The Engineering Method (EGR 110): Midterm Lab Report

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Measurements and Bridge Design / Test

North Central College

Fall 2018

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Executive Summary:

On the first day of class, we discuss the differences between the engineering method and scientific method. Both involve figuring out measurements, analyzing data, and experimentation; however, the engineering method is used by engineers to come up with solutions to a problem.

For our first homework assignment, we had to create eight rectangles and two cylinders in Solid Works and print them out. All the rectangles had different dimensions. For us, the dimensions consisted of different thicknesses or heights. They included .2 mm, .4mm, .8 mm, and 1.6mm. Because there are eight rectangles, 2 of them had each dimension. For each of these rectangles, they had a length of 50 mm and a width of 15 mm. For the cylinders, both had a length of 50 mm and a diameter of 10 mm. In addition, we had to extrude 8.50 mm in diameter out of them; therefore, these cylinders had a thickness of 1.5 mm. After I had all these parts created in Solid Works, I imported them into Slic3r PE. This program displays the build plate on the 3D printer, so I know exactly how the parts will be printed out. I laid one .2 mm rectangle flat and another .2 mm rectangle on its side. I did this for every dimension. I also laid one cylinder on its side and the other on its base. After adjusting to the correct filament settings, I exported the G-code onto an SD card. I then inserted the card into the printer and I selected the file I saved the G-code under.

When the parts were printed out, I had to measure them and examine their differences. One major thing that happened was that the printer failed to print out the 8 rectangles, two were missing. These two were printed on their sides and one had a thickness of .2 mm and the other .4 mm. I found out that the printer's nozzle was unable to print these vertically because it had a diameter of .4 mm.

After finishing this assignment, our Professor, Dr. Harwath, gave us another. This assignment included measuring metal parts, designing a bridge, and making this lab report. I was assigned with a partner for this assignment, his name is Chris. We measured the metal parts with a Vernier caliper separately and then compared our results. For these parts, we had to measured at three different points on the caliper and determine which point gives the most accurate reading. After calculating the averages and standard deviations for the measurements, we determined that the bottom and middle points gave the most accurate readings. This exercise helped us with measuring the parts that we printed out. All these measurements are discussed in detail in this report.

Lastly, me and Chris had to come up with a design for the bridge in Solid Works. This bridge had to follow certain constraints and compete in the bridge competition to see how much weight it could hold. The bridge had a length of 177.8 mm and a width of 48 mm. The deck of the bridge was .6 mm thick and the height was 20 mm. This bridge was held by two frames each one was 2.5 mm thick. We followed all the constraints besides one, the weight. The bridge was around 4.5 g overweight, so I had to cut some pieces off it. In the end, it weighed exactly 20 g, the maximum weight. Our bridge was able to hold 24 g before it finally broke.

All the information mentioned above is in this lab report. This page isn't as detailed as the pages below. Use the table of contents to navigate around.

Safety Review:

i. Moving Parts: Whenever the printer is on and printing something, keep all body parts away from the machine and gears. Never stick your hands or anything near the moving parts. Make sure you avoid the “pinch points” on the printer. The printer doesn’t care what is there and it will crush it.

ii. Nozzle: The printer’s nozzle can get up to between 260 degrees Celsius and 280 degrees Celsius. This is extremely hot and dangerous. Never touch the nozzle when you are printing or when it's warming up because it has the potential to give you third degree burns.

iii. Hot Filament: Be wary of the hot filament the printers spits out. Make sure you never touch the filament coming out of the nozzle because this is when it's the hottest and it will burn you.

iv. Motor: The printer has a motor in it, and these parts move. Make sure you don’t get it wet or put anything inside of it. You might break the printer or harm yourself.

v. Fan: The printer has a fan and this moving part is open. Make sure you never stick anything by this part. Anyone with long hair, make sure you avoid this moving part.

vi. Cord: Make sure the electric cord to the printer isn’t damaged or wet. If it is, make sure you notify everyone about it and find help.

vii. Carrying Printer: You should never really have to carry the printer. However, if you do, make sure you are wary of its weight and it is unplugged. And obviously, never move it when it is printing!

