The cheiroballistra

Producing a viable weapon based on historical manuscripts, archaeological finds and experimentation

Introduction

The *cheiroballistra* (gr. χειροβαλλιστρα) is an iron-framed torsion-powered ballista described in a similarly-named manuscript, “Heron's hand-ballista, construction and dimensions” (gr. Ἥρωνος χειροβαλλίστρας κατασκευὴ καὶ συμμετρία”). Like in all torsion ballistas, the propulsive force of the cheiroballistra comes from two bundles of twisted elastic cord wound around the bars in the washers. A pair of throwing arms is used to twist the bundles and thus transmit energy via the bowstring to the bolt. In the Roman weapons the spring cord was made from sinew, but in modern reconstructions twisted nylon cord is an excellent functional substitute.

My reconstruction is based on the premise that the *cheiroballistra* manuscript is essentially complete in that it describes all the major parts of the machine. I've tried to follow a few key principles while doing the reconstruction:

- The gaps in the manuscripts are filled based on archaeological finds and practical tests
- Measurements from other ancient manuscripts are not used as-is or adapted to the cheiroballistra
- The reconstruction is made to fit the manuscript, not vice versa
- I've tried to be transparent in what is known, and what is subjective

This has led me to construct the cheiroballistra as a fairly light (~10 kilo), stomach-cocked, inswinging weapon, in which all parts (fortunately) work perfectly together. Alternative approaches taken by some scholars have required heavy “amending” of the supposedly corrupt cheiroballistra manuscript (e.g. Marsden 1999b; Wilkins 1995, 2000). In particular the torsion spring diameter of the cheiroballistra has been often increased under the assumption that the size given in the manuscript is too small to produce an efficient weapon.

Manuscript editions and translations

An early edition of the cheiroballistra manuscript and Latin translation was published by Wescher as a part of his *Des poliocetique des Grecs* (1867: 123–134). A few modern translations exist, of which the most noteworthy are those of Marsden (1999b: 212–217) and Wilkins (1995: 5–59). The original manuscript diagrams, while quite corrupted due to repeated copying, are available in Wilkins' (1995), Schneider's (1906: 142–168) and Wescher's (1867: 123–134) editions. The latter two are freely available on the Internet. My own English translation (http://ballista.wikia.com/wiki/Translation_of_Cheiroballistra) is not yet complete and has so far focused on clearing up the parts where other translations have differing interpretations.

Besides the cheiroballistra, there are several other ancient manuscripts that describe Greek and Roman torsion and non-torsion artillery (see Marsden 1999b). Some of the information in them is also applicable for the cheiroballistra.

Dating of the cheiroballistra

The cheiroballistra is a direct descendant of earlier torsion-powered weapons that were in use by 306 BC at latest (Campbell 2011: 682). These, in turn, were preceded by crossbow-like ballistas that used a composite bow as their power source and which seem to have been invented around 399 BC under the name *belly-bow (*gr. γαστραφέτης) (Campbell 2011: 679). It is quite possible that these earlier ballistas with composite bows were not entirely replaced by torsion-powered artillery. In fact, composite bow ballistas may have survived until, or were reinvented in late antiquity under the name of *arcuballista* (Campbell 2011: 680; Veg. Mil. 2.15).

Marsden (1999a: 209) dated the *cheiroballistra* manuscript to 60-150 AD. Similar machines are clearly visible in the Trajan's column which was erected in 113 AD (e.g. Campbell 2003: 37). All datable archaeological finds of the cheiroballistra-type weapons are from the Roman Imperial Era (see Baatz 1974: 51, 53; 1977: 141; 1978: 4, 9,14). The same type of weapons seem to be described in anonymous author's *De Rebus Bellicis (18)* and in Procopius' *De Bello Gothico (I. 21. 14-18)* according to Marsden's (1999b: 244–248) translation and interpretation. So the evidence indicates that cheiroballistra style iron-framed weapons were in active use by the Dacian wars, and that they were still in use at the end of the fourth century (Baatz 1978: 9) and possibly even in Justinian's Gothic wars (535–554 AD). That said, many of the archaeological finds elude precise dating due to lack of context information (Baatz & Feugère 1981: 201–202; Kayumov et Minchev 2010: 327).

