Final Design Report

Team Mountain Arm

Conner Magnuson - cmagnu01@calpoly.edu
Marco Lopez - mlope106@calpoly.edu
Jordan Ambrose - joambros@calpoly.edu
Amanda Lingle- alingle@calpoly.edu
# Table of Contents

<table>
<thead>
<tr>
<th>Section</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive Summary</td>
<td>Page 3</td>
</tr>
<tr>
<td>Chapter 1: Introduction</td>
<td>Pages 3-7</td>
</tr>
<tr>
<td>Chapter 2: Background</td>
<td>Pages 7-13</td>
</tr>
<tr>
<td>Chapter 3: Design Development</td>
<td>Pages 13-20</td>
</tr>
<tr>
<td>Chapter 4: Description of the Final Design</td>
<td>Pages 21-26</td>
</tr>
<tr>
<td>Chapter 5: Product Realization</td>
<td>Pages 26-32</td>
</tr>
<tr>
<td>Chapter 6: Design Verification</td>
<td>Pages 32-38</td>
</tr>
<tr>
<td>Chapter 7: Conclusions and Recommendations</td>
<td>Pages 38-39</td>
</tr>
<tr>
<td>Acknowledgements</td>
<td>Page 39</td>
</tr>
<tr>
<td>Appendices</td>
<td>Pages 39-54</td>
</tr>
</tbody>
</table>
Executive Summary:

QL+ Challenger, US Navy Veteran, and transhumeral amputee Cassie Perando needed a way to backpack comfortably and independently while wearing a transhumeral prosthesis, as this is something that she enjoys doing often. The current prosthesis she wears causes pinching while wearing a backpack. To eliminate this issue, we decided to design and create a dynamic, pin-lock socket. This design decision allowed for a comfortable fit for Cassie that will not interfere with the backpack straps. As a secondary suspension system, we designed a sports bra with straps that attach to her opposing side and connect to the front and the back of the prosthesis’ socket in order to spread the force of the prosthesis over a larger surface area. To complete the prosthesis, the following components were purchased: E400 elbow, a NEXO Forearm Kit, a Quick Disconnect wrist adapter, and a stainless steel cable system. After testing individual components and obtaining feedback from Cassie, the components were assembled into a final product. The product had to be built separately due to COVID-19. The handoff of the product to Cassie was postponed due to a final fitting that needs to occur in person. This could not be performed during the end of spring quarter due to the pandemic, but is expected to occur in mid-June. Overall, with the successful manufacturing of the final product, regardless of challenges stemming from the pandemic, we were able to meet our engineering and customer requirements, while keeping the cost low.

Chapter 1

Introduction:

The proposed project, a backpacking-compatible transhumeral prosthesis, was led by the Cal Poly senior design team “Mountain Arm,” and sponsored by Quality of Life Plus (QL+). QL+ is a nonprofit organization that facilitates the innovation of new devices to help aid America’s patriots, ranging from those who have served in the military to first responders. QL+ finds these patriots in need or “challengers” as QL+ calls them, and then partners with different universities such as Cal Poly in order to have student projects to create adaptations or devices to meet the challenger’s needs. QL+ has found the challenger Cassie Perando, a US Navy Veteran, and has sponsored team Mountain Arm to head the project Cassie has created.

Cassie is a left-transhumeral amputee (above the elbow amputation) who uses a body-powered prosthesis. This means Cassie uses shoulder movements and arm flexions to lock her prosthesis’s elbow and to open and close the metal hook, or terminal device, attached at the end of her prosthesis. Living in Oregon, Cassie enjoys going backpacking outside. A problem for Cassie when she backpacks, is that her backpack strap rubs and gets pinched at her shoulder where the backpack meets the attachment of her prosthesis. Since her prosthesis is body powered, it is important that the strap does not get in the way of her movements. Our goal was to build a new prosthesis that changes how she attaches it to her arm so that it does not get in the way of her backpack.

Additionally, Cassie’s terminal device on her prosthesis (the component that replaces her hand) is not designed for fine motor skills, which makes it difficult for Cassie when she backpacks to tie knots for her fishing line or for her to use zippers to get in and out of her tent. Originally, our additional goal was to be
able to design a modified terminal attachment for Cassie’s new backpacking prosthetic that allows her to perform fine motor skills such as these. However after consulting with the QL+ provided prosthetist Tim Bump and local prosthetist Matt Robinson, the scope of our project would have been too large if our team focused on both the arm attachment to the residual limb and designing a terminal device.

Based on the fact that we only had nine months to design, build, and test our device, we came to the conclusion to focus on designing the socket and attachment of the prosthesis to Cassie’s residual limb as this solves the main problem of Cassie’s ability to backpack while wearing a prosthesis. We additionally built the rest of the arm portion of the prosthesis using a purchased kit that is available through the company Fillauer.

This project not only could have an impact on Cassie’s lifestyle, as this device is meant to help her when she is out backpacking, but has the potential to affect other amputees' lives as well. The design of this device could be transferable to other amputees who also enjoy similar activities in the outdoors as Cassie does.

Team Mountain Arm is made up of four Cal Poly engineers who have partnered with QL+ and Cassie for their senior design project class. This project took place over the span of one school year at Cal Poly, or 9 months.

The first quarter of the school year, the team learned more about Cassie’s needs and problems, began background researching devices that already exist, learned to work as a team, brainstormed design ideas, and decided on a conceptual design. Winter quarter was spent finalizing this conceptual design and beginning the process of building our prototype. Spring quarter was spent building the prototype, testing and reiterating the design, and finalizing the prosthesis to meet Cassie’s needs of being compatible with her backpack.

Objectives:

Our primary objective was to design a prosthetic arm that would improve the quality of life for our client, Cassie Perando, by enabling her to engage in her pastime of backpacking comfortably and independently. More specifically we intended to improve comfort around the shoulder, be compatible with multiple backpacks, lightweight, customized to her, and stay within the allocated budget.

<table>
<thead>
<tr>
<th>Spec. #</th>
<th>Parameter Description</th>
<th>Requirement of Target (units)</th>
<th>Tolerance</th>
<th>Risk</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Price</td>
<td>5,000 USD</td>
<td>Max</td>
<td>L</td>
<td>S</td>
</tr>
<tr>
<td>2</td>
<td>Shoulder Lateral Range of Motion</td>
<td>90 Degrees</td>
<td>Min</td>
<td>M</td>
<td>S, I</td>
</tr>
</tbody>
</table>
The range of motion requirements are based on minimum values for an adult female [1]. We believe that the range of motion of the elbow is at low risk to meet compliance, whereas the shoulder is at a slightly higher due to inherent risks involved with this movement and restriction of motion through use of straps. The range of motion measurements may be tested with low precision by using a protractor.

The anthropometric requirements for forearm length, forearm circumference, wrist circumference, and shoulder to elbow length requirements are all based on measurements of Cassie’s right arm and residual left limb. These requirements are included in order to balance the symmetry between her right arm and the prosthesis. The circumference requirements are set as max in order to ensure that clothing that fits over her right arm will also fit with her prosthesis. These requirements were low risk due to our ability to design around Cassie’s dimensions and make modifications where necessary if dimensions are out of spec when we have the final meeting with Cassie.

The force required to accidentally remove the device has been placed in the requirements in order to quantify the amount of force the prosthesis takes to slide off the residual limb. This is important because it would be very inconvenient for Cassie if the prosthesis was not adequately secured and fell off when picking up a heavy load. Originally to test this requirement, a 25 lb load would have been attached to the
prosthesis while the user wears it. If the prosthesis slides off while being worn, then it fails the test. There is a possibility when we perform the final fitting with Cassie, we will be able to perform this test.

Since the prosthesis will be used in a wet environment, sweat from exercise and/or potential rain/humidity while backpacking, it is important to put requirements on the corrosion rate of the materials used in manufacturing the prosthesis. In order to verify this requirement, we chose materials based on tabulated data on corrosion rates.

The temperature operating range requirement is specified in order to give an upper and lower limit on the temperature of the working environment. Plastics and metals behave differently depending on the temperature they are working in. When plastics get cold, they become stiffer and easier to break. Furthermore, when metals vary in temperature, they change in size due to thermal expansion. Critical components such as hinges, rubber rings, and silicone sleeves can change depending on the temperature, so we want the device to work within the range of temperatures one would likely encounter while backpacking. To test this requirement, we had hoped to have put the finished device in an environmental chamber and check the performance of the hinges and plastic components at either extreme. However, due to COVID-19 this test could not be performed and have to instead rely on the research that we put into choosing materials that will work for the temperature range needed.

The weight of the prosthesis, minus the weight of the terminal device, has been set to a maximum value of 5 pounds. During our third meeting with Cassie, she informed us that her right arm weighs 7 lbs and her current carbon fiber prosthesis weighs about 5 lbs (with the terminal device). Cassie informed us that the lighter the prosthesis is the better, and since carbon fiber is not being used in this design, keeping the prosthesis under 5 pounds was a medium risk requirement. In order to test this requirement, we analyzed the weight of the prosthesis by designing in 3D CAD software, inputting material densities, and summing up total weight. Furthermore, once the final prosthesis was manufactured, we were able to weigh the prosthesis.

**Management Plan:**

For this project, Amanda is the main contact point for both Cassie and Vanessa. As a whole, the work has been evenly distributed between group members. Fall quarter we all worked together on everything in order to be cohesive in our design decisions. In order to efficiently use the time allotted to us for this project, the work on the secondary attachment and socket design was split at the beginning of winter quarter. Amanda and Jordan’s primary task was to work on the secondary attachment while Conner and Marco were tasked to finish working on the socket design. This does not mean all work was separated, the team still worked together on major decisions and provided support for the other duo’s task.

