Zen and the Art of a Craftsman's Journey: Lessons Learned While Designing and Prototyping a Period-Inspired Roman Trigger Mechanism for a Euthytone Catapulta Ballista in SCA Siege Combat

By Joshua Berry (aka Montgomery Josh the Hilariously Awesome)

For the Arts and Science's Competition at Yule Revel themed on Growth as a Craftsman

10 December, 2022

Executive Summary

This entry into Yule Revel's competition on growth as a craftsman chronicles my journey from a technical, tooling, and emotional point of view through the engineering archaeology of designing a Roman-style trigger mechanism for a Sige engine used in Rattan Combat. At the start of this project, I had technical skills from numerous household and robotics projects but lacked the mindset and experience to do precision fabrication of parts. Through many mis-steps trying to use a wooden trigger claw and lessons learned on basic wood and metal crafting I refined the design into something reliable and safe I can share with the Siege community. During this process, I re-claimed myself as a builder by finally acquiring the tools and skills to make parts the right way. I am not yet a master craftsman, but the growth over this project enabled me to continue that journey.

Table of Contents

Table of Figures

Table of Exhibits

Introduction

Siege Combat in the SCA requires two equally challenging fields: the Marshal Activities associated with using the engine in combat, and the A&S component associated with the engineering and building the siege engines. The A&S side of siege is often overlooked as many teams simply acquire the standard siege engine, an Arbalest design designed by Docmo Kincaid years ago. The designs have not progressed much, only being updated as the SCA requirements change. Over the years, some groups have built and used other designs, such as a Roman Ballista, but at least in the East these have not been used in years. One of these was a Roman Euthytone Catapulta designed by Brun Canutessan in the early 2000's with one built by him and one by the Legion XXIV used at Pennsic War.

I have been interested in Siege since joining the SCA and wanted to build a working Ballista for use in Pennsic and other events. The Brun designs contain a lot of detail and are an excellent start. Unfortunately, the Brun designs omit a few key components and require some engineering development to complete the designs. In the Summer of 2022, I started the journey to build a prototype so I could understand how torsion engines worked and learn the nuance of their design and construction, in addition to Roman Engineering. After completing this initial prototype, my intention was to then develop a complete set of updated plans with assembly instructions and guidance on tuning and calibrating one so that others throughout the SCA could build their own and improve upon my design and methods.

One of the key components of this protype that required significant engineering development was the trigger mechanism because the original Brun design used a non-period trigger. This document focused on the "lessons learned" in developing the trigger from both points of view of my learning about the design and my growth as a craftsman. When appropriate, I referenced historical and modern exemplars and documentation but did not want to make this document a treatise on ballista trigger design nor an academic discussion on the differences between historical documents.

These designs, while making a reasonable attempt to look and function as a period siege engine would, were intended to have differences from period. The engines to be built using these designs were not museum pieces or even working demonstration pieces, but rugged devices meant for use in SCA combat in inclement weather with safety as a priority. Where there was ambiguity in component design or materials, I supplanted some period tooling and materials with modern equivalents. I adjusted the design based on live experimental tests to validate the trigger released the bow string only when the user intended to fire. In addition, this project was predicated on modern siege engineers to be able to build quickly using available materials and with modern tooling available in a home DIY workshop. This project was meant as a way to re-ignite Siege in the East, not create impediments by limiting craftsmen and women to period tooling. Thus, the final designs are given based on different workshop tooling levels, including one with access to a forge to make key components as the Romans would.

In addition to having a buildable set of plans for the trigger and the learning about building it, there was also another personal outcome of this project. This was my first Arts and Sciences competition entry. I chose to focus on just the trigger because it allowed me to discuss a narrowly-focused topic and have a finished prototype for Yule. There are aspects to the overall ballista outside of main design such as using period Roman joinery and finishing techniques that I could not have ready in time and would greatly expand the size of this document. In writing and submitting this documentation I set myself up for future competitions based either on another component or the completed design.

Background on the Ballista

The larger ballista prototype project this trigger mechanism was built for is an older period Euthytone Catapulta design, commonly called a Torsion Ballista as shown on the cover page. It functioned similar to a cross bow except instead of energy stored in a bending prod, it was stored in two rope bundles. They were capable of firing either rocks or arrows / bolts by swapping out the bow string for a pouch.

Within the SCA, the dominant siege weapon is the "Docmo Arbalest". This is a weapon that looks and functions as a scaled-up crossbow, that fires the same 48" bolts as a Ballista. This design has been in use for over 20 years and is well supported by vendors who make individual components.

All siege engines are limited in their capability for the safety of the populace. These limits include a specified bolt, a limit on the power of shooting between 40 and 80 yards, and other building codes such as wrapping around moving parts in case they fail.

Ballista Variants

In classical documentation there are other types of ballistas referenced: a Scoprion, a Palantone and a Cheriabalista.

Figure 1: Roman Scorpio

Figure 2: Roman Palantone

Figure 3: Roman Cheriaballista

- A Scorpion was a slightly scaled-down version of the Euthytone Catapulta, whose major difference was a single middle station instead of two stations as with this Ballista.
- A Palantone Ballista was an evolution of the Euthytone improving the geometry to allow for a longer arm swing.
- A Cheriaballista was the final version of the Roman Ballista that changed the arms to swing inward and was made solely out of metal.

The extants and other documentation in this entry used sources that described these variants of an Euthytone ballista. In some cases, a Scorpion and a Ballista were used interchangeability. Many of the sources including <<LIST>> discussed the confusion in naming the different variants as well as confusion over time as to the specific engineering of each. With respect to the trigger mechanism, the Vitrivous Cheriabalista documentation was the only period record of a trigger design.

Critical Components of the Euthytone Catapulta Ballista

This ballista trigger mechanism contained the following components used throughout this entry:

1. Claw: a two pronged catch that physically holds the bow string in a cocked position until firing
2. Claw Fingers: the two pieces of the claw that bend down to capture the string, allowing the bolt to sit against the bow string.
3. Hinge / Fork: a support for a hinge pin to allow the claw to rotate
4. Trigger Shim: a rotating piece that prevents the claw from moving and when removed initiates the firing
5. Trigger base plate: a solid metal plate for the other trigger mechanism components to connect
6. Slider: a wooden component of the ballista that hold the arrow / bolt. The trigger mechanism is connected to this and moved with it as the slider moves to capture the bow string.
7. Bow String: the rope that connects the two ends of the swing arms and imparts force onto the bolt being launched
8. Swing Arms: two arms connected to the rope bundles that rotate as the ballista is cocked into the firing position.

The Need to Design a Period Inspired Trigger

When researching Ballista designs, I found many sources that guided me through this process. One of these was the plans for a Euthytone Catapulta that Brun Canutessan developed 20 years ago for use in SCA Siege Combat. I downloaded and reviewed his plans and noticed a few gaps such as no details about the swing arms and a few missing dimensions. I contacted him and learned he only built one ballista and did not update his plans with changes he made while building it. He has not used his prototype since then and is focused on making and selling crossbows.

Even though there were other plans available including treaties on ballista design, I chose to base my first ballista on Brun's design because he created them for SCA siege combat. Given the constraints of combat, I felt the work to complete his designs would be less than trying to design a ballista from scratch using descriptions so it fully met SCA siege rules.

While researching swing arm designs, I found the "LEGION XXIV CATAPULTA PAGE" (https://www.legionxxiv.org/catapulta/). This page described how a group of Roman re-enactors built Catapulta Ballistas, including one that followed Brun's designs for a Pennsic War in the early 2000's. They discussed replacing their non-period trigger with one that is period. I reviewed Brun's design and found the trigger mechanism design in Figure 4 below. This was a type of trigger used in crossbows, not siege weapons.

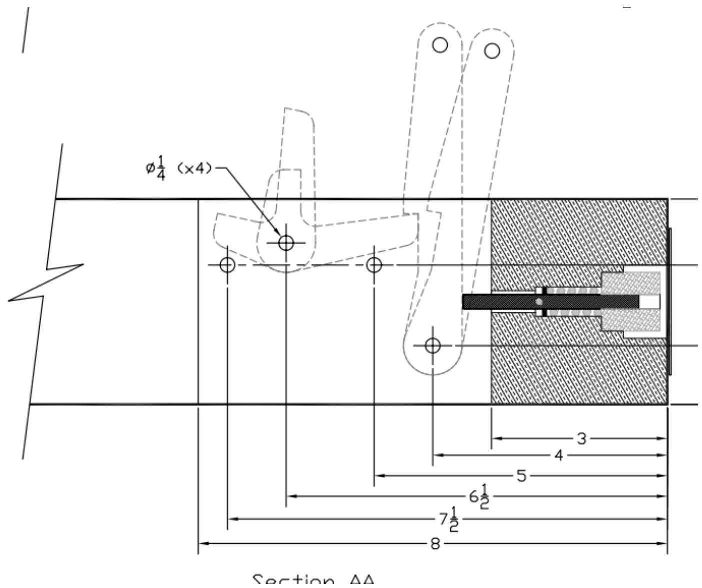

Figure 4: Brun Modern Trigger Mechanism

The legion page gave details on their non-period and period triggers. These are included as Figures 5 and 6 below. Both pictures were the same engine using the same bow string before and after the upgrade. The Brun design used a separate loop with one finger to hold the string. The Roman Ballista design used two fingers to hold the rope. This is further discussed in the Period Trigger Design and Methodology section.

Figure 5: Roman Legion Original Brun Trigger

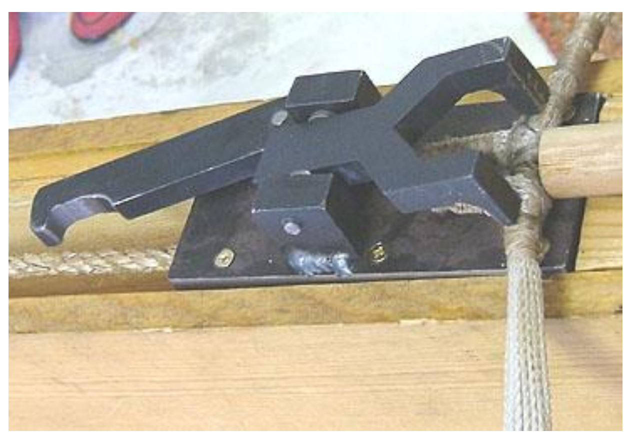

Figure 6: Roman Legion Period Trigger

At this point in the process, I could have chosen to build the ballista as designed, or I could have chosen to use the trigger from the Docmo Arbalest and grafted it onto a ballista. In terms of SCA Siege Combat, the period correctness of a part like a trigger is not a concern only that the overall engine looks like something that could have been period and operates safely, without misfires. This is because in combat functionality, safety and survivability take precedence over period. Instead of taking the easy route and building the fully flushed out Brun design, I made the conscious choice to replace the Brun trigger design to use a period correct trigger. In making this decision, I knew I would have to spend significant time in the engineering as I could not find detailed plans for an SCA legal Roman period trigger mechanism and I was not equipped at home to perform metal work.

Output of this Project

The Ballista plans I started with were detailed in some areas but incomplete with respect to details on some of the components, assembly instructions, and guidance on tuning and calibration. The objective of the larger ballista prototype was an opportunity for me to learn about ballistas and the process of making ballistas so I could update the designs to fill in the gaps and update them for current SCA specifications. Therefore, the output of the larger exercise were the designs and manufacturing / assembly instructions. If my first prototype ballista was not combat ready, I planned on building a second one based on the lessons learned and design changes from the first.

With respect to the trigger mechanism this A&S entry focuses on, the primary output of this exercise were the designs of the trigger components and the guidance I learned while making them. The physical triggers produced along the journey were secondary outputs of this process to show mis-steps and why certain design choices are not viable and why some tooling was required. As mentioned in the deviations from period, I placed a high value on a safe and working ballista trigger mechanism over period materials and tools. This is because the output of this project was a set of plans for a production trigger that will be used in combat.

