Walker Tray
Senior Project Design

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Abstract

Sean is an individual with Cerebral Palsy, a disability that affects one's balance, muscle tone, muscular coordination, posture and control. Sean utilizes a walker to aid in maintaining his balance and muscular coordination when ambulating. This enables him to walk independently and leads to improved muscle strength and coordination. When walking, Sean places both hands on the walker to maintain balance and thus the ability to walk and carry items at the same time is compromised. Sean would like to be able to transport items while in use of his walker. The goals of this senior project design are to develop a device to be attached to his current walker that will allow Sean to transport items and be of minimal interference. The Walker Tray Device is the product designed to satisfy this need and the following report details the process of this design development.
1 Introduction

Dr. Kevin Taylor first presented the project known as “Walker Tray” during the senior design presentations. He introduced himself as the founder of Activity4All (A4A), which is a program that aims to provide community members of all levels and abilities with opportunities for recreation and exercise. Through this program, he identified the individual that this project pertains to Sean Freed, an active ten-year old who would like to add a modification to his current Nurmi Neo gait trainer walker, which will facilitate in carrying/transporting items hands-free. Currently, when Sean uses his walker it is necessary that he use both hands to remain balanced, limiting the number of items he can carry. The walker has a backpack attachment for Sean's storable items, but backpacks are limited to what you can store in them and in accessibility. That is where the need for a design team came in. Sean needs a method to be able to carry things, for example his school lunch tray, popcorn, or dinner.

The design, build, and test team for this project consists of three Senior Mechanical Engineering students: Marlene Troncoso, Judy Lantaca, and Miriam Krage. In addition, Senior Kinesiology student Claire Francis was hired on. Together, we have researched and defined what the design need is, and developed a way to solve it. This process involved asking questions and listening to our clients, Sean and his mother, Gaby. From there, we utilized design ideation methods to come up with a variety of concepts that solve the user's problem. This report will describe this process, our evaluation results, and the details of the final design. Further included are the steps following the choosing of the final design, which are safety awareness and how we plan to test the design.

2 Background and Research

Sean is an individual with Cerebral Palsy, a disability that affects one's balance, muscle tone, muscular coordination, posture and control. Sean utilizes a walker to aid in maintaining his balance and muscular coordination when ambulating. This enables him to walk independently and leads to improved muscle strength and coordination. When walking, Sean places both hands on the walker to maintain balance and thus the ability to walk and carry items at the same time is compromised. To continue to improve Sean's independence, providing a way for Sean to walk and transport items at the same time would allow Sean to have less dependence on others.

The design is concentrated on Sean's current walker; the make and model were obtained through online research using photographs of Sean and his walker provided by Dr. Kevin Taylor. The
walker shown in Figure 2.1 is a Nurmi Neo gait trainer by Ottobock. This pediatric walker is designed for children who can walk but need a little extra support. Extensive knowledge of this particular model was crucial to designing an attachment for it. Some of the key features provided by the manufacturer, which were beneficial to this project, are listed below:

**Features and Benefits**

- Available with three different depth and height adjustable grip bars
- Grip bar with universal grips can be adjusted to reduce the width between grips
- Extra high grip bar with forearm supports and vertical hand grips is angle adjustable
- Grip bar with mini grips which is ideal for smaller children because it provides a lower grip height and/or shorter width between grips
- Anti-tip bars provide stability to prevent tipping - *Does not have*
- Friction brake applies to the rear wheels to slow forward progression/speed during ambulation
- Friction can be increased or decreased by adjusting the interior setscrews.
- Caster swivel wheel locks could be locked in straight alignment to help control lateral movement during ambulation.
- Quick release feature allows for quick unlocking as gait development progresses
- Fold up seat helps build endurance for ambulation over greater distances

![Figure 2.1 Image of the Ottobock™ Nurmi Neo gait trainer walker.](image)

In order to accommodate both Sean and his mother, these key features were conserved. In addition, there is potential that the warranty, provided to all customers for the walker, may be voided if an uncertified technician conducts modifications or repairs. This information was obtained via the manufacturer's website and can be provided. This information was disclosed to Gaby during our first meeting with her and Sean.

**2.1 Research on Current and Similar Products**

Currently there are not many attachments available for posterior walkers. The Nurmi Neo walker that will be modified in this project has an available basket attachment. This add-on sits in the back of the walker, but conflicts with Sean's current backpack add-on. Some of the other
attachments available are interchangeable handgrips, seat add-on, and anti-tip supports. While these are helpful attachments, none of them solves Sean's specific needs. This research helped us conclude that there are currently no marketable for posterior walkers, which could fulfill Sean's need.

![Figure 2.2 Image of Patent No. 4659099](image)

![Figure 2.3 Image of Patent No. 3957071](image)

Furthermore, patent research was conducted to see what kind of designs are out on the market today. Some keywords included "attachments for walkers" and "attachment for wheelchairs". While many patents were examined, there were some common design features between them. One of these features is a tray that folds, or slides away from the top of the walker and stores in the front or side of the walker. An example of this feature can be seen with Figure 2.2. Another type of walker attachment is a part-tray, part-storage box. Some of these designs have drawers or pockets for various types of objects, seen in Figure 2.3. In addition to flat trays, there are a number of designs that include indentations for drinks, silverware, or plates. Lastly, all of these patents utilize the front bar of the walker, or part of the handgrip area in order to attach to the walker. These features were considered when designing the final product.

![Figure 2.4 Image of a modern school desk with a swivel table.](image)
Due to the limited information of walker attachments, it was decided to look into surfaces or desks for inspiration. This search began with the traditional school desk design for inspiration of how desks are shaped to accommodate for books and laptops. The more modern school desk shown in Figure 2.4 shows a joint arm that can move for better adjustability. The attachment of Figure 2.5 is used on a standing desk to create a movable surface to place one's laptop or other various items. This is with a thicker, two lever arm system. While these designs are not strictly for walkers, they are good examples of movable surfaces, and their shapes.

In order to get a better understanding of Sean’s need we visited Sean and his mother Gaby at their home in Grover Beach, Ca. We started this visit by first speaking with Gaby and asking her questions that would help us define the problem better. The information, suggestions, and needs for the project became clearer. She wanted a smaller tray that Sean can use to carry items while in a store and his lunch tray at school. The modification needs to be created in a way that those items do not easily slip off the device. It should be assembled in a way where she does not have to take the attachment off, it should be portable, and should not interfere with the walker’s folding mechanism. Gaby sees this design as an opportunity to allow Sean to express his independence by being able to transport items from one location to another. We then turned our focus to Sean, and observed his movements while in and out of his walker around the house. Gaby suggested we all go outside and take a walk up the sidewalk to the mailbox. This allowed us to observe how swift Sean can be.

Observations made during our visit with Sean:

- Sean favors his right-hand when holding items.
- The walker’s main function is to aid his balance.
- His movements range in speeds and include quick side-to-side turns.
- Sean has a slight tendency to look down while walking.
- The walker Sean owns is very agile and rides smoothly due to large rubber tires.
- Sean prefers to keep at least one-hand on the walker while idle.
- Hand-strength and coordination is great.
- Keeping the current toe-to-toe footprint of the walker is crucial.
- The walker is lightweight and compacts nicely.
- Model does adjust in height, and is currently at half its capacity.
- Grips on the walker are removable and held with setscrews.
- Home driveway is not very steep and slight disturbance when entering the home.
3 Objectives

Success within the design process was determined by how well we solved the previously mentioned problem statement. It is common design practice to set forward guidelines derived from a problem statement. This required detailed research and analysis into what the sponsor and customer were truly seeking with this design. These individual guidelines came in the form of specifications, which were detailed and quantifiable promises to our customer. It was only through initial research that we are able to develop these standards. If we were to fail to identify the real problem and needs of the customer, we could have jeopardized the quality of our specifications, thus compromising the progress of the design. The specification list does not describe the final design, but served more like a template for the concepts the team came up with. These specifications are mainly demands either given to us or decided through interactions with Sean and Gaby. Table 8 in Appendix A, displays the specifications we have compiled that assisted in designing/critiquing the designs. As seen in the table, the specifications or "requirements" laid out by the team are labeled under the column of features. These features are broken down into more specific sections that the team felt described the project. The first feature was geometry, which described any physical specifications of the project such as storage footprint. The second, kinematics, listed the design specifications for any motions. For example, required time for a motion to occur was listed so that the device is not overcomplicated and does not take too long to initiate. The lists then continued to develop for a dozen other features, with each title describing what each detail underneath it involved. These included the requirements that the material itself must abide by, safety requirements, assembly, maintenance and more. These specifications normally had a quantified value that was given to us or safety standards that were researched. Verification of the specification was listed as well, which told the team that the best way to meet a specification with a risk indicator, which told the team how difficult it might have been to achieve it.

To help understand the importance of each aspect of this project as well as how they relate to one another, a Quality Function Deployment (QFD) Matrix/House was used and can be seen in Appendix B. The QFD helped remind the team what the focus or requirements are, and it minimized the chance to misinterpret the needs of the customer. As seen in the figure, the customer requirements or "what's" are placed on the left side with methods of how these were going to be achieved on the top. Each one of the customer requirements were weighted depending on the team's judgment of its importance and their relation was marked with the methods or "how's" that were developed. They could have either a negative, positive, or no relation at all to a specific requirement. The "how's" also had indicators of how they relate to other "how's" and it works in a similar way. The last correlation compared the "what's" to that of existing products from other companies. There are no existing products that match the needs of our sponsor. With the "what's," "how's," weights and correlations in place, a value was tallied at the bottom which gave a relative weight of how important each one was compared to one another.
4 Design and Development

4.1 Ideation Phases
Throughout the course of this project, we have been encouraged to keep a logbook and sketch out any designs that may come into our minds at any given moment. In addition to this independent method of thinking, we sought out alternative ways to encourage creative design thinking. To this end, we participated in a design thinking exercise where we used various materials, such as paper and Popsicle sticks, to make physical representations of the designs. Figure 4.1 shows Miriam working on one of the prototypes, and Figure 4.2 shows some of the prototypes the team developed. These prototypes started the ideas that lead to the concepts: fan, flower, centerfold, roll, and 3D motion designs. Therefore, this method was instrumental in generating ideas for this project, which is heavily based on ergonomics.

After the design thinking process, the team had a lot more thoughts and examples of ideas that were worth pursuing. To organize these thoughts, we tried out a more common style of ideation. A method based on defining various features was chosen. For this method, the team agreed upon several features and listed them all out in a grid like manner. These features were attachment, signals, activation, shape, material, storage and motion. We each voiced ideas for each category and Marlene wrote them on a white board. Then we were able to take different features from each column and mix and match them to form new ideas. Some ideas that were created here include the joint arm, lever storage, and the twisting activation method seen in the final design.

4.2 Design Concepts
After the implementation of several ideation techniques, we were able to design many concepts. These top designs have been screened to filter out some of the unrealistic concepts, which would only expend our time during the evaluation process.
Figure 4.3 Hand-sketch of design concept known as "Umbrella"

The design shown in Figure 4.3 is a rendering inspired by the truss-mechanism rain umbrellas deploy, hence the concept name Umbrella. This concept includes an extended walker arm designed to store this mechanism within it, the foldable truss would be activated in the same fashion as standard umbrellas, thru a button. A material would be unfolded and placed over this truss. This low profile design would appeal to the user because it could easily be concealed; we aim to not bring attention to the user's disability. This idea, although creative, is not practical in terms of providing a stable and strong surface for the user. The inability to use a hard material to mount on to the retractable surface would cause issues when trying to satisfy the requirement of having a level surface. In addition, this design obtained a low safety value due to the foreseen problems between the user and device. These included pinch points within the truss, fast activation, and bending of truss system.

Figure 4.4 Hand-sketch of design concept known as "Bowl"

Figure 4.4 is a rendering of a surface style that is flat and can transform into a bowl by applying minimal hand force, which will unlock the surface. This transformation of surfaces would benefit the user's ability to transport geometries that are more complex. The overall goal is to allow the user be able to carry items from one place to another, so the fact that this design increases the
variety of items is very appealing. This concept brought up some manufacturing feasibility concerns regarding the choice of material and the transformation mechanism. In addition, safety issues with pinch points were considered since the user would be deploying the transformation with their hand.

Figure 4.5 Hand-sketch of design concept known as "Roll-Out"

Figure 4.5 demonstrates a sketch rendering of a rollout surface that provides the user with a low profile retractable surface. The mechanism would involve one similar to the ones found in an automobile seat belt, which allows the user to adjust, lock, and retract material length. This concept would be integrated onto an extended walker arm that would also have to be designed. The user would simply pull on a magnetic strip at the end of the rollout surface, which would attach attractively to a metal counterpart on the other walker arm. The concept is ingenious and would involve some extensive materials research due to the need for a strong but flexible surface.
Figure 4.6 Hand-sketch of design concept known as "Palette"

Figure 4.6 is a sketch of a design rendering of a surface that resembles an artist's palette, as well as a method of how we plan to attach this surface to the walker. This design is inspired by ergonomics, by being aware that the surface will be near the waist of the user and controlled by their hands. The surface is shaped to provide comfort to the user's abdominal region and hands. The attachment design is completely new walker arm that provides a swiveling support arm, similar to the one in Figure 2.4. This design would support the surface and provide the user with additional surface motions, allowing ease of access into and out of the walker.

Figure 4.7 Hand-sketch of design concept known as "Pop-Out"

Figure 4.7 is a rendering of a design that includes both a conceptual round surface style and method of attachment. The surface shown is circular in shape, which in our personal opinion is more aesthetically appealing than a square tray. This design will also have integrated pop-out compartments for the user's drink or to hold other small items. The compartment could ideally be manufactured to collapse or pop out, the main point is that it will be embedded within the surface. In addition to this surface, the sketch includes a way to attach such a surface to the walker. This method is through designing a rod that is of the same diameter as the current walker arms and using the existing point of connection. This would allow us to simply loosen the
setscrews and exchange walker arms. This way of attaching the design on the walker is appealing because Sean is able to return to his original set-up if needed. The figure demonstrates an extended version of the current arm, allowing the surface to be attached further out in front of the user, and therefore will not hinder his current walking gait.