viii. Clean Workstation: It is critical that you keep your workstation clean and you put everything away where it belongs. A dirty workplace will eventually lead to accidents and someone might get hurt.

ix. Crowded Workplace: Whenever the printers are crowded with people, make sure you avoid bumping into anyone or just move out of the way.

x. Stool: Whenever you need to use the stool, make sure it locks into place. You should be about to hear it. And move it back to where it belongs after you are done with it.

xi. Water & Food: Make sure you never eat in the lab and you keep the area clean. Whenever you see a puddle of water on the floor or anywhere in the lab, notify everyone and clean it up.

xii. Backpacks & School Work: Make sure your belongings are in a safe place and away from walk ways. Anyone can trip over your stuff and this could lead to an accident.

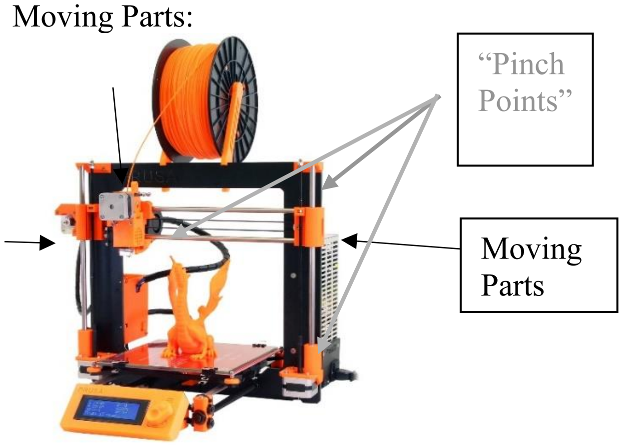
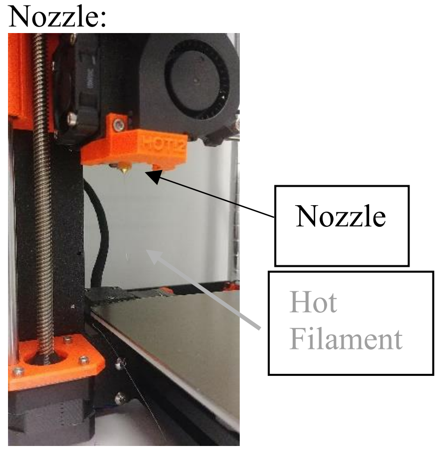
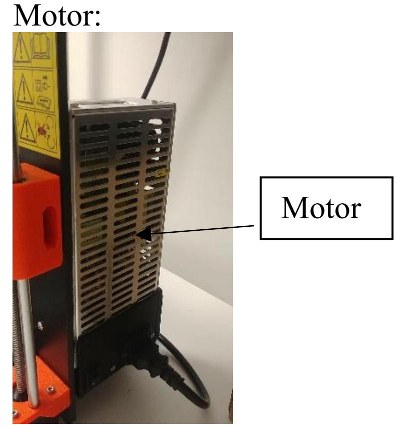
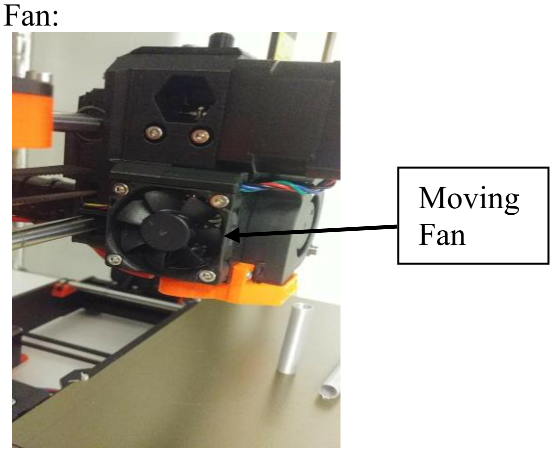
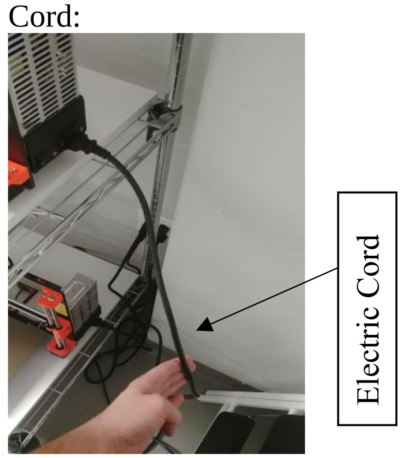
xiii. Horseplay & Running: Whenever you are in a lab like this one, all your attention should be on is your task and avoiding potential accidents. You should never run or goof-off in the lab because this will lead to accidents.

