Adaptive Floor Hockey Device

Senior Project Design Report

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DISCLAIMER

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Abstract

Sean is a young boy living with ataxic cerebral palsy. Ataxic cerebral palsy affects Sean's balance and coordination, so he uses a walker to increase his mobility. Sean would like to play Special Olympics Floor Hockey but his walker prevents him from participating. The goal of this Senior project was to develop a device to be attached to his previous walker to allow Sean to play floor hockey in the least restrictive environment possible. The Adaptive Floor Hockey Device is the product we designed to satisfy this need, and the following report details how our final product was developed.

Introduction

The purpose of this mechanical engineering senior project at California Polytechnic State University, San Luis Obispo, was to design and build an adaptive walker for a young boy named Sean to play Special Olympics Floor Hockey. Sean is seven years old and was born with Ataxic Cerebral Palsy, a rare, less severe form of Cerebral Palsy causing poor muscle tone, coordination, and balance. Sean has the strength to support his body weight, but due to a lack of balance he uses a walker to help steady his upper body and increase his mobility.

Figure 1. Sean using his walker while practicing hockey.

Our goal was to adapt Sean's walker (Figure 1) to allow him to play Special Olympics Floor Hockey as competitively as possible. We aimed to design an adaptive device for his walker that would improve his stability and control while holding a floor hockey stick. Sean has the physical strength and ability to run at a comparable pace with children his age, but handling the stick and walker at the same time is difficult and restricts his mobility.

Our team of mechanical engineering students consisted of Chris Gaul, Ricardo Gaytan, and Matt Spaulding in addition to assistance from Shannon Brant, a senior kinesiology student. Funding for this project was provided by a National Science Foundation grant acquired by Dr. Kevin Taylor, Chair of the Kinesiology Department, along with Dr. Brian Self and Dr. Jim Widmann, both of the Mechanical Engineering Department at California Polytechnic State University, San Luis Obispo.

Professor Sarah Harding was the senior project faculty advisor, and Michael A. Lara, the Regional Sports Advisor for Special Olympics Southern California, was the project sponsor. Our stakeholders were Sean, his mother, the National Science Foundation, Dr. Kevin Taylor, Dr. Jim Widmann, Dr. Brian Self, and Special Olympics. This project is especially important since it has given Sean the opportunity to play hockey for the first time. Michael Lara of Special Olympics sponsored the project because of his on-going work with adaptive devices for people with disabilities through Special Olympics and California Polytechnic State University, San Luis Obispo. The National Science Foundation is "the source for approximately 20 percent of all federally supported basic research conducted by America's colleges and universities,"[1] and "the only federal agency whose mission includes support for all fields of fundamental science and engineering."[1]

Background

The following sections discuss four different topics related to the project that impacted the final design. Research on ataxic cerebral palsy was compiled because it was necessary for the team to understand the extent of the physical limitations for Sean and others in his position. We also have included information regarding disability education that has helped us better understand the idea of inclusion and how to respectfully communicate with people who have disabilities. Research into floor hockey's history and guidelines gave us a better idea of the structure of the sport and the expectations of players' skills. A section on the typical equipment utilized by Special Olympic floor hockey athletes is also included. Lastly, the background concludes with a section describing existing technology that may be useful in our design.

Ataxic Cerebral Palsy

Cerebral palsy is an umbrella term for a group of non-progressive brain disorders affecting body movement, coordination, and balance. The onset of cerebral palsy may occur during pregnancy, birth, or a few months after birth and is caused by damage in one or more parts of the brain responsible for motor control (chiefly the cerebrum). It is rarely known what specifically causes cerebral palsy in an infant due to the developing nature of the brain. Cerebral palsy can have a number of effects on mental and physical ability, like poor muscle tone, problems with coordination and balance, slowed speech and response, and mental retardation.[2]

There are nine types of cerebral palsy, each with different characteristics and severities. The most common type of cerebral palsy is spastic (or pyramidal) cerebral palsy. Muscles are stiff and movements can be jerky or awkward. Spastic cerebral palsy is defined by which part of the body is affected. Approximately 70-80% of all cerebral palsy cases are defined as spastic.[3]

One of the rarest forms of cerebral palsy is ataxic cerebral palsy, affecting only 5-10% of all people will cerebral palsy. Ataxic cerebral palsy falls under the category of Dyskinetic (or extra pyramidal), which chiefly affects muscle coordination and balance. Ataxic cerebral palsy is one of the less severe forms of cerebral palsy, where most patients have an awkward or unsteady gait but usually have the ability to walk and even run with the use of specialized walkers or walking assistance. Since muscle coordination is affected, speech is usually slow and deliberate, but mental capacity is not diminished. In fact, more times than not a patient exhibits higher than average mental abilities, but the brain struggles to communicate these signals through the nervous system.[4]

Sean has ataxic cerebral palsy, and the preceding section describes him well. While his coordination and balance are affected, he still has the ability to run at almost full speed with the use of his old walker, and is an extremely bright young boy. Sean has all the skills and abilities to play hockey, he just required a device that integrated a floor hockey stick with his walker.

Disability Education

Unfortunately, throughout history people with disabilities have often been unwelcomed or put down in society. We can utilize adaptations in many different ways to encourage and facilitate inclusion of all people. The goal of adaptation is not to make it easier on a person with a disability; rather, the purpose of the device is to enable the person to accomplish the same tasks as an able bodied person.[5] There is a need for a tool that the person can use to succeed in the world. In Sean's case, this need is in floor hockey.

The disability etiquette presentation given by Shannon Brant of the Kinesiology Department included several key points that can be highlighted here. The primary focus should always be the client (Sean) over the product, and maintaining the least restrictive environment (LRE) possible for Sean's mobility with the device that was created for him. It is also important to treat any future clients with the Guidelines to Inclusion, including but not limited to:

- Keeping in mind the LRE concept.
- Treating the person with respect and compassion, not pity.
- Expressing a willingness to work on a case-by-case basis, and assuming that all disabilities present their own unique challenges and opportunities.
- Keeping focus on empowerment and inclusion of all individuals regardless of ability.

These guidelines were used to facilitate our communication with Sean, and can be employed when communicating with all people with disabilities.[5]

Floor Hockey History and Guidelines

Special Olympics Floor Hockey was introduced for the first time as a Special Olympics sport in the Winter Special Olympics of 1970. It is a modified version of ice hockey that is usually played on smooth, flat surfaces with shoes instead of skates. Thus, similar rules and requirements of ice hockey apply to floor hockey. A floor hockey team consists of six players: one goalkeeper, two defenders, and three forwards. Official games have three 9-minute periods with a 1-minute break between each period. There are three line shifts per period and by the end, the total number of lines played by any player must not exceed the total number of lines played by any other teammate by more than one line, with the exception of the goalie. Special Olympics Floor Hockey has three official events: Individual Skills Competition (ISC), Team Competition, and Unified Sports Team Competition. ISC has five different competitions: Shoot Around, Pass, Stickhandling, Shoot for Accuracy, and Defense. ISC scores of each player are used to place the athletes in the appropriate division of the sport. Team competition is the traditional game played solely by Special Olympics athletes. Unified Sports Team Competition is played with both Special Olympic athletes and partners.[6] Figure 2 below depicts players participating in team competition.

Figure 2. Athletes compete for the puck in a game of Special Olympics Floor Hockey.[7]

Equipment

Special Olympics Floor Hockey requires typical ice hockey equipment such as a helmet, shin guards, gloves, and elbow pads. The obvious differences between both sports are the shoes, sticks, and pucks. Running shoes must be worn by all the athletes on the playing surface. The hockey sticks used are rods or dowels made of wood or fiberglass ranging from 3-5 feet in length with a diameter of about one inch. The bottom of the stick is rounded with a felt tip to lessen friction. The puck is a circular felt disc of about 5-8 ounces with an outer diameter of 8 inches and a center-hole diameter of 4 inches.[6]

Existing Products/Technology

One of the first steps in our research was to find United States patents that would relate to our project. Due to the unique nature of the adaptive floor hockey device we designed, there were no patents that directly pertained to our project. No patents currently existed or were pending that described adapting any type of hockey stick for persons with disabilities or that described adapting walkers for use in sports. Additionally, there were very few United States patents that pertained to Special Olympics related games, and none that mentioned Special Olympics Floor Hockey. As we delved into the design process, we performed more patent research on individual components of our design, however throughout the course of the project we were unable to find any patents that related to our project as a whole.[8]

During the design process the team received the aluminum tube walker (Figures 3 and 4) Sean was previously using for his everyday activities. It was a relatively lightweight piece of equipment that allowed Sean to move quickly on smooth surfaces. It was also strong and stable enough to support Sean's entire body weight. This is important because as Sean runs, he likes to lift his feet up off the ground and coast on his walker for small stretches of time. Additionally, the walker did not have any components across the front, which allows Sean complete freedom of motion when he is running without worrying about running into his own walker. The walker also had brakes that automatically engage if it starts to roll backwards, which was important for Sean's safety when walking up inclines. One major drawback of this walker, however, was the wheels. The wheels resembled the wheels of a shopping cart, and they rattled and wobbled when Sean was running at full speed.

Figure 3. Sean's aluminum tube walker.

Figure 4. Rendering of Sean's walker at the start of the project.

Figure 5. The Nurmi Neo Gait Trainer[9]

We were able to use his aluminum tube walker for our device because Sean acquired a new Nurmi Neo Gait Trainer (Figure 5) for his everyday use at the beginning of the project. The Nurmi Neo Gait Trainer has many of the same positive qualities as Sean's aluminum tube walker. It is lightweight, strong, and stable, and it has the same basic structure that is unobtrusive to Sean's movement. The Nurmi Neo Gait Trainer has higher quality wheels, and angled handgrips that are more comfortable for Sean to use.[10] Since Sean acquired the Nurmi Neo Gait Trainer at the start of the project, the team was able to use his aluminum tube walker for our design and final product. This is the only time Sean's Nurmi Neo Gait Trainer will be mentioned since it did not directly influence the scope of our project. For the entirety of this report we will be referencing his aluminum frame walker simply as "Sean's walker."

In summary, there weren't any specialized walkers for floor hockey on the market during project development, but there were several designs of adapted walkers used for increasing stability and mobility that helped us adjust Sean's walker based on his needs. Gait trainers and other walkers in the market were examined to see how they solved similar problems we needed to account for. The addition of new components and wheels was eventually employed to meet our design requirements, as discussed later in this report.

Objectives

The overarching goal of the project was to enable Sean to play Special Olympics Floor Hockey. Before designing an appropriate device for Sean, it was important to translate the needs of Sean, his mother, and our sponsors into engineering specifications. Our final device has the potential to increase the quality of Sean's life by allowing him to safely and competitively participate in Special Olympics Floor Hockey.

Through interviews with those involved, we discovered our device needed to:

- Give Sean at least as much mobility as he currently has with his normal walker. This includes speed and maneuverability of the walker.
- Be comfortable for Sean to use. He should not have to perform any movements over the course of a floor hockey game that he finds awkward or painful.
- Be stable and strong. It should support Sean's full body weight without ever being in danger of tipping or breaking.
- Withstand years of use. It must be durable, so that it will not weaken and break over time. It also must be height-adjustable, so that Sean can continue to use it as he grows.
- Be completely safe for Sean. It should not tip or break, even under conditions beyond the intended use of the device. It also should be free of sharp corners or pinch points that could hurt Sean.
- Be reasonably repairable. The components of the device should be simple enough that Michael Lara or Sean's mother would be capable of repairing it if something were to break.
- Be easy to use. It should not be more difficult for Sean than it is for any other player to gain control of the puck, run with it, pass it, or shoot it.

Engineering Specifications

We applied quality function deployment (QFD) to our design by using the House of Quality. Quality function deployment is a design tool used to create the crucial relationships between customer needs and engineering specifications. The House of Quality is a diagram relating these customer requirements with engineering specifications, in addition to noting a positive or negative correlation between different specifications. The House of Quality can be seen in Appendix A.[11] By using this tool, we were able to gain a better understanding of our client's needs and translate them into quantitative engineering specifications. Table 1 on the following page lists the engineering specifications that we have developed to ensure that our device meets Sean's needs.

Table 1 is a summary of the numeric values of our major design parameters. The requirement/target column indicates the value that we hoped to reach for the given design parameter. As can be seen in the tolerance column, these are not absolute values but instead they represent the ideal target values for each parameter, with a range of values being acceptable. The risk column indicates how difficult the requirement would be to achieve; a high (H) risk indicates that it will be difficult, a low (L) risk indicates that it will be easy, and a medium (M) risk indicates that it falls somewhere in between. Lastly, the compliance column shows how we will assess whether or not we met each requirement, either through analysis (A), testing (T), inspection (I), or some combination of these assessments.

Table 1. Specifications for the Adaptive Floor Hockey Device.

Spec #	Parameter Description	Target Goal	Tolerance	Risk	Compliance
1	Additional weight added to walker	5 pounds	max	M	A, I
2	Pinch points	0	max	M	I
3	Vertical stick movement	2 inches	min	L	I
4	Area of stick movement on floor	2 square feet	min	H	A, I
5	Time to acquire puck	2 seconds	min	M	T
6	Distance puck can be passed/shot	10 feet	min	M	T
7	Height adjustment range	6 inches	min	L	I
8	Force applied downward at any point on walker handle to tip it	20 pounds force	min	L	A, T

The “additional weight” requirement was a medium risk because it was strongly dependent on the materials that we chose to use. The “pinch points” requirement was a medium risk because it required an additional step of designing to eliminate any pinch points present in our final product. The “vertical stick movement” requirement was low risk because it required very little overall movement in the system (less than two inches to position the stick over the edges of the puck). The “area of stick movement on floor” requirement was evaluated to be high risk because it required multiple degrees of freedom in the stick movement mechanism. The “time to acquire puck requirement” and the “distance puck can be passed/shot” requirement were both determined to be medium risks because they relied on Sean’s testing of the device to ensure these requirements were met. The “height adjustment” requirement was a low risk because Sean’s old walker was already height adjustable, and “the downward force” requirement was a low risk because the walker was stable when we received it.

Management Plan

Staying on schedule and effectively managing communication were essential during the development of this project. To ensure this occurred, our team spent a minimum of ten hours per week meeting together and discussing project details, designs, and potential problems in an attempt to maximize efficiency. The team was adamant about keeping close communication with each other, as well as with Michael Lara, Sean, and his mother throughout the entire design process.

While team cohesion was essential for a project of this magnitude, we broke up individual tasks based on the strengths and skills of each team member to maximize efficiency. All three members were adept technical writers, so we divided all research and documentation evenly between the three mechanical engineers, with each team member taking an editorial role before any final documents were released.

Chris Gaul was especially skilled in the areas of mechatronics and electro-mechanical systems, so if any mechatronic issues presented themselves, Chris led the effort to come to an appropriate design solution. He also had more programming experience and expertise than the rest of the team, which was useful when using Matlab to solve engineering equations.

Ricardo Gaytan excelled at structural, static and dynamic analysis. These facets of mechanical engineering proved to be extremely useful in the material selection and design process. Design for manufacture is one of the most crucial aspects of any senior project, and Ricardo's skills proved very useful in this regard.

Matt Spaulding also excelled at structural analysis, but his major strength for the project came in his skills using SolidWorks to develop the solid model of each design iteration. Understanding how components fit together and the clearances associated with multiple assemblies saved countless hours in the shop and maximized manufacturing efficiency, while reducing costs by preventing material waste.

Shannon Brant was a kinesiology student paired with the team. Her primary role was to educate the team of mechanical engineers regarding disabilities, in addition to facilitating communication between the team and Sean's family.

Method of Approach

In order to ensure that our final device was completed in a timely manner, we outlined a methodical procedure that we followed over the course of the project.

Our first step was to perform extensive background research to give us an understanding of ataxic cerebral palsy, Special Olympics Floor Hockey, and any existing devices that perform similar functions to our desired device. This research helped us to better understand the scope of the project regarding Sean's physical limitations. The results of our research are discussed in detail in the Background section earlier in this report.

Next, we conducted interviews with Michael Lara, Sean, and his mother to determine their requirements for the Adaptive Floor Hockey Device. We worked together with them until we were able to narrow down their needs into a set of objectives for our project. Then, by using a QFD House of Quality, we were able to convert these needs into quantitative engineering specifications. These specifications are covered in depth in the Objectives section of this report, and were later used to choose the best design for each design problem in the Idea Selection section.

After developing the requirements our product must meet, we began brainstorming and formulating as many ideas and options as possible. At the conclusion of our brainstorming and sketching sessions, we moved forward with idea selection as outlined in the Idea Generation and Idea Selection sections of this report. The evaluation of the various design concepts was done through the use of decision matrices, engineering analysis and, most importantly, testing physical prototypes with Sean. Once we chose the best overall design that most effectively met our engineering specifications, we continued the design process by filling in the smaller details, like how to attach our device to the Sean's walker, and what kind of stick geometry would work best.

After finalizing our design in early January, we finished the remaining design objectives in the detailed design phase. This process included stress analysis and material selection of individual parts in the system, specification of part tolerances, final prototype construction, and machining procedures, in addition to failure modes analysis, testing plan development and production of a detailed bill of materials. Summaries of these documents can be found later in this report, with more detailed information in the Appendices. We made small revisions to our earlier designs during this process, following the results of continued prototype testing with Sean. The design phase officially concluded with the writing of the Critical Design Report and a Critical Design Review with our sponsor Michael Lara and Dr. Kevin Taylor, Chair of the California Polytechnic State University Kinesiology Department during the last week of January.

Next we purchased material and began our final prototype manufacture after receiving approval from our client and sponsor. During the last 3 months of the project we proceeded to manufacture two very similar products, one labeled the "final prototype design" and the last and final product that we delivered to our client was labeled the "final product." The differences between these last two designs are subtle, but necessary for our desired level of performance. These last two designs and the differences between them are discussed at length in the "Final Prototype Design" and "The Final Product" sections to follow in this report.

Idea Generation

To begin our brainstorming sessions we followed a format similar to the process presented by IDEO, a multidisciplinary design firm specializing in innovative and creative designs. First the team spent a few hours drawing up sketches and taping them to the wall of the design room. The purpose for this exercise was to be as creative as possible without considering any limitations. As more ideas and designs were taped to the wall, sketches became more refined and detailed. The number one rule of this session was to never exclude an idea because it might be too infeasible, expensive, or difficult to manufacture. It was important to start at the far extremes of the design spectrum to give us the best shot at covering all the available options. Examples of these preliminary sketches are shown in Figure 6 on the following page.

Figure 6. Sketches from our initial brainstorming session.

Once the team was content with the quantity and quality of design sketches we brainstormed over the different concepts and how we might incorporate them into our device. We discussed ideas such as push-button shooting, gear drives, pneumatics, springs, bearings and hinges to make sure that nothing was omitted from our list of possible designs. When the team came to an agreement that we had a diverse group of creative and feasible engineering solutions, we transitioned from idea generation to idea selection.

Idea Selection

Overall Design

The first step in the idea selection process was to determine which holistic design was best suited for Sean and his walker using our wall of ideas. We started by narrowing the field down to five general designs using engineering intuition and our sense of design. The designs incorporating electrical systems like motors, gears and power screws were pushed aside first due to the weight of battery packs and fragility of conducting wires. A motor driven gear train or power screw would also be fairly heavy in relation to the weight of Sean's walker, which was contradictory to our primary goal of a lightweight, non-restrictive device.

Next we noticed that each one of the three team members had sketched some variation of a horizontal rail system for the floor hockey stick to slide along. As we looked at the design wall we also noticed a large percentage of drawings involved some combination of pivot arms, hinges, universal joints, and bearings. After a quick discussion regarding how we could synthesize different ideas together, we decided to move forward and compare five designs, each with their own unique benefits and drawbacks. See Figure 7 below for a sketch of each overall idea.

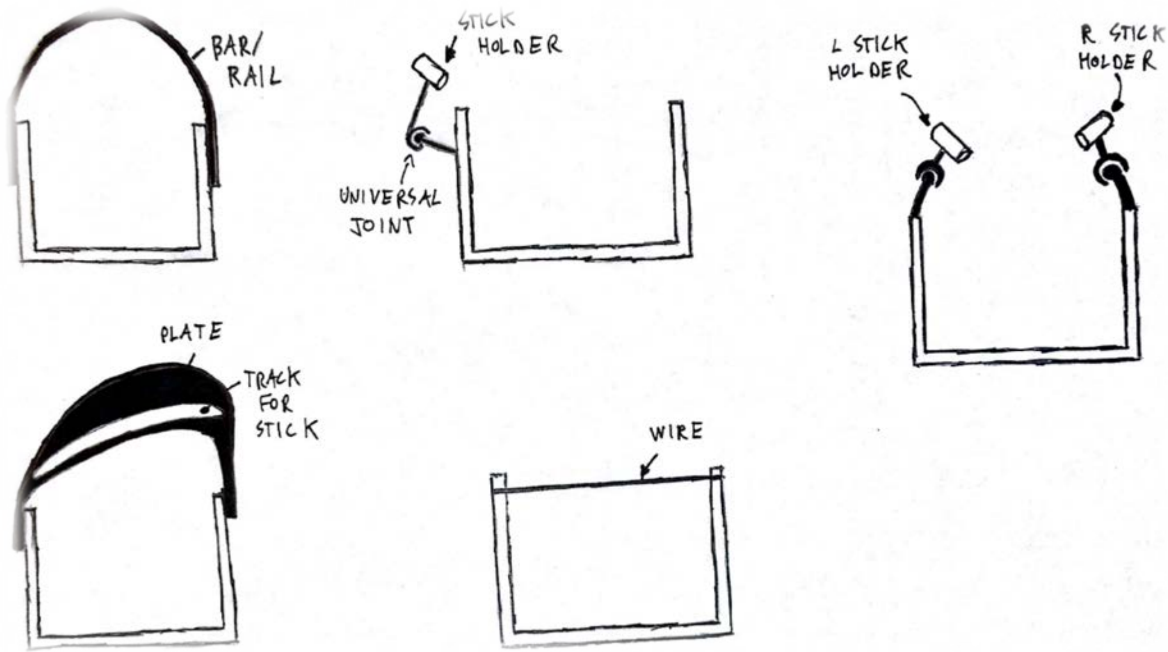


Figure 7. Simplified overhead drawings of the five different concepts we initially considered.

Concept Descriptions

1. The Bar/Rail System: A curved bar or “rail” rigidly attached to the walker in the horizontal plane, where the bearing and hockey stick assembly slides along the rail.
2. Pivot Arm: Arm rigidly attached to left side of walker, connected to another rod by a universal/ball joint combination which holds the end of the stick.
3. Two Sticks (left and right sides): Follows the same kind of logic as the “Pivot Arm.” Instead of having one complicated mechanism on Sean’s left, there are two smaller, simpler pivot arms holding a stick on each side of the walker.
4. Track in Plate: Similar to the “Bar/Rail System,” where the stick will follow the track cut into the plate.
5. Wire: By far the simplest of the five designs mentioned. Simply consists of a wire running directly across the front of the walker handles.

