Hybrid or Counterpoise? A Study of Transitional Trebuchets

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HYBRID OR COUNTERPOISE? A STUDY OF TRANSITIONAL TREBUCHETS

by

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Submitted to the
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requirements for the
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Michael J. Basista
HYBRID OR COUNTERPOISE? A STUDY OF TRANSITIONAL TREBUCHETS

Michael J. Basista, M.A.
Western Michigan University, 2004

This study investigates the engineering and use of a proposed type of trebuchet in the Middle Ages. A study by a prominent historian has suggested the existence of a type of siege weapon that made use of both human and gravitational forces to fire its projectile. My research will investigate this claim by examining select sources, reviewing the engineering principles involved, and determining the viability of such a machine.

After dealing with this theory I will offer my own new interpretation made from the sources. This interpretation will center on the application of ancient technology to make trebuchets more efficient. The theory involves the idea of counterpoising the mass of the components and projectiles with the use of a small weight. Much of the prior work on this subject has been speculative and based upon unclear primary sources. My research will offer a more solid basis for interpretation based upon work in physical principles as well as historical sources.
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Chapter One: Introduction and Historiography

The trebuchet was the largest and most fearsome weapon of the Middle Ages. Its mere appearance at sieges was sometimes enough to cause a castle garrison to surrender. For almost five hundred years the trebuchet was the most powerful weapon in the world. Its use has been documented from third-century A.D. China to Hernando Cortes in the New World. Napoleon III experimented with them and they are still used today, though for very different reasons. Like all machines and almost all weapons the trebuchet did not spring fully formed into the arsenals of the Middle Ages. It underwent a constant chain of improvements and alterations from humble staff sling to formidable wall-crusher.

A weapon of the size, complexity, and ferocity of the trebuchet cannot help but draw attention to itself, both from contemporaries and historians. The historiographic record of the trebuchet in Europe stretches at least as far back as the ninth century and up to the latest work of modern historians. The bulk of this work,

1 While besieging Stirling Castle in 1304 Edward I began construction of a large trebuchet. Seeing the huge artillery piece being constructed the garrison surrendered. Edward refused to allow the garrison to leave the castle until the trebuchet, named Warwolf, had been tested. Michael Prestwich, Armies and Warfare in the Middle Ages: The English Experience (New Haven, 1996), 300.


3 Louis Napoleon Bonaparte and I. Fave, Etudes sur le passé et l’avenir de l’artillerie (Paris, 1846-1871.)
though, is devoted to detailing its use in sieges and not to its construction. This is not to say that this issue has been ignored; instead, it has been dealt with primarily in the mixed realms of physics, engineering, and amateur reconstructions. Those sources that bridge the gaps between the aforementioned fields and history provide the most insight into its construction and usage in medieval warfare.

There are two main types of trebuchets, a human-powered version and a version powered by a large weight. Both designs work on the lever principal and offset masses. A third transition type of trebuchet that utilizes both human and gravitational power has been hypothesized. The hybrid trebuchet, as it is known, is described as having a small counterweight that adds gravitational pull to the downswing of the throwing arm.\(^4\) The hybrid trebuchet does not function in the manner described. Instead of a small counterweight the sources instead are describing a counterpoise. A counterpoise does not add power to a trebuchet, but, rather, it makes the entire machine more efficient.

The earliest studies of the trebuchet are those that are contemporary with its usage. These medieval sources are varied in both their scope and their accuracy. There is everything from accounts of sieges written by monks to detailed illustrations with an eye towards reconstructing a trebuchet. There are a plethora of sources detailing sieges from either a defender's or attacker's point of view that give insight into their use. Most of these accounts are unclear to a modern reader, or provide little accurate detail about sizes and projectile weights. The sources most useful to this

\(^4\) Chevedden, "Hybrid Trebuchet," 179-222.
study are those that provide accurate descriptions of the construction and types of the trebuchet.

Those medieval sources include the work of Conrad Kyeser, *Bellifortis*. *Bellifortis* was produced in its final form in 1405 as a text describing various siege machines and tactics. Many of the designs are fanciful and were never produced in reality. The work simply served as a way for Kyeser to depict some ideas he had regarding engineering new siege engines. What is useful, however, is the illustration of a counterweight trebuchet on folio 30 recto. This illustration is the most accurate depiction of a trebuchet from the Middle Ages that we have. The components are all correct and in the proper place. Most useful, though, are the measurements placed on key parts of the trebuchet. These measurements provide us with a reliable source for the size of a counterweighted trebuchet.⁵

Another medieval source is Aegidio de Colonna’s *De Regimine Principium*. This work is a set of recommendations for Philip IV of France written before he took the throne. Unlike Kyeser, Aegidio does not offer ideas for siege engines or serve up fanciful engineering ideas. Instead he gives advice on everything that could be of use to a prince who would soon be king. These include advice on making laws and enforcing them as well as advice on siegecraft. Aegidio describes the four types of

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trebuchets he is familiar with and lists the benefits of each. He describes three types of counterweight devices and one human-powered machine.6

Both of these medieval sources are taken by historians as accurate and have significant merit for the modern researcher. They provide startlingly accurate depictions of medieval trebuchets and stand out among other medieval sources for it. At a time when trebuchets were still shown larger than the castle they were attacking Kyeser's work depicted a trebuchet complete with measurements as he saw them. Aegidio's work also provides accurate descriptions of how the various types of trebuchet functioned and were thought of in the Middle Ages.

The Renaissance largely ignored the information of the Middle Ages and especially the weapons and tactics that prevailed then. Instead they focused on their own military knowledge. Because of this there was little study into trebuchets or non-gunpowder artillery until the romantics of the Victorian age began to study the Middle Ages. Then a small group of scholars resumed, beyond naming conventions, the debate.7 These scholars worked both with medieval sources and their own reconstructions to divine information about antiquated weapons.

Louis Napoleon Bonaparte, grandson of the French emperor, did an early study regarding trebuchets. His work focused on rebuilding trebuchets and studying them in that manner, a pattern that some modern researchers still use. His work, a

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7 For more information on the issues of naming see Rogers, Latin Siege Warfare in the Twelfth Century, appendix III.
four volume study involving other types of catapults as well, described a massive
trebuchet built for testing purposes. This machine provided useful information before
its premature retirement after only a few shots due to a failing throwing arm. Perhaps
the most useful bit of information, certainly for other reconstructionists, is that a
trebuchet can fire backwards.\footnote{8}{The first shot had a range of –70m.} Other useful information gleaned through his
reconstruction includes the nature of the sizes and just how big and sturdy the
trebuchet components needed to be. The design of Napoleon’s trebuchet initially
called for a thirty-ton counterweight. The throwing arm was too slender to support
this weight. Through the first tests, with a counterweight loaded to only one third of
its capacity, the arm was damaged beyond repair and the tests ended.\footnote{9}{Bonaparte and Fave, \textit{Etudes sur le passé}.}

One of the scholars who worked with the trebuchet in the late 1800’s was
Giovanni Canestrini. His work \textit{Arte Militare Meccanica Medievale} analyzes and
reproduces fanciful designs from various medieval works, including Kyeser and
medieval editions of Valturius. His work shows different designs of siege engines.
Canestrini offers little information about the designs and even less about the actual
martial viability of any of the designs. As a result actual weapons mirror completely
nonsensical designs. Naturally the value of this work is more for those studying the
revival of interest in the Middle Ages during the Victorian Era.\footnote{10}{Giovanni Canestrini, \textit{Arte Meccanica Militare Medievale} (Milan: 1946)}

An English scholar named Ralph Payne-Gallwey produced a seminal work on
the crossbow with a brief treatise on medieval artillery pieces. Payne-Gallwey’s
work, published in 1903, devotes much of its bulk to understanding the crossbow; however, he also devotes chapters on ancient and medieval artillery. Like Napoleon III, Payne-Gallwey built a reconstruction of a trebuchet, though with better results. Payne-Gallwey's machine fired with some success and was able to establish the accuracy of the counterweight trebuchets. The idea of a traction trebuchet was dismissed as not physically possible. Instead, he said that the force of gravity would exceed the speed of the pulling crew. This shows that he did not fully understand the differences in construction of a traction trebuchet. His interpretation is likely based on his own reconstructions as counterweights. The sizes of machines that he works with would preclude the use of a pulling crew. A throwing arm of a mass necessary to function in a counterweight machine would not need a large weight to be heavier at the short end of the arm.  

Two other European scholars produced works that dealt with siege engines during this time period. One, Marcellin Berthelot, wrote a study in 1900 of siege engines and other engineering plans based on a military engineer's book from the end of the fourteenth century. His work provides good analysis and solid information, though much of it has been superseded by more modern scholarship.  

Also writing at this time was W. Gohlke. He produced a brief article examining the artillery of


both the classical and medieval periods. Again, this work has largely been surpassed, though it did play an important role in stimulating other German and German-speaking historians into a study of artillery.\textsuperscript{13}

A small group of studies from the middle of the twentieth century builds upon the work of the Victorian Era studies. These studies include a translation of an Arabic text on siegecraft written for Saladin and a foray into medieval architects. The first of the studies from the middle of the last century worth examining here is Claude Cahen’s brief work, “Un traite d’armurie compose pour Saladin.” This work dealt with an Arabic book that was written for Saladin about artillery. It is one of the first times that an Arabic source was used in a European study on siege engines. This is significant because many of the developments that made the trebuchet more powerful than the staff sling occurred in or near Arab-controlled areas. This work brought the Arabic sources from the Middle Ages, long left untouched by western scholars, into the debates that would follow as the study of siege engines picked up.\textsuperscript{14}

Also of value from this period is the work of John Harvey. Harvey did a survey of public records and was able to produce a comprehensive study of English medieval architects. This book, while not specifically about siege engines or machines, provides valuable information about the men responsible for building and designing them. A surprising number of the architects listed had at some point in

\begin{itemize}
\item \textsuperscript{13} W. Gohlke, “Das Geschutzwesen des Alterums und des Mittelalters.” \textit{Zeitschrift fur Historiche Waffenkunde} 6 (1912-1914), 61-65.
\item \textsuperscript{14} Claude Cahen, “Un traite d’armurie compose pour Saladin” \textit{Bulletin d’etudes orientale} 12 (1947-1948), 16-18.
\end{itemize}
their careers worked on a siege engine of some type. Most useful, however, is the presence of architects who became master engine builders. At least one even earning the title of trebuchetor and functioning in the service of the king. The value in this work is not a study of how the engines worked but in examining the human element of building a trebuchet.15

The studies in the past thirty years both far outnumber and expand upon the work done by the early scholars of siege engines. These studies do everything from examining artwork to engaging in exhaustive readings of medieval sources. The amount of information now known about trebuchets is surpassed only by the amount known when they were still devastating weapons of war. The modern historical approach to trebuchet study is twofold. There are those scholars who study them via first hand accounts at sieges and other similar sources. The second approach is an older one that is being re-attempted by modern scholars. These historians attempt to interpret not only the use but also the construction of siege engines based on the surviving depictions of them in sources. These sources occasionally are devoted solely to trebuchets as manuals for their use: though, more often these depictions are secondary in the work. In some cases these two approaches merge and a work is written analyzing trebuchets on the basis of both illustrations and accounts.

The most valuable source to come out of this period is the work of Finnish historian Kalervo Huuri. Huuri organized a monumental work that established for the first time a claim for the Chinese invention of the trebuchet. After that he shows the diffusion of the device westward through the Mediterranean region. This was the first

15 John Harvey, English Medieval Architects (London: 1954.)
and clearest tracing of the movement of the trebuchet and played an important role in further studies on the trebuchet even up to this day.\(^{16}\)

Paul Chevedden is among the most important and most prodigious of the modern historians working on the issue of the trebuchet today. He has produced six substantial articles and numerous papers on the subject and continues to work on it today. Chevedden’s work fills a void left by many of the modern historians, namely critical examination of Arabic sources. Chevedden has covered the span of the trebuchet from its earliest inventions and use in the Mediterranean through its final form as massive counterweight machines.\(^{17}\)

The trebuchet also plays a central role Kelly DeVries’ seminal work, *Medieval Military Technology*, since in this study a large portion of the work is devoted to artillery. DeVries traces the development and diffusion of the trebuchets and offers evidence backing up each of the examples in this section. This work is of utmost

\(^{16}\) Kalervo Huuri, *Zur Geschichte des Mittelalterichen Geschutzwesens aus Orientalischen Quellen* (Helsinki: 1941.)

importance in that De Vries gathers together the information of the specialists on the trebuchet and presents them in a succinct form.\textsuperscript{18}

One other historian that works today is Donald R. Hill. Hill's work is primarily devoted to Islamic technology and to this end he has done work with trebuchets. The work he has done with trebuchets is especially useful in that it provides not only the descriptions from accounts and illustrations but that he also is able to construct a mathematical model to illustrate the effects slight changes can have on the efficacy of a trebuchet. His work shows just how important the ratio of the throwing arm is to the firing capability, as well as other seemingly minor things like the release angle and the sling.\textsuperscript{19}

The trebuchet was invented in China and a study of its Chinese roots was definitely required to better understand its early development. Joseph Needham conducted the much needed research in this area. Needham's work focuses on Chinese technology; from his work he was able to present information regarding the invention of the trebuchet and then its re-adoption in the counterweight form. This information is helpful in determining both the timeline of construction and also the route of diffusion from the Middle East. From Needham it is possible to fix the dates of invention to the fifth century and also the spread of the trebuchet back into China.

