Guns versus armour: A technical and historical exploration of the protective quality of armour versus gun performance in the period 1450-1700

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Introduction

On an icy cold morning in the park of Mirabello, outside the walls of the Italian city of Pavia, a force under the personal command of Francis I of France found itself under attack by a Habsburg army. The date: 25 February 1525. The encounter ended in a crushing defeat for the French troops. Armoured from head to toe, the 'gens d'armes', essentially traditional knights, were routed by the Imperial Habsburg foot-soldiers with their impressive arsenal of firearms.

The chapter 'Armour in decline' in Ewart Oakeshott's study *European weapons and armour* (2000) opens with a brief account of the terrible ravages inflicted on those old-fashioned French knights by the imperial harquebuses.[1] The Battle of Pavia, writes Oakeshott, was a decisive moment in military history, because it brought the realisation that a full suit of armour consisting of iron plates would eventually vanish from the battlefield.[2] It is true that knights clad in heavy armour gradually lost ground to the far more lightly armoured infantry, who increasingly dominated theatres of war over the subsequent decades. But defensive plate armour remained in widespread use well into the seventeenth century and even after 1700.

In general, however, European armies gradually discarded their armour as time went on, most notably in the course of the seventeenth century. They did so in stages. Pieces protecting the arms and legs were jettisoned earlier than the cuirass (comprising breast and back plates) and the helmet. Protecting the head and torso, of course, had been the basis of every suit of armour from the earliest times.[3]

Fig. 1 Breastplates tested: left BP1 (c. 1630, German); right BP2 (c. 1645, Dutch)