As our senior project group discussed the advantages and disadvantages of varying concepts we slowly gained a clearer picture of how each concept could be manufactured, but most importantly we either gained confidence or lost faith in its ability to perform given Sean’s needs. Up to this point in the idea generation and selection process our trio was very confident that the bar/rail system was going to be our best solution, but for verification we evaluated the five concepts within a traditional decision matrix.

Table 2. A precursory, qualitative comparison of the five device concepts.

Concept #	Concept Name	Pros	Cons
1	Bar/Rail System	Lightweight, stable, greatest freedom of motion of any concept.	Safety: Fall concern with rail and stick in front of Sean.
2	Pivot Arm	If functioning properly and smoothly, Sean should be able to control the stick quickly and precisely.	High risk of part/assembly failure, no access to puck on right side of walker, awkward biomechanics.
3	Two Sticks (Left and Right)	Access to the most floor area out of all five concepts	Very unwieldy, increases walker footprint greatly, difficult to turn walker.
4	Track in Plate	Plate can be rotated to adjust track curvature.	Accomplishes same goal as the Rail but will automatically have more material, heaviest of all concepts.
5	Wire	Extremely easy to manufacture and test.	Safety: Sharp wires can lacerate, wire would have to cross inches in front of Sean.

Referring back to our "House of Quality" derived from quality function deployment, we updated our list of customer requirements and the relative weights of each requirement. Weighing each requirement accurately according to the project goals was essential for a decision matrix to output the correct design solution. We chose a scale from 1 to 5; a rank of 1 being for the least important requirements, 5 being for the most crucial customer needs. As can be seen in the decision matrices to follow, the most important customer requirements were found to be: creating the least restrictive environment possible, overall device safety, Sean's comfort while using the device, and the general ease of use. These customer requirements were incorporated into every part of our design, including other system-specific requirements.

Once the customer's requirements were weighted, the team proceeded to rate each concept versus the datum, or the standard product Sean would use if he wanted to play floor hockey today. Since no product exists for Sean's needs, we chose the datum to be a simple two and a half foot length of one inch diameter PVC attached to the left side of his walker using an elastic bungee cord. We chose this as the datum because it would be difficult to find any other materials more accessible or easily constructed than bungee cords and PVC.

In the following decision matrices a minus sign signifies the concept does not meet that customer requirement as well as the datum. Subsequently, a plus sign signifies that the concept meets the customer requirement better than the datum, which is ultimately our goal. A double negative or double positive means the concept performs far better or far worse than the datum, so the points associated with that requirement are doubled and either added or subtracted from that concept's total.

Table 3. Decision matrix used to determine which of the five overall concepts would function best.

Customer Requirements	Relative Weights	Bar Track	Track in Plate	Pivot Arm	Wire	2 Sticks (L and R)	DATUM (Bungee)
Lightweight	4	-	-	-	+	-	0
LRE	5	+	+	+	+	0	0
Durable	3	+	+	0	--	0	0
Low cost	2	-	-	-	-	-	0
Few pinch points	5	+	0	-	+	-	0
Easily repairable/replaceable	3	-	-	-	-	-	0
Easy to adjust height	2	+	+	+	+	0	0
Difficult to tip/stable	4	-	-	-	0	0	0
Easy to manufacture	1	-	-	--	-	-	0
Acquire puck quickly	5	+	+	-	+	0	0
Easy to maneuver	5	+	+	-	+	-	0
Fast puck speed	4	+	+	-	-	0	0
Aesthetically pleasing	2	+	+	0	-	+	0
Comfortable	5	+	+	-	-	-	0
Safe for other players	5	+	+	-	--	-	0
Applicable to other walkers	2	-	-	-	-	-	0
Range in X	4	++	+	+	+	+	0
Range in Y	3	++	+	+	0	0	0
TOTALS :		**+ 39**	**+ 27**	**- 32**	**- 5**	**- 26**	**0**

Table 3 clearly illustrates what the team was feeling early in the ideation process: the bar/rail system was the most effective of the five designs for Sean's walker. In addition to this conclusion there were a couple of other interesting pieces of information that can be seen from this decision matrix.

First off, it was not surprising that the track in plate system scored closely behind the rail. Both systems performed similarly with respect to how Sean manipulated the stick and the constraints placed on his arm movement. The rail system eventually won out because of the larger floor area the rail allowed the stick to access, as well as the absence of pinch points on the rail. The fixed angle slot in the plate would force the stick to stay at the same angle to the horizontal, limiting Sean's access to the puck. There was also a risk of pinching between the sliding stick and the edge of the slot in the plate.

We were surprised by one thing, and that was how much better the wire scored than the pivot arm or dual stick assembly. The wire most likely had an artificially high score with respect to the other systems due to the safety issue. We knew from the beginning of this analysis that the wire was not an intelligent design option, but we followed through with the process to verify our decision matrix was evaluating ideas correctly; that is, good designs score well, and poor designs do not. We decided that the wire was so unsafe that it probably deserved 3 or 4 negatives in the safety column, but we set the rules at a double sign maximum for all categories. The pivot arm and dual stick systems scored as low as they did because of the team's general belief that both assemblies would be so bulky and awkward that Sean would barely be able keep up with the speed of the game due to the added weight, let alone handle the puck efficiently.

It is important to note that for the rest of this report we will be calling this semi-circular rail design the "curved rail."

Stick Attachment Method

Once the curved rail was established as our best option, we realized that all five of the past concepts were assumed to attach to Sean's walker, thus the stick was always attached to the walker as well. This led us to change our direction away from finalizing the rail system details, and instead towards verifying that rigidly attaching Sean's stick to his walker was the best option. We compared four different methods of attachment against the bungee datum: attaching the stick to the walker (using the curved rail), attaching the stick to Sean (similar to a forearm brace), attaching Sean to the walker to leave his hands free for the stick, and lastly a free stick structure, where the stick would have no permanent connection to Sean or the walker, but have its own source of mobility. Sean's mobility and safety were once again our top concerns, but since we were focusing on the stick assembly there was also an emphasis on how easy it would be to maneuver the puck as well as Sean's comfort level while playing.

The results from Table 4 on the following page conclusively show that attaching the stick to the walker was in fact the best design choice. We felt confident in these results since attaching the stick to Sean scored just 12 points over the bungee and PVC datum as compared to attaching the stick to the walker which scored a staggering 36 points over the datum. The other two options fall right where the team expected; attaching Sean to the walker would greatly limit his mobility, and employing the use of a free floating stick structure was simply infeasible given the playing conditions.

Table 4. Decision matrix to verify the method of stick attachment.

Customer Requirements	Relative Weights	Attach Stick to Walker	Attach Stick to Sean	Attach Sean to Walker	Free Stick Structure	Datum (Bungee)
Lightweight	4	-	0	0	-	0
LRE	5	+	+	-	-	0
Durable	3	+	+	+	+	0
Low cost	2	-	-	-	-	0
Few pinch points	5	+	+	+	+	0
Easily repairable/replaceable	3	-	-	-	-	0
Easy to adjust height	2	+	+	+	+	0
Difficult to tip/stable	4	0	-	-	-	0
Easy to manufacture	1	-	-	-	-	0
Acquire puck quickly	5	+	+	0	-	0
Easy to maneuver	5	++	-	-	--	0
Fast puck speed	4	+	0	0	+	0
Aesthetically pleasing	2	+	+	-	-	0
Comfortable	5	++	+	-	--	0
TOTALS :		**+ 36**	**+ 12**	**- 17**	**- 32**	**0**

Walker Attachment Method

Up to this point in the idea selection and design process we had used our creativity, engineering intuition, qualitative methods of comparison, and quantitative tools like decision matrices to conclusively determine that the curved rail system most efficiently satisfied our customer's requirements regarding mobility, general ease of use, comfort and most importantly safety. We then verified that rigidly attaching the rail (and subsequently Sean's hockey stick) to the walker was also the safest, most comfortable option.

The next design problem we faced was how to attach the ends of the rail to Sean's walker. As can be seen in the Conceptual Design section of this report, we used bungee cords and duct tape to rigidly attach the rail to the walker during early testing with Sean, but this was far from an acceptable attachment method for the final product. So we brainstormed and sketched the different ways we could attach two cylindrical metal members together (Figure 8), since we knew this would mostly likely be the geometries we'd working with.

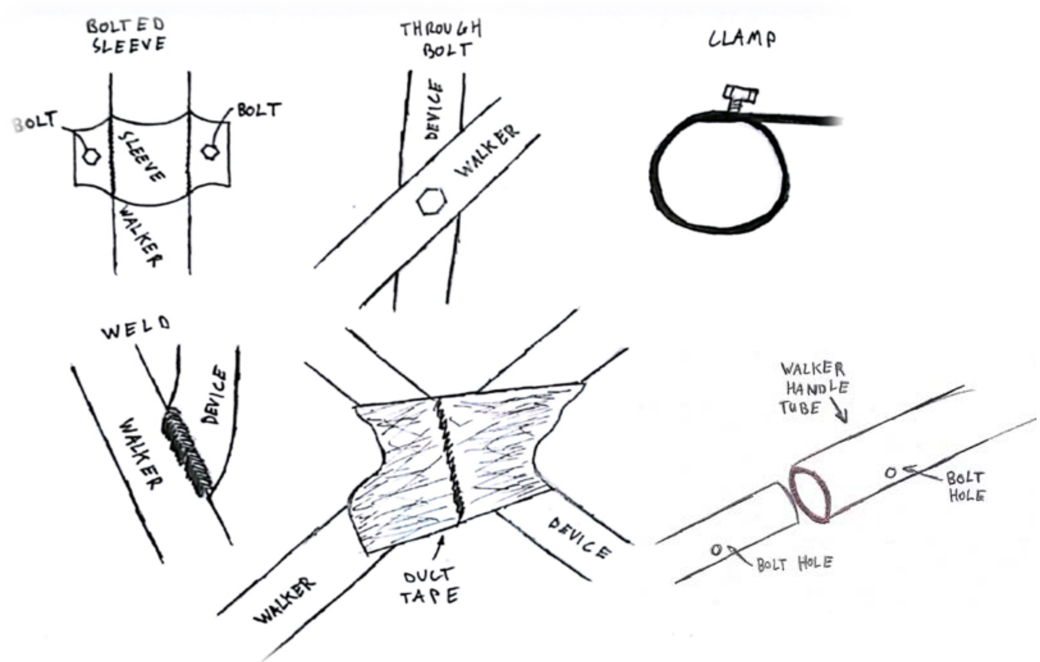


Figure 8. Options for attaching the rail and stick assembly to the walker.

Table 5. Determining which rail-to-walker attachment method best suited our customer's requirements.

Customer Requirements	Relative Weights	Bolted Sleeve	Through Bolts	Clamp	Inside Tubes	Weld	Duct Tape	Datum (Bungee)
Easy to manufacture	1	-	-	-	-	-	0	0
Few pinch points	5	+	+	0	+	+	0	0
Low cost	3	-	-	-	-	-	0	0
Durable	3	++	++	++	++	++	--	0
Structural rigidity	4	++	+	+	++	++	0	0
Easy to repair/replace	3	-	-	0	-	-	0	0
Lightweight	4	-	0	-	+	0	0	0
Aesthetically pleasing	2	+	+	+	++	++	--	0
Easy to adjust height	2	+	+	+	0	0	0	0
Effect on walker CG	4	-	0	-	+	0	0	0
Easy to attach/detach	2	-	-	-	+	-	0	0
TOTALS :		+ 6	+ 10	0	+ 26	+ 14	- 10	0

Similar to the wire concept or free floating stick structure designs discussed earlier in this report, the duct tape was added to the list of potentials to ensure the attachment method decision matrix (Table 5) was successfully differentiating between terrible ideas and plausible/sound ones. Since the duct tape was by far the worst performing concept, and the only one worse than the bungee cord datum, we were confident in our decision process and decided to move forward with inserting the welded rail tubing into the handle tubes of Sean's walker. By inserting the curved rail directly into the walker and using the same bolts from the walker to hold the curved rail in place, we ensured the rail was both easily removable and extremely rigid when attached.

Design Process Summary

From September through January our team was deeply immersed in the design process. It began by defining customer needs and requirements, then translating those requirements into engineering specifications, and subsequently designing a product that would meet those specifications (Table 6). This design process, coupled with prototype construction and testing (discussed in later sections of this report) concludes the core of the design process.

Table 6. Summary of our major design decisions from the first quarter of the project.

Sub System	Option A	Option B	Option C	Option D	Option E	Option E
Bracket	Bolted Sleeve	Through bolt	Clamp	**INSIDE TUBES**	Duct Tape	Weld
Horizontal (floor) movement	Ball Joint	Universal joint	Pin	Hinge	**BEARING(S)**	
Vertical Movement	Ball joint	Universal joint	Pin	Hinge	**BEARING(S)**	
Horizontal mobilitiy	Track in Plate	**BAR/RAIL TRACK**	Wire	Static	Unattached	
Downward Force	Spring at bracket	Spring in stick	Spring in stick holder	Structural Block	**STICK WEIGHT**	
Shoot/pass actuator	**SEAN'S POWER**	Electric Motor	Solenoid	Piston	Spring	
Stick End/Tip	**STANDARD**	Scoop	Combination			

Conceptual Model Construction

Over the span of the first quarter of this three-quarter long project, we met with Sean and his mother on three separate occasions to test three different prototype ideas. The development of our conceptual model was greatly influenced by the needs and physical capabilities of Sean. We had designed our prototypes with the goal of allowing Sean to be able to do as much as he could under his own power. It was an iterative process of designing, testing, and redesigning after each testing session.

Introductory Meeting – October 5th 2012

The first time we met Sean was at the Friday Club meeting at California Polytechnic State University San Luis Obispo where Special Olympics athletes play and exercise with personal assistance and equipment from the university's Kinesiology Department. This meeting was crucial for the design process since this was the first time we got to assess Sean's physical abilities. Our first test consisted of attaching a PVC stick to his walker with bungee cords. The stick was attached to his left side because his mother had informed us that he was left hand dominant. As mentioned earlier in the Idea Selection section, this apparatus served as the datum in our decision matrices because this is what Sean's mother would most likely use if he were to play at that time. It was an inexpensive solution that was also easy to set up and very lightweight. While the bungee-PVC device served its testing purpose, we immediately noticed problems with this apparatus.

Figure 9. Sean swinging the PVC stick upwards in an uncomfortable movement.

The PVC stick simply attached to one side of his walker with bungees did not satisfy the main design concerns that we aimed to solve. After watching him play with this set-up, we realized that it was unsafe for him and for other players because the stick could swing up to eye level very easily. The way in which the stick was located also made it very awkward for him to move the stick around (Figure 9). It was also uncomfortable for his wrist because the continual maneuvering of the stick was straining his arm over time. The configuration of this design also limited his range of motion to his left side, so this solution was deemed unacceptable.

A few good possibilities for our next design arose from our first meeting with Sean. It was interesting to see that Sean began to use his stick as a support for balance instead of his walker's handle. This was important because we realized that we had to now design our system to be able to support some of Sean's weight. We also installed a horizontal bar at waist level in front of Sean and he was able to have the same mobility as before. This proved to be a crucial piece of information in the next design phase.

Second Meeting – November 7th 2012

The second time we met with Sean was to test our preliminary rail system. The rail was made by connecting two steel braided flexible hoses together with a collar sliding over it. The rail was then attached to his walker at handle height with bungees. The PVC hockey stick was inserted through a second collar as seen in Figure 10.

Figure 10. Mock-up for our first rail system.

We quickly noticed improvements from our first meeting with Sean. He had a wider range of motion with his hockey stick and it was easier to run with. It was more comfortable on his wrist which meant less effort to move the puck than with just a stick attached to his left handle. He was also able to acquire the puck faster and his motion was safer since the stick did not swing upwards. We also noticed that he was able to switch the stick to his right hand when he wanted to move the puck on his right side.

The few problems we ran into were mainly due to the materials we selected. First of all, the flexible hose was not sturdy enough for him to lean on. Then the connection between the two hoses made it difficult for Sean to slide the collar across the center of the rail. Another issue with this testing apparatus was that Sean still had trouble gripping the stick due to the stick's steep angle, compared to the horizontal plane of his handles. When he would lose grip of the stick, the stick would fall through the collar and onto the floor, which is something we wanted to prevent in our next prototype test.

Third Meeting – November 16th 2012

We refined our rail system design for our third meeting with Sean. We made our rail by bending a solid steel rod into an 18 inch diameter half circle with 8 inch long straight ends to attach to the walker using bungee cords. The rod was more rigid than the flex hose and it allowed him to apply a greater downward force on the system. Also, since the rod was a solid piece it was easier to slide the stick across the rail. We also designed a new stick with a different geometry along with a collar system to improve our previous design, as mentioned in the Idea Selection section. The stick handle was made so that it resembled his walker's handle and it made it easier for him to grab and control the stick. The new collar system with a rod support was useful in preventing the stick from falling onto the floor when he would release the stick. By creating a rod and collar assembly we allowed for complete range of motion: stick rotation, sliding along the rail, swinging from the rail in both planes, and stick extension.

One of the new problems we encountered was that our new design actually allowed for too many degrees of motion. His arm was unable to effectively maneuver the stick from side to side and quickly acquire the puck. We solved this problem by taping one of the pivot points at the rail collar reducing the apparatus' freedom of motion (Figure 11). Another problem with this prototype was that Sean had trouble sliding the stick once the PVC collar was close to the end of the arc of the rail. In order to fix this we used two knots of tape, one on each side of the rail, to shorten the arc length of the rail. We realized that shortening the arc did not affect his range of play.

Figure 11. Second prototype for the rail system, taped to reduce motion.

Following this meeting we discussed possible solutions, manufactured test pieces, and decided on a final design for each component of the project. In addition to the curved rail, sliding collar, and stick components we decided to include the walker wheels into the scope of our project as well. The team decided that the original wheels that came with Sean's walker were far too clumsy and slow, and that for our design to truly succeed, all four wheels would need to be replaced. The following section discusses how we designed each subassembly from early January to late March of 2013.

Final Prototype Design

Figure 12. SolidWorks rendering of Sean's original aluminum walker.

Figure 13. SolidWorks rendering of our final prototype design with new wheels, rail, collars, stick holder and stick.

Figure 12 on the previous page depicts the walker we received at the beginning of the project, while Figure 13 shows our final prototype design. The process we took to reach this point has been documented in the previous sections, and the next three sections will enumerate why each specific component was designed, what we learned from testing this final prototype with Sean, and the small changes we made to the device before manufacturing the final product and delivering it to our client. In this section each of the five sub-assemblies are discussed in detail, consisting of: the new aluminum plate and bracket for the front wheels, the new five inch diameter wheels replacing both the front and rear wheels, the curved rail, the rail and stick collar subassembly that connects the stick to the rail, and lastly the design for Sean's specialized floor hockey stick and stick holder.

Front Wheel Subassembly

For our final prototype we decided to replace the front wheels of the walker with higher quality wheels based on research from both internet sources and medical suppliers' suggestions. The old wheels were not smooth enough and they simply did not satisfy the needs of an active seven year old. The old caster wheels rattled as they rolled along concrete, similar to how common shopping cart wheels rattle, and they swiveled poorly also. The new, upgraded wheels that we purchased were 6267 Invacare wheels from Wallace Home Medical Supplies. The products they carry, including the Invacare wheels, are called durable medical equipment or DME. These five inch diameter wheels were suggested by the staff at Wallace Home Medical Supplies, who are trained to handle all aspects of patient care. They possess adequate knowledge to educate and train customers on equipment prior to any purchase. The wheels were made with a hard, gel type rubber which produces less vibration at the legs of the walker.

Figure 14. 6267 Invacare wheels in the new front wheel subassembly.

We also removed the bulky metal plates used on the old wheels which limited the wheel's rotation. The front overhanging plate limited the rotation of wheels to approximately sixty degrees to the left and right which we decided was unacceptable. Our final prototype design allowed the front wheels to freely rotate 360 degrees and the addition of a five inch long aluminum plate widened the wheel base. This addition helped prevent Sean from accidentally kicking either of the front wheels and by widening the wheel base the walker became more stable, as can be seen in Figure 14.

Rear Wheels

The three inch rear wheels that originally came with the walker were replaced by five inch diameter 6271 Invacare wheels, shown in Figure 15. The three inch wheels were made of plastic and they also had a sprocket system to prevent the walker from rolling backwards, but these two features combined make a lot of unwanted noise. After speaking with Sean's mother we learned that Sean no longer requires brakes on the rear wheels because he had developed enough strength to maintain himself in a balanced position. Removing the rear brakes will prove especially useful when he starts playing because he would be able to step back and reach a puck that is slightly behind him. The Invacare wheels were the same material and style as the new front wheels, but without the fork and bearings for swiveling. They offered the same benefits of a smoother rolling action and quiet ride. The reason the team chose these five inch wheels as opposed to the three inch wheels was because the staff at Wallace Home Medical Supplies recommended that size based on their experience. They said that they have noticed that other customers feel that the walkers roll better and smoother with bigger wheels.

Figure 15. 6271 Invacare unidirectional wheels.

Curved Rail

Choosing the curved rail was one of the first design decisions we made since it acts as the structural connection between Sean's stick and his walker. The rail allowed the stick and swivel collar to slide from Sean's left side all the way to his right giving Sean's stick the best "zone of action" or access to the most floor area possible. This allowed him to acquire the puck quickly, and the curved nature of the rail assisted with the swinging motion required to pass and shoot the puck accurately. See Figure 16 below for the SolidWorks rendering of our final prototype curved rail design.

Figure 16. SolidWorks rendering of our final prototype curved rail design.

The larger diameter tubing that supports the curved rail is ¾ inch outer diameter aluminum tubing, while the curved rail itself is ½ inch outer diameter aluminum tubing. We chose the larger ¾ inch tubing as the support structure for a couple of reasons. Mainly, the larger the diameter of the tubing is, the stronger the overall part will be. The details regarding the engineering analysis can be seen in the

Engineering Analysis section later in this report, in addition to hand calculations in Appendix B. Another reason ¾ inch tubing was an ideal size was due to the fact that the tubing that acted as Sean's walker handles had an inner diameter of ¾ inches. This means that the welded rail fit snugly inside the handles, with just enough clearance to be inserted all the way to the rear bolts, but tight enough so that the rail did not vibrate or shake when in use. Figure 16 also shows three symmetric through-holes in the side of each of the horizontal members of the rail support structure. When the rail subassembly was inserted into Sean's walker handles, the bolts that held the front supports of his walker together also rigidly held the rail to the walker as well. This attachment method serves two purposes: the geometry of the attachment prevents motion in every direction so the rail can't twist, slide, or rotate in any way, and secondly the three holes allow for user adjustment. As Sean grows older and his arms become longer it is important to have as much size adjustment as possible, so in the future the holes farther back down the rail can be used (as opposed to the front most pair of through-holes) to extend the rail outwards by one inch increments at a time.

In addition to the ¾ inch support structure tubing we chose ½ tubing for the curved rail due to the compromise between strength and weight, as well as the relationship between the rail diameter and the collar subassembly that holds the stick. It was found that significant forces are required to dent or kink the smaller tubing, it is lightweight in comparison to solid aluminum rod and steel tubing, and it is an ideal diameter for the swivel collar geometry.

