A
Modern Reconstruction
of
Vitruvius' Scorpion

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For further information, check out our web site at:
http://www.eg.bucknell.edu/~whutchis/scorpion

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This binder of information is supplied to help anyone who is interested in reproducing Roman or Greek torsion-powered artillery. If you would like copies of any of the information presented here, or a set of the detailed plans for construction of Vitruvius' scorpio, please leave your name and contact information on the information request list in the front pocket of the binder.

Glossary of Terms

- **Torsional artillery** – Stone or arrow throwing artillery powered by twisted skeins of hair or sinew rope. "Torsional" is a modern description of the power source referring to the torsion applied to the springs to increase the force exerted on the arms.
- **Washer** – a bronze cylinder that rotates to tighten the springs.
- **Pin** – Iron bar that the rope is wrapped around; held by the washer
- **Rebate** – Iron plate attached to the hole carrier that the washer turns in; an innovation in early Greek artillery
- **Scorpion or Scorpio** – Term used to describe an arrow-shooting catapult.
- **Springs** – the skeins of rope that are tensioned and twisted to provide power to the catapult.
- **Mortise-and-tenon** – Mortise-and-tenon joints consist of a mortise (a recess cut into a piece of wood that accepts a tenon) and a tenon (a tongue at the end of a board that fits into a mortise). Think tab 'A' fitting in slot 'B.' The tenon is the tab, and the mortise is the slot.
- **Quarter-cut** – British term for quarter-sawn wood. Boards cut from a log that's first cut into 4 equal pieces as opposed to plain-sawn wood, where the boards are formed by cutting across the entire width of a log. Quarter sawing improves stability and appearance, but reduces the yield from a log.
- **Stanchions** – another term for the uprights that separate the two hole-carriers. The scorpion has 2 end or side stanchions, and a thicker center-stanchion.

Section 1
General Description of the Project

What is it?

A reproduction of an arrow-shooting ballista based on a description by Vitruvius, the 1st century BC Roman author of *Ten Books on Architecture*.

Project Goals

Our goal was to produce a working siege engine of authentic proportions and appearance that could be used at demonstrations as part of a display of siege-craft.

Sources

Our main source for the construction of this scorpio was Vitruvius' description "On the Design of Scorpions"[1] as presented by E.W. Marsden in his 1971 book, *Greek and Roman Artillery, Technical Treatises*. Other translations and interpretations of the Vitruvian text[2] were consulted for consistency. Marsden, Iriarte and Wilkins also translated the text of Heron's *cheiroballistra*, which was referred to for details of the trigger construction. Several archaeological finds of frame plating pieces, washers and bolt or arrow heads were consulted for verification and will steer future work.

Historical Background of Torsional Artillery

Artillery powered by twisted bundles of sinew or hair ropes was standard equipment in Early Imperial Roman[3] legions. We have a clear picture of how this artillery was constructed because of the survival of a series of descriptive technical manuals. Early "torsional" artillery as described by Greek writers Heron and Philon was divided into two categories: engines for hurling stones (palintones) and those designed to shoot arrows (euthytones). The size of these engines was based on either the weight of the stone to be fired or the length of the arrow. The construction of the two types of engines varied primarily in the arrangement of the spring (i.e. bundle of rope) holders.

In approximately 25 BC the Roman writer Marcus Vitruvius Pollio published a treatise on architecture in 10 books (*De Architectura Libri Decem*) for the Imperator Augustus. A section in the tenth book, machines, describes both stone throwing (ballistae) and arrow firing (catapults or scorpio) torsion engines that have improved characteristics over the earlier Greek designs. These improvements consisted of a change in the aspect ratio of the frame holding the spring ropes, a different arrangement for the ratchet and pawl system and

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[1] See section 2 of this document for our annotated text
[2] Wilkins and Thayer
[3] The early imperial period in Rome was from approximately 25 BC to AD 193

curved arms. These improvements all let to an increase in power over the older designs.

Around AD 100 a description of a more advanced engine, the *cheiroballistra*, was written by another author named Heron. This engine, with a metal frame holding the springs, represents the final form of two-armed torsional artillery, It is fairly certain that catapults depicted on Trajan's column were of this latter type (see Figure 1). The final description of torsional artillery occurs in the fourth century AD, where Ammianus and other anonymous authors describe the single-armed stone thrower called an *onager* whose use continued through the Middle aAges until it was supplanted by the trebuchet[4]

Abb. 8. Carroballista von der Trajanssäule.
(Schramm. I. Aufl. Fig. 8.)

Figure 1 – Ballista depicted on Trajan's Column
from Schramm, Fig. 8

Who was Vitruvius and why did we choose him as a source?

Rowland and Howe present an excellent background of Vitruvius in their edition of his *De Architectura*. His twenty-year military career started at the beginning of the Roman civil war between Caesar and Pompey. He was a Caesarian and Augustinian staff architect who spent much time on campaign. He was, along with three others, placed in charge of repair and construction of ballistae by Augustus, for which he received a pension.[5] In the section describing ballistae, Vitruvius personally vouches for the stone-thrower's calibration formulae, which he has "found correct in practice."[6] We found these qualifications compelling, and felt that the engine described by Vitruvius would be representational of Early Imperial Roman artillery.

Another reason for choosing Vitruvius was that early in the project we felt that we could build an engine that might have been constructed in Europe in

[4] Marsden, 1971, 249
[5] Marsden, 1971, 3
[6] Marsden, 1971, 189

the middle ages. Manuscripts of Vitruvius were available to Western scholars after the 8th century, and were printed in multiple editions in the early 16th century.[7] However, it's clear that a medieval engineer could not have produced a working engine from just the text of Vitruvius alone due to insufficient detail about the trigger mechanism and the washers. The scant evidence that does exist for two-armed torsion engines in the Middle Ages[8] indicates they were not designed along Vitruvian lines. Baatz asserts that the earliest reconstructions from the Greek and Roman text was in the middle of the nineteenth[th] century.[9] This project is therefore presented as a reproduction of a Roman engine, not a medieval interpretation.

Who would have made one in period?