\textsuperscript{18} Kelly DeVries, \textit{Medieval Military Technology} (Peterborough Ont.: 1991)

\textsuperscript{19} Donald R. Hill, "Trebuchets," \textit{Viator} 4 (1973) 99-114.
from Arab armies.\textsuperscript{20}

There are also historians who have offered smaller works that are valuable for specific areas of trebuchet research. Carroll M. Gillmor has an insightful article detailing the earliest occurrences of the traction trebuchet in Western Europe. This area of research was previously ignored, as most historians were content to say that the spread into Europe was difficult to pinpoint but probably occurred by the ninth or tenth century.\textsuperscript{21} D. J. Cathcart King also provides valuable research on the trebuchet. His work attempts to address the issue of naming practices and how to resolve the differences between a trebuchet, a mangonel, and a perrière. This work, though well reasoned and researched, does not account for all of first hand descriptions and nomenclature of medieval sources.\textsuperscript{22}

There are several other historians that touch upon the trebuchet without focusing on it directly. Many of these historians discuss the nature of a particular siege or series of sieges. Likewise the larger issue of how the siege fit into the picture of medieval warfare has garnered much research; but the majority of these sources offer no valuable insight, instead simply restating secondary source material.

There is a final group of people researching the trebuchet and other siege engines. These are the reconstructionists. Rather than relying on medieval accounts


or depictions they use these as a starting point for building their own trebuchets. This is not a new technique, as it has been in place since the first scholars turned their attention to trebuchets in the nineteenth century. The drive to build or model these machines is not uniform but as diverse as the people that build them are. They are built for everything from museum demonstration pieces to throwing pumpkins for distance.

One of those people who reconstruct trebuchets and produces publishable results is Peter Vemming Hansen. His work for the Falsters Minder Museum in Denmark has been beneficial to all students of siege engines and, indeed, medieval construction techniques in general. Through his efforts several trebuchets have been built and an entire craft village has been developed for the purpose of building these machines. His reconstructions include a hybrid style machine and a counterweighted machine. The findings based on these reconstructions have been of use in providing real-world quantifiable numbers. The findings have allowed us to evaluate the veracity of the medieval sources. Hansen's work on the counterweight machine in particular provides insight into the power and accuracy of the larger machines.23

Another reconstructionist, W.T.S. Tarver, built and extensively tested a traction trebuchet. His machine and the subsequent findings have provided valuable information for historians. The machine, a large counter-poised traction trebuchet,
was tested with varying numbers of pulling crews and shots. His work allows the confirmation of the power and ability of the traction-powered machines. The crews of his machine include full size crews as well as small skeleton crews. The range of the numbers Tarver provides can account for a substantial amount of the accounts in medieval sources.  

The greatest value for the reconstructionist sources comes in quantifying the data to figure out the mathematical and physical limitations of the machines. This allows historians to estimate the power of the machines and determine more accurately their roles in sieges and the understanding of the science behind them. These sources provide a reasonable starting point to examine the viability of a hybrid trebuchet.

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Many conflicts of the Middle Ages were not resolved in pitched battles in open fields. Instead defenders would sequester themselves inside a fortification and the attackers would lay siege outside of the walls. There were then three major ways a castle would fall and often a siege was resolved through a combination of all three techniques. One way is by starvation; in this instance the attacker has cut off all supplies to the defenders and waits them out. This process was time consuming, with sieges lasting for over a year in some cases if the defenders had sufficiently stocked castles. A second method is through diplomacy; in these cases the defenders would often agree to surrender the castle if they are not reinforced within a set period of time. The third scenario for the fall of a castle is to take it by force. In this case the attackers use every means available to breach the castle walls and make it inside to battle the defenders face to face. It is in this third scenario that advanced weapons known as siege engines were employed to destroy the walls.

Siege engines can be classified into two major groups: those that are torsion powered, and those that are referred to as rotating beam engines. Within both of those classifications there are distinct subgroups that provide further distinction as to the operation of the machines. Torsion-powered machines generate kinetic energy

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from twisting skeins of rope and then releasing them. Rotating beam engines rely on an offset of forces and, in general, work on a lever principle.\textsuperscript{27}

The torsion-powered engines can be subdivided into two categories based on the throwing arms. The first group and most likely the oldest are the two armed torsion catapult. These engines resemble large crossbows in both form and function. Initially these engines relied not on torsion power but on a flex in wood: a bowstring was strung on a single large beam. When the bowstring was drawn back the beam bent, creating potential energy in the wood caused by the flex. Upon releasing the string the beam snapped back into place accelerating the bowstring forward and launching the projectile. The projectiles for these engines were often large arrows or darts, though some early sources indicate that stones were also used as ammunition.\textsuperscript{28} Eventually two smaller beams held in place by twisted skeins of rope replaced the single beam. These ropes are what generated the energy on these engines. The two smaller beams gave them the designation of two-armed torsion machines, though they are often known in modern terms as ballistas.

The second subcategory of torsion-powered machines is the single-armed engines. These are the catapults of Wil E. Coyote cartoons. These machines function by drawing back a single throwing arm positioned vertically and held in place within a large twisted skein of rope. The arm was drawn back by twisting the skein of rope until the arm could be held in the firing position. When released the skein attempted


\textsuperscript{28} Chevedden, “Late Antiquity,” 137.
to untwist itself as much as possible and the arm was propelled forward with great violence. To keep the skein from untwisting entirely and to stop the throwing arm and launch the projectile a large crossbeam is placed across the top of the machine. The arm slams into the crossbeam during the firing, stopping the arm but allowing the projectile to carry on. The violence of the arm hitting the crossbeam would cause the entire machine to kick forward giving them the common names of Onager and Mangonel, both referring to the kicking of donkeys.²⁹

The arm in single-armed torsion machines often ended simply in a cup to hold the projectile, though there is some evidence that later versions employed a sling to increase the length of the arm and thereby increase its mechanical advantage.³⁰ With a sling holding the rock attached to the end of the arm the range is increased by the sling swinging in an arc around the back of the arm. When a predetermined point in the arc was reached one end of the sling released, hurling the rock with more energy than could be imparted by the acceleration of the throwing arm by itself.

The second main category of catapults is those that rely on a rotating beam. These machines rely on a single large beam that rotates freely on a central axle. The beam itself is positioned so that there is a long end and a short end. The long end, that which has the most distance from the axle, is where a sling is attached to hold the projectile. The short end is where the force is applied to accelerate the longer side of the arm and throw the projectile. These are the trebuchets, and again there are two


³⁰ Chevedden, “Late Antiquity,” 137.
major types. The oldest of these is the traction trebuchet which relied on humans pulling on the short side of the throwing arm. The second and vastly more powerful type is the counterweight trebuchet. This type of trebuchet replaced the human pulling crew with a large counterweight either fixed to or hanging from the short end of the throwing arm.

The traction trebuchet is a very old machine. Its earliest incarnations were improvements on the ancient weapon, the sling. The sling generates more power than simply throwing a projectile by effectively making the arm longer. Making the arm longer generates more rotational speed and generates more power. By fixing the sling to the end of a staff the throwing arm is extended even further and thereby generating more rotational energy and imparting more power to the projectile. The next step to increase the power of the sling was to mount it on a vertical pole for support. With the staff mounted the operator could now pull on the end of the staff with his entire body weight, rather than using muscular power alone.  

The traction trebuchet was developed from the mounted staff sling. By using more than one person to pull the throwing arm the power is increased even more. From this rather simple revelation came larger throwing arms, more elaborate support structures, and heavier projectiles. The single pole holding the throwing arm was inherently unstable, particularly as the throwing arm is pulled on violently. Expanding the support structure from one pole, first to two and then to more, made the throwing arm more stable, more accurate, and able to have multiple pullers. By

this point the simple staff sling was becoming something entirely different; it had evolved into the traction trebuchet.\textsuperscript{32}

The traction trebuchet consists of a throwing arm attached to an axle supported by a framework. The axle divides the throwing into two unequal lengths at a ratio most commonly 5:1 to 7:1.\textsuperscript{33} A frame, usually triangular shaped, supports the axle. The frame is mounted to a wooden base to maintain the structural integrity of the support frame. The shorter side of the throwing arm has varying numbers of ropes attached to it; these ropes are for the crew manning the engine to pull on to provide the power. On the long end of the throwing arm is the sling. The sling has one side attached slightly before the end of the throwing arm, and at the very end of the throwing arm is a hook. The loose end of the sling would be attached to the hook when the arm is resting in the down position and the projectile is loaded. When fired the crew pulls at once, the throwing arm rotates, and the projectile swings out in the sling. When the sling reaches its apex the loose end slips off the hook and the projectile flies free of the sling.

A crew member was also placed at the sling to assist in the firing. This crew member, the firer, played the most important role in the firing process. His job was to insure that the shot fired correctly. To begin with he had to keep the shot in the sling, properly seated, and ready to fire. This was achieved by holding the shot within the sling directly. The next step in the firing process was when the crew pulled; the slack

\textsuperscript{32} Needham, “China’s Trebuchets,” 109.

\textsuperscript{33} Donald R. Hill, “Trebuchets,” Viator 4 (1973), 114
in the sling was taken up as the arm began its swing. The firer held onto the sling even as the arm began to move. By holding onto the sling as the arm was swinging the arm would flex under the additional weight of the firer. As the arm gathers speed the firer releases the sling and the wood straightens out snapping the arm forward. Without the firer hanging onto the sling the sling swings outward away from the center axle. The release timing of the sling is important. An early or late release would negatively affect the trajectory of the shot; too early and there is not enough flex in the wood, too late and the additional weight of the firer would slow the arm’s rotational velocity too greatly.

The first traction trebuchets were built with relatively small support structures of lightweight poles. Correspondingly, these are termed pole-framed trebuchets. The pole-framed trebuchet is a rather small and weak siege engine. The pulling crews were small, on average from eight to forty men. This many men on a small machine would be quick but largely ineffective against large castle walls. To damage the thick walls of castles larger projectiles were needed, and larger projectiles meant everything else about the machines also had to be bigger. The throwing arm and the support structure grew right along with the projectile weight. Soon the simple pole-framed trebuchet had given way to a larger trestle-framed machine.\(^{34}\)

A trestle-framed trebuchet was constructed not from small poles but substantial timbers. The support structures built with these timbers were large and heavy. In addition to increasing the size of the timbers the support structure was

designed differently. Instead of simple triangular shaped bracing, which was sufficient in a pole-framed engine, the trestle-framed version had reinforcing beams across the triangular uprights to strengthen the support structure. These reinforcing beams, known as trestles, give the trebuchet its name. The trestle-framed trebuchet was likely invented in the west and spread back east during the Crusades. This is evidenced by the name -- the Frankish trebuchet -- given to it by the Arab chroniclers.

The traction trebuchet was invented in China possibly as early 385 B.C. but definitely by the third century A.D. It stayed in Chinese lands for some time before spreading westward into first Arab and then Greek lands. Its use is believed to be documented in the Miracula of St. Demetrius at the siege of Thessalonika by John I in 597 A.D. The Muslims made use of them during the conquest of the seventh and eighth centuries.

The first clearly documented appearance of a traction trebuchet in Europe is believed to be in 885 at the siege of Paris. The accounts of Abbo describe a siege


38 Chevedden, “Hybrid Trebuchet,” 181.

39 Chevedden, “Hybrid Trebuchet,” 179-222.
weapon being constructed outside the walls of Paris by the attacking Norse. The weapon is not described in great detail but the account does provide enough clues to suggest that the weapon in question is not a torsion device. Also counter to the idea of the weapon being a torsion-powered device is the distinct lack of any evidence for torsion powered machines for a long period of time after the fall of Rome. The knowledge of constructing and operating these machines seems to have disappeared, along with the Roman Legions, from Europe.

Carroll Gillmor attempts to trace the connection between the traction trebuchet and its use in the west in the ninth century. Gillmor analyzes in detail the account of Abbo and the reasons why his description reflect a traction trebuchet. The main evidence for this belief, other than the somewhat fuzzy description, is the use of the word mangana. This is one of the first instances of the word mangana appearing in western texts, the new word indicating a new machine. Through earlier uses of the word Gillmor is able to trace the traction trebuchet to the siege of Angers in 873 and a reference to it in the Vita Hludowici, written circa 850, during the account of the siege of Tortosa in 808-809. These accounts do not provide a description of the machine, so it is hard to determine the nature of these machines. What these accounts do successfully is show a possible route of transmission of the idea through Aquitaine

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from Muslim Spain. Gillmor instead suggests a route through Italy from Byzantine sources. Gillmor hedges her bets by suggesting that the machine entered Western Europe from both Italy and Spain at the same time.

The traction trebuchet’s use in sieges was widespread geographically, though its effectiveness was limited in most siege encounters. The projectiles thrown by traction trebuchets were small, generally only around one hundred kilograms at the upper limits of known machines. These rocks would have little effect on all but the smallest fortifications. Because of this the use of the traction trebuchet was limited largely to support roles in sieges. The traction trebuchet would be employed as anti-personnel weapon by both the attacker and defender. The attackers would use the traction trebuchet to harass the garrison and also to force the defending archers to break their fire and seek cover. By being able to disrupt the firing of the archers the traction trebuchet made it possible for a siege tower to be advanced to the walls, or to rush materials to fill in a moat. It was also employed for psychological warfare. The attackers would throw the heads of captured spies or defenders back over the walls and into the castle. This would have two effects: the first and most obvious effect would be the lowered morale when your friend’s head landed on you; the second effect would be the possibility of spreading disease in early attempts at germ warfare. A defending garrison, often low on food and clean water, was ripe for disease to

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46 For some sizes see Appendix.
spread like wildfire through its ranks, and extra rotting body parts would only serve to accelerate any diseases that might be festering.  

