Pop-A-Wheelie Design Team

Mechanical Engineering Department

California Polytechnic State University

San Luis Obispo

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Sponsor: *Break The Barriers*

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Statement of Disclaimer

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Nomenclature

Table 1: Symbols

lb_f	Pounds Force
in	Inches

Executive Summary

The purpose of this report is to illustrate the Pop-a-Wheelie design team's progression and implementation of a concept in regards to the project sponsored by Break the Barriers (BTB). The Pop-a-Wheelie design team was tasked to design two devices that will be attached onto wheelchairs. The devices should facilitate the independence of user's ability to pop-a-wheelie and return to an upright position without any assistance. After a list of specifications was agreed upon, the design process initiated. All customer specifications are listed in Objectives section located in Chapter 1: Introduction. A complete engineering specification table can be found in the QFD chart, located in Appendix A: Design Concept Tables. Many concepts were generated to satisfy specifications; however, only one was chosen. The Swing Dancer is the best design concept that will sufficiently address the maximum number of specifications. Refer to the Discussion of Conceptual Designs section in Chapter 3: Design Development for more details on each concept. The justification for the Swing Dancer is located in the Specifications Satisfied by Top Concept section in Chapter 4: Description of the Final Design. In each case, the Swing Dancer either fulfilled the specifications fully or adequately. Detailed analysis was done to verify the loads on the device; the max load found is 11.25 lbs. per wheel. The safety factor determined is 25.6 and the max compressive load the support bars in Model #1 can withstand is 672 lbs without buckling. Detailed calculations and descriptions can be found in Appendix E: Detailed Supporting Analysis. A detailed list of components used in the design can be found under the Cost Analysis section also in Chapter 4: Description of the Final Design. From the test procedures performed on the attachment, the weight was calculated to be 10.0 lbs. and the cost of producing it is $489.28 while the second model was found to only weigh 7lbs and costing $113.89 due to using the extra material from the first model to build it. Based on all the information justified in this report, the recommended next step is to proceed with using the device in a real world situation. It is only then that our device can truly pass the ultimate test of helping the Barrier Breakers to spread their message of "inclusion" around the world.

Chapter 1: Introduction

Introduction

Break the Barriers is a non-profit organization founded in October of 1985 by Deby Hergenrader and her husband, Steve. Deby's sister, Kathy was diagnosed with Down syndrome but her condition didn't hinder her in any way from learning gymnastics by watching her sister train for gymnastic competitions. Since Deby was a skilled and decorated gymnast, she dedicated her free time to train Kathy. Kathy participated in numerous Special Olympics with Deby as her trainer. It was through Kathy, that Deby found the inspiration to open Break the Barriers after an injury forced her to stop competing. Now, Break the Barriers is a 32,000 square foot facility, which has been completely funded by donations. Because of their renowned program that allows kids with all abilities to take part in; they are able to provide a place for 3000 students from the surrounding districts in Fresno, CA to enjoy their facility. They have made their mark in the world and they are recognized as a National Role Model for Inclusion. According to Deby, inclusion is the act of integrating kids with different "abilities" in the same activities. These activities include learning martial arts, weightlifting, dance performances, gymnastics, etc.

The latter of these, gymnastics (or floor routines), is what inspired the "Barrier Breakers" to contact Professor Kevin Taylor to see if there were students interested in a senior project in this field. Their idea was for students to design and build a wheelchair attachment that gives the users the ability to tilt backwards. Professor Taylor contacted the Mechanical Engineering department in search of students willing to team up with kinesiology students to create a senior project team that will achieve the needs of this project.

The target end user will be the performers on the "Barrier Breakers" who are currently using unmodified wheelchairs in their dance routine. Some of the performers have limited use of their legs while others are unable to control any muscles below their abdominals. When designing the attachment, it is necessary to design for the most extreme case; the ones who have no motor control of their legs. This became the most critical part of the design process because the design will require a method of raising the chair back up to the original position for someone who will not be able to use their hips to help lean the chair into position.

Problem Definition

The project must accomplish two primary goals:

1. Allow the user to tilt their wheelchair parallel to the ground
2. Return to an upright position without assistance from other gymnasts

As suggested by BTB, we were given two secondary goals:

1. Allow the user the ability to spin 360° while parallel to the ground
2. Design the device to be light enough as to not interfere with performers abilities

Objectives

The Pop-a-Wheelie design team planned, coordinated, designed, and tested an attachment for several models of wheelchairs that are currently used by the Barriers Breakers in their dance routines. The attachment will allow the dancers independence in choreography and performing their dance routine. Thereby, allowing them more freedom to tilt back in their wheelchair, almost parallel to the ground and "pop" back up to sitting position with ease.

After discussing the project with BTB, we were able to produce a list of specifications and goals that we would implement into our design.

- Weight equal or less than 10 lb.
- Supports a maximum of 250 lbs.
    - Dancer will lift and carry partner
    - Dancers will form human pyramid
- Supports a minimum of 50 lbs.
- Attachable to 3-4 different types of wheelchair
- Durable
    - Average of 6 hours practice time a week
- Detachable from wheelchair
- 2 products
    - 2 dancers on traveling team
- Titanium or Aluminum material
- Aesthetically appealing

- Make user more independent
    - Dancers will be able to tilt back and pop up without assistance from partner
- Safe
- Fun

From this list of specifications and desirables from BTB, we generated a list of engineering specifications that will accomplish these objectives. A Quality Function Deployment (QFD) or House of Quality table was generated to compare and explain our specifications that were derived from customer's needs which are included in Appendix A: Design Concept Tables.

After talking to BTB, we were able to produce 14 customer specifications. They are listed in the on the left side of the Figure 65: QFD Chart, below the "Demanded Quality" heading. They are also weighted based on how important each customer specification is in comparison to one another, as shown under the "Weight/Importance" column. "Safe" is our highest rated quality with 14.0 while "Affordable" received a rating of importance of 0.0. From there, we created functional requirements based on the list of 14 customer specification. They are located to the right of "Quality Characteristics" and below "Column #."

Here is how the customer specifications relate to our Quality Characteristics:

- Lightweight: Relates to "weight must not interfere with dancing capabilities" since we do not want to restrict the dancers ease of movement by creating a heavy or bulky attachment.
- Adjustable: Corresponds to "tilt" because we want the user to have multiple angles where they can lean back; not just one position.
- Durable: Coincides with "must withstand heavy use" since the dancers are going to do stunts and lifts with the design and we want it to be able to endure and last long.
- Adaptable: Goes with "must fit different types of wheelchair" since the dancers have about 3-4 different types of wheelchair. We want to make a product that will be easily attachable to the wheelchairs without any modifications to them.
- Affordable: Relates to "minimal cost" because we want to keep the price of production down due to a limited budget.
- Quick Release for Engaging and Disengaging: Corresponds to "wheels must not interfere with dancing partner" and "ability to engage/disengage." Typically in a routine, the dancers in wheelchair are dancing with a partner as well as the entire Barrier Breakers team so we do not want the product to interfere with other dancers.

- Springs for Impact: Coincides with “springs must dampen the force caused by dropping back” and “springs must not oscillate” because the sponsors want a device that might possibly be used to let the dancer fall back quickly in their chair. A spring is desired to absorb the impact and dissipate the force from the fall.

- Weight Tolerance: Goes with “must withstand additional weights” because the dancers usually lift their partner and form a human pyramid. This will add more weight to the chair and we need to design for this situation

- Maneuverability: Relates to “must rotate” and “must keep speed with large wheel.” We do not want to slow the dancers down or restrict their movements in any way. The more freedom they have, the more tricks and dance moves they can do. Thereby, having the chair rotate while keeping up with the speed of the large wheels will provide all the freedoms they need.

- Detachable: Goes with “must detach for travel purposes” since Barrier Breaks are an international team and they travel to many countries to perform and inspire people. We want the device to be easily and quickly detach so they can stow it away along with their chairs during flight.

- Users Are Independent: Relates with “no sharp edges”, “users must operate by themselves” and “no pinch points.” It’s relates to safety when we want no sharp edges or pinch point because we want the dancers to be as independent as possible while performing and sharp edges and pinch points will create a hazard.

- Stability: This one also relates to “must withstand additional weight” and springs and rotating because we want the device to be stable and steady while the dancers are performing. Relates to safety

- Aesthetics: Coincides with “must be pleasing to the eyes” for performances since they are performers and we want to make a product that will look pretty. We would also like to make it glow in the dark if possible.

- Safe: Lastly, this one goes with “must not fail.” That is an understatement since we want to create a product that is safe for the user as well as the dancer. Safety is always a concern when designing.

From these Quality Characteristics, we formulated our Engineering Specifications, located at the bottom, to the right of “Target or Limit Value.” We then rated the difficulty of achieving these specifications with a scale of 0-10 with 0 being easy to 10 being difficult prior to designing and building the device. The ratings are found below the specs and we had “Takes one Person” to operate as being the most difficult to achieve with an 8 and having it “Spin 360 degrees” being the easiest to achieve with a rating of 0.

To the right of the QFD, we compared 3 other wheelchairs in use for similar applications such as dancing and reclining the chair. However, none of them satisfy what the sponsor is looking for. Ratings and a color coded chart are provided for clarity on the top of the QFD.

Lastly, the QFD has the roof of the chart which serves as a correlation for how our Quality Characteristics relates to one another such as how “Weight must not interfere with dancing capabilities” had a “Strong Correlation” to “Tilt.” The correlations are our interpretations they are rated in a legend which can be found on the upper left corner of the QFD. All the ratings are there for reference if desired. Once again, the QFD can be found in Appendix A: Design Concept Tables.

Using the QFD, we were able to generate a table that outlined the project’s most important parameters. By assigning target values to each parameter, the parameters that have the highest risk. This is shown in the table below.

Table 2: Pop-A-Wheelie Formal Engineering Requirements

Spec #	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Weight	10 lbs.	Max	H	A, T, I
2	Adjustable	45-85 Degrees	Max	H	A, T, I
3	Durable	5 Years	Max	M	T, I
4	Adaptable	4 Chairs	Min	H	T
5	Cost	$500.00	Max	L	A
6	Weight Tolerance	500 lbs.	Min	M	A
7	Size	1 ft.	±1 inch	L	A, I
8	Detachable	5 minutes	±3	L	A, T
9	Independent	1 user	Max	H	I
10	Stability	1.5 Spring constant	Max	M	A, T
11	Safe	3 (factor of safety)	Min	L	A
12	Maneuverability	360 Degrees of Motion	Max	H	I
13	Delivery Date	2-Jun-11	Max	H	I
14	Maintenance	6 months	Min	L	I

Under the “Risk” column, L is for low, M is for medium and H is for high. Above, we have 6 high risk parameters: Weight, Adjustable, Adaptable, Independent, Maneuverability, and Delivery Date. Here are some clarifications for these ratings.

1. Weight: We don’t want to restrict the dancers’ movement and the weight of the attachment is directly correlated to how much movement they have.

2. Adjustable: In order to accomplish the requirements set up by BTB, the user need to be able to recline from sitting position to about 45-85 degrees from vertical.
3. Adaptable: The device will need to be able to fit to about 3-4 different types of chair since the dancers have a variety of wheelchair types.
4. Independent: BTB wants a device that will help the users be "as independent as possible." This means, they will not require a partner to help them in any facet of their routine.
5. Maneuverability: The dancers will be attempting high speed stunts and the device should not inhibit them from performing to their max capabilities.
6. Delivery Date: The device should be fully completed by June 2, 2011 for the clients to utilize and perform with.

Under the "Compliance" column heading, we have different stages of design that our specifications will be administered. "A" represents the analysis stage, "T" is the testing stage and "I" stands for inspection stage.

Project Management

Our team consists of 3 members: Thuyen Nguyen, Shaun Van't Hul, and Mackenzie Hill. Each had different tasks and responsibilities that were essential to the success of the project. Several tasks and responsibilities require the attention of all members and will be listed.

Here is an overview of tasks and responsibilities that each member had:

Table 3: Individual Responsibility/Tasks

Thuyen Nguyen	Shaun Van't Hul	Mackenzie Hill
Concept Generation	Concept Generation	Concept Generation
Documentation of project progress (Gantt Chart)	External department communication; i.e. contact with Kinesiology Department	Documentation of project progress (Gantt Chart)
Sponsor Communication	Documentation of project progress	DVP (Design Verification Plan)
Analysis of Concept	Analysis of Concept	SolidWorks Modeling
Material Procurement	Material Procurement	Material Procurement
Designer	Designer	Designer

Machinist	Machinist	Machinist
Aesthetics	Aesthetics	Demo Planning
Demo Presentation	Demo Correspondent	Demo Presentation

Collaboration and communication of all responsibilities for manufacturing considerations, prototype fabrications, and testing are imperative. By working together these crucial steps of design aided to avoid miscommunications.

Included in Table 12: Gantt Chart is a detailed chart with milestones and deadlines for deliverables necessary for the successful completion of this project. The chart is divided in to two sections. The left side is a description and title of tasks with the estimated days and dates for completion. On the right side is a graph representation of each task with a blue bar spanning the start date to finish date.

For example, on the third row, first column, there is a number 1 to represent task one. The second column shows the progress of the task. There is a check to show that the task has been completed, otherwise, there is a calendar to represent the uncompleted task. The third column is the task name, for this example, it is “Write Introduction Letter to Sponsor BTB.” The fourth column is the estimated days for completion of task followed by the actual dates the task starts in column 5 and ends in column 6. On the right side, there is a blue line on Tuesday, October 5, 2010 with a black line in the middle. The blue line spans the duration of the task, for this example, the task lasts one day so the blue line cover only one day. The black line through the middle of the blue one shows that the task is completed. This corresponds to the check mark on the left side of the chart. Please refer to the Gantt chart in Appendix F: Project Timeline for clarity.

Timeline

Some important dates that deserve to be noted are the design reviews, prototype testing and the Design Expo. The Critical Design Review, scheduled for February 11, 2011, took place in Fresno. Material procurement started upon the sponsor's approval of the design. Manufacturing the prototype started once materials were ordered and received. Prototype building and testing was done March through May, with approximately two visits to Fresno during that time to observe the user and gain feedback on the device. Senior Project Expo was on June 2, 2011 at Cal Poly in San Luis Obispo. The table below highlights these dates:

Table 4: Important Dates

Event	Date
Critical Design Review	February 11th
Material Procurement	February 15th – March 31st
Manufacturing	February 26th – May 31st
Prototype Testing 1	May 28th
Prototype Testing 2	May 29th
Senior Project Expo	June 2nd

Testing

In Appendix F: Project Timeline, we've outlined all of the necessary test procedures that are considered and implemented. There are 17 items listed in the left most column that are specifications or clause references that we are planning to test. Listed under "Test Responsibility" are the names of the Pop-a-Wheelie design team that are in charge of the tests. The next column is the test stage and currently, we are in the process of procuring materials and building the device. Once the prototype is completed, testing will be administered; therefore, the current "Test Stage" is DV, or Design Verification stage. Under "Samples Tested" are "Quantity," and "Type" which refer to the number of times we are running the test and what type of test we are running, respectively. Furthermore, under "Type" are 3 potential types of test that are administered with A being "Concept Verification," B refers to "Design Verification," and C represents "Product Validation." Test descriptions will be explained thoroughly in a latter section including their acceptance criteria. The start dates and finish dates are estimations since many factors will influence the actual dates of testing. Factors such as delivery date and order date for material procurement as well as actual testing duration are subject to change. However, the absolute deadline for all testing and prototype assembly is June 2nd, 2011 since that is the Senior Expo.

Chapter 2: Background

Existing Products

The first step in receiving this project was to make sure there were no existing products available that already accomplished the desired goals. In order to verify this, an extensive patent search was done using different outlets and researching existing products that allowed a person in a wheelchair to 'pop-a-wheelie' and still have the ability to roll forward. A few relevant products and patents were found but they did not accomplish the important specifications outlined by our customer, Break the Barriers. On the following pages are short summary of the products that are closely related to the product we hope to create.

Center-of-Gravity Tilt-in-Space Wheelchair

This product, Patent # 7007965(45), allows the wheelchair to be used like a rocking chair. It can lean back to a semi vertical position and stay there by a locking mechanism. It works by having an additional piece that does not come with the standard wheelchair. The addition is a curved rod that allows the chair portion of the wheelchair to slide along, tilting the chair in the process. As stated before, this is not an attachment; it is a wheelchair made specifically for the rocking chair effect. The rocking wheelchair does provide some good insight on ways that we could implement into the design of the attachment to allow the Pop-a-Wheelie chair to tilt back by way of a curved rod. However, the challenge is to figure out a way to attach this rod to the existing types of wheelchairs that the Barrier Breakers currently use.

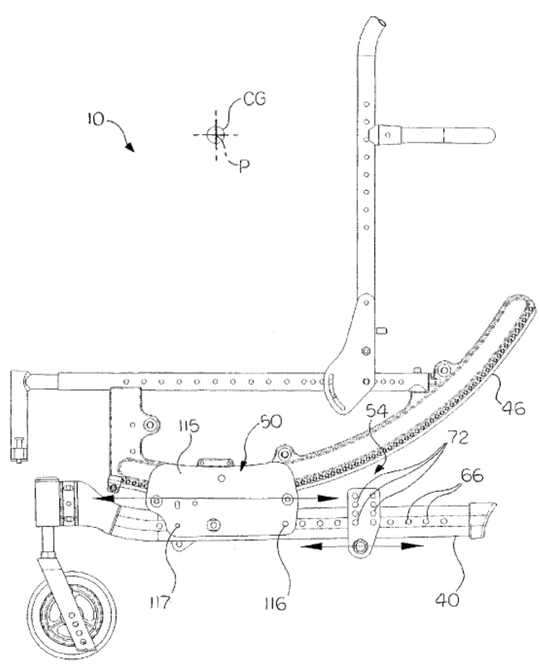


Figure 1: Center-of-Gravity Tilt-in-Space Wheelchair (1)

Twirl Dance Wheelchair

The Twirl Dance Wheelchair is a wheelchair manufactured by Invacare. This is an existing product that anyone can buy for $2,536. It allows the user to spin at a very fast speed by employing a single wheel permanently attached to the back end of the wheelchair. This design is the only design that is the most similar to the product we will likely design except that the wheel is attached permanently and it does not allow the user to tilt backwards. From this design, we were able to generate some ideas of how to attach a wheel to the back of the chair. A possible aspect to use is a rod with a wheel at the end and attaches to the main frame of the wheelchair. This proved to be helpful when designing a method to accomplish allowing the user to spin while tilted backwards. The main modification we would change about this design in place the wheel behind the back rest instead of on the ground.

Figure 2: Twirl Dance Wheelchair (2)

Reclining Attachment for Wheelchairs

On June 14, 1966, patent number 3256040 was issued for the "Reclining Attachment for Wheelchairs." This is an attachment that is secured onto the anti-tip bar and is clamped onto part of the frame. This device allows the user to tilt their wheelchair back to a 40 degree tilt from vertical by implementing two anti-tip rods keeping the wheelchair at that angle. The idea is very simple and lightweight. The way in which they attached their device to the chair will be very useful as it requires only a small clamp to attach itself to the chair. For our project, however, instead of only tilting 40 degrees, we need to allow the user to tilt back to 85 degrees and spin. This will require us to change our design to account for a larger tilt radius, so our anti-tip rods will be placed directly behind the back rest near the guiding handles. Also, instead of just two rods, these will have to be changed to wheels to allow the user to spin and dance in the wheelchair at this tilted angle.

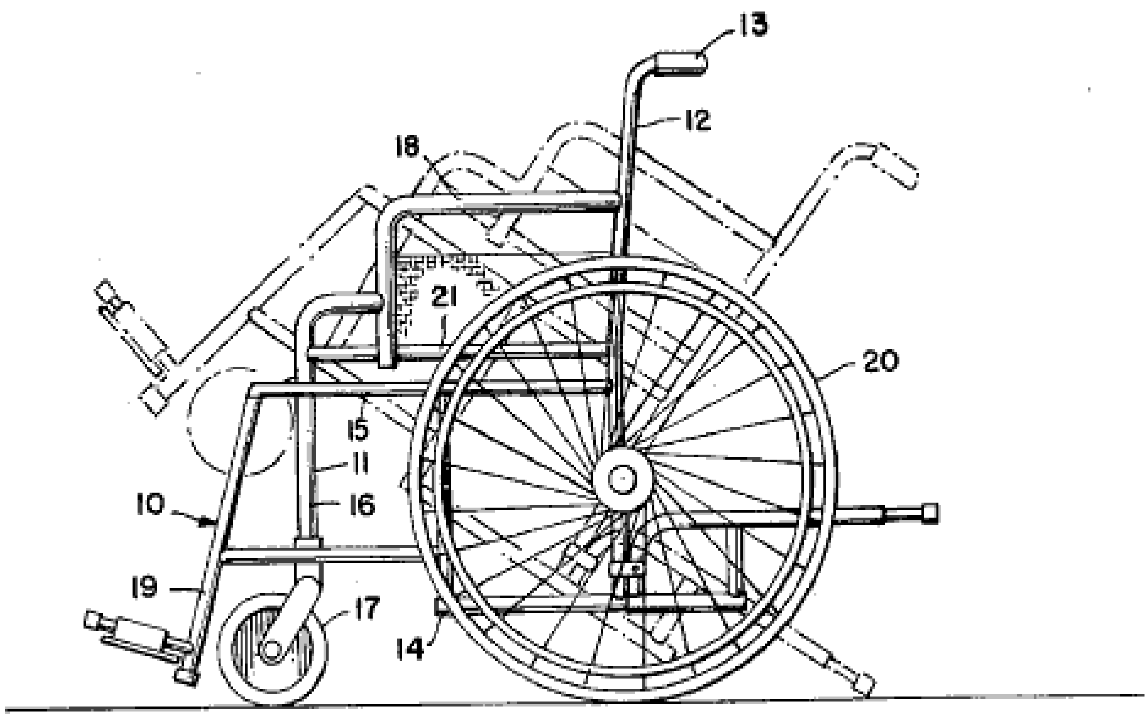


Figure 3: Reclining Attachment for Wheel Chairs (3)

From these existing products, the most useful idea that we will be able to implement will be attaching our wheels to the frame. We thought that the Reclining Attachment was a good idea and we saw the areas we could improve on it to make it more stable and durable, as this attachment will have to endure extreme wear and tear while being used by the dance team. The most exciting aspect of doing the background research for this product is realizing that there isn't anything currently available like the product we are designing.

