Model Magnetic Levitation Train - Harnessing the Power of Superconductors

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Abstract:

The goal of this project was to create a fully functioning magnet levitating train capable of making sharp turns and crossing a bridge without coming off the track. Over the course of the second semester many stages were completed, moving from a simple plank bridge to an elaborate track and bridge system. We chose this project because of our high interest in alternative methods of transportation. This project allowed us to explore key concepts of superconductivity and truss bridges. We have successfully built a track and bridge that when paired with a freezing superconductor exhibits the key features behind the theory of superconductivity.

I. Introduction

After sifting through various ideas such as a quadcopter skeleton and defense turrets, we settled on creating a bridge. This bridge idea came from one of our group members who had visited San Francisco during the month of January and was able to experience the beauty of the newly made Bay-Bridge. This remodeled version of the Bay Bridge has incorporated a light show that flashes different patterns during the night time. We both found this beautiful and thought that it would be a cool thing to try and re-create. This is how we got to the idea of building a model bridge. The bridge we are creating will explore how a structure is designed and made, when trying to eliminate it from breaking under non ideal situations. This project will also focus on creating a good looking bridge that drivers will enjoy driving on. The roadway that we will be adding uses magnets and superconductors, exploring (potentially) a means of transportation in the future that could be integrated onto a bridge.

Bridges are extremely useful and critical to society; they just simply can't fail or else many human lives would instantly be lost. Bridges have always been an engineering challenge to design and implement. We'll primarily gain knowledge regarding how to design and build a bridge, and the basic physics and design choices behind a specific model. We'll also learn how superconductors work with magnets as well as how to integrate a magnetic superconductor system into a small model bridge. We'll learn how to hook up multiple LED's together, and program them to have various patterns using a microcontroller(an Arduino).

Bridge History and Design:

A bridge by itself is an interesting thing to explore because of how simple of an idea it is ,yet difficult because of the variation of complexity in some designs. There are hundreds of different bridge designs but they all essentially do the same thing, allowing people, cars, and trains to traverse a deep canyon or waterway by connecting the two sides. There are many to see different takes and approaches to creating a bridge, each design has pros and cons. It is also interesting to observe the evolution of a certain bridge type over time. For example, in which situations would a simple Pratt Truss bridge be better(with regards to money and use efficiency) than a Howe Truss bridge?

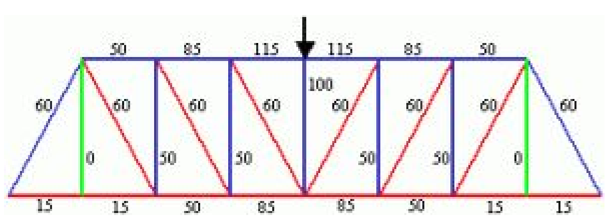

Figure 1(above): a diagram displaying the fundamental design concepts behind a Pratt Truss Bridge. Blue lines represent compressions and red lines represent tension. Green lines represent no effective load.

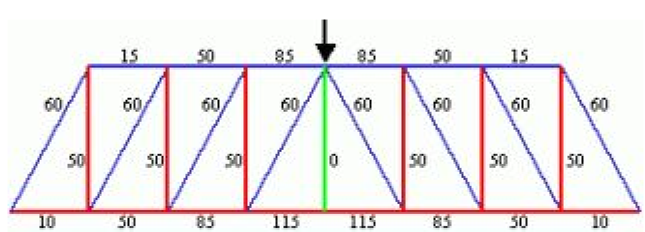

Figure 2(above): a diagram displaying the fundamental design concepts behind a Howe Truss Bridge. Blue lines represent compressions and red lines represent tension. Green lines represent no effective load.

Both of the above Truss diagrams show how an equal load is distributed amongst each part of the bridge. While both the Howe Truss and the Pratt Truss base their designs off of the fundamental principle of balancing compressions and tensions over the span of the bridge, each is slightly different. The Howe Truss' strategy is to distribute the load so that the beam at the very middle of the bridge has effectively no load, while the Pratt Truss' bridge strategy is to distribute the load so that the vertical beams at the very end of the bridge have effectively no load. The Pratt Truss Bridge would be ideal in a situation in which a middle support beam can be erected from below the bridge to support the middle vertical truss beam, and when side supports from beneath the bridge on either side aren't ideal. The Howe Truss Bridge would be ideal under the opposite circumstances.

Researching to figure out the answer to questions like this intrigues us. Bridge design will be relevant to our society as long as grounded transportation is the norm. As long as driving a car and riding a bike are the two most popular forms of transportation, bridges will be utilized for getting across large areas of previously impassable terrain, such as a large body of water or a wide, deep valley. Bridge design and construction will be relevant for as long as bridges are needed, which will be a very long time, until effective, cheap, and widespread personal jetpacks become the norm.

As one may guess, the first bridges ever were simple "plank" or "beam" bridges, simply large pieces of wood or a long, flat, thin stone laid across a thin stream to get across. Gradually, as the bridges and the areas they had to cross became larger, a simple piece of wood laid across from side to side didn't hold enough weight, so supports were added, sticking out of the stream and supporting the beam[1]. Before the 19th Century, bridges were made explicitly from stone, and the most popular bridge type was an arch.

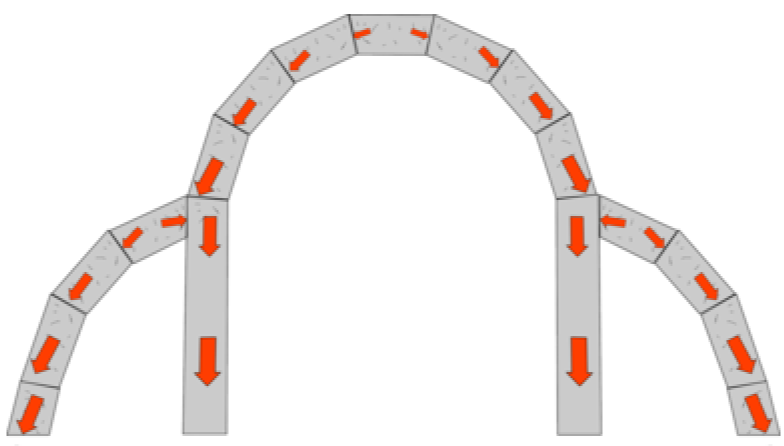

Figure 3(above): a diagram which displays the basic physics behind stone arches.

The arrows in Figure 3 represent net force vectors that act on each stone. The stones

[1] "History of Bridges." *History World*. History World, n.d. Web

which have two force vectors are displaying two components of force instead of one net force vector.

Stone arches basically assume the full weight if its burden onto the central stone, often called a keystone, and then proceed to distribute that weight evenly to the neighboring stones. The weight distribution continues down each side until eventually all of the mass sums into vectors going completely downward, into the earth.

These bridges were popular because they were relatively easy to design and the implement cost wasn't too great as they were made out of what were essentially just really large rocks[2]. Then, as woodworking became more popular, a type of wooden arch bridge was pioneered which would later be known as the first 'truss' bridge. A 'Truss Bridge' is a bridge which combines multiple smaller triangular structures together to distribute stress on the bridge away from a certain point, causing certain 'trusses' or beams to be compressed or stretched.