That design had three variants:

1. A basic one intended for the casual siege engineer in a DIY-class home workshop made from laminated strips of metal,
2. A design for a siege engineer with a professional-class workshop or outsourced manufacturing made from a solid billet of metal,
3. A period accurate design for a siege engineer with access to a metal forge and proper forging tools.

Because the siege community is inclusive to all levels of craftsman, this design took the varying levels of tooling into account. All of the designs shared a common architecture, with the differences being a result of how they were made.

Personal Skillset at the Start of this Project

This document chronicled my journey in learning about the design and manufacture of a period style trigger for a Roman Ballista, as well as my journey in growing my skills and tools as a weapon maker and metal smith. To understand this journey, it is important to understand where I started in the Summer of 2022.

As an engineer, I was experienced in designing and building. I had built robotics but either using pre-made components or making parts using a 3D printer or simple hand tools. I made a number of home improvements and smaller projects like throwing targets out of wood. These needed rough cuts with simple connections using screws and glue but did not need the precision of detailed siege engine parts. I had used power tools and equipment but mostly for wood, not metal and certainly not a metal forge. My home was not equipped with a formal workshop and did not have tools other than a chop saw and hand power tools. My workspace was limited to a garage and driveway.

Summary of Lessons Learned and Personal Growth

The lessons and discovery during the project can be broken down into groupings. Some of the lessons were specific and tactical to a specific task while others were broader and strategic in nature. The specific lessons germane to each step along the process were included where applicable, with the overall growth here.

Roman Period Design and Manufacturing Techniques

The obvious learning and growth during this project was my learning how the Romans manufactured their tools and the specifics surrounding the trigger in particular. In researching how they built them, I learned about the historians who documented them and how that knowledge was passed through the ages. I also learned about the various groups and individuals who made modern reconstructions and ancient weapons as well as those designs and interpretations of the ancient text.

When there were not specifics given for specific details, I had to either research and learn them or experiment and determine the most appropriate solution given the critical importance of not misfiring.

Basic Wood and Metal Working Techniques

As embarrassing as this may be to admit in writing, many of the problems I encountered in the overall project (including the trigger misfiring) were because of improper basic metal and wood working techniques. For example, one of the reasons for the early misfires was because I did not mill the top of the slider flat for the trigger claw to press against. That gap led to the bow string slipping underneath one of the claw's fingers and misfiring, firing the ballista without me pulling the trigger shim. Other misfires were due to misaligned holes from using a hand drill without guides or using a punch / small pilot hole. I obviously learned how to make straight holes and properly align components.

I created the initial trigger out of wood because I did not have enough experience in metal working. Over the course of this project, I became familiar with tools and techniques such as bending thicker pieces of steel and better ways of cutting metal. As I became comfortable working with steel and the appropriate tools, my techniques in the tools grew with each component I created.

While pausing at the end of the test and calibrate phase, I researched other basic techniques such as allowing wood to acclimate to the environment and milling the wood in stages to minimize effects of warping as the wood ages. At this point I also researched Roman wood and metal working techniques, including making curved laminated wood for the swing arms. I incorporated those into the final design and in my next steps of making a trigger mechanism in a modern and period forge. Specifically, I took the approach of using thin strips of material to make the trigger claw due to my lack of tooling to make one from a solid piece of steel.

Home Workshop Tooling

At the start of this project, my home workshop was completely inadequate to make a ballista, including the detailed metal work for a functional trigger. Early in the project I had to go to multiple friends' homes to use their tools. Over the course of this project and the trigger, I acquired appropriate tools and knowledge on how to use them: wood planer, a bandsaw, drill press, hand drill guide, belt sander, metal bender, Dremel cutoff wheel and others. In some cases, I did not know some of the tools existed such as a jig for a hand drill. In other cases, I did not know home-scaled versions of a metal bender existed.

While writing this document and designing / building the final design shown in the Exhibits, I taught myself how to use each of the tools and added them to my home workshop. The learning process was not limited to using each tool but using them in conjunction with each other and other considerations for a home workshop such as dust collection and workspace to mount or use a tool.

Also, I learned a painful lesson in trueing up tools. My chop saw and other tools have variability in their settings for different cut angles. Sometimes "zero" on the gauge is not 90 degrees from the cutting surface, leading to slightly out of square cuts. I spent a lot of time diagnosing fitment issues that were due to not adjusting various tools to be square. I also learned about upgrading DIY-grade bandsaws so they function with aluminum and steel.

Design Methodology

As I learned a new tool and technique, my design methodology changed to adapt to it. By the time I arrived at my final design, I approached the design in a completely different way than when I started thinking of terms of bending flat metal stock into parts required. For me, this was the biggest growth because it fundamentally changed how I viewed component design.

Period Trigger Designs and Manufacturing

When trying to recreate a Roman ballista there were two primary historical sources: documents by Vitruvius and Heron, two period authors. Every other book and analysis were based on translations and interpretations of these texts, plus practical knowledge gained from building reproductions. Most of the reconstructions of ballistas used analysis of Vitruvius' including E.W. Marsden in "Greek and Roman Artillery, Technical Treatises". Vitruvius does not include details on the trigger, thus modern reconstructions rely on works derived from Heron's "cheiroballistra" for the trigger mechanism.

There were also archaeological sources of surviving metal components but none for the trigger mechanism.

Also of note is the differences in interpretation of the ancient texts, and various historians filling in details with supposition. Some of the ancient descriptions contradict each other and some within themselves. Numerous sources describe this and attempt to explain some of it away as mistranslations or corruption of the original text over the centuries. Campbell's paper "Ancient catapults: Some hypotheses reexamined" tries to reconcile some of these issues, but even with his analysis of other historian's work we do not have definitive and complete set of plans for an Euthytone Catapulta. Most of the reconstructions were attempts to build based on what information they could find, extrapolate from descriptions translated in another language, or use from other extant sources such as the cherioballista.

Given the lack of documented period trigger mechanisms for an early-period ballista, I used sources across the different types of weapons as extant examples for design. All follow the same architecture with the difference being in the shape on the claw, specific measurements, and style of the components. I chose having a safely working trigger that might have small details that might break from historical over complete period accuracy.

Roman Metalworking Techniques

The Romans were known for their engineering prowess, including those meant for war. With respect to siege weapons, they used iron with forging it as their primary process. Either joining separate pieces through forge welding or adding features and shapes to the metal by traditional hammer and anvil techniques. For a ballista, they would have made the metal parts in a central location, then cut down wood at the site of the siege for the rest of the ballista.

To cut the metal hot, they would use a chisel to "cut" the claw forks it then hammer and anvil to stretch and form it. To make holes they would use a punch to drift open the hole, again while hot.

There are no known instances of the Romans using glue or adhesives in metalworking.

The Greek and Roman Artillery page, Forging the claw | Greek and Roman Artillery Wiki | Fandom has detailed steps showing how they likely made a trigger using period techniques.

Basic Trigger Design

The basic design of a Roman trigger is given in Figure 7, from Seige-Engine (http://www.siege-engine.com/TriggersAndCatches.shtml)

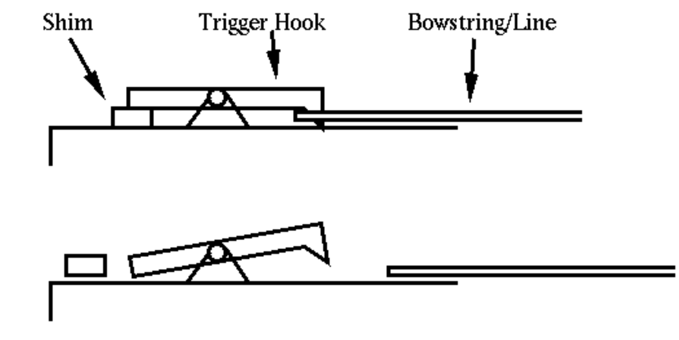

Figure 7: Basic Roman Trigger Concept

More specifics on the components are given in "A Reconstruction of Vitruvius' Scorpion", which references Iriarte's description of a Cheiroballistra.

In all versions of a Roman trigger, a shim prevents a claw from rotating. The front of the claw has fingers that capture the bow string. When the trigger shim is moved (and the shim removed), the claw is free to rotate around the hinge. The sloped shape of the claw fingers translates the tension force of the bowstring to lift the claw, thus freeing the bowstring to launch.

The claw for an arrow-shooting ballista has two fingers. These are intended to surround the arrow so the bow string is in contact with the arrow. Thus, the fingers must be spaced enough for the specific arrow being fired.

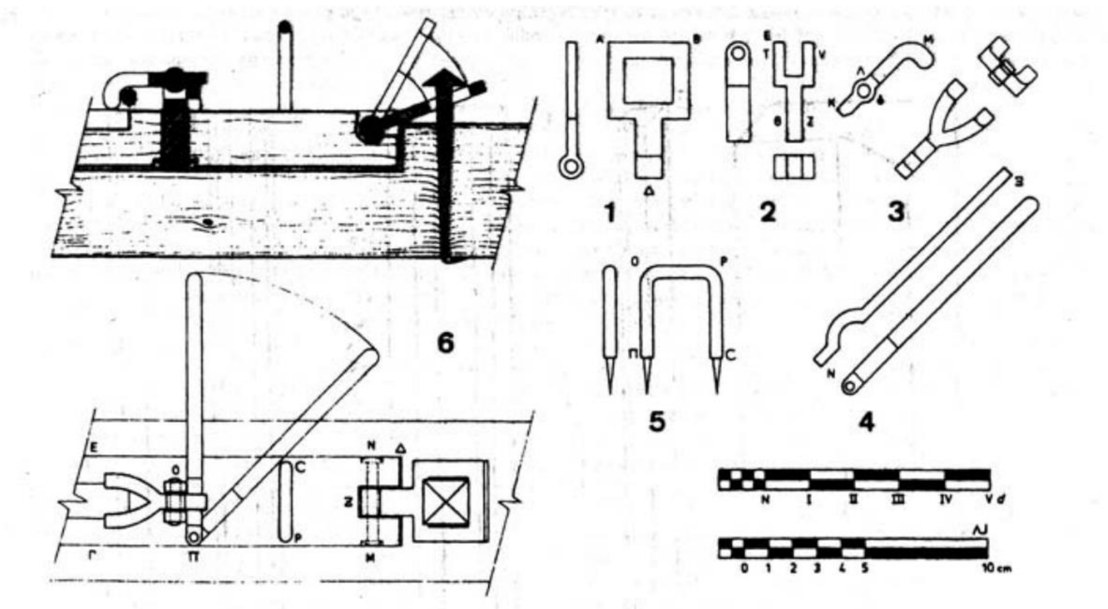

Fig. 3: 1. The 'handle'. 2. The fork. 3. The claw. 4. The trigger. 5. The pitarion. 6. Assembled trigger mechanism. Longitudinal section and plan.

Figure 8: Cheiroballistra Trigger Mechanism

Modern Recreations and Exemplars

When various groups have created modern reconstructions, they have made different versions of the trigger. All of them are different but follow the overall design of the claw and trigger shim enumerated above in Figure 8. In the case of the trigger shim, there were disagreements as to its orientation. From "A Reconstruction of Vitruvius' Scorpion":

> *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.*

Their "Figure 6" is Figure 8 above.

