

2222482_EHalifax_ACDA5024_L 5_Technical_Authoring_Report_ Final

by Emalie Halifax

Submission date: 18-Apr-2024 05:36PM (UTC+0100)

Submission ID: 229867892

File name:

43089_Emalie_Halifax_2222482_EHalifax_ACDA5024_L5_Technical_Authoring_Report_Final_518250_1683608917.pdf
(1.78M)

Word count: 3392

Character count: 21363



Emalie Halifax

The Performance of the Longbow Against Plate Armour at the Battle
of Agincourt

University of Wales Trinity Saint David
Technical Authoring ACDA 5024

Ordnance, Munitions and Explosives Degree Apprenticeship
Academic Year: 2023 - 2024

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Executive Summary

The Battle of Agincourt took place on 25th October 1415 on a field near Agincourt, France. England's King Henry V, commanding a force primarily consisting of longbow-equipped archers, was intercepted by a larger French army, who outnumbered them 5-1. It is the heavy reliance on the longbow that many historians claim lead to the English victory at Agincourt. Through an understanding of penetration mechanics, combined with theoretical calculations and experimental data this report outlines otherwise.

At the time of the battle, the longbow was used in conjunction with the needle bodkin arrowhead, for defeating chain mail and the heavy war bodkin arrowhead for penetrating plate armour. Calculations show a 110lb bow would not have the energy nor the velocity required to penetrate early 15th Century plate armour. This is reinforced by experiments conducted by Ted Todeschini and Dr Tobias Capwell, the data from which shows that a heavier 150lb bow cannot consistently penetrate steel plate armour. Computer simulation from Magier et al shows significant arrowhead deformation from a needle bodkin arrowhead impacting 2mm thick steel plate armour, while the heavy war bodkin arrowhead simulation demonstrated full penetration to a depth of 12mm but did not factor in the textile worn underneath the plate armour.

This report shows experimental evidence of penetration of steel plate armour in ideal environments with a bodkin arrowhead. The experiments explored do not factor medieval battle conditions and penetration is not consistent. Further study incorporating the variation of battle and the effect of the archer needs to be explored to fully understand the power of the medieval longbow.

1 Introduction

Many historians have attributed the English victory at the Battle of Agincourt in 1415 to the penetrative capability of the longbow combined with the needle bodkin arrow. Through an understanding of penetration mechanics, and data taken from previously conducted experiments and simulations, it can be determined this may not have been the case.

1.1 Summary of the Battle

The Battle of Agincourt took place on 25th October 1415 between the English and the French. Henry V travelled to France to claim the Duchy of Normandy as he perceived it to be his birth right. After a successful siege at Harfleur, the two sides met near Agincourt in France with the exact location being determined by the French. The French outnumbered the English 5-1. The breakdown of each force is shown in Table 1-1 [1, 2, 3] and Figure 1 illustrates their initial formations.

Table 1-1 - Force Breakdown

English Force Breakdown	
Men-at-Arms	900
Archers	5,000
French Force Breakdown	
Men-at-Arms	30,000
Cavalry	1,200

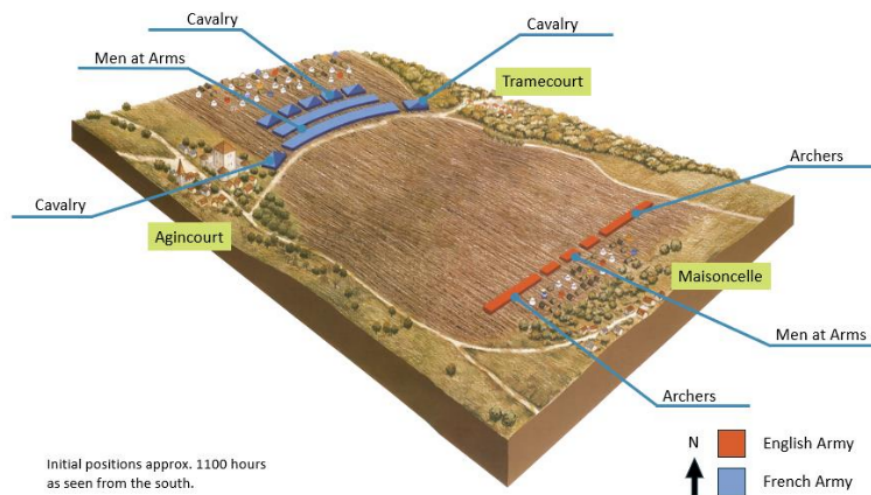


Figure 1 - Initial Battle Formations

The battle commenced with Henry V advancing his men after a long standoff with the French. The breakdown of the battle is outlined in Figure 2.