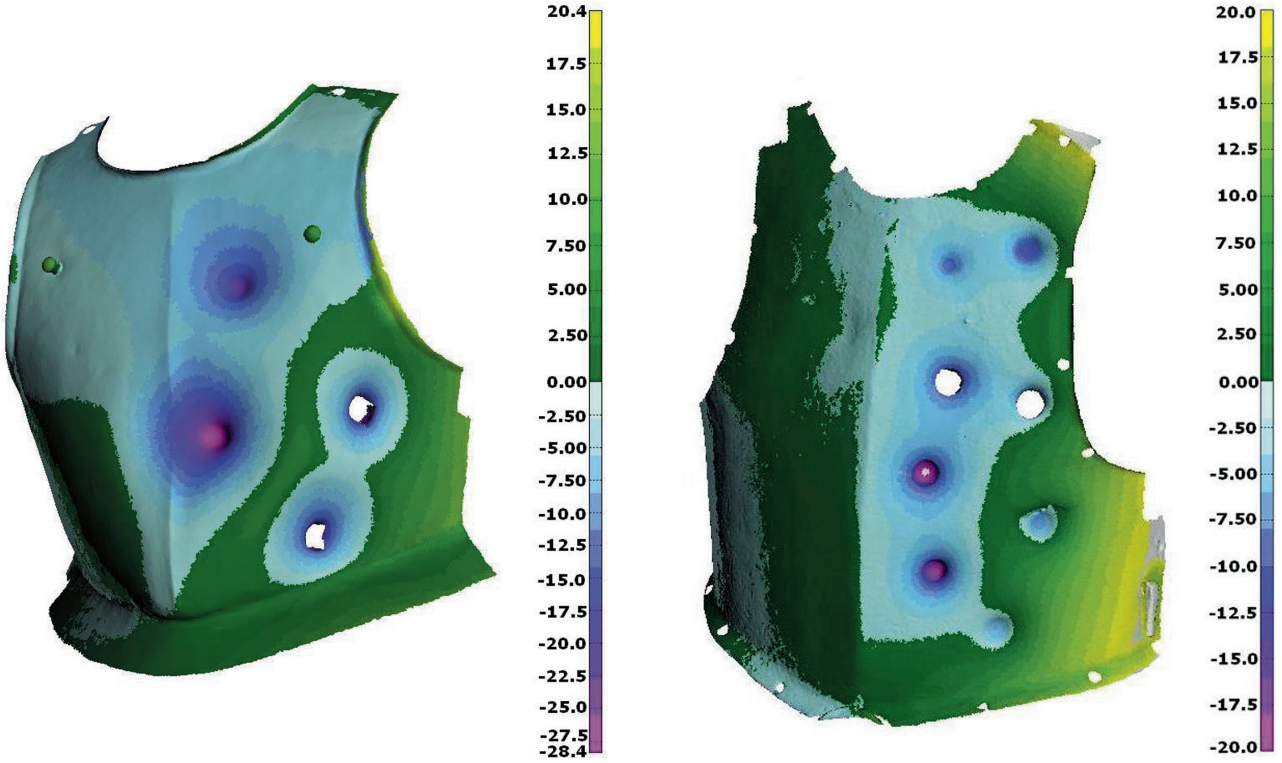

Fig. 2 3D laser scan showing the profile of breastplates after ballistic testing

This article examines the development outlined above by presenting a brief overview of the sources cited in the literature followed by a technical materials analysis and ballistic tests on authentic suits of armour. The historical material will illuminate the uses of armour in armed conflicts, answering questions like: what sections of suits of armour were worn in the sixteenth and seventeenth centuries? Which military units wore them? What tactics were used? How much did military planners know about the significance of matters such as armour thickness and shape, critical firing distance, and the capacity of armour to withstand bullets from different types of firearms? All such aspects are relevant, of course, to the key question of whether or not armour provided adequate protection. There was no precise understanding of the interrelationships between these different aspects of the problem in the seventeenth century, however. The second section of this article will therefore report on a destructive ballistic analysis of two breastplates. On the basis of these experiments, we present a materials-science model that has been used to derive the critical thickness of armour for different firearms in the period 1450-1700. This model helps to clarify the question of why and when seventeenth-century armour eventually proved ineffective.

Sources on the protective quality of armour

It is interesting to look briefly at some passages in source texts, 'sample' quotations that on the one hand illustrate the gradual shift away from plates of armour and on the other hand reveal that this change did not follow a clear-cut linear path. Where the States army is concerned – that is, the army raised by the States General in the Dutch Republic (also known as the United Provinces) – it is most illuminating to consult the 'Ordre op de wapeninge' (Regulations governing protective armour) drawn up in 1599 by Stadholder and Captain-General Maurits of Nassau, prescribing the standard armour to be worn in the field by the different army units and imposing fines for non-compliance.[4]

The *Ordre op de wapeninghe van de Compaignien Ruyteren Cuirassiers van deze Landen voerende corte-roers* prescribed the armour to be worn by pistol-bearing members of the mounted cavalry, also known as cuirassiers. We read that these pistol-bearing cavalrymen, essentially the successors to the traditional knights with their spears or lances, were expected to wear a 'headpiece' (helmet), a gorget, cuirass, shoulder and arm armour, and a gauntlet or armoured glove on the hand carrying the bridle'. In addition, cuirassiers had to be 'armoured from the belt to the knees with both thigh-pieces and knee-pieces'.[5] Clearly, around 1600, cuirassiers were still virtually clad in full suits of armour.

	Acronym for weapon	Average bullet weight (g)	Average bullet calibre (mm)	muzzle velocity (m/s)	velocity at 30 m (m/s)	velocity at 100 m (m/s)	muzzle energy (J)	energy at 30 m (J)	energy at 100 m (J)
Wheel-lock musket, Suhl, 1593	M1	10.84	12.3	427	349	238	998	660	307
Matchlock musket, Styria, 1st quarter 17th c.	M2	17.38	14.3	449	378	264	1752	1242	606
Wheel-lock musket, rifled, 1st half 17th c.	M3	32.06	17.5	392	342	260	2463	1875	1084
Wheel-lock pistol, Nuremberg, c. 1620	P1	9.56	11.8	438	355	-	917	602	-
Flintlock musket with combined matchlock, Suhl, 1686	M4	30.93	17.5	494	426	305	3774	2807	1439
Flintlock musket converted from matchlock c. 1700	M5	27.54	16.8	474	406	291	3094	2270	1166
Flintlock musket converted from matchlock c. 1700	M6	32.16	17.6	451	391	287	3271	2458	1324
Flintlock musket converted from matchlock c. 1700	M7	34.25	17.8	467	406	300	3735	2823	1541
Flintlock pistol, Ferlach, c. 1700	P2	14.45	13.5	385	323	-	1071	754	-