The Romans obtained most of their knowledge of artillery from assimilated Greek sources, and never really developed their own "brand" of artillery during the early imperial period. It appears that artillery engines, both stone-throwing and arrow-shooting, were built at central arsenals near the Mediterranean Sea. Each legion was equipped with an allotment of artillery and may have been trained to construct more on the spot as needed[10]. An engine of this size would probably have been constructed at an arsenal and assigned to a legion or permanent fort. The archeological find at Caminreal in Spain in 1984 consisted of the metal plating, washers and rebates from a scorpio of approximately the same size as the one we have reproduced here[11], so we know that engines of this size were built by the Romans. That find has been dated to 80-72 BC, about 50 years after Vitruvius wrote *De Architectura*.

How did we construct the scorpio and what materials were used?

The planning behind this project has been ongoing for years. Actual work on the scorpio started over seven years ago after some research on building a catapult turned up the Marsden books. This led to preliminary work done on the drawings as part of an exercise in learning AutoCAD, the drafting package used to generate the plans. After an initial set of drawings was completed, some lumber was obtained from a local mill, planed and cut to size for some of the frame pieces. Work then halted on the project for more than 4 years.

In the fall of 2002 interest in the project was renewed and a partnership was formed to complete the engine. At that point, the wood for the uprights and center post had been roughed out, and pieces for the top and bottom of the capital, or hole carrier, had been shaped. Complete drawings of the conceptual

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7 Payne, 54-55
8 Illustration from the *Romance of Alexander* as depicted in Gravett, 20
9 Baatz, 1
10 Marsden, 1969, pp. 174-188
11 Vicente, *et al*, 167

design had been completed, and a piece of tubular bronze had been acquired for the washers. Nothing else was started.

This is a complex device, with a large number of parts and sub-systems. It seemed the woodworking would take the longest, so we concentrated on completing the case, slider and hole carrier first. We then tackled the base and arms while working on the washers, rebates, trigger and winch mechanisms. An initial debate was whether we would try to complete the entire engine with hand-tools and period Roman techniques or just use modern power tools. Some of the woodwork had already been done with power tools, so we decided, due to the lack of slave labor, we would use a mix of power tools and hand tools. Mortise and tenoning was done mostly by hand, as was shaping the arm string grooves and drilling many of the holes. We felt that if an operation was just as easy to do by hand, we'd do it that way and improve our skills. If it was removal of a large quantity of wood, or a part that had to be straight for the scorpio to work, the power tools were used.

Details of how we addressed each section of Vitruvius' description can be found in the second section of this document, along with the relevant sections of text.

Wood

There is a dearth of information as to what woods were used to construct siege engines in period. Len Morgan of the Roman Military Research Society is noted to have used "quarter-cut" oak in one of his reproductions.[12] Schramm[13] and Marsden both built reproductions of similar engines, but don't mention what materials they used. Our shop supply consisted mainly of maple and cherry boards. Many sections of the engine are built of boards one spring diameter (3 inches) thick. No local mill could supply 3 inch thick oak so we used what we could get. Thicker sections were laminated using 1 inch stock when necessary. We were able to obtain some 2" red oak that was used for the arms and windlass drum. The handspikes were turned from ash tool handles.

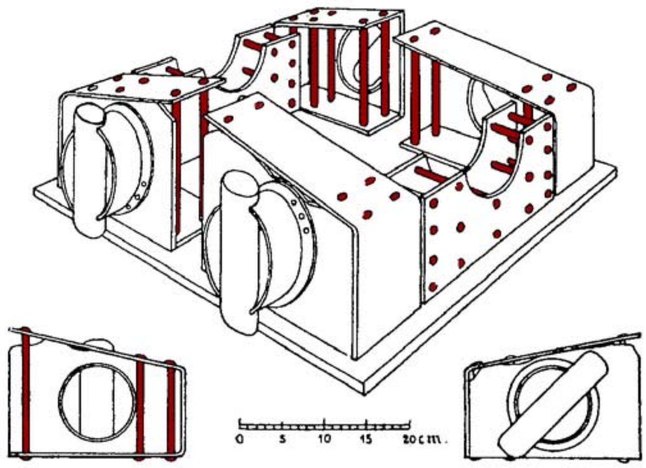
Wood on the scorpio was finished with linseed oil and some beeswax for the slider and channel. The base was sealed with a modern water-based finish as we felt it would receive the brunt of water and weather contact.

Metal

Most of the iron parts were built from standard mild steel. Steel parts were "blued" for the most part to prevent corrosion. The pivot pin for the trigger mechanism and the pins that the spring-cord is wrapped around are tool steel for added strength. The washers are turned (not cast) from a free-machining bronze stock that was obtained from a commercial metal supplier. Some pins to hold metal braces on are formed from ¼" brass brazing rod. Archeological

[12] Wilkins, 90-91.
[13] Schramm, 66.

evidence shows that iron plating was held onto catapult frames by long rivets similar to the way we mounted the rebate plates for the washers. (See Figure 2 for an example.) The trigger mechanism and a couple of other parts are held together with threaded fittings to facilitate disassembly in case of problems.



The Ampurias frame.

Figure 2 – Plating from the Ampurias find long rivets shown in red
from Wilkins, Fig. 1

Cordage

Due to the unavailability of sinew or hair rope, and the excessive difficulty of producing it ourselves, we used a braided polypropylene rope for the spring cord. Actual sinew, polypropylene and nylon were tested in a tensile testing machine to determine their stress-strain properties. As shown by the diagram in appendix 4, the polypropylene rope is a fair substitute for sinew. Sinew fibers are included on the materials page in appendix 1. As the springs are wound in opposite directions, we felt the braided rope, with no twist direction, would make it easier to tune the two springs to the same power. The cord used to draw back the slider is just commercial sisal, chosen for it's ultimate tensile strength and appropriate appearance. The bow-string was wound from and served with linen thread, samples of which are included with the materials page in appendix 1. The string consists of over 100 strands, and is doubly served in the center. The string was then coated with beeswax to protect the fibers. A frame was constructed to wind the string, which was made in the same manner as a crossbow string.[14] Pictures of the string-winding process are presented in appendix 2.