The defenders eventually began to place their own trebuchets inside the castles to return fire. These trebuchets were employed to force the attackers to camp farther back from the walls. The trebuchets, with the archers, made it a dangerous proposition to stand within roughly a two hundred yard area outside the castle walls. Also, trebuchets were used to fire on the attackers’ siege weapons. There are accounts from the Crusades of attackers’ siege weapons being destroyed or damaged by the defenders’ artillery. The lighter and smaller frame of the traction trebuchet made it possible for the defenders to reposition the machines and turn them to face the attackers’ artillery. In addition to those methods trebuchets could also be used as anti-personnel weapons during an attack. A few well-placed shots could easily slow or break up an organized attacking force as it was moving towards the castle walls.

The traction trebuchet had many advantages in siege warfare. The simple design and construction made it both easy and cheap to both design and build. Also the pole-framed trebuchet used little timber compared to other siege weapons such as towers and battering rams. In fact Rogers refers to it as “the simplest such machine


48 Jim Bradbury The Medieval Archer. (New York: 1985), 5-6. See Also Appendix.

49 Rogers, Latin Siege, 58.
Besides the simplicity of the construction and use, the traction trebuchet has an impressively rapid rate of fire. Tarver was able with minimal amounts of practice to fire four rounds a minute with some accuracy. Aegidio de Colonna also stated that the traction trebuchet was faster than any of the other types of trebuchets. As already mentioned above, the pole-framed trebuchets were small enough to move and aim with some ease. This, along with the person holding the sling being able to aim the shot by holding the sling slightly to the left or right, makes the traction trebuchet more amenable to firing at different targets.

The traction trebuchet had several drawbacks that necessitated the development of larger and more powerful weapons. Most importantly, the projectile hurled by a traction trebuchet, even a large one, is only approximately one hundred kilograms. The large traction trebuchets that throw projectiles of that weight require massive timbers, huge support structures, and, most importantly, large numbers of men on the pulling crews. Trestle-framed trebuchets would have already sacrificed many of the advantages of mobility and simplicity that the pole-framed trebuchets enjoyed. Also, the large crews of traction trebuchets make easy targets for defending

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soldiers to attack. According to Donald R Hill, these trebuchets are "wasteful of manpower and vulnerable to attack." It is easy then to see why a counterweighted trebuchet was needed.

The counterweight trebuchet was developed from the traction trebuchet with a slight change in the design. Instead of a crew of men pulling on the short end of the throwing arm a large weight was employed to produce the downward force necessary to launch a projectile. These counterweights were large; some have suggested sizes up to ten tons. Counterweights this massive required equally large support structures and throwing arms. These machines were capable of throwing rocks weighing over one hundred kilograms and in some cases over two hundred kilograms. Finally the trebuchet was an engine capable of destroying castle walls.

The counterweight trebuchet does not differ significantly from the large trestle-framed traction trebuchets in terms of design. The major differences are simply in the scale of the construction. Whereas a traction trebuchet had to be small enough to be fired using only human power a counterweight trebuchet was not limited by such restrictions. Instead, it could be as large as would be feasible for the soldiers and carpenters pressed into building it could make. This means that these

54 Hill, "Islamic Trebuchets," 109.


56 Appendix.
weapons quickly grew to enormous sizes and were throwing projectiles of sizes that had before only been imagined.

There are some other minor differences in the counterweight designs. The sling was extended from a shorter sling to a much longer version. The longer version extended the length of the arm even more, further raising the power capabilities of this machine. A second minor difference was the ratio of the throwing arm had changed. The traction trebuchet operated with a rather uneven ratio between the long and the short arm as mentioned above. The larger counterweight trebuchet made use of smaller ratios in arm lengths. Whereas the traction trebuchet had a ratio of 5:1 to 7:1, the counterweight had a ratio of 3:1 or even as low as 2:1. 57 Another area where the counterweight and the traction trebuchet differ is in the firing release. The traction trebuchet had a man holding the shot in the sling and releasing it at the proper times; this firer also held the throwing arm in the down position. A ten-ton counterweight precludes the use of humans to hold down the throwing arm and a hundred-kilogram projectile is beyond the ability of most single men to hold. The human firer was replaced with a firing pin mechanism whereby a rope attached to a pin of some sort could be pulled releasing the throwing arm. 58

The weight that gives the counterweight trebuchet its name was attached to the short end of the throwing arm. The long side of the throwing arm was drawn down and the short side with the weight was raised into the air. When the long side

57 DeVries, Military Technology, 137; and Hill, “Trebuchets,” 114.

58 There is no precise information regarding the shape or function of a firing mechanism, though Payne-Gallwey offers a likely interpretation.
was released the short side fell, accelerating the long side and the sling and the shot arced outward. Again when the sling reached the proper angle the projectile was loosed and the shot was on its way. There were two types of counterweight, the fixed weight and the free swinging weight. The fixed weight was attached directly to the throwing arm while the free swinging weight was hung in large baskets or boxes on a pivot from the end of the throwing arm. The pivoting weight allows the weight to fall in a much straighter line and thereby impart more energy into the swinging arm.\(^59\)

Where the counterweighted trebuchet was invented has never been sufficiently documented or proven by anyone. Kelly DeVries places its invention in the Mediterranean area in the mid-twelfth century, with its earliest use at the 1165 siege of Zevgmion by Byzantine forces.\(^60\) DeVries, however, does concede that the Byzantines may have learned of it from another source. Donald R. Hill agrees with DeVries' assessment of its origin being in the Mediterranean region.\(^61\) Joseph Needham points to a slightly different idea, arguing that it was a development that was made in diverse locations contemporaneously based on similar technology, though he credits it to Arabic sources.\(^62\)

Regardless of where the counterweight trebuchet was invented it moved quickly throughout the world: into Northern Europe, the Middle East, North Africa, and beyond.

\(^{59}\) Aegidio, *De Regimine*, 427.


\(^{61}\) Hill, “Trebuchets,” 104.

\(^{62}\) Needham, “China’s Trebuchets,” 111.
and back into Asia where the trebuchet was born. The later Crusades likely helped spread the knowledge of the counterweight trebuchet as both Muslims and Christians alike fought in sieges that featured the counterweight trebuchet. According to DeVries the Muslims were quite fond of the weapon and it played a major role in their sieges in the Holy Land.

The earliest references to the larger counterweight machines come from the late twelfth century. The earliest European source places a counterweight trebuchet at Castelnuovo Bocca d'Adda in 1199 in northern Italy. An even earlier appearance is in an Arab military manual written for Saladin in 1187. Chevedden tries to place the machines earlier than that in Greek sources, pushing the time of invention to the late eleventh century, including at the siege of Nicea in 1097. The most conclusive evidence, though, is that which comes from the later half of the twelfth century, all from Byzantine sources. This is suggestive of a Byzantine invention of the machine. Following the later dates, that invention spread first into Arabic armies and then into the Christian armies back to Europe.

The counterweight trebuchet was not used in the same manner as the traction trebuchet; instead, it was used for battering down the very walls of a fortification. These machines were capable of throwing projectiles large enough to destroy towers

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63 DeVries, Military Technology, 138; and Needham, “China’s Trebuchets,” 111.

64 DeVries, Military Technology, 138.

and walls. Some sources suggest that the shots were capable of destroying defenses in a single shot. The counterweight piece was also used for psychological warfare. One effect is seen in Edward I’s adventures with War Wolf, where simply by constructing a trebuchet the garrison was willing to surrender. A second psychological effect would be when the counterweight trebuchet was used to hurl dead animals and dead soldiers into the defending castle. As mentioned with traction trebuchets this had the twofold effect of spreading disease and lowering the garrison’s morale. What had changed from the traction trebuchet to the counterweight is that now horses and mules as well as entire bodies could be thrown by the trebuchets, increasing the likelihood of disease.

This powerful new weapon’s potential in sieges was quickly realized and it was employed to devastating effect in sieges. Edward I used trebuchets to great effect in his wars against the Scots, with thirteen trebuchets hurling 600 stones at the siege of Stirling in 1304. At the siege by the Crusaders of Acre in 1191 artillery pieces wrought destruction upon the walls of the city, one source saying the walls had been brought down to only the height of a man. While it is unclear based on the available sources if this was counterweight or traction trebuchets, the damage inflicted is indicative of the larger counterweighted machines. Huuri agrees with this


69 In Rogers, *Latin Siege*, 228.
assessment, suggesting that both traction and counterweight trebuchets were being employed.70

The counterweight trebuchet has many advantages over the smaller traction trebuchet. First among these advantages is the size of its projectiles. Shots ranging from fifty to over two hundred kilograms were possible. These shots would hit with drastically more force than the smaller shots from human-powered trebuchets. Crew sizes would also be an advantage. Once the treadwheel had been added to the trebuchet to draw back the arm, the numbers of crew members necessary to draw it back is significantly less than what was required to move it using only a block and tackle system attached to the arm.71 A smaller firing crew provides fewer targets for the defenders’ archers and sallies to attack.

Another advantage to the counterweighted machines is accuracy. A weight attached to a beam will fall at the same rate and in the same way almost every time. Most importantly for power and distance it will fall with the same force each time. This provides an alternative to the human pulling crew providing the force where the force is variable from throw to throw based on the humans’ performance. Aegidio addressed this issue among the types of counterweighted trebuchets by saying that those with a fixed counterweight attached to the throwing arm are the most accurate

70 Kalervo Huuri, *Zur Geschichte des Mittelalterlichen Geschutzwesens aus Orientalischen Quellen*. (Helsinki, 1941) 94.

71 No dates have been suggested for the addition of the treadwheel to the counterweight trebuchet. However one can expect that this was a rapid development based on the prevalence of treadwheel cranes as illustrated in Andrea Matthies, “Medieval Treadwheels: Artists’ Views of Building Construction” in *Technology and Culture*, (Baltimore, 1992) 511-547.
whereas those with a swinging weight throw farther and with more force. By combining the two, creating a trebuchet with both a fixed weight and a swinging weight, a compromise between the two was achieved. 72

The counterweight trebuchet also had drawbacks to its effectiveness, though by and large these were outweighed by its advantages. The counterweight trebuchet had a slow rate of fire as compared to the traction trebuchet. The throwing arm had first to be steadied after a shot as the rotational inertia gave way to friction after the shot. Then a cable of some sort had to be attached to the long side of the throwing arm. This cable was used to draw the arm back into a firing position. Once down, the throwing arm was attached to the firing mechanism, the sling was repositioned, and a shot was loaded. This process took place after each shot and took up most of the time and manpower that was required to use a trebuchet.

Another disadvantage the counterweight had was its own complex design. A traction trebuchet is a rather simple machine that with a dedicated (or motivated) team of builders could likely have been constructed in only a few days. Likewise, the only materials needed for a traction trebuchet’s construction are wood, rope and iron fittings -- all things readily available in a military camp. 73 The counterweight trebuchet was a larger and more complicated machine. It required a large amount of a heavy material to provide a counterweight. The design of its support structure was,

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72 Aegidio, De Regimine, 427.

73 DeVries, Military Technology, 138
by necessity, stronger and larger, requiring larger, specially selected, pieces of lumber and much more time to construct.

Based on the above understandings of traction and counterweight machines it is now possible to examine the viability of hybrid trebuchets. The hybrid machines described by Chevedden operate using much of the same techniques and technology as the above detailed trebuchets. The similarities and differences of the hybrid machines from the accepted forms can provide additional information about their use, construction, and roles in sieges.
Chapter Three: The Hybrid Trebuchet, from Traction to Counterweight Engines

The traction trebuchet by itself was not overwhelmingly powerful; its use was limited largely to a supporting role in most sieges. What was needed to make the trebuchet a truly important piece of siegecraft was a way to make it more powerful. The traction trebuchet was restricted to smaller projectiles, generally under fifty pounds. During the twelfth century the counterweight trebuchet with its massive weights had become the new weapon of choice in most sieges led by Western Europeans. The step up, however, from the smaller human-powered engines to the enormous counterweight devices was not the application of ancient technology to newer ends, but, rather, somehow a quantum leap in design. The supposed transition between the traction and the counterweight trebuchet was called a hybrid trebuchet and is depicted as having both a partial counterweight and a pulling crew to launch the projectile.

The traction trebuchet was severely limited by its smaller supporting pole frames. The Frankish trebuchet was developed in Western Europe with a much larger design for its support structures. This trebuchet was still human powered but had incorporated the trestle frame design for the supporting structure. A more structurally sound frame allowed for the components of the throwing arm and axle to increase in size. The increase in size would also indicate an increase in weight of the throwing arm itself and allow for an increase in the weight of the projectile in the sling. Yet it was necessary to keep the weight of both the arm and the missile light enough to be launched efficiently by a human-powered crew. The solution seems to have been a
small counterpoise on the short side of the throwing arm that offset this increased weight and still enabled the human crew to pull with effective amounts of force to fire a missile.

There are many representations of human-powered trebuchets from the Middle Ages. Many of these representations show engines that could be interpreted as hybrid machines. Frequently these images will show what looks to be a large block of wood or some other sizable piece of material attached to the short end of the throwing arm. Other descriptions will indicate large pieces of wood being used in the construction but without any actual clue as to their place in the machine.