Table 1 Test firing selected 17th century weapons [after Krenn, 1991]

This situation did not change until the second quarter of the seventeenth century, when the cuirassiers gradually discarded the knee-pieces of their armour, followed by the thigh and arm-pieces.[6] By the 1630s, all that remained was a helmet and cuirass together with a breastplate and backplate worn over a buff coat, the skirt of which, with its overlapping tabs, fell over the thighs, protecting the lower body. With these changes, cuirassiers gradually grew to resemble more closely the harquebusiers who served as the light cavalry within the States army. The Regulations from 1599 teach us that the harquebusiers (also called carabineers because they bore carbines, firearms midway between pistols and muskets), switched before 1600 to armour protecting a smaller proportion of the body – consisting merely of helmet, gorget, and cuirass.[7]

Records are found of individual cavalrymen and even entire companies who dispensed with iron protective armour altogether in the second quarter of the seventeenth century, fighting in their buff coats. These coats provided the comfort and freedom of movement that were needed in the tactical deployment of cavalry bearing firearms.[8] One example of a cavalryman who fought in a buff coat without a cuirass is Count Hendrik Casimir, stadholder of Friesland, who was mortally wounded in the night of 3 July 1642 in a cavalry attack on the small town of Hulst in the province of Zeeland Flanders. Hendrik was felled 'by a pistolshot from behind that pierced his belt and coat and went upwards, lodging in his spine. This shot immediately debilitated and paralysed his entire lower body'.[9]

But we also find accounts of cavalrymen fighting in European theatres of war in the 1640s wearing almost full suits of armour. That protective armour could save lives is clear, in any case, from Richard Atkyn's terrifying account of a clash between two pistol-bearing cavalrymen at the battle of Roundway Down in 1643, during England's Civil War: 'I then immediately struck into him, and touched him before I discharged [my pistol]; and I am sure I hit him, for he staggered and presently wheeled off from his party and ran... in six score yards I came up to him, and discharged the other pistol at him and I am sure I hit his head for I touched it before I gave fire and it amazed him at present, but he was too well armed all over for a pistol bullet to do him any hurt, having a coat of mail over his arms and a headpiece that was (I am confident) musketproof...' [10]
Note that the marksman evidently held his pistol against his adversary's helmet at the moment of firing, or possibly a fraction of a second earlier. This tactic is also described by Henry Hexham in his *Principii ofte eerste gronden van de oorloghskonste* ('Principles of the art militairie', 1642): 'And some are of the opinion that a horseman should not shoot before he has placed his pistol under his enemy's armour or against some part of his body that is not armoured.'[11]
However, we also find evidence that some soldiers loathed what they saw as the excessive protection of their body