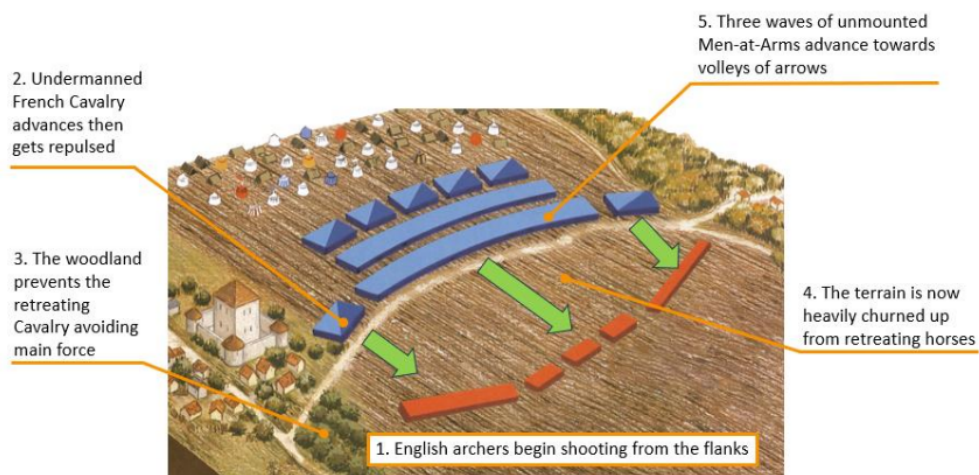


Figure 2 - Events of the Battle

2 The Armour

To assess the longbow's lethal potential, an understanding of the armour worn needs to be developed as it was the main challenge the bow faced. Through the advancement of armour, we can track the development of the weapon [4]. Medieval armour was expensive to acquire and maintain [4] indicating soldiers would not have worn it if it did not provide adequate protection on the battlefield.

2.1 Men-at-Arms Armour

Until the mid-13th century armour consisted mainly of chain mail [5] with pieces of steel gradually added. Chain mail was created with interconnecting metal rings to provide protection and flexibility, with the potential for repair and modification if needed. As metal working techniques advanced, plate armour became more popular. Figure 3 shows a model of the type of armour worn by the French and English men-at-arms during the Battle of Agincourt. The utilisation of layered materials was key to the effectiveness of medieval armour. Textile armour such as a gambeson, a long-padded coat, offered shock protection from an impact and increased penetration defence. Archers typically wore textile armour as they require more flexibility and mobility [4, 5].

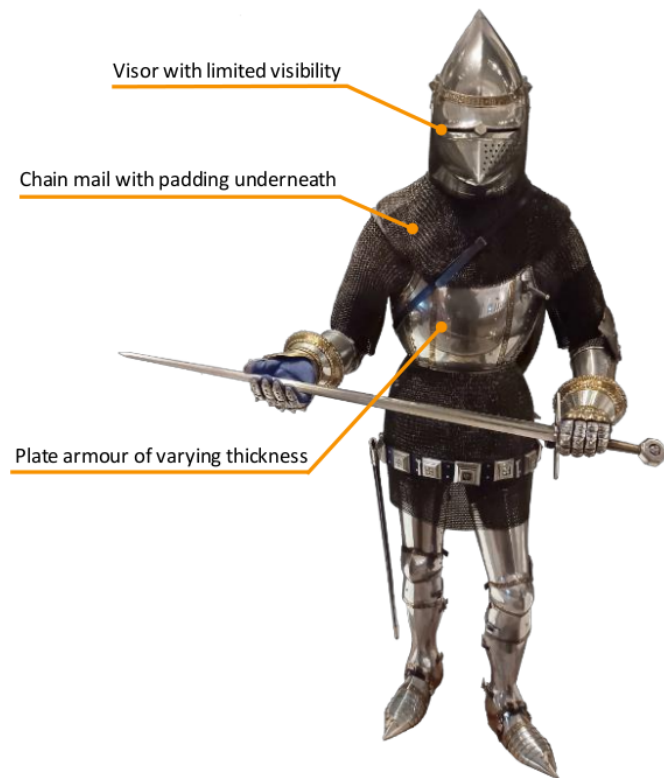


**Figure 3 - Typical Armour Worn by the English and French Men-at-Arms
Highlighting Key Elements**

2.2 Horse Armour

Prior to the 15th Century horses would have been armoured with padded textile, leather or chain mail with plate armour being introduced towards the end of the century. Armouring a horse was expensive, therefore, variation in quality and amount worn was to be expected. The head, chest and neck would have been prioritised for protection.

