Spring 2019

Recumbent Bicycle Balancing Aid

James Hager
jsh92@zips.uakron.edu

The University of Akron
Mechanical Engineering

Senior Design Project

Recumbent Bicycle Balancing Aid

Team Members:
James Hager
Scott McMullen
George Rusinko
Ryan Schaffer

Faculty Advisors:
Heidi Cressman
Dr. Scott Sawyer

Table of Contents

Project Introduction

For our senior design project, our team will be consulting to create a balancing aid system intended for the recumbent bicycle shown below in *Figure 1*. The owner of the bicycle is Robert Henderson, a former United States Navy sailor from Northeast Ohio who picked up biking and skiing while he was stationed in Maine in the late 80's. While there, he took to the mountains on the rugged terrain and brought this passion of biking back home to share with his wife, Johanna once he completed his service to his country. Biking became an integral part of the Henderson's lifestyle and was one of their favorite family activities.

However, 14 years ago, Robert was diagnosed with Parkinson's Disease which has greatly affected his body and thus his riding ability. His family came to Akron seeking an engineering team to help design something to help him get back to riding again. Studies have shown that the act of balancing and riding a bicycle can reduce the tremors and shakiness caused by Parkinson's Disease. Through the University of Akron's Engineering Service Design Team, our team connected with Robert and his family and we were able to borrow the recumbent bicycle from them to work on our design.

The bicycle shown below is what Robert's wife Johanna brought to us in an attempt to create a system that stabilizes it so that Robert can once again enjoy his passion for biking. Our task was to create a system based off of this bicycle that would allow Robert freedom in biking but also keep him stable at all times.

Figure 1: Recumbent Bicycle Owned by the Hendersons

Concept Development

The aim of the project was to develop a device or method to stabilize Robert's recumbent bicycle. The mechanism or design would be created to help stabilize the bicycle while allowing the rider to maintain balance through his own efforts. The designed concept would allow the bicycle to operate with low friction and should respond to the weight of the rider without overcompensating. This requirement would ensure that the bicycle can be ridden with an expected amount of physical exertion but remain stable and safe at the same time.

In order to achieve a level of sophistication suitable for a senior mechanical engineering design project, the response and stability of the device are to be provided by a spring system, with a damper if necessary. The design is intended to be compact to reduce the addition of material or bulk to the stock frame of the bicycle. Therefore, the dimensions are limited to remain within the current width established by the handlebars and pedals on either side of the frame. In order to transport the bicycle safely and simply, the idea was to keep the system within those dimensions so as be quickly disassembled and reassembled for travel. The device is intended to remain within the vertical confines of the bicycle and has been restricted to fit beneath the bottom of the seat at any point on the bicycle. Further, the design is preferred to be relatively easy to remove from the frame of the bicycle. This aspect will allow the user to conserve space during transportation of the bicycle and will allow for easy modifications and repairs on the device and bicycle if necessary.

Black Box

Before designing the system to stabilize the bicycle, we had to define the main functions and reasons for those functions. The black box diagram, as seen in *Figure 2* helped us organize our thoughts and reasons for the system. As seen in the function box, the system needed to stabilize the bicycle. In order to achieve this, certain inputs had to be taken into account. We wanted the majority of the structure to remain static but we also wanted some variability. The reasoning primarily hinged on the surfaces that Robert would be able to ride on. A largely static system allows for strength, and the springs prevent the changes in terrain and variations in the ground from affecting Robert's ride. Another function of the springs is to provide the ability for Robert to lean into his turns while keeping him stable. From this function box, we were able to derive an objective tree with numerous design characteristics in order to complete the task of stabilizing the bicycle.

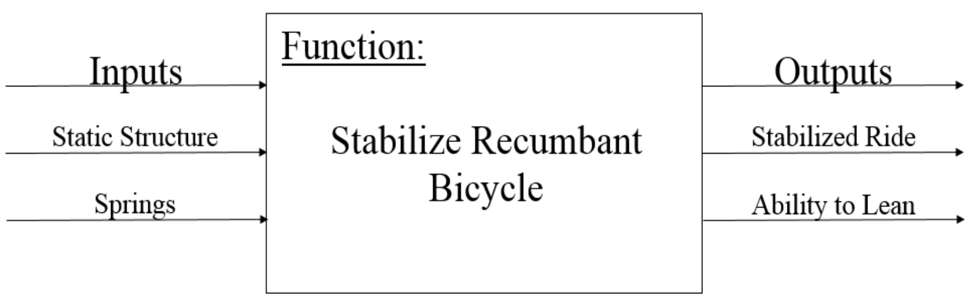


Figure 2: Design Function of the System

Objective Tree

In order to streamline the design, each function and purpose was given a specific number, based on the scale factor of 1, to rate the importance to the system's functions. Using the "black box" as seen in *Figure 2,* four main areas were identified as top priority in the bicycle stabilizing system. These areas were cost, service, size and safety. Under each of these categories were sub-groups of more specific attributes necessary to the success of the stabilizing system. As seen on the objective tree in *Figure 3*, safety was the number one concern of this project due to Robert's condition. The system needed to be durable, reliable, and versatile, and include the ability to traverse many terrains over many riding cycles. The design must function to keep the rider stable to ensure a ride without falling but also allow the freedom to lean into the turns. After safety, both cost and service were deemed equally important, minimizing material and manufacturing cost as well as simplifying replacement, repair and maintenance. The design was intended to minimize components to enable replacement and easy repair after assembly. This also meant that the system could be disassembled for traveling purposes. The system was designed in seven sub-assemblies and each sub-assembly was evaluated for its ease of repair and replacement. Finally, size was constrained such that the balancing aid was not larger than the bicycle itself. Ergonomically, the rider's position on the bicycle and ease of mounting and dismounting the bicycle were considered. These two actions are necessary and the mechanism should not cause interference. The objective tree and black box assisted the team in organizing our thoughts and concepts into main categories in order to move forward in the design process.

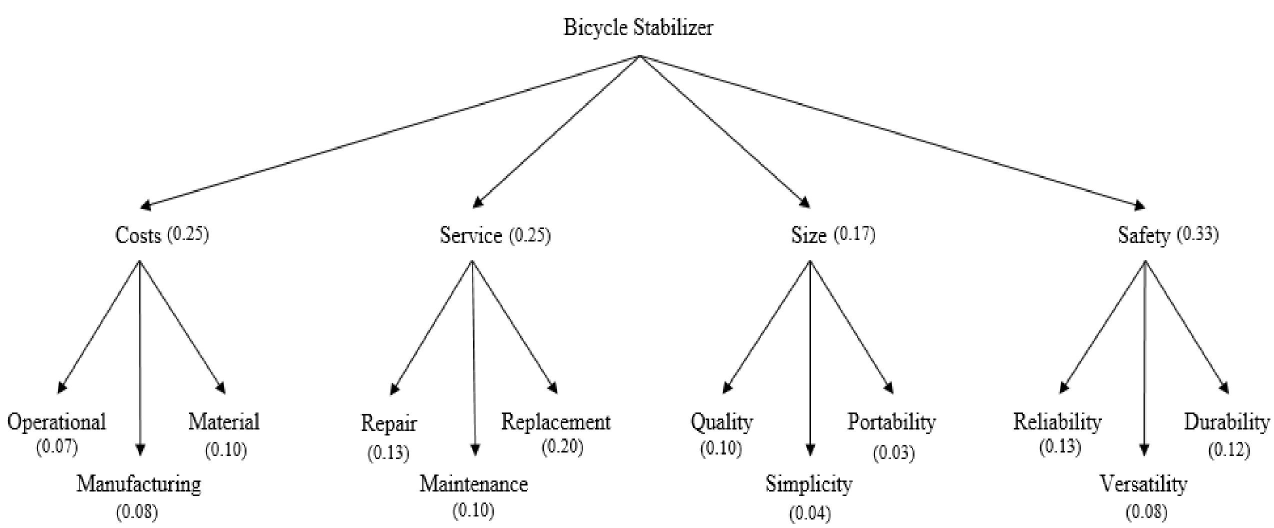


Figure 3: Objective Tree Rating System for Streamlining the Design Process

Morphological Chart

Once we established the function of the system and the design criteria, we came up with six important areas to consider when designing the system. As seen in *Figure 3*, the six sections were the following: where to attach the system, how to attach it, what type of spring to use, what type of damping system to use, what type of wheel system and what material to use for the wheel. Under each part, we had multiple options based off of the physical bicycle itself on how to achieve each area. Once each of the components was considered , we then chose six potential designs by adding numbers in the different components' respective boxes. These six numbers can be traced through the chart as shown below. After the six designs were chosen, multiple concept sketches were drawn for the system as seen in *Figure 4*.

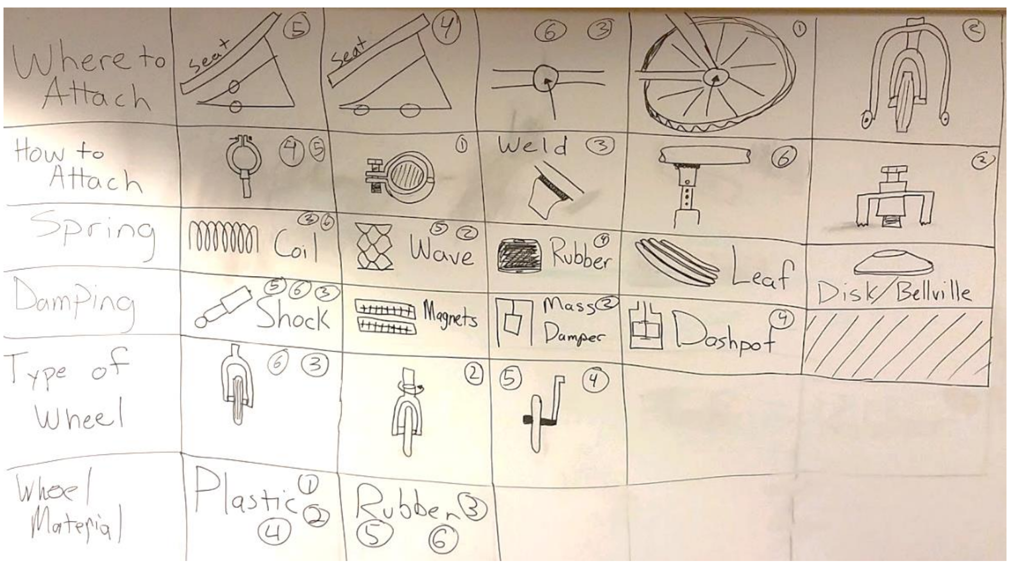


Figure 3: Morphological Chart Containing Design Ideas

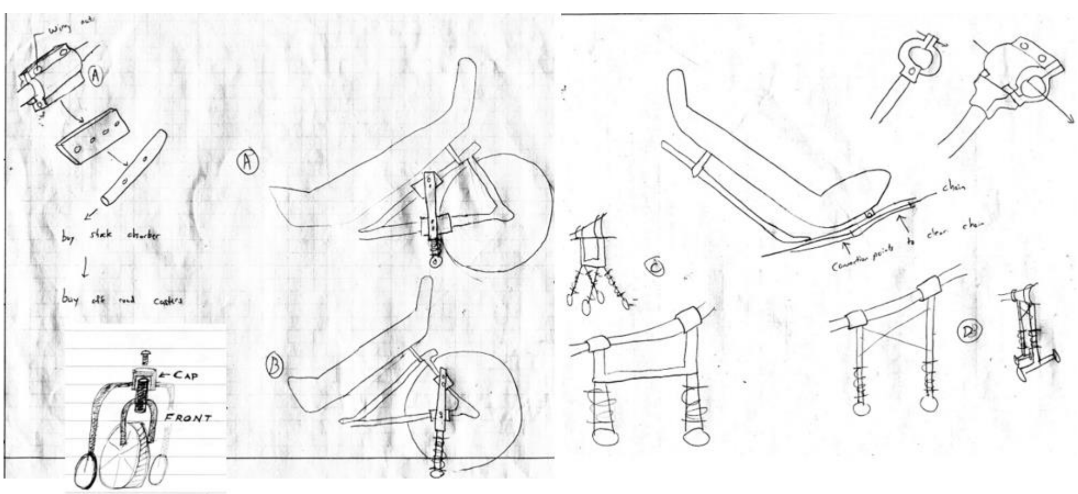


Figure 4: Concept Sketches Based off the Morphological Chart

Decision Matrix

After the six designs were sketched, they were rated in regards to the objective tree by each of the four group members independently. Then we compiled our individual scores and averaged them into one chart as seen in *Figure 5*. This helped to see how each design ranked in regards to the objective tree and also how each design fared compared to one another. After compiling our matrices, we decided to move forward with the design that contained a coil spring, rubber wheel that was non-rotating, a shock (eventually eliminated for simplicity's sake) and a connection right underneath the rider to maintain the center of gravity. This design concept was selected, but required slight alterations throughout the design phase.

Weighted Decision Matrix

			Design 1			Design 2			Design 3			Design 4			Design 5			Design 6		
		Evaluation Criteria	Weight Factor	Score	Rating	Weight Factor	Score	Rating	Weight Factor	Score	Rating	Weight Factor	Score	Rating	Weight Factor	Score	Rating	Weight Factor	Score	Rating
Costs	0.25	Operational	0.07	2.333333	0.163333	0.07	2	0.14	0.07	3	0.21	0.07	4	0.28	0.07	3.666667	0.256667	0.07	3.333333	0.233333
		Manufacturing	0.08	3.333333	0.266667	0.08	1.333333	0.106667	0.08	3	0.24	0.08	3	0.24	0.08	2.666667	0.213333	0.08	2.666667	0.213333
		Material	0.1	3	0.3	0.1	1.333333	0.133333	0.1	2	0.2	0.1	2.333333	0.233333	0.1	2.333333	0.233333	0.1	2.333333	0.233333
Service	0.25	Maintenance	0.1	3.666667	0.366667	0.1	3.333333	0.333333	0.1	1.666667	0.166667	0.1	3.333333	0.333333	0.1	3.666667	0.366667	0.1	3	0.3
		Repair	0.13	2.666667	0.346667	0.13	2.666667	0.346667	0.13	2.666667	0.346667	0.13	2.666667	0.346667	0.13	3.333333	0.433333	0.13	2	0.26
		Replacement	0.02	3.666667	0.073333	0.02	1.666667	0.033333	0.02	2.333333	0.046667	0.02	1.666667	0.033333	0.02	2.666667	0.053333	0.02	2.333333	0.046667
Size	0.17	Portability	0.03	3.333333	0.1	0.03	3	0.09	0.03	1.333333	0.04	0.03	3.666667	0.11	0.03	3.666667	0.11	0.03	2.333333	0.07
		Simplicity	0.04	3.666667	0.146667	0.04	1.333333	0.053333	0.04	2.666667	0.106667	0.04	2.666667	0.106667	0.04	2.666667	0.106667	0.04	2	0.08
		Quality	0.1	1.666667	0.166667	0.1	2	0.2	0.1	3	0.3	0.1	2.666667	0.266667	0.1	4	0.4	0.1	4	0.4
Safety	0.33	Reliability	0.13	2.333333	0.303333	0.13	2.666667	0.346667	0.13	4	0.52	0.13	4	0.52	0.13	3.333333	0.433333	0.13	3.333333	0.433333
		Versatility	0.08	2.333333	0.186667	0.08	2	0.16	0.08	1.666667	0.133333	0.08	2.666667	0.213333	0.08	2.333333	0.186667	0.08	2.333333	0.186667
		Durability	0.12	2.666667	0.32	0.12	2.666667	0.32	0.12	3.666667	0.44	0.12	3.666667	0.44	0.12	3.333333	0.4	0.12	3.333333	0.4
	1	Totals			2.74			2.263333			2.75			3.123333			3.193333			2.856667

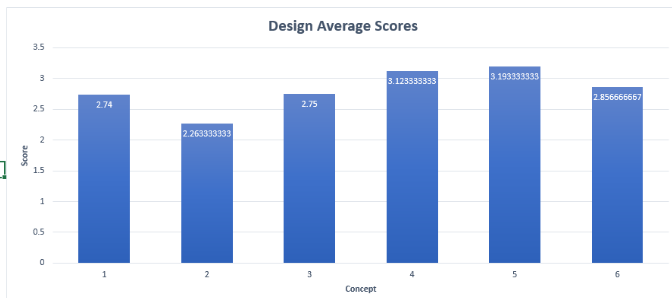


Figure 5: Averaged Results from Our Individual Decision Matrices

Moog Design Review

As part of the concept design process, two detailed ideas were reviewed by engineers outside of our design team. Paul Kiser and Darren Ressler, full-time engineers for Moog Flo-Tork, Inc. graciously provided input on the concepts and models in consideration. At that time, two designs had been roughly modeled as SolidWorks assemblies. The first version submitted for review utilized telescoping tubes that activated a spring in compression. In order to keep the bicycle balanced properly, two apparati would be required, one placed on either side of the bicycle. Each spring would compress when the rider leaned toward its respective side and conversely, the springs would extend when the rider leaned away from its respective side. This scenario would ensure constant contact with the ground from both supports. The springs would also compress and extend during the ride on uneven terrain, or when they were rolled over rocks, roots, etc. The model that was shown at the design review can be seen in *Figure 6* in a very early, unfinished state.

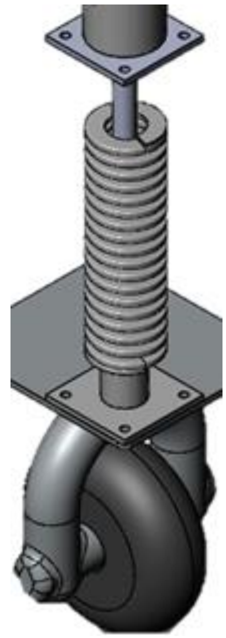


Figure 6: Compression Spring Model Shown at Design Review

For this concept, the spring provided the support system during normal riding operation. The compression spring also served as the damping system. The spring was intended to be designed with a stiffness that would ensure that the device reacted to the rider’s weight, providing enough responsive force to maintain the rider’s balance, especially during turning or leaning. The following two attachment points for the system to the bicycle were considered: either at the spoke of the rear wheel or to the frame underneath the seat. Minor concerns for this design did included the fact that the springs were exposed to the elements where debris could lodge between the coils and decrease the performance of the spring.

The second design shown for review incorporated a slender bar that would enable components of the wheel assembly to pivot. The device would be able to sway left and right with the wheels remaining in contact with the ground or riding surface. The Moog design review raised a few key concerns about this design. The swaying action of the wheel assemblies could cause safety issues by allowing the wheels to sway inward towards the bicycle and potentially hit the rider or interfere with the operation of the bicycle. Another concern was the weight and rigidity of the bar. The bar had two theoretical, welded contact points with the bicycle. Depending on the tilting action, the bar and wheel assembly could change the center of gravity slightly, resulting in tipping of the bicycle. Even though this design was met with some criticism, it sparked constructive criticism and allowed for a few of the ideas to eventually be considered for the final design of the system. One side of the system can be seen in *Figure 7* along with a few labels showing the motion of the system with the movement of the bicycle and rider.

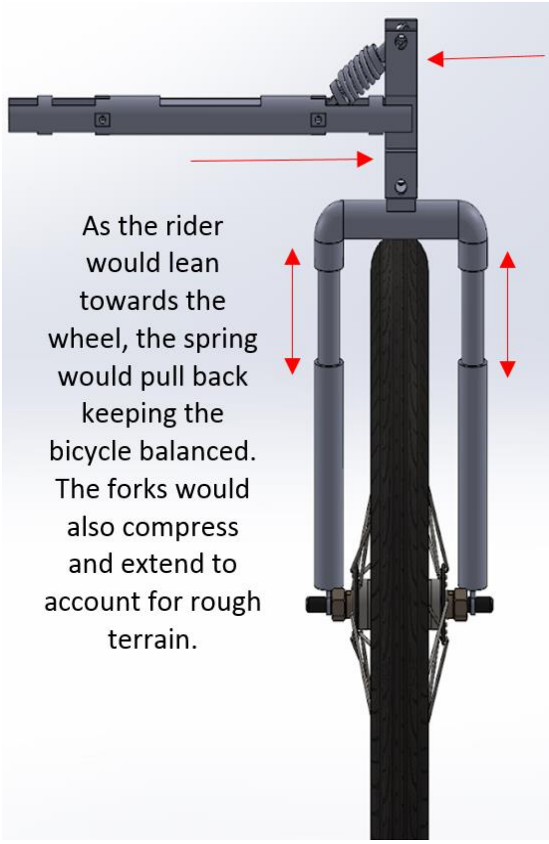


Figure 7: Oscillating Bar Concepts Shown at Design Review

From the review of these two designs, a new concept was conceived. Darren, an alumnus of The University of Akron, had worked on a vehicle design for his senior project and had encountered similar design constraints and issues. He recommended that a bar be included to unite the devices into one single mechanism. The intention was to reduce the degree of freedom in the devices by requiring that they both move as one object. The bar would ensure that one wheel could not stray far from the frame of the bicycle as that would require the pulling of the other wheel toward the frame. In this way, the wheels and spring devices would work together to ensure stability and balance. The point of contact for the single mechanism was changed to add increased stability and strength when connecting the support to the bicycle. Mimicking the way the seat is attached to the frame, the device was redesigned to be bolted to the frame through slots in the device. The slots were chosen in order to allow for adjustments to the mechanism after installation. The design was changed to contain the springs inside the tubes of the device, keeping them clean and fully functional. With the help of the Moog engineers, we had the general design formed for the system and concluded the concept design stage. The next step in our process was to start modeling and creating the entire system to fit the specifications of the physical bicycle we had been given from the Hendersons.

Embodiment Design

Embodiment design principles used throughout the process include, but are not limited to, clarity of function, simplicity, safety, division of tasks and self-help. As previously mentioned, each sub-section of the system has a specific function; the central support connects the system to the frame, the tubes and springs compress allowing for tilting, and the wheels are the contact points to the ground. Each portion of the system has been designed in the simplest fashion, to date, given the constraints of the geometry of the frame. There are points of continued improvement for the design, however.