Current State of the Art

As far as the customer is concerned, the performers in wheelchairs use a model called Quickies. There are currently around 10 different models of quickies and the price of one can range from $1,000 - $7,000 depending on the model. The ones that are used by the dancers are the extremely lightweight models. The Quickie is different than a standard wheelchair because they have a much simpler frame and they have removed unnecessary support bars. When designing the concept for the project, we were able to procure a couple models to gain an idea of what we were working with. The main concern we had when analyzing the wheelchairs is the limited space in the support bars that we will be able to clamp our attachment to. This aspect played a very large role in how we constructed our design.

Figure 4: Quickie Q7 (4)

Chapter 3: Design Development

Design Process

In order to come up with and implement the best solution to the problem, there are various stages and check points in the design process. After gaining a full understanding of the need, the market, and the technologies, we can accurately define the problem, conceptualize, evaluate/analyze, form a detailed design, manufacture, and validate the product.

In the problem definition stage, the engineers fully understand the needs of the client and formulate specifications to meet every desire the client has for the product. These specifications will have a series of tests associated with them to insure the product is safe and compatible with the needs of the user. A patent search was completed to see what others had done in the same concept area in order to be aware of devices and products that could be improved to fit the specific need. This stage was completed, with the meeting to understand the specifications of the need, an extended patent search which has been discussed in the background and can be seen in the Existing Products section in Chapter 2: Background and the quality function development (QFD), also discussed earlier and can be seen in Appendix A: Design Concept Tables.

The conceptual stage is where various idea generation techniques are used to develop as many alternative solutions, plans or strategies as possible that satisfy the problem definition or specifications. Some of these methods include brainstorming, alternative action, morphological analysis, and scamper. Brainstorming allows many ideas to be produced. The quantity in this exercise matters and incorporates building on previous ideas to improve them as well as jump to new ideas. It creates a space for the imagination to be stretched as long as judgment is withheld. Alternative action helps a designer to look into new directions and possibilities for solutions. A list of verbs is created and with each verb new ideas are associated with it. Example, the verb change could produces ideas such as change lengths, color, texture, elements, components, image, timing, destination, etc. A morphological analysis is also a list technique consisting of picking several attributes or subcomponents of the whole system, listing alternative solutions or ideas for each attribute or subsystem, and then randomly connecting the entries on the lists to each other to create a whole solution. Scamper relies on a lateral thinking approach to finding other alternative solutions. Scamper stands for substitute, combine adapt, modify, put to other uses, eliminate, rearrange or reverse.

Each idea or combinations of ideas is evaluated on how well the design specifications are met as well as analytical calculations. Some ways that eliminate ideas are asking colleagues or teachers, asking the client, and using scientific analysis of the idea. Colleagues and teachers possess a wealth of knowledge and expertise and may be able to help analyze an idea and determine its advantages and disadvantages. Clients provide different knowledge and varied

opinions about their personal preferences from these entities to help make decisions about conceptual ideas and their characteristics. Another approach to analysis of ideas is to use scientific analysis to determine the feasibility and virtue of an idea. This includes engineering analysis, statistical analysis, computer simulation and modeling and others depending on the idea and issues involved. If there are multiple options after this process a decision matrix is used. The decision matrix contains all the required specifications, through which all ideas are evaluated. Each characteristic is listed then points are given in comparison to existing product. Then a weight factor is incorporated to assign the importance value of a characteristic. In the end, the largest positive value would be the best choice.

When the top idea is selected a detailed design is created. This includes calculations, detail drawings of all parts, detail plans of assembly, bill of materials, economic considerations, safety considerations, performance and quality requirements and selection of components and other parts necessary for purchase from other vendors.

The manufacturing stage is the implementation of all the design specifications into a product. Some parts are ordered and purchased from vendors and other parts are created and assembled in the machine shop. When the prototype is completed testing is done to validate that all the design specification were achieved. This design process is an iterative method meaning that repetition is necessary to develop the best product. For instance, if after picking the top idea, during the analyzing stage, a requirement is not met to withstand the necessary amount of force exerted on a part, then it is necessary to go back to the conceptualization stage and find a better idea that meets all design requirements.

Discussion of Conceptual Designs

After reviewing the existing products that are currently available, we tried to come up with a way to incorporate all the designs into a single attachment that will meet the design specifications as set by our sponsor. We were able to come up with four main concepts, not including our final design.

- Collar Concept
- Gear Box
- Linkage System I
- Linkage System II

These concepts are described in detail on the following pages.

Collar Concept

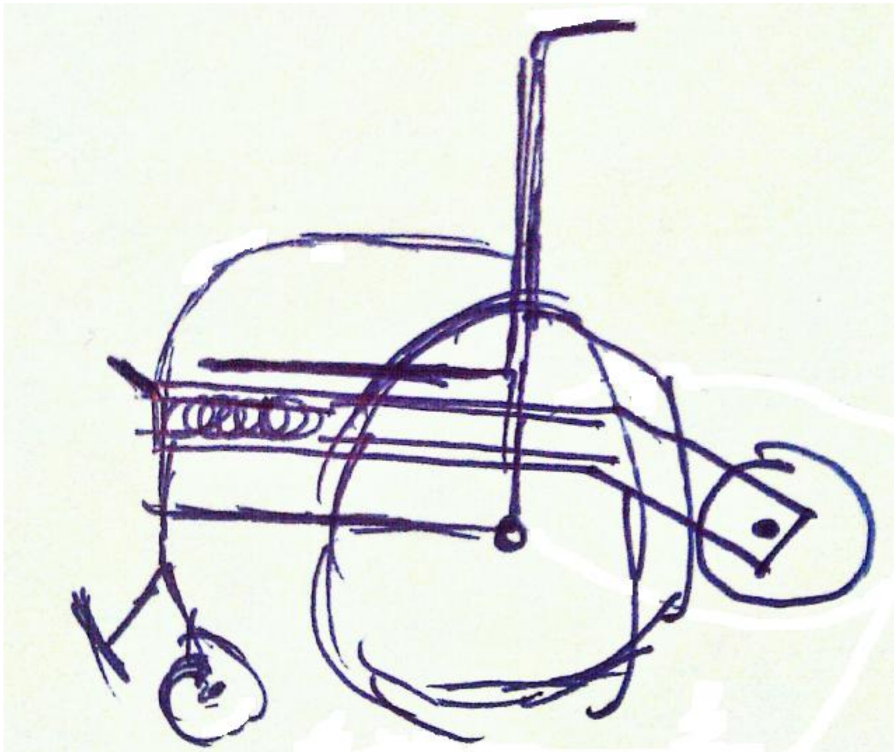


Figure 5: Sketch of Collar Concept

The first concept we came up with involves using collar to attach an attachment to the bottom of the chair. This concept will have a handle on the front of the attachment extending 6 inches from the bottom of the seat on the wheelchair. On the back of the attachment, there will be a wheel with springs that will support the weight of the user when they tilt backward by 85 degrees (from horizontal). As they push on the handle, the wheel will be pushed backwards which will raise the chair into the upright position. This is described in detail in the following pictures and bullets.

Attachment

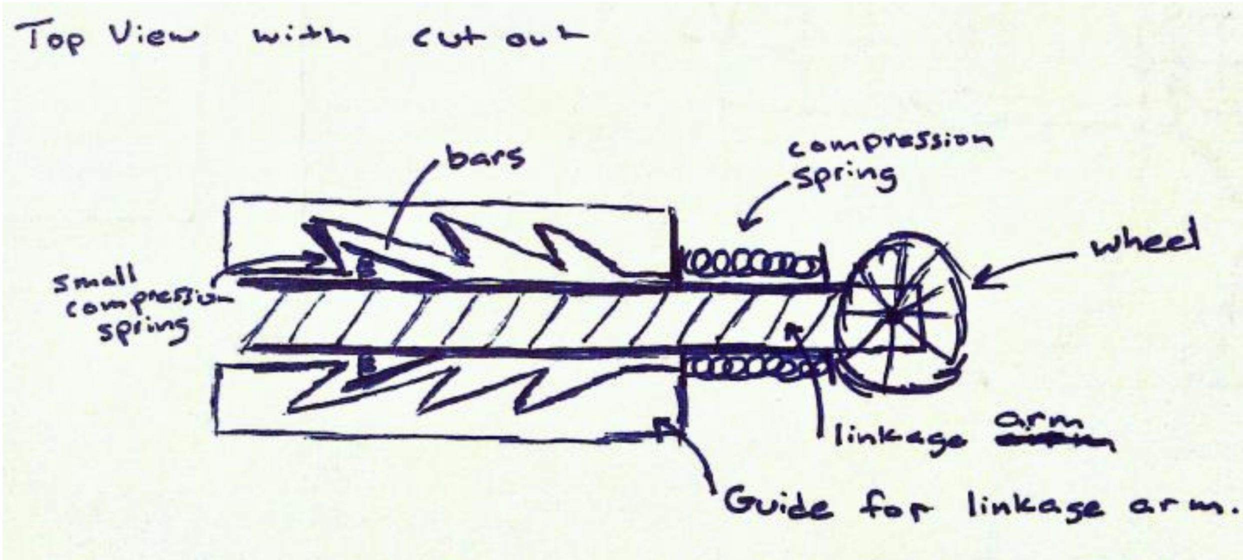


Figure 6: Sketch of Mechanism underneath the Wheelchair

1. Guide: This allows the user to push on the linkage arm to raise themselves back into an upright position or to different tilt angles. This guide has angled cuts in it that will act as grooves for the bars to 'snap' into place locking the wheelchair into the different tilt angles.

2. Linkage Arm: The linkage arm will initially start in a compressed state. In this compressed state, when the user tilts backwards, they will be in the 85 degree tilt position. As the user pushes on the linkage arm via the handle (shown on the next sketch) the linkage arm will be pushed outwards allowing the chair to move into a 60, and 45 degree tilted position.

3. Wheel: It will have springs to dampen the landing as the user tilts backwards. It will also have the ability to turn 360 degrees which will allow the user to spin while they are tilted. There will be a bar connecting two of these wheels to add to the stability of the wheelchair while they are leaned back. Having a second wheel will also help displace the force on two contact points which helps dampen the effects of tilting backwards in the wheelchair.

4. Compression Spring: This spring will want to pull the linkage arm back into the initial starting point. This is where the guide keeps the linkage from going all the way back into that position and will essentially lock the bar into the set angle positions.

5. Bar Compression Spring: This will push the bars against the edges of the guide and into the grooves when the linkage arm is pushed into position. The user will be able to feel the vibrations of the bars 'snapping' into the different grooves so they will know when they can stop pushing on the linkage arm. When the user is in snapped into the last position, they will be at 45 degrees. If they push past that last position the weight of the user will make the wheel chair fall back into an upright position due to gravity.

6. Bars: These will be two small 2-inch long steel bars. They are what will lock the user into the different angles.

Handle

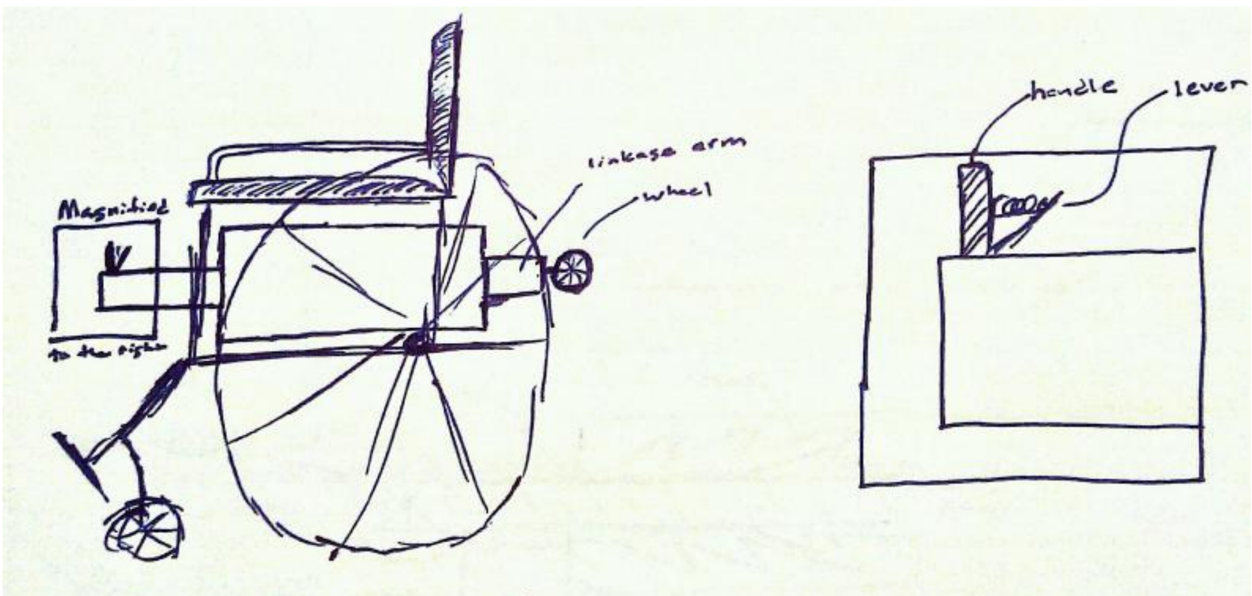


Figure 7: Magnified View of Handle Mechanism

1. Handle: This handle allows the user to slide the linkage arm through the guide to raise the wheelchair from a tilted position. It will be covered in a rubber in case other performers come into contact with it.

2. Lever: The lever will allow the user to collapse the bars inward to allow the linkage arm to be pulled back into the initially position.

Clamps

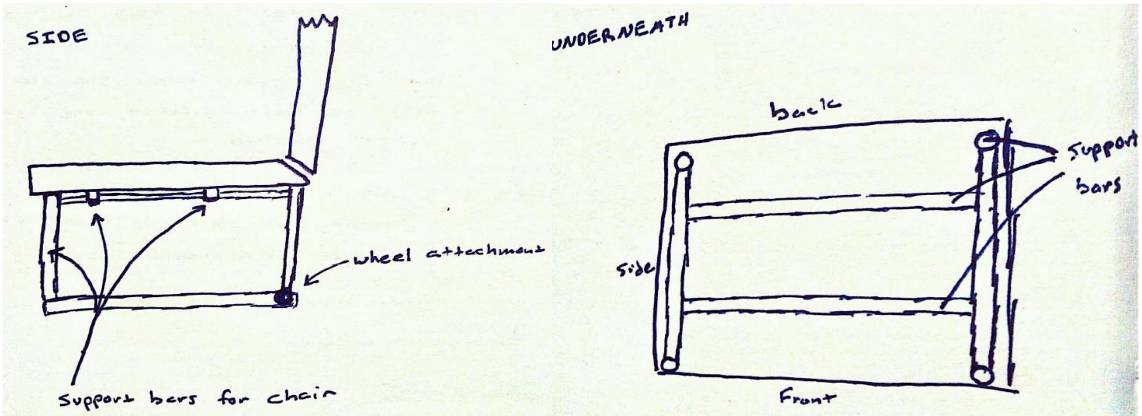


Figure 8: Sketch Demonstrating Location of Attachment Points

1. Support Bars: Almost all models of wheelchairs these bars. We are going to be able to use this to our advantage and attach our attachment using at least six clamps. Four clamps will be attached to the bars, supporting the weight of the user, going across the bottom of the chair and two clamps will attach to the front supports. The guide will be circular and the clamps will attach to collars on the guide so the clamps can be easily moved to adapt to the different types of wheelchairs.

Possible Additions and Concerns

- We need to make sure that the attachment will fit under a small child's wheelchair but not be too small to lack the structural integrity for a 250lb performer.
- The placement of the wheel behind the user may have to be moved to a higher location (preferably behind the user's back) so they are properly supported while they are parallel to the ground.
- There is an ergonomics concern with the concept as we are unsure if the users will like having a protruding member sticking out from underneath their chair and extending 6 inches.

Gear Box Attachment

The second concept we came up with is very similar to the first concept except we use a different system of raising the user back into an upright position. This concept integrates the use of gears and a system similar to a brake cable on a bicycle. It is a much simpler design, as the pieces that will make up the system require less custom-made pieces. This design will also invoke the use of torsional springs, which will allow the user to return to an upright position with minimal effort.

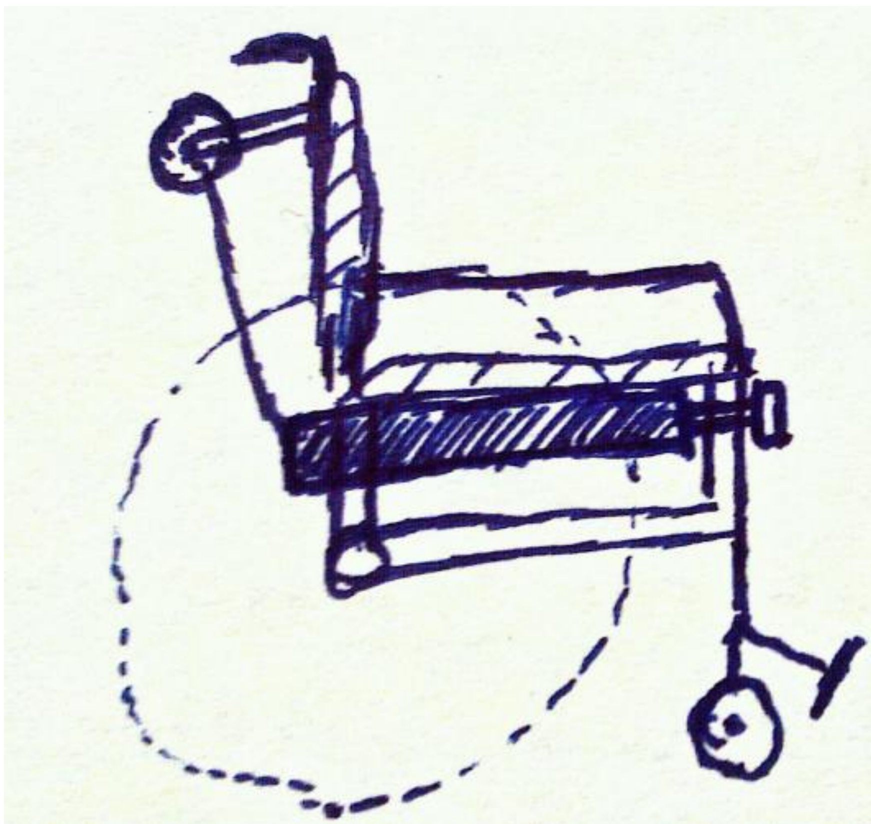


Figure 9: Sketch of Gear Box Attachment

This is what the full design will look like when attached to the chair in an upright position. As shown in the figure, there will be a handle that protrudes no more than 1 inch from underneath the seat. On the back, the wheel will not extend more than an inch past the large wheel's outer diameter.

Wheel and Linkage Arm

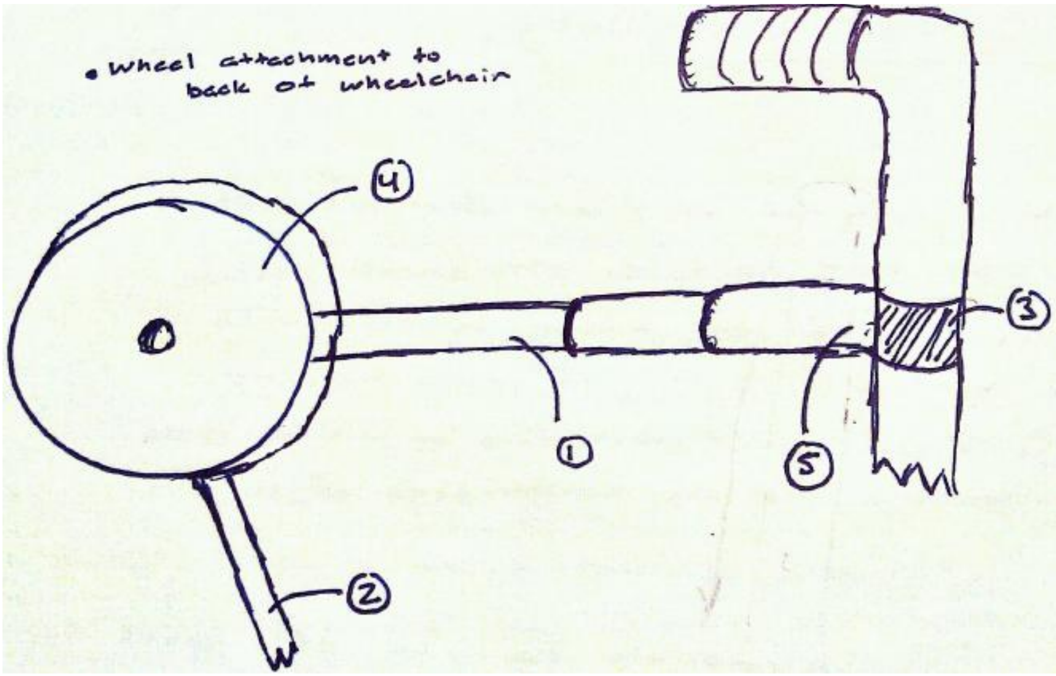


Figure 10: Sketch of Linkage Arm Mechanism

1. Extendable Linkage Arm: This arm attaches to the axle of the wheel. It will extend when the user pulls on the handle, tightening the cable.

2. Cable: This cable attaches to a coil inside the gear and spring housing (shown later). When the cable is pulled or tightened, it will force the wheel to extend away from the chair in a circular, downward path, which will push the chair into an upright position. This cable will also attach to the wheel's axle.

