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29. Ships, shot and splinters: the effect of 17th-century naval ordnance on ship structure

Abstract

In 2014 the Friends of the Vasa Museum carried out live firing trials of an accurate replica of the main ordnance system used on the Swedish warship *Vasa*, sunk in 1628. The purpose of the trials was to assess the ballistic performance of this type of lightweight 24-pounder bronze gun, its effect on ship structure and the ergonomic aspects of servicing the piece. This article reports on the effect aspects of the trials, with specific attention to the affect that the details of ship structure have on the creation and dispersion of splinters inside the ship.

Introduction

The conventional impression of the nature of naval warfare in the age of sail and broadside gunnery is one of chaos, noise and horrific carnage. Men cut down by cannonballs, clouds of deadly flying splinters and torrents of blood in the scuppers have been staples of naval fiction from the novels of Tobias Smollett to films such as *Master and Commander*. While there were no doubt moments like this, surviving after-action reports suggest a much less consistent picture. There are plenty of cases of terrible casualties, but there are also notable accounts such as the fate of the English third-rate *Plymouth* (58 guns) at the battle of Lowestoft in 1665. Captain Thomas Allin was beset at close range for over two hours by up to nine Dutch ships, including the flagship, who "paid [him] handsomely" and caused great damage to the ship, but suffered only four dead and six wounded (Allin 1939: 294; see also Fox 2009: 94). The ship was sufficiently damaged that *Plymouth* was forced to retire to make repairs before re-engaging. Allin was knighted for his bravery after the battle and was not among those suspected of cowardice on the basis of low casualties (Fox 2009: 101). How can this be? Certainly shot size has something to do with it, since larger shot have more impact energy and thus more destructive potential, but even where heavy guns were in use there is a wide variation in the actual damage done. Were some guns or gunners simply better than others? Did some ships stand up to the pounding of artillery better?

Artillery theorists in the age of the broadside gunnery considered the resistance of the hull to shot to be directly proportional to the thickness of timber (Schultz 2000), and practical tests carried out in the 18th and 19th centuries derived rules of thumb that established how many inches or centimetres of oak that a shot of a given size could penetrate with a given charge. No attempt was made to account for the effect of different layers of timber crossing at different angles or gaps between layers, as it was assumed that all of this effectively averaged out due to the volume of fire sustained. They therefore reasoned that differences in effect were due to different weights and speed of shot, or differences in gunnery and tactics. For example, much has been made, both then and now, of the difference between English gunners, who fired on the upward roll of the ship, and Dutch gunners, who fired on the downward roll (for example, Fox 2009: 57). Analysis of the physics suggests that the difference in accuracy and effect is probably much less than thought (Hocker et al., forthcoming).

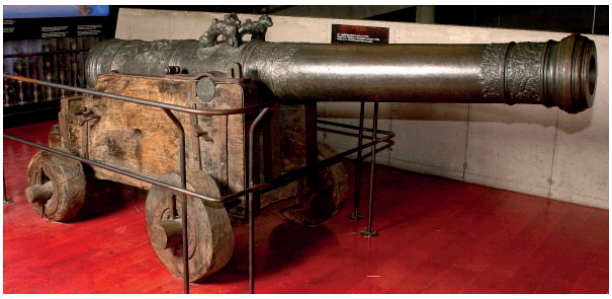


Fig. 1. The main armament of *Vasa*: one of three original 24-pounders recovered from the ship, mounted on an original carriage (photo from Vasa Museum archive).

As part of a larger research program centred on the nature of naval warfare in the 17th century, the Vasa Museum initiated a project to test the ballistic properties and effectiveness of the armament of the Swedish warship *Vasa*, built 1626-1627 and sunk on its maiden voyage in 1628. The primary weapon carried was a lightweight bronze muzzle-loading gun of a new design developed for the army in 1620 (Figs. 1 and 2). This gun, called in Swedish sources either a *demi-cartog* (demi-cannon) or *24 pundare* (24 pounder), reflects trends seen in several other countries at the same time, towards lighter, shorter guns which could take advantage of the better combustion characteristics of gunpowder developed during the 16th century (Brusewitz 1985). Three original guns of this type, of the 46 carried by *Vasa*, were recovered from the wreck, and nine others of the same type are known from the wreck of *Kronan* (sunk 1676; Einarsson 2016). These show a consistent set of dimensions, with a straight bore of 146