The number of hours our team invested in the project varied from week to week, depending on the need. Our minimum hours invested per week were 6 hours, varying to a maximum of 12 hours per week. Every group member was expected to attend all class periods, as well as to attend and be timely to all planned group meetings outside of the classroom. Group meetings outside of our regular class time were planned and communicated throughout the quarter but would normally take place on Tuesdays from 11 am to 12 pm or on the weekends, if mutually agreed upon. In addition to this, we had biweekly meetings with
our sponsor for updates. With Cassie having limited cell service, contacting her was always a challenge. We tried to speak with Cassie biweekly Fall quarter when design decisions were being made, but it was dependent on her availability. Winter quarter we met only a couple of times with Cassie and in spring quarter we mainly communicated with Cassie through our QL+ representative, Vanessa Salas. It was less necessary to gain feedback from Cassie spring quarter as we had determined the customer requirements and therefore focused on building the prosthesis.

Due to COVID-19, our timeline for spring quarter got shifted, and relatively simple tasks became more difficult. With everyone separated across the state, Conner became in charge of manufacturing the prosthesis at home while Amanda sewed the secondary attachment in SLO. We all continued to meet weekly over Zoom to work on the project and discuss decisions that needed to be made.

Chapter 2

Background:

After looking at different existing products that also attempt to create compatibility between backpacks and upper-limb prosthetic devices, it was evident that there have been a variety of designs. The primary method for securing a body-powered, above-elbow prosthetic device is by different strap/harness techniques, according to Lt. Robert J. Pursley’s “Harness Patterns for Upper-Extremity Prostheses” article. The first harness type is the Figure 8 Harness exemplified in Figure 1, which our challenger Cassie Perando currently utilizes.

![Figure 1: Figure 8 Harness for Upper-Limb Prosthesis [1]](image)

Advantages of this harness is that it is a very easy-to-use dual control system, meaning that a simple arm flexion is able to control and operate the terminal device. It has a very functional, yet simple design,
consisting of a lateral support strap that rests above the cross on the user’s back. The second above-elbow harness type found is the Chest-Strap Harness, shown in Figure 2.

Figure 2: Chest Strap for Upper-Limb Prosthesis [1]

This type of harness is recommended for lifting heavy loads, which could be seen as an advantage when backpacking. However, chest straps tend to be less secure, causing movement that results in rubbing and discomfort. The last type of harness researched is the Above-Elbow Triple Control Harness, shown in Figure 3.

Figure 3: Above-Elbow Triple Control Harness for Upper-Limb Prosthesis [1.1]

This harness uses arm flexion to produce flexion of the forearm, which then allows for arm extension to provide elbow-lock control. Then, extreme flexion of the shoulder, which could be as simple as a shoulder shrug, allows for operation of the terminal device. An advantage of this type of harness is the ability to
control and operate the terminal device without having to first lock the elbow, and a disadvantage of this type of harness is the complexity and difficulty of the fabrication of this device [1.1].

After speaking with Cassie, she suggested trying to create a prosthesis design that includes a pin lock system, to replace the need for a harness. However, prosthetist Matt Robinson recommended against getting rid of the harness or any other secondary system of attachment entirely. Instead, we decided to use a secondary system of attachment that utilizes a sports bra that attaches to the prosthesis. Cassie specified that she does not need an active arm, she only needs it to be passive, so this eliminates the need for a cable that actuates her terminal device. After speaking to Cassie winter quarter however, we realized some problems might occur if we choose to get rid of it, and so we decided to add the cable. The other cable on her prosthesis locks and unlocks her elbow which she already pulls on manually, so we changed that cable to a pull tab. The usage of the pin lock system is much more common for lower-limb prostheses than upper-limb prostheses. An example of a pin lock system is shown below in Figure 4.

![Figure 4: Pin Lock System General Example [2]](image)

The pin lock system works by consisting of a drawdown clutch-lock and cushioned end-pad. The pin lock interfaces with a locking liner, which is placed into the distal end of the socket, to ultimately create a connection between the rest of the prosthetic arm and the user’s residual limb. It can then be tightened down with the shuttle-lock and will remain securely engaged, until the user presses the shuttle-lock to release the attachment [2.1].

Advantages of the pin lock system include that it is a secure and simple method of suspending the prosthesis, that there is no need for a suspension sleeve, it is less cumbersome than other forms of prosthesis suspension, and that many pin locks are able to provide audible feedback when engaging the locking system which reassures the user that the prosthesis is securely attached. Disadvantages of this type of system include that it can cause distal tissue stretching and that some users may struggle with aligning the pin with the plunger pin hole [2].
A product that seemed applicable to the specific Backpacking Prosthetic project is Ottobock’s Body Harness for trans-humeral amputees. This prosthetic device uses a body harness that looks very similar to backpack straps, shown in Figure 5.

![Ottobock’s Body Harness for Upper-Limb Prosthesis](image_url)

According to their website, it is the “world’s first soft harness for above-elbow fittings with myoelectric or passive elbows, features an arm sling and sleeve that are completely removable” [3]. It allows for a more natural body-powered movement and higher individual control. This could relate to a possible solution to Cassie’s proposed project because the straps of this prosthetic harness relate so closely to those of a backpack.

In obtaining background information, it was also helpful to get more information from Cassie about her current prosthesis and terminal device, both of which are shown below in Figure 6. Between her prosthesis and the terminal device, there is a joint that allows for wrist flexion. In addition to this, there is also a bump switch located below the elbow that rotates the wrist of the prosthesis. As was stated earlier, after speaking with Cassie further, it was evident that the main difference that she would like to see in her new prosthesis compared to her current one is for it to be a pin lock system.
After changing the scope of the project to focus primarily on the attachment system and talking to QL+’s recommended prosthetist Tim Bump, we found Fillauer’s NEXO line that would allow us to purchase a kit to eventually build the prosthesis, rather than trying to redesign and recreate everything ourselves. All of the NEXO systems are very simple to build and are 50% lighter than existing prostheses. The NEXO Transhumeral system, seen in Figure 7, allows for an easy connection to a variety of different elbows and includes a damping ring to reduce vibration [4].

There are a total of four main NEXO Transhumeral Kits. The NEXO Kit for Medium Elbows has two options-- the Kit with the Quick Disconnect Wrist and the Kit with the Friction Wrist. The NEXO Kit for Large Elbows has the same two kit options with the Quick Disconnect Wrist and the one with the Friction Wrist. There are also elbows available for purchase, such as the E-200 Medium Elbows (2.4 inch diameter) for NEXO with 11 and 9 locking positions, the E-400 Large Elbows (2.8 inch diameter) for NEXO with 11 and 8 locking positions, and the E2 Electric Elbow with a 2.4 inch diameter or a 2.8 inch diameter [4].

Another important part of the project is choosing between a dynamic socket and a static socket. The socket is the part of the prosthetic device that connects the residual limb to the other components of the
prosthetic arm in this case. It is a very significant part of the decision matrix because the socket-residual limb interface, especially the pressure and force distribution, can have a tremendous effect on patient satisfaction and function. A dynamic socket, shown in Figure 8, is adjustable to volume changes and consists of an elastomeric liner that is embedded with a multitude of sensing elements that continuously monitor the socket fit and fluidic bladders/channels that allow for an incompressible fluid to move into or out of the bladders to achieve the desired fit [5]. In comparison, a static socket is more rigid and non-adjustable, making it potentially less comfortable for the user, especially during activities such as exercise in which volume changes in the limbs are inevitable.

![Dynamic Socket Diagram](image)

**Figure 8: Example of a Dynamic Socket with Elastomeric Liner [5]**

In addition to researching a variety of designs, there are also many standards and codes that need to be reviewed and considered for this project. Of the World Health Organization’s *Standards for Prosthetics and Orthotics*, [6] the applicable standards for this project that we will address include but are not limited to:

*No. 15: Strategies for raising awareness about prosthetics and orthotics services should be established, including rights-based, social and economic arguments.*

*No. 18: International standards should be used for national classification of prosthetic and orthotic products.*

*No. 24: Affordable prosthetic and orthotic products that are cost–effective, of good quality and context appropriate should be developed and made widely available.*

*No. 32: Prosthetics and orthotics service units should have at least one prosthetist and orthotist to supervise and guide clinical and technical work.*
No. 39: Service users should be given the opportunity to choose their service provider and technology, including components and materials, according to their need, among the options available in the country and the limits set for financing or reimbursement.

No. 43: Maintenance and repair services should be an integral part of a prosthetics and orthotics service delivery system.

No. 48: Prosthetics and orthotics service providers should define and adhere to a plan for equipment maintenance and replacement.

No. 56: Users or caregivers should make the final decision about the acceptability of the fit and function of the prosthesis or orthosis.

No. 58: Prosthetics and orthotics service users should be followed up regularly.

