2020

uOttawa

Prosthetic Foot Testing Apparatus

Presented by: "TOE.io"

Team Members:

Cheikh, Hind

Galagedara, Niki

Ghosh, Devang

Markic, Nathan

Roy, Amesh

Faculty of Engineering

University of Ottawa

Abstract

A detailed report that establishes an effective development of prototypes, testing analyses, and a final prototype with all its features, operations, and concerns for a prosthetic foot testing device.

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1 Introduction

The biomechatronics laboratory at the Tecnologico de Monterrey University located in Guadalajara, Mexico is a research lab that specializes in lab-and field-testing of prosthetic components in both static and dynamic tests. A problem they face is an inability to test foot prosthetics on their able-bodied researchers. As such, they required a digital model for a prosthetic foot testing apparatus that replicates transtibial behavior and may be worn by these researchers for their testing needs. In the world of prosthetics, scientists have been limited as active foot amputees were the only subject capable of testing the prosthetics produced. However, this device breaks that limitation and allows for any researcher to don different prosthetics to effectively analyze their properties and capabilities.

The main demand for this product also relied on its key requirements. The lab needed an apparatus with i) a rigid connection between the mount and prosthetic foot, ii) the ability to allow researchers to quickly change between different prosthetic foot models, and iii) useful mountable accessories for capturing movement for assessments. These were all important necessities as they provide an easy, strong, and effective device to be used by these researchers.

Through extensive CAD testing and developing, this particular product by *TOE.io* is a one-of-a-kind model. This apparatus has been developed over months, resulting in many changes to vital elements such as material, mechanisms, and stress capacities. In all these aspects, this device passed with flying colours and each iterative step has been carefully analyzed and presented. This information will aid in the future development and refinement of such testing devices ensuring that the world of prosthetic analyses is open and achievable by all.

2 Product

2.1 Features, Functions & Capabilities

The final prototype can be sub divided into five main sub-assemblies/systems that are all crucial for the device to carry out its purposes. These six assemblies are the i) tibial strap, ii) foot frame, iii) foot straps, iv) camera mount, and the v) upper and lower height adjustment. *Figure 1* shows the final rendered prototype, and *Figure 2* displays a labeled diagram of the prototype. In the following sections, each sub - assembly/ system will be broken down further and elaborated upon. Please note that all technical drawings, closeups of figures, and any additional views can be found in the appendices.

Figure 1: Final Prototype Render

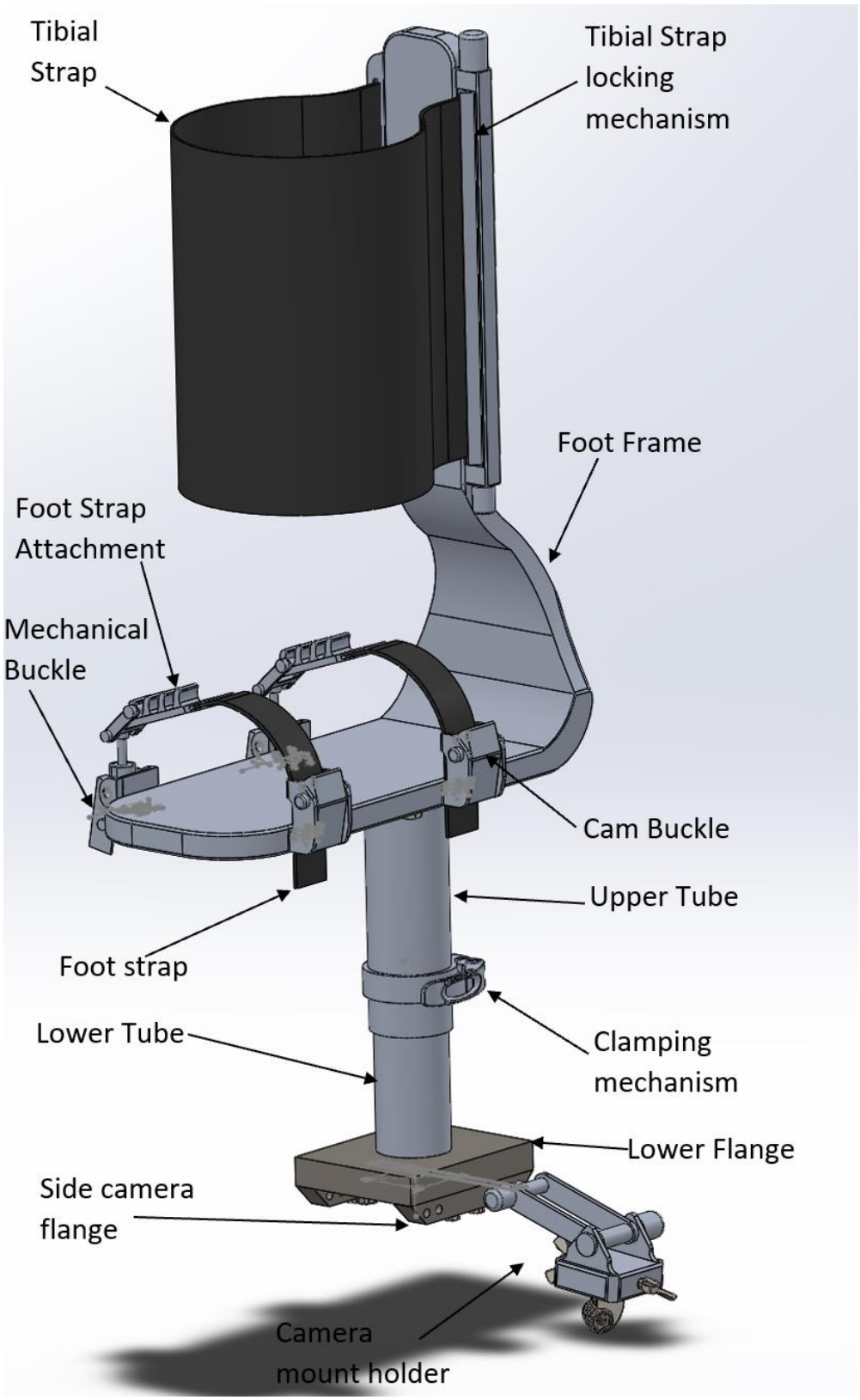

Figure 2: Diagram of Final Prototype

i) Tibial Strap

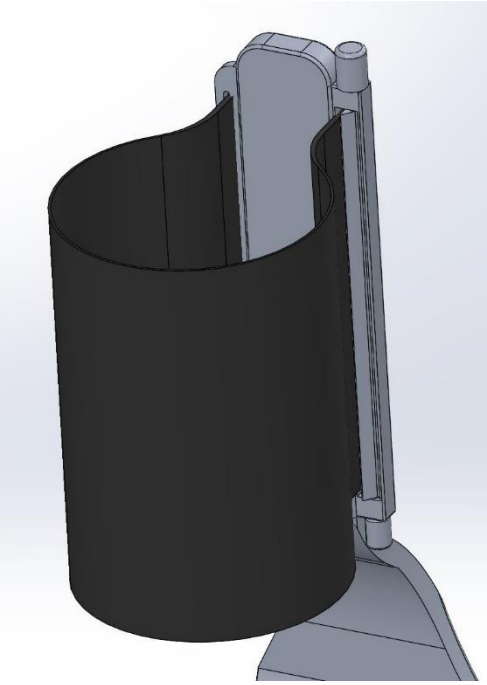

Figure 3: Tibial Strap Assembly

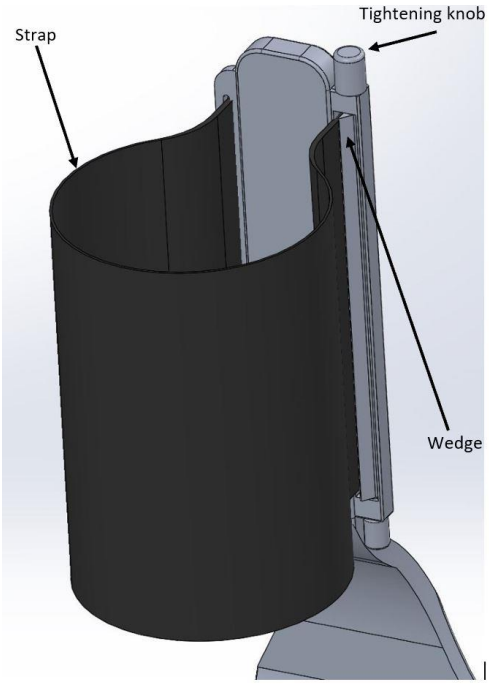

Figure 4:Diagram of Tibial Strap Assembly

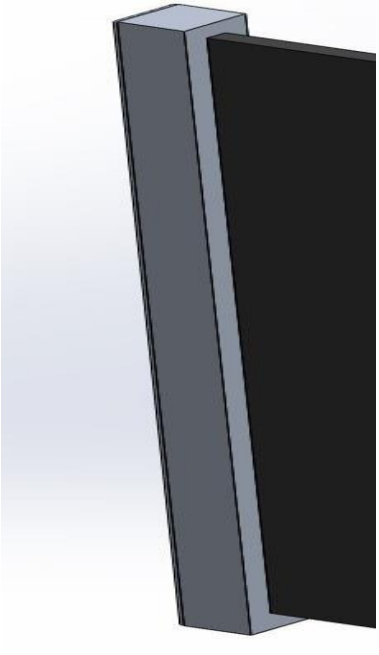

Figure 5: Tibial Belt Attachment

The tibial strap assembly (*Figure 3*) consists of the belt, the mechanical tightening mechanism, and the belt attachment. The belt itself is a fabric belt that wraps around the user's sub – patellar region and restricts leg motion when the device is in use. The belt attachment attaches onto one end of the belt as show in *Figure 4* and does not allow the belt to pass through the belt hole on the foot frame.

Regarding the belt locking mechanism (*Figure 5*), the belt is slid through the opposite belt hole on the foot frame and pulled through as much as the user desires. The upper knob can then be turned, pressing the wedge against the belt, and restricting movement of the belt using friction. The height of the tibial strap is 20cm to allow the required motion restriction and is 3mm thick.

ii) Foot Frame

The foot frame is the main point of application of force from the user's foot and is designed to allow for maximum force displacement. The frame also contains the two fixation devices for the tibial strap and can be found on the upper portion of the frame. In addition, the frame also has mounting holes at specified locations in order to attach the required buckles for the feet straps and can be seen on the sides of the frame, adjacent to where the user's foot will be located. Moreover, the bottom of the frame also contains holes to allow for the upper height adjustment assembly to be attached. Images of the foot frame (including its technical drawing) and its functions can be found in the following pages.