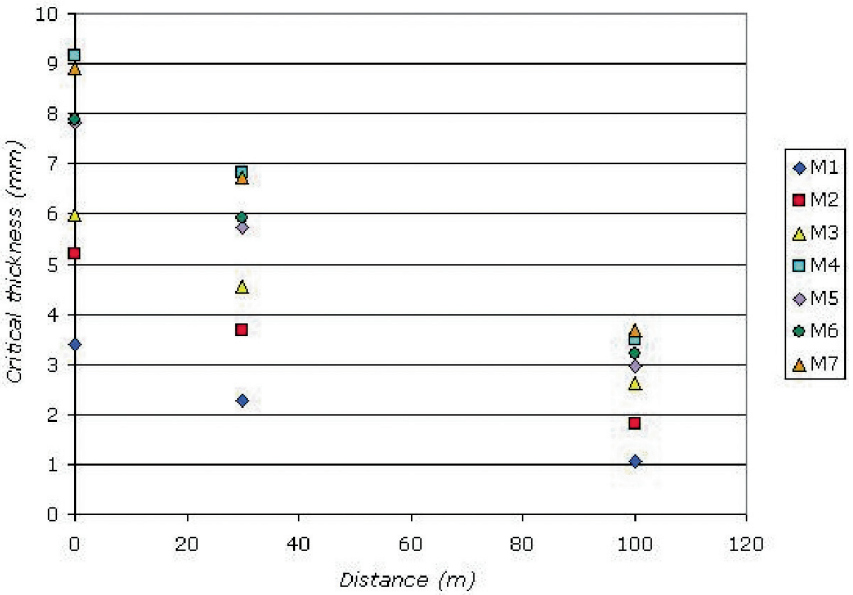

Fig. 3 Critical thickness of armour at variable distances for different 17th-century muskets based on test-firing experiments [Krenn, 1991]; for weapon acronyms (M1-7), see Table 1.

with iron armour. Thus, Sir Edmund Verney wrote in 1639, after the king had ordered him to arm himself 'as [a] cuirassier in russett armes with gilded studs or nayles': 'It will kill a man to serve in a whole cuirass. I am resolved to use nothing but back, brest and gauntlett. If I had a pott for the hedd that were pistol-proofe, it may be I would use it, if it were light, but my whole helmet will bee of noe use to mee at all.' [12]

It is noteworthy that Verney uses the word 'pistolproof' here, in contrast to the 'musketproof' cited earlier by Richard Atkyn. Helmets and cuirasses were tested to make sure that they could withstand bullets before being distributed to the troops. In this exercise, a distinction was made between bullets fired by a pistol or a musket; pistol bullets obviously had less penetrative power.[13]

Armour varied in thickness and consequently in the capacity to withstand bullets. This factor was taken into account when issuing armour to companies. In the States Army, twenty-five of the best horsemen in each company of a hundred cuirassiers were issued with heavy-duty cuirasses and leg-plates.[14]

By the 1650s all that remained of the armour was a cuirass consisting of a breast- and backplate, and during the Nine Years' War (1688-1697), this last piece of iron protection also vanished from the armour worn by the ranks of the States Army.[15] Not permanently, however: in the early years of the eighteenth century, the cuirass enjoyed a distinct revival among the States cavalry. The Dutch historian Olaf van Nimwegen has shown that in 1707 (during the War of the Spanish Succession) it was decided to equip the States cavalry with cuirasses again, to be ordered at the expense of the national treasury.[16] This decision was prompted by a change of tactics, which prescribed that cavalry squadrons must not use firearms when facing the enemy, but charge the hostile troops, sword in hand. The cuirass was needed to protect the horsemen from enemy fire during the charge. The cuirasses to be ordered consisted of a breast- and backplate of differing thicknesses. The breastplate had to be proof against a snaphaunce (an early type of flintlock, successor to the musket) fired from a distance of about 15 metres, while the backplate had to withstand pistol shots fired from an approximate range of 11 metres.

Van Nimwegen shows that the armour was in fact distributed to the States regiments in the course of 1707. This means that over 6,000 cuirasses, produced in the German-speaking territories, found their way to officers and men. In the years that followed, however, it seems that the cavalrymen expressed widespread aversion to this reintroduction of heavy body armour. Their dogged defiance was nothing new. From ancient times, officers and soldiers had objected to the wearing of body armour, which, though it provided a certain amount of protection during battle, also gave rise to considerable discomfort.

Technical Examination and Ballistic Testing of Breastplates

The source study reveals that those concerned were aware of critical factors such as the thickness of armour, firing distance, and the difference in penetrative power between pistol and musket bullets. What is more, due consideration was given to what one would nowadays refer to as 'quality control and assurance'. On high-quality (i.e. expensive) suits of armour, one will sometimes find dents in the breastplate. A dent of this kind served as a sort of guarantee of quality; it indicated that the cuirass had been tested and found to be proof against musket bullets.

A great deal of technical research has been conducted in the past on firearms and suits of armour. Historical armour has been studied and relevant properties like hardness, thickness and the microstructure of the metal have been determined for a sizeable number of sixteenth- and seventeenth-century breastplates.[17,18] In addition, the gun performance of various historical firearms has been studied in test-firing experiments.[19,20] But there is a 'missing link' in historical weapons research, in that the two sets of data have not been combined. Until recently, the performance of breastplates *versus* firearms was poorly understood. So how much protection did historical armour really offer? To answer this question, let us look at the findings of a recent experiment involving historical breastplates.