Chapter 3

Design Development:

Following the Project Requirements Document due in early fall, Team Mountain Arm continued to meet with Cassie to finalize the specifications that she wanted for her prosthesis. Cassie expressed that she was content with using her right arm to manually adjust the elbow, wrist, and terminal device of the prosthesis. Manual adjustment eliminated the need to introduce a cable system to our prosthesis, however as stated above, later conversations led us to realize a cable system was still needed. Team Mountain Arm conducted further research on the following three areas: possible ways a transhumeral prosthesis can be attached to the body, possible materials available that would best suite the specifications (ex. a lightweight material for the socket of the prosthetic), and the terminal device was looked at with emphasis on dexterity and grip strength. We met with Tim Bump, the QL+ prosthetist, and Matt Robinson, a local prosthetist, to explain our project scope and goals. It was highly suggested that we limit the scope of our project. We decided to focus solely on designing the attachment and then buying the elbow, forearm, and possibly the terminal device. After research and idea generation, we came up with 6 top concepts for attachment (in detail after Figure 11). Matt Robinson also suggested having a secondary suspension system, so we limited the options to either a vest or a sports bra. We presented our conceptual design to the team advisor, sponsor, and to Cassie. We worked on finalizing different last aspects of our design winter quarter which will be described below. Following approval, began ordering parts at the end of spring quarter. The prototype was manufactured and assembled separately due to COVID-19. Conner picked up the pulled sockets and parts that had been ordered to SLO where he took them back home to finish manufacturing and assembly. Amanda sewed and assembled the secondary attachment at her home in SLO. The team will be meeting Cassie in SLO for a final fitting mid-June where the final product will be given to Cassie.
Figure 9: Project Flow Chart
The fitting process of the socket is part of the project (circled in Figure 9) that is started before the finalization of the design concept. Traditionally, sockets are made by a series of positive and negative molds which are used to form the socket shape. We began this process by 3D scanning Cassie’s residual limb and made a positive mold of her current pin lock socket that she uses for swimming. This positive mold was then wrapped with plaster to form a negative mold. Later, this negative mold was filled with a plaster mixture to form a positive mold representing the shape of the residual limb plus the silicone liner. The positive mold will then be altered by adding or removing plaster in order to decrease or increase the pressure distribution in certain areas. Once an acceptable shape was achieved and deemed by the prosthetist’s experience, a clear thermoplastic socket was manufactured.

Once the fabrication of the test socket was complete, we had planned to ship the diagnostic socket to Cassie and receive feedback to determine whether socket modifications and adjustments need to be made. However, after discussing with local prosthetist Matt Robinson, this was deemed an unnecessary step because the mold was based exactly on her current pin lock socket. Based on the visual judgment of the prosthetist, and feedback from Cassie, several final dynamic sockets were pulled. Multiple were made in order to perform testing.
We limited the possible ways to attach a prosthesis into 6 top concepts. The top concepts chosen were: a pin lock system (Figure 11A), a lanyard system (Figure 11B), a squeeze ratchet system (Figure 11C), a horizontal pin lock system (Figure 11D), a removable harness attachment system (Figure 11E), and a socketless socket system (Figure 11F). For the pin lock system (Figure 11A) description, refer to Figure 4 in the background section. The lanyard system (Figure 11B) is similar to the pin lock system, except instead of using a pin to lock the prosthesis into place, it uses a strap. The squeeze ratcheting system (Figure 11C) uses knobs located at the bottom of the socket to adjust the size until a proper fit onto the residual limb. The horizontal pin lock system (Figure 11D) is also similar to the regular pin lock system, but instead of having a pin (attached to a liner) latching onto the locking mechanism (bottom of the socket), the pin and locking mechanism is switched. The locking mechanism is attached to the liner where it can be inserted at the bottom of the socket which would then allow for a pin to be inserted on the side of the socket and through the locking mechanism. The removable harness system (Figure 11E) is just a harness with an easily removable attachment point to the socket of the prosthesis. The socketless socket system (Figure 11F) is a highly adjustable and breathable socket that uses many straps to tighten or loosen the socket onto the residual limb.

With these 6 concepts, we developed a pugh matrix (located in Appendix B) comparing them to Cassie’s current prosthesis. The pin lock system came out to be the clear winner. The lanyard system was a close second, but the only problem was that it would be slightly more difficult to put on, which could be an annoyance after putting on the prosthesis several times. For the horizontal pin lock, we would have to
make our own liner with the locking mechanism attached to it. However, Matt Robinson highly suggested against developing our own liner, which thereby eliminated this concept. The removable harness attachment system was also not chosen because that would end up leaving the prosthesis as a hanging weight, which is not recommended. Both the squeeze ratcheting system and the socketless socket were examples of dynamic sockets. We really liked the idea of the dynamic socket, so we decided to incorporate an adjustable socket into our design which will be described in more detail below.

**Chosen Attachment System**

After going through the decision process as explained prior, we decided that the best attachment system to Cassie’s residual limb would be the pin lock system. This system would solve the problem of getting in the way of the backpack strap because the prosthesis won’t go up and over her shoulder the way her current prosthesis does. Instead, the prosthesis won’t ride quite as high up her arm and shoulder, thus the backpack strap won’t get caught.

Although other design attachment systems we came up with would also solve this problem, what aided in our decision to go with the pin lock, was the fact that Cassie already uses a pin lock system. She uses this system for another one of her specialized prostheses (for swimming), and she prefers this attachment system over her current attachment system because the pin lock is more comfortable to wear. This made the pin lock the ideal choice because not only does it solve the problem of backpacking, but our user already knows how to use this system and is comfortable using it.

![Figure 12: Cassie using her Swimming Pin-Lock Prosthesis](image)

Initially, our main concern with the pin lock design was how well it would perform when she is sweating from working out. When she is backpacking, she will be sweating, and the water volume in her arm will fluctuate. Since the pin lock system uses friction between the wearer’s skin and the silicone sleeve to stay attached to the residual limb, introducing sweat could possibly affect the friction which could result in the prosthesis falling off (see Figure 13). However, after consulting Cassie, we discovered that she currently
wears her pin lock system while she runs because it’s more breathable than her regular day-to-day prosthesis.

Figure 13: Friction Forces Between Skin and Silicone Liner [9]

Secondary Suspension

In addition to the primary attachment, we decided to incorporate a secondary suspension system to be attached to the prosthesis. After talking with local prosthetist Matt Robinson, he said we need a secondary suspension system in order to ensure Cassie’s prosthesis isn’t just a “hanging weight” when she is backpacking. This will help to redistribute the force from the prosthesis to more of her body instead of just her shoulder and residual limb. We debated designing either a sports bra or breathable vest that Cassie will wear for this attachment.

After considering Cassie’s needs and the overall needs for the project, it was concluded to move forward with a sports bra design. This decision was made for several reasons. First off, Cassie already wears a sports bra while backpacking. The best course of action when designing is to minimize components and keep it as simple as possible. This makes it easier on the customer and also reduces risk of misuse and breaking of components. By going with a sports bra design instead of a vest, it is one less thing that Cassie has to be worried about while gathering all she needs to backpack. Additionally, it is much simpler to modify a sports bra. We could not find any vest designs that were easily modifiable to the needs we required the design to meet. Most were either too bulky or got in the way of the backpack straps. The sports bra on the other hand is so streamlined to the body, it doesn’t get in the way of the backpack straps. Based on this line of reasoning, our secondary attachment incorporates a sports bra harnessing design. Details on the sports bra/strapping design will be touched on further in the ‘Final Design’ section of the report.
Figure 14: Example of Secondary Suspension Vest

Socket Type

Our team made the decision to move forward with a dynamic socket. As explained prior, dynamic sockets are adjustable which makes it the ideal choice for our design for several reasons. Since Cassie lives in Oregon and we are located in California, it makes it difficult for us to meet with her often enough to make sure the socket has a perfect fit. With the dynamic socket this will ensure Cassie has a fit that she likes and will be happy wearing because she can adjust it to her preference.

We worked winter quarter to finalize the design for our socket. We researched different thermoplastics and other materials to make the socket out of. We additionally researched which adjustment system we wanted to use.

Socket Design - design decision: Adjustable Panels vs QuickFit Straps

There are typically two different ways to enable adjustment of a dynamic socket. First there's the adjustable panel method, where panels are cut out of the socket and cables are laminated within the carbon fiber layup as seen and the left side of Figure 15. Second there’s the adjustable strap method, where the socket is divided up into multiple moving parts and adjustment is made with straps (see right side of Figure 15). We ultimately decided to pursue the strap method to reduce the possible modes of failure and to increase the ability to swap out parts for testing repairability.
For the type of adjustable strap, we decided to go with the Click Medical QuickFit strap. We chose this option because it's designed to be operated by one hand, designed for small 1mm adjustments, and are able to withstand loads of 150+ lbs (see attachment E). These straps are often used in orthopedics for making quick adjustments as seen in the right side of Figure 16. QuickFit straps come in three different widths: 1, 1.5, and 2 inches. After consulting with prosthetist Tim Bump, we decided to go with two 1 inch straps.
The entire device is depicted in Figure 17, which shows all of the necessary parts and how they fit and work together. First, it shows the secondary suspension system depicted as a reinforced sports bra with a strap that connects to the socket in the front and back. Additionally, it shows a dynamic socket with two adjustable ratchet knobs similar to that of the Boa® ratcheting system [10]. Lastly, the figure shows the Fillauer NEXO [4] transhumeral kit along with a Fillauer E400 elbow [11]. The E400 elbow was chosen because Cassie currently uses the elbow and favors its 11 manual adjustment options.
The socket is made out of Ottobock Thermolyn PP-C thermoplastic. There are two attachment points at the top of the socket to connect our secondary suspension system with the prosthesis. There are three cutouts in the inner socket along with 2 QuickFit straps to allow for dynamic adjustment of the socket. A Fillauer Shuttle Lock is implemented at the bottom of the static socket to allow for the pin and liner to firmly attach to the socket. The static socket is secured to the E-400 elbow with a customized ¼-20 chicago bolt and nut (see figure 19). This bolt also allows for rotational adjustment of the socket relative to the elbow for final fitting of the prosthesis. To lock the bolt in place, a belleville washer was placed under the bolt.
The E-400 and NEXO transhumeral forearm kit was purchased from Fillauer. The NEXO transhumeral kit consists of a left and right saddle upright, an upright connector, dampening ring, 5 PEEK rods, and a Quick Disconnect wrist. Details on both the E-400 elbow and NEXO kit are in Appendix E.

