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Appendix A: Prototype III

Part I: Shape

Figures 1 & 2 show the full body of Prototype III, this prototype has all of the desired features, including ergonomic shape, height adjustment, handle adjustment, comfortable padding, and energy return.
Figure 3: Prototype III CAD
This is the CAD drawing for the body of our third prototype. It incorporates the bend we want to a lesser degree so that it is hopefully more comfortable for the user. By using a combination of manual bending and right angle connectors, we hope to quickly move from a drawing to testing to make any final tweaks that we may need.
Part II: Shoulder
Since testing prototype II, we decided that the wrapped padding worked better than the stacked padding. We ordered more foam and used the various thicknesses at densities to layer the foam as it wrapped around the crutch. We were able to build up the ends of the shoulder pads as to make an indent in the middle that would hold the armpit when walking. This prevented the crutches from slipping out when walking. Spray adhesive was used to hold the foam on the EMT to prevent it from rotating during use.

Figure 4: Prototype III Shoulder padding Cross Section
Cross section and side view of the shoulder pads. The indent is not apparent until weight is applied to the top due to our wrapping order.

Figure 5: Prototype III Side View
Part III: Handle

“Infinitely” adjustable handle:

Currently, the only height adjustment in the crutch is built into the lower leg, and therefore, the distance between the handles and the armpit pads are a fixed distance. While people of similar heights have similar arm lengths, being able to make this crutch usable and comfortable for an 18” span of heights necessitates a movable handle. Rather than replicate the bottom leg bolt hole mechanism between the handle and the armpit pads, we decided that we would create a handle that can translate along the length of the crutch, and be secured in at any reasonable height. Realistically, the handle will be limited to the length of pipe between the upper bend at the armpit, and the start of the bottom adjustability, which is more than enough room.

Figures 6 and 7: Handle Clamp Assembly

The handle clamp is a three-part design, consisting of the clamp body, the stud, and the handlebar. The clamp body and the handle are aluminum parts, the stud is steel threaded rod. The clamp body is designed to have enough clearance to slide along the length of the pipe when the clamp bolt is loose, yet provide enough clamping force to prevent translation when tightened. To accomplish this, the center hole diameter was machined to provide a .005” clearance around the pipe, as the diameter of the pipe varied by about .005”. This allows the clamp to get by the largest parts of the pipe without sticking. To provide a clamping force, a ¼-20 bolt closes the .06” gap when tightened, effectively reducing the diameter of the center hole, and removing the clearance that allows the pipe to slide. The bolt hole is threaded on one side of the gap and counterbored and clearanceed on the other to allow the bolt to pull the two sides together. The clamp seems to provide enough clamping force without excessive deformation in the gap. The stud is 5/16-18 threaded rod and is attached into threaded holes on both the clamp and the center of the handle.
Moving forward, the body could be made into a two-part design by using a lathe to reduce the diameter and cut threads into the end of the aluminum handle and directly screw into the clamp body, eliminating the need for a stud, and simplifying the assembly process, at the expense of extra machining. Additionally, using pipe that has a higher tolerance, rather than conduit, would allow a tighter starting clearance, which would cause less deformation when clamping, and more contact surface area on the inside of the clamp. Finally, thread lock or a set screw needs to be implemented on the stud to keep the handle from loosening. Threadlock is most likely enough, but a set screw would be a more robust solution.
Part IV: Adjustability

Figure 8: Adjustability CAD Model
This is the drawing for the bottom portion of our third prototype. The holes allow it to accommodate people of heights from 5’ 8” to about 6’ 6”. After building we determined a realistic height range.

Figure 9: Prototype III Adjustability
The actual amount of adjustability in the crutch was approximately 12” allowing for adjustability to our desired height range
Part V: Crutch Foot (Energy Return)
The MD Crutch Foot:
To create traction, we purchased a premade, off-the-shelf crutch foot. This foot is meant to fit the MD Crutch which we have identified in previous presentations as a close market competitor. With a little convincing, we got it to fit tightly inside a 1” conduit as seen in the figure below, however, this was not the ideal setup. We purchased it for its design and the curved contact area that it rolls slightly to follow the user’s motion and keep constant contact with the ground. The foot will be attached to the lower leg section, which will be 1” conduit. The lower leg will slide over the smaller ¾” conduit of the upper crutch for adjustability purposes. It should also be noted that conduit measures an outside diameter while pipe measures an inside diameter, so the foot may fit better into a 1” pipe.

To make the foot fit onto the lower leg of the crutch, we machined an aluminum adapter. This adapter shown in figure 10 and 11, is an inch and a half aluminum round stock that was turned down on one end to have the same diameter as the inside of the one-inch conduit, and the opposite has an ellipse pocket milled into it to match the MD foot. The foot is a tight fit into the adapter, and two opposing set screws firmly secure the foot into the adapter. On the opposite end, two short bolts secure the adapter to the conduit, with clearance holes sized to so that the bolts tighten the assembly but still allow the conduit to sit on the aluminum shelf, not the bolts themselves. One thing to note is that there are now 5 different sizes/types of fasteners on the crutch. Ideally, the three sizes of Allen wrench could be reduced to one.

Figure 10: MD Crutch Foot

Figure 11 and 12: MD foot with adapter, as used in the final design
Appendix B: Prototype II

Part I: Shape

Figure 1: Prototype II CAD
This is an image of the CAD drawings for crutch prototype II. This was designed before the machine limitations were known. Therefore, the prototype looks slightly different due to the pipe bender’s limitations. The dimensions were based on what we believed to be desirable to fit our height range of users, from the overall height to the area available for vertical adjustability. The lengths of the handles and shoulder rests were determined by merely measuring to see how wide a shoulder and hand are. We also just wanted to get our hands on a physical prototype, so we tried to keep it simple but still test out a few features.
The shape of Prototype II can be seen in figure 2-4. The left and right crutches have some small differences that were used to compare in testing. One crutch uses a different diameter conduit than the other, and one was done using the pipe bender while the other utilizes elbows. The wrapping of the padding and the adjustability are also slightly different as seen in other sections. Variables such as pipe diameter, handle wrap, bend angles, and adjustability was tested.