A Reconstruction of Vitruvius' Scorpion

http://www.eg.bucknell.edu/~whutchis/scorpion/

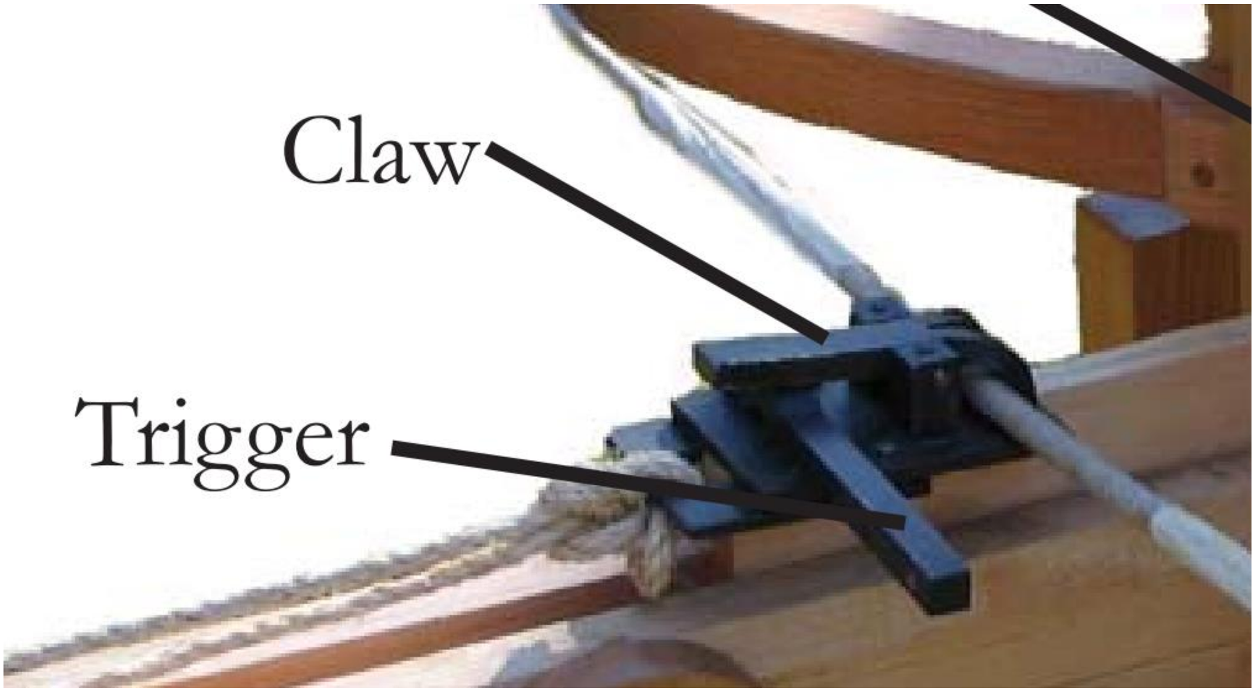

Figure 9: A Reconstruction of Vitruvius' Scorpion Trigger

This view of their trigger shows their construction and a metal plate.

A suggested reconstruction of Vitruvius' Stone-thrower

From "A suggested reconstruction of Vitruvius' Stone-thrower: de Architectura X, 11, 4 – 9" by Alan Wilkins

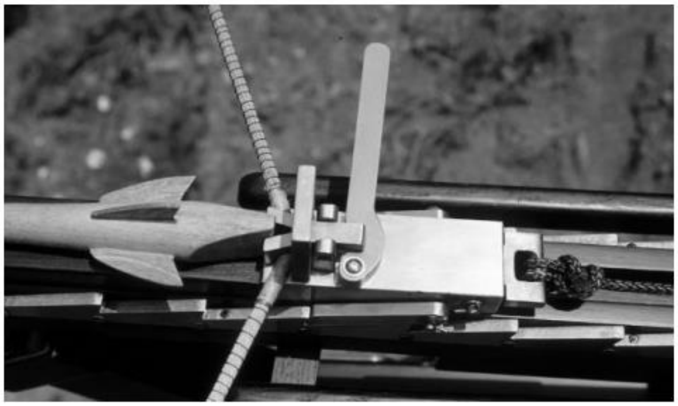

Figure 10: Vitruvius' Arrow Trigger Example

Note in this rawing how the trigger is turned as described above. Also note this example uses a metal plate to connect all of the components.

Figure 11 below shows the single finger trigger for the stone thrower which uses a loop in it's rock pouch. In all other ways, this trigger is identical to the two prong version other than a smaller scale because it does not need to have two fingers holding the bow string.

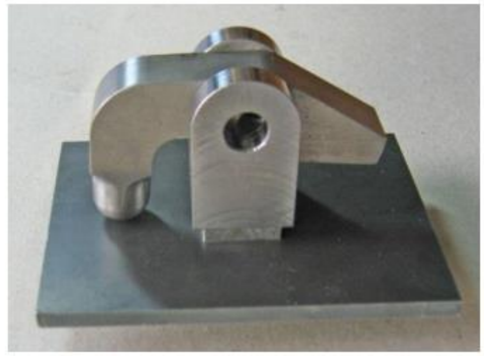

Figure 11: The trigger from the Stone Thrower

LEGION XXIV CATAPULTA PAGE

https://www.legionxxiv.org/catapulta/

As previously discussed, Legion XXIV has made multiple Ballista's, including one or more of the Brun design. Figures 12 and 13 show this. Looking at Figure 13 it is clear they made this by welding different pieces together.

Figure 12: Top view of the Legion Trigger

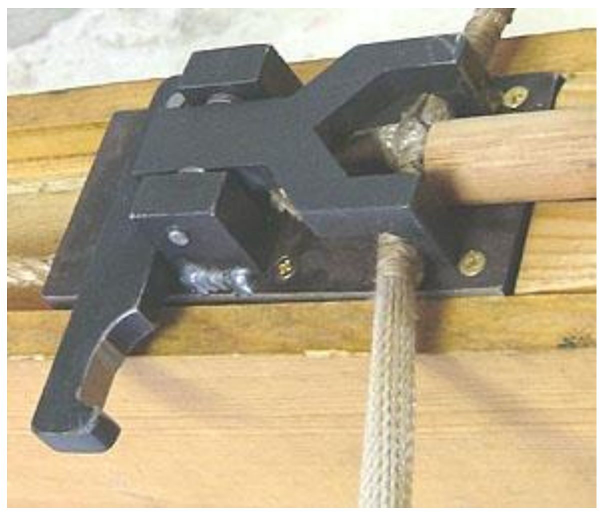

Figure 13: View of the Trigger When Closed

Greek and Roman Artillery Wiki

https://ballista.fandom.com/wiki/Cheiroballistra_triggering_mechanism

This page includes details on the parts as described in Figure 8 above. They give specifics on the dimensions for each part an discuss inconsistencies in the documentation. This is the closest to what a period trigger would look like because it was formed in a forge.

Figure 14: Greek and Roman Artillery Wiki Trigger parts

Intentional Deviations from Period

As discussed previously, the overall Ballista project was not intended to be a museum piece or even a working demonstration model. This design was meant for a SCA compliant combat ready siege weapon. It should look like a period piece, but it must function within the SCA Combat Siege guidelines, it must be able to handle active combat where it could be hit be incoming siege bolts and combat archers, struck by Heavy Rattan Fighters and be exposed to the elements.

Above all, *this trigger must release the bow string, but ONLY when the user intentionally rotates the trigger shim*. For safety, this consideration took precedence over all other considerations including period design, materials, tooling, and manufacturing technique. When there was any ambiguity as to the period design, I erred on the side of safety and chose a solution that worked over a theoretical solution of what the Romans might have done given the lack of trigger details in Vitruvius.

Also, SCA Siege engines need to be designed so they can be built by Siege Engineers with all levels of workshops available. The cost of tooling and time should not be a barrier of entry for an operational siege weapon nor should a requirement to use period materials and tooling. Therefore, there are a number of intentional deviations from the known Roman materials, process, and design.

Design Deviations

The overall design of the trigger was the classic Roman design. From a geometrical design point of view, I choose the following deviations from the known period. Also note, the parts given in Figure 5 above are for a Cheiroballista, not a Ballista. As commented in points (5) through (7) below, these items are not considered part of a Ballista and are later additions to the Cheiroballista.

1. The width of the claw's interior is extended to 1 1/4 inch to accommodate the SCA-legal bolt to be fired.
2. As a consequence of (1), adjusted the proportions of the claw for the wider width.
3. Per SCA rules, addition of a lockable "safety" pin to prevent unauthorized firing, and to prevent misfire when the weapon is cocked but a hold is called.

4. For attaching components, using threaded bolts / lock washers instead of rivets. This is discussed in both the material and manufacturing sections. From a design point of view, using threaded bolts allows for disassembly and repair. Using lock nuts / washers prevents the bolts from working themselves loose.
5. The fork design described in the Cheiroballista is meant to slide through the wood of the slider and be secured on the other side. Also, there are no extant pieces showing this design for a Ballista, just a Cheirobalista. I decided to use a metal plate as the base of the trigger mechanism as shown in other roman designs. Thus, I changed the fork's design to be a piece that could be bolted to the base plate.
6. The Cheiroballista documentation shows latch to prevent the Ballista slider from moving. The Ballista design I am using has a latch build into the winch mechanism that will keep the slider in position, thus I did not include the latch.
7. The Cheiroballista documentation also shows a handle to aid in moving the slider. This is not part of any exemplar or known early period design and was not needed. This I did not include the handle.

Material Deviations

For safety and practical reasons, I do not think using raw iron smelted and forged in a period furnace is appropriate because of the unknown quality and strength of iron produced in this manner. Therefore:

1. Using modern mild steel for the components instead of iron. This will have greater strength and quality control than melting pure iron. In addition, the steel will be more weather resistant. Steel is a form of iron thus the change is not a significant one.
2. Using modern bolts instead of hand-forged pins and rivets. Modern bolts will be able to withstand more load than a period pin and the use of modern locknuts and washers is a safety consideration. Also using bolts allowed for disassembly whereas a rivet is a permanent connection.
3. During the design journey, I used wood and aluminum for the early prototypes. This was for the following reasons:
    a. Initially, I did not have the tooling for steel.
    b. I had a lot of wood leftover from the build of the rest of the Ballista.
    c. I had aluminum stock left over from previous projects, and because it is softer than steel, I was able to work it with the tools I had at the time.

    Although wood proved to be too weak even when reinforced with aluminum, I was able to verify the overall design using it, thus saving from the high cost of buying steel to experiment with. As discussed in the Journey, I was able to build a fully functioning trigger using aluminum to prove the design, knowing I would be using steel for the real design.

4. The final design was made out of steel.
5. To "weld" steel components together I used JB-Weld, a modern adhesive. This is because I do not have a forge to forge-weld metal together. There are no known instances of Romans using adhesives for metal.

Manufacturing and Tooling Deviations

I do not have a metal forge at my home. I designed the trigger assuming most siege engineers or component makers would not either and would instead use modern tools. If this trigger were intended to be a museum piece, it might make sense to try and use period tools, but this is a practical utility siege engine where the speed of modern tooling can't be ignored, nor can the safety of the precision from using modern tooling. Thus, I placed a consideration on making this from available aluminum or steel using equipment Siege Engineers would have in a home workshop: a DIY-grade bandsaw. More advanced metal workers might have professional-grade bandsaws and metal mills. In the final design section, I give three methods for making the claw based on the tooling.

During the journey, I acquired a number of tools to make these and other components at home so I had the equivalent of a DIY-workshop with a basic bandsaw capable of cutting thinner pieces of steel but not thick ones. Therefore, I made the following manufacturing deviations.

For a metal smith with a basic DIY-grade home workshop:

1. Made the claw by laminating 3/16 inch thick steel plate using JB-weld as an adhesive. This plate is readily available and serves as the base plate. It is thick enough to be strong yet thin enough for a DIY-grade band saw to cut. By using steel plate, I can use a bender to put in the curves and have the look of a solid piece that was split in two.
2. Made the fork / hinge by bending the 3/16 steel into a "U" shape with two "L" shaped side supports. This allowed me to get the desired geometry without having to use a professional bandsaw to cut a solid block.
3. Used a modern band saw to cut the steel. This allowed me to make precise cuts.
4. Used a modern belt sander to clean metal edges an surfaces
5. Used a modern tap-and-die to tap in threads in the bottom plate for bolts to secure the fork / hinge, trigger, and safety.