The largest self-help area of this design are the central support arms. They are angled to be similar to the angle of the tubes and wheels in order to disperse the forces evenly, but they also serve as point of contacts for the central frame. Another area of self-help is the entire system itself as it acts as a kickstand while the bicycle is stationary. Not only does this add stability while riding the bicycle, but it also helps the rider mount and dismount with ease. Since the bicycle is able to stand stationary, there is less movement for the rider to contend with when trying to achieve these tasks.

For the central connection pieces, the design of the seat was taken heavily into account. As seen in *Figure 8*, the seat is mounted to the frame using a through bolt and spokes, which are adjustable. This same idea was adopted for the design of the connection point for the central support, where a through-bolt would secure the central support in place along with its contact point at the kickstand bracket. It was convenient to draw inspiration right from the bicycle itself as well as keep the design consistent with the design of the bicycle.

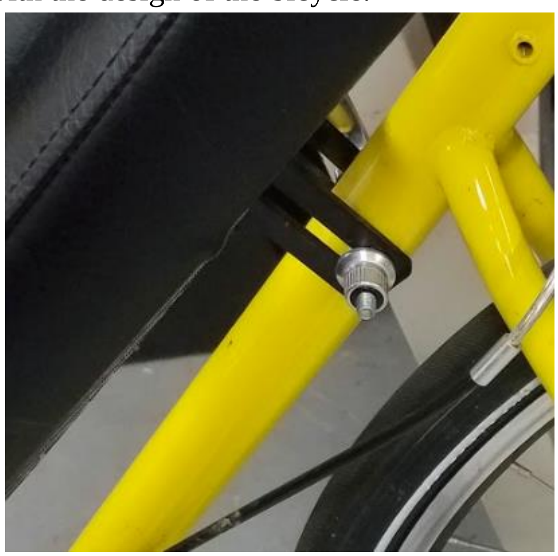


Figure 8: Seat Connection from which Inspiration for the Central Support was Drawn

The idea for one of the two first designs was originated by visualizing automotive struts. For a vehicle, the large spring coupled with the shock absorber allows the tires to travel over rough or bumpy terrain and keep the vibrations from transferring to the cabin. The apparatus for the bicycle should perform in a similar manner. A vertical compression spring is used to provide the reactive and opposing forces required by such a design. Establishing a pre-compression value of

the springs will provide a method of keeping the supportive wheels on the ground, even when the bicycle is at rest. The sustained force will also allow the mechanism to increase its length as the rider leans away from the wheel during a turn. Again, the intention is to maintain contact between the tire and the ground during riding so as to help with balance and stability. As the rider leans toward one side of the bicycle, the spring on the respective side will compress further and increase the force applied. The rider should experience some aid in coming out of the turn and the spring will also prevent the rider from overbalancing and losing control.

The telescoping tubes were included to prevent buckling and other unpredictable movements of the spring. By encasing the spring in its own cylindrical section, the motion of the spring is constrained to vertical compression and expansion only. During riding, the tube will prevent the wheels from sliding perpendicular to the direction of the velocity of the bicycle, important in maintaining functionality of the wheel. Clearance values are designed in such a way that the section of inner tubing that exists fully in the outer tube should never reach the top of the outer tube, nor should the inner tube be extended completely to the mouth opening of the outer tube during normal riding operation. The increased length of this section of inner tube, more clearly visible in *Figure 9*, prevents instability of the lower section of small tubing. Without this supportive length in the outer tube, the wheel would likely have an undesirable range of motion and the device may lose its vertical shape during riding resulting in a buckling failure of the system. Both sections of tube are fitted with a “lip” to prevent the inner section from being pulled completely out of the outer section should the mechanism ever be removed from its designed position on the bicycle frame.

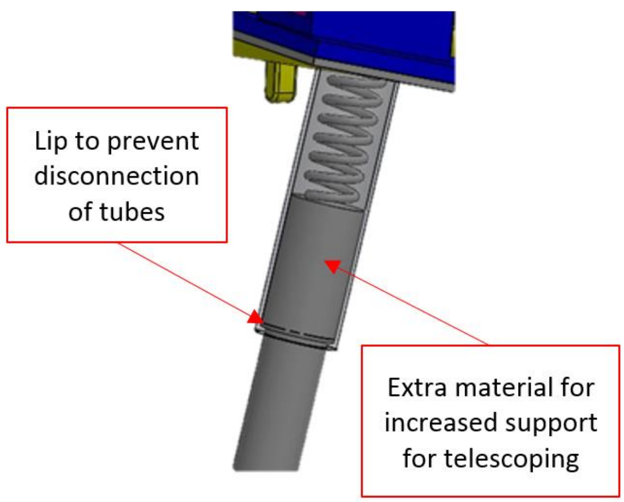


Figure 9: Extended Length of Inner Tube Designed for Increased Stability

As seen in the fully labeled assembly in *Figure 10*, the system is symmetric and contains two of every major component, excluding hardware and the central support. This model was fitted to a model of the frame of the real bicycle; each crucial dimension was carefully added to ensure

similarity between the model and the real bicycle. Thus, when prototyping components from the SolidWorks models, the dimensions would closely match those of the real bicycle.

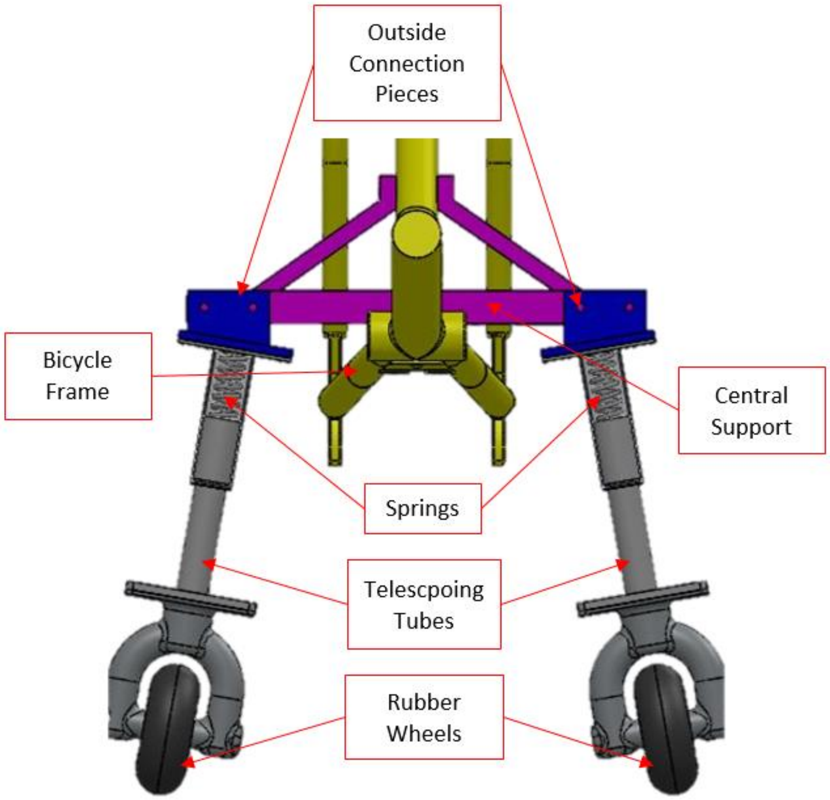


Figure 10: Full Assembly Model of Updated Design

As the rider leans the bicycle, the points on the frame make an arc whose center point is located along the axis of the bicycle's contact with the ground. The mechanics of this rotation is shown more clearly in *Figure 11*. This motion also influences the additional tires since they are not located along the axis of the front and rear tires. The angle at which the device is mounted is integral in preventing these tires from changing their position relative to the axis of the front and rear tires as the bicycle rotates. The distance from ground to the point of contact of the bicycle and the mechanism is measured to be 15 inches. Hence, the radius of the arc that will be made by the point of contact is also 15 inches. Therefore, the tire should make contact with the ground at a point along this arc, 15 inches away from the axis of the front and rear tires. As the bicycle rotates, the arc will continue to contain the point of contact of the tire, and the tire will not slide perpendicular to the direction of the velocity of the bicycle. The angle created by the bicycle is also experienced by the rider when leaning either left or right.

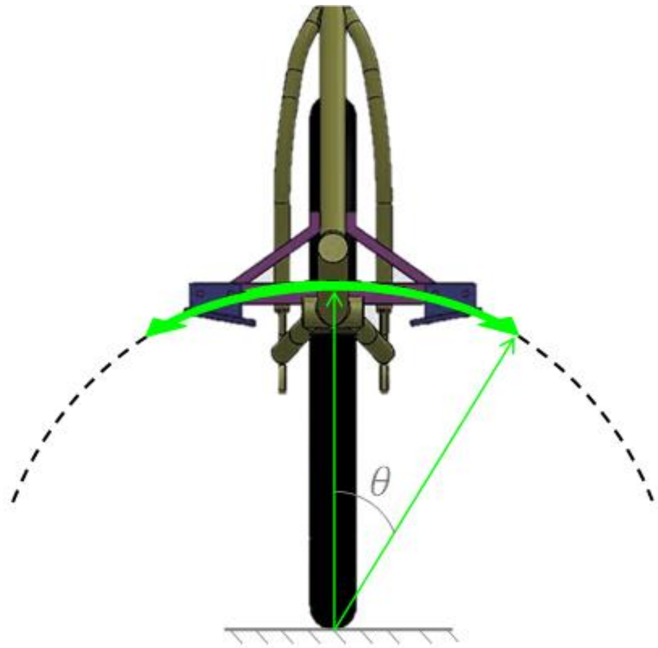


Figure 11: Rotational Motion of Bicycle During Turning or Balancing Action

Finite Element Analysis

First Design

The first iteration of the subassembly was analyzed before manufacturing to ensure safety and to reduce the number of 3D-printed models. Total deformation, strain and stress, and factor of safety of the central support and other components of the final assembly were analyzed via ANSYS Workbench. Due to the time constraints of utilizing the program, constraints were created in the program to decrease the solution process time. Bolts that would be installed in the manufacturing phase of the project were changed to simple rods. Element size of the mesh (dividing the model into elements) had to be changed from the default setting to a smaller element size for more accuracy. Two further subassemblies of the complete subassembly were created in order to produce a more efficient and effective analysis.

To utilize the ANSYS workbench, support surfaces needed to be established in the program. The support surfaces are (prong ends) of the central support bar and the bottom of the central support bar where it will rest on the kickstand bracket of the bicycle frame. Forces that will act on the subassembly are determined by the weight of the rider. The subassembly is designed to resist the force applied by the rider of 300 lb. There are three situations that were tested for each setup; tilting on one side, opposite forces on each side, and force exerted in the same direction.

The results of the first subassembly, as seen in *Figure 12*, are indicated in the figures below. The effects of the rider leaning the bicycle to one side are illustrated. The gradients in each figure indicate areas of different colors to illustrate the maximum to minimum values of the type of analysis. Red is the maximum value obtained while the blue is the minimum value. On the top left

hand of each figure, the type of analysis will be displayed. In the analysis, maximum pressure of 30 psi will be acting on the bracket.

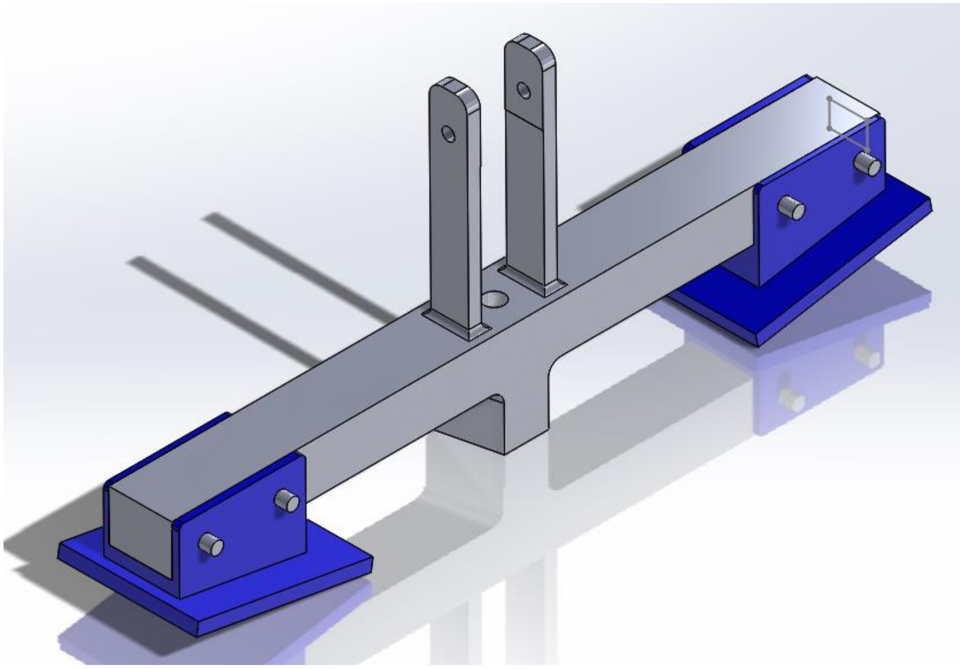
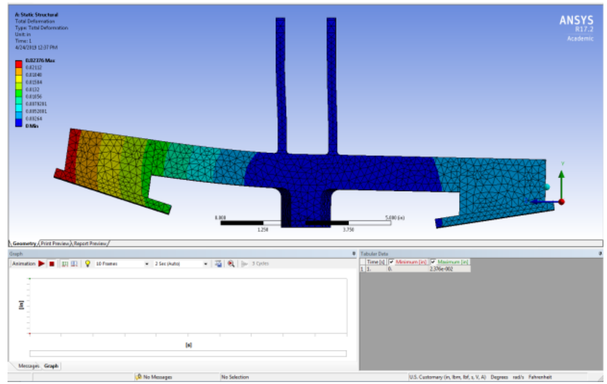
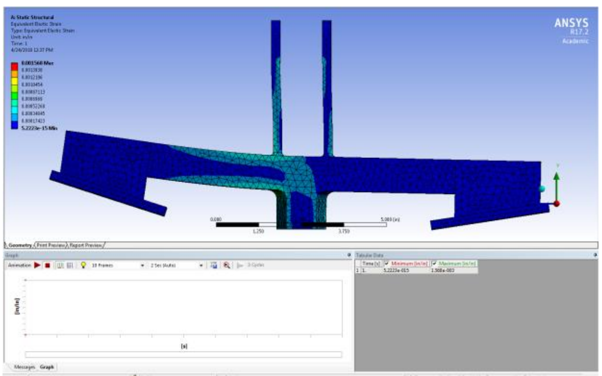
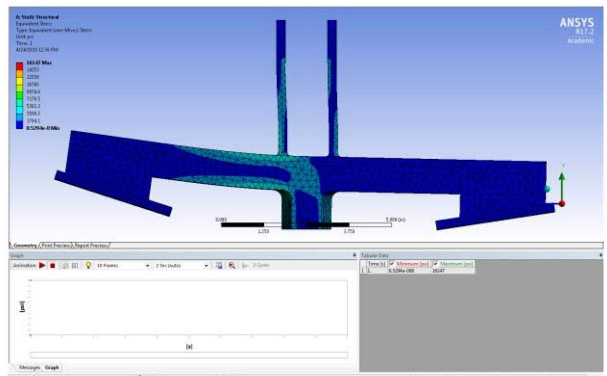
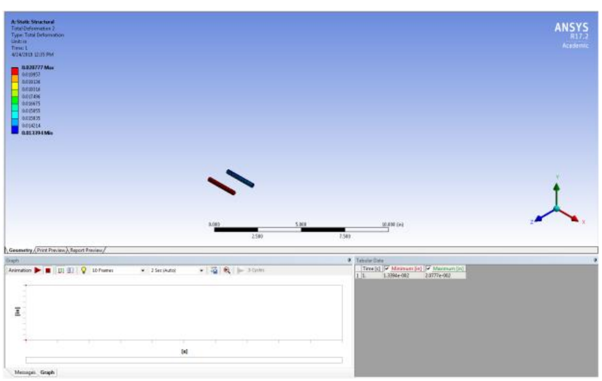
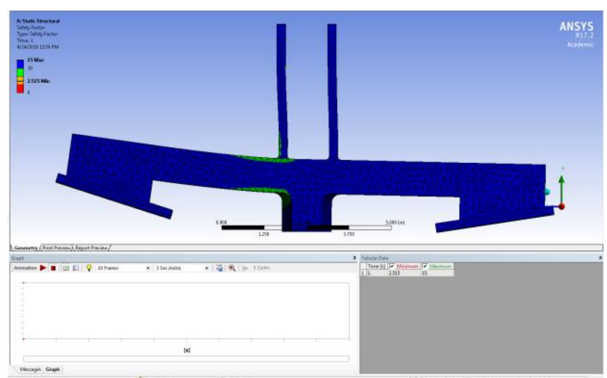
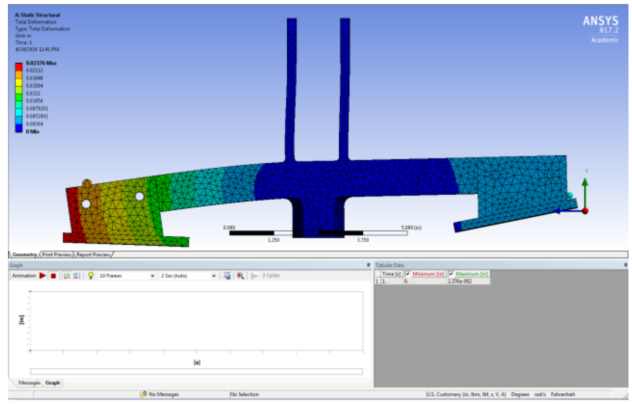
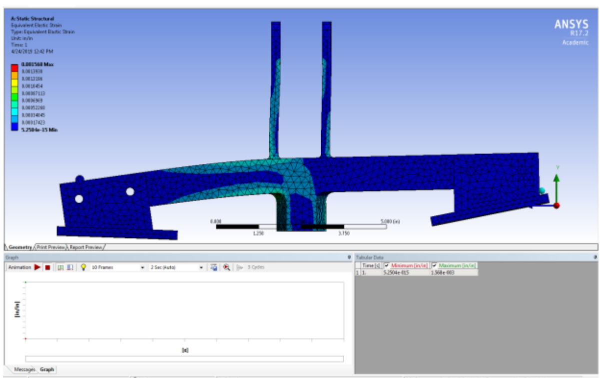
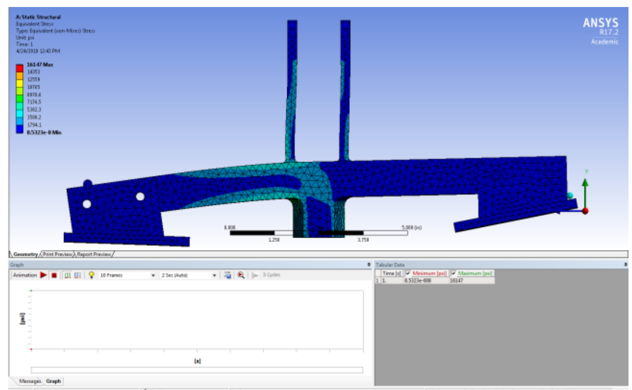
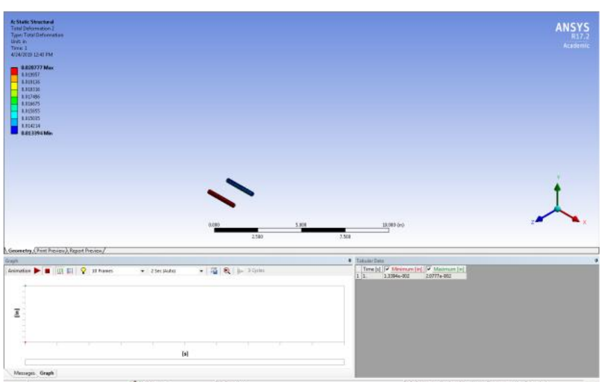
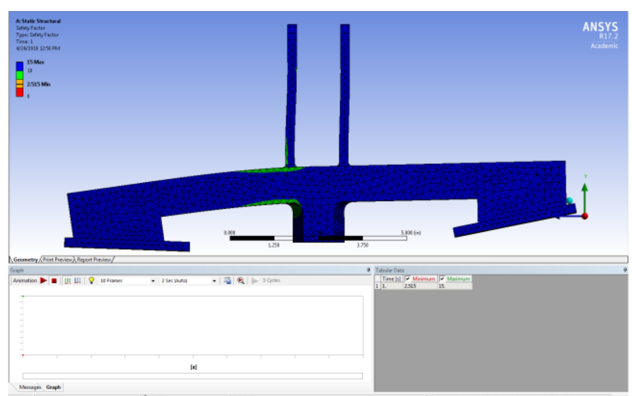


Figure 12: First Design of Central Support with Outside Connections

Pressure on Subassembly acting on one direction (+Y)	 *Figure 13: Deformation Pressure Acting on One Side of Subassembly*
 *Figure 14: Strain Pressure Acting on One Side of Subassembly*	 *Figure 15: Stress Pressure Acting on One Side of Subassembly*
 *Figure 16: Deformation, Pressure Acting on One Side of Subassembly, Pins Isolated*	 *Figure 17: Factor of Safety, Pressure Acting on One Side of Subassembly*

Pressure on Subassembly acting on one direction (-Y)	 *Figure 18: Deformation, Pressure Acting (-Y) on One Side of Subassembly*
 *Figure 19: Strain, Pressure Acting (-Y) on One Side of Subassembly*	 *Figure 20: Stress, Pressure Acting (-Y) on One Side of Subassembly*
 *Figure 21: Deformation of pins, Pressure Acting (-Y) on One Side of Subassembly*	 *Figure 22: Factor of Safety, Pressure Acting (-Y) on One Side of Subassembly*

Figures 23-27 indicate results of forces in opposite directions. If there were uneven surfaces when riding, one spring would be in tension and the other spring would be in compression. The central support bar now appears “rippled.” Pressure at 30 psi is still used for both surfaces of both brackets.