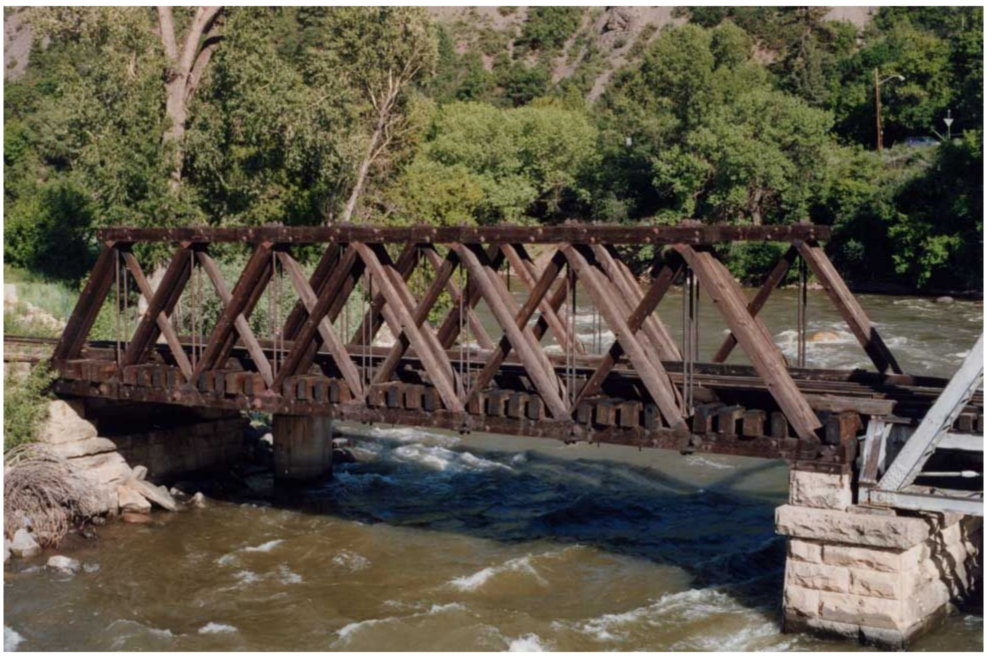

Figure 4(above): an implementation of a Truss Bridge in real life.

Because the wood material was weaker than stone, more advanced designs of the basic arches were made out of wood, forming the basic 'truss', a bridge element structure that is comprised of triangular units[3]. From that point, truss bridge design really took off, with various truss variations coming to light such as the Fink, Bollman, and Pratt truss designs. But, as time went on, vehicles that needed to cross the bridge became heavier(horses to cars, passenger trains to natural resource transportation trains), wood became less ideal, giving way to steel and the modern truss design that we see today[4]. It has evolved into one of the most popular bridge designs because of how effective it is for its simple design.

As of with the bridge, LED's can be arranged in virtually unlimited patterns for an

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[2] "Historic Truss Bridges." *Project for PATH*. Pennsylvania Transportation & Heritage, n.d. Web.
[3] Ibid.
[4] Calvert, J. "Evolution of Trusses." *Evolution of Trusses*. N.p., n.d.

extremely high number of colors, effects, and uses. Apart from their energy efficiency, LED's have a nice clean and bold look to them, and are relatively easy to wire up. But, when your goal is to wire up enough LED's to create a grid or a trail for the purpose of displaying an enjoyable pattern, the task becomes quite challenging. We'll be using an Arduino to control them, and don't yet know how so many LED's will work with an Arduino and the software used by the Arduino to control them. Led's are probably the most up and coming form of light as of right now. They surpassed incandescent lights because of their efficiency(with regards to power consumption) and looks, and currently, light technology is nearly as popular a choice for this purpose.

The history of LEDs dates back to 1939, when scientists in Hungary filed a patent regarding a lighting device which was based on a variant of silicon carbide that emitted white, yellowish white, or greenish white light depending on how pure the silicon was. From there, a patent filed by a Czech(Kurt Lehovec) 13 years later referred to the silicon carbide as emitting light but specifically for commercial use[5].

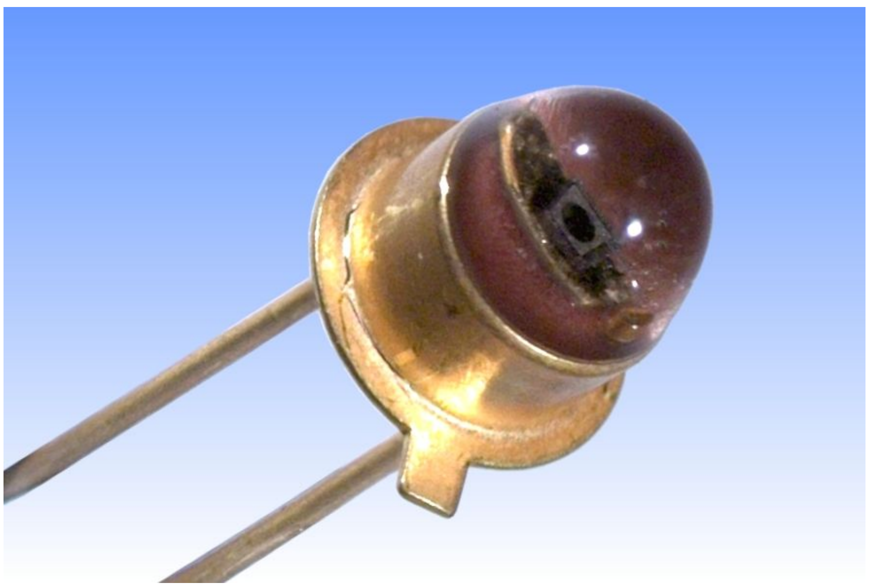

Figure 5(above): a photo of one of the first LED's.

LED's create light through the phenomenon of Electroluminescence, where a material emits light when electric current or an electric field passes through it. The electrons from the current or field fill electron holes within the material when sent through. The electron holes are created because the material lacks its normal amount of electrons and therefore has a positive charge. The number of electron holes can be easily altered by "doping" the original material, by adding other elements to the semiconductor. Thus, two separate semiconductors are formed within the same material, and the boundary between these two semiconductors is called a p-n junction. Current can only pass through these junctions in one way, and when an electron passes from one semiconductor to another, it fills an electron hole, emitting light(in the form of

[5] "50 Year History of the LED | Electronics Weekly." *Electronics Weekly*. Metropolis Media Publishing, 11 Oct. 2012.

photons)[6].

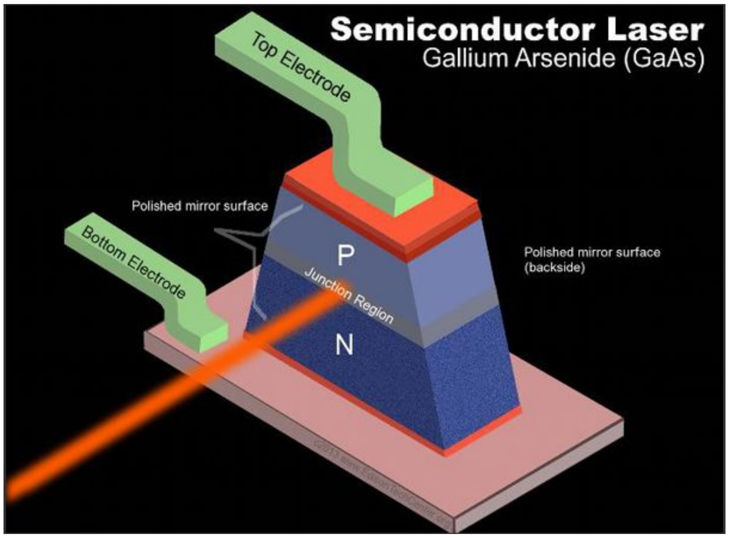

Figure 6(above): an illustration of how a p-n junction interacts with electrodes.

