Three Dimensional Modeling of a Wind Turbine In SolidWorks

Group 38: Aidan Sussman, Andrew Zhu, Agnese Sanavio, Samantha Berry,

Chester Zelaya, and Shelby Respicio-Evans

Department of Mechanical Engineering, University of California, Berkeley

Engineering 26: Three Dimensional Modeling for Engineering

Professor Ken Youssefi

December 11, 2020

Project Summary

Wind has been used for years as a source of energy. It is now being looked at as a way to generate electricity in a fashion that is renewable and environmentally-friendly, while still functioning as a powerful energy source. Wind turbines are now used as an energy source by creating structures with a rotor and turbines that allow wind to turn the blades of the turbine, which spins the generator and creates electricity [energy.gov]. With the tools learned throughout this semester, our design team has created a 3D model (using the program SolidWorks) of our take on the most optimal wind turbine.

Figure 1: Capricorn Ridge Windfarm in Sterling County, Texas

For this project, we were required to design and stress test a wind turbine with the following restrictions: a maximum height of 16.00 ±1/6 inches, a maximum volume of 25 in^3 of ABS plastic, and a length and width to fit within a 12 x 12 in platform. The motor we were designing for is a Maxon A-max motor which was 26mm x 45mm. With these restrictions sought to create a wind turbine that minimized the displacement when a force was applied to it while attempting to use as little material as possible.

After careful consideration of each of our team member's designs, as well as many trials of optimization, our group decided on a final wind turbine design based on the displacement, volume, and overall stability. Through these modifications, we created a design that minimized the amount of material while still focusing on maximizing the stiffness to weight ratio, as the project requires.

Table of Contents

Introduction

One of the key needs of any modern day society is energy, but the major sources of energy are unsustainable and have various negative environmental impacts, “including climate change, acid rain, freshwater consumption, hazardous air pollution, and radioactive waste” (U Michigan). Renewable energy can help to reduce these environmental effects.

Over the past 70 years the US has shifted to using more and more renewable energy, and is projected to double renewable energy consumption over the next 30 years.

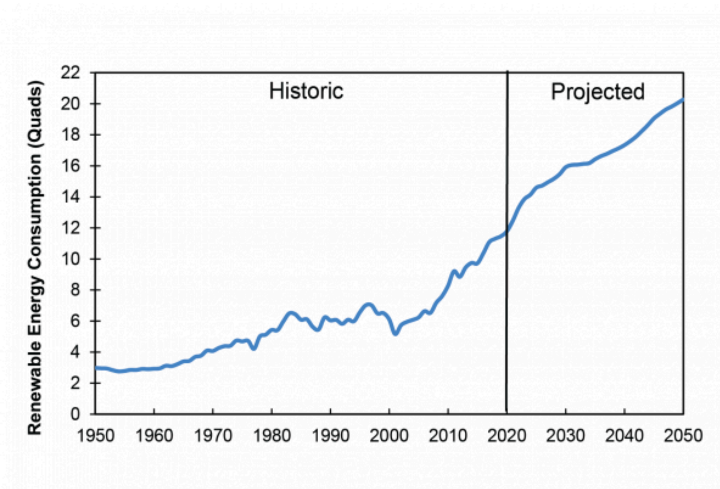


Figure 2: US Projected Renewable Energy Consumption EIA Monthly Energy Review July 2020.

As the engineers of the modern world are trying to become more efficient with their energy usage, they begin encountering some difficulties. The initial problem engineers had to face when trying to transform the way energy was being used was the fact that fossil fuels were already so efficient. They had to make wind turbines enough of a competitor for advancements to be made. For this to work, they decided they needed to plant so called “wind farms” so they get the most use out of the wind in the area. They needed to create the most amount of windmills with the least amount of volume and with the least amount of displacement from the force exerted on them. The perfect combination of efficiency, output, and cost.

The basic concept of a wind turbine is to convert the energy from the motion of passing wind into rotational energy. Turbines are made up of four main parts: the tower, the blades, the nacelle (rotor assembly), and the generator.

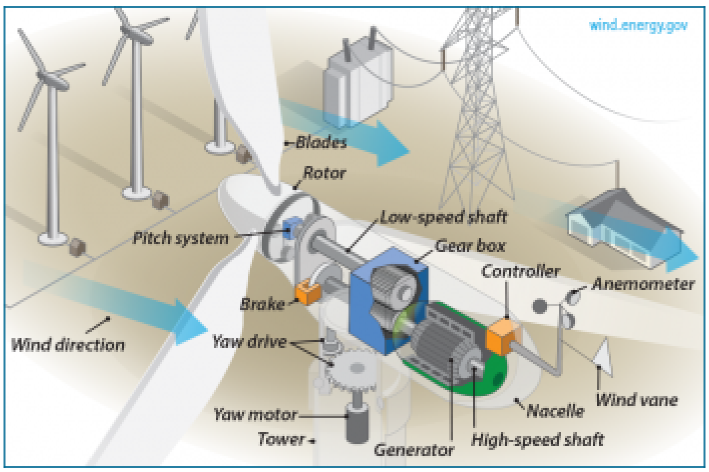
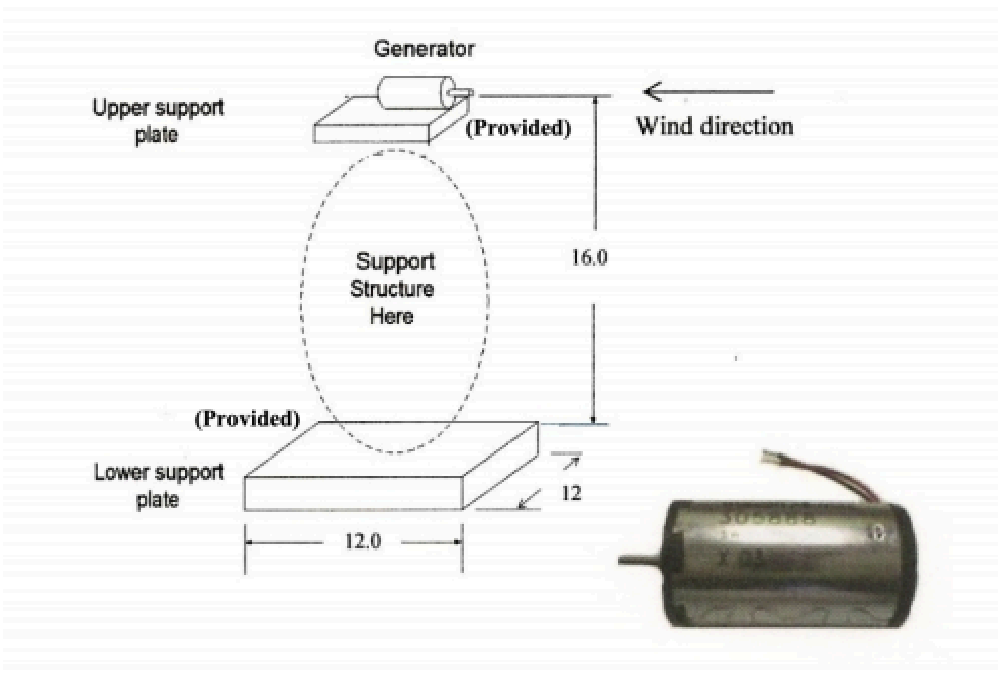


Figure 3: Diagram of a wind turbine Source: (Office of Energy Efficiency and Renewable Energy)

Turbine towers are built at least 80 meters tall in order to interact with the most uninterrupted, direct wind. As wind starts to flow past, the wind turbine is rotated in order to face the strongest wind (AWEA). The wind then flows across the blade, creating a difference in pressure, this difference of pressure creates a lift force that overpowers the drag force on the blades, creating rotation (Energy Gov). In order to convert this rotation into a useful amount of energy, the rotor is connected to a gearbox that increases the speed of rotation by a factor of 100 (AWEA). The final step is to use a generator to collect the maximized rotational energy. Our job was to incorporate all this knowledge into our newfound project.

The instructions were simple, create the sturdiest design with the least amount of material. We had sets of constraints that we had to abide to. For starters, the volume of our project could not exceed 25 in^3, it had to be symmetrical, the bottom of the base to the middle of the motor had to be 16 in, and we had to use a Maxon A-Max 6.0 VDC, 26mm x 45mm. Everything else was up to us to create a windmill with the least displacement.



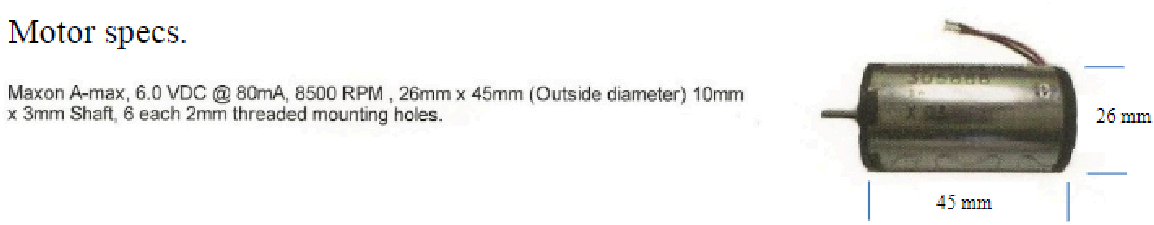
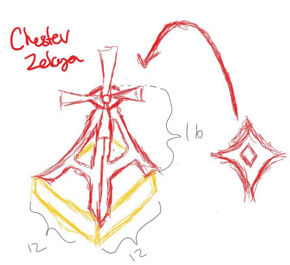


Figure 4a: Dimensional requirements for our project. Figure 4b: Maxon Motor Specifications

We began by creating rough sketches of what we aimed to construct, keeping in mind all our parameters and limitations with manufacturing. We then split up, designing various tower designs based on our individual intuition through SolidWorks. This included a design that was focused around a truss system, one design that was focused around triangular structures, etc. We kept testing each design with SolidWorks simulations to find which overall design type had the best success based on FEA analysis. We fixed the contact points to the ground, meshed our designs using ABS and forced 2kg of force into the back wall of where the motor was to see who had the lowest displacement. We then met to compare the benefits and drawbacks of each of our designs, some which included excess volume or excess displacement. Afterwards, we began improving our individual designs using the new found knowledge of each other's approaches. We then choose the design with the minimum displacement to mass ratio, being Chester's tower concept. Our next goal was to optimize that structure by understanding why it was so successful compared to the other designs and what it could improve on from the other designs.

Individual sketches and models with descriptions of each team members design process:



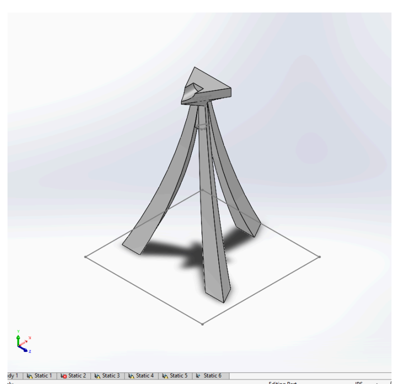
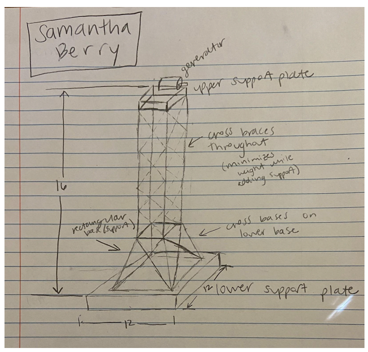


Figure 5a: Chester's concept design drawing. Figure 5b. Chester's concept design CAD

Chester: *"I originally wanted to go for the simple approach of a square base with structures that were curved and able to splice the "wind", but afterwards found out that the triangular shape was much more stable. The top was also made into a triangular shape for hypothetical aerodynamic circumstances. The insides were hollowed to reach the 25 in*^{3} *constraint."*



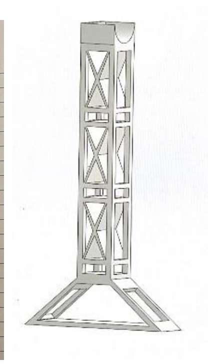


Figure 6a: Samantha's concept design drawing. Figure 6b. Samantha's concept design CAD

Samantha: *"For my design I chose to create a model with rigid geometric shapes in order to keep the entire structure stable. I started with a trapezoidal base and rectangular body, fixed with a cylindrical generator support on top. I then focused on creating a truss-like design throughout the tower to lower the volume while still keeping the main structure intact. Windows were then cut through the base and the sides of the body to remain within the 25in*^{3} *volume restraint."*

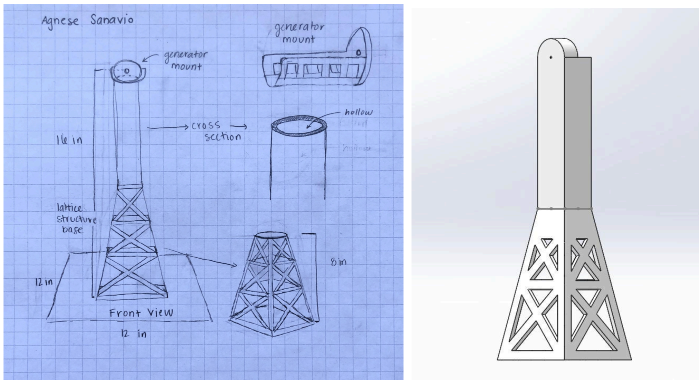


Figure 7a: Agnese's concept design drawing. Figure 7b. Agnese's concept design CAD

Agnese: *"For my original design I chose to create a turbine with a sturdy base and a simple, light-weight design for the upper half. The base used a truss design which created stability for the structure while still allowing for a light-weight approach. The upper half was a simple hollowed out rectangular prism with the motor mount at the top. The design met the sizing constraints and was just under the 25in^3."*

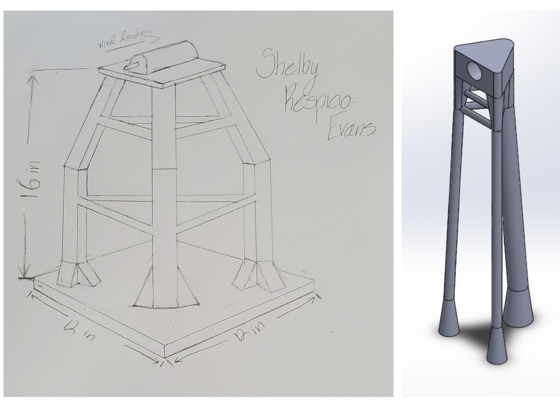
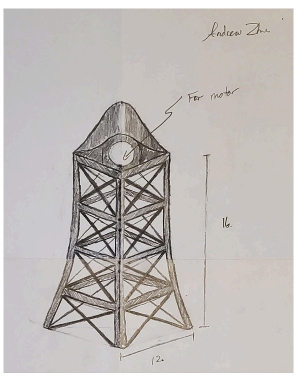


Figure 8a: Shelby's concept design drawing. Figure 8b. Shelby's concept design CAD

Shelby: *"When designing my wind turbine, I wanted to maximize the amount of support it received while also minimizing the amount of material used. To accomplish this, I used 3 different support beams to hold the top platform where the motor was. Once I started to recreate my design, however, I found that my original sketch used too much material, so I reworked the support pillars by making them circular and hollowing out certain parts of them, and raised the connecting beams to be under $25in^3$ in material while minimizing the maximum displacement of my turbine."*



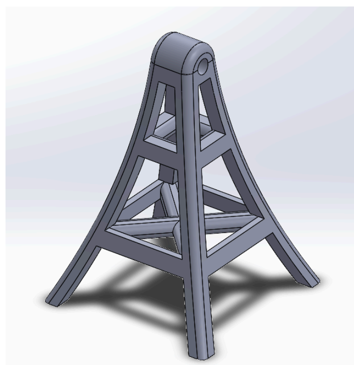
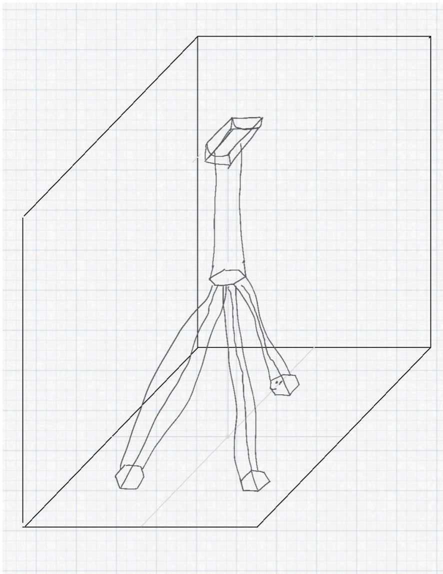


Figure 9a: Andrew's concept design drawing. Figure 9b. Andrew's concept design CAD

Andrew: *"For my sketch, I wished to implement a truss design as it is known to tolerate compressive and tension forces in bridges. However, due to SolidWorks FEA simulation constraints, I was unable to execute a three dimensional model that could be properly tested due to meshing failures. As a result, I reduced the amount of diagonal support beams and thickened the main legs which inevitably changed the original design. My design was discarded after failing to meet the volume requirements while maintaining viable minimal displacement values."*