![Figure 4.8 Hand-sketche of design concept known as "Center Fold"](image)

This design, in Figure 4.8 features a lever system that is connected to a folded and stored table at the hub of one of the walker’s wheels. When this lever is pulled, a bar would raise the table to the proper position. Then the table would unfold from the center using hinges connected to the plates. While this design has a good use of storage, the durability and usability of this design makes it rank lower during the evaluation process.

![Figure 4.9 Hand-sketche of design concept known as "Fan"](image)

The fan design of Figure 4.9, which was inspired by Chinese folding fans, exhibits plates that could be pulled out into a fan shape. These plates would be thin and thus have a very low storage footprint. Then these plates would be stored underneath the handle where all that would be needed to activate it is a pull towards the user. While this design was innovative, there were concerns about the durability of the thin plates, and weather they could be made relatively seamless. The material required would have to have a lot of strength with very little flexibility. In
addition, there was some concern that by being stored underneath the handle, Sean would have a more difficult time using the handle. With a redesign of the fan being further out it could have been an option, except the durability issue was still a problem. Making this design a discarded option.

The 3D-Motion design of Figure 4.10 was loosely based on a showerhead idea. The table would be connected to a tube that could adjust in any direction. It would be connected before the handle, and the tube would extend under and past the handle to the surface. This design had diverse functionality, but the durability of such a tube was put into question. The tube would have to be flexible enough to move, but rigid enough to stay in place when locked down. In addition, the more traditional desk shape made it not as easy to store away in a discreet fashion.
This desk design shown in Figure 4.11 is an idea that incorporates the standard desk design seen on chairs in large lecture halls. The table would be attached on the existing vertical bar on the right side of the walker and unfold from the inside and lock in the middle of the walker. Two pivot points, one on the attachment area and one under the table itself, help make it a simple system. Being that the surface mimics that of a standard desk, it is relatively simple to make this a robust and reliable system. However, because of its robust system there would be issues in trying to reduce the weight and make it low profile. If weight were to be lowered, it would compromise the rigidity of the system, which can cause an issue if Sean were to use this device unknowingly as a support for walking.

![Figure 4.12 Hand-sketch of design concept known as "Channel Gate"](image)

The sketch seen in Figure 4.12 is a low profile retracting design that is inspired by an existing fence design known as a channel gate. The device would store away a little off the right side of the right walker grip and retract forward via a retracting system similar to that of a keyboard table that retracts out from under the computer table. When retracted outward, a second motion would allow the collapsible portion to retract towards the left of the walker where it would lock onto the other grip. This retracting system would be the base of an unfolding surface that would lay on top of it and stay via magnets (see right side of Figure 4.12). When not in use, the folding surface would store in a compartment at the rear of the walker. This is a very creative and low profile design, however, the main worry was that there are far too many moving parts in this system for a 10 year-old to maintain to have it work consistently for at least a few years.
The sketch in Figure 4.13 is a collapsible table titled, the "Flower" design. The name describes the table itself, which when not in use collapses downward around the main shaft or "stem". To use this device, Sean would grab a collapsed flower that is stored in the rear of the walker and place it in the holder ring that swings out in front of him. Gravity would then do most of the work, as it falls through the holder the ring would force the collapsed part of the table to come together and lock in position via magnets built in the table (see right of Figure 4.13). The swing arm holder would exist on the right handle of the walker (see bottom left of Figure 4.13), and whenever Sean wanted to bring it out to use the table it would simply unlatch and pivot around to whatever position he wanted the table to be. This was another unique design that although creative, it poses a high risk of Sean pinching his fingers between them or any of his clothing.

4.3 Evaluation Process
In order to proceed with the project, a single design had to be chosen from the top ten designs, Figures 4.3 – 4.13. The first evaluation process involved developing a list of criteria we as a team determined to be crucial to the final design. Each design was judged on single-criteria at a time to eliminate favoritism within a single design. Studies have shown that when judging a single design against multiple criteria at a time, individuals tend to give high ratings to their favorite design. Evaluation process was conducted with all members present, and we had to all agree on individual ratings, this promoted discussions, which lead to the discovery of design flaws perhaps not seen by other members. Figure D.1 in Appendix D, demonstrates the results of this evaluation process.

The top three designs were determined to be Palette, Pop-Out, and Fan. The sum of their ratings were very close and therefore it was difficult to pick a single design based of this evaluation process. We analyzed each of these designs for any detrimental 0 or 1 ratings, allowing us to
question the design. The concept known as the Fan received a 1 in Diverse Functionality, due to its non-flat surface, small area span, and limit to one surface motion. In order to better see the area spans of these surface shapes we rapidly prototyped several of them out of foam core, shown below.

![Rapid prototypes of surface shapes constructed out of foam core.](image)

Having a physical representation of some of these surfaces allowed us to gain a real-life perspective as to what Sean would be handling. We were able to eliminate shapes like the fan because Sean would not be able to safely transport his lunch tray on it, a required specification.

Several in-person team meetings were held to further discuss the results obtained from the technical evaluation table. We discovered that it would be best to approach a final design by choosing the best method of attachment and the best surface style and integrating the both. This idea led us to contemplate on why the Palette had received such a high score, and primarily it was because the method of attachment seemed durable and provided motion versatility. We soon realized that although multiple motions are a positive feature, are not a necessary requirement to solving the overall goal, which is to allow Sean to transport items from one location to another. Therefore, the fact that the Palette design provided horizontal motion was not substantial enough to make it a great design. We then focused on being able to provide Sean with a sturdy and non-hindering design that would allow him to comfortably walk in his walker and safely place items on the surface. By going back and refreshing what the overall design objective was we were able to devise a single design.
The final design featured an activation trigger in the walker's handgrip, which would unlock the surface from its vertical stored position, and into a ready to use horizontal table. This motion would be smooth and consideration was given to the user's hand strength and comfort. The surface itself was planned to be made of carbon fiber, a strong and lightweight material, and have an accommodating slip-resistant area. In addition, the surface would have a concealed cutout, which would be revealed when in need of a drink holder. Added motion to the table was also planned to be incorporated through a hand-activated lock and unlock positioning system, which would provide beneficial planar motion for Sean.

Further testing and research was then conducted before moving into design manufacturing. Some of the concerns we wanted to resolve included:

- Quantifying Sean's ability to lift with his hand
- Hand comfort when simulating the activation motion
- Quantifying the walker balance
- Appropriate length of the arm extension
- Will the surface store nicely in the designed space?

This preliminary design allowed us to move forward and continue to conduct more testing with Sean. After careful attention to details and frequent visits with Sean, we were able to assemble a well thought out final design.

As a more detailed design began to take shape the overall design of the mechanism gained some modifications. The most major change that was decided was that the table would rise with assistance from a spring. This would make it more convenient for Sean to use the table at any time. The other changes involved the tray's surface. After a discussion with the Freed family, the tray was altered to not change direction horizontally. It was also decided that the cup holder would detract from the table's usability. More specifics on their changes can be seen in section 6 The Final Design.
4.4 Concept Design Hazard Identification Checklist

A sound design not only covers the specifications we have laid out, but also abides by most if not all existing safety regulations and hazard identifications we find and can think of. The Design Hazard Identification checklist, see Appendix E, is not solely meant for the safety of Sean, but also for those around him. Negligence in design safety can result in the injury of others if the device is used incorrectly or poorly designed. In the concept evaluation of our eleven designs, safety (or ability to make safe) was one of the criterion used in deciding the final concept design. With a final design in mind, a more detailed observation checklist was gone through to make sure that we are aware of every possible potential hazard and that we could account for it. This checklist is in the form of questions we asked ourselves where we feel the project can lead to safety issues. Many of these questions derive from US safety regulations we have researched regarding children’s toys, and safety information we have gained through lab experience.
5 Design Management

5.1 Team Roles
Individual leadership is something we believe will be key during our advancement in this project. Member responsibilities were assigned by having each team member take on a role he/she felt will benefit their future career roles.

Marlene Troncoso - Team Relations and Project Progress Lead

As head of team relations, it was Marlene's responsibility to make sure the team communicated and worked together throughout this project. Member participation throughout this project was important; therefore, assigning responsibilities fell under her role. In addition, as head of project progress Marlene maintained the progress calendar, oversaw deadlines, and managed project budget.

Judy Lantaca - Team Fabrication and Prototype Lead

As head of the team's fabrication and prototyping, it is Judy's responsibility to make sure any appropriate tooling or raw material is in the team's possession prior to any manufacturing. During any manufacturing, it is also Judy's responsibility to make sure the team follows correct shop safety protocol to make sure nobody is injured or to prevent the damaging of shop tools/tooling. Lastly, if any manufacturing needs to be outsourced, Judy will be in charge of communicating with the fabricator to make sure there is no confusion in part drawings or anything of the sort.

Miriam Krage - Team Ideation and Testing Lead

As head of the team's ideation and testing, Miriam was responsible for idea generation, setting up, and monitoring tests to evaluate the project. For ideation, this included finding methods of idea generation, organizing the meetings, and providing any tools necessary to stimulate creativity in the group. As for testing, Miriam was in charge of researching viable testing methods and in the future will set up tests, and record the test results. This will include testing for all the prototypes and the final product.

Claire Francis - Team Communications and Resource Lead

A head of team communications and resources, it has been Claire’s responsibility to communicate between various people and the team, and discover the resources available to the team. In particular, Claire needed to stay in contact with Dr. Taylor, the project sponsor, and the Freed family. She also had to keep the rest of the team updated on all of these discussions. In response to resources, Claire needed to discover the budget information and handle any donations that the team could receive for this project. As the Kinesiology major on this project, it was Claire's responsibility to ensure that the modification made to Sean's walker is functional for Sean to use and that the modification encourages Sean to increase/maintain independence.
5.2 Team Scheduling

Successful building of this design required detailed planning and deadline setting. This important aspect of the management plan was addressed through the form of a schedule that the group followed the entire year, see Table J.1 in Appendix J. This master schedule, known as a Gantt chart, is a preferred project organizational method by our administrative advisors. The Gantt chart demonstrated in Table 5.1, demonstrates the tasks specific to our Winter Quarter. The tiles in blue pertain to activities that are important, but not critical to meeting deadlines, whereas the activities in red are critical in time of completion.

<table>
<thead>
<tr>
<th>ACTIVITY</th>
<th>START</th>
<th>DURATION (weeks)</th>
<th>Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>W1</td>
</tr>
<tr>
<td>Detailed Design</td>
<td>W1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Design Analysis</td>
<td>W2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Design Analysis</td>
<td>W2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>CAD Modeling</td>
<td>W2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Full Detailed CAD</td>
<td>W3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>FMEA Report</td>
<td>W3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Spring Analysis</td>
<td>W3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Extension Analysis</td>
<td>W3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Research Materials</td>
<td>W3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Manufacturing Plan</td>
<td>W3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>CDR Presentation</strong></td>
<td>W5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Build Prototypes</td>
<td>W5</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td><strong>Status Report</strong></td>
<td>W5</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Reconfigure Design</td>
<td>W6</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Suppliers Confirmed</td>
<td>W6</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Machine Extension</td>
<td>W7</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Testing</td>
<td>W8</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Build Tray Prototype</td>
<td>W8</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Team Evaluation #2</td>
<td>W9</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>W9</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

Table 1 Gantt chart for the project, for the winter 2015-2016 quarter.

This type of design project allowed us to produce low budget prototypes that we built in house and tested with Sean. Sean’s maintains a busy schedule and meetings must be scheduled weeks in advanced, via email with his mother. Therefore, we must stay on a strict project schedule so we are able to set and keep these visits with him. We do our best to have an agenda prior to meeting with him, so that we are able to be aware as a team of the objectives and remain efficient during each visit. These formal agendas of what we would like to obtain during each visit are kept on our global drive, along with other very important documents and files pertaining to this design project. This online record keeping allows us to share valuable information with one another and our advisors, all while staying organized.
6 The Final Design

6.1 Design Description

The final design includes an ergonomically shaped surface tray, which has been tested and designed with the user in mind. In addition, we have designed a concealed mechanical apparatus, which assists in the tray’s movement. The mechanism accomplishes the following key tasks:

- Provides a method of attaching and securing the tray to the existing walker.
- Allows the tray to have a 90° motion, for in-use and stored positions.
- Assists in activating the tray for ease of use.
- Delivers firm support of the surface.
- Permits the user to transport small items.

This design is lightweight, strong, and aesthetically pleasing, all-important factors to our sponsor. Figure 6.1 highlights the complete look of our design. Figure 6.1 demonstrates how the device is connected to the walker’s right existing handlebar (with respect to the user). This was implemented by modifying the black rubber handgrip and removing material so that the design could slide into the handlebar. As mentioned before, this final design features a manual trigger, which resides underneath the tubing, close to the user’s hand. When not in use, the tray locks in place, approximately horizontal to the floor. When the spring loaded pull pin is activated, releases the stored energy of the pre-loaded torsional spring within the extension. This energy is enough to raise the surface 90 degrees and into its secondary lock position. The motion of this mechanism is assisted through the implementation of grease, intended to smooth the tables rise speed. This consideration prevents an immediate rise of the device, which could potentially harm the user.
Figure 6.2 Image of the final tray surface made out of carbon fiber composite.

An important aspect to this project was the design of a tray that would allow Sean to transport small items while in the use of his walker. The figure above is a photo of the lightweight and strong carbon fiber composite we manufactured. The shape of this tray was derived during multiple prototype-testing visits with our user. Multiple surface shapes were designed out of various materials, which were then installed and tested by having Sean interact and use the surface. The above shape in Figure 6.2 was configured with the assistance of Sean and his mother. This process is discussed further in Chapter 8.2: Redesign Process. We believe this final design meets and exceeds all of Sean’s expectations.

Figure 6.3 Exploded view of the final assembly.