Secondary Attachment Design

The secondary attachment consists of several components: a Nike sports bra (size large), a strap, velcro and a buckle. Our design will have a strap riveted to the top back portion of the socket. The strap will then be pulled across the back to Cassie’s right side. Here, the strap will be velcroed to the bottom right side of
the sports bra. The strap will continue to be wrapped and velcroed around the sports bra to the front center point of the sports bra. The strap is then twisted and pulled up and diagonal to the left side of her body. A buckle will be permanently attached to the front portion of her prosthesis. The strap will be through the buckle permanently. The strap can then be pulled back down on itself to the ideal tightness and velcroed back to the strap. We are additionally incorporating a stainless steel cable system so Cassie can actuate her terminal device and easily change elbow positions. The cable system is currently not built into our final prototype because the cable needs to be attached in person as mentioned earlier. Cassie is planning to make a trip mid-June so the cable system will be incorporated at that time. A list of all components and sizes can be referred to in Appendix F.

Cost breakdown

QL+ did not give us a maximum budget, but we planned from the beginning of the project to keep the costs below what is currently available on the market for a similar device. In our research, we’ve seen that a body powered prosthesis will range anywhere between 5,000 to 10,000 US dollars with insurance agencies fronting the cost. Since we did much of the work ourselves, this was placed at low risk and compliance will be based on similarly existing designs. Our preliminary cost estimate came to $2000 (can be seen in Appendix D), which is well below the requirement of $5,000.

Additionally, we received an educational discount from Fillauer for the E-400 elbow and the NEXO kit, which happened to account for a bulk of the cost. We received the E-400 elbow for free, leaving us to only need to purchase the NEXO Kit and the Quick Disconnect Wrist. This then left our total cost at $1339.60. A breakdown of the final cost for our project can be seen in Appendix J.

Overall, keeping our costs low enables the QL+ organization to fund more projects to help more military vets. Since we made only one prosthetic arm as this is completely customized to Cassie, there was no need to worry about mass manufacturing costs. Additionally, prostheses in general cannot be mass manufactured as each prosthesis has to be tailored to the wearer’s exact fit.

Material, Geometry, Component Selection

Socket

As stated before in the background, we built a dynamic socket with a pin lock and liner. Additionally, we chose to use QuickFit straps for making adjustments. With this in mind, we needed to be able to select a material that would be best suited for the socket.

Thermoplastic sheet materials are typically more widely used in the field of orthopedics technology. Additionally, ratchet tightening mechanisms like the Click Medical QuickFit straps as seen in Figure 17 are often used on orthopedics. The group of polyethylene (PE) and polyproplyenes (PP) are particularly well suited for the fabrication of prostheses and orthoses [16]. These materials are lightweight and offer long-term functionality in orthopedics technology as well as prosthetics.

Polypropylene is characterized by low density and excellent stiffness [13][14]. Due to its high elasticity and good strength, this type of plastic material is used very frequently. However, it is difficult to process
because of its narrow temperature forming range and sensitive surface in a thermoplastic state. To achieve
good results, high performance heating devices such as infrared ovens and precision application
techniques are required [15].

We then needed to decide between the two main types of polypropylenes: polypropylene copolymer
(PP-C) and propylene homopolymer (PP-H). PP-H has a high strength-to-weight ratio and is stiffer and
stronger than the copolymer [13][14]. These properties combined with good chemical resistance and
weldability make it a material of choice in many corrosion resistant structures. PP-C is a bit softer but has
better impact strength. It’s tougher and more durable than propylene homopolymer[13][14]. We
ultimately decided to go with Thermolyn PP-C because it tends to have better stress crack resistance and
greater toughness at lower temperatures than homopolymer at the expense of a small reduction in other
properties [15].

Secondary Attachment (Sports Bra)

For the sports bra, we chose a large Nike Sports Bra (seen in Figure 17). This specific sports bra was
chosen from the market because this is an item that Cassie currently wears often and is very comfortable
with. The strap will be a Nylon Climbing Webbing Strap with Nylon Thread. This strap is made for rock
climbing and is extremely durable yet smooth against the skin. The nylon component of the strap allows it
to be elastic enough to accommodate for the prosthesis, but it will not overstretch to the point where it is not
able to appropriately support the prosthesis from her opposing side. The strap is also outdoor compatible.
The strap will be attached to the sports bra through the use of velcro. Velcro is easily incorporated into the
sports bra fabric and was recommended to us by Matt Robinson, the local prosthetist. Additionally a small
piece of vegetable leather will be sewn on the end of the strap that is riveted to the socket in order to
prevent fraying of the strap. The strap will be attached to the prosthesis using an 18-8 Stainless Steel
Anchor Plate 1 ¾” Webbing Width. This component and material were chosen because it is lightweight
and durable. The webbing width being 1 ¾” allows it to be able to effectively work with the 1 inch
climbing strap while also allowing for an adequate amount of clearance to ensure the two components
work together properly. A Stainless Steel cable system will additionally be incorporated once we have a
final fitting with Cassie.

Safety Considerations

There are a few potential hazards that have been taken into consideration throughout the development of
our design. The elbow joint, that will be purchased, has the potential to create a hazard to Cassie by
causing pinching. Any risk involved with the elbow pinching is something that Cassie already deals with
with her current prosthesis, so to address this hazard, we will ensure to remind her of this potential issue
so she is aware of it when using our designed device. In addition to this, the prosthesis attachment system
could potentially be a hazard in the way that the edges of the socket could potentially be sharp. We will
address this issue by doing our best to sand and soften down any sharp edges, especially those that will be
in contact, or very close to, Cassie’s skin. The last potential hazard we took into consideration while
brainstorming this design is in regards to the materials being involved with the manufacturing of the
prosthesis. After talking to Cassie, we have been able to confidently conclude that she does not have any
known allergies to the materials we will be using. There are also a few potential hazards in using the
one-inch Quick Fit straps addition to aid in the socket’s fit. The straps are adjustable to tighten and loosen as necessary to ensure a perfect fit. Tightening the straps too much could lead to discomfort for Cassie’s residual limb. In addition to this, straps could also have the potential to snap, causing potential discomfort. A safety consideration regarding the sports bra component is potential discomfort due to the sports bra being too tight and rubbing. We will ensure to thoroughly explain all of these safety considerations with Cassie so she is aware of the potential hazards while utilizing and wearing the prosthesis and additional components (Appendix H).

Maintenance and Repair Considerations

It is recommended that Cassie cleans the inside of the socket with either soap and water or alcohol cleaning swabs each day in order to prevent the socket from smelling and reduce bacteria from growing in the socket. If using an alcohol swab, it is recommended to let the socket fully dry before putting on to reduce drying out the skin on her residual limb.

In terms of maintenance, it is recommended Cassie stops by a prosthetist every 6 months for routine maintenance checks. There, a professional can make any minor adjustments as needed. This is standard procedure for any prosthesis. Additionally, if Cassie hears any squeaking or cracking, she should immediately go see the prosthetist. Majority of the socket parts will be under warranty and the prosthetist can quickly find a replacement part if that is the need. The quickfit straps could break from cinching too tight. We are purchasing extras for testing purposes and will give these to Cassie to use as a replacement if one of her prior straps break.

In terms of the sports bra, five modified sports bras were made for Cassie so in case she loses them or they wear out, she has plenty. It is recommended she wash the modified sports bras just like she’d wash a regular one as washer machine friendly velcro was used. Furthermore, an extra QuickFit strap will be included with the prosthesis in the event that one of the straps on the prosthesis fails.

Chapter 5

Product Realization

Manufacturing Process: Dynamic Socket

Our initial concept and prototype had a single thermoformed socket with cutouts to allow for adjustment. However, later we found out from Matt Robinson that polyurethane foam was unable to bond properly to the Thermolyn PP-C plastic, and therefore required us to have both a rigid static socket and a flexible dynamic socket.
Initially, we intended to process the thermoplastics at the Hanger Clinic in San Luis Obispo under the guidance of Matt Robinson using the following process [15]:

1. Place wet plaster cast in the oven.
2. Set the oven to recommended processing temperature for the thermoplastic sheet material.
3. After approx. 1 hour (infrared oven) – 1½ hours (convection oven) place the thermoplastic sheet material in the oven next to the wet plaster cast.
4. Allow the sheet to sag by at least 1/3 of the model.
5. Take out the plaster model, immediately clamp it into the vacuum suction device and prepare it for vacuum forming. (silicone grease to the dummy/plaster model)
6. Vacuum-form the sheet as usual.
7. Turn off the vacuum after cooling to room temperature and then demould it.

However, due to COVID-19, we were unable to thermoform the sockets ourselves. Instead, we outsourced the manufacturing of the inner and outer sockets to a shop based out of Santa Barbara. Once the sockets arrived, Conner signed a release of liability agreement and brought the parts home for the final manufacturing and assembly.

To make the cutouts in the dynamic socket, Conner used a coping saw with a spiral scroll blade to cut 10mm wide open slots as shown in figure 22.
In order to do a carbon fiber layup from home, some ingenuity was required due to lack of resources. After doing some research, a vacuum bagging process was found that uses a FoodSaver® food vacuum bagger [3.1]. The carbon fiber layup for the static socket was done using three layers of a carbon fiber/fiberglass weave, two longitudinally and one laterally, with general purpose epoxy resin applied with a brush to each layer. Once all the layers were positioned, a small balloon was inflated and placed in the opening of the socket to hold the fibers in place. Next, a layer of teflon release fabric, perforated film, and breather cloth were placed around the socket. This was then placed in a double-sealed bag and vacuum was drawn till excess resin was seen in the breather cloth. Next, the bag was sealed and resin cured for 12 hours at room temperature.

After the resin finished curing, the socket was removed from the bag lightly sanded down to remove surface defects. Then one last coat of resin was applied thinly to the surface to give it a glossy finish.
Figure 24: Finished carbon fiber static socket.