3. Clamp: A clamp is used to attach the linkage arm to the frame of the wheelchair. This will be circular so it will have the ability to fit any radius as there are multiple types of chairs.

4. Wheel: This wheel will have the ability to spin 360 degrees and also be equipped with springs in the axle to help dampen the force of tilting backwards.

5. Linkage Arm Spring: Inside the linkage arm, there will be a spring that will cushion the impact of the user falling backwards. There will also be a torsional spring inside the housing to force the system back into place after it is pulled.

Gear and Spring Housing

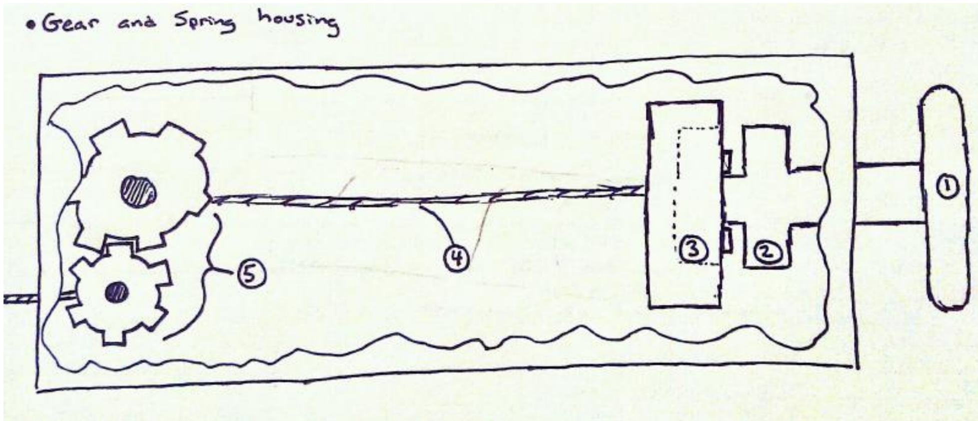


Figure 11: Sketch of the Inner Components of the Gear Box

1. Handle: This will be a twistable handle that will stick out a maximum of 3 inches when fully deployed from underneath the front of the seat. It will be coated in a rubber casing to account for the performers possibly hitting it while dancing

2. Block: A square block will be a part of the bar that is attached to the handle. This is used to 'lock' the chair into position.

3. Housing for the Block: The housing will allow the block to fall into set grooves to keep the handle from twisting and releasing the cable. It will look like this from releasing the cable. It will look like this from a top view

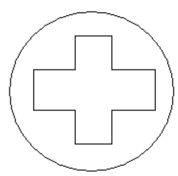
   

   Figure 12: Model of Locking Mechanism

   This will allow the user to only have to turn the handle a quarter turn to tighten the cable.

4. Cable: A cable is attached to the handle and the big gear. When the handle is twisted, the big gear will turn a quarter turn.

5. Gears and Springs: Springs (not shown) will be attached to the two gears. When these gears turn, the attached torsional springs will provide resistance. As the big gear turns a quarter turn, the small gear will turn one whole revolution, pulling the wheel down into a different angle.

Possible Additions and Concerns

- We may need to redesign the wheel-cable-linkage arm system. Main concerns with the current concept are that it will not be able to handle the forces and moments that are placed on the linkage arm.
- The gear and spring housing case may have to change to account for the clamps that will have to be attached to allow for the different sizes of wheelchairs.

Linkage System I

The third concept that we came up with is the Linkage System. As a team, we really liked this design as it is simpler than our two previous ideas. The key features that we changed from our previous designs are:

- The method in which one may up-right themselves.
- We reduced the amount of parts used to accomplish our goals
  - By doing this, we can reduce our cost, the ease of use, and the amount of maintenance needed.
- There is more support for the user using this design.

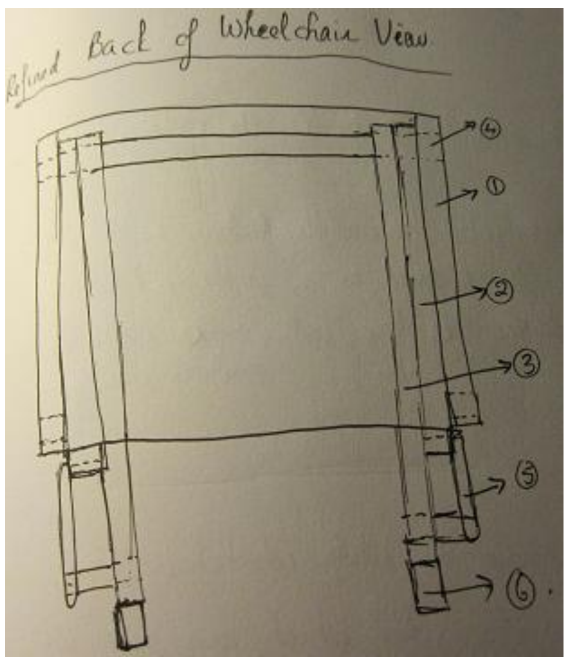


Figure 13: Sketch of Linkage System I

As shown on this sketch, on the back of the chair, we plan to add 6 members onto the back of the wheelchair. These members are described in detail in the later sketches.

Four Bar Linkage

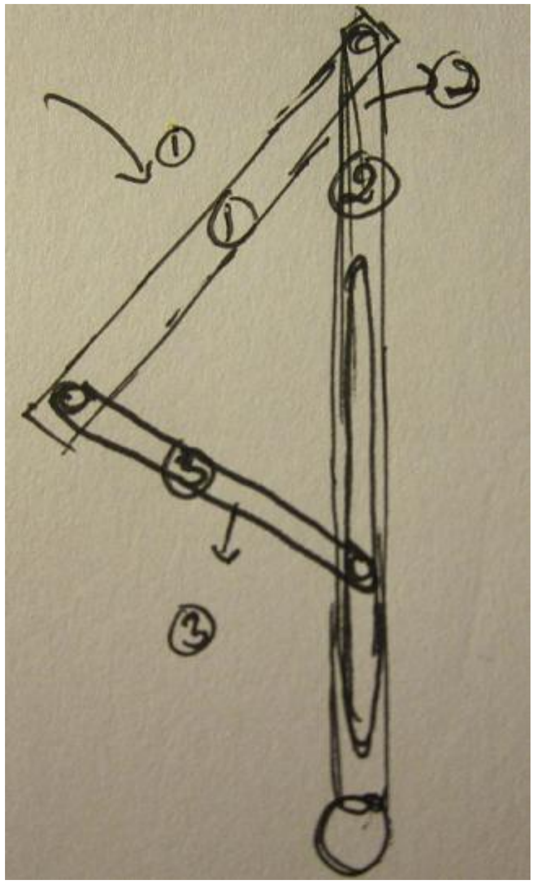


Figure 14: Sketch of Four Bar Linkage

1. Large, Square Rod: It extends the length of the support bar on the back of the wheelchair. It will be adjustable to account for the different sized wheelchairs that we are designing the attachment for. This bar will remain rigid and it will be attached to the support bar in two places along with a thin, circular, metal rod going through the top of it.

2. Long, Circular Rod: This will also be adjustable depending on the size of the wheelchair. It will extend about 4 inches past the bottom of the seat of the wheelchair. At the bottom of this rod is where the shock absorber and wheel are attached to (described later). It will have a long rectangular section cut out of it for the small bar that attaches the square rod to the circular rod.

3. Little Bar: This little bar is used to keep the two main bars in contact with each other. It will act as a guide for the large circular rod as it is constrained to stay within the cut out section in the circular rod. This in turn will constrain the large circular rod to a set path giving the user support at any angle they are tilted at.

Locking System

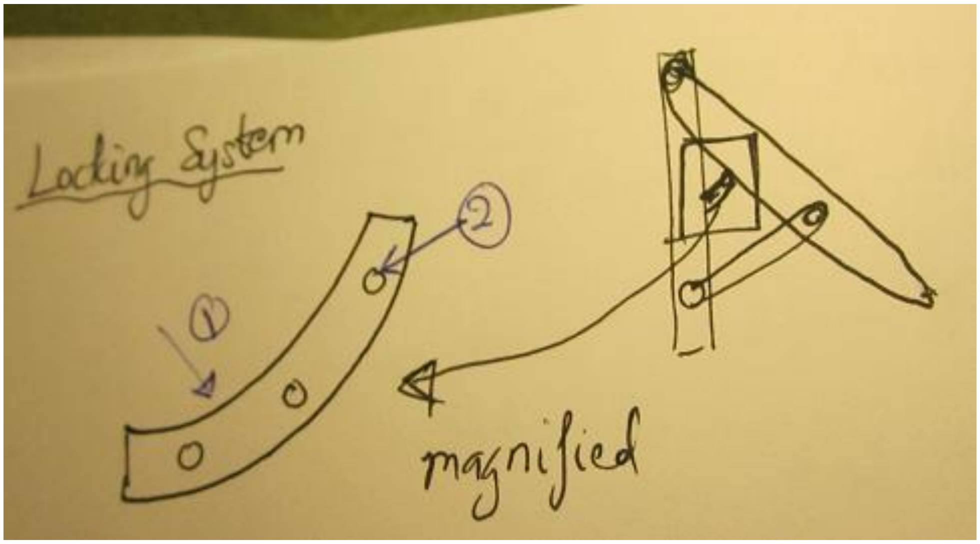


Figure 15: Sketch of Locking Mechanism

1. Curved Member: A thin, circular piece of metal, attached to the large, square rod near the top, will have three circular holes cut into it. These holes will correspond to three different angles between the square rod and the circular rod. They will be set to 80, 60, and 45 degrees from horizontal correlating the angle the user is tilting backwards in their chair.

2. Push Button: A circular push button on the face of the circular rod will be locked into one of the three circles cut into the piece of metal. When the user wants to change to a different angle, they simply have to push the button to adjust this.

Attachment

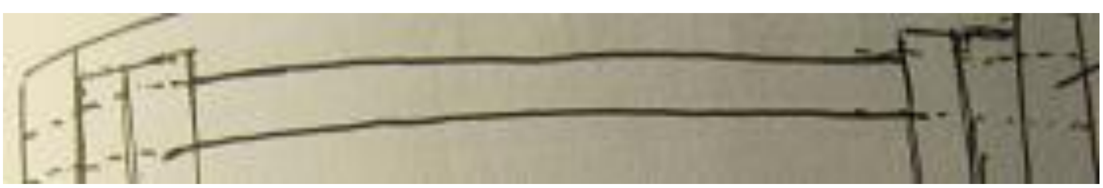


Figure 16: Location of Attachment Points on Wheelchair

1. Thin, Metal Rod: There are two support bars that we will be attaching a thin metal rod that will act as an axle for the long, vertical, circular rod to pivot about. Depending on the analysis which will take place once a concept is finalized, we may add bearings inside the circular rod. The thin, metal rod will also go through the top of the square rod but because the square rod is fixed, it will not act as an axle for it and the clearance between the two will be kept at a minimum.

2. Collars: The way that the thin, metal rod will attach to the support bars are by collars. These collars will go around the support bars and will be adjustable to fit any size diameter for the different sized wheelchairs.

3. Cuts: A small cut will have to be made into the back rest that covers the support rods to allow the collars to securely clamp onto them. There will be four cuts but depending on the type of cover, this may be reduced as we will utilize the gaps the cover already has.

Wheels and Shocks

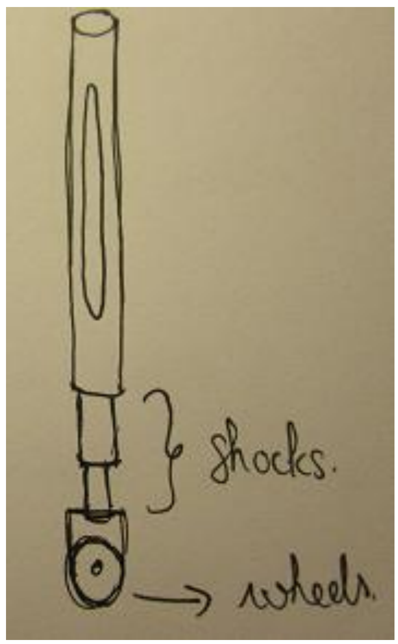


Figure 17: Sketch of Damping System

1. Shocks: After looking at some bicycles with shocks used to absorb heavy impacts, we decided to try to incorporate that into our design to cushion the landing of the user when they tilt backwards. If we can't find a shock small enough for our design, we will custom make one to fit our needs using a spring inside two hollow tubes set to different diameters. This will essentially act as a homemade shock. This shock will be attached to the bottom of the large, circular rod.

2. Wheels: Attached to the shock will be our wheel. This wheel will be able to spin 360 degrees allowing the user to spin while tilted at any angle. As soon as the user tilts back to 45 degrees, these wheels will come into contact with the ground and help ease the force of tilting all the way back.

Handles

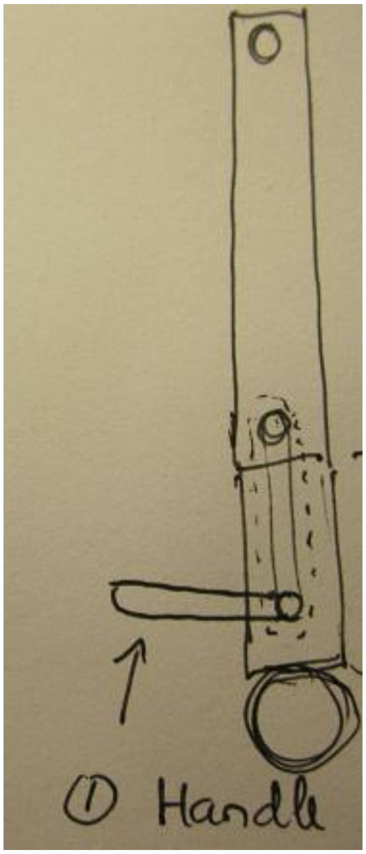


Figure 18: Sketch of Handle Mechanism

1. Handles: The handles will be attached to the little bar. As the user pushes the handles outward, they will raise him to a different angle, closer to the upright position.

Possible Additions and Concerns

- With this design, the main concern is the space between the big wheels and the actual chair frame. We sat in the chair and felt that there is plenty of space for the user to put their hands down there and reach the handle. There is still a small chance that the handle might cause a pinch point directly under the seat as the user is pulling the handle to get back into the sitting position.
- The device, mainly the rod might not be robust enough to support all the weight. That depends on the material and how we design the linkage bars.
- May add safety stopper to remove pinch points between the wheel and the handle.
- The users, especially kids, might not be able to reach the handle since their arms are shorter.

Linkage System II

After taking the 'Linkage System I' to be reviewed by Break the Barriers in December, we received great feedback and thought it necessary to redesign a few aspects that were overlooked. We are pleased that our new design is simpler than before but incorporates the ideas given to us by the team members on the Barrier Breakers and some safety features were added that concerned the team.

Some of the features that changed are:

- A less complex three bar linkage system.
- Reduced the amount of parts
- Redesigned the collar attachment to support more force
- Got rid of shocks and introduced the use of springs in the collar to dampen the force
- Only allowed one angle to be used (45°)
- Wheels used are the light up wheels manufactured by Quickie®
- Removed the need for a complex locking system
- Added safety features

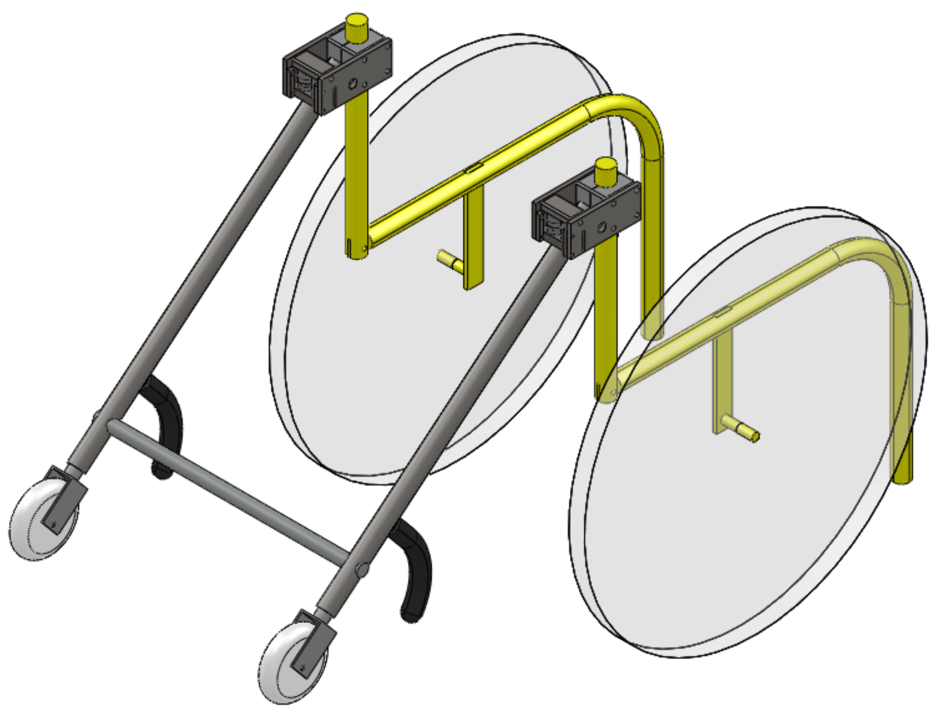


Figure 19: Model of Linkage System II

As shown by Linkage System I we have reduced the initial 6 components down to 2 major systems with 3 subsystems.

Described in detail will be:

- Collar System
- Swing Arm
- Springs
- Miscellaneous (Wheels, Castor, Connecting Rod)

Collar System

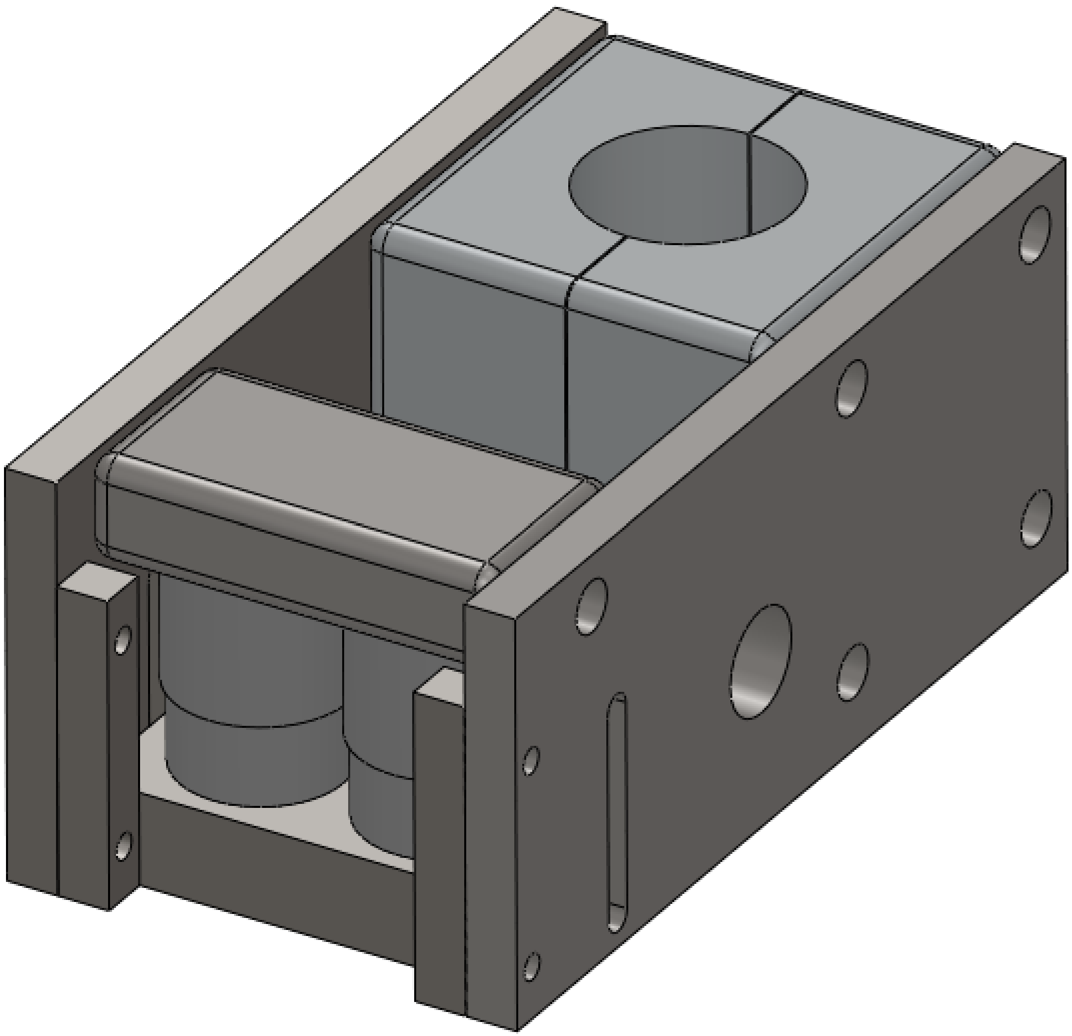


Figure 20: Model of Collar System

This is a picture of the entire collar system with the swing arm removed and not attached to a wheelchair. Below is an exploded view of the system without the springs.