Adhesives and connections

There are many locations on the engine where wooden parts are glued together. This was done in a thoroughly non-period fashion, as modern

[14] Payne-Gallway, 110-113

adhesives were always used. There is no evidence that any gluing was done in period. If it *had* been glued in period, some sort of hide glue would have been used. Early experiments with using hide glue for laminating arms for the scorpion were unsuccessful, as the glue failed when these test arms were exposed to high temperature and humidity. We plan on using the scorpion outdoors in the summer, so we felt hide glue might not be the best choice. Face gluing was done mainly with Titebond II, and dowel gluing was done mainly with Gorilla glue. Some screws were used in parts we thought we might need to disassemble in the future, but we concealed their appearance as much as possible. The angled joints in the base were connected with biscuits, or jointer plates, as we were rushing to complete it before Pennsic last Summer. The steel plates and nails are almost purely decorative. We plan on building another base with a different and more authentic design in the future.

Section 2
Analysis and Summary of the Vitruvian Text
and other supporting documents

In the following text, the number and names from 3 different translations are combined. The text in Times that makes up the bulk of the description is from E. W. Marsden, *Technical Treatises*, 1971 and was the text we used for most of the project. The text in Arial is from the second source we encountered, a web translation by Bill Thayer available at: http://www.ku.edu/history/index/europe/ancient_rome/E/Roman/Texts/Vitruvius/10.html. There are significant differences in this version, and in our minds, most of those are in error. Finally, text in **bold** is from Alan Wilkins 2000 article in the *Journal of Roman Military Equipment Studies*. A fourth translation, that of Roland and Howe, is available in print, but was not consulted for this project.

There are numerous problems with the information presented in the extant text of Vitruvius,[15] especially with the transmittal of the numerical information. If we're trying to read his text as a construction manual, then the numerical descriptions are vital. However, cardinal numbers were represented in "Roman" numerals that could easily lose digits and fractions were variously represented as full words or by a system of letter-numerals and signs that may have confused copyists.[16] Any diagrams that may have accompanied the original text have been lost in transmission and there are several cases where Vitruvius may refer to diagrams for explanation. We can only infer from other sources what he means in those cases.

As you will see, a variety of assumptions have to be made to complete a working engine from this description. The explanations presented after each paragraph will clarify our approach to the reconstruction.

> (X.10.1) Now I shall describe machines invented for protection in war and preservation of security, that is, the designs of scorpions and ballistae, and to what proportions they can be constructed. All dimensions of these engines are calculated from the given length of bolt [**arrow**] which the particular engine is intended to shoot. Let the diameter of the holes in the frames, through which are stretched the twisted sinews that hold the arms, be one ninth of this (i.e. of the length of the bolt).

In this introductory paragraph, Vitruvius sets forth the design basis of the arrow shooting ballistae or scorpion. We chose an arrow length of 27 inches, the so called 3-span length. This in turn leads to a hole (or spring) diameter of 3 inches. For this reproduction, we have stretched 125 feet of $^5/_8$ inch diameter polypropylene rope into each hole. Photographs of the stretching process are included in appendix 2.

> (2) The height and width of the frame [capital] [**capitulum**] should be designed in accordance with the diameter of these same holes. Let the beams [plates][**tabulae**], which are at the top and bottom of the frame

[15] No original text of *De Architectura* is extant. Source manuscripts from the 8th to 11th centuries form the basis for translations.

[16] Wilkins, 78

> [capital] and are called hole-carriers [parallels] [**peritreti**] be made 1*f* [17]thick, 1¾*f* wide, 1½*f* wide at the ends. The right and left side-stanchions [side posts] [**parastaticae**] are to be 4*f* high excluding tenons, $^5/_8$ [5] *f* thick; the height of the tenon is ½ [$^3/_4$] *f*. The distance from side-stanchion to hole is to be ¼ [¾] *f*, and likewise the distance from hole to centre-stanchion [**mediana parastatica**] is to be ¼ [¾] *f*. The thickness [width] of the centre-stanchion is to be 1 ¾ [1¼] *f*, its width [thickness] 1*f*.

Our hole-carriers have been laminated from three one-inch thick pieces of maple, for a total thickness of 3 inches. By adding up the hole diameters and the distances listed from the side stanchions and center stanchions, the length (long axis) of the hole-carriers works out to 6 *f*, or in our case 18 inches. We made ours a little longer than this to reinforce the joint at the corner. The width (front to back) of the side-stanchions is not listed, nor are there any details about the cut-outs for the arms or the compensating bulge. We assumed the top and bottom of the side-stanchions matched the width of the ends of the hole-carriers – 1½ *f*.

By looking at 3 pieces of archeological evidence, we can conclude the side-stanchions had both cut-outs for arms and a curved front. First, the iron frames from the Ampurias[18] and Caminreal[19] finds both have semi-circular cut-outs in the plating to accommodate arms. See Figure 2 and Figure 3 for details. Secondly, the Caminreal frame has a corresponding bulge on the front, as does the depiction of a ballista on the tombstone of Vedennius (Figure 4).[20] In addition to this physical evidence, Vitruvius describes the curved cut-outs and front of the side-stanchions in his description of the stone-throwing ballista.[21] This led us to construct our side-stanchions with a cut-out and curved front. Without the cut-outs, there would be too little room for the arms to swing, and without the front curves, the side-stanchions would be too slender to support the hole carriers.

The center-stanchion is not described as having any tenons, but it must have some means of connecting to the top and bottom hole-carrier. We cut tenons in the center-stanchion the same height as the side-stanchions (½*f*) and 1/3 the thickness (side-to-side) of the stanchion. A corresponding mortise was cut in top and bottom hole-carrier, and the joint was plated over with an iron strap. The side-stanchions were glued in place and pinned with oak dowels.

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[17] Marsden uses "*f*" from "foramen" as the unit measure equal to 1/9th the length of the bolt to be fired. Others use "holes" or D for this measure.