Main components

The wooden *case* (1) forms the core of the weapon. The case has a female dovetail matching the male dovetail of the wooden *slider* (2). The rear-end of the slider has the triggering mechanism composed of several steel parts: *the trigger* (3), *the claw* (4), *the fork* (5), *the pitarion* (6), *the handle* (7) and a steel rod (8) The steel *field-frames* (9) and *washers* (10) made from bronze or steel house the sinew torsion spring bundles (11), through which the arms composed of wooden *cones* (12), steel *bars* (13), soft iron *hoops* (14) and wrappings (15) are inserted. The *little ladder beams* (16) are made from steel and held at a proper distance by wooden *rungs* and *crosspieces* (17). The little ladder is braced against the wooden *projecting block* (18) under the case and attached to the case with *T-clamps* (19) made from steel. The notches in *tenons* (20) in the little ladder beams are locked into the the field-frame bars inside the lower *pi-brackets* (21) and tightened using *wooden shims* and *wedges* (22). The field-frames are further stabilized by the *little arch* (23), the ends of which are inserted into the upper pi-brackets (24) and held in place by *pairs of pins* (25) and *wooden wedges* (26). The *crescent-shaped piece* (27) is attached to the end of the slider to serve as a stomach-rest during cocking. The *bowstring* (28) is inserted into the *hooks* (29) at the end of the bars.

Preparations for use

Each cord in the torsion spring is stretched using the winch in the stretcher. The power output of the weapon is directly proportional to the amount of pretension applied to the cords during this phase. Once the torsion spring bundles are full of cord, the arms are inserted between the two halves of the springs. The washers at the top and bottom of the field-frames are rotated against the direction of the arm rotation to increase tension further and to ensure that arms are rotated synchronously during pullback. Finally the washers are locked in place using *pins* (30) going through *holes in the washer rim* (31) and in the *field-frame rings* (32).

Using the cheiroballistra

The Cheiroballistra's is fairly simple weapon to operate. The trigger is first pulled from under the claw. The slider is then pushed forward, the claw locked to the bowstring and trigger pushed under the claw. This way the bowstring is locked to the slider. The slider is then braced against a sufficiently hard surface, and the operator pushes the weapon with his belly while simultaneously pulling the handle with both hands. This rotates the arms in the torsion spring bundles from their forward-pointing position, first towards the case, and then towards the operator, for an arc of 90-120 degrees. Once the slider has been fully drawn back, the handle is pushed through the steel rod attached to the case, so that the slider is locked into place. Finally a bolt is inserted into the *groove* (33) in the slider and pushed between the fingers of the claw against the bowstring.

The cheiroballistra can be aimed accurately by bracing the left elbow against the hip and by placing the crescent-shaped piece behind the neck from the right side. The right hand is thus free to operate the trigger. Using this technique the weight of the weapon is actually an asset in that it stabilizes the weapon a great deal. The point of balance of the cheiroballistra, which is near the projecting block, also helps stabilize the weapon.

Performance

While several real-life reconstructions of the cheiroballistra and similar machines have been made (e.g. Marsden 1999b; Wilkins 1995/2000; Iriarte 2000/2003; Hart & Lewis 2010), very few of them have even approached the power and range of a weapon suitable for war. The only modern reconstruction I know of that has probably reached, or even surpassed, the power level of Roman ballistas of equal size is the “Firefly” from Nick Watts (http://wattsunique.com/blog/). The Firefly is based on the Orsova artifacts (see Baatz 1974: 54; Baatz 1978: 9) and is thus significantly larger than the *cheiroballistra*. The velocity and energy of Firefly's bolts is highly impressive: according to Nick's chronograph it can shoot a 521 gram bolt at 96.3 m/s, yielding 2424 joules of kinetic energy. This amount of energy means that the Firefly's bolts are capable of perforating 6mm thick plate steel, as well as many other more creative targets placed in their path.