3 The Weapon System

3.1 The Longbow – The Delivery System

Medieval longbows consisted of the bow and bow string as shown in Figure 4. Yew wood from Southern Europe was the ideal material for the bow due to its specific structure. The textures in the wood provide strength properties for a bow with a large pulling force with the required elasticity to prevent breaking [4, 6]. It was difficult to obtain resulting in a diverse range of wood materials being used. The key features of the medieval longbow are listed in Table 3-1.

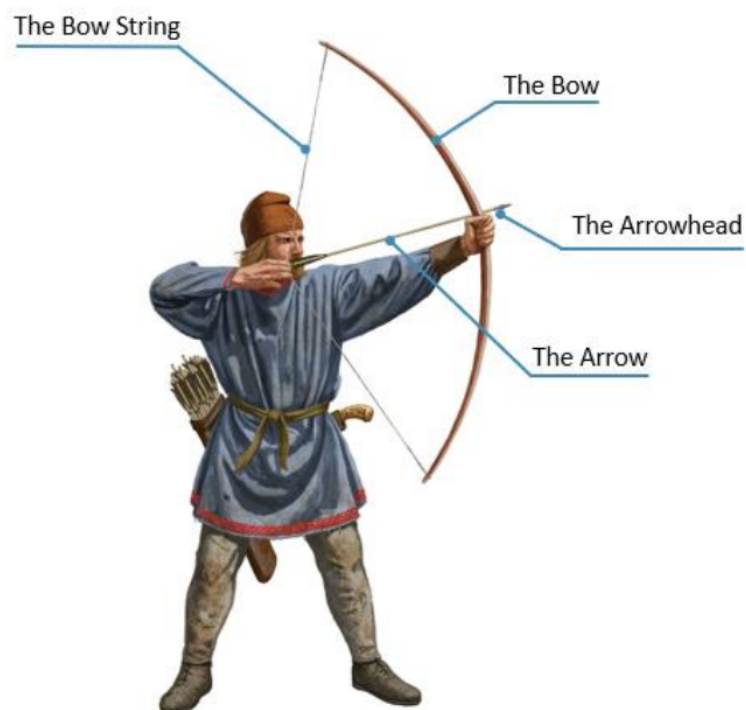


Figure 4 - Components of the Medieval Longbow

Table 3-1 - Key Features of the Medieval Longbow

Draw Weight	90 – 150lb
Average Pulling Force	300 – 500N
Length	Up to 6ft
Potential Range	Up to 350 yards

The requirement of drawing a bow to full length under harsh battle conditions requires archers to have sufficient strength and technique, along with the physical stamina to last the duration of the battle.

3.2 The Arrowhead – The Ordnance

As shown in Figure 4 the arrowhead is situated at the end of the arrow. Arrowheads are metal tips shaped depending on their desired purpose. During the battle of Agincourt there were two arrowheads designed for penetrating armour:

- The Bodkin Needle Point (Figure 5 [7]) designed to penetrate chain mail.



Figure 5 - Bodkin Needle Point Arrowhead

- The Heavy War Bodkin (Figure 6 [8]) designed to penetrate plate armour.



Figure 6 - Heavy War Bodkin Arrowhead

The arrowheads would have been made from an assortment of metals with wrought iron being the most readily available. There is some evidence of the tips being hardened with the addition of brass [9] to increase their strength to aid penetration.

4 Penetration Mechanics

4.1 Energy Transfer

When an arrow is in flight it undertakes a sequence of energy transfers as illustrated in Figure 7.