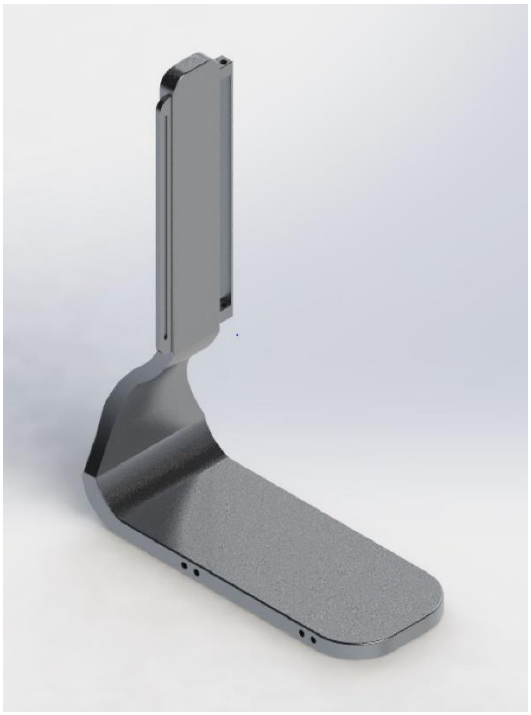

Figure 6: Foot Frame Render

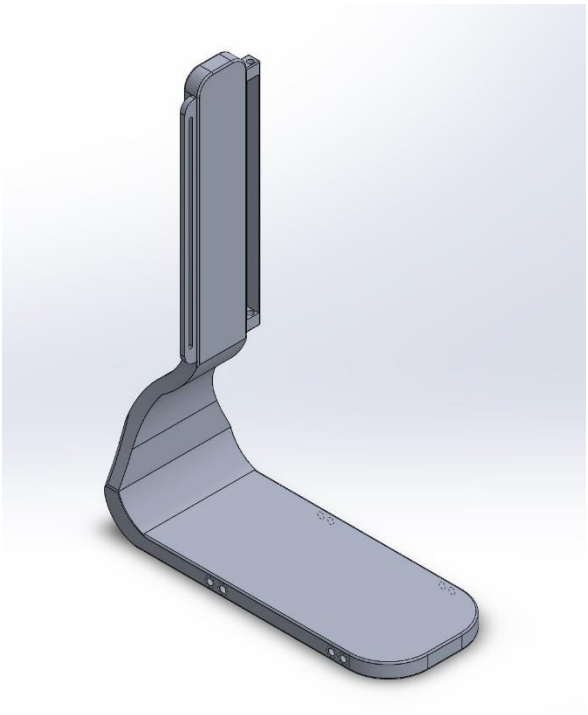

Figure 7: Foot Frame Un-rendered

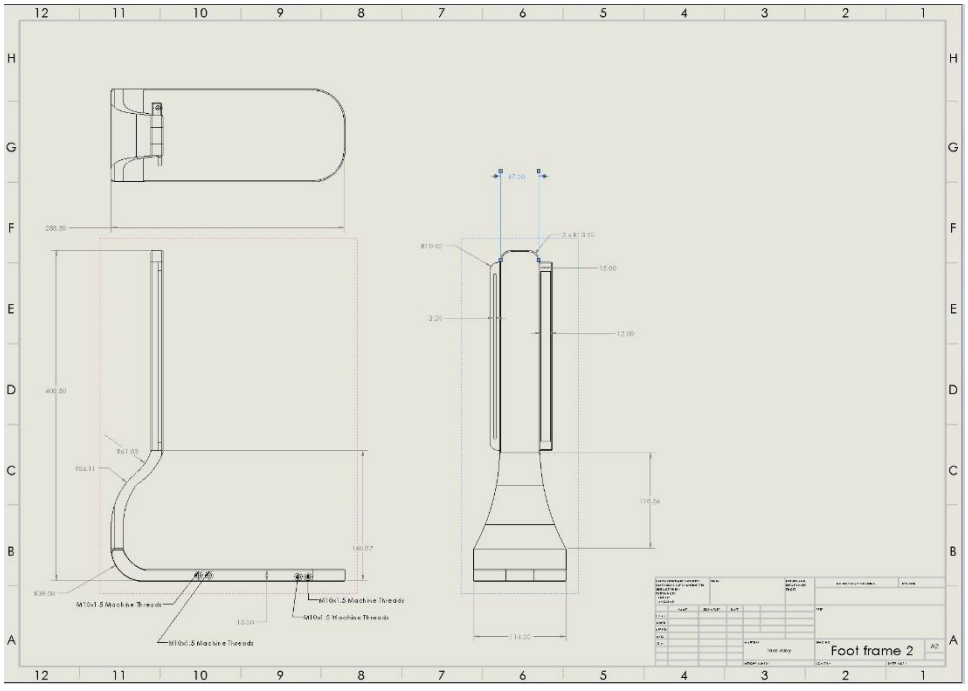

Figure 8: Foot Frame Technical Drawing

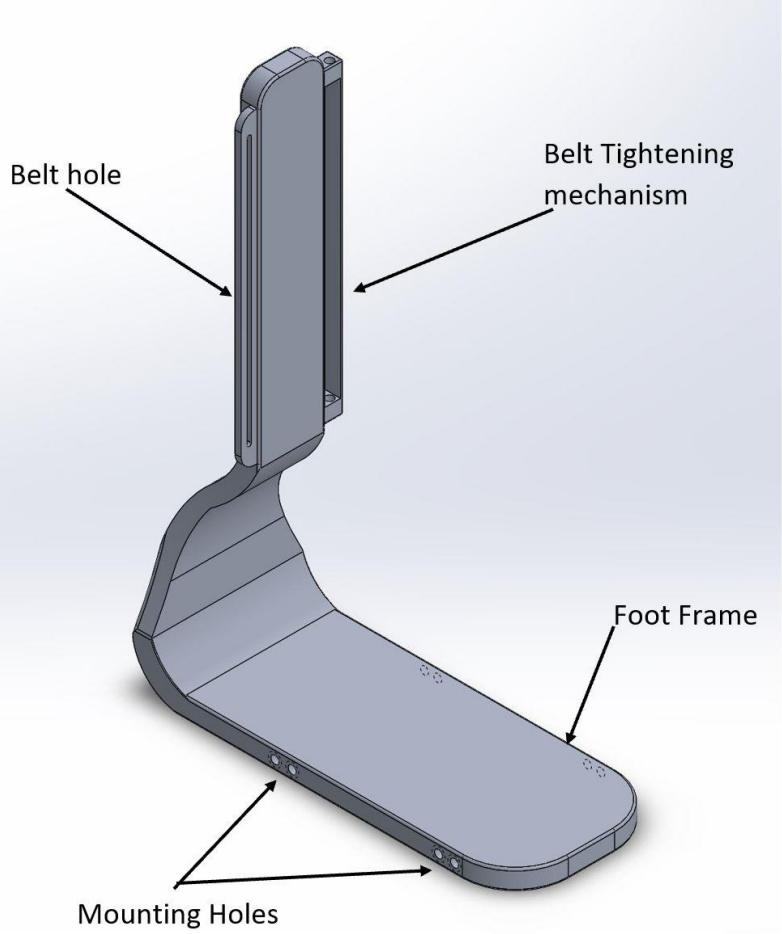

Figure 9: Diagram of Foot Frame

Figure 6 shows the final rendered image of the foot frame with a material of 1060 Alloy. *Figure 7* displays the technical drawing of the foot frame with all relevant dimensions. The frame was also designed to accommodate for the protrusion of the heel and was designed to be 410mm tall, roughly the height from the bottom of the foot to the sub – patellar region of a 5”6’ reference user. Note that the fixation devices for the tibial strap will be elaborated upon further in the coming sections.

iii) Foot Straps

The main purpose of the foot strap assemblies is to restrict motion of the foot while the user is using the device and ensure that the foot remains on the frame. This sub system contains two sets of buckles on the two sides of the frame that are attached with countersunk screws and the mounting holes on the frame. The buckles on one side of the frame are designed to resemble the tightening mechanisms on skis or roller blades, such that the buckle grabs on to a groove located on the belt strap attachment and is then secured by tightening the buckle. On the opposite side of the frame, there are two cam buckles attached by the mounting holes and countersunk screws that allow the user to tighten the strap simply by pulling it through the buckle. *Figures 10 and 11* show various views of the foot strap assembly.

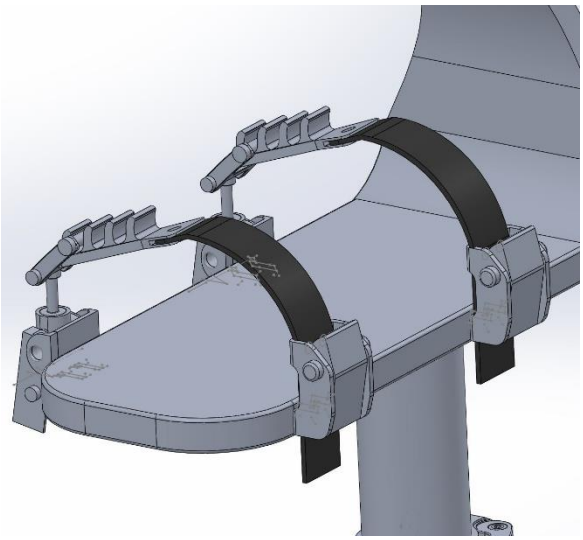

Figure 10: Foot Strap - Inner View

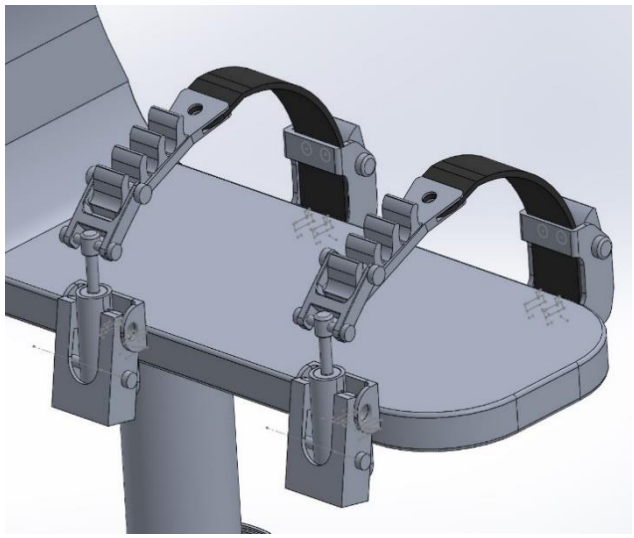

Figure 11: Foot Strap - Outer View

iv) Camera Mount

The camera mount assembly consists of two main parts: the camera holder and the flange attachments, both of which can be seen in *Figures 12 and 13* on the following page.