Part II: Shoulder

The two methods for adding cushion and grip on the handle and underarm were evaluated. The method on the right is wrapping the length of padding around the pipe and on top of itself until the desired thickness is achieved. The left design involves cutting squares of padding out and stacking them along the length of the pipe. This method involves more work but has the potential for creating contours and shapes in the pad. The square padding was comfortable at first but caused a pinched nerve in the underarm, so it had to be scrapped. Therefore the wrapping method was chosen for the next prototype.
Part III: Handle

Figure 6: Prototype II Handle
Prototype II was made of conduit (EMT), and a T joint was used to add on a section for the handle as shown in the image above. This worked well for our purposes but does not allow for adjustability in the height of the handle in relation to the shoulder section.

Figure 7: Prototype II Handle Padding
The two methods for adding cushion and grip on the handle and underarm were evaluated. The method on the right is wrapping the length of padding around the pipe and on top of itself until the desired thickness is achieved. The left design involves cutting squares of padding out and stacking them along the length of the pipe. This method involves more work but has the potential for creating contours and shapes in the pad. The square padding was not comfortable or easy to grip with the hand, so this idea was scrapped and the wrapping method was used instead.
Part IV: Adjustability

Figure 8: Adjustability in the lower leg of the crutch. This section of the crutch provides about 10” of adjustability of the lower part of the crutch. Unfortunately, at this time, in order to adjust the handle to shoulder distance, the pipe must be removed and replaced with a pipe of a different length. This feature was replaced with a completely free adjustable handle for Prototype III.
Appendix C: Prototype I

Part I: Shape

Figure 1: Prototypes Ia and Ib
Prototype Ia was a conceptual design created from cardboard to test different feet and handle placements. Its shape was a simple T to allow it to hold weight. Prototype Ib was shaped from EMT conduit. The design was meant to bring the crutch out and away from the body to accommodate wider hips and different body types.

Part II: Handle

Figure 2: Prototype Ia and Ib Handles
These prototypes used scrap handles that were found. Duct tape was used to attach the handle to Prototype Ia. As seen in the image, this did not work all that great but was a decent visualization of where the handle should be placed and which direction it should face. For Prototype Ib, a lathe was used to attach a band to the handle that fits around the bent conduit. This allowed it to be adjustable on the shaft of the crutch but did not provide adequate support.
Part III: Crutch Foot (Energy Return)

Figures 3&4: Semi-Circle Foot Design
We created a lamination of multiple segments of PVC pipe. Secured to the block with rubber bands, we were able to see the effect of multiple laminations on the stiffness of the PVC. The downside to this design is in creating a robust, and durable production version. The design works by allowing the wood block to apply a force down on the inside of the PVC and the PVC flattens, creating a larger radius of curvature. As the force from the block decreases, the PVC returns to its original curvature, and the block is pushed back up. It operates in virtually the same way that a leaf spring in a vehicle operates. To make an effective leaf spring, the spring must be free to change length as it compresses, leading to the use of assemblies with pins and rollers. A rigid mount does not permit the leaf spring to change in length and will inhibit the deflection that we want. To create an assembly for the crutch that will effectively work like a leaf spring does not provide enough benefits to be worth the resources. Fatigue life, permanent deformations, and a small contact patch lead us away from this idea.

Moving forward, we wanted to have a foot design that maximizes contact with the ground, and a separate assembly that provides the energy return to the user. Designing a foot that also has an energy return is not worth the time. No constraints are forcing us to combine them, so our time is better spent working on them separately, and then combining the two assemblies.
Appendix D: Preliminary and Unused Ideas

Part I: Crutch Foot (Energy Return)

Idea 1: Cheetah Leg

The diagram shows how a cheetah foot is designed to work in prosthetics. We thought we could incorporate a similar design to get some energy return from the foot.

The original idea behind the crutch foot was to create something that would work like the flex foot cheetah prosthetic leg. The shape and material properties would allow the foot to absorb impact and provide a restoring force that would propel the user forward. After initially investigating composite materials, which were deemed to be too much of an initial cost regarding resources and time, we investigated other materials. The goal of the foot is to deflect under load as the user places their weight on it, and then as the user continues their stride, restore to their original shape and provide the user some of their energy back.
Idea 2: Curved Wood:

The bentwood prototype showed some promise but was too complicated to be worth pursuing. Bending wood can be accomplished by kerf-bending, laminations, and steam bending. We investigated kerf bending and found that on a piece of plywood, the kerf needs to be cut all the way through to the last ply and veneer. The pictures above show the plywood as it is cut to various depths. If the kerf only reaches the second to last layer of the plywood, the ninety-degree orientations of the plys will still keep the wood stiff, but significantly weaker than the full thickness. If the last ply is reached, then the wood will bend, since all of the remaining wood is running in the same direction. The plywood that was used was covered with a maple veneer that is the most flexible part of the plywood. The veneer gave the kerf cut plywood most of its bending properties as the last ply started to crack when bent. The plys of plywood had little effect on the bending in the end. Ideally, a bent shape would not be made out of kerf cut plywood, but of laminated veneer.