Frame of Collar System

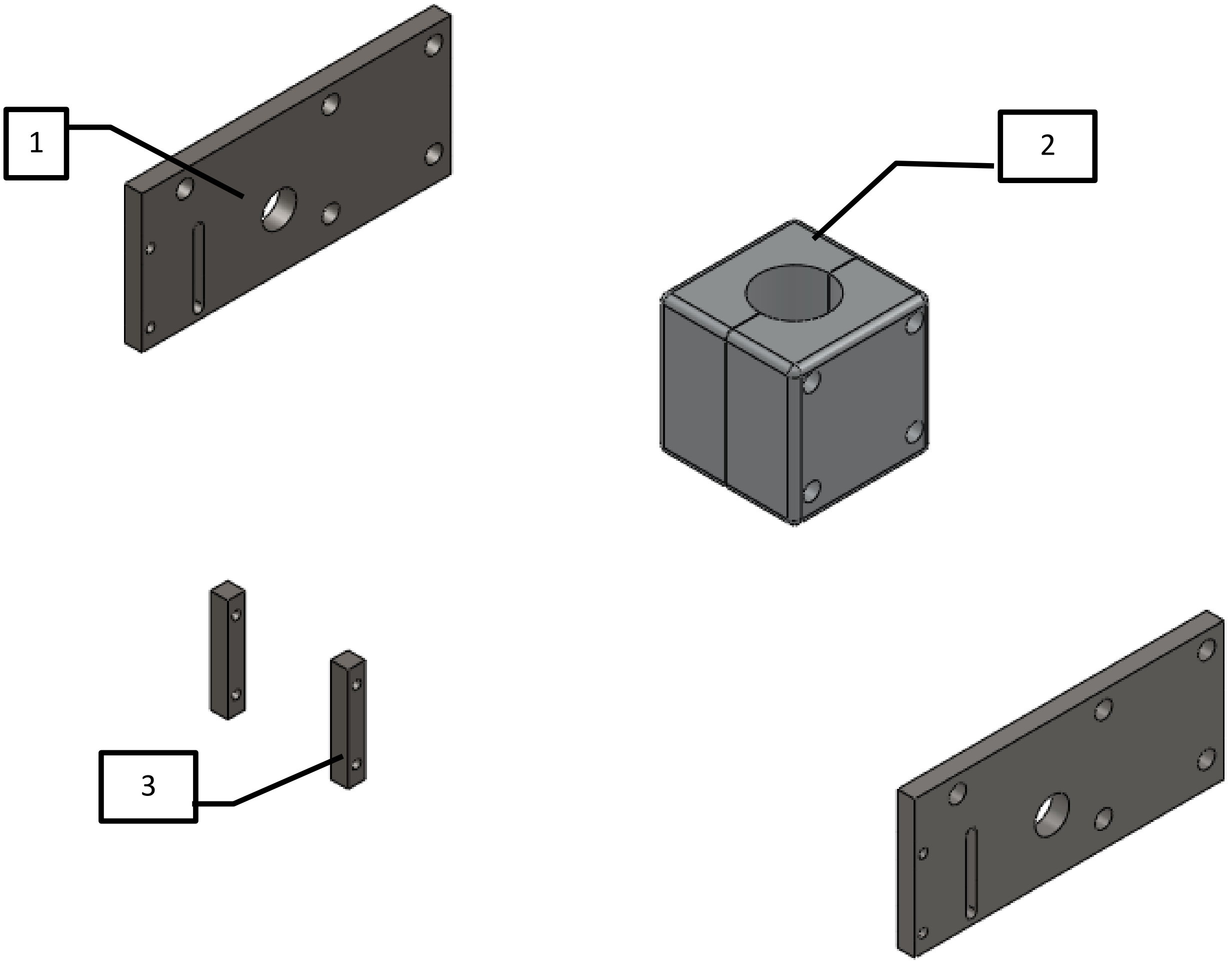


Figure 21: Exploded View of Collar System without Spring System

1. **Side Plate**: These two plates are made out of steel and be .25 inches thick. They are a support piece that reinforces the entire assembly. There are 2 pin holes, 4 bolt holes, 1 hole for the axle of the swing are, and 1 channel for the spring slider (described later)
2. **Collar**: A square block of aluminum has a hole bored through it. That piece is cut in half to form a clamp to go around the wheelchair's support bars. A rubber piece is placed within the hole to ensure the piece is clamped on securely, won't slip, when the sidewalls secure it in place.
3. **Slider Guide**: Two steel bars, are be attached to the sidewalls using screws. They help keep the spring slider (described later) within the confines of the collar system.

Springs

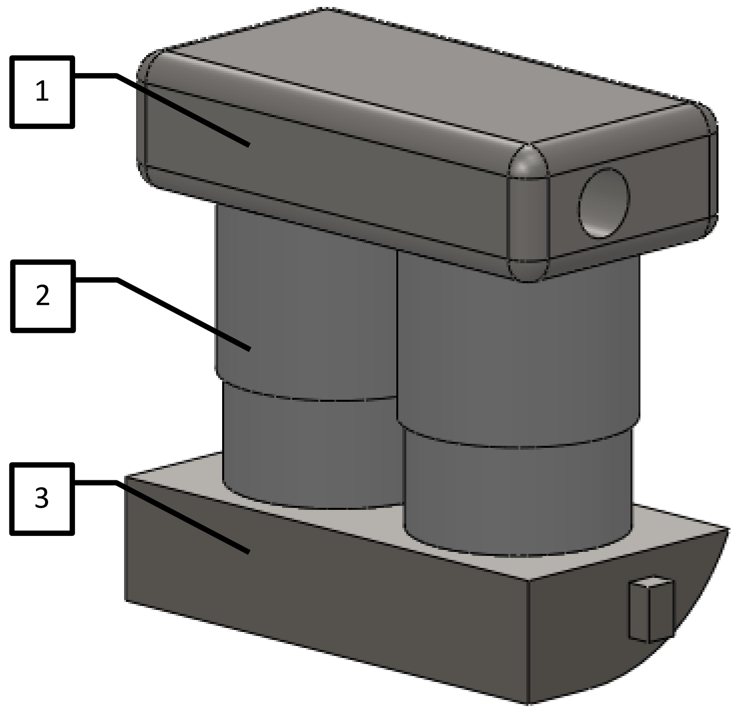


Figure 22: Model of Spring System

1. **Spring Stopper**: Springs are used to dampen the force caused from tilting backwards. They are compressed against this support bar. It is made out of aluminum as well.
2. **Spring Casings**: In order to make sure that there are very few pinch points, we are encasing the entire spring assembly inside two copper sleeves.
3. **Spring Slider**: This piece is what the bottom of the springs are attached to within the casings. As the swing arm (described later) swings backwards, allowing the wheelchair to tilt backwards, the slider slides up, compressing the spring. The knob on the side of the slider piece fits into the channel on the sidewall to provide a way for it to slide up and down as the spring compresses and decompresses. The slider is also curved so it remains in contact with the swing arm at all times.

Spring Casing

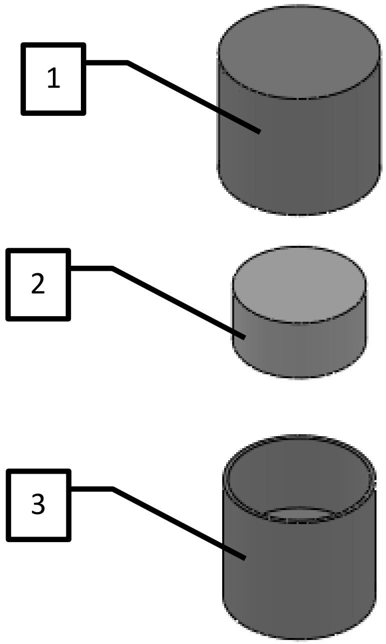


Figure 23: Exploded View of Spring Casing and Slider Rod

1. **Large Casing**: This casing will be made out of copper, as stated earlier, and will have a length longer than the maximum compressed length of the spring to ensure that the springs are not damaged when they compress.
2. **Spring Dowel Rod**: Inside of the spring is an aluminum rod that is 1/8th of an inch longer than the large casing. This comes in contact with the spring slider before the springs can compress completely. The reason we have this here is to provide an additional safety feature in case the springs are not able to handle the amount of force when the user tilts backwards in the wheelchair.
3. **Small Casing**: A smaller diameter copper casing is used for the lower part. This has the ability to slide inside the large casing to allow the spring to compress and to keep fingers from getting pinched.
4. **Spring** (not shown): A spring is coiled around the spring slider rod. It has a compressed rate of 101.4 lbs. /in. There are two on each collar to provide a total for 405.6 lbs. of resistance to the user tilting backwards. These can be adjusted to resist less weight to accommodate for people weighing less than 130lbs.

Swing Arm

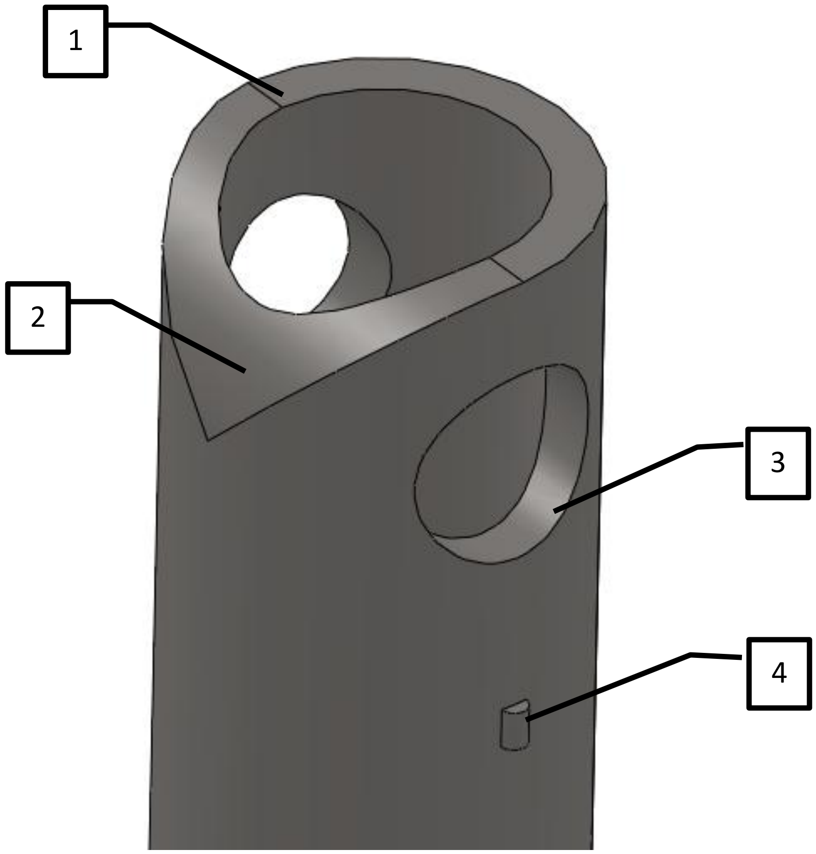


Figure 24: Model of the Top of the Swing Arm

1. **Swing Rod**: The swing arm is the main piece that supports the wheelchair and user while they are in a tilted position. It is made of solid steel, 1 inch in diameter.
2. **Fillet**: The swing arm has a fillet cut out of it so when the bar swings, it will remain in contact with the clamp on the collar system. This ensures that the force is transferred to the support bars for the wheelchair while also being absorbed by the collar system. The main purpose is to provide many outlets for the force to be dispersed about over the entire assembly.
3. **Axle:** A .25-.5 inch steel rod will be placed through the side wall and act as an axle for the swing arm. Because most of the force is transferred to the collar using the filleted edge, there should be little force going to the axle. However, it is very close to a press fit within the side wall as an added safety feature should there be a large amount of force on it. The force is transferred to the perpendicular sidewalls.
4. **Detent:** A detent system is used so that the user can push the swing arms back into a 25° angle. When they take their hands off of the handles (shown later), the swing arms stays in place allowing the user the ability to tilt the wheelchair backwards onto the castor wheels (shown later) and into a tilted position.

Miscellaneous

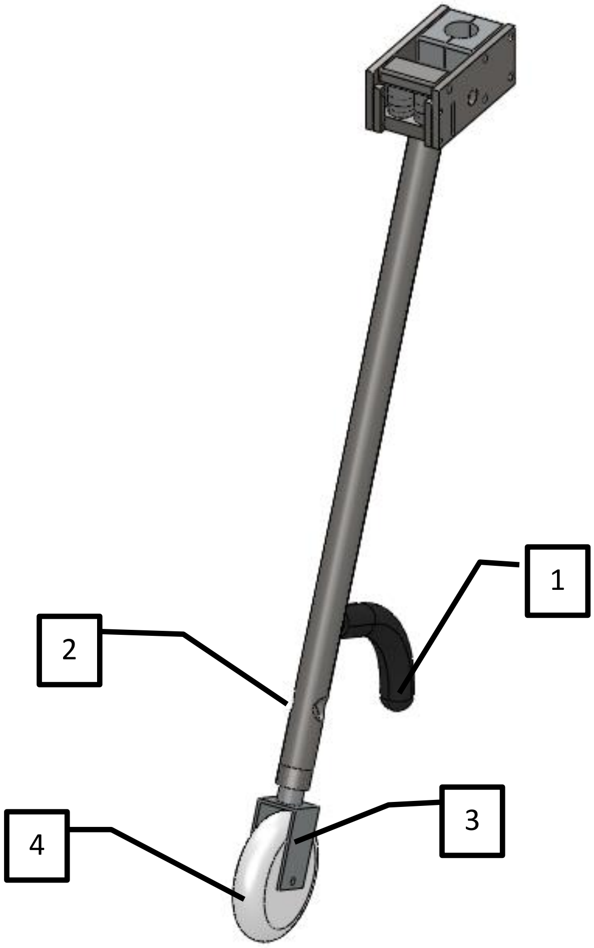


Figure 25: Model of Swing Arm and Collar

1. **Handle**: A curved handle is welded onto the swing arm. It is be 6 inches in length with an inch diameter. We purchased bicycle bullhorn handle bars and cut them to our specified length to be used with our attachment.
2. **Connecting Rod**: A connecting rod is placed between the two swing arms to make sure that the arms don't buckle to the sides when in use. They also allow the user to use only one arm to activate the mechanism in order to tilt backwards
3. **Castor Fork:** The castor fork provides the castor wheels the ability to spin 360° so the user is able to turn whichever way they desire while performing. We ordered this part from a well-known manufacturer that specializes in wheelchair components.
4. **Castor Wheel:** The castor wheels were selected by the team so we are using two light-up castor wheels.

Swing Dancer

This system is discussed in our description of the final design (chapter 4) as it proved to be our best design supported by the concept selection methods used.

Concept Selection Method

Table 5: Decision Matrix

Key: 1 = Good 0 = Neutral -1= Bad	Protruding Lever Box		Tension Gear Box		Linkage Assembly		Linkage Assembly II	
Specifications		*Weight Factor		*Weight Factor		*Weight Factor		Weight Factor
Weight (W)	-1	-.033	1	.033	1	.033	1	.033
Adjustable (Adj)	-1	-.055	-1	- .055	1	.055	1	.055
Durable (D)	1	.044	0	0	1	.044	1	.044
Adaptable (Ada)	1	.087	1	.087	1	.087	1	.087
Cst (C)	0	.011	0	0	0	0	0	0
Weight Tolerance (WT)	-1	-.109	-1	-.109	1	.109	1	.109
Size (S)	-1	-.055	0	.055	0	0	1	.055
Detachable (De)	-1	-.076	1	.076	1	.076	1	.076
Independent (I)	1	.131	1	.131	1	.131	1	.131
Stability (St)	-1	-.065	0	.065	1	.065	1	.065
Safe (Sa)	1	.153	1	.153	1	.153	1	.153
Maneuverability (Man)	-1	-.076	1	.076	1	.076	1	.076
Delivery Date (DD)	1	.098	1	.098	1	.098	1	.098
Maintenance (Mai)	1	.005	1	.005	0	0	1	.005
Total		.049		.659		.927		.987

Table 6: Comparing Specifications to Determine Weight Factor

W vs Adj		**Adj**	Adj vs D		**Adj**	D vs. Ada		**Ada**	Ada vs. C		**Ada**	C vs. WT		**WT**
W vs. D		**D**	Adj vs. Ada		**Ada**	D vs. C		**D**	Ada vs. WT		**WT**	C vs. S		**S**
W vs. Ada		**Ada**	Adj vs. C		**Adj**	D vs. WT		**WT**	Ada vs. S		**Ada**	C vs. De		**De**
W vs. C		**W**	Adj vs. WT		**WT**	D vs. S		**D**	Ada vs. De		**Ada**	C vs. I		**I**
W vs. WT		**WT**	Adj vs. S		**Adj**	D vs. De		**De**	Ada vs. I		**I**	C vs. St		**S**
W vs. S		**W**	Adj vs. De		**De**	D vs. I		**I**	Ada vs. S		**Ada**	C vs. Sa		**Sa**
W vs. De		**De**	Adj vs. I		**I**	D vs. St		**St**	Ada vs. Sa		**Sa**	C vs. Man		**Man**
W vs. I		**I**	Adj vs. St		**St**	D vs. Sa		**Sa**	Ada vs. Man		**Man**	C vs. DD		**DD**
W vs. St		**St**	Adj vs. Sa		**Sa**	D vs. Man		**Man**	Ada vs. DD		**DD**	C vs. Mai		**C**
W vs. Sa		**Sa**	Adj vs. Man		**Man**	D vs. DD		**DD**	Ada vs. Mai		**Ada**			
W vs. Man		**Man**	Adj vs. DD		**DD**	D vs. Mai		**D**						
W vs. DD		**DD**	Adj vs. Mai		**Adj**									
W vs. Mai		**W**												

WT vs. S		**WT**	S vs. De		**De**	De vs. I		**I**	I vs. St		**I**	St vs. Sa		**Sa**
WT vs. De		**De**	S vs. I		**I**	De vs. St		**St**	I vs. Sa		**Sa**	St vs. Man		**St**
WT vs. I		**I**	S vs. St		**St**	De vs. Sa		**Sa**	I vs. Man		**I**	St vs. DD		**DD**
WT vs. St		**WT**	S vs. Sa		**Sa**	De vs. Man		**Man**	I vs. DD		**I**	St vs. Mai		**St**
WT vs. Sa		**Sa**	S vs. Man		**S**	De vs. DD		**DD**	I vs. Mai		**I**			
WT vs. Man		**WT**	S vs. DD		**DD**	De vs. Mai		**De**						
WT vs. DD		**WT**	S vs. Mai		**S**									

WT vs. Mai		**WT**

Sa vs. Man		**Sa**	Man vs. DD		**Sa**	DD vs. Mai		**DD**
Sa vs. DD		**Sa**	Man vs. Mai		**Man**			
Sa vs. Mai		**Sa**						

***Weight Factor = (3W 5Adj4D8Ada1C10WT 5S7De12I6St14Sa7Man10DD 0.5Mai)/92.5**

Each was divided by 92.5 to get individual Weight Factor, shown above in Table 6: Comparing Specifications to Determine Weight Factor, under "Weight Factor Column."

The 3 tables comparing the specifications were made to clarify and show which specification is more important. The most important specification has the highest the Weight Factor (WF). By multiplying the WF with the ratings of 1, 0, or -1 for the specifications, we acquired a weight rating. Adding the column of WF for the different concepts, we get a total WF. The concept with the highest total WF is the one that we will choose to apply. As shown above, the Linkage Assembly and Linkage Assembly II are the concepts that have the highest WF's, .927 and .987, respectively. They satisfy the specification more adequately than .659 for the Tension Gear Box and .049 for Protruding Lever Box. The Swing Dancer Assembly was fabricated based solely upon the LAII with a few minor adjustments. It WF should be as high if not higher than LAII since we modified LAII in order to fabricate the Swing Dancer.

Chapter 4: Description of the Final Design

Description and Layout

Swing Dancer(s)

After the completion of building the Linkage System II, we began the testing stage. It was through this process that we found that the design had some minor flaws. These flaws are listed below.

- Slider: The slider's design proved to limit the mobility of the swing arms. Originally we thought that these would slide smoothly when the swing arm came in contact with the rounded edge of the slider. However, when the swing arm pressed against the slider, it would twist in place and seize; forcing the swing arm to stop from leaning back any further than 5°.
- Spring Casings: The spring casings that were supposed to house the springs proved to be extremely difficult to keep in contact with the slider and stopper while the spring was being compressed within. The casings would detach and oppose the ability of the spring to operate smoothly. This also hampered our swing arm from swinging out to the desired angle of tilt.
- Stopper: Due to the springs pushing up on the stopper when the slider compressed them, the stopper would often twist. This was caused by the swing arm pushing against the slider at different angles as it started to swing back. As the angle increased, more force was transferred from the slider to the spring causing the stopper to twist in place. This forced the swing arms to stop rotating back into the fully activated position.
- Detent: Although the detent did not decrease the mobility of our device, we found that it was also an unnecessary feature. The swing arms automatically swing backward when the user starts to tilt backwards because of the amount of weight at the bottom of the swing arm coming from the support rod, caster forks, and casters.

Due to these components limiting our design and overall performance, we decided to try using the device without the limiting components. The justification for testing our apparatus in this manner came from over designing our attachment with too many safety features and 'checkpoints.' After taking out the stopper, springs, spring casings, slider, and slider guides, we found that by just relying on the flat edge on the top of the swing arm, the device functioned perfectly. As stated earlier in the report, the springs and adjoining components were added as extra safety features to help cushion impact or reduce the speed of descent into the tilted back position. However, after removing those pieces, not only did the device perform safely but it was also able to achieve a lower angle of tilt than predicted along with being lighter and the overall cost was lowered. The following section is an updated version of the Linkage System II

with the unnecessary components removed, which we are calling the "Swing Dancer". As per our sponsor's request, we designed two models of the Swing Dancer. The designs differ slightly from each other as the first model was made to support the maximum weight range while the second model was made to support a person closer to the minimum weight range. We decided to make these models specific to the two gymnasts using our attachments for a more customized feel; however, our design could be made into a standardized model that would support both dancers. The only variation in a standardized model is the swing arm lengths, which are specific to the height of the chair supports on each gymnast's wheelchair. In the following pages, the Swing Dancer's components are discussed in detail.