xiv. Lights: While there are people in the lab, you should never turn off the lights. This could lead to chaos and accidents.

xv. Outlets: Make sure you plug and unplug everything correctly into the outlets on the walls.

xvi. Communication: Whenever you have an issue or a problem in the lab, make sure you communicate it with everyone and you get help immediately.

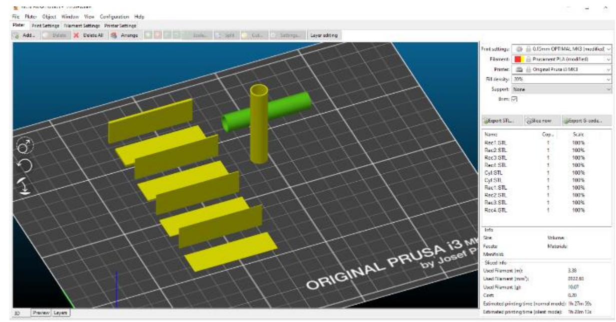
Photos:

Moving Parts: 	Nozzle: 	Motor: 
Fan: 	Cord: 	Outlet:  Stool: 

Cost Analysis:

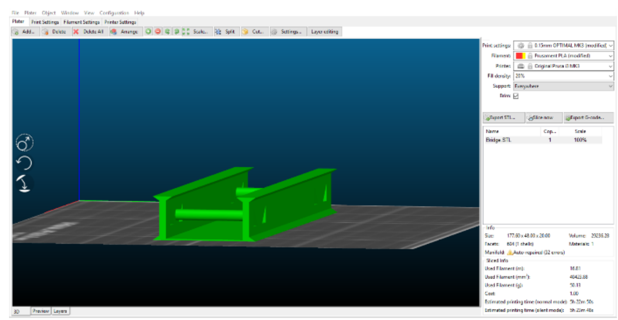
The table below shows how expensive each part was to build and how much filament I used. I printed out three things, the parts, my original bridge, and the final bridge. All three of these are included in the tables below. Here are my following results.

Filament Measurement	Results:
Used Filament (m):	3.38
Used Filament (mm^3):	8122.68
Used Filament (g):	10.07
Time:	5279 s
Estimated Printing Time (Normal Mode):	1hr 27m 59s
Estimated Printing Time (Silent Mode):	1hr 28m 13s
Cost:	
Cost (US Dollars)	.20



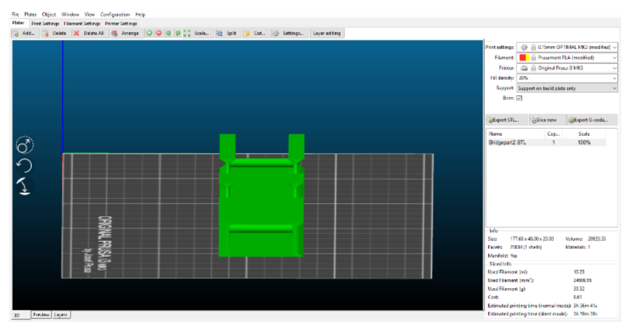
Parts:

Filament Measurement	Results:
Used Filament (m):	16.81
Used Filament (mm^3):	40423.88
Used Filament (g):	50.13
Time:	19370 s
Estimated Printing Time (Normal Mode):	5hr 22m 50s
Estimated Printing Time (Silent Mode):	5hr 23m 48s
Cost:	
Cost (US Dollars)	1.00



Original Bridge Design:

Filament Measurement	Results:
Used Filament (m):	10.23
Used Filament (mm^3):	24609.55
Used Filament (g):	30.52
Time:	14201 s
Estimated Printing Time (Normal Mode):	3hr 56m 41s
Estimated Printing Time (Silent Mode):	3hr 59m 39s
Cost:	
Cost (US Dollars)	.60



Final Bridge Design:

Although I have supplied the cost of printing, I still must show the overall cost, this is called the "build cost." The build cost involves how much electricity I used plus the cost of the filament, which I have already supplied. The next page has a table of the build cost.