This sub – assembly allows users to attach a GoPro camera onto the device in order to capture footage of the foot prosthetic in use. The holder allows for easy camera mounting with a universal GoPro mount and features 360-degree adjustment. To fix the position of the holder, the knobs and wingnuts can be tightened. The camera mount flanges get attached to both sides of the lower flange with the use of M5 fasteners and mounting holes at the correct locations on the lower flange. The arms of the camera holder can be slid through the set of holes of the camera mount flanges and then fixed in position using collars that are tightened with Allan keys.

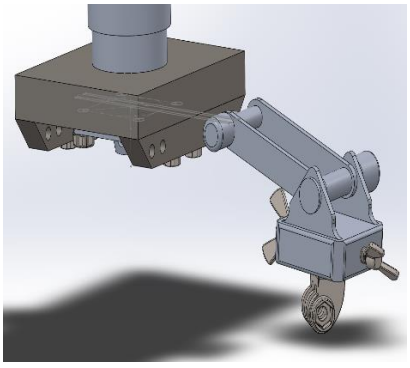

Figure 12: Camera Mount Render

Figure 13: Camera Mount Un-rendered

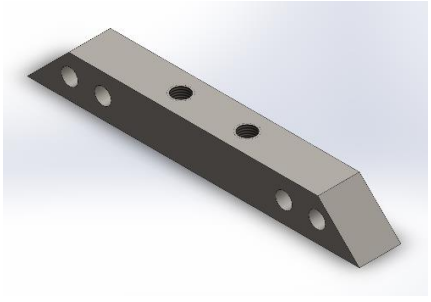

Figure 14: Camera Mount Flange

v) Upper and Lower Height Adjustment

Figures 15 and 16 show the upper and the lower height adjustment assemblies, respectively. Note that *Figure 17* is an alternative view of the lower height adjustment assembly. The overall system consists of two concentric tubes that allow for 100mm of adjustment and can be tightened using a clamping mechanism, whose behaviour resembles bike seat height adjustment devices.

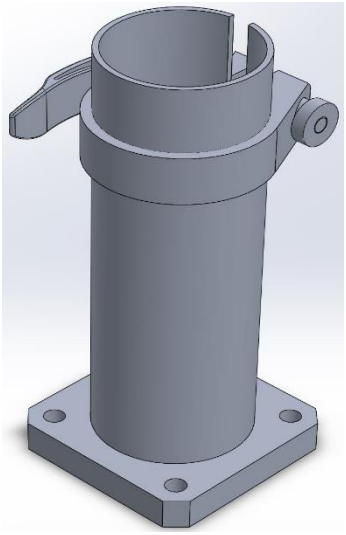

Figure 15: Upper Assembly

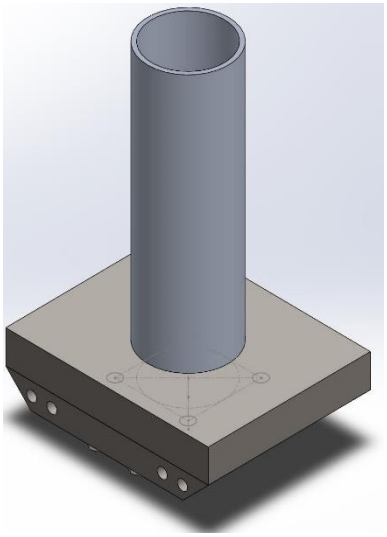

Figure 16: Lower Assembly

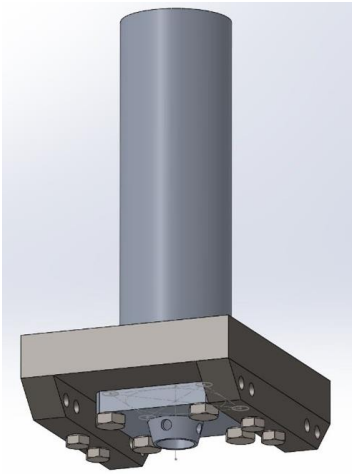

Figure 17: Lower Assembly - Alternative View

The upper height adjustment module contains an upper flange, a tube with an outer diameter of 44.2mm and inner diameter of 40.9mm, and the tube clamping device. The upper flange contains mounting holes so it can be attached to the bottom of the foot frame using the appropriate fasteners. The tube is attached to the flange with an all – around weld and allows for the lower height adjustment assembly to slide in. It is important to note that the upper tube contains a notch to allow the clamping mechanism to tighten the two concentric tubes. The clamping mechanism is press – fitted onto the upper tube and allows users to control the height of the entire assembly by sliding the two concentric tubes to the desired height, then tightening the clamp.

The lower assembly contains a tube with an inner diameter of 36mm and outer diameter of 40mm, a lower flange, two side camera flanges, and the pyramid female adapter. It is important to note that the same fixation method (all - around weld) is used to secure the flange to the tube. Additionally, the tube of the lower assembly is designed to concentrically fit within the tube of the upper assembly while considering the required radial clearance. Users also have the option of attaching the side camera flanges to lower flange by using M5 fasteners and the specified mounting hole patterns located on the bottom of the lower flange. Finally, the lower flange also contains mounting holes to attach the female pyramid adapter by using M6 fasteners.

2.2 Design Process

The prosthetic testing device had various requirements which involved a comprehensive design process that lead to the final product. This includes needs of the client, universal compatibility, meeting target specifications, and multiple reiterations of prototypes that consisted of load testing simulation and refinement of components.

1. The initial step of the entire design process started with identifying the clients' needs. This list included components that needed to be included such as a GoPro mount, accessory mount, and female pyramid connector for the device to attach to all types of prosthetic footings. Needs were then ranked by priority to determine which aspects hold precedence when prototyping.

2. The following step involved a ranked list of metrics that needed to be met such as the weight capacity, degree of flexibility on plantar and dorsiflexion, height range and time it takes to swap the prosthetic foot from the device. Based on the metrics, benchmarking was done with other similar products to understand what other designs were like and at which metric they excelled in. The two main products we used to compare are the *OPRA Implant system* and the *Niagara Foot.* Target specifications were determined from benchmarking to have a set range of what our metrics should be in (200kg for load capacity, accommodate size 6-11 US men shoe sizes etc.).

3. Based on the requirements, 15 designs were sketched during the ideation phase by all group members. All designs were then on a Weighted Average Decision Matrix to determine which designs were the most viable based on its weighted score.

4. We then narrowed all the designs from 15 to 3 of the following sketches:

Figure 18: Top Individual Sketch Concept 1

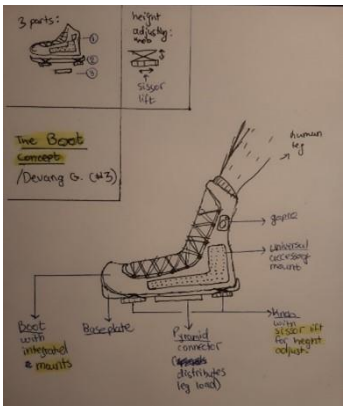

Figure 19: Top Individual Sketch Concept 2

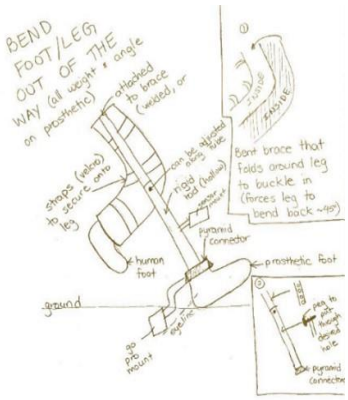

Figure 20: Top Individual Sketch Concept 3

After comparing the advantages and disadvantages of each of the selected sketches we had comprised of a group design that integrates certain elements of the 3 sketches and custom component designs such as height-locking and foot securement methods.

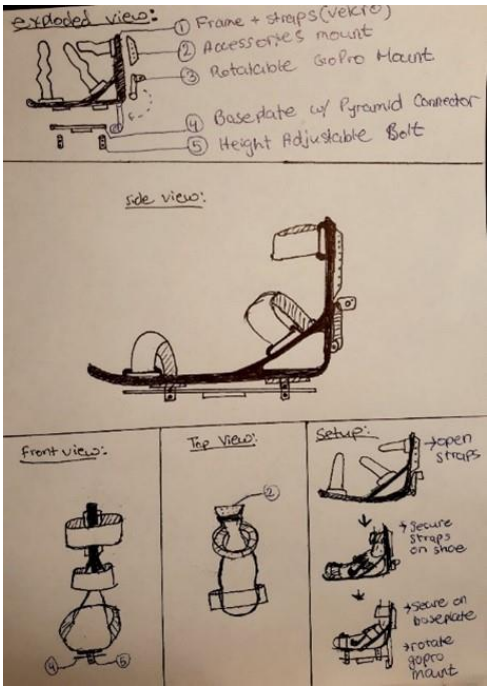

Figure 21: Group Design 1

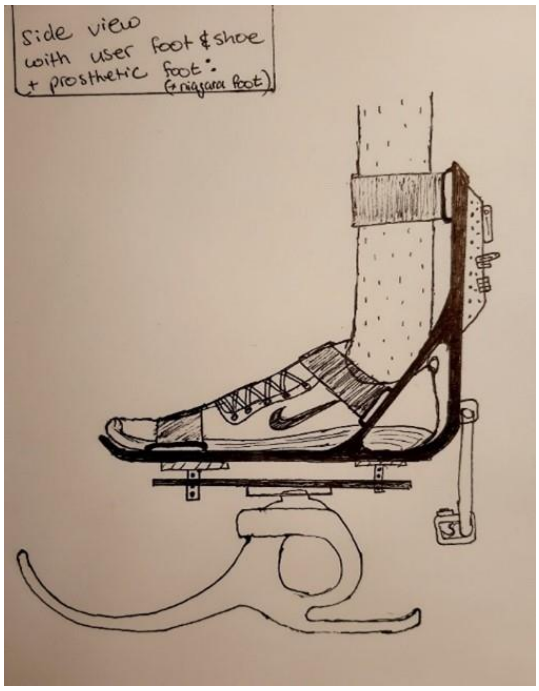

Figure 22: Group Design 1 - Alternative View

Benefits and drawbacks of the group design were then compared to determine which aspects needed to be refined for the CAD prototype. Some benefits included how the snowshoe-designed mount accommodates all foot sizes and is quickly secured in place. While some drawbacks included unequal weight distribution on the pyramid connector, and instability of the camera arm.