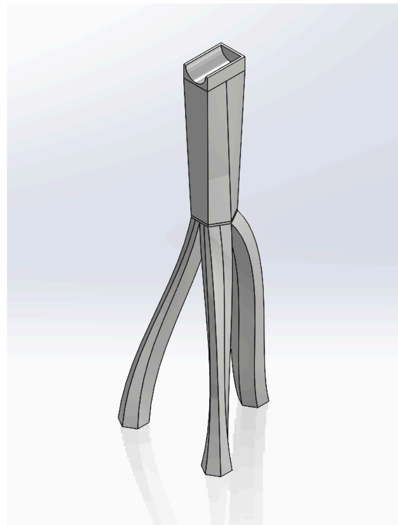
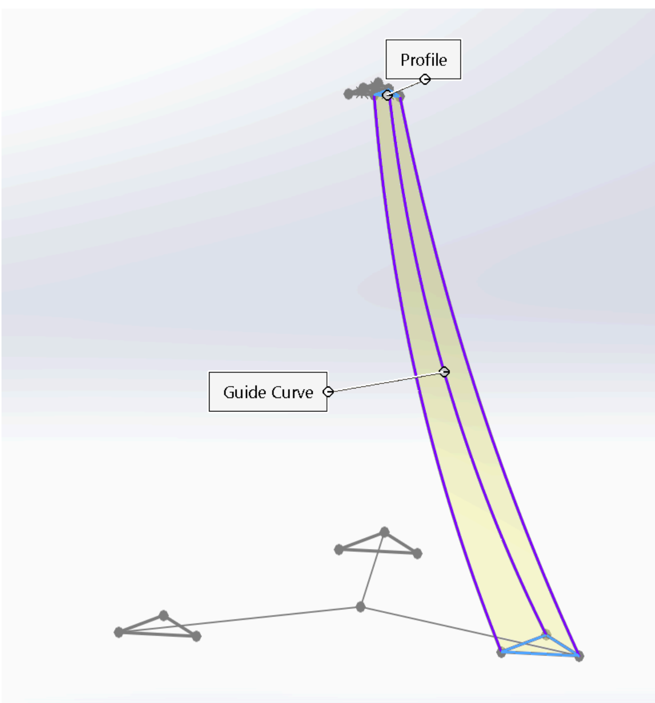


Figure 9a: Aidan's concept design drawing. Figure 9b. Aidan's concept design CAD

Aidan: *"I originally approached this problem by identifying and isolating the three major elements of the tower: The fixtures to the lower base plate, the legs, and the top motor mounting section. In regards to the fixtures I believed that three hexagonal "feet" would be the best approach as hexagons and would provide a strong foundation, (we later found that the triangular approach provided slightly better support). For the legs I believed that the biggest variable would be the convergence point (the point at which the three "legs" met). For this I thought about 2/3 of the total height (about 11 inches) was ideal, but we later found a higher convergence point was better. Lastly for the "head" of the tower I believed that minimizing the weight and making it as simplified as possible was ideal. In order to create this design I started by creating the hexagon base profile and lofting it to another hexagon offset at the predetermined convergence point. I then extruded the remainder of the tower up to the 16in maximum height. Lastly I created the motor mount by creating a sketch profile and extrude cutting through the top portion."*

Design

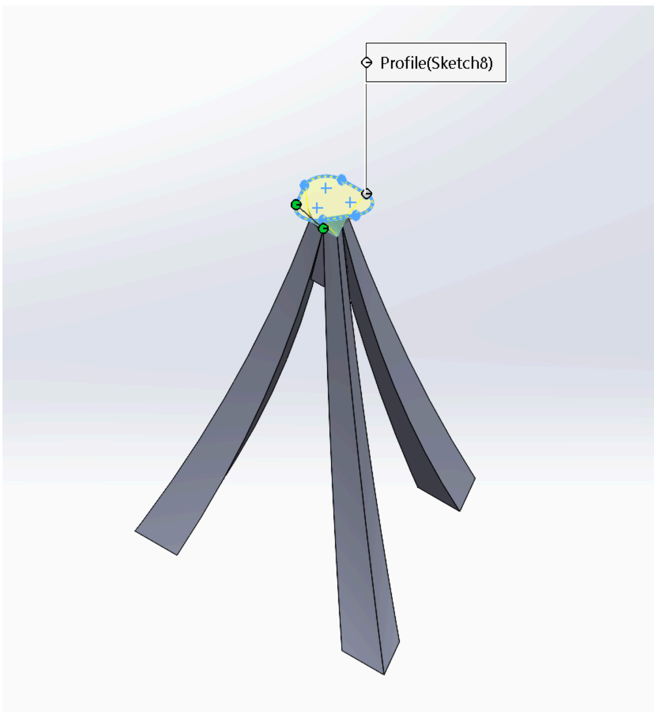
In order to model our tower, we utilized SolidWorks, a CAD (Computer-Aided Design) software that allows us to 3D model our design as well as perform various simulations and optimizations. Our tower is designed around the basic idea of triangular geometries for all major components. This includes both the shape and position of the legs that are fixed to the lower support plate, as well as the mounting structure that houses the generator. In order to create our final design we utilized multiple SolidWorks tools: loft, sweep, extrude, fillet, revolve cut, SolidWorks topology study, and SolidWorks design study.



To create the legs of our tower, we utilized the loft tool in order to connect the tower's triangular profiles together for each leg. We first created the base sketch (making sure to keep the base radially symmetrical). We then created a offset sketch 14 inches above the base. We then created three guide curves using 3D Sketched splines and then lofted the two profiles together using the splines as guides.

Figure 10: Loft preview showing creation of supporting legs for the tower

We then utilized an additional loft in order to connect the legs to the motor mount, and create the foundation for the "head" of our tower. This part of our tower would be utilized to house and mount the motor (generator). After the loft was performed we then extruded the remainder of the tower up to the 16" height requirement as outlined in the project description and as shown in *Figure 4a*.



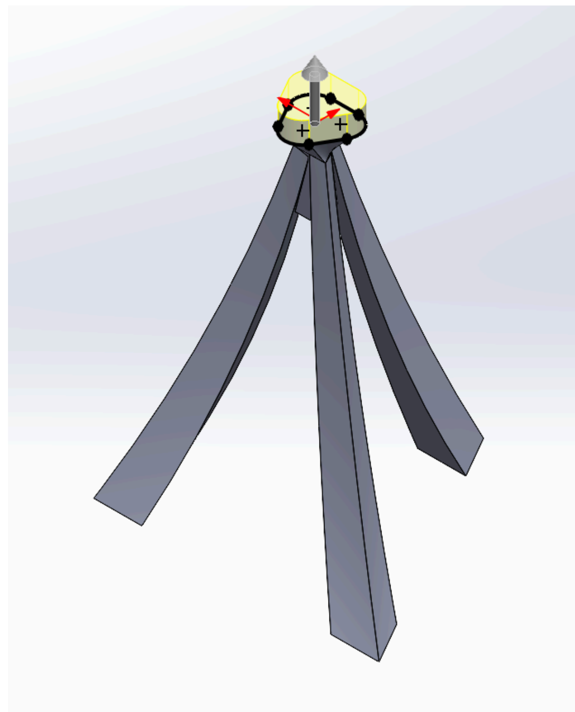


Figure 11a: Loft Preview showing creation of the foundation for our tower "head"

Figure 11b: Extrude Preview showing creation of the tower "head" for the motor mount

After that we utilized an extrude cut to create the cavity for the motor (generator) to be mounted to. We made sure that the center of the circular extrude cut was exactly 16" from the base of our tower (in compliance with the 16" height requirement as outlined in the project description and as shown in *Figure 4a*.) and we made sure the circular cut had a diameter of 26mm or about 1.02in, in order to accommodate the dimensions of the motor (as outlined by *Figure 4b.*).

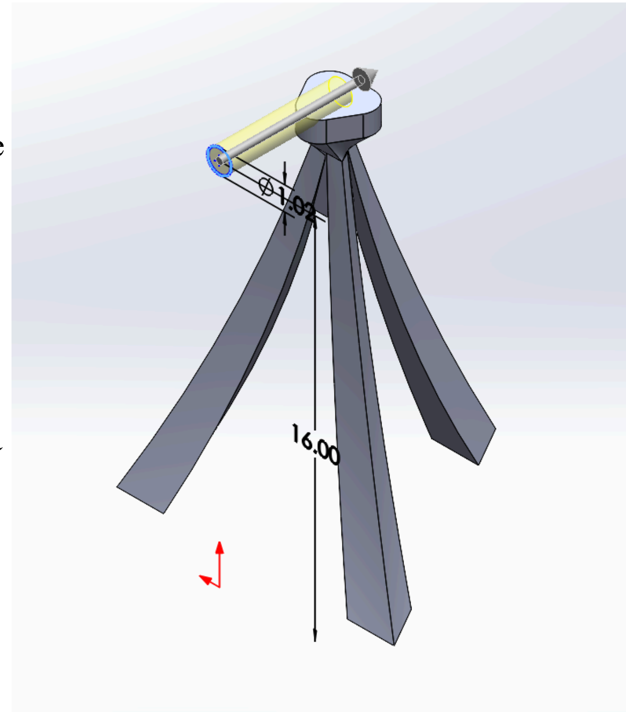


Figure 12: Preview of Extrude Cut in order to create cavity to house the motor

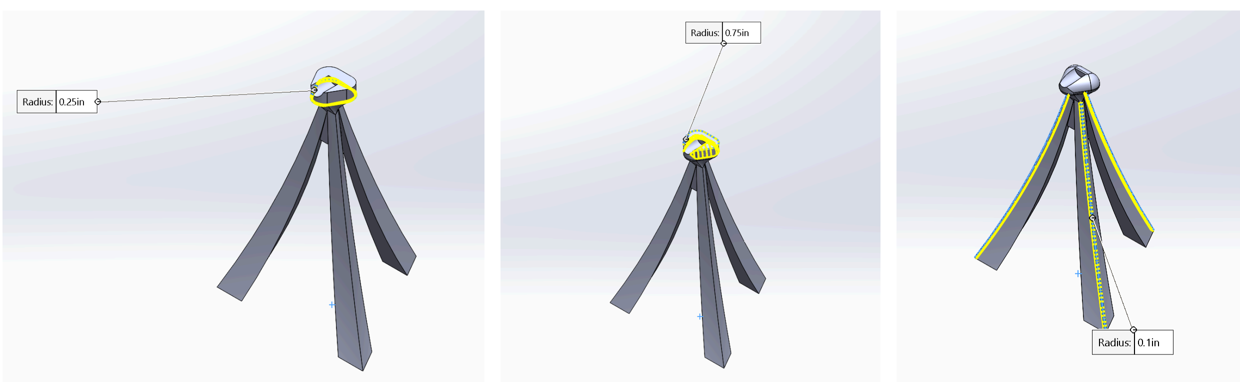
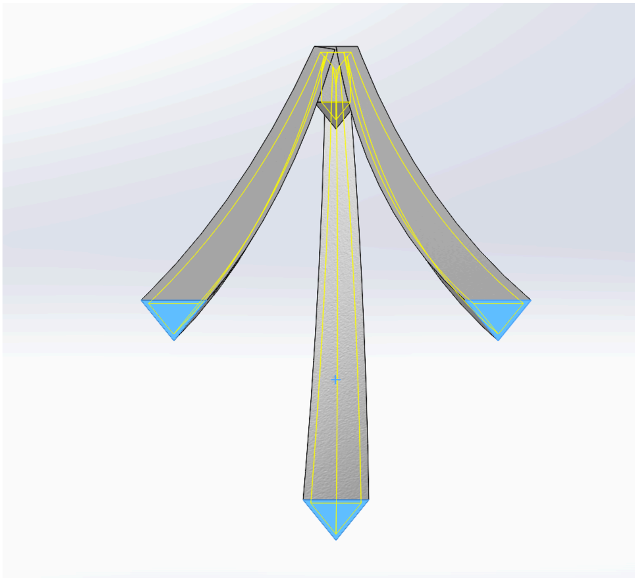


Figure 13a, 13b, 13c: Preview of Fillet Operation for Bottom of Tower "Head", Top of Tower "Head", and each of the Tower's Supporting legs, respectively.

Lastly we utilized the fillet tool in order to remove unnecessary volume that wouldn't contribute significantly to the overall stiffness of our tower.



We also realized that we could remove additional unnecessary material by shelling our legs. This worked without compromising the overall integrity and stiffness of the tower because the overall shape of the supporting legs remained and we could utilize the extra volume gained towards expanding the distance between the legs and the size of the contact with the lower support plate.

Figure 14: Preview of Shell Operation for supporting legs

With our generalized Design finished we ran a static simulation with the proper fixtures as shown in *Figure 25*. We then looked at the stress plot since unlike the displacement plot or FOS plot, the stress plot can show us the location of the weakest points of our structure and where our structure is bending from. The stress plot showed us that our structure needed further support between the legs so we created circular tube-like trusses by utilizing the sweep tool, to create a circle sweep along a 3D circular sketch. We choose to use circular support since they would be both efficient at connecting the legs, but also radially symmetric, and wouldn't favor any direction of force. After performing an additional Stress plot it showed an improvement on the stress on the front legs.

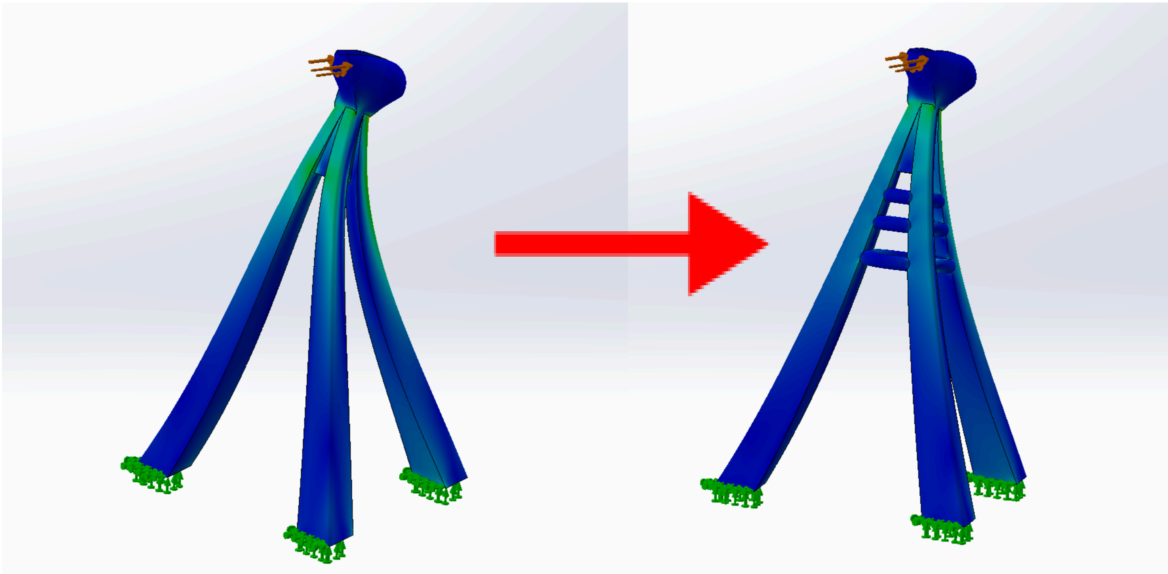


Figure 15a: Initial Stress Plot showing areas of high stress on the two front supporting legs

Figure 15b: Stress Plot after adding Circular Trusses showing reduced stress on the two front supporting legs

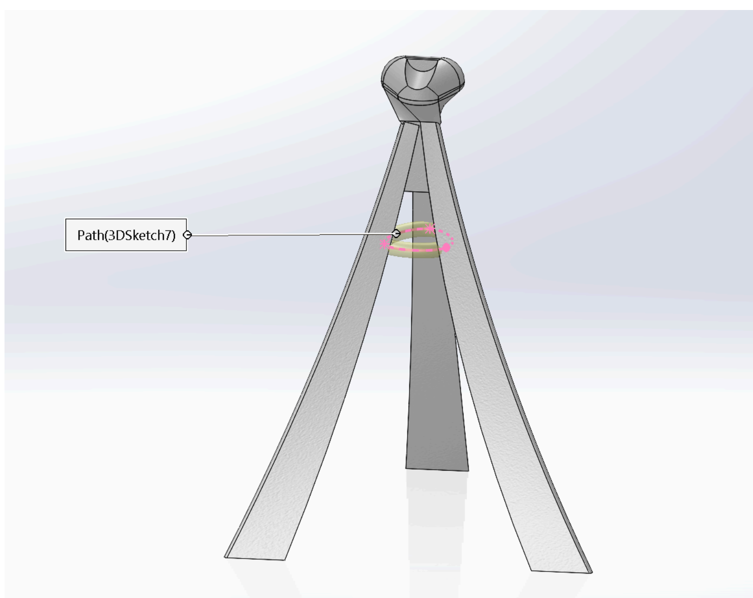


Figure 16: Preview of Sweep Operation showing creation of the torus shaped trusses