Pressure on Subassembly acting on both sides in opposite directions of subassembly (+Y, -Y)

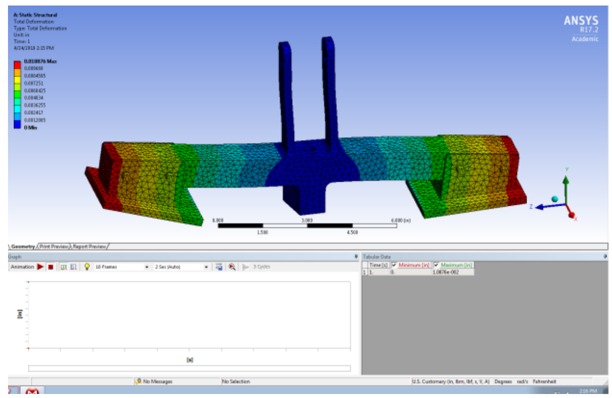


Figure 23: Deformation, Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

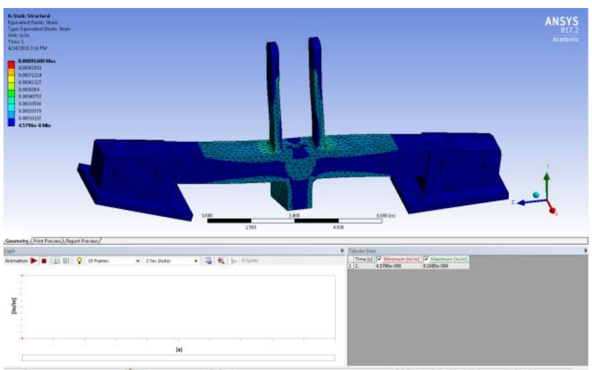


Figure 24: Strain,Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

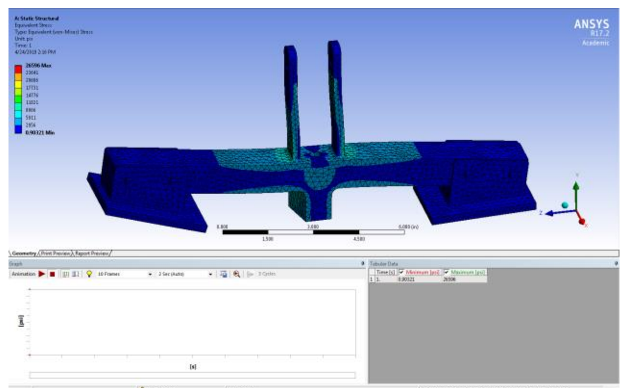


Figure 25: Stress, Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

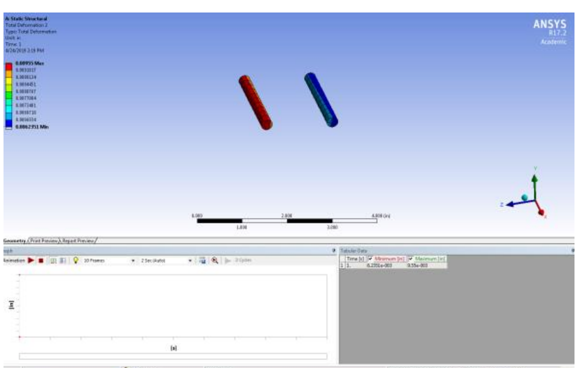


Figure 26: Deformation, Pressure Acting on One Side of Subassembly, Pins Isolated

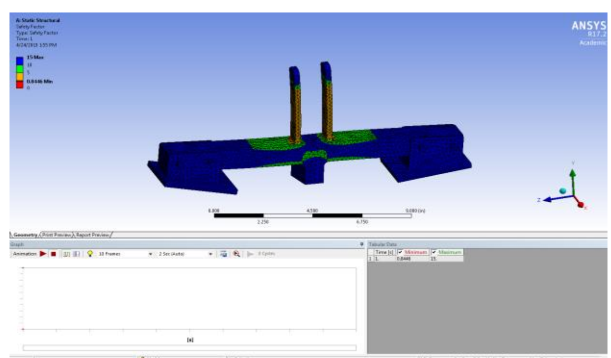


Figure 27: Factor of Safety, Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

Crossbar Redesign

After careful considerations, the design was changed further. The prongs were changed to be more structurally sound by creating angles of the arms instead of straight down.

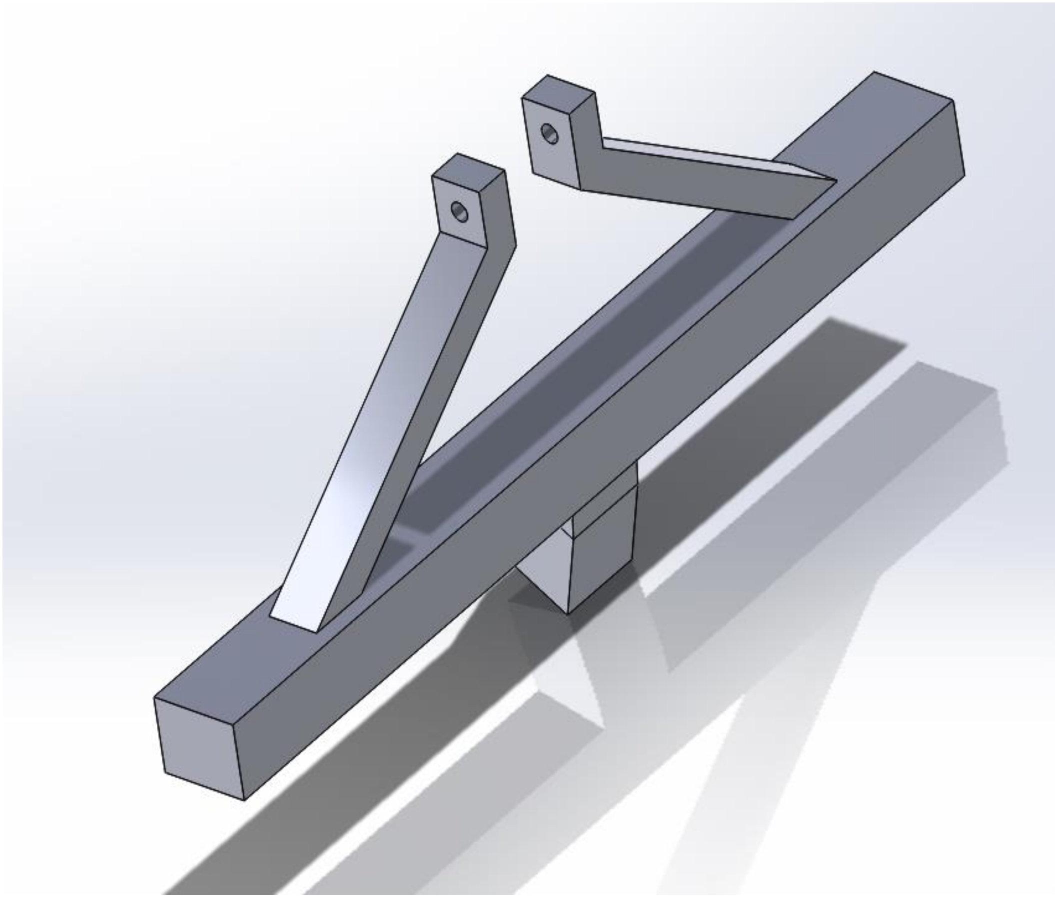
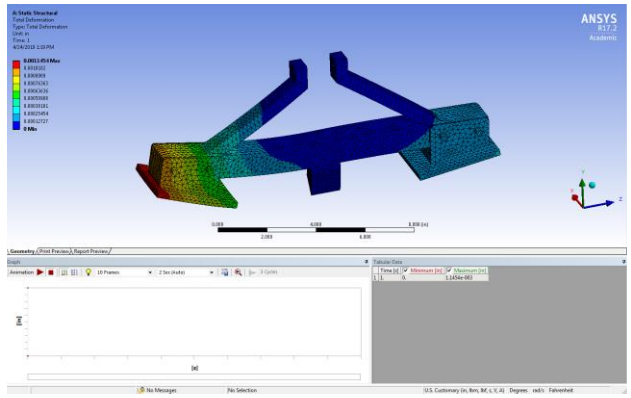
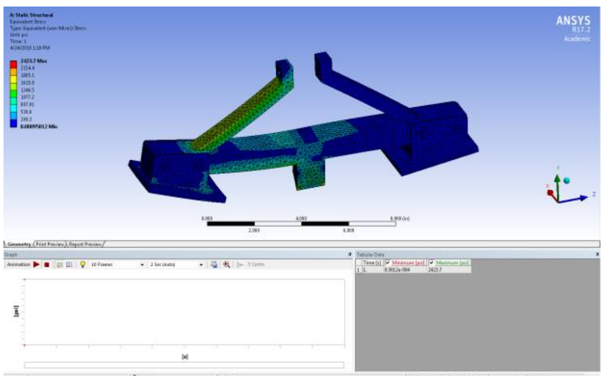
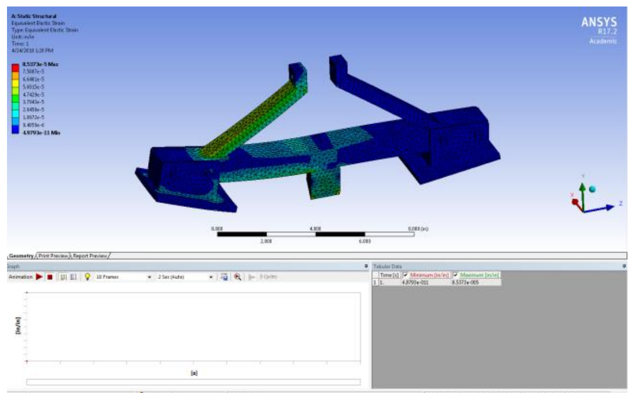
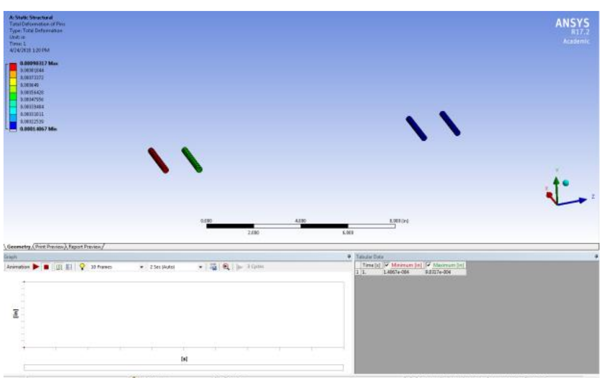
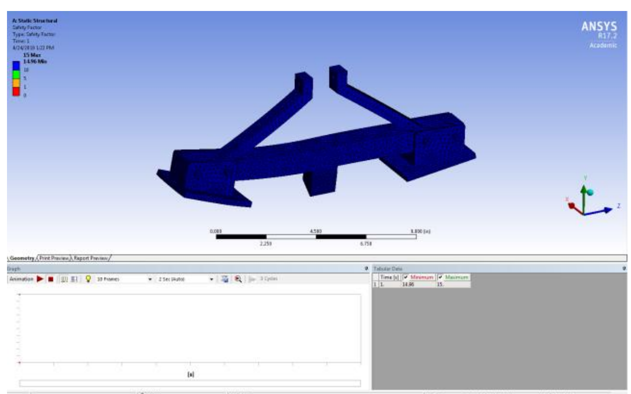


Figure 28: 3D Model of the Redesigned Central Support

Another small design change was the addition of an angled notch found underneath the crossbar. This design change was made as a result of 3D printing the original crossbar, not the FEM analysis. Our team needed to add the extra material to level the part and provide a more ergonomic fit on the bicycle.

Pressure on Subassembly acting on one side in (+Y) direction	 *Figure 29: Deformation, Pressure Acting on One Side of Subassembly (+Y)*
 *Figure 30: Stress, Pressure Acting on One Side of Subassembly (+Y)*	 *Figure 31: Strain, Pressure Acting on One Side of Subassembly (+Y)*
 *Figure 32: Deformation, Pressure Acting on One Side of Subassembly, Pins Isolated*	 *Figure 33: Factor of Safety, Pressure Acting on One Side of Subassembly (+Y)*

Pressure on Subassembly acting on both sides in opposite directions (+Y, -Y)

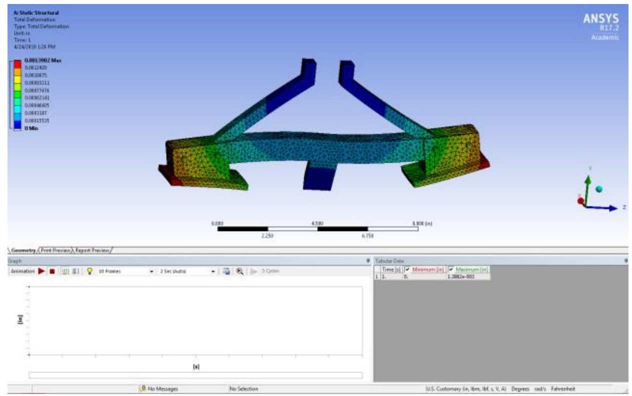


Figure 34: Deformation, Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

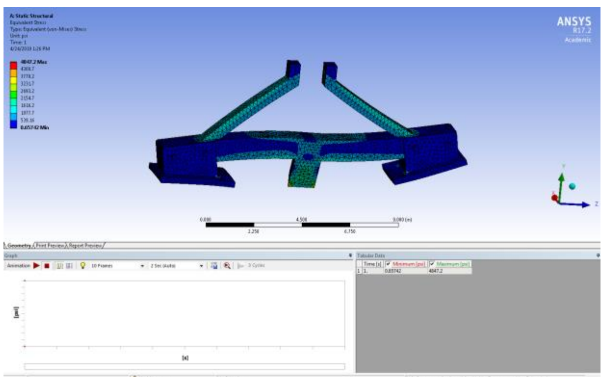


Figure 35 Stress, Pressure Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

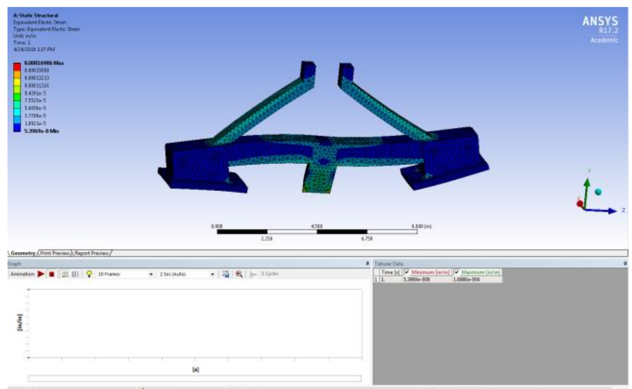


Figure 36: Strain, Pressure Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

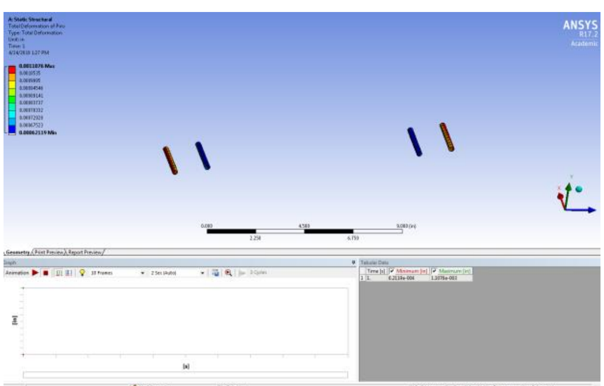


Figure 37: Deformation, Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

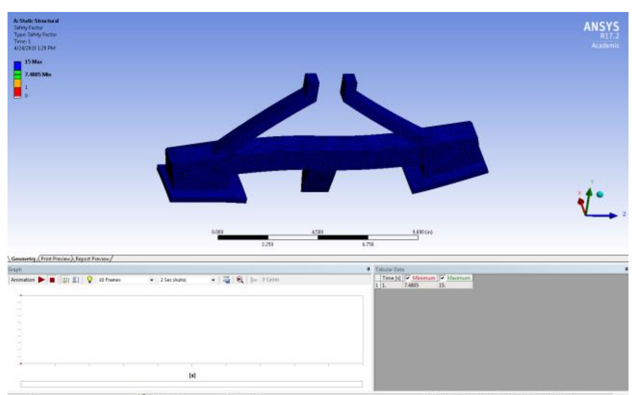


Figure 38: Factor of Safety, Pressure Acting on Both Sides in Opposite Directions of Subassembly (+Y, -Y)

Another case to consider is the loss or failure of the bottom pin. In that case, the two points of contact are the prongs to the frame of the bicycle. *Figure 39* shows the results from analyzing this situation.

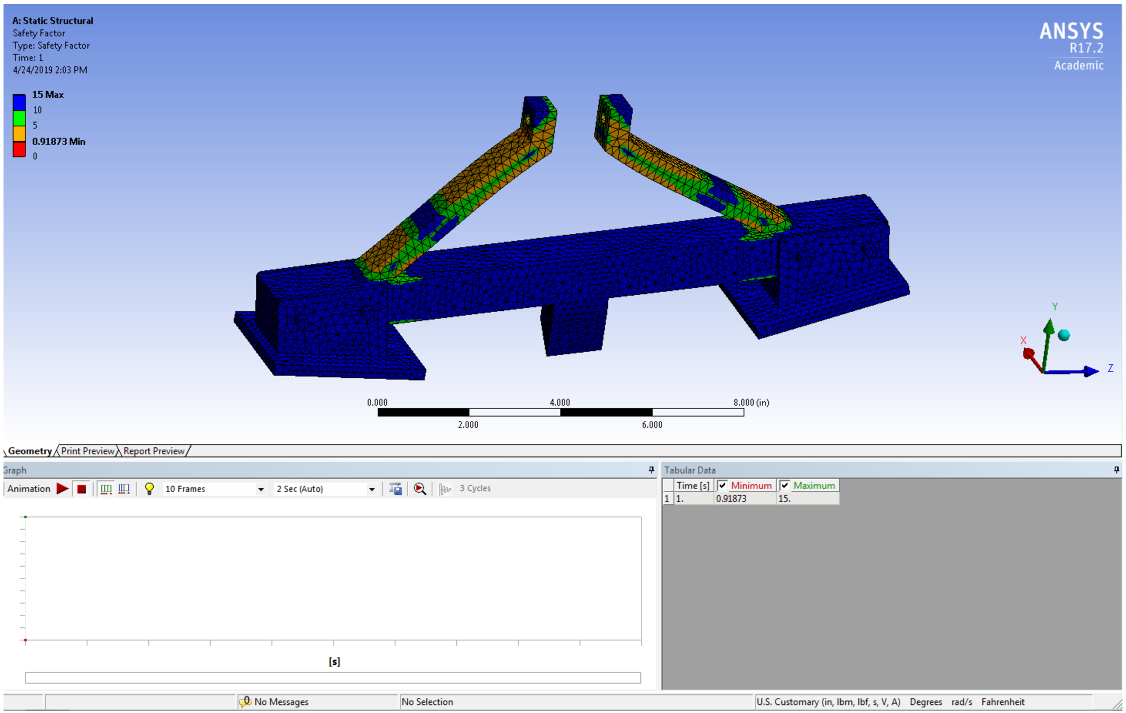


Figure 39: The Analysis if the Bottom Surface Was Not Secured (Factor of Safety)

The second subassembly is meant to analyze modal analysis and harmonic response of the springs. A total of 14 modes were analyzed. For the harmonic response, forces of 300 lbf were applied to the connection between the wheels and tubing. The second subassembly is in Figure 18 below. The forces applied are in the positive and negative directions. Detailed results are in the FEM Analysis section of the appendix (*Figures 50-55*).

To design a balance assist system that would both support the rider and operate in tandem with the bicycle safely, the central cross bar was required for both strength and safety. The implementation of finite element analysis helped us analyze and redesign this particular part for the best possible result. In addition to this analysis, our team was also able to 3D print prototypes of our parts which are pictured, the first iteration, shown in *Figure 40* and most recent in *Figure 41*. A printed model was most beneficial for fitting the part onto the bicycle itself and validating all the measurements. However, 3D printing the entire bicycle was not a practical solution and finite element analysis gave us valuable information on the bicycle's performance.

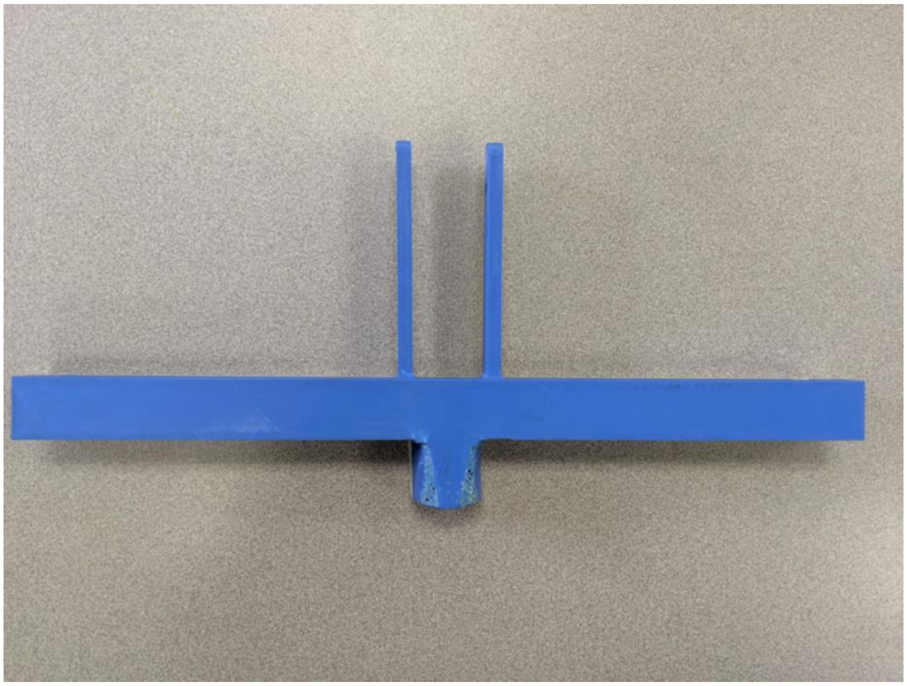


Figure 40: 3D Printed Model of Subassembly of Initial Design

One of the features of the crossbar that we determined could not be changed were the three points of contact to the frame of the bicycle. The two through holes at the top of the part and the block at the bottom must remain the same. These three points of contact prevent the system from experiencing immense torsion during riding. Another feature that remained the same was the length of the crossbar. Each side extends 7.5” from the center of the part, and therefore, the bicycle. This is so the telescoping arms that attach to the crossbar can support the rider as he rides. The initial results showed that there was considerable stress and deformation in the central part of the crossbar. Since all of the fixed supports were in the center portion of the crossbar, and the forces were being exerted on the outside of the arms, the moment created on the part produced an undesirable amount of stress.