These same descriptions of the hybrid machine have led some to interpret incorrectly the design as a conscious attempt to add the force of gravity on the counterweight to the down pull of the crew. This theory has several problems with it that will be explained in detail below. Rather than an attempt to add the falling weight to increase the speed of the throwing arm, these weights were more likely a new technique based on ancient technology. It was a use of the same technology used in irrigation equipment, cranes, and even swords to offset the weight of the arm and enable it to be easily launched by a complement of soldiers during a siege.

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74 For example see the Crusader Bible and the Maciejowski Bible.

The traction trebuchet was effective as a support piece of artillery during a siege; it was not, however, effective for inflicting damage to any serious fortifications. As the arms race of castles and sieges escalated, fortifications developed thicker walls and more complicated architecture. As the walls grew thicker the small missiles fired by the traction trebuchet had little effect. This did not preclude their use in sieges; rather, as has been shown above, they were useful in keeping the archers in check while towers and ladders were advanced to the walls or moats were filled so the foot soldiers could attack. Siege commanders and engineers could see that this particular weapon had much more potential in sieges than as anti-personnel weapons. If the projectiles could be made larger they could have a devastating effect on the very walls of the fortifications themselves; rather than shooting small rocks, they could be used to hurl boulders to wreak devastation and havoc on the defenses. Before the machines were stepped up to this size, however, they went through a period of growth and transition from human-powered to gravity-powered.

The primary proponent in the secondary literature for the idea of a hybrid trebuchet is Paul Chevedden who first lays out the details of this particular machine in an article in a festschrift for Joseph O'Callaghan. In this article Chevedden cites many various, primarily Arabic, sources. In a later article, "The invention of the counterweight trebuchet: a study in cultural diffusion," Chevedden once again

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describes the hybrid trebuchet, placing it as early as at the Viking siege of Paris in 885.\textsuperscript{77}

Chevedden explains the hybrid trebuchet through Arabic sources and several medieval illustrations. He depicts it as using a blend of both human and gravity power. What is perhaps most important is his description of its development. Chevedden states that “it does not appear to require great inventiveness” to add weight to the traction trebuchet to add power to its throwing arm.\textsuperscript{78} He then goes on to explain that it was probably through experiments that artillerists learned that by adding weights to the butt end of a traction trebuchet’s throwing arm they could increase its power. The approximately four hundred years between the advent of the traction trebuchet in the West and the development of the counterweight trebuchet is blamed largely on the technological innovation that is required to shift from the known successful traction trebuchet to the more risky counterweight device. Chevedden even says that the success of the traction version was itself enough to stymie the development of any improvements on it. What would likely be more of an issue would be the professionalization of the soldiers.

Soldiers prior to the twelfth century were largely conscripts who served as part of their feudal commitments, not full time soldiers. It is entirely possible that the feudal troops had little or no previous experience in war or combat.\textsuperscript{79} Those

\textsuperscript{77} Chevedden, “Counterweight,” 99.

\textsuperscript{78} Chevedden, “Hybrid Trebuchet,” 183.
professional soldiers that were in the armies were nobles who had little training in the fields that would lead to serious developmental changes in siege engines. Thus it was not success or any particular fear of changes that stalled the shift from human to gravity power but a lack of training towards engineering. It was not until a more professional army was employed that serious attempts to improve on the trebuchet could begin. Also, those soldiers who had built a trebuchet for previous sieges would not necessarily be present at the next siege to offer their advice. The lack of a professional engineer building the trebuchets would have more impact that most anything else.

Chevedden goes on to detail machines that he interprets as having both a counterweight and a pulling crew. Chevedden’s sources and descriptions of the hybrid trebuchet stretch from the Mediterranean and the Middle East to the Latin West and even ranging into the Scandinavian regions. The earliest of these hybrid machines that he describes is at the siege of Paris by Norsemen in 885–886\(^79\). Another is described at the siege of Manzikert in 1054, The most detailed description, however, comes from the siege of Damietta in 1218. This hybrid trebuchet is described as having a 370 kg weight and a 185 kg projectile.

\(^79\) The issue of professionalization of feudal soldiers is largely undecided, though for an analysis of the issues involved with feudal levies, see Bernard Bachrach, “Military technology and garrison organization: some observations on Anglo-Saxon military thinking in light of the Burghal Hidage,” Technology and Culture, 3, no. 1 (Chicago, 1990) 1-17.

\(^80\) Chevedden, “Hybrid Trebuchet,” 196. And also “Counterweight Trebuchet,” 99.
Perhaps the most difficult issue when dealing with arms and armour of any kind in the Middle Ages is the difficulties in naming practices. Specific weapons rarely had set names. The trebuchet is no exception; according to Chevedden, many of the Arabic names for trebuchets are based on the design of their support structure, following the Chinese naming practices.\(^81\) The earliest trebuchets were pole-framed devices that were clearly based on and influenced by the Chinese engines. The Arabic term 'arradah refers to these earliest pole-framed designs and the term manjaniq then refers to a larger and sturdier trestle-framed device. Chevedden then refers to Arabic technical literature that specifies three different names for trestle framed engines based solely on the design of the support: first is the Arab trebuchet with a trapezoidal frame, next is the Persian or Turkish trebuchet which had a triangular frame based upon the Greek lambda, and last is the Christian or Frankish trebuchet with a trestle in the shape of an isosceles triangle.\(^82\)

These differentiations in the naming of trebuchets based on the shape of its support structure continue in the European languages as well. However, the variety of languages makes it harder to name specifically types of trebuchets beyond noting that the structure of a trebuchet gave it its name. The most general naming conventions in Latin that can be applied to trebuchets are the manganellus for the lighter pole-framed engines and the petraria for the larger trestle-framed versions.

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\(^81\) Chevedden, “Hybrid Trebuchet,” 199.

\(^82\) Chevedden, “Hybrid Terbuchet,” 199.
Chevedden’s sources now cause some problems, as the naming practices for trebuchets have already been established and have no basis on the propulsion systems, size of the projectile, or even size of the machine. Therefore, because the names had already been established, a hybrid version of the trebuchet did not get a separate name for the new type of machine. To deal with these names Chevedden interprets sources describing “big” trebuchets as attempts to describe a hybrid trebuchet using the existing naming conventions. However these sources offer little or no description of the “big” trebuchets. Another issue here is that there are only two references to a “big” trebuchet prior to the twelfth century, after which point it most likely refers to counterweight trebuchets.  

Western sources present a similar terminological problem. Many of the terms that Chevedden interprets as meaning hybrid trebuchets refer either to large trebuchets such as magna petraria or to terms, for instance the term “Balearic,” that are also applied to counterweight machines. Balearic was used as a term for the most powerful weapon in the siege arsenal, including the counterweight trebuchet. The Old French term chaable or calabre is also applied by Chevedden to the hybrid trebuchet. His rationale for this interpretation is the basis of those terms in the word chable, which can mean both rope and hoisting tackle. According to Chevedden, this suggests that the name stems from the cables attached to the main beam for a pulling crew to use. However, the alternate meaning of “hoisting tackle” can easily suggest that a block and tackle system was used to draw back the arm, as is shown and

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83 Chevedden, “Hybrid Trebuchet,” 201.
described in accounts of a counterweight machine.\textsuperscript{84} Perhaps most problematic for Chevedden, however, is the descriptions in Spanish sources. Once again, there are no specific terms coined or applied to hybrid trebuchets. And the most detailed descriptions in the \textit{Siete Partidas}, a law code of Alfonso X compiled in 1265, offer two genres of trebuchet: those powered by a counterweight and those powered by human traction power. There are no descriptions of a genre-breaking hybrid machine in the \textit{Siete Partidas}.\textsuperscript{85}

Other medieval sources also refute the idea of a European hybrid machine. Aegidio de Colonna in his \textit{De Regimine Principum} offers up advice to young Philip IV (1285–1314) of France prior to his taking the throne. Some of the advice included here is on warfare and in particular siege warfare. Aegidio describes four styles of trebuchet and their respective benefits and faults. First is the trebuchet with a fixed counterweight attached to the butt end of the arm. According to Aegidio this type was the most accurate though did not have the longest range. The second type had a hanging counterweight that was allowed to swing freely. This type had a longer range but was less accurate than the fixed counterweight designs. The third type had both a fixed and hanging counterweight. This type was to combine the best attributes of both the first two types. The fourth type of trebuchet is that which is pulled by human power. This trebuchet could throw stones at a much faster rate than the other types of machines, but the stones were much smaller.

\textsuperscript{84} Chevedden, “Hybrid Trebuchet,” 208-211

\textsuperscript{85} Chevedden, “Hybrid Terbuechet,” 211-212.
That Aegidio does not include a type of machine that has both a weight and humans pulling on it at the same time suggests that this type did not exist or was not very successful as a weapon. If this type of trebuchet was known to Aegidio then surely he would have included it in his descriptions. Likewise, it is unlikely that he took for granted that these human-powered machines would have weights on the throwing arms, as he does include the description of the third type of machine as having both hanging and fixed counterweights. Also, the hybrid machines as described by Chevedden fire substantial stones that have a devastating effect on fortification walls. Aegidio says clearly that these types of machines were less powerful than the first three types of trebuchets described above.

There are several fundamental problems with a siege engine that is powered by both human and gravity power. There would almost certainly be issues with coordinating a pulling crew and a trigger man to release the sling holding the projectile. On top of that the pulling crews described by Chevedden would be prime targets for archers and cavalry attacks. Finally, the sources that Chevedden bases his interpretations on are not overwhelmingly convincing.

Assuming that these machines were fired in the same manner as the traction trebuchet they were based on, the sling would be released by a shooter holding the sling at the proper time. This technique would likely lead to issues with coordinating a pulling crew and a shooter to release the sling holding the projectile. In order to fire effectively a hybrid trebuchet of any size, a large pulling crew and one or more soldiers holding the sling would be required. Chevedden’s sources often indicate pulling crews of well over a hundred men, in some cases upwards of 600 men are
used as a pulling crew. While the arm would actually rest in the cocked position when no one is pulling on it, it has been shown with traction trebuchets that pre-tensioning the sling and pulling ropes improves the coordination of the crews and thereby improves the fire. Pre-tensioning with the weights indicated would require more than one person to hold the projectile in the sling.

Needham’s research on Chinese trebuchets has some valuable information to add here. According to his research traction devices with 157 and 250 haulers both required two commanders for use; this makes it easy to believe that more than one holder would be required for launching artillery shots. Then to do this all day for several hours at a time would most certainly fatigue even the hardiest firing crew. On top of the issues just in holding down the throwing arm for it to be loaded and fired, a high level of coordination would be required to fire effectively the trebuchet. Any soldier pulling late on the ropes would have virtually no effect on the already moving throwing arm, therefore everyone on the pulling crew would have to pull simultaneously or else the rotational speed of the arm, and, more importantly, the sling holding the projectile would be adversely affected. As well as getting everyone to pull at the same time it would be of the utmost importance to make sure that the sling is released at the right time. With a crew of 600 men all pulling at once the

86 Chevedden, “Hybrid Trebuchet,” 187.

timing to release the sling would be of importance not only for the performance of the engine but also for the safety of the soldiers holding the sling.

A late release of the sling could easily cause the holder to end up being flung himself at least some height into the air. While the sling should not be free as the throwing arm begins moving the timing of the release is still important. Holding onto the sling once the arm is in movement would cause the arm to bend slightly and create a flex in the wood. This flexing would create a spring effect in the wood, adding the force of the wood straightening itself out to the rotational force giving extra force to the throw.

Peter Vemming Hansen, as a researcher with the Falsters Minder Museum in Nykobing, Denmark, has supervised and written on the experimental reconstruction of several trebuchets of various types. According to his research one of the hardest issues to address is how much flex to impart on the arm. Hanging too long on the relatively weak machines built for demonstration purposes slowed the arm speed to such a point that it impaired the throwing power. An early release would not impart enough flex to the throwing arm. It was difficult to coordinate properly the release of the sling with one holder and twenty pullers, taking several tries to begin to achieve satisfactory performance. It could therefore be extrapolated from this data to a machine having six hundred pullers and at least two holders that it would take multiple tries, even with a seasoned crew, to begin to achieve results that would be militarily useful.88

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Another issue that would be of concern, certainly for the holders, would be holding on too long to the sling. Assuming two holders and a pulling crew of six hundred if one of the holders were to cough, sneeze, or in some other way miss the timing for release the ensuing lift into the air, though brief, would certainly not be pleasant. While possible, one would not actually expect the holder himself to be flung with the projectile, however, he would quickly be several feet in the air. When he did let go of the sling he would land quite heavily, perhaps on the machine itself, causing possibly serious injury.

After the problems with coordination of the pulling crew and the holders the unlucky crews’ situation would hardly improve. A group of more than 600 soldiers manning one machine with little or no defensive capability would be an easy target for archers, artillerists, and quick moving cavalry forces. Several secondary sources suggest that this more than anything else necessitated and provoked the shift from traction to counterweight machines. W. T. S. Tarver’s work with a traction trebuchet reconstruction has suggested that a smaller crew makes it possible to build a defensive structure around the crew to protect it from incoming archery fire. The possibility of building a structure large enough to successfully shield 600 men pulling on the ropes would require large amounts of resources, manpower, and time.

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89 Vemming Hansen, Reconstructing a Medieval Trebuchet, 9.


91 Tarver, “Traction Trebuchet,” 158.
Likewise, it would be difficult for the holders to properly aim the projectile with their view obscured by the defensive structure.