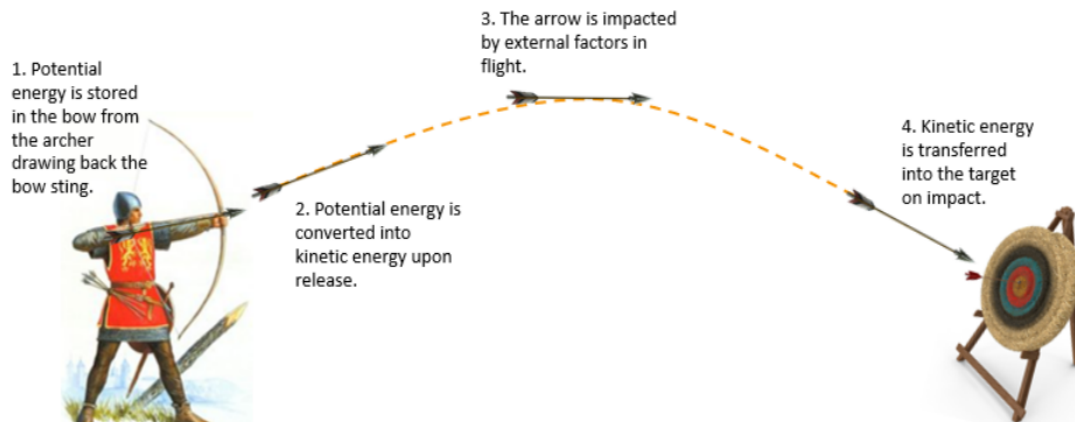


Figure 7 - Energy Transfer of an Arrow in Flight

4.1.1 Elastic Potential Energy

The bow string behaves like a spring, where it is subject to Hooke's Law, where the force required to extend the draw string is directly proportional to the distance extended. The graph in Figure 8 [10], illustrates this relationship, showing a slight curve to factor in the bows' efficiency – the ability to transfer potential energy into kinetic energy.

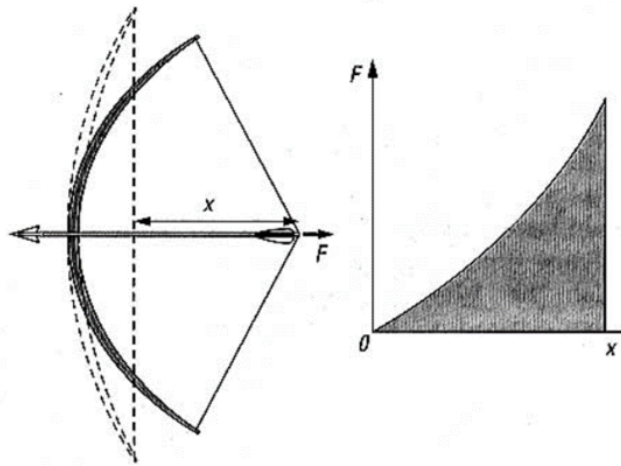


Figure 8 - Elastic Potential Energy of a Bow

The Potential Energy of a bow can be expressed as:

$$E_p = \frac{eFx}{2} \quad (4-1)$$

Where e is the bow efficiency, F is the force required to draw the bow in Newtons (N) and x is the draw distance in meters (m).

4.1.2 Kinetic Energy

While in motion the kinetic energy of an arrow is determined by its mass and velocity as illustrated by the kinetic energy equation:

$$E_k = \frac{1}{2}mv^2 \quad (4-2)$$

Where m is the mass of the arrow in kilograms (kg) and v is its velocity in meters per seconds (ms^{-1}).

Factoring that some potential energy is transferred to the bow when an arrow is released, the energy transfer can be expressed as:

$$E_p = E_{k \text{ arrow}} + E_{k \text{ bow}} \quad (4-3)$$

$$\frac{eFx}{2} = \frac{1}{2}mv^2 + \frac{1}{2}km_bv^2 \quad (4-4)$$

Where m_b is the mass of the bow in kilograms (kg) and k is the total kinetic energies of the bow after the arrows release. This principle allows the initial velocity to be calculated using equation (4-5).

$$v_i = \sqrt{\frac{eFx}{(m + km_b)}} \quad (4-5)$$

Depending on the thickness of armour there is a minimum velocity required for penetration and this can be calculated using equation (4-6).

$$v_{Lim} = \left[16.38 \frac{d^3}{W} \left(\frac{p}{\cos \theta d} \right)^{1.12} \right]^{0.5} \quad (4-6)$$

Where v_{Lim} is the minimum velocity for penetration in meters per second (ms^{-1}), d is the penetrator calibre in millimetres (mm), W is the projectile weight in kilograms (kg), p is the armour thickness in millimetres (mm) and θ is the impact angle.

Since a projectile in flight is affected by external factors like gravitational pull and air resistance the kinetic energy will reduce over a distance. The mass will remain constant therefore the velocity will reduce. Being able to calculate the initial velocity and comparing this to the limiting velocity for penetration will support the penetration analysis.

4.1.3 Theoretical Calculations

The parameters and assumptions for a 110lb bow are given in Table 4-1 [11].