One slice of veneer itself is not strong enough to support the load we need when bent into the shape we need. By laminating multiple pieces together, we could get the strength we need. A fixture would bend each piece of veneer into the shape it needs to be and held there while the glue dries. The product would take the shape of the fixture once it is removed and be much stronger than each ply by itself. The downside is that the wood is now stressed. Each piece of veneer has a bending moment applied to it as it is bent into the fixture, and upon removal, the stresses still exist. For our application, we intend to apply a load to the foot repeatedly and expect it to take the load, deflect, and then force itself back into the original shape. The deflection that comes from loading and unloading will cause stresses by itself, so it is not optimal to start with wood that is already stressed.

To bend wood without creating more stress than necessary, steam bending can be used. By steam bending wood, most of the bonds in the wood that keeps it from bending are released by the heat and moisture of the steam, and the wood will easily bend. When steam bent wood is applied to the same bending and gluing fixture as before, it will result in a final piece with much less stress. To an extent, the new curved shape is the shape where the wood is unstressed and the shape it will return back to when deformed. However, in practice, some stresses do still exist.
Wood bending is not something that is easily modeled or calculated and is prone to having lurking variables. Factors like the type of wood, the moisture content or steam added, the direction of the grain, the number of layers, the radius of curvature all make it difficult to model a bentwood foot. Also, it is difficult to try to model any non-isotropic and homogeneous material that is forced into a strange geometry. It is possible to use wood veneer and bending methods to get what we are looking for in our crutch foot. However, being able to predict the properties of a foot by modeling or even by testing is beyond the scope of this project. It is even possible that we could get a foot that works well, but the chances that we would be able to optimize the foot for different users is improbable. The wood foot showed some promise, but the time and resources to get it right are not worth it for this project.

Idea 3: PVC Pipe

Figures 4,5&6: Show the stages of design for a PVC based cylindrical foot

The PVC prototype also seemed to show some promise. Instead of molding wood into a curved shape, PVC pipe can be used. Compared to wood, PVC is isotropic, homogenous, and is already found in the shape we need. By cutting a small segment off of the PVC, it is no longer a strong cylinder, but a much more compressible C shape. The 2 ½” and 4” PVC seemed to give a reasonable amount of deflection and also a strong restoring force. The downsides we noted is the fatigue of PVC, and how it can easily be driven out of the elastic region. By bending slightly too far, the PVC will not return to its original shape, and it will not provide the same restoring force. To combat this, we created a stop with a threaded rod, which allows us to adjust the maximum deflection before the rod contacts the lower inner circumference of the PVC. While the PVC seemed to work, it is not easily optimized for our use, as it only comes in set diameters, and its curved shape leads to a small contact patch with the ground, reducing traction.
Idea 4: Belleville Washers

Energy Return was originally going to be apart of the foot design. By separating them, we can approach both with a separate set of constraints and goals. The first idea in separating them is to use a spring in line with the crutch body. The spring should be able to support a max load of about 400 lbs, or about 200 lbs per crutch. The spring should also deform about \( \frac{1}{2} \)” under the user's weight. It is possible that to adjust to different users, different springs with spring rates optimized for each weight is the best way to go.

Figure 7: shows various configurations of Belleville washers

*From:* http://springipedia.com/belleville-washers-stacking.asp

The first type of spring we looked at is Belleville washers or disc springs. The Belleville washer is a conical washer that has a geometry and material properties that allows it to act as a spring. As the load is applied, the disc is compressed, and its height changes. As its maximum load is reached, its shape is close to a traditional flat washer. As the weight is removed, the washer returns to its original cone shape, as a well-designed washer is always operated in its linear elastic range. Each washer is designed using its geometry and material properties to have a specific load and deflection. Combinations of washers can be thought of as series or parallel, similar to electronic circuits. In parallel, each washer adds to the load it can take but retains the same deflection. As a stack of parallel washers deforms, it cannot deform more than one washer by itself. Series, on the other hand, allows for an increase in deformation with every additional washer. The load capability of the series stack is still the same as one individual washer, but with an increase in deformation. Combinations of series and parallel washers make it possible to adjust the load and deflection to suit different users, which made it an attractive idea. However, when calculated and priced, the amount of washers needed to be a suitable design is often much too large. The maximum deflections are too small, and once enough are stacked in series, it becomes an expensive, heavy design. Even using large diameter and specialty Belleville washers do not make it feasible.
Part II: Shoulder

Figure 8: Preliminary design for underarm support. This preliminary design shows a more comfortable design with the broader middle portion to allow for more comfort and weight distribution; while the narrower points allow for less chafing and more comfort for the user.

Shoulder pad:
· https://www.vivehealth.com/blogs/resources/best-pads-for-crutches
· https://www.healthambition.com/best-padding-crutches/
· https://medium.com/@crutchezeus/what-makes-the-best-crutch-pad-foam-c80a9e22dbfc

Material:
· http://www.essentialchemicalindustry.org/polymers/polyethene.html
Also has smaller options available


Also has smaller options available
Part III: Handle
Since we planned to use EMT tubing for the structure of the handle, some premade handles were considered to go over the tubing:

Bicycle handles:
Most bicycle handles are 7/8” in diameter so they would not work very well for ¾” or 1” tubing, motorcycle handles are 1” but they are not usually as soft in the grip

Replacement handles:

Figure 9: Crutch handles
Actual replacement handles for crutches are ¾” inside diameter, so they would fit over the conduit and can be found on Amazon at:
https://www.amazon.com/Medline-Crutch-Foam-Hand-Grip/dp/B00A3PQ09M?crid=B1S47C3FECBO&keywords=crutch+hand+grips&qid=1540773695&sprefix=crutch+han%2Caps%2C145&sr=8-6&ref=sr_1_6
$6.34

Other Options:

1” Diameter:

Figure 10:
This figure shows foam grips that would go over tattoo needles to give the artist a better grip. They fit 1” tubing but are only 1.75” long, so several would be needed for one handle. They come in packs of 20pcs and can be found on Amazon at
https://www.amazon.com/SUPREME-Memory-Tattoo-Stainless-Disposable/dp/B07F29VYZB?keywords=1%22+diameter+grip&qid=1540772772&sr=8-151&ref=sr_1_151
$21.99
Figure 11:
This figure shows grip tubing. It comes in sections of 26”, so it would have to be cut to size. It comes in packs of 2 and can be found on Amazon at [https://www.amazon.com/Trim-Lok-D1E50M30-26-13-Grips-Grip-Tek-Tubing/dp/B01HRJJ59I?keywords=3%2F4%22+diameter+grip&qid=15407773182&sr=8-104&ref=sr_1_104](https://www.amazon.com/Trim-Lok-D1E50M30-26-13-Grips-Grip-Tek-Tubing/dp/B01HRJJ59I?keywords=3%2F4%22+diameter+grip&qid=15407773182&sr=8-104&ref=sr_1_104) for $20.41.

Figure 12:
This figure shows barbell adapters that give the user a larger area to hold. They are not exceptionally soft, but there are several diameter and padding thickness options. They can be found on Amazon at [https://www.amazon.com/Iron-Bull-Strength-Alpha-Grips/dp/B00B6JKRSY?keywords=1%22+diameter+handle+grip&qid=1540771777&sr=8-68&ref=sr_1_68](https://www.amazon.com/Iron-Bull-Strength-Alpha-Grips/dp/B00B6JKRSY?keywords=1%22+diameter+handle+grip&qid=1540771777&sr=8-68&ref=sr_1_68) for $24.91.

Figure 13:
This figure shows what are described as kung-fu grips. They appear similar to bike grips and have an inside diameter of 1” so they would fit over 1” conduit. They can be found on Amazon at [https://www.amazon.com/Biltwell-GR-KFU-01-BK-Black-Kung-Grips/dp/B014MZ8GQ8?keywords=1%22+diameter+grip&qid=1540772508&sr=8-77&ref=sr_1_77](https://www.amazon.com/Biltwell-GR-KFU-01-BK-Black-Kung-Grips/dp/B014MZ8GQ8?keywords=1%22+diameter+grip&qid=1540772508&sr=8-77&ref=sr_1_77) for $17.95.

Any Diameter: There are several options such as grip tapes and sheets that will fit over any diameter.
Figure 14:
The above figure shows a roll of grip tape. This would work for any surface and can be combined with other foam tapes or sheets to provide additional padding. The size is 1.7mm x 60” and it can be found on Amazon at:
https://www.amazon.com/Silicone-Handles-Fitness-Sporting-Equipment/dp/B01MR4AXIR/ref=pd_sim_328_1?_encoding=UTF8&pd_rd_i=B01MR4AXIR&pd_rd_r=e22822dc-db14-11e8-8b2a-43f93729c796&pd_rd_w=4BOni&pd_rd_wg=CL3J7&pf_rd_i=desktop-dp-sims&pf_rd_m=ATVPDKIKX0DER&pf_rd_p=18bb0b78-4200-49b9-ac91-f141d61a1780&pf_rd_r=V5XQXD3S85N2VY2PTEAF&pf_rd_s=desktop-dp-sims&pf_rd_t=40701&psc=1&refRID=V5XQXD3S85N2VY2PTEAF
$9.99

Figure 15:
The above foam rolls will fit any diameter and can be cut to shape. They can be paired with the grip tape above to make the surface better for human contact. It does not appear to be as cushy as some options but may come in handy for other surfaces. Can be found on Amazon at:
https://www.amazon.com/Grip-Tek-Foam-Grip-Wrap-Applications/dp/B01COIYW4K?keywords=3%2F4%22+diameter+grip&pd_rd_i=B01COIYW4K&pd_rd_r=2196960b-450e-4edc-90d0-cc6cd7313d4e&pd_rd_w=DrBoM&pd_rd_wg=p0wep&pf_rd_i=3%252F4%2522+diameter&pf_rd_m=ATVPDKIKX0DER&pf_rd_p=be4e4b33-ff1d-476e-a827-fb55b7e4763f&pf_rd_r=0J1FNN5PA9ESY1EWJSR8&pf_rd_s=loom-desktop-bottom-slot&pf_rd_t=301&qid=1540774303&ref=sxbs_sxwds-stvpy2
$16.00

These grips and handles were disregarded so that the handle and underarm supports could match.
Part IV: Crutch Shape
Preliminary Designs:

Figures 16&17: Preliminary Sketches
The figures above show some preliminary designs that were a compilation of several group members’ ideas. It shows the side view of two different designs along with predicted dimensions to fit. These designs were not used as prototypes 1a, and 1b were more free-form than following a design plan.

Shape Visualization:

Figures 18&19: Chicken Wire
These images show a section of chicken wire that was bent to test different ideas for shapes. This material was beneficial for visualizing shape
Appendix E: Testing

Testing Schedule
When testing treat your dominant leg as the injured leg. For each test use the typical crutch first and then use the prototype for direct comparison. Rate the prototype on a scale from 1-5.