It would also have to be a very large support structure that could enable a pulling crew of over a hundred men to effectively pull at once on the end of the throwing arm. Tarver’s reconstruction, though clearly not as large as the machines described by Chevedden, operated with at most twenty members on the crew. According to his experiments it was most effective with the crew pulling directly on the butt end of the throwing arm straight down rather than at an angle. This positioning also enables the defensive structure mentioned above. To be able to crowd over a hundred men directly under the butt of the throwing arm would require a very wide stance for the support structure and a wide end on the throwing arm for the necessary ropes to attach to. This need for a wide end may account for the descriptions and depictions of large traction trebuchets that caused Chevedden to believe that these machines had counterweights.  

The final problem is the size of medieval armies themselves. An army of 10,000 men with four of the large traction trebuchets with crews near the size of those described by Chevedden would have over one fifth of the army manning the trebuchets, assuming that the crews were made up of soldiers. Even during the rather static action of a siege having one fifth of an army in a relatively defenseless position is not a sound military tactic. The rapid fire rate of the traction trebuchet is not

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enough to provide the crews with an amount of safety. Many sources, including Chevedden's, reveal the presence of siege engines in the defending castle.\(^93\)

The defenders would see the attackers' trebuchets being constructed and have plenty of time to adjust the placement of their own engines in order to bombard the artillery of the attackers.\(^94\) All but the large counterweight trebuchets were in at least the accepted long distance of archers.\(^95\) Unexpected sallies made by the defenders' cavalry could quickly overrun the crews manning a traction trebuchet before any serious defense could be mounted. A serious attack made by defenders on the large pulling crews could easily lead to substantial numbers of casualties. With a fifth of an army committed to working the siege engines, a successful attack on the trebuchets could drastically reduce the number of fit men for fighting, thereby making it more difficult to maintain a siege.

As mentioned above, Chevedden's sources are not overwhelmingly convincing. Many of the sources that Chevedden interprets as referring to the hybrid trebuchet are ambiguous. Sources that are most often interpreted as referring to either traction or counterweight engines, Chevedden reads as referring to hybrid machines.

Many of Chevedden's sources referring to traction trebuchets are rather clear and accepted as human-powered engines. Likewise the route described by


Chevedden for the introduction and spread of the traction trebuchet from its invention in China to the Latin West is not questioned. However, the sources that are introduced as evidence for the hybrid machine is questionable. Chevedden addresses the evidence raised by Randall Rogers in *Latin Siege Warfare in the Twelfth Century*, claiming that the pictorial evidence that Rogers sites is inconclusive, yet later on he makes use of similar sources himself.

Chevedden will often refer to illustrations of what he perceives to be hybrid trebuchets. Often these illustrations show a larger butt end of the throwing arm. Some depictions show what appears to be a large beam oriented either horizontally or vertically across the end of the throwing arm. Attached to this beam are the rings for the pulling crews' ropes to anchor to the beam. Chevedden interprets these beams as large blocks of wood or some other heavy material positioned there in a deliberate attempt to serve as a counterweight. Other illustrations show the throwing arm being thicker at the base end. Once again this is interpreted as a counterweight mechanism.

There are more mundane reasons for both of these features in the illustrations. The beams across the butt end serve two purposes: the first is to serve as an anchor point for the support braces such as those shown on the trebuchet in the Crusader Bible. The second function of these beams is to spread the force of the crews pulling more evenly as well as spreading out the positioning of the pullers themselves to give them more room to pull. The thicker base shown on some trebuchets need not be a

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96 Chevedden, "Hybrid Trebuchet," 186.
conscious effort to increase the weight at that end of the throwing arm, but rather a way of showing that the arm tapers.

Chevedden first offers evidence in the form of primary accounts of trebuchets in use at various sieges. While describing the power that traction engines achieved in China Chevedden offers up a machine that had a crew of 250 men pulling the ropes and this machine fired stone shot weighing between 53.7 and 59.7 kg a distance of 77 meters.\(^97\) When two Armenian descriptions of trebuchets, there known as *babans*, are entered into evidence for the hybrid version the descriptions of what could be large traction trebuchets are interpreted as hybrid machines. The machines described by Chevedden weighed from 1,875 to 2,250 kg, had a pulling crew of four hundred men and launched stone shot weighing from 111 to 200 kg.\(^98\) What is lacking in these descriptions is how much a possible weight that would indicate definitively that there was a counterweight on these machines would have weighed. The information given here does not rule out the possibility of large traction trebuchets built on Frankish style trestles.

Looking more closely at the two previous machines described by Chevedden reveals a rather predictable event. The size of the pulling crew for the hybrid machine was approximately twice the size of the large traction trebuchet, and, correspondingly, the weight of its shot, if the lower weight of 111 kg is used, is also

\(^{97}\) Chevedden, "Hybrid Trebuchet," 183

\(^{98}\) Chevedden, "Hybrid Trebuchet," 187.
approximately twice the size of the earlier traction machine. A simple doubling of the pulling crew corresponds to a shot weight that is twice that of the earlier engine.

Even this 111 kg weight for projectiles is not so easily proven. According to the Armenian source the baban fired a shot weighing 60 litras. An Armenian litra weighed approximately one third of a kilogram, so 60 litras would weigh just about 20 kg. Chevedden deems this size projectile far too small for this size machine. So instead of sticking with the unit of weight given directly by his source he instead relates the litras to the Syrian ratl to reach the more acceptable weight of 111 kg and by ascribing the issue to a scribal error where 60 litras instead should be 600 litras.\(^99\)

Chevedden also reads descriptions of trebuchets being used to hurl various projectiles beyond their normal shot. Accounts of trebuchets being used to throw earth-filled sheep skins to attempt to fill in ditches built around city walls are used as evidence for the presence of hybrid machines in Arabic sources in 838. By ascribing a weight of 100 to 150 kg to these sheep skins Chevedden places these objects outside what he deems the capability of traction trebuchets. However, he offers no evidence for how he came by these weights.

Chevedden also offers the size of the pulling crews as evidence for a hybrid trebuchet. Crews up to 250 men are still categorized as traction trebuchets: once the machines require pulling crews of more than 400 men they are now hybrid machines.\(^100\) For example, the Arabic account of the conquest of Sind has a trebuchet

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100 For instance compare 213-4 with the machines described on 186-188.
referred to as "The Bride," this machine, with a crew of 500 men, is thus labeled as suggestive evidence for a hybrid trebuchet. Chevedden thereby ignores the naming practices and possibility that rather than being a new type of artillery they are instead large traction trebuchets built to a size to accommodate large numbers of men on a pulling crew in order to throw larger projectiles.

Another issue with Chevedden's sources is the rather imprecise use of the term "pullers." Chevedden uses the number of pullers described for a trebuchet to mean solely those men pulling on the ropes of a traction or hybrid trebuchet. Yet in his own examination of sources he describes soldiers in other positions as pulling a trebuchet. There can be several possible needs for men to pull trebuchets. There is the obvious position of pulling the ropes on the butt end of the throwing arm. This is largely how Chevedden uses the term pullers. However, some of his sources offer other possible interpretations of the term pullers. In describing a very large trebuchet used in the battle of Manzikert in 1071 his sources describe the trebuchet as being so large as to be transported in 100 carts pulled by 1,200 men. The crew of men that were tapped to move the trebuchet to the battle could thus also be called pullers. By this reasoning a trebuchet that was moved by 600 pullers could easily be mistaken as a machine that had a crew of 600 men pulling the ropes.

There is another possible meaning for pullers that need not apply to the men pulling on the ropes of a traction or hybrid machine. A counterweighted machine

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101 Chevedden, "Hybrid Trebuchet," 190.

102 Chevedden, "Hybrid Trebuchet," 188.
requires some form of force to draw back and prepare the arm to fire. Even with the treadmills shown in several medieval illustrations, a substantial number of men would be required to pull back the throwing arm. On machines without a treadmill most likely a block and tackle system could be used to draw the arm back. This system of drawing back the arm would require a substantial crew pulling on the ropes in unison, and these men could also be described as a pulling crew. This interpretation would agree with the already mentioned term *chaable* as referring not to the cables and ropes of the men pulling on the butt end of the throwing arm but instead to the tackle used by the men to pull back the throwing arm. Other possible pullers would be those who pull the rocks up to load the machine.

The prevalence of the sources examined by Chevedden should not be ignored. There were clearly at least a few traction trebuchets built with some characteristics of both traction and counterweight trebuchets. The issue here is that a hybrid trebuchet with a counterweight and a team of pullers does not work as described by Chevedden. Other interpretations of his sources, as well as the findings of other researchers, suggest some other possible models of how the larger traction trebuchets worked.

There are a number of possibilities for how the sources can be read. One possibility is that the trebuchets known in their native tongues as “big” or “large” trebuchets were just that: traction trebuchets built to a much larger size. The sources that Chevedden cites sometimes offer credence to that interpretation. For example the account of the Siege of Paris in 885–886 by Abbo refers to *mangana* being
prepared with “beams with great weight” *(magno cum pondere ... tigna).*\(^{103}\) The conventional reading of this source is “beams of great weight” or heavy beams for the main throwing arm. Chevedden, however, reads this phrase differently, as beams being prepared with great weights. In this reading it is not the beams that have a great weight but instead the beams are prepared and have great weights placed on them.\(^{104}\) Based on this evidence Chevedden says that the siege engines used in the siege of Paris were hybrid trebuchets. If one were to extrapolate on the conventional reading it is easy to interpret the accounts not of hybrid trebuchets but of larger traction machines. Larger designs would require larger and therefore heavier pieces of wood, and the largest single pieces of wood, the throwing arms, would be the heaviest pieces as well. This simply shows that there is additional room for interpretation.

As discussed above there is also evidence that the traction trebuchet became larger and heavier in construction once it entered into the arsenal of sieges in the west. There are numerous accounts and descriptions, particularly during the Crusades, that make mention of “Frankish trebuchets.”\(^{105}\) These trebuchets are generally described in such a way as to suggest that they are built of a trestle-frame design which offered more substantial support than the previous simpler pole-framed trebuchets.

\(^{103}\) Chevedden, “Hybrid Trebuchet,” 196.

\(^{104}\) Chevedden, “Hybrid Trebuchet,” 196.

\(^{105}\) Chevedden, “Hybrid Trebuchet,” 199.
These Frankish trebuchets would allow for a more substantial amount of force to be applied to the throwing arm. By building the Frankish traction trebuchets to a larger size, for example to a size rivaling that of the later counterweight designs, it would be possible to have larger pulling crews and larger projectiles as well. The largest of these traction machines could likely accommodate over one hundred men on the pulling crew easily. Taking into account the issues with the large pulling crews described above, these pulling crews, even with one-fifth of the men pulling late would still be able to fire projectiles considerably larger than those fired with pole-framed trebuchets with their smaller pulling crews.

In an article, published in the year 2000 Chevedden attempts to address some of his critics and clarify his position regarding the hybrid trebuchet. In this article Chevedden offers little new evidence for the existence of a hybrid machine; instead, he attempts to offer an explanation of its mechanics and demonstrate the viability of his descriptions. One of the first areas addressed in this article is that of the size of the pulling crews.

The article attempts to show that a crew of 600 men will fit under a reasonably sized support structure; it disregards the safety or efficacy of the crew during conflict though. 600 men, trapped behind the wooden shield also described, at the density suggested, namely five people per square meter, creates a dangerous situation in warfare. Should a fast moving cavalry force attack the trebuchet’s crew, or if the machine itself be set on fire, the crew is effectively trapped by both the

defensive structure and more importantly by the density of the people under the machine. With the defensive wall and the trestle structure the avenues for escape are narrowed significantly. So when a crew of 600 men packed at a density of five men per square meter attempts to run through these openings the possibility of men being trampled is increased; additionally, the bottlenecks would drastically slow the men trying to escape.

The other attempt to explain the 600 pullers at Damietta is to suggest that these pullers need not have worked all at once. Instead it is suggested that these 600 pullers worked in shifts. If this is the case then this crew need not indicate a hybrid machine. If the 600 men worked in three shifts of 200 men then the pulling crew would be roughly the same size as large traction trebuchets.

The article then tries to explain the hybrid trebuchet as a system where the weight is used as a counterbalance. While there is some merit in this interpretation the method and data used in the article are inaccurate. First addressed is the issue of the distribution of the weights. Using the hybrid trebuchet from the Siege of Damietta the engineering analysis attempts to show the balance effect of the weights and projectiles. This particular engine had a projectile of 185 kg and a weight of 370 kg. The analysis now supposes a 2:1 beam ratio, where the long arm is twice the length of the short arm. This ratio is incorrect to be applied to this trebuchet. The hybrid trebuchet would work fundamentally as a traction trebuchet, so the same


108 Cf. the tables of Chinese trebuchets in both the 1998 and 2000 articles.
reasons to have a long ratio on a traction trebuchet are the same reasons to have a long arm ratio on a hybrid. The short ratio of 2:1 is convenient for balancing the two weights; however, there are still problems that are created by these numbers. With a 2:1 arm the weight would try to rest with the short end hanging down when unloaded; this would require the arm to be drawn back and cocked before each shot. Simply the arm would be unbalanced when unloaded, and would stay unbalanced until the projectile is loaded. The other mistake made in the engineering analysis is the assumption of no inertia for the beam. The inertia of the beam would not be an insignificant amount of force. Ignoring the moment of inertia simplifies the calculations but does not accurately create a mathematical model for the trebuchet.