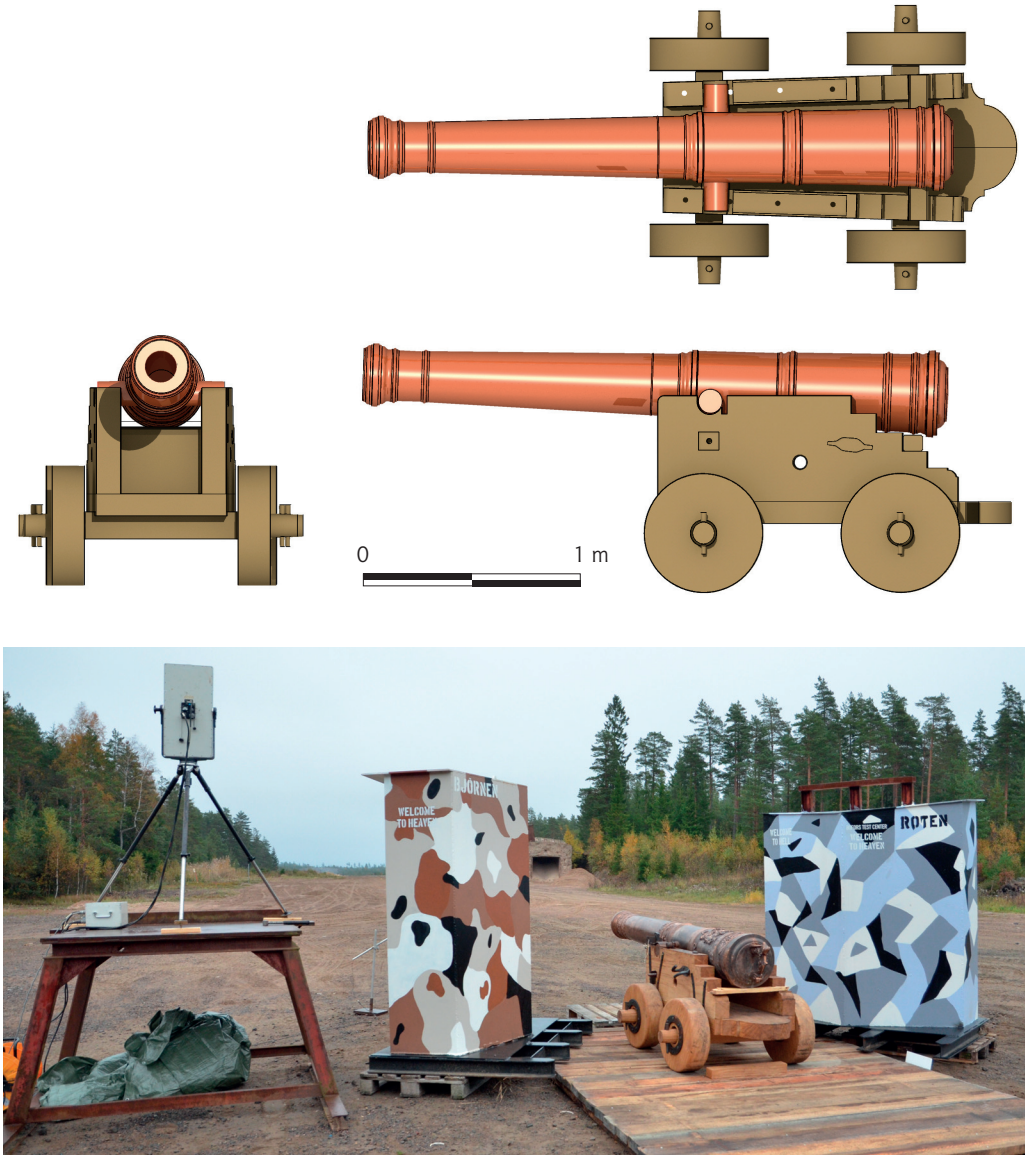


Fig. 2. The replicated gun and its carriage. A. Principal dimensions (drawing by Fred Hocker, Vasa Museum). B. The gun as set up for proofing on the Bofors range (photo by Richard Belles).