In 1989 a ballistic experiment was performed at the Landeszeughaus (Graz, Austria), involving a single shot fired with a historical gun at an original breastplate.[21] However, this study did not look at other relevant properties, such as the hardness and microstructure of the armour. Furthermore, the data were too meagre to yield a general model on the protective quality of 17th-century armour.

A recent study at Delft University of Technology (Delft, the Netherlands) involved multiple test shots at two pieces of historical armour.[22,23] The breastplates were purchased from a British historical weapons dealer following consultation with the Royal Armouries in Leeds (fig. 1). Relevant material aspects such as the thickness, composition, microstructure, hardness and tensile strength of the metal were determined. Subsequently, the armour was subjected to destructive ballistic testing at the TNO's Prince Maurits Laboratory (Ypenburg, the Netherlands). Lead bullets were fired frontally at the breastplates with varying amounts of gunpowder to control bullet energy. Depending on the energy, the test shots resulted in a bullet stop or full perforation of the armour, as indicated in fig. 2.
A linear relationship was found to exist between the thickness of the armour and the bullet energy needed for full perforation. This yielded a so-called *critical thickness* for seventeenth-century armour to withstand the impact of a lead bullet with a given radius and velocity. This model was then combined with data on gun performance obtained by Krenn et al. in earlier experiments.[24] Table 1 lists a number of historical weapons and their performance in terms of bullet weight and velocity at variable distances, determined by test-firing. Fig. 3 shows the corresponding critical thickness necessary for the wearer to survive bullet impacts at the distances given in table 1. It shows clearly that the two Delft breastplates, with average thicknesses of 5 mm (BP1) and 1.8 mm (BP2) respectively, provide dramatic differences in pro-

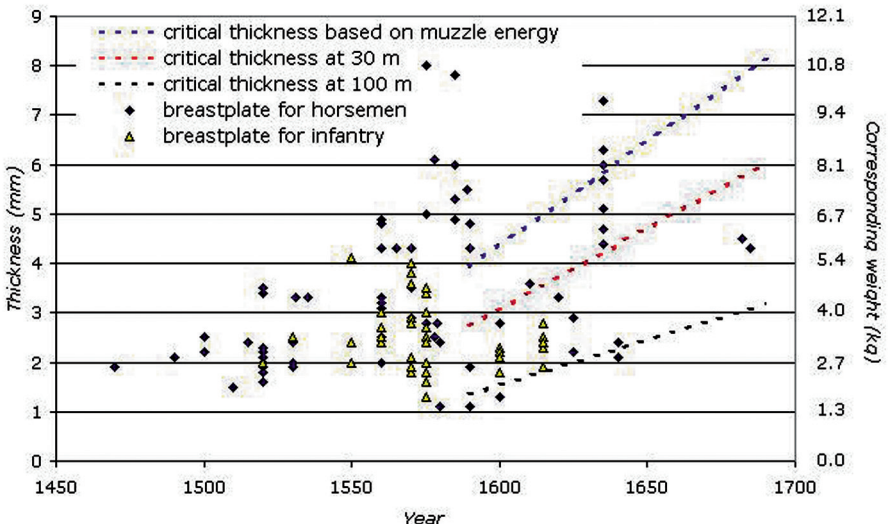

Fig. 4 Critical musket-proof thickness of armour over time; armour thickness measured by Williams et al. (see notes 17-18)

tection. While BP1 would survive the impact of most firearms at a distance of 30 m, BP2 merely offers protection against an older, late sixteenth-century wheel-lock musket at 100 m. All other firearms cause perforation at any distance. These findings enable us to examine gun performance relative to armour thickness for the period 1450-1700. Fig. 4 shows the thickness of both infantry and cavalry breastplates and the critical thickness for test-fired 17th-century muskets. It shows clearly that increasing gun performance is paralleled by greater armour thickness with the passage of time.