For a metal smith with a professional workshop, or outsourced component manufacturing:

1. Made the claw from a single piece of metal cut / milled to size without bending or forging

For a metal smith with access to a forge and forging tools, no deviations from materials and tools.

My Personal Journey and Lessons Learned

Since the point of this initial build was to learn about Ballistas and Siege Weapons in general, I took a phased approach similar to an agile software development methodology: I built enough of the ballista to get me to a point where I could move forward with other components or hit a critical milestone. I knew I would be refining most of the components thus I did not try to get everything perfect the first time.

In many cases, ballista part design was interdependent on each other. I had to refine the design in stages with groups of parts refined together as I learned. In other cases, I was severely limited by my lack of a workshop and tooling. While I had experience in making "things" and building, a ballista was a challenge I did not yet have the skills and tools for. Following my divorce in 2020 I did not have a lot of tools, even though I had space for them following purchasing a new home in 2022. I was fortunate to have local SCA members who offered their workshops to make some of the wooden ballista parts. As I learned, I identified what equipment I needed and worked to acquire them so help me get to the next level. Initially I tried to build the ballista using borrowed tools because I did not yet view myself as a builder, yet. In many ways I was finding myself as a person and within the Society.

Specifically for the trigger mechanism, I quickly learned my simple hand tools / jigsaw without a vice would not allow me the precision to cut detailed parts, even in wood. I learned lessons in basic woodworking and metal smithing. I learned about using adhesives for metal. I learned what tools are suitable for what materials. The journey to be able to build a working metal trigger for the ballista is also the journey of me starting to build the home workshop I had been wanting for a long time.

This is also the journey of trying to resurrect Siege in the East Kingdom. Throughout this process, I was vocal and public with the progress I made in developing the Ballista, including failures. I did not do this simply out of a need to stroke my own ego, but because I knew by showing my progress and injecting a sense of energy into Siege, it would inspire others and enable those that follow me to build their own Ballista's and make their own improvements to the design.

My journey started with conversations at Pennsic 49 to find people interested in Siege. I met a number of others, but did not find anyone active. In fact, the East did not have a single engine there and paid the price on the battlefield. After Pennsic, I spoke to his Majesty Ryou as he would be the Warlord for Pennsic 50. When I asked him what kind of weapon he wanted, he mentioned Ballistas, not Arbalests. Thus, I did a lot of research into generic ballistas including many of the videos cited. I then found the Brun design and spoke to him about the old plan. It was during this time I discovered some of the previously discussed gaps in the plans and decided to use a period correct trigger.

Phase 1: The initial Ballista pilot

Figure 15: Lack of a Trigger

This phase was centered around proving a torsion ballista could fire a standard SCA siege bolt at all. As shown in the figure 15, I built the base torsion frame and slider and attached some dowel for torsion arms and paracord for a temporary bow string. There was no winch to pull the slider back nor a stand. I used a backyard patio set to hold the ballista.

There was also no trigger. I "cocked" the ballista using a finger to hold the string and pull it back. Remarkably, I was able to launch a bolt about 10 yards, but learned a few key lessons:

1. Using my finger is not a long-term solution. It might make for a fun story but having purple fingers is a not a good look for me.
2. It takes a LOT of focus to hold back a bow string with one hand while trying to record a video on a phone using the other.
3. I really don't like the sound of my voice. I already knew this, but these videos confirmed it.
4. I should wait until someone else is home before recording so they can hold the camera.
5. My Golden Retriever won't retrieve SCA Siege Bolts. She will, however chase them as they skip along the grass.

I was able to post pictures and videos online, and start the conversation that this is "real". I wasn't just bloviating when I talked about Siege. This started the "buzz" online and in private conversations.

Phase 2: A fully realized Ballista for River Wars

With River Wars approaching in a few weeks, and being an event in my local barony, I wanted to display the prototype there even as a static display. There are a lot of people who either are not online or do not follow me. Having something real, tangible, and functional would go a long way in getting other people excited about Siege and even get recruits to get authorized. The event also became a Royal Progress event which meant the King and Pennsic 50 warlord would be there. This would be an opportunity to talk to him about it.

As previously mentioned, the closest exemplar I found was the upgraded Roman design by the Legion XXIV (https://www.legionxxiv.org/catapulta/) for an engine using the Brun design for SCA use. At the time I did not have the raw steel nor the tooling to work with it. I had simple hand tools for wood. Not even a vice. To work around this, I cut some of the scrap lumber into blanks and drew out an initial shape of the claw using the Roman Legion shape as an extant.

I attempted to cut them out both using a hand saw and a jig saw. That failed as given in Figure 16. I then tried another piece, this time pre-drilling two holes for the interior corners. That also failed miserably as shown below in Figures 17 and 18 and Exhibit 1.

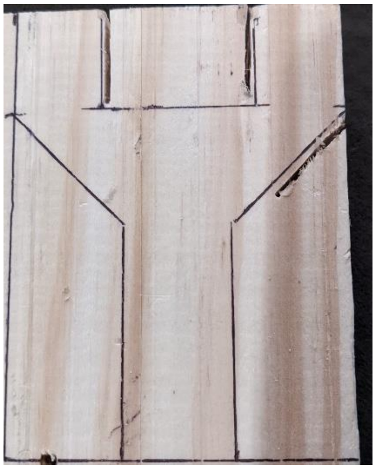

Figure 16: Errors in Cutting Wood Blank

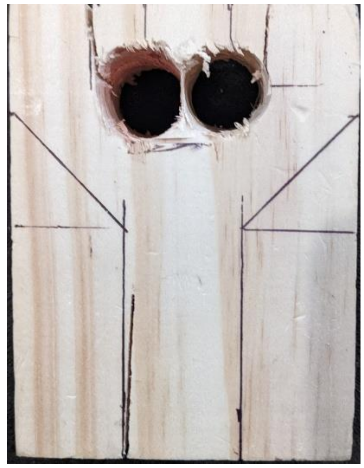

Figure 17: Top View of Errors in Drilling

Figure 18: Bottom View of Errors in Drilling

I also traced out blanks for the initial set of hinges, over-engineering them to sit on top of the slider rail.

These failures were because of the following:

1. The portable table I was using would shake, even with the blank secured tightly using clamps.
2. Both the handsaw and jigsaw were not cutting in a vertical line with respect to the board. Even when the top was properly aligned, but bottom wasn't.
3. The hand drill and spade bit also were not vertical and I had a tough time getting the bit in the precise location. The bit was rough and the drills torque was hard to control on such a small piece, causing the damage to the back as shown in Figure 18.

No matter how much I cried and screamed at my tools, it was clear I would not be able to cut the initial claw and hinges without different tools. Thankfully I was able to head to a colleague with a bandsaw who was able to cut out the initial claw and hinges.

At this point I learned the following:

1. There would be a bandsaw in my future for cutting detailed parts. Even with a vice, a jig saw is too violent for precision cuts.
2. For precise holes in wood, I should use a forstner bit.
3. For all future holes, I would need something to ensure a vertical hole such as a drill press or portable jig to make a hand drill make vertical holes.
4. I would need a workbench and a vice to securely hold a part and have a solid base to work from.
5. I am lucky to be in a Society where so many people wanted to help me on my journey.

When I came home from this friend's workshop, I cut out grooves in the claw for the bow string to rest in and mounted the trigger, hinges, and claw as given in Figure 19. The hinges didn't fit perfectly. I assumed it was imperfections in the bandsaw cutting so I sanded the inner surfaces until they fit better. Later troubleshooting proved it was an uneven surface on the slider. To provide for a rigid connection between the trigger and claw, I attached the aluminum piece on the top as given below in Figure 22.

As this was an initial trigger to show the concept would work, I attached the claw to the hinge using deck screws. I added the rest of the Ballista parts and built a base. At last, I had a complete Ballista and was eager to see it shoot a bolt.

Figure 19: Hinge and Claw Mounted

Figure 20: Wide View of the Trigger in Relation to the Ballista

Figure 21: View of the Complete Trigger Mechanism

Figure 22: Side View of the Mk 1 Trigger

Under light pre-tension of the torsion springs, the trigger held the bowstring. However, under any kind of load on the bow string, it misfired sending the bolt off the slider without me pulling the trigger. I spent the next few days diagnosing the problems:

1. When we made the slider, we did not mill the top of it. As a result, the surface the hinge mounted to and the trigger pressed against was not level nor even. The claw had a tendency to twist a little and the bow string would slip under a low spot in the slider's surface.
2. The initial bow string was a single paracord. Doubling up and twisting made it effectively thicker. This increased the point of a misfire but didn't solve the problem.
3. Inserting a shim between the top of the trigger and bottom of the claw helped to keep the claw pressed down to a point but was not a long-term solution.
4. The wooden trigger started to quickly wear from the force of the claw pressing down on it.

I made a number of fixes, including planning down the slider where the hinge connected and the claw pressed against the slider. The ballista could support more pre-load but still misfired as the claw twisted a little.

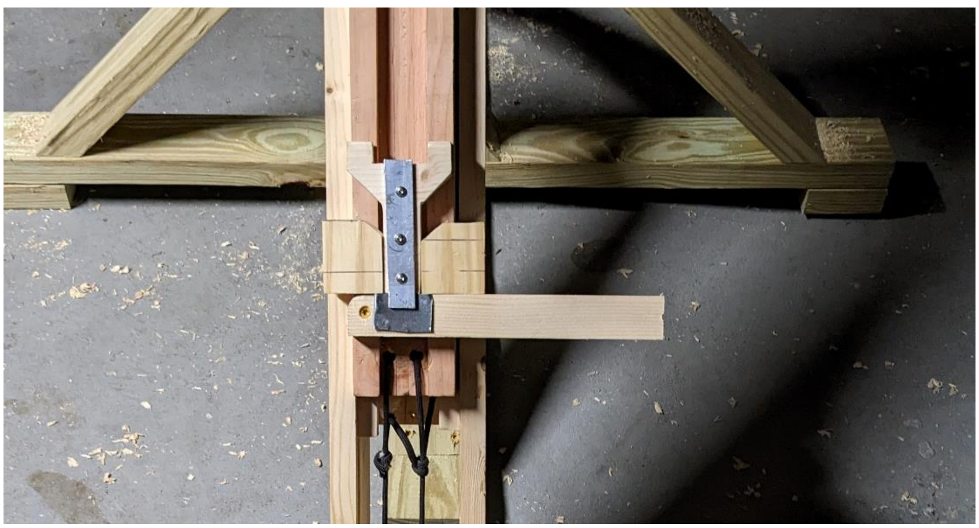

Figure 23: Top View of Trigger with Shim

I found some scrap aluminum and braced the bottom of the claw to prevent the twisting. Finally, she could support a medium-level of tension on the bow and shoot. This was the night before we were to leave for River Wars. I tried one last shot under medium pre-load. When I cocked the slider back there was a large BANG and the bolt misfired.

Laying in front of the ballista were the bottoms of the trigger's fingers. The wooden part failed. The night before we had to leave for River Wars. I stopped crying and regained my composure long enough to make some aluminum fingers for the claw (Figures 24 and 25). Clearly seen in the pictures are tool marks from using plyers and other tools to bend the aluminum. At first these fingers were vertical and held a LOT of tension on the bow string. I released the trigger and nothing. The claw didn't move. I forgot there needs to be an angle on the fingers so the force of the bow string would push the claw up. Adjusting the fingers solved the problem. She could hold a medium load and only fire when I wanted her to. The missing wood in the claws and adjusted aluminum fingers are show below.