Cost Parameters:

- Machine Time = $1 / hr
- Material Cost = $20.00 / kg
- Equation: (Est Printing Time (Normal) sec/ 3600 sec)($1.00) + (Used Filament g / 1000 g)($20.00) = Cost

Item:	Calculations:	Cost:
Parts	(5279 sec/ 3600 sec)($1.00) + (10.07 g / 1000 g)($20.00) =	$1.68
Original	(19370 sec/ 3600 sec)($1.00) + (50.13 g / 1000 g)($20.00) =	$6.38
Final	(14201 sec/ 3600 sec)($1.00) + (30.52 g / 1000 g)($20.00) =	$4.56
Total:	1.68 + 6.38 + 4.56 =	**$12.62**

"Build Cost"

Build Cost:

Overall, all my designs cost a grand total of $12.62, and this includes the printing filament and the electricity the printer used. As you can see, using these 3D printers are very inexpensive considering what you can build. I didn't include this in the tables; however, I used 23.25 g in scrap for giving my designs support while printing. This means I spent $0.47 on filament scrap, but this cost does not include the cost of electricity. So, I probably spend around $2.47 on just what I needed to give my designs support to be printed out correctly.

Saving Money:

After experiencing 3D printing with hands-on work, I have thought of a couple of ways to save money with the printing process. For example, you can check how much your design weighs before printing it; therefore, you don't waste an unnecessary amount of filament. Another way is trying to use the least amount of scrap as possible. Although support is important for your design, sometimes, you really don't need it and your design will be fine. By cutting down on support, you will save money on scrap and electricity. The last way of save money with printing is designing your product in a way that doesn't use much filament for support. Or even better, putting it on a nice angle on the build platform. These techniques will exponentially save you money if you follow them correctly.

Measurement Exercise:

The table below contains all the measurements that I took for the metal parts and the parts I printed out. For the metal parts, I measure the long bearing, circular bearing, and the long rod. In addition to my measurements, my lab partner, Chris, also recorded his measurements for the same metal parts. We did this section together to see which point on the Vernier caliper gives the most accurate measurement. I will go into more detail about this below. Lastly, I measured the parts I printed out, which includes the following: 8 rectangles and 2 cylinders.

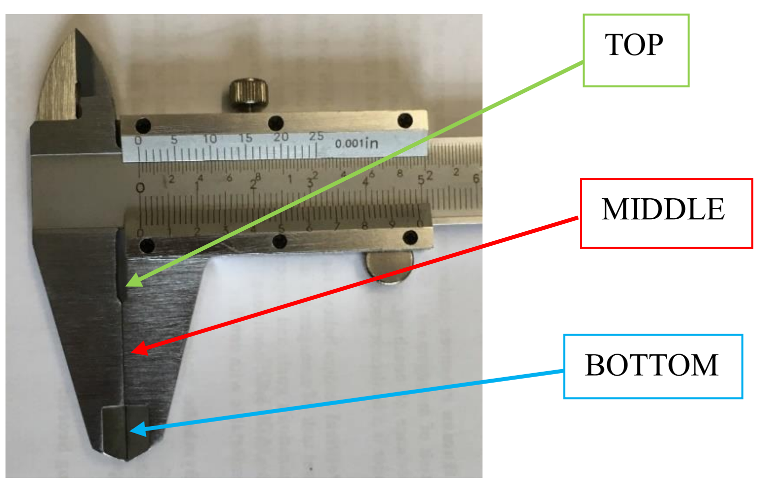
Printed Parts Exercise:

	Bottom	Middle	Top
Rectangle 1 (Flat)			
	Bottom	Middle	Top
Height	49mm	49mm	47.6mm
	1.929in	1.929in	1.874in
Width	14.1mm	13.8mm	12.65mm
	.555in	.543in	0.498in
Thickness	.3mm	.3mm	.3mm
	.012in	.012in	.012in
Rectangle 2 (Flat)			
	Bottom	Middle	Top
Height	50.9mm	50.8mm	49.4mm
	2.004in	2in	1.945in
Width	15.6mm	15.8mm	14.2mm
	.614in	.622in	.559in
Thickness	.5mm	.5mm	.5mm
	0.02in	.02in	.02in
Rectangle 3 (Flat)			
	Bottom	Middle	Top
Height	50.2mm	50.2mm	48.8mm
	1.98in	1.98in	1.921in
Width	15.3mm	15.3mm	13.8mm
	.602in	.602in	.543in
Thickness	.9mm	.9mm	.9mm
	.035in	.035in	.035in
Rectangle 3 (Side)			
	Bottom	Middle	Top
Height	49.9mm	49.9mm	48.3mm
	1.965in	1.965in	1.902in
Width	15mm	15mm	13.5mm
	.591in	0.591in	.531in
Thickness	.9mm	.9mm	.9mm
	.035in	.035in	.035in
Rectangle 4 (Flat)			
	Bottom	Middle	Top
Height	50.1mm	50.2mm	48.7mm
	1.972in	1.976in	1.917in
Width	15.3mm	15.3mm	13.7mm
	0.602in	.602in	.539in
Thickness	1.8mm	1.8mm	1.8mm
	.071in	.071in	.071in
Rectangle 4 (Side)			
	Bottom	Middle	Top
Height	50.1mm	50.1mm	48.5mm
	1.972in	1.972in	1.909in
Width	15.1mm	15mm	13.5mm
	.594in	.591in	.531in
Thickness	1.8mm	1.8mm	1.8mm
	.071in	.071in	.071in
Cylinder (Base)			
	Bottom	Middle	Top
Height	50mm	50mm	48.7mm
	1.969in	1.969in	1.917in
Diameter	9.9mm	9.9mm	8.4mm
	0.39in	.39in	.331in
Thickness	.8mm	.8mm	.8mm
	.031in	.031in	.031in
Cylinder (Side)			
	Bottom	Middle	Top
Height	49.9mm	49.9mm	48.5mm
	1.965in	1.965in	1.909in
Diameter	9.7mm	9.7mm	8.1mm
	0.382in	.382in	.319in
Thickness	.8mm	.8mm	.8mm
	.031in	.031in	.031in

Metal Parts Exercise:

	Chris' Data			My Data			Results		
Long Bearing									
	Bottom	Middle	Top	Bottom	Middle	Top	Average	SD	mm/in
Height	24	24.1	25	23.8	23.9	23.89	24.115	0.445589	mm
	0.937	0.941	0.94	0.937	0.941	0.94	0.939333	0.0017	in
Diameter	14.9	14.9	13.4	14.9	14.9	13.4	14.4	0.707107	mmin
	0.587	0.587	0.528	0.587	0.587	0.528	0.567333	0.027813	
Circular Bearing									
	Bottom	Middle	Top	Bottom	Middle	Top	Average	SD	mm/in
Diameter	21.9	21.9	20.5	21.9	21.9	20.5	21.43333	0.659966	mm
	0.862	0.862	0.807	0.862	0.862	0.807	0.843667	0.025927	in
Height	6.9	6.9	5.4	6.9	6.9	5.4	6.4	0.707107	mm
	0.272	0.272	0.213	0.272	0.272	0.213	0.252333	0.027813	in
Long Rod									
	Bottom	Middle	Top	Bottom	Middle	Top	Average	SD	mm/in
Diameter	8	8	6.5	8	8	6.5	7.5	0.707107	mm
	0.315	0.315	0.256	0.315	0.315	0.256	0.295333	0.027813	in

Points on the Vernier Caliper:



Metal Parts Explanation:

As you can see, both of our measurements were pretty much the same except for the height of the long bearing. Even at all three points, most of our measurements were the same. From this exercise, we learned that the bottom and middle points of the Vernier caliper give the most accurate measurements compared to the top. With most of our measurements, the top was always off by -1.5 mm or -.059in. Due to this offset, our averages and standard deviations were skewed. And as a result, we learned that it was best to measure with either the middle or bottom of the caliper.