(± 0.7) mm diameter and 2650 (± 10) mm length from breech to muzzle. Exterior diameter varies slightly, but the maximum wall thickness at the breech is approximately three-quarters of the bore, which would qualify the piece as a bastard in English terms. Metal and casting quality varies substantially, with the alloy of the twelve surviving pieces covering a range from 90-98 per cent copper. All contain some tin (up to 6 percent) with various quantities of other metals, primarily lead and zinc. Total weight varies between 1210-1290 kg.

In addition to the tubes, gun carriages, loading equipment, ammunition and charge canisters were also found, so it is possible to replicate the entire artillery system reliably. Ammunition comprised round shot, crossbar shot, scissor shot, chain shot and case. Round shot size varied from 135-142 mm (corresponding to 9.18-10.63 kg in weight), with the average falling at 139 mm and 9.99 kg, which is very close to the nominal 24 Swedish pounds (9.96 kg). The only significant missing components were gunpowder and the paper cartridges in which it was loaded, although this proved to be less of a research issue than one might think. It is not possible to replicate original gunpowder, since the exact nature of the constituents is not known, nor are the details of the manufacturing process. In any case, original gunpowder was of highly variable quality and performance, and would introduce an uncontrollable variable into the tests. The important property for this test, the muzzle velocity generated, can be calculated from contemporary gunner's tables, which provide ranges for given charges and elevations (Holmstedt 1985), and so the tests could proceed on the basis of modern gunpowder used in quantities which would generate 17th-century muzzle velocities. It was thus not possible to investigate the internal ballistics of the gun in detail, but this is of only minor relevance to the tactical performance.