[18] Schramm, 44-45

[19] Vicente, *et al.*, 170

[20] Wilkins, 80

[21] Marsden, 1971, 191

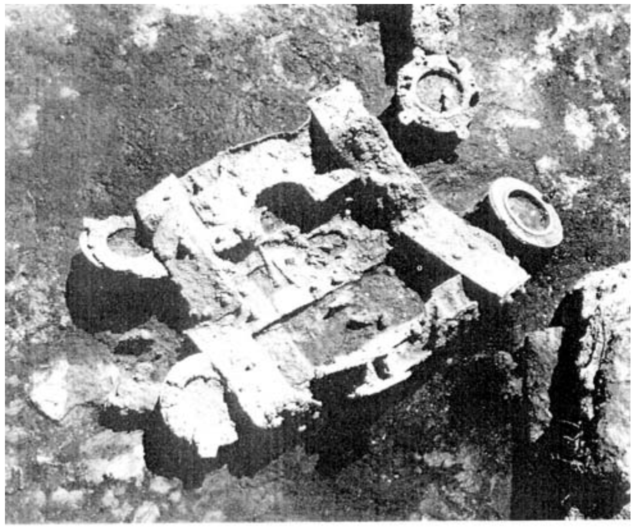

Figure 3 – The iron frame from the Camireal scorpio
from Vicente, *et al*, Fig. 3

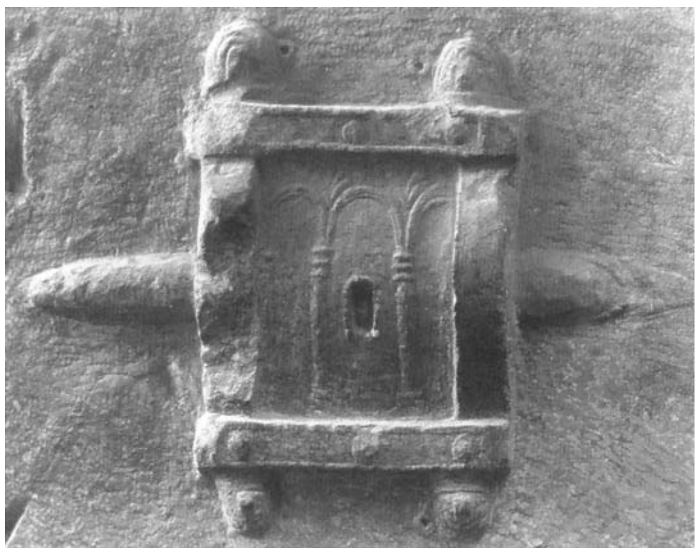

Figure 4 – Carving from the tomb of Vedennius depicting a catapult or scorpion
from Schramm, fig 10

(3) Let the aperture [space][**intervallum**], where the arrow is placed in the centre-stanchion, be ¼ *f* wide [**high**]. Let the four external corners [**outside angles**] be fitted, both on the sides and on the front and rear faces, with iron plates [hoops] and bronze [copper] bolts or nails.[22]

Let the length of the case [channel][**canaliculus**], which is called συριγξ {syrinx or groove}[23] in Greek, be 19*f*; the length of the side-pieces [slips][**regulæ**], which some call cheek-pieces [bucculæ] and which are fastened to the case on the right and left sides, is to be 19*f*; their height and thickness [**of the combined piece**] is 1 [½] *f*.

[22] This plating was quite extensive on the Ampurias catapult frame, see **Figure 2.**
[23] Wilkins, 81

All translators agree that the size of the opening for the arrow is listed at ¼ *f*, but this is not wide enough for the slider to protrude through the stanchion. Even though the slider is only ¼*f* wide at the top, it's closer to ½*f* wide at its base. An embossed battle shield (**Figure 5**), assumed to be from a three-span scorpio,[24] has an opening for the arrow and slider that is ¼ *f* at the top, but wider than ½*f* for most of its height. We chose to cut an opening ¼ *f* at the top, but profiled at the base to fit the slider.

We have not yet fitted the scorpio with iron reinforcing plates, although it's clear from the archeological evidence that historical engines were fitted with extensive plating.[25]

The case is 1*f* by 1*f* and 19*f*, or 57 inches long. That length includes a tenon that was cut to attach the case to the center-stanchion. Our method of construction for the cheek pieces follows Marsden's recommendations[26] for ease of manufacture: the pieces that make up the dove-tail grove are cut separately then glued and dowelled in place on top of the case. They were cut in such a way to leave an opening at the top of ¼ *f* for the slider. These cheek pieces are $^{1}/_{3}f$ high, with the remainder of the case (made up of 2 laminated pieces of maple) $^{2}/_{3}f$ high. Nowhere does Vitruvius or any other writer describe the angle of the dovetail formed; we chose 30º. Further examination of the Cremona battle shield shows an additional rectangular cut-out below the arrow opening. I agree with Wilkins[27] that this is for a tusk-tenon that would allow removal of the case from the spring frame. We did not use this method to attach our case and frame.

Abb. D. Cremona (Italien). Schutzschild eines Katapults der *legio IIII Macedonica* (Bronzeblech; Maße: 31,5 mal 22 cm; Foto D. Baatz)

Figure 5 – The Cremona Battle Shield
from Schramm, Fig. D

Also, two side-pieces [slips] are fitted, between which the windlass [**sucula**] is inserted, and these have a length of 3*f*, a breadth of ½*f*. The breadth [**thickness**] of the backpiece [**buccula**], which is then fastened on and is called the bench, or the box [camillum][**case**] by some people, and

[24] Schramm, IX
[25] See the articles on the Ampurias, Hatra and Caminreal finds for details.
[26] Marsden, 195
[27] Wilkins, 88

> which is secured with dovetails, is 1*f*; its height ½ [**1¾**] *f*[28]. The length of the windlass is 4 [8 $^1/_8$] *f*, its thickness (i.e. diameter) is $^5/_{12}$ [9] [$\mathbf{^9/_{12}}$] *f*.

This paragraph describes the box that is attached to the rear of the case to hold the windlass that is used to draw the scorpio. We built a box 9 inches long, 4 inches high and 5inches wide out of one-inch thick maple (rather than the 1½-inch thick material specified in Vitruvius' text). The back piece is dovetailed along two sides, and fitted to the side-pieces, and the whole box is glued together and dowelled to the case. The total length of our case and box is greater than 19*f*, as specified in the previous paragraph, but acts as an effective counter-balance to the weight of the spring frame. Openings were cut on either side of the box to mount the windlass axle. The wood section from above the round axle opening was nailed onto an iron strap that was in turn screwed to the top of the box. This iron piece acts to retain the axle in place during drawing. Our axle is somewhat shorter than 4*f* (12 inches), but we had no choice in its size, as it was purchased for the project as-is. The diameter of our axle (2 inches) falls between the $^5/_{12}$ and $^9/_{12}$ *f* (1.25 to 2.25 inches) specified in the text. The axle is mounted so the top of the axle is at the same height as the trigger plate.