A more likely series of calculations is available in Donald R. Hill’s earlier article “Trebuchets” in Viator. These calculations are not as complex as the engineering analysis in Chevedden’s article; instead, they are more exhaustive and detailed. Hill takes into account the weight and inertia of the wooden beam and also adds the force of friction into the equations to determine a level of mechanical efficiency. Most importantly for this case is the range of beam ratios that Hill uses. He works the calculations with several different beam ratios to show the impact of the ratio on the performance of the trebuchet. What is shown is that the lighter trebuchet, essentially a traction trebuchet, works best with the higher ratios and the counterweight has the greatest range with the lower ratios. With the 2:1 ratio of

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Chevedden’s article the hybrid trebuchet would have a shorter range. More likely, to work properly, this trebuchet had an arm ratio of closer to 4:1 or higher. When taking into account the inertia of the beam itself the weight on the short arm would likely be able to achieve equilibrium with the unloaded long arm.111

One issue raised by increasing the size of the traction trebuchets is reflected partially in the account of the siege of Paris. The heavy beams mentioned by Abbo would be of a weight that would be substantial enough to affect the performance and perhaps even viability of the large traction trebuchets. This is where Chevedden’s interpretations may offer some valuable insight. Rather than applying counterweights to the throwing arms to add their weight to the force being used to fire the machines, it is viable to believe that a weight could be added to the end of the throwing arm as a counterpoise. The effect would be to negate the actual weight of the throwing arm as much as possible.

By balancing the weight of the throwing arm on both sides of the fulcrum any force applied to the short side would act only on the weight of the projectile and not the combined weight of the throwing arm and the projectile. The effect would be that a pulling crew on a large counterpoised trebuchet could throw a projectile of a greater weight than an identical crew on a smaller traction trebuchet. Also a larger crew, given the additional room of the larger frame, could throw substantially larger projectiles than those thrown with smaller pole-framed trebuchets.

111 See Figure 8 (center of gravity loaded vs. unloaded counterpoised trebuchet).
The concept of using a counterpoise to lift and move heavy weight would not be unknown to medieval engineers, or even to many civilians. Machines and devices at that time made use of a counterbalance to increase lifting capacities. Cranes and wells would both have used a counterbalance design to counteract the weights of the raising arms and their loads.\textsuperscript{112}

The oldest counterpoised device was the \textit{shaduf}, or water sweep, an irrigation device employed by the ancient Egyptians. The \textit{shaduf} was used to raise water out of wells and rivers. Essentially a counterpoised lever, the \textit{shaduf} had a single arm supported by a frame to hold it. The frame split the arm into two unequal lengths on a pivot. The shorter arm would have a small weight of various materials attached. The longer side had a bucket on the end which was dunked into the water. When empty the long arm is lighter than the short arm; however, when the bucket is full the arm is balanced somewhat evenly. By balancing the weight between the two ends evenly the average power input is evened out. The amount of effort that went into moving the water from one place to the next was minimized because the counterweight lifted the full bucket from the water and then the operator made use of the lever advantage to raise the counterpoise and dip the bucket again.\textsuperscript{113}

The \textit{shaduf} originated in the Middle East and was used there continuously up to the present day in some rural areas. It would be a simple step for Islamic armies to adopt this technology to military ends. Indeed, Donald Hill points to it as a likely

\textsuperscript{112} For an explanation of the \textit{Shaduf} see below

source of inspiration for the counterweighted machines. The basic idea behind a
counterpoised trebuchet is there; some modifications, however, are necessary to
transform the shaduf into a weapon of war. The counterpoise's weight ratio is not the
same for a trebuchet as for a shaduf. In the shaduf the weight should be balanced
when the weight is applied to the long arm; however, on a trebuchet the counterpoise
would serve to balance the long arm when empty. When loaded the long arm of a
trebuchet should be heavier than the short arm and the counterpoise. Also, the force input for a shaduf ideally should be low, to make it easier to move large amounts of
water over long periods of time. Because a trebuchet works on an unequal
application of force, the power input should not equal zero, but, instead, should be
significantly greater than the force required to move the projectile. What the shaduf
attempts to do is to minimize the work by making each portion of the process equal to
each other, meaning that the amount of power used to raise the full bucket of water is
not significantly different than the amount needed to lower the empty bucket.
Additionally a shaduf is moved slowly by only one or two men at a time, whereas the
counterpoised trebuchet employs a pulling crew of dozens of men and moves with
great velocity and violence.

Another possible genesis for a counterpoised trebuchet comes from quayside
cranes used in loading and unloading ships. The operation and construction of these
types of cranes are very similar to the shadufs described above. The quayside cranes
of this type are not well documented in the medieval period. I suspect that there are
several reasons for the lack of documentation of these types of cranes. These
counterpoised cranes were not as commonly employed throughout Europe as the
larger and more mechanically powerful treadwheel cranes. It is also possible that they were so common as to not be interesting or noteworthy to the medieval artists. The treadwheel cranes were used to hoist large loads and were often used in construction of cathedrals and other large buildings. Treadwheel cranes, if medieval descriptions are accurate, were also sometimes used for loading and unloading ships as well.\textsuperscript{114}

The more common use and sight of treadwheel cranes over most of Europe would make them more prevalent in artists' depictions and manuscript descriptions than a counterpoised quayside crane. Also, the majority of cranes depicted in painting and illuminations are shown in constructing cathedrals and also a number of them are shown in biblical illustrations of the building of the tower of Babel.\textsuperscript{115} This does not preclude the possible existence of counterpoised quayside cranes, but, rather, shows just how common the treadwheel crane was during the later Middle Ages. There are at least two illustrations of counterpoised cranes or lifting devices from the Middle Ages. One is a crane shown in Kyeser's \textit{Bellifortis}, the other is from Robert Valturio's \textit{De Re Militari}, showing a counterpoised device for lifting soldiers over a castle wall.\textsuperscript{116} These devices may only be fanciful and were never actually built but it does still illustrate that the idea behind a counterpoised crane was known.


\textsuperscript{115} Matthies, “Medieval Treadwheel,” 519-520, 528, 530, 532.

\textsuperscript{116} Konrad Kyeser, \textit{Bellifortis}, fol. 32v; Valturio in Giovanni Canestrini, \textit{Arte militare meccanica medievale.} (Milan, 1946), 170.
The problems with the counterpoised crane being the inspiration for a counterpoised trebuchet are also the same as the *shaduf*. Once again, the quayside crane is used slowly and with a net work of nearly zero so as to make it easier to move cargos over several hours at a time. There are, however, some possibilities that make the quayside crane more viable than the *shaduf* as inspiration for the trebuchet. The cranes would likely have been operated by larger crews than the *shaduf* and been built larger with a sturdier frame than the rather lightweight *shaduf*. The quayside crane could serve to bolster an argument for a northern European invention of a counterpoised trebuchet.

There is a final possible source of inspiration for the counterpoised trebuchet that would be familiar to every soldier of the Middle Ages and indeed to most of the populace itself. A sword pommel serves largely the same function as a counterpoise on a trebuchet throwing arm. The pommel at the bottom of a sword serves to balance the blade’s weight and make it a more effective weapon. The pommel is attached onto the sword beneath the grip of the sword and counteracts most, but not all, of the weight of the blade itself. While a sword lacks the axle that the trebuchet throwing arm swings by it does move in similar arcs while being used by a soldier in battle. Also the force applied to a sword is exclusively on one end of the weapon and it moves with great speed.

Despite lacking an axle, a sword does have a balance point where the weight of the sword is evenly distributed between the blade and the hilt. The sword functions almost as a lever around this balance point: when properly swung the tip moves forward, the pommel moves backward, and the balance point stays almost still.
The location of this balance point in relation to the grip of the sword affects the performance of the sword in its user’s hand. A balance point closer to the hilt makes the sword effectively lighter and faster; it hits, however, with less force. Conversely, a balance point farther down the blade and closer to the tip would make the sword feel heavier and thereby slower for the user to recover from blows. However, it would hit with significantly greater force than a more evenly balanced weapon.

Ideally a sword balances two to four inches in front of its hilt. This too reflects the balance necessary for a counterpoised trebuchet; the weight should be slightly heavier towards the long arm when the trebuchet is loaded.

While the pommel of a sword adds a significant amount of weight to the weapon, sometimes as much as one quarter the total weight, its placement affects the rotational inertia of the weapon drastically.\textsuperscript{117} Elaborating on the above examples can illustrate this point better. The sword with the balance at the pommel end, in this case it would have a larger than normal pommel, would bring the center of gravity closer to the balance point. If the sword had a weight of three pounds and the pommel weighed two of those three pounds there would be less than a pound of weight that was more than a hand’s span from the hilt. The sword, as it was swung and moved about, would require less torque to move about its axis.

Likewise, the sword with all the weight at the tip, having a smaller than normal pommel, would have greater rotational inertia. If this sword were also to weigh three pounds but the pommel was only about one-half of a pound then over

two pounds of weight would be outside a hand span of the of the hilt. This sword would feel to the user much more like an axe or a hammer than a sword, and would act accordingly.

Similarly, a small counterpoise attached to the short end of a trebuchet throwing arm would increase the actual weight, but the perceived weight of the throwing arm would decrease and, in fact, if properly balanced would negate most of the perceived weight of the throwing arm. With the weight negated when the firing crew pulled on the ropes they would only be pulling against the relatively light weight of the projectile, with lever advantage, instead of the weight of the projectile and the throwing arm.

There is reconstructive evidence for the viability of a counterpoised trebuchet. Tarver describes adding a small weight to counteract the weight of the throwing arm. The weight added to the throwing arm was not intended, as Chevedden describes, to add gravitational downforce, but as a balance mechanism. The ranges and projectiles listed in Tarver’s writings reflect the use of a counterpoised traction-powered trebuchet rather than a hybrid. Likewise the counterpoised trebuchet allows smaller pulling crews to be used with some efficiency; he lists a skeleton crew of four pullers firing a medium sized projectile approximately sixty meters consistently. This reflects an increased efficiency of force as opposed to Chevedden’s descriptions, which instead show a system of diminishing returns.\(^{118}\)

\(^{118}\) Tarver, “Traction Trebuchet,” 156.
This is not to say that all trebuchets reconstructed in this manner work with the same effectiveness. In fact a hybrid trebuchet designed by Peter Hansen Vemming for the Middelaldercentret in Nykøbing, Denmark worked so poorly as to be retired from demonstration purposes to serve instead as a piece of advertising sculpture for the Centre itself. The failure of the Middelaldercentre’s hybrid trebuchet can perhaps be attributed to its design being based not on the idea of a counterpoised trebuchet, but of a hybrid trebuchet as described by Chevedden. Rather that specifically weighting and balancing the weight based on the corresponding weight of the longer section of the throwing arm, the additional weight was intended to impart gravitational downforce to the pull of the crew. This type of setup would, in point of fact, not be a traction trebuchet, but, instead, be a very light counterweighted trebuchet. Had special attention been paid to the placement of weight as a counterpoise, the results would likely have been much more effective.119

The two major physics concepts at work on a trebuchet are the balance of torques – the weight of the projectile on the long arm, and the throwing force, either from weight or pulling crew, on the short arm – and moment of the rotational inertia. The moment is how much work is done on the end of the lever, and is a measure of torque. This is important in trebuchets because it is a measure of how much effort is required to accelerate the throwing arm around in an arc to launch the projectile effectively. In a traction trebuchet the crew pulling on the short end of the throwing arm provides this torque. In a counterweighted version this is provided for by the

119 http://members.iinet.net.au/~rmine/middel4.html
counterweight falling when the trigger mechanism is released. In the hybrid model described by Chevedden the torque is supposed to come from both the weight falling and the crew pulling.

If instead of trying to add the torque generated by the falling weight to the torque generated by a pulling crew the weight served to counterpoise the throwing arm, then the issue of rotational inertia would be addressed more directly. Rotational inertia is what maintains or inhibits circular motion of a weight mounted along an axis. Rotational inertia, for example, is what keeps a wheel spinning on its hub even after no force is being applied to it. Likewise, the rotational inertia of a wheel must be overcome before it can change its velocity. Something with a large amount of inertia would be hard to move initially, though once it was rolling would continue to roll easily and stopping it would equally as hard as starting it going in the first place.

Inertia is explained in Newton’s First Law of Motion. It states that an object at rest tends to stay at rest unless acted upon by an outside force; likewise an object in motion tends to stay in motion unless acted upon by an outside force. Rotational inertia functions much the same way, though it describes motion around a central axis as opposed to in a straight line. The higher the inertia the more force required to set in motion and also the more force to stop its motion once it has begun to move.

A child’s seesaw is a lever similar in construction to a trebuchet in its basic principle. It is easiest, however, to move a seesaw up and down when the two children are of approximately the same weight. When the two children weigh the
same amount the forces acting on the lever arm of the seesaw are equal. In this case the seesaw is in equilibrium and it takes only a small amount of additional force to move the seesaw up or down. The rotational inertia of this seesaw would be low as it takes only a small amount of force to move the beam in either direction once the weights and distances of the children are even. It would take only a small amount of torque to move the children so the moment of the seesaw could be low as well.

If, however, a large amount of torque were applied then the acceleration of the beam would be high, and, if high enough, the child on one side could go flying. By reducing the amount of torque required to move the beam initially and lowering its rotational inertia, it becomes easier to accelerate the beam. This would occur because the forces would still attempt to achieve equilibrium by virtue of being on a lever. So the torque applied on one side would manifest itself with a force equal to the amount of torque applied, but in the opposite direction.