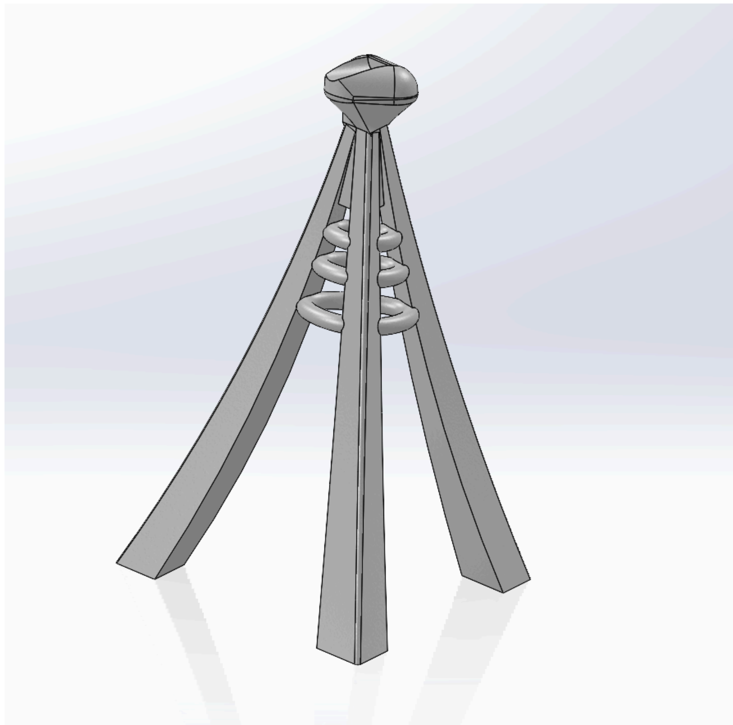


Figure 17: CAD Drawing showing the final generalized design for our Turbine Tower

Once we had the final generalized design we used SolidWorks design study to optimize the dimensions of our tower in order to create the best stiffness to weight ratio. We gave SolidWorks various sketch dimensions as parameters that it could change in order to find the optimal dimensions. This included the size of the contact points with the lower support plate (the “feet”), the distance between each of the supporting legs, and the size of each of the circular truss supports. We then gave the design study the goal of minimizing the volume and minimizing the displacement based off of the static simulation that we set up as shown in *Figure 25*. The design study also has the ability to add constraints and for this project a logical constraint to add would be the maximum allowed volume of 25 cubic inches. We decided to set both volume and displacement to monitor only on the design study constraints. The reason we did this has to do with one of the biggest limitations with SolidWorks' design study. SolidWorks' design study does a good job of optimizing parts, but can only work with sketch dimensions that have already been made, and lacks the ability to look at other solid areas of a part. This is where the topology study comes into play. Solidworks' topology study has the ability to find areas of a part that are less important to our overall goal, which is to maximize the stiffness to weight ratio. Since we knew we were going to perform a Topology study we wanted our design study to go a little over our maximum volume constraint so that we could utilize the topology study in order to cut away at the optimal sections. We then made sure that the collection of the maximum values for each of the variables would only increase our volume by about 30-40%, which we could then reduce using the topology study.

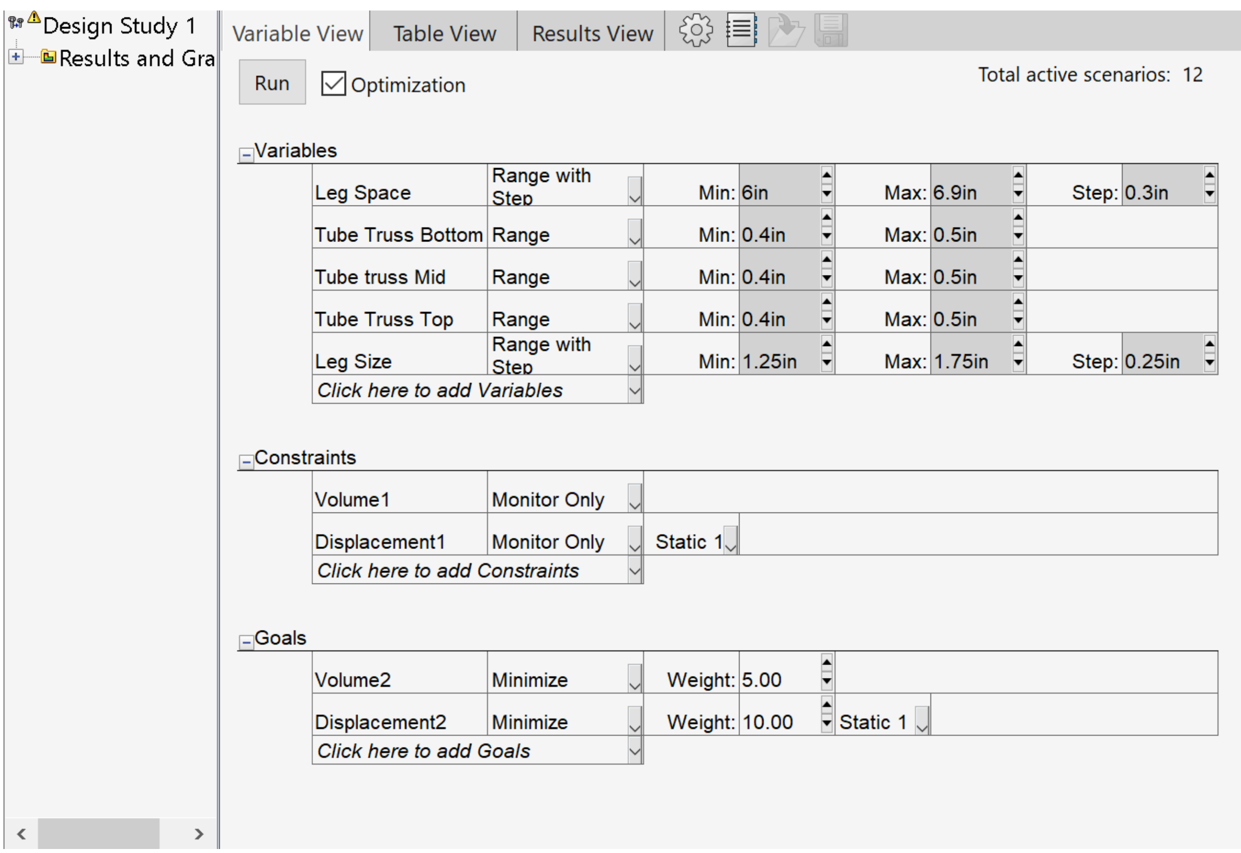
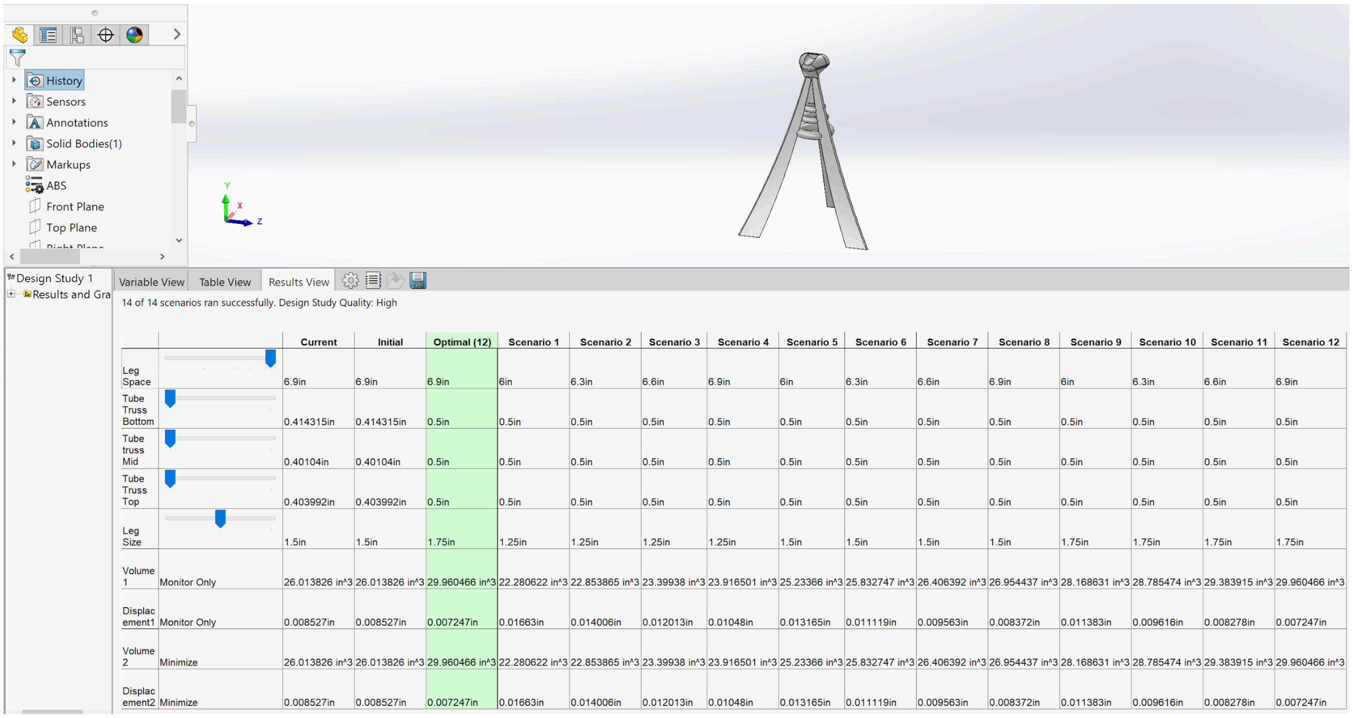


Figure 18: SolidWorks Design Study Input Parameters (Variables, Constraints, and Goals)



		Current	Initial	Optimal (12)	Scenario 1	Scenario 2	Scenario 3
Leg Space		6.9in	6.9in	6.9in	6in	6.3in	6.6in
Tube Truss Bottom		0.414315in	0.414315in	0.5in	0.5in	0.5in	0.5in
Tube truss Mid		0.40104in	0.40104in	0.5in	0.5in	0.5in	0.5in
Tube Truss Top		0.403992in	0.403992in	0.5in	0.5in	0.5in	0.5in
Leg Size		1.5in	1.5in	1.75in	1.25in	1.25in	1.25in
Volume 1	Monitor Only	26.013826 in^3	26.013826 in^3	29.960466 in^3	22.280622 in^3	22.853865 in^3	23.39938 in^3
Displacement1	Monitor Only	0.008527in	0.008527in	0.007247in	0.01663in	0.014006in	0.012013in
Volume 2	Minimize	26.013826 in^3	26.013826 in^3	29.960466 in^3	22.280622 in^3	22.853865 in^3	23.39938 in^3
Displacement2	Minimize	0.008527in	0.008527in	0.007247in	0.01663in	0.014006in	0.012013in

	Scenario 4	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Leg Space	6.9in	6in	6.3in	6.6in	6.9in	6in	6.3in	6.6in	6.9in
Tube Truss Bottom	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in
Tube truss Mid	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in
Tube Truss Top	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in	0.5in
Leg Size	1.25in	1.5in	1.5in	1.5in	1.5in	1.75in	1.75in	1.75in	1.75in
Volume 1	23.916501 in^3	25.23366 in^3	25.832747 in^3	26.406392 in^3	26.954437 in^3	28.168631 in^3	28.785474 in^3	29.383915 in^3	29.960466 in^3
Displacement1	0.01048in	0.013165in	0.011119in	0.009563in	0.008372in	0.011383in	0.009616in	0.008278in	0.007247in
Volume 2	23.916501 in^3	25.23366 in^3	25.832747 in^3	26.406392 in^3	26.954437 in^3	28.168631 in^3	28.785474 in^3	29.383915 in^3	29.960466 in^3
Displacement2	0.01048in	0.013165in	0.011119in	0.009563in	0.008372in	0.011383in	0.009616in	0.008278in	0.007247in

Figure 19: SolidWorks Design Study Output with Optimal Dimensions Highlighted and Model Shown

When the design study finalized, we noticed that the wider our tower was and the less top-heavy, the lower the displacement of our tower was. The Design study had given us the optimal dimensions with each tubular truss having a diameter of 0.5”, the triangular footprint of the legs being 1.75” each, and the profile distance from the center to the end point of each leg being 6.9”. This also gave us a minimized displacement of 0.007246” and an equally minimized volume of about 29.96 cubic inches.

Since we were 20% over the maximum volume constraint, we then used another SolidWorks simulation tool in order to figure out what material was needed and what could be removed. In order to do this we used SolidWorks' Topology study. We gave the study the static simulation data from *Figure 25* and gave it a goal of maximizing the stiffness to weight ratio, with the constraint that we needed to reduce our volume by about 60%. Since we are using the output of our topology as a guide for what material to remove we decided to have it calculate a little of twice as much then needed to remove so we had a more detailed reference. We also gave the simulation constraints about what material to preserve, being the region around the motor mount, whose geometry needed to remain unchanged. Lastly we gave an additional constraint that the topology study had to be radially symmetrical, so that (especially with regards to the legs) it would follow the guidelines of the project.

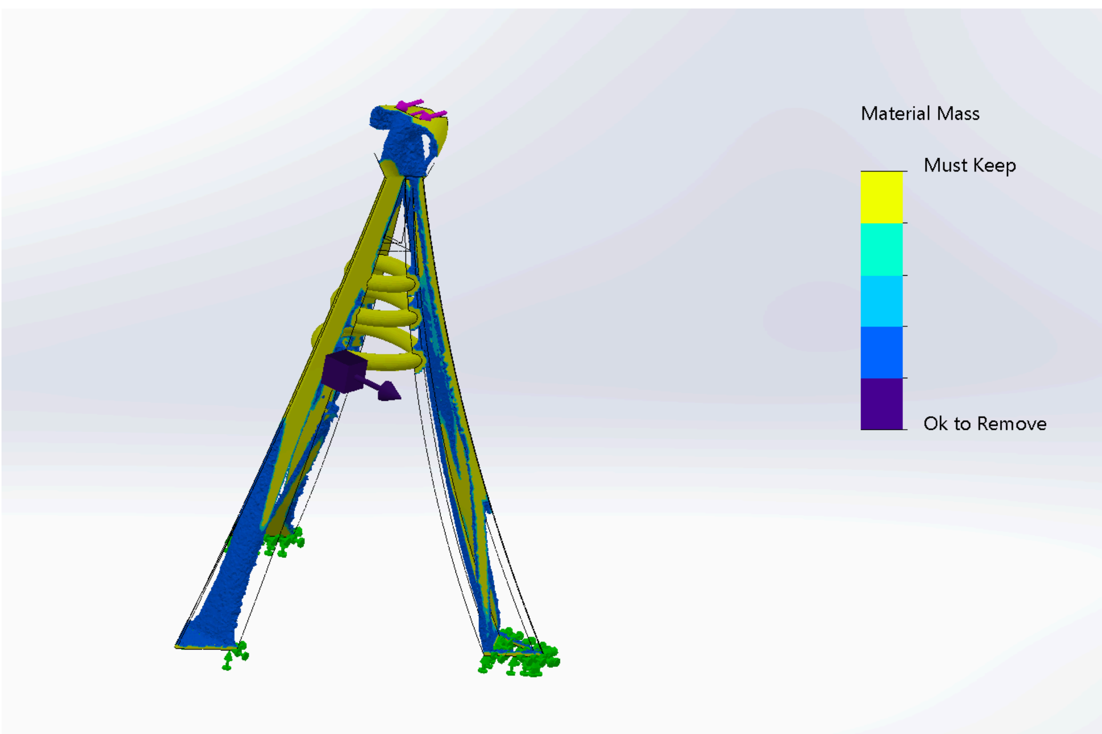


Figure 20: Output of Topology Study showing regions that can be removed to reduce volume calculated based off of the static simulation

Once the simulation was done running, we used the topology model given as a reference for what material we could remove and then created holes to make our tower less top heavy.

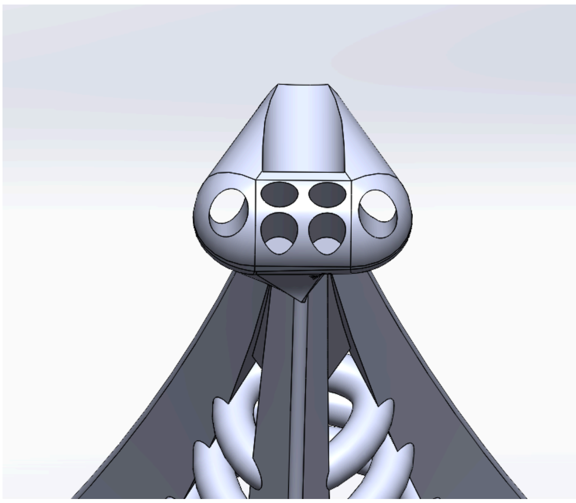


Figure 21: "Cheese Holes" to reduce volume

The first thing we did was create "cheese holes" on the back of the "head" of our tower. We did this by creating a 3D sketch and extrude cutting based off of the general area that our topology study stated we didn't need the material.