Printed Parts Explanation:

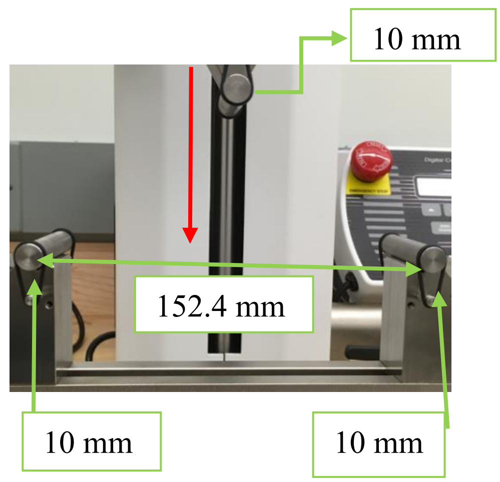
If you have been paying close attention to this report, you have probably noticed that two side rectangles are missing from my printed parts. This is due to the nozzle of the 3D printer. The nozzle is .4 mm in diameter; therefore, it was unable to print the .2 mm thick rectangle and the .4 mm thick rectangle. Both rectangles were laid on their sides and the printer's nozzle was unable to print these vertically. This was probably due to how big the nozzle was in diameter. Hypothetically, let's say the nozzle was .1 mm in diameter, then the printer might have been able to get these rectangles printed. All the measurements were close to what I anticipated, give or take 1 mm. They probably weren't exact because I had to take them off the brim myself, which may have either increase or decrease the size of the dimension.

After bending, touching, breaking, and twisting the printed parts, I noticed a couple of things. Obviously, as the rectangle thickness went up, it was harder to manipulate the rectangles because they were stronger and more stable. The .2 mm and .4 mm thick rectangles were easy to fold; however, if I tried folding the .8 mm and 1.6 mm rectangles, they would break in half. The two rectangles that were printed on their sides didn't differ significantly from the ones that weren't. But the cylinder that was printed on its side was totally different from the one that was printed on its base (standing up). For some reason, the side cylinder had a smaller diameter and it wasn't as stable compared to the other one. The cylinder that was printed on its base was a lot stronger and harder to break. I guess this was probably due to the printing process. It was easy for the printer to print the cylinder vertically than on its side.

Specification:

Below I will discuss about the bridge constraints that I had to follow to compete in the bridge competition. In addition, I will show how my bridge followed all these constraints.

Bridge Constraints:

Constraints Consist of the Following: 1.) PLA filament only 2.) Maximum weight: 20 g 3.) Bridge may extend 20 mm above to 5 mm below top tangents of support pins 4.) Bridge must have a solid deck between 48 mm and 50 mm wide. The deck must be .6 mm thick. The bridge length had to be 177.8 mm. 5.) Not allow to have hooks that captures the support pins. 6.) Bridge load will be placed in the center by a 10 mm diameter pin. Nothing can obstruct the load pin.	Load Machine & Pins: Pins = Force = 

Scenario:

Let’s say there was a river and I had to build a bridge to get across it. This bridge must be at least the length of the river, 177.8 mm. And it must be between 48 and 50 meters wide, so multiple people can walk across it at the same time. The deck needs to be .6 mm thick, so nobody falls through the bridge. This bridge also cannot be more than 20 mm in height because then it would be touching the surface of the water. Lastly, the bridge cannot be over 20 g, or it could possible collapse. The bridge must be able to handle a lot of weight in the middle because people might want to go fishing on this bridge and they will probably fish in the middle of the bridge.

Bridge Design:

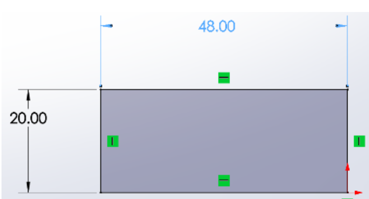
Before I started designing my bridge on Solid Works, I was thinking about how my bridge would follow all these constraints. I knew I wanted my bridge to hold a lot of weight; therefore, I wanted the frames on the bridge to be thick and strong. Even though it might be heavy, it would be able to hold weight. I also did not want it bending. After thinking about it, I loaded up Solid Works and began working on it. The process below describes how I built my bridge while following the required constraints.