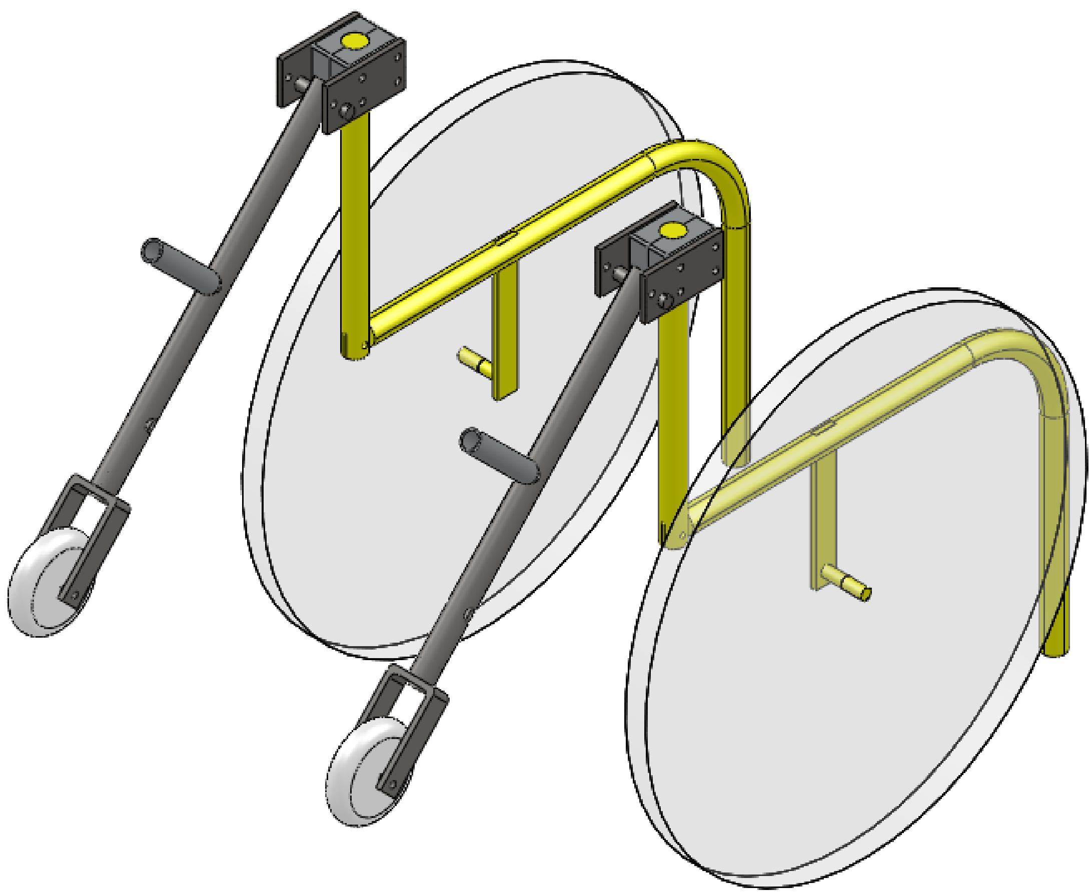
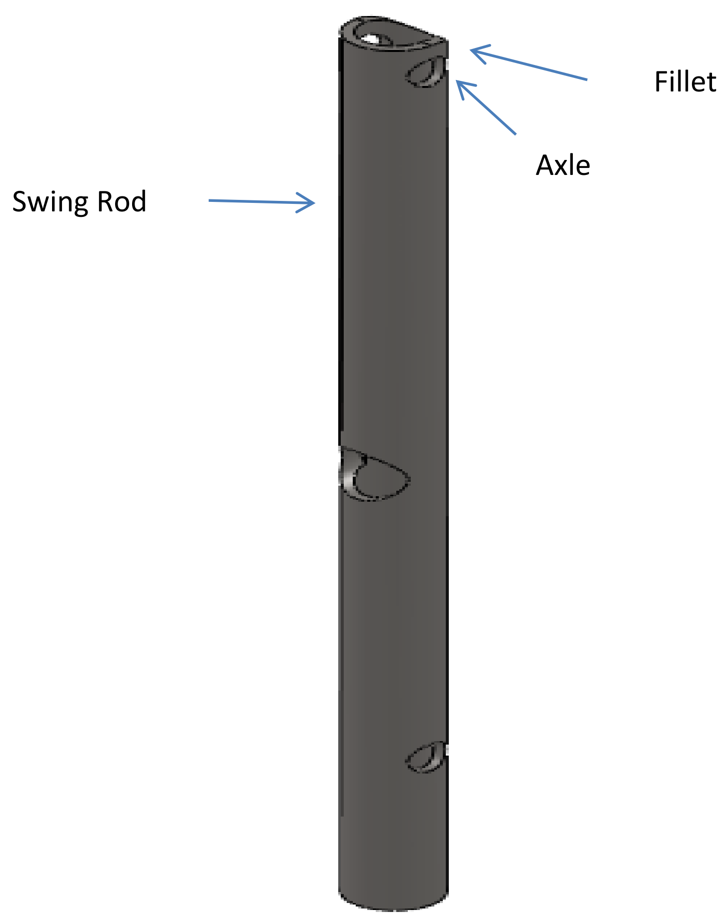


Figure 26: Entire Swing Dancer Assembly

Swing Arms



1. **Swing Rod:**
   a. Model #1: As stated in the previous description (pg. 43) of the swing arm, we designed the rod to be extremely strong by ordering 1" diameter steel rods with ¼" thickness. After running some calculations, we found the factor of safety to be way above 3. This is discussed in Analysis section.
   b. Model #2: When designing the swing arms for the lighter gymnast, we decided to go with a much lighter rod. We choose the same diameter but the thickness is 1/16th. This will allow the attachment to weigh a significant amount less than Model #1's as the gymnast using this model will not require as much support.
2. **Fillet**: See previous description (page 43)
3. **Axle:** See previous description (page 43)

Collar System

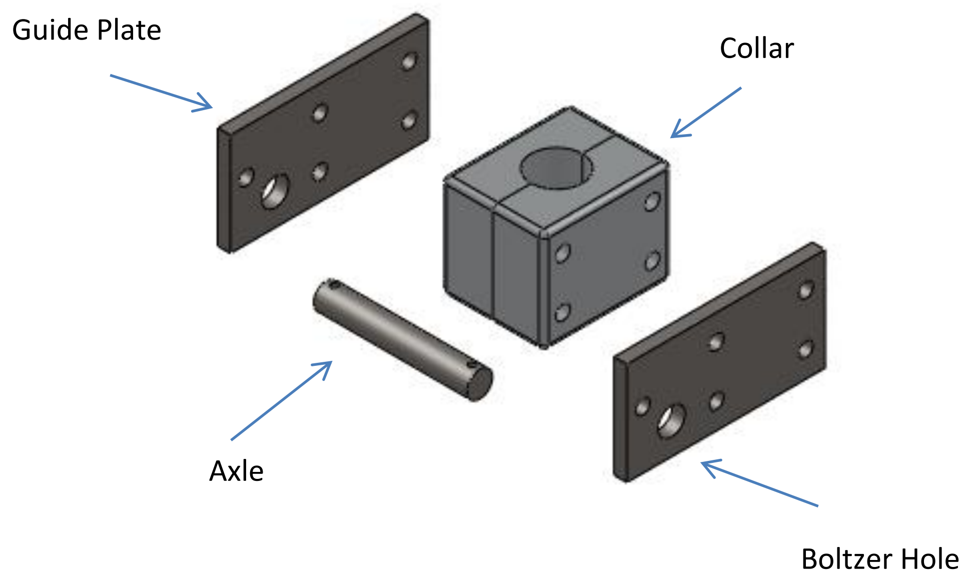
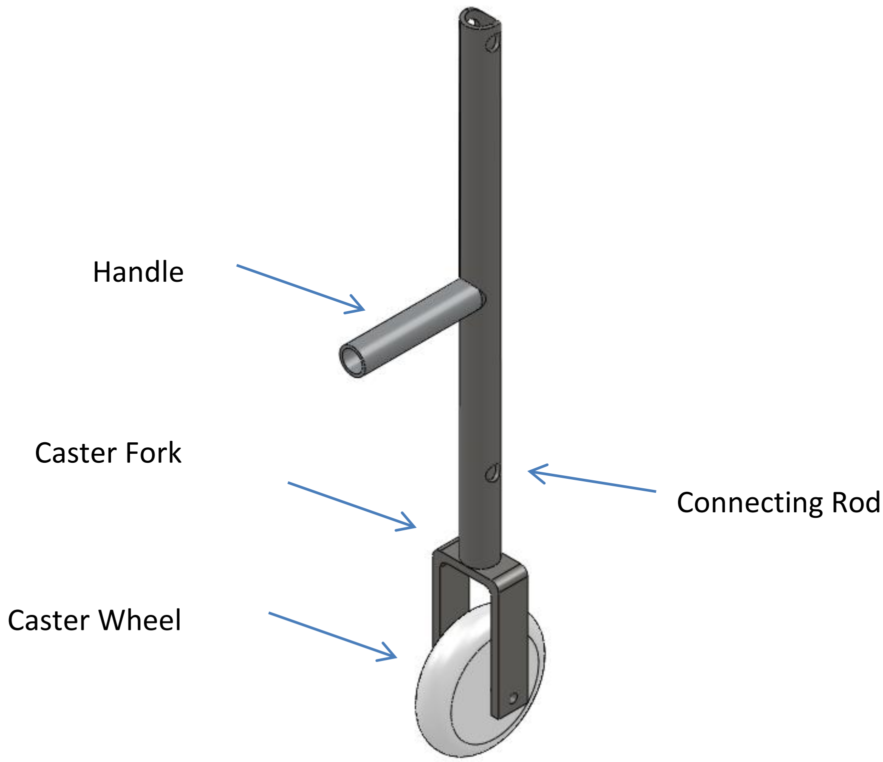


Figure 27: Collar System Exploded View

1. **Side Plate**: A minor change from the previous design (pg. 40) is a shortening in the length of the plate. This is due to no longer needing the screw holes, channel, or slider guide holes.
2. **Collar**: See previous description (page 40)
3. **Bolter**: This is a new addition to the previous designed collar. We felt that because we got rid of multiple safety features, we needed to add one to ensure our device still had a way to stop rotating backwards in case of a component failing. This is a ¼" bolt that will go through the side plates and will stop the swing arms from rotating any further back

Miscellaneous



1. **Handle**: Instead of using a curved handle (as discussed on page 44) we decided to use a straight handle that is four inches long. We found during preliminary testing that in case of a swing arm failure, when the straight handle came into contact with the ground, it prevented the user from hitting their head on the ground when falling over. We attached these to the swing arms by using T.I.G. welding. A rubber cap was placed on the ends of the handles to ensure there would be no exposed, sharp edges.
2. **Connecting Rod**: A change that we made to the previous design (as discussed on page 44) is instead of threading the ends of the rods and running the risk of stripping the threads with repeated use, we decided to use screws as pins to keep the swing arms in place on the connecting rod.
3. **Castor Fork:** After receiving the caster forks from the manufacturer, we realized that our previously concept would not work during the assembling process (as discussed on page 44). We decided instead to attach the caster forks directly to the swing arm using the bolt they were attached to and welding it to the bottom of the swing arm.
4. **Castor Wheel**: See previous description (page 44).

How the Design Works

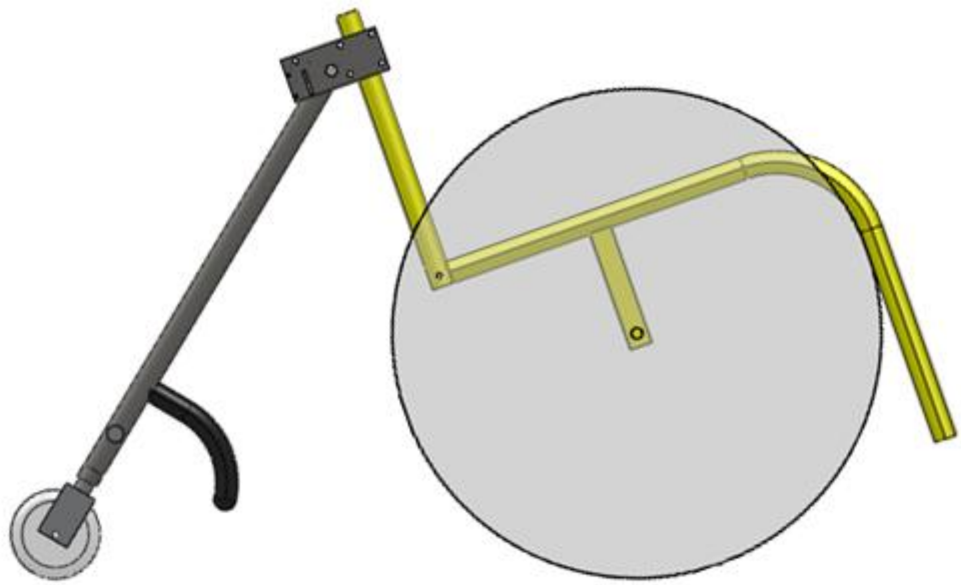


Figure 28: Wheelchair tilted at 25°

The entire system is attached to a wheelchair by taking the seat cushion off the chair and fitting the collar system around the wheelchair's support rods. The collar is secured around the support rods by a series of 4 - ¼" bolts. These bolts also affix the aluminum side plates to the collar.

When the user is ready to use the attachment, they simply need to turn the wheels forward with a moderate amount of force while leaning backwards. When the wheel chair starts to lean backwards, because the swing arms are bottom heavy, the rods will start swinging backwards until they come into contact with the ground. Once the wheels land on the ground, the user needs to continue rolling the large wheels forward causing the swing arms to continue rolling backwards. The weight of the user plus the forward rolling motion will ensure the swing arms become fully engaged. At a fully engaged position, the entire assembly will achieve a tilt of 32°-42°

To upright the wheelchair from the tilted position, the user needs only to reach behind the seat and pull on the handle bars towards themselves while leaning forward. As the swing arm is pulled closer to the chair, the chair will gradually reduce the angle of tilt. Once the user reaches the 25° mark, the center of gravity will be in front of the big wheels point of contact with the ground causing a moment around that point of contact. This causes the chair to fall forward into the upright position. An alternative, and better method, is to use a moderate amount of force to roll the chair forward and stop the wheels from rolling abruptly causing the chair to tilt

forward. Please refer to Appendix G: Installation Guide/User Manual for a more complete manual of how to use this device.

Specifications Satisfied by Top Concept

In choosing the best concept, we had our customer specifications as well as engineering specifications in mind. While comparing the concepts; Protruding Gear Box, Tension Gear Box, Linkage Assembly (I and II) and Swing Dancer, we wanted to choose the concept that satisfied most of if not all of our specifications. The concept that satisfied the majority of the specifications was the Swing Dancer.

The Swing Dancer is light, simple and easy to manufacture. The weight of it is 10 lbs. or 7 lbs. depending on the model. It is designed to be durable, adaptable and adjustable; the details were portrayed in Swing Dancer(s) in Testing Methods. As for the Cost, please refer to the Cost Analysis. The design is compact since no more than 5 inches will protrude from the back of the chair and therefore will not interfere with the other dancers. The Swing Dancer is virtually hidden and there is no need to detach it. The design is able to withstand about 500lbs of force since there are two swing arms, one on each side of the chair frame. The two linkages attached on the wheelchair frame will provide stability. It is independent and safe for the user to use since they need only to use their own body weight to rise and lower the chair with and additional option of using the handles to raise the chair. Details of this handles are described in the Miscellaneous section in Chapter 4: Description of the Final Design. The attached wheels on the Swing Dancer will achieve the desired maneuverability since they allow the user to roll forward and backward. However, the ability to turn a full 360° was hampered by the design of the casters used. After building the device, we realized this flaw. A solution to this is provided in Chapter 7: Conclusion and Recommendations. With a simple design, were able to finish with the time frame given and maintenance will be cheap and easy.

Analysis

In the process of designing, one of the most important steps is to analyze the device for loads and stresses that can cause failure. This step is important since it shows the relationship between all of our components and how they function together. Analysis helps determine the weakest point in the device or points that can be designed better. Analysis also helped us determine the strength and weight of the device; resulting in material selections which directly affect the weight of the design. Analysis was done on the Swing Dancer to prove that it is safe to use and enabled appropriate material selection.

A Free Body Diagram (FBD) was created in order to identify all forces that are acting on the device. As the device is inactive, no force acts on it; Figure 29: FBD of Wheelchair at Rest shows a representation of FBD. In this figure, W is the weight of the user, N_1 is the force on the small front wheel and N_2 is the force on the big wheel.

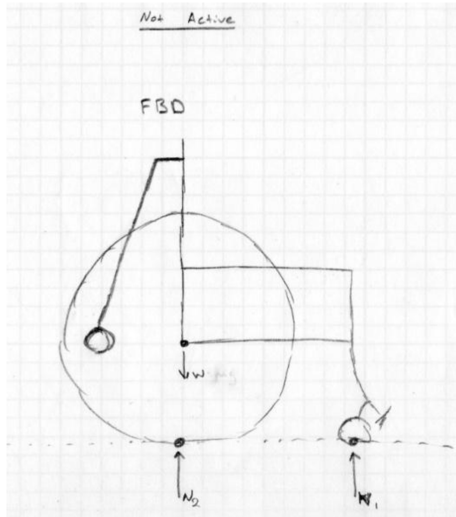


Figure 29: FBD of Wheelchair at Rest

A detailed analysis was done to find out what the forces are when the Swing Dancer is making contact with the ground. The minimum angle of tilt that users can be in when gravity takes control and pull them back to the sitting position is 25 degrees from vertical. A Free Body Diagram (FBD) in Figure 30: FBD of Wheelchair Tilted at 25° shows all the forces that are acting. W is still the weight of the user, and it is located at the center of gravity, CG. With the CG located in front of the two contact forces, R_1 and R_2, the user will return to a sitting position. R_1 and R_2 are contact forces on LAII and big wheel, respectively. Calculations were done to show that R_1 is -2.9 lbs. while R_2 is 252.9 lbs. and W is given at 250 lbs. A sample calculation justifying the forces can be found in Figure 87: Analysis at 25°.

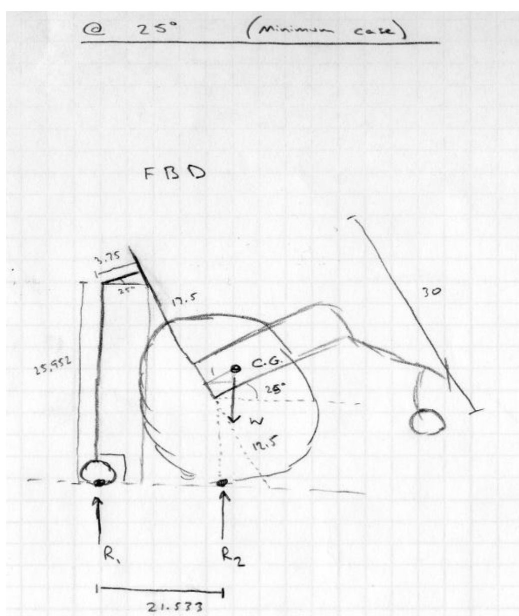


Figure 30: FBD of Wheelchair Tilted at 25°

The max angle that the user can tilt back is 32-42° from horizontal. A FBD showing forces acting on the Swing Dancer can be seen in Figure 3. With the CG of the user conservatively estimated at about 3 inches from the back of the seat, the FBD shows that the weight is between the two contact forces, R_1 and R_2. The weight of the user is now being actively supported by the Swing Dancer and the big wheel. Distances calculated in Figure 31: FBD of Wheelchair Tilted at 45° was used in calculations for R_1 and R_2. The detailed analysis to find R_1 and R_2 are in Figure 88: Analysis at 45° R_1 and R_2 are calculated to be 22.5 lbs. and 227.5 lbs. respectively.

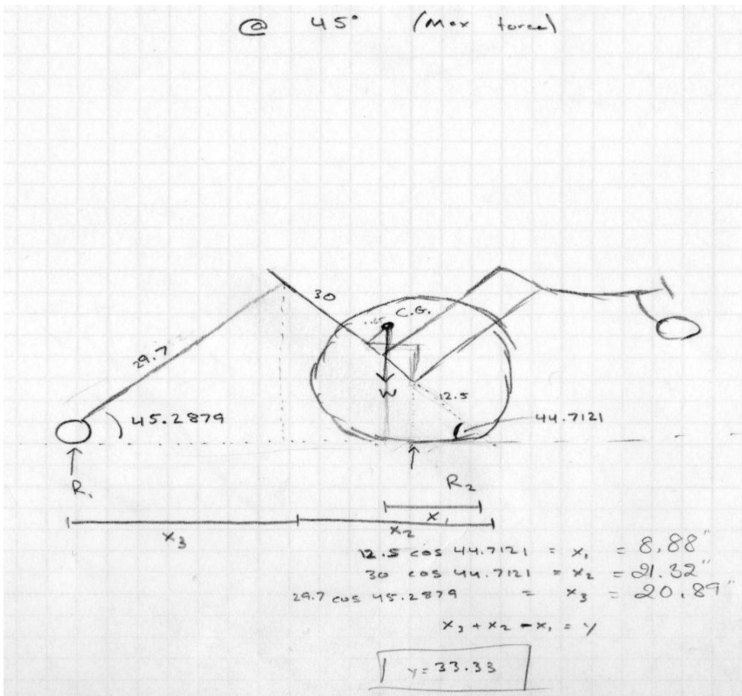


Figure 31: FBD of Wheelchair Tilted at 45°

The Swing Dancer supports the weight of the user and the loads that the device is subjected to are compressive. With a bar under compressive load, buckling is the main concern since the device should be strong enough to hold up the weight without failing. Applying the analysis for buckling, the max load that will cause failure is 672 lbs. Figure 89: Buckling Analysis is where the calculation can be seen.