5. Prior to the first CAD prototype, a client meeting was held where feedback was received from the group design concept. Based on the feedback, a refined group design was made:

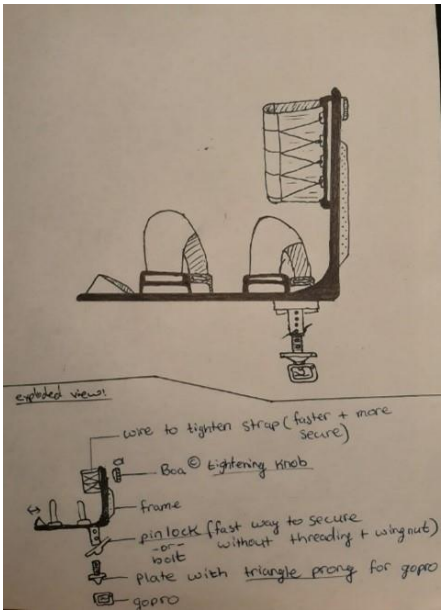

Figure 23: Final Design Concept 1

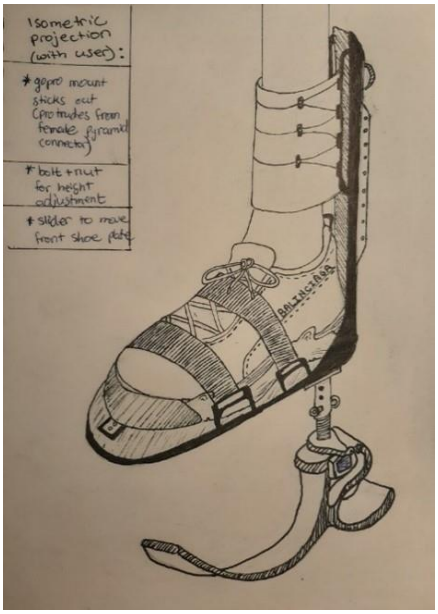

Figure 24: Final Design Concept 1 - Alternative View

Adjustments for the refined concept mainly includes a one point contact between the baseplate and prosthetic, a taller backplate to support the calves, a more supportive tibia strap, a mounting position of the pyramid connector that accurately represents human-like weight distribution on the ankle, and a more secure camera mount.

6. Based on the refined design, a CAD model was made which became Prototype 1:

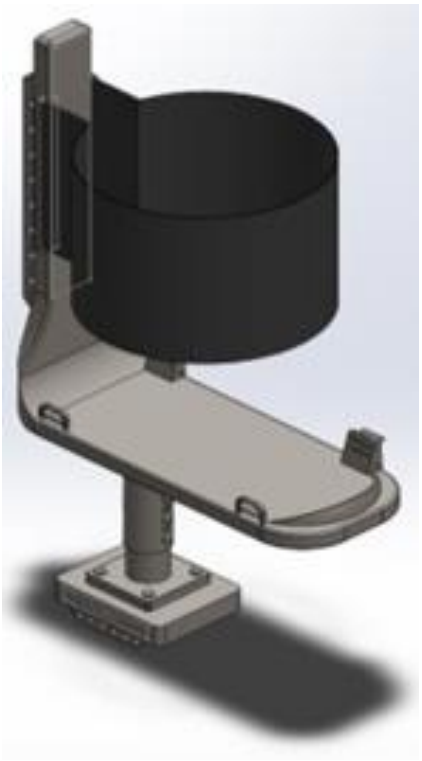

Figure 25: Prototype 1

Figure 26: Prototype 1 - Alternative View

This model was made to scale and included the appropriate materials used for the frame and flanges (1060 alloy), clamps for shoe securement (medical grade titanium), and tibia strap (woven fabric).

7. Using Solidworks, a stress analysis test was conducted on the design to determine which components require more reinforcement and how well it can operate with a 200 kg load.

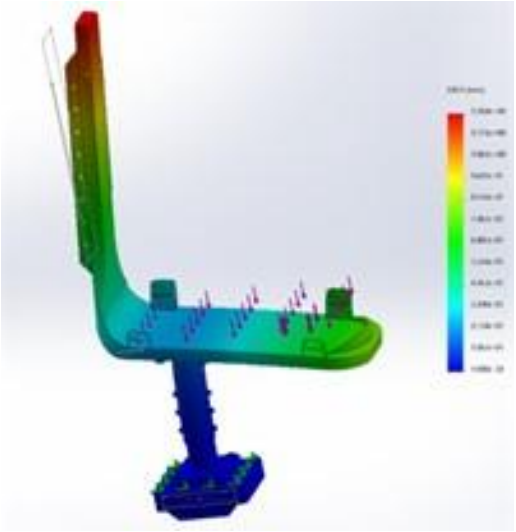

Figure 27: Prototype 1 Stress Test 1

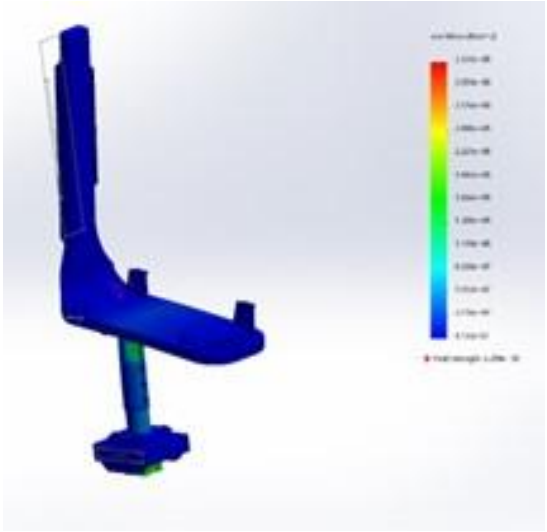

Figure 28: Prototype 1 Stress Test 2

8. A second client meeting was held, and feedback was received based on Prototype 1. This time, the refinements that needed to be made were much smaller but involved more detail. These modification included: having to use specific tubes (ST&G) for the height adjustment module, making a thinner baseplate, removing accessory mount, refining the tightening mechanism for the tibia strap, using thumb screws to tighten the camera mount, relocating the camera mount to a position that has better viewing angles for the attached prosthetic foot, adjusting the back plate to the shape of a human heel, and more efficient foot-securement clamps. These elements can be found in detail in the figures below.

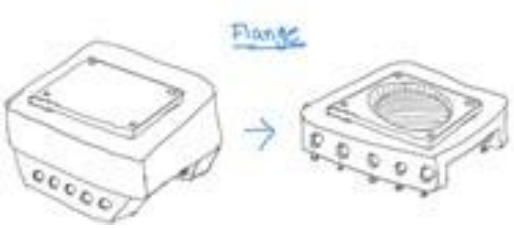

Figure 29: Flange Thinning

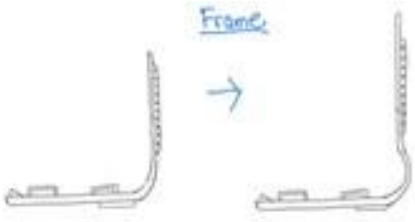

Figure 30: Heel Adjustment

Figure 31: Efficient Foot Securement Clamps

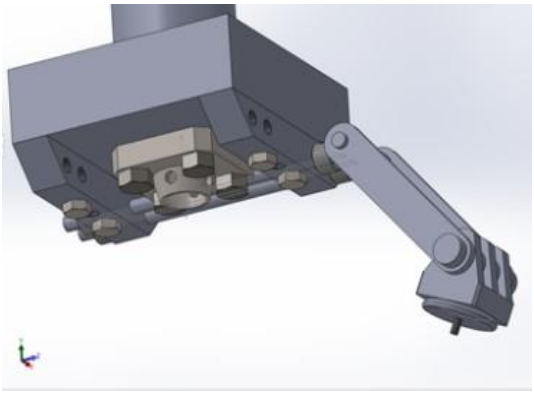

Figure 32: Camera Mount Relocation

Figure 33: Tightening Camera Mount

Through all these analyses and readjustments, we were able to produce our final prototype design pictured below.

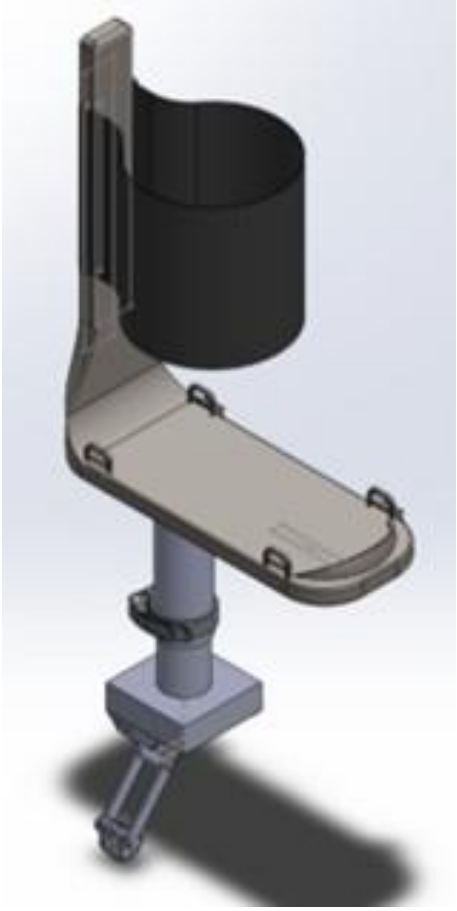

Figure 34: Final Prototype Design

2.3 How It Works

1. Grab a prosthetic foot that includes a male pyramid adapter attached to it.
2. Secure prosthetic foot to the testing apparatus using the adjustment screws on the female pyramid adapter.
3. If using two testing apparatuses, repeat steps 1-2 on the other apparatus.
4. Adjust the height of the prosthetic foot on the testing apparatus.
5. Mount camera onto the camera mount accessory arm.
6. Attach camera mount accessory arm to the prosthetic foot testing apparatus.
7. Place foot into the testing apparatus.
8. Secure foot with the two straps.
9. Secure tibia with the tibia strap.
10. Perform testing.

For additional information on our prosthetic foot testing apparatus, please go to:

https://makerepo.com/nmark032/gng-2101-b13-prosthetic-foot-testing-apparatus

2.4 Health and Safety

It is important to consider the weight of the user while using this apparatus. The design was built to accommodate users that weight up to 100kg, but for added safety, the device was designed to withstand weight up to 200kg. It is not recommended to exceed the weight restriction of 100kg.

2.5 Troubleshooting

Due to the project being conducted entirely virtually, and the requirement being a CAD file there are no applicable troubleshooting methods.

3 Conclusion

3.1 Recommendations for Future Work

Going forward there are multiple changes that could be made to improve the function and usage of the device. For future designs/ work one improvement that could be made includes integrating a system that allows the device to accommodate users with different length of feet. This change can be made by making the front part of the foot frame into a telescoping system that can slide out and lock at the desired location.