If the seesaw were not balanced and the forces acting on either side of the arm were not balanced, then the force required to move it in would be more difficult in one direction and easier in the other. For example, if one child were heavier than the other the weight on the heavier child would make it easier to move that side of the arm down and the opposite side would be easier to move up. Conversely, the side with the heavier child would require more force to move up and the lighter side would require more force to move it down. In fact, the heavier side would require the

\[120\] See figure 4.

\[121\] See figure 5.
difference in the weights to move it higher and the same amount of force would be
required to move the lighter side down.

The centers of gravity on the various types of trebuchets illustrate how the
counterpoise affects the effectiveness of the pulling crew. The center of gravity on a
traction trebuchet is relatively far down the throwing arm. This means that, just as
with the blade heavy sword mentioned above, it takes more force to overcome the
moment of inertia to begin the arm swinging. The center of gravity on a
counterpoised trebuchet is moved closer to the axle than it is with the traction
trebuchet. This equates to the properly balanced sword; the counterpoise lessens the
amount of force required to overcome the moment of inertia. This means that the
same pulling crew from the traction trebuchet operating a counterpoised trebuchet
that is otherwise identical would throw the projectile a greater distance because more
of the force applied is acting on the projectile rather than on the throwing arm. The
center of gravity on a counterweighted trebuchet is actually on the short side of the
arm, meaning that the throwing would rest with the short arm in the down position.

We should not see the hybrid trebuchet as a development towards the
counterweight trebuchet. Instead it is an improvement on the existing technology.
The shift from a traction to a counterweight machine does not signal a progression of
science but instead is the quantum leap in design mentioned earlier.
A final means of determining the usefulness of the hybrid trebuchet is through examination of primary sources relating to sieges. The tasks assigned to the trebuchet were different based on its type. As already described above, the traction machine was used for support roles as it was unable to inflict much damage on thick stone walls, but had a quick rate of fire. The massive counterweighted devices could wreak havoc upon the castles and cities it was used against, but its slow rate of fire required additional support to defend it from attackers. If the hybrid trebuchet was as powerful as indicated by Chevedden then it should be used in a manner similar to the counterweight trebuchet and not simply for support. By examining the way in which sieges were resolved in the time prior to the advent of the hybrid trebuchet, it can be shown that the hybrid trebuchet did not show a significant increase in power over the traction devices.

The clearest sources for the use of siege machines and siege resolutions in the time prior to the eleventh century are Arabic sources describing the conflicts during the expansion and growth of Islam. Of these sources the history written by al-Tabarî is the most extensive, spanning thirty-nine volumes in modern edition. This work was produced circa 915 A.D. in Iraq. It is Tabari’s work that will provide a basis for discussion of Arabic primary sources.

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Tabari's work is by no means focused on military expeditions or matters, though it does provide some details about the various sieges. Examination of these sieges leads to some conclusions about the siege methods employed by Arab armies prior to the Crusades. The siege methods employed are focused more on ending the sieges without opening a breach in the walls. Instead the besieging army attempts to draw out the defenders to a pitched battle, gain access to the castle through trickery or some other means, or the siege is resolved without conflict. In a few rare occasions siege machines are employed; in no cases is the trebuchet (or any stone thrower) mentioned as resolving a siege by destroying walls.

The first resolution for sieges, that of drawing out the defenders to do battle, is by far the most common. This method is the easiest and probably the oldest way to resolve a siege. In this case the attacking army arrives at the defenders' fortification and may besiege it for a short time. During this time the defenders or the attackers may be waiting for reinforcements. As well there may be talks about ending the siege going on between the attackers and the defenders. Once the armies have agreed that the fortification will not surrender and the siege will not be lifted then the discussions of battle begin.123 The battle may occur on an agreed upon date or the defenders may simply emerge ready to fight. In more than one instance as the two armies faced one another on the field the battle was avoided and the issue settled with single combat.

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123 For an instance of the agreed upon battle see the siege of Banu Tamim in Tabari, The Victory of the Marwanids, trans and ed. Michael Fishbein (Albany: 1990), 62-63.
In either case, single combat or full battle, the siege is decided by force outside of the city.124

The siege of al-Taif involved heavy combat. The Arab army, led by Muhammad, laid siege to the city manned by the Thaqif. The Thaqif sequestered themselves inside the city after the initial engagement with the Muslims. The attacks on the walls went, according to Tabari, in the following manner:

[That day] a number of the Messenger of God's companions went under a testudo and advanced up to the wall [to make a breach in it]. Thaqif showered them with scraps of hot iron, so they came out from under [the testudo], and Thaqif shot them with arrows, killing some of them.125

This engagement shows, with among the most detail in Tabari, the means by which force could be used to resolve a siege.

The second method commonly employed to end sieges in Tabari is through trickery. The deception included the use of spies or other agents gaining access into the city walls. The siege of Tustar is one example of a siege being resolved in this manner. The attackers enter into the city via a water outlet that was learned of through betrayal. In this case the attackers avoided the pitched field battle that more commonly resolved sieges. It was made evident that while the traitor was ill thought

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125 Tabari, The Last Years of the Prophet, trans and ed. by Ismail K. Poonawala (Albany, 1990), 23.
of, the deception involved in taking the city was well regarded.\textsuperscript{126}

It was also common for the siege to be ended without armed conflict. In these cases often the two opposing leaders would meet personally or, more commonly, exchange messengers to work out a truce or surrender. A surrender can be seen in the taking of the city Hamadhan. In this city the Islamic forces had initially called for a surrender, which some of the inhabitants complied with. Those who did not comply stayed in the city and prepared to defend it. Once the entire Islamic army arrived and besieged the city those who had fortified sued for peace. The only stipulation they asked for was that the people who had stayed in the town be given the same treatment as those who had surrendered when first called for. The leader, Nu‘aym b. Muqarrin, accepted the terms for peace and accepted tribute from the city, but inflicted no damage or harm.\textsuperscript{127}

In none of the sieges mentioned in Tabari’s work is a siege ended by the walls being battered down by siege engines of any sort. This is as expected: the siege engines of the time were not powerful enough to bring down a wall. There are several mentions of catapults of some sort mentioned in Tabari. Though the more commonly used siege engine is the \textit{testudo}, basically a wheeled shelter from projectiles to enable the attackers to get closer to the walls, stone throwers are used.\textsuperscript{128}

\begin{flushright}
\textsuperscript{127} Tabari, \textit{The Conquest of Iran}, 19-20.
\textsuperscript{128} The \textit{testudo} is known by several other names as well including, the mantlet, “cat,” or “gattus”; for more information see Christopher Marshall, \textit{Warfare in the Latin East}, (New York, 1992), 213.
\end{flushright}
The majority of the stone throwers seem to be in the hands of defenders rather than the attackers. In some instances the attackers do have catapults of some sort, and as in the siege of Bahurasir the people, not the walls, were bombarded with projectiles. In this siege, even after the defenders had surrendered the attackers had to scale the city walls to gain access; they could not bring them down. The frequent mention of the castles having trenches around them also indicates that the catapult was not a major factor in attacking cities. A trench has no effect on a projectile in flight and a trench dug far enough from the walls to keep a catapult out of range is indefensible from the city. The major purpose of these trenches then is to defend the walls from direct attack by hand or by device.

The bigger issue here is still within the naming practices. The stone throwers mentioned are never accurately named in the translation and the Arabic word al-majaniq means roughly only stone thrower, providing no way to identify accurately the type of machine. In a siege encounter in 880 there is mention of ballistas hurling rocks; however, there is little evidence to suggest that the Arabic armies had knowledge or made use of these Roman machines. More importantly, the ballista had fallen out of use in sieges as the power of the Roman armies dwindled; they were not in use after the fall of the Roman Empire.  

131 Kelly DeVries, Medieval Military Technology (Peterborough Ont.: 1991)137.
are another form of siege engine, possibly a traction trebuchet, and the Roman machine is named by the English translator rather than the Arabic source.

Another source for the siege technology as late as the tenth century is a Byzantine siege manual written by Heron of Byzantium.132 This manual describes the construction and use of various siege machines of the Byzantine armies. Like many military manuals much of this is copied from earlier manuals, specifically manuals by Apollodorus of Damascus and Heron of Alexandria; the author does, however, add some of his own contemporary machines to the manual.133 The vast majority of the machines depicted in this work are not projectile machines. Instead, they are designed to protect troops as they advance to the walls. Also included are mobile towers and battering rams. The machines are often protected in some way from arrows, but also, according to Heron, against stones and other projectiles from catapults, suggesting that the defenders were more inclined to use artillery than the attackers.

At the time this manual was written the Byzantines were in conflict with the still expanding Islamic empire. It is against these enemies that Heron intends the manual to be used.134 The lack of projectile weapons and emphasis on devices to either climb over the walls or to attack the walls directly suggests that there were no


133 Sullivan, Siegecraft, Intro. vii.

134 Sullivan, Siegecraft, Intro. vii.
machines capable of bringing down the walls from a distance. It is likely, then, the Muslims did not have a machine capable of breaching the walls from a distance either, or else such a step forward in military technology would have been adopted by the Byzantines, as has been shown by David Nicolle.135

Later sieges took advantage of technical innovations that enabled the siege commanders to keep their men out of harm’s way for longer and breach walls from a distance. The sieges that employed counterweight trebuchets with effectiveness were ended in a very different manner than those that did not employ such devastating artillery. The siege of Acre in 1291 is a good example of how a siege is resolved using counterweight trebuchets.

The Islamic siege of Crusader Acre is reputedly the largest gathering of trebuchets assembled at a single encounter. Accounts indicate that there were at least seventy-two trebuchets and possibly as many as ninety-two employed by the Islamic besiegers.136 This siege ended rather rapidly, in less than two months. Their bombardment weakened the defenses, making a full assault on the city successful. The city was not completely taken in that time; pockets of resistance still remained. The Templars, for instance, retreated to the safety of their tower and continued to fight from there. The Templars in their tower engendered a mini-siege as the Muslims tried to remove the Christian threat in the city. In this case the tower was


brought down not by the large and awkward artillery pieces, but by mining. The continued fighting after the walls had been breached indicates that a surrender agreement had not been reached and the city was taken by force. Likewise, there are no reports of starvation being a deciding factor; the most likely major impact on this siege was then the use of the siege engines to subdue the Christian populace and to open breaches in the walls.  

The siege of Acre is not the only siege that was resolved with the use of siege engines. By the thirteenth century the Islamic armies had fully adopted the use of counterweight trebuchets in sieges, and other siege devices such as the earlier testudo or the crusaders' siege towers were not employed to any great extent. At numerous sieges the Muslim trebuchets forced the Christian forces to capitulate. At Caesarea in 1265 the Muslims forced the surrender of the highly fortified citadel in less than a week.  

The Templars were forced to retreat from their newly constructed Beaufort Castle in 1268 when faced with twenty-six Muslim engines. When coupled with the extensive manpower of the Muslim armies for a full assault the trebuchet was even more effective. The sieges of Crac des Chevaliers and Gibelcar in 1271 both were resolved largely through the use of Islamic artillery to weaken the defenses prior

137 D.P. Little, “Fall of ‘Akka,’” 174.


to an assault. Of the nine major sieges begun by the Islamic armies, starting with Crac des Chevaliers in 1271 and ending with Sidon in 1291, bombardment by siege engines played a significant role in six of them.

The siege of Damietta in 1218, according to Chevedden, provides the clearest description of the hybrid trebuchet. This machine is equipped with a counterweight of 370 kg and fires a shot weighing 185 kg. A two to one weight ratio of counterweight to projectile would not be sufficient to fire the projectile by itself, so a pulling crew would be necessary to operate it. A study of the circumstances of the siege of Damietta shows, however, that the actions of the besieging Christians are not consistent with having a powerful trebuchet capable of inflicting damage to the walls of the city.

Oliver of Paderborn was a German cleric who had preached the Fifth Crusade in his native lands and then went on the crusade himself. He then provides a first hand account of the siege of Damietta as well as the surrounding events. His account provides detailed information about the events of this siege, as well as other actions following the siege. Chevedden has stated that the hybrid trebuchet was a more powerful version of the trebuchet and able to inflict damage on fortified walls. The clearest description of a hybrid trebuchet comes from this siege, with the machines launching a projectile weighing 175 kg. A projectile of this size and with

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this power should, according to Chevedden, damage the walls severely and serve as a siege-ending piece of artillery. However, the actual actions of the siege and the account of Oliver are not consistent with that interpretation.

When beginning the siege the Crusaders found themselves facing a port city with a defended harbour. The mouth of the harbour was protected by a chain that could be run across the harbour to prevent the access of ships into the city. To take the city, the Crusaders had to first remove this impediment to their progress, particularly the fortified tower that held the chain. Initially the Crusaders tried to destroy the tower through bombardment by siege engines. Oliver plainly states that “the tower could not be captured by the blows of petraries or of trebuchets (for this was attempted for many days).”\textsuperscript{143} The first approach to taking this tower shows clearly that the trebuchets in place at Damietta were not as powerful as indicated by Chevedden.

Instead of taking the tower with trebuchets, another approach had to be tried. This approach involved building a siege tower across two ships that were joined together and sailing it close to the tower. Once they sailed the ships to the tower a terrible fight broke out between the defenders of the river tower and the Crusaders. Eventually the Crusaders managed to take control of the river tower and were able to continue the siege.\textsuperscript{144} Interestingly enough, artillery did play a part during the attack involving the ships, though in defense by the Egyptians and in support of the attack

\textsuperscript{143} Oliver, \textit{Damietta}, 25.