As for the device, it's imperative that the user will be able to operate it easily and independently. Therefore, calculations for pull force when in max tilted position were generated. A FBD is below in Figure 90: Max Pull Force Analysis showing the forces with R_1 and R_2 from the previous calculation for 45° tilt. F is the pull force and f is the force of friction. F and f are equivalent and their value is 9 lbs. The value for R_1 was found to be 22.5 lbs.; however, that force corresponds to both wheels on the support bars. Each wheel sees only 11.25 lbs. and this force was used to calculate the max pull force which was stated above, 9 lbs. The calculations can be seen in more details in Figure 90: Max Pull Force Analysis.

Factor of safety is the ratio of max material strength to max design load. In this case, the max design load our device will support is 11.25 lbs., this is the force on each wheel calculated at max tilt angle. The max tensile strength for AISI 1030 Annealed Steel is 62000 psi. This strength was used as the material strength to calculate the Factor of Safety. A value of 25.6 was calculated for the Factor of Safety. Details can be found in *Appendix E* under "Factor of Safety Calculation Bending Stress on Support Bars."

Cost Analysis

Table 7: Bill of Materials and Cost (Model #1)

Assembly	Part	Material	Geometry	Quantity	Price [USD]	Item #
Collar						
	Sidewall(M)	6061 Aluminum Alloy	4.5" x 2" x .25"	4	$15.39	8975k713
	Collar (M)	6061 Aluminum Alloy	2" x 2" x 2"	2	$31.72	9008k531
Swing Arm						
	Swing Arm (M)	4130 Alloy Steel	Length: 16", OD: 1", ID: .5"	2	$77.71	89955K8
	Axle (M)	4130 Alloy Steel	Length: 3", OD: .5", ID: .402"	2	$0.00	
	Connecting Rod (M)	4130 Alloy Steel	Length: 16.5", OD: .5", ID: .402"	1	$22.61	89955k26
	Caster Wheel (Q)	Rubber	4" x 1"	2	$72.00	RP183000
	Caster Fork (S)	Aluminum		2	$260.00	US456
	Handles	Steel	Length: 4" , OD .75"	2	$0.00	Donated
Miscellaneous						
	Bolts (M)	Zinc-Plated Steel Grade 5	36" x 2" x .25"	10	$8.07	91247a553
	Screws (H)	Zinc	#4 –40 x ¾ "	8	$1.18	030699274611
	Nut (A)	Steel	¼" Coarse Thread	10	$0.60	
Total				35	**$489.28**	

*Key: M= McMaster-Carr, S= Spring Life, Q= Quickie Wheelchairs, A= Ace Hardware, H= Home Depot

Table 8: Bill of Materials and Cost (Model #2)

Assembly	Part	Material	Geometry	Quantity	Price [USD]	Item #
Collar						
	Sidewall(M)	6061 Aluminum Alloy	4.5" x 2" x .25"	4	$20.26	8975k683
	Collar (M)	6061 Aluminum Alloy	2" x 2" x 2"	2	$0.00	9008k531
Swing Arm						
	Swing Arm (M)	Low-Carbon Steel Tubing	Length: 21", OD: 1", ID: .87"	2	$11.78	7767t23
	Axle (M)	4130 Alloy Steel	Length: 3", OD: .5", ID: .402"	2	$0.00	
	Connecting Rod (M)	4130 Alloy Steel	Length: 16.5", OD: .5", ID: .402"	1	$0.00	89955k26
	Caster Wheel (Q)	Rubber	4" x 1"	2	$72.00	RP183000
	Caster Fork	Aluminum		2	$0.00	Donated
	Handles	Steel	Length: 4" , OD: .75"	2	$0.00	Donated
Miscellaneous						
	Bolts (M)	Zinc-Plated Steel Grade 5	36" x 2" x .25"	10	$8.07	91247a553
	Screws (H)	Steel	#4 - ½ "	8	$1.18	030699274611
	Nut (A)	Steel	¼" Coarse Thread	10	$0.60	
Total				37	**$113.89**	

*Key: M= McMaster-Carr, Q= Quickie Wheelchairs, A= Ace Hardware, H= Home Depot

Safety Considerations

With regards to the safety of the users, many concerns were addressed and analyzed. Using steel as the material for the support bars will help add to the rigidity of the device. The risk of performers accidentally kicking or rolling into the bars and bending it is addressed. Steel handles a higher bending load than aluminum even though it is heavier. As for sharp edges and pinch points, round fillets are designed into the device to eliminate sharp points and all pinch points will be covered. The main concern is the user falling back and hitting their head if the device was to slip from under them. However, a stopper was integrated to limit the device from slipping to far; 90° from its rest position is the max angle that the device can attain.

Maintenance and Repair

Ease of assembly and disassembly were specification for the device hence, maintenance are minimal. In order to maintain the device, it is recommended to remove the device from use and wipe it down with a clean, dry towel. Use water if necessary and add lubricant to moving joints. The pivots for the support bars and wheels potentially require lubrication. All parts are painted and coated with rust resistance materials. As for repair, the device has minimal moving parts and all parts are off the shelves, replaceable materials; therefore, repair will be cheap and easy. Refer to Cost Analysis, for detail parts list if the need to replace components arises.

Chapter 5: Product Realization

Material Procurement

Most of the materials for manufacturing were ordered through McMaster-Carr. As for the casters and the caster forks, they were ordered from Quickie Wheelchair and Spring Life, respectively. BTB donated 2 wheelchairs from the beginning of the project in order for us to experiment and get measurements. The chairs were both Quickie models and one is an adult-size and the other is a kid-size. Overall, the list of materials and prices can be found in the Bill of Material and it can be found in Chapter 4, under the "Cost Analysis" section.

Manufacture Processes

All materials, sizing and dimensions are specified in the BOM. Below is a detailed manufacturing process that is recommended in the order of machining.

Swing Dancer Assembly

- Collar Assembly
    a. Side Plate
        i. Cut ¼ inch thick sidewall to dimensions specified by Solidworks

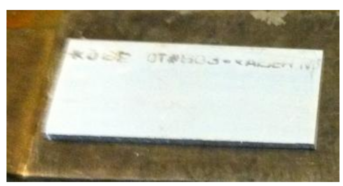


Figure 32: Cut Side plate using bandsaw

        ii. Drill five 9/32 inch holes according to the locations specified by Solidworks model

Figure 33: Side Plate with bolt holes

iii. Drill one 17/32 inch hole with locations specified by drawings

Figure 34: Side Plate about to receive the 17/32 axle hole

iv. Grind all sharp edges off of sidewalls

Figure 35: Grinding edges of side plate

1. Quantities: 4
2. Tools Recommended: Horizontal Bandsaw for cutting sidewalls to size, drill press with specified drill bit sizes for holes and grinding wheel for grinding fillets

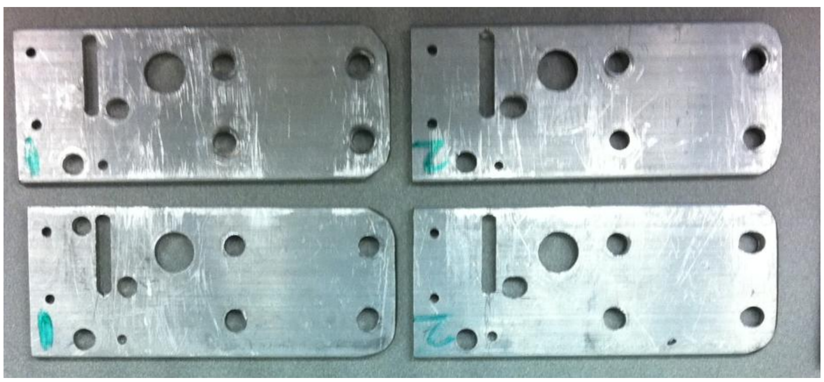


Figure 36: Side plates for one Swing Dancer

b. Collar
    i. Cut 2 inch thick block to size

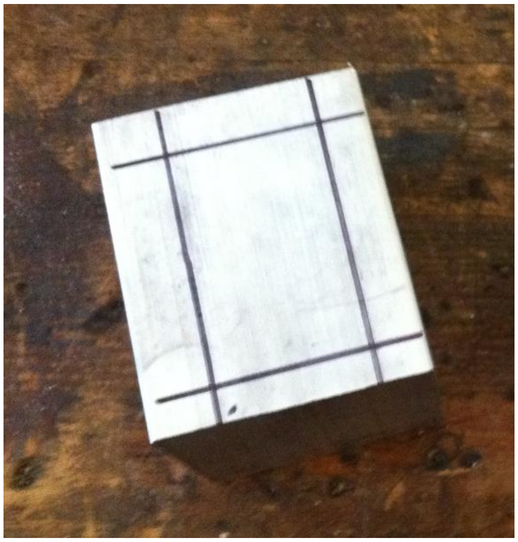


Figure 37: Cut collar to size

ii. Drill 9/32 inch holes with locations specified

Figure 38: Drilling four 9/32" holes in collar

iii. Drill 1 inch hole in the block where specified

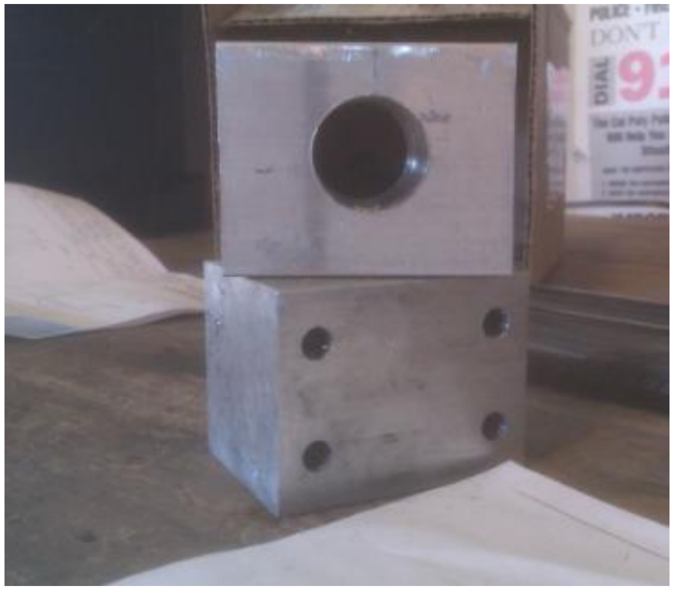


Figure 39: Collar with Frame hole and 4 bolt holes

iv. Cut block into halves as specified

Figure 40: Cut Collar

v. Grind and debur all sharp edges off of Collar

Figure 41: Deburring sharp edges on Collar

vi. Glue on rubber insert to prevent slipping when attached to the wheelchair frame.

Figure 42: Collars with rubber insert

1. Quantities: 2
2. Tools Recommended: : Horizontal Bandsaw for cutting collars to size, drill press with specified drill bit sizes for holes and grinding wheel for grinding fillets

Figure 43: Set of Collars and bolts for the Swing Dancer

a. Axle
   vii. Cut axle to length

Figure 44: Axle cut to size

   viii. Drill 2, 1/8 inch holes where specified for screws

Figure 45: Completed Axle

1. Quantities: 2
2. Tools Recommended: : Horizontal Bandsaw for cutting axles to size, drill press with specified drill bit sizes for holes

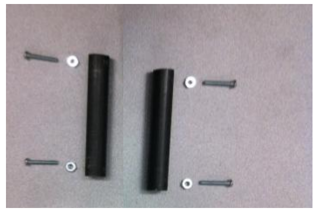


Figure 46: Two Axles for the Swing Dancer

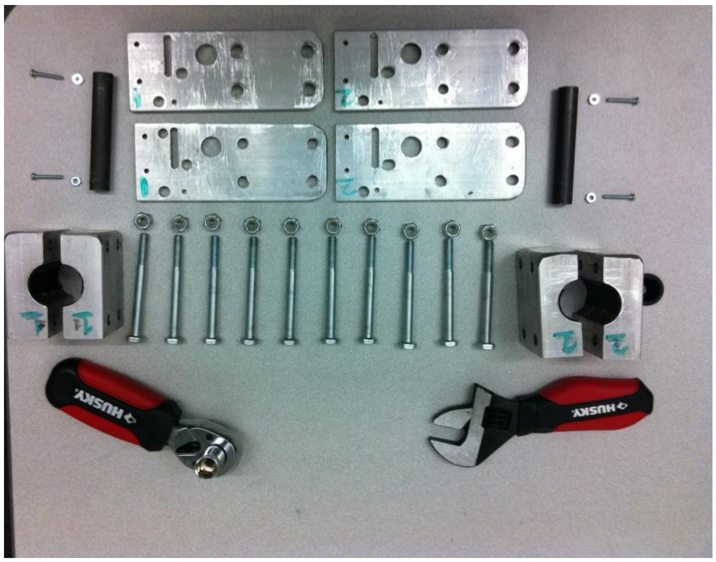


Figure 47: Complete Collar Assembly

- Swing Arm Assembly
    a. Swing Arm
        i. Cut rod to length required for different chair heights

Figure 48: Swing Arm rods cut to size

ii. Drill two ½ inch holes where specified for the axle and the connecting rod

Figure 49: Axle hole on Swing Arm

Figure 50: Connecting Rod hole on Swing Arm

iii. Fillet off the end where the axle hole is located; this will allow smooth

Figure 51: Fillet on Swing Arm

iv. swinging motion

Figure 52: Check swinging motion of Swing Arm

1. Quantities: 2
2. Tools Recommended: : Horizontal Bandsaw for cutting swing arms to size, the mill with specified drill bit sizes for holes and grinding wheel for grinding fillets

b. Handle

i. Cut handle to length

Figure 53: Handle Cut to Length

ii. T.I.G weld the handle on to the swing arm where specified

Figure 54: Handles Welded

iii. Round off all sharp edges from cutting

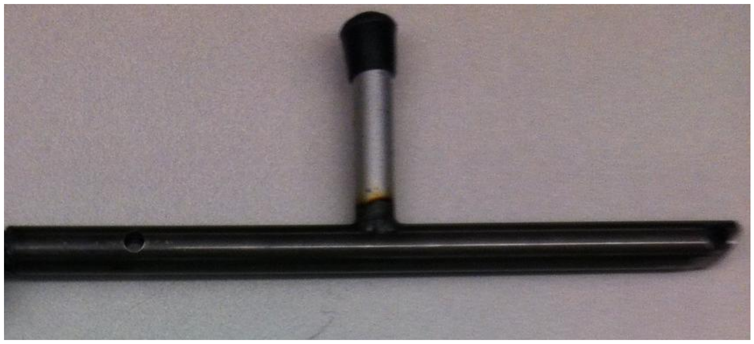


Figure 55: Swing Arm and Handle

1. Quantities: 2
2. Tools Recommended: : Vertical Bandsaw for cutting handles to size and grinding wheel for grinding fillets

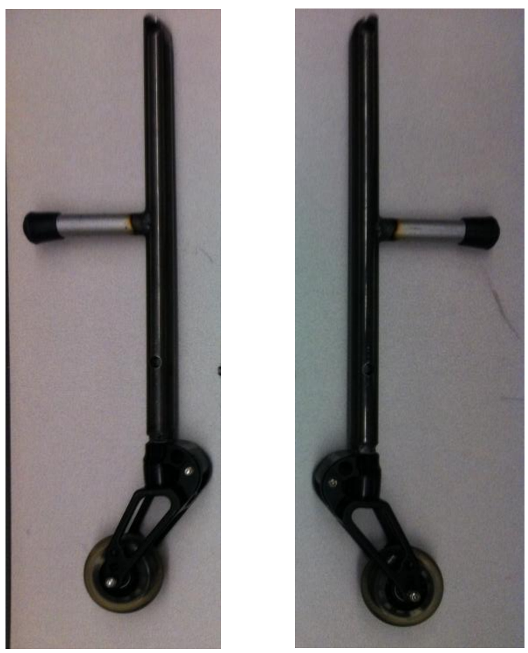


Figure 56: Swing Arms for Swing Dancer

c. Connecting Rod

   i. Cut the connecting rod to length

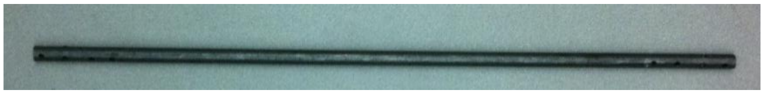


Figure 57: Cut Connecting Rod

   ii. Drill 8, 1/8 inch holes where specified for screws

Figure 58: Connecting Rod holes

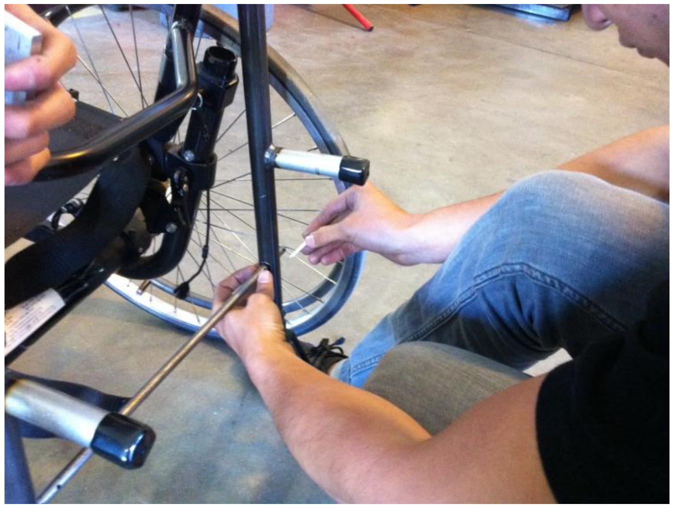


Figure 59: Attaching Connecting Rod to Swing Arms

1. Quantities: 1
2. Tools Recommended: : Horizontal Bandsaw for cutting connecting rods to size, drill press with specified drill bit sizes for holes

- Notes: Remove all burrs and fillet off of surfaces and corners for added safety.

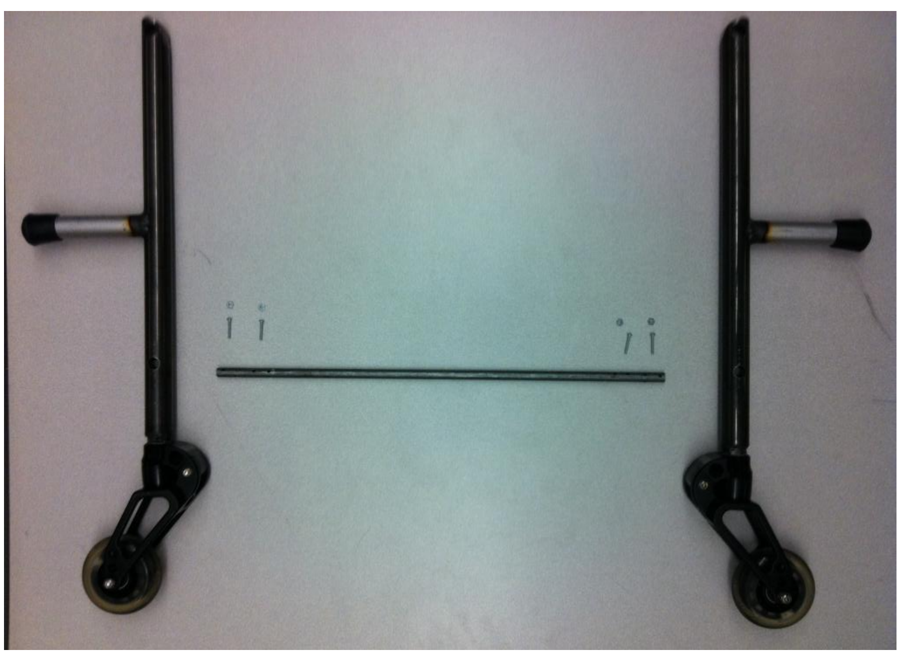


Figure 60: Complete Swing Arm Assembly

Product Realization

In manufacturing the Swing Dancer(s), we found that it was difficult to drill the holes on the swing arms. The ½ inch thick tube was difficult to drill using conventional drill press; in addition, the drill press was not accurate for precise holes. It's imperative for the holes on both swing arms to be aligned since they have the same rotation axis and they will swing together. If they are off centered, the swinging motion will be compromise and they won't swing smoothly. The locations for the holes need to be extremely accurate; thereby, a mill was used. Even with a mill, drilling holes through a ½ inch thick walls is time consuming and difficult. The first time we drill the holes, it took approximately 2 hours to drill one and the cutting tools got damaged and needed to be replaced. After drilling the axle holes and the connecting rod holes, we found that the holes for the connecting rod were off centered. This created a problem for the swing arm and they did not line up correctly.

We recommend several solutions we found while making the second assembly:

1. Thinner tubes: The swing arms did not need to be ½ in thick; we over design this part since all the forces will be concentrated here. However, as the calculations revealed, the swing arms are subjected to only 11.25 lbs. We recommend using 1/8 inch thick tubes for ease of machining.
2. Finding the center: Using a center finder tool in the mill, it helps to drill an accurate hole.
3. Face the tube: Cutting a flat face on the tube will prevent the drill bit from slipping while cutting and it also help save some time.
4. Drill both arms: Clamp the two arms together so the hole will be perfectly align.
5. Step drill: Step drilling is where you start with a small drill bit and progressively increase the bit size until you arrive at the specified size. This method saves the tool and save some time.

For better stability, it is important for making the holes on the swing arms align perfectly. They need to be align so the connecting rod will go through them with ease; thereby making them move together. If the holes are off when the device is engaged, the swing arms tend to bow out.

We recommend several solutions:

1. Followed step 4 above: Drill both arms together
2. Installing the collars correctly: Make sure the collars are straight when installing. If they are not, the arms will bow out independently and won't be aligned.

The swinging motion of the swing arms can be improved. As of now, the axles connecting the swing arms to the side plates are not smooth.

We recommend:

1. Adding press fit bearing to the side plates and sliding the axles through them for the arms to swing smoothly.

The swing arms can be improved for swinging smoother and less grinding against the collars. Our swing arms are grinded down to create a fillet in order for it to swing freely. The grinding is not a good method since it is inaccurate and it is more of a trial and error process. We want the swing arms to move against the collars yet only contacting the collar at the final position of tilt. Sometimes, the collars and the swing arms contact each other as the arms move. This creates friction between the two parts, slow the arms down and it also damages the collars and the arms.

