Medieval Gunpowder Research Group

The firing trials

Report number 1 - September 2002

The Ho Experiments

Middelaldercentret, Nykøbing, Denmark

Introduction

In 1999 the Middelaldercentret in Nykøbing, Denmark, made a replica of the small gun in the Historical Museum, Stockholm, the Loshult gun, and carried out a series of test firings (Hansen 2001). The powder used for these tests was acquired from a commercial company and made to two formulae provided by the Centre:

Table 1
Gunpowders used in 1999 trials

Formula	*% saltpetre*	*% sulphur*	*% charcoal*
Marcus Graecus (c. 1300)	*66.6*	*11.2*	*22.2*
Rothenburg (c. 1377-80)	*66.6*	*16.7*	*16.7*

These tests were highly successful and proved that this small gun, assumed to be representative of guns of the middle decades of the 14th century, could fire arrows, lead balls and grapeshot. It proved itself against a variety of targets and showed that this type of artillery would have been an effective weapon[1].

Although these tests answered a number of questions concerning whether or not this type of weapon would have been effective it left unanswered as many more. Most important were questions about the type of powder that would have been available to the 14th century gunner. Central to this question is the type of saltpetre that would have been available. Kramer (1996: 51-2) argued that the saltpetre that could be produced from the processes that are described in contemporary accounts would have been calcium nitrate ($Ca(NO_3)_2$) and not the, to modern views, more usual potassium nitrate (KNO_3). Calcium nitrate would have been as effective as the potassium salt but it is highly hydroscopic and would readily absorb moisture from the atmosphere. He argued that this helped to explain the accounts of the spoiling of powder and the frequent mentions of the need to repair it. This problem can be alleviated by the addition of a potassium salt, potash, to the manufacturing process. Biringuccio mentions this additional process in his work Pirotechnia:

> Then, having tested the earth that you wish to work, either by taste or in some other way to assure yourself that it contains saltpeter, make a great heap of it in the middle of the room where you are to work. Near that heap, make another less than half its size which is composed of two parts of quicklime and three of cerris or oak ashes, or some other ashes that give a sharp, strong taste. Then mix these two heaps together very well and with this composition fill the tubs that you put astraddle up to within a pa/mo of the mouth. Or, if you do not wish to mix the earth, ashes, and lime together, first put a pa/mo of earth in the bottom of the tubs, and then another layer of a dito or two of ashes and lime. In this way, putting the two things in layer by layer, fill all the casks, tubs, and other vessels that you have prepared up to within a pa/mo or half a braccio of the top, as I told you above. (Biringuccio 1540: 406).

He goes on to say:

> Each time it boils, it forms a foam and swells up so much that if one is not watchful it sometimes runs over and spills, and much that is good is carried away. If you wish to prevent this, make a strong lye of three-quarters of soda, or ashes of cerris or oak, or of olive-bush ashes (which are perfect), and one-quarter of lime. Further, for every hundred pounds of water dissolve four pounds of rock alum. When the kettle boils proceed to throw in one or two jugfuls of this lye at a time, especially when you see

> that the saltpeter water rises in foam. When this has been in but a short time you will see the water subside and become clear and beautiful and of a bluish color. Boil this until the fine watery parts evaporate and the salt - petery parts become thick so that the water congeals when taken out and put in chests or vats to cool. (Biringuccio 1540: 407)

However the assumption by Kramer is that, as this process is not referred to in the Feuerwerkbuch, in fact not until the Pirotechnia of 1540, it was unknown before this and so the saltpetre must have been calcium and not potassium nitrate.

The performance of gunpowder is also affected by two other considerations, its composition – i.e. the proportions of saltpetre, sulphur and charcoal – and its physical state – basically the size of the particles into which it is formed. This physical aspect of gunpowder has been the cause of much confusion by modern writers when referring to medieval and early modern gunpowder. In this report the following terms will be used:

Table 2
Proposed and agreed terms used for gunpowder types

Rough powder	*Gunpowder made by the simple mixture of powdered saltpetre, sulphur and charcoal.*
Meal powder	*Gunpowder made by first mixing the dry, powdered ingredients. These are then dampened by adding water or other liquid, for example alcohol, and further ground together. The resultant paste is then dried and finally ground up into a fine powder*
Fine incorporated powder	*Gunpowder made as for meal powder but when wet it is formed into small granules or corns before it is dried*
Coarse incorporated powder	*Gunpowder made as for meal powder but when wet it is formed into large granules or corns before it is dried*