Collar Subassembly

The collar subassembly was the component of our design that attached the hockey stick to the welded rail so the stick could slide along the rail. At the core of the design development for the collar subassembly was this problem: the two collars needed to allow the many degrees of freedom that we wanted the stick to have, and at the same time prevent the degrees of freedom that we wished to eliminate. To solve this problem we created the design of two collars that swivel against each other, as shown in Figure 17.

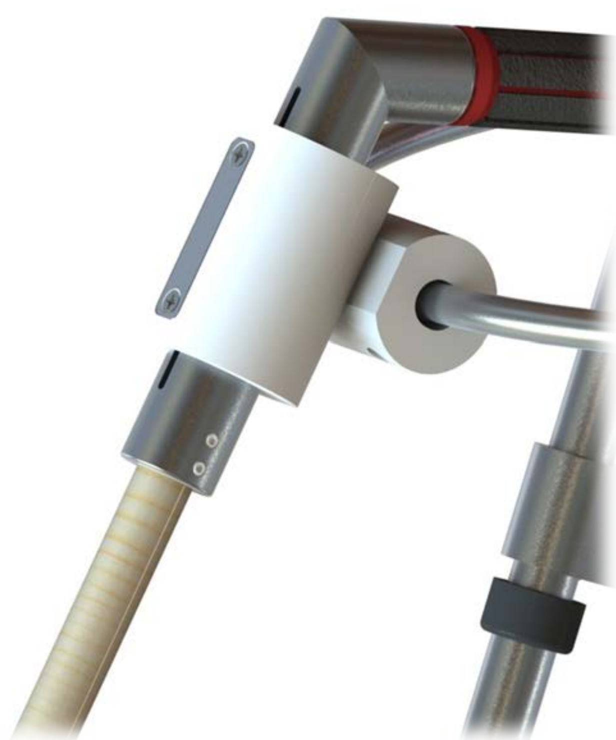


Figure 17. SolidWorks render of the collar Subassembly on the rail, with the stick holder through it.

One collar was designed to slide along the rail that was connected to the walker, and this created two degrees of freedom. One was the motion of the collar back and forth along the rail, which allowed Sean to access both sides of the walker with his stick. The other degree of freedom was the rotation of the collar about the rail. This allows Sean to lift his stick off of the floor by pushing down on the handle, using the collar around the rail as a pivot point. This motion allows Sean to put his stick through the hole on the inside of the puck, and to knock away the stick of an opponent who has possession of the puck. This collar was intended to be constructed out of two pieces so that it can be attached around the rail. The two pieces have stepped slots cut into them that mate together, and the pieces were then fastened to each other using four #8-32 socket head cap screws.

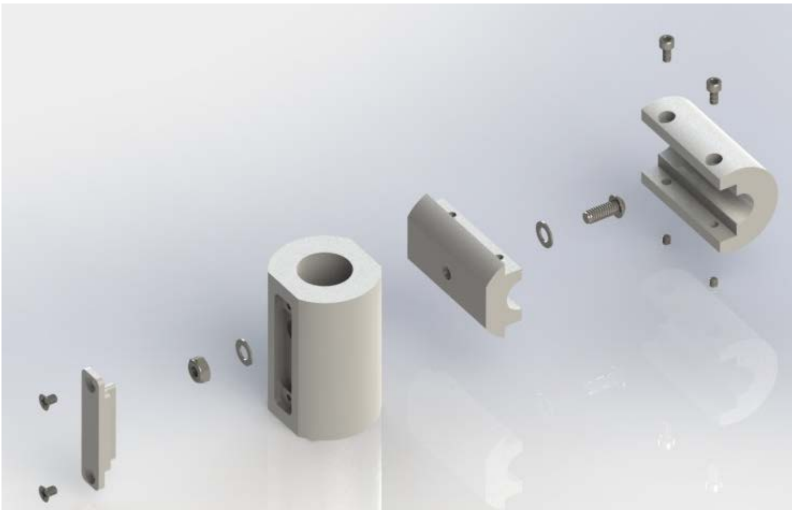


Figure 18. Exploded view of the Collar Subassembly.

A second collar swivels about a ¼-20 bolt that connects it to the first collar, creating another degree of freedom. This swivel motion allows Sean to perform the motion used by other players to pass and shoot the puck. The bolt connecting the two collars was not tightened all the way down to allow the collar to rotate around it. To prevent loosening of the nut that holds the bolt in place, a locknut with a nylon insert was selected, and Loctite was used in between the nut and the bolt. The second collar holds the angled aluminum hockey stick holder. This created an additional degree of freedom by allowing the stick to slide up and down vertically through the collar. This motion enables Sean to reach further out in front of him to acquire the puck. Without this motion, Sean would only be able to put his stick inside the puck at a fixed distance from his walker. There is also a tab piece that mates with a cutout in the back of the collar and attaches with two #8-32 flat head machine screws. This tab sticks out inside of the collar and travels through a slot machined into the aluminum stick holder (Figure 19). This prevents the stick holder and stick from twisting inside of the collar, since we had determined this to be an unwanted degree of freedom at the time. We found from our meetings with Sean that he was not strong enough to control this particular type of motion of the stick.

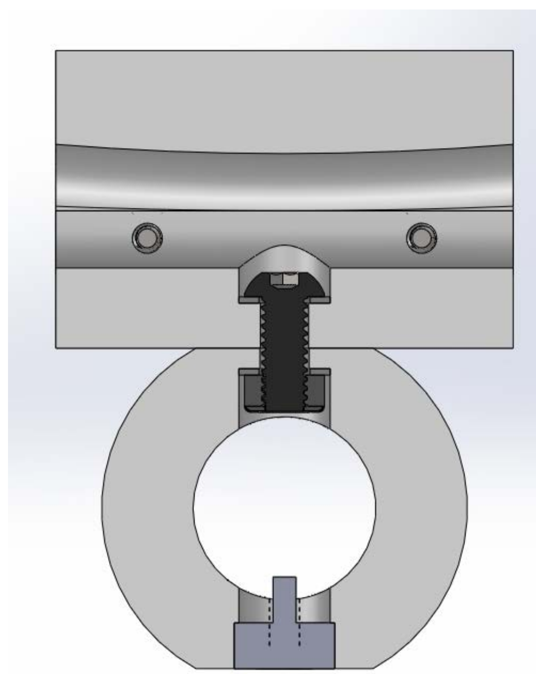


Figure 19. Section view of the Collar Subassembly. Notice the curvature of the hole through the rail collar and the tab protruding into the stick collar.

Both of the collars were designed to be machined out of Delrin Acetal Resin. This plastic was selected because it is self-lubricating, which reduces friction in the collar, and is an easily machinable material. For this prototype we decided that the tab should be machined out of rapid-prototyped ABS plastic. In the next two sections of this report we detail why we changed the material of the tab to aluminum. Additionally, the extensive use of replaceable fasteners in this design makes the collar subassembly easy to repair if necessary.

Stick and Stick Holder Assembly

The complete stick assembly consists of a wooden stick and an aluminum stick holder that also acts as the handle of the stick. The stick holder was designed to be made of two pieces of 1.125 inch outer diameter and ¾ inch inner diameter aluminum tubing welded together to form a 110° angle. One piece of aluminum tubing acts as Sean's stick handle. The end of this piece was designed to be reduced down to 0.875 inch outer diameter to accommodate a standard rubber bike handle grip (as can be seen in Figure 17) so that the device would be comfortable for Sean to hold for an extended period of time. The other piece of aluminum tubing is meant to attach the stick. This piece has a slot machined in the top that will mate with the tab mentioned in the collar subassembly to prevent the stick holder from rotating inside the collar. Set screws were installed into the four threaded holes at the bottom of the stick holder to fasten the wooden stick in place. A wooden stick was chosen to create the least restrictive environment for Sean. A typical Special Olympics Floor Hockey Stick is approximately 1.125 inches in diameter, but we chose a ¾ inch diameter stick for Sean to reduce the weight for our final prototype. After testing with Sean we found this stick was in fact too thin, and changed this dimension for the final product. We designed the stick to have a semispherical, sanded down tip and then covered it in felt to reduce the friction between the stick and the playing surface, and increase the friction between the stick and the puck.

Final Prototype Testing

When we completed our final prototype we were fairly certain there would be a couple of design changes required to ensure we gave Sean the best product possible, so after completing construction of the final prototype we met with Sean and his mother for our last testing session in early March. After observing Sean use our device to play floor hockey for an extended period of time we were pleased with the performance of our design, but as we expected there were a couple issues that one last design iteration would solve.

Figure 20. Sean testing our final prototype after the tab had sheared off, allowing for free stick rotation.

First off, the front wheel subassembly performed extremely well. Sean was able to run at full speed, and the speed at which he could turn the walker exceeded our expectations. Also the rail and collar subassembly performed well and allowed him to slide the stick from left to right along the rail as fast as his arm could move, and the collars allowed for very fluid stick movement.

Where the design fell short however was in the rear wheels, the tab in the collar, two critical dimensions of the rail, and the stick diameter. The rear wheels were simply bolted into the side of the walker supports with a bearing, and their rotation was not as fluid as desired. The ABS plastic tab in the stick collar (which prevented the stick and stick handle from rotating inside the collar) sheared off quickly into our testing session, but this turned out to be beneficial for our design purposes. After shearing we realized we should give the stick 180 degrees of rotation inside the collar to allow Sean to hold the handle in line with his walker handles as seen in Figure 20. We also noticed that the rail dropped too far vertically downward, and extended too far outward in front of Sean. Lastly the stick was only ¾ of an inch in diameter, and aesthetically it looked too thin in relation to the rest of the stick handle. Therefore we decided to make adjustments to these components as discussed in the next section.

The Final Product

Rear Wheel Subassembly

The rear wheel sub-assembly underwent some changes after testing the final prototype because our client wanted the option of having the rear wheels swivel. The rear wheels used for our final product were the same as the front wheels, five inch diameter 6267 Invacare wheels. We decided to replace the unidirectional assembly which consisted of bolting the wheels with washers to the already existing rear legs. In our final product, the rear wheels were attached to the aluminum casters that were originally used as the front wheel subassemblies on the original walker. The caster system was perfect for our new requirements. The overhanging semi-circular plate allows the wheels to rotate about 60 degrees left and right. A metal bar on the inner part of the wheel acts as a locking mechanism to make the wheel unidirectional if desired. Sean will use the rear wheels in the unidirectional mode until he can build up enough strength to balance himself with all four wheels able to swivel.

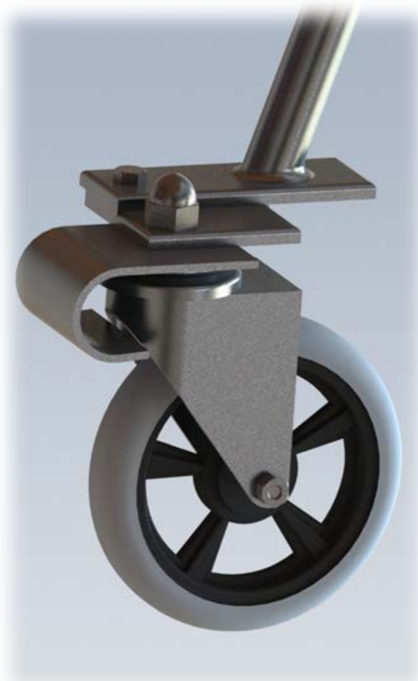


Figure 21. Rear Wheel Subassembly with reused caster system and new Invacare wheels.

Curved Rail

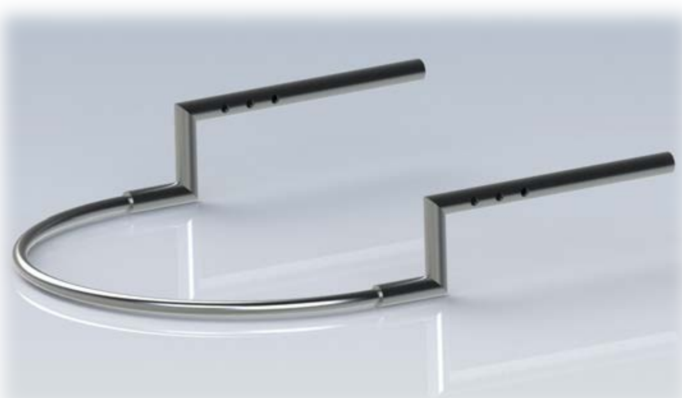


Figure 22. Curved Rail for the Final Product.

As mentioned earlier, two critical dimensions were changed on the curved rail and the support structure that holds it in the walker. As can be seen by Figure 16 in the previous section, the rail support bars drop four inches before extending out laterally to form the curved rail. We noticed that this vertical drop was too large and that Sean was required to bend over slightly to operate the stick. Also, we noticed Sean was forced to lean too far outward when sliding the stick across the center point of the rail. Thus we reduced the vertical drop from 4.5 to 3.5 inches, and brought the rail closer to Sean by two inches.

Collar Subassembly, Stick Holder, and Stick

Because the ABS rapid-prototyped tab sheared off so quickly, we had it machined on a CNC mill out of aluminum for the final product. However, when the tab sheared off during our testing, we discovered that Sean was capable of handling the rotation of the stick in the stick collar, but was unable to recover if the handle rotated a full 180 degrees around. To accommodate this, the 0.125 inch slot in the aluminum stick holder was changed into a much larger 180° slot. The new slot allows Sean to rotate the stick only 90° in each direction. This also allows the stick handle to be parallel with Sean's walker grips when the stick is all the way at one end of the rail, which was very comfortable for Sean.

The stick diameter was increased from ¾ of an inch to one inch to be more robust and withstand the cyclic loading it will endure from playing multiple games of floor hockey. To accommodate this, the size of the stick holder was increased to a one inch inner diameter and a 1.25 inch outer diameter, and the inner diameter of the stick collar was increased to 1.25 inches to accommodate the new stick holder.

Figure 23. Stick handle is now able to rotate 180 degrees inside the stick collar.

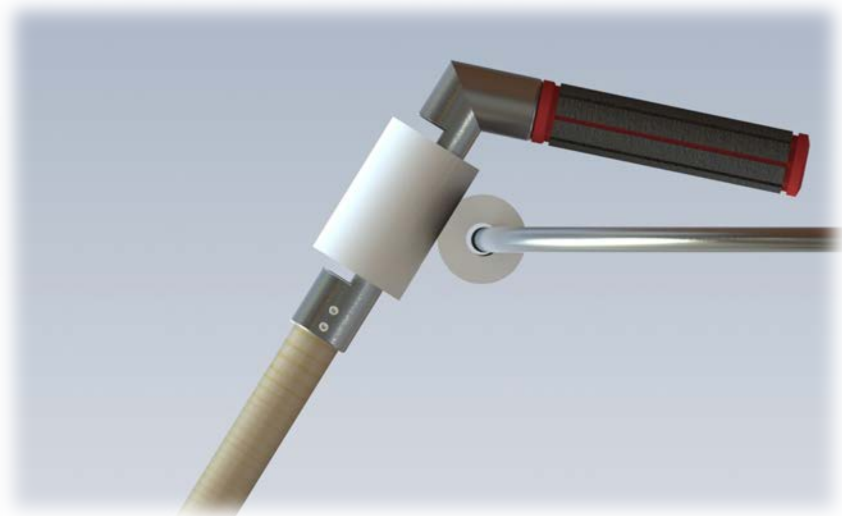


Figure 24. Side view of the stick handle in the stick collar, highlighting the 180 degree, four inch long cutout in the stick holder.

Final Product Manufacturing

Front Wheel Subassembly

The first step in replacing the front wheels of the walker was to unfasten all of the old components, including the wheels and aluminum plates attached to the front legs of the walker. Since we were not using any of the old aluminum plates for the front wheel subassembly, we machined our own aluminum extension plate which extends five inches outward on each side of the walker. The half inch thick rectangular stock of aluminum was cut to length on a horizontal band saw, and the edges of the two extension plates were ground down and polished ensuring no sharp edges were present. We then used a drill press to drill

0.31 inch and 0.44 inch diameter holes in each plate. The 0.31 inch hole was used for a ¼ inch diameter bolt to attach each plate to its respective walker leg, and the 0.44 inch hole was used to attach a 3/8 inch diameter bolt to each wheel. See Figure 14 for clarification. The final step was to assemble the plate with the new free-rotating Invacare wheels inside their brackets.

Rear Wheel Subassembly

The new, rear wheel installation started with removing the new wheels from the 0.875 inch diameter rear legs of the walker that we had installed during our final prototype testing. Then the old front wheel caster subassembly was unbolted from the fork and metal plate assembly. The old wheels were removed from the caster assemblies, and the new Invacare wheels were then bolted onto the original front fork and metal plate assembly. Once the new five inch wheels were bolted on, we raised the legs with the built in notches on the walker frame to account for the extra height added from the caster assembly and the larger diameter wheels. Note the rear wheel subassembly involved no machining of components; just a simple wheel replacement was required.

Curved Rail

As mentioned in the Final Prototype Design section, the curved rail is comprised of two different aluminum tubing sizes. The larger tubing has an outer diameter of ¾ of an inch with a wall thickness of 0.125 inches, and ½ inch inner diameter. The smaller diameter tubing has an outer diameter of just ½ of an inch, with a wall thickness of 0.12 inches and an inner diameter of 0.26 inches. We selected 6061-T6 aluminum for both tubing sizes due to the ease of access, low cost, machinability and weldability of this type of aluminum.

Figure 25. Matt Spaulding heating the curved rail before rolling.

The first step we took in the rail manufacturing process was to bend the curved rail to our desired 15.75 inch diameter. Instead of simply bending the tube in a tube roller, we first heated the entire tube section with a propane torch to prevent the tube from kinking or fracturing during the bending process, as shown in Figure 25. Once the rail was sufficiently hot, we proceeded to bend the tube in the three cylinder tube roller. We had experience using this piece of equipment from our prototyping phase, so we knew to cyclically heat and roll, then heat and roll until we had the desired bend radius.

Next we manufactured the larger diameter tubing pieces that act as the support structure for the rail. The long, horizontal sections of ¾ inch tubing were placed in a lathe and the wall thickness was reduced until the straight ends of the curved rail support tubes snugly inserted into the larger walker handle tubing on the walker frame. Even though the inner diameter of the larger walker handle tubing is close to the outer diameter of the

Figure 26. Cutting one of the pieces of the curved rail support tubing at a 45 degree angle.

smaller curved rail support tubing, we needed to reduce the outer diameter of the rail support tubing to allow for a clearance fit. Then all the sections of the ¾ inch outer diameter support tubing were cut at 45 degree angles on a horizontal band saw as shown in Figure 26. Once we finished with the 45 degree cuts we ground down the edges of each piece to ensure each piece fit together to form a perfect 90 degree angle.

Figure 27. Exploded view of the curved rail showing the location of each weld.

After the bending, lathing and cuts had been made we were ready to weld the seven components together, as shown in Figure 27. Simon Rowe, a certified welder and welding instructor at Cuesta College in San Luis Obispo was contracted to perform the aluminum TIG welding. We knew how important these welds were to the structural integrity of the curved rail and the aesthetic finish we desired, so we felt the need to have this work performed by a certified welder. See Figures 28 and 29 below for how the components were welded to form one solid part.

Figure 28. Simon Rowe welding one side of the curved rail support structure together.

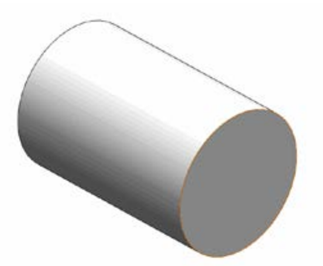
Figure 29. Simon Rowe welding the curved rail to one side of the support structure.

After welding the curved rail and each side of the support structures into one solid aluminum piece, we then inserted the subassembly into the walker and drilled each one of the three holes in the curved rail support tubes that were inserted into the walker tubes. These are the holes that allow the bolts that hold the walker frame together to go through the curved rail subassembly, rigidly attaching the curved rail to the walker frame.

Collar Subassembly

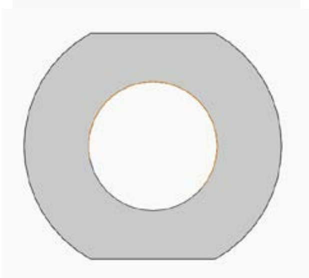
The majority of the time spent manufacturing the collar subassembly was spent machining the Delrin components. Below is the order of operations we employed to produce these components, with descriptions of what machines were used, how the parts were fixtured, and what cutting tools were used.

Stick Collar

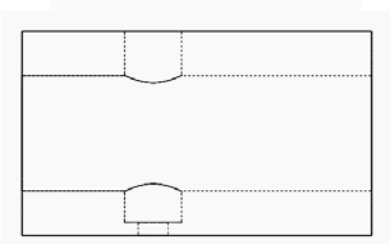


Use chop saw to cut 2 in outer diameter Delrin stock to three inch length.

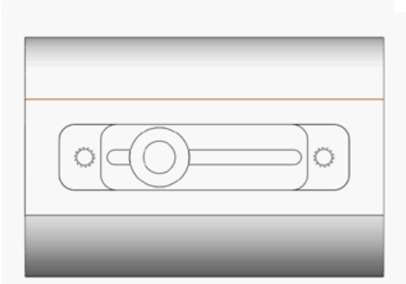
Use lathe to center drill one inch diameter hole.



Use mill and ¼ inch flat end-mill to machine one of the flat surfaces. Flip part and machine the other flat surface.

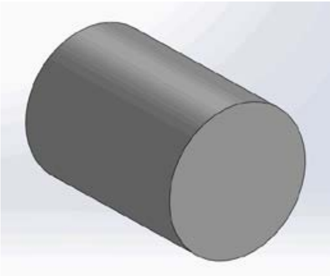


Use drill press with ½ inch counter bore bit to add counter bore feature from opposite side of collar, then switch to 17/64 inch drill bit to drill through-hole.

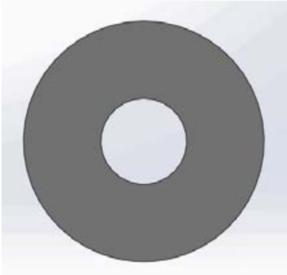


Fixture collar in mill. Use ¼ inch end-mill to cut shallowest slot, then the smaller slot. Switch to 0.125 inch bit and mill the through-slot. Switch to #29 drill bit and put in the through-holes for the #8-32 tapped holes. Switch to #8-32 tap and tap the holes.

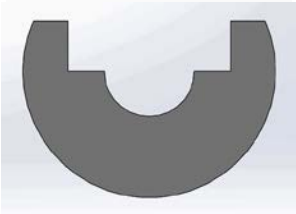
Rail Collar – Back



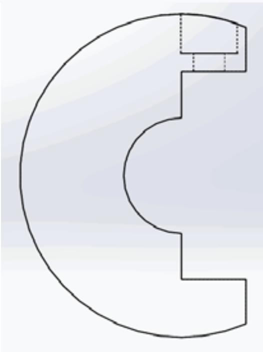
Use chop saw to cut 1.75 inch outer diameter Delrin stock to 2.5 inch length.