We decided to then pocket the supporting legs of our tower in the regions that the topology study indicated could be removed. In order to do so while also remaining radially symmetric we utilized a revolve cut which took the pocket sketch and cut it through all three legs.

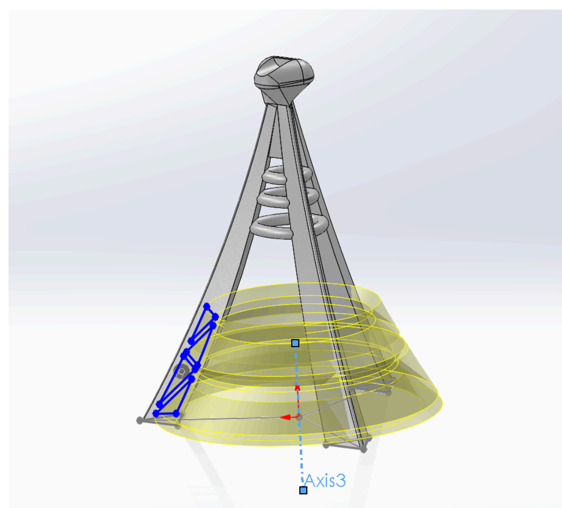


Figure 22: Revolve Cut to create pockets

Our final result was our original tower design optimized. Our last step was to verify that we met the clearance for the blade which can be confirmed by *Appendix C*.

CAD Drawings:

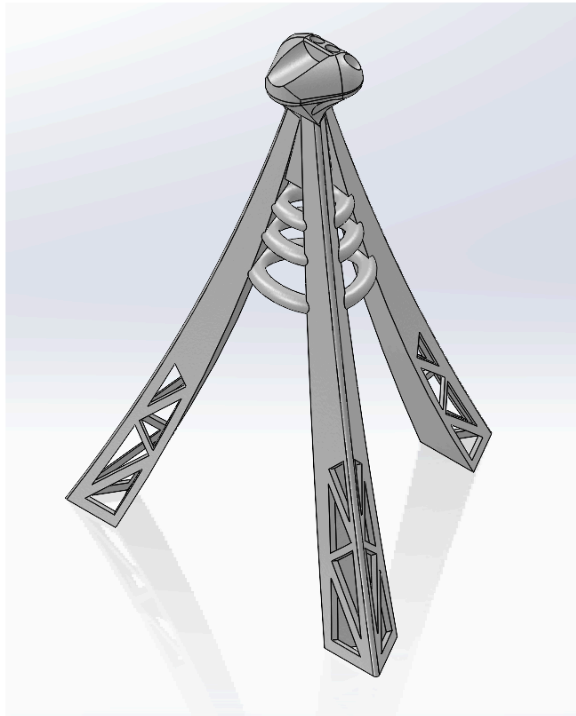


Figure 23: Final CAD Design for our Turbine Tower Structure

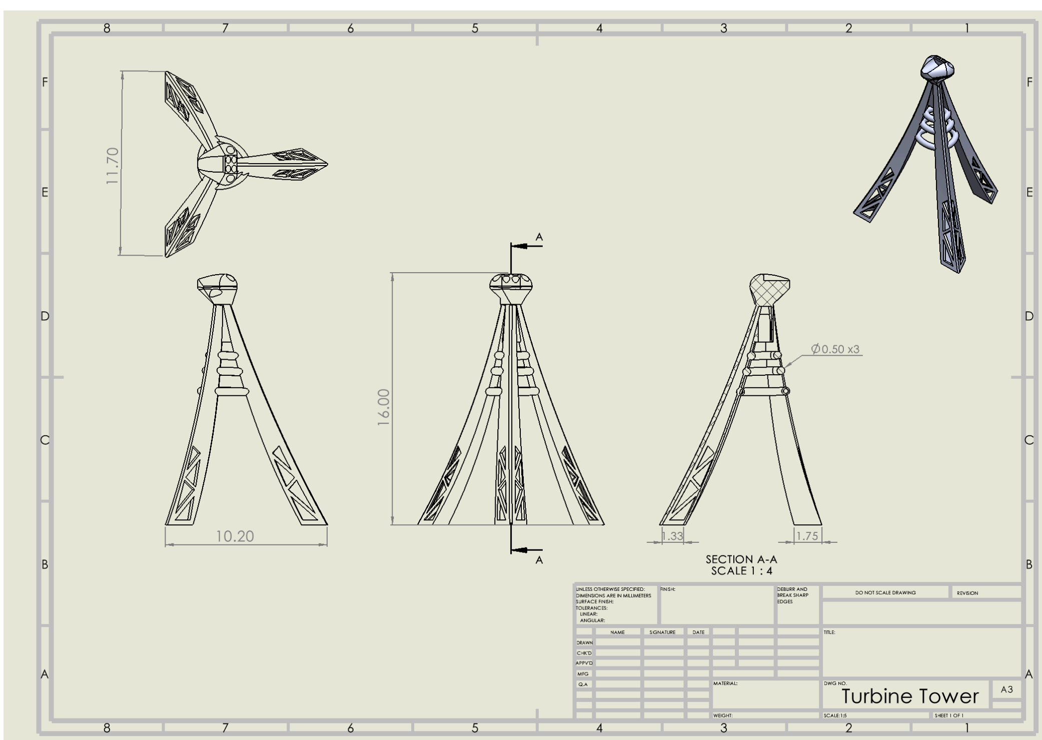


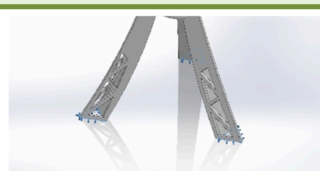
Figure 24: 2D Drawing for our Turbine Tower Design showing constraint dimensions

FEA Simulation Data:

Material Properties

Model Reference	Properties	Components
	**Name:** ABS **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 2.99991e+07 N/m^2 **Tensile strength:** 3e+07 N/m^2 **Elastic modulus:** 2e+09 N/m^2 **Poisson's ratio:** 0.394 **Mass density:** 1,020 kg/m^3 **Shear modulus:** 3.189e+08 N/m^2	SolidBody 1 (Turbine Tower)
Curve Data:N/A		

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 3 face(s) **Type:** Fixed Geometry

Resultant Forces

Components	X	Y	Z	Resultant
Reaction force(N)	-19.6149	-0.0287183	0.00649107	19.6149
Reaction Moment(N.m)	0	0	0	0

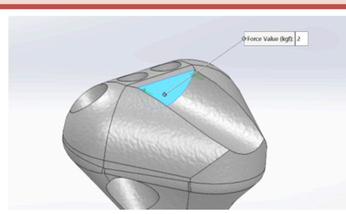
Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 0.1-2 kg (Step 0.1)

Figure 25a: Material Properties of our Turbine Tower for SolidWorks Static Simulation

Figure 25b: Fixture Properties of our Turbine Tower for SolidWorks Static Simulation

Figure 25c: Load Properties of our Turbine Tower for SolidWorks Static Simulation

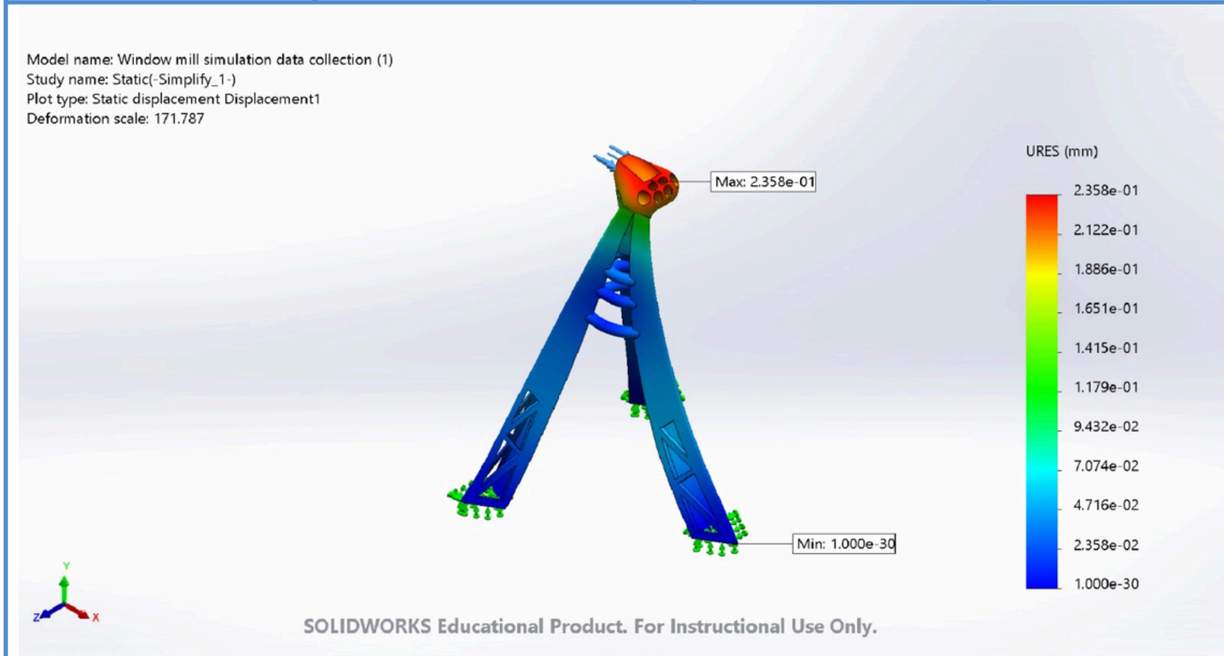
Mesh information

Mesh type	Solid Mesh
Mesher Used:	Curvature-based mesh
Jacobian points for High quality mesh	16 Points
Maximum element size	0.361224 in
Minimum element size	0.0722448 in
Mesh Quality	High

Total Nodes	89256
Total Elements	47983
Maximum Aspect Ratio	5,553.6
% of elements with Aspect Ratio < 3	84.4
Percentage of elements with Aspect Ratio > 10	0.344
Percentage of distorted elements	0
Time to complete mesh(hh;mm;ss):	00:00:06
Computer name:	

Figure 25: Mesh Information of our Turbine Tower for SolidWorks Static Simulation

Name	Type	Min	Max
Displacement with 2Kgf Load	URES: Resultant Displacement	0.000e+00mm Node: 102	2.358e-01mm Node: 19546



Turbine Tower-Static-Displacement

Figure 26: Displacement Plot of our turbine tower with a 2kgf applied load

Displacement Chart Description: With a 2kgf load we get a maximum displacement of 2.358e-0.1mm (0.2358mm) or about 0.009283in and a minimum displacement of about 1.000e-30mm or about 3.937e-32in (or essentially 0). The Displacement Plot shows that our peak deflection occurs at the back of the top of our tower, which is what we'd expect since the applied load is located nearest to the back of the top of our tower. The Displacement plot also shows minimal deflection for the supporting legs of our tower and only shows significant deflection above the point of maximum stress (as shown in *Figure 27*). This is because the point of maximum stress is the origin at which our part begins to bend. Since our part is fixed to the lower supporting plate it will bend and deflect a greater distance the further you go above the maximum stress point.

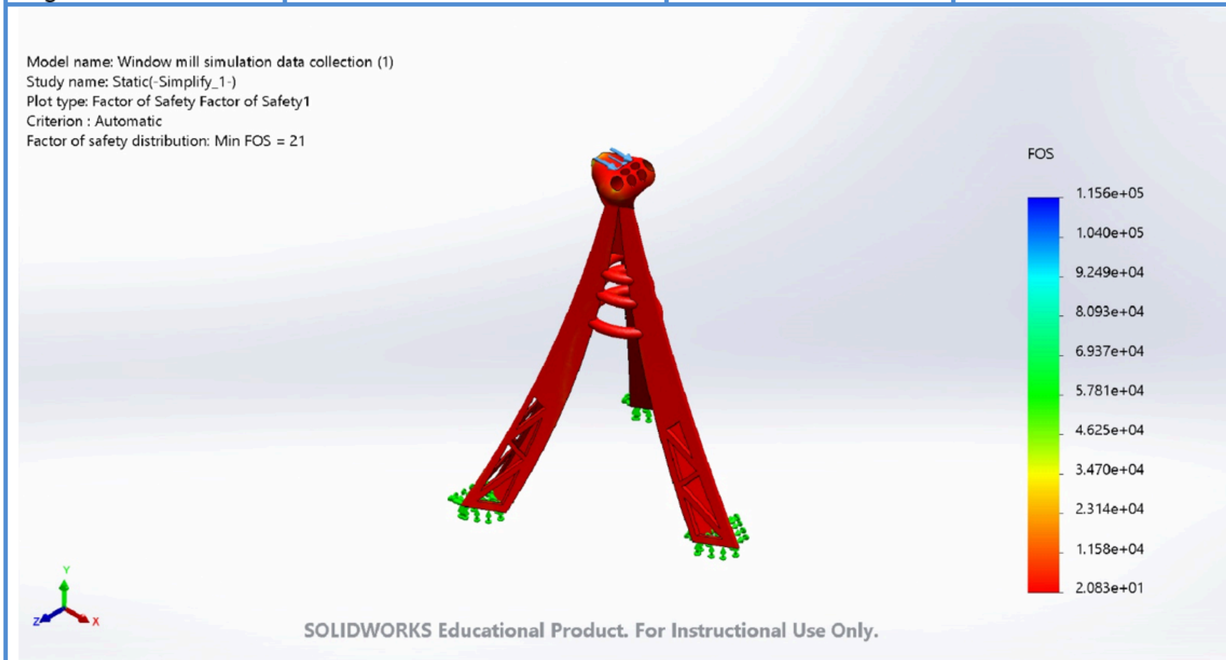
Name	Type	Min	Max
Stress with 2Kgf Load	VON: von Mises Stress	2.595e+02N/m^2 Node: 46609	1.440e+06N/m^2 Node: 14601

Turbine Tower-Static-Stress

Figure 27: Stress Plot of our turbine tower with a 2kgf applied load

Stress Chart Description: With a 2kgf load we get a maximum applied stress of 1.440e0.6N/m^2 (or about 2.089e0.2psi), and a minimum stress of 2.595e0.2N/m^2 (or about 0.376psi). The point of maximum stress is located on the back supporting leg directly below the “head” of our turbine tower. This is expected since the region of applied force is pushing directly above that point, and thus would cause that region to bend the most. Additionally the applied load is pushing a more massive region of our tower (the “head”) compared to the area of indicating higher stress so it is more susceptible to succumb to the load, creating an area of higher stress. There are also small areas of stress on the trussed regions of our pockets that is most likely due to the limited material supporting that region. Overall the regions of relatively high stress are non-problematic since the stress is relatively low compared to the yield strength. This idea is reaffirmed by our Factor of Safety Plot (*Figure 28*).

Name	Type	Min	Max
Factor of Safety with 2Kgf Load	Automatic	2.083e+01 Node: 14601	1.156e+05 Node: 46609



Turbine Tower-Static-Factor of Safety

Figure 28: Factor of Safety Plot of our turbine tower with a 2kgf applied load

FOS Description: With a 2kgf load we get a minimum Factor of Safety of 20.83, and a maximum Factor of Safety of 1.156e0.5. The factor of safety plot takes into account the applied stress in each region and compares it to the yield strength of our material. For our Turbine Tower we are using ABS which is a plastic polymer with a yield strength of about 3.0e0.7. Since our Factor of Safety is significantly above 1 this shows that our tower is extremely far from failing and breaking. The majority of our turbine tower maintains a factor of safety of around 21 with a few small regions on the "head" of our tower having a higher factor of safety. Overall this shows that our part doesn't experience extremely high area's of stress relative to our part's overall yield strength. This is confirmed by referencing the Stress Plot from *Figure 27*.