This combination of physical and chemical properties affects the performance of the resultant gunpowder. The current tests were undertaken in order to begin to understand what effect each of these has. These tests would concentrate on changes of composition and attempt to replicate some of the formulae in medieval sources. The following proportions were used:

Table 3
Powder proportions

Powder	*Saltpetre*	*Sulphur*	*Charcoal*
Codex 600	*2 (22.2%)*	*5 (55.6%)*	*2 (22.2%)*
Rouen	*2 (50%)*	*1 (25%)*	*1 (25%)*
Lille	*5 (55.6%)*	*2 (22.2%)*	*2 (22.2%)*
Marcus Graecus	*6 (66.7%)*	*1 (11.1%)*	*2 (22.2%)*
Rothenburg	*6 (75%)*	*1 (12.5%)*	*1 (12.5%)*

Note: a mistake was made in calculating the proportions of the Rothenburg powder. That used for the 2002 experiments was as given above. That used for the 1999 experiments was 4-1-1 (66.7% - 16.7% - 16.7%)

All these would be perfomed with rough powder using either a lead ball or an arrow. In addition a trial with meal powder would also be tried.

Raw materials

Sulphur

The raw sulphur was acquired on a visit to Iceland by Peter Vemming and Jens Christiansen in March 2002. This raw material was brought back to Denmark and purified. It was heated in an oil bath to approximately 150°C. A simple metal sieve, similar to a tea strainer, was used to skin off the scum that formed as the material melted until the resultant material appeared to be clean. The molten sulphur was then poured through a cloth held in a metal sieve into a small mould approximately 70 mm in diameter. When first cast the sulphur appeared a dark lustrous yellow. With time this changed to a dull paler yellow colour.

Figure 1 Pouring the molten sulphur through a cloth in a metal sieve into a mould

Figure 2 The mortars and pestles used to prepare the powder

Once refined, the sulphur was prepared for making the powder by first breaking up the cakes. They were placed between two layers of cloth and hammered on an anvil to break them into smaller pieces ready for the mortar. The small pieces were then ground up to a fine powder in the wooden mortar using a wooden pestle. The resultant powder was finally sieved.

Charcoal

Charcoal was produced at the Medieval Centre by the traditional method of burning wood without oxygen in a clamp. The wood chosen was alder.

Figure 3 Alder wood cut ready for making into charcoal

Figure 4 The charcoal heap after firing and ready for opening

Figure 5 Charcoal selected for making gun-powder

Clean charcoal was selected from the clamp and broken up on the anvil in the same way as for the sulphur. It was then ground to a fine powder using a wooden mortar and pestle and the resultant powder sieved.

Saltpetre
Saltpetre was acquired from 2 sources. The first was calcium nitrate made by Klaus Leibnitz from the detritus collected from an old stable and outhouses. This was purified by Klaus and then further refined by G W Kramer who stated that the resultant material was 90% $Ca(NO_3)_2.4H_2O$. We experienced difficulties igniting gunpowder made with this calcium nitrate and were obliged to substitute modern, commercial potassium nitrate (KNO_3) as supplied by the manufacturer in preparing all the gunpowder recipes given below.

Powder preparation.
Rough powder (dry mixed gunpowder)
The separate components, as described above, were weighed in the proportions needed for each type of powder and simply mixed together using a sieve and large pieces of paper. The powders were swirled and mixed for approximately 1 – 2 minutes.
Meal powder (wet mixed gunpowder)
A few grams of alcohol, (40%) were added to a dry mixture of the Marcus Graecus powder and this was ground in the mortar for about 10 minutes. This powder was then spread in a thin layer on aluminium trays and dried for 36 hours. The resultant dry powder was then ground up into a fine powder.
150 g of each type of powder was prepared. A small portion, a few grams, of each recipe was tested by applying a lighted match in order to check that it would ignite. The required amount of each type of powder, as in the firing schedule, was then weighed into small plastic containers ready for the test firings.