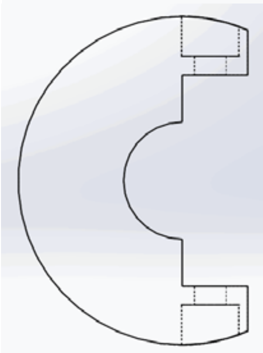
Use lathe to center drill 0.625 inch diameter hole.



Use mill and ¼ inch flat end-mill to machine off top portion of the cylinder. Use same bit to machine the inner slots.

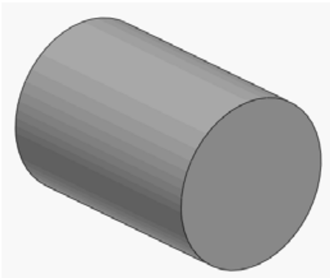


Fixture collar on its side on mill. Use 5/16 inch counter bore to add counter bore features, then switch to #16 drill bit to drill through-holes.



Flip collar and perform the same operations described above.

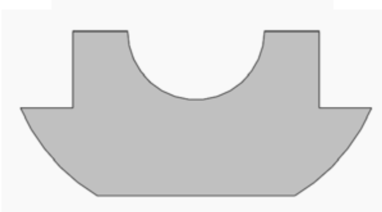
Rail Collar – Front



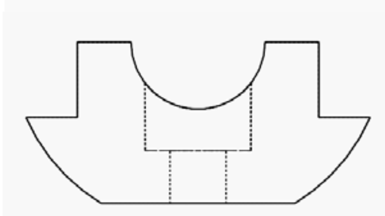
Use chop saw to cut 1.75 inch outer diameter Delrin stock to 2.5 inch length.

Use lathe to center drill 0.625 inch diameter hole.

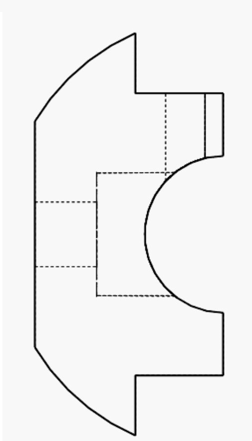
Use mill and ¼ inch flat end-mill to machine flat surface onto the cylinder.



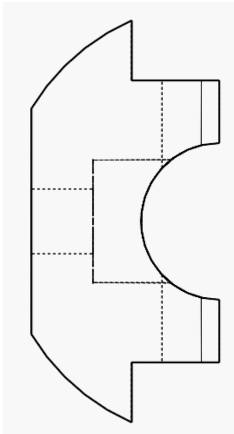
Use mill and ¼ inch flat end-mill to machine off top portion of the cylinder. Use same end-mill to machine the outer slots.



Use drill press with ½ inch counter bore bit to add counter bore feature, then switch to 17/64 inch drill bit to drill through-hole.



Fixture collar on its side on mill. Use #29 drill bit and drill the through holes for the #8-32 tapped holes. Switch to #8-32 tap and tap the holes.



Flip collar and perform the same operations described above.

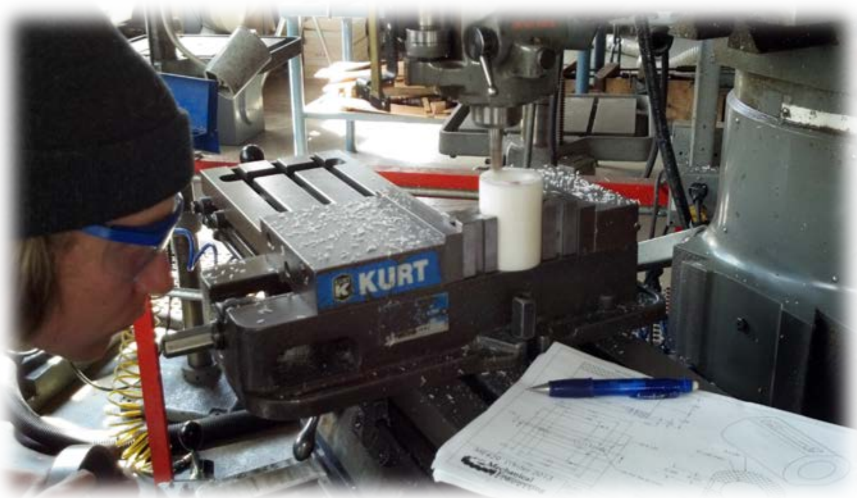


Figure 30. Chris Gaul milling the end of the stick collar down to a 3 inch length with precise, flat edges.

Figure 31. Milling the flat spot on the stick collar that mates with the flat end of the rail collar.

Tab

The aluminum tab in the Delrin stick collar that prevents the stick handle from rotating more than 180 degrees was produced by a lab technician on a CNC mill. The tab was made from a ¾ inch square piece of 6061-T6 aluminum stock, and we also purchased a specialized three flute, 3/8 inch diameter end mill for the CNC mill. The three flute end mill increased the quality of the surface finish, which was important for the tab to tightly fit inside the Delrin stick collar.

Stick Holder and Stick

The stick holder was machined from 1.25 inch outer diameter by ¾ inch inner diameter aluminum tubing. A 55° cut was made using a horizontal band saw to create two pieces with 55° ends. For the piece that holds the stick, a one inch drill bit was placed in the tail stock on a lathe to create the one inch deep depression that allows the one inch outer diameter wooden stick to fit snugly inside the depression. A mill was used to drill the pilot holes for the set screws, and the threads were hand tapped. For the handle, the end was turned down to 0.875 inches on a lathe (Figure 32), and a lubricant was used to slide on the rubber bike grip. Simon Rowe welded these two pieces together to complete the aluminum stick holder during the same welding session that the curved rail was welded (Figure 33). The actual wooden stick was cut to a 24 inch length from one inch diameter pine dowel rod using a vertical band saw. We used a belt sander to make the end semispherical, and then glued felt around the semispherical end to simulate the traditional Special Olympics Floor Hockey sticks.

Figure 32. Using a lathe to turn down the outside diameter of the handle portion of the aluminum stick holder. The bike grip can now slide over the handle.

Figure 33. Simon Rowe welding the two pieces of the aluminum stick holder together.

Figure 34. The final product, as delivered to the client. Both the rail and stick collars were painted black (as requested by Sean) in addition to the wooden stick.

Engineering Analysis

Tipping

We performed a tipping analysis to see how much force would need to be applied at the end of the rail on the walker to tip the walker over. We determined that the worst case scenario for tipping would be if Sean's walker ran into something that stopped the front the wheels turning and kept the walker from moving forward. Below is a free body diagram of the system in this scenario:

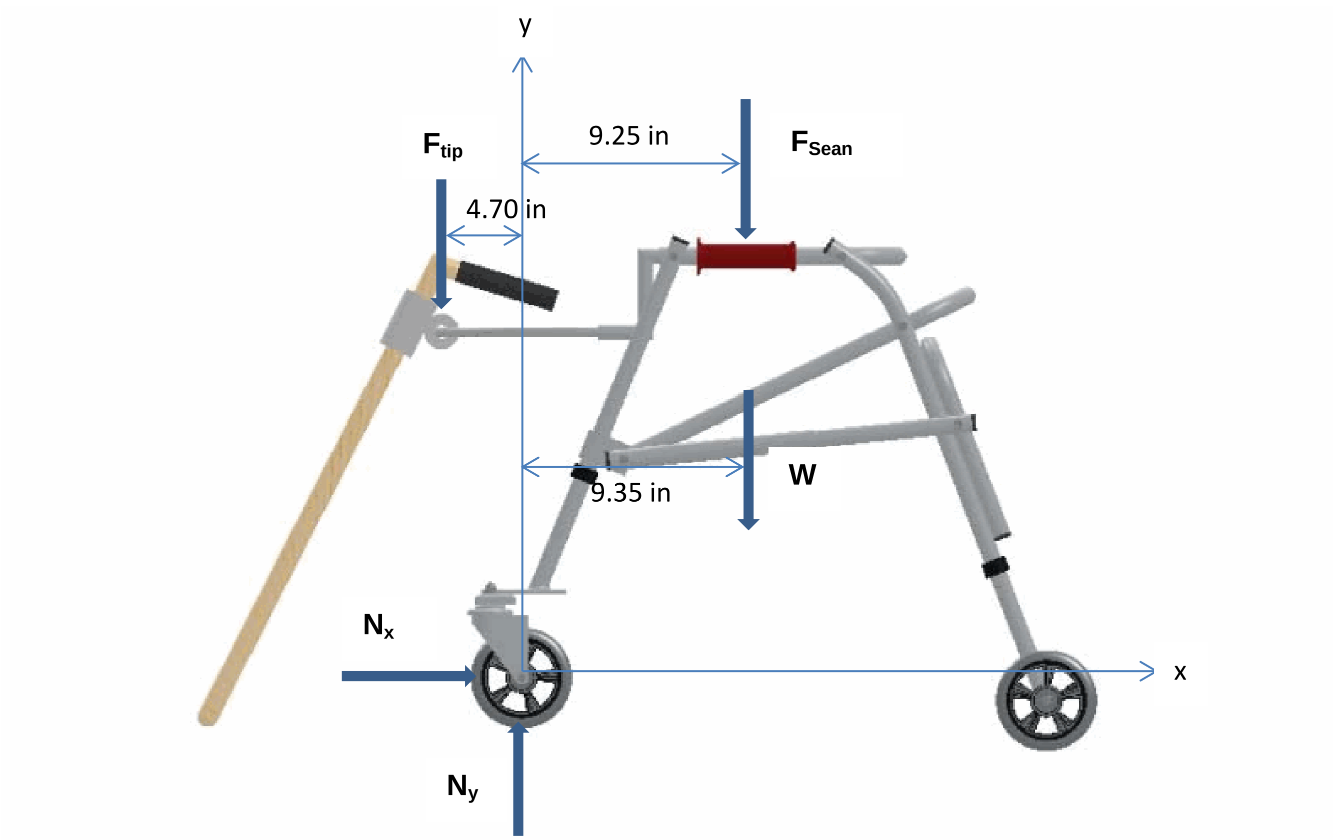


Figure 35. Free Body Diagram used to perform tipping analysis.

F is the force that Sean is applying downwards on the railing. F is the force that Sean is applying downward on his handles. W is the weight of the entire walker, including all components that we have added to it. The weight (11.68 lbf) and the location of the center of gravity were found using mass properties in SolidWorks.

If the sum of the moments about the origin is equal to zero, then the walker is on the verge of tipping:

$$\Sigma M_O = 0 \qquad \text{(Eq. 1)}$$

$$F_{tip}(4.70\ in) - F_{Sean}(9.25\ in) - W(9.35\ in) = 0 \qquad \text{(Eq. 2)}$$

$$F_{tip} = \frac{W(9.35\ in) + F_{Sean}(9.25\ in)}{4.70\ in} \qquad \text{(Eq. 3)}$$

From this result, we determined the force required to tip the walker based on how much weight Sean is applying at the handles. If Sean applies no force down on the handles, then it will require 23.2 lbf to tip the walker. This is a good result, considering that Sean needs his walker for balance, and applying no weight to it would be unlikely. Sean weighs about 75 lbf, so a good approximation of an actual scenario would be if he were supporting 1/3 of his weight on his walker handles, or 25 lbf. In this case, it will require 72.4 lbf to tip the walker. This is a large enough force that we feel confident in the stability of this walker.

Front Wheels

A key area of interest for failure of the wheels is the bolt connection at each of the front wheels where the fork connects to the extension plate. The bolt we selected was a 3/8-16x1.5 grade 5 bolt. Points of stress concentration are at the fillet under the head of the bolt, at the start of the threads, and at the thread root fillet in the plane of the nut. Washers were added to prevent an increase in stress concentration at the fillet due to burrs or sharp edges at the bolt holes. We also chose a nut of equal grade as that of the bolt. The purpose of the nut is to have its threads deflect to distribute the load of the bolt more evenly to the nut.

It was calculated that the bolt would elongate by only 0.000065 inches under a 100 pound load, which is an insignificant elongation for an estimated max force that the walker might be loaded to during floor hockey. This total elongation was found using Equation 4.

$$dl = \frac{FL}{EA} \qquad \text{(Eq. 4)}$$

The effective stiffness of the bolt and stiffness of the members in the clamped zone were calculated to be 334.5 ksi and 3.78x10^{6} psi, respectively. The fastener stiffness and stiffness of members were found using Equation 5 and Equation 6 shown below.

$$K_b = \frac{A_d A_t E}{A_d l_t + A_t l_d} \qquad \text{(Eq. 5)}$$

$$K_m = \frac{0.5774\pi E d}{2ln\left(5\left(\frac{0.5774l+.5d}{.5774l+2.5d}\right)\right)} \qquad \text{(Eq. 6)}$$

The strength of the bolt under a 100 pound force was then analyzed. The total stress from the preload stress (initial bolt tension from tightening the nut) and the stress under the 100 pound load resulted in a value of 4.3 ksi by using Equation 7 shown below.

$$\sigma_b = C\left(\frac{P}{A_t}\right) + \sigma_i \qquad \text{(Eq.7)}$$

The SAE minimum proof strength for a grade 5 bolt is S_p=74 ksi, therefore the total stress after the 100 pound load is only 6% of this value. This means that a 100 pound load is magnitudes lower than the force required for the bolt to fail.

Welded Rail

The following analysis was performed on the welded rail assembly assuming a 100 pound force was acting downward on the rail at the center of curvature. This is our "worst-case scenario" so we could develop an idea of the absolute maximum forces, moments and stresses that could act on the rail assembly. See Appendix B for detailed hand calculations.

First a static analysis was performed on the entire rail assembly to determine reaction forces and moments at the walker handles, using Equations 8 and 9.

$$\sum F_y = 0 \qquad \text{(Eq. 8)} \qquad\qquad \sum M = 0 \qquad \text{(Eq. 9)}$$

Given a 100 pound force acting downward at the forward most point of the rail, and the rail assembly weight of 1.15 pounds (found using SolidWorks Mass Properties Tool), it was found that the reactions at the walker handles were 50.575 pounds per handle, with a moment of 557.09 lb-in at each handle. While a force of this magnitude would tip the walker over, in case the walker is somehow rigidly fixed to the ground (blocked by another player, for example), it is necessary to find these reactions. Now that these basic reaction forces were found, the rest of the rail assembly analysis covers the ½ inch outer diameter curved rail, since the rail will be experiencing most of the forces during use.

Given the same loading conditions (100 pound force acting downwards), the reactions were found using Equations 1 and 2. The forces and moment reactions were found at the ½ inch to ¾ inch interface to be 50.185 pounds and 394.4 pounds respectively. Using this force (shear force at the interface) the maximum planar shear stress at the weld was found to be 700.6 psi. The maximum shear stress due to the torsion on the rail was also found to be 34.747 ksi, at a twist angle of 8.25° and a maximum theoretical deflection based on this twist angle to be 1.14 inches. Maximum planar shear stress was found using Equation 10, maximum torsional shear stress was found using Equation 11, and twist angle was found using Equation 12.

$$\tau_{\substack{max \\ plane}} = \frac{2V}{A} \quad \text{(Eq. 10)} \qquad \tau_{\substack{max \\ torsion}} = \frac{Tr}{J} \quad \text{(Eq. 11)} \qquad \theta = \frac{TL}{GJ} \quad \text{(Eq. 12)}$$

The final analysis that was performed on the curved rail was a curved beam in bending analysis to determine the stresses on the inside and outside tube walls. Instead of a 100 pound force acting vertically downwards on the rail, this analysis was performed where a 100 pound force was acting horizontally on the rail, once again to determine absolute maximum stresses. The fine details of the calculations can be found in Appendix B with the other calculations, but the two fundamental equations to determine stress in the walls are shown below in Equations 13 and 14.

$$\sigma_{inner} = \frac{F}{A} + \frac{Mc_i}{Aer_i} \quad \text{(Eq. 13)} \qquad \sigma_{outer} = \frac{F}{A} - \frac{Mc_o}{Aer_o} \quad \text{(Eq. 14)}$$

Collar

In our engineering judgment, the first component in the swivel collar to fail would be the ¼-20 x 5/8," grade 5 steel bolt that the two collars pivot around. Because we are not fully tightening this bolt, and therefore not applying a preload, a standard bolt analysis is not appropriate. Instead, we will treat the bolt as a simple cylinder. We chose a diameter of 0.1887 inches, the minor diameter of the bolt we used, to make sure that our calculations were conservative. To simulate a scenario that could potentially cause the bolt to break, we will apply an impact force, P=100 lbf, to the bolt in tension.

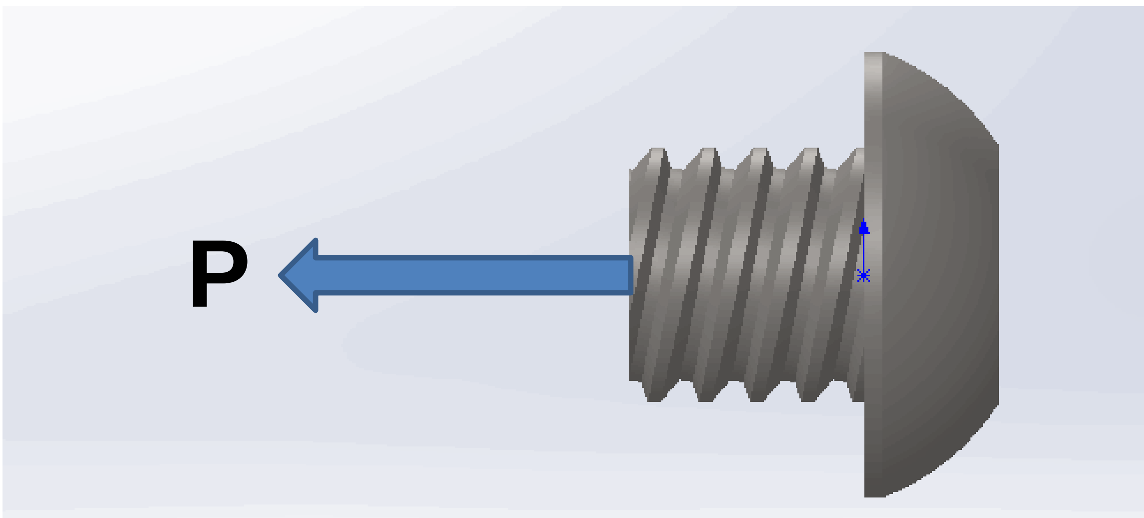


Figure 36. 100 pound force applied to ¼-20x5/8" bolt.

We then found the tensile stress on our ideal cylinder by first finding the area (Equation 16):

$$A = \frac{\pi}{4} D^2 \qquad \text{(Eq. 15)}$$

$$A = \frac{\pi}{4}(0.1887\ in)^2$$

$$A = 0.02797\ in^2$$

And then applying the general equation for tensile stress (Equation 16):

$$\sigma = \frac{P}{A} \qquad \text{(Eq. 16)}$$

$$\sigma = \frac{100\ lbf}{0.02797\ in^2}$$

$$\sigma = 3.58\ ksi$$

The stress was found to be 3.58 ksi, which is a good result. According to *Shigley's Mechanical Engineering Design*, 9th edition, the minimum yield strength for grade 5 steel bolts is 92 ksi. Our result is only 3.9% of this value, so we are very far from yield.

Additionally, we found the elongation of the bolt under the load of this impact force (modulus of elasticity of steel obtained from *Shigley's Mechanical Engineering Design,* 9th edition):

$$\delta = \varepsilon L$$

$$\delta = \frac{\sigma}{E} L \qquad \text{(Eq. 17)}$$

$$\delta = \frac{3576\ psi}{28 \times 10^6\ psi}(0.625\ in)$$

$$\delta = 7.98 \times 10^{-5}\ in$$

This amount of elongation is trivial, and we were confident in these results.

Testing

In order to validate our design, we needed to properly test it. Luckily, our final prototype was very similar to the final product so we could test our final prototype without fear of structural failure. Table 7 on the following page is a summary of the tests we performed on the walker. The Acceptance Criteria was the result required for our product to pass the test. The test stage for all tests was DV, design verification, which means that the tests were used to verify that our design is acceptable.

Test number one was conducted to ensure that the walker was safe as far as tipping was concerned. We placed stops on the front wheels to prevent them from moving and loaded our welded rail as far out as possible. It took 22 lbf of weight to tip the walker over, which was above the 20 lbf minimum that we considered to be a safe loading condition.

Test number two and test number three were both performed to ensure that Sean will have a full, smooth range of motion when using our device. These tests verified that our product has the full range of motion that we intended it to have. These tests were performed on our final product as well as our final prototype.

Test number four was designed to assess the strength of our welded rail. We fixed the ends of the rail and hung 100 lbf of weight from the end of it. To pass, the rail needed to show no sign of plastic deformation after the weight was removed. Most importantly, the rail could not fracture or break in any dangerous way. The rail passed this test, so we feel confident that Sean will be safe using our device, even if the rail is subjected to an abnormally high degree of loading.

Test number five ensured that the bolts that hold our collar subassembly together will not fail. We attached the rail collar to the rail and suspend 100 lbf of weight from the stick collar. This tested both the main ¼-20 bolt that fastens the two collars together and the four #8-32 bolts that hold the two halves of the rail collar together. The collar subassembly passed this test, so we are confident that it will not break while Sean is using it.

Table 7. A description of the tests performed on the critical components of the project.

Item No.	Test Description	Test Responsibility	Test Stage	Acceptance Criteria	Result	Pass/Fail
1	Hang weight from rail until walker tips forward.	Knuckle Pucks	DV	> 20 lbf	22 lbf	Pass
2	Slide collar all the way around the rail.	Knuckle Pucks	DV	Full range of motion with no "sticking" points	Motion is unimpeded	Pass
3	Slide stick holder all the way through the collar.	Knuckle Pucks	DV	Full range of motion with no "sticking" points	Motion is unimpeded	Pass
4	Clamp ends of the rail assembly; hang 100 lbf of weights from the end; measure deflection.	Knuckle Pucks	DV	No plastic deformation	Slight deformation, fully elastic	Pass
5	Assemble swivel collar around a rail so that stick collar hangs down; hang 100 lbf from inside of stick collar; measure deflection.	Knuckle Pucks	DV	No plastic deformation	Slight deformation, fully elastic	Pass

Failure Analysis (FMEA)

FMEA stands for Failure Mode and Effect Analysis. FMEA is an engineering tool used to evaluate the reliability of components and systems within a given design. The purpose of this kind of analysis is to determine how components could potentially fail, why these components would fail, how often and how severe these failures could be, and then determine the best course of action to prevent such failure from occurring. So in a way FMEA is a “worst case scenario” exercise to prepare for potential failures during product use. We have performed an extensive engineering analysis and outlined our testing plan in an effort to mitigate such failures, but FMEA is a useful tool to determine the parts at the highest risk of failure. Table 8 below is a greatly condensed version of the full FMEA that can be found in Appendix D. Occurrence, severity and detection rankings are also detailed in Appendix D.

Table 8. Major results from the Failure Modes and Effects Analysis.