Another improvement that can be made is the removing most of the lower assembly (lower flange, lower tube and female pyramid adapter, and replacing it with an ST & G tube with a female pyramid adapter attached within the tube as pictured in the figure below(figure x). This change would reduce the weight of the overall device as well as add a required touch of simplicity. Furthermore, if this improvement were to be made, the inner diameter of the upper tube would need to be change in order to accommodate the new lower tube's outer diameter. In addition, the camera mount system would need to be relocated, or an additional attachment would need to be designed.

Figure 35: Stainless Steel Recommendation

Thus, *TOE.io* has created a valuable device that allows researchers to further analyze and effectively assess many foot prosthetics. In this project, the needs of clients at the biomechatronics laboratory at the Tecnologico de Monterrey University were carefully examined in order to produce this product.

The comprehensive and vast testing, along with the elaborate design process, produced a final apparatus that is strong, easy to use, and supports a camera mount. The iterative design approach, continuous emphasis on critical functionalities and target specifications, and the valuable feedback received also aided in making sure this design was the most viable and effective product to use.

It is with great conviction that *TOE.io* provides this device, ad believe it is a sufficient tool that may be used by researchers in the world of prosthetic testing. With the anticipation that future engineers may use this product as a steppingstone for their own products, this report provides the necessary information to elaborate and further develop a foot prosthetic testing apparatus.

4 Bibliography

https://stngco.com/product-details/1211/

https://protosthetics.com/wp-content/uploads/2018/06/Niagara-Information-and-Modifications.pdf