Once the static socket was secured to the elbow, shrink-wrap tubing was added to the pull-tab to enable easy one-handed locking and unlocking operation of the elbow. Next, a cable clamp was screwed into the socket to hold the cable in place. Lastly, a ¼ inch hole was drilled through the socket to insert the release button for the Shuttle Lock.

Figure 25: Assembling Nexo Transhumeral kit.

To assemble the forearm, the elbow unit was unlocked and in its fully extended position. Second, the saddle uprights were attached to the elbow unit and joined with the upright connector. Then the PEEK rods were shortened to the desired length from elbow axis to distal end with approximately an inch to spare. This will allow for angle and length adjustments. The PEEK rods were cut to length using a hacksaw. Next, the PEEK rods were placed into the saddle assembly and set screws were tightened to 20
in-lb. Then, the Damping ring was slid over the PEEK rods. Lastly, the quick disconnect wrist was attached with set screws tightened to 20 in-lb.

Manufacturing Process: Secondary Attachment

Velcro was sewn to the bottom right side of five black Nike sports bras using a brother® HS-2500 computerized sewing machine. The velcro was cut into 14 inch strips and placed with pins for placement before the sewing began. A number two stitch pattern was used which is designed for stretchy fabrics and to provide reinforcement according to the sewing machine manual.

Figure 26: Sewing velcro to sports bras. A, velcro pinned to sports bras for placement. B, Amanda sewing the velcro to the sports brsas using the sewing machine.
Figure 27: A, computerized sewing machine used along with the adjustable sewing mannequin, adjusted to Cassie’s specifications sizes. B, sizing strap using measuring tape across sewing mannequin.

Velcro was additionally sewn into a 46 inch long climbing strap. A 12 inch strip was sewed to match the strip on the sports bra and two 4 inch strips of opposite velcro were additionally sewn so that when the strap is pulled to ideal tightness through the buckle, the strap can velcro back on itself.

Secondary Attachment Addition

In the beginning of Chapter 3, it was emphasized that the team would not be implementing any cable system into the prosthesis design. However, after speaking in detail with Cassie about the cable system, the team had some concerns about getting rid of the cable system all together. The team replaced the cable responsible for locking/unlocking the E-400 elbow with a lift tab because she manually pulls on that cable with her right hand on her current prosthesis anyways. It was discovered that if we get rid of the other cable that is responsible for moving the forearm and opening the terminal device, it could be potentially uncomfortable for her to have a normal gait if her forearm is stiff or free-swinging (depending on if the elbow is locked/unlocked). At the end of winter quarter, the team decided that attaching a cable system would be ideal. With the unusual times in spring due to COVID-19, the team focused on addressing how to build the original design. A cable system was ordered, but didn’t arrive until the end of the quarter due to slow shipping times because of COVID-19. The cable system could not be added to the final design without an in person fitting with Cassie. The lengths of the cable need to be fitted to her size and this was not possible without Cassie. However, Cassie is expected to come later in June and the team plans to meet with her then to do a final fitting and attach the cable system.

Strap Orientation

After Amanda wore the sports bra with the strap attached, the velcro would bulge in the front center when she pulled the front part of the strap diagonally across her body. On the mannequin this problem wasn’t
noticeable, but when she put it on, this problem quickly arose. When she switched to twisting the front strap before pulling it across, the strap rested nicely across the chest rather than bulging out.

Figure 28: A, final twisted version of strap on bottom right portion of sports bra. B, original strap with no twisting.

Chapter 6: Testing Verification

Specification verification checklist

<table>
<thead>
<tr>
<th>Parameter Description</th>
<th>Requirement</th>
<th>Tolerance</th>
<th>Measured Value</th>
<th>Satisfies Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>5,000 USD</td>
<td>Max</td>
<td>1,340 USD</td>
<td>✔</td>
</tr>
<tr>
<td>Shoulder Lateral Range of Motion</td>
<td>90 Degrees</td>
<td>Min</td>
<td>TBD</td>
<td>TBD</td>
</tr>
<tr>
<td>Range of motion of elbow</td>
<td>120 degrees</td>
<td>Min</td>
<td>125 degrees</td>
<td>✔</td>
</tr>
<tr>
<td>Distance from Backpack Strap to Prosthesis</td>
<td>0.25 inches</td>
<td>Min</td>
<td>~ 1 inch</td>
<td>✔</td>
</tr>
<tr>
<td>Forearm Length (Olecranon to Styloid)</td>
<td>9.25 inches</td>
<td>±0.25 inches</td>
<td>9.5 inches (will be adjusted to exact length)</td>
<td>✔</td>
</tr>
<tr>
<td>Forearm Circumference</td>
<td>9.5 inches</td>
<td>Max</td>
<td>8.9 inches</td>
<td>✔</td>
</tr>
<tr>
<td>Wrist Circumference</td>
<td>6 inches</td>
<td>Max</td>
<td>6 inches</td>
<td>✔</td>
</tr>
<tr>
<td>Feature</td>
<td>Specification</td>
<td>Notes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>--------------------------------</td>
<td>-----------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>GIH Joint (shoulder) to Elbow</td>
<td>13.5 inches ± 0.5 inches</td>
<td>14 inches ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force to Accidentally Remove Device</td>
<td>25 lbs Min TBD</td>
<td>TBD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature Operating Range</td>
<td>20 to 120 °F Min, Max Inner Socket: -4 to 200 °F</td>
<td>Materials ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrosion Rate</td>
<td>0.02 mm/year Max Materials chosen</td>
<td>Materials ✔</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight (without terminal device)</td>
<td>5 lbs Max 2.58 lbs ✔</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Tests**

**Elbow Range of Motion:**

To test the elbow range of motion, a protractor was placed at the pivot point of the elbow and the forearm was moved from fully extended to closed. This gave us a range of 125 degrees which is within our minimum spec of 120 degrees.

![Testing elbow range of motion.](image)

**Forearm Length (Olecranon to Styloid)**

The forearm length was measured to be 9.5 inches, which is at the maximum spec limit. However, we intend to shorten the forearm to the optimum length during the final fitting process to Cassie.
Figure 30: Measuring forearm length.

Forearm and Wrist Circumference

A measuring tape was used to measure the circumference of the forearm which is 8.9 inches, which is below our max spec of 9.5 inches. Additionally, the wrist was measured to be right at 6 inches, which is right at the max spec limit. These dimensions are important to insure clothing that fits over her other arm will also fit over her prosthesis.

Figure 31: Measuring forearm and wrist circumference

GIH Joint (shoulder) to Elbow

The length of the socket and elbow came in right at 14 inches, which is right at the maximum spec value. This length is slightly above the nominal length target because the extra space in the static socket allows Cassie to use any sized pin length. A shorter static socket would have required customized pin length in order to fit inside the lock.
Corrosion Rate and Temperature Range

The Thermolyn PP-C thermoplastic is a great plastic for use outdoors and should easily withstand the heat while backpacking. Cassie’s current prosthesis that she uses for outdoors has an E-400 elbow and she has not reported anything negative in terms of withstanding the outdoor conditions. Throughout the device, we decided against using materials like copper or brass rivets due to eventual corrosion. Instead, we are primarily using stainless steel chicago screws.

Weight (without terminal device)

For the scope of this project, we aimed to keep the prosthesis under 5lbs. The prosthesis was weighed using an electronic scale which came out to be 2.58 lb. We are not including the addition of Cassie’s terminal device, but most weighed around 0.5 lbs. Adding that to the prosthesis will result in a total weight of approximately 3 lbs, which is well below the 5 lb requirement and thus meets our specification.
**Distance from Backpack Strap to Prosthesis**

The pin lock system rests close to the skin based on ensuring the proper trimline fit for Cassie as described previously. Since there is no piece going up over Cassie’s shoulder like there is with her current prosthesis, there should be an acceptable amount of distance between the backpack strap and prosthesis that the strap won’t get caught and pinched. This was tested with an adjustable sewing mannequin wearing the final design and a backpacking backpack. There were no issues with the system while wearing the backpack and the distance was 1 inch which passed our minimum distance requirement of .25 inches.

![Figure 34: Final Product with a backpacking backpack](image)

**Sports Bra Durability**

The original plan was to use a strain gauge and a 5lb weight to attach to the sown-on strap with velcro to see if it could be supported. The team didn’t have access to the necessary equipment to perform this test with the complications of COVID-19, so instead the team reformed this test into a more qualitative one. Amanda tried on the sports bra and tugged at the sown-on attachments in multiple directions to assess its durability.
Remaining Tests

Our original plan was to meet with Cassie sometime in the Spring Quarter to perform tests necessary to fully verify our engineering requirements. However, the situation with COVID-19 had forced us to adapt some of our tests as mentioned above in this chapter. The following in Table 3 show the remaining tests that could not be performed without Cassie’s assistance.