Sub Assembly	Parts That Will Most likely Fail	Occurrence Ranking (1-10)	Severity Ranking (1-10)
Walker Frame	Hardware loosening	6	3
Front Wheels	Hardware loosening	6	4
Rear Wheels	Hardware loosening	6	4
Welded Rail	Hardware loosening that attaches rail to walker	5	5
Collar Subassembly	Hardware breaks through collar	5	8
Stick	Set screws loosening that hold stick	6	8

After performing a Failure Modes and Effects Analysis for each of the five sub-assemblies in our system, we were pleased to find that the highest risk of failure was hardware loosening at the numerous bolted connections present on the walker and in our design. We were pleased with these results because we expected this to be the case, but more importantly tightening nuts and bolts is very easy to do given a couple of simple tools.

We have determined that hardware may need to be tightened across the walker every six months depending on the rate of use, while the rail hardware and collar hardware may need to be inspected every three months. We came to these conclusions based on the frequency of the walker use, the regular impact forces the device will be experiencing in use, and the fatigue loading on the walker and sub-assemblies over time. Our biggest concern are the set screws holding the stick inside the aluminum stick holder, but we designed the holder to clamp the stick in place using four set screws, which should more than account for regular impact loading. Also, we gave Sean and his mother a number of extra hockey sticks when we delivered the product, just in case anything catastrophic ever happens to the stick.

The severity ranking for each failure is equally as important as the occurrence ranking. If a component never fails than failure could be relatively severe, but for parts that have higher failure rates, severity becomes a serious issue. If a part catastrophically fails, we are morally obligated to ensure that injury to Sean and other players is prevented to the best of our abilities. From our analysis we found that the severity of hardware loosening would most likely not even cause performance loss, so we are not concerned about hardware loosening in the walker. However if the hardware starts to loosen in the rail-to-walker connection a minor performance loss is expected since the rail could begin rattling and vibrating as the collar slides along the welded rail. The swivel collar and stick have relatively high severity rankings because if either of these components fails the unit would be inoperable. We debated the severity of stick failure since splinters and sharp edges could injure Sean, but we determined there is an equally high risk of other players' sticks splintering.

Bill of Materials

Table 9 below shows a complete Bill of Materials for the entire project, organized by each prototype/final design.

Table 9. Materials and manufacturing costs for each design phase.

Date of Purchase	Items Purchased	Design Phase	Total
11/5/2012	Steel braided hose and PVC	First prototype	$33.56
11/9/2012	PVC	Second Prototype	$6.94
11/9/2012	PVC and Various Fasteners	Second Prototype	$54.76
11/11/2012	PVC	Second Prototype	$6.59
11/12/2012	PVC and Steel Rod	Seocnd Prototype	$24.50
11/14/2012	Foam, clamps, PVC	Second Prototype	$10.00
1/11/2013	0.5" AL Solid Rod	Third Prototype	$10.15
1/16/2013	0.5"x0.16" Steel Round Tube	Third Prototype	$16.46
1/16/2013	0.035" OD AL Tube	Third Prototype	$17.26
1/18/2013	0.75" AL Solid Rod	Third Prototype	$11.67
1/18/2013	JB Weld	Third Prototype	$7.55
1/28/2013	5" swivel wheels, 5" & 3" fxd wheels	Third Prototype	$112.77
2/19/2013	0.75 and 0.5 AL Tube	Final Prototype/Product	$95.91
2/27/2013	2.25" Delrin Rod	Final Prototype/Product	$29.17
3/5/2013	1.25" AL Tube, Various Fasteners	Final Prototype/Product	$73.09
4/29/2013	3/4" Square AL and 3/8" Endmill	Final Prototype/Product	$48.58
5/2/2013	CNC Mill Labor - Aluminum Tab	Final Prototype/Product	$104.00
5/4/2013	Welding Labor	Final Prototype/Product	$80.00
Project Total			**$742.96**

Recommendations

Although we have been able to redesign various areas for improvement throughout our iteration process, we feel there is still room for further development in future models of this adaptive floor hockey device. The following are some recommendations for future engineering groups:

a. Outsource the manufacturing of the curved rail.
    i. Having a professional machinist bend the rail will improve uniformity and accuracy of measurements.
b. Make more precise cuts of aluminum bars for better welds.
c. Minimize material used to reduce cost and weight.
d. Consider using different materials for the stick and rail. Consider carbon fiber for a lighter device.
e. Make the rail more easily detachable from the walker so other users don't have to crawl under it to fit in the walker.
f. Adapt device for attachment to multiple walkers.
g. Adapt device for a wider demographic.

Conclusion

The adaptive floor hockey device we constructed was specially designed for the needs and requirements of Sean to allow him to participate in Special Olympics Floor Hockey. Ultimately, Sean will be able to improve his strength, balance, and coordination by continuing to play floor hockey as he grows. This is why we have designed and manufactured a fully functional device and not just a prototype. We finished this project content with the final product, and very appreciative of the lessons we have learned.

With our device, Sean will be able to compete in a local Special Olympics Floor Hockey league, but more importantly he will be able to interact and have fun with people of his own age in a healthy, competitive atmosphere. We would like to thank Dr. Kevin Taylor, Chair of the Kinesiology Department at California Polytechnic State University, San Luis Obispo, as well as Dr. Brian Self and Dr. Jim Widmann both of the Mechanical Engineering Department. Their efforts led to the acquisition of the National Science Foundation grant that made this project possible, and we are very thankful for their time and energy. We would like to thank Michael Lara, Regional Sports Advisor of the Southern California division of Special Olympics for his positive attitude and youthful energy that reminded us what the true purpose of this project was: to learn, experience, and have fun. We would like to extend a huge thank you to our faculty advisor, Professor Sarah Harding, for the three quarters she spent helping us refine our design. Her advice was instrumental in keeping the team working together towards a common goal, and she was always willing to share her knowledge and experience. We are extremely grateful for all of the time and energy she devoted to our questions. And last but certainly not least we would like to sincerely thank Sean and his mother Gabrielle for all the time they devoted to meeting with the team and testing different prototypes. We had a lot of fun running around with Sean, and we are excited to see his floor hockey future develop.

Good communication with Sean and his family, our sponsors, and our advisor as well as the use of our engineering knowledge have allowed us to produce a successful product. This project has taught us that there is a great need for engineers to design assistive devices for the purpose of breaking limitations caused by disabilities. We hope Sean enjoys using our device for many years to come and that future Cal Poly students continue to work towards making the lives of people with disabilities more exciting and diverse.

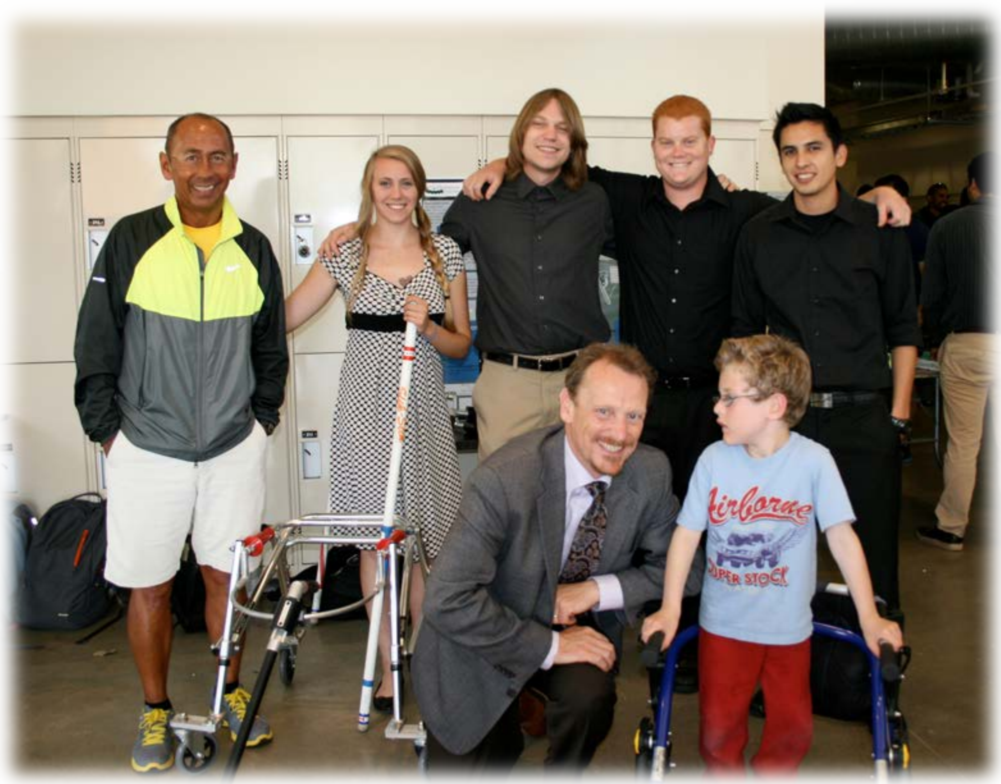


Figure 37. Top row: Michael Lara, Shannon Brant, Chris Gaul, Matt Spaulding, Ricardo Gaytan. Bottom row: Dr. Kevin Taylor, Sean.

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Appendix A

Quality Function Deployment (QFD) – House of Quality

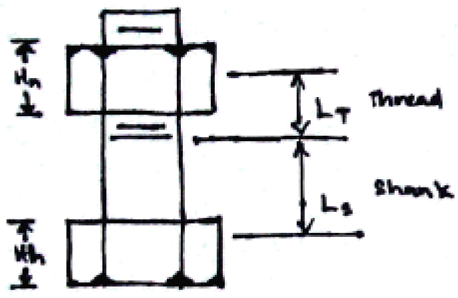
Direction of Improvement:
Maximize ▲ Minimize ▼ Hit Target **X**

Customer Desciption:
1 = Sean Freed, Gabrielle Freed
2 = Michael Lara, Dr. Kevin Taylor
3 = NSF, Special Olympics

Customer Requirements	Importance	A: Weight of bracket/device	B: Number of Uses before failure	C: Area of stick movement on floor	D: Range of stick movement vertically	E: Time to Acquire puck (posession)	F: Distance puck can be passed/shot	G: Height Adjustment	H: Weight on handle w/out tipping	I: Cost of Materials
Direction of Improvement		▼ Minimize	▲ Maximize	▲ Maximize	▲ Maximize	▼ Minimize	▲ Maximize	▲ Maximize	▲ Maximize	▼ Minimize
Walker/Support Structure										
Least Restrictive Environment	4			9	9	9	3	1		3
Lightweight	5	9	3					1	3	9
User comfort (Hand Grips)	5*		1	9	9	3	3		9	1
Does not limit mobility/speed	4	9	3	9	3	9	3		9	3
Wheels roll smoothly	5	3	9						9	9
Stability	5	9	3	9	3	1	3	3	9	3
Durability	4	3	9	1	1		1	3	3	9
Collapsible	2	1	3	3	3		3	1	3	9
Height Adjustable	5	1	3	3	3		3	9	3	9
Easily repairable	2	3	9	3	3		3	3	3	3
Safety	5*	3	1	1	1	1	3		9	3
Inexpensive	2	9	3	3	3		3	1	3	9
Aesthetics	3		1	1					1	1
Stick, Stick Bracket/Stick Support Structure										
User comfort	5*	1		9	9		3			1
Aesthetics	2			1	1					1
Least Restrictive Environment	4			9	9	3	9			3
Durability	3	3	9	1	1		1			9
Height Adjustable	5	3	3	3	3		3	1		9
Easily repairable/replaceable	3	3	3	3	3		3			3
Accuracy of stick movement	3	9	3	3	3	9	1	1		1
Ease of stick movement	4	9	3	3	3	9	9			3
Safety	5*	3		1	1		3			1
Inexpensive	5	3	3	3	3		3			9
Specification Target		5 lbs	25000	2 ft²	2 in	1 seconds	20 ft	6 in	100 lbf	$1,500

Front Wheels

Front Wheel Bolt Analysis



BOLT

3/8" – 16 x 1.5 Grade 5
Medium Strength Steel

Stretching of Bolt

$$dl = \frac{FL}{EA}$$

where $A = 0.7854\,(d - 0.9743/n)^2$

$A = 0.7854\,(3/8 - 0.9743/16)^2$

$A = 0.07749\ in^2$

$$dl = \frac{(100\ lb)(1.5\ in)}{(30 \times 10^6\ psi)(.07749\ in^2)}$$

$dl = 0.000065$ inches

Bolt Strength

Values From Shigley's Mechanical Engineering Design

Given : $d = 3/8$" and pitch = 16

Grade 5 steel

washer thickness : $t = 0.083$" washer size : 3/8" I.D. = .438" O.D. = 1.00"

Nut thickness: $H = 21/64$" width = 9/16"

thickness of all material squeezed between face of bolt and face of nut $\Rightarrow l = 1$"

Fastener Length: $L > 1" + 21/64" \Rightarrow L > 1.328125"$

Thread Length : $L_T = 2d + \frac{1}{4}$ in

$L_T = 2(3/8) + 1/4$

$L_T = 1"$

Length of unthreaded portion in grip $\Rightarrow l_d = L - L_T = 21/64"$

Length of threaded portion $\Rightarrow l_t = l - l_d = .671875"$

Area of threaded portion $\Rightarrow A_t = \frac{\pi}{4}\left[D - \frac{0.9743}{P}\right]^2$ ASME Standard

$A_t = 0.007749 \text{ in}^2$

Area of unthreaded portion $\Rightarrow A_d = \frac{\pi d^2}{4} = .110 \text{ in}^2$

Fastener Stiffness: $$k_b = \frac{A_d A_t E}{A_d l_t + A_t l_d}$$

$$k_b = \frac{(.110)(.00775)(30\times10^6\ psi)}{(.110)(.671875) + (.00775)(21/64)}$$

$$\boxed{K_b = 334536\ lbf/in}$$

Stiffness of Members: $$K_m = \frac{0.5774\,\pi E d}{2\ln\left(5\,\frac{0.5774l + 0.5d}{0.5774l + 2.5d}\right)}$$

$$k_m = \frac{0.5774\,\pi\,(10.3\times10^6 psi)(3/8)}{2\ln\left(5\,\frac{.5774(1) + .5(3/8)}{.5774(1) + 2.5(3/8)}\right)}$$

$$\boxed{Km = 3.78\times10^6\ lbf/in}$$

Preload Stress: $\sigma_i = \frac{F_i}{A_t}$ where F_i ≡ initial bolt tension from tightening the nut

$$\sigma_i = \frac{(25\ lbs)}{.00775\ in^2}$$

$$\sigma_i = 3225.81\ psi$$

Stiffness Constant: $$C = \frac{k_b}{k_b + k_m} = \frac{334536\ psi}{334536\ psi + 3.78\times10^6\ psi} = .081306$$

Stress Under Service Load:

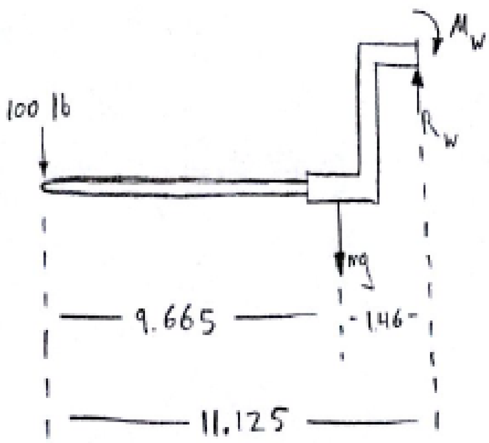
$$\sigma_b = (0.081306)\frac{(100)\ lb}{.00775\ in^2} + 3225.81\ psi$$

$$\sigma_b = 4274.92\ Psi$$

$$\boxed{\sigma_b = 4.3\ kPsi}$$ < 74 Kpsi (Min. proof strength) SAE specification

Static Analysis

Given 100 lb force acting downward on Front of curved Rail:



$\Sigma F_y = 0$

$-100\ lb - mg = R_w$

$R_w = 100\ lb + 1.15\ lb.$

$R_w = 101.15\ lb$ total

Therefore the reaction at each handle is $R_A = R_B = \frac{1}{2}(R_W) = \underline{50.575\ lb}$

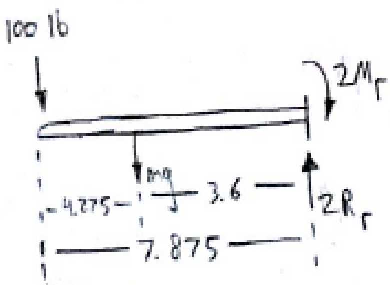
$\Sigma M = 0$

$(100\ lb)(11.125\ in) + (1.15\ lb)(1.46\ in) - M_w = 0$

$M_w = 1112.5\ lb\text{-}in + 1.679\ lb\text{-}in$

$M_w = 1114.179\ lb\text{-}in$ Therefore the reaction at each handle is $M_A = M_B = \frac{1}{2}M_W = \underline{557.09\ lb\text{-}in}$

Curved Rail Analysis



$\Sigma F_y = 0$

$-100\ lb - .37\ lb + 2R_r$

$2R_r = 100.37\ lb$

$\underline{R_r = 50.185\ lb}$ at both ends of rail.

$\Sigma M = 0$

$(100\ lb)(7.875\ in) + (.37\ lb)(3.6\ in) - 2M_r = 0$

$2M_r = 787.5\ lb\text{-}in + 1.332\ lb\text{-}in$

$M_r = \underline{394.416\ lb\text{-}in}$ at both ends of rail.

Max Shear Stress on Curved Rail

From Statics analysis: **$R_r = 50.185$ lb** at each connection

Aluminum Tubing is 0.5" OD and 0.26" ID

the cross sectional area: $A_r = \frac{\pi}{4}OD^2 - \frac{\pi}{4}ID^2 = \frac{\pi}{4}(.5)^2 - \frac{\pi}{4}(.26)^2$

$A_r = 0.1963 - 0.05309 \text{ in}^2$ **$A_r = 0.143257 \text{ in}^2$**

Max shear stress: $\tau_{max} = \frac{2V}{A}$ for hollow tube

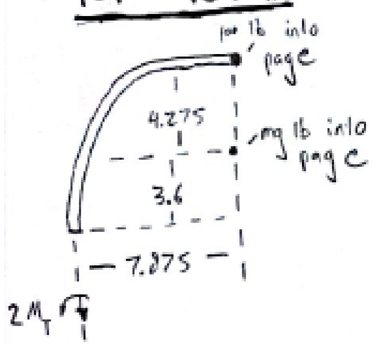
then $\tau_{max} = \frac{2(50.185 \text{ lb})}{0.143257 \text{ in}^2}$ **$\tau_{max} = 700.63 \text{ lb/in}^2$** at each end of rail

Torsion on Curved Rail

This analysis treats the curved rail as a 7.875 in long Straight tube.

To determine torque imparted by 100 lb force downwards:

TOP VIEW



$\Sigma M = 0$

$(100 \text{ lb})(7.875 \text{ in}) + (.37 \text{ lb})(7.875 \text{ in}) - 2M_T = 0$

$2M_T = 787.5 \text{ lb-in} + 2.91375 \text{ lb-in}$

$2M_T = 790.41375 \text{ lb-in}$

$M_T = 395.21$ lb-in at each end of rail

then torque: **$T = 395.21$ lb**

Polar Second Moment of Area: $J = \frac{\pi}{32}(OD^4 - ID^4)$ for hollow tube

$J_r = \frac{\pi}{32}(.5^4 - .26^4)$ then **$J_r = 0.005687 \text{ in}^4$**

$\tau_{max\,torsion} = \frac{T r_{out}}{J} = \frac{(395.21 \text{ lb})(0.5 \text{ in})}{0.005687 \text{ in}^4}$ $\tau_{max\,torsion} = 34746.8 \text{ lb/in}^2 =$ **34.747 KSI**

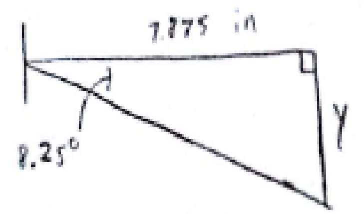
For 6061-T6 Aluminum: modulus of Rigidity $G = 3.8 \times 10^6$ psi

Angle of Twist: $\theta = \frac{TL}{GJ} = \frac{(395.21 \text{ lb})(7.875 \text{ in})}{(3.8 \times 10^6 \text{ psi})(.005687 \text{ in}^4)} = 0.144 \text{ rad}$

$\theta = 0.144 \text{ rad}\left(\frac{180°}{\pi \text{ rad}}\right)$ then **$\theta = 8.25°$**

Max Theoretical Deflection from Torsion

For 7.875 in radius bend and $\theta = 8.25°$ twist at coil ends



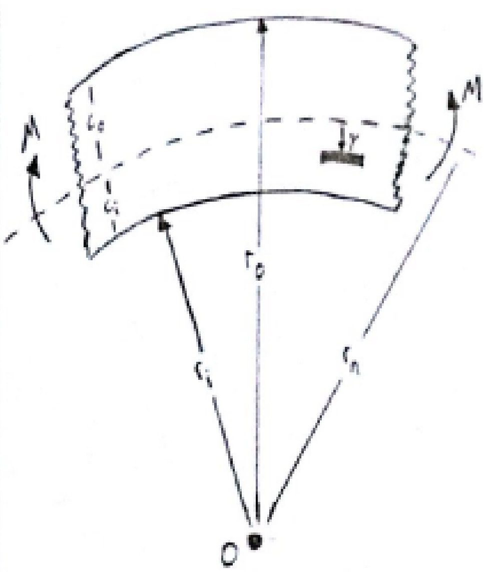
$$\tan(8.25°) = \frac{Y}{7.875}$$

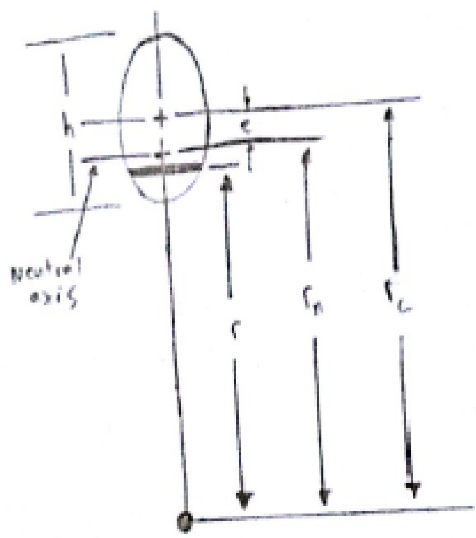
then $Y = 7.875 \tan(8.25°)$

$Y = 1.14$ in.