Table 4
The trials

Shot number	*Powder type*	*Powder weight g*	*Ammunition*	*Ammunition weight g*
Ranging shot	*Marcus Graecus wet incorporated*	*50*	*Lead ball*	*184*
1	*Marcus Graecus*	*50*	*Lead ball*	*184*
2	*Marcus Graecus*	*50*	*Lead ball*	*184*
3	*Rothenburg*	*50*	*Lead ball*	*184*
4	*Rothenburg*	*50*	*Lead ball*	*184*
5	*Marcus Graecus wet incorporated*	*50*	*Lead ball*	*184*
6	*Marcus Graecus wet incorporated*	*50*	*Lead ball*	*184*
7	*Commercial meal pow der*	*50*	*Lead ball*	*184*
8	*Commercial meal powder*	*50*	*Lead ball*	*184*
9	*Commercial rifle powder*	*50*	*Lead ball*	*184*
10	*Commercial rifle powder*	*50*	*Lead ball*	*184*
11	*Commercial cannon powder*	*50*	*Lead ball*	*184*
12	*Commercial cannon powder*	*50*	*Lead ball*	*184*
13	*Lille*	*20*	*Arrow*	
14	*Rouen*	*20*	*Arrow*	
15	*Lille*	*50*	*Arrow*	
16	*Rouen*	*50*	*Arrow*	
17	*Lille*	*50*	*Lead ball*	*184*
18	*Rouen*	*50*	*Lead ball*	*184*

Tests
The tests were carried out on the Danish Army testing ground at Oksbol, using a replica of the Loshult gun.

Figure 6 The test set up. The gun and radar is on the left with the radar behind it. The vehicle to the right contains the office and computer

The gun, set on its wooden bed, was elevated to 45o and set into the sand. The radar to measure velocity and range was set behind the gun.

Figure 7 The gun on its bed set at 45°

Figure 8 The gun and radar set up.

For each test the following loading procedure was carried out:
1. A piece of commercial priming fuse was inserted into the touch hole and held in place.
2. The prepared gunpowder charge was tipped into the muzzle of the gun
3. The powder was gently tamped down the barrel with a wooden dowel
4. The lead ball or arrow was inserted into the muzzle and forced down the barrel.
5. The lead ball or arrow was hammered home down the bore using a wooden mallet

Figure 9 Loading the gun with a measured charge

Figure 10 The ball is hammered home

The velocity of the shot and its range were measured by radar.

Figure 11 The radar equipment in the base vehicle

Results

The radar equipment was capable of measuring the velocity of the bullet or arrow as it travelled down the range giving figures for both the initial muzzle velocity and the range achieved – more accurately the distance where the bullet or arrow first hit the ground.

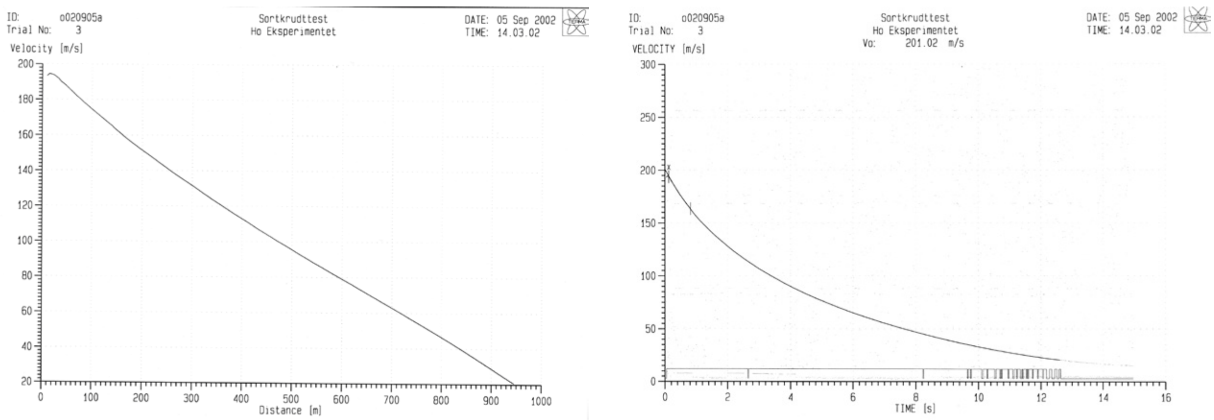

Figure 12 Sample graphs of the results for each test shot. On the left the velocity plotted against range. On the right velocity plotted against time

The results for each test shot are tabulated below:

Table 5
Results

Shot number	*Powder type*	*Powder weight g*	*Ammunition*	*Muzzle velocity ms⁻¹*	*Range m*
Ranging shot	*Marcus Graecus wet incorporated*	*50*	*Lead ball*	*(150)*	*(620)*
1	*Marcus Graecus*	*50*	*Lead ball*	*69*	*275*
2	*Marcus Graecus*	*50*	*Lead ball*	*133*	*500*
3	*Rothenburg*	*50*	*Lead ball*	*210*	*945*
4	*Rothenburg*	*50*	*Lead ball*	*142*	*535*
5	*Marcus Graecus wet incorporated*	*50*	*Lead ball*	*165*	*-*
6	*Marcus Graecus wet incorporated*	*50*	*Lead ball*	*188*	*835*
7	*Commercial meal powder*	*50*	*Lead ball*	*145*	*(750)*
8	*Commercial meal powder*	*50*	*Lead ball*	*157*	*820*
9	*Commercial rifle powder*	*50*	*Lead ball*	*240*	*905*
10	*Commercial rifle powder*	*50*	*Lead ball*	*268*	*1060*
11	*Commercial cannon powder*	*50*	*Lead ball*	*224*	*1100*
12	*Commercial cannon powder*	*50*	*Lead ball*	*230*	*955*
13	*Lille*	*20*	*Arrow*	*-*	*-*
14	*Rouen*	*20*	*Arrow*	*(20)*	*(43)*
15	*Lille*	*50*	*Arrow*	*87*	*360*
16	*Rouen*	*50*	*Arrow*	*63*	*205*
17	*Lille*	*50*	*Lead ball*	*126*	*690*
18	*Rouen*	*50*	*Lead ball*	*110*	*630*

Note: Figures in brackets are approximations due to instrument problems
The ranging shot enabled the range staff to set their equipment to the correct ranges for maximum accuracy. It is included here for completeness.

The replica gun used in these experiments had a slightly larger bore than the replica used in the earlier experiments and for which the lead bullets were made. This meant that they did not fit so tightly in the barrel and this might have affected the ranges we obtained.

What is, perhaps, surprising is that all the powders exploded and ejected the ball or arrow with considerable force. There had been some speculation that this type of simple gunpowder, rough powder made by a quick and rapid mixing, might not ignite explosively. The fact that the charges were heavily restrained and tamped down hard is one possible explanation. Williams (1974: 116-7) reported that in his trials unless the powder was well tamped down the powder 'would not explode at all'.

The second general point is the variability of the results. For example the tests with Marcus Graecus powder gave results of $68ms^{-1}$ and $133ms^{-1}$. Whether this was due to variability in the powder and its mixing or in the way that the gun was loaded is impossible to be certain and needs to be investigated further. The results for the commercial powders are more consistent and this might indicate that the problem is with the mixing of the powder – a view also supported by the more consistent results of the wet incorporated Marcus Graecus powder.

Although the number of results is small it is possible to discern some trends. There does appear to be an increase in muzzle velocity with increasing proportion of saltpetre. The following table lists some of the results and is highly selective.

Table 6
Proportion of saltpetre and muzzle velocity

Powder	*Proportion of saltpetre*	*Muzzle velocity - ms^{-1}*
Rouen	*50%*	*110*
Lille	*55.6%*	*126*
Marcus Graecus	*66.7%*	*133*
Rothenburg	*75%*	*142*

The results for the wet incorporated powder indicate that it was slightly more powerful than the equivalent rough powder and also more consistent – both results which are reflected in contemporary literature.

The two low nitrate powders, Lille and Rouen, gave considerably reduced muzzle velocities. However their ability to propel the arrows was remarkable – the result of tests 15 and 16 show reasonable muzzle velocities of 63 and 87 ms^{-1}.

Summary and conclusions

On the basis of experiments carried out with a replica of the Loshult gun by the Medieval Center in Denmark and the production of saltpetre by traditional methods by Klaus Leibnitz (with the assistance of Gerhard Kramer), a research group was established to investigate and produce early gunpowders and test them in a series of experiments

Charcoal was made in a clamp, sulphur was collected in Iceland and saltpetre made according to early manufacturing processes.

The group agreed on a nomenclature concerning early gunpowder recipes. Various mixtures and types of powder were made to be used in a series of test firings. These took place at the army shooting range at Oksbøl in Denmark Although only 19 shots were made the trials clearly demonstrated the need for experimental research when dealing with early gunpowder. There is no doubt that the research group has opened up a tiny window and that further experiments will be extremely rewarding and will help us develop a fuller understanding of the making and use of early gunpowder.

