance of musket balls fired without wadding showed a closer resemblance to some of the original 17th Century musket ball than those fired with wadding. It was thought that wadding would have increased the muzzle velocity of the musket by preventing gas leakage past the musket ball in the barrel. This was found to be the case, but the effect was surprisingly low. Variations in bore diameter showed a significant variation in velocity, especially when fired without a wad because of the change in gas leakage past the ball but produced little change on the outcome of the final resting position of the musket ball.

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