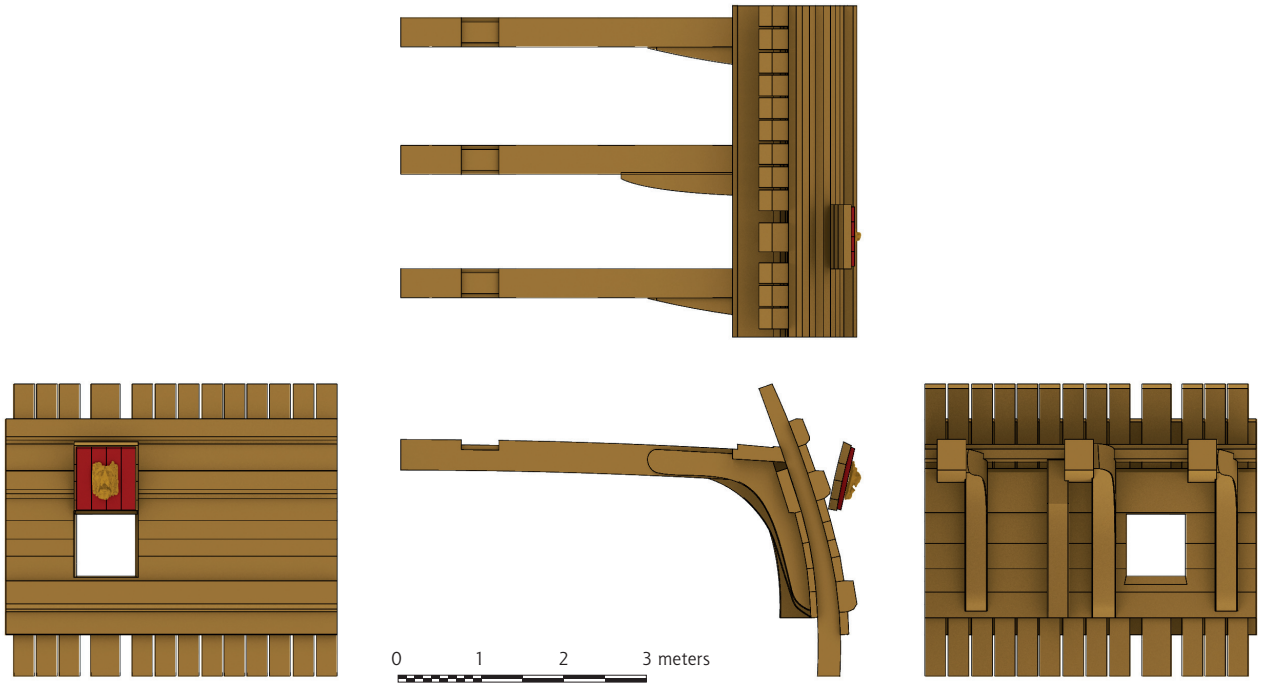


Fig. 3. Construction of ship side test article (drawing by Fred Hocker, Vasa Museum).

Because the tests were aimed at assessing not just range and accuracy, but also effect, a replica section of ship side was constructed. In similar projects carried out elsewhere (see, for example, Hildred 2011: 112-129), wooden targets have also been built, but these are often simplified structures of planks fastened to wooden uprights. We wished to determine if the construction of the hull had a demonstrable affect on the type and amount of damage sustained, and so we took care to replicate the actual construction of *Vasa* as closely as possible for a 4-meter length at the level of the lower deck, just above the waterline. This included the irregular framing plan and the inclusion of the knees and riders supporting the beams of the deck above (Fig. 3).

Trials were carried out at a fully instrumented modern proving range, the Bofors Test Center (BTC) in Karlskoga, Sweden over two weeks in October 2014.

Research design

The tests were designed to assess three significant areas of performance:

1. Ballistics: range and accuracy, or in more concrete terms, can you hit what you aim at, and how far away?
2. Effect: Penetration and damage, or what happens if you hit what you aim at?
3. Ergonomics: Human factors and rate of fire, or how fast can you shoot and how does it affect the gun crew?

A program of fire that eventually grew to 54 rounds was developed to answer each of these questions. It was felt counterproductive to assess all three areas simultaneously, as it would involve too many simultaneous variables. The initial trial proofed the gun, demonstrating that it would not blow up in use. The gun was proofed according to the BTC range standard, generating 130 per cent of the working breech pressure without damage or distortion to the gun. This trial was also used to determine the working "service" charge. In the 1620s, the nominal charge for this gun was one-third the weight of the ball, or 8 pounds (3.3 kg), but modern powder has more "push" than 17th-century gunpowder, so it was expected that the actual working charge would be lower. 3.3 kg was the full proof charge, generating a breech pressure of 74 MPa (10,800 psi) and a muzzle velocity of 399 m/sec. Contemporary gunner's tables suggest that normal muzzle velocities for guns in this class were lower, in the high subsonic to transonic region (Schultz 2000; Holmstedt 1985). Reducing the charge to 2.65 kg brought the breech pressure within the safe range determined by BTC and the muzzle velocity down to 350-360 m/sec, or just over the speed of sound. A nominal reduced charge of 2.2 kg was also established, producing 300 m/sec.

Range and accuracy were assessed first on an open range with a backstop at 1000 m. Different combinations of powder and round shot size were fired to evaluate what effect the different sizes of shot found in the ship and different charges might have on muzzle velocity and accuracy. Elevation was kept to 3 degree 30 minutes or less, since the original gun could not be elevated above this. Instrumentation available for these trials included Doppler radar, which records velocity, high speed video, GPS for plotting the fall of shot, "pressure eggs" for measuring internal breech pressure over time, and conventional photo and video cameras.

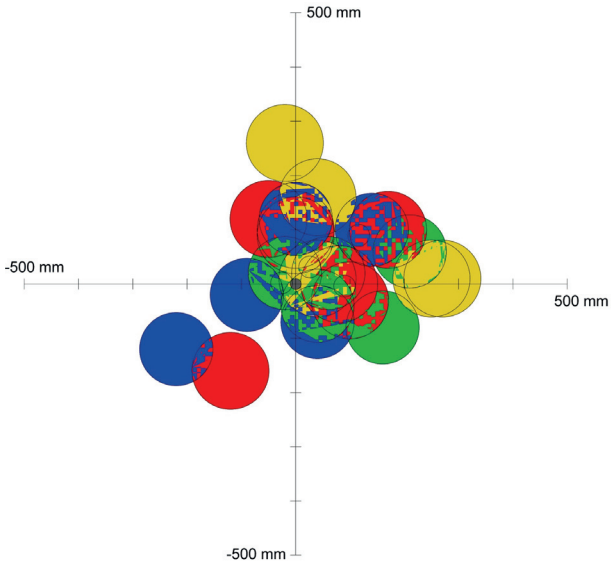


Fig. 4. Shot grouping at 20 m (drawing by Fred Hocker, Vasa Museum).