Table 4-1 - Parameters and Assumptions of a 110lb Medieval Longbow and Needle Bodkin Arrow

Draw Weight (Force)	489.5 N
Draw Length	0.7112 m
Mass of Arrow	0.065 kg
Mass of Bow	1 kg
Bow Efficiency	0.9
Kinetic Energies	0.04 J
Acceleration due to gravity	9.81 ms ⁻²
Impact Angle	30°
Armour Thickness	2.5 – 45 mm
Diameter of Arrow Shaft	11.11 mm

To determine the kinetic energy of an arrow released from a 110lb bow, the initial velocity needs to be calculated using equation (4-5).

$$v_i = \sqrt{\frac{eFx}{(m + km_b)}}$$

$$v_i = \sqrt{\frac{0.9 \times 489.5 \times 0.7112}{(0.065 + (0.04 \times 1))}}$$

$$v_i = 54.63 \text{ ms}^{-1} \quad (4-7)$$

The kinetic energy at release is shown in (4-8).

$$E_k = \frac{1}{2}mv^2$$

$$E_k = \frac{1}{2} \times 0.065 \times 54.63^2$$

$$E_k = 96.99 \text{ J} \quad (4-8)$$

The graph in Figure 9 [3] illustrates the kinetic energy for arrows at varying distances. It highlights the required penetration energy for different types of armour. Comparing the kinetic energy from the 110lb bow at release, it can be

shown it would not have penetrated an average quality steel breastplate requiring 160J of energy for penetration.

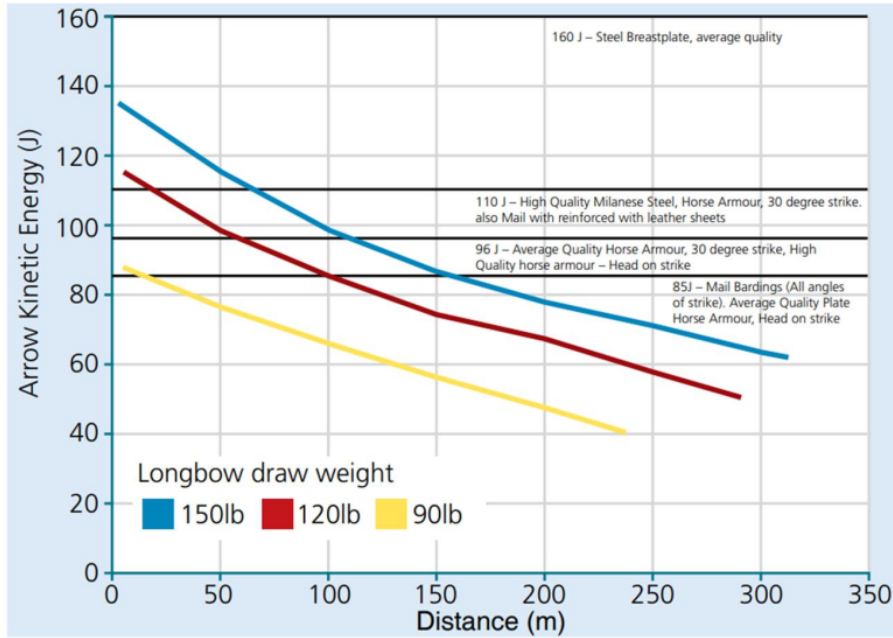


Figure 9 - Arrow Kinetic Energy at Range

Equations (4-9) and (4-10) show the minimum penetration velocity at a 30° impact angle for armour 2 and 4mm thick respectively to represent the variation in armour thickness.

$$v_{Lim} = \left[16.38 \frac{d^3}{W} \left(\frac{p}{\cos \theta d} \right)^{1.12} \right]^{0.5}$$

$$v_{Lim} = \left[16.38 \frac{11.11^3}{0.065} \left(\frac{2}{\cos 30 \times 11.11} \right)^{1.12} \right]^{0.5}$$

$$v_{Lim} = 243.91 \text{ ms}^{-1} \quad (4-9)$$

$$v_{Lim} = \left[16.38 \frac{d^3}{W} \left(\frac{p}{\cos \theta d} \right)^{1.12} \right]^{0.5}$$

$$v_{Lim} = \left[16.38 \frac{11.11^3}{0.065} \left(\frac{4}{\cos 30 \times 11.11} \right)^{1.12} \right]^{0.5}$$

$$v_{Lim} = 359.59 \text{ ms}^{-1} \quad (4-10)$$

Comparing this to the initial velocity of the arrow (54.63 ms^{-1}) combined with knowing the velocity will decrease over distance, it can be assumed the arrow would not have the required velocity to penetrate plate armour.

4.2 Experimental Application

4.2.1 Armour Penetration Test

Experiments have been conducted to analyse the penetration capability of the longbow. One such test was produced by Ted Todeschini and Dr Tobias Capwell on the penetration of plate armour [12]. Recreation medieval armour was fired at with bodkin arrows from a 150lb longbow in a series of experiments. The armour used in Figure 10 was based on the collection in Churburg Castle – one of the most important surviving sets of 14th and early 15th Century armour.