We recommend:

1. Using a CNC: This machine will do all the grinding and fillet to a precise size; making a perfect fillet.

When installing the collars on to the chair, make sure there are no spaces between the two faces. Getting the collars fit on the chair is a challenge. We added a piece of bike tire rubber to the 1 inch hole on the collars. The purpose is to add more grips between the chair frame and the collars. The rubber worked great; however, they added unnecessary spaces between the collars and the chair frame. The added space changed the bolt lengths and making our bolts too short. The rubber essentially made the 1 inch hole bigger than we designed for. This changed all the dimensions in our design. Added spaces were a huge problem for us.

We recommend:

1. Cutting a bigger hole: Measure the thickness of the rubber that will be used. Then cut the holes according to the rubber thickness. Adding the rubber thickness to the 1 inch hole; thereby, making a bigger hole and accounting for the rubber. This will reduce the spaces between the collar faces.

The Swing Dancer(s) cannot rotate 360 degrees while in the tilted position. This is one shortcoming we did not account for when designing the device. While in the tilted position, the caster forks were not perpendicular to the floor. We wanted the device to spin 360 degrees but once the device is engaged and tilted, the axis of rotation for the forks was off, making it impossible for the wheels to spin 360 degrees. Our device will roll back and forth with ease; however, we cannot spin while in the tilted position.

We recommend:

1. Accounting for angle of tilt: Calculate and test out the angle of tilt for the device. Then attach the caster with the same angle on to the swing arms. Making the caster perpendicular to the ground will be a key for the wheels to spin 360 degrees. There might be better ways but solve this problem.
2. Making an attachment for the caster forks: Instead of welding on the caster forks, make an attachment that will allow the caster to spin freely.

One of the safety features that we have is the bolt that acts as a max angle delimiter. The bolt connects to the side plates exactly the same way as the other bolts to the collar piece. The dimensions and specified in the drawings. However, this feature is flawed since the bolt has the potential to shear and break if too much force is exerted.

We recommend:

1. Design a more safety features: Add a thicker stopper for the swing arm. Drill two holes through a thick material that will be clamped between the side plates. This will prevent the swing arms from going past the recommended angle. With a thick rectangular of square piece, it will provide better resistance to shear than a bolt.

When securing the axles and connecting rod to the swing arms, better methods can be used. We drilled 1/8 inch holes through the axles and the connecting rods in order to secure them to the swing arms. At first, pins were used to secure the axles and the connecting rods. Later on, we used screws to secure them and they proved to be more effective since the pins tend to slip out. However, if the holes were threaded, they will be more secure.

We recommend:

1. Thread the holes: The 1/8 inch holes in the axles and the connecting rods should be threaded. We didn’t have a good method to thread them since the tools we used were ineffective at creating a good thread. With threading, the axles and the connecting rods will be secured with screws.

Chapter 6: Design Verification Plan

Testing Methods

The 14 specifications and clause references will be outlined below in specific detail. Test conductors will be all three members of the CPDW team. All members must verify and approve all acceptance criteria specified for testing. Acceptance criteria are listed in “Test Plan” in Table 9: Development Verification Plan will be used as preliminary guidelines for initial tests. The test numbers given below correspond to the “Item Number listed in the Test Place in Table 9: Development Verification Plan. Their numerical values and order are in no way representative of their importance nor do they represent the order of testing.

1. Weight of 10 lbs.
   Administered by: Mackenzie Hill (MH)
   Acceptance Criteria: ±0.5 lbs.
   Test Description: The device will be placed upon a scale that will measure its weight. Its weight will be recorded within 3 significant figures.
   Test Results: Pass.
      The total weight of the attachment for Model 1 is 10 lbs. and the attachment for Model 2 chair is 7 lbs.

Figure 61: Swing Dancer weight

2. Adjustable 45-85°
   Administered by: MH
   Acceptance Criteria: ± 5°
   Test Description: Once the prototype is built, it will be attached and tested by lowering the user into different positions. The positions are then measured by a ruler and a protractor for appropriate angles with a tolerance listed above.
   Test Results: Fail.
   The angle achieved by the device is 32°- 42° from the vertical position.

Figure 62: Angle achieved by Swing Dancer

3. Durable for 5 years
   Administered by: Shaun Van't Hul (SVH)
   Acceptance Criteria: σ = 97%
   Test Description: TBD. The device is estimated to see less than a million cycles; therefore, fatigue analysis is not applicable. However, if a test installation set up is available, the device will be cycled from 0-100 lbs. in compression for one million+ cycles in order to test for durability.
   Test Results: Pass.
   This was a difficult criterion to test. Thus, calculations were done to approximate the life span and fatigue. With estimations for applied forces and repeated cycles, the life of the Swing Dancer exceeds 5 years.

4. Adaptable to 4 different wheelchairs
   Administered by: MH
   Acceptance Criteria: Pass/Fail
   Test Description: The device will be adaptable to many different wheelchairs. The dancing team will remove their seat covers and attach the device to the support frame of their wheelchair. The device must function properly after attaching itself to the different frames. The device must attach to a minimum of 4 wheelchairs with ease to receive a "pass." Otherwise, "fail" will be designated.
   Test Results: Pass.

   We were able to fit the attachment to three different chairs that we had access to and the function of the device was not compromised.

Figure 63: Adaptable attachment

5. Cost under $500
   Administered by: MH
   Acceptance Criteria: ≤ $500
   Test Description: After all the materials are procured, the receipts will be tallied and the sum must be less than $500.
   Test Results: Pass

   The total cost for Model 1 chair is $489.28.
   The total cost for Model 2 chair is $113.89.

6. Weight tolerance of 300 lbs.
   Administered by: Thuyen Nguyen (TN)
   Acceptance Criteria: ≤ 300 lbs.
   Test Description: The device will be subjected to a max load of 500 lbs. and must function properly. A maximum of 300 lbs. of weights will be added to the center of mass of the chair via a cable hanging off of the chair frame. The wheelchair will be in its final tilt position of 37° with the 300 lbs. of weights hanging at its center of gravity.
   Test Results: Pass.

   The Swing Dancer was able to withstand 300 lbs. of weight on it. However, the wheelchair started buckling before our device showed any signs of weakness. This leads us to believe that the attachment needs to be on a chair whose backing is not connected with horizontal screws as the chair will start to strip said screws when a great amount of force is placed on the chair at an extreme angle.

7. Size 1 ft. of extension
   Administered by: MH
   Acceptance Criteria: ≤ 1 ft.
   Test Description: The device will be properly installed onto the frame of the wheelchair. After installation, a ruler or measuring tape will be utilized to measure the distance of extrusion from the chair frame. The device must not exceed 1 ft. of extrusion.
   Test Results: Pass.

   In the vertical position the attachment only protrudes 5 inches. While the device is in use, however, the distance increases to about a foot and a half which was expected.

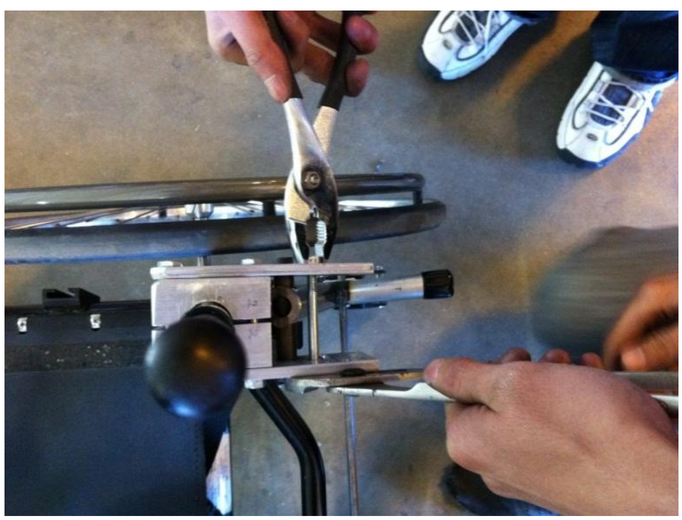


Figure 64: Extension of Swing Dancer

8. Detachable in 5 minutes
   Administered by: MH
   Acceptance Criteria: ≤ 5 min
   Test Description: Once the device is fully and properly installed, a stop watch will be used to measure the amount of time it takes to remove the device from the wheelchair. The removal time must not exceed 5 minutes.
   Test Results: Pass.
      Detaching the device only takes about two minutes to accomplish alone and about one minute with assistance. However, one person alone was not able to completely assemble the attachment in less than 5 minutes; it took approximately 10 min single handedly. However, assembly can be done prior to the performance and assembly time decreases when help increases. With two people assembly time took approximately 5 minutes.

9. Independence
   Administered by: MH
   Acceptance Criteria: 1 user
   Test Description: The user will display the ability to operate the device by pushing and pulling on the handle. They will use the device to go from sitting position to a full tilt position without the help of any other performers.
   Test Results: Pass.
      The user is entirely independent when using the device. There is no necessary help to “pop-a-wheelie” or return to the original position. The only help one would need is for assembling and disassembling if time is limited.

10. Factor of Safety
    Administered by: TN
    Acceptance Criteria: ≥ 3
    Test Description: Analysis was done to prove that the allowable strength is more than 3 times the allowable load.
    Test Results: Pass.
      Even with the removal of safety features the factor of safety lies well above 3, at 241, ensuring a safe product.

11. Maneuverability 360^o
    Administered by: MH
    Acceptance Criteria: ≥ 360^o
    Test Description: The user will tilt back to the lowest position and then they will attempt to spin themselves in circles. The casters will be able to spin 360^o since they are attached to a swivel.
    Test Results: Fail.

    As mentioned previously, we were not able to devise a way for the purchased casters to be implemented in our design to have rotational functionality.

12. Delivery Date
    Administered by: MH
    Acceptance Criteria: 6/2/11
    Test Description: This is the absolute deadline for completion. Everything must be completed on or before this date since the Senior Expo is taking place.
    Test Results: Pass.

    We are scheduled to have everything completed by June 2 and are on track.

13. Coverage of pinch points
    Administered by: MH
    Acceptance Criteria: No pinch points
    Test Description: All potential pinch points will be designed out of the device or covered with rubber casing. Users will not be subjected to any pinch points.
    Test Results: Pass.

    All pinch points are covered by protective rubber, increasing safe use of the product.

14. Fillet of sharp corners
    Administered by: MH
    Acceptance Criteria: r = 2 mm
    Test Description: All sharp point and corners will be filleted and sanded. The users will do a touch test to see if the fillet is smooth enough for their comfort. Pending the inputs of the users, bigger radius might be implemented.
    Test Results: Pass

    All edges and corners coming in contact were rounded to a minimum of 2 mm. The majority of the radii are larger, increasing comfort and safety.

Table 9: Development Verification Plan

TEST PLAN									
Item No	Specification or Clause Reference	Test Description	Criteria Accepted	Liable for Test	Test Stage	SAMPLES TESTED		TIMING	
						Qty.	Type	Start date	Finish date
1	Weight 10 lbs.	Use scale	10 ± 0.5 lbs.	MH	DV	1	B	5/23/2011	6/2/2011
2	Adjustable 45-85º	Measurement and Analysis	$\pm 5^0$	MH	DV	3	B	5/23/2011	6/2/2011
3	Durable 5 years	Fatigue Analysis	σ = 97%	SVH	DV	1	B	5/23/2011	6/2/2011
4	Adaptable to 4 chairs	Attachment Test at BTB	CR / NC	MH	DV	4	B	5/23/2011	6/2/2011
5	Cost under $500	Receipts	≤ $500	MH	DV	1	B	5/23/2011	6/2/2011
6	Weight Tolerance 500 lbs.	Force Analysis	≥ 500 lbs.	TN	DV	1	B	5/23/2011	6/2/2011
7	Size 1 ft. back extension	Measurement	≤ 1 ft.	MH	DV	1	B	5/23/2011	6/2/2011
8	Detachable 5 min	Time Test	≤ 5 min	MH	DV	5	B	5/23/2011	6/2/2011
9	Independent 1 user	Test at BTB	1 user	MH	DV	4	B	5/23/2011	6/2/2011
10	Safe FS of 3	Factor of Safety Analysis	≥ 3	TN	DV	1	B	5/23/2011	6/2/2011
11	Maneuver 360º	Rotation Test	360^0	MH	DV	5	B	5/23/2011	6/2/2011
12	Delivery Date 6/2/11	Final Model Complete	before 6/2/11	MH	DV	1	B	5/23/2011	6/2/2011
13	Covers for all pinch points	Locate all pinch points and cover them	all covered	MH	DV	2	B	5/23/2011	6/2/2011
14	Fillet radius of 2mm for edges	Measure Test	≥ 2 mm	MH	DV	2	B	5/23/2011	6/2/2011

Table 10: Design Verification Test Report

TEST REPORT						
Item No	Specification or Clause Reference	Test Description	TEST RESULTS			NOTES
			Test Result	Qty. Pass	Qty. Fail	
1	Weight 10 lbs.	Use scale	Pass			Model 1 weighs 10lbs and Model 2 weighs 7lbs
2	Adjustable 45-85º	Measurement and Analysis	Fail		All	32 – 42 degrees Note: This was discussed with Sponsor and approved
3	Durable 5 years	Fatigue Analysis	Pass	All		Varies on usage but fatigue calculations pass
4	Adaptable to 4 chairs	Attachment Test at BTB	Pass	All		
5	Cost under $500	Receipts	Pass			Model 1 costs $489.28 Model 2 cost $113.89
6	Weight Tolerance 500 lbs	Force Analysis	Pass	All		Calculations
7	Size 1 ft back extension	Measurement	Pass	All		
8	Detachable 5 min	Time Test	Pass	All		To attach takes longer
9	Independent 1 user	Test at BTB	Pass	All		
10	Safe FS of 3	Factor of Safety Analysis	Pass	All		Calculation FS of 241
11	Maneuverability 360º	Rotation Test	Fail		All	Note: This was discussed with sponsor previously and approved
12	Delivery Date 6/2/11	Final Model Complete	Pass	All		
13	Covers for all pinch points	Locate all pinch points and cover them	Pass			
14	Fillet radius of 2mm for edges	Measurement Test	Pass			

Chapter 7: Conclusion and Recommendations

After numerous modifications to the assemblies and design concepts, we came up with the Swing Dancer. We realize that the design process is open-ended, and the design can always be improved upon. We changed our design at least 4 times and finally came up with one that satisfies a lot of specifications agreed between the sponsor and our team. Even though some specifications were not achieved, the sponsors are happy and were open to modifications on a few specs. After we completed the Linkage Assembly II (LAII), we went to test it. To our surprise, we discovered a new concept, the Swing Dancer. We realized that we have over designed the LAII; therefore, we took out the spring assembly, making our design much simpler. This process is described in Chapter 4: Description of the Final Design. With the new design, we recommended several lessons learned in Chapter 5: Product Realization. This chapter outlines the manufacture processes and recommendations on how to save time and materials while machining the device. Overall, we outlined several ways to improve upon our project for others who would like to continue with the design. We are happy with the results of the testing and the functionality of the Swing Dancing Assembly. We hope BTB will have as much fun showing the world the Swing Dancer as we have during the process of designing it.

Shoutouts

Finally, we, the Pop-a-Wheelie design team would like to thank BTB for sponsoring our project and being graceful hosts to our several visits. We thank Dr. Taylor for presenting the project to us and Professor Widmann for a year-long of advising.

References

1. Sunrise Medical HHG Inc. “Center-of-Gravity Tilt-in-Space Wheelchair.” Patent 7,007,965. 7 March 2006.

2. Invacare Corporation. *Invacare Product Catalog: Twirl Dance Wheelchair*. 2010. Web. 14 Oct. 2010.

3. Mize Etal, W. E. "Reclining Attachment for Wheel Chairs." Patent 3,256,040. 16 June 1966.

4. Southwest Medical LLC. *Quickie Wheelchair Product List.* 2011. Web. 3 February 2011.

Appendices

Appendix A: Design Concept Tables

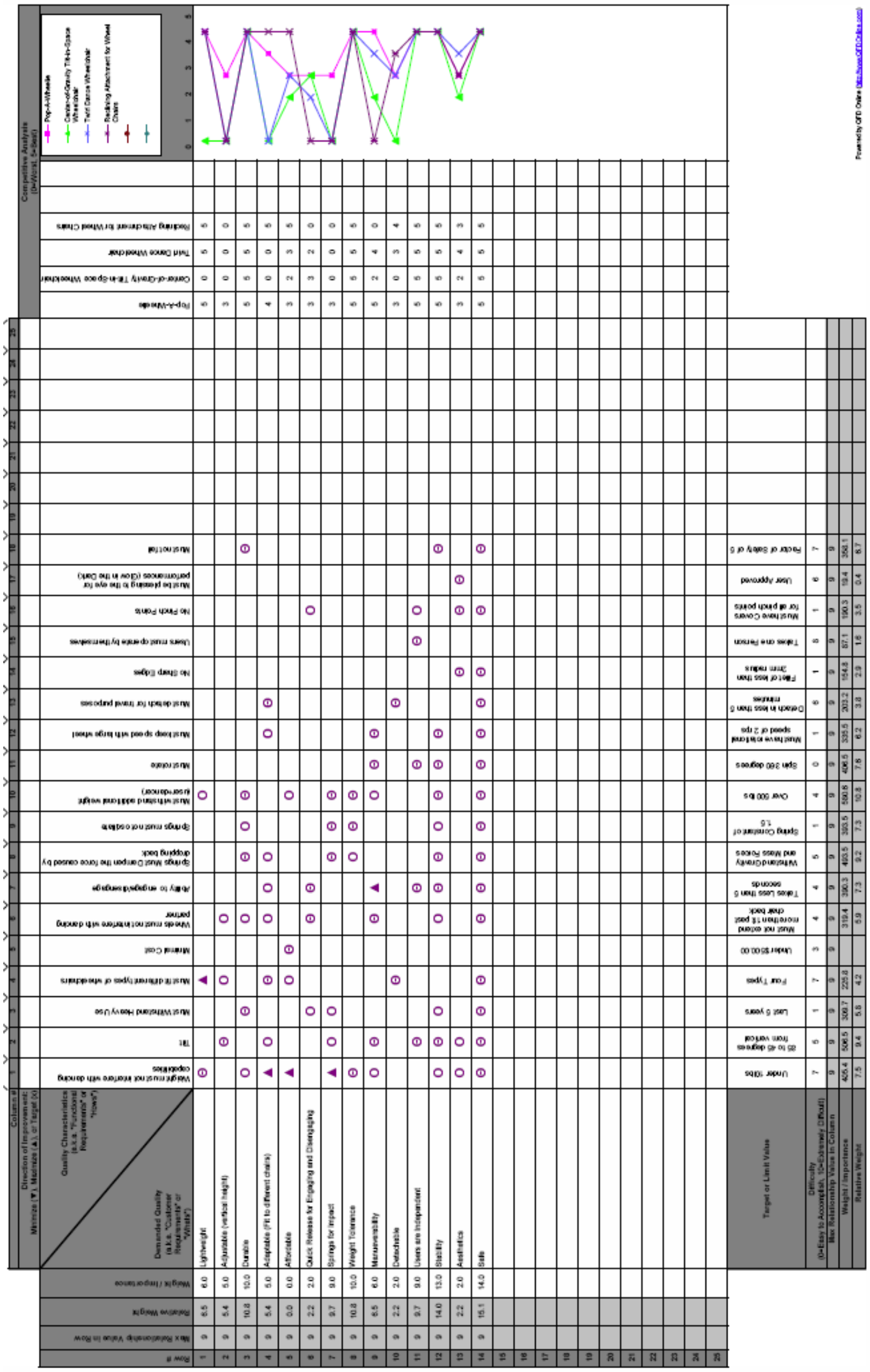
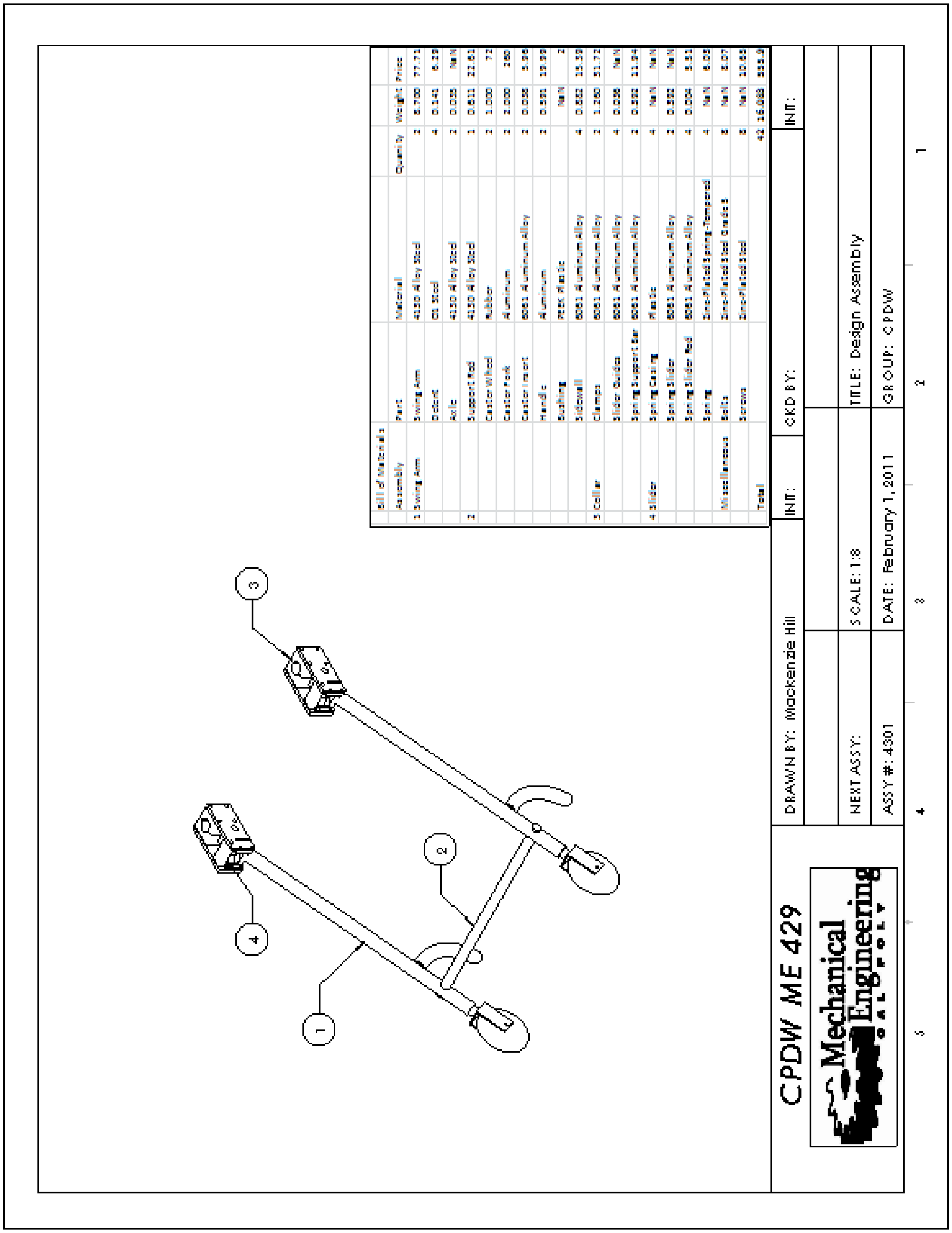


Figure 65: QFD Chart

Appendix B: Assemblies

Linkage System II

Included here is the Linkage System II due to us completely manufacturing this device before realizing the changes that had to be made to make the Swing Dancer.