Maximum Displacement vs. Applied Load Chart:

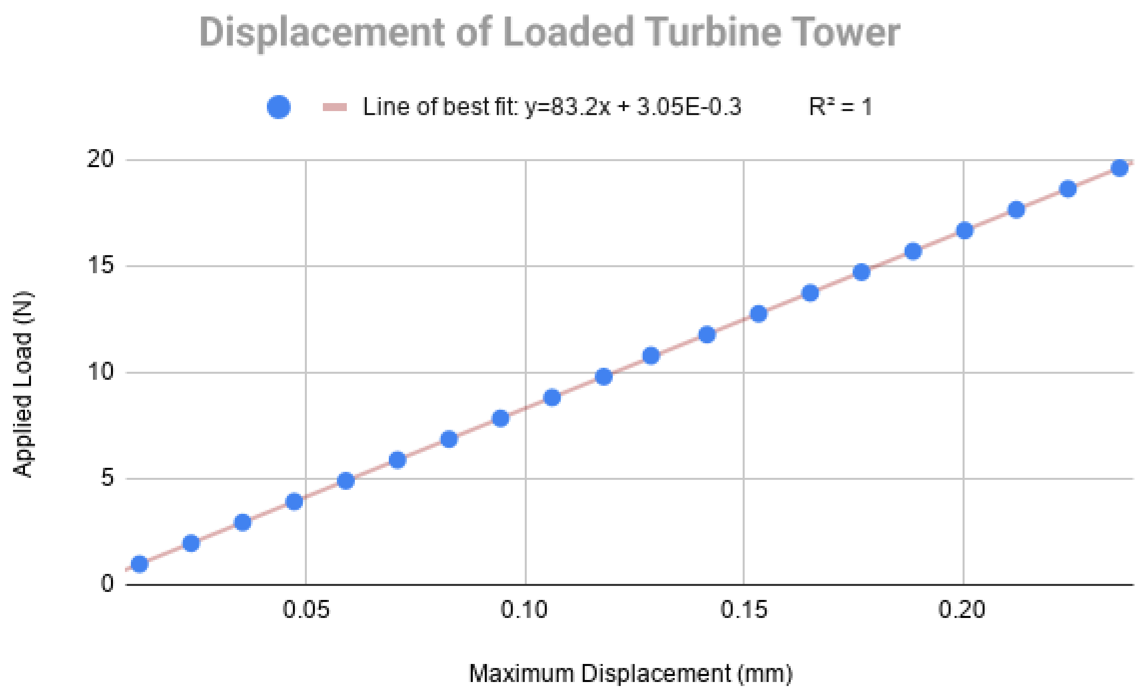


Figure 29: Maximum Displacement vs. Applied Load Graph showing line of best fit

The Maximum Displacement vs. Applied Load Chart illustrates that the Maximum Displacement is linearly proportional to the applied load. The data for this chart can be found in *Appendix A*. We utilized google sheets, a googled backed Spreadsheet program in order to graph our displacement vs applied load chart, and to run the calculations to create the line of best fit. Our Turbine tower has a stiffness of k = 83.2N/mm which is found by taking the slope of our line of best fit. Google Sheets also calculated an R^2 (Correlation factor) of 100% meaning our data is perfectly linear.

Weight of Tower:

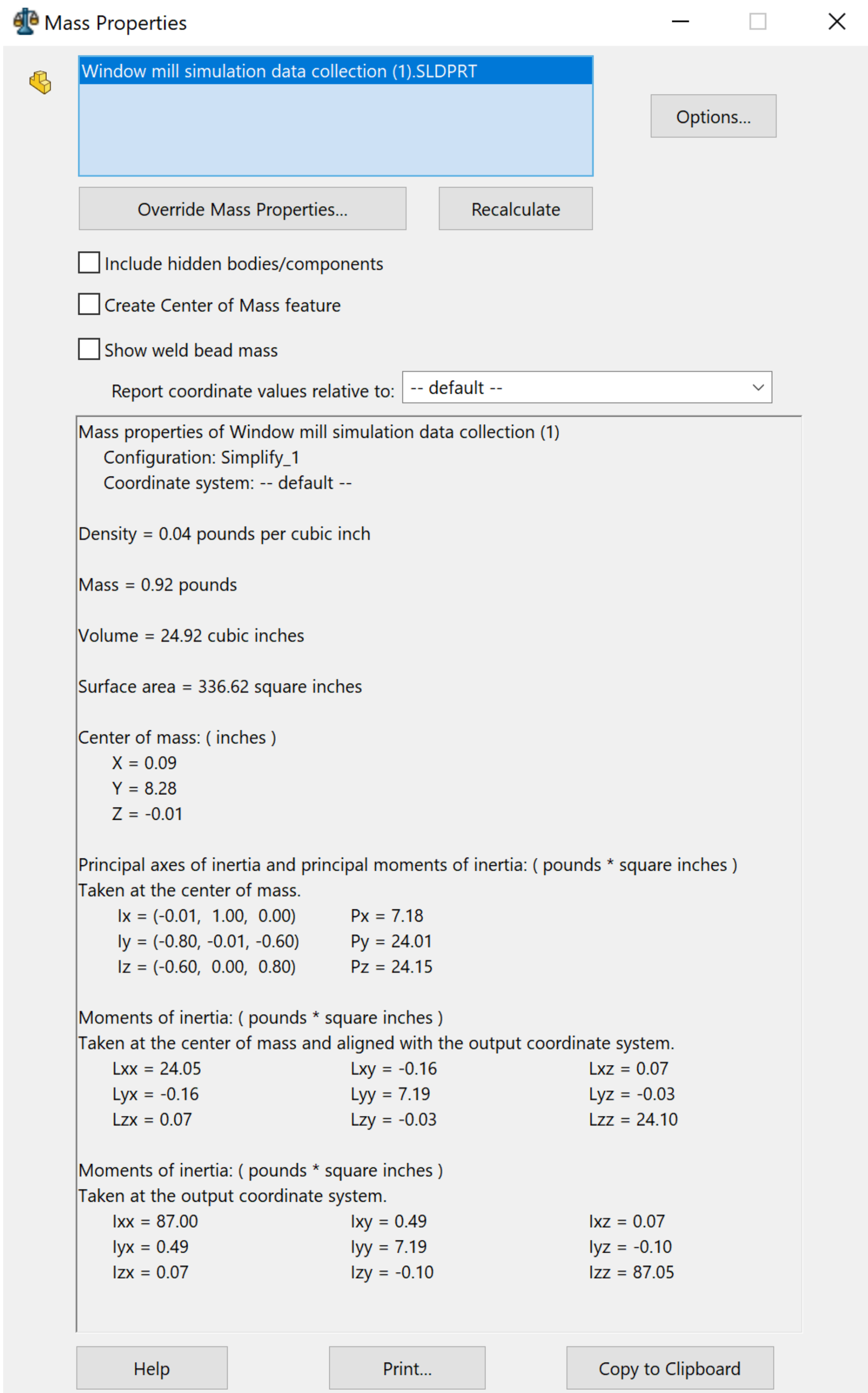


Figure 30: Turbine Tower Mass Properties

Conclusion

This engineering project tasked our group with the goal to create a wind turbine structure with a high stiffness constant while adhering to a plethora of constraints and specifications. Under normal circumstances, our group wished to utilize the SolidWorks CAD software to create a viable design and then fabricate a physical prototype using a fused deposition modeling machine (3D printer) to test inside a wind tunnel. However, due to extenuating circumstances, the prototyping phase of our project was never seen to fruition. Instead, our group utilized the SolidWorks Simulation Add-In to test each member's individual designs, and converge and improve on the most viable and effective design.

To begin our design process, we each sketched a separate wind turbine. We then designed our models based on our sketches, following the constraints and specifications given to us, and met to present and discuss our designs with our teammates. We convened again, a week later, with updated designs and from here we chose a "winning" design. This winning design underwent more modifications and was run through SolidWorks' Topology Study to optimize the stiffness constant while keeping within the given constraints. With every iteration our team members made, we convened to compare data from our simulations run on SolidWorks, such as our design's maximum deflection, total volume, and maximum stress. We recorded this data and made plots for displacement, stress, and safety factor for our final design.

Our final design, a three legged design with rings for reinforcement, was finalized after four weeks of iteration. Throughout the design process we focused on minimizing our maximum deflection while maintaining the proper volume and sizing constraints. We used the SolidWorks Topology Study to optimize our chosen design. After some design studies we finalized this design and began compiling our simulation results.

As a group, we believe that one of the biggest takeaways from this project was the amount of iterations required to reach a satisfactory final design despite our best attempts to foresee all the possible setbacks. In anticipation of this and to make an efficient use of time, our team designed six different designs in an effort to explore the different design possibilities for a wind turbine structure. It was fascinating to see design changes even when translating our two dimensional sketches on paper into three dimensional models on SolidWorks CAD software. The differences between our initial best candidate design and the final design also had noticeable differences, reflecting our efforts to minimize volume and displacement.

Although we were unable to create a physical manifestation of our ideas and truly test the capabilities of our final product, we believe the results displayed from SolidWorks FEA simulations provide promising evidence that it would have achieved the desired results both in the scaled-down testing phase and under realistic environment circumstances.

Future Improvements

There are a couple improvements and changes that we wish to highlight to further enhance our final wind turbine design.

Because we did not have the opportunity to create a rotor blade component of our wind turbine, the method we used to determine the best wind turbine design involved applying a direct, centralized load to the back end of the motor cartridge in order to simulate wind fluid effects on the wind turbine. A better course of action would have been to use a flow simulation to more accurately mimic the fluid nature of wind on the structure and rotor blade. This would have provided a more accurate result of how much our structure would displace since the force and torque loads on the structure are more evenly dispersed.

A minor but notable improvement that we wished to implement more effectively was SolidWorks's Topology Optimization feature. This feature enables the user to first create a design and have SolidWorks optimize this design according to set constraints, such as minimizing displacement. If this was used from the beginning, we may have been able to minimize the amount of changes needed to our individual designs and what is now our final design. This could have saved our group more time to focus on testing and reiterating the final design.

References

Basics of Wind Energy. (n.d.). Retrieved December 08, 2020, from https://www.awea.org/wind-101/basics-of-wind-energy

How Do Wind Turbines Work? (n.d.). Retrieved December 08, 2020, from https://www.energy.gov/eere/wind/how-do-wind-turbines-work

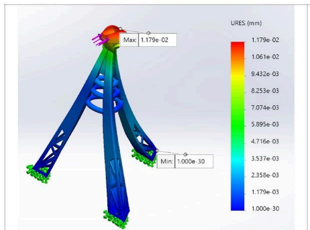
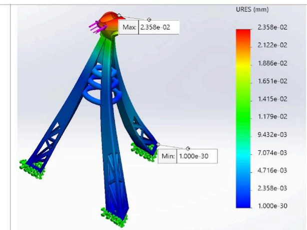
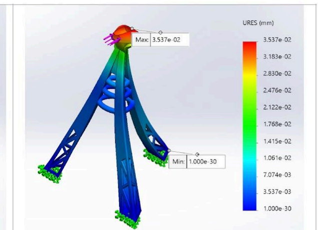
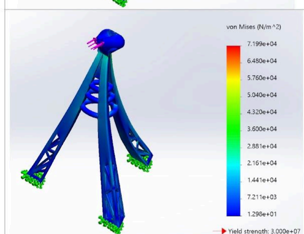
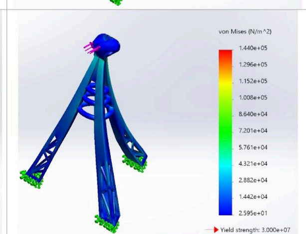
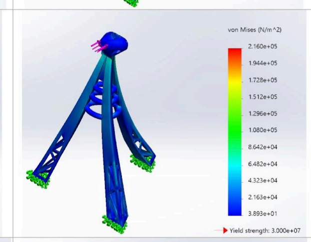
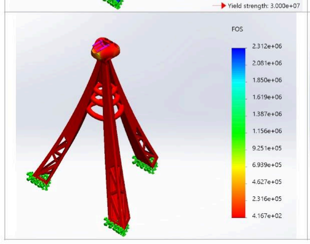
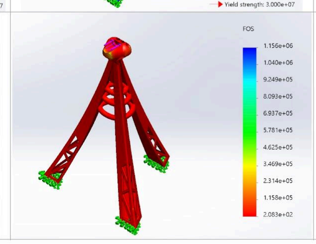
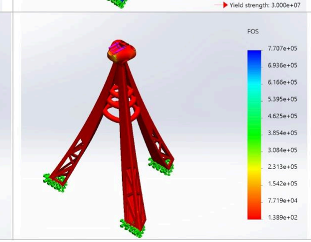
U.S. Renewable Energy Factsheet. (n.d.). Retrieved December 08, 2020, from http://css.umich.edu/factsheets/us-renewable-energy-factsheet

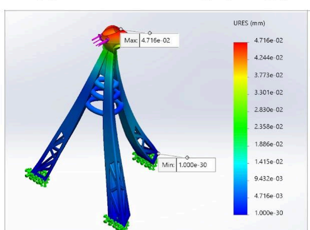
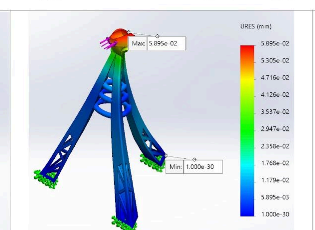
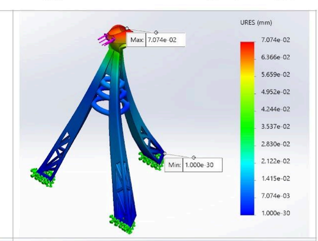
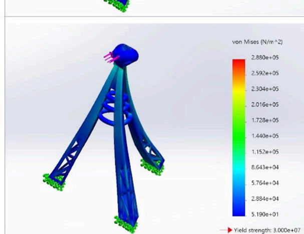
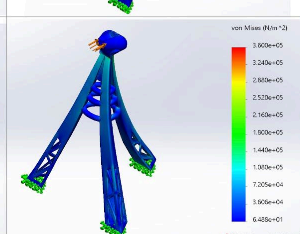
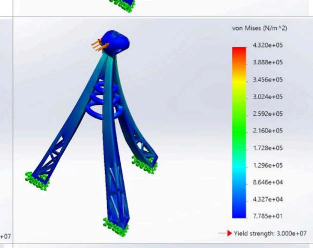
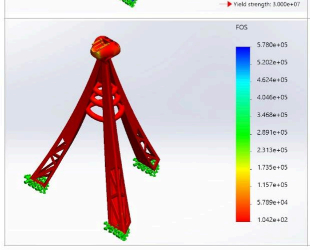
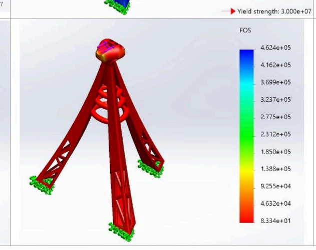
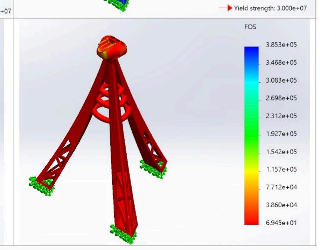
Appendix:

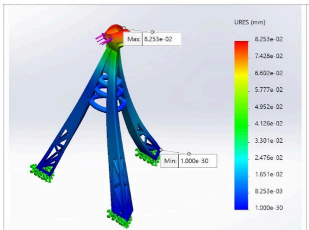
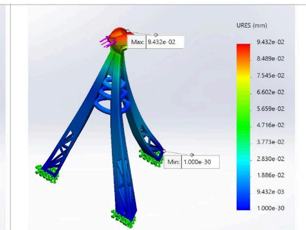
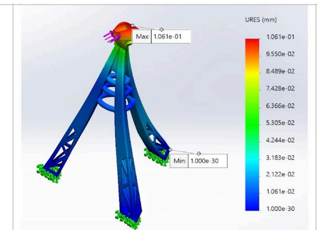
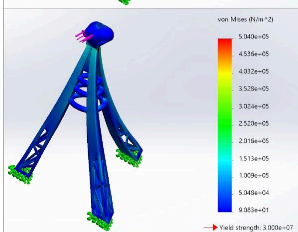
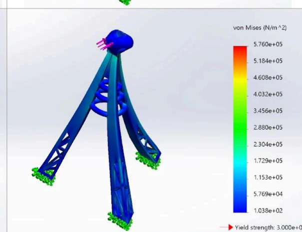
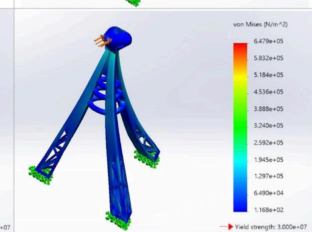
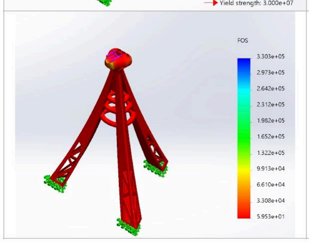
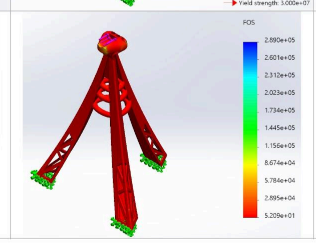
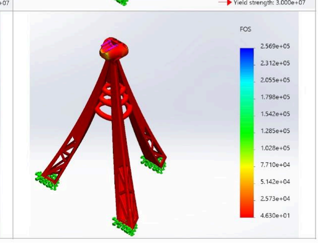
A: Maximum Displacement vs. Force Data Table