The exploded view in Figure 6.3 demonstrates a complete look at all the components involved in this design. Parts 1, 2, and 3 are parts that already exist on the current walker but were added to the CAD to show how the apparatus integrated with the current walker. Individual detailed drawings and part specification sheets can be found in Appendix G.
A structured Bill of Materials (BOM) includes leveled assembly information for all parts shown in the figure above. Additional information regarding the drawing number and supplier, if any, aids in organization of this build. Extra consideration was given to the drawing numbers to facilitate during assembly. Figure 6 and Table 6.1 includes the three sub-assembly series, which make up the overall mechanism. Exploded drawings for these assemblies can be found by looking for the appropriate drawing number “DWG #” in Appendix G.

Figure 6.4 Labeled exploded view of final design.

Table 2 Structured bill of materials for final design.

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SW001</td>
<td>Current existing handle bar</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>SW003</td>
<td>Current existing handle bar grip</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>SW100</td>
<td>Internal Components sub assembly</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>SW107</td>
<td>1/4-20” high holding set screws</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>SW106</td>
<td>Stainless steel snap ring</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>SW202</td>
<td>Rotating sleeve that’s fixed to the table</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>SW203</td>
<td>Mounting points for the table to the collar</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>SW204</td>
<td>3/8-24 hex head bolts</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>SW205</td>
<td>3-D printed end cap</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>SW301</td>
<td>Handle bar extension</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>SW302</td>
<td>Quick-release button to hold extension</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>SW303</td>
<td>Pin that fixes the shaft to the collar</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>SW304</td>
<td>Seat that holds the spring plunger</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>SW305</td>
<td>Retractable spring plunger to lock table</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>SW306</td>
<td>Final tray design</td>
<td>1</td>
</tr>
</tbody>
</table>
The following is a detailed description of how each part is used:

**Part No. 4 - Drive Shaft**
The drive shaft (4) is the component that transfers the spring’s energy to the collar (10) holding the tray (9). This transfer of energy is accomplished through designed spring holders (5); see Figure 6.1.4, which depicts how these parts have been placed within the apparatus. This rotational motion occurs through two independently rotating spring-holders, fixed via specific setscrews (8). Cone-set-screws were chosen for this application because of their known holding capabilities. The spring holder, which will be the driving-holder, will transfer energy to the shaft, which will rotate freely within the extension (14), but rotate the outer collar (10).

This allows the drive shaft to rotate freely in the stationed-holder, which subsequently behaves like a sleeve bearing. The stationed-spring holder is on the left of the drive shaft on Figure 6.1.4, while the drive-spring holder is on the right. The end of the drive shaft, which will rotate the collar, is fixed using a stainless steel pin. To ensure there is no overturn the shaft sleeve bearing and the spring holder fixed to the drive shaft have interlocking legs.

*Figure 6.5 CAD model of how the spring, drive shaft and spring holders interact.*
Part No. 5 – Spring Holders
The spring holders are the parts of the device that are not just hold the spring, but allow the spring to be pre-loaded. Seen in the left of Figure 6.1.4, these two spring holders are closely fitted over the drive shaft. The stationed-holder on the right of the spring sits loose on the shaft, but it is fixed to the extension tube with a setscrew. The drive-holder seen on the left of the spring is fixed to the shaft, also with setscrews. In addition it has a 90 degree extended piece that prevents overturn in the spring mechanism.

Part No. 6 – Torsional Spring
The spring being used for our application is what is known as a straight offset torsional spring, specifications can be found in Appendix F. A torsional spring was chosen because of the motion involved with our device, while the straight offset ends were chosen due to limited radial housing space and the ease of being able to constraint the protruding style ends. This is located in the extension, which is 0.745 inches in diameter. Most of the other type of spring ends would result in difficult dimensioning of other parts. Examples of these different ends can be seen in Figure 6.6. Other spring ends stick out further than the outer diameter of the coils and so to provide the same amount of torque calculated a larger extension would be needed to account for a spring that is sticking out. On the other hand, if a smaller spring was used to provide the same amount of torque, that would result in a smaller drive shaft which would increase the risk of failure.
Figure 6.8 Different examples of spring ends for torsional springs.

**Part No. 7 - Shaft Sleeve Bearing**
The shaft sleeve bearing has been designed to be machined from a cylinder that is turned down to allow the drive shaft to fit inside with a clearance of .002"-.004". This sleeve bearing will serve as the secondary support for the drive shaft. It is very important for this drive shaft to be stable during rotation. Due to its low speed and partial rotational motion, we do not need to account for critical speed effects. Also, a corresponding leg was manufactured at the end to interlock with the spring holder. Preventing overturn of the spring.

**Part No. 8 - Set Screws**
The setscrews chosen for this design are known as cone-set-screws, which are recommended for applications requiring high "hold" and good corrosion resistivity. Success of this design relies heavily on the fact that none of the described rotating parts held by setscrews will experience any slipping.

**Part No. 9 - Tray**
As mentioned previously, the table tray is the main component of the device that defines the entire project. The shape of this tray was determined during our interactions with Sean. It sits right at the edge of the handle to his walker, which is close enough for him to conveniently use as well as not topple the walker over. On the edge of the tray is a rubber lip that can fold up or down (above or below) the top surface of the tray, which will act as a barrier to prevent anything from rolling off if need be.

**Part No. 10 - Collar**
The collar is going to be the part the drive shaft rotates, which in turn rotates the brackets that the tray is assembled too. The collar slips over the extension with roughly .001"-.003" in clearance. This clearance allows an easier twisting of the collar as well as enables us to test to see if that much clearance is enough to allow a dampening grease to be introduced which dampens the movement of the table when the entire device is activated.
Part No. 11 - Tray Brackets
The tray brackets are machined parts, which slide over the collar and are fixated via setscrews and JB Weld, for extra support. The position at which these are mounted at on the collar were crucial in getting the table to start and stop in the correct position. Once fixed, the tray was then mounted onto the both of them with bolts. All the features are seen more clearly on Figure 6.1.7.

![Figure 6.9 CAD model of the tray supports.](image)

Part No. 12 - Shoulder Bolts
The 3/8”-24 pitch shoulder bolts chosen are standard ones sized to thread though the tray supports as well as the tray itself. These fine threaded bolts were picked for the extra strength they provide. For the length 1.5” bolts were bought and shortened to about 1” so that they would lie flush on the bracket.

Part No. 13 - Single Button Straight Leg
This specific button is the same type of button that is used on crutches. With a high resistance to corrosion, it is a practical and proven way to enable the locking of the device itself to the existing walker handle bar.

Part No. 14 - Extension
The extension is going to be the main support of the entire device. With the grip cut to expose the opening of the tube, it slides into the hollow tube that is the current handle and locks in via a spring-loaded button (Part No. 15). This extension shaft houses the spring, spring holders and drive shaft, which are used to provide the necessary torque to rotate the collar and table.

Part No. 15 - Shaft Lock Pin
The shaft lock pin is the part that connects the rotating drive shaft to the collar that then allows the collar to rotate. This pin is a shortened quick release pin without a ring sticking out, to prevent any accidental releasing of this pin. A press fit was used in conjunction with an end cap to prevent such accidents.

Part No. 16 - Plunger Seat
This plunger seat is simply a cylinder turned down on the lathe, tapped, and welded onto the collar so that the spring plunger can be threaded into it. This is a necessary piece because the wall thicknesses of the collar/extension are not thick enough to allow the plunger to be properly attached.

**Part No. 17 - Spring Plunger**
The spring plunger is the means of activating the device. It is positioned on the right side of the table and close to the user so that it is easy to reach. In the tray's down position, the spring plunger (when threaded into the welded pin seat) locks the device in place by inserting its plunger into the collar and extension through aligned holes. When the plunger is activated/pulled, the plunger first exits a hole in the extension that allows for the release of the pre-loaded spring and the rotation of the driveshaft/collar/table. After traveling 90°, the plunger aligns with a new hole that is machined in the extension and its internal spring forces it to lock into place.

**Part No. 18 - End Cap**
For safety as well as aesthetic reasons, the end of this collar was covered with an end cap so it is not an exposed tube end. This cap was custom made and 3-D printed to cover both the end pin and the hole in the collar.

### 6.2 Ergonomic and Functionality Section

The final design has implemented Sean’s needs and abilities and will prove to be very functional for him. His right hand is dominant, so placing the tray on his right side and having him activate the tray with his right hand will be the most natural for him. Sean does not have any limitations in his hands or arms and thus activating the tray will not be an issue. It should be recommended that Sean activate the tray while in a static position where he can be the most balanced and not have to simultaneously walk and pull the tray at the same time. The table integrates within the existing handlebar, which is an important feature because it keeps the walker less bulky and the tray will be less noticeable; maintaining the idea that this tray is an addition for Sean’s benefit and should not lead to him standing out. The carbon fiber material of the tray is lightweight and strong; perfect for the use for an 11-year-old. It was important that the tray is lightweight because any added weight to the walker may place him off balance or make it difficult for him to ambulate. With this strong material, there is not a great concern that items he places on there are likely to fall and cause an injury. Incorporating a slip resistant material section to the tray increases the functionality of the tray by allowing Sean the option to place a variety of different objects on the tray without being worried that they might not be stable. Lastly, the shape of the tray increases functionality for Sean by not being a complete rectangle and blocking Sean into his walker; he can easily have the tray employed and maneuver in and out of the walker if he desires.

### 6.3 Testing Plan

Throughout the prototyping and final development phases of this project, testing was a very important component. In order to be prepared for this testing a few measures were taken. The first being, a Failure Modes and Effects Analysis (FMEA) showing the parts of the design that could fail and how they would fail. This helped to define the areas that
needed particular testing. Next, a list of tests that needed to be completed on the final design and the corresponding testing equipment was identified. Finally, a Design Verification Plan and Report (DVPR) was completed. This plan defined the tests required and provided a place to transcribe the results.

6.3.1 Failure Modes and Effects Analysis (FMEA)
In every design, there are a number of incidents that can occur. In order to plan for these incidents, a failure modes and effects analysis (FMEA) was preformed see Table 9 in Appendix G for this information. In this analysis, there were some areas that were identified, which required more attention. The main areas of concern included the walker handle extension, the damping system, and the spring.

The walker handle extension was determined to be the highest risk method of failure. The walker handle extension was not only identified as the support piece of the entire assembly, but also as one of the most likely places of failure due to the thin walls of the tubing. The tubing structure could deform during loaded conditions. This would render the extension unusable and possibly dangerous to the user. To address this probable failure analysis was performed to verify that the extension material strength would suffice.

The next area of concern was the damping system. The collar was designed to hold damping grease on the inside area between the collar and the extension bar. The major concern was if the collar was dislodged that the grease would leak out. Causing the table to rise faster, and possibly covering Sean's hand with grease. Therefore, a planned force test was added to the DVPR, and non-toxic grease was chosen.

The internal spring was another area of concern identified by the FMEA process. The two possible issues that were found were overstretch in the spring and possible dislodging of the spring out of the spring holder. For the overstretch issue, a test was added to verify that the spring would withstand over twisting and repetitive use. The spring holder will be double-checked during the assembly phase.

Three other parts were identified which had relatively low priorities. These were the table surface, the activation pin, and the activation handle. The table, which was designed to be made out of carbon fiber, was found to have a low possibility of breaking, but a strength of the composite test will be done for reassurance. The activation pin was found to have a possibility of jamming, so a reliability test was added to the DVPR. Finally, the possibility of damaging the activation handle was identified. This had a low probability of occurring, and the part is easily available so no further action was planned.

6.3.2 Design and Verification Plan and Report (DVPR)
To ensure the validity and overall safety of the design a series of tests were planned. These tests were created based on the specification sheet and the FMEA. In addition, a summary list of the required materials for each test, Table 11 in Appendix G, was created to assist in preparation for each of the tests. Some of these tests were altered or eliminated due to new information. Test results can be found in Chapter 8.
Analysis was performed on the extension bar to theoretically discover that the extension bar could potentially deflect 0.014 inches, see Appendix F, Problem F.2. Since this is a crucial area of the design, a bend test was fashioned to test the real deflection. A 40lb. load will be applied to the end of the extension bar and the deflection will be measured using calipers. In addition, various lengths of filler materials will be tested within the test piece. This would show if extra support is needed and at what length.

**Test No.1 - Bend Test on the Extension Bar**
The next test that was considered on the extension bar is a crash test. The walker could fall or be pushed into something, so the bar will be tested to see how it will respond in such scenarios. For the test it was determined that the walker should be able to handle a 40lbf impact force without affecting the surface or function of the bar. This will be done by dropping a 3.33lbm +/- 0.2lbm bar, of a length of about 1in, from a 1ft height. This mass was calculated using the following work-energy method (see Appendix F ProblemF.4).

**Test No.2 - Crash Test on the Extension Bar**
The overstretch in the spring was also tested. It would be possible that if used incorrectly the spring could become overstretched. To ensure that the spring would be able to resume its functionality after such an event the spring will be stretched by 360 degrees past its normal position while on a rod. Then it must be able to lift the table.

**Test No.3 - Test Table’s Ability to Hold Load**
Another major test that was performed was the ability of the table to hold the required load. This will simply be done by setting loads of 2.5lbs up to 10lbs on the table, measuring the deflection, and making sure the table is stable. Specifically, that the table will hold the load stable, table will not collapse under the weight, and the deflection is less than 0.5inches.

**Test No.4 - Test Table’s Ability to Rise**
The fourth test was the table’s ability to lock into place consistently and reliably. To check this the mechanism will be activated and stored 20 times. During these activations the mechanism must not jam, break, or in any way cause a hindrance to the user.

**Test No.5 - Overstretch Test on the Spring**
Over many uses, springs also tend to lose the tension that they provide. To make sure the spring was able to operate consistently it will be twisted by 90 degrees 20 times. To pass the test the spring must be able to withstand this motion and raise the table within 5sec of its original average rise time.

**Test No.7 - Time to Activate Test**
Since a specific user will use the tray there are some ergonomic functions that also needed to be tested. The first of these is the time to activate test. This test was first be performed by Miriam to find a general time of activation, and then by Sean.

