Trebuchet

Final Report

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by

Group 26

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Introduction

The trebuchet is a medieval siege engine that derives from the ancient sling. These massive machines are a testament to medieval engineering; trebuchets were used in combat from the 6th to the 16th century in Europe. The first trebuchet concept appeared in China, known today as the traction trebuchet. This machine was basically an enlarged slingshot. A group of people would pull on the short arm, launching the long arm which has a sling. This concept spread far throughout the world, from China to Byzantine, and then to Scandinavia. During the 12th century in Europe was the first time the world saw the counterweight trebuchet, the most recognized design today. Once these machines saw mainstream use, a medieval arms race of sorts began. Engineers began to redesign walls, fortifying them and allowing space for defensive trebuchets. The traditional castle, employing few towers and large wall surfaces, shifted into a trebuchet oriented style – many artillery towers and short walls. It wasn't uncommon for trebuchets to be used to hurl rotting corpses or manure into enemy fortresses, spreading disease and distraught. The trebuchet was one of the defining weapons until the introduction of gunpowder, when cannons became the weapon of choice.

We decided to choose the trebuchet as a project because of its majestic history, and its raw ability to harness gravity as a weapon. We set out with the goal of building a mechanically efficient trebuchet that could throw a golf ball over 60 meters, while keeping the throwing arm less than three feet.

Types of Trebuchets

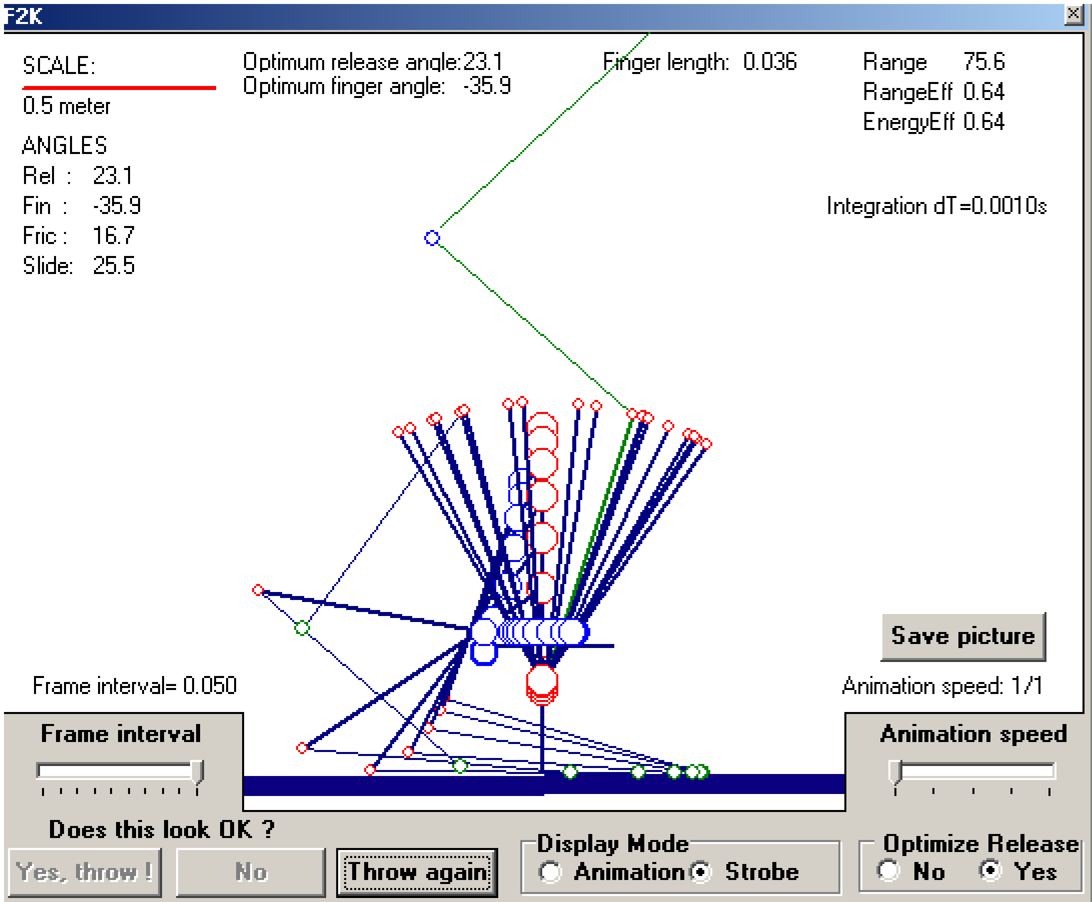
While researching the trebuchet we found many designs of the classic machine. The swinging counterweight trebuchet's major flaw is that a large amount of force is lost due to the swinging motion of the counterweight. Gravity is all that powers the trebuchet, and rather than an efficient straight drop, the swinging wastes a large amount of potential energy in the wrong direction. Wheels can be added to absorb some of the directional force, and many historians argue over whether or not past civilizations actually used wheeled trebuchets. However, even with wheels, the problem remains: potential energy is wasted.