Figure 7(above): a photo of a modern LED.

The first patent for an "LED"(by invocation of the actual term) was filed by American scientists working for RCA in which they mentioned that the materials emitted a green glow. From then until 1987, various researchers around the world invented different colored LED's, starting with orange, and then yellow and green. In 1987, the first LED's for household use were sold and implemented by HP in vehicle brake and traffic lights. After their first implementation,

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[6] "LED Lights - How It Works - History." *LED Lights - How It Works - History*. Edison Tech Center, n.d. Web. 15 Mar. 2015.

new colors were developed such as blue and white, in rapid succession[7].

Metallic materials that at near absolute zero temperatures reach a state at which electricity passes through with literally no resistance have got to be one of the most if not the most interesting phenomena in the realm of Physics. The fact that they conduct electricity without any resistance to the current flowing through it is just amazing. Superconductors are relevant to the real world in technologies, such as use in maglev(magnetic levitation) applications such as super high speed trains, super particle accelerators, electricity generators, industrial power supply(for example from a plant/factory to a city miles away), and supercomputers, to name a few[8].

Superconductors first became a concept when in 1911 a Dutch physicist cooled Mercury to a temperature of 4 Kelvin and observed that its resistance simply disappeared. Then, in 1933, two German researchers observed that a superconductor when cooled to extremely cold temperatures actually repels a magnetic field, a phenomenon called the Meissner Effect.

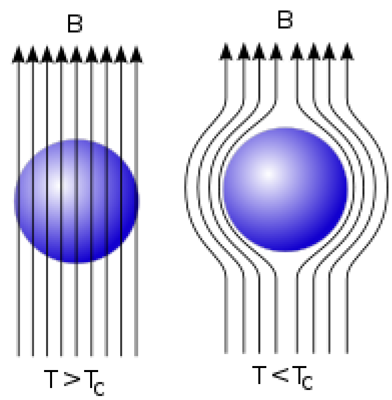

Figure 8(above): a simple graphic illustrating the Meissner Effect.

This basically means that a magnet can be levitated over a superconductor. Over the next thirty years or so, various superconductive alloys and compounds were discovered, each with their respective superconductive temperature, ranging from 2K-18K. The first industrial use of a superconductor was in a particle accelerator at the in the US in 1987[9].

Some may think that all superconductors function in the same way, but in the world of superconductors there exist two very different types of superconductors. The first being "Type I superconductors" which loose superconductivity very easily when placed under a magnetic field. These superconductors are often times referred to as "soft conductors" because of their perfect embrace of the Meissner Effect. Because they follow the Meissner Effect so well, it often times lead to a quick deterioration of superconductivity. This is depicted in the graph below where $\mu_o M$ represents the level of magnetization, and H represents the applied magnetic field. The level of superconductivity in type 1 superconductors stops abruptly at point A or in other words when it gets past its critical temperature.

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[7] Ibid.

[8] "Superconductor Uses." *Superconductors.org*. N.p., n.d. Web. 04 Feb.

[9] "Superconductor History." *Superconductors.org*. N.p., n.d. Web.

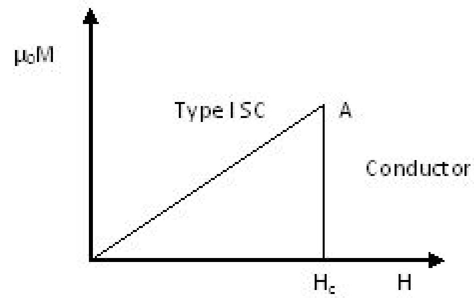

Figure 9(above): Graph representing the abrupt change between the superconductive change and the conductor stage in type 1 superconductors. Hc representing the critical magnetic field level while $\mu_o M$ represents the level of magnetism.

The next type of superconductors, Type II Superconductors, loose superconductivity gradually; as opposed to Type I's that loose superconductivity very quickly. In contrast to Type I "soft conductors" Type II "hard superconductors" obey the Meissner Effect to an extent but not fully. This means that instead of repealing all magnetic field lines, it allows for a few to get through causing for flux pinning to occur. Flux pinning is a phenomenon where a superconductor is "pinned" in space above a magnet, which is essentially what allows us to create a levitating object. The graph below depicts the long period of superconductivity in type II superconductors. Instead of coming to an abrupt end it slowly deteriorates, leading to an increased superconductive stage. Because Type II superconductors do not lose superconductivity quickly they make for good project usage, which is why we have decided to use Type II conductors for our bridge.

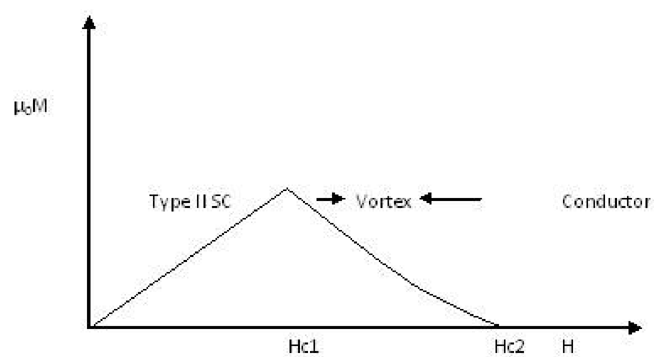

Figure 10(above): This graph shows the start and end of the Superconductor stage in Type II conductors. Hc2 represents the end of the Superconductor stage.

II. Design

In February,we worked on various prototypes for the physical bridge, and planned to work on the superconductor and LED integration later. The main reasoning behind doing three different iterations of bridge designs was to redesign and improve each time we broke a bridge during testing so that the next design would be better.

The main reasons behind us using a Truss bridge design is because of it's relative simplicity in design and make, the efficiency of the bridge with regards to material and time spent on the design, and it's looks. We chose to use wood as our primary building material because there was already a lot of it at our disposal and it looks quite nice. We designed these bridge prototypes to be about 14 inches long so that they were large enough to conduct testing on while not being so large as to cause inconveniences and waste material. We have made three iterations of bridges and we will be using the last iteration as the basic prototype for our final bridge product.

Our first bridge design was pretty much a fancy looking plank bridge. We designed the Truss structure within Adobe Illustrator along with the cutout for the bridge base. The reason we decided to do something so simple for our first iteration was so that we'd get the workflow and basic technique down. After the laser cutter finished cutting the ¼ inch wood, we used wood glue and clamps to secure the truss structures to the base. What we learned from making this first prototype is that we had to come up with a more advanced bridge structure than a simple plank, and that the laser cutter was a really valuable asset to have. It saved us a lot of time from having to cut pieces of plywood and screw them together.