Scale 1-5
1 = Substantially worse; 2 = Moderately worse; 3 = About the same; 4 = Moderately better; 5 = Substantially better

<table>
<thead>
<tr>
<th>Task</th>
<th>Rating</th>
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<tbody>
<tr>
<td>Walk up and down the hallway in Esbenshade</td>
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<tr>
<td>Go up and down the ramp inside Esbenshade</td>
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<tr>
<td>Stand in one place while leaning on crutches for 1 minute</td>
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<td>Go and down the steps</td>
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<td>Get in and out of a chair</td>
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<td>Get in and out of a desk</td>
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<td>Try moving around with a heavy backpack</td>
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<td>Try opening a self-closing door manually</td>
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<td>Comfort</td>
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<td>Overall ease of use</td>
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Note: Test weight limit, test traction in wet conditions, test stability at an angle
Below is the Waiver form for our volunteers:

In Consideration of the risk of injury while participating in SAA Crutches Testing (the “Activity”), and as consideration for the right to participate in the Activity, I hereby, for myself, my heirs, executors, administrators, assigns, or personal representatives, knowingly and voluntarily enter into this waiver and release of liability and hereby waive any and all right, claims, or causes of action of any kind whatsoever arising out of my participation in the Activity, and do hereby release and forever discharge Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich, and Catherine Stencler, located at 1 Alpha Drive, Elizabethtown, Pennsylvania 17022, their affiliates, managers, members, agents, attorney, staff, volunteers, heirs, representatives, predecessors, successors and assigns for any physical or psychological injury, including but not limited to illness, paralysis, death, damages, economical or emotional loss, that I may suffer as a direct result of my participation in the aforementioned Activity, including traveling to and from an event related to this Activity.

I AM VOLUNTARILY PARTICIPATING IN THE AFOREMENTIONED ACTIVITY AND I AM PARTICIPATING IN THE ACTIVITY ENTIRELY AT MY OWN RISK. I AM AWARE OF THE RISKS ASSOCIATED WITH TRAVELING TO AND FROM AS WELL AS PARTICIPATING IN THIS ACTIVITY, WHICH MAY INCLUDE, BUT ARE NOT LIMITED TO, PHYSICAL OR PSYCHOLOGICAL INJURY, PAIN, SUFFERING, ILLNESS, DISFIGUREMENT, TEMPORARY OR PERMANENT DISABILITY (INCLUDING PARALYSIS), ECONOMICAL OR EMOTIONAL LOSS, AND DEATH. I UNDERSTAND THAT THESE INJURIES OR OUTCOMES MAY ARISE FROM MY OWN OR OTHERS’ NEGLIGENCE, CONDITIONS RELATED TO TRAVEL, OR THE CONDITION OF THE ACTIVITY LOCATION(S). NONETHELESS, I ASSUME ALL RELATED RISKS, BOTH KNOWN OR UNKNOWN TO ME, OF MY PARTICIPATION IN THIS ACTIVITY, INCLUDING TRAVEL TO, FROM, AND DURING THIS ACTIVITY.

I agree to indemnify and hold harmless Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich, and Catherine Stencler against any and all claims, suits or actions of any kind whatsoever for liability, damages, compensation or otherwise brought by me or anyone on my behalf, including attorney’s fees and any related costs, if litigation arises pursuant to any claims made by me or anyone else acting on my behalf. If Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler incurs any of these types of expenses, I agree to reimburse Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler.

I acknowledge that Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler and their directors, officers, volunteers, representatives and agents are not responsible for errors, omissions, acts or failures to act of any party or entity conducting a specific event on behalf of Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler.
I ACKNOWLEDGE THAT THIS ACTIVITY MAY INVOLVE A TEST OF A PERSON’S PHYSICAL AND MENTAL LIMITS AND MAY CARRY WITH IT THE POTENTIAL FOR DEATH, SERIOUS INJURY, AND PROPERTY LOSS. The risks may include, but are not limited to, those cause by terrain, facilities, temperature, weather, lack of hydration, condition of participants, equipment, vehicular traffic and actions of others, including but not limited to, participants, volunteers, spectators, coaches, event officials and event monitors, and/or producers of the event.

I ACKNOWLEDGE THAT I HAVE CAREFULLY READ THIS “WAIVER AND RELEASE” AND FULLY UNDERSTAND THAT IT IS A RELEASE OF LIABILITY. I EXPRESSLY AGREE TO RELEASE AND DISCHARGE Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler AND ALL OF ITS AFFILIATES, MANAGERS, MEMBERS, AGENTS, ATTORNEYS, STAFF, VOLUNTEERS, HEIRS, REPRESENTATIVES, PREDECESSORS, SUCCESSORS, AND ASSIGNS, FROM ANY AND ALL CLAIMS OR CAUSES OF ACTION AND I AGREE TO VOLUNTARILY GIVE UP OR WAIVE ANY RIGHT THAT I OTHERWISE HAVE TO BRING A LEGAL ACTION AGAINST Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler FOR PERSONAL INJURY OR PROPERTY DAMAGE.

To the extent that statute or case law does not prohibit releases for negligence, this release is also for negligence on the part of Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler, and its agents, and employees.

In the event that I should require medical care or treatment, I agree to be financially responsible for any costs incurred as a result of such treatment. I am aware and understand that I should carry my own health insurance.

In the event that any damage to equipment or facilities occurs as a result of my or my family’s willful actions, neglect or recklessness, I acknowledge and agree to be held liable for any and all costs associated with any actions of neglect or recklessness.

This Agreement was entered into at arm’s-length, without duress or coercion, and is to be interpreted as an agreement between two parties of equal bargaining strength. Both the Participant, _________________________________, and Elizabethtown College, Audrey Shultz, Austin Reth, Kyle Lumbert, Gerald Romich and Catherine Stencler agree that this Agreement is clear and unambiguous as to its terms, and that no other evidence will be used or admitted to alter or explain the terms of this Agreement, but that it will be interpreted based on the language in accordance with the purposes for which it is entered into.

In the event that any provision contained within this Release of Liability shall be deemed to be severable or invalid, or if any term, condition, phrase or portion of this agreement shall be determined unlawful, or otherwise unenforceable, the remainder of this agreement shall remain in full force and effect, so long as the clause severed does not affect the intent of the parties. If a court
should find that any provision of this agreement to be invalid or unenforceable, but that by limiting said provision it would become valid and enforceable, then said provision shall be deemed to be written, construed and enforced as so limited.