Vitruvius mentions "pawls" in the corresponding section of his description of the stone-throwing ballista. Marsden[29] interprets this to mean that the axle in the rear of the case had a circular ratchet attached. We followed that interpretation in our engine.

> (4) The length of the claw [epitoxis] is ¾*f*, its thickness ¼*f*, the thickness of the block [**chelonium (shell)**] is the same. The length of the σχαστηρια [**schasteria**] or trigger [chelo or manucla] [**handle**] is 3*f*, its breadth and thickness ¼ [¾] *f*. The length of the slider [bottom of the channel][**canalis fundus**] is 16*f*, its thickness ¼ [¾] [$\mathbf{^6/_{16}}$]*f*, its height ¾ [½] *f*.

This is a confusing passage describing the trigger mechanism and the slider. Marsden[30] notes that the trigger size doesn't necessarily depend on the size of the catapult. If the dimensions listed was followed for our 3-span scorpio, it would call for a "claw" that's only 2¼ inches long, but ¾ of an inch thick. Rather than using these dimensions, we used the *cheiroballistra* trigger description (see below) and illustrations from Schramm's text[31] to design a trigger that seems to be in scale with the rest of the scorpio.

Our slider is built up of two pieces – the angled base and the rectangular top. These pieces were glued and dowelled together, then filed to slide easily in the case. It's the recommended length, width and height. A semi-circular groove was cut in the top to act as an arrow guide, and the trigger plate was inset at the rear.

> The ground-base of the column [columella] is 8*f* (long); the breadth of the joist [plinth], in which the column is set up, is ¾*f*, its thickness 5/8 [3/12] *f*. The length of the column up to the tenon [**cardo**] is 12*f*, its breadth [width] ¾*f*, its thickness ¾ [5/6] *f*. There are three supporting legs [**capreoli**] of which the length is 9*f*, the width ½*f*, the thickness 7/16 [5/6] *f*.

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[28] A case where Marsden was clearly mistaken. If the box were less than the height of the channel, then the windlass axle would not fit properly.

[29] 1971, 204

[30] Marsden, 1971, 195

[31] Plate 1

Although Philon, in the description of the base for his engines, describes a hexagonal center column[32] Vitruvius makes no mention of the shape of the column, just its breadth and thickness. Because of this, we built a rectangular center column, and placed the legs on 3 sides of the column. Our column is 6 inches too tall based on the text, but it seems to be at a comfortable height for firing the engine. Marsden points out that the base dimensions don't work for every spring diameter[33], which in our minds gave us some leeway to alter the base size. We added, as did every other reconstruction, a second ground-base board that crosses the first one at the column joint. Our pieces are joined with a lag-screw attached from the bottom for mechanical strength.

> The length of the tenon [head of the small column] is 1½ [1¾] *f*; the length of the universal joint [**caput columellae**] is 2 [3/8] [**1½**] *f*; the length of the cross-piece [**antefixum**] ¾*f*, and its thickness 1*f*.

Our tenon at the top of the column is an iron pin of the listed length. The universal joint is constructed of 3 pieces of maple, glued and dowelled together. Drilling the case for the pin through the upper part of the universal joint is one of the last things that can be done – the scorpio has to be essentially complete to find the best balance point for this pin. We drilled ours a little early in the process, and as a result the scorpio is a little frame-heavy.

> (5) The lesser [**minor**] column to the rear, which is called αντιβασις [**antibasis = counterstay**] in Greek, is 8*f* long, ¾ [1½] [**½**] *f* wide, 5/8 [3/12] *f* thick. The stay [base (subjectio)] [**subiectio(underprop)**] is 12*f* long, and of the same width and thickness as the lesser column. Above the lesser column, there is a block or cushion [chelonium or pillow] 2½*f* long, 1½[2½] [½]*f* high[34], ¾ [1¾] *f* wide.

Our stay, or underprop, is connected to the main column by two cheek-pieces of maple and an iron pin. We chose to attach the counterstay, or lesser column, to the block on the underside of the case via another pin. Our block, as noted, is a little too tall, but is effective in holding up the case of the scorpio when the engine is on the workbench. This block is glued and dowelled to the case, and was extensively mortised by hand, so we were reluctant to replace it when we saw the figures from Wilkins indicating it was too tall. After setting up the engine for preliminary testing, we noticed the counterstay slid off the side of the stay too easily, so we glued and dowelled two pieces of wood to either side of the stay to help hold the lesser column in place. Wilkins[35] asserts that the counterstay should be attached to the stay, and not to the underside of the case. The block would act as a socket for the counterstay, and would make it only useful for loading. We felt that the repeatable accuracy of the engine would be improved if the counterstay were used to fix the elevation of the case during firing. To support that function, we cut steps into the stay and a matching point into the counterstay.

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[32] Marsden, 1971, 147

[33] 1971, 196

[34] Our "cushion" is too tall because we built it using Marsden's measurements. Another clear error on his part.

[35] 85

(The diameter) of the drum [**carchesium**] for the handspikes [**scutulae**] [mortices in the axles] is 2½*f*, its [**the**] thickness [**of the hole in the drum, for the handspikes**] ½ [2½] *f*; [their thickness also two holes and three quarters wide]. [**The width of the drum is 1*f***]. The length (of the handspikes) [transverse pieces] including the tenons to be inserted (in the drum) is 10 [**7**] *f*, their width [**and thickness**] is ½ [1½] *f* and their thickness is ½ [10] *f*.

This is more details about the winding drum at the rear of the case. We cut the drum from a 2" thick piece of red oak, and attached it to the metal axle with tapered dowels. The handspikes are ash tool handles, with a short section turned down to match the hole diameter in the drum. They are a little long, but are about the right thickness.

The length of the arm [**bracchium**] is 7*f*, its thickness at the base 9/16 [3/12] [**5/8**] *f*, and at the tip 7/16 [½] *f*; its curvature [**curvatura**] is 8*f*.

Here is, according to Marsden,[36] one of main the innovations of this engine: the description of the curved arms. We, along with all previous reconstructions, interpreted the curvature to mean the radius of curvature of the arms is 8*f*, or in our case, 24 inches. Our arms were cut out of a 2 inch thick red oak plank, and shaped by hand to match the listed dimensions. After some initial testing, we felt the arms needed some sort of stop on them to keep them from sliding into the springs. This may be because we used polypropylene rope for the springs, or it may be that we don't have the springs wound tightly enough to grip the arms properly. We added an oak "finger" that was dovetailed into the outer surface of the arms to catch the rope bundle. Other reproductions of similar engines[37] have elaborate hooks and stops on their arms. We're planning on building an additional set of laminated arms for the engine and will build them without the hook installed.