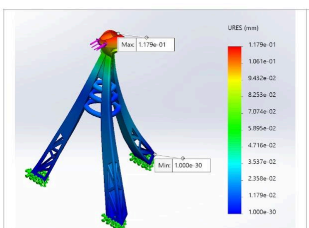
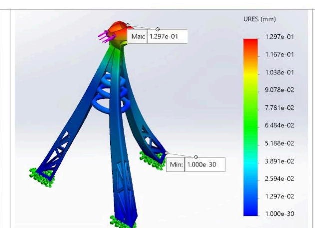
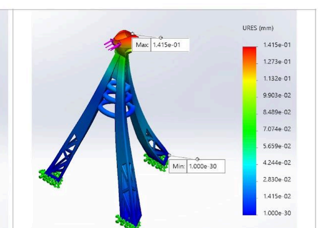
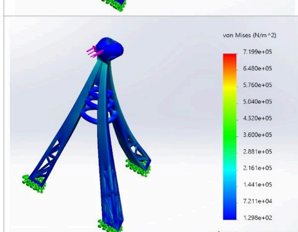
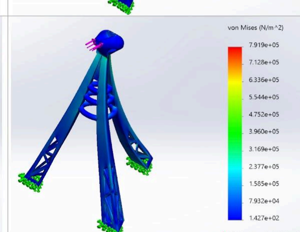
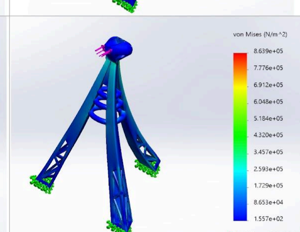
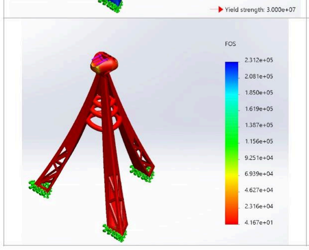
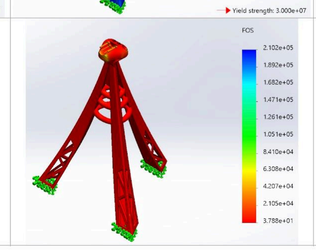
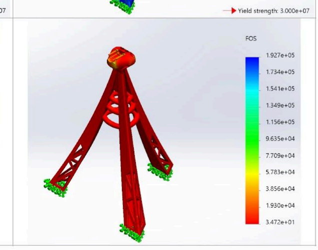
Applied Load (kgf)	Applied Load (N)	Maximum Displacement (mm)
0.1kg	0.980665N	0.01179mm
0.2kg	1.96133N	0.02358mm
0.3kg	2.94199N	0.03537mm
0.4kg	3.92266N	0.04716mm
0.5kg	4.90332N	0.05895mm
0.6kg	5.88399N	0.07074mm
0.7kg	6.86465N	0.08253mm
0.8kg	7.84532N	0.09432mm
0.9kg	8.82598N	0.1061mm
1.0kg	9.80665N	0.1179mm
1.1kg	10.7873N	0.1287mm
1.2kg	11.768N	0.1415mm
1.3kg	12.7486N	0.1533mm
1.4kg	13.7293N	0.1651mm
1.5kg	14.71N	0.1768mm
1.6kg	15.6906N	0.1886mm
1.7kg	16.6713N	0.2004mm
1.8kg	17.652N	0.2122mm
1.9kg	18.6326N	0.2240mm
2.0kg	19.6133N	0.2358mm

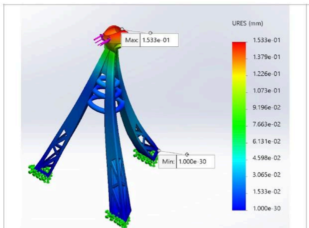
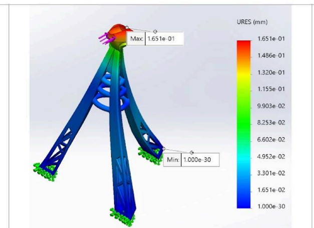
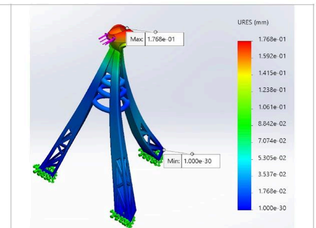
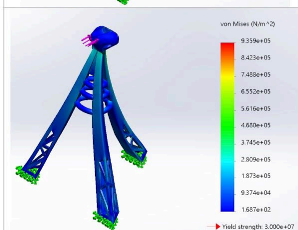
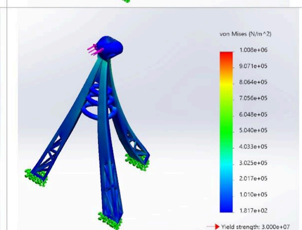
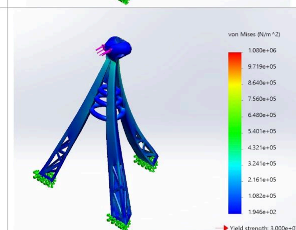
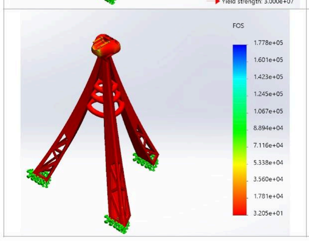
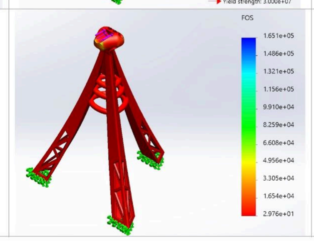
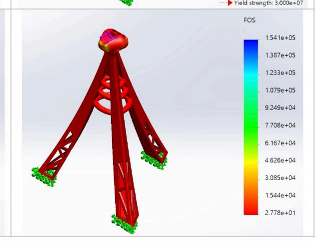
B: Simulation Data for each Applied Load (100g-2000g with step: 100g)

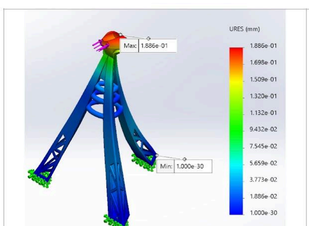
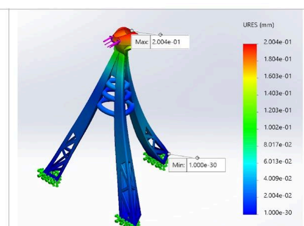
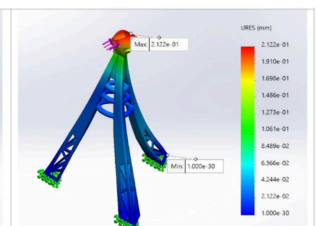
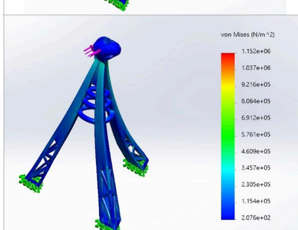
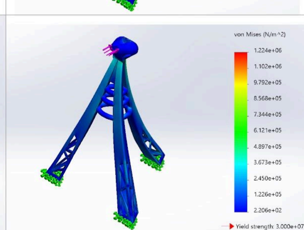
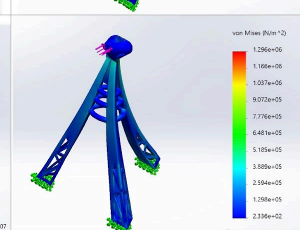
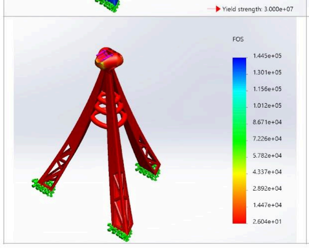
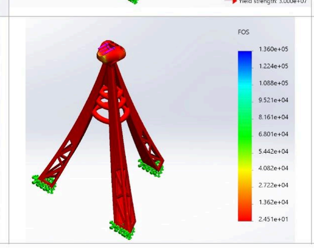
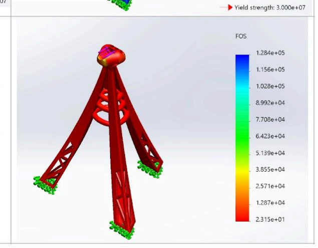
	Applied Load of 100gf (0.1kgf)	**Applied Load of 200gf (0.2kgf)**	**Applied Load of 300gf (0.3kgf)**
Displacement Plot			
Stress Plot			
Factor of Safety Plot			

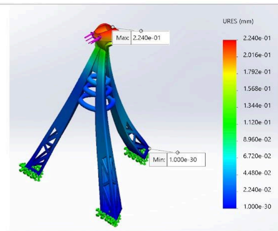
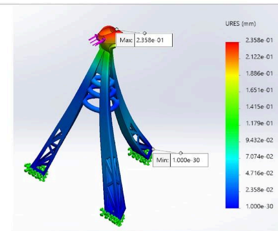
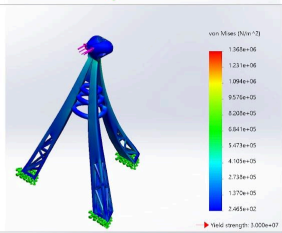
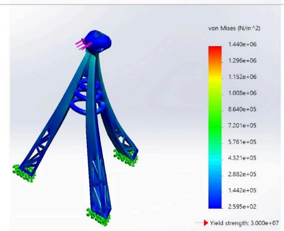
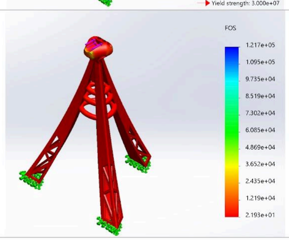
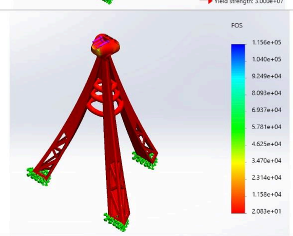
	Applied Load of 400gf (0.4kgf)	**Applied Load of 500gf (0.5kgf)**	**Applied Load of 600gf (0.6kgf)**
Displacement Plot			
Stress Plot			
Factor of Safety Plot			

	Applied Load of 700gf (0.7kgf)	Applied Load of 800gf (0.5kgf)	Applied Load of 900gf (0.6kgf)
Displacement Plot			
Stress Plot			
Factor of Safety Plot			

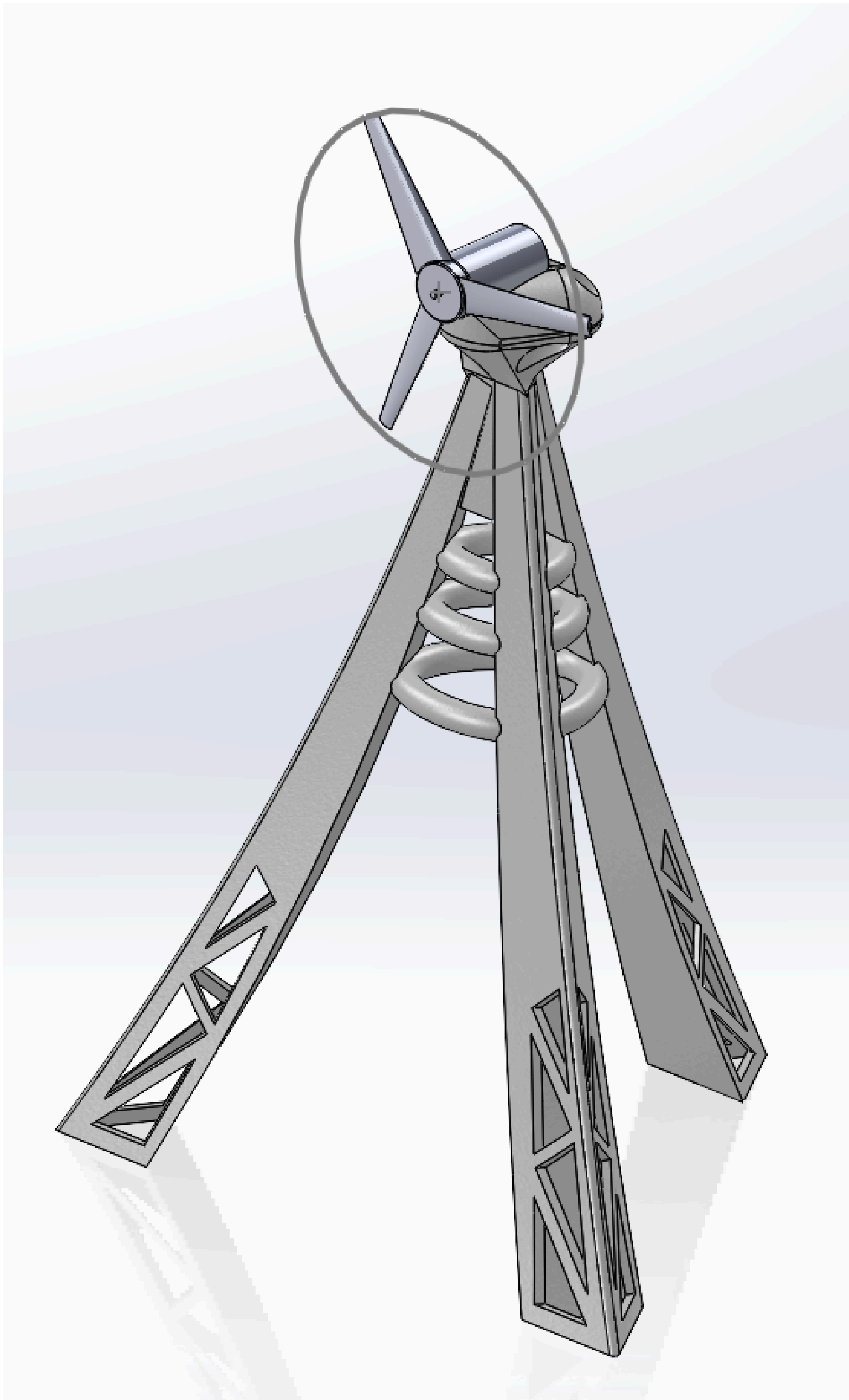
	Applied Load of 1000gf (1.0kgf)	Applied Load of 1100gf (1.1kgf)	Applied Load of 1200gf (1.2kgf)
Displacement Plot			
Stress Plot			
Factor of Safety Plot			

	Applied Load of 1300gf (1.3kgf)	Applied Load of 1400gf (1.4kgf)	Applied Load of 1500gf (1.5kgf)
Displacement Plot			
Stress Plot			
Factor of Safety Plot			

	Applied Load of 1600gf (1.6kgf)	Applied Load of 1700gf (1.7kgf)	Applied Load of 1800gf (1.8kgf)
Displacement Plot			
Stress Plot			
Factor of Safety Plot			

	Applied Load of 1900gf (1.9kgf)	Applied Load of 2000gf (2.0kgf)
Displacement Plot		
Stress Plot		
Factor of Safety Plot		