5 Appendices

Appendix A. Technical Drawings of Parts/Assemblies

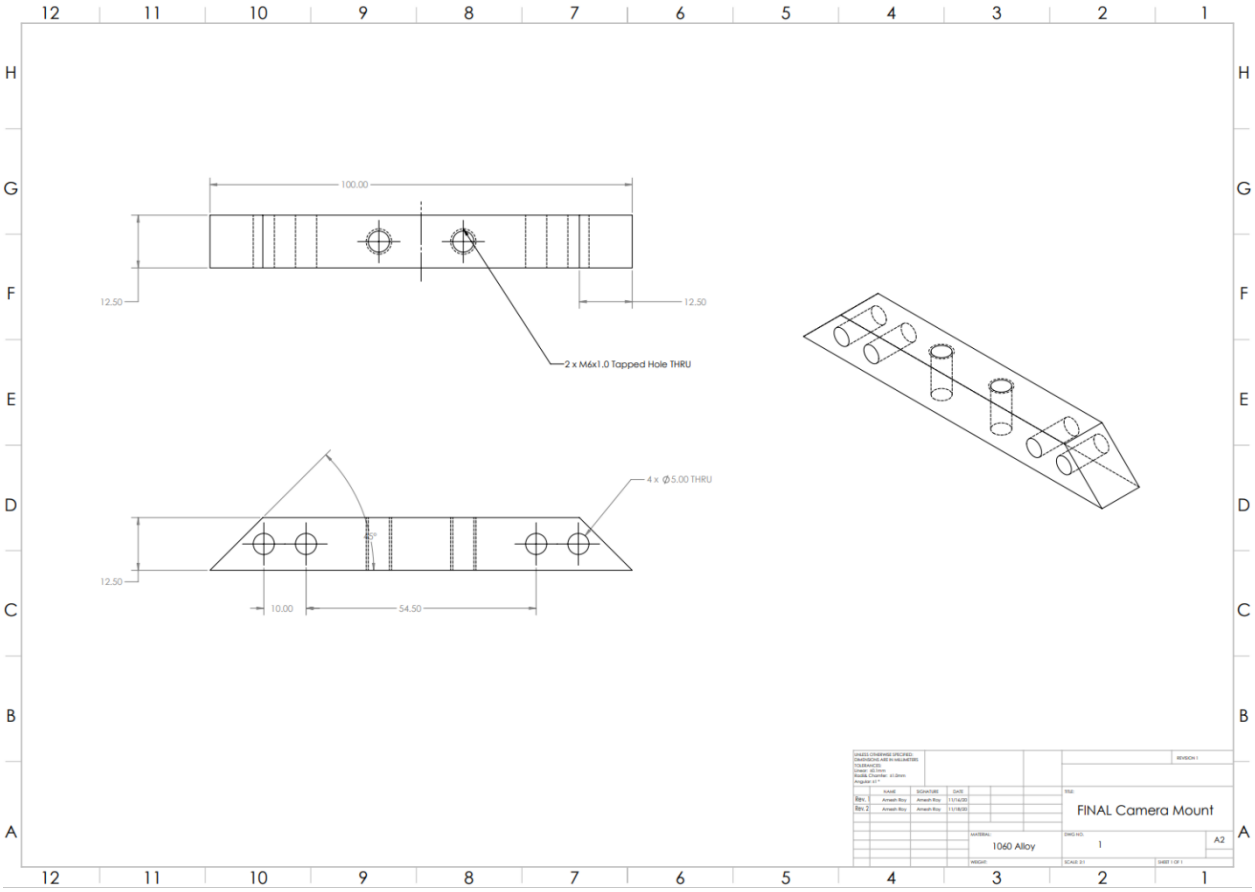

Figure 36: Camera Mount - Side Flange

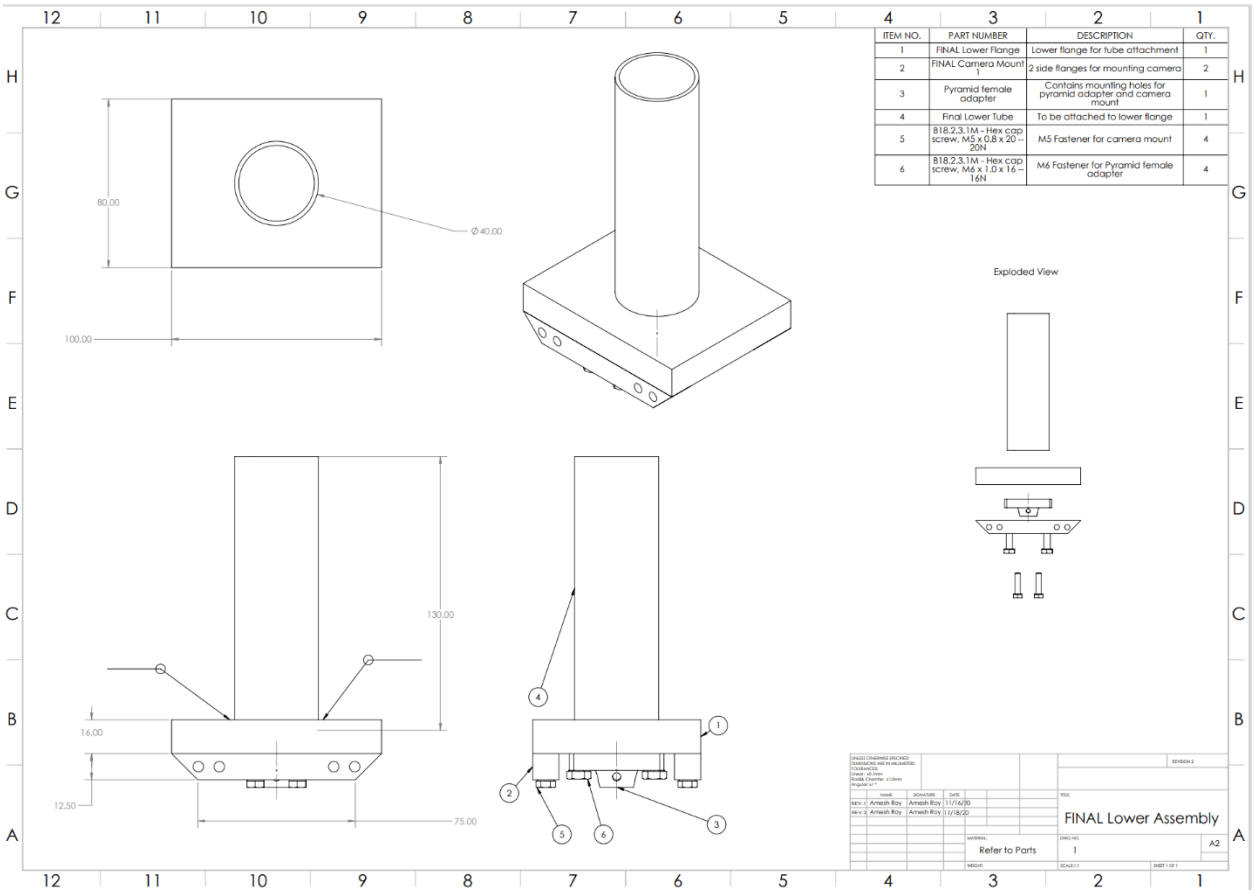

Figure 37: Lower Assembly

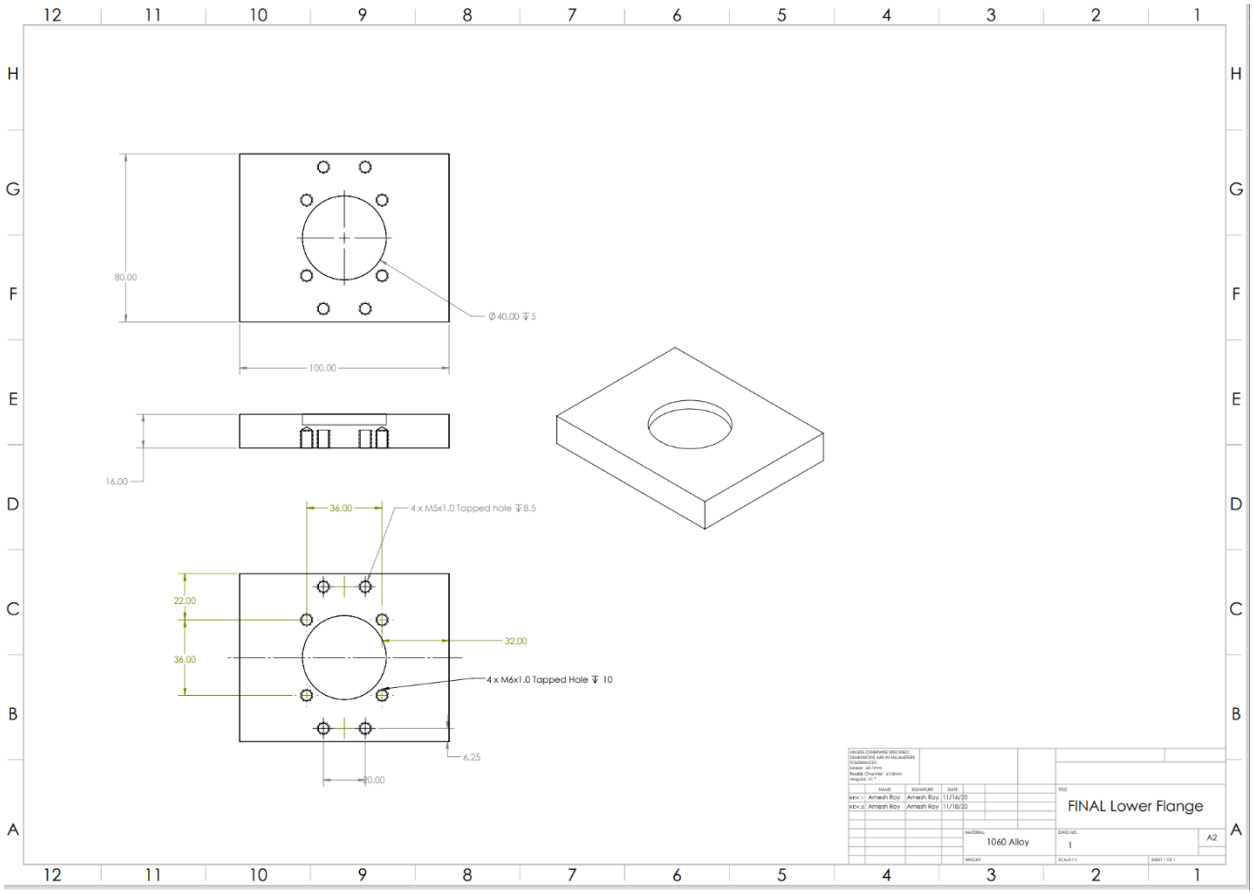

Figure 38: Lower Flange

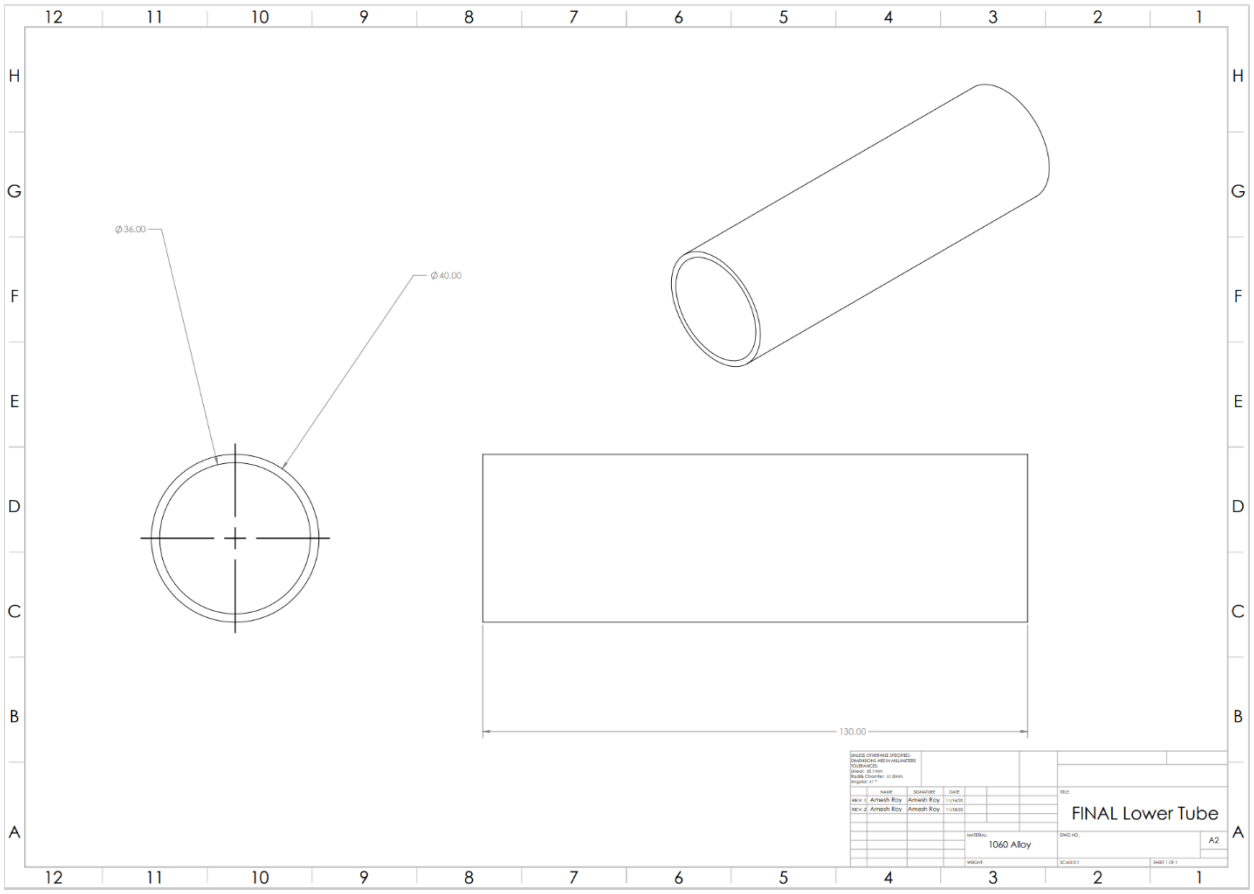

Figure 39: Lower Tube

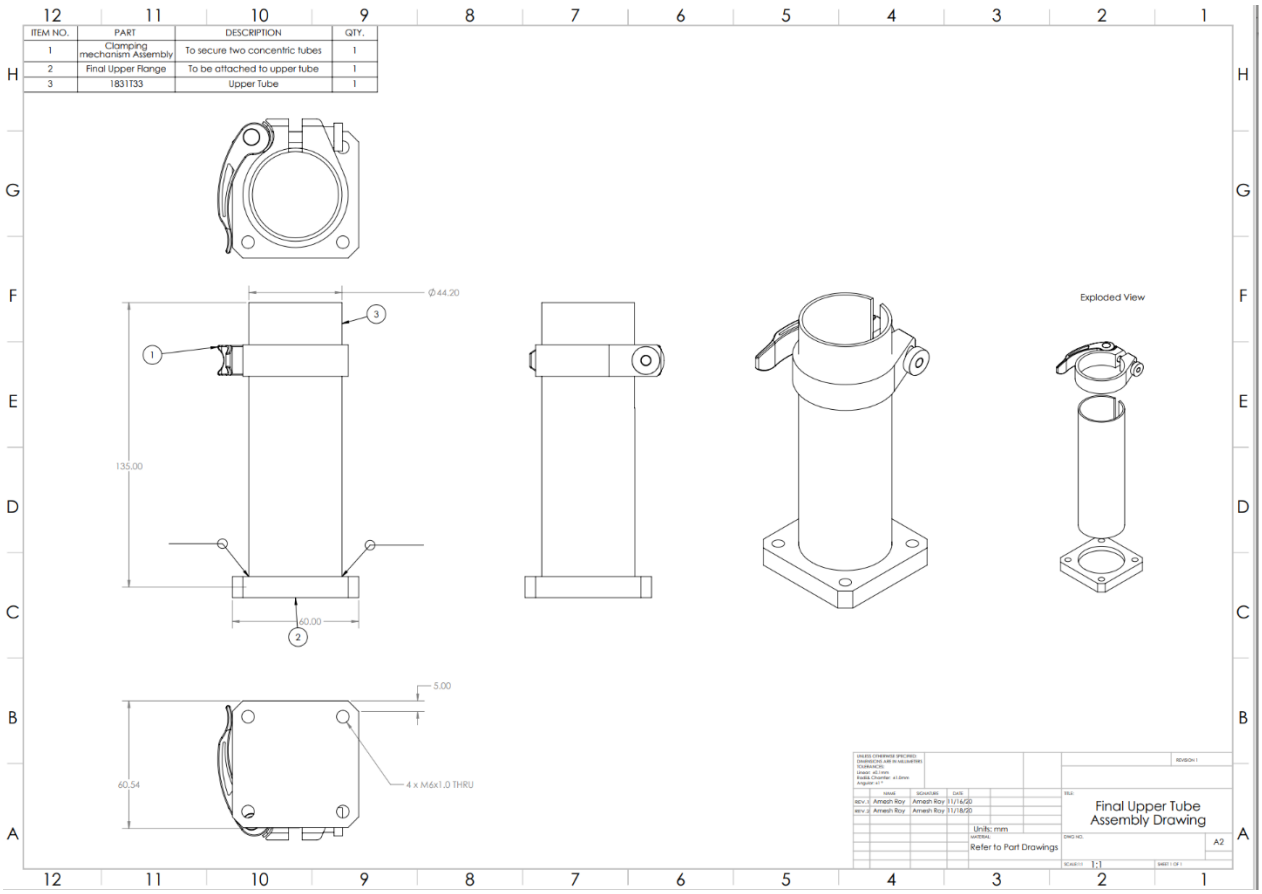

Figure 40: Upper Assembly

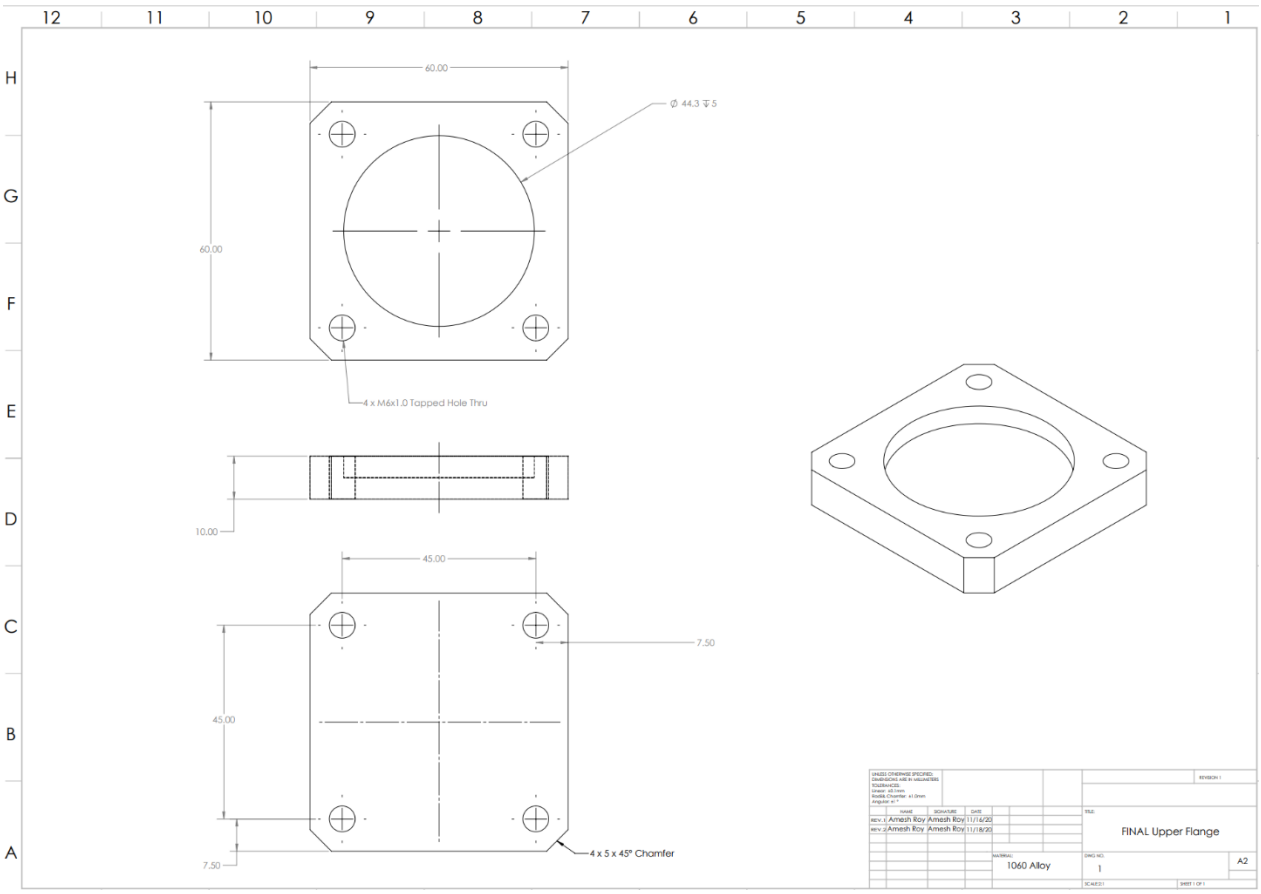

Figure 41: Upper Flange

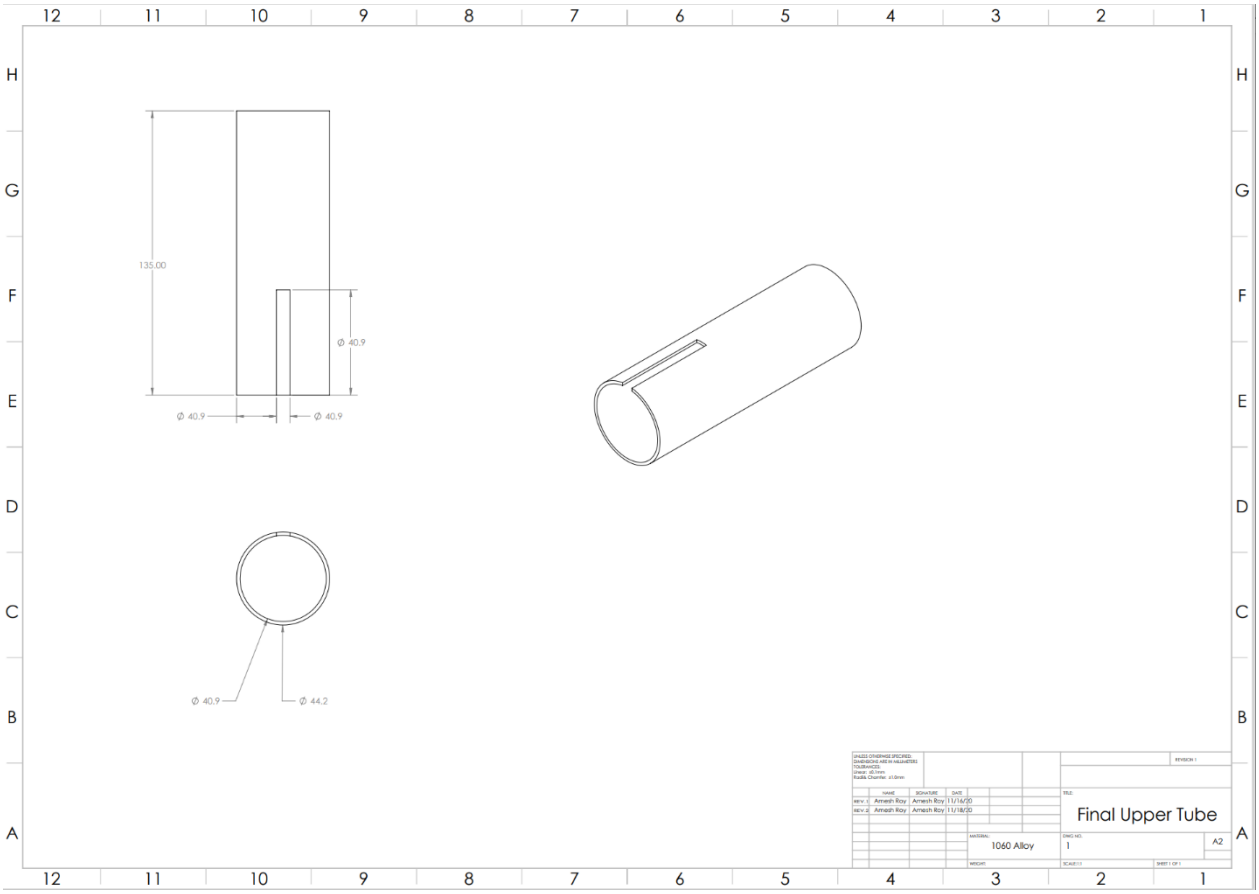

Figure 42: Upper Tube