Although some groups of combatants continued to use pieces of iron protective armour (aside from helmets) well into the eighteenth and even in the early nineteenth century, it is fair to say that armour was gradually discarded as an element of military equipment in the latter half of the seventeenth century. To a large extent, this was attributable to the increasing penetrative power of firearms, which were becoming a pervasive presence on the battlefield. To protect oneself from this firepower, as fig. 4 makes clear, iron plates would have had to be of such thickness and weight as to make them virtually impossible to wear.

Notes

1 E. Oakeshott, *European weapons and armour. From the Renaissance to the Industrial Revolution*, (Woodbridge, 2000).
2 Oakeshott 2000, 197.
3 Oakeshott 2000, 193.
4 M. de Jong, *'Staat van Oorlog': Wapenbedrijf en militaire hervorming in de Republiek der Verenigde Nederlanden, 1585-1621*, (Hilversum 2005), 30.
5 J.B. Kist, R.B.F. van der Sloot, J.P. Puype, W. van der Mark, *Musket, Roer en Pistolet. 17de-eeuws wapenhandwerk in de Lage Landen*, (The Hague 1974), 143.
6 J.P. Puype, 'Hervorming en uitstraling. Tactiek en wapeens van het Staatse leger tot de Vrede van Munster en hun invloed op andere Europese landen', in *1648. Vrede van Munster. Feit en verbeelding*, Jacques Dane ed., (Zwolle, 1998), 47-81, 67.
7 Kist 1974, 143.
8 E. Sint Nicolaas and H. Stevens, 'Kolders. Van modieus militair kledingstuk tot slagveldreliek', *Bulletin van het Rijksmuseum*, 56/2 (2006).
9 '... zijnde met een pistoolscheut van achteren door de Riem en Koller opwaerts in de rugge-graedt gequetst wierde. Door dese scheut terstondt sijn geheel onderlijf geroert ende sonder gevoelen zijnde'. Quoted in Sint Nicolaas and Stevens, 2006.
10 Quoted in David Blackmore, *Arms and armour of the English Civil Wars*, (London, 1990), 10.
11 'Ende sommige zijn van die opinie dat een ruyter behoort niet te schieten eer hij zijn pistool onder zijn vijants rustinge geset heeft ofte tegen eenige plaetsen van zijn lijf dat ongewapent is.' Quoted in Dutch in O. van Nimwegen, 'Van vuurkracht naar stootkracht en vice versa: Veranderingen in de bewapening van het Staatse leger tijdens de Spaanse Successieoorlog (1702-1712)', *ArmamentariaI*, 30 (1995), 101.
12 Quoted in Oakeshot 2000, 210.
13 Quoted in Oakeshot 2000, 209.
14 Quoted in Van Nimwegen 1995, 89.
15 Quoted in Van Nimwegen 1995, 42.
16 Quoted in Van Nimwegen 1995, 52-54
17 A.R. Williams and A. De Reuck, The Royal Armoury at Greenwich 1515-1649: A History of its Technology, (Dorchester, 2002).
18 A.R. Williams, The Knight and the Blast Furnace: a History of the Metallurgy of Armour in the Middle Ages & the Early Modern Period, (Leiden, 2003).
19 P. Krenn, *Von alten Handfeuerwaffen: Entwicklung, Technik, Leistung*, [exhib. cat. Landeszeughaus] (Graz 1989), 72-73, 109.
20 P. Krenn, 'Test-Firing selected 16th-18th Century Weapons', *Military Illustrated*, 33 (1991), 34-38.
21 Krenn 1989, 72-73.
22 S. Leever, *For Show or Safety? A Study on Structure, Ballistic Performance and Authenticity of Seventeenth Century Breastplates*, [Master's thesis at the Dept. Of Materials Science and Engineering, Delft University of Technology, 2005], also published in *Arms and Armour*, Royal Armouries, Leeds.
23 S. Leever, D. Visser, W. Kockelmann, J. Dik, 'An archaeometallurgical study of two harquebusier breastplates using time-of-flight neutron diffraction', *Physica B: Condensed Matter*, 2006, forthcoming.
24 Krenn 1991, 109.