I, the undersigned participant, affirm that I am of the age of 18 years or older, and that I am freely signing this agreement. I certify that I have read this agreement, that I fully understand its content and that this release cannot be modified orally. I am aware that this is a release of liability and a contract and that I am signing it of my own free will.

Participant’s Printed Name: _____________________________________________________

Participant’s Emergency Contact Name: __________________________________________

   Emergency Contact Number: (_____ ) - ________ - _________

Signature: __________________________________________________________________

Date: ______/_______/2019
Appendix F: Team Contract

Updated Team Contract

Team Name: SAA Crutches

Date: 01/25/19

Members: Kyle Lumbert, Austin Reth, Scott Romich, Audrey Shultz, and Caity Stencler

Meeting Time & Place: Atwood’s Lab, Thursdays at 5:30-6:30 pm

Purpose

Successful teams have common goals and a shared commitment to success as a team. They establish common understandings by which they manage relationships, joint achievements, member responsibilities, and project information to achieve their collective goals. In this exercise, you will collectively develop a “team contract” that defines how you will operate your team for success. Benefits from this activity include consensus understandings, effective and efficient teamwork, and enjoyable working relationships.

Team Relationships

As a team, define consensus expectations about productive within-team relationships. What constitutes the relationships needed for productive, enjoyable teamwork? How are these relationships developed and maintained? In the spaces provided, please address these issues.

1. INCLUSIVE CLIMATE. Describe what is required for all members of the team to feel safe and valued, and explain members’ commitments to achieve this inclusive climate.

   - Make sure everyone’s voice and opinions are heard
   - No judging others for ideas or life issues
   - Have an open dialogue at all times
   - Be willing to evaluate an idea before passing a judgment

2. MEMBER COMMITMENT. Identify ways the team will systematically strengthen member commitments to the team and establish a clear team identity for all members.

   - Make sure meeting times work for everyone
   - Assign certain tasks to people and allow them to accomplish them
- Allow each member to have a say in the group direction
- Distribute work that allows people to do the tasks they are willing and capable of completing
- All members should be willing to help another team member if they ask for or require assistance on a task

3. **CONFLICT RESOLUTION.** Define the strategy your team will use to resolve conflicts that arise and leverage these challenges into opportunities for growing team performance.

- Talk it out
- Do not take sides
- Hear all sides of the conflict
- Try to come up with a solution
- All conflict should be resolved via a group consensus. If consensus cannot be reached, a decision can be made via majority vote or by a decision of the advisor

**Joint Achievements**

As a team, define consensus expectations about **team goals** and **joint achievements**. How will goals be used to drive overall team performance? In the spaces provided, please address these issues.

1. **GOAL ESTABLISHMENT.** Define the team and project goal(s) to which all team members are committed. “Our team is committed to . . . .”

   - Making an excellent product
   - Putting our best foot forward
   - Each individual pulling their own weight
   - Providing a product that will improve the lives of those who are permanently or temporarily handicapped.

2. **PLANNING AND MANAGEMENT.** Describe how your team will establish plans, execute plans, and review progress with regard to achieving team goals. How will these processes be managed, and by whom?

   - Plans will be established by what needs to be done and when
   - The people who are most interested in the topic will take the lead
   - As a group, we can decide this but ultimately someone will be the “manager”
   - Possibly use the software that was recommended in the lecture to stay organized.
   - Everyone should have an idea of other members work projects so that the product will fit together correctly
3. **JOINT WORK PRODUCTS.** Describe how your team will conduct meetings and joint work so that synergies yield high-quality work products (decisions, ideas, reports, prototypes, etc.) that benefit from the unique contributions of all members.

- Open forum
- Have fun but stay on task
- Everyone takes responsibility for a part of the project
- Sharing ideas and explaining the reactions one has to other’s ideas rather than a yes or no. This can lead to collaboration and possibly better ideas as a result
- Utilize tools such as GoogleDocs so that other team members can proofread, edit and collaborate on important work.

**Member Contributions**

As a team, define your consensus expectations about **individual team member contributions**. How will work be allocated, performance standards be established, and performance reviewed to ensure member productivity? In the spaces provided, please address these issues.

1. **WORK ALLOCATION.** Define how work will be allocated to individual members of the team. Address issues of leadership, backup, and fairness.

   - Fairness will remain neutral in the fact that everyone’s interests and strengths will be taken into consideration before allocating work
   - Want and interest is a big part of this decision
   - Any complaints should be brought up in the meeting and resolved then

   Members should be willing to ask for/provide aid to/from other members without consequence. The workload should be shared, and if called upon to take up some extra slack.

2. **PERFORMANCE QUALITY.** Describe your team’s plan for achieving high performance from each team member. Address work standards and accountability that will ensure success. Who is responsible to whom, and on what timeline?

   - An individual’s work quality is the responsibility of themselves
   - Everything will be completed before the due date to give room for revisions
   - Everyone produces a work product that reflects the rest of the group.

   The Gantt chart should be followed as closely as possible and all assignments should be completed thoroughly to the best of your ability. The Gantt chart will be updated regularly.
3. **Member Growth.** Describe your team’s plans for growing team member capabilities and responsibilities over the duration of your project. How will you prepare all members for growth and leadership in a complex, changing world?

- Constructive criticism is not personal, but it is a chance to get advice from peers.
- Nothing will be handed in before others look it over
- If someone needs help, assist them, but do not do the work for them
- Work together versus competing with one another
- Make sure everyone has a responsible workload (i.e. no one has more or less work than others)

Should a group member be struggling with a task they are expected to ask for assistance. Group members should be willing to work with others to help them improve within a certain skill set.