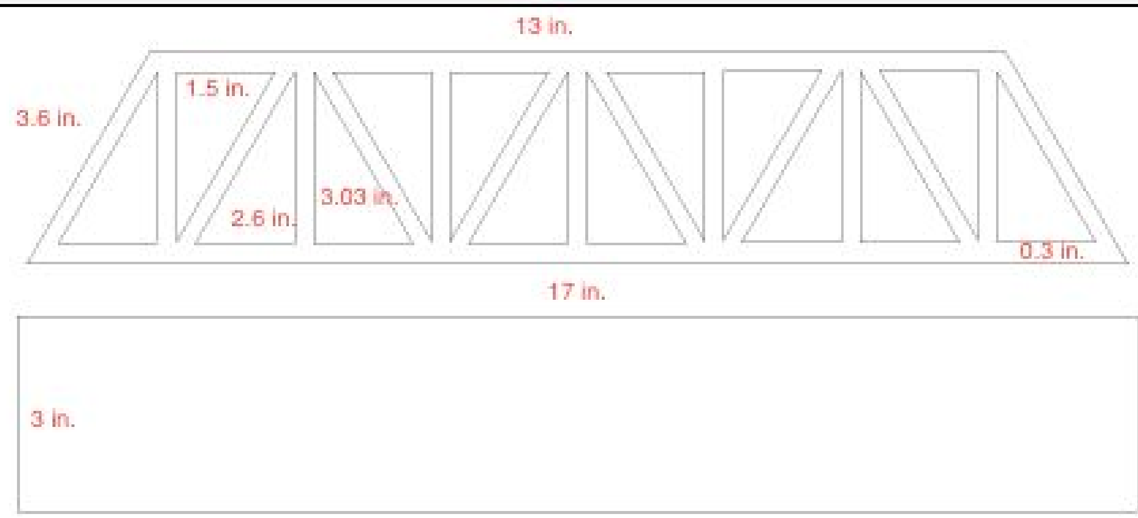

Figure 11(above): The laser cutter file for our first bridge prototype. The bridge was 17 inches long, with the top being 13 inches long. The side diagonals were 3.6 inches long, and the triangles had sides of 1.5, 2.6, and 3.03 inches. There was a 0.3 inch border between sides and the plank was 3 inches wide.

Figure 12(above): The CAD mockup of our first bridge prototype.

Our goal for the second bridge design was to actually utilize the truss structure rather than just adding it on top of a plank. We achieved this by adding struts to the bridge, laying across the bridge, placed at each 90 degree angle on lower triangles. This way, the plank would distribute force to the struts, which would in turn distribute force to the truss structure. The assembly process for this second iteration was similar to the process for the first iteration. We first glued the struts to the truss structures, and after the glue dried, dropped a plank in from the top that rested on top of the struts. What we learned from this prototype is that the strut integration functioned very well while also adding an extra aesthetic element.

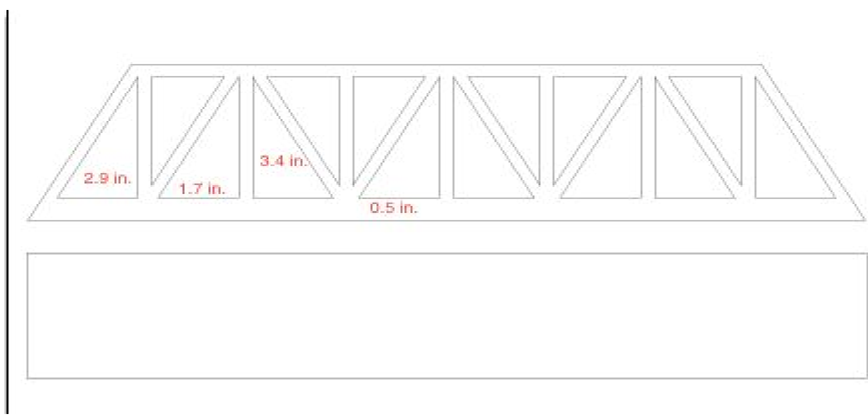

Figure 13(above): The laser cutter file for our second bridge prototype. The only measurements which changed from the first bridge prototype were that of the larger triangles and the border width on the bottom. Each of the larger triangles(the smaller triangles have the same dimensions as in the previous design) has side lengths of 1.7, 2.9, and 3.4 inches.

Figure 14(above): The CAD mockup of our second bridge prototype.

Our third and most recent prototype was very similar to the second iteration in that it combined both struts and truss structures. The large difference is that the struts went through the base of each truss structure instead of resting inside of the lower triangles. The reason we made this change was that we felt it would more evenly distribute the load-instead of the struts being in contact with the strut structure on only two sides, it would be in contact with the strut structure on all four side. We know from conducting tests with a force plate that placing struts within the bridge structure rather than onto it(struts on top of the triangle trusses) created a bridge that withstood a greater amount of force.

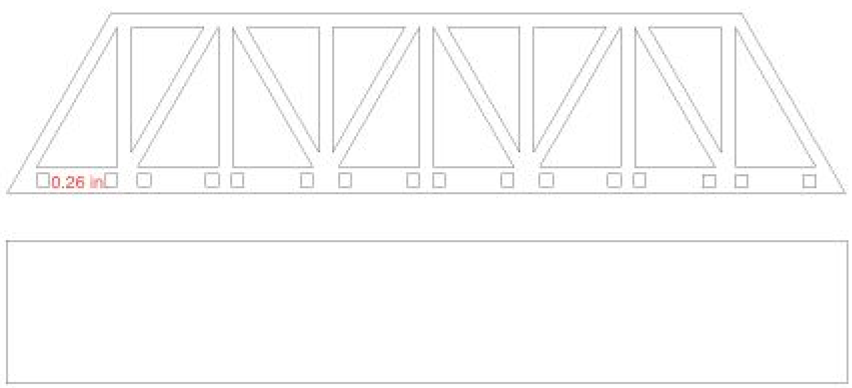

Figure 15(above): The laser cutter file for our third bridge prototype. The only measurements which changed from the second bridge prototype were those of the small squares you see. Each side of the small square measures 0.26 inches and is meant from the struts to pass through.

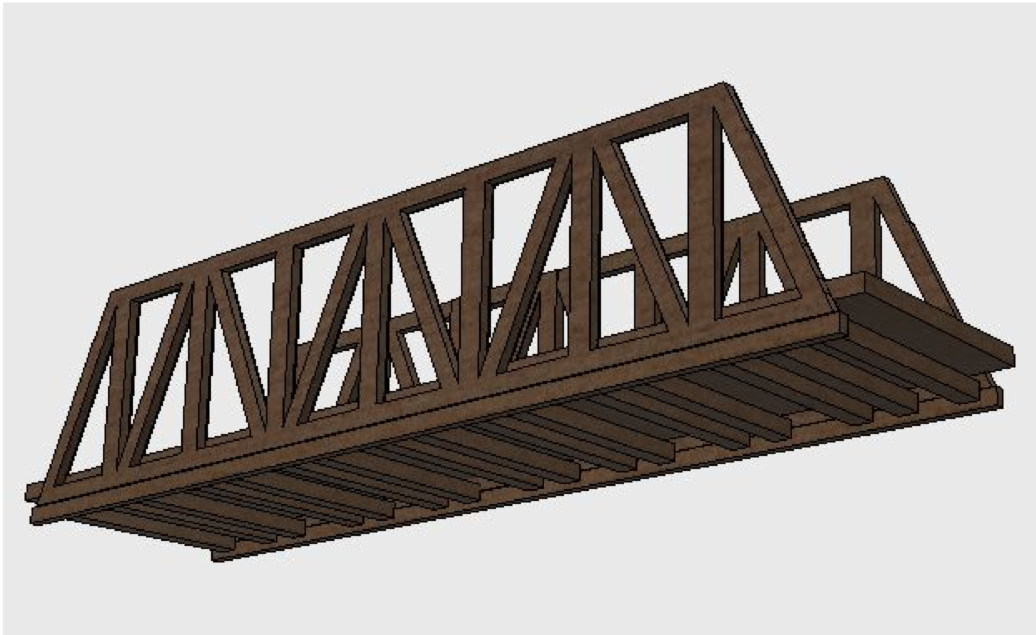

Figure 16(above): The CAD mockup of our third bridge prototype.