**Test No.8 - Time to Exit Test**
Similar to the time to activate test, there needed to be a time for Sean to exit the walker test. This test will required Sean to attempt to leave the walker by first storing the tray away, and then without storing the tray. This is to ensure that Sean has the ability to leave the walker comfortably while the tray is in the upright positon. Both of these were to be performed in under 5sec.
**Test No.9 - Time to Disassemble Test**
The third ergonomic test was to verify if the tray attachment can be removed quickly and easily if the owners chose to do so. This test was performed first by Miriam, and then by Sean's mother Gabby. The attachment was intended to be removed from the walker in 1min =/- 30sec.

**Test No.10 - Temperature of Table Test**
Since Sean will be using the walker all year long, inside and outside the heat retention of the table needs to be tested. The attachment was to be left outside on a hot day in the sun for 1 hour. Judy will then take temperature measurements every 10min using a thermometer. At any time, the attachment temperature cannot exceed 104 degrees Fahrenheit. In addition, the heat should not deform or damage the attachment.

**Test No.11 - Damping Test**
Finally, a test was conducted to see the effectiveness of the damping grease. The physics of damping grease are still difficult to predict so the testing also was used to determine the amount of grease necessary to use in the system. This test will required the mechanism to be activated and the damping system should cause the table to gradually rise and reach the end position without slamming.

### 6.4 Engineering Analysis

#### 6.4.1 Tubing Deflection
In our engineering judgment, we sought it critical to ensure the strength of the tubing structure of the extension that supports the mechanism. This analysis involved determining the maximum deflection of the tubing we selected for our final design. These preliminary calculations aided in determining whether we should consider the wall and length sizes to be a problem.

Simple beam theory was applied for the analysis, the use of simple geometries along with standard shaped tubes or plates allowed this simplification to be valid. In addition, all parts of this project are modeled as either a cantilever beam or a simply supported beam.

Maximum deflection for the aluminum tubing was calculated to be 0.014 inches at a max load condition, see Appendix F. This deflection although minor, is unwanted considering the tolerances we are working with are in the hundredths. This analysis led us to consider alternative higher strength materials, specifically those with higher tensile modulus, like steel. A secondary calculation was performed for steel tubing, under the same dimensions, and only changing the value of the tensile modulus. This resulted in a maximum deflection of 0.004 inches; see Appendix F, a 65% deflection reduction in comparison to Aluminum. This large decrease in deflection is desirable for this part, considering its application in this design.

#### 6.4.2 Spring Torque
Another important design concern was the selection of the internal spring. The main factor that determined the spring needed was the torque required in order to lift the table. Therefore, the first calculation was to determine the torque that the tray exerted on the collar which was found to be 7.2 [lb. •in]. From there a spring had to be designed to provide that amount of torque and fit
within the required parameters of the extension. These were the length of the spring could not exceed 1 inch and the outer diameter of the spring could not be greater than 0.7 inches.

In addition, some parameters had to be chosen in order to full define the mechanism. One of these was the material selection of the spring. Due to its availability and uses in smaller applications music wire wire was selected. Other decisions included a torsional spring with straight offset ends with a preliminary pitch of 0.09 inches. Finally, MATLAB was used to solve the necessary equations.

It was found that the spring variable that had the greatest effect on the torque was the spring wire diameter. Therefore, it was made the variable to vary in the MATLAB program. From there the number of coils, inner diameter, radial spring constant, and the torque provided by the spring was calculated. Resulting in a recommended spring wire diameter of 0.08 inches and a spring torque of 13.979 [lb. \( \cdot \text{in} \) for one revolution of twist. A written out example, and the MATLAB script can be found in Appendix A. However, the availability of off the shelf springs is limited, and custom spring costs are very high, so a spring that closely matched these parameters was chosen.

### 6.4.3 Shaft Pin Shear Stress

Design consideration was given to the locking pin that holds the shaft to the collar. The question was whether the pin would be strong enough to withstand the torque of the spring and the force of the safety factor of 40lbf. stated in the design specifications. To begin, the shear analysis of the pin was chosen to be a single shear and not a double shear, since there is only one potential critical point. A conversion was used to translate the 7.2 [lb. \( \cdot \text{in} \)] of torque to a force that the pin would experience. This number, 14.4 lbf was much smaller than the force from the factor of safety and so the 40lbf was used in the rest of the analysis. A simple hand calculation of shear stress was applied to the chosen 3/16-inch, diameter alloy steel pin. The analysis resulted in a shear stress of 1449 psi. Under ASME B18.8.2, the force for an alloy steel with our design dimensions must not be subjected to anything greater than 4150 psi. This preliminary analysis and factor of safety concludes our pin to withstand designed conditions.

### 6.4.4 Tray Composite Layers

Desiring a lightweight and strong tray surface we opted for sandwich-composite material process. As previously mentioned, a balsa core wood with carbon fiber layers was chosen as the final materials for the tray. This decision was based on the fact that the carbon fiber was donated and not being purchased. Calculations for how thick the layers had to be were made to ensure it could withstand the specified loads. With a factor of safety of 4, a 40-lbf load was used. The moment taken from the edge of the tray surface was calculated to be 240 lbf-in. The balsa core thickness was measured to be 0.375 in. resulting in a load of 640 lbf. This load would determine the shear stress that would be applied over the cross-sectional area of the tray. Final thickness was estimated to be 0.00267 in. Dr. Mello used his experience in composites and suggested we do 4 layers thus increasing our thickness to 0.01in. This was done to each side of the tray in orientations also suggested by Dr. Mello: 90°, 90°,45°, and 90°. Additional \( \frac{1}{2} \) section layers (2), were added to the underside of the tray only to account for the brackets being fastened there. These two layers were in a 45° then 90°. Figure demonstrates a sketch of the final layup order.
6.5 Budget Management

Sponsorship of this project lied primarily within the Cal Poly Mechanical Engineering department. Our team sought out additional sponsorship with success coming from Ottobock, the manufacturers of Sean’s current walker. A gift of a new Nurmi Neo Gait Trainer, estimated to be $700, allowed us to become more familiar with their product and design for exact dimensions. Our co-sponsor Dr. Mello of the Mechanical Engineering department assigned an initial project budget of $500. This budget includes all materials and costs for both prototyping and final design.

<table>
<thead>
<tr>
<th>ITEMS</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
<th>Price Ea.</th>
</tr>
</thead>
<tbody>
<tr>
<td>304 Stainless Steel Tube</td>
<td>12&quot; Length – 304 Seamless Tubing</td>
<td>2</td>
<td>$17.00</td>
</tr>
<tr>
<td>Aluminum Stock</td>
<td>1&quot;Length - 0.75&quot; Diameter, 6061 Aluminum</td>
<td>1</td>
<td>$2.60</td>
</tr>
<tr>
<td>Stainless Steel Drive Shaft</td>
<td>2' Length - 0.75&quot; Diameter, 303 Stainless Steel</td>
<td>1</td>
<td>$17.40</td>
</tr>
<tr>
<td>Shaft Lock Pin</td>
<td>316 Stainless Steel, 3/16&quot; Diameter</td>
<td>1</td>
<td>$3.68</td>
</tr>
<tr>
<td>Torsion Springs</td>
<td>10.4 lb.-in Torsion Spring</td>
<td>20</td>
<td>$7.80</td>
</tr>
<tr>
<td>Tube Lock Button</td>
<td>410 Stainless Steel</td>
<td>1</td>
<td>$7.66</td>
</tr>
<tr>
<td>Retractable Spring Plunger</td>
<td>3/8&quot;-24, 1.6-3.6 lb. Nose Force</td>
<td>1</td>
<td>$14.17</td>
</tr>
<tr>
<td>Ball Bearing</td>
<td>Self-Align OD 0.69&quot; Shaft Diameter</td>
<td>1</td>
<td>$16.57</td>
</tr>
<tr>
<td>Set Screws</td>
<td>316 Stainless Steel, 1/4&quot;-20 Thread</td>
<td>1</td>
<td>$6.99</td>
</tr>
<tr>
<td>Cap Screws</td>
<td>316 Stainless Steel Socket Head Cap Screw</td>
<td>1</td>
<td>$4.50</td>
</tr>
</tbody>
</table>
This limited amount in funds required a detailed budget management plan, which can be seen in Appendix I. This spreadsheet accounts for the cost of parts and manufacturing labor if needed. In addition, columns with detailed shipping information allows us to order parts simultaneously form one vendor to save on shipping. Part responsibilities; were assigned to members to ensure accountability within the design. The summarized total cost estimation on Table 3 was shown and approved by our sponsor Dr. Mello, during Critical Design Review. The pricing reflected on this table was based on internet research and local hardware store pricing. Items on the table include off the shelf parts, raw material needed to manufacture parts, 3D Printing quotes for prototyped parts, and additional fees for shipping and manufacturing material.

### 6.6 Material Selection

Material selection was a step in the process of designing the final product. In the context of product design, an important goal is to choose material that minimizes costs while meeting the overall design performance goals. Consideration to the environment and physical applications of the design were the basis for our material selection.

The environment for this design was Sean's hometown Grover Beach, California. Being just a few minutes from the Pacific Ocean increases the moisture and salinity content in Sean's environment, making this the perfect conditions for a corrosion attack on metal surfaces. The overall design incorporates the use of specific alloy metals, due to their availability and material properties. Table 4 gives a list of parts and their chosen material.

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Qty.</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extension</td>
<td>1</td>
<td>304 Stainless Steel</td>
</tr>
<tr>
<td>Collar</td>
<td>1</td>
<td>6061 Aluminum</td>
</tr>
<tr>
<td>Drive Shaft</td>
<td>1</td>
<td>303 Stainless Steel</td>
</tr>
<tr>
<td>Spring Holder</td>
<td>2</td>
<td>6061 Aluminum</td>
</tr>
<tr>
<td>Tray Support</td>
<td>2</td>
<td>6061 Aluminum</td>
</tr>
<tr>
<td>Spring</td>
<td>1</td>
<td>Music Wire</td>
</tr>
<tr>
<td>Surface Tray</td>
<td>1</td>
<td>Divinycell Core &amp; Carbon Fiber</td>
</tr>
<tr>
<td><strong>Shaft Lock Pin</strong></td>
<td>1</td>
<td>316 Stainless steel</td>
</tr>
<tr>
<td>-------------------</td>
<td>---</td>
<td>----------------------</td>
</tr>
<tr>
<td><strong>Pull Pin Seat</strong></td>
<td>1</td>
<td>304 Stainless Steel</td>
</tr>
<tr>
<td><strong>Shaft Sleeve Bearing</strong></td>
<td>1</td>
<td>6061 Aluminum</td>
</tr>
<tr>
<td><strong>Set Screws</strong></td>
<td>5</td>
<td>316 Stainless Steel</td>
</tr>
<tr>
<td><strong>Push Button</strong></td>
<td>1</td>
<td>410 Stainless Steel</td>
</tr>
<tr>
<td><strong>Spring Plunger</strong></td>
<td>1</td>
<td>Steel</td>
</tr>
<tr>
<td><strong>Socket Head Screws</strong></td>
<td>2</td>
<td>316 Stainless Steel</td>
</tr>
</tbody>
</table>

The selection of a material for a machine part or structured member was an important decision, and for the most part was made before finalizing the dimensions of the parts.

Many of our parts required a material with strength and stiffness characteristics, which is why we decided to look into alloy metals. Aluminum and stainless steel were our top candidates due to their geometry versatility, ease of manufacturing, and good corrosive resistance. Figure 6.11 demonstrates a comparison of these two materials in areas of material properties as well as costs. We were able to identify that stainless steel is by far a stronger and stiffer material. Therefore, steel was chosen for parts experiencing high forces and aluminum was chosen where possible to try to minimize the overall weight of our design, to meet specification goals.

![Figure 6.11 Material Comparison for Aluminum 6061 and Stainless Steel 304](image)

An example of this selection process is demonstrated for our extension part. The extension is designed to have a very small wall thickness in the range of 0.035-0.065 inches, these values were obtained from researching available stock tubing sizes. This requirement put an emphasis on selecting a material that will be resistive to deflection under loads. Therefore, a key property was the elastic modulus, which is the ratio of the force exerted upon a body to the resultant deformation, and is greater in stainless steel by a factor of 2.9. Therefore, our final decision was stainless steel for the extension tubing, and although this is a limited budget design, we decided pricing to not be a limiting factor due to the high priority of this part’s critical failure effect.
6.7 Manufacturing Plan

The final design incorporated off the shelf parts as well as parts that were manufactured by us from raw materials. Successful completion of this design build relied on a pre-determined manufacturing plan. The Cal Poly campus offers many in-house manufacturing spaces that provide free equipment rental and the helpful staff needed to complete our parts. Table 5 lists the parts requiring shop time and the necessary information required to reserve certain equipment. A more detailed table can be found in Appendix H. This organization table ensures that each member planned and was aware of the required actions needed to build their assigned parts. In addition to reserving equipment we reserved the time of certain staff members who specialize in manufacturing processes.

<table>
<thead>
<tr>
<th>Person in Charge</th>
<th>Part No.</th>
<th>Location</th>
<th>Equipment</th>
<th>Estimated Time</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miriam</td>
<td>SW101</td>
<td>Mustang 60</td>
<td>Lathe, Drill Press</td>
<td>2 hours</td>
<td>Winter Qtr.</td>
</tr>
<tr>
<td>Miriam</td>
<td>SW102</td>
<td>Mustang 60</td>
<td>Saw, Drill Press, Mill</td>
<td>4 hours</td>
<td>Winter Qtr.</td>
</tr>
<tr>
<td>Marlene</td>
<td>SW201</td>
<td>Mustang 60</td>
<td>Laser Cutter</td>
<td>2 hours</td>
<td>Winter Qtr.</td>
</tr>
<tr>
<td>Marlene</td>
<td>SW201</td>
<td>192-135</td>
<td>Composites Bench</td>
<td>9 hours</td>
<td>Spring Qtr.</td>
</tr>
<tr>
<td>Judy</td>
<td>SW202</td>
<td>Mustang 60</td>
<td>Lathe, Drill Press</td>
<td>3 hours</td>
<td>Winter Qtr.</td>
</tr>
<tr>
<td>Judy</td>
<td>SW203</td>
<td>Mustang 60</td>
<td>CNC, Drill Press</td>
<td>5 hours</td>
<td>Winter Qtr.</td>
</tr>
<tr>
<td>Marlene</td>
<td>SW301</td>
<td>41-104</td>
<td>Lathe</td>
<td>3 hours</td>
<td>Winter Qtr.</td>
</tr>
</tbody>
</table>

6.8 Maintenance and Repair Considerations

This walker modification was also designed so that there would be little to no maintenance required from the Freed family. Anything that goes uncontrollably wrong in the design in which the Freed family could not avoid or fix would be a fault on our part. After installation, only a few items are required to be maintained and repaired.