### Team Information

As a team, define consensus expectations about the **handling of project information.** How will communication within and outside the team be managed? How will ideas and decisions be documented? In the spaces provided, please address these issues.

1. **Internal Communication.** Define how notifications, records of meetings, exchange of information, and other in-team communications be conducted to empower all members for success. What communication protocols should be followed by each member?

   - The Group-Me chat will be the main source of communication
   - Audrey will be keeping team minutes and just making sure the team stays on track.
   - If you have an issue, speak up
   - Google-Doc is the best way to complete projects as a team

   We will use a google doc and GroupMe as the main forms of communication

2. **Stakeholder Communication.** Define communication expectations for your team interactions with key outside stakeholders. With whom will you communicate regularly? Who is responsible? How will appropriate confidentiality be maintained?

   - Everyone is expected to answer chats and emails
   - Again, everyone is responsible for keeping in contact with the team
   - Scott is responsible for keeping in contact with Dr. Atwood
The advice of Dr. Atwood will be used as a valuable resource.

The team should/will come up with what will remain confident and be put in this section as follows:

- Personal problems, health issues, and any other requested private information shall remain within the team.

3. **Knowledge Assets.** Define how project information assets will be developed and safeguarded.

What project records will be maintained and by whom? How will personal design journals and team records be developed to produce the greatest value? How will documentation be monitored?

- Google Docs will keep all others in a shared folder to avoid being lost or unsaved; this also prevents choppiness in reports.
  - If possible, all records should be digitized (scanned or photographed if necessary) and placed into the group’s Google Docs folder so that it is easily accessible to everyone.

**Roles and Responsibilities**

Complex projects require shared leadership – different individuals leading different portions of the project. As a team, identify for each member the **leadership or backup responsibilities** for which this person is accountable to the team.

(a) Please describe in 50 to 100 words your **rationale** for selecting areas and individuals to lead areas.

Audrey was selected to be the secretary because she enjoys taking the minutes and obsessively checking to make sure that everything is turned in. Scott was put in charge of relations due to him being more social and a people person. Kyle was made lead person due to his outgoing personality, charisma, and presentation skills. Austin was put in charge of CAD because he is the most experienced CAD user in the group. Finally, Caity was made editor due to the joy she derives from editing papers and correcting errors.

(b) Please **assign** each member to important roles and **identify** key responsibilities of each role.

Member name: Audrey Shultz
<table>
<thead>
<tr>
<th>Job titles or roles</th>
<th>Principal responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secretary</td>
<td>Take minutes, makes sure everything gets turned in on time, double check that assignments were turned in</td>
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</tbody>
</table>

Member name: Scott Romich

<table>
<thead>
<tr>
<th>Job titles or roles</th>
<th>Principal responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relations</td>
<td>Keep in contact with an advisor, all group members, and everyone else involved in the project</td>
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</tbody>
</table>

Member name: Kyle Lumbert

<table>
<thead>
<tr>
<th>Job titles or roles</th>
<th>Principal responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead Person</td>
<td>Keep the group on task, take lead in certain areas if needed, Help wherever needed, and approve anything if needed</td>
</tr>
</tbody>
</table>

Member name: Austin Reth

<table>
<thead>
<tr>
<th>Job titles or roles</th>
<th>Principal responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD</td>
<td>In charge of all CAD files, approves all drawings and assemblies</td>
</tr>
</tbody>
</table>

Member name: Caity Stencler

<table>
<thead>
<tr>
<th>Job titles or roles</th>
<th>Principal responsibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Editor</td>
<td>Proofreads all group submissions, turn in assignments</td>
</tr>
</tbody>
</table>
• Formal report as indicated in the previous PR: Progress reported since last 491 report (Contract Fulfillment)
• Specific objectives for completion by next PR: Strong planning for next Sprint (Contract Proposal)
• Updated rough plan for all project reports and final reports through the end of the project
Appendix G: Possible improvements to the current crutch.

- **Material**
  - Conduit was chosen for its low cost and the fitting selection that made prototyping easier. We have slowly phased out the fittings, so using conduit is no longer helpful. Conduit is much heavier than aluminum, and the sizing does not make it conducive for the sliding assembly.
  - Choosing aluminum tubing moving forward would be the next logical step. Aluminum could be sized to get closer tolerances on the slide, reducing the size of the bushings needed to bridge the gap. The same design would be lighter in aluminum. It is also easier to achieve acceptable surface finishes in aluminum.
  - In a production setting, it is possible to bend pipe to a tight 90 degree, unlike what we were able to achieve. We struggled with kinks in the small radius of the bend. Production pipe bending machines pull the pipe through the machine as it bends, removing the concentration of material that stacks up on the small radius. This would allow us to use a continuous piece through the shoulder support and remove that fitting.

- **Handle assembly**
  - These parts would likely be cast into one part, reducing the need to machine the whole assembly. Ideally, the part would be investment molded, but with some finishing and machining of the center hole, sand cast molding would be needed. The sizing of the expansion gap may need to be reduced to prevent the user from clamping down too tight on aluminum.