Process of Creating my Design:

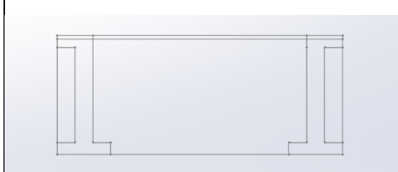
1.) So, I started out building my bridge by creating a rectangle in Solid Works that had a length of 20 mm and a width of 48 mm. This rectangle was created on the front plane. These dimensions followed the constraints for height and width.
2.) On the rectangle, I drew out the spaces I was not going to use or cut out. This included making the deck .6 mm thick. I then extruded the drawing 177.8 mm, which followed the length requirement.
3.) I now had a 3D part in Solid Works that looked something like a bridge, so I then cleaned up the design by cutting down the edges. I then added features for the bridge; for example, I cut out holes and arches. In addition, I also added two bars connecting both sides together. After doing all of this, I fillet the edges and holes.
4.) When I printed out my final bridge, it was overweight. It had to lose around 4.5 g of weight. Instead of printing another bridge, I decided to cut it down.
5.) I cut off the bottom edges and the space between the arches. Because of cutting, I was able to get my bridge to weigh exactly 20 g, which fulfilled the required weight.
6.) Finished design! – Followed All Constraints!

Photos:

1.) Creating Rectangle:



2.) Drawing and Extruding: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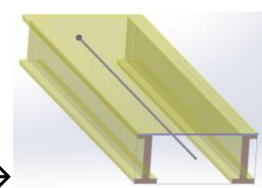
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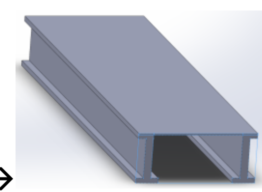
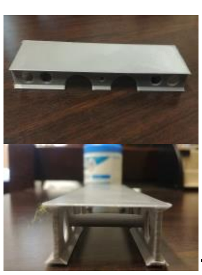


4.) & 5.)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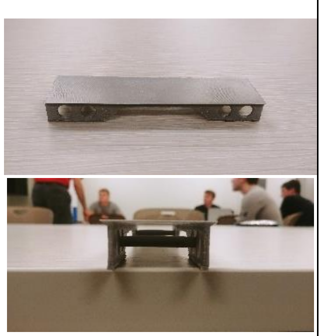
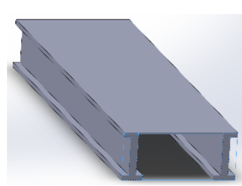


3.) Features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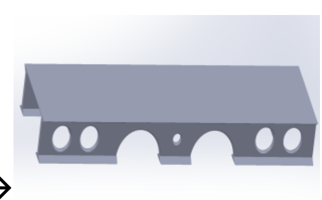
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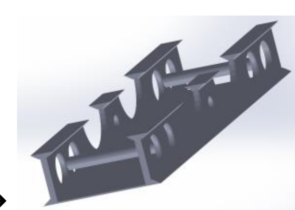


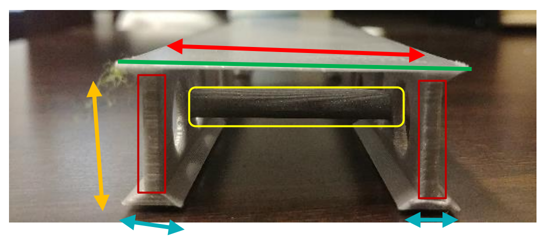
Concept:

So, I came up with a bridge that addressed all the following constraints. I have already explained how I did this above, so I won't explain it again. However, below is a picture of the final bridge design with all the following constraints shown. As you can see, my bridge has every constraint that was addressed above. There are two pictures of the final bridge, one before cutting and one after cutting. The bridge I cut up is the final bridge that I competed with in the competition.