If food or drinks are used on the device and it is spilled, then a simple cleaning of the device is required. This cleaning can be done with a simple wet paper towel and soap (for those extra stubborn spills). Setscrews and socket heads should be out of the way of these spills, but if a spill does get on them, there is no worry for they are stainless.

Automobile dampening grease will be used to slow the motion of the table. The grease used in industry is engineered to be that, under standard conditions, it would not need replacing for the life of our device. However, if something were to happen where grease would need to be added, this could be done by simply removing the quick release pin used to lock the shaft to the collar. With that done, the collar can be removed and the appropriate amount of grease can be added.

With Loctite being used to keep the screws in place, there should not be any loose screws. However, by the off chance that this does occur, a simple tightening using a ¼” Allen wrench/hex key will fix the issue.
If pressed in too far there is a possibility that this button can be stuck inside the extension. The push button is the same exact ones used in crutches, where it is a button connected to spring metal. Since this is located at the end of the extension, which is opened, reaching this button with your fingers should not be hard and so realigning the button with the hole is all that is required to fix this.
7 Product Realization

With a design set and parts ordered, manufacturing of the tray began with the simplest parts to help the team better visualize the final product. This started with the seat plunger mount, collar and extension. Also because this project involved a lot of ergonomic iteration, some of the parts were 3-D printed as prototypes to help finalize designs. Most of the machining was done on manual machines in the Cal Poly Mustang 60’ Machine Shop.

Seat Plunger Mount

1. A 304 SS rod was turned down, drilled and tapped all on a manual Southbend Lathe to match the McMaster plunger threads of 3/8-24.
2. Since the mount was planned to be welded onto the collar, a concave cut was made at one end of the mount using a ¾” ball endmill on a manual Bridgeport Vertical Mill to best match the profile of the collar. A Scotch-Brite wheel was then used to refine that profile (to make the welding portion of the manufacturing easier) since the OD of the collar is roughly 1”, see Figure 7.1.

![Figure 7.1 Final machined mount for the plunger to be threaded into.](image)

Collar

1. A 304 SS tube was cut to length and bored out to match the OD of the extension tube. This was done in two operations on the manual Southbend Lathe because we were limited by the length of the boring bar available at the machine shops.
2. A manual mill and a rotary chuck were used to locate and drill the holes on the collar that were meant for the plunger locking mechanism and the pull pin used to rigidly attach the collar to the drive shaft. With the rotary chuck, we were able to index the holes for the lock exactly 90 degrees from one another, see Figure 7.2.
Figure 7.2 Using the manual mill and rotary chuck to index and drill into the collar.

3. Once this part as well as the collar was finished, we were then able to weld them together, see Figures 7.3 and Figure 7.4.

Figure 7.3 Welding setup of the seat plunger mount on the collar.

Figure 7.4 Stainless steel collar part with visible welded mount and shaft pin hole.
Extension

1. 1-ft of 0.875" OD x 0.065" wall T-304 Seamless Stainless Tube was turned down on a manual lathe to the desired part drawing specifications. Since the wall thickness was fairly thin to begin with and was going to be turned down more, there was concern when securing the tube into the 3 jaw chuck. Although by reducing the depth of cut taken each pass, the amount of stress that the tube underwent was reduced. Also, marring the surface of the part was another concern since the part needed to slide into the collar, and so a little trick used to avoid that was to use a paper towel to preserve the surface of the extension, see Figure 7.5 and Figure 7.6.

![Figure 7.5 Lathe setup for turning round tubing to make the extension.](image)

![Figure 7.6 Carbide tooling used to turn down tube stock.](image)

2. Next, a hole was drilled using a drill press which would hold the push-lock button. This process was done while the extension was inserted into the walker to ensure both holes were aligned.
3. The push button could then be easily slipped into the extension as shown in Figure 7.7 and Figure 7.8.
Hand Grip Modification

1. In order for the extension to fit into the walker’s handle and still have use of the hand grip, some alterations needed to be made. Using an X-Acto Knife, a 1” hole was cut out of the right-hand-grip which would allow for the extension to slide into, see Figure 7.9.

2. The hand grip was adjusted back onto the walker using compressed air, see Figure 7.10.

Figure 7.7 Extension with push button installed.

Figure 7.8 Completed extension part with reduced diameter, holes, and lock button.

Figure 7.9 (Left) Original hand grip, (right) modified hand grip with extruded hole.
Once those parts were clear from burs and polished, the internal spring mechanism components were manufactured. This consisted of the drive shaft, spring holders, and shaft sleeve bearing.

**Drive Shaft**

1. For rigidity and a lower coefficient of thermal expansion, 304 SS was used for the drive shaft. A rod was turned down on a manual lathe with a $\frac{1}{4}$" step down.
2. On the end with the step down a hole was drilled to fit the pull pin that connects the shaft to the collar so that as the shaft rotates the collar does as well.
3. Towards the end of the shaft a .030" wide .020" deep snap ring groove was cut, see Figure 7.11. Cutting tools for snap rings are not so readily available for multiple sizes and so a custom snap ring grooving tool was ground down from a High Speed Steel (HSS) blank using a bench grinder. This snap ring as well as the set screws will help prevent the drive shaft/collar from being pulled out of the extension.

**Shaft Sleeve Bearing**

1. Since this part, as well as the spring holders, are not structural pieces, they were made out of 6061 Al. Turning, facing, center drilling and parting of this piece was done on a manual lathe. The center hole needed to act as a bearing for the drive shaft and so a .251" reamer was used to make a smooth hole with an appropriate tolerance.
2. The side hole and sections were drilled and cut using the mill and an indexing C5 collet holder (an almost identical setup as the one for the collar). Although, because the lip on the part would’ve complicated how this was held in the collet holder, the part wasn't parted to size until after the sectioned cut was made.

*Spring Holders*

1. Set up and machining for this part was exactly like the shaft sleeve bearing where most of the part was done on a manual lathe and the holes drilled on the mill.
2. The holes on the other hand which held the legs to the straight offset springs were done using a rotary vice and a manual mill. The center of the vice/part was found using an edge finder and from there the hole was located and drilled. Since the hole was extremely small, the small increment knob for the z-axis was used to prevent loading the drill bit too much and breaking it. Figure 7.12 shows the spring holders and sleeve bearing installed onto the drive shaft.

*Figure 7.12 Image of spring holders assembled in mechanism.*

*Offset Springs*

The torsional springs started out with regular ends which had to be bent to straight offset ends.

1. To ensure the spring was bent evenly, and in the right position it was placed in a vise and bent in the desired geometry.
2. Additional bending and straightening was done using a pencil blow torch and pliers, as shown below.
Once the basic spring mechanism and the supporting tubes were in place, construction began on the exterior parts. All of these parts required specialty tooling such as a CNC mill, vacuum compressor and 3-D Printer.

Tray

1. The first step in manufacturing the tray was to create the balsa wood core. The core provides the main structure for the carbon to properly lay up against, see Figure 7.14.

2. The tray shape was then cut out using a Universal Laser Systems X2-660 laser cutter, see Figure 7.15. The laser machine uses Adobe Illustrator to determine what type of action/shape is to be made.
3. Since neither carbon nor balsa wood can be threaded for the bolts to connect the bracket and tray, potted inserts were machined using a manual lathe. These potted inserts are aluminum cylinders with 3/8-24 threads in them. The potted inserts were then placed into the balsa wood and glued down, see Figure 7.16.

4. For the tray surface a type of prepared carbon known as "pre-preg", which is a common term for carbon that has already been impregnated with the correct ratio of resin to carbon, was used versus a started wet layup to ensure an even layup.

5. Layers for carbon fiber are: 90°, 90°, 45°, 90° both sides. Additional small 3”x7” layers of 45°, 90° were added for reinforcement where the brackets will be mounted.

6. When the layers were set, the dry fabrics were then added to finish the setup. These dry fabrics consist of and go in order of peel ply, perforated ply, and fleece. Peel ply goes directly on top of the carbon layer and is designed to be easily removed from a cured carbon surface. Perforated is a thin layer of plastic paper that allows excess resin to seep through when the vacuum is initiated. Lastly, fleece is used to capture and remove that excess resin from the carbon layers. Figure 7.17 shows all of these
layered on top of one another in addition to the vacuum bag sealant, known as "vacuum bag tape."

7. After the carbon was cured all dry fabric and vacuum bag tape was removed. It was here when we realized that the edge of the tray compressed slightly, leaving a not so even edge, see Figure 7.18. The edges were repaired using a fiberglass-bondo, a body working filler commonly used to repair the bodies of automobiles, see Figure 7.19. During this process the tray surface was covered in painter's tape to avoid damaging it. This filler is applied, allowed to cure, and then sanded to achieve the desired shape. Initial sanding consisted of 220-grit-sandpaper and the finishing grit was 800-grit wet sand paper.
Once the body of the tray was repaired it was off to painting using spray cans. With the tape still in place, the edging was done first using a primer and then coated with a gloss black. Roughly 3 coats of gloss black were used. The tape was then removed and about 5 layers of clear coat was added to the entire tray, see Figure 7.20.

8. For the "anti roll off" system, a thin neon green tube was used. This tube was used as lining around the edge of the tray and adhered using clear 5-minute epoxy. Once the lining was all laid down a final few coats of clear coat was sprayed on the entire tray and polished to a shine, see Figure 7.21.
Figure 7.21 Finalized tray with clear coat and rubber edging.

Brackets

1. The tray brackets were the only part that involved relatively complex machining that couldn't be done on a manual machine, and were made using a Haas Tool Room Mill. Nathan Harry, the CNC Supervisor for the Mustang 60' Machine Shops, used the CAD model of the part to process the G-Code which told the machine what to cut. Figures 7.22 and 7.23 show the machining set up and final part.

Figure 7.22 Extruded rectangular Al 6061 fixed to the mill table ready to be machined.
The two brackets after they had been machined, deburred, and polished.

End Cap

1. The end cap was fist designed using SOLIDWORKS, and saved as a .STL program type.
2. Next, it was loaded into Cura, a 3D-printing program, where settings were altered to insure a clean and accurate print.
3. Finally, the cap was printed with a Printrbot, which uses 1.75mm PLA filament, see Figure 7.24.

Figure 7.24 A Printrbot 3-D printer which was used to fabricate the end cap.

Prototype Collar and Brackets:

1. A combination collar and bracket part, the red part in the picture below, was printed using a high resolution Stratasys 3-D printer located in the ASME Club room. This part was used to test the location of the spring plunger and the movement of the system.
2. Two green brackets were printed to verify the height and angle of the table, see Figure 7.25.

![Prototype pieces](image)

*Figure 7.25 The two 3-D printed prototype pieces, the collar (left) and two brackets (right).*

As stated before, much of the design and manufacturing was ergonomic driven and so multiple iterations of each part were done. Aggregate machine time was not the issue as all of these parts were relatively simply and small. However, set up and tear down of the machines is what multiplied the expected work time, and with these parts being done on different days it made the total manufacturing time be 20% machining and 80% set up/tear down. In hindsight, some time would have been saved if testing and machining were done on the same day so the machine set ups wouldn’t have to be torn down after a part was made. Although even a simple idea like that was difficult because that would require setting up multiple meetings for either Sean and his mother to come to campus or the team visiting them. The biggest asset to the manufacturing process was being allowed access to the shops after hours, which enabled the team to not have to tear down a work station after every iteration so that other students could work.
8 Design Verification

To ensure the functionality of the final product, tests were performed; most of them being qualitative tests. Our upmost concern with the implemented design is its operational safety when Sean is using the tray modification. In order to determine the effectiveness of these detailed safety considerations for Sean, we performed the several tests proposed during our critical design review. Figure 8.1 demonstrates the results of these tests.

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Test Description</th>
<th>Acceptance Criteria</th>
<th># of Tests</th>
<th>Date</th>
<th>Result</th>
<th>Qty. Pass</th>
<th>Qty. Fail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bend Test on the Extension Bar</td>
<td>Must Withstand 10lbs +/- 5lbs and Deflect Less Than 0.5 in</td>
<td>5</td>
<td>18-Apr</td>
<td>Pass</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>Test Table's Ability to Hold Load</td>
<td>Table Must Hold 10lbs +/- 5lbs Without Failure</td>
<td>1</td>
<td>23-May</td>
<td>Pass</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>Test Table's Ability to Rise</td>
<td>Must Lock into Place 25 times</td>
<td>25</td>
<td>23-May</td>
<td>Pass</td>
<td>25</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>Over Stretch Test on the Spring</td>
<td>Must Be Able to Return From 180 Degree Turn</td>
<td>10</td>
<td>23-May</td>
<td>Pass</td>
<td>10</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>Reliability Test of the Spring</td>
<td>Must Turn Full 90 Degrees 30 Times</td>
<td>30</td>
<td>23-May</td>
<td>Pass</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>Time to Activate Test</td>
<td>Must Activate Within 3 sec</td>
<td>30</td>
<td>23-May</td>
<td>Pass</td>
<td>30</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>Time to Exit Test</td>
<td>Must Be Able to Exit Within 5 sec</td>
<td>5</td>
<td>23-May</td>
<td>Pass</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>Time to Disassemble Test</td>
<td>1 min +/- 30 sec to Remove From Walker</td>
<td>5</td>
<td>23-May</td>
<td>Pass</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>Temperature of Surface Test</td>
<td>Less Than 104 Degrees Fahrenheit on a Hot Day</td>
<td>1</td>
<td>23-May</td>
<td>Pass</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>Damping Test</td>
<td>Table Rises to Upper Position Without Slamming</td>
<td>25</td>
<td>23-May</td>
<td>Pass</td>
<td>25</td>
<td>0</td>
</tr>
</tbody>
</table>

8.1 Testing

Prototype Testing

After a final design had been chosen it was important to put priority on several necessary parts that needed to be manufactured. Additionally, a quick prototype collar and bracket piece was 3D printed, see Figure 7.25, to allow us to test without having to wait for the rest of the parts to be machined.