Other reconstructions often have the arms stopping at the end of their swing with the heels striking a pad at the back of the center stanchion. There's no evidence in the text that this arrangement was intended. On our scorpion, the bowstring stops the arm motion before any part of the arm strikes the frame.

(6) These machines are built to the above dimensions, with either additions or subtractions. If, for instance, the frames [capitals] have been made higher than they are wide, in which case they are termed over-sprung [anatona], there will be a reduction in (the length of) the arms so that, to compensate for the spring being weaker on account of the height of the frame, the shortness of the arm may produce more violent propulsion. Should the frame [capital] not be so high (sc. as it is wide), in which case it is termed undersprung [catatonum], on account of its excessive power the arms will be constructed with slightly greater length so that they may be easily pulled back. Just as a lever, if it is five feet long, can lift a certain load with the effort of four men, and, when it is ten feet long, raises the same load with two men: so, on exactly the same principle, the longer the arms are, the more easily they are pulled back, the shorter they are, the harder it is to pull them back.

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[36] 1969, 200-201

[37] "Building the Roman Catapult," a BBC video production shown on Discovery

I have now described the designs of catapults, from what parts and sections they are built up.

The ideal Vitruvian case is 6*f* by 6*f*. The archeological finds at Caminreal and Ampurias frames are both somewhat under-sprung (too short). Our engine is also somewhat under-sprung, as the width of the frame turned out to be 19 inches, 1 inch too wide. We did not intend for this to happen, but an error crept into the project somewhere, and by the time we discovered it, it didn't seem worth the trouble of starting over. It's nice to know the Romans had similar problems.

On the Stretching and Tuning of Ballistae and Catapults

(12. I) Beams of very generous length are obtained and bushes[38] [cheeks] are fixed in them, in which windlasses [axles] are inserted; on the inner edges of the beams in the middle certain shapes are cut and chiseled out, in which excisions the frames [capitals] of catapults are fitted and locked with wedges, so that they cannot move as tension is being applied. Then, the bronze washers are fitted on to the frames, and the iron bars, which the Greeks call επιζνγιδες, are placed on them.

(2) Next, the ends of the ropes are threaded through the holes in the frames [capitals] and passed through to the other end; next, they (the rope-ends) are fastened to the windlasses and turned, so that the ropes, stretched by levers by means of windlasses, when plucked by hand, have an equal sound-response in each case. Then, the ropes are secured in the holes by wedges, so that they cannot unstretch [slip]: thus, after being passed through to the other end, they are stretched in the same way by levers by means of the windlasses until they sound the same note. Thus, by locking (the ropes) with wedges, catapults are tuned to the same note by means of musical sounds.

We did not build a windless to wind our spring, as we knew it would be many weeks between winding and our test firing. Over that time, any tension applied by stretching the cord during winding would dissipate as the rope relaxed. We did wind the springs as tightly as we could by hand, and used wedges to maintain the tension as we went. See the winding photos in appendix 2 for visual details.

Text from Heron's *cheiroballistra*[39]

Now we shall describe points concerning the trigger-mechanism. Make a handle ΑΒΓΔ of iron, with the shape illustrated below; let there be a rectangular tenon ΕΖΗΘ with the part ΕΖ in the form of a double bracket; a claw ΚΛΜ; a trigger ΝΞ; a rivet-plate ΟΠΡΣ. Let the handle ΑΒΓΔ be bored through at Δ ; and let the board ΓΔ in the first figure be bored through at ΜΝΞ at Μ and Ν with a round hole right through, and at Ξ with a rectangular hole. Then let the handle be so fitted that a pin may be pushed through Μ and Ν and through the hole Δ of the handle and riveted. Having bored holes in the double bracket ΕΘ at Τ and Υ, and in the claw ΚΛΜ at Φ, and having inserted a pin both through the holes Τ and Υ and through Φ we rivet it in such a way that the claw can move freely around it.

[38] 'bushes' is here used as shorthand for the seat for a bushing, or spacer, not a shrubbery.
[39] Marsden, 1971, 213-215b

Let the claw have an incision ΔM, 1*f* long. Then, marking off the length ΔO of 5*f* on the board ΓΔ, and boring a hole at O, we lower the double bracket EΘ into it and rivet it, so that it stays firm. Then, boring through the trigger NΞ at N, and the board ΓΔ, the one in the first figure, at Π, which is 4*f* from M, we insert a pin through the hole in the trigger and through the hole Π and rivet it so that the trigger NΞ can turn freely around it. Again, marking off the distance ΞP from the handle ABΓΔ, we bore a hole at P; again, from there we measure 4½ *f*, as PΣ, and bore a hole at Σ, and thus we incorporate the rivet-plate in the board ΓΔ which appears in the first figure. Here it is.

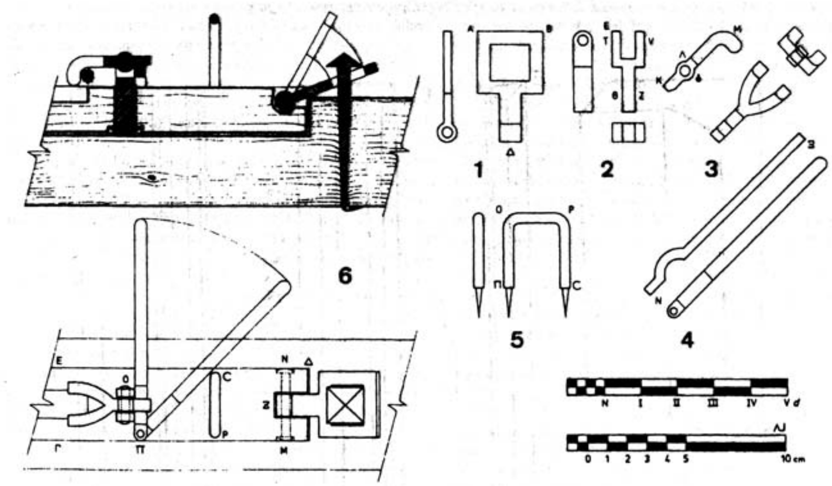

Fig. 3: 1. The 'handle'. 2. The fork. 3. The claw. 4. The trigger. 5. The pitarion. 6. Assembled trigger mechanism. Longitudinal section and plan.