Table 3: Remaining Tests

<table>
<thead>
<tr>
<th>No.</th>
<th>Test</th>
<th>Description</th>
<th>Equipment</th>
<th>Acceptance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Comfortability</td>
<td>● Cassie tries on the socket to check for comfort</td>
<td>N/A</td>
<td>Pass/Fail based on Cassie’s Feedback</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Marks areas of discomfort</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Shoulder Range of Motion</td>
<td>● Wear prosthesis, lateral shoulder range of motion is measured</td>
<td>Goniometer</td>
<td>Min: 90°</td>
</tr>
<tr>
<td>3</td>
<td>Force to Accidentally Remove Prosthesis</td>
<td>● Wear prosthesis, 5 lb weights will be added in increments until 25 lbs</td>
<td>Weights</td>
<td>Supports 25 lbs</td>
</tr>
<tr>
<td>4</td>
<td>Practical Outdoor Test</td>
<td>● Cassie uses the prosthesis with secondary attachment while backpacking</td>
<td>Backpack</td>
<td>Pass/Fail based on Cassie’s Feedback</td>
</tr>
</tbody>
</table>

Comfortability

Since our socket is based on 3D scans of Cassie’s current swim pin lock socket, our socket should be a comfortable fit. Especially because we chose to create a dynamic socket in order for Cassie to find the ideal tightness by adjusting the Quickfit straps. We expect she will find it very comfortable. This cannot be fully confirmed however until Cassie wears the socket herself and gives us feedback in mid-June.
Lateral Shoulder Range of Motion:

The pin lock is an attachment system Cassie has used in the past and should have no problems with accessing full range of motion. Additionally, with the 3D scan of Cassie’s residual limb, we used CAD software to ensure the trim line of the socket meets her preferences and ensure that the range of motion requirement is met. The final way to test this would be to have Cassie wear the socket and rotate her arm. This test has not been performed because we haven’t had a final fitting due to COVID-19, but we expect to perform this test when we meet with her in mid-June.

Force to Accidently Remove Device

The device will be secured to the arm due to the friction between the silicone liner and contact with the skin. We planned to use the same silicone liner that Cassie uses for her other pin lock system. We expect this will be sufficient enough to keep the arm from accidently falling off but we will do tests on Cassie to ensure this. There is also the secondary suspension system attached to the prosthesis which will aid in preventing a force large enough to accidentally remove the device. To test this, 5 lb weights would have added to the wrist with the elbow fully extended till a total weight of 25lbs is loaded. If no visible slippage was observed, then the prosthesis would have passed the test. Due to COVID-19 this test was not performed.

Practical Outdoor Test

We planned to have Cassie wear the final design and her backpacking backpack and perform tasks she would outside such as hiking, bending over, and grabbing something from off the ground. These tests did not occur due to COVID-19. We expect that Cassie will give us feedback on what using our device is like while backpacking once we give her the final product.

Chapter 7

Conclusions and Recommendations

Despite the pandemic derailing our manufacturing and testing plans, we successfully built a prosthesis with a secondary attachment system that is ready to be worn by Cassie. The prosthesis has been tailored to her size and built to her needs which we based our engineering requirements on. Unfortunately, we were unable to perform several tests needed to verify a few of our engineering requirements because they required Cassie’s involvement. We still intend to complete the tests after the submission of this report. We have been speaking with our sponsor, Vanessa, about organizing a meeting with Cassie in mid-June. During this meeting we will perform the final fitting and finish the remainder of these tests (see Table 3). As mentioned in Chapter 5, the cable system did not arrive until late in the quarter. Therefore, we will also be fully attaching the cable system during the meeting with Cassie in mid-June. The final piece needed for Cassie to use the prosthesis to go backpacking is a terminal device. As stated before, building a terminal device alongside the prosthesis is outside the scope of this project. We recommend that a future project should be made on the design and manufacturing of the terminal device as per the needs outlined by Cassie. We recommend manufacturing instead of purchasing because there are currently no
commercially available terminal devices available that have the ability to do the majority of the functions that Cassie wishes to do while backpacking.

Acknowledgements

This project would not have been able to happen without the help and support of so many people. We would first like to thank everyone from QL+, especially Cassie Perando, Vanessa Salas, and Jon Monett. Without these three, this project literally would not have existed. Next, we would like to thank the two prosthetists who gave a substantial amount of their time and effort to help us with our project: Matt Robinson and Tim Bump. Additionally, we would like to thank Fillauer and George Leonne for supplying various supplies for the carbon fiber layup.

Overall, this project would not have happened without the support from the Interdisciplinary Senior Project Class of 2019-20. Karla Carichner, Jim Widmann, Lily Laiho, and Vladimir Prodanov were more than helpful throughout the entire year, leading us through each phase of our project.

Appendices:

Appendix A References


Appendix B QFD, decision matrices etc., as appropriate

**Currently, we don’t have all our targets precisely set, but know we will be able to find and set these values in the near future.

Pugh Matrix for Primary Attachment System

* Ultimately decided to move forward with concept 1: the Pin n’ Lock system.
Appendix C Final Drawings (schematics, software diagrams, part drawings, bill of materials)
Appendix D List of vendors, contact information, and pricing

Tim Bump, Resident Prosthetist/Orthotist and Fillaur contact - (541) 786-2003, tstevebump@gmail.com

Matt Robinson, Local Prosthetist/Orthotist (Hanger Clinic, San Luis Obispo) - (805) 546-8666, amrobinson@hanger.com

Click Medical, (970)- 670-7012, derek@clickmedical.co.

Fillauer, (800)-251-6398, 2710 Amnicola Highway, Chattanooga, TN 37406

McMaster, (630) 833-0300, chi.sales@mcmaster.com

WilloWood, 1.800.848.4930, customerservice@owwco.com

Table 4: Project Cost (Final Cost in Appendix J)

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEXO Transhumeral QD Kit</td>
<td>$382.00</td>
</tr>
<tr>
<td>E-400 Elbow</td>
<td>$436.00</td>
</tr>
<tr>
<td>Mini G Lock</td>
<td>$100</td>
</tr>
<tr>
<td>Adjustable Straps</td>
<td>$40 X 4</td>
</tr>
<tr>
<td>Thermolyn PP-C Plastic</td>
<td>$200</td>
</tr>
<tr>
<td>Nylon Webbing</td>
<td>$15</td>
</tr>
<tr>
<td>Miscellaneous Hardware</td>
<td>$50</td>
</tr>
<tr>
<td>Plaster</td>
<td>$20.00</td>
</tr>
<tr>
<td>Sports Bra</td>
<td>$30.00 X 5</td>
</tr>
<tr>
<td>Buckle</td>
<td>$30</td>
</tr>
<tr>
<td>Check Socket and Representative Socket</td>
<td>$250</td>
</tr>
<tr>
<td>Quickfit TRS Adapter</td>
<td>$100</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>$100</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$2000</strong></td>
</tr>
</tbody>
</table>
Appendix E Vendor supplied component specifications and data sheets

### NEXO Transhumeral Kits

<table>
<thead>
<tr>
<th>Description</th>
<th>Elbow Diameter</th>
<th>Kit with Quick Disconnect Wrist</th>
<th>Kit with Friction Wrist</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEXO Kit for Medium Elbows</td>
<td>2.4 in. (6.1 cm)</td>
<td>158500</td>
<td>158600</td>
</tr>
<tr>
<td>NEXO Kit for Large Elbows</td>
<td>2.8 in. (7.1 cm)</td>
<td>158501</td>
<td>158601</td>
</tr>
</tbody>
</table>

*Pending*

### E-200 Medium Elbows for NEXO

<table>
<thead>
<tr>
<th>Description</th>
<th>Locking Positions</th>
<th>Elbow Diameter</th>
<th>Elbow</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEXO E-200, with Outside Cable</td>
<td>11</td>
<td>2.4 in. (6.1 cm)</td>
<td>50690</td>
</tr>
<tr>
<td>NEXO E-200HD, with Outside Cable</td>
<td>9</td>
<td>2.4 in. (6.1 cm)</td>
<td>50691</td>
</tr>
</tbody>
</table>

### E-400 Large Elbows for NEXO

<table>
<thead>
<tr>
<th>Description</th>
<th>Locking Positions</th>
<th>Elbow Diameter</th>
<th>Elbow</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEXO E-400, with Outside Cable</td>
<td>11</td>
<td>2.8 in. (7.1 cm)</td>
<td>50692</td>
</tr>
<tr>
<td>NEXO E-400HD, with Outside Cable</td>
<td>8</td>
<td>2.8 in. (7.1 cm)</td>
<td>50693</td>
</tr>
<tr>
<td>NEXO Powerbow, Stainless Steel with</td>
<td>5</td>
<td>2.8 in. (7.1 cm)</td>
<td>60667</td>
</tr>
<tr>
<td>Outside Cable Exit</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### E2 Electric Elbow available from Motion Control

<table>
<thead>
<tr>
<th>Description</th>
<th>Size</th>
<th>Elbow Diameter</th>
<th>Elbow</th>
</tr>
</thead>
<tbody>
<tr>
<td>E2 Electric Elbow</td>
<td>Medium</td>
<td>2.4 in. (6.1 cm)</td>
<td>5016096</td>
</tr>
<tr>
<td>E2 Electric Elbow</td>
<td>Large</td>
<td>2.8 in. (7.1 cm)</td>
<td>5016099</td>
</tr>
</tbody>
</table>

### NEXO Transhumeral Replacement Parts

<table>
<thead>
<tr>
<th>Model</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>158280</td>
<td>NEXO Quick Disconnect Wrist, Transhumeral V-20</td>
</tr>
<tr>
<td>158281</td>
<td>NEXO Wrist Adapter Ring, Transhumeral</td>
</tr>
<tr>
<td>158282</td>
<td>NEXO Friction Wrist, Transhumeral</td>
</tr>
<tr>
<td>158162</td>
<td>PEEK Rod, 1/4 x 12 in., Transhumeral</td>
</tr>
<tr>
<td>158520</td>
<td>NEXO E-Series Saddle Upright RH</td>
</tr>
<tr>
<td>158521</td>
<td>NEXO E-Series Saddle Upright LH</td>
</tr>
<tr>
<td>158522</td>
<td>NEXO E-200 Upright Connector</td>
</tr>
<tr>
<td>158523</td>
<td>NEXO E-400 Upright Connector</td>
</tr>
<tr>
<td>158525</td>
<td>NEXO Lift Tab</td>
</tr>
<tr>
<td>158590</td>
<td>NEXO 5-Rod Damping Ring</td>
</tr>
<tr>
<td>880092</td>
<td>Screw 6-32 x 1/4 in.</td>
</tr>
<tr>
<td>880102</td>
<td>Set Screw, 10-32 x 1/4 in.</td>
</tr>
</tbody>
</table>
E-400 Elbow