Testing of Sean's interactions with the design was conducted at his home, both inside and outside. Sean was asked to grab and place things on the tray and walk around the home.
with them. Observation of his motions and tendencies during these tasks were recorded via video and examined. Results determined that a new tray shape needed to be designed.

A variety of initial tray shapes were constructed using foam core. These mock-ups gave a quick estimation of surface options. Then we made thin wood prototypes of the best designs and had a meeting with the Freed family. At this meeting we realized that Sean is very mobile and will frequently leave his walker and return. Therefore, the decision was made that the tray should have a sloped angle so that Sean could leave the walker without storing the tray.

![Figure 8.1 Image of all of the prototype tray surfaces.](image)

At that point another wooden table prototype was used to test some of the other components of the mechanism. While performing this testing Sean sometimes left the walker to grab various items. He was able to make it past the tray, but only barely so. This did not take into account that Sean could grow within the next few years and would no longer be able to leave the walker with the tray raised. So the rounded edge of the walker was removed. The rounded edge piece would have allowed for Sean to carry larger items with more ease, but it was decided the extra space was worth the size cut to the tray. Especially with the use of the non-slip material which covered the tray.

![Figure 8.2 Previous rendering of the tray surface.](image)
Load Test

The most important aspect of this design is its ability to carry loads. A standard load of 10 lbf was set within our specifications and was applied to the final design using pre-calibrated workout weights. Increments of 2.5 lbf were added to the walker up to 12.5 lbf. Through visual inspection of the tray and components we deemed this design to be safe to carry loads of 10 lbf. Testing to determine maximum capable loading was not conducted since that would require testing for destruction of our final product. Figure 8.1 demonstrates a visual of our testing method.

Spring Testing

The spring mechanism is a feature that distinguishes this project from just an average tray, and so its reliability was paramount in the success of our final build. Testing of the spring’s ability to provide sufficient torque to raise the tray required the manufacturing of most of the components. Figure 8.2 shows how this spring is installed within the mechanism. Torque was applied and the spring endured both clockwise and counterclockwise range of motions. The torsion spring fractured, see Figure 8.3, during an overstretch of 270° in the
opposite intended deflection. This failure allowed us to restrict the range of motion to $90^\circ \pm 30^\circ$ for preload.

![Figure 8.5 Spring Mechanism Testing Setup](image)

![Figure 8.6 Fractured Torsion Spring](image)

The testing of our spring-activated-mechanism early on in the project allowed us to detect an inconsistency in its performance. The spring is required to deflect $90^\circ$ and provide sufficient torque to lift the tray, but the initially ordered spring was unable to achieve this torque for a full $90^\circ$ motion. To remedy this situation a preload was added, this provided enough stored energy within the spring to lift the tray. Future testing later determined that the spring would be prematurely fail due to the increased preload which was causing distortion in the spring coils. The inability for the spring to provide enough energy was inferred to be due to the increase of the weight of our final. The spring was not just trying to lift the 0.5 lbf tray but the weight of the drive mechanism which was made of heavy metals. The final weight of the system and tray was measured to be 1 lbf. Torque was obtained with consideration to the new center of mass distance of the final tray, and calculated to be 3.6 lbf-in. A re assessment of our spring choice was made with consideration given to the new torque.

Installation of the new spring allowed us pass all of our tests and move forward with our project. This failure to account for added weight cost us time and money, but served to be an invaluable engineering lesson.

Damping Testing

Initial damping testing was conducted after the collar was manufactured. The prototype tray was taped to the collar in place of the brackets. Then grease was placed along the inside of the collar and slid onto the extension tube. Rags were used to absorb any excess grease. It was then tightened into a vice to simulate the walker. The completed system can
be seen in Figure #. To conduct the test the tray was lifted to two different angles, 90 degrees and 180 degrees, dropped and timed. This was done for an initial no grease state, thin grease, and thick grease. The results can be found in Table 8.2.

![Figure 8.7 Damping Test Setup](image)

### Table 7 Damping Test Results

<table>
<thead>
<tr>
<th></th>
<th>No Grease</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>90 Degrees</td>
<td>180 Degrees</td>
<td>90 Degrees</td>
</tr>
<tr>
<td>1</td>
<td>0.1</td>
<td>0.3</td>
<td>1.0</td>
</tr>
<tr>
<td>2</td>
<td>0.1</td>
<td>0.3</td>
<td>1.1</td>
</tr>
<tr>
<td>3</td>
<td>0.1</td>
<td>0.4</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>0.1</td>
<td>0.4</td>
<td>1.2</td>
</tr>
</tbody>
</table>

After the spring mechanism was fully assembled, a damping was revisited. The spring experienced more friction than anticipated and did not raise as quickly. Therefore, a grease was chosen based on its ability to reduce the friction in the system and not as a damper. Dow Corning High Vacuum Grease was used for its good lubrication, resistance to temperature changes, and it was food safe.
9 Conclusion and Recommendations

Ultimately, this project has been a challenging and fulfilling process. We were able to tailor this tray for Sean, and still have a versatile design. Since the entire attachment is only connected at one point, this tray could be put on various sized walkers, wheelchairs, or anything that has the proper diameter tube. All that would have to be altered is a single hole far enough into the tube. Another aspect to note is that the carbon fiber tray itself would be very expensive to manufacture on a larger scale. If this project was to be made on a wider scale the tray surface could be changes to wood or an injected molding plastic. This would lower cost, and introduce custom variety to the attachment. However, regardless of the tray’s commerciality, we are very pleased with the outcome of this project. The overall cost was finalized at $426.65 which is $114 over our estimated budget. We believe that this final design embodies safety, ergonomics, and meets the objective to expand Sean’s independence.
References

When to Test: Incorporating User Testing into Product Design
https://www.usertesting.com/blog/2013/03/04/when-to-test-incorporating-usability-testing-into-product-design/


# Appendix

## A. Design Specifications

*Table 8 Engineering Specifications for the Hands-Free Walker Modification*

<table>
<thead>
<tr>
<th>No.</th>
<th>Feature</th>
<th>Measured Value</th>
<th>Unit</th>
<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>Modification Type</td>
<td>Attachment</td>
<td>-</td>
<td>Inspection</td>
<td>Low</td>
</tr>
<tr>
<td>1.2</td>
<td>Max Width</td>
<td>10</td>
<td>inches</td>
<td>Inspection</td>
<td>Medium</td>
</tr>
<tr>
<td>1.3</td>
<td>Walker footprint</td>
<td>2x3</td>
<td>feet</td>
<td>Inspection</td>
<td>Low</td>
</tr>
<tr>
<td>1.4</td>
<td>Number of Prototypes</td>
<td>1</td>
<td>-</td>
<td>Inspection</td>
<td>Medium</td>
</tr>
<tr>
<td>1.5</td>
<td>Method of Handling</td>
<td>Hands</td>
<td>-</td>
<td>Test</td>
<td>Low</td>
</tr>
</tbody>
</table>

2. Features, "KINEMATICS"

<table>
<thead>
<tr>
<th>No.</th>
<th>Feature</th>
<th>Measured Value</th>
<th>Unit</th>
<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>Max motions for activation</td>
<td>3</td>
<td>-</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>2.2</td>
<td>Max activation Time</td>
<td>3</td>
<td>seconds</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>2.3</td>
<td>Max activation force required</td>
<td>1</td>
<td>lb.</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>2.4</td>
<td>Max deactivation &amp; exit time</td>
<td>5</td>
<td>seconds</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>2.5</td>
<td>Tipping resistance</td>
<td>Stable</td>
<td>-</td>
<td>Test</td>
<td>Low</td>
</tr>
</tbody>
</table>

3. Features, "FORCES"

<table>
<thead>
<tr>
<th>No.</th>
<th>Feature</th>
<th>Measured Value</th>
<th>Unit</th>
<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1</td>
<td>Max product weight</td>
<td>5</td>
<td>lb.</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>3.2</td>
<td>Max load to withstand</td>
<td>10</td>
<td>lb.</td>
<td>Analysis</td>
<td>Medium</td>
</tr>
</tbody>
</table>

4. Features, "MATERIALS"

<table>
<thead>
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<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.1</td>
<td>Toxic surfaces</td>
<td>0</td>
<td>-</td>
<td>Inspection</td>
<td>Low</td>
</tr>
<tr>
<td>4.2</td>
<td>Max inclination to overcome stiction</td>
<td>10</td>
<td>degrees</td>
<td>Test</td>
<td>Medium</td>
</tr>
</tbody>
</table>

5. Features, "SIGNALS"

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<tr>
<th>No.</th>
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<th>Measured Value</th>
<th>Unit</th>
<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.1</td>
<td>Max physical input signals</td>
<td>3</td>
<td>-</td>
<td>Analysis</td>
<td>Low</td>
</tr>
<tr>
<td>5.2</td>
<td>Max output signals</td>
<td>3</td>
<td>-</td>
<td>Analysis</td>
<td>Low</td>
</tr>
</tbody>
</table>

6. Features, "SAFETY"

<table>
<thead>
<tr>
<th>No.</th>
<th>Feature</th>
<th>Measured Value</th>
<th>Unit</th>
<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.1</td>
<td>Max outdoor surface temperature</td>
<td>104</td>
<td>°F</td>
<td>Compare</td>
<td>Low</td>
</tr>
<tr>
<td>6.2</td>
<td>Thermal conductivity (Aluminum)</td>
<td>124</td>
<td>BTU/(hr·ft·°F)</td>
<td>Inspection</td>
<td>Low</td>
</tr>
<tr>
<td>6.3</td>
<td>Minimum visible distance from feet</td>
<td>2</td>
<td>feet</td>
<td>Analysis</td>
<td>Medium</td>
</tr>
<tr>
<td>6.4</td>
<td>Max amount of pinch points</td>
<td>0</td>
<td>-</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>6.5</td>
<td>Occupant retention</td>
<td>Free to move</td>
<td>-</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>6.6</td>
<td>Surface coating lead limit</td>
<td>0.009</td>
<td>percent</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>6.7</td>
<td>Number of sharp edges</td>
<td>0</td>
<td>-</td>
<td>Compare</td>
<td>Low</td>
</tr>
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7. Features, "ERGONOMICS"

<table>
<thead>
<tr>
<th>No.</th>
<th>Feature</th>
<th>Measured Value</th>
<th>Unit</th>
<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.1</td>
<td>Locations to try and avoid</td>
<td>Left/Rear</td>
<td>-</td>
<td>Analysis</td>
<td>Medium</td>
</tr>
<tr>
<td>7.2</td>
<td>Styling</td>
<td>Transparent</td>
<td>-</td>
<td>Test</td>
<td>Medium</td>
</tr>
<tr>
<td>7.3</td>
<td>Table position</td>
<td>Adjustable</td>
<td>-</td>
<td>Compare</td>
<td>Medium</td>
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8. Features, "MANUFACTURING"
<table>
<thead>
<tr>
<th>No.</th>
<th>Feature</th>
<th>Measured Value</th>
<th>Unit</th>
<th>Verification</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.1</td>
<td>Tolerances</td>
<td>+/- 0.01</td>
<td>inches</td>
<td>Test</td>
<td>Low</td>
</tr>
<tr>
<td>8.2</td>
<td>Disinfectant safe</td>
<td>Yes</td>
<td>-</td>
<td>Test</td>
<td>Low</td>
</tr>
</tbody>
</table>

9. **Features,"ASSEMBLY"

9.1 Special tooling required | 0 | - | Inspection | Low |
9.2 Max assembly time       | 2 | minutes | Test | Low |
9.3 Max amount of tools needed | 4 | - | Test | Low |

10. **Features,"TRANSPORTATION"

10.1 Max disassembly time | 1 | minutes | Test | Low |
10.2 Max overall weight    | 10 | lb. | Test | Low |
10.3 Pieces to transport   | 1 | - | Test | Low |

12. **Features, "USAGE"

12.1 Life expectancy        | 5 | years | Inspection | Medium |
12.2 Optimal working temperature | 70 | °F | Test | Low |

13. **Features, "MAINTENANCE"

13.1 Max cleaning time      | 30 | seconds | Test | Low |
13.2 Maintenance time       | 1 | minutes | Test | Low |
13.3 Max inspection time    | 30 | seconds | Test | Low |

14. **Features, "RECYCLING"

14.1 Parts to recycle       | 1 | - | Analysis | Low |
14.2 Parts to separate before disposing | 1 | - | Analysis | Low |
B. Design Quality Function Deployment

Table 9 Quality Function Deployment, QFD, for walker modification design.
C. **Preliminary Design Evaluation**

Description of the evaluation *Criteria* listed in Figure D.1:

- "Ability To Make Safe", which judges how safe we believed we could make the design be,
- "Ease of Employment", which is how effortless would it be to the user to activate the design,
- "Storage Footprint", which is the overall space the design will take up when stored on the walker,
- "Durability", which is based on how long we believe the design's life cycle to be,
- "Diverse Functionality", this depicts the design's diversity in items it can transport as well as how the user transports them,
- "Manufacturing Feasibility", which is how achievable is the overall building of this design.

These six criteria are an emphasis to the project problem, as well as any successful design.