It was during this late night test and calibration session I added a thin metal plate to the top of the trigger shim (Figure 24)

Figure 24: Repaired Claw with Aluminum Fingers

Figure 25: Top View of Repair

From this I learned the following:

1. Unless I made the trigger out of a very solid hard wood and with a thick set of fingers, wood could not be the claw, at least the fingers. It is even risky around the hinge hole as it could wear away quicky.
2. The trigger shim would need to also be metal to prevent misfire due to wear
3. The final design should be mounted on a solid metal surface to remove the imperfections in wood and any deformations or compressions in the wood.
4. While leveling the top of the slider, I learned how to plane wood using a hand planer
5. Having a longer hinge that touches the claw prevented some twisting.
6. Moving the hinge point closer to the front of the claw also prevented some twisting.
7. I did not have the tooling to accurately and repeatedly bend metal. I will need to buy a hand brake or similar tool for this.
8. Having a critical part break the night before leaving for a demo is not a pleasant feeling, but should be expected.

The ballista's presence at River Wars was a resounding success. We didn't have to fire her to get the buzz and have the conversation with the Warlord for Pennsic 50. The "hacked up" look of the trigger mechanism was a talking point because the "battlefield repairs" made it look Roman.

Phase 3: Test and Calibrate

Following the static display at River Wars, I spent the next few weekends testing and calibrating most of the systems in the Ballista. This was not limited to the trigger. I had her to shooting further as I tightened the rope bundles for a higher pre-load. The trigger started to misfire again. The claw was not tight with respect to the base hinges and shifted under tension from the bow string. I drilled a second hole for a new hinge pin position in case the problem was the hole in the wood wearing.

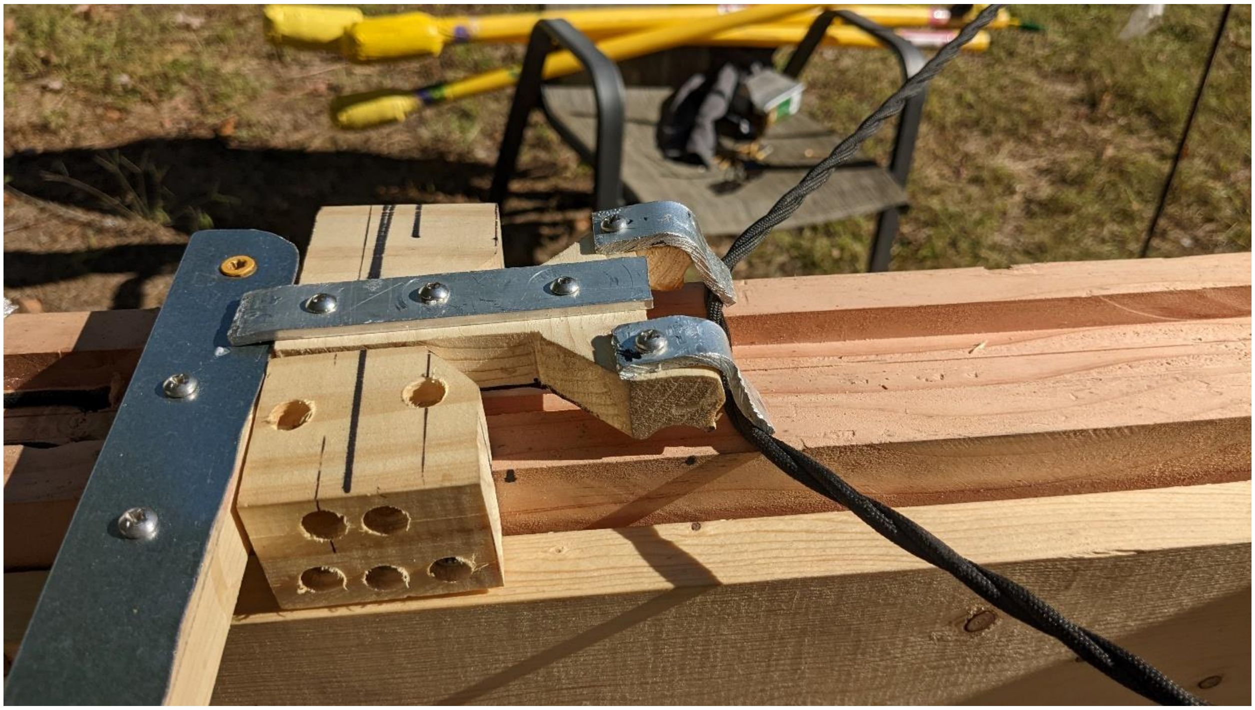

Figure 26: Evolution of the Wooden Claw

This worked for a few launches of the bolt then became loose. As I tightened the screws in each side of the hinge, the claw shifted position. Further diagnosis revealed the problem: the deck screws inserted through the hinge blocks started to touch in the hinge hole and caused one of them to shift, thus shifting that side of the claw.

I had to redesign the hinge. Using wood bases with deck screws from each side failed as a design. I had to use a single pin or bolt. I took the Roman approach of using what was available and used pre-drilled brackets and bolts from my robotics work for the hinges. I also added a reinforcement to the trigger shim that not only added strength but allowed the trigger to sit flat given the longer fingers from the aluminum extensions. I added aluminum strips to the slider for a flat and level surface to prevent the bow string from slipping under the claw fingers. This is given in Figure 27.

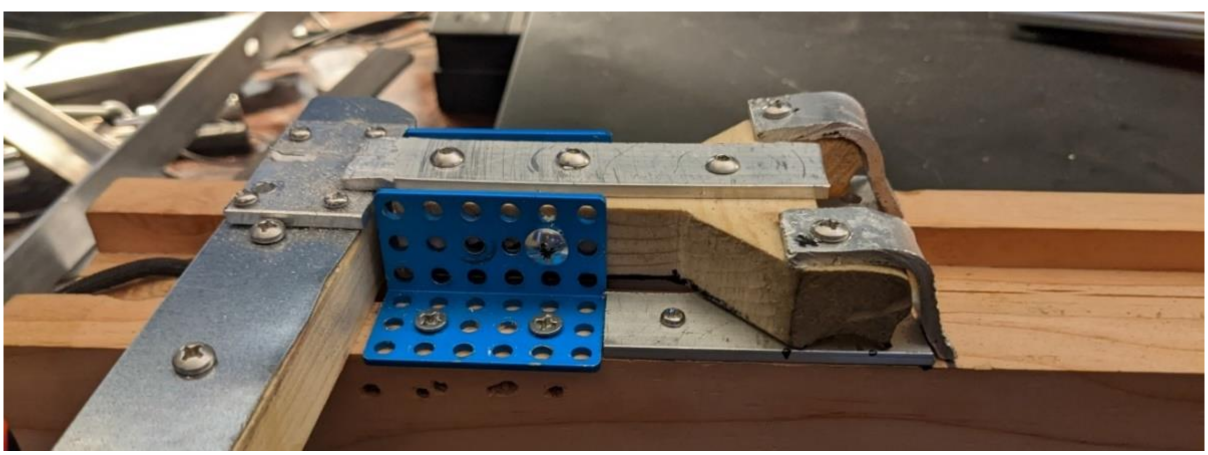

Figure 27: Final Design of the Wooden Claw

During this re-design, I learned a number of points:

1. Using deck screws instead of a bolt was a bad idea as the screws eventually touched, forcing one out of alignment.
2. Using the pre-drilled brackets allowed me to drill straight and use a bolt as a hinge. This solved the alignment issue.
3. I would need precision tooling when making future hinges without pre-drilled holes.
4. Having a flat and level surface to contact the claw's fingers prevented the bow string from slipping out.
5. The longer hinge allowed for better alignment for the soft wood.
6. Moving the pivot closer to the front of the claw minimized the effect of any loose part fitment.

With this redesign, I was able to continue tuning and adjusting the rest of the Ballista. She was able to shoot approximately 20 years until she started to misfire again. Careful examination of the claw showed a vertical crack at the neck juncture which led to one of the fingers lifting prematurely. The experiment in using a wooden core for the trigger failed.

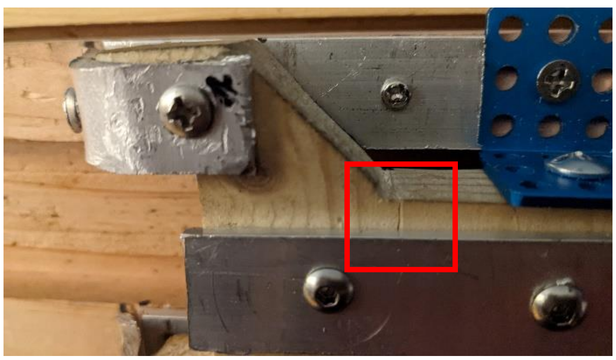

Figure 28: Top View of Claw Failure

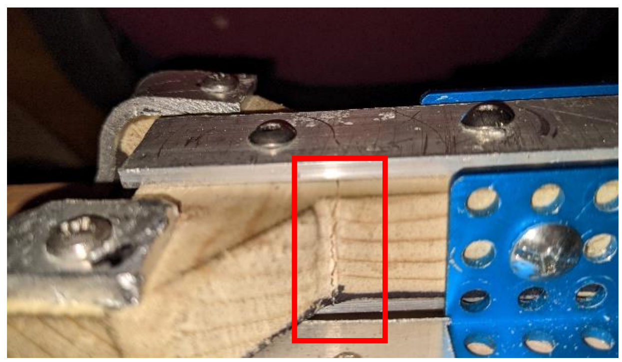

Figure 29: Side View of Claw Failure

Phase 4: A working trigger out of Aluminum

After yet another misfire and a failed component, I stood there with the trigger in my hand, sure of how it should work but unable to turn design into a working reality. I looked at it the same way Jon Pertwee looked at a dematerialization circuit in the smoky remnants of his console room. I was going to have to go outside of my experience and knowledge to learn the nuance of the part, rethink my methodology, and get the tools to make it properly. I stuck with the wooden trigger far longer than I should have. Early in the ballista build I was not ready to re-tool for metal work. My finances were still tight from the house purchase and I wanted to wait until late Fall at least before making any big purchases.

I documented the failure of the Phase 3 trigger and set it aside in my "box of bad decisions". I wanted to keep this as a display piece and reminder that even when you spend a lot of time on something, that doesn't mean it's the right long-term solution even if it was the right intermediate approach.

Back to my designing. I had aluminum square tubing and flat bar stock from a prior project which I could use to make something to prove the design and continue work on testing the ballista. The wooden claw proved the geometry but not the materials. I learned how to use adhesives to "weld" aluminum and built a short piece that was a rectangle without the neck that caused the failure in the wood. Unfortunately, it was too wide to mount the brackets and not split the slider wood. I added a neck and reinforced the joint using aluminum angle tubing. This version had a solid piece on top that connected the two fingers for additional strength.

The original hinge hole for the shorter rectangle version is visible in Figure 30 below. Also note, this design had a metal roof on top of the claw for additional strength.

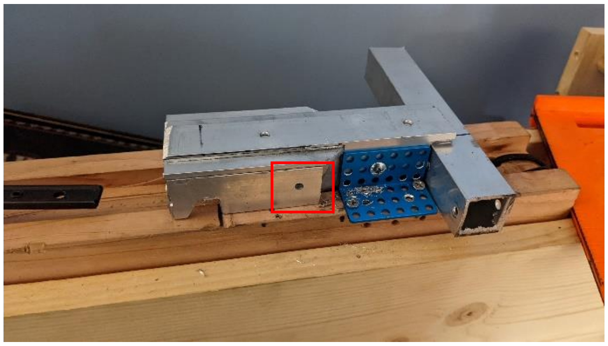

Figure 30: Side View Aluminum Claw

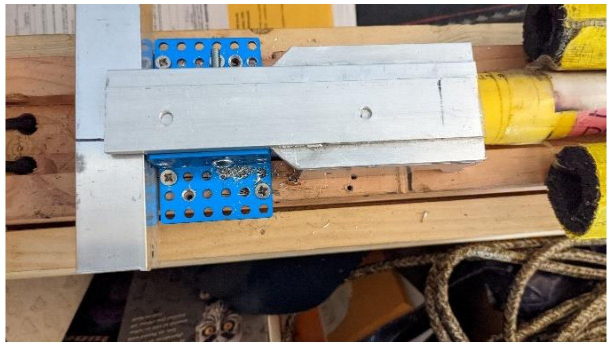

Figure 31: Top View Aluminum Claw

I used an aluminum square tube for the trigger shim. I mounted the new claw to the slider and tested her under increasingly higher loads. She was solid and did not misfire once. I could see some wear on the trigger (Figure 32), but did not see a need to reinforce it.