Since determining the final design of bridge that we'd like to use we have constructed the final bridge that we will be using. The final bridge utilized both truss structures and struts but was longer than any of the prototypes we had built previously. Thus, we determined that the best way to prolong the bridge was to create a segment in the middle that included struts and trusses that connected the two extensive parts of the bridge together.

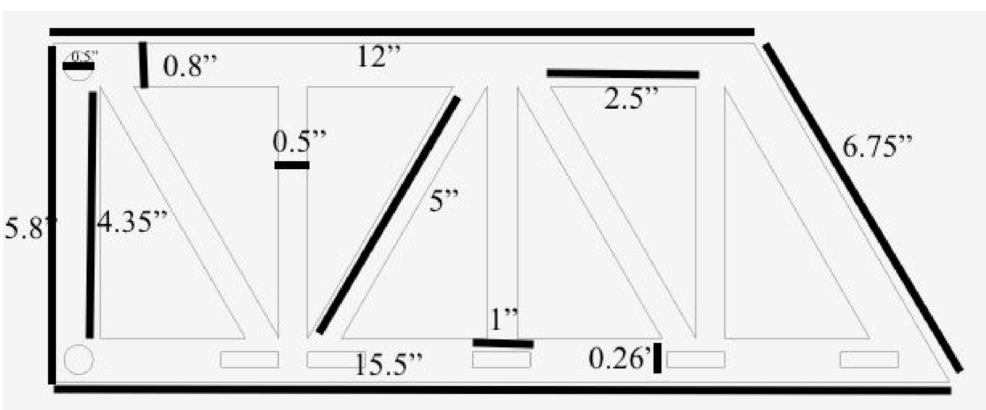

Figure 17(above): A portion of the second to last laser cutter file for our bridge. Each side of the bridge has two of these sections which were connected by a piece shown in figure 18. The most recent revision of the bridge has ¼" diameter holes for smaller bolts.

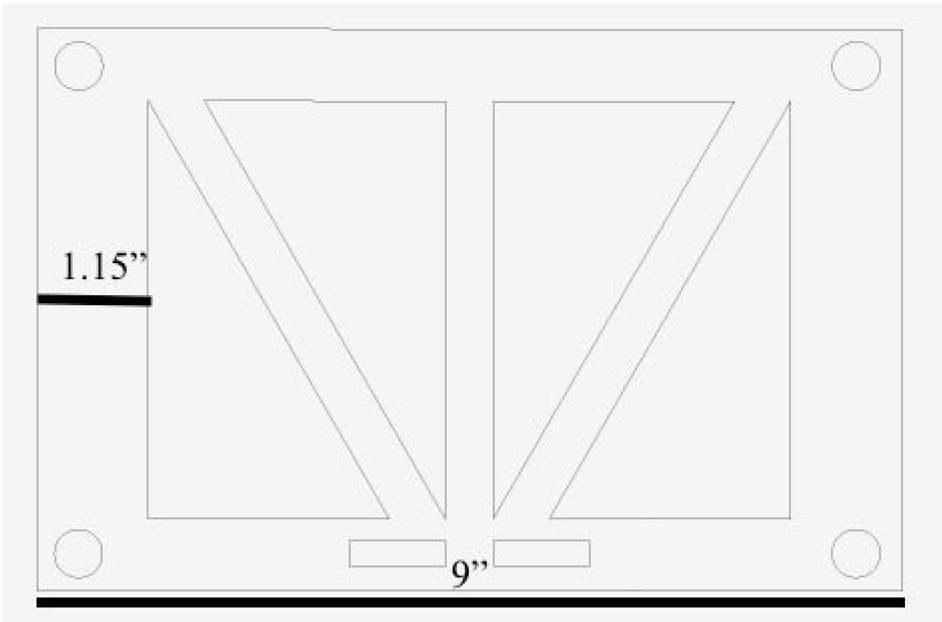

Figure 18(above): A portion of the final laser cutter file for our bridge. Each side of the bridge has one of these sections which connect two pieces that are shown in figure 17.

Figure 19(above): A photo of our final bridge. The different pieces are currently connected with metal bolts but we plan to replace those with either plastic or wood as they may interfere with magnetic fields which may in turn affect the superconductor's path.

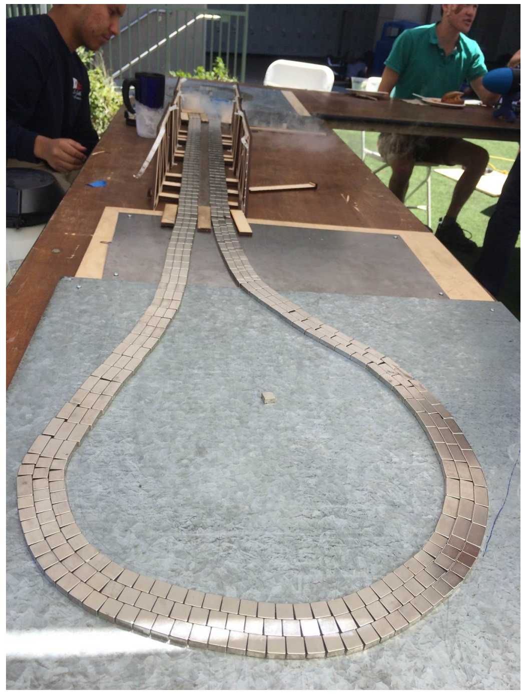

Figure 20(above): A photo of the whole product in action at Menlo's Maker Faire. You can see the full magnet track with both loops.

The superconductor track consists of a thin iron sheet with strong neodymium magnets laid on top. Each lane is three magnets wide; the magnets are laid in a specific configuration such that the two outside magnets are oriented (with regards to the magnetic poles on the longer sides) in the same way and the inside magnet is oriented in the opposite way that the outside magnets are oriented. The superconductor will follow the path of a very large loop with straightaways along the bridge and will follow almost full circles at each end of the bridge. Each of the semi-circles were designed so that the superconductor would be able to move at a decent velocity while not falling off of it's track