Max deflection from torsion is **1.14 in**

Curved Beam in Bending Geometries





R = 0.25 in (OD)

r_o = radius of outer fiber
r_i = radius of inner fiber
h = depth of section
r_c = radius of centroidal axis
r_n = radius of neutral axis
c_o = distance from neutral axis to outer fiber
c_i = distance from neutral axis to inner fiber
e = distance from centroidal axis to neutral axis
M = bending moment

$r_o = 8.125$ in
$r_i = 7.625$ in
$h = 0.5$ in
$r_c = 7.875$ in

Curved Beam in Bending Analysis

$$r_n = \frac{R^2}{2\left(r_c - \sqrt{r_c^2 - R^2}\right)} = \frac{(0.25\,in)^2}{2\left(7.875 - \sqrt{7.875^2 - .25^2}\right)} = \frac{0.0625\ in^2}{0.0079385\ in}$$

$r_n = 7.87302$ in

$c_o = r_o - r_n = 8.125 - 7.87302$ in $= 0.25198$ in

$c_i = r_n - r_i = 7.87302 - 7.625$ in $= 0.24802$ in

$e = r_c - r_n = 7.875 - 7.87302$ in $= 0.001985$ in

$A = 0.143257\ in^2$ cross section of tube

Given a horizontal force $F = 100$ lb acting horizontally on Front of rail:

$M = F r_c = (100\ lb)(7.875\ in)$, $M = 787.5$ lb-in

Stress on inner radius of tube:

$$\sigma_i = \frac{F}{A} + \frac{Mc_i}{Aer_i} = \frac{100\ lb}{0.143257\ in^2} + \frac{(787.5\ lb\text{-}in)(.24802\ in)}{(.143257\ in^2)(.001985\ in)(7.625\ in)}$$

$\sigma_i = 698.046$ psi $+ 90078.5$ psi $= 90776.5$ psi

$$\sigma_i = 90.777\ KSI$$

Stress on outer radius of tube:

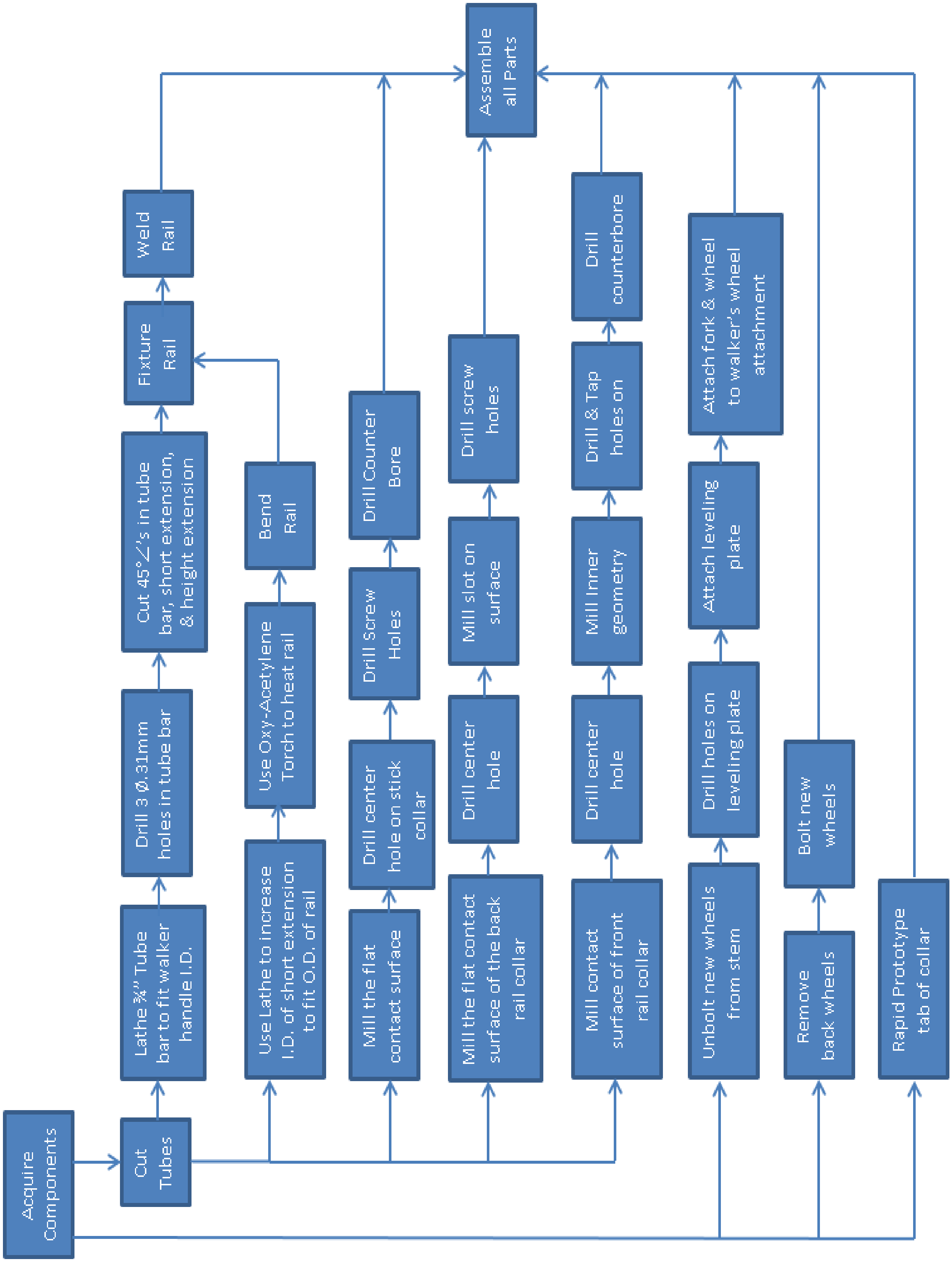
$$\sigma_o = \frac{F}{A} - \frac{Mc_o}{Aer_o} = \frac{100\ lb}{0.143257\ in^2} - \frac{(787.5\ lb\text{-}in)(.25198\ in)}{(.143257\ in^2)(.001985\ in)(8.125\ in)}$$

$\sigma_o = 698.046$ psi $- 85884.9$ psi $= -85186.9$ psi

$$\sigma_o = -85.187\ KSI$$

Appendix C

Manufacturing Flowchart



Sub Assembly	Functions	Part That Could Fail	Severity Ranking (SR) 1-10	Potential Effects of Failure	Occurance Ranking (OR) 1-10	Detection Ranking (DR) 1-10	Risk Priority Number	RPN (%)
Walker Frame	Supports Sean's body weight. Supports rail and stick sub assemblies. Gives Sean the increased mobility.	Bolts loosening	3	Annoying sound and vibration, decrease in control	6	6	108	**1.08**
		Bolt fracture	10	Walker tubes disconnect, legs free rotate, catastrophic loss of support	1	6	60	0.6
		Spring-loaded tabs misalign	4	Leg falls out or compresses into tube	4	6	96	0.96
		Spring-loaded tabs fracture	7	Leg falls out or compresses into tube	3	6	126	**1.26**
		Tube denting/kinking	7	Uneven rolling, uneven loading	2	6	84	0.84
		Tube fracture	10	Catastrophic loss of support, injury potential	1	6	60	0.6
		Weld failure	8	Catastrophic loss of support	1	6	48	0.48
		Rubber handle slips	7	Hard to maneuver walker, awkward movement	1	6	42	0.42
Front Wheels	Allows for walker horizontal motion. 360 degree wheel rotation facilitates mobility.	Bolts loosening	4	Annoying sound and vibration, decrease in control	6	6	144	**1.44**
		Bolt fracture	8	Catastrpohic loss of support/loss of wheel attachment	1	6	48	0.48
		Rubber wheel material chips	4	Uneven rolling, uneven loading	3	6	72	0.72
		Rubber wheel material fracture	8	Extremely uneven rolling, difficult to manuever	1	6	48	0.48
		Plastic wheel mainframe fails	10	Catastrophic loss of support, sudden stop, injury potential	1	6	60	0.6
		Aluminum plate fractures	10	Catastrophic loss of support, sudden stop, injury potential	1	6	60	0.6
		AL wheel bracket fractures	10	Catastrophic loss of support, sudden stop, injury potential	1	6	60	0.6
		Ball bearings stick	7	Hard to maneuver walker, difficult turning	5	6	210	**2.1**
Rear Wheels	Allows for walker horizontal motion. In line wheels (no rotation) provide stability.	Bolts loosening	4	Annoying sound and vibration, decrease in control	6	6	144	**1.44**
		Bolt fracture	10	Catastrpohic loss of support/loss of wheel attachment, injury potential	1	6	60	0.6
		Rubber wheel material chips	4	Uneven rolling, uneven loading	3	6	72	0.72
		Rubber wheel material fracture	8	Extremely uneven rolling, difficult to manuever	1	6	48	0.48
		Plastic wheel mainframe fails	10	Catastrophic loss of support, sudden stop, injury potential	1	6	60	0.6
Welded Rail	Supports the rail-stick collar sub assembly. Allows for 25.75 inches of horizontal motion. Protects Sean from injury.	Bolts loosening	7	Annoying sound and vibration, decrease in control	6	6	252	**2.52**
		Bolt fracture	10	Rail disconnects from walker, catastrophic loss of support, injury potentia	1	6	60	0.6
		Tube denting/kinking	7	Difficult to slide collar and maneuver stick	3	6	126	**1.26**
		Tube fracture	10	Catastrophic loss of support, injury potential	1	6	60	0.6
		Weld failure	10	Catastrophic loss of support, injury potential	1	6	60	0.6
Rail-Stick Collar	Connects the stick to the rail. Allows for stick to slide along rail. Allows for stick extension. Allows for stick swing.	Bolts loosening	6	Annoying sound and vibration, decrease in control	5	6	180	**1.8**
		Bolt fracture	7	Collar disconnects from rail and/or stick, loss of control	1	6	42	0.42
		Plastic deformation	6	Difficult to slide collar on rail/stick through collar	3	6	108	**1.08**
		Plastic Fracture	8	Collar disconnects from rail/stick, no longer functional	1	6	48	0.48
Stick	Allows Sean to possess of the puck. Allows Sean to pass the puck. Allows Sean to shoot the puck. Acts as another walker handle.	Wood glue failure	8	Stick breaks apart, no longer functional	4	6	192	**1.92**
		Wood screw disconnect	8	Stick breaks apart, no longer functional	3	6	144	**1.44**
		Wood splintering/cracking	8	Stick breaks apart, likely loss of functionality	3	6	144	**1.44**
		Plasti-Dip handle eroding/sliding	6	Difficult to maneuver stick and precisely control	2	6	72	0.72

Rating	Description	Severity Ranking (Severity of Effect)
10	Dangerously high	Failure could injure the customer or an employee.
9	Extremely high	Failure would create noncompliance with federal regulations.
8	Very high	Failure renders the unit inoperable or unfit for use.
7	High	Failure causes a high degree of customer dissatisfaction.
6	Moderate	Failure results in a subsystem or partial malfunction of the product.
5	Low	Failure creates enough of a performance loss to cause the customer to complain.
4	Very Low	Failure can be overcome with modifications to the customer's process or product, but there is minor performance loss.
3	Minor	Failure would create a minor nuisance to the customer, but the customer can overcome it without performance loss.
2	Very Minor	Failure may not be readily apparent to the customer, but would have minor effects on the customer's process or product.
1	None	Failure would not be noticeable to the customer and would not affect the customer's process or product.

Rating	Description	Occurance Ranking (Potential Failure Rate)
10	**Very High:** Failure is almost inevitable.	More than one occurrence per day or a probability of more than three occurrences in 10 events (Cpk < 0.33).
9	**High:** Failures occur almost as often as not.	One occurrence every three to four days or a probability of three occurrences in 10 events (Cpk ≈ 0.33).
8	**High:** Repeated failures.	One occurrence per week or a probability of 5 occurrences in 100 events (Cpk ≈ 0.67).
7	**High:** Failures occur often.	One occurrence every month or one occurrence in 100 events (Cpk ≈ 0.83).
6	**Moderately High:** Frequent failures.	One occurrence every three months or three occurrences in 1,000 events (Cpk ≈ 1.00).
5	**Moderate:** Occasional failures.	One occurrence every six months to one year or five occurrences in 10,000 events (Cpk ≈ 1.17).
4	**Moderately Low:** Infrequent failures.	One occurrence per year or six occurrences in 100,000 events (Cpk ≈ 1.33).
3	**Low:** Relatively few failures.	One occurrence every one to three years or six occurrences in ten million events (Cpk ≈ 1.67).
2	**Low:** Failures are few and far between.	One occurrence every three to five years or 2 occurrences in one billion events (Cpk ≈ 2.00).
1	**Remote:** Failure is unlikely.	One occurrence in greater than five years or less than two occurrences in one billion events (Cpk > 2.00).

Rating	Description	Detection Ranking Definitions
10	Absolute Uncertainty	The product is not inspected or the defect caused by failure is not detectable.
9	Very Remote	Product is sampled, inspected, and released based on Acceptable Quality Level (AQL) sampling plans.
8	Remote	Product is accepted based on no defectives in a sample.
7	Very Low	Product is 100% manually inspected in the process.
6	Low	Product is 100% manually inspected using go/no-go or other mistake-proofing gauges.
5	Moderate	Some Statistical Process Control (SPC) is used in process and product is final inspected off-line.
4	Moderately High	SPC is used and there is immediate reaction to out-of-control conditions.
3	High	An effective SPC program is in place with process capabilities (Cpk) greater than 1.33.
2	Very High	All product is 100% automatically inspected.
1	Almost Certain	The defect is obvious or there is 100% automatic inspection with regular calibration and preventive maintenance of the inspection equipment.

Appendix E

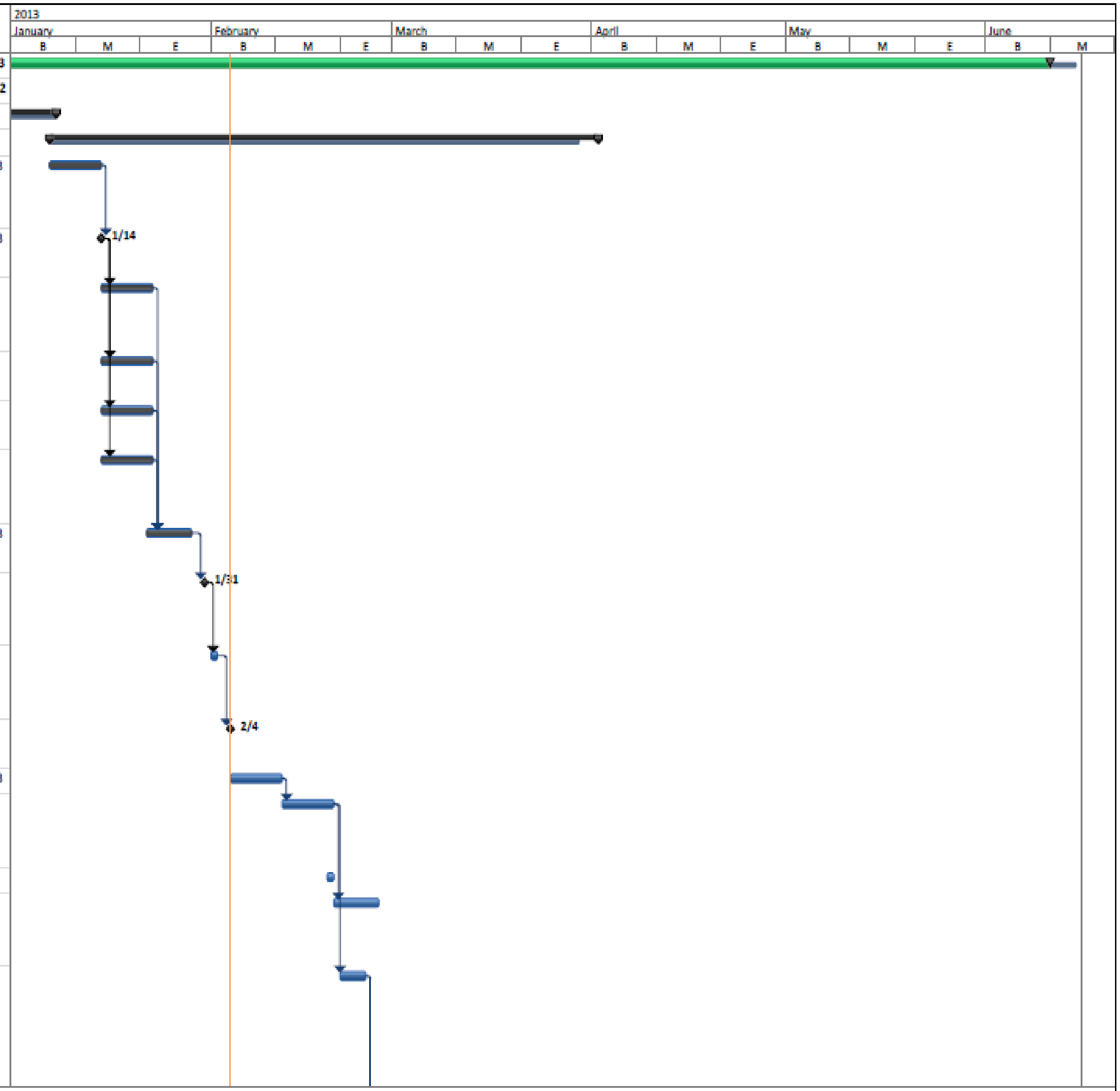
Bill of Materials

Date of Purchase	Items Purchased	Design Phase	Manufacturer/Supplier	Subtotal	Shipping	Sales Tax	Total
11/5/2012	Steel braided hose and PVC	First prototype	The Home Depot	$31.15	$0.00	$2.41	$33.56
11/9/2012	PVC	Second Prototype	The Home Depot	$6.44	$0.00	$0.50	$6.94
11/9/2012	PVC and Various Fasteners	Second Prototype	The Home Depot	$50.70	$0.00	$4.06	$54.76
11/11/2012	PVC	Second Prototype	The Home Depot	$6.12	$0.00	$0.47	$6.59
11/12/2012	PVC and Steel Rod	Seocnd Prototype	The Home Depot	$22.74	$0.00	$1.76	$24.50
11/14/2012	Foam, clamps, PVC	Second Prototype	The Home Depot	$9.28	$0.00	$0.72	$10.00
1/11/2013	0.5" AL Solid Rod	Third Prototype	McCarthy Steel	$9.42	$0.00	$0.73	$10.15
1/16/2013	0.5"x0.16" Steel Round Tube	Third Prototype	The Home Depot	$15.24	$0.00	$1.22	$16.46
1/16/2013	0.035" OD AL Tube	Third Prototype	Miners Ace Hardware	$15.98	$0.00	$1.28	$17.26
1/18/2013	0.75" AL Solid Rod	Third Prototype	McCarthy Steel	$10.81	$0.00	$0.86	$11.67
1/18/2013	JB Weld	Third Prototype	Miners Ace Hardware	$6.99	$0.00	$0.56	$7.55
1/28/2013	5" swivel wheels, 5" & 3" fxd wheels	Third Prototype	Wallace Home Medical Supplies	$104.90	$0.00	$7.87	$112.77
2/19/2013	0.75 and 0.5 AL Tube	Final Prototype/Product	Onlinemetals.com	$70.51	$18.30	$7.10	$95.91
2/27/2013	2.25" Delrin Rod	Final Prototype/Product	McMaster.com	$21.92	$5.61	$1.64	$29.17
3/5/2013	1.25" AL Tube, Various Fasteners	Final Prototype/Product	McMaster.com	$62.44	$5.97	$4.68	$73.09
4/29/2013	3/4" Square AL and 3/8" Endmill	Final Prototype/Product	McMaster.com	$39.97	$5.61	$3.00	$48.58
5/2/2013	CNC Mill Labor - Aluminum Tab	Final Prototype/Product	Mustang '60 Machine Shop	$104.00	$0.00	$0.00	$104.00
5/4/2013	Welding Labor	Final Prototype/Product	Simon Rowe - Certified Welder	$80.00	$0.00	$0.00	$80.00
Project Total							**$742.96**

Appendix F

Project Timeline

ID	Task Mode	Task Name	Duration	Start	Finish
1		**Senior Project**	**193 days**	**Tue 9/18/12**	**Mon 6/10/13**
2		**Project Definition**	**26 days**	**Tue 9/18/12**	**Tue 10/23/12**
11		**Design Phase**	**56 days**	**Wed 10/24/12**	**Mon 1/7/13**
29		**Build, Test Phase I**	**62 days**	**Mon 1/7/13**	**Mon 4/1/13**
30		Find parts, test manufacturing capabilities in shop	6 days	Mon 1/7/13	Mon 1/14/13
31		Finalize Majority of Design	0 days	Mon 1/14/13	Mon 1/14/13
32		Test Rail Manufacturing Methods	6 days	Tue 1/15/13	Tue 1/22/13
33		Finalize BOM, Manufacturing Plan	6 days	Tue 1/15/13	Tue 1/22/13
34		Finalize SolidWorks Model	6 days	Tue 1/15/13	Tue 1/22/13
35		FMEA, Strengths and Qualitiave Analysis	6 days	Tue 1/15/13	Tue 1/22/13
36		Critical Design Presentation Prep	5 days	Tue 1/22/13	Mon 1/28/13
37		Critical Design Presentation to Lara and Taylor	0 days	Thu 1/31/13	Thu 1/31/13
38		Write, Edit, Revise Critical Design Report	1 day	Fri 2/1/13	Fri 2/1/13
39		Critical Design Report Due	0 days	Mon 2/4/13	Mon 2/4/13
40		Order ALL Parts	6 days	Mon 2/4/13	Mon 2/11/13
41		MANUFACTURE "ROUGH DRAFT" CONSTRUCTION	6 days	Tue 2/12/13	Tue 2/19/13
42		Ethics Presentation	1 day	Tue 2/19/13	Tue 2/19/13
43		Test "Rough Draft" Construction with Sean	6 days	Wed 2/20/13	Tue 2/26/13
44		Tweak design based on manufacturing process and test with Sean	3 days	Thu 2/21/13	Sun 2/24/13