In order to compensate for this, our team made some changes to the design of crossbar. The new 3D printed design can be seen in *Figure 41* where the major design change was choosing to have the support arms hold the frame of the bicycle at a 45° angle from each side. This turns the total crossbar into a triangle shaped frame like a truss. Now that there is more support reaching out farther on the crossbar, there should be less stress and deformation experienced when forces are applied on the ends.

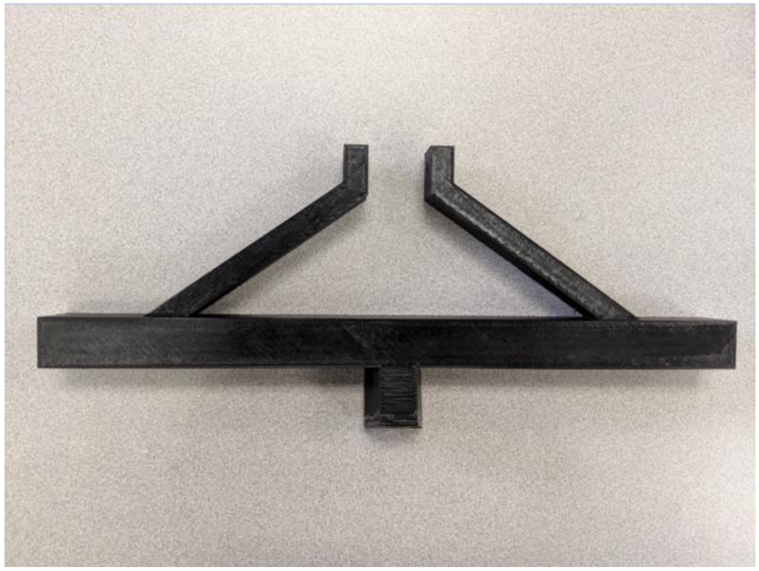


Figure 41: 3D Printed Model of Subassembly of Updated Design

The conclusions gathered from finite element analysis suggest the design has the required safety factor and very little deformation. The results granted confidence in the design and the prototyping and manufacturing phase was able to begin.

After deciding the final design of the central crossbar, the modal analysis and frequency response features in ANSYS were used to understand the natural frequencies of the subassemblies and the mode shapes of the spring. The results of the modal analysis are in the ANSYS Testing section of the appendix (*Figures 56-69*) and the frequency response is in the ANSYS Graph section of the appendix. One of the modes demonstrates the deformation that may occur when the bicycle is in motion (see *Figure 42*).

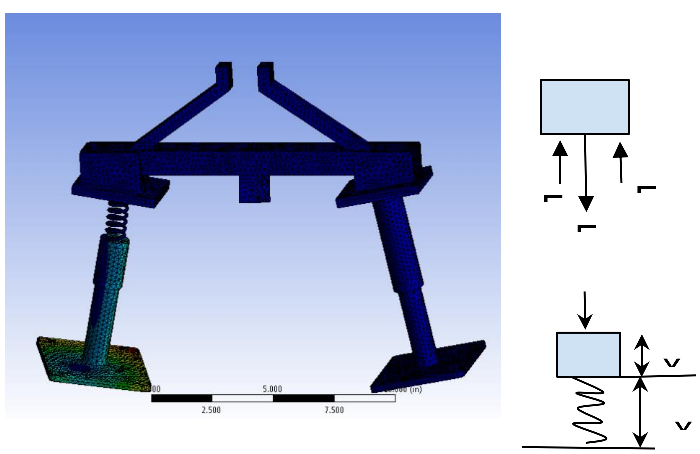


Figure 42: Modal Analysis, First Vibration Mode of full assembly

Prototyping/Manufacturing

Much of the early concepting for this project was aided by the university's 3D printing capabilities. Prior to manufacturing a metal central frame support prototype, we printed and verified three different re-designs on the physical bicycle rather than the model. Adding these physical models to the frame and inspecting their impact allowed for more accurate changes. As seen in *Figure 43,* the first iteration had the support bars positioned vertically as to not interact with the chain as the bicycle is ridden. Having an angle was not deemed necessary at the time of the first design.. The second design in *Figure 44* included an overall angle (to match the angle of the bicycle frame) to the forks, as well as new angled support forks to create more contact for the support and provide increased strength. This design allowed for the forces to be transferred through the support directly to the points of contact. For the final design, the entire piece was then set on an angle from the bottom connector to allow for straight connections off the sides to the wheel-spring assemblies. This can be seen on the base of the black model in *Figure 45*. The 3D printing capabilities were also used to create one of the outside connection brackets shown in *Figure 46*. As predicted, the pieces fit together, with a tight tolerance, since everything was printed to the most accurate dimensions according to the model.

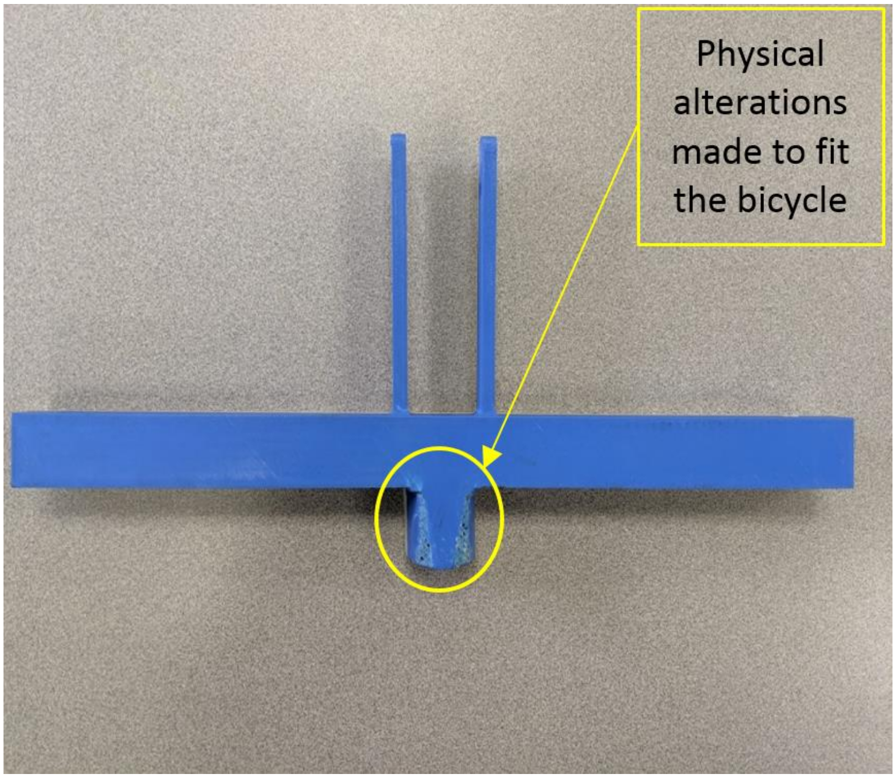


Figure 43: Design One of the Central Support Connection

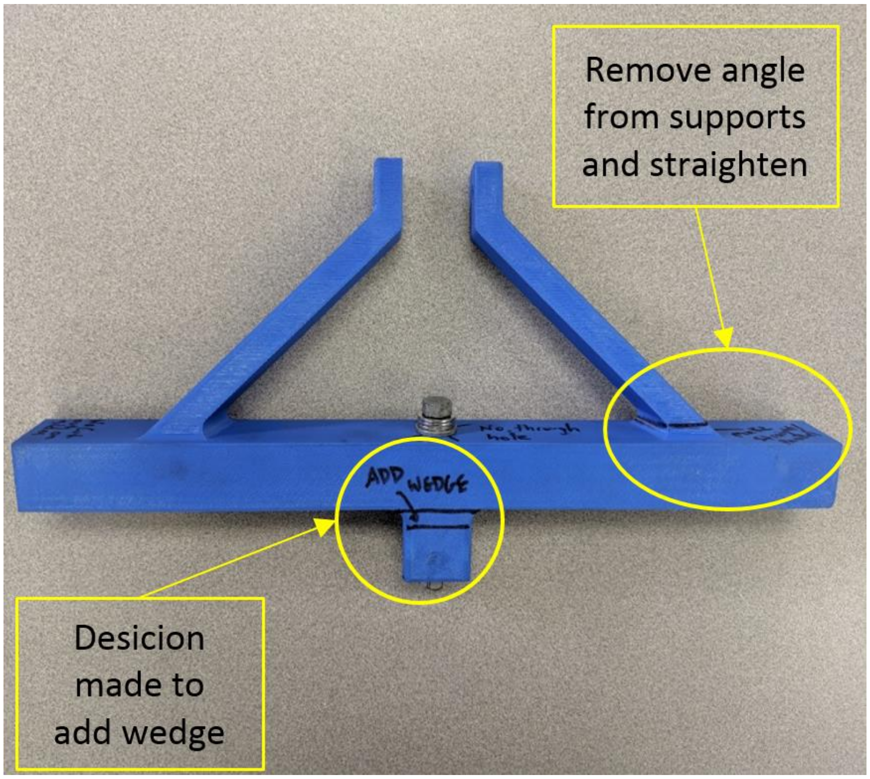


Figure 44: Design Two of the Central Support Connection with Angled Support Arms

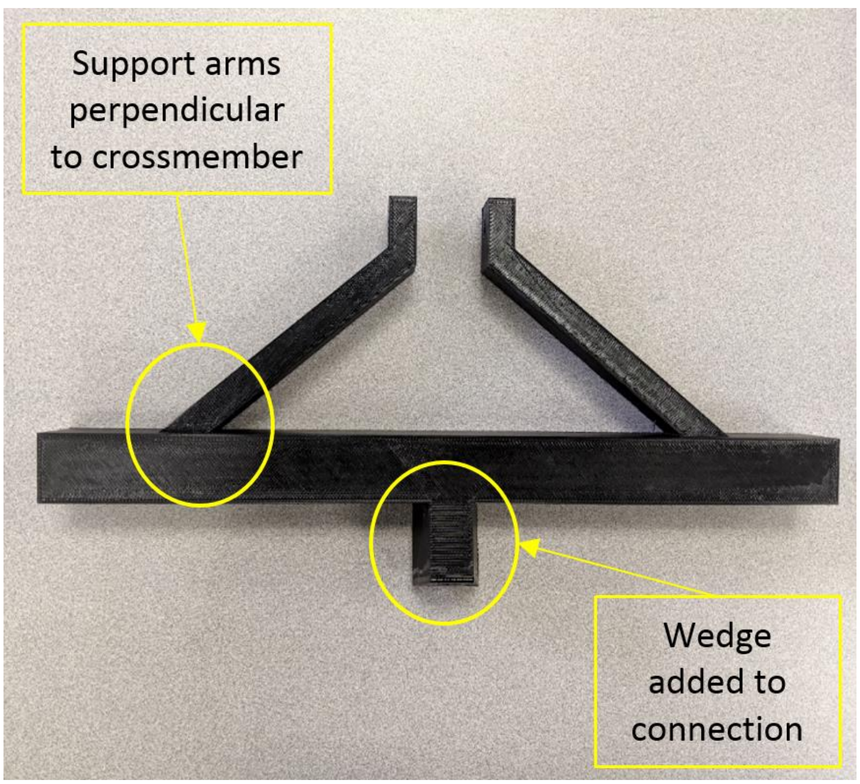


Figure 45: Design Three of the Central Support Connection with Straight Support Arms and Wedge

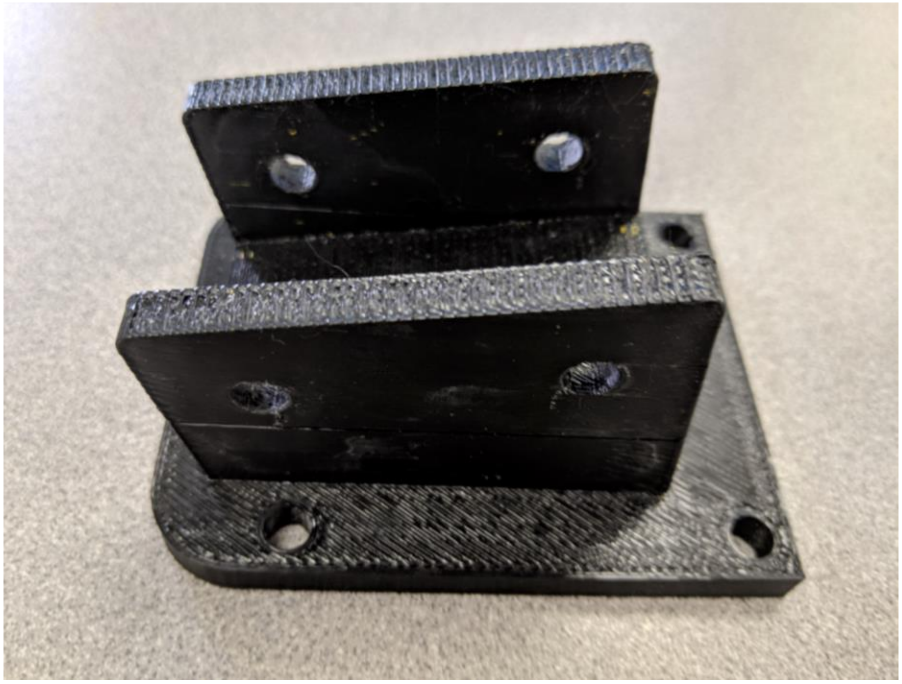


Figure 46: Outside Connection Piece Initial Design

Improving the design simplicity allowed for an efficient build of the central support component. Using the 3D-printed models and their respective drawings (see appendix *Drawings 1-9*), the central support piece was able to be built in one day. The manufacturing process took place as follows:

1) The central crossmember bar was cut to length
    a) 14 inches long (we had 6 inches of material left over)
    b) 4 through holes were drilled to print using a drill press (*Figure 47*)
2) The top two connection bricks were cut to length
    a) A through hole was drilled to print in each with the drill press
    b) The edges were chamfered using a grinding wheel so the weld would have space to fill with material
3) Using the 6 inches of material leftover from the central crossmember bar, a mock "bicycle frame" was made
    a) A through hole was drilled to replicate the necessary height of connection on the real bicycle frame
4) Each support arm was cut to print using a band saw
    a) The edges were chamfered using a grinding wheel so the weld would have space to fill with material
5) The mock "bicycle frame" was spot welded to the central crossmember bar to give reference to the location of the top connection bricks
    a) Both top bricks were "bolted" into the "bicycle frame" in order to give the location of the components

   b) The support arms were added to the assembly and spot welded into place
   c) The bolt was removed and the "bicycle frame" was knocked out
6) Both sides were completely welded into place
7) The bottom connection piece was cut from the stock piece
   a) Each side was angle cut to match the print
   b) The bottom was drilled with the drill press
   c) Once the hole was drilled, it was hand-tapped so the stud could be incorporated as seen in *Figure 48*
8) With the leftover side pieces from the previous step, the wedge piece was created
   a) The two pieces were temporarily welded together and checked to the print
   b) They were then welded to the bottom connection piece
9) That assembly was then placed and fully welded to the bottom of the central crossmember bar
10) Each welded area was ground down and the entire assembly was sandblasted and prepared for painting
11) The final prototype assembly was primed and painted to match the bicycle as close as possible

This prototype, as seen in *Figure 49* and *50* was made from standard AISI 1020 Low Carbon/Low Tensile Steel purchased from Standard Welding and Steel Products in Medina, Ohio. Each weld was done using a small MIG (Metal Inert Gas) welder from Lincoln Electric. It was productive to manufacture the central support to understand the process that would eventually have to be done for the final product. One of the drawbacks of this completed prototype was the weight as it came in at a little over six pounds. This was one of the concerns we had when we first purchased the material and we immediately thought that perhaps we could use a lighter material such as aluminum.

Figure 47: Drilling One of the Four Holes in the Central Crossmember

Figure 48: Tapping of the Kickstand Connection Piece

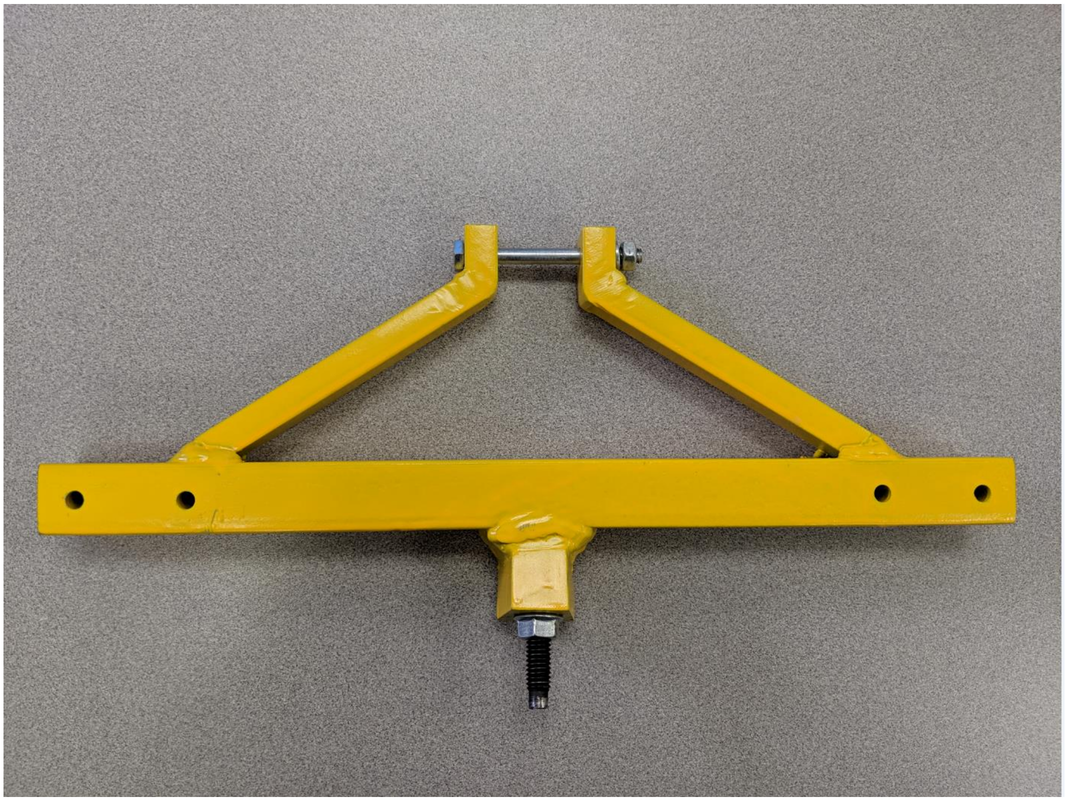


Figure 49: Manufactured Prototype Based Off of Third 3D-Printed Design

Figure 50: Manufactured Prototype Placed on the Bicycle for Dimension Check

Discussion/Design Changes

Much of the progress on this project was made possible with on-campus resources at Akron. For example, our Concepts of Design course taken in the fall illustrated the importance of the design process which included the Function Diagram, Objective Tree, Morphological Chart and Decision Matrix. The university also provided the SolidWorks and ANSYS programs in the mechanical engineering laboratories in Auburn Science and Engineering Center. Through the Engineering Service Design Team, we had the opportunity to have a design review day with engineers from Mook Inc who provided us with valuable feedback for our design.

Outside of the university, Standard Welding and Steel Products was also helpful in providing us with affordable material for our first steel prototype. Will-Burt has been helpful thus far in discussing possible design changes as well as assistance in future manufacturing. Once our final assembly in SolidWorks was completed, we had the opportunity for a review by the engineers from the Will-Burt Company. These manufacturers of mobile telescoping tower solutions and pan and tilt positioners also do rapid prototyping which would prove useful. Their engineers sent us a

redesign that combines our crossbar and our connector pieces. From the initial images they sent us, it appears as though they have gone with more sheet metal to reduce weight rather than using solid steel components. The new model can be seen in *Figures 50* and *51* as well as an assembly view in *Figure 53*.