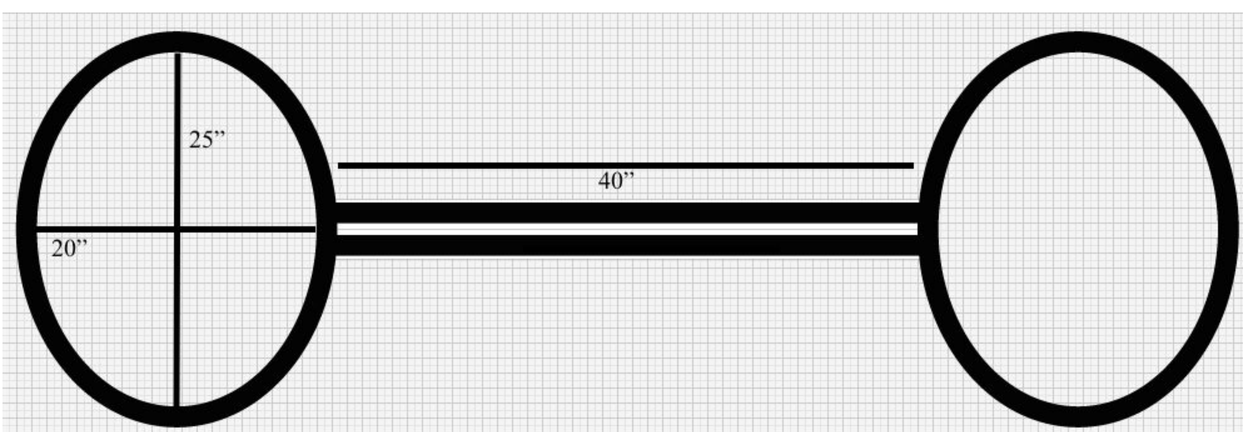

Figure 21(above): A design mockup of how we plan the final superconductor track to look like. There will be two lanes on the bridge, and each of the loops isn't a full loop; the superconductor *will travel around everything in one whole loop.*

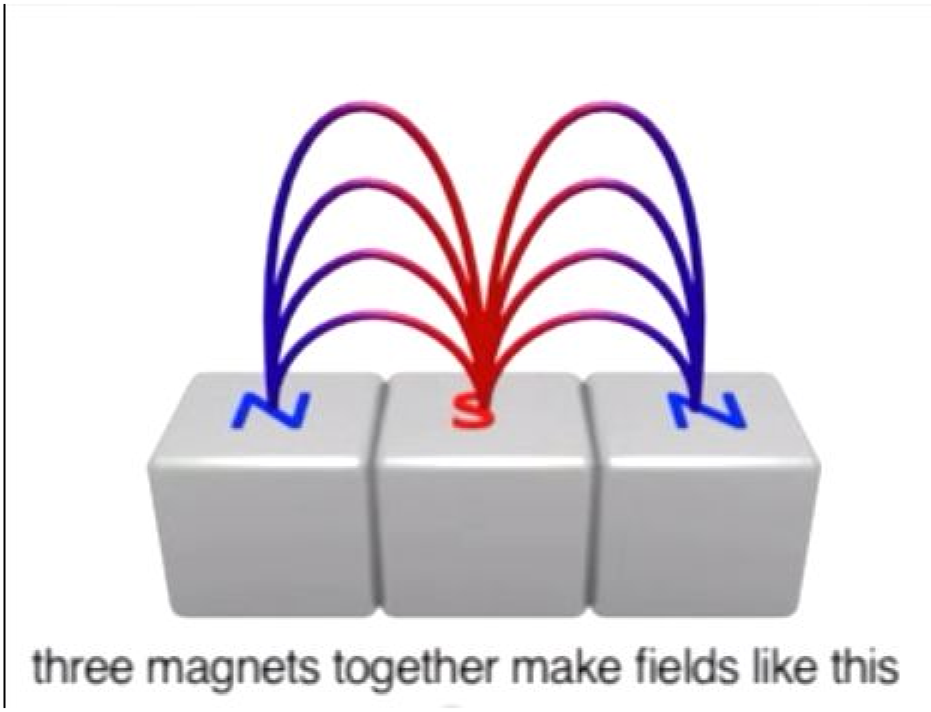

Figure 22(above): A illustration of the orientation magnets are set up in when being used for a superconductor track.

The construction of the whole magnetic path went almost all according to plan. However, each loop was originally constructed with too tight of a curvature, so an additional iron plate was added to the end of each loop so as to add additional spacing to allow each curvature to be widened and lengthened. Each of the loops plus their respective added iron plates are fastened to a thin sheet of plywood to allow for easier and safer modification and movement.

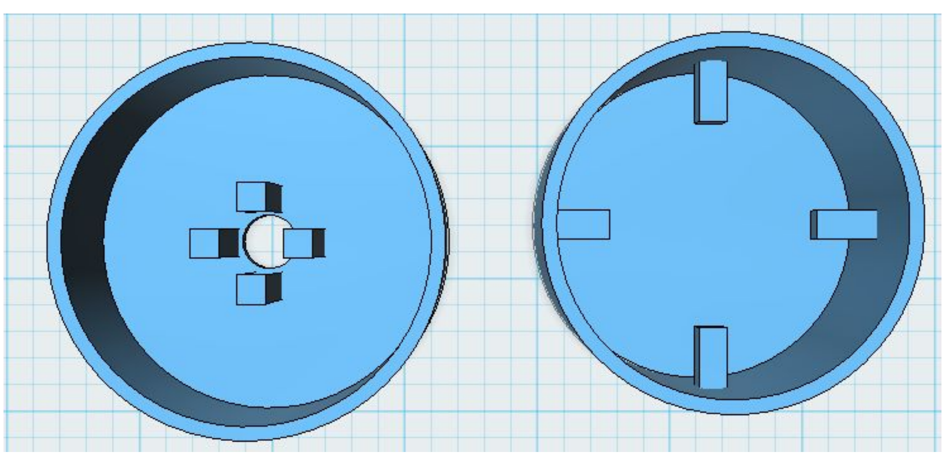

Figure 23(above): A screenshot of the 3d CAD file of the superconductor holder. The pillars are to secure the superconductor in its place. There is space in between the pillars for *styrofoam, which acts both as a fastener for the superconductor and an insulator.*

A holder for the superconductor was designed in 123D Design and 3D printed using a Makerbot. The goal for it was to expedite and standardize each run of the superconductor. The long extrusions from both the bottom of the cap and the sides of the bottom part help to ensure that the superconductor does not move before, during, or after its quantum locking. The space in between the spacers and the superconductor/wall allow for styrofoam to be placed to furthermore secure the superconductor in it's place as well as insulate it so that the superconductor stays cool for longer. The hole in the middle of the lid serves the purpose of allowing the nitrogen gas to escape. If the gas wasn't allowed to escape, it would accumulate within the holder, increasing pressure until a certain point where the holder would explode.

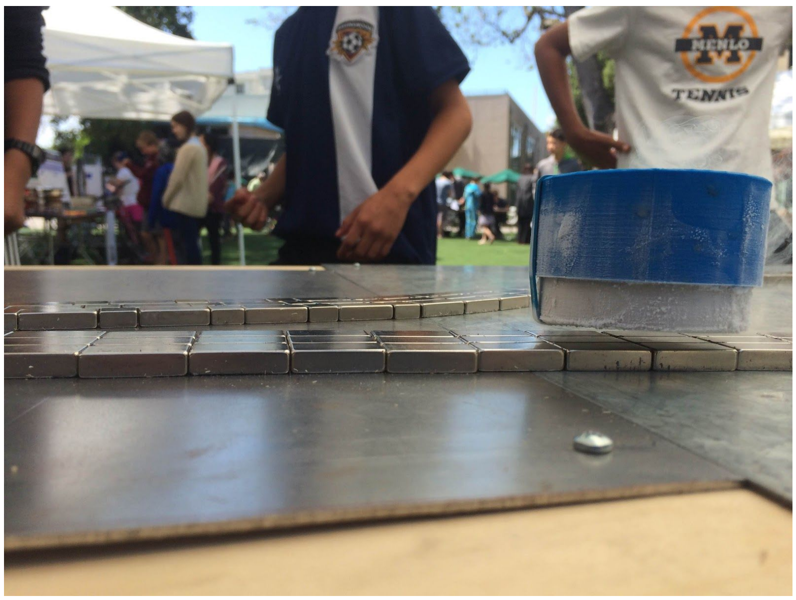

Figure 24(above): A photo of the superconductor and holder in action. Instead of normal liquid condensation forming on the outside, ice forms. The rubber band serves the purpose of ensuring that the superconductor stays tightly in it's place.