On the second day of research we found something we didn't expect to find; a modern renaissance of trebuchet design. We discovered several groups of hurling enthusiasts who continue to build and improve their machines. Two modern designs stood out: the floating arm trebuchet and the "King Arthur." The floating arm trebuchet "(FAT)" introduces a system which allows the counterweight to drop straight down along a guided track, reducing stress on the arm and increasing efficiency. The FAT's throwing arm has wheels, which roll along a track on the frame to guide the arm after the release. The King Arthur is a machine that has the arm and counterweight stand extremely erect, which allows small counterweights to be very effective. This style of trebuchet is quite unique because of its double trigger system, after the initial pull, a second trigger is automatically pulled at the exact moment which the arm should start swinging, maximizing efficiency. The size constraint effectively ruled out the King Arthur as a design choice, so we decided to build a FAT. That was, until we found out there are subtypes of the floating arm design. There is the "Floating Arm 2000 (F2K)," which adds an additional wheel on the frame to increase mechanical advantage; the Floating Arm King Arthur, an impressive combo of the modern designs, and the Floating Everything Trebuchet, which has no counterweight guide. Ultimately, the F2K was the best choice for us. While it was among the hardest to build, it provided an efficient solution that fit within our constraints.

A King Arthur style trebuchet in the cocked position. This design, while producing the best results today, would not scale down well (FAKA).

Design

Our design process began with us searching for simulators. It didn't take us long to find simulators for every style of trebuchet, including one for the F2K. We were only able to use a demo version (RLT,) which meant that a few options were disabled and saving was forbidden. We input the weight of a golf ball, and the length of the throwing arm as well as the counterweight track guide to three feet. After a few hours of tweaking, we got an idea of what our dimensions should be and our first range estimate; 74 meters working optimally. We then started our drafting work, using ruler and compass to try and put our ideas and simulator work on paper. Frustration ensued, so we turned to the computer and began to use Solid Edge to model the trebuchet in 3D. It was a relatively simple process, as Connor and Chris had some experience using another CAD program called Solid Works. After the 3D model was done, we ordered our lumber: three lengthy 2x4's and a plywood base. We cut all our 2x4's into 2x2's, which allowed us to save on lumber and have a uniform beam to work with. We couldn't find any solid explanation of just how the wheel system works on the F2K, so we ended up looking for several pictures of the track system and try to work off of them. A visit to the hobby store helped clear that problem up, as we talked to the clerk who happened to know quite a bit about RC cars, and was able to help us figure out which axle and wheel combo we needed. One of the major challenges we encountered during the design process was learning how to take all parts of the trebuchet into account. We went back to the simulator and found you can change the finger angle and length, and the finger is just the little piece of metal at the end of the throwing arm that releases the sling. The slightest change could alter the trajectory of the trebuchet greatly.



The simulator program we used. This is one of the later trials we did, still looking to throw 70+ meters. Unfortunately, results to this point have not come close. (RLT).

Building

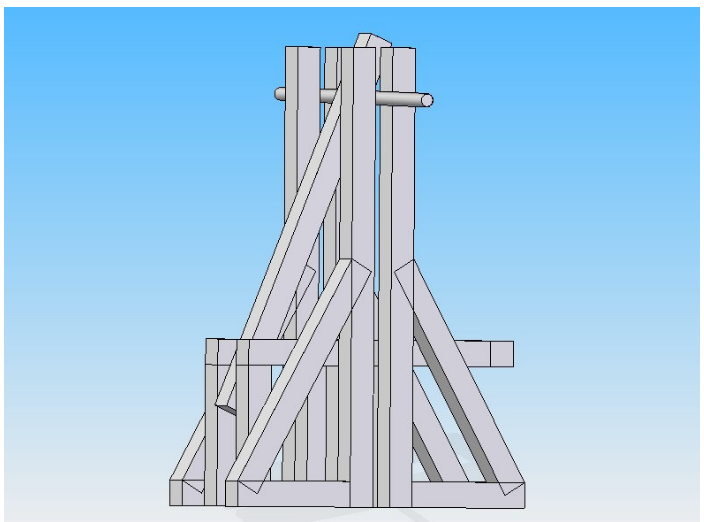
Our building process began quite late. Design was taking a bit longer than expected, so we were a little rushed with building. On the first day of building we started with trimming our 2x4's into 2x2's and eventually to the various length's we needed. Cutting the 2x2's and copper tubing had its own complications due to lack of communication, causing excessive trips to the machine shop.