Digby Stevenson's (1995/1997) cheiroballistra reconstruction was, according to Wilkins (2000: 97), also fairly powerful; Stevenson himself had estimated by pacing a range of 300 meters for his 42.5 gram bolts. This is fairly impressive given the bolt size, especially as Stevenson's reconstruction used real sinew springs, not nylon like all the other reconstructions.

My own reconstruction has roughly tripled its performance since I first shot it some years ago. At the moment I've managed to squeeze out about 69 m/s using a 49 gram bolt, giving 117 joules of energy. Based on the amount of cord in the springs 150 joules is enough to reach the Firefly's performance level. Firefly's bolt velocities could be reached by dropping the bolt weight to about 20 grams. It should be noted, however, that these results do not represent the maximum performance of the cheiroballistra: this is evident from the fact that even with this reasonably high power level the weapon can be cocked fairly easily with stomach pressure alone, without assisting the pull with the handle, as was probably done in the Roman cheiroballistras. I estimate that the maximum power output of the weapon will finally settle to the 150-200 joule range when using nylon spring cord, depending on the bolt weight. Whether the same power level can be reached with sinew spring cord is a question that remains unanswered. The rate of fire of the cheiroballistra has not been exactly measured, but with practice at least 3 bolts could be shot every minute.

To give these numbers a *rough* context, an average modern “primitive” 70 lbs all-wood, straight handbow shoots a 32.5 gram arrow at 53.99 m/s, yielding 47 joules of energy (Baker 2000: 114-115). Bows heavier than this required highly trained archers (e.g. Karpowicz 2007). It should be noted, however, that exceptionally well made composite bows *could* have much improved performance, surpassing 100 joules in war-weight bows (Karpowicz' 2008: 51). Some heavy, winched late-medieval crossbows weighed about the same as the *cheiroballistra*, and could shoot a 75 gram bolt about 420 meters (Payne-Gallway 1903: 14). The velocity of the Payne-Gallway bolt is unknown, but must have been in the 70–80 m/s range, giving the bolt 184–240 joules of energy.

Penetration and long-range tests with the cheiroballistra have to wait until the reconstruction is fully tuned, but it seems clear that at moderate ranges the cheiroballistra bolts could easily cut through shields and light armor. Unarmored troops could probably be injured and killed even near the extreme range of the weapon. It still remains to be seen whether the bolts pack enough punch to cut through heavy plate armor at close range. Based on the maximum range of the Firefly (over 800 meters) the cheiroballistra should have a maximum range of 600 meters or more.

The research process

The process for recreating the cheiroballistra can be summarized like this:

> Make a component. It breaks, does not work properly or does not match the sources well enough. Modify or remake the component. It breaks again, does not work well or does not match the sources. Rinse and repeat until the component works well, does not break and matches all the sources very closely.

This has been is a highly iterative and time-consuming process. There have been or will be 2-10 versions of each component before the final version. The weapon is now at the phase where the strength and basic form of most of the components and their manufacturing process has mostly settled down, and very few genuinely new issues tend to pop up. The only thing that remains is to see how much power can be squeezed out of it. The end result is gravitating towards a machine that very precisely matches the manuscript and the archaeological finds and most importantly, is a very effective weapon for its size. The fact that I've followed ancient manufacturing methods as far as reasonably possible has also yielded many useful insights into the weapon itself.

All the work I've done on the cheiroballistra has been documented in the *Greek and Roman Artillery Wiki* (http://ballista.wikia.com/wiki/Greek_and_Roman_Artillery_Wiki) which I created at the very early stages of the project in August 2010. Additional resources such as CAD drawing are made available on GitHub (https://github.com/mattock/cheiroballistra). My approach was and is to publish and share my results as they come, instead of keeping them in the drawer until they were "ready". This approach has clearly paid off as far as the project's visibility is concerned (tip: google for "cheiroballistra").