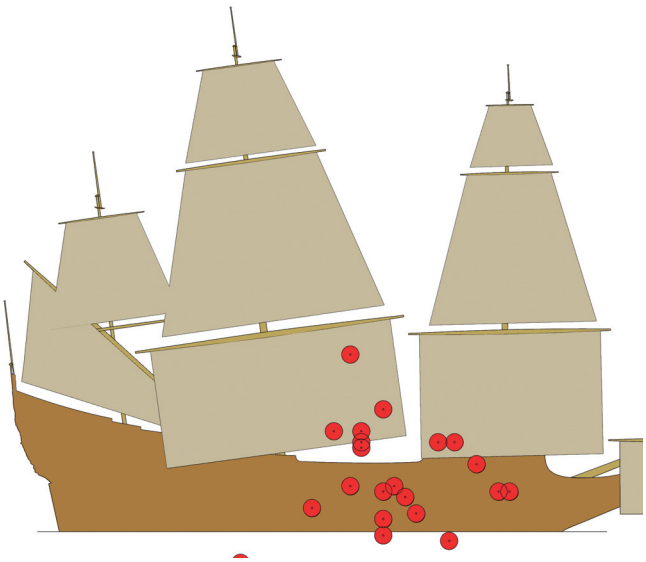


Fig. 5. Theoretical shot grouping at 1000 m, against a silhouette of Vasa, extrapolated from 20 m group without allowing for variations in velocity (absolute best-case scenario) (drawing by Fred Hocker, Vasa Museum).

Effect trials were carried out at a different range within the BTC complex. The reconstructed ship side was mounted with the waterline at ground level 32 metres from the gun. Since the range and accuracy data had already been established, it was not necessary to fire at actual combat distances, where many shots would miss the relatively small target. Instead, the charge could be adjusted to produce impact velocities simulating any desired range. We chose to fire at simulated ranges of close quarters (full charge of 2.65 kg) and 200 metres (reduced charge of 2.2 kg), as well as what might be considered extreme long range, over 700 metres (charge of 1.1 kg). For the effect trials, different size shot were not used, but shot which represented the average size found in the ship (139 mm diameter, 9.99 kg weight). Crossbar and scissor shot were trialed, and chain shot were fired at a reconstructed fore topgallantsail. We also tested two rounds of case shot, consisting of 215 lead musket shot of 18 mm diameter (0.71 calibre) packed in wood chips in a wooden tube. Instrumentation included high speed video of the target, Doppler radar, and witness packets of aluminium sheet over Styrofoam, a standard material used in modern ballistic splinter trials for recording the spread and penetration of shrapnel and splinters. A block of ballistic soap, covered in woollen cloth, was also used to assess the protective effect of the typical clothing of the period. This part of the test was coordinated and the results analyzed by Sofia Hedenstierna and her team at the Swedish Defense Research Institute (FOI; for a fuller report see Hedenstierna and Halldén 2015).

Ergonomic aspects could not be evaluated to the level desired due to safety restrictions. It was not allowed to stand near the gun while it was fired, nor to stand in front of it to load it, which necessitated a non-historic (and much slower) loading process. It was possible to measure sound levels around the gun with sound pressure metres.