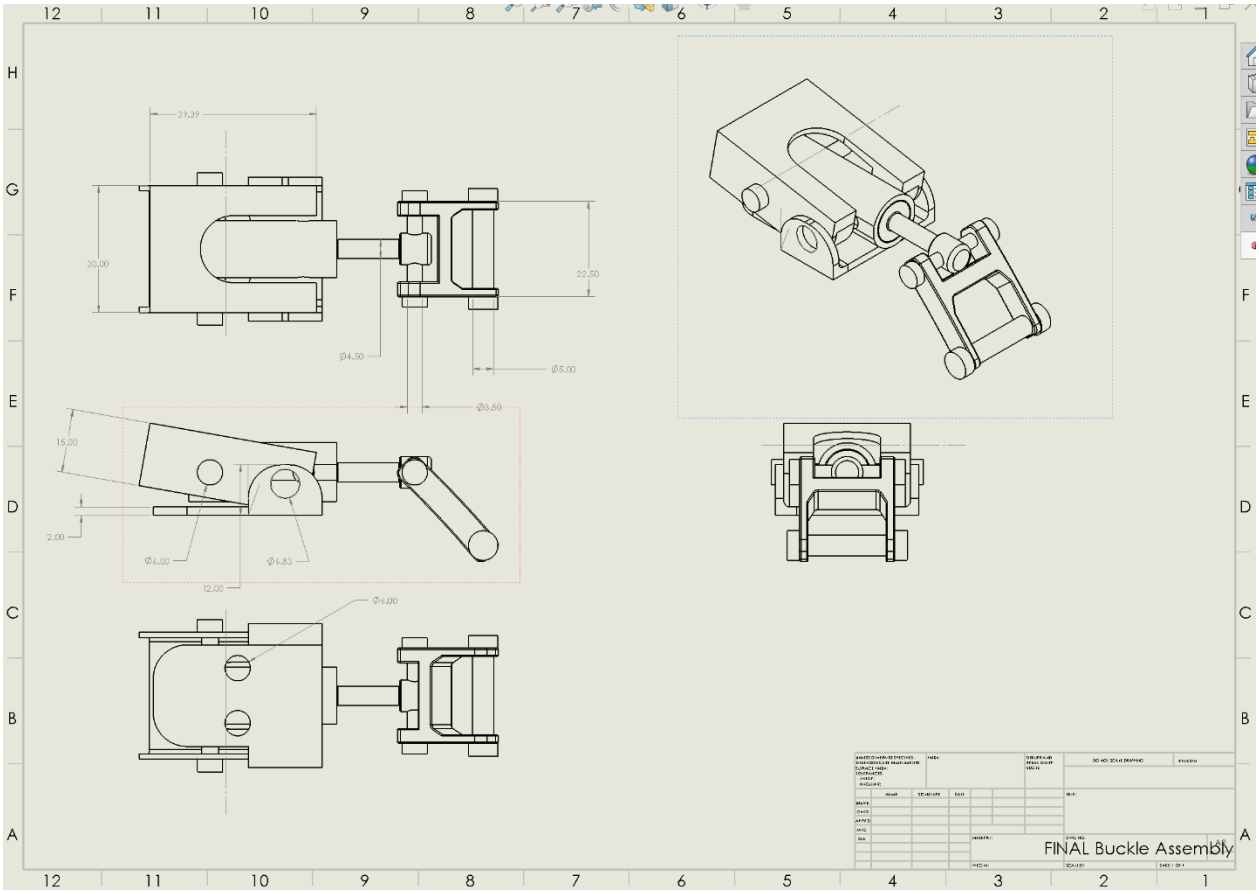

Figure 43: Mechanical Buckle Assembly

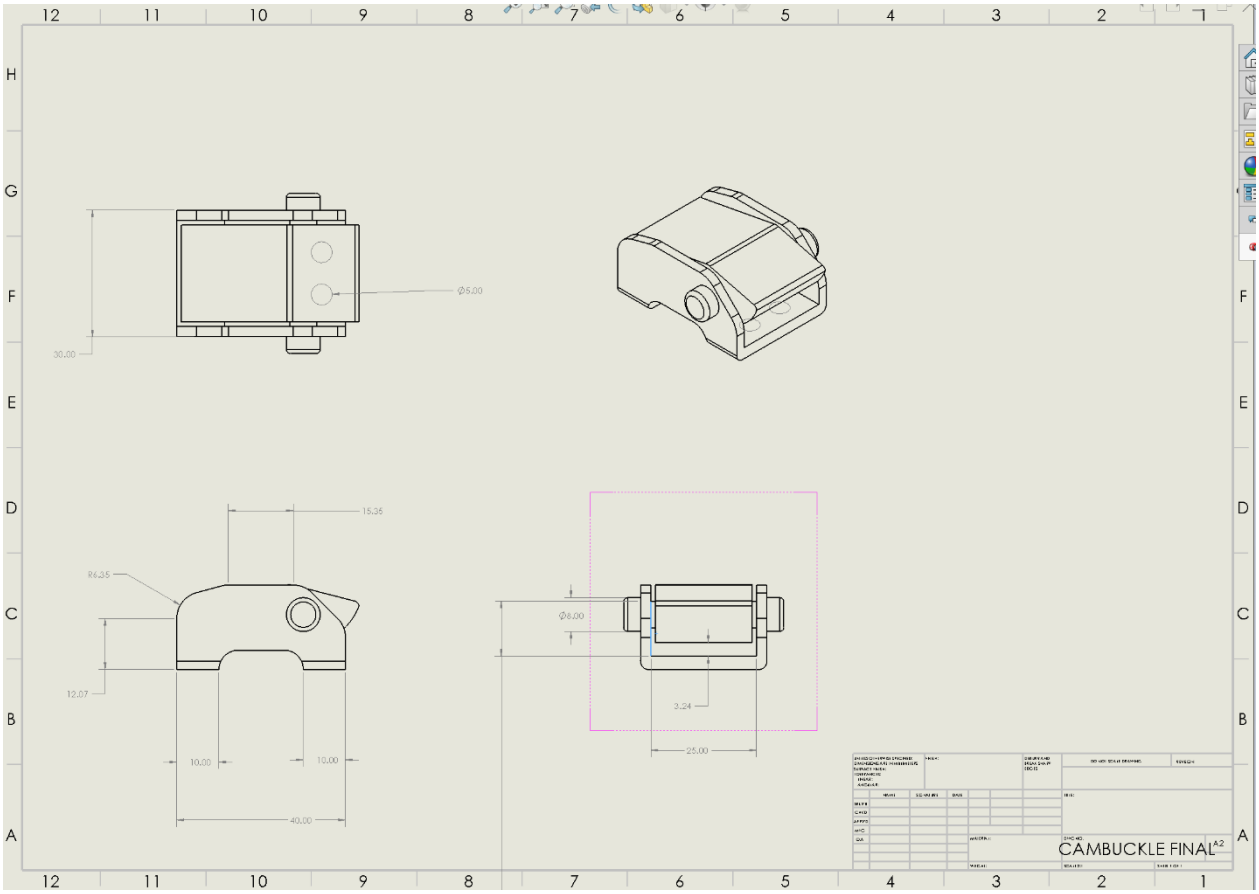

Figure 44: Cam Buckle Assembly

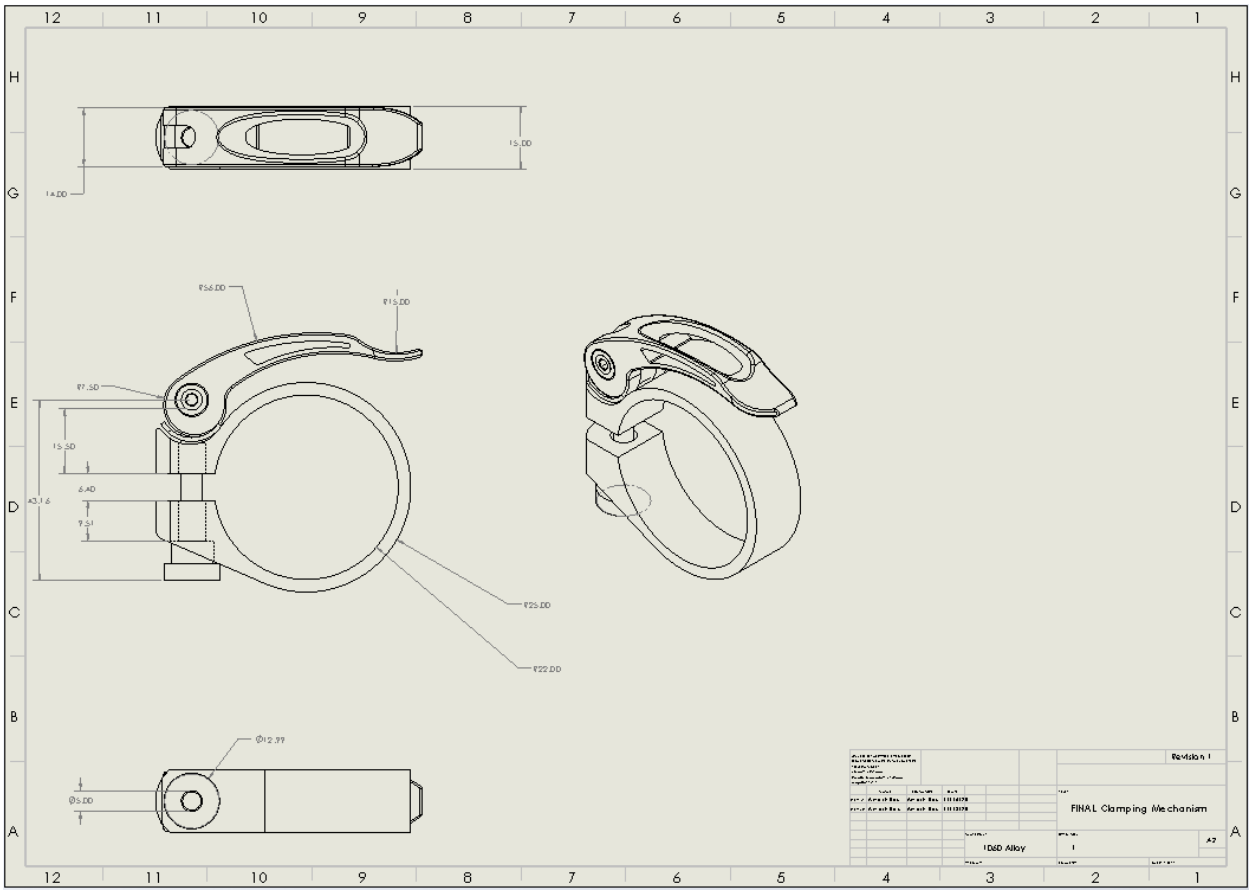

Figure 45: Clamping Mechanism

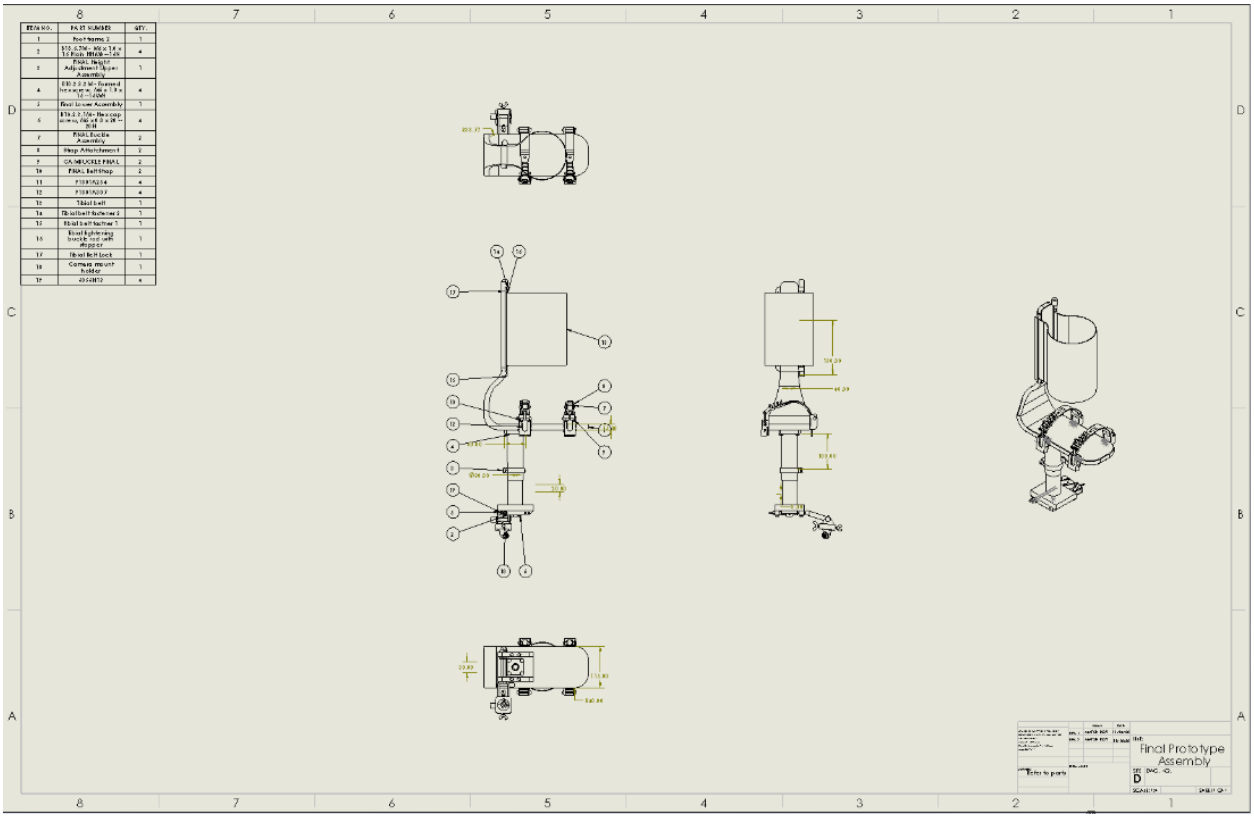

Figure 46: Final Prototype

Appendix B – Bill of Materials

ITEM NO.	PART NUMBER	Material	QTY.
1	Foot frame 2	1060 Alloy	1
2	B18.6.7M - M6 x 1.0 x 16 Plain HHMS --16N	Alloy Steel (SS)	4
3	FINAL Height Adjustment Upper Assembly	Refer to Assembly	1
4	B18.2.3.2M - Formed hex screw, M6 x 1.0 x 16 --16WN	1060 Alloy	4
5	Final Lower Assembly	Refer to Assembly	1
6	B18.2.3.1M - Hex cap screw, M5 x 0.8 x 20 --20N	Alloy Steel (SS)	4
7	FINAL Buckle Assembly	1060 Alloy	2
8	Strap Attatchment	1060 Alloy	2
9	CAMBUCKLE FINAL	1060 Alloy	2
10	FINAL Belt Strap	Woven Fabric	2
11	91801A254	Alloy Steel (SS)	4
12	91801A307	Alloy Steel (SS)	4
13	Tibial belt	Woven Fabric	1
14	Tibial belt fastener 2	1060 Alloy	1
15	tibial belt fastner 1	1060 Alloy	1
16	Tibial tightening buckle rod with stopper	1060 Alloy	1
17	Tibial Belt Lock	1060 Alloy	1
18	Camera mount holder	1060 Alloy	1
19	6056N13	Alloy Steel (SS)	4