Robert D Smith
October 2002

Statement

By the end of the experiments the group agreed on an ethical way forward for using and publishing results from the experiments:

No one can use the experimental results before a research report has been produced and agreed by the entire group. Following this the report will be made public and can be obtained from the Medieval Center or the Royal Armouries in Leeds, either as a printed text or via the Internet from the respective home pages.

Medieval Gunpowder Research Group

Peter Vemming Hansen	Middelaldercentret, Nykøbing F, Denmark
Jens Christiansen	Middelaldercentret, Nykøbing F, Denmark
Lars Barfod	Denmark
Gunnar Bentzen	Norway
Klaus Leibnitz	Germany
Bert Hall	University of Toronto, Canada
Robert Smith	Royal Armouries, UK
Jorgen Svender	Artillerisholen i Varde, Denmark

Partcipants
Ruth Brown, UK
Kjeld Gerdrup, Denmark

Acknowledgements
A project such as this involves a great many people to make it work. We would like to thank the Artillery School in Varde and the Oksbøl Camp for hosting the test firings and engineer Jorgen Svender for enabling all this to happen and the Medieval Center for hosting the group and preparing the seminar.

An early participant in the project was G W Kramer whose untimely death in early 2002 deprived us of his experience and knowledge during the actual experiments. We gratefully acknowledge the work he carried out in collaboration with Klaus Leibnitz on the production of the saltpetre for these trials.

Notes

1 After publishing the results of test firing trials of a replica of the Loshult gun, Peter Vemming was contacted by Klaus Leibnitz. At a meeting in Denmark, at the home of Lars Barfod, it was proposed to produce gunpowder in a medieval manner as far as possible. Following this suggestion the Medieval Center in Denmark decided to go ahead with experimental work and contacted Jorgen Svender from the Varde Artillerishole, who agreed that the Danish Army would host test firing. The Medieval Center subsequently invited a group of participants suggested by Klaus Leibnitz, Peter Vemming and Robert Smith. The Medieval Center carried out all the necessary practical preparation - making a saltpetre pit, collecting sulphur from Iceland and making charcoal – for the seminar. This was held at the Medieval Center at the beginning of September 2002 and at the Army shooting range at Oksbøl.

References

Biringuccio V 1540 *Pirotechnia*. Translated by C S Smith and M T Gnudi 1943 Basic Books, New York.

Hansen P V 2001 *Rekonstruktion og skydeforsog med Loshultkanonen*. Middelaldercentret, Nykobing.

Kramer G W 1996 'Das Feuerwerkbuch: its importance in the early history of black powder'. In B J Buchanan (ed) *Gunpowder: The History of an International Technology*: 45-56. Bath University Press.

Medieval Gunpowder Research Group
Contact list

Peter Vemming Hansen – Director mag. art.
Middelaldercentret, Ved Hamborgskoven 2, DK 4800 Nykøbing F, Denmark
Telephone +45 54 86 19 34
Fax +45 54 86 18 34
Mobile 21 45 49 82
peter@middelaldercentret.dk

Jens Christiansen - Blacksmith
Middelaldercentret, Ved Hamborgskoven 2, DK 4800 Nykøbing F, Denmark

Lars Barfod – Fireworker and pyrotechnician
Baldersvej 19, Tune, DK-4000 Roskilde, Denmark
Telephone + 46 13 83 44
Fax + 46 13 93 30

Gunnar Bentzen - Pyrotechnician
Postboks 6630, Rodeløkka, 0502 Oslo, Norway
Telephone + 22351208
Mobile 90919484
gunnar@cfc.no

Klaus Leibnitz
Röderweg 2c, Postfach 1024, D-97737 Gemünden, Germany
Telephone + 093 51 2351
Klaus.Leibnitz@t-online.de

Professor Bert Hall
IHPST, Room 316 Victoria College, University of Toronto, Toronto, Ontario, 5S 1K7 CANADA
Telephone +1 (416) 978-4945
Fax +1 (416) 978-3003
bert.hall@utoronto.ca

Robert Smith – Head of Conservation
Royal Armouries, Armouries Drive, Leeds, LS10 1LT, UK
Telephone +44 (0)113 220 1920
Fax +44 (0)113 220 1917
robert.smith@armouries.org.uk

Jorgen Svender - Weapons engineer
Horens Artillerishole i Varde, Varde, Denmark
svender@mil.dk