The articles in the Wiki (99 and counting) as well as my blog postings (http://ballista.wikia.com/wiki/User_blog:Samuli.seppanen) cover a range of topics from forging ballista parts to analysis of the machine and existing scientific research on the subject. The Wiki also serves as an open forum for other Greek and Roman Artillery aficionados, which unfortunately are far and few between.

Acknowledgements

I would like to thank Nick Watts for his valuable tips and correspondence over the years. Moreover, the excellent performance of his Orsova reconstruction ("Firefly") motivated me to start this project in the first place. I'm also very grateful to Veijo Niinikoski for letting me use his workshop to forge the ballista parts. I'm also in debt to my dear friend Visa Immonen, who has helped me acquire many important scientific articles, which were incredibly hard to find. I also owe thanks to fellow enthusiasts on the RomanArmyTalk forums who have similarly helped me locate some hard to find scientific articles. My job has also been made much easier by all the people who have followed the recent, positive trend of publishing their articles on the Internet, instead of in rare and exclusive scientific journals. Finally I would like to thank my fiancee for bearing with me for all these years, despite the incredible amount of time I've spent on this research project.

References

Baatz, Dietwulf 1977. The Hatra ballista. *Sumer, Vol. 33.* 141-151.

Baatz. Dietwulf 1978. Recent Finds of Ancient Artillery. *Britannia, Vol. 9.* 1-17.

Baatz, Dietwulf & Feugère, Michel 1981. Eléments d'une catapulte romaine trouvée à Lyon. *Gallia.*

Tome 39 fascicule 2. 201-210.

Baker, Tim [1992] 2000. Bow Design and Performance. *Traditional Bowyers Bible, Volume One*. 43-116.

Campbell, Duncan 2003. *Greek and Roman Artillery 399 BC - AD 363.* Osprey Publishing Ltd.

Campbell, Duncan 2011. Ancient Catapults: Some Hypotheses Reexamined. *Hesperia: The Journal of the American School of Classical Studies at Athens, Vol. 80, No. 4.* 677-700.

Hart, V. & Lewis, M. 2010. The Hatra ballista: a secret weapon of the past? *Journal of Engineering Mathematics 2010 vol. 67.* 261-273.

Iriarte, Aitor 2000. Pseudo-Heron's cheiroballistra a(nother) reconstruction: I. Theoretics. *Journal of Roman Military Equipment Studies Volume 11*. 47-75.

Iriarte, Aitor 2003. The Inswinging Theory. *Gladius XXIII*. 111-140.

Karpowicz, Adam 2007. Ottoman bows -an assessment of draw weight, performance and tactical use. *Antiquity 81*. 675-685.

Kayumov, Ildar et Minchev, Alexander 2010. The ΚΑΜΒΕΣΤΡΙΟΝ and other Roman military equipment from Thracia. *Proceedings of XVII Roman Military Equipment Conference in Zagreb.* 327-345.

Marsden, E.W. [1969] 1999a. *Greek and Roman artillery. Historical development.* Oxford University Press Inc. Oxford.

Marsden, E.W. [1971] 1999b. *Greek and Roman artillery. Technical treatises.* Oxford University Press Inc. Oxford.

Payne-Gallwey, Ralph [1903] 1990. *The crossbow. Medieval and modern, military and sporting. It's construction, history & management.* Albert Saifer publisher. London.

Schneider, R. 1906. Heron's Cheiroballistra. *Mitteilungen des Kaiserlich Deutschen Archäologischen Instituts. Römische Abteilung 21.* 142-168.

Stevenson, D. 1995. *Heron's Cheiroballistra, with an appendix on the manufacture of sinew rope. BA dissertation.* University College London.

Wescher, C. 1867. *Poliocétique des Grecs. Traités Théoretiques. Récits Historiques.* Paris

Wilkins, Alan 1995. Reconstructing the cheiroballistra. *Journal of Roman Military Equipment Studies Volume 6*. 5-59.

Wilkins, Alan & Morgan, Len 2000. Scorpio and cheiroballistra. *Journal of Roman Military Equipment Studies Volume 11*. 77-101.