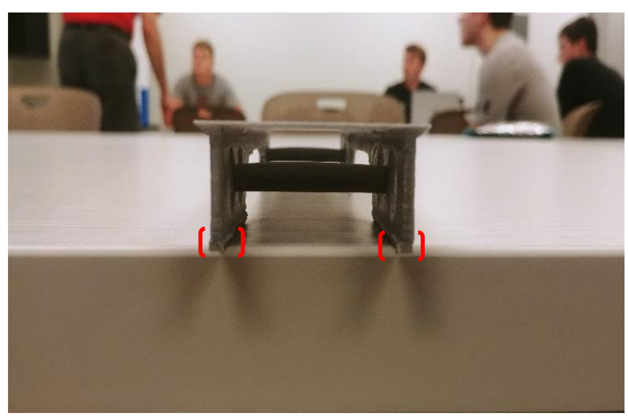
Design:

__**Before Cutting**__: (Still must follow the weight constraint)

Length (←→) = 177.8 mm
Width (←→) = 48 mm
Height (←→) = 20 mm
Big Circles (←→) = 10 mm
Small Circle (←→) = 5 mm
Arches (←→) = 28 mm
Thickness (←→) = .6 mm
Bars Thickness ([]) = 5 mm
Frame Width ([]) = 2.5 mm
Base length (←→) = 9mm



__**After Cutting**__: (Final Bridge)



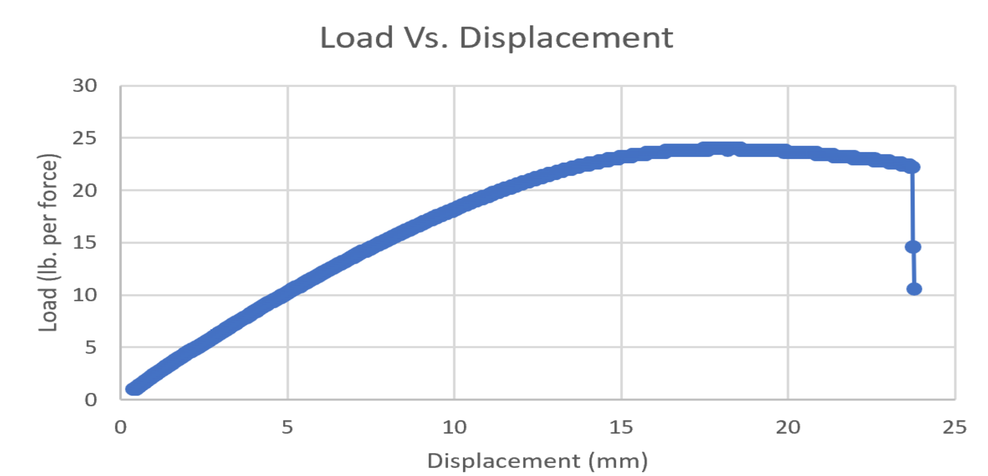
Scenario:

I was able to make a bridge to get across the river. The bridge's length and width were correct. The height wasn't higher than 20 mm and the deck was .6 mm thick. The bridge was exactly 20 g in weight. Overall, the bridge was able to do its job. Here's a picture of the final bridge with the river:

Photo:

Verification:

On Tuesday, October 9th, I tested my bridge and I came out with the results below. The test consisted of a machine that put weight on the midpoint of the bridge. For my bridge, it was able to hold 24 lbs. before collapsing. After it reached its maximum load, the weight slowly decreased because the bridge was bending. The bridge immediately collapsed when it started to bend. This isn't included in the graph; however, my bridge failed at 56.9 seconds. My bridge was able to hold 544.3 times its weight. This calculation can be found below the graph. The graph for this experiment is right below and I also explain the experiment in more detail below.



Weight Ratio:
(lb. of Force) / (Bridge's Weight) = (24 lb.) / (20 g = .0440925 lb.) = 544.31
Meaning:
According to this calculation, my bridge was able to hold 544.31 times its weight.

Bridge (Before):

Bridge (After):

Bridge Test Explanation:

Process of the Experiment:

1.) Bridge was placed on the end pins.
2.) The midline pin pushes down on the bridge. It slowly puts weight on the bridge until it starts to bend or break.
3.) Eventually the bridge comes to a point when it either breaks or bends to far down.