Features & Benefits

- Eight to eleven locking positions and accommodates lift assist unit on medial or lateral side
- Heavy duty saddle straps for the E-400 available on special order
- Supplied with caucasian elbow cap unless otherwise specified
- Available with outside or inside cable exit

Ordering Information

50650  E-400 Standard Size Elbow: Outside Cable Exit, 11 Locking positions;
       2-1/4 x 8 in. (5.7 cm) Diameter; 2-1/8 in. (5.4 cm) Elbow Axis to Socket
       End; 15 oz. (420 g)
50651  E-400A, Same as 50650 with Inside Cable Exit, 11 Locking Positions
61658  E-400HD-A Standard Size Elbow; Inside Cable Exit, 8 Locking Positions,
       Heavy Duty Saddle and Gear Sector; 15 oz. (420 g)
50652  E-400HD Standard Size Elbow; Outside Cable Exit, 8 Locking Positions,
       Heavy Duty Saddle and Gear Sector; 15 oz. (420 g)
60149  E-400XHD: Standard Size Elbow; Outside Cable Exit, 8-Locking
       Positions, Extra Heavy Duty Gear Sector, Heavy Duty Saddle, 17 oz.
       (480 g)
60665  Power-Bow; Standard Size Elbow; Outside Cable Exit, 8-Locking
       Positions, Stainless Steel Frame, Cam and Reinforced Extra Heavy Duty
       Gear Sector, Heavy Duty Saddle, 21.2 oz. (597.5 g)

Elbow Assembly

A  62441  Short Sleeve
B  62440  Long Sleeve
*C  62243  Internal Assembly, E-400 and E-400HD
     62245  Internal Assembly, E-400A and E-400HD-A
D  50725  Cable Housing Assembly, E-400, E-400A, E-400HD and Power-Bow
     56191  Cable Housing Assembly, E-400HD-A
E  50667  Lock Nut
F  60668  Belleville Washer (2 required)
G  50658  Turntable, E-402, 400HD
      50659  Turntable, E-400A
H 50665 Cork Washer
I 50719 Shaft
J 50729 Outside Washer (2 required)
K 50740 Screw (2 required)
L 50724 Cable Assembly, E-400, E-400HD, E-400XHD and Power-Bow
    55705 Cable Assembly, E-400A and E-400HD-A
M 50729 Washer (2 required)
N 62235 Gear Sector, E-400 and E-400A
    62236 Gear Sector, Heavy Duty for E-400HD-A, E-400HD and E-400XHD
    62237 Gear Sector, Extra Heavy Duty for E-400XHD and Power-Bow
*O 50746 Yoke Assembly, E-400, E-400A, E-400HD-A and E-400HD
    60143 Yoke Assembly, E-400XHD
    60664 Yoke Assembly, Power-Bow
P 50730 Elbow Saddle Assembly, E-400 and E-400A
    50728 Elbow Saddle Assembly, E-400HD-A, E-400HD, E-400XHD
        and Power-Bow
Q 50742 Sheet Metal Screw, E-400, E-400A, E-400HD-A, E-400HD and E-400XHD (4 required)
    51057 Sheet Metal Screw, Power-Bow (4 required)
R 50741 Elbow Cap, Caucasian, E-400, E-400HD
    54419 Elbow Cap, Dark Brown, E-400
    54422 Elbow Cap, Medium Brown, E-400
    54425 Elbow Cap, Light Brown, E-400
    53926 Elbow Cap, Caucasian, E-400A
    54418 Elbow Cap, Dark Brown, E-400A
    54421 Elbow Cap, Medium Brown, E-400A
    54424 Elbow Cap, Light Brown, E-400A
S 50427 Anchor
T 50747 Hanger
U 50680 Bolt
V 50678 Screw (4 required)
W 50722 Bearing (2 required)

*Note: See below for sub assembly information

Elbow Sub Assemblies

62243 Internal Assembly, E-400 and E-400HD
62245 Internal Assembly, E-400A and E-400HD-A

Includes
  *AA 62242 Internal Cage Assembly for E-400 and E-400HD
  62246 Internal Cage Assembly for E-400A and E-400HD-A
  BB 50677 Base for E-400 and E-400HD
      60661 Base for E-400A and E-400HD-A
  CC 50679 Screw for E-400, E-400A, E-400HD-A and E-400HD (3 required)
  DD 50680 Bolt for E-400, E-400A, E-400HD-A and E-400HD
  EE 50715 Locking Bar Spring for E-400, E-400A, E-400HD-A and E-400HD
      50744 Cable Guide for E-400A and E-400HD-A only (not shown)

50748 Yoke Assembly

Includes
  Z2 50671 Yoke
  AAA 50675 Nut
BRR  50674    Bumper  
CCC  50758    Yoke Cover, Right  
DDD  50761    Screw  

60143    Yoke Assembly, E-400 XHD  
60664    Yoke Assembly, Power Bow  

62242    Internal Cage Assembly, E-400 and E-400HD  
62246    Internal Cage Assembly, E-400A and E-400HD-A  
62248    Internal Cage Assembly, E-400XHD and Power-Bow  

Includes  
FF    62246    Cage for E-400 and E-400HD  
62242    Cage for E-400A and E-400HD-A  
62239    Cage for E-400XHD and Power-Bow  
GG    50684    Cam Bearing  
HH    50631    Screw (2 required)  
II    50667    Cam for E-400, E-400A, E-400HD, E-400HD-A, E-400XHD  
60697    Cam for E-400XHD and Power-Bow  
JJ    50619    Spring  
KK    50701    Washer  
LL    50160    Retaining ring  
**MM    50709    Ratchet Assembly  
NN    50714    Locking Bar  
OO    50813    Case Pin  
PP    50712    Cable Pin  
**QQ    55561    Lever Assembly  
RR    50746    Lever Swivel  

50709    Ratchet Assembly  

Includes  
SS    50711    Spacer  
TT    50712    Screw  
UU    50708    Keeper  
VV    50710    Ratchet  

55561    Lever Sub Assembly  

Includes  
WW    50630    Pawl  
XX    50705    Spring  
YY    50706    Pin  
ZZ    50688    Lever  

For more information and ordering, email Customer Service or call 1-800-251-6398.
NEW QuickFit™
Straps & Buckles

With QuickFit™ Straps and QuickFit™ Buckles, you can easily add on micro-adjustable straps with a buckle that never wears out.

The QuickFit™ Strap
Micro-Adjustable
Empower patients to quickly and easily control fit and comfort throughout the day. Each "click" of the dial moves the strap 1mm for the perfect fit every time.

Improved Compliance
Patients LOVE having adjustability to create proper fit, which means they wear their devices more often.

One-Handed Use
Adjustment and closure can be operated with only one hand.

The QuickFit™ Buckle
Self-Locating Buckle
Powerful magnetic buckle clicks itself into place and holds strong all day.

One-Handed Use
Easily operate with only one hand.

Never Wears Out
The QuickFit™ Buckle design allows straps to last the life of the product by eliminating repetitive hooking and unhooking of Velcro.

<table>
<thead>
<tr>
<th>SKU</th>
<th>Size</th>
<th>Item No.</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>QuickFit™ Strap</td>
<td>1&quot; / 25mm</td>
<td>OK1400-130-05</td>
<td>• Prefabricated, durable, and install in minutes</td>
</tr>
<tr>
<td>QuickFit™ Buckle</td>
<td>1.5&quot; / 38mm</td>
<td>OK1410-130-05</td>
<td>• Velcro closure</td>
</tr>
<tr>
<td>QuickFit™ Buckle</td>
<td>2&quot; / 50mm</td>
<td>OK1420-130-05</td>
<td>• 100mm (4&quot;) of adjustable travel</td>
</tr>
<tr>
<td>QuickFit™ Buckle</td>
<td>1&quot; / 25mm</td>
<td>OK1405-000-05</td>
<td>• Usable strap length Max. 0.70m (30&quot;) / Min. 0.2m (9&quot;)</td>
</tr>
<tr>
<td>QuickFit™ Buckle</td>
<td>1.5&quot; / 38mm</td>
<td>OK1415-000-05</td>
<td>• Cut to size</td>
</tr>
<tr>
<td>QuickFit™ Buckle</td>
<td>2&quot; / 50mm</td>
<td>OK1425-000-05</td>
<td>• Made in USA</td>
</tr>
</tbody>
</table>

Click Medical | www.ClickMedical.co | 970.670.7012 | info@ClickMedical.co
## Appendix F Detailed supporting analysis

### Table 5: Weight of Prosthesis

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mini G Lock</td>
<td>2.4 oz</td>
</tr>
<tr>
<td>Thermolyn Plastic PP-C</td>
<td>.64 oz</td>
</tr>
<tr>
<td>Buckle</td>
<td>16 oz</td>
</tr>
<tr>
<td>QuickFit Straps</td>
<td>4.8 oz</td>
</tr>
<tr>
<td>NEXO Forearm</td>
<td>18 oz</td>
</tr>
<tr>
<td>E-400</td>
<td>15 oz</td>
</tr>
<tr>
<td>TRS QuickFit Adapter</td>
<td>.80 oz</td>
</tr>
<tr>
<td><strong>Total Weight</strong></td>
<td><strong>3.6 lbs</strong></td>
</tr>
</tbody>
</table>

### Table 6: Secondary Attachment Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Size/Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nike Compression Sports Bra</td>
<td>Large</td>
</tr>
<tr>
<td>Climbing Webbing</td>
<td>46 inches long, 1 inch wide</td>
</tr>
<tr>
<td>Velcro</td>
<td>Right Side to Center Chest: 12 inches On Pull Back Strap: 4 Inches</td>
</tr>
</tbody>
</table>
Appendix G Gantt chart
## Appendix H Safety Check List