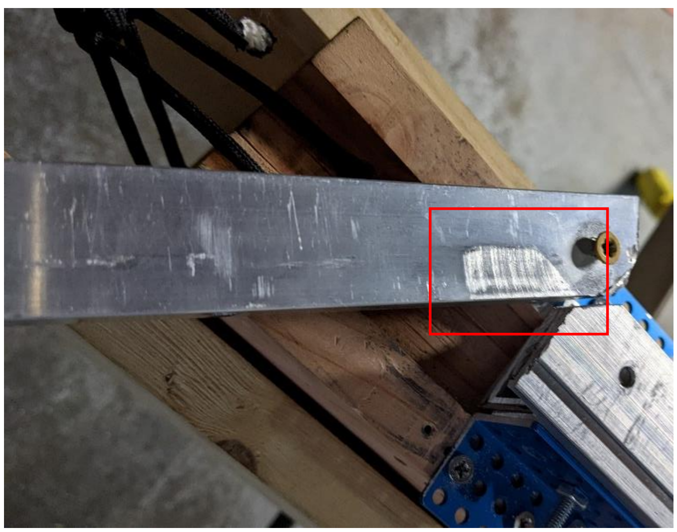

Figure 32: Early Wear on the Trigger Shim

Since then, the trigger has not had any problems but I learned a number of lessons in making and using it:

1. How to bond metals using adhesives.
2. My home workshop needs a proper workbench with a vice to hold material
3. The bolt for the hinge is enough to have a mechanical bond between the claw's parts in addition to the adhesives
4. Dremel cut off wheels can cut metal but a simple hacksaw was better. Neither were precise when cutting without a workbench and vice. A bandsaw would be ideal for more precise cuts.

5. The final design would need a neck to connect to the hinge with it flaring out for the claw's fingers to hold the string. The slider is not wide enough for a square shape.
6. A curved design would be better than the squared solution the Roman Legion used.
7. Even though aluminum is easier to work with, it will quickly wear out and will need adjustment. Steel is the best material; thus, I would need to focus on tooling to make steel and/or seek alternate routes of working with the Blacksmith Guild, individual metal workers in the SCA, or set up a relationship with an outsourced company to make the parts.

With this new trigger, I continued the test and calibration. I had the ballista bolts shooting 30+ yards, with flight anomalies due to improper fletching of the bolts. There were some pieces of the ballista that needed adjustment before I can shoot the full 50 yards to see if this trigger mechanism design was strong enough to handle the load. That said, this aluminum trigger proved the overall design concept and taught me a number of lessons to apply when making the final trigger design.

I suspended work on the Ballista so I could focus on other SCA activities: getting authorized for Combat Archery and coordinating with others on starting Siege groups in the East Kingdom. Other than the trigger mechanism for this competition, I have not worked on the ballista since.

Phase 5: The initial "Production" design / A&S writeup

At this point, I had a functional trigger that likely could be used in a combat scenario. I did not have to work on a final trigger design until I did a complete tear down and rebuild of the rest of the Ballista for wood finishing and adding design changes from the myriad lessons learned in making a torsion spring Ballista. That in itself may be the subject of future A&S entries, especially the journey in generic wood working and design of the curved and laminated swing arms.

Yule had a personal connection to me. 2021 Yule was when I first saw a gentle in a beautiful Great Kilt and instantly felt that would be my persona. It was also the first time I heard of A&S and saw a display. I wanted to give back to the event by adding an entry this year. I was not able to create a proper write up for previous events because I was either working them (River Wars) or focused on getting authorized for Combat Archery (100 Minutes War / Novice Day).

However, when I had time I thought ahead to the other components of the ballista including making curved swing arms. I researched how they were made of laminated wood (thin strips bent to the curve needed then glued together). I paused a video from Tod's Workshop to count the layers in his ballista and was distracted by a deer outside my window for a moment. When I looked back at the screen, it blurred for a second and I superimposed the existing design I had for the trigger of laminated metal but straight pieces. It dawned on me: I could get the curves I needed in the claw using this same approach!

The process of writing up this documentation in itself was a learning process. It forced me to aggregate all of the sources I had used, and while reviewing them found details in the Roman trigger design I had overlooked such as the scale in Figure 8. In writing up my design to include the three tiers of a workshop, I re-thought about the tooling required to make the trigger in a DIY-grade home workshop and researched lower-cost alternate to some tools. In this process, I discovered metal bending tools in the $60 range and realized I could use this in my design to bend thinner strips of metal to the curves I needed.

I wrote the majority of this documentation leaving the final design blank so I could refine my thoughts. I had initially thought about just sketching the plans and documenting the proposed manufacturing steps. As I wrote the main body of this write-up it became clear I needed to actually make it because the entire process of this initial Ballista was to incrementally design, build, and refine due to lack of documentation and clear plans. I could not simply end the trigger journey with a theoretical design. I also wanted to show the final design in a way that people could physically interact with, thus I decided to build it.

At that moment I grew as a craftsman. Not simply by learning a new tactical skill but in the decision that followed and change in my mindset.

I looked over my finances. In the time since I started the ballista, I recovered financially from the moving costs and improved a number of other financial conditions which allowed me to invest in the beginnings of a proper fabrication workshop. People joked about the SCA being an expensive hobby, and they were right. Siege was something I have been talking about since I first learned about it and something I wanted to do for me because of the joy I get in building and enabling others to build. Many people have commented about the contagious joy I share with others, and what would be more fun than doing a build to shoot giant yellow Q-tips at people in armor?

It was time I invested in myself. No more shortcuts. No more getting it to barely work using tape and gum. No more compromises. Why did I work do hard all of these years getting better as an engineer, if I couldn't take my building seriously? I was time I built the trigger the way I wanted to from the start with the tools I knew I needed to do the job right to begin with.

Over the Thanksgiving / Black Friday weekend, I ordered tooling and equipment to make the final trigger design: a workbench, a DIY-grade band saw, a benchtop belt sander, a workbench mounted metal bender, a tap and die kit, and other tools…**,** I also purchased a piece of 3 inch wide, 3/16-inch-thick mild steel.

Now I finally had the right mindset, and I learned the following and grew as a fabricator:

1. How to use a bandsaw
2. How to use a metal bender
3. How to use a tap and die set (to make threads)
4. How to use a belt sander for metal
5. How to use adhesives to bond steel
6. I am worth spending money on

The growth at this point was a complete mindset change. As an engineer and fabricator who mostly worked in wood or 3D-printing, I thought in terms of taking a solid piece and making it into the part required. By designing the trigger to use flat stock that was thin enough to work, I was thinking in terms of how many metal products are made: start with flat metal and bend it to shape. While this concept is not how the Romans built their ancient Ballista parts, it is how they built their crossbows and how the metal parts for the Arbalests used in SCA Siege were built, so it is period and a practice used in the Combat Siege community. But for me as a toolsmith, it opened a whole new genre for part making including being able to make the metal parts needed for the Docmo Arbalists that are commonly used for Siege.

Making that leap to bending metal allowed me to change my designs so they were simpler and easy to make. Of all of the lessons I learned during this journey from using tools, to manufacturing techniques, to materials this one is the biggest lesson because it fundamentally changed the way I thought about making parts.

With this new paradigm in mind, I decided to essentially start over in my design approach from using the square design the Roman Legion used to the curve design that looks closer to period. I was not going to merely make an incremental change from the aluminum trigger and replace it with steel, I was going to revolutionize my approach but using the small design and manufacturing lessons learned over the past few months including my thought of making the curves using laminated metal. While I would not have a design that is identical to how the Romans would have made it in a forge, I would also have a design and manufacturing steps I could make in my garage with available tooling – a design I could share with others so they could make it in their garage. Using laminated pieces allowed me to have the look of how the Romans made it but with the ability to make it without a forge.

Back at the drawing board, I referenced the original dimensions and altered them to fit the as-build ballista and an SCA bolt. This drawing is given in the Final Design section.

As the tools arrived, I spent time getting to know each of them and how well it cut various wood. I took one of the failed blanks for the wooden claw, Figure 16, and re-cut it on the bandsaw then finished the part using wood chisels and the belt sander (Exhibit 4). A few months ago, I did not have the tooling or experience in the tools to complete this.

Figure 33: Bent Laminations

I then practiced cutting aluminum, making quick progress out of cuts that had taken me significantly longer using a hacksaw and Dremel metal cutoff wheel. Then I made a mistake and tried to cut the steel I had so I could experiment with the bender. That quickly dulled the blade. I learned a painful lesson in matching the bandsaw blade to the material. I ordered more blades that could cut either aluminum or steel.

When the new blades arrived, I installed them in the bandsaw and quickly made a laminated claw using 1/8” aluminum bar stock (Figures 33 through 35). Given the dulling of the last blade when trying steel, I made the decision to focus the rest of my time on having an aluminum claw before Yule.

Figure 35: Laminate Claw Clamped and Glueing

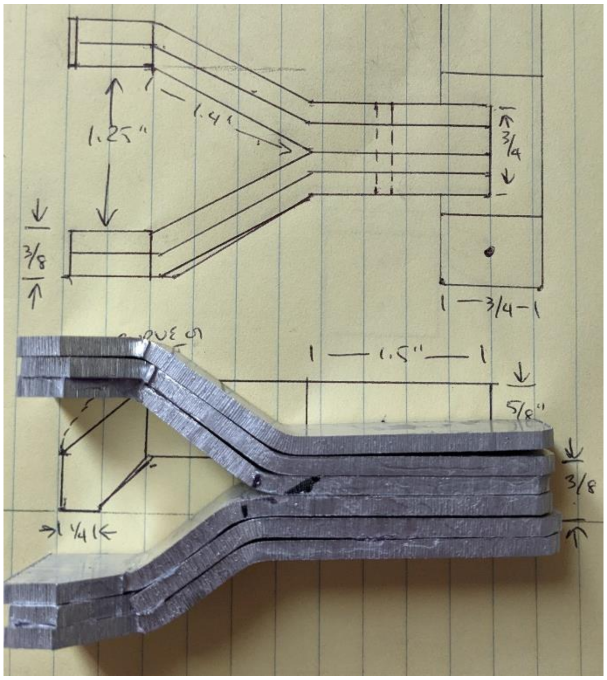

Figure 36: Laminated Claw Comparison to Design

As visible in Figure 36, the rough forming of the claw is very close to the scale drawings with the main difference being the number of laminate layers. The drawings were for 2 layers of 3/16 steel.

Also note in Figure 37, the claw fingers are crooked. When I analyzed the bender, I found there to be a space between the bending arm and the main body. This resulted in the arm being out of alignment when I used it. Before I made another, I would need to shim the main arm so bends come out square.

In addition to the minor defect from the bender calibration I noticed the locations of the bends on the blank varied based on which layer the individual piece was for as well as the radius. I experimented with how to make the bends and came up with the instructions in the final design.

Figure 37: Skewing of the Claw Feet

I cut the end of the initial claw to length and finished the part as best I could on the belt sander so it looks like it could have a hole drilled and be mounted to a working ballista as shown in Figure 38 and in Exhibit 5. Note the bends are not completely aligned so there are some gaps between layers. If gapping becomes a problem in production, I will add a single piece of aluminum to the top of the claw for additional strength.