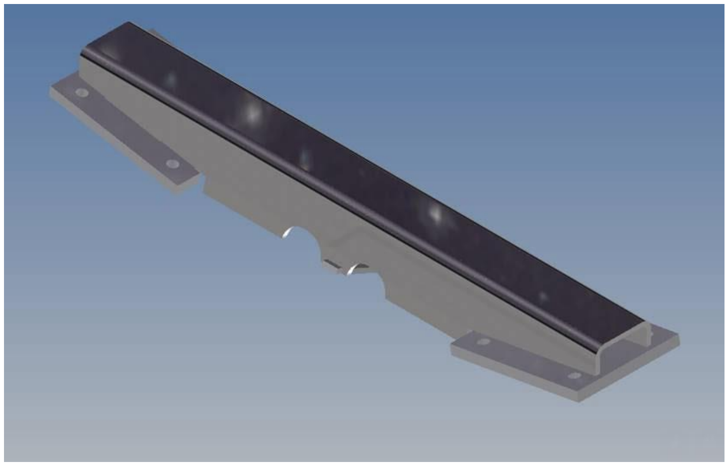


Figure 51: Isometric Top View of Will-Burt's Central Support Redesign

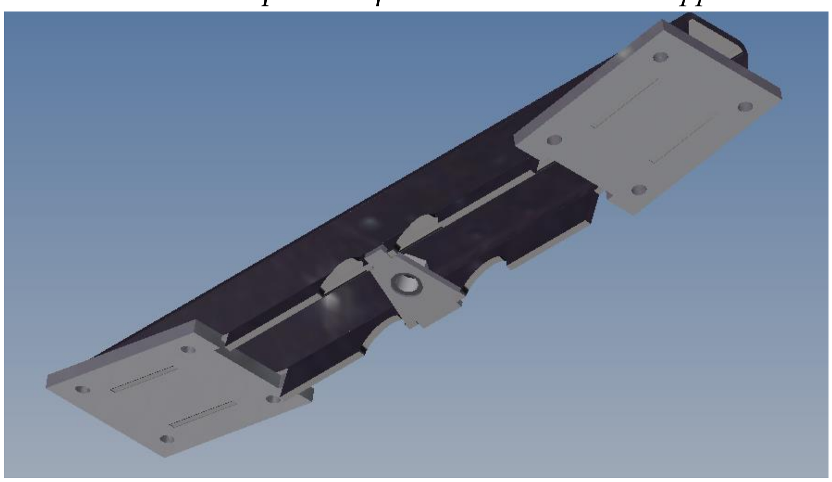


Figure 52: Isometric Bottom View of Will-Burt's Central Support Redesign

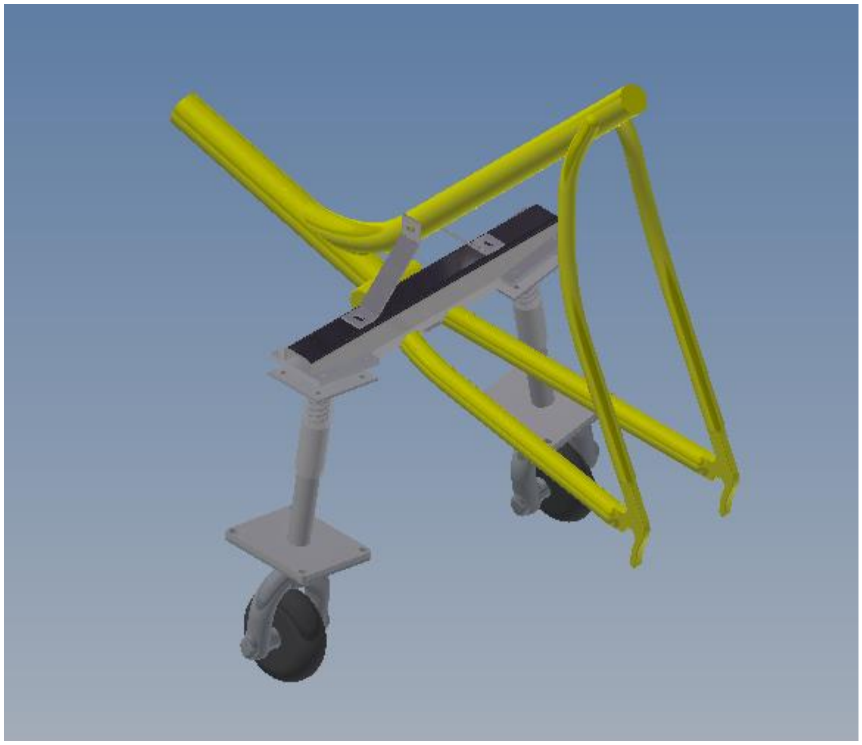


Figure 53: Isometric Assembly View of Will-Burt's Redesign

Along with the design changes from Will-Burt, we also decided to make a change to the way in which the top of the central support contacted the frame of the bicycle. The primary reason for this change was that we did not want to make any alterations to the bicycle itself as they are quite expensive. Drilling a hole through the frame is a one time procedure and if a mistake was made then the entire project would be in jeopardy. Another consideration taken into account was the possibility of taking this design (or the eventual final design) to the manufacturer of these bicycles as a potential sellable addition for customers with similar conditions who still have a passion for riding.

As seen in *Figure 54*, we decided to explore the possibilities of a clamshell style connection to the top of the central support. This idea should offer similar stability as well as strength without puncturing the frame of the bicycle. The current possibility (shown in light grey) is comprised of three pieces, left, right and top. Each of the pieces has tabs to connect to the other ones and the left and right pieces would have a part that would connect to the support arms as well. These also had to be redesigned in order to accomodate this design change. We believe the combination of Will-Burt's alterations and this clam shell idea will not only save costs on material and manufacturing, but also preserve the originality of the bicycle itself. Each design change adds more individual components and complexity, but should offer the most efficient and effective means to create the central support system as it is integral to the system working as a whole.

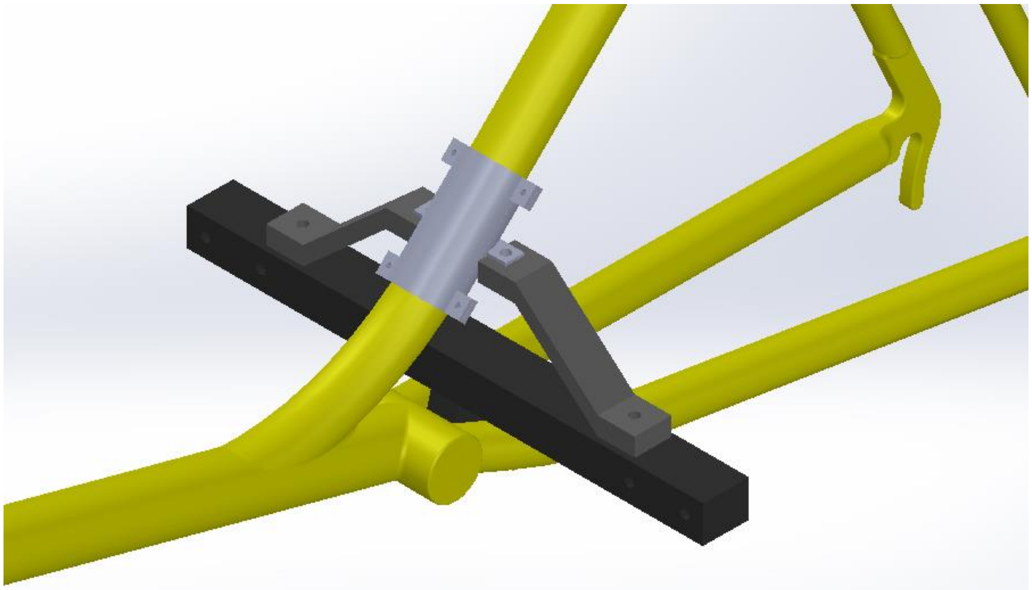


Figure 54: Isometric Assembly View of Clamshell Top Connection Concept

Future tasks that we can pursue would include testing the various iterations of our design. Before our team delivers a completed project, we must ensure that the balancing aid is safe and operates properly. Another aspect of the design that should be looked at are the compressible arm. Instead of manufacturing our own design, we would consider implementing shocks or absorbers that we would purchase and redesign our connection points so they could incorporate them. It is important that our team considers all options to ensure that the final design is the most optimal and safe. This emphasizes that safety is the most important input in our design and we want to deliver a product that can safely assist the rider get back to riding the recumbent bicycle.