**SENIOR PROJECT CONCEPTUAL DESIGN REVIEW HAZARD IDENTIFICATION CHECKLIST**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?</th>
</tr>
</thead>
<tbody>
<tr>
<td>✔️</td>
<td></td>
<td>Can any part of the design undergo high accelerations/decelerations?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will the system have any large moving masses or large forces?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will the system produce a projectile?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Would it be possible for the system to fall under gravity creating injury?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will a user be exposed to overhanging weights as part of the design?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will the system have any sharp edges?</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Will all the electrical systems properly grounded?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will there be any large batteries or electrical voltage in the system above 40 V either AC or DC?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will there be any explosive or flammable liquids, gases, dust fuel part of the system?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Can the system generate high levels of noise?</td>
</tr>
<tr>
<td>✔️</td>
<td></td>
<td>Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc…?</td>
</tr>
<tr>
<td>✔️</td>
<td></td>
<td>Will the system easier to use safely than unsafely?</td>
</tr>
<tr>
<td></td>
<td>✔️</td>
<td>Will there be any other potential hazards not listed above? If yes, please explain below?</td>
</tr>
</tbody>
</table>
Appendix I Fabricating Mini G Lock into Socket

1. Modify the model according to the instructions in the Alpha Liner Instructional Socket.

2. Remove 1/2 (12 mm) of height from the stack and of the model to ensure a proper fit for the Thermoplastic Tooling. The flat surface should be perpendicular to the long axis of the cast in both planes.

3. Using a 5/8 inch bit, drill a 1/2 (12 mm) deep hole in the center of the flat surface prepared in Step 2.

4. Thread the short end of the Thermoplastic Tooling as shown in the diagram.

5. Thread the Thermoplastic Tooling and attach/bolt into the hole drilled in Step 3. Position the Thermoplastic Tooling so that it is flush with the flat surface prepared in Step 2. Fold the Thermoplastic Tooling in the desired rotational alignment (regard to the placement of the holes) before proceeding to Step 6.

6. Blend the Thermoplastic Tooling with distal surface of models, removing as little material from the model as possible.

7. Apply the Post Sticker (provided with each G-Lock to the model cavity on the distal surface of the Thermoplastic Tooling).

8. Place the Thermoplastic Cap in an oven for fifteen to twenty minutes at the same temperature that is used to heat the socket material.

9. If using a nylon hose as a vice, take off the nylon hose where the model meets the Thermoplastic Tooling. Hold the end of the hose down onto the model.

Note: Do not allow the nylon hose to extend above the tip of the model. Air leaks may occur in the finished socket if the nylon hose extends past this point.

10. Make sure that the rotational alignment is still correct with regard to the placement of the 4 holes, then fabricate the thermoplastic socket using standard procedures.

11. After the socket has cooled sufficiently, sand the raised center boss on the distal surface of the Thermoplastic Tooling. Remove the Post Sticker.

12. Wearing head protection glasses, remove the raised center boss of the Thermoplastic Tooling. Place the Thermoplastic Cap from the oven, insert the raised surface into the corresponding oval in the raised center boss of the Thermoplastic Tooling. Tighten the bolt with 12 (3 mm) wrench until tight.

13. When the tooling has cooled sufficiently, and holes through the distal end of socket with a 5/8 inch bit. Using the Thermoplastic Cap as a drill guide.


15. Remove the socket from the model in the normal manner.

16. Drill a 5/8 inch (16 mm) deep hole in the center of the model.

17. Finish all edges of socket in normal manner to prevent discomfort to wearer.

18. Clean the interior of socket thoroughly to prevent dirt or debris from adhering to the G-Lock.

19. Insert the G-Lock into the socket, bring up the four holes in the G-Lock with the four holes in the socket. It may be necessary to apply some polyethylene jelly to the G-Lock to aid in the insertion.

20. Insert the G-Lock into the socket, bringing the four holes in the G-Lock with the four holes in the socket. Insert the G-Lock into the socket and install the Lock Ring and Button.

Note: If the O-ring around the outside of the G-Lock is not seating properly:
1) Pull the O-ring out of its groove;
2) Install the two rubber bands that were included in the tooling kit into the groove;
3) Re-install the G-lock.
4) The G-lock will now extend farther out from the surface of the G-lock, resulting in a tighter seal.

21. Thread into the lock.

22. Attach the desired component(s) to the socket. Choose to make sure that the length of exposed screws to engage with the G-Lock at between 47.0 mm and 47.05 mm. Refer to the picture in Step 20 in the Lamination Fabrication Instructions.

23. If using the socket in a retentive prosthesis:
   a. Apply Loclix (50 mL Resin) Threadlock to the screws, and the screws to the 5/8 inch (12 mm).
   b. Apply Loclix (50 mL Resin) Threadlock to the screws to the 5/8 inch (12 mm).

Note: It is necessary to change the position of the Lamination Tooling when replacing the components. WillowWood recommends fabricating a new test socket. Refer to the Thermoplastic Fabrication Instructions.

24. Re-seam the Lamination Tooling to the model if necessary.

25. Proceed to the Lamination Fabrication Instructions.

LAMINATION FABRICATION INSTRUCTIONS

Materials Included in the Lamination Tooling Kit (sold separately - Part No. 700-GL-495):

- Lamination Cap Bolt
- Lamination Cap
- Lamination Tooling (includes four Dowel Pins)
- Button Retention Device
- Button (Snap) Tooling (Includes Mucous Socket Head Cap)

1. Place the prepared and smooth cast with attached Lamination Tooling in a laminating fixture.

2. Apply Lubricant to the threads of four screws in Dowel Pins, and insert the pins into the Lamination Tooling. Ensure that all four Dowel Pins are securely seated and of the same height when fully inserted.

3. Pull half the length of a nylon hose over the cast and tooling. The other end of the hose where the model meets the Lamination Tooling. Fold the end of the hose over.

Note: Do not allow the nylon hose to extend above the tip of the model. Air leaks may occur in the finished socket if the nylon hose extends past the tip of the model.

4. Apply a PVA bag over the cast and tooling.
## Appendix J Final Product Total Cost Breakdown

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Price/Ea</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nike Women’s Victory Compression Sp - 1</td>
<td>1</td>
<td>$35.00</td>
<td>$35.00</td>
</tr>
<tr>
<td>Melkoor Bonded Nylon Sewing Thread, 1</td>
<td>1</td>
<td>$7.99</td>
<td>7.99</td>
</tr>
<tr>
<td>BlueWater 1” Climb-Spec Tubular Web 1</td>
<td>1</td>
<td>$13.50</td>
<td>13.50</td>
</tr>
<tr>
<td>Weather-Resistant Hook and Loop, 9500</td>
<td>1</td>
<td>$10.57</td>
<td>10.57</td>
</tr>
<tr>
<td>Olson Saw SF63507 Fret Saw 1</td>
<td>1</td>
<td>$19.65</td>
<td>19.65</td>
</tr>
<tr>
<td>Olson Saw FR49000 Skip Tooth Scroll Saw Blade Assortment</td>
<td>1</td>
<td>$12.95</td>
<td>12.95</td>
</tr>
<tr>
<td>Olson Saw SP46500 Spiral Scroll Saw Blade</td>
<td>1</td>
<td>$10.48</td>
<td>10.48</td>
</tr>
<tr>
<td>Hex Drive Binding Barrel and Screw 1/4”-20 Thread Size, for 1/2”-3/4” Mate 1</td>
<td>1</td>
<td>$15.54</td>
<td>15.54</td>
</tr>
<tr>
<td>(10) #8-40 x 1/2” Flat Head Socket Cap 2</td>
<td>1</td>
<td>$2.87</td>
<td>2.87</td>
</tr>
<tr>
<td>Anchor Plate, 1 In., SS, PK2</td>
<td>1</td>
<td>$16.29</td>
<td>16.29</td>
</tr>
<tr>
<td>System Three 0102K40 General Purpose 1</td>
<td>1</td>
<td>$19.95</td>
<td>19.95</td>
</tr>
<tr>
<td>T-Handle Hex Keys 7/32” Size, 9” Overall Length</td>
<td>1</td>
<td>$8.81</td>
<td>8.81</td>
</tr>
<tr>
<td>Nike Women’s Pro Swoosh Sports Bra, 1</td>
<td>4</td>
<td>$22.50</td>
<td>90.00</td>
</tr>
<tr>
<td>Weather-Resistant Hook and Loop, 9500</td>
<td>4</td>
<td>$10.57</td>
<td>42.20</td>
</tr>
<tr>
<td>Leather Strip 8706K51 1” Wide x 36” Long x 5/64” Thick</td>
<td>1</td>
<td>$9.65</td>
<td>9.65</td>
</tr>
<tr>
<td>0.75” ID, 1” OD, 0.028”- 0.034” Thickness 1</td>
<td>1</td>
<td>$7.14</td>
<td>7.14</td>
</tr>
<tr>
<td>NEXO Kit + Wrist</td>
<td>1</td>
<td>$482</td>
<td>482</td>
</tr>
<tr>
<td>Ottobock Plastic</td>
<td>1</td>
<td>$200</td>
<td>200</td>
</tr>
<tr>
<td>Test Socket</td>
<td>1</td>
<td>$250</td>
<td>250</td>
</tr>
<tr>
<td>Cable Kit</td>
<td>1</td>
<td>$85</td>
<td>$85</td>
</tr>
<tr>
<td><strong>TOTAL COST</strong></td>
<td></td>
<td></td>
<td><strong>$1,339.60</strong></td>
</tr>
</tbody>
</table>