I spent a lot of time with this initial laminated claw at the belt sander. This specific piece could never be used in a working ballista as I didn't like how the front end twisted and the gaps between laminations introduced potential weak areas, but it showed this process could work with shims added to the bender and some practice.

Figure 38: Laminated Claw After Sanding

While finishing the initial laminated claw, the new bandsaw blade cut through the aluminum base with ease. At this moment I had another "ah-ha" moment. If it could cut through the laminated base so easily it should be able to cut through a solid aluminum billet. I ordered a package of 6 blocks of 1 inch by 2 inch by 4 inch, to build the design for a "professional shop", both replicating the square shape the Roman Legion used and the curved shape of the laminated claw that looks closer to a forged method. I did not abandon the lamination technique, however I did not feel the need to build another before Yule since I prefer the solid billet design, even though the laminated looks more interesting.

Figure 39: Tops of Laminated and Solid Claw

My attempts at making a solid piece claw went quickly. I had become comfortable with how this new blade worked on the bandsaw. I only had one problem making it because I performed the long cut of the bottom section first which dulled the blade and broke some teeth. The laminated and solid claw are nearly the same proportions as shown in Figures 39 through 41, and are Exhibits 5 and 6**.**

After making this from a solid block of aluminum, it is clear that a DIY-grade bandsaw can be upgraded to make a solid aluminum claw and would be the method of choice in either the square or curved design, for an aluminum claw. However, I would need to update the order of my cuts as cutting the bottom of the trigger first damaged a few of the tips of the bandsaw, making the remaining cuts slightly erratic.

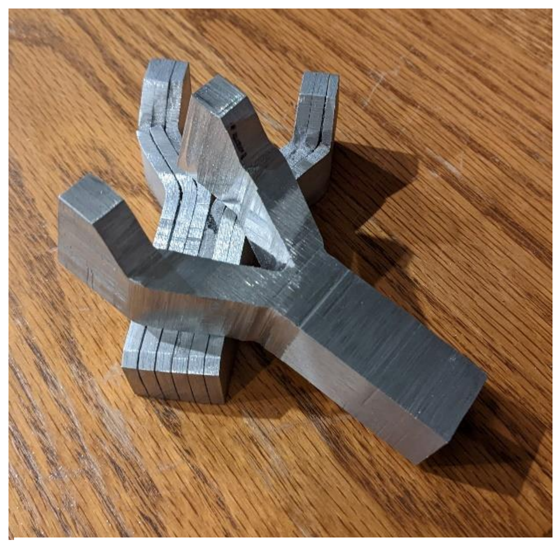

Figure 40: Bottoms of Laminated and Solid Claw

Figure 41: Laminated and Solid Claw Side by Side

Because of the choice to focus on aluminum before starting on steel in case steel dulled by bandsaw blades, I did not have time to create either of the designs in steel. However, the process would be the same to make a laminated claw to understand that process and tooling, then see if my bandsaw could cut through a solid piece.

For the competition, I choice to not mount the aluminum claws into a hinge and show it fully working. I already had working trigger mechanisms from the Phase 4 trigger (Exhibit 3) so judges and gentles in attendance could see how it worked. By leaving the various final design claws separate, people could pick them up and I could show some of the nuance of each component.

I learned a lot while making the solid billet version of the claw, mostly practical experience cutting a solid billet of aluminum and to make the shortest cuts possible even if it means the eventual cuts of the bottom would not be square without a brace. Also, the part would frequently get hot so I kept water nearby to cool it off.

Making the solid claw took approximately 45 from start to finish, including sanding and using a file for interior surfaces. Given the time spent (wasted) trying to make a wooden claw function because I did not have the tools, being able to make this in a relatively short time period shows my growth as a craftsman. As I focus on final assembly of the prototype ballista and I make one or more based on any adjustments from testing, I expect that time to decrease and the beauty of the part to increase.

The Final Design

Based on the successful results of the trigger shown in Figures 39 through 41, I was confident this design could function reliably and safely, and be built by future siege engineers. This design focused on the claw as that was the most difficult to make.

Also to note: following manufacture of the aluminum claws (Exhibits 5 and 6), I realized the center dimension of the space between the trigger claw fingers should be 1.5 inches, not the 1.25 inches I used in making the example pieces. I updated the dimensions below but chose to not make additional pieces as the mismeasurement has no bearings on the growth in skill set to make the part out of metal.

Design Constraints

In making this design, I placed myself under the following constraints for purposes of practicality and giving future siege engineers flexibility in how they construct their triggers:

1. Given the problems I faced in having a bandsaw strong enough for the steel I purchased, I designed this so it could be made out of either 1/8 inch aluminum or 3/16 steel, or a solid billet with the difference being the thickness of the materials affecting the layer count and some dimensions. The preference is for steel given its longevity but if a siege engineer does not have the tooling to cut or drill holes in steel, they have the option for aluminum.
2. Made the trigger mechanism so it could be disassembled for any repairs or adjustments. Some of the exemplar triggers have components welded together, e.g. hinges to the baseplate. Others have parts riveted together or pins peened over for a permanent connection. This also makes it easier to make them using an interchangeable parts mindset.
3. Designed all holes and threads for M4 machine bolts. Future siege engineers could use any size bolt. I chose this standard size because I have a wide assortment of M4 bolts in various lengths.
4. Allowed variability in the design and manufacturing process to fit the tooling and skill of the builder.
5. When discussing Greek and Roman Ballista's all measurements are given in terms of "d" or "f" which is the size of the hole in the torsion frames for the rope bundles. This hole in this ballista is 3.5 inches. However, other sources such as the Cheiroballista wiki (https://ballista.fandom.com/wiki/Cheiroballistra) give "d" as a Greek dactyls (1.93cm). When extrapolating the trigger mechanism to either the ballista hole or a dactyls as a basis, the claw and other components did not fit properly as they were too big or too small. This mismatch of part dimensions was also discussed in the ballista fandom wiki. Therefore, I used the approximate ratio of dimensions given but scaled it to this ballista design.

Design Specifics

This overall design assumed the claw could be made from any of the means described below and function the same. Only the appearance would be different.

Claw

I measured out the size of the gap between the claw's fingers needed for an SCA Siege bolt, and followed the dimensions given in the Vitroulus as summarized below from ballista.fandom.com (Cheiroballistra triggering mechanism | Greek and Roman Artillery Wiki | Fandom):

> *The claw (σχαστηρία, ΚΛΜ) is well-known from older artillery pieces, so there is little disagreement on it's general form (see Marsden 1971: 219-220; Wilkins 1995: 17; Iriarte 2000: 52-53). The claw has a 1 dactyl long incision and has a horizontal, round hole at Φ. This hole is used for the claw axle which also goes through holes in the fork.*

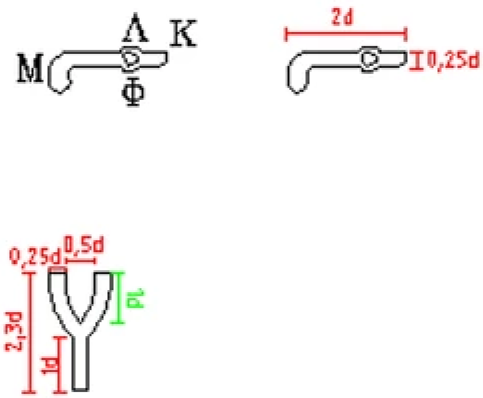

Figure 42: Detailed Measurements for the Trigger

Using these proportions as a guide, designed the claw as given in Figure 43 below. The overall dimensions:

1. Claw finger width: 3/8 inch
2. Claw gap: 1.5 inches
3. Claw finger length: 1.75 inches
4. Claw base length: 1.75 inches
5. Claw base width: ¾ inches
6. Hinge pin hole: 7/8 inch from the rear of the claw, 5/16 high (halfway)

Using 4 pieces of the 3/16 steel stock, the thickness of the claw core is ¾". At one inch, each set of two steel layers will bend at an approximate 22.5 degree angle. The bottom of the claw fingers were sanded to be straight. Note: the laminated method may be wider than the solid piece.

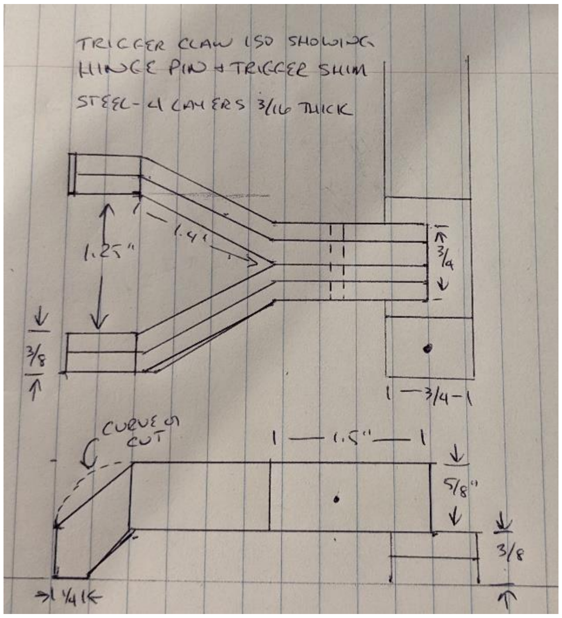

Figure 43: Top and Side Views of Craw and Shim

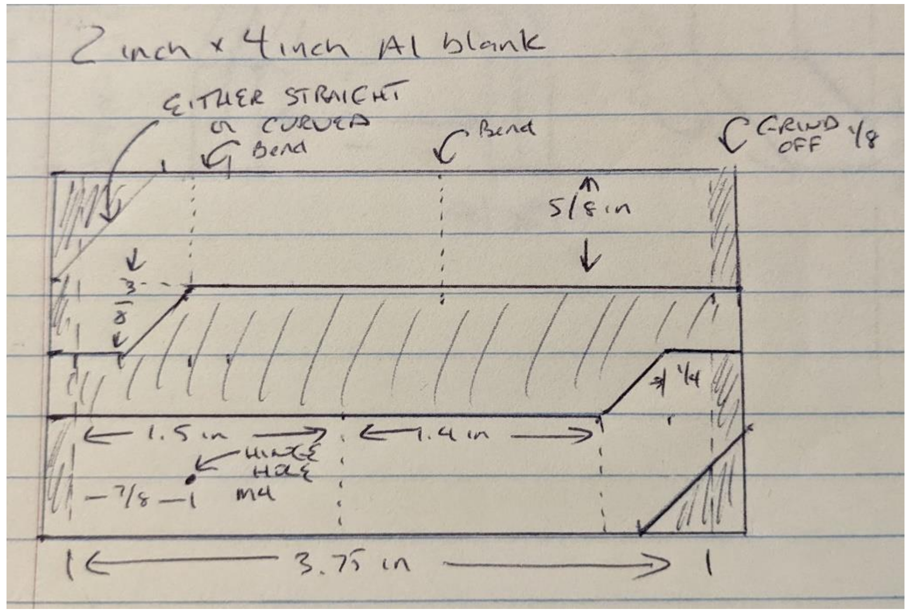

Figure 44: Trigger Claw Layer Blanks

Each of the layers of the claw was based on a blank cut from flat steel or aluminum as shown in Figure 32 bent into shape, and glued together. Each part blank included approximately 1/8 inch of material to account for uneven edges. These were to be filed or removed using a belt sander to achieve the final dimension.

If the claw was to be made out of aluminum instead of steel, it will need three layers on each side instead of two.

Fork / Hinge

The hinge is made from three pieces: a center "U" bracket, and two "L" brackets as shown in Figure 45. These give two layers at each side of the claw. Each is mounted to the base using two M4 bolts.