Figure 6 - Aitor Iriarte's diagram of the cheiroballistra trigger mechanism
from Iriarte, Fig. 3

This very detailed description boils down to a simple and effective trigger. A metal bar, split to receive the nock of the arrow (the claw), pivots on an axle held between two blocks. The trigger (or snake) has a short curve partway along its length. Some reconstructions have mounted this with curve (or bump) lying on its side so the trigger clears the back of the claw sooner. We believe, as is shown in Figure 6, that the curve should be mounted so that it's directly under the rear part of the claw. Doing it this way makes adjustment of the trigger mechanism much easier, since you only need to file the top of the bump, and not adjust the thickness of the entire trigger bar. It also allows for a thinner trigger that is less wasteful of metal. Our trigger mechanism works very well, although we may shorten up the rear portion of the claw to allow for a quicker release.

Washers and Rebates

Although not described in the Scorpio section, Vitruvius does describe washers in the section on the stone-throwing ballista.[40] He notes, in addition to the general dimensions, that the holes should be elliptical by an amount equal to the tightening-bar. This would allow more spring-cord to be wrapped on a washer for a given diameter. Wilkins[41] asserts that no such washers have yet been found. It may be that the complexity of this

[40] Marsden, 1971, 191
[41] 88

construction was not deemed worth the extra power that would be available. Many extant washers have reinforcing shelves cast in beneath the openings for the bars, as illustrated in Figure 7[42] and Figure 8. Our washers do not have this feature.

(Photo: D. Baatz)

B. Hatra ballista. Bronze washer resting on counter-plate (after cleaning) (p. 5).

Figure 7 – Washer from the Hatra ballista
from Baatz, Plate IIIa

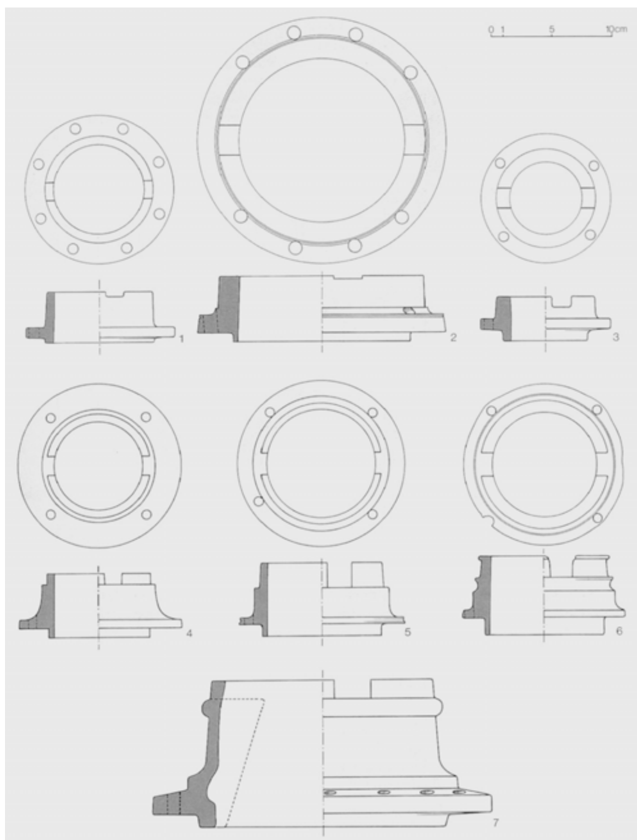

Abb. F. Spannbuchsen aus Bronze. 1–3 Ephyra, 4–6 Cremona, 7 Hatra (nach Röm. Mitt. 87, 1980, 286 Abb. 2). Maßstab 1 : 4

Figure 8 – Schematics of various washer finds
from Schramm, Fig. F

The method of retaining the tension in the springs is only hinted at in the texts. It is only by examining the archeological record we can learn that the Greeks and Romans

[42] Schramm, VIII

devised an ingenious technique to adjust and maintain the twist of each spring. In most cases the only remains we have of a catapult or ballista are the washers rebates from the frames. In the three cases previously mentioned (Hatra, Cainreal and Ampurias) we also have the metal plating from the frame and the rebates that the washers turned in. In all three of these cases the washer was drilled with 1 or more holes spaced at regular angles. The rebates were also drilled with holes spaced regularly, but at a different angle of separation. This leads to an effect in which different pairs of holes line up at angles of rotation much smaller than the spacing of either set of holes. Our washers and rebates use this system, with 3 pairs of holes drilled in each washer and 8 pairs of holes in each rebate. The washer holes are spaced at 15º and the rebate holes are spaced at 22.5º. Two sets of holes line up every 7.5º of twist, or 1/48th of a revolution. This mechanism is described clearly in Landels *Engineering in the Ancient World,*[43]and is a type of vernier adjustment.

Finally, there's the issue of how to grip the washers to apply a twist to the spring. We believe that Vitruvius' description of the pin that the cord is wrapped around as a "tightening-bar"[44] is a clue. We built two custom spanners that grip the protruding ends of the bars and allow us to tighten two washers at a time in opposite directions. This balances the torque applied and does not put undue stress on the case-to-frame joint. After the spring is twisted, steel pins (the vernier pins) are placed through the holes in the washer and the holes in the rebate to lock the washer in place. The force on the string can be balanced by twisting one spring an extra hole or two. We have not yet tightened the springs as far as we can for a full-power shoot – we'll work our way up to full power as we use the engine in the upcoming year.

Arrows

Two bolts were constructed for test firing the scorpio. Points were hand-forged and machine ground based on an extant example.[45] Although there are a few extant ballista bolts, the best-preserved one is apparently sized for a *cheiroballistra*[46]. We decided for that an initial trial, we'd just make oversized arrows. Shafts are an un-tapered ½ inch diameter, and have been stripped down by hand from ash and oak. Both of these shafts have been fletched with feathers, although other artillery reconstructions have used wooden or leather flights.[47] Points were attached with modern ferrule-tight, and the fletch was glued in place before being wrapped.