Figure 10 - Armour used for Penetration Experiment

The experiments involved an archer firing a longbow at approximately 15m away from the target. Throughout the experiment the target was positioned in different directions to represent possible positions of the French force.

Figure 11 and Figure 12 show the arrow deflecting off the plate armour and the chain mail. In both incidents the armour has protected the wearer with the arrow remaining intact after impacting the chain mail.

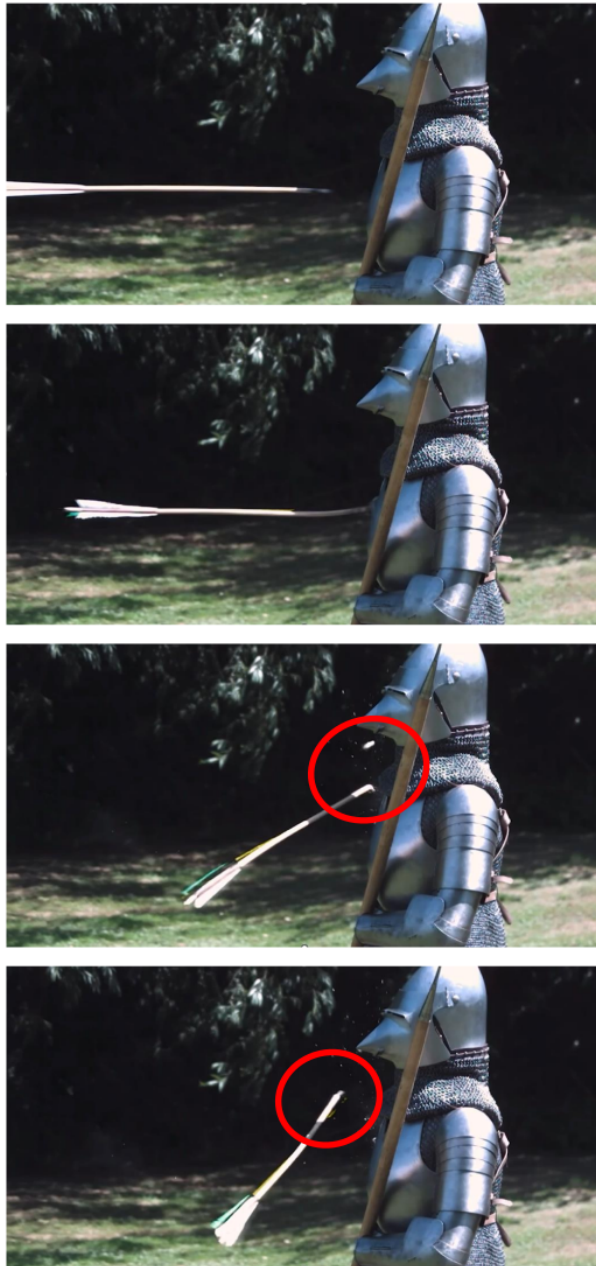


**Figure 11 - Experiment Footage Showing Deflection off Plate Armour with Target
Positioned Face on to Archer**



Figure 12 - Experiment Footage Showing Deflection off Padded Chain Mail with Target Positioned at a Three-Quarter Profile to Archer

There is evidence to support some instances of the armour failing to protect the wearer during the battle [13]. These fatalities can be attributed to weak points in the armour, namely exposed chainmail and exploitable gaps or overlaps in the armour. Figure 13 and Figure 14 highlight these weak points.



Figure 13 - Experiment Footage Showing an Arrow Penetrating Chainmail with Target Positioned Face on to Archer with Head Down



Figure 14 - Experiment Footage Showing Arrow Penetrating Through a Gap in Plate Armour with Target Positioned in a Three-Quarter Profile to Archer

The effect of hardened tips on penetration was also explored in the experiment. Figure 15 shows hardened tips impacting the helmet, resulting in moderate deformation. The armour was not fully penetrated by the arrowhead, showing it provided a significant level of protection. Figure 16 shows the arrowhead penetrating the breast plate, resulting in a hole in the armour. The arrow was

deflected only after going through the plate armour, highlighting the benefit of wearing additional layers of mail or textile that could potentially prevent a fatal wound.

These experiments show penetration was possible but highlight the inconsistency of bodkin arrows being capable to fully penetrate plate armour.