C: CAD Assembly Showing Turbine with Enough Clearance for 6” Blade Profile



D: Additional CAD Operation References

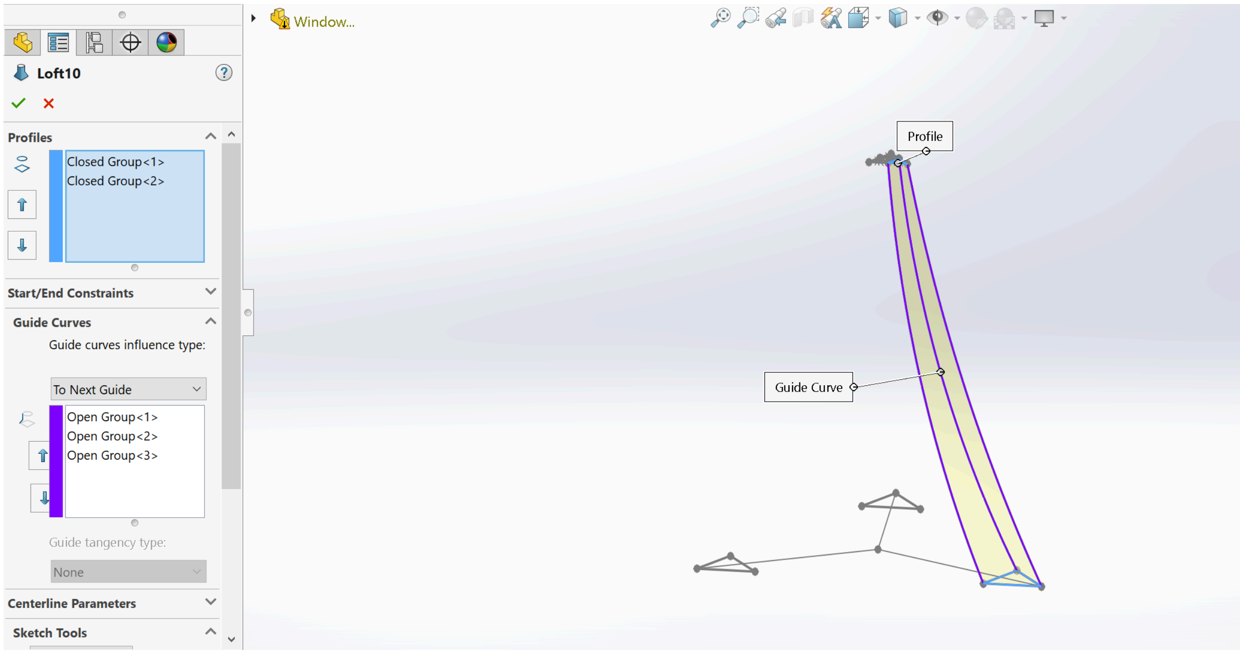


Figure D1: Loft Operation for creating each support leg

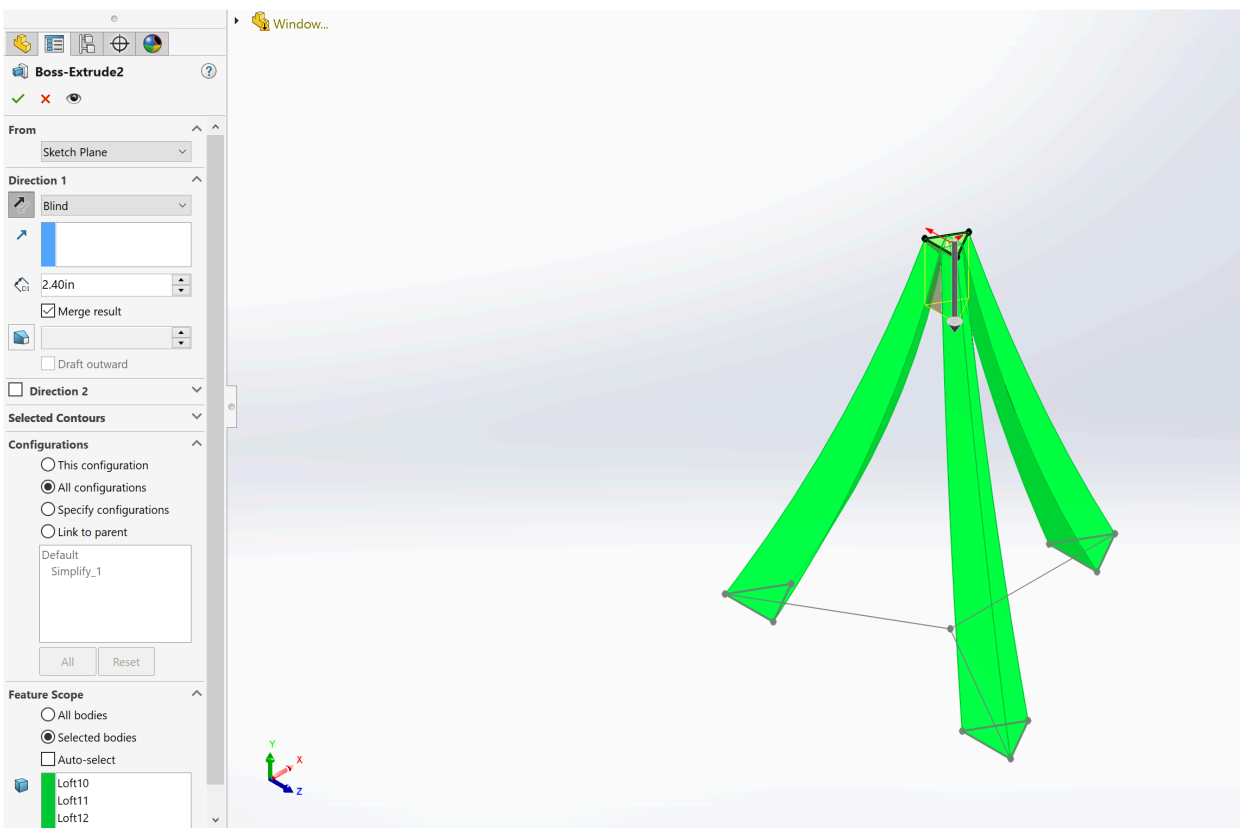


Figure D2: Extrude Operation for connecting the three lofted support legs

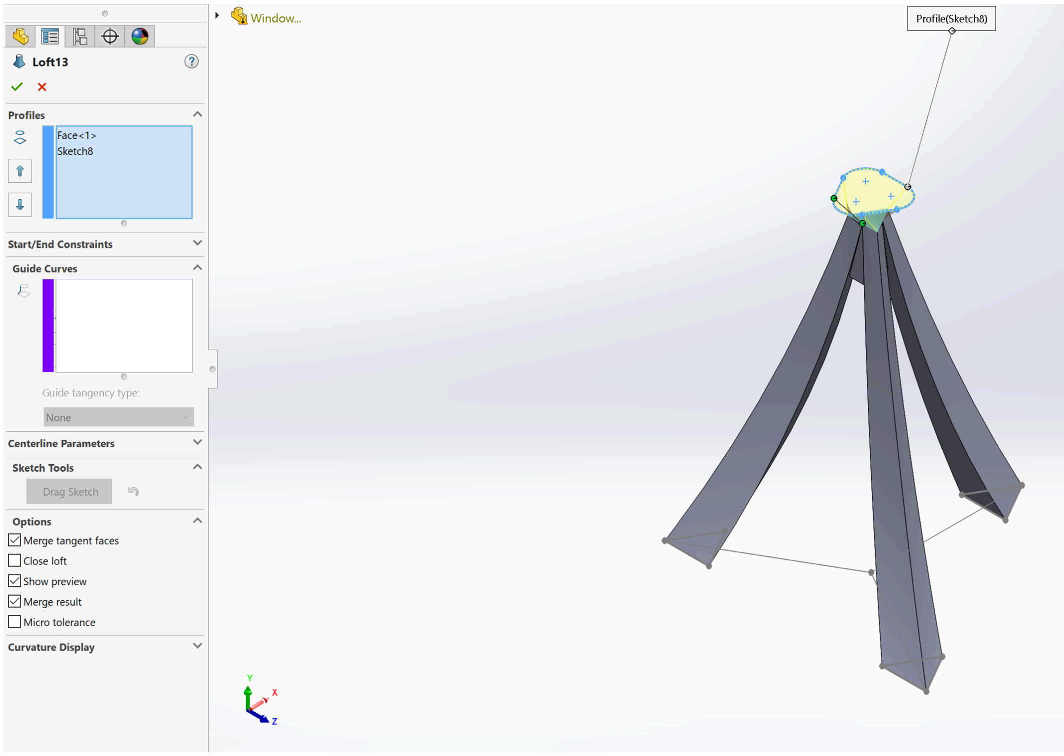


Figure D3: Loft Operation for creating the foundation for the Tower Head

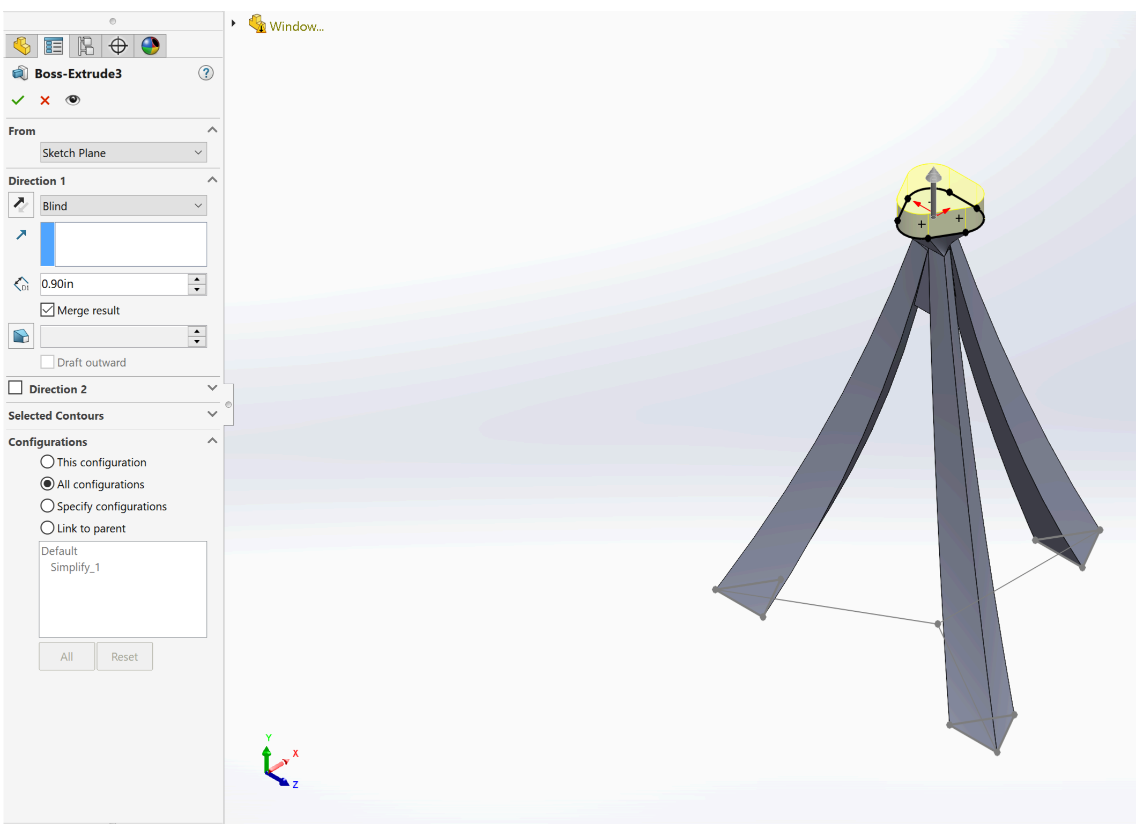


Figure D4: Extrude Operation for creating the tower head to mount the motor

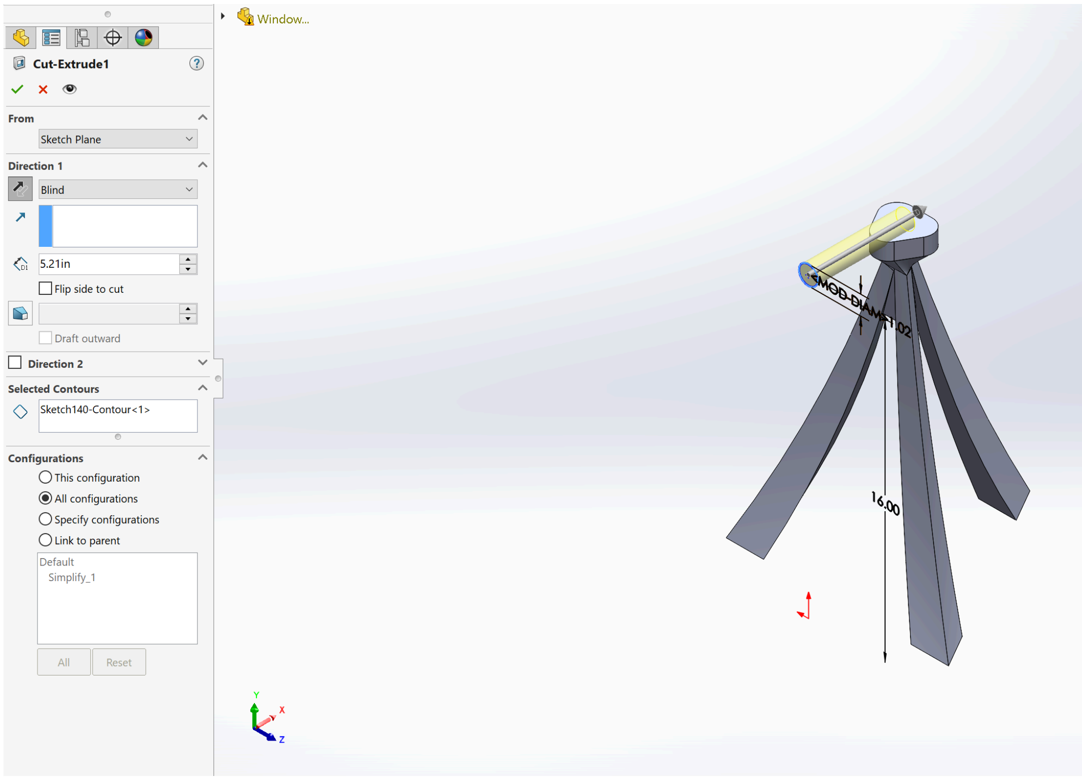


Figure D5: Extrude Cut for creating the cavity to mount the motor

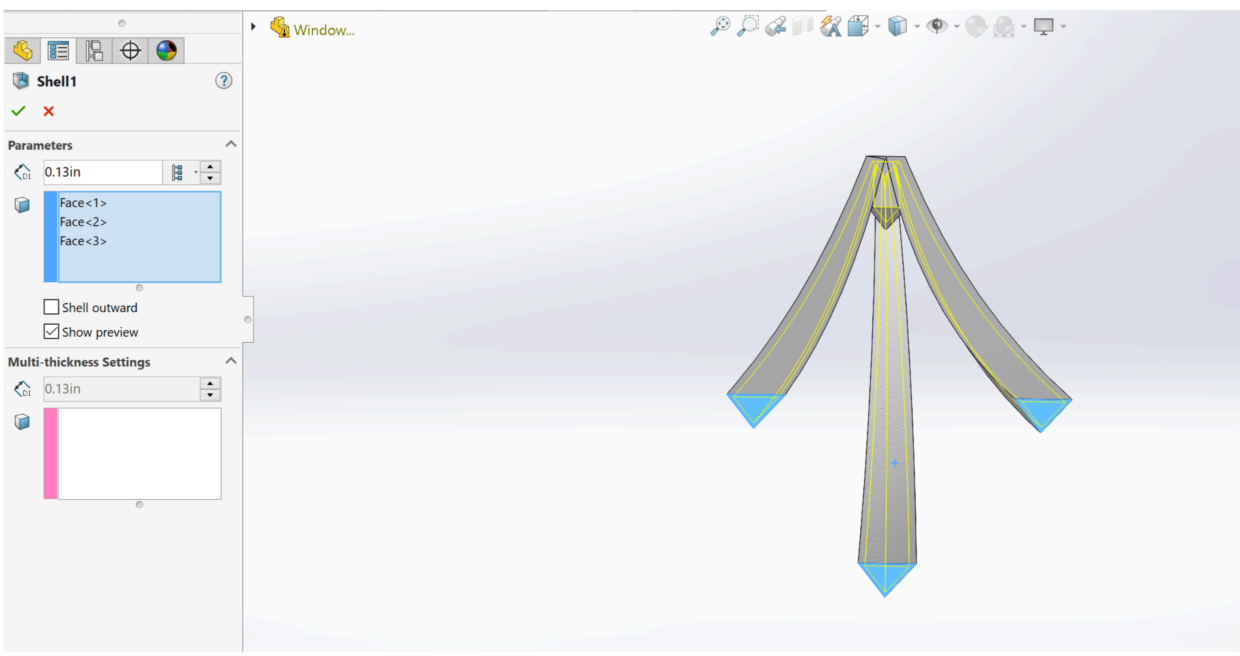


Figure D6: Shell Operation to reduce the volume of the supporting legs

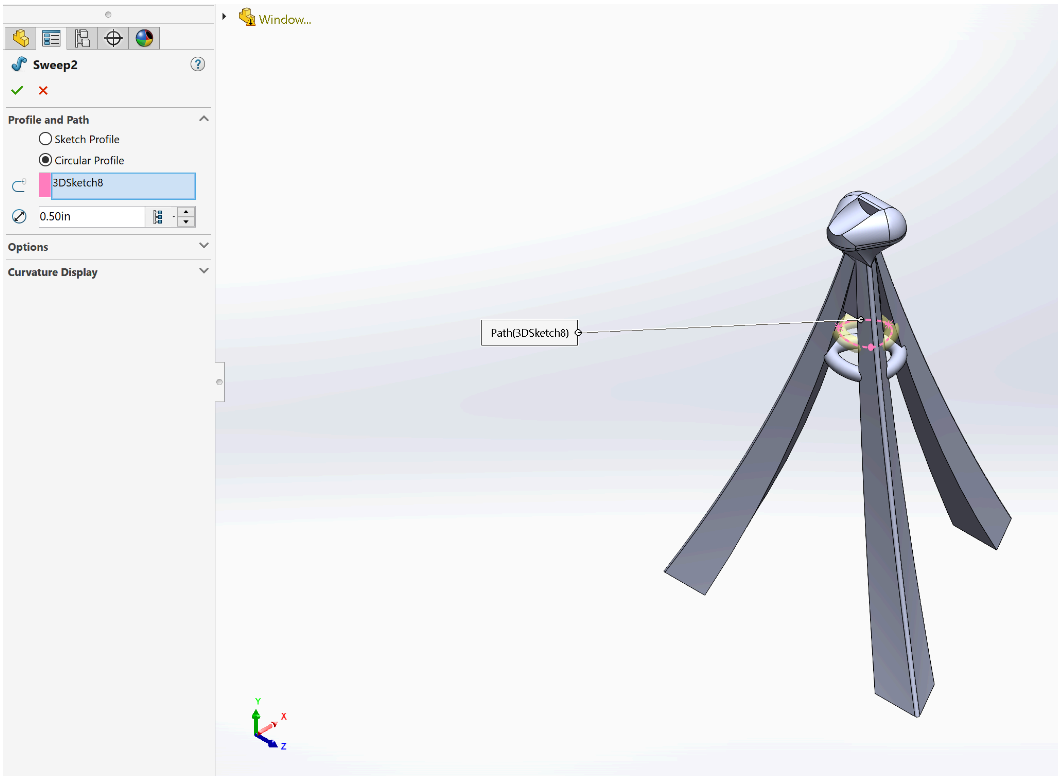


Figure D7: Sweep Operation to create the Torus Shaped Trusses

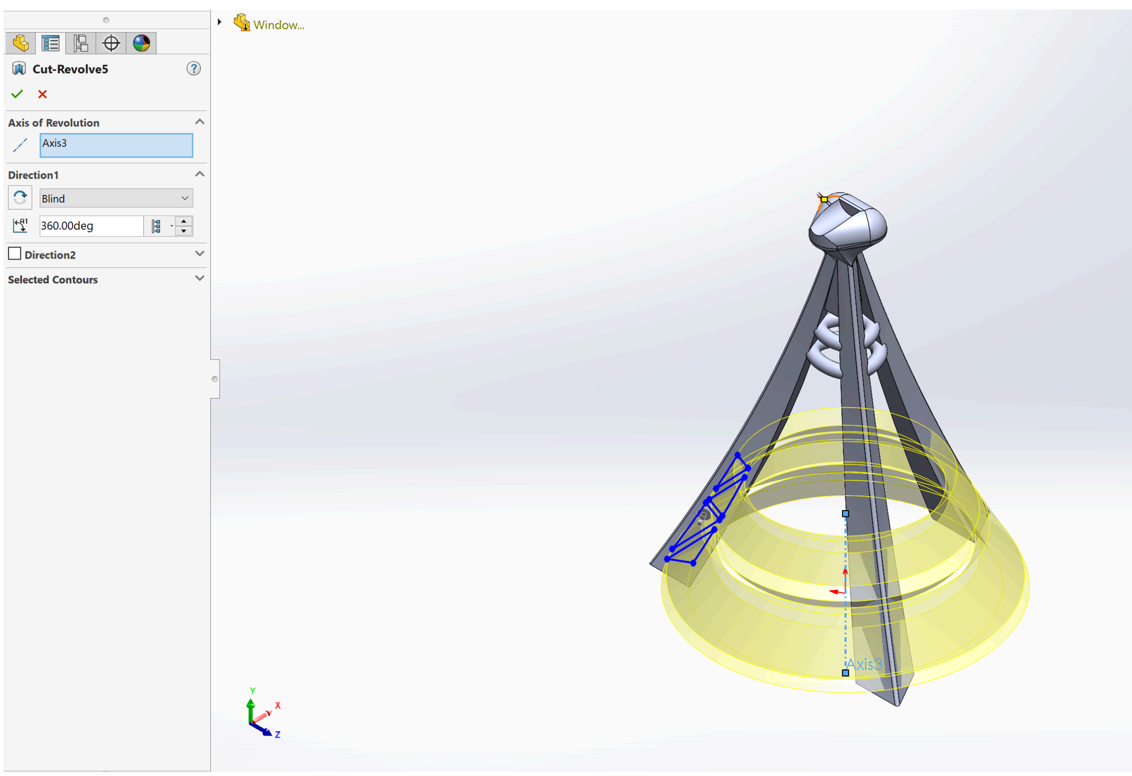


Figure D8: Revolve Cut Operation to pocket the supporting legs

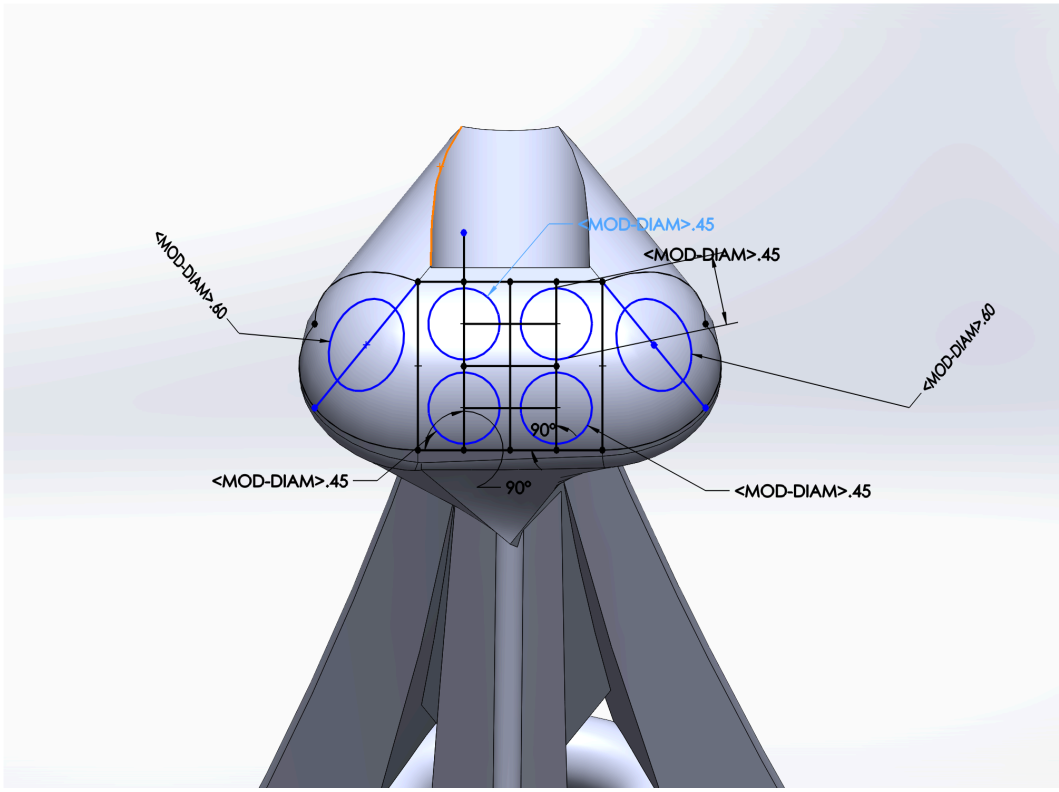


Figure D9: 3D Sketch to create relief holes to reduce top heaviness

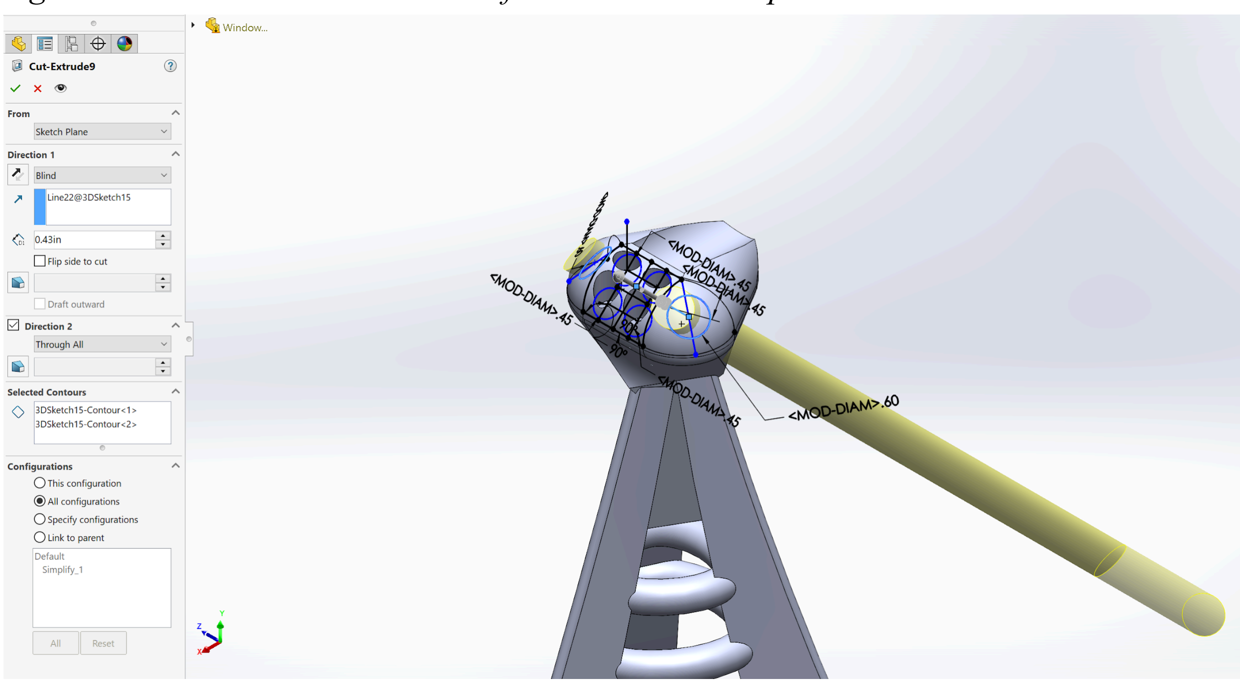


Figure D10: Extrude Cut Operation to create relief holes to reduce top heaviness

E: Additional Topology Simulation References

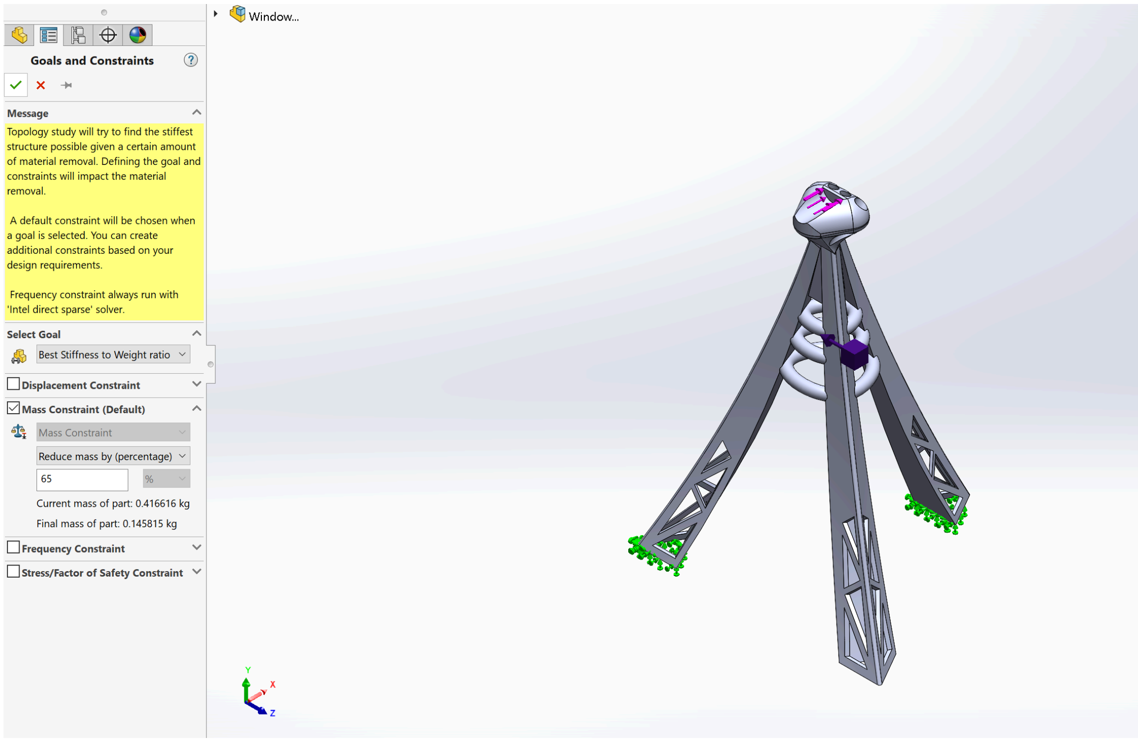


Figure E1: Topology Study Goals - Best Stiffness to Weight Ratio

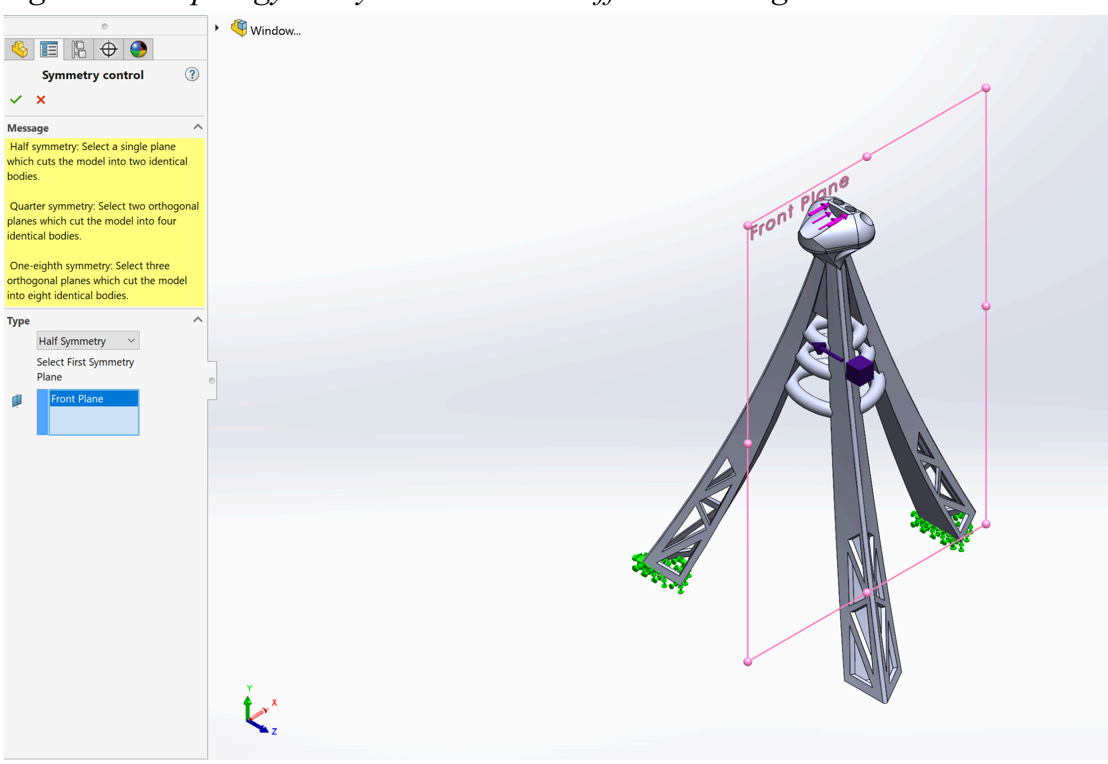


Figure E2: Topology Study Symmetry Constraints

F: Course Evaluations

Samantha Berry:

Berkeley

Fillout Task List
Task Owner: Samantha Berry
Project Title: [ENGINEERING] Fall 2020 Evaluations
Category: COE-2020
Subcategory: Fall

Subject	Due date	Status
ENGIN 26 LEC 001 3 DIMEN MOD DES	Sunday, December 13, 2020	Completed
ENGIN 26 LEC 001 3 DIMEN MOD DES (EVAL FOR GSI)	Sunday, December 13, 2020	Completed

Mobile Version | Standard Version

blue

Chester Zelaya:

Berkeley

Fillout Task List