<table>
<thead>
<tr>
<th>Points</th>
<th>Evaluation</th>
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</thead>
<tbody>
<tr>
<td>0</td>
<td>Unsatisfying</td>
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<tr>
<td>1</td>
<td>Just Acceptable</td>
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<tr>
<td>2</td>
<td>Sufficient</td>
</tr>
<tr>
<td>3</td>
<td>Good</td>
</tr>
<tr>
<td>4</td>
<td>Very Good</td>
</tr>
</tbody>
</table>

*Table 10 Evaluation Wtechnical table demonstrating results for the design concepts.*

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Design</th>
<th>Umbrella</th>
<th>Bowl</th>
<th>Roll-Out</th>
<th>Palette</th>
<th>Pop-Out</th>
<th>Center-Fold</th>
<th>Fan</th>
<th>3D-Motion</th>
<th>Desk</th>
<th>Channel Gate</th>
<th>Flower</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability To Make Safe</td>
<td>2</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Ease of Employment</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>4</td>
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<tr>
<td>Storage Footprint</td>
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<td>4</td>
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<td>4</td>
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<td>1</td>
<td>1</td>
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<tr>
<td>Manufacturing Feasibility</td>
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<td>3</td>
<td>2</td>
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<td>ΣPMAX</td>
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<td>17</td>
<td>13</td>
<td>20</td>
<td>19</td>
<td>10</td>
<td>19</td>
<td>16</td>
<td>15</td>
<td>10</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>
D. Design Hazard Check List

1. Are there any visually obvious unsafe components to the device?
   a. Pinch Points
      • Current possible pinch points would be the bottom of the table and the twisting handgrip. The US Consumer Product Safety Commission (USCPSC) has standards in reducing the amount of pinch points for toys, which will use as a baseline.
   b. Sharp Edges
      • Can be avoided if care is taken during the build process. In addition, the USPSC has standards in reducing this as well.

2. Are there any materials being used whose properties can be potentially hazardous?
   a. Bearing grease
      • Harmful if swallowed and if it gets on Sean’s hands and he rubs his eye, this problem can be avoided if any grease or lubricant being used is properly sealed.
   b. Poor surface material
      • Things such as uncured carbon, cracked wood, or rust can cause splinters or scratch Sean or anyone interacting with said device. This can be avoided during the fabrication process if care is taken while building.
   c. High flammability risk
      • Nothing in our design seems to have this risk, unless a highly flammable grease or surface paint is used. If any grease is sealed or any spray is cured properly, this should not be an issue.
   d. Lead based paint
      • Any paint being used will be tested for lead content and compared to the USCPSC standard for allowable lead on surfaces exposed to children.

3. What movements are there, how could they be hazardous, and how can that hazard be reduced/removed?
   a. Table drops too fast and slams
      • A solution to this will probably be bump stops or dampeners to slow that movement down.
   b. Table rises too fast and oscillates
      • An idea posed by our advisor is tightly packed grease inside the pivot point to slow this movement down.
   c. Table swings too fast/far and can hit Sean or any bystander.
      • Bump stops will possibly be used to limit the motion of the table and not cause a swinging weight.

4. What accidents could the user/bystander be potentially experience?
   a. Bumping the activation button
      • Designing for this button to have decent resistance would reduce this from happening. What also could be done is a button guard that could flip up when the device is to be initiated.
   b. Unlocking the table swivel
      A locking mechanism that offers some resistance or a locking mechanism that does not unlock with a simple bump would solve this issue.
E. Engineering Analysis Calculations

*Walker Rail Extension*

**Problem F.1:** Find the max deflection for a 6.5 in. Aluminum 6061-T6 tube, with an OD of 0.815 in and wall thickness of 0.035 in, if a max load of 10 lb. is to be applied vertically at the free end.

![Model of a force applied to the free end of a tube.](image)

**Known:** Modulus of Elasticity, \( E \), of Al-6061 = 10.0 x 10^6 psi

**Analysis:**

Area Moment of Inertia, \( I \), for a tube:

\[
I = \frac{\pi}{4} \left( r_2^4 - r_1^4 \right)
\]

![Figure A.2 Area Moment of Inertia for Annulus](image)

\[
l = \frac{\pi}{4} \left[ (0.4075in)^4 - (0.3725in)^4 \right]
\]

\[
l = 0.00653 \text{ in}^4
\]

**Deflection Max:**

\[
\delta_{\text{max}} = \frac{FL^3}{3EI}
\]

\[
\delta_{\text{max}} = \frac{(10 \text{ lb f.})(6.5 \text{ in})^3}{3(10.0 \times 10^6 \frac{\text{lb f.}}{\text{in}^2})(0.00653 \text{ in}^4)}
\]

\[
\delta_{\text{max}} = 0.014 \text{ in}
\]

Therefore, the maximum deflection of an Aluminum 6061 tubing with 0.815” OD and wall thickness of 0.035” is 0.014.
Problem F.2: Find the max deflection for a 6.5 in. Steel tube, with an OD of 0.815 in and wall thickness of 0.035 in, if a max load of 10 lb. is to be applied vertically at the free end.

Model of a force applied to the free end of a tube.

Known: Modulus of Elasticity, $E$, of Steel = 29.0 x 10^6 psi

Analysis:

Area Moment of Inertia, $I$, for a tube: $I = \frac{\pi}{4} (r_2^4 - r_1^4)$

\[ I = \frac{\pi}{4} [(0.4075\text{in})^4 - (0.3725\text{in})^4] \]

\[ I = 0.00653\text{ in}^4 \]

Deflection Max:

\[ \delta_{max} = \frac{FL^3}{3EI} \]

\[ \delta_{max} = \frac{(10 \text{ lbf.})(6.5 \text{ in})^3}{3(29.0 \times 10^6 \text{ lbf./in}^2)(0.00653 \text{ in}^4)} \]

\[ \delta_{max} = 0.004 \text{ in} \]

Therefore, the maximum deflection of Steel tubing with 0.815” OD and wall thickness of 0.0.35” is 0.004 inches. This is 65% smaller than the deflection of Aluminum tubing determined in Problem B.1.
Spring Selection Calculation

Problem F.3: Need to find spring design that provides enough torque to lift the tray.

Known: Table Parameters and Spring Parameters.

Analysis:

Parameter to Alter Wire Diameter
\[ d = 0.08\text{in} \]

Table Parameters:

\[ F = 0.5\text{lbf} \quad \text{Force of table} \]
\[ L_{abs} = 4\text{in} \quad \text{Length from table center of mass to spring} \]

Torque due to force of the table
\[ T = F \times (L_{abs})\text{ lbf*in} \]
\[ T = 0.5\text{lbf} \times 4\text{in} \]
\[ T = 2\text{lbf*in} \]

Spring Parameters in inches:

\[ Do = 0.693 \quad \text{Outer spring diameter} \]
\[ Lo = 1 \quad \text{Free spring length} \]
\[ Ls = 0.693 \quad \text{Length of spring moment arm} \]
\[ p = 0.09 \quad \text{Spring Pitch} \]

Spring material: Music Wire Table

\[ E = 28.5 \times 10^6\text{Mpsi} \quad \text{Modulus of elasticity} \]

Relations between parameters:

Inner spring diameter in inches
\[ Di = Do - 2 \times d \]
\[ Di = 0.693\text{in} - 2 \times 0.08\text{in} \]
\[ Di = 0.613\text{in} \]

Mean coil diameter in inches
\[ D = Do + d \]
\[ D = 0.693\text{in} + 0.08\text{in} \]
Spring Selection Calculation

\[ D = 0.773\text{in} \]

Number of Coils

\[ Na = \frac{Lo - d}{p} \]
\[ Na = \frac{1\text{in} - 0.08\text{in}}{0.09\text{in}} \]
\[ Na = 10.22 \]

Spring constant radial lb.*in/rev

\[ kr = \frac{E \times d^4}{10.8 \times D \times Na} \]
\[ kr = \frac{28.5^6\text{psi} \times 0.08^4\text{in}}{10.8 \times 0.773\text{in} \times 10.22} \]
\[ kr = 13.979 \text{ lbf*in/rev} \]

Torque the spring provides from Hooke's Law lb.*ft

Fraction of twist rev
\[ \delta = 1\text{rev} \]

Torque lb.*in
\[ Ts = kr \times \delta \]
\[ Ts = 13.979 \text{ lbf} \times \frac{\text{in}}{\text{rev}} \times 1\text{rev} \]
\[ Ts = 13.979 \text{ lbf} \times \text{in} \]

The torque of the spring is greater than the torque of the table thus the spring is acceptable.

From this a shaft diameter can be chosen

\[ d_{rod} = D_t - d_{allow} \]
\[ d_{rod} = 0.613\text{in} - 0.05\text{in} \]
\[ d_{rod} = 0.563\text{in} \]
**Extension-Bar Crash Test Calculation**

**Problem F.4:** Need the proper size of mass to drop from a 1 ft height to create a force of 40 lbf.

**Known:**

Force:

\[ F = 40 \text{lbf} \]

Acceleration Due to Gravity:

\[ g = 32.174 \frac{\text{ft}}{\text{sec}^2} \]

Height:

\[ h = 1 \text{ ft} \]

Length of Contact:

\[ r = 0.0833 \text{ ft} \]

**Analysis:**

Use the relationship between work \( W \) and Potential Energy \( PE \)

\[ W = PE \]

\[ PE = m \times g \times \Delta h \]

\[ W = m \times g \times \Delta h \]

\[ m = \frac{W}{g \times \Delta h} \]

The second relationship needed is that work is equal to force times length of contact \( r \).

\[ W = F \times r = 40 \text{lbf} \times 0.0833 \text{ft} \]

\[ W = 3.33 \text{lbf} \times \text{ft} \]

Then use work in the above equation to find mass.

\[ m = \frac{3.33 \text{lbf} \times \text{ft}}{32.174 \frac{\text{ft}}{\text{sec}^2} \times 1 \text{ft}} \]

\[ m = 3.33 \text{lbm} \]
**Quick Release Pin Shear Calculation**

**Problem F.5:** Determine if the quick release pin will not shear under the load of the spring or the safety factor load of 40lbf.

**Known:** Spring Torque:

\[ T = 7.2 \text{ lbf} \times \text{in} \]

Distance from the center:

\[ r = 0.5 \text{ in} \]

Pin diameter:

\[ D_{\text{pin}} = \frac{3}{16} \text{ in} = 0.1875 \text{ in} \]

**Schematic:**

**Analysis:**

Single shear is defined as follows:

\[ \tau = \frac{P}{A} = \frac{F}{A} \]

Where,

\[ A = \pi \times \left( \frac{D}{2} \right)^2 \]

Must convert torque into force:

\[ F = \frac{T}{r} \]

\[ F = \frac{7.2 \text{ lbf} \times \text{in}}{0.5 \text{in}} \]

\[ F = 14.4 \text{ lbf} \]

This force is much lower than the safety factor force, so this will be used for shear:
\[
\tau = \frac{40lb f}{\pi \times \left( \frac{0.1875in}{2} \right)^2}
\]

\[
\tau = 1448.66 \text{ psi}
\]

Looking up single shear strengths for a 3/16\textsuperscript{th} steel pin we find that under ASME B18.8.2, the force for an alloy steel of such dimensions to experience single shear it would have to be undergoing 4150 psi. This far exceeds even our safety factor so if anything something else will break before the pin does.
Tray Composite Calculations

Determine the thickness of the carbon fiber required to support the specified loading conditions.

Load, $F = 10 \text{ lbf}$

Factor of Safety, $N = 4$

Tray Width, $w = 7 \text{ in}$

Tray length, $l = 6 \text{ in}$

Tray thickness, $t = 0.375 \text{ in}$

$S_u = 80,000 \text{ psi}$

Corrected Load, $F_c$:

$$F_c = F \times N = 10 \text{ lbf} \times 4$$

$$F_c = 40 \text{ lbf}$$

Area, $A$:

$$A = w \times l = (7 \times 6) \text{ in}^2$$

$$A = 42 \text{ in}^2$$

Moment, $M$:

$$M = F_c \times l = 40 \text{ lbf} \times 6 \text{ in}$$

$$M = 240 \text{ lbf} \cdot \text{in}$$

Shear Load, $P$:

$$P = \frac{M}{t} = \frac{240 \text{ lbf} \cdot \text{in}}{0.375 \text{ in}}$$

$$P = 640 \text{ lbf}$$

Thickness of Carbon, $t_c$:

$$\sigma_x = \frac{P}{\frac{w}{2} t_c}$$

$$t_c = \frac{P}{wS_u} = \frac{640 \text{ lbf}}{\frac{6 \text{ in}}{2} \times 80,000 \text{ psi}}$$

$$t_c = 0.0026 \text{ in}$$

Multiplying this thickness by 4 we obtain 0.011 inch thickness for each side.
Snap Ring Load Calculations

NOTE: The following are calculations to determine whether the chosen snap rings from McMasterCarr are durable enough to withstand the expected loads. These equations were obtained from Smalley Steel Ring Company, a company that specializes in various types of snap rings.

Ring Shear:

Problem F. 6: Determine the force needed to shear the snap ring, when a safety factor K=3 is used.

Known: Shaft diameter:

\[ D = 0.25 \text{ in} \]

Ring thickness:

\[ T = 0.025 \text{ in} \]

Yield strength of ring material, Stainless Steel:

\[ S_s = 31,200 \text{ psi} \]

Schematic:

Analysis:

Allowable thrust load based on ring shear is defined as follows:

\[ Thrust \ Load = P_R = \frac{D \times T \times S_s \times \pi}{K} \]

Inputting the known values we get:

\[ P_R = \frac{(0.25 \text{ in}) \times (0.025 \text{ in}) \times (31,200 \text{ psi}) \times \pi}{3} \]

\[ P_R = 204 \text{ lbf} \]

A maximum force of 204 lbf is allowed before the snap ring will shear.
**Groove Deformation:**

**Problem F. 7:** Determine the force needed to deform the groove, when a factor of safety $K=2$ is used.

**Known:**

- Allowable thrust load based on groove deformation:
  
  $P_g = 65 \text{ lbf}$

- Shaft diameter:
  
  $D = 0.25 \text{ in}$

- Groove depth:
  
  $d = 0.020 \text{ in}$

- Yield strength of groove material, 304 SS:
  
  $S_Y = 31,200 \text{ psi}$

**Schematic:**

![Schematic Image]

**Analysis:**

Allowable thrust load based on groove deformation is defined as follows:

$$\text{Thrust Load} = P_g = \frac{D \cdot d \cdot S_Y \cdot \pi}{K}$$

Inputting known values we get:

$$P_g = \frac{(0.25 \text{ in}) \cdot (0.020 \text{ in}) \cdot (31,200 \text{ psi}) \cdot \pi}{2}$$

$$P_g = 245 \text{ lbf}$$

A maximum force of 245lbf is allowed before the groove will begin to deform.