We placed the LED's on the inside of the bridge facing inward to minimize the harsh glare of the bare LED strip. If the strip were placed on the outside, it would detract from the beauty of the bridge design. Placing the strip on the inside allows the light to create more of a glow around the bridge rather than strong direct lighting.

III. Theory:

A bridge is held up by the reactions created by its supports, and the loads are forces exerted by the weight of the object plus the bridge itself. A beam bridge, or in other words a plank held by two ends, is the simplest form of a bridge. This type of bridge is not able to carry large loads because of compression forces and tension forces that act upon it. These forces sometimes end up not equaling out to zero and cause for bridges to "buckle", meaning that the compression force overpowers the ability of the bridge to handle compression and results in it collapsing. In order to add more resistance to the forces acting on a bridge we add trusses.

Trusses make a bridge's beam more rigid, due to the transfer of force from a single point to a wider area in the triangle design of the truss. Because of the larger area the base allows for the bridge to squander the compression and tension forces.[10]

Superconductivity is a phenomenon where exactly zero electrical resistance is present in certain material when cooled below a certain temperature.[11] There are two types of superconductors. Type 1 superconductors are composed of pure metals while type 2 superconductors are made of alloys. Superconductors work by changing the path of a magnetic field and not allowing for it to pass through the metal, by not passing through the metal it creates a surface current that goes on forever since it no longer has energy loss. This is all made possible because of Cooper Pairings, which at its simplest is when a pair of electrons come together during at low temperature and create a surface with zero resistance.[12] These surface currents create a magnetic field of its own that then repels against a magnet since two like poles always repel; this phenomena is called the Meissner Effect.[13]

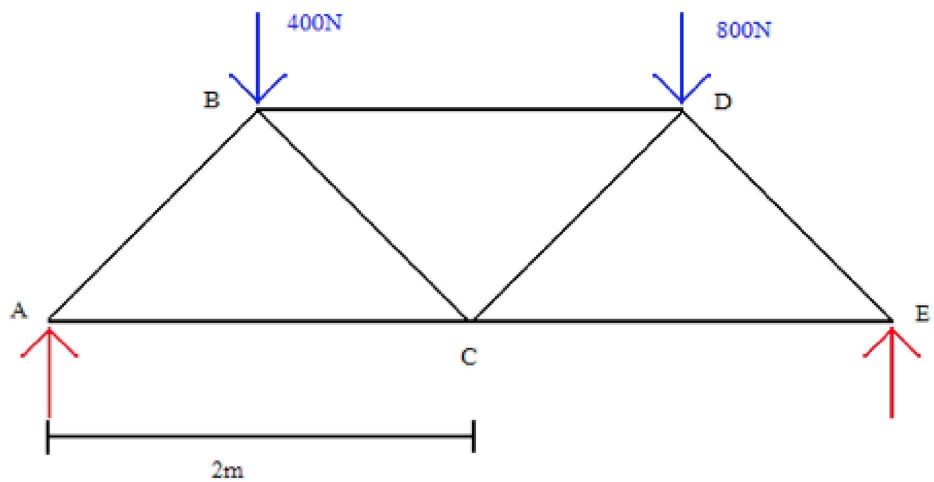

Figure 25(above): Diagram showing the forces that act upon a truss. Blue arrows represent tension force caused by gravity of bridge and cars. and red arrows represent compression force when sitting on ground.

IV. The Next Step

The next step in our project is to basically put the finishing touches on each of the three major parts: bridge, track, and lighting. We need to figure out how to design the bridge struts so that they keep the bridge perpendicular to the ground while also keeping its width at a desirable distance. As of right now, we have glued a small piece of wood to the outside of each of the

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[10] Calvert, J. "Evolution of Trusses." *Evolution of Trusses*. N.p., n.d. Web. 05 Feb. 2015.

[11] Gerbis, Nicholas. "What Is Superconductivity?" *HowStuffWorks*. HowStuffWorks.com, n.d. Web. 06 Feb. 2015.

[12] Nave, Carl R. (2006). "Cooper Pairs". *Hyperphysics*. Dept. of Physics and Astronomy, Georgia State Univ. Retrieved 2008-07-24.

[13] Bardeen, J., N. Cooper, and J. R. Schrieffer. *Theory of Superconductivity*. Vol. 108. Illinois.

struts so that the bridge doesn't slide off that side.

We also may install a sort of roof structure to ensure that the sides of the bridge stay perpendicular and don't wobble; the roof structure also helps with the horizontal strength of the bridge. The bridge itself has held up to any weight we have managed to put on it, and the bolt securing the long pieces to the short pieces have been replaced with plastic nuts and bolts so that they don't interfere with the track and the superconductor.

As always, the track has been the most problematic part of the project recently. Each time the manets don't line up perfectly with the ones in front of them, the superconductor (and subsequently its holder) wobble slightly, and when this happens multiple times in a row, the effect is multiplied and the holder touches the track, introducing lots of friction and slowing the superconductor down. We're going to improve the track connections between each of the loop sections and the bridge portion; as of right now, the magnets on the edge repel each other and cause each other to move out of their correct position. We will also continually work on straightening the magnets out, as well as straightening out a portion of one loop which we feel is curved too tight currently.

The LED integration will be the largest portion of the work we have to do. The LED's will be integrated facing inward along the top and sides of each of the sides of the bridge; there may or may not be a shroud over the top to reduce the glare and produce more of a glow. A circuit needs to be created that does two things: synchronize the two led strips together by connecting them to the same voltage pins and trigger those led strips through the use of a tripwire. Each time the superconductor enters or exits the bridge portion of the track, the LED's will toggle on or off. The LED's will be attached either using epoxy or zip ties.

We will also design a new holder for the superconductor. This holder will appear like an actual train and be thinner so that the bridge can more easily accommodate it. There will also be a hole in the top for the nitrogen gas to escape, simulating the steam of a steam engine. It is important that the model isn't too heavy and that it still has space for styrofoam (insulation).

V. Results

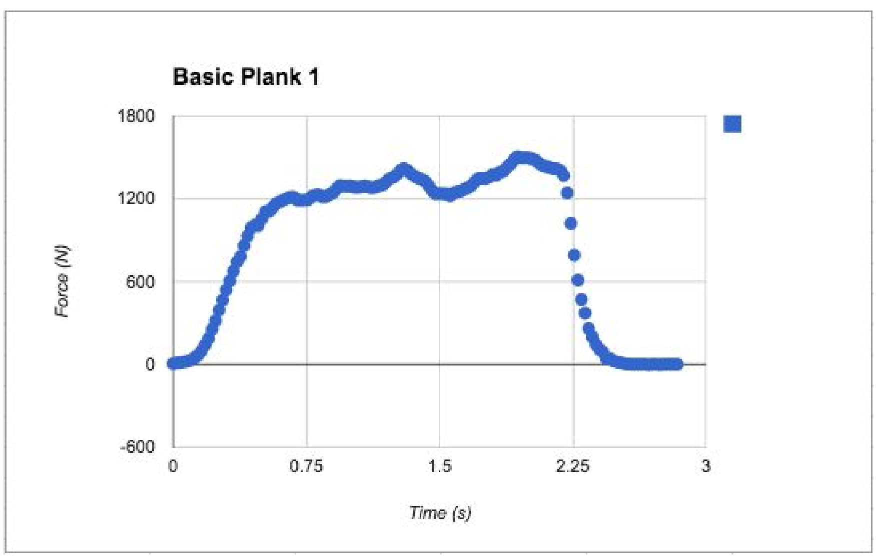

Figure 26(above): a graph displaying the force over time impressed upon our first basic plank *prototype.*

Figure 26 displays the force-time graph that we constructed after collecting data with a force plate for our first bridge. The first bridge was a plank with the struss structures glued on top, and as per the graph, withstood about 1500 Newtons before breaking.