There was a little lack of communication between those working on the CAD and those building off the dimensions, but we were able to correct things relatively easily. Overall the model allowed us to place things easily while building. Another one of the nice things the CAD allowed us to do is measure the overlapping diagonal braces, allowing us to cut them with no issues.

While the issues of cutting wood to match CAD took precious time, the overall benefit of a 3D model was worthwhile. The base of the frame was constructed according to the specifications of the CAD. Many joints have flawed angles, and some sections of wood had lengths that were off by a fraction of an inch. These flaws were likely due to the horizontal band-saw, which was inaccurate.

Adam and the other machine shop workers were infinitely helpful. Utilizing their expertise, our materials and design, the trebuchet's development leaped forward. We walked in with a frame, plywood, wheels and axles. They helped us design and weld a launching mechanism out of an old grill. They provided guidance for whatever questions we had, as well as suggesting alternatives to our ideas that were difficult to fabricate. They used tools we were too inexperienced to use. Overall they provided a friendly atmosphere in which we were able to get things done effectively.

While constructing the trebuchet, we found various materials at our disposal. We had steel dowels and tire weights to act as our counterweight. While assembling the weight boxes we noticed that weights would fall out of spaces between the pieces of wood; to fix this problem we filled in the spaces with the nearby caulk which was available, though looking back on the situation we believe that we should have used wood glue instead. We also needed an axle for the arm and weight-boxes; a wood axle would break and there were no steel axles available. We ended up settling for a PVC pipe as our axle, in order to mimic the weight of steel and make it more rigid we filled it with lead shot.



This is the CAD frame of the trebuchet. It was an indispensable tool in the building process.

Testing

During the first test of our launching mechanism, after the trigger was pulled, the copper wheel axle snapped. We ended up swapping the axle for a larger steel one, and the wheels for a larger, sturdier pair. Our first actual tests were disappointing; it came as no surprise though, considering our sling was made with no real research done. The first launch went nowhere, the second; backwards. The trigger mechanism was having problems too, but those were solved after we drilled the holes they rest in bigger. The next problem we deduced was that the sling was too long. One of our sources said that the sling length should be equal to the long arm of the throwing arm to maximize efficiency, but ours was not getting proper movement at all. We also exchanged the various tire weights and steel dowels in our weight box for a load of bb's, to keep the weight boxes more balanced, and add a few pounds of counterweight. After these changes, we tried our trebuchet again, and we noticed that the weight boxes hit the ground. This is a major hit to efficiency, so we ended up moving the location of the wheel axle of the throwing down an inch. As of this point we are still working to improve our sling, we have not found a design that releases the golf ball satisfactory every launch.

The completed trebuchet, the design remained close to the CAD model.

Conclusion

While our trebuchet itself does not throw correctly at the moment, we have had plenty of successes along the way. We were able to learn about ourselves during our project time; none of us have a passion for mechanical engineering. We had originally planned to work with Python, so we formed a group of three; looking back we could've definitely used another member knowing we wouldn't get our first option. Working with Solid Edge, the simulators, and other design work were far more interesting to us; in fact we spent too much time designing and didn't leave enough time for building. The design would work mathematically, but we weren't able to fabricate our trebuchet due to our lack of experience. We chose one of the hardest styles of trebuchet to build, which in retrospect is a huge mistake. It was definitely the most interesting of all the types, and we felt that it was within our reach, but before we knew it we were running out of time. At the same time, we felt the classic trebuchet was too easy. We knew we would've been able to build it; there are hundreds of resources for a swinging counterweight trebuchet. What hooked us on the F2K was that it was unique and challenging, and almost unheard of.

Sleep is important. Our entire group ended up notorious for staying up late and it hurt our productivity to wake up every morning with very few hours of sleep. The counselors are a great group of people and a great resource, and they certainly assisted us in staying awake. We didn't catch on to the fact that they sleep during the day until sometime later.

It's extremely frustrating to look at our trebuchet's firing action because it looks exactly as it should. Our trebuchet feels like its minutes away from working, as soon as we tweak a few more things it will work. We have several ideas on what we can do to make it work: move the wheel axle to prevent weight boxes from hitting the ground, change the sling design to actually release at the same point every time; shorten the sling, make the sling release finger longer, etc. Really it comes down to lack of knowledge on how to build the sling, we have the length correct, but it's hard to find information on just how a sling works on the F2K style. The wheel system doesn't work; the wheels hit the track and come to a complete stop at the gap, unfortunately there was no time for us to fix it.

On the final day of testing for projects, we tested our arm for the first time in a competition setting. The first fire split the throwing arm in half. We did manage to launch the golf ball 64 feet, but the sling released very early.

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