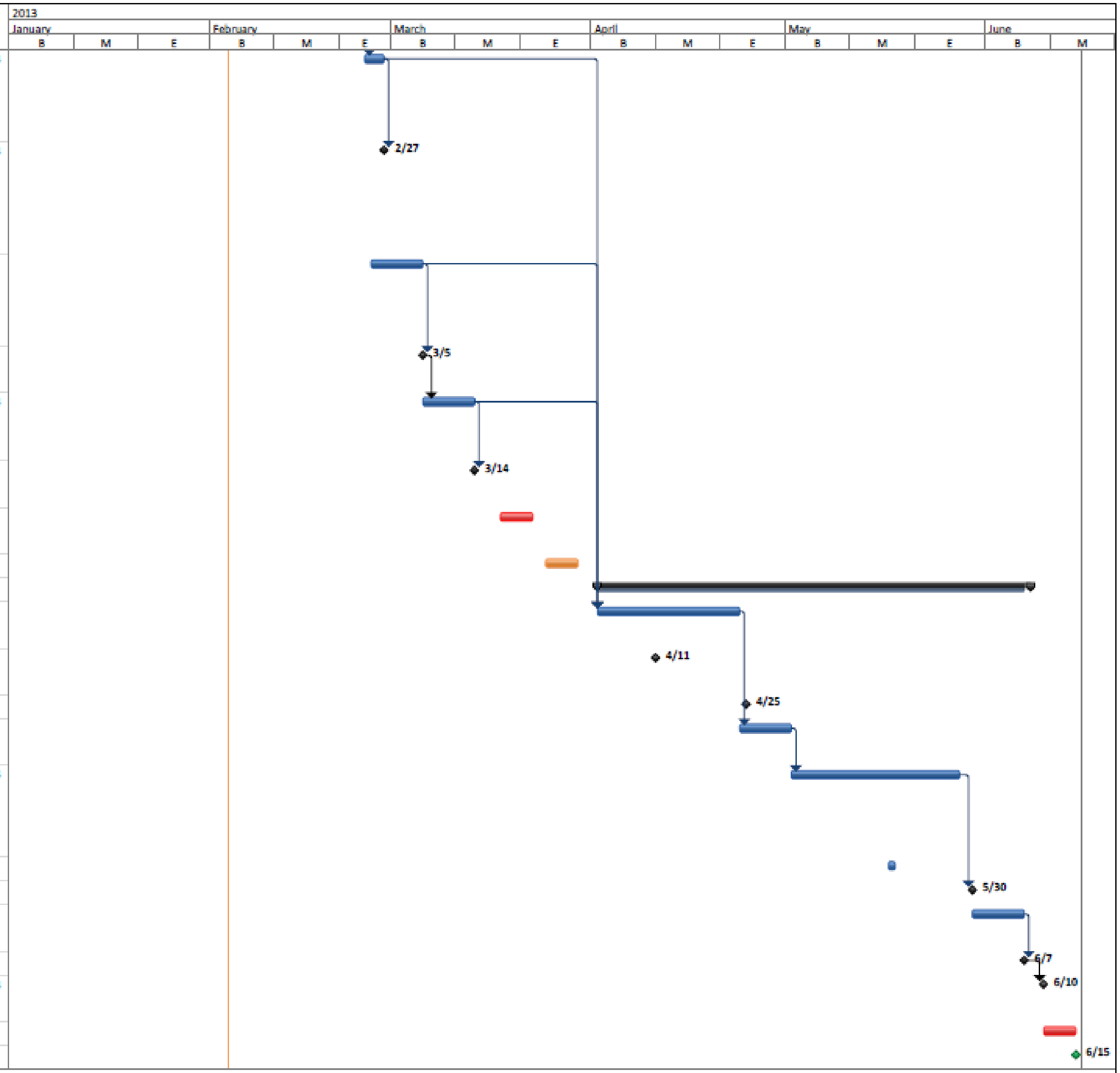


Project: Project Timeline
Date: Mon 2/4/13

Task, Split, Milestone, Summary, Project Summary, External Tasks, External Milestone, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, Deadline, Progress

Page 1

ID	Task Mode	Task Name	Duration	Start	Finish
45		Re-order necessary parts based on small design changes	3 days	Mon 2/25/13	Wed 2/27/13
46		**EVERYTHING READY FOR FINAL MANUFACTURE "FINAL DRAFT" Construction**	0 days	Wed 2/27/13	Wed 2/27/13
47		Prep Documentation for Manufacturing and Test Review	6 days	Tue 2/26/13	Tue 3/5/13
48		**Manufacturing and Test Review**	0 days	Tue 3/5/13	Tue 3/5/13
49		Write, edit and revise End of Quarter Report	6 days	Wed 3/6/13	Wed 3/13/13
50		End of Quarter Report Due	0 days	Thu 3/14/13	Thu 3/14/13
51		Winter Quarter Finals	5 days	Mon 3/18/13	Fri 3/22/13
52		Spring Break	5 days	Mon 3/25/13	Fri 3/29/13
53		**Build, Test Phase II**	**49 days**	**Tue 4/2/13**	**Fri 6/7/13**
54		**FINAL MANUFACTURE**	16 days	Tue 4/2/13	Tue 4/23/13
55		Project Update Memo to Sponsor	0 days	Thu 4/11/13	Thu 4/11/13
56		Senior Exit Exam	0 days	Thu 4/25/13	Thu 4/25/13
57		Final Testing with Sean	6 days	Wed 4/24/13	Wed 5/1/13
58		Any necessary work (mostly aesthetics) to prepare for Expo	18 days	Thu 5/2/13	Mon 5/27/13
59		Senior Survey	1 day	Fri 5/17/13	Fri 5/17/13
60		Senior Expo	0 days	Thu 5/30/13	Thu 5/30/13
61		Write, edit, revise Final Report	6 days?	Thu 5/30/13	Thu 6/6/13
62		Final Report Due	0 days	Fri 6/7/13	Fri 6/7/13
63		Upload Report to Library	0 days	Mon 6/10/13	Mon 6/10/13
64		Spring Quarter Finals	5 days	Mon 6/10/13	Fri 6/14/13
65		**GRADUATION**	0 days	Sat 6/15/13	Sat 6/15/13

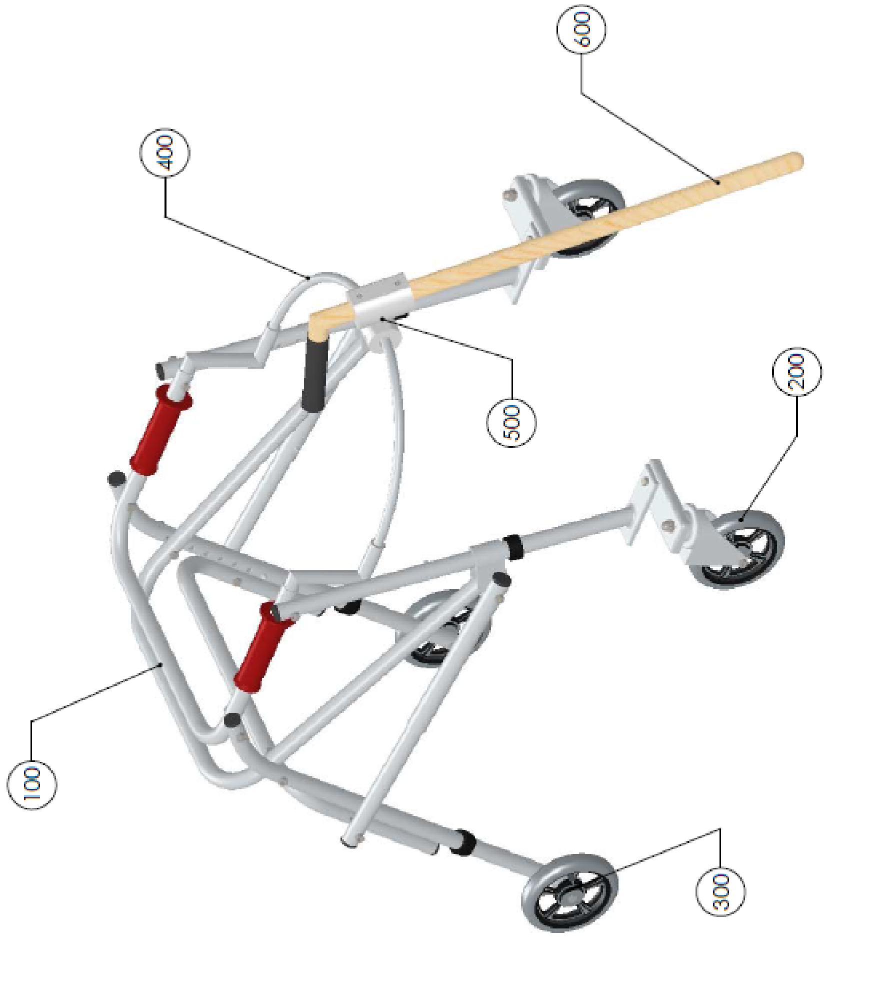


Project: Project Timeline
Date: Mon 2/4/13

Task, Split, Milestone, Summary, Project Summary, External Tasks, External Milestone, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, Deadline, Progress

Page 2

Sub Assembly Series Number	Sub Assembly
100	Walker Frame
200	Front Wheels
300	Rear Wheels
400	Welded Rail
500	Rail-Stick Collar
600	Stick
700	Full Assembly



ME329 *Fall 2012*

Mechanical Engineering CAL POLY

SCALE: 1:8

UNITS: inches

TOLERANCE: NA

DWG #: 700-2

PART: Final Design With Labeled Sub Assemblies

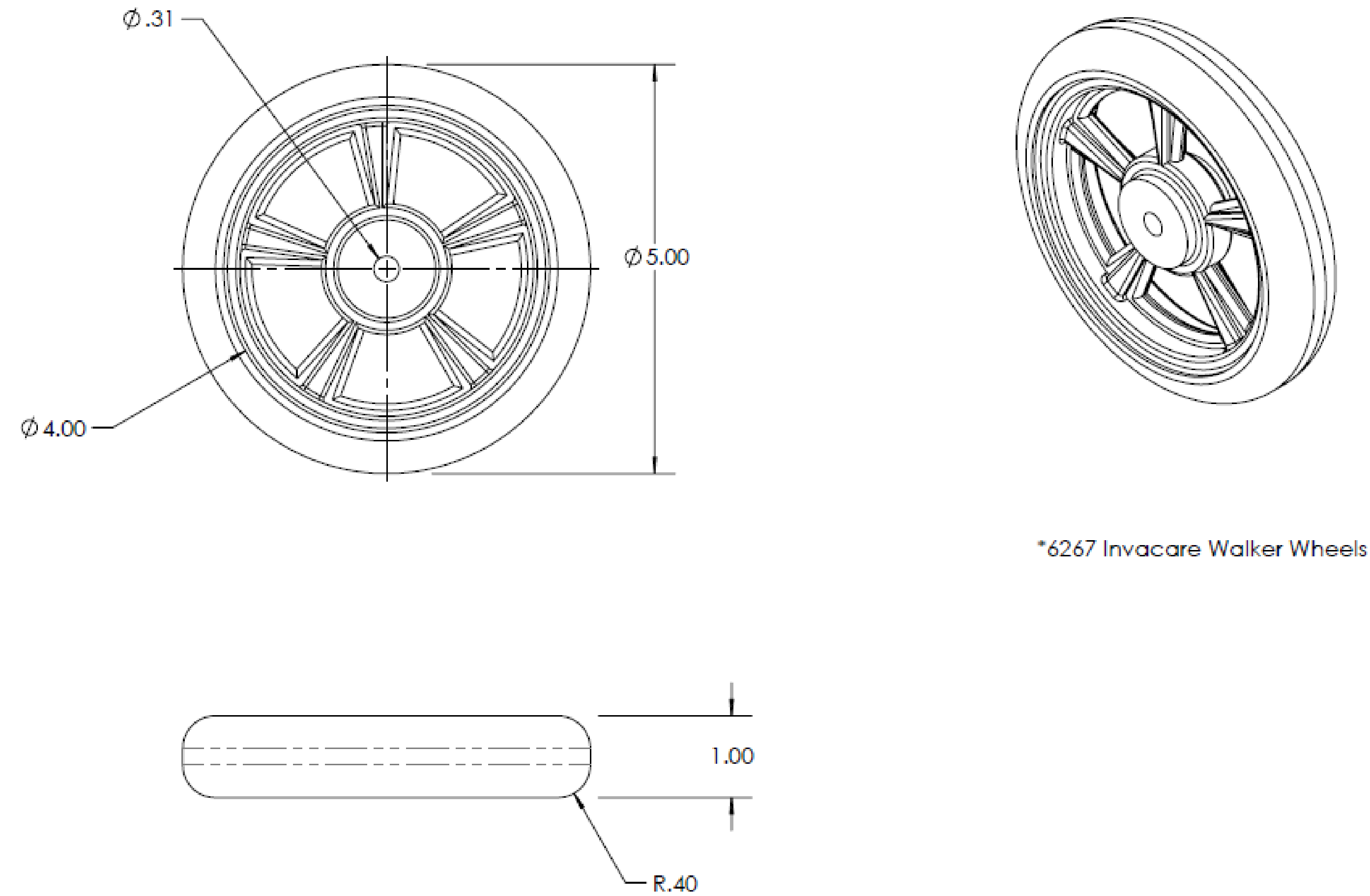
MATERIAL: Various

DATE: 1/29/2013

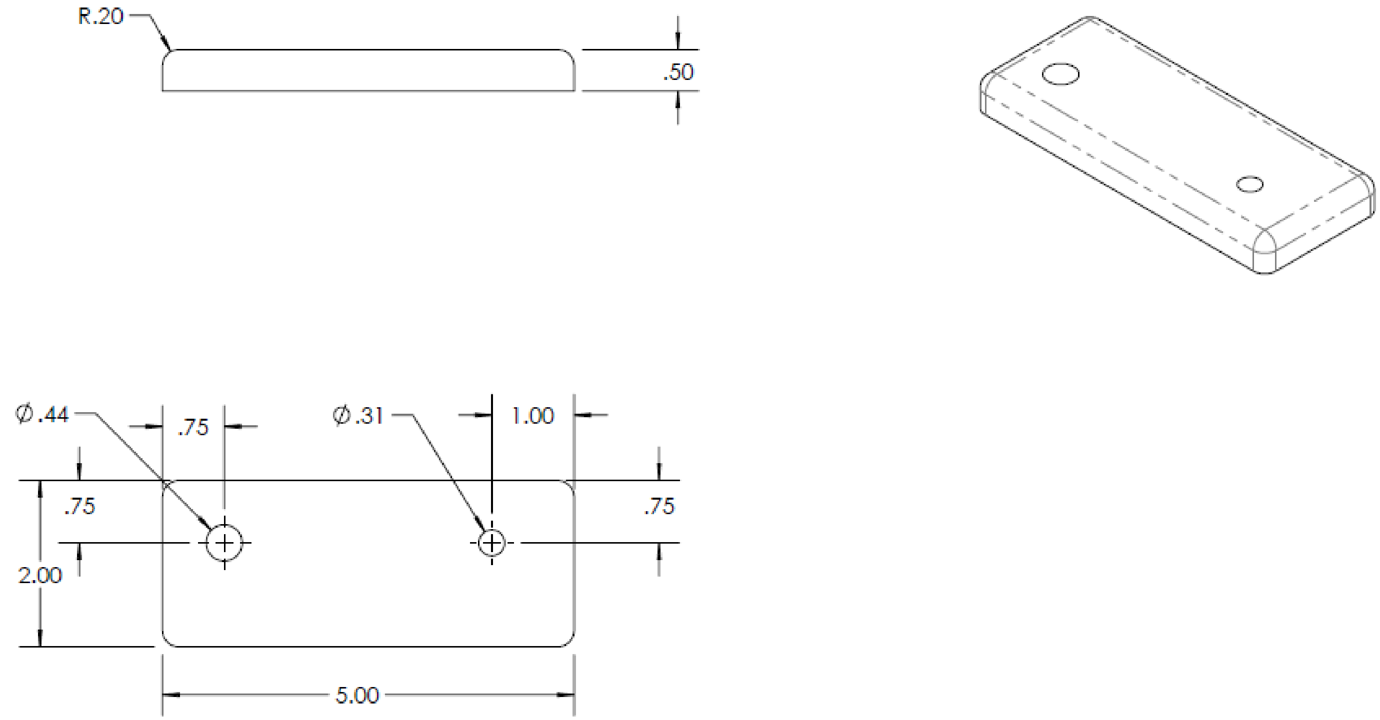
TEAM: The Knuckle Pucks

ME429 Winter 2013	SCALE: 1:14	PART: Final Design With All New Components
Mechanical Engineering CAL POLY	UNITS: inches	MATERIAL: Various
	TOLERANCE: NA	DATE: 1/29/2013
	DWG #: 700-1	TEAM: The Knuckle Pucks

5 4 3 2 1

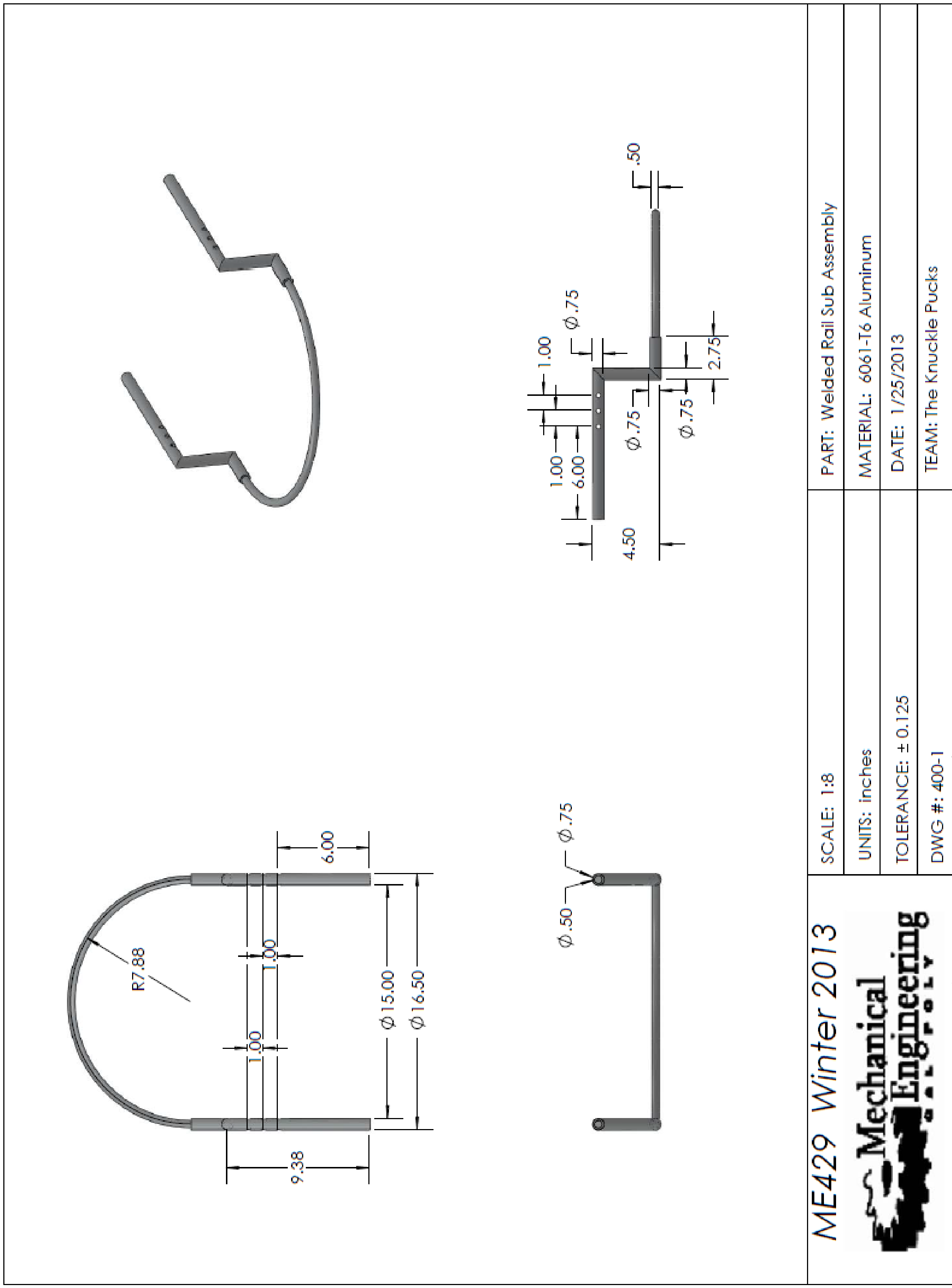


ME429 Winter 2013	SCALE: 1:2	PART: New Wheels
Mechanical Engineering CAL POLY	UNITS: inches	MATERIAL: Rubber/Plastic
	TOLERANCE: ± 0.125	DATE: 1/28/2013
	DWG #: 200-1	TEAM: The Knuckle Pucks

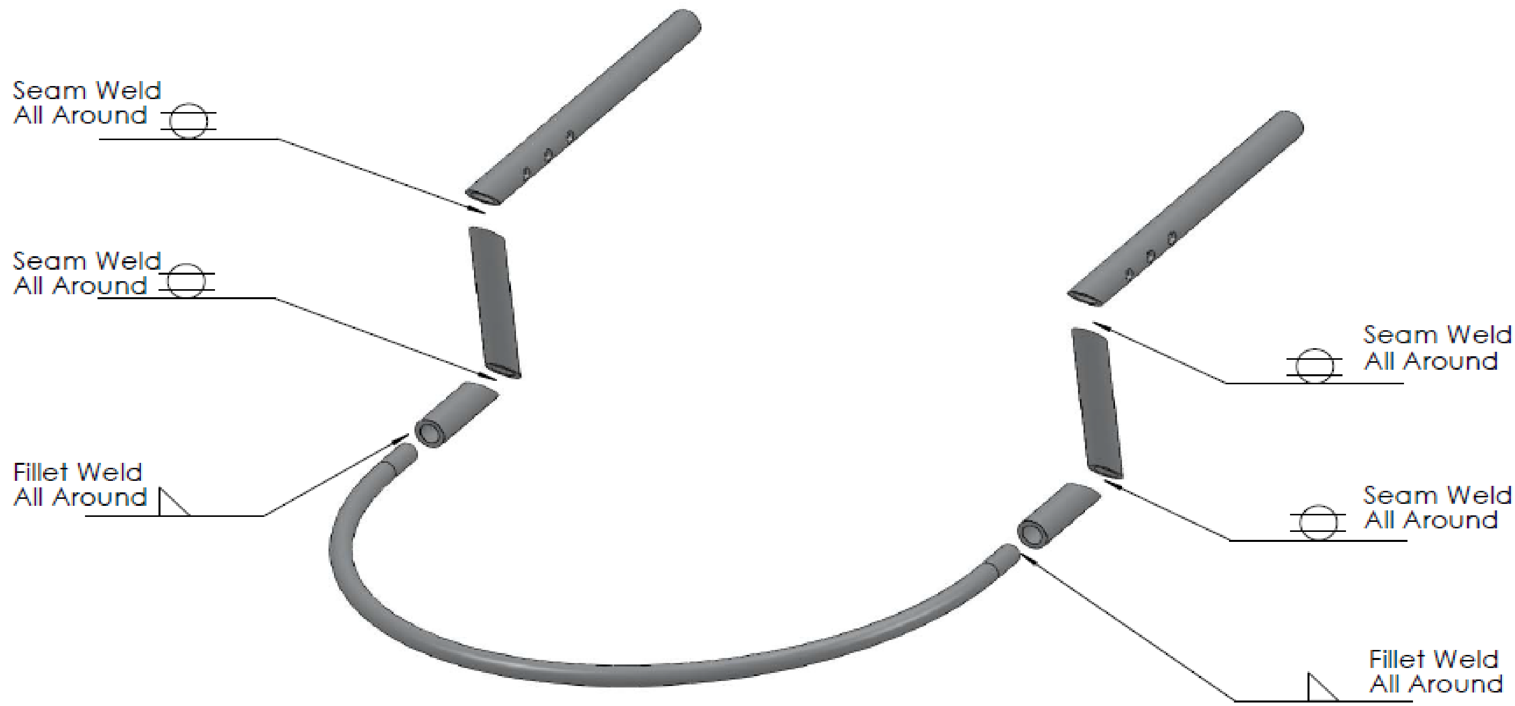


ME429 Winter 2013	SCALE: 1:2	PART: Right Front Wheel Extension Block
Mechanical Engineering CAL POLY	UNITS: inches	MATERIAL: 6061 Aluminum
	TOLERANCE: ± 0.125	DATE: 1/28/2013
	DWG #: 200-2	TEAM: The Knuckle Pucks