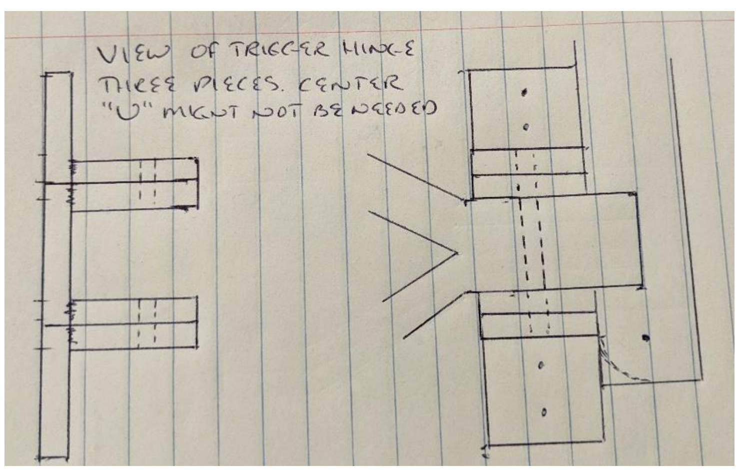

Figure 45: Rear and Top Views of the Hinges

Trigger Shim

The trigger shim has two designs:

1. Glued / Pinned: A single piece of metal ¾ inch wide and as long as needed with another layer glued under the claw as given in Figure 31. For aluminum, there is another layer required.
2. Bent: One piece curved to get the total height of 3/8 inch under the claw.

Either can be used. Design 2 is the more period correct but requires greater skill with a metal bender to get the bends correct for the piece of metal to come back to the same level. Beginners will prefer the simpler design 1.

Regardless of the method of construction, the top of the trigger may need to be filed to account for variances in the thickness of the claw.

Trigger Base

The base is a solid piece of metal**.** The holes for bolts are drilled and tapped to accept a M4 bolt. The holes to mount the trigger mechanism to the wood slider are countersunk to accept flat head countersunk screws.

The front of the plate has a section removed to allow the bolt to make contact with the bow string when it is help captive by the claw fingers. This should be to the rear of where the claw fingers make contact with the base.

A variant of this design is to have the holes drilled through and use a locknut on the other side of the base. In this design, the slider may need material removed to provide clearance for the nuts.

Materials and Manufacturing – At a Home Workshop

The main components are straight forward to make from the designs. Only the claw requires specific instructions. The choice of material is at the discretion of the siege engineer. Steel is preferred for its better wear and longevity but aluminum is easier to work in a home workshop.

To make the claw using the laminated method if your bandsaw is not capable of cutting through a block of aluminum or steel:

1. Cut the blanks from the flat metal stock (3/16 steel, 1/8 aluminum). 4 if using steel, 6 if using aluminum. For the hinge pin hole, drill using a TBD size bit. This is smaller than needed. Later we will open it to the final dimension. Making it smaller now accounts for any variation when bending and gluing, and makes the final hole drill easier.

   Note: with access to a home CNC, use it to cut the blanks.

2. Place two of the blanks in the bender (3 if AL), finger side in with the two pieces clamped together. Make the first bend at a 22.5 degree angle.
3. Keeping the pieces together, reverse them in the bender so the inner is now the outer and perform the second bend to form half of the claw core.
4. Bend the other side using the reverse side.
5. Using JB-weld (or other adhesive), glue the 4 (6 if AL) pieces together using clamps. Allow the pat to cure based on the adhesive's instructions.
6. Widen the hinge pin hole
7. Using a belt sander or file:
   a. Smooth the back to remove the extra 1/8 material

b. Smooth the front to remove the extra 1/8 material
c. Level out the bottom of the fingers
d. Round over the outside of the fingers where it touches the bow string. This curve does not need to be large, just enough so the corner won't add excessive wear on the bow string

To make the claw using the professional-grade workshop, get a bi-metal blade (14 TPI) for your bandsaw that is capable of cutting aluminum and/or steel. If that blade is capable of cutting through a small block or either material, make the claw out of a solid block.

Materials and Manufacturing – A Professional Workshop

To make the claw, start with a solid 1 inch by 2 inch by 3.75 inch (or larger) block of metal. Cut or mill the bottom 3/8 material from the billet leaving the fingers at the front. Cut or mill the shoulders in, creating the claw base. Cut or mill the middle of the billet. If it is easier, drill a hole near the back of the fingers first. Drill the hole for the hinge pin.

If the workshop has access to a CNC mill, use the 3D CAD files to automatically mill it.

When cutting using a bandsaw, make the cuts in the following order while pausing frequently to cool the billet:

1. Remove the two shoulders, cutting on the utside of the lines so the precise dimension can be sanded,
2. Remove the space between the two fingers second. If the bandsaw can make the curve, do it by cutting the edge. If not, nibble out the space through successive parallel transverse cuts. If you prefer, use a drill to drill the corners first.
3. Remove the "bottom" 3/8 inch first. The blank will not lay flat on the table, but if this was cut first, the thickness of the billet could damage the bandsaw blade.
4. Sand and finish the piece, including sanding the part to the right dimensions.
5. Using one of the remnants of the shoulder as a brace under the neck in the drill press, drill the hinge pin hole.

Materials and Manufacturing – Access to a Metal Forge

To make the claw, start with a 5/8 thick piece of steel, heat one end and use a forge chisel to split one end. Work the two fingers to 1.25 inches apart. Bend the fingers down so the total height of the claw in 1 inch. Adjust the width if needed to 1.25 inches.

Use a belt sander to level the base of the claw fingers and to round the edges as necerrary.

Next Steps

My journey in growing while making the trigger mechanism is not complete. As time permits over the Spring of 2023, I will spend time in colleagues' workshops or find members of the SCA Blacksmith Guild who have forges and proper working equipment to make a trigger mechanism as the Romans would. These may or may not be used in actual Siege Combat, but will give me experience making the part as the Romans did to appreciate it.

Computer CAD Documentation

To facilitate manufacturing, I will take the hand-drawings for the trigger and enter them into a 3D Computer Aided Design program. This will allow future engineers to quickly make design changes. It will also allow them to create a Computer Aided Machine script to use a CNC mill to make the parts.

While the use of computer technology and automated manufacturing is clearly not period, it will allow siege engineers to either make parts quicker or to outsource the part making to professional metal shops. This is a practice used by weapons makers throughout the SCA, including the rubber band guns used at Pennsic 49.

Hand Making a Trigger Using a Modern Forge

The first step in this process is to use a modern gas-powered forge and modern tools to make a claw. This will give me experience working metal and allow me an opportunity to use other modern tools to do finishing work on the claw.

Hand Making a Trigger Using a Coal Forge

Once I have experience using modern tools to forge steel, find a colleague with a coal forge and hand tools to make a claw as the Roman's would have without the use of modern tools. Given my comfort in the quality of the output and the precision of the dimensions, this may likely only be used for A&S competitions.

Final Testing and Calibration

Because this trigger mechanism is not a stand-alone project, When I disassemble and perform the rebuild and final testing of the overall Ballista in preparation for live Combat and/or Target Siege, I will be testing every aspect of the trigger mechanism functionality at full load. I assume there will be small changes to this design such as the dimensions but do not expect any significant changes to the overall shape or functionality.

This may include testing both a steel and an aluminum trigger to compare their performance and reliability. If both function well, will note any differences for future engineers guidance.

Concluding Thoughts

I was unsure about entering the Yule competition. Originally, I wanted to focus on my "dress kilt" garb because of finding my persona one year ago. However, when I saw the theme about improving myself as a craftsman it gave me the incentive to finish the trigger and write this document. I gave this entry a sub-title of "Zen and the Art of a Craftsman's Journey" a few days before the contest because for me, the journey I started – and will be on for some time – is a journey of re-claiming myself after my divorce and allowing myself to have the workshop I have wanted for decades. It's the journey of telling myself that I will no longer build inadequate parts and waste time making them work because I lacked the tools or skills. I have a long journey ahead of me as I look to tear down and properly finish my prototype ballista, then build a second one made from oak logs in my backyard. Deciding I was worth learning the skills to build this trigger right was a giant leap for me. My growth on this journey was far beyond learning tools and techniques; it was viewing myself as a serious craftsman instead of a dilettante who tinkers.

References and Sources

To learn about Ballistas and their triggers I had a number of different sources. Some were directly cited here and others were for background that I used along my journey. There is a third group of sources that I did not have access too (in some cases they are out of print), but were instrumental in the sources I used. I am including them here in case they become available.

Sources Cited in This Document

These are sources I directly referenced in this document

1. Brun Canutesson, "Roman Euthytone Catapulta" in the pdf "Torsion Ballista Plans" dated 16 May 2002.

   This is the original set of plans created by Brun Canutesson, a SCA member currently residing in the Kingdom of Meridies. A copy of this can be downloaded from the EK Siege Engine Facebook page: https://www.facebook.com/groups/5551134271600733/files/files

2. Legion XXIV, a Roman re-enactment group who created Siege Engines for Pennsic and other uses. Their main web page is: https://www.legionxxiv.org/Default.htm There are two pages I referenced:
   a. https://www.legionxxiv.org/catapulta/ dated 08 July 2008
   b. https://www.legionxxiv.org/ballista.htm dated 27 December 2009
3. Greek and Roman Artillery Wiki, a page discussing numerous topics regarding siege wespons with focus on the Cheriabalista. Their main page is https://ballista.fandom.com/wiki/Greek_and_Roman_Artillery_Wiki. I cited two of their sub-pages:
   a. Cheiroballistra triggering mechanism | Greek and Roman Artillery Wiki | Fandom (https://ballista.fandom.com/wiki/Cheiroballistra_triggering_mechanism)
   b. Forging the claw | Greek and Roman Artillery Wiki | Fandom (https://ballista.fandom.com/wiki/Forging_the_claw)
4. "A Reconstruction of Vitruvius' Scorpion". This was a project by two students at Bucknell, Wade Hutchison and Steve Godfrey aka Gille MacDhnouill and Nanzydon the Traveler in 2004. Their website is http://www.eg.bucknell.edu/~whutchis/scorpion/. This includes a downloadable pdf with their discussion.
5. Seige-engine.com is a website created by a team in the annual "Pumpkin Chunkin" contest in Delaware. The webpage used was http://www.siege-engine.com/TriggersAndCatches.shtml.
6. Alan Wilkins and Len Morgan, 2018: 'A suggested reconstruction of Vitruvius' Stone-thrower: de Architectura X, 11, 4-9', Journal of Roman Military Equipment Studies 18. A version is available at: http://www.romanarmy.net/pdf/Reconstruction%20of%20Vitruvius%27%20Ballista%20Ver%201-05.pdf
7. Docmo Arbalest. The Docmo Arbalest is the de-facto standard siege weapon used in the SCA. It resembles a giant crossbow and was designed by Docmo Kincaid in the early 2000's. His website is : http://www.ballistaplans.com
8. D.B Campbell, "Ancient catapults: Some hypotheses reexamined", https://www.academia.edu/1141718/Ancient_catapults_Some_hypotheses_reexamined

9. Tod's Workshop, https://www.youtube.com/@tods_workshop
    a. "Tod's new artillery piece - BALLISTA or CATAPULTA?" - https://www.youtube.com/watch?v=HzWOenll1KQ
    b. "CATAPULTA Increasing Power Pt1" - https://www.youtube.com/watch?v=RUBJY-oxeGk
    c. "CATAPULTA INCREASING POWER PT 2" - https://www.youtube.com/watch?v=AYe3GmlZi5M

Background Sources Used in My General Ballista Knowledge

1. William Dean, "The Ancient Artillery of Saalburg (Translated), Two Treatises on Greek and Roman Artillery", Published Independently, 2018.

Other Sources References by My Sources

1. E.W. Marsden, "Greek and Roman Artillery, Technical Treatises". This is the bible used by many reconstructionists. However, it is no longer in print and expensive to find.
2. Iriarte, A, 2000: "Pseudo-Heron's cheiroballistra a(nother) reconstruction: I. Theoretics", Journal of Roman Military Equipment Studies, 11, 47-75. This was referenced by "A Reconstruction of Vitruvius' Scorpion".