- **Lower leg assembly**
  - The lower leg assembly would not require many changes. In a production setting, CNC machines and process can drill the line of 16 holes much faster than a student on a manual mill can.
  - The bolt that secures lower leg to the upper needs to be revisited. In its current state, the bolt rattles when the crutch is axially loaded and unloaded. With some kinds of bushings, the rattle from metal on metal can be reduced.
  - Potentially move to a clamp type design like the handle. Use the clamping force to secure the leg, which allows for infinite adjustment through the range.
  - Instead of a bolt, use spring loaded pins to secure the legs. Unfortunately, drawing and annealing are not processes that the fab lab is capable of completing, or we would be able to use the current standard crutch spring loaded pin for the adjustment. The current design uses an annealed piece of steel that expands inside the pipe. The only example we had only came with one pin, and the pin was too short to reach the lower leg.
Alternatively, a classic spring loaded detent could work, if the parts can be sized to fit inside the upper leg. This would require a spring-loaded chamber that would push two pins out into the holes on the lower leg. With the current prototype and the large clearance between the upper and lower leg, it was not possible to do this type of design. As the clearance between the legs decreases, the length of the pins can also decrease, which makes fitting the assembly into the upper crutch leg easier.

- Bushings
  - The 3d printed bushings we printed worked, but moving forward, it should be drawn or extruded. Also as clearances between the crutch legs change, the bushings need to be resized.

- The foot adapter
  - Like the handle, this part could be cast. The tolerances on this part are not as critical, as it does not need to slide up and down and interact with the tolerance of the pipe. An inexpensive sand cast with a post process finishing of the exterior faces would be satisfactory.

- MD foot
  - Ideally, this foot would be produced in-house, and with a circular post, rather than an ellipse. This would eliminate needing an adapter, and it could be sized to fit the diameter of the lower leg. The foot appears to be a two-stage injection molded part. The first part is hard plastic, which creates the general geometry. This is the part where we would change the shape geometry of the post. Then the part is put into another mold, where it is covered in a softer rubber. We would like to make this rubber thicker and/or softer, as to get more energy return back to the user.
Appendix H: PDS Information.

Complete Pugh Table for 32 PDS

This table shows the complete pugh table for the 32 product design specifications. Looking at this, we are able to compare each aspect of the product with each specification based on the results it is easy to see which aspect from each category is superior. A subjective numerical value is given to each so that bias can be eliminated. The following link can be used to view the Pugh table.

https://docs.google.com/spreadsheets/d/1K1lNbq38VqxqtxsIQBv0N5EOA7ZjLBWrKjGSNWZmqk/edit?usp=sharing.

The 32 Pugh Subgroups:

1. **Performance**: The crutches will be able to hold up to 250 lbs without any bending or variation of incorrect posture.

2. **Product cost**: Our product cost goal is to remain under $75 for the customer to purchase.

3. **Quantity**: Each “product” would be a left crutch and a right crutch (2).

4. **Aesthetics**: Crutch should not be bulky or gaudy (sleek: <10% unneeded material or space).

5. **Ergonomics**: Crutch should not deviate more than 5% from posture, not slip when put in a 45° position, and be able to store out of the way of others (be ⅓ of the space when extended fully).

6. **Process**: The process should take less than four weeks to assemble for the prototype, and when produced, the crutches should be produced fluidly and within a 3-hour time span.
7. **Company constraints:** Must be able to be manufactured using tools and materials with less than 5% waste.

8. **Legal:** This product will reduce lawsuits compared to other crutch types by at least 20%.

9. **Environment:** Should be able to be used indoor/outdoor on both paved, smooth, and rough ground (does not have to be usable on ice, but should be usable on a wet floor).

10. **Competition:** Be able to address more than ¾ of customer complaints.

11. **Manufacturing:** Must be able to be manufactured using currently available tools and materials.

12. **Materials:** The material used now (aluminum) is one of the weakest metals when it comes to malleability, so a metal with a better ratio of ductility and malleability to strength will be chosen.

13. **Customer:** Crutches should fit most body types and heights such as heights from 4’10” to 6’5” and weight up to 250 lbs.

14. **Timescales:** Must be designed with a completed prototype within three semesters.

15. **Market constraints:** The product will be the only one design like it on the market.

16. **Installation:** Be able to be quickly picked up and used within 15 seconds.

17. **Life in service:** The product will have a warranty up to the first six months, and replacement parts will be available to purchase for under $20.

18. **Shipping/distribution:** N/A.

19. **Size:** The product should be large enough to support 250 lbs and be able to adjust to heights anywhere between 5’ and 6’.
20. **Product lifespan:** The product will be able to last up to 8 months without any repairs or mechanical attention, and the product itself should be usable for up to 10 years without replacement.

21. **Quality/reliability:** The product should make the customer at least 75% more comfortable by reducing pain, and the customer should feel safe using the product for any period longer than 15 minutes.

22. **Testing:** The product will be tested at least five times before it is given to a patient to test.

23. **Patents:** N/A.

24. **Documentation:** N/A

25. **Maintenance:** Cost less than $20 to replace or fix parts.

26. **Packing:** Shipping cost less than $15.

27. **Weight:** Crutches should weigh less than 10 lbs total.

28. **Standards:** The product should not have a safety factor under 1.5 to maintain the standards that the team intends.

29. **Shelf life:** Should not show any decay over time if stored in at room temperature in a dry place.

30. **Safety:** Weight of crutches should not harm anyone if they tip over onto them.

31. **Political / Social:** Should not interfere with any local or national laws.

32. **Disposal:** The product should be at least 80% recyclable to be able to reduce the amount of unnecessary waste.
Figure 1: This is the House of Quality we created during Junior year to help with our decision making.
Figure 2: This is the Pugh Table we used to help figure out what material we wanted to make the crutch out of.

<table>
<thead>
<tr>
<th>Material</th>
<th>Strength</th>
<th>Shapeability</th>
<th>Durability</th>
<th>Cost</th>
<th>Time</th>
<th>Weight</th>
<th>Resistance to environment</th>
<th>Total +</th>
<th>Total ±</th>
<th>Total -</th>
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<tbody>
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<td>s</td>
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<td>-</td>
<td>+</td>
<td>-</td>
<td>3</td>
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<tr>
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