\textsuperscript{144} Oliver, \textit{Damietta}, 25-28.
by the Crusaders. The ship-borne siege tower included a defense structure of netting and hides to defend the tower from fire and artillery fire. As the tower moved into position the defenders in the city moved at least six machines to the city walls to bombard the tower. The Crusaders made use of their own machines which, while ineffective against the fortified tower, were able to destroy at least one of the Egyptian machines. Also of note is that the shot of the Egyptian machines was compared to hail falling from the sky, suggesting a rapid rate of fire not available with large counterweight machines. The siege of Damietta continued for 19 months, ending in surrender for the Muslim defenders. This, along with the way in which the trebuchets were used in the siege, is inconsistent with the Crusaders having a powerful type of trebuchet.

Another siege described in Oliver's account is the siege of Chateau Pelerin in 1220. In this siege Coradin leads an attack on the Crusader outpost of Chateau Pelerin. Coradin, fearing an attack by the Crusaders, constructed a wall between the fortress and his own camp. From inside this wall he began a bombardment of the castle with "one trebuchet, three petraries, and four mangonels." The bombardment of these eight machines "could not move one stone from its place in the new towers and the middle wall." Once again siege engines were used in defense

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145 Oliver, Damietta, 26.
146 Oliver, Damietta, 26.
147 Oliver, Damietta, 67.
148 Oliver, Damietta, 68.
as a counter battery. The Crusaders’ own battery of a trebuchet, a petrary, and a
mangonel were used against the Muslim engines, successfully destroying the
trebuchet and a petrary. Coradin lifted the siege without success after about a month
because of a fear of Christian reinforcement.\(^{149}\)

The sieges of Oliver’s accounts show that the trebuchets present did not have the impressive power that Chevedden claims the hybrid trebuchet had. If the account of the siege of Damietta, the siege from which Chevedden interprets the clearest evidence of the hybrid trebuchet, shows that the siege is resolved in the same manner as the earlier sieges, then the entire theory regarding the power of the hybrid trebuchet is questionable. It is clear from the later sieges, such as Acre, that the power of the counterweight trebuchet was a definitive factor in resolving sieges. The Muslim armies especially adopted the widespread use of the counterweight trebuchet to supplement the numerical advantage they enjoyed in the sieges in the Holy Land. The superiority of numbers that the Muslim armies had was often the single most important factor in resolving a siege; the counterweight trebuchet made that advantage even more effective.\(^{150}\) The hybrid trebuchet, however, does not show the devastating power that could bring down a wall or impede the development of a counterweight trebuchet.

\(^{149}\) Oliver, *Damietta*, 68.

Chapter Five: Conclusion

The power of the trebuchet cannot be questioned. The construction principles and techniques are less concrete. The development of the trebuchet is also not so clear. What can be clearly determined is that the physics required for a hybrid machine to utilize both gravity and human power is not effective. Instead of adding power, the counterweight that Paul Chevedden describes serves mainly as a counterpoise, balancing the weight of the throwing arm.

The physics at work on a hybrid trebuchet do not generate significantly greater power. Instead, the counterweights described by Chevedden in his articles point to a different interpretation of the sources that would provide an increase in the performance of a trebuchet. By using a small weight to counterpoise the throwing arm, the center of gravity of the throwing arm is moved closer to the pivot point, making the arm easier to accelerate from a stopped position.

The easier it is to move the arm from a stopped position the more efficient the manpower pulling on the arm works. This increased efficiency allows for less men pulling on a trebuchet to achieve the same performance as a larger team on a non-counterpoised trebuchet. Also the full crew pulling on a counterpoised machine would throw larger projectiles a greater distance. The increases in the performance of the counterpoised trebuchet would quickly make themselves apparent to the operators using the machines.

A counterpoise may also have been the only way in which a large traction machine could function. As the size of the trebuchet increased the weight of the components, particularly the throwing arm, also increased. By employing a
counterpoise much of the weight of the throwing arm, likely the heaviest piece of the machine, would be mostly negated. Without the counterpoise the weight of the arm being pulled by the crew could easily require so much force to move that the projectile would not be accelerated fast enough.

The larger sizes of counterpoised trebuchets required many things. The bigger the component pieces the more coordination required to produce them. As the machines grew larger they began to require materials that were no longer part of the normal supplies of a war camp, such as elements of a counterpoise. The heavy items used to counterpoise a heavy throwing arm require the beginnings of a centralized government to locate, produce, and move to a siege.\textsuperscript{151} Likewise large straight pieces of timber may not be readily available at a siege site. The only sure way to have the required components for a large counterpoised trebuchet was to plan ahead and supply the materiel oneself.

The inspirations for a counterpoised lever would have existed all around a warrior in the Middle East. The \textit{shaduf} is a counterpoised irrigation device invented and used widely throughout the Holy Land. Both Arabs and Christians would have seen and been familiar with the device and could have employed similar technology. Another possible genesis would have been the very weapons the soldiers were carrying with them. A sword is functionally a lever with the pommel serving as a counterpoise. With these and other possible sources for the science involved, creating a counterpoised trebuchet would not have been a difficult task.

In addition to the physical issues with the hybrid trebuchet the support for it in actual use in sieges is not present. The clearest description of a hybrid trebuchet comes from the siege of Damietta in 1218. By examining the sources for this siege then one should see evidence of artillery with increased power. Instead, however, the Christian sources explicitly state that the trebuchets that they employed in the siege were not powerful enough to be effective against the city walls. Evidence for a powerful trebuchet capable of ending sieges of its own accord does not appear in the historical accounts until the thirteenth century.

Most importantly, Chevedden calls the hybrid trebuchet a step in the process of creating a counterweighted trebuchet. This is incorrect. A hybrid trebuchet, while not functionally possible, does not significantly change in operation from a traction trebuchet. The large pulling crew serves the same function to launch the projectile and the means of firing is identical. A hybrid or counterpoised trebuchet is simply an improvement on the traction trebuchet. It is not a new step in design towards a large counterweighted device. The drive to use weight to provide the force to launch the projectile does not have a basis in the previous technology. The role the counterpoise plays in the trebuchet does not impart gravitational force to the throwing arm; instead, it counteracts the weight of the throwing arm.

We should not see the hybrid trebuchet as a development towards the counterweight trebuchet. Instead it is an improvement on the existing technology. The shift from a traction to a counterweight machine does not signal merely a progression of science but instead is the result of a quantum leap in design.
APPENDIX

Sizes of Trebuchets and Their Components in Source Material
## Sizes of Trebuchets and Their Components in Source Material

<table>
<thead>
<tr>
<th>Source</th>
<th>Throw.Arm</th>
<th>Weight</th>
<th>Men</th>
<th>Projectile</th>
<th>Range</th>
<th>Misc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Krizek/Heffst</td>
<td>11.5M/37.7ft</td>
<td>&gt;10 tons</td>
<td>N/A</td>
<td>&gt;300kg</td>
<td>200m/350m</td>
<td></td>
</tr>
<tr>
<td>Krizek/Krasna</td>
<td>13m/42.6ft</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Krizek/Hradec</td>
<td>11.5m/37.7ft</td>
<td>4000kg</td>
<td>N/A</td>
<td>8kg-12kg</td>
<td>445m</td>
<td></td>
</tr>
<tr>
<td>Hansen 1</td>
<td>6.5m/21.3ft</td>
<td>1 ton</td>
<td>N/A</td>
<td>15kg</td>
<td>125m</td>
<td></td>
</tr>
<tr>
<td>Hansen 1</td>
<td>5.5m/1.0m</td>
<td>2000kg</td>
<td>N/A</td>
<td>47kg</td>
<td>100m</td>
<td></td>
</tr>
<tr>
<td>Hansen 1</td>
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<td>2000kg</td>
<td>N/A</td>
<td>15kg</td>
<td>180m</td>
<td>Sling=4.8m</td>
</tr>
<tr>
<td>Hansen/Nap</td>
<td>10.3m</td>
<td>4500kg</td>
<td>N/A</td>
<td>24lb</td>
<td>175m</td>
<td></td>
</tr>
<tr>
<td>Hansen/Nap</td>
<td>10m/.3m</td>
<td>4500kg</td>
<td>N/A</td>
<td>22cm shell</td>
<td>145m</td>
<td></td>
</tr>
<tr>
<td>Hansen/Nap</td>
<td>10.3m</td>
<td>4500kg</td>
<td>N/A</td>
<td>27cm shell</td>
<td>120m</td>
<td></td>
</tr>
<tr>
<td>Hansen/Nap</td>
<td>10.3m</td>
<td>4500kg</td>
<td>N/A</td>
<td>32cm shell</td>
<td>120m</td>
<td></td>
</tr>
<tr>
<td>Hansen/Hyb</td>
<td>6m/1.7m</td>
<td>80kg</td>
<td>20</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Tarver</td>
<td>4.9m</td>
<td>Light*</td>
<td>20</td>
<td>2.5kg</td>
<td>100m</td>
<td>40” sling</td>
</tr>
<tr>
<td>Tarver</td>
<td>4.9m</td>
<td>Light</td>
<td>20</td>
<td>1.9kg</td>
<td>137m</td>
<td>40” sling</td>
</tr>
<tr>
<td>Tarver</td>
<td>4.9m</td>
<td>Light</td>
<td>20</td>
<td>8kg</td>
<td>40m</td>
<td></td>
</tr>
<tr>
<td>Tarver</td>
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<td>Light</td>
<td>8</td>
<td>1.6kg</td>
<td>40m</td>
<td></td>
</tr>
<tr>
<td>Tarver</td>
<td>4.9m</td>
<td>Light</td>
<td>16</td>
<td>2-3kg</td>
<td>60m</td>
<td></td>
</tr>
<tr>
<td>Tarver</td>
<td>4.9m/41”sling</td>
<td>Light</td>
<td>16</td>
<td>4.7kg</td>
<td>81,79,76,77,76,76,76</td>
<td>40” hookset</td>
</tr>
<tr>
<td>Tarver</td>
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<td>Light</td>
<td>16</td>
<td>3.9kg</td>
<td>77,89,94,89,94,89,89</td>
<td>40” hookset</td>
</tr>
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<td>4.9m</td>
<td>Light</td>
<td>15</td>
<td>4.7kg</td>
<td>100,90,105,100,105,93</td>
<td>40” hookset</td>
</tr>
<tr>
<td>Tarver</td>
<td>4.9m</td>
<td>Light</td>
<td>4</td>
<td>3.1kg</td>
<td>65,65,52,69,55,69,55,69</td>
<td>40” hookset</td>
</tr>
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<td>Tarver</td>
<td>4.9m</td>
<td>Light</td>
<td>14</td>
<td>3.1kg</td>
<td>145m</td>
<td>40” hookset</td>
</tr>
<tr>
<td>Hansen 3</td>
<td>6.5m</td>
<td>1000kg</td>
<td>N/A</td>
<td>15kg</td>
<td>83-87m 4 shots</td>
<td>5m sling</td>
</tr>
<tr>
<td>Hansen 3</td>
<td>6.5m</td>
<td>1500kg</td>
<td>N/A</td>
<td>15kg</td>
<td>100-105m 4 shots</td>
<td></td>
</tr>
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<td>Hansen 3</td>
<td>6.5m</td>
<td>2000kg</td>
<td>N/A</td>
<td>15kg</td>
<td>153-170m 5 shots</td>
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</tr>
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<td>1000kg</td>
<td>N/A</td>
<td>15kg</td>
<td>160m</td>
<td>T/S 34mm</td>
</tr>
<tr>
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<td>2000kg</td>
<td>N/A</td>
<td>15kg</td>
<td>152m</td>
<td>T/S</td>
</tr>
<tr>
<td>Tarver</td>
<td>4.9m</td>
<td>Light</td>
<td>2</td>
<td>1.6kg</td>
<td>40m</td>
<td></td>
</tr>
<tr>
<td>-------------</td>
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<td>-------</td>
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<tr>
<td>Tarver</td>
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<td>2-3kg</td>
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<td>Tarver</td>
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<td>Light</td>
<td>16</td>
<td>4.7kg</td>
<td>81,79,76,77,76,7 6</td>
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<tr>
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<td></td>
<td></td>
<td></td>
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<td>40° hookset</td>
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</tr>
<tr>
<td></td>
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<td>N/A</td>
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<td>N/A</td>
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<td>400</td>
<td>111-200kg</td>
<td>N/A</td>
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</table>

* While Tarver mentions specifically that he has a counterpoise weight attached to the throwing arm, he does not give a weight saying only that it is “light”.

** Hill’s calculations take into account friction he gives the machines a mechanical efficiency of 70%.
Figure 1: Traction Trebuchet
Figure 2: Hybrid Trebuchet
Figure 3: Counterweight Trebuchet
Figure 4. Seesaw in equilibrium showing equal forces on both sides. Any amount of force in either direction will move the seesaw.

Figure 5. Seesaw now has twice the weight to the left, so the force pushing down on the left is also doubled. The 150 newtons of force on the left is matched by 150 newtons on the right. The 75 newtons pushing down on the right is matched by 75 newtons pushing up. The seesaw would rest with the left side down unless a force of more than 75 newtons is applied to the right side.

Figure 6. Seesaw has doubled the length on the left. While the weights are the same the difference in the length has doubled the forces. Again the seesaw will rest with the left side down unless a force of more than 75 newtons is applied to the right.
Figure 7. Center of Gravity for a traction trebuchet shown loaded (left) and unloaded (right).

Figure 8. Ideal centers of gravity for a counterpoise trebuchet shown loaded (left) and unloaded (right).

Figure 9. Center of gravity for a counterweight trebuchet shown loaded (left) and unloaded (right).
Bibliography

Primary Sources


Secondary Sources