Figure 15 - Experiment Footage Showing a Hardened Tipped Arrowhead Impacting a Helmet with The Target Positioned at a Three-Quarter Profile to The Archer

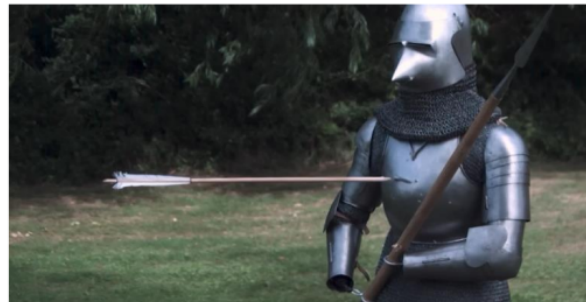
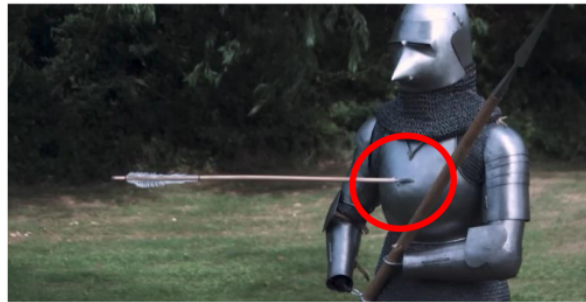


Figure 16 - Experiment Footage Showing Perforation of Plate Armour with The Target Positioned at a Three-Quarter Profile to The Archer

4.2.2 Computer Simulation Testing

Computer simulation allows further analysis using penetration mechanics. A report by Magier et al [6] used historical data to analyse the penetration capabilities of arrows tipped with both needle bodkin and the heavy war bodkin arrowheads respectively on steel plate armour.

Initial analysis was conducted on the external ballistics of a yew arrow and an arrowhead with a mass of 96g from a 150lb longbow. An initial velocity of 53 ms^{-1} and a maximum range of 250m were calculated. The atmospheric parameters and the drag coefficient were constant for the simulation to simplify the calculations. Table 4-2 summarises the ballistic results [6]. It can be shown the kinetic energy at the maximum range is 21% lower than at 25m with the impact angles changing significantly towards the maximum range.

Table 4-2 - Arrow Flight Parameters at Select Ranges

Distance (m)	Angle of Shooting (°)	Impact Velocity (ms^{-1})	Kinetic Energy at Impact (J)	Angle of Impact (°)
25	2.6	52.1	130.4	2.6
50	5.2	51.3	126.1	5.3
75	7.9	50.4	122	8.1
100	10.7	49.6	118.2	11.1
125	13.8	48.8	114.5	14.5
150	17.1	48.1	111.2	18.2
175	20.8	47.5	108.2	22.3
200	25.2	46.9	105.6	27.2
225	30.8	46.5	103.6	33.3
250	43	46.4	103.4	52.1

Figure 17 [6] shows the results of the impact simulation highlighting the state of the arrowheads and armour at the point of collision. The impact angles of 2.6° and 52.1° are used to illustrate the effects at short range and maximum range. It can be seen at the shorter distance, with the higher impact energy, that the outcome of the impact is dependent on the type of arrowhead. The needle bodkin arrow causes permanent deformation to the armour and significant deformation

to the arrowhead, whereas the heavy war bodkin arrow fully penetrates the armour with a total penetration depth of 24mm. At maximum range the arrowheads ricochet from the surface causing temporary deformation from the needle bodkin and permanent deformation from the heavy war bodkin.

The work by Magier et al, shows complete penetration of steel plate armour with a 2mm thickness at 25-50m range is possible however the penetration distance is low. The armour worn during the battle of Agincourt was inconsistent in quality therefore the material properties would not have been uniform. The simulated results do not consider the battlefield environment and physical capabilities of the archers.