According to the data, the snap ring will fail before the groove will deform. However, both values are far beyond the expected loads and so the snap ring chosen will be okay to use and abuse.
<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>DESCRIPTION</th>
<th>QTY.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SW001</td>
<td>Current existing handle bar</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>SW003</td>
<td>Current existing handle bar grip</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>SW100</td>
<td>Internal Components sub assembly</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>SW107</td>
<td>1/4-20&quot; high holding set screws</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>SW106</td>
<td>Stainless steel snap ring</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>SW202</td>
<td>Rotating sleeve that's fixed to the table</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>SW203</td>
<td>Mounting points for the table to the collar</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>SW204</td>
<td>3/8-24 hex head bolts</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>SW205</td>
<td>3-D printed end cap</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>SW301</td>
<td>Handle bar extension</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>SW302</td>
<td>Quick-release button to hold extension</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>SW303</td>
<td>Pin that fixes the shaft to the collar</td>
<td>1</td>
</tr>
<tr>
<td>13</td>
<td>SW304</td>
<td>Seat that holds the spring plunger</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>SW305</td>
<td>Retractable spring plunger to lock table</td>
<td>1</td>
</tr>
<tr>
<td>15</td>
<td>SW306</td>
<td>Final tray design</td>
<td>1</td>
</tr>
<tr>
<td>ITEM NO.</td>
<td>PART NO.</td>
<td>DESCRIPTION</td>
<td>QTY.</td>
</tr>
<tr>
<td>---------</td>
<td>----------</td>
<td>--------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>SW101</td>
<td>Steel shaft that is rotated by the spring</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>SW102</td>
<td>Aluminum sleeves that control spring travel</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>SW103</td>
<td>Provides torsion for table lift</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>SW104</td>
<td>Sleeve bearing to support the drive shaft</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>SW105</td>
<td>1/4-20&quot; high holding set screws</td>
<td>2</td>
</tr>
<tr>
<td>A1</td>
<td>PART NO.</td>
<td>DESCRIPTION</td>
<td>QTY.</td>
</tr>
<tr>
<td>----</td>
<td>----------</td>
<td>-------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>1</td>
<td>SW301</td>
<td>Handle bar extension</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>SW302</td>
<td>Quick-release button to hold extension</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>SW303</td>
<td>Pin that fixes the shaft to the collar</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>SW304</td>
<td>Seat that holds the spring plunger</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>SW305</td>
<td>Retractable spring plunger to lock table</td>
<td>1</td>
</tr>
</tbody>
</table>
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   XXX = ± .01
   XXXX = ± .005
   ANGLES = ± .1
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   XXX = ± .01
   XXXX = ± .005
   ANGLES = ± 1°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX

1/4-20 UNC THRU

Φ.065
Φ.250
Φ.735

.368
.320
.905
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   XXX = ± .01
   XXXX = ± .005
   ANGLES = ± .1°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   XXX = ± .01
   XX = ± .005
   ANGLES = ± 1°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   XXX ± 0.1
   XXXXX = ± 0.005
   ANGLES = ± 1°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX

Cal Poly Mechanical Engineering
Sean’s Walker Mod
Date: 5/31/16
Dwg. #: SW205
Title: End Cap
Material: PLA
Scale: 2:1

Drawn By: Midam Krage

84
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   XXXX = ± .01
   XXXX = ± .005
   ANGLES = ± 1°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX
Retractable Spring Plunger for Thin Material without Locking Nose

PART NUMBER 8507A11
NOTES:
UNLESS OTHERWISE SPECIFIED:
1. ALL DIMENSIONS IN INCHES
2. TOLERANCES:
   X.XX = ± .01
   X.XXX = ± .005
   ANGLES = ± 1°
3. INSIDE TOOL RADIUS .01 MAX
4. BREAK SHARP EDGES .01 MAX
High Hold Cone Point
Set Screw

PART NUMBER 90778A401

McMASTER-CARR CAD
http://www.mcmaster.com
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Information in this drawing is provided for reference only.

0.250"

1/4"

118°

1/8"-20 Thread

1/8"
Hex
## G. Failure Mode and Effects Analysis (FMEA)

<table>
<thead>
<tr>
<th>Component / Function</th>
<th>Potential Failure Mode</th>
<th>Potential Mechanism(s) of Failure</th>
<th>Local Effects of Failure</th>
<th>Next Higher Level Effect</th>
<th>System Level Effect</th>
<th>End Effect</th>
<th>Probability, P</th>
<th>Severity, S</th>
<th>Detection, D</th>
<th>Priority, P<em>S</em>D</th>
<th>Recommended Action(s)</th>
<th>Responsibility &amp; Target Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walker Handle</td>
<td>Extension</td>
<td>The alloy tubing is too thin, can handle loads.</td>
<td>The tray device becomes unsupported.</td>
<td>The tray gets bent, kinked, or stretched.</td>
<td>The tray is deformed.</td>
<td>The tray becomes unsupported.</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>490</td>
<td>Analysis &amp; testing on this critical area to make sure tube is structurally sound.</td>
<td>Marlene will be in charge of conducting material and structure tests. 03/25/16</td>
</tr>
<tr>
<td>Internal Spring</td>
<td>Spring Stretch</td>
<td>Spring stretches over a long period of time.</td>
<td>Spring stretches over a long period of time.</td>
<td>Spring would not provide any torque.</td>
<td>Bending of spring over a long period of time.</td>
<td>Twisting table far past pin set position.</td>
<td>4</td>
<td>7</td>
<td>70</td>
<td>280</td>
<td>Test the overstretch capability of multiple springs.</td>
<td>Miriam will be in charge of spring lifetime tests. 03/03/16</td>
</tr>
<tr>
<td>Spring Holder</td>
<td>Spring Stretch</td>
<td>Spring is pushed out of the holder.</td>
<td>Spring is pushed out of the holder.</td>
<td>Spring holder would be raised manually.</td>
<td>Spring would not be raised manually.</td>
<td>Table would not be able to raise the table to upper position.</td>
<td>1</td>
<td>7</td>
<td>1</td>
<td>10</td>
<td>Test the overstretch capability of multiple springs.</td>
<td>Miriam will be in charge of testing mechanism reliability. 03/31/16</td>
</tr>
<tr>
<td>Activation Handle</td>
<td>Handle Bent or Completely Broken</td>
<td>Handle is bent or completely broken off.</td>
<td>Handle is bent or completely broken off.</td>
<td>Handle would not be able to actuate the mechanism.</td>
<td>Mechanism can not be activated.</td>
<td>Table would not be able to raise or lower.</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>1</td>
<td>Test reliability of mechanism.</td>
<td>Miriam will be in charge of testing mechanism reliability. 03/31/16</td>
</tr>
<tr>
<td>Activation Pin</td>
<td>Damping</td>
<td>Grease Leaks</td>
<td>Grease Leaks</td>
<td>Grease Leaks would not be able to be applied to the collar.</td>
<td>Table would not be able to be locked in place.</td>
<td>The table would not be able to be locked in place.</td>
<td>4</td>
<td>7</td>
<td>28</td>
<td>28</td>
<td>Use food grade grease. Force test the collar to see when grease would appear.</td>
<td>Miriam will be in charge of testing grease seal. 03/31/16</td>
</tr>
</tbody>
</table>
Table 12 Table Summarizing the Necessary Materials and Testing Equipment.

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Test Title</th>
<th>Materials Being Tested</th>
<th>Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bend Test on the Extension Bar</td>
<td>Stainless Steel Tube, Filler Metal</td>
<td>Calipers, 40lb Weight, Rope</td>
</tr>
<tr>
<td>2</td>
<td>Crash Test on the Extension Bar</td>
<td>Stainless Steel Tube</td>
<td>3.33lb weight</td>
</tr>
<tr>
<td>3</td>
<td>Test Table's Ability to Hold Load</td>
<td>Table Connected to Assembly</td>
<td>5-40lb Weights, Ruler</td>
</tr>
<tr>
<td>4</td>
<td>Test Table's Ability to Rise</td>
<td>Complete Assembly</td>
<td>None</td>
</tr>
<tr>
<td>5</td>
<td>Over Stretch Test on the Spring</td>
<td>Torsional Spring</td>
<td>None</td>
</tr>
<tr>
<td>6</td>
<td>Reliability Test of the Spring</td>
<td>Torsional Spring</td>
<td>Stop Watch</td>
</tr>
<tr>
<td>7</td>
<td>Time to Activate Test</td>
<td>Complete Assembly</td>
<td>Stop Watch</td>
</tr>
<tr>
<td>8</td>
<td>Time to Exit Test</td>
<td>Complete Assembly</td>
<td>Stop Watch</td>
</tr>
<tr>
<td>9</td>
<td>Time to Disassemble Test</td>
<td>Complete Assembly</td>
<td>Stop Watch</td>
</tr>
<tr>
<td>10</td>
<td>Temperature of Surface Test</td>
<td>Table</td>
<td>Stop Watch, Thermometer</td>
</tr>
<tr>
<td>11</td>
<td>Damping Test</td>
<td>Complete Assembly, Grease</td>
<td>Thermometer</td>
</tr>
</tbody>
</table>
Table 14 Manufacturing plan with descriptions and responsibilities.

<table>
<thead>
<tr>
<th>Person in Charge</th>
<th>Activity</th>
<th>Part No.</th>
<th>Location</th>
<th>Equipment</th>
<th>Person of Contact</th>
<th>Estimated Time</th>
<th>Start Date</th>
<th>End Date</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miriam</td>
<td>Sizing Drive Shaft</td>
<td>SW101</td>
<td>Mustang 60</td>
<td>Lathe, Drill Press</td>
<td>Any Shop Tech.</td>
<td>2 hours</td>
<td>Winter Qtr.</td>
<td>TBD</td>
<td>Bring 303 Stainless Steel Round Stock</td>
</tr>
<tr>
<td>Miriam</td>
<td>Machine Spring Holders</td>
<td>SW102</td>
<td>Mustang 60</td>
<td>Saw, Drill Press, Mill</td>
<td>Any Shop Tech.</td>
<td>4 hours</td>
<td>Winter Qtr.</td>
<td>TBD</td>
<td>Bring 6061 Aluminum Round Stock</td>
</tr>
<tr>
<td>Marlene</td>
<td>Tray Core Manufacturing</td>
<td>SW201</td>
<td>Mustang 60</td>
<td>Laser Cutter</td>
<td>Any Shop Tech.</td>
<td>2 hours</td>
<td>Winter Qtr.</td>
<td>TBD</td>
<td>Bring Balsa Wood/Divinycell H83 Foam Core</td>
</tr>
<tr>
<td>Marlene</td>
<td>Carbon Fiber Process</td>
<td>SW201</td>
<td>192-135</td>
<td>Composites Bench</td>
<td>Dr. Mello</td>
<td>9 hours</td>
<td>Spring Qtr.</td>
<td>TBD</td>
<td>Have Core Prepped and Ready, 3 (3hr.) Labs</td>
</tr>
<tr>
<td>Judy</td>
<td>Machining the collar</td>
<td>SW202</td>
<td>Mustang 60</td>
<td>Lathe, Drill Press</td>
<td>George Georgiou</td>
<td>3 hours</td>
<td>Winter Qtr.</td>
<td>TBD</td>
<td>6063 Aluminum tube stock</td>
</tr>
<tr>
<td>Judy</td>
<td>Machining the tray supports</td>
<td>SW203</td>
<td>Mustang 60</td>
<td>CNC, Drill Press</td>
<td>Nathan Harry</td>
<td>5 hours</td>
<td>Winter Qtr.</td>
<td>TBD</td>
<td>6063 Extruded Aluminum Bare Rectangle</td>
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<td>Marlene</td>
<td>Machine Extension</td>
<td>SW301</td>
<td>41-104</td>
<td>Lathe</td>
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<td>3 hours</td>
<td>Winter Qtr.</td>
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<td>Bring 304 Stainless Steel Tubing-Prepped</td>
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<td>ORDER DATE</td>
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<tr>
<td>Stainless T-303 Annealed Cold Finish</td>
<td>SW101</td>
<td>2.0</td>
<td>$9.05</td>
<td>$12.00</td>
<td>Miriam Marlene</td>
<td>2/19/16</td>
<td>online metals.com</td>
<td>23-Feb</td>
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<td>Aluminium 6061-T651 Cold Finish Round</td>
<td>SW102</td>
<td>1.0</td>
<td>$4.54</td>
<td>$6.02</td>
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<td>2/19/16</td>
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<td>23-Feb</td>
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<td>Music Wire Torsion Spring, 90 Degree</td>
<td>SW103</td>
<td>1.0</td>
<td>$106.80</td>
<td>$0.00</td>
<td>Miriam Marlene</td>
<td>2/19/16</td>
<td>Various McMaster-Carr</td>
<td>22-Feb</td>
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<td>High Hold Cone Point Set Screw, Type 316</td>
<td>SW105</td>
<td>1.0</td>
<td>$6.92</td>
<td>$9.45</td>
<td>Judy Judy</td>
<td>2/19/16</td>
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<td>Stainless 304/304L Seamless Tube 1/2&quot; OD</td>
<td>SW202</td>
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<td>Stainless 304/304L Seamless Tube</td>
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<td>Bondo Fiber Glass Filler</td>
<td>SW302</td>
<td>1.0</td>
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<td>$0.00</td>
<td>Marlene Marlene</td>
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<td>Home Depot</td>
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<td>Type 410 SS Quick Release Button 0.45&quot;</td>
<td>SW302</td>
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<td>$7.66</td>
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<td>Quick Release Pin, Type 316 SS 1/16&quot;</td>
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<td>$3.68</td>
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<td>Socket Head Cap Screw, Zinc Plated Alloy</td>
<td>SW305</td>
<td>2.0</td>
<td>$6.55</td>
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<td>Aluminium 6061-T651 Bare Extruded</td>
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<td>Retractable Spring Plunger 3/8&quot;-24x48&quot;</td>
<td>SW307</td>
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<td>3D Printer Filler</td>
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