5 4 3 2 1



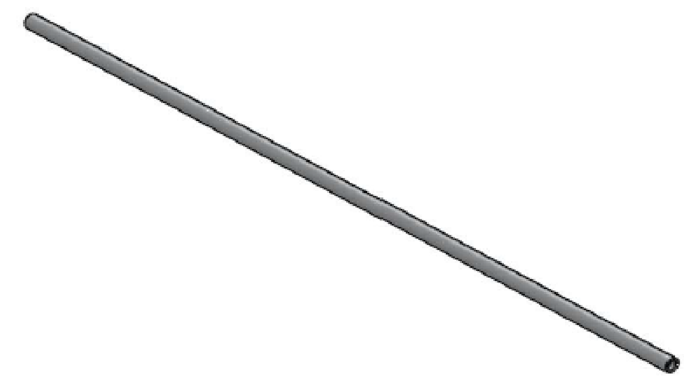
ME429 Winter 2013
Mechanical Engineering
SCALE: 1:8
UNITS: inches
TOLERANCE: ± 0.125
DWG #: 400-1
PART: Welded Rail Sub Assembly
MATERIAL: 6061-T6 Aluminum
DATE: 1/25/2013
TEAM: The Knuckle Pucks
R7.88
1.00
1.00
6.00
9.38
Ø15.00
Ø16.50
Ø.50
Ø.75
1.00
6.00
1.00
Ø.75
Ø.75
Ø.75
2.75
4.50
.50

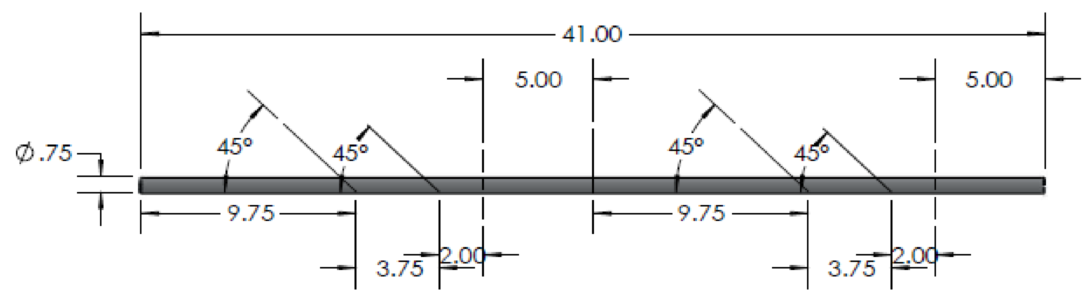


NOTE: Half Circle Curved Tube Will Be Inserted Into 0.75" OD Tube at a 1" Depth Before Fillet Welding

ME429 Winter 2013	SCALE: 1:4	PART: Welded Rail Sub Assembly
Mechanical Engineering CAL POLY	UNITS: inches	MATERIAL: 6061-T6 Aluminum
	TOLERANCE: ± 0.125	DATE: 1/25/2013
	DWG #: 400-2	TEAM: The Knuckle Pucks

5 4 3 2 1



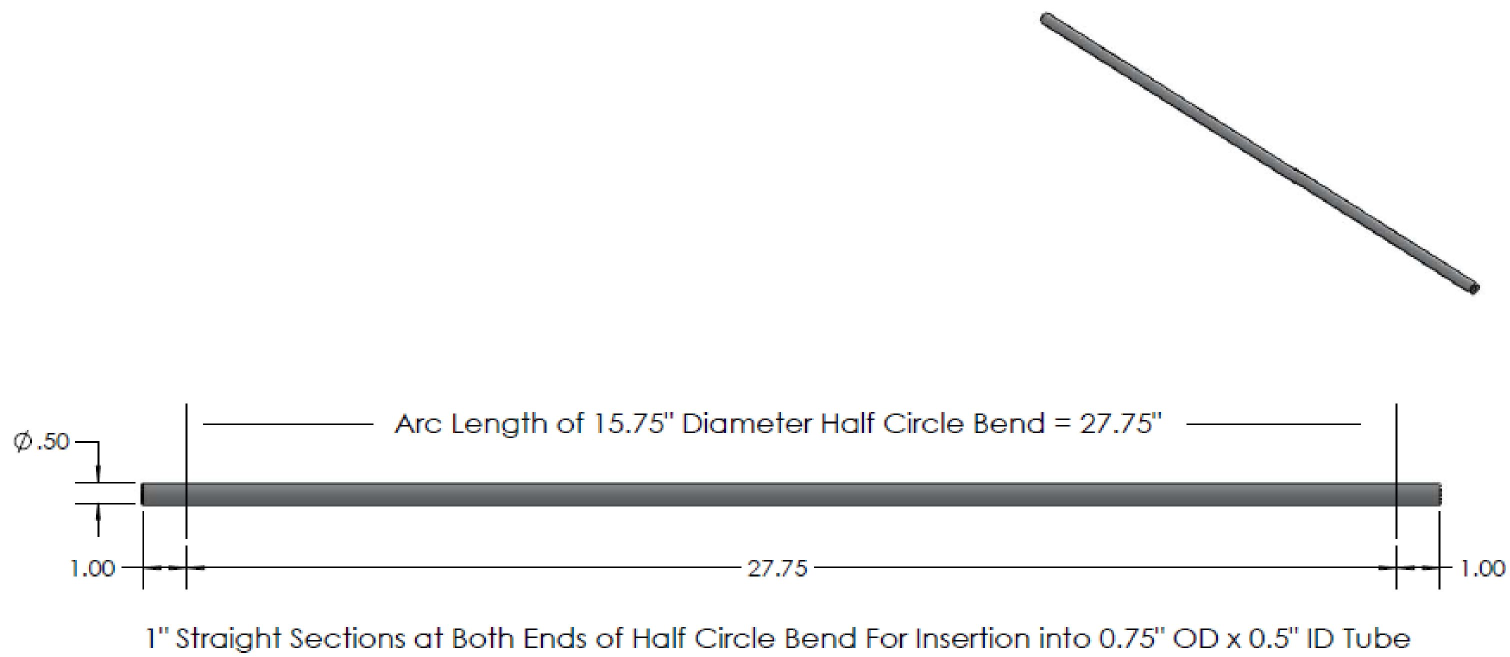


NOTE: 5" Sections (Denoted By Centerlines) Used for Fixturing 2" Long Piece Into Lathe To Turn Down Inner Diameter of 0.75" OD Tube To Create A Clearance for the 0.5" OD Curved Rail to Be Inserted at 1" Depth Before Welding.

NOTE: A 0.125" Gap Will Exist Between Each Cut Due to Chop Saw Blade Thickness (Not Shown).

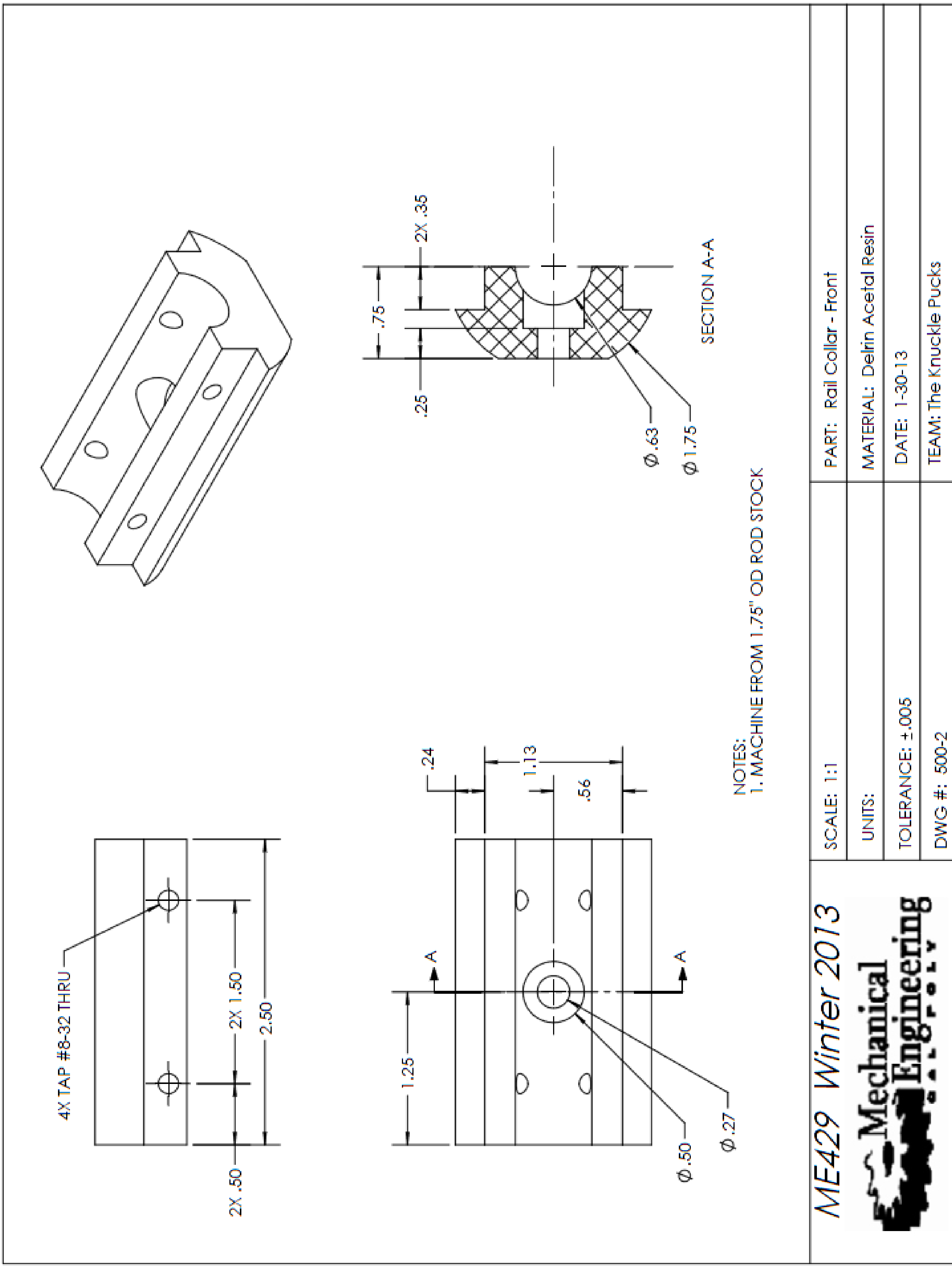
ME429 Fall 2013	SCALE: 1:4	PART: 0.75" OD Tube For Welded Rail Sub Assembly
Mechanical Engineering CAL POLY	UNITS: inches	MATERIAL : 6061-T6 Aluminum
	TOLERANCE: ± 0.125	DATE: 1/25/2013
	DWG #: 400-4	TEAM: The Knuckle Pucks

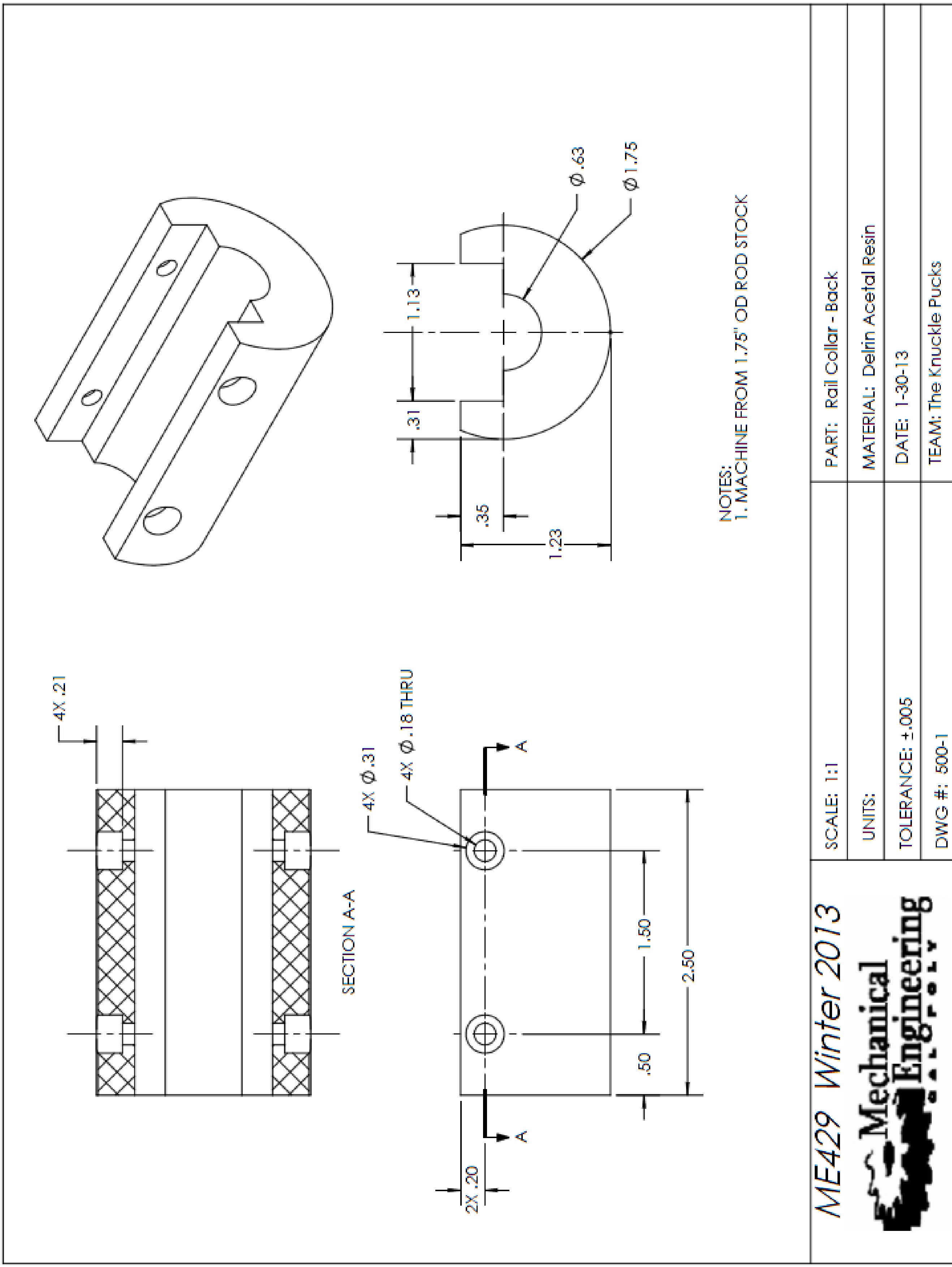
5 4 3 2 1

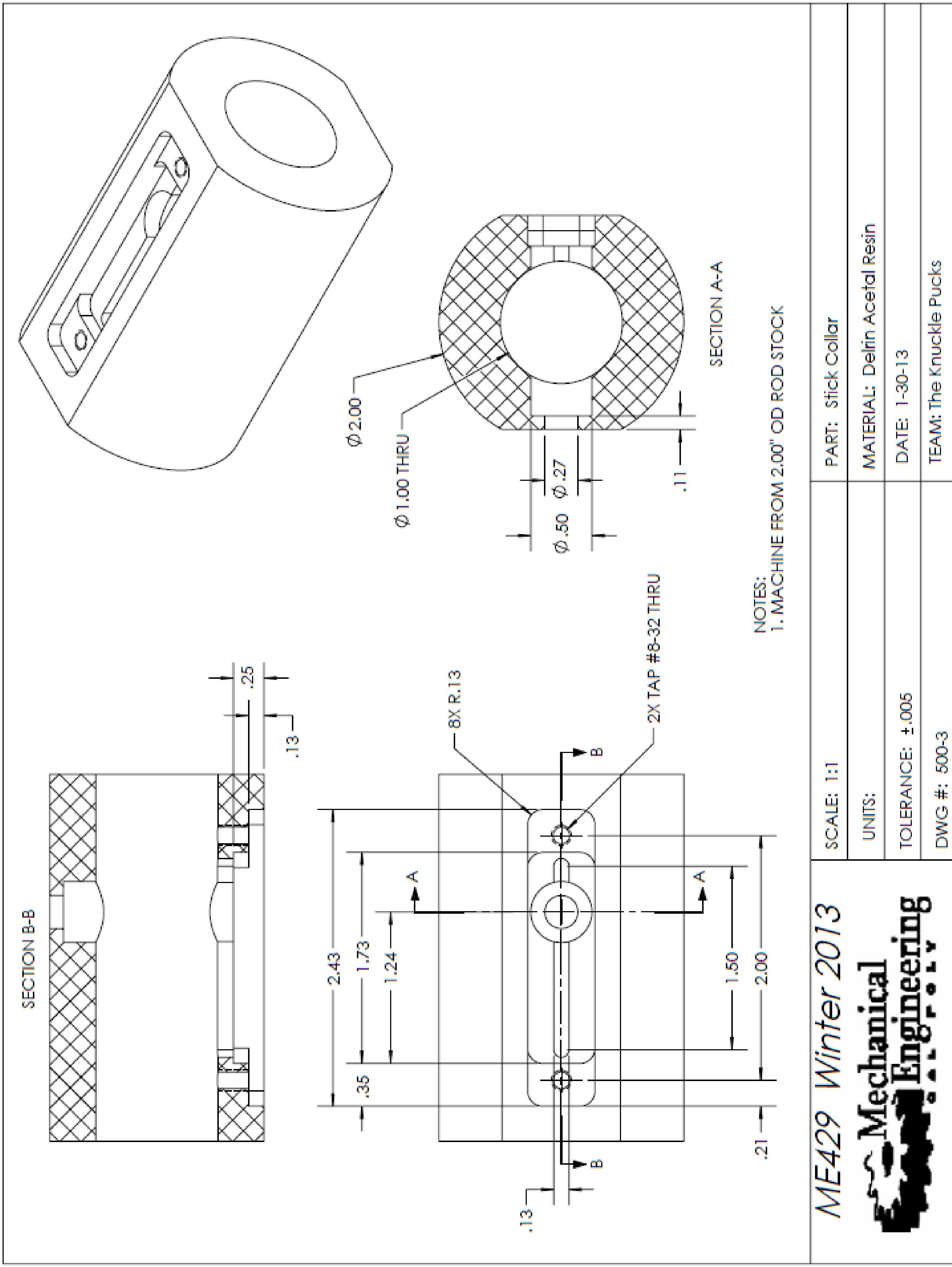


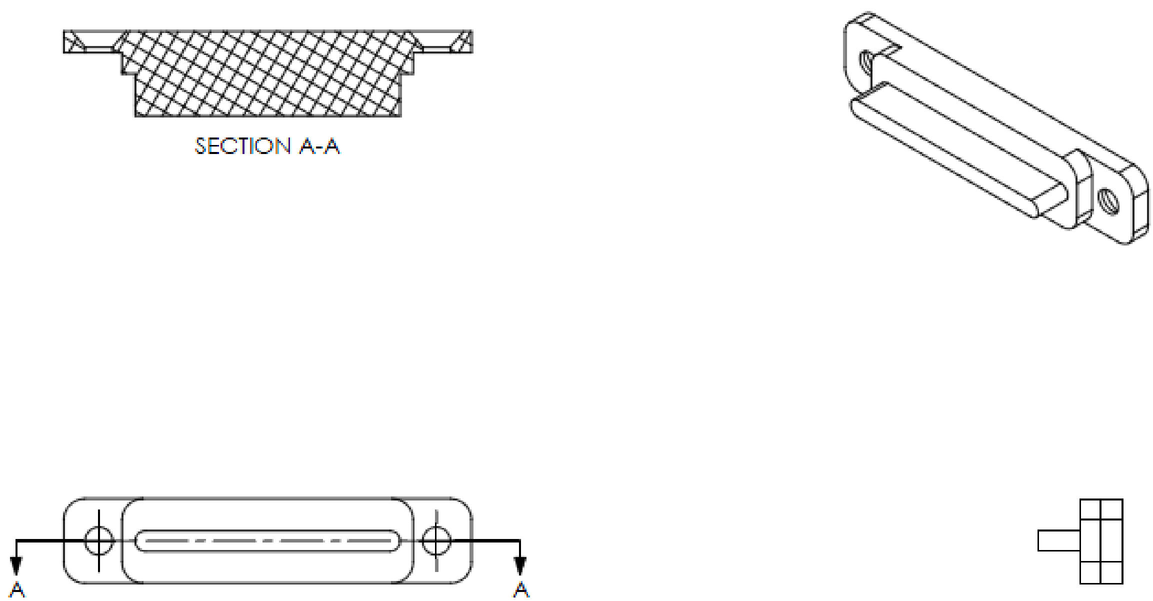
ME429 Winter 2013	SCALE: 1:4	PART: 0.5" OD Tube For Welded Rail Sub Assembly
Mechanical Engineering CAL POLY	UNITS: inches	MATERIAL: 6061-T6 Aluminum
	TOLERANCE: ± 0.125	DATE: 1/25/2013
	DWG #: 400-3	TEAM: The Knuckle Pucks

5 4 3 2 1


4X TAP #8-32 THRU
2X 1.50
2.50
2X .50
1.25
A
A
Ø .50
Ø .27
.24
1.13
.56
2X .35
.75
.25
SECTION A-A
Ø .63
Ø 1.75
NOTES:
1. MACHINE FROM 1.75" OD ROD STOCK
ME429 Winter 2013
Mechanical Engineering
SCALE: 1:1
UNITS:
TOLERANCE: ±.005
DWG #: 500-2
PART: Rail Collar - Front
MATERIAL: Delrin Acetal Resin
DATE: 1-30-13
TEAM: The Knuckle Pucks
1
2
3
4
5


ME429 Winter 2013
Mechanical Engineering
PART: Rail Collar - Back
MATERIAL: Delrin Acetal Resin
DATE: 1-30-13
TEAM: The Knuckle Pucks
SCALE: 1:1
UNITS:
TOLERANCE: ±.005
DWG #: 500-1
NOTES:
1. MACHINE FROM 1.75" OD ROD STOCK
SECTION A-A
4X .21
4X Ø.31
4X Ø.18 THRU
2X .20
.50
1.50
2.50
1.13
.31
.35
1.23
Ø.63
Ø1.75
A
A


SECTION B-B
.25
.13
8X R.13
2X TAP #8-32 THRU
B
A
2.43
1.73
1.24
1.50
2.00
.35
.21
.13
Ø 2.00
Ø 1.00 THRU
Ø .27
Ø .50
.11
SECTION A-A
NOTES:
1. MACHINE FROM 2.00" OD ROD STOCK
ME429 Winter 2013
Mechanical Engineering
PART: Stick Collar
MATERIAL: Delrin Acetal Resin
DATE: 1-30-13
TEAM: The Knuckle Pucks
SCALE: 1:1
UNITS:
TOLERANCE: ±.005
DWG #: 500-3



NOTES:
1. PART TO BE RAPID PROTOTYPED
2. SEE CAD MODEL "TAB" FOR COMPLETE DIMENSIONS

ME429 Winter 2013	SCALE: 1:1	PART: Tab
Mechanical Engineering CAL POLY	UNITS:	MATERIAL: ABS Plastic
	TOLERANCE:	DATE: 1-30-13
	DWG #: 500-4	TEAM: The Knuckle Pucks

5 4 3 2 1