Results

The ballistic results are discussed in a separate publication (Hocker et al., forthcoming), but are summarized here. Range at elevations up to 3 degrees 30 minutes is up to 1000 m, with rapid decay in velocity from transonic to high subsonic speeds and more gradual decay thereafter. With the standard charge, the ball retains enough speed at this distance to penetrate the hull, and even after striking the ground several rounds destroyed rocks and penetrated steel structural plate at the backstop. Accuracy is what one might expect from a loose-fitting sphere travelling down a smooth bore. A test panel at 20 metres showed a group about 500 mm in diameter (Fig. 4). In a best case scenario, with all rounds travelling at the same speed (not actually the case) the spread of shot is still smaller than the side of the ship at 200 and 400 metres, but by 1000 m only about 40 per cent of the shot will strike the hull, although a significant number will hit the sails (Fig. 5). This particular gun groups slightly to the right and high of the point of aim, which is also a typical quirk of smooth-bored artillery. Every gun has a personality, and it was part of the gunner's skill to know what each gun's idiosyncrasies were and exploit them.

Although these data suggest that the gun could be useful at ranges up to 1000 m, this is misleading. We were firing from a fixed position at a fixed target. On a real ship, the roll would make it very difficult to hit anything the size of a ship's hull more than 200-300 metres away with reliability, although if the intention was to damage the sails and slow an enemy ship down, firing at ranges of 1000 m might still be productive. One problem with longer ranges is that due to the drop of the ball over distance, the aiming point has to be progressively higher (more than 10 m above the top of the masts at 1000 m), and with no way to measure distance to the target, accuracy would be even worse at long range.



Fig. 6. Hits on the exterior of the ship side test article (photo by Evelyn Ansel, Vasa Museum).

Although it was not possible to carry out an accurate test of rate of fire, continuous fire drills with all safety protocols in place still allowed a round every 4.5 minutes. The actual loading time is only about 30 seconds, so it seems reasonable that the rates of fire attested in later periods, of a round every 90 seconds or even less, were readily achievable by a practiced gun crew. Sound pressure levels behind the gun are only a sixth of those at the muzzle, so the noise would not have been immediately deafening, especially if one remembers that the crew are protected from much of the muzzle blast by the side of the ship.

Effect

Twelve rounds were fired at the ship side (Fig. 6), eleven for hits (one round flew below the point of aim and through the open gunport). Eight of the hits were round shot, plus one crossbar shot and two scissor shot. The round shot struck with velocities from 350 m/sec down to 180 m/sec, and except for one scissor shot, all passed completely through the structure of the side and carried on beyond the target. The first round (round 37), on a full charge, passed through the planking and ceiling, travelled another 500 meters before striking the perimeter road of the range, flew another 200 meters through the forest, limbing trees as it went, before scoring a direct hit on a 40 cm pine tree, which it cut in half before carrying on into the bog behind. One round passed through the side and then tunnelled 70 cm into the breadth of the waterway before striking a knot and dropping out of the bottom of the timber. A 24-pound round shot, at any velocity, has an enormous amount of destructive energy and there is little to suggest that any type of ship construction of the period would be effective at stopping such a round.

What is more interesting is how the shot damages the timber, and what happens to the crew inside the target. Here, we were able to distinguish between two key factors that determine the amount of damage and danger to the crew.

First, ball speed determines the speed of the splinters created. High speed video of the rounds penetrating the hull shows that splinters created on the interior are travelling slightly faster than the exit speed of the ball. They are ballistic projectiles in their own right, with air resistance and gravity acting to slow them and bring them to the deck. It is possible to plot this data and correlate it with the penetration data from the witness packets to assess danger to the crew.

Second, the location of the strike relative to the construction determines how much energy the hull extracts from the ball, slowing it down, as well as the size and velocity of the splinters. The thicker the section of the hull, the larger the exit splinters will be. A round passing only through the planking, framing and ceiling leaves a small exit hole and makes only small splinters, while one striking on a knee or rider will leave a much bigger hole on the interior and create much bigger, if slower splinters. The following two examples give some idea of the range of possible results.