Appendices

ANSYS Testing

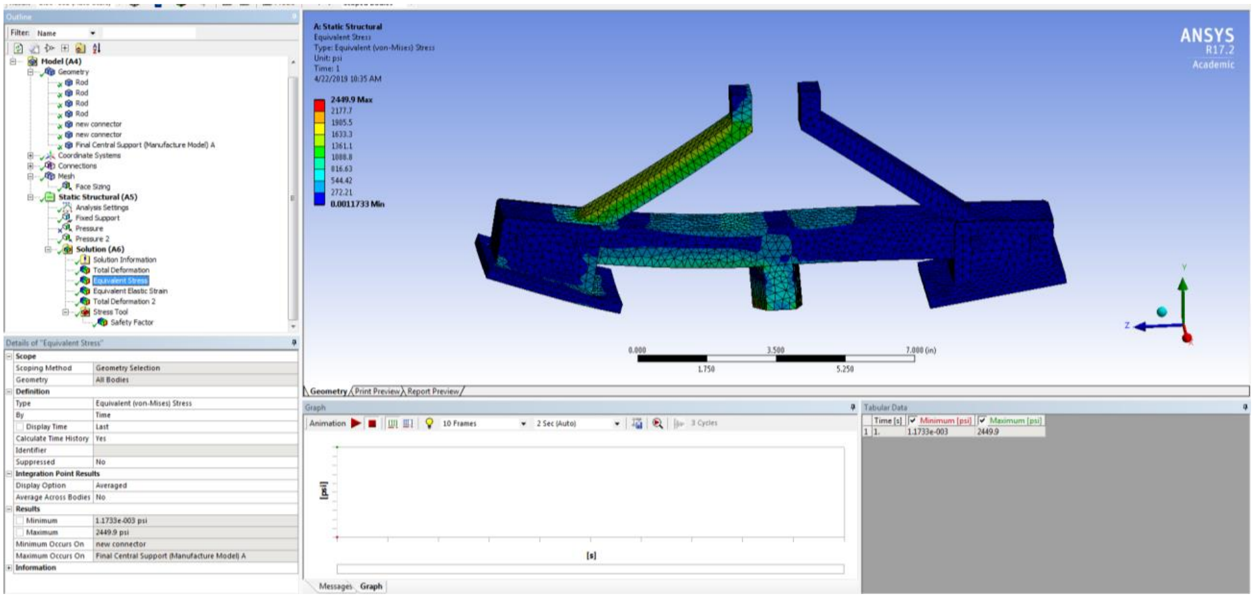


Figure 55: von Mises Stress

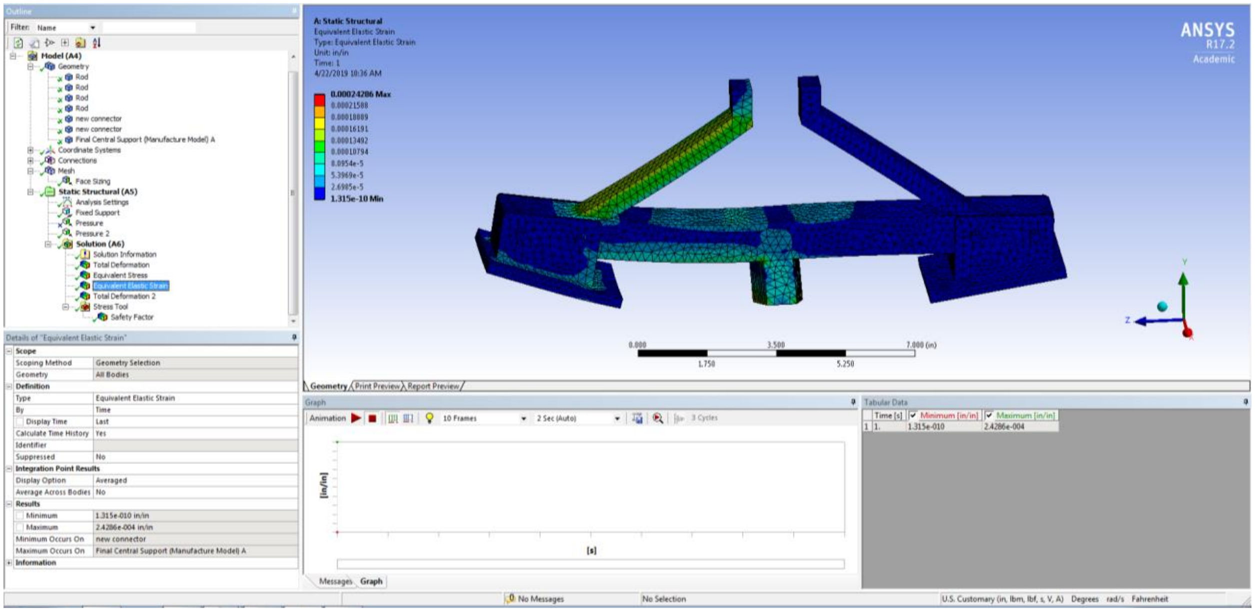


Figure 56: Equivalent Elastic Strain

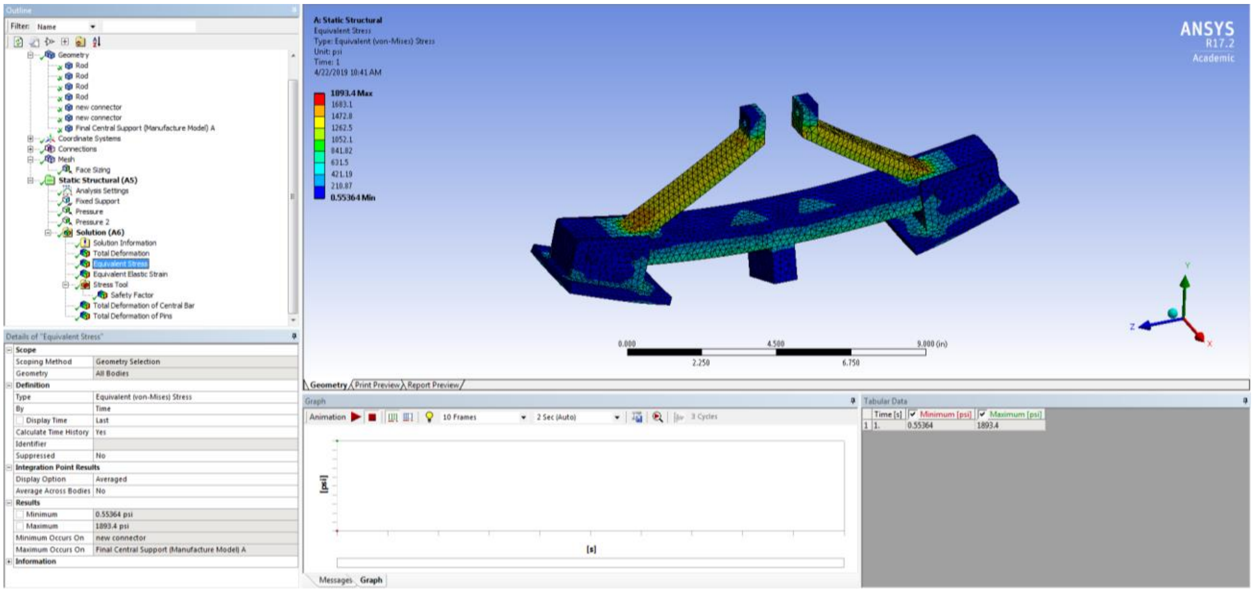


Figure 57:von-Mises Stress

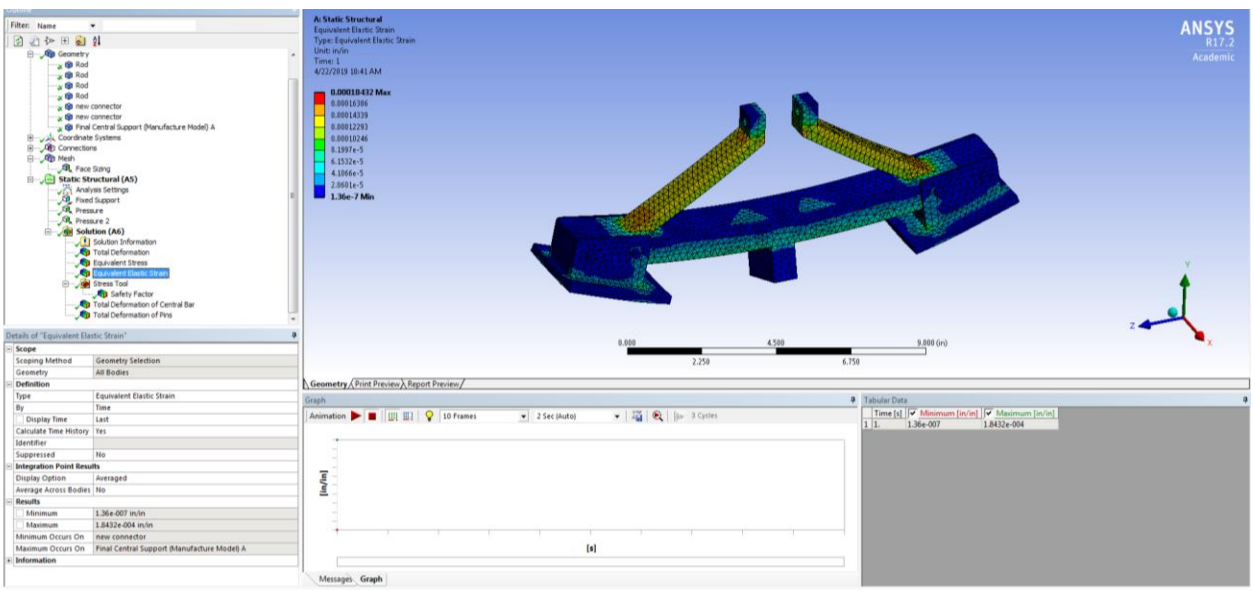


Figure 58: Equivalent Elastic Strain

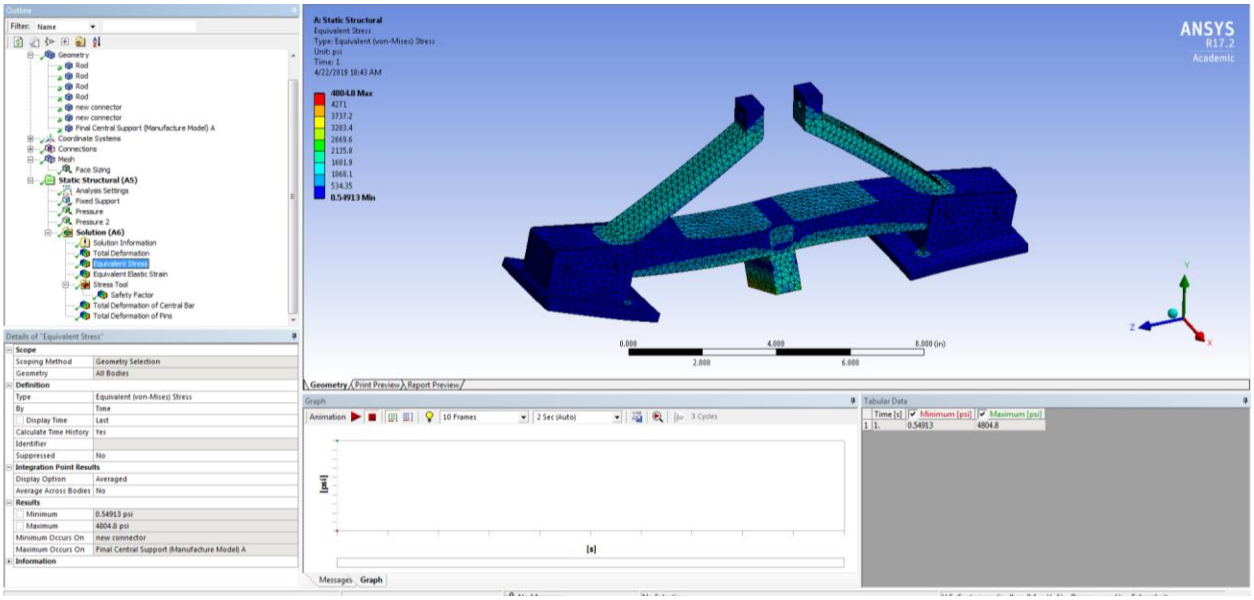


Figure 59: von-Mises Stress

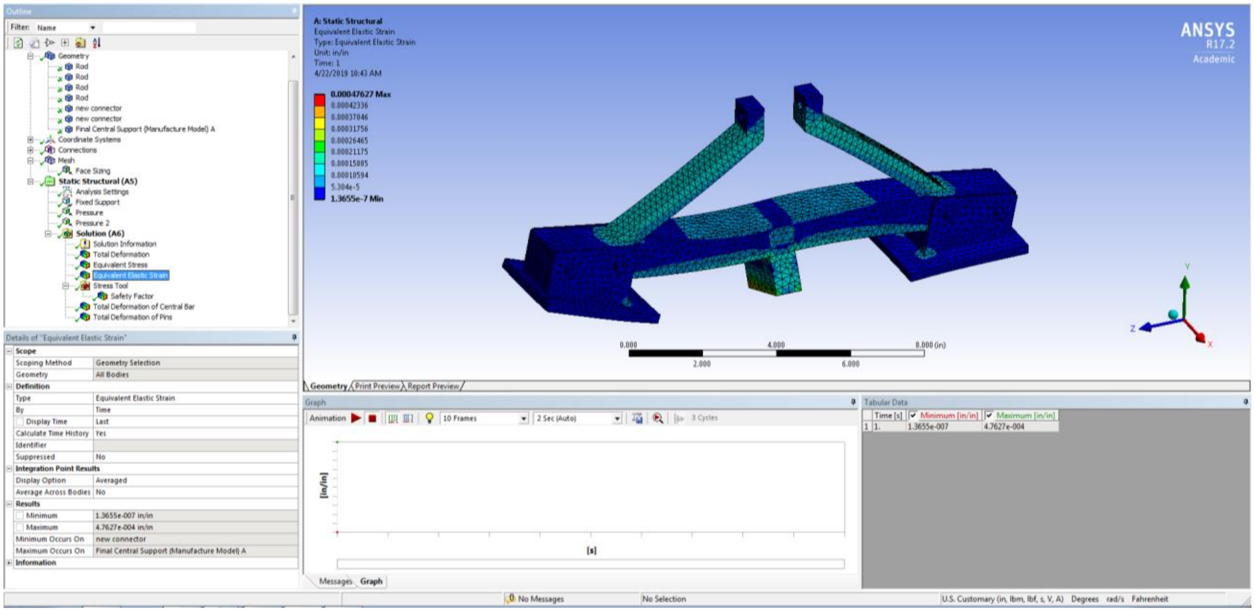


Figure 60: Equivalent Elastic Strain

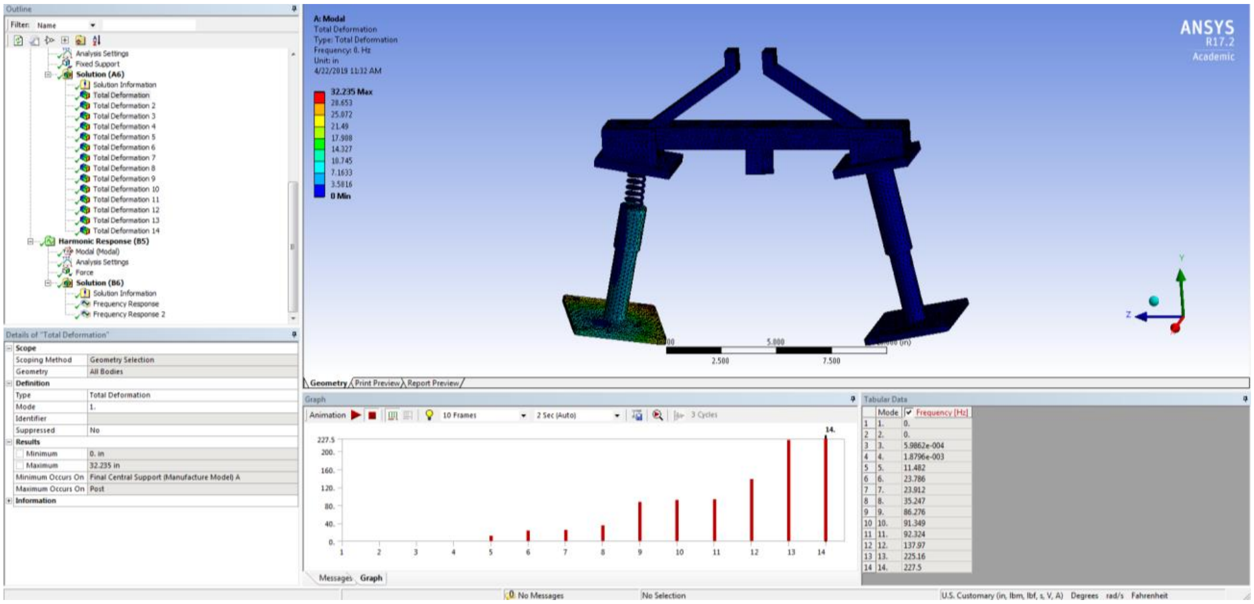


Figure 61: Mode 1 of Modal Analysis

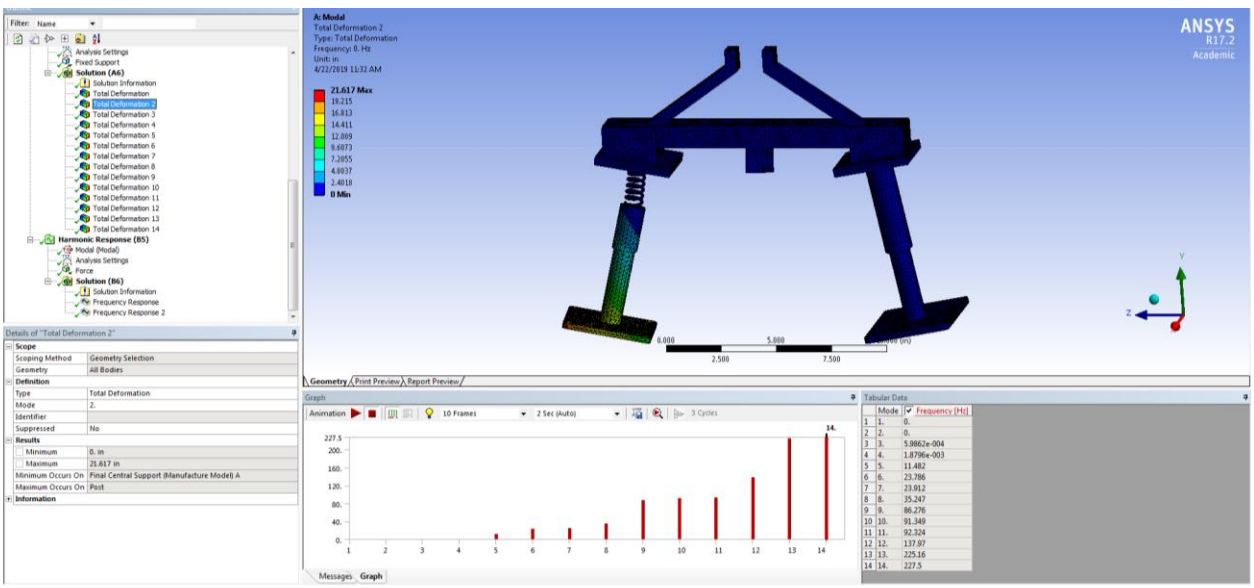


Figure 62: Mode 2 of Modal Analysis

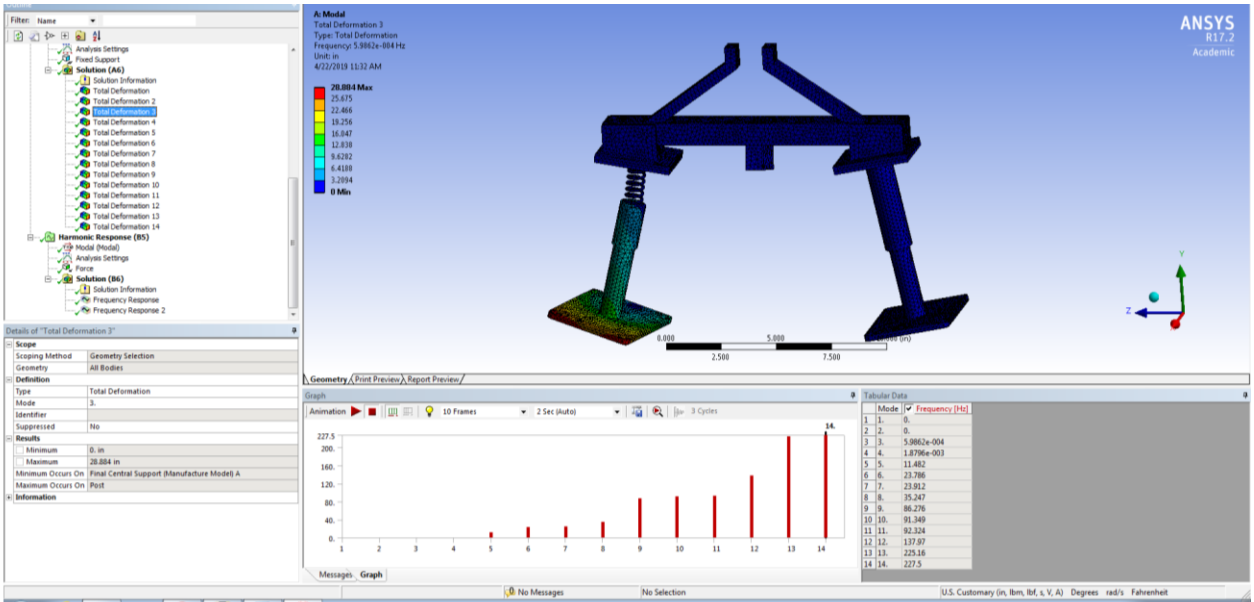


Figure 63: Mode 3 of Modal Analysis

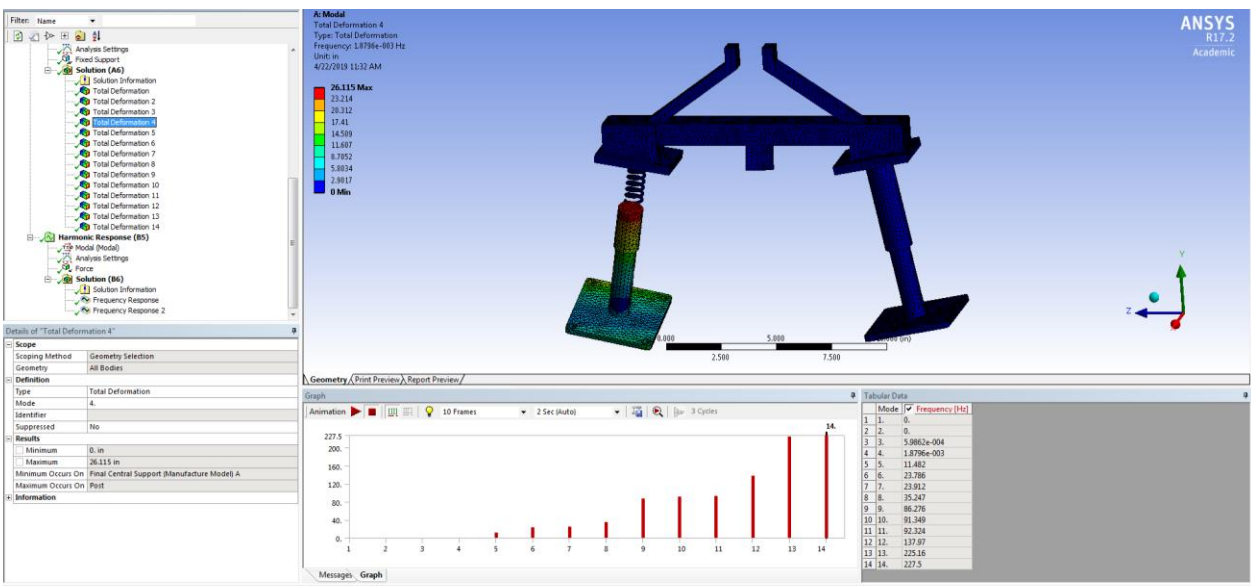


Figure 64: Mode 4 of Modal Analysis

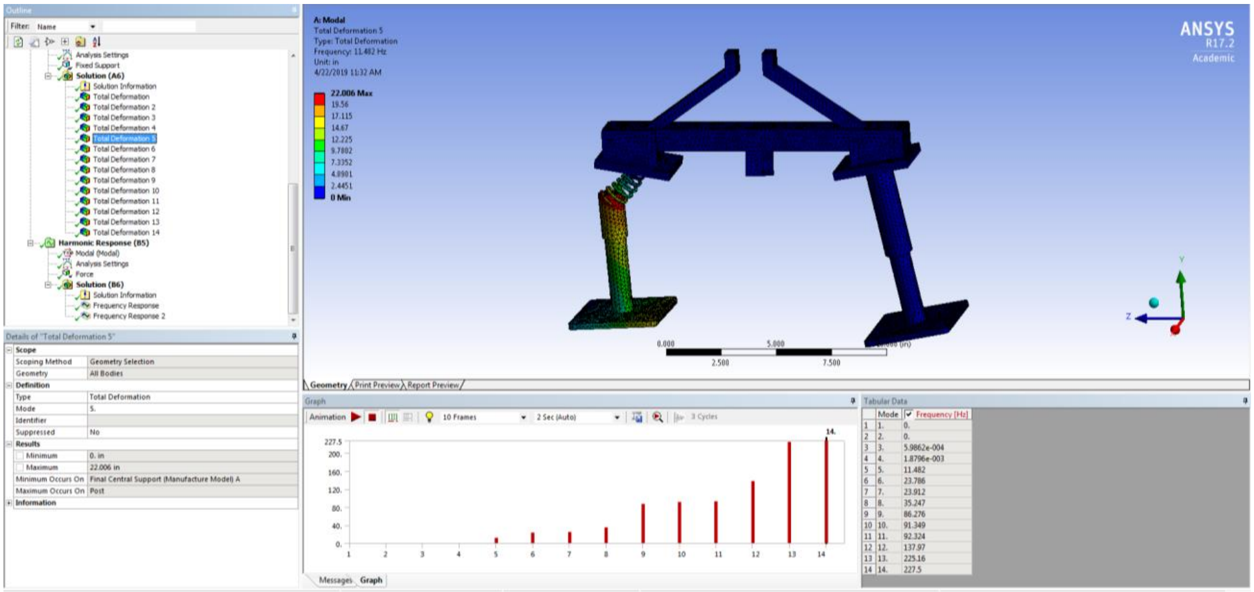


Figure 65: Mode 5 of Modal Analysis

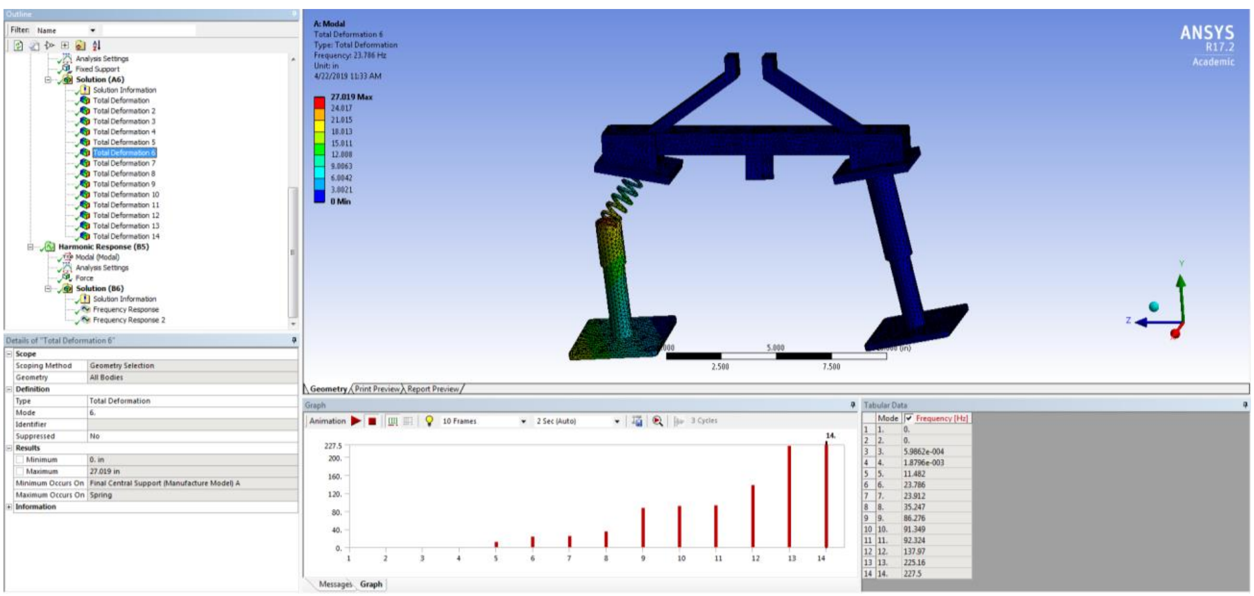