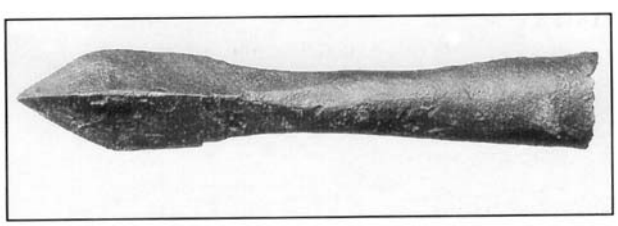

Figure 9 – Catapult bolt head
from Gravette, 19

[43] 115
[44] Marsden, 1971, 191
[45] Gravett, 19
[46] Wilkins, 95
[47] Wilkins, 93

Section 3

Future Plans

- As of the time this is written, March of 2004, we have not yet had a high-power test of the engine. That is the first order of business once the weather warms up and our archery range is available.
- As discussed in Section 2, our base was built with a literal reading of the Vitruvian text. There are some minor problems with the backstay remaining in place during drawing and washer adjustment. We will probably build another base with a hexagonal central column and a hinged backstay. We shouldn't have to change anything on the scorpio itself to do this, and can re-use the universal joint as well.
- The frame should be more extensively plated with iron if we want to present this as an accurate reproduction of a Roman catapult.
- We plan on carving a Roman legion designation in the side of the case.
- The washers we used were machined, not cast, and lack the internal support shelf that many period washers had. We plan on machining one more washer with our remaining bronze and using that as master form to cast additional washers. Before that happens, we need to improve our sand-casting setup to handle the larger pour required.
- Laminated arms will be built to decrease the chance of arm breakage.
- We will continue to investigate the possibility of obtaining hair or sinew rope. We will at least look for a better color of polypropylene rope. I estimate that an additional 20 to 30 feet of rope would fit in each hole, so if we do re-wrap the springs, we'll increase the power available.
- Spare strings need to be made

Bibliography

Baatz, D. 1978: "Recent Finds of Ancient Artillery, *Britannia* **9**, 1-17

An article discussing the find of a 3rd century AD stone-throwing ballista at Hattra. It also discusses the find of *cheiroballistra* frame pieces at Orşova, Romania.

Gravett, C., 1990: *Medieval Siege Warfare*, Osprey, Elite series; v. 28

Although most of this Osprey book deals with medieval siege engines, it has several illustrations of torsional engines.

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

An interpretation of the *cheiroballistra* as a hand-held weapon. Contains good commentary on pseudo-Heron's text. Describes a general approach to reproducing ancient Roman artillery, and contains a good description of the *cheiroballistra* trigger mechanism.

Landels, J.G., 1978: *Engineering in the Ancient World*, Univ. of California

Although somewhat dated, this book has a clear description of the washer-tightening mechanism used on period engines.

Marsden, E. W., 1969: *Greek and Roman Artillery. Historical Development,* Oxford

Eric Marsden's two books, in which he used his mechanical insight to interpret Greek and Roman artillery manuals, are the starting points for all reconstructions we could find. Every article consulted for this project compares their interpretations with Marsden's. The Historical development volume presents copious background on where and when siege engines were used in the ancient world, and provides a framework to understand the details presented in the treatises volume.

Marsden, E. W., 1971: *Greek and Roman Artillery. Technical Treatises*, Oxford

In this volume, Marsden presents translations of all the extant Greek and Roman texts. He clearly points out some errors from earlier translations, such as a confusion between Greek and Roman weight and length measures. He also provides extensive notes on the text, clearly aimed at the potential modern siege engineer. Marsden's approach to reconstructing ancient engines is strongly influenced by the pioneering work of Schramm, as is his translation of Vitruvius.

Payne, A, 1999: *The Architectural Treatise in the Italian Renaissance*, Cambridge

A volume discussing the influence of Vitruvius on renaissance architects. Useful for background information on Vitruvius.

Payne-Gallwey, R., 1958: *The Crossbow*, Bramhall House

We did *not* consult any of Payne-Gallwey's sections on siege engines, as they are seriously flawed, but instead used his crossbow information to guide our string construction.

Rowland, I and Howe, T, eds, 1999:*Vitruvius, Ten Books on Architecture,* Cambridge

The latest translation of Vitruvius, we came across this after construction was underway. Primarily used for background information on extant manuscript copies of Vitruvius

Schramm, E, 1918: *Die antiken Geschutze der Saalburg*, Reprint, Bad Homburg, 1980

Schramm used early translations to build replicas of every major type of torsional artillery. This reprint of the impossible-to-find original adds some updated archeological evidence in a preface.

Thayer, W., 30 Arpil, 2003, "Vitruvius on Architecture, Book X", *LacusCurtius: Into the Roman World,* <http://www.ku.edu/history/index/europe/ancient_rome/E/Roman/Texts/Vitruvius/10.html>, (March, 2004)

This translation of the relevant sections of Vitruvius has a variety of errors in the numerical data for the scopion dimensions. It was identified as a source we could link to from the web site for the project without violating the copyright on Marsden's work. The text is useful as an on-line reference, but the numerical data cannot be used as-is.

Vicente, J, *et al.*, 1997: "La catapulta tardo-republicanana … de 'La Caridad' (Caminreal, Teruel), *Journal of Roman Military Equipment Studies*, **8,** 167-99

A paper describing the archeological find, along with CAD drawings of the metal plating, washers and rebates found at Caminreal.

Wilkins, A, 2000, "*Scorpio* and *Cheiroballistra*", *Journal of Roman Military Equipment Studies*, **11**, 77-101

An excellent paper that discusses the translation of Vitruvius, with several corrections to Marsden's translation. It also includes a discussion about a reconstruction of a 3-span scorpion very similar to our engine. He also has data on the power and firing accuracy of the scorpion and a cheiroballistra – they shot bolts at a dummy wearing period roman armor and discuss the results.

Supporting Documentation

- Marsden's Vitruvius translation and comments
- Wilkin's paper on re-creating the scorpio
- Selected illustrations from Schramm
- Baatz's paper on "recent finds"
- Iriarte's paper on the *cheiroballlistra*
- Vicente, *et al.*, La catapulta …. Caminreal
- Illustration of the washer mechanism from Landels

Appendices

1. Material Samples
2. Work-in-Progress Photos
3. Other documentation not directly relevant to this project
4. Data and results from fiber tests
5. Design drawings of the scorpion components