Round 37 (Fig. 7), striking the hull at 350 m/sec between the knees and riders, and thus passing only through the planking, framing and ceiling, creates small splinters, weighing c. 7 g each, with an initial velocity of about 318 m/sec (not much slower than a musket shot). The speed decays quickly, due to the high surface area relative to mass, but the witness packets indicate that such splinters will penetrate woollen cloth up to 7 m away, exposed flesh



Fig. 7. Splinters generated by round striking the thinnest part of the structure at 350 m/sec (photo by Bofors Test Center).

up to 13 m away and eyes up to 24 m away. However, only splinters which strike with the point will penetrate, and splinters which strike side-on are deflected by woollen cloth, although they will still cause significant bruising (the mass is simply too small to have much effect). Where penetration occurs, it is typically shallow (less than 5 cm), which may be a serious but not necessarily incapacitating wound. Since the interior of the ship is only about 9 m wide, men are at risk all the way across. The ball itself still has enough energy to pass through the other side of the ship, and the high-speed video shows that it blows a large quantity of splinters back through the hole on its way through, so men on the other side of the ship would be endangered twice by the same round.

A peculiarity of the structure noted in this trial is that for rounds that strike between the knees and riders, these timbers act like shutters to focus the cloud of lightweight splinters, compressing it into a dense stripe rather than a cone. A man standing in the way of this stripe will also be struck by the ball itself, which is almost invariably fatal, while a man standing a half meter to one side of the path of the ball will be untouched. One could argue that this is not a very effective round, since the damage is extremely limited.

In contrast, round 45 (Fig. 8), striking at a lower speed and passing through one of the knees creates splinters travelling at only 180 m/sec. A 7 g splinter at this speed will not penetrate cloth beyond 2 m, flesh beyond 6 m or cause eye injury beyond about 13 m. However, striking the knee or rider creates much larger splinters, perhaps up to a meter long and weighing several kilograms. These have more impact energy, and they are large enough to cause blunt force trauma, breaking bones as well as penetrating deeply at distances of 6 meters or more. Unlike a strike between the knees and riders, there is nothing to focus or compress the cloud, so its effect is more widespread

A high velocity round, all other factors being equal, is thus more likely to causes injury to those in the path of the splinters, but there are a number of mitigating factors. On balance, it may be that the location of the strike is more important than the velocity, in which case the construction of the ship could have a distinct effect on the result. This helps to explain why a ship could take a large number of hits but suffer only small casualties. There is a high degree of random chance involved, and it was probably not possible for the people of the time to observe, measure or evaluate the relevant factors accurately.

The mechanism that creates splinters is also of interest. Except at initial contact, the ball itself does not break the wood fibres. It creates a shock wave that moves through the timber ahead of the ball, rupturing fibres, breaking fasteners and shattering timbers. As the high-speed video shows, the splinters are travelling ahead of the ball, not following it. The greater the thickness of timber, the larger the wavefront becomes. This is why a ball passing through the side and a knee creates larger splinters, while a ball passing only through the planking and ceiling only makes small splinters. The difference can also be seen in the exit holes on the inside of the hull. Where the ball misses the internal timbers, the exit hole in the ceiling is not much larger than the ball, but where it passes through a knee or rider, the pattern of ruptured fibres shows an expanding are of damage (Fig. 9).

A significant tactical paradox here is that if one is facing a ship armed with heavy guns, such as *Vasa*'s 24-pounders, it would be advantageous to have a lightly built ship rather than a heavy one. A heavily-built ship cannot stop a 24-pound ball, but it will create larger and



Fig. 8. Splinters generated by round striking a rider futtock at 260 m/sec (photo by Bofors Test Center).

more dangerous splinters. A lightly built ship will not slow the ball down very much, but the ball will punch a clean hole and make a small cloud of light, largely harmless splinters. This may also help to explain differing results in battle, where smaller, lighter ships suffer less damage and fewer casualties than expected.

The nature of the damage done to the ship is also significant. A round shot passing through the planking, framing and ceiling does only localized damage to the structure, usually punching a clean hole through the timber. Such damage can be readily repaired in battle (thus the find of shot plugs on warship wrecks such as *Kronan* (Einarsson 2016)), and more permanent repair does not require significantly invasive dismantling of the hull structure. Because of the widening of the shock wave front in thicker, solid timber, the damage is larger and more complicated to repair. Such rounds, instead of simply punching a hole, may damage surrounding timbers which were never actually contacted by the shot itself. Crossbar and scissor shot do the same thing when fired into the hull, creating more widespread damage which is more complicated to repair than round shot.