Figure 66: Mode 6 of Modal Analysis

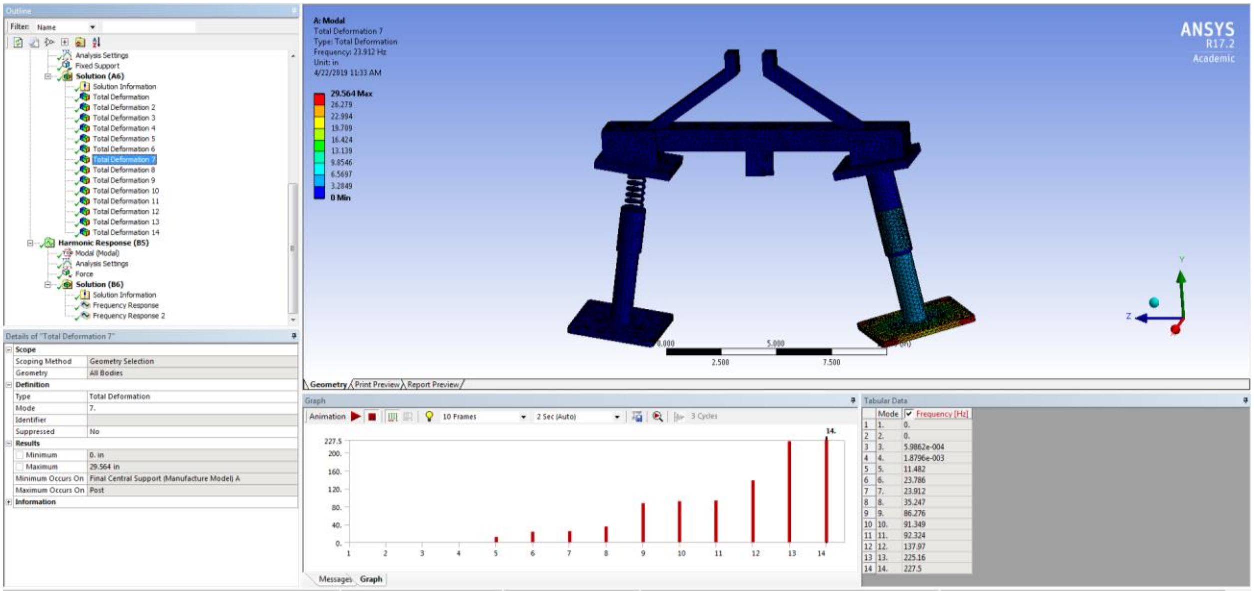


Figure 67: Mode 7 of Modal Analysis

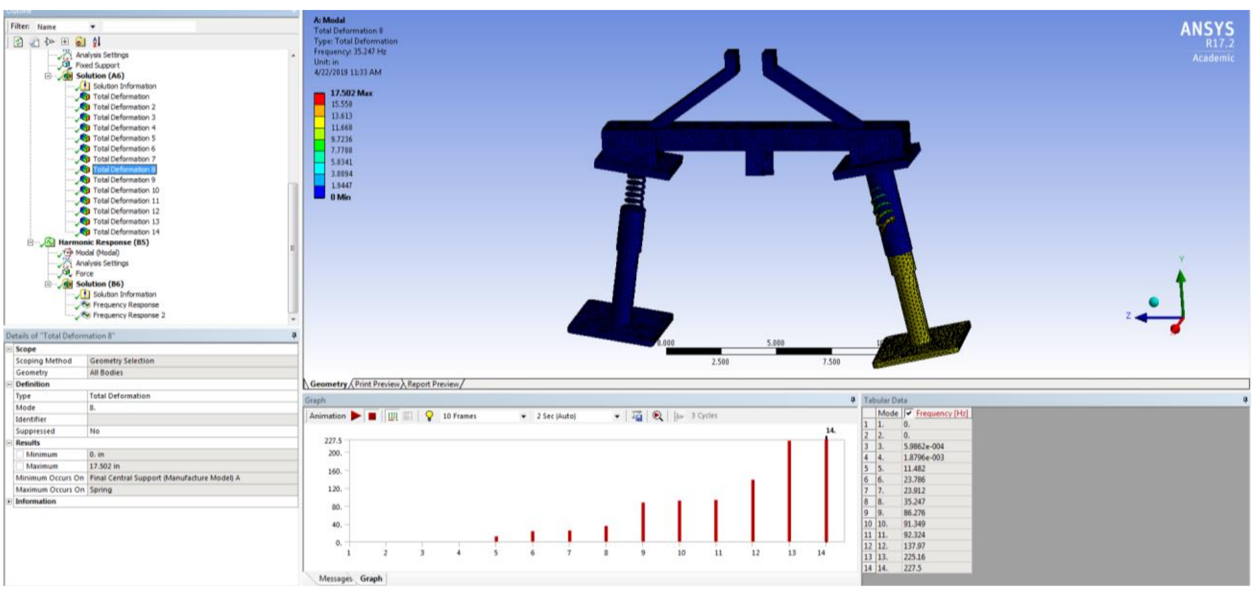


Figure 68: Mode 8 of Modal Analysis

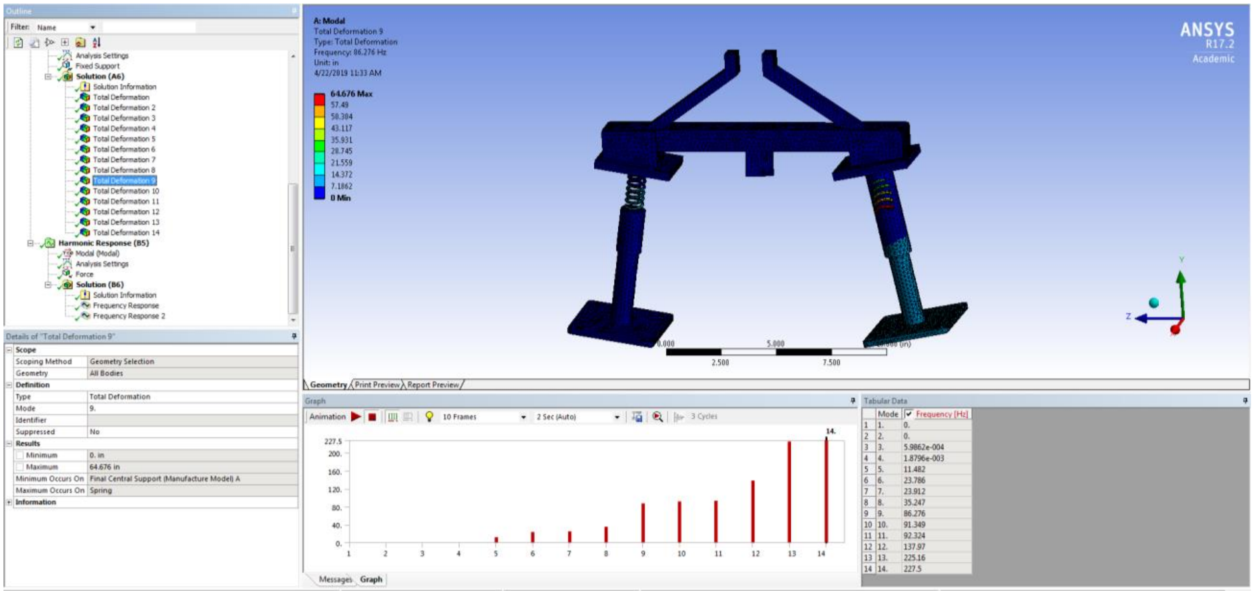


Figure 69: Mode 9 of Modal Analysis

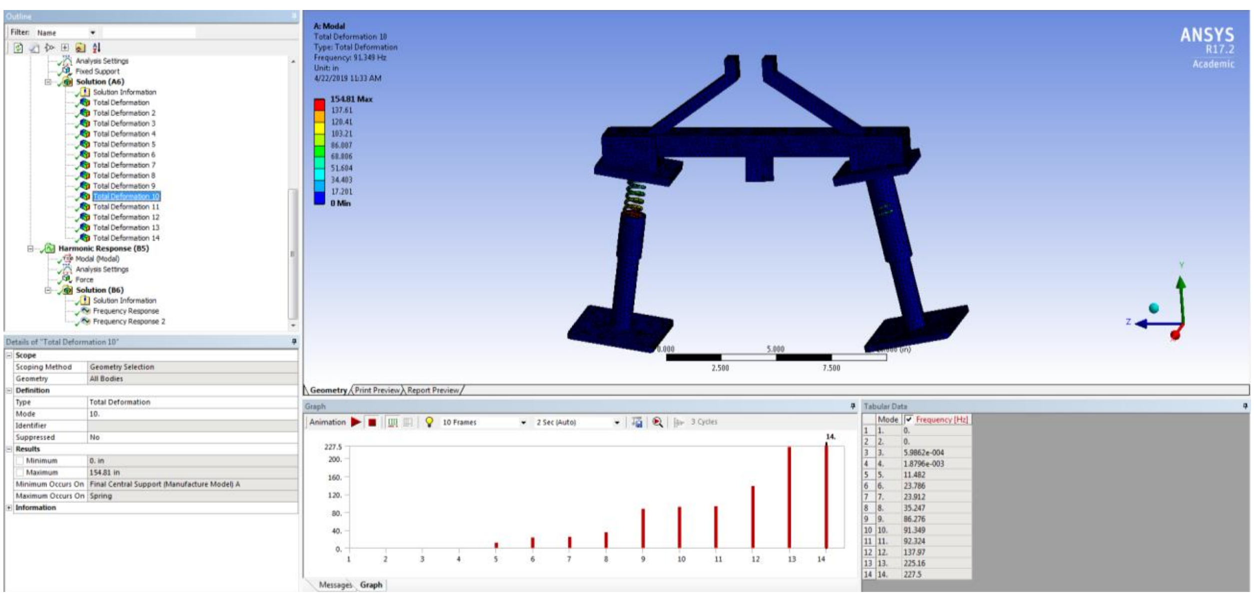


Figure 70: Mode 10 of Modal Analysis

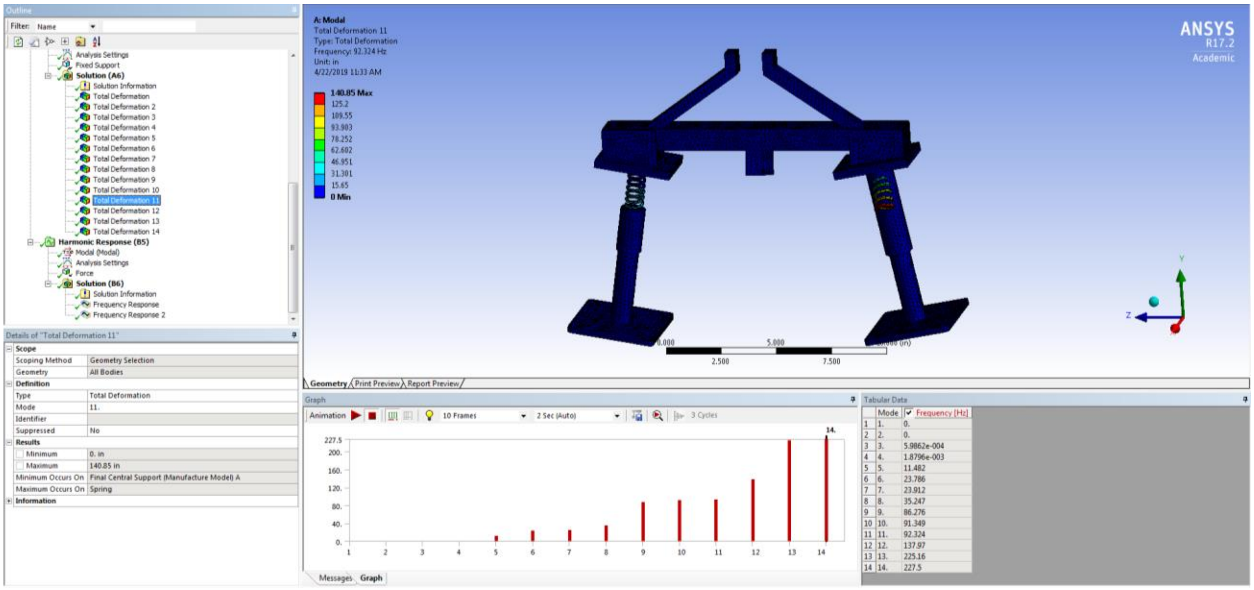


Figure 71: Mode 11 of Modal Analysis

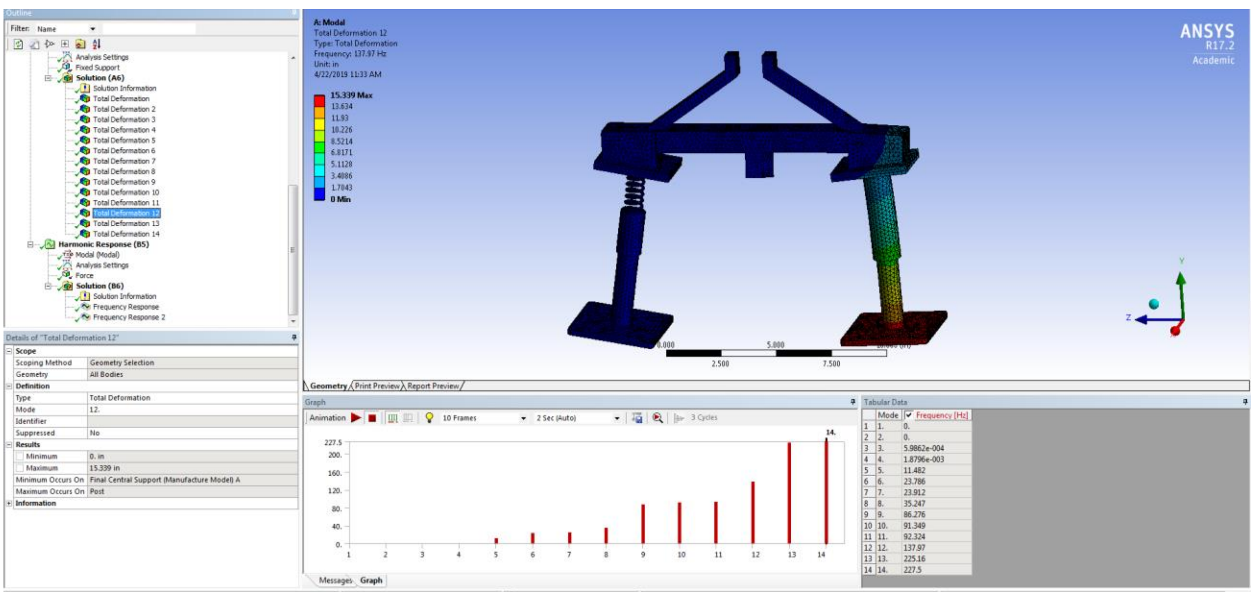


Figure 72: Mode 12 of Modal Analysis

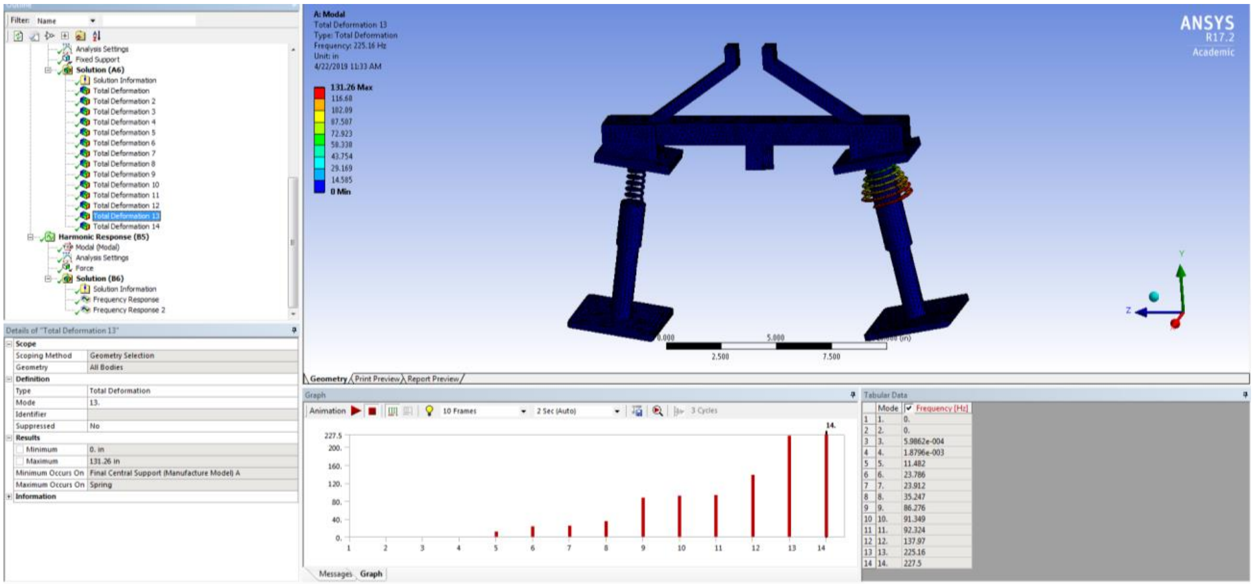


Figure 73: Mode 13 of Modal Analysis

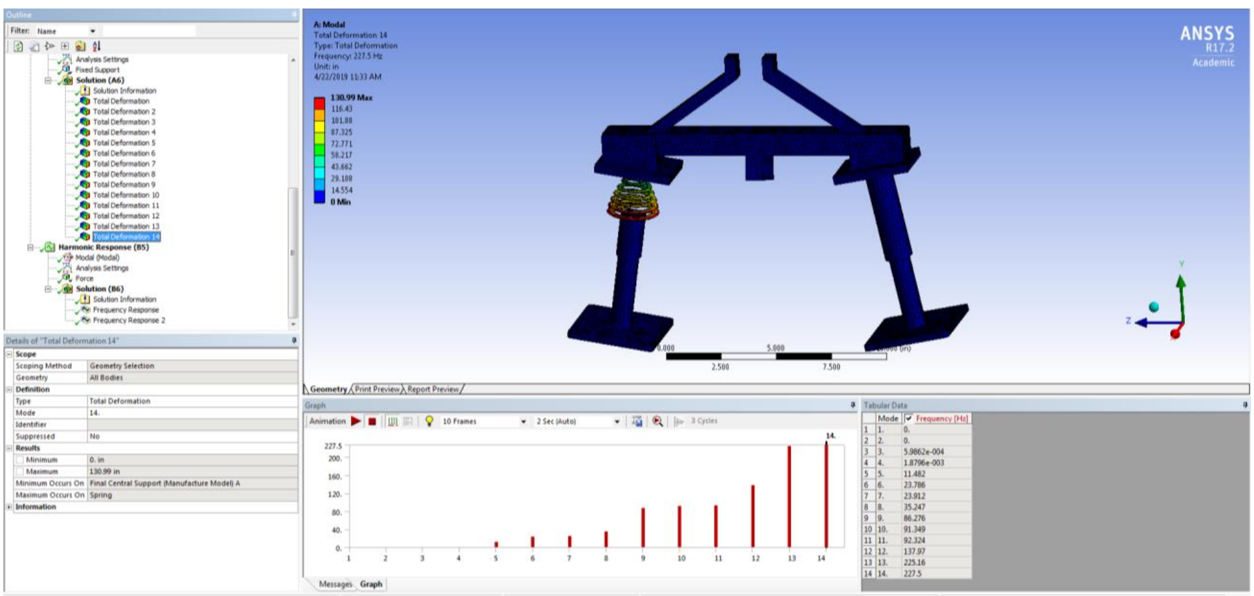
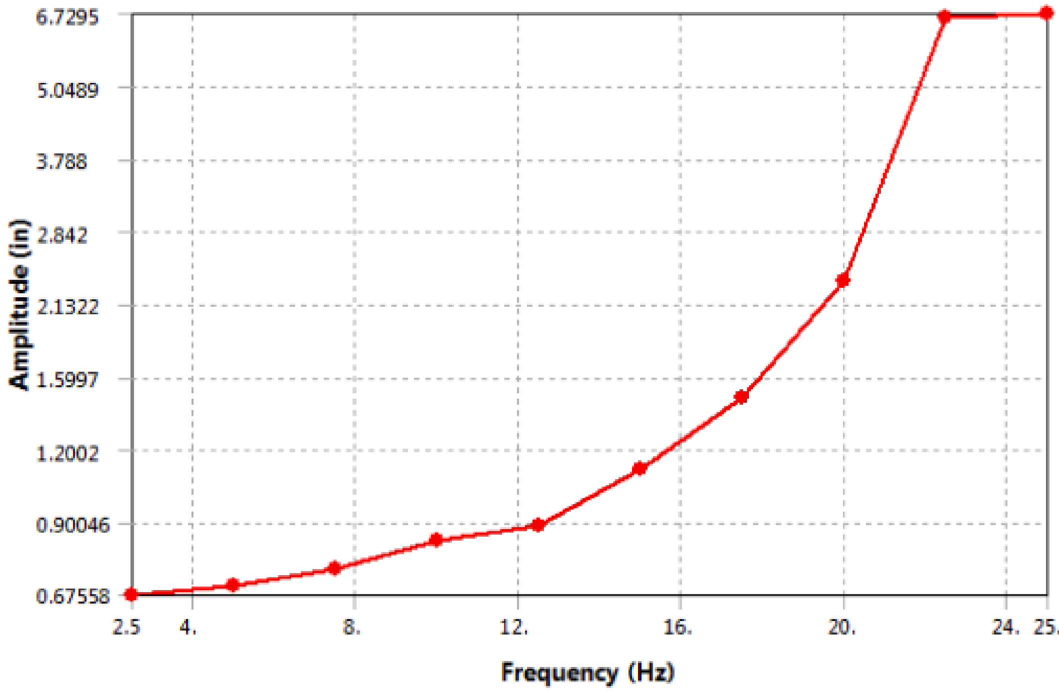
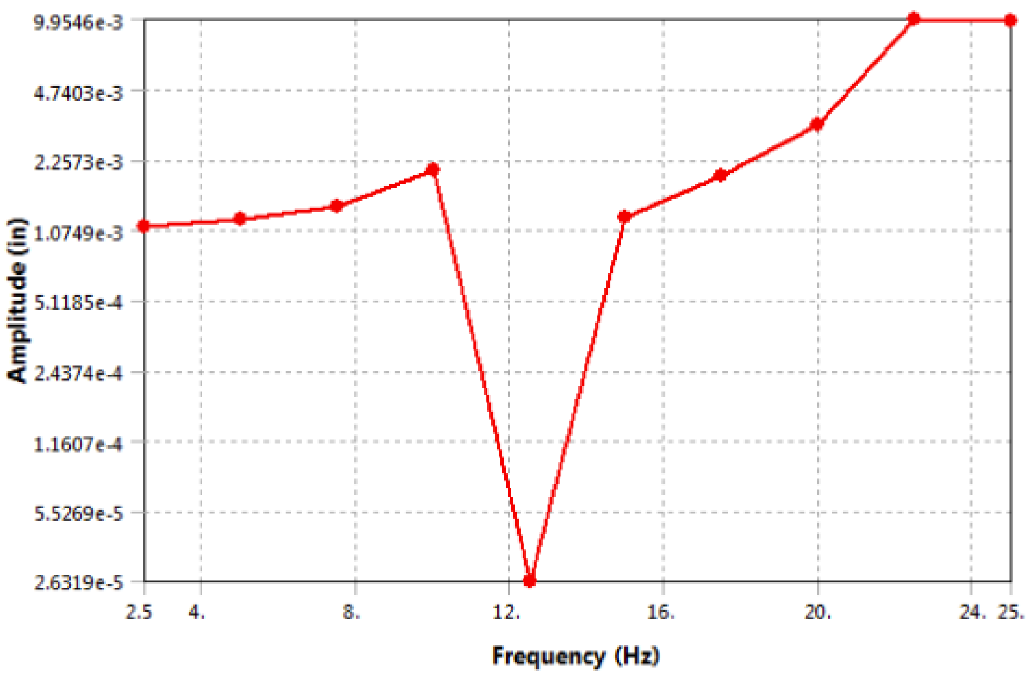


Figure 74: Mode 14 of Modal Analysis

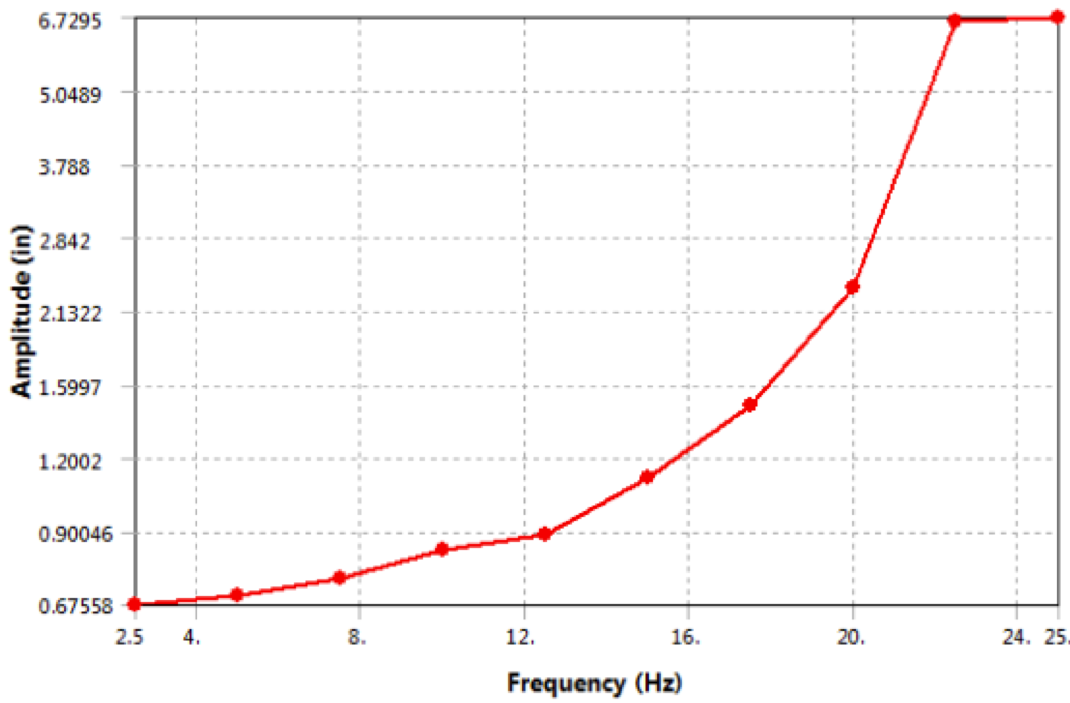
ANSYS Graphs



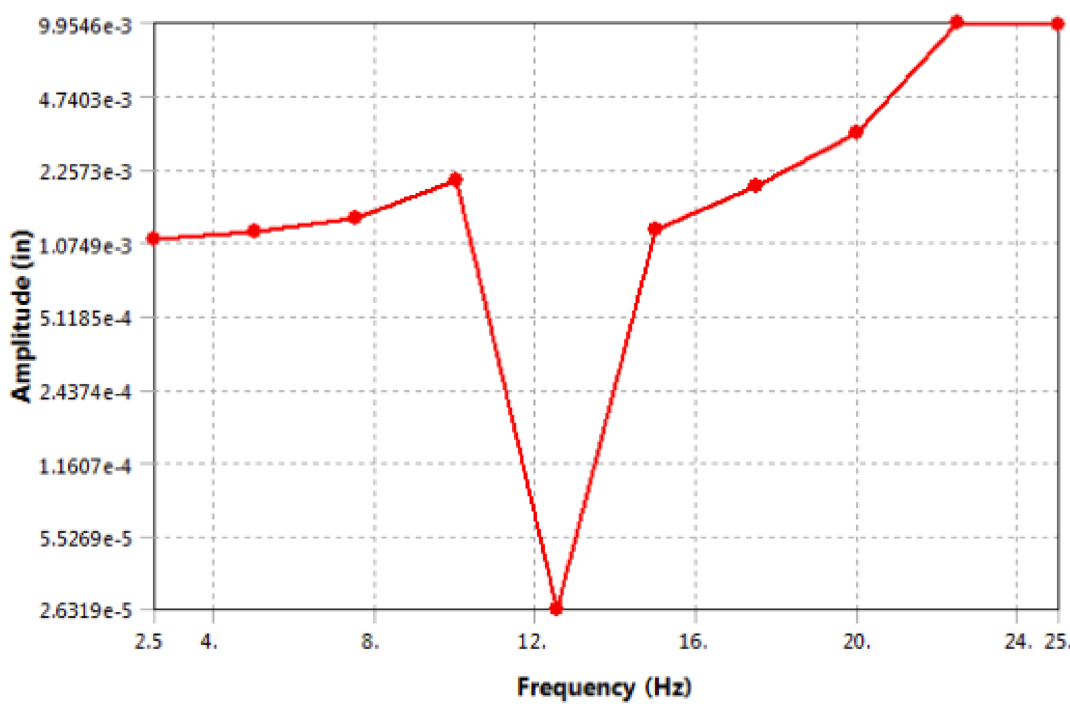
Graph 1: Measure of amplitude at a force of -300 Lbf to the left leg of system.