Task Owner: Chester Zelaya
Project Title: [ENGINEERING] Fall 2020 Evaluations
Category: COE-2020
Subcategory: Fall

Subject	Due date	Status
ENGIN 26 LEC 001 3 DIMEN MOD DES	Sunday, December 13, 2020	Completed
ENGIN 26 LEC 001 3 DIMEN MOD DES (EVAL FOR GSI)	Sunday, December 13, 2020	Completed

Mobile Version | Standard Version

blue

Aidan Sussman:

Berkeley

Fillout Task List
Task Owner: Aidan Sussman
Project Title: [ENGINEERING] Fall 2020 Evaluations
Category: COE-2020
Subcategory: Fall

Subject	Due date	Status
ENGIN 26 LEC 001 3 DIMEN MOD DES	Sunday, December 13, 2020	Completed
ENGIN 26 LEC 001 3 DIMEN MOD DES (EVAL FOR GSI)	Sunday, December 13, 2020	Completed

Mobile Version | Standard Version

blue

Three Dimensional Modeling of a Wind Turbine In SolidWorks

Agnese Sanavio:

Berkeley

Fillout Task List

Task Owner: Agnese Sanavio

Project Title: [ENGINEERING] Fall 2020 Evaluations

Category: COE-2020

Subcategory: Fall

Subject	Due date	Status
ENGIN 26 LEC 001 3 DIMEN MOD DES	Sunday, December 13, 2020	Completed
ENGIN 26 LEC 001 3 DIMEN MOD DES (EVAL FOR GSI)	Sunday, December 13, 2020	Completed

Mobile Version | Standard Version

blue

Andrew Zhu:

Berkeley

Fillout Task List

Task Owner: Andrew Zhu

Project Title: [ENGINEERING] Fall 2020 Evaluations

Category: COE-2020

Subcategory: Fall

Subject	Due date	Status
ENGIN 26 LEC 001 3 DIMEN MOD DES	Sunday, December 13, 2020	Completed
ENGIN 26 LEC 001 3 DIMEN MOD DES (EVAL FOR GSI)	Sunday, December 13, 2020	Completed

Mobile Version | Standard Version

blue

Shelby Respicio-Evans:

Berkeley

Fillout Task List

Task Owner: Shelby Respicio-Evans

Project Title: [ENGINEERING] Fall 2020 Evaluations

Category: COE-2020

Subcategory: Fall

Subject	Due date	Status
ENGIN 26 LEC 001 3 DIMEN MOD DES	Sunday, December 13, 2020	Completed
ENGIN 26 LEC 001 3 DIMEN MOD DES (EVAL FOR GSI)	Sunday, December 13, 2020	Completed

Mobile Version | Standard Version

blue