Fig. 9. Expanding area of damage in thicker timber on the inside of the structure (photo by Richard Belles).

Conclusions

The tests carried out on the *Vasa* 24-pounder show that this weapon could be deadly at short range, and still effective against rigging at medium ranges, but its usefulness at longer ranges was probably limited. This suited the tactical model of the Swedish navy in the 1620s, and also made the gun potentially effective as field artillery, the role for which it was initially developed and extensively used by Swedish forces in the Thirty Years War. Historical sources and archaeological finds indicate that some guns of this type were still in use in the second half of the 17th

century, but by then the broadside tactics developed in the Anglo-Dutch Wars put a premium on longer range and better accuracy, which required higher muzzle velocities. Lightweight guns such as this 24-pounder were largely abandoned, as they did not have the strength for the larger, faster-burning charges needed. It is hardly surprising that when most of *Vasa*'s guns were raised in 1663-1665, the state had no interest in them and the entrepreneurs were allowed to export them. The presence of a deck of these guns on *Kronan* in 1676 probably has more to do with the symbolic prestige value of bronze guns tied to Gustav II Adolf than their actual utility, since that ship carried an armament full of antique and obsolete trophy guns (Einarsson 2016).

In the tactical and strategic environment of the 1620s, which emphasized the capture of enemy ships over their destruction, the goal was to injure as many enemy crew as possible without causing irreparable damage to the ship. This gun was well suited to that task. There is documentary evidence that the Swedish navy was aware of this delicate balance, as the officers of the navy did not want large, heavily armed ships such as *Vasa* and the other big ships ordered by the king (Glete 2010: 395-409); they preferred smaller ships and boarding tactics over gunnery for another two generations, and it was standard Swedish doctrine to blow up one's own ship to prevent its capture by the enemy. This was laid down in fighting instructions (Fleming 1628), and successfully carried out by the crew of *Solen* at the Battle of Oliwa in 1627; the artefacts from that ship can be seen in the museum hosting this conference.

References

Allin, Thomas, 1939. *The Journals of Sir Thomas Allin, 1660-1678*, vol. 1, R.C. Anderson (ed). Navy Records Society 79. London.

Brusewitz, Bengt, 1985. Beväpning och övrig tygmaterial, in *Kungliga Artilleriet: Yngre vasatiden*, Jonas Hedberg (ed.), pp. 61-98. Stockholm.

Einarsson, Lars, 2016. *Regalskeppet* Kronan*: Historia och arkeologi ur djupet*. Stockholm.

Fleming, Henrik, 1628. *Instruktion för Flottan på Danzigs Redd I September 1628* (MS; Riksarkivet Flottans handlinger, Sjöexpeditioner 1600-1648). Published in Marinstaben, 1937, *Sveriges Sjökrig 1611-1632*, pp. 264-268. Stockholm.

Fox, Frank, 2009. *The Four Days' Battle of 1666: The Greatest Sea Fight in the Age of Sail*. Barnsley. (Originally published 1996 as *A Distant Storm*).

Glete, Jan, 2010. *Swedish Naval Administration 1521-1721: Resource Flows and Organisational Capabilities*. Leiden and Boston.

Hedenstierna, Sofia and Malin Halldén, 2015. *Värdering av människans sårbarhet för sekundärsplitter från skrovsida i ek: Sårbarhetsanalys i samband med projekt Vasakanon*. Swedish Defense Research Agency report 4094-SE. Stockholm.

Hildred, Alexzandra, 2011. Brass guns, in *Weapons of Warre: The Armaments of the* Mary Rose, Alexzandra Hildred (ed.), pp. 17-129. Archaeology of the *Mary Rose* 3. Portsmouth.

Hocker, Fred, Torsten Lindh and Sofia Hedenstierna, forthcoming. Testing 17th-century naval ordnance: the Vasa Cannon Project.

Holmstedt, Nils 1985. Skjutteknik, in *Kungliga Artilleriet: Yngre vasatiden*, Jonas Hedberg (ed.), pp. 99-120. Stockholm.

Schultz, Johan, 2000. *Ballistik på 1600-talet: Ett samspel mellan vetenskap och teknik*. Royal Institute of Technology, Stockholm.