Graph 2: Measure of amplitude at a force of -300 Lbf to the right leg of system.

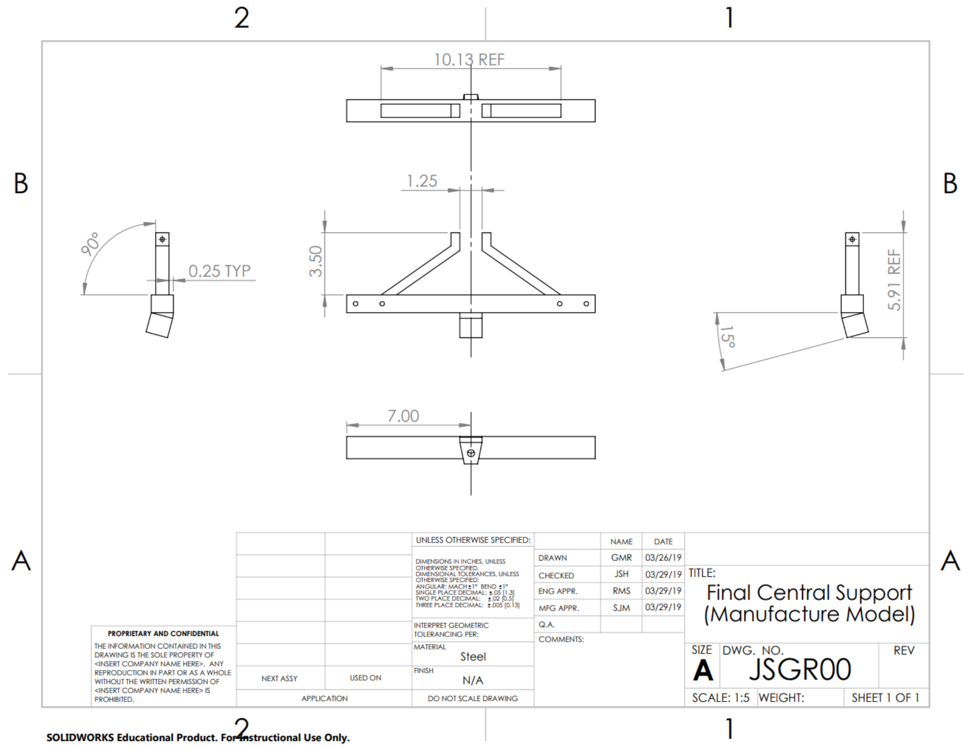


Graph 3: Measure of amplitude at a force of 300 Lbf to the left leg of system.

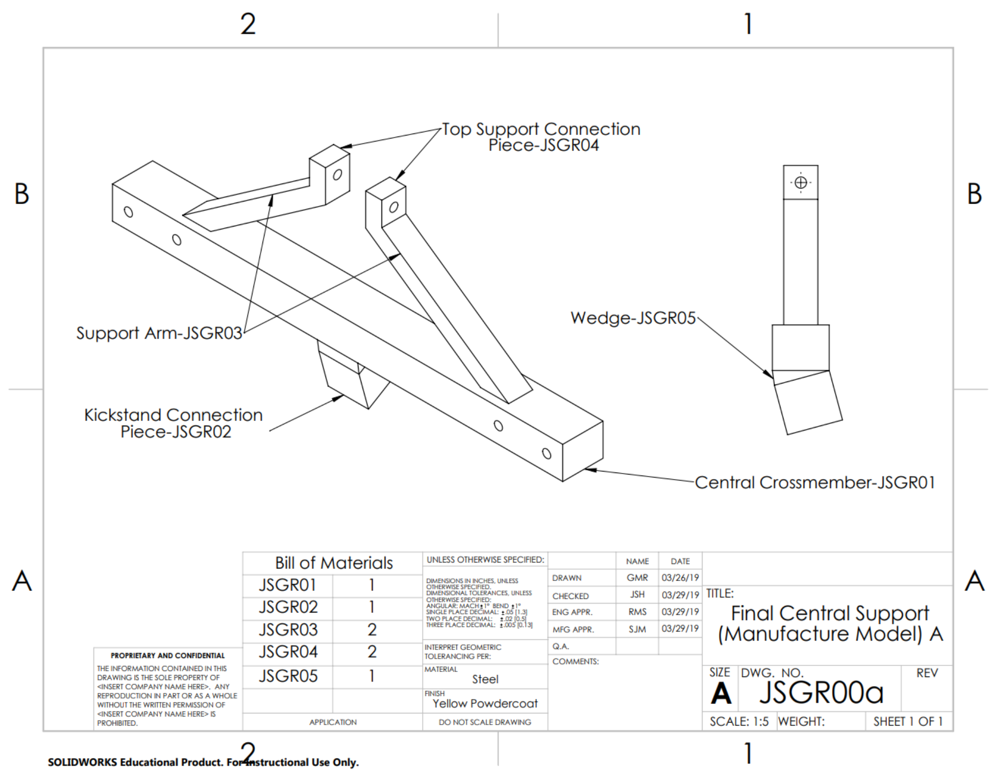


Graph 4: Measure of amplitude at a force of 300 Lbf to the right leg of system.

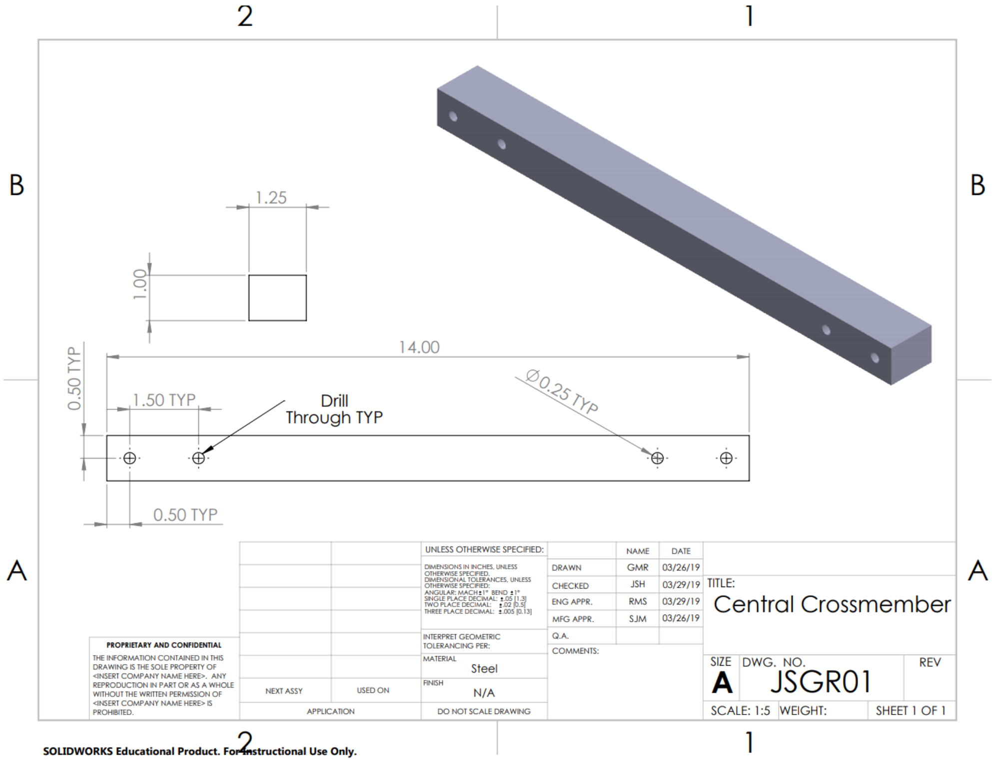
SolidWorks Drawings



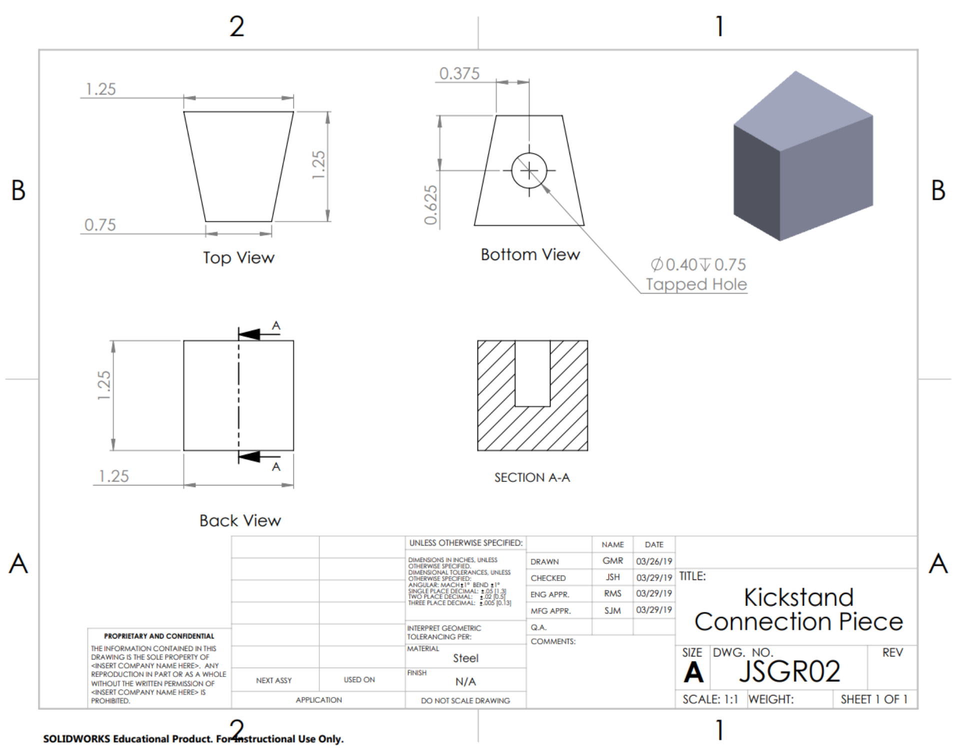
Drawing 1: Final Central Support



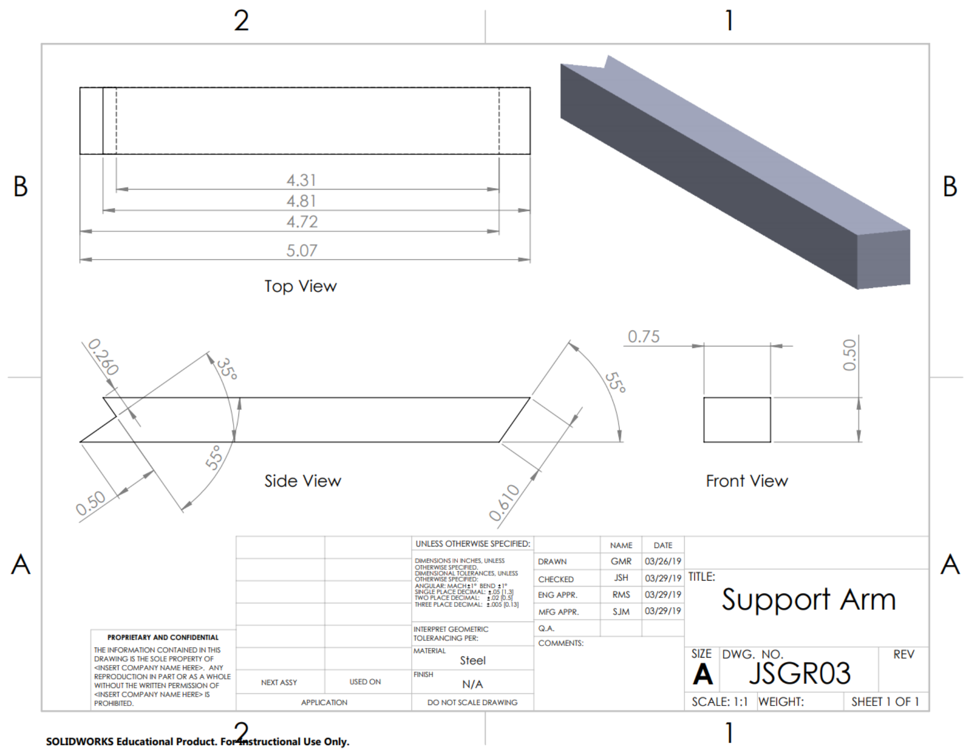
Drawing 2: Final Central Support



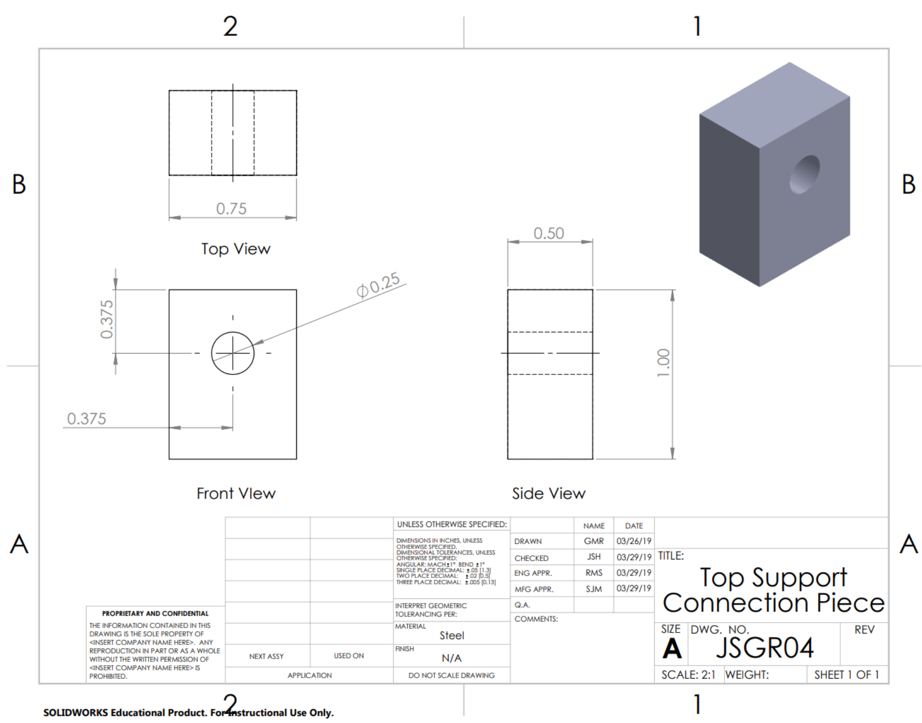
Drawing 3: Central Crossmember



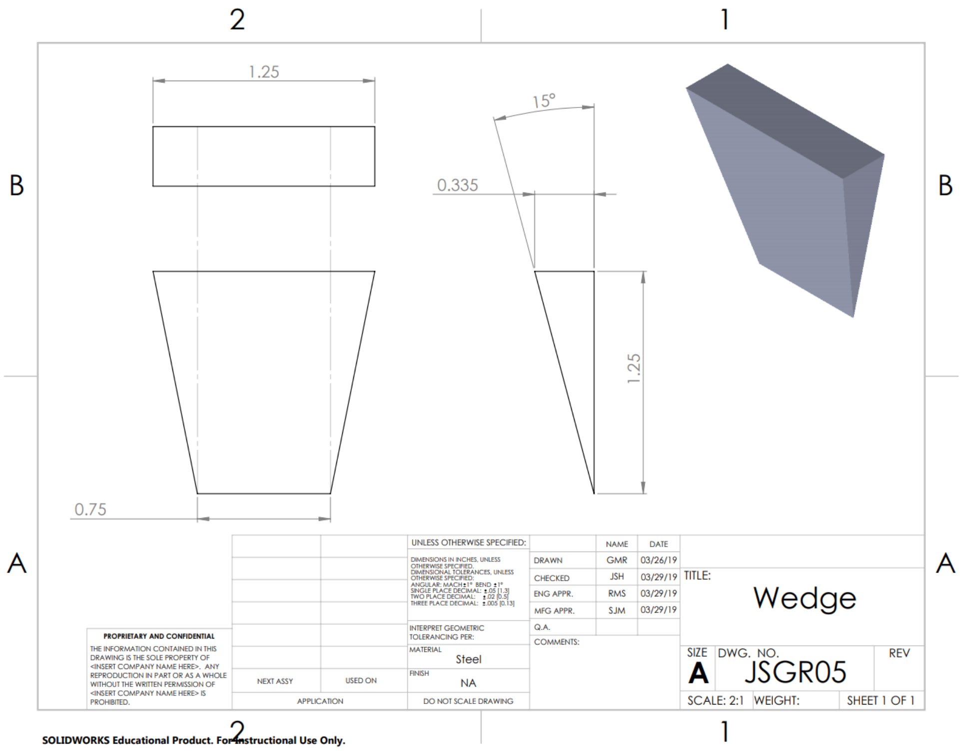
Drawing 4: Kickstand Connection Piece



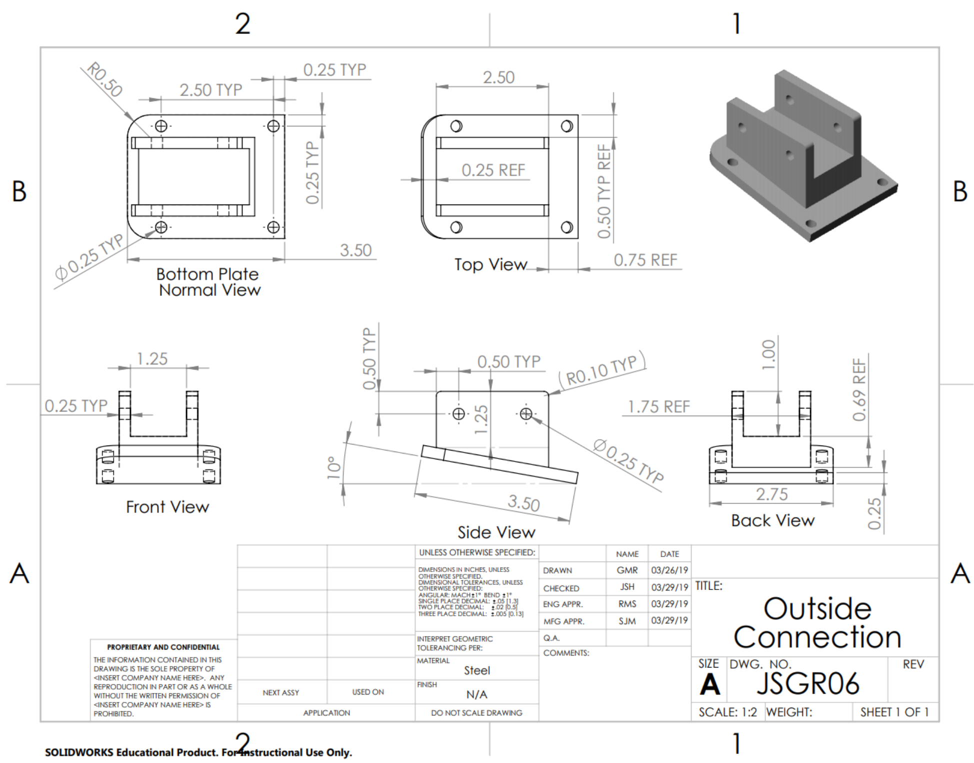
Drawing 5: Support Arm



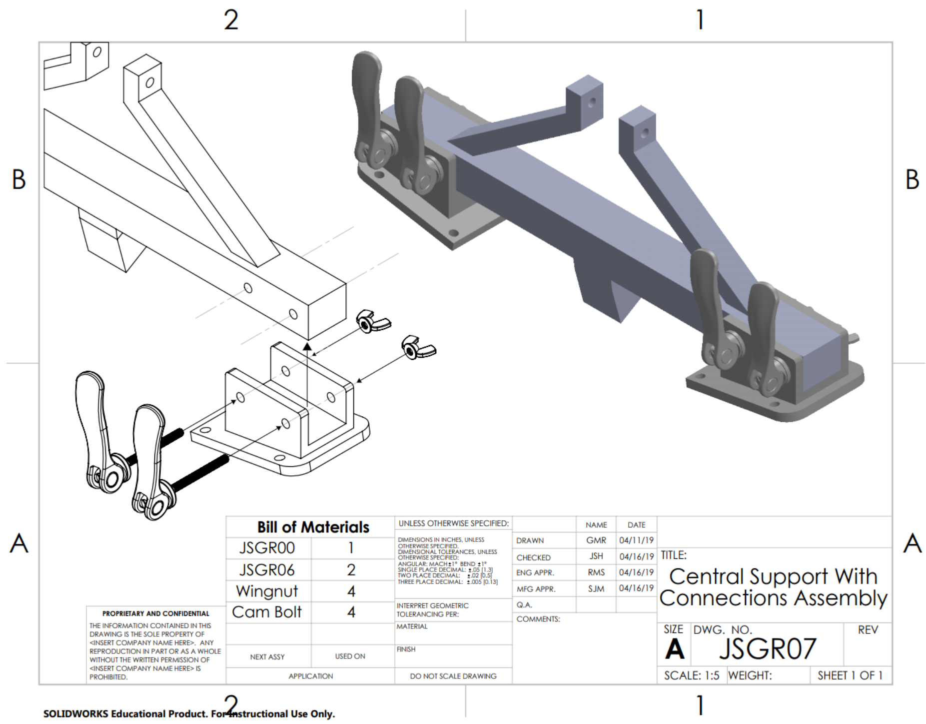
Drawing 6: Top Support Connection Piece



Drawing 7: Wedge



Drawing 8: Outside Connection



Drawing 9: Central Support with Connections