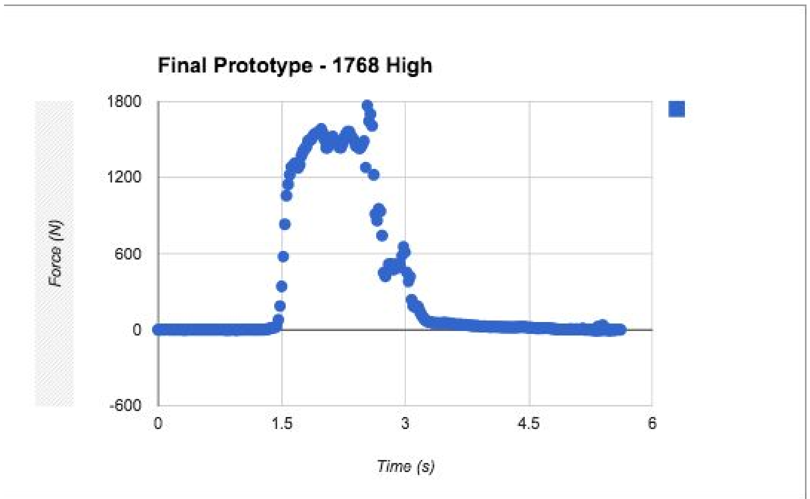

Figure 27(above): a graph displaying the force over time impressed upon our final prototype.

Figure 27 displays the force-time graph that we constructed after collecting data with a force plate for our final prototype. Our final prototype used the design where a plank is placed on top of struts which were put through side of the truss structure. (The final bridge design is similar to the final prototype in that it uses wider struts and an iron plank instead of a wood one). The final prototype withstood a force of 1768 Newton's before breaking.

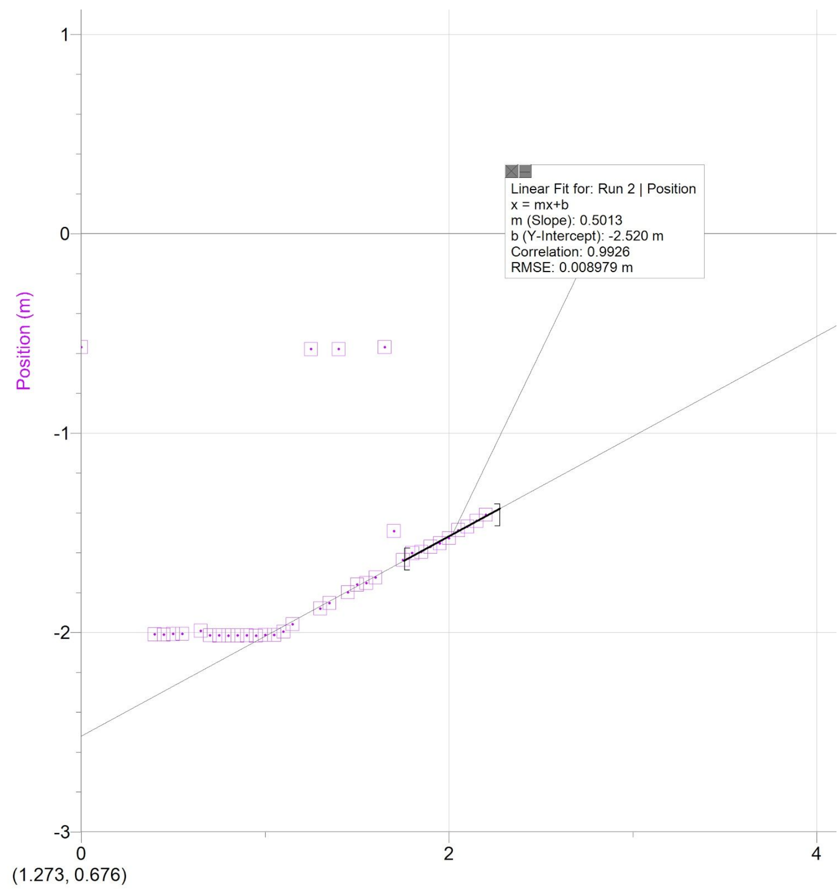

Figure 28(above): A graph of a sample run to determine the velocity of the superconductor.

In order to determine the maximum velocity that the superconductor could travel along the track at, we measured the pulling force needed to pull it off of the track while locked, the mass of the superconductor, it's holder, and the styrofoam, and averaged the radii of both loops. using the equation $F_c = mv^2/r$, we calculated the maximum velocity to be 1.5 m/s.

Figure 28 depicts a graph of the superconductor position as a function of time, measured with a motion sensor. The slope of this graph, **ΔPosition/ΔTime**, shows the velocity of the superconductor, given from the equation x=vt, where x represents position, v represents velocity, and t represents time. The slope in the graph in figure 28 is 0.5; we calculated the maximum velocity of the superconductor to be 1.5m/s.

VI. Appendices

Appendix A: Parts list

Name	**Cost**	**Where We Will Get it From**
Bridge Wood	$0	Menlo School Laser Cutter
LED Strips	~ $12 for 16ft	Amazon.com
Arduino + Wires	$0	Menlo School Lab
Magnets	~ $300	magnets4less.com
Liquid Nitrogen	~ $150	Menlo School

Appendix B: Website URLs

http://www.paprojectpath.org/historic-truss-bridges
https://mysite.du.edu/~jcalvert/tech/truss.htm
http://www.historyworld.net/wrldhis/PlainTextHistories.asp?historyid=ab97
http://www.electronicsweekly.com/news/components/led-lighting/50-year-history-of-the-led-2012-10/
http://www.superconductors.org/history.htm
http://www.superconductors.org/uses.htm
http://en.wikipedia.org/wiki/Superconductivity
http://yclept.ucdavis.edu/course/242/Publ/BCS.pdf
http://science.howstuffworks.com/environmental/energy/superconductivity1.htm
http://www.magnet4less.com/product_info.php?manufacturers_id=&products_id=255
http://www.amazon.com/LEDwholesalers-Flexible-SMD3528-Adhesive-2026WH/dp/B002Q8V8DM
http://makezine.com/2010/06/10/ask-make-how-do-trusses-work/
http://ojhsbridges.weebly.com/uploads/3/2/6/6/3266881/4810343.gif?300
http://ojhsbridges.weebly.com/uploads/3/2/6/6/3266881/6855640.gif?318
http://www.thenakedscientists.com/HTML/uploads/RTEmagicC_Arches-flying-buttress.png.png
http://www.lamptech.co.uk/Images/LED%20Lamps/LED%20Monsanto%20MV1.jpg
http://www.edisontechcenter.org/LED.html

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