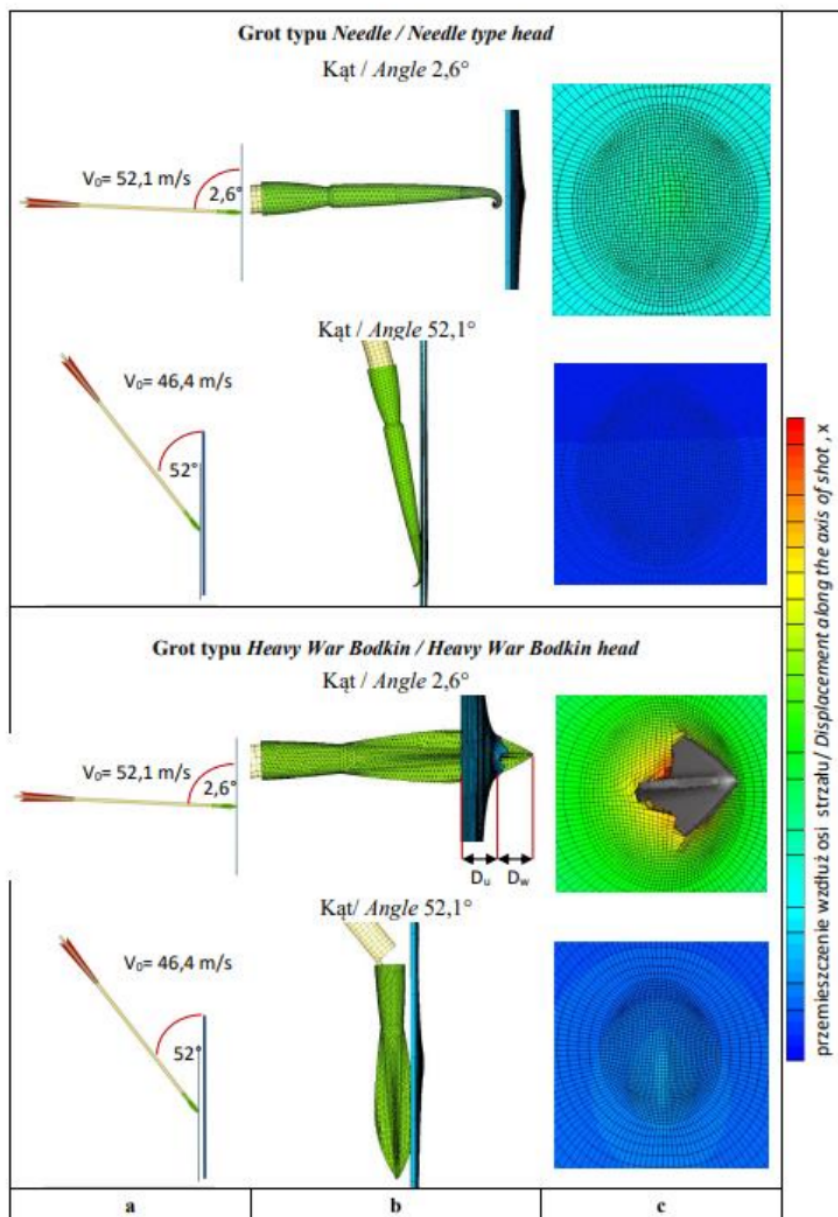


Figure 17 - Results of Numerical Analysis for Impact of Arrows into Steel Armour: A) Parameters of Impact, B) State of Components After Impact, C) Displacement of Armour Elements

5 Conclusion

Battles are won and lost by a combination of factors and forces, and it can be difficult to separate the significance of a weapon or troop. The experiments and simulations discussed in this report indicate that during the Battle of Agincourt, Henry V would need to use his archer-heavy force in a tactically advantageous way to overwhelm the French through sheer volume of arrow-fire, or in combination with other factors on the battlefield, rather than through the lethality of the longbow by itself.

This is evidenced through theoretical calculations and experimental data that shows bodkin arrows would not penetrate plate armour without specific criteria. The penetration capability is dependent on the initial velocity of the arrow, the angle of impact and distance from the target.

A medieval battlefield presents an inconsistent environment, with the quality of armour worn and the consistency of arrows fired all varying to a degree. The experiments referenced do not factor in these inconsistencies. Further study incorporating allowances for variation of battle conditions, as well as the effects of an individual's physical strength and endurance on the combat-effectiveness of archers, needs to be explored to fully understand the power of the medieval longbow and bodkin arrows.

6 References

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FINAL GRADE

46/50

GENERAL COMMENTS

Dear Emalie,

This is an exceptional report, that is at a Level 6, not Level 5 standard. I would generally split my comments into summary and detail, but in this case the feedback is relatively simple - see below. I have awarded you 92% which is an exceptional mark by my standards.

You clearly understand the fundamentals of technical authoring because you have used all the techniques taught such as the power of tables, imagery and gestalt. Figure 11 is gestalt if you hadn't planned it, using imagery to follow a sequence to get to the conclusion desired. If I were the historian I would have difficulty arguing for the longbow as the decisive factor.

You follow a logical sequence in the report, which describes a journey of competence in technical writing, OME and computational mathematics. All the equations are correct, and you have clearly undertaken additional study to determine the most powerful references to use. The tables of results are powerful too, clearly showing at various distance and angles of obliquity what is likely occur.

Your referencing is also credible, and where not, you argue the case in the text.

Finally, your executive summary and conclusion bound a competent study into the battle and its contributing factors, that would pose a conundrum to anyone who wanted to go toe to toe with you on your views.

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