	Bill of Materials					
	Assembly	Part	Material	Quantity	Weight	Price
1	Swing Arm	Swing Arm	4130 Alloy Steel	2	8.700	77.71
		Detent	O1 Steel	4	0.141	6.29
		Axle	4130 Alloy Steel	2	0.035	NaN
2		Support Rod	4130 Alloy Steel	1	0.611	22.61
		Caster Wheel	Rubber	2	1.000	72
		Caster Fork	Aluminum	2	2.000	260
		Caster Insert	6061 Aluminum Alloy	2	0.058	5.96
		Handle	Aluminum	2	0.591	19.99
		Bushing	PEEK Plastic		NaN	2
		Sidewall	6061 Aluminum Alloy	4	0.882	15.59
3	Collar	Clamps	6061 Aluminum Alloy	2	1.260	51.72
		Slider Guides	6061 Aluminum Alloy	4	0.036	NaN
		Spring Support Bar	6061 Aluminum Alloy	2	0.592	11.94
4	Slider	Spring Casing	Plastic	4	NaN	NaN
		Spring Slider	6061 Aluminum Alloy	2	0.592	NaN
		Spring Slider Rod	6061 Aluminum Alloy	4	0.004	5.51
		Spring	Zinc-Plated Spring-Tempered	4	NaN	6.05
	Miscellaneous	Bolts	Zinc-Plated Steel Grade 5	8	NaN	8.07
		Screws	Zinc-Plated Steel	8	NaN	10.65
	Total			42	16.083	555.9

Figure 66: Entire Assembly

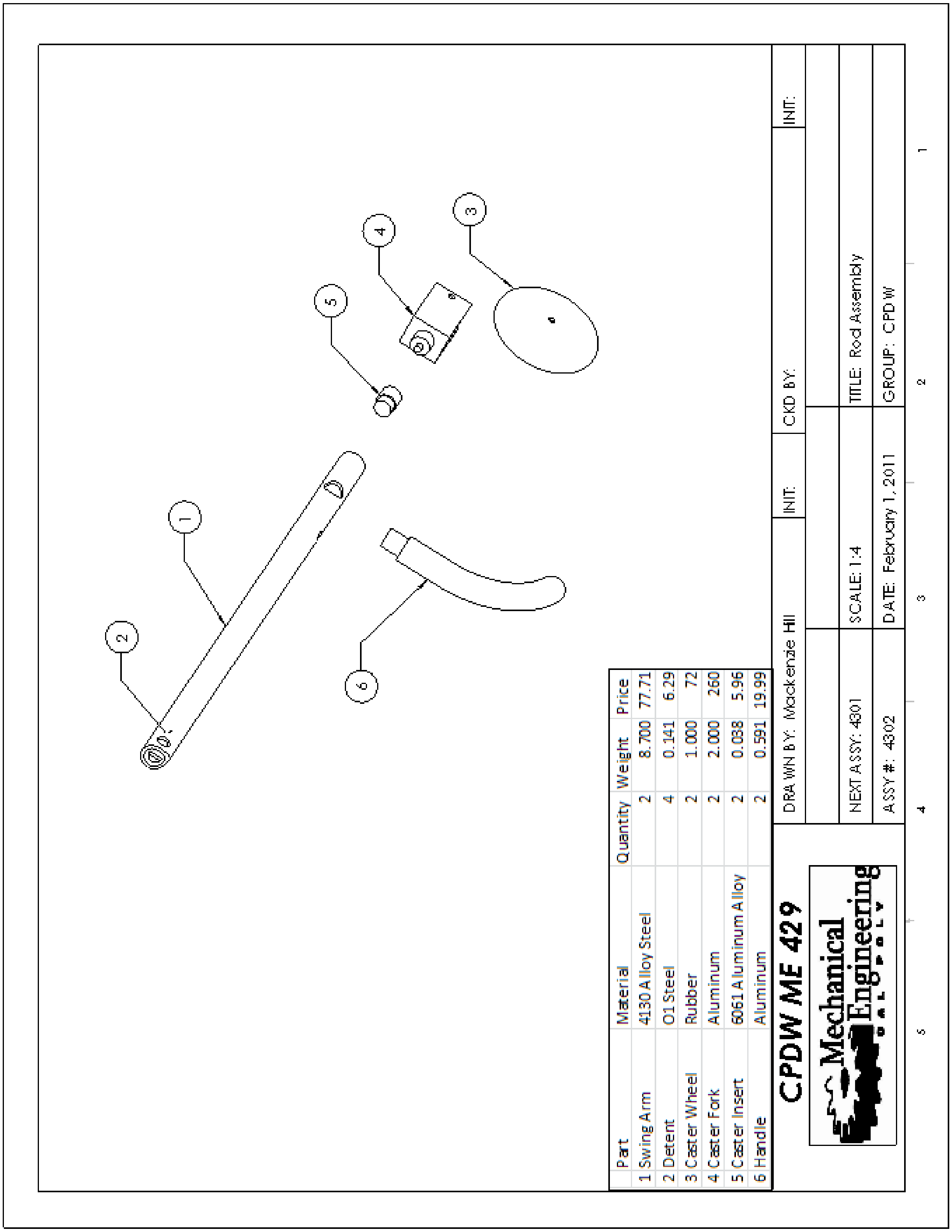


Figure 67: Swing Arm Assembly

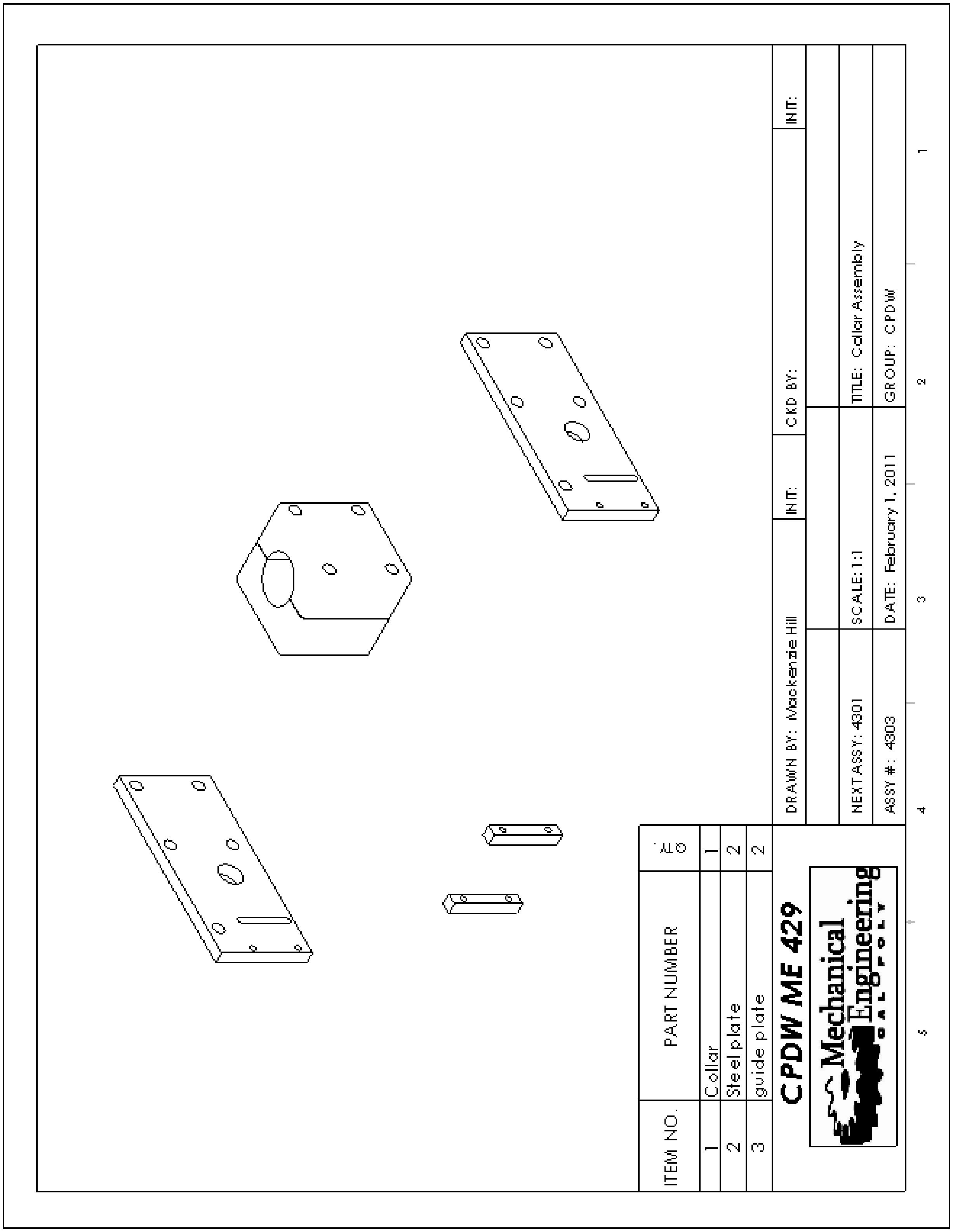


Figure 68: Collar Assembly

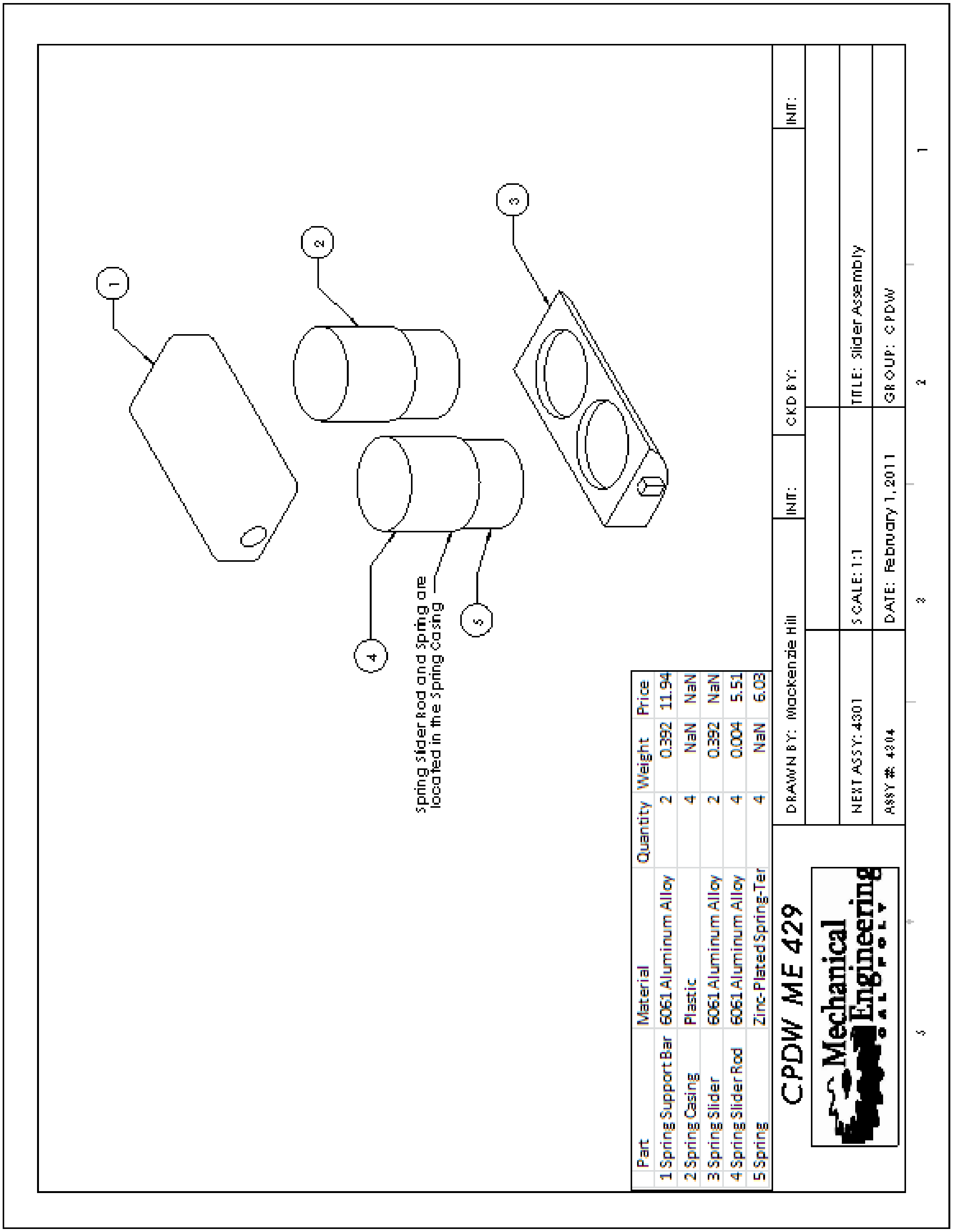


Figure 69: Spring Assembly

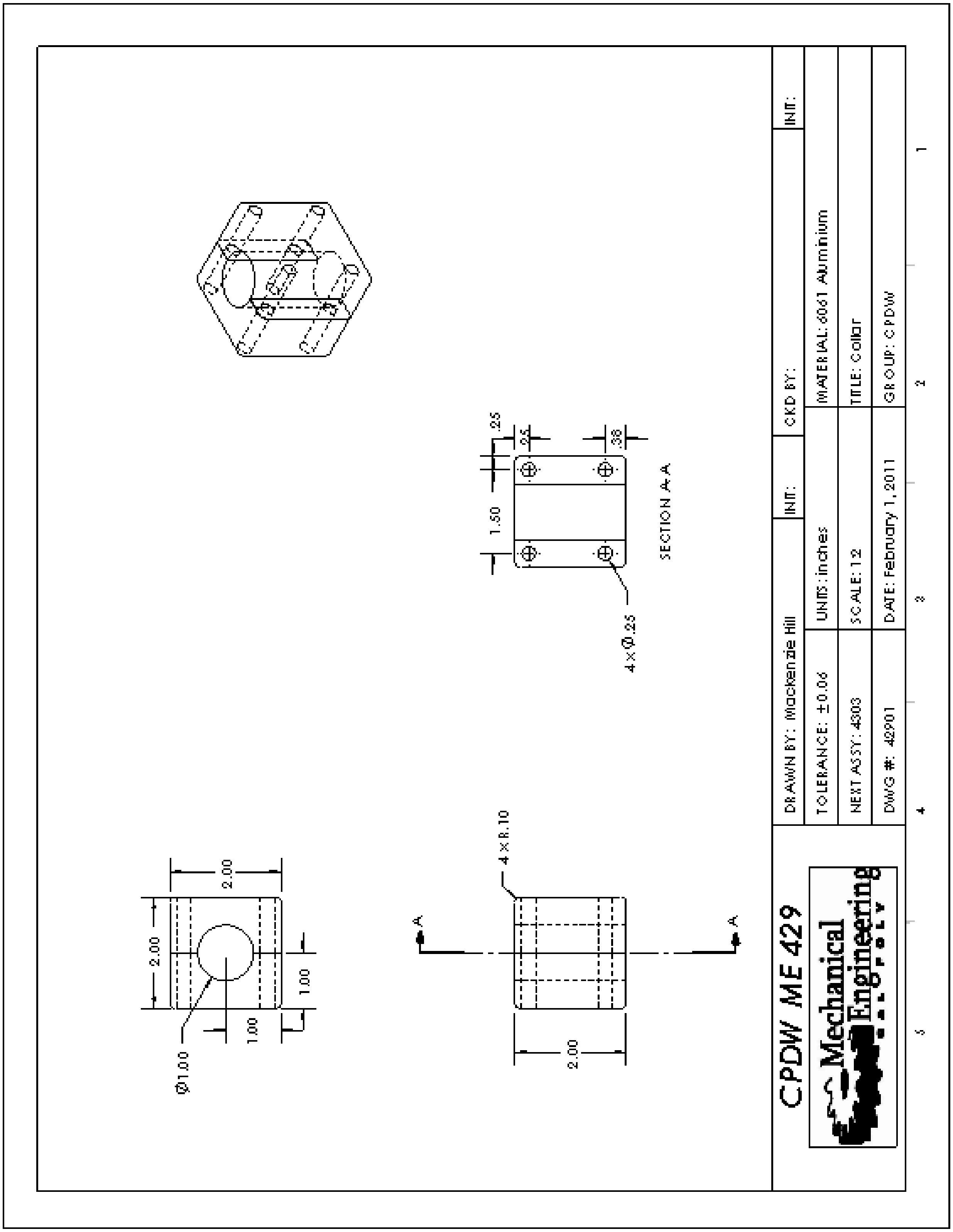


Figure 70: Detailed Drawing of Collar

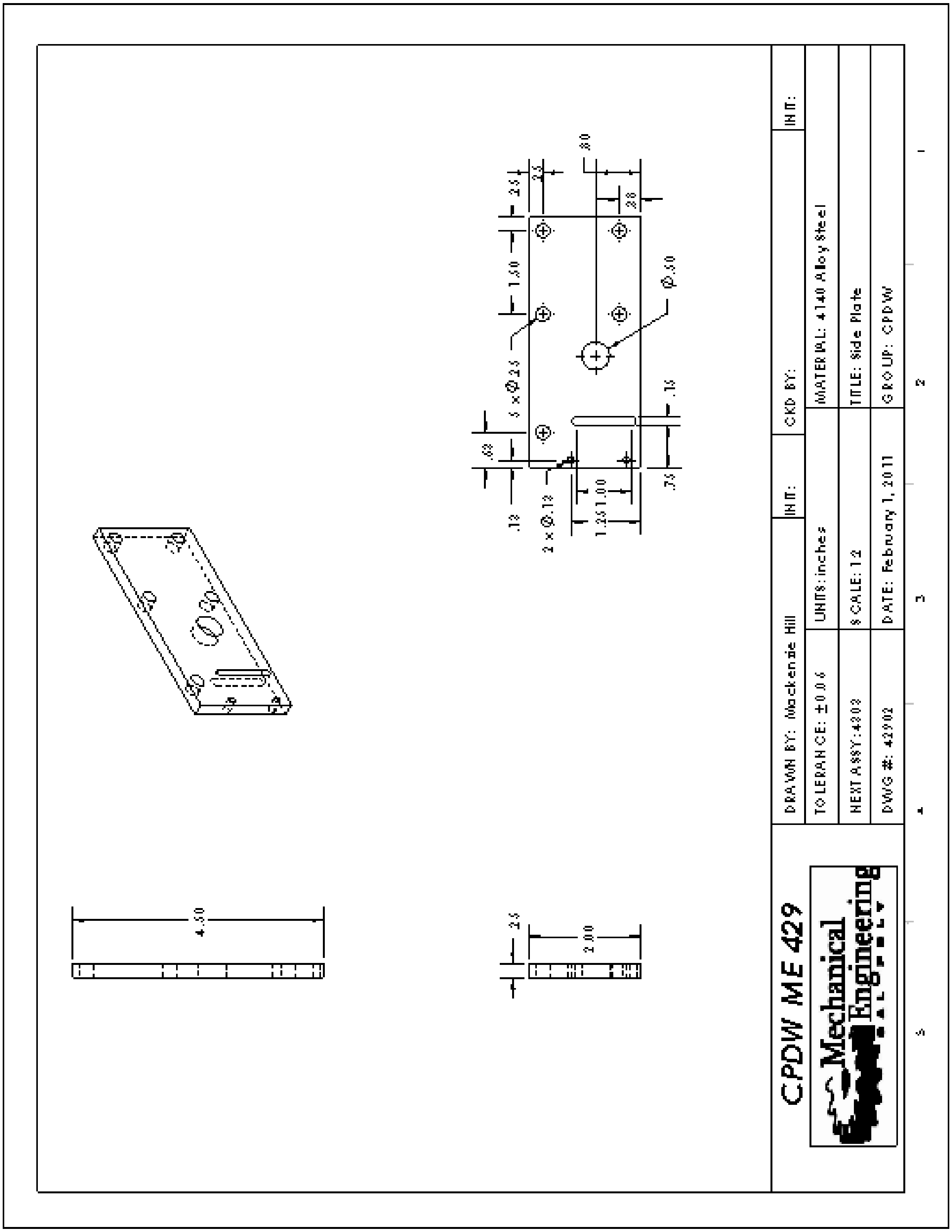


Figure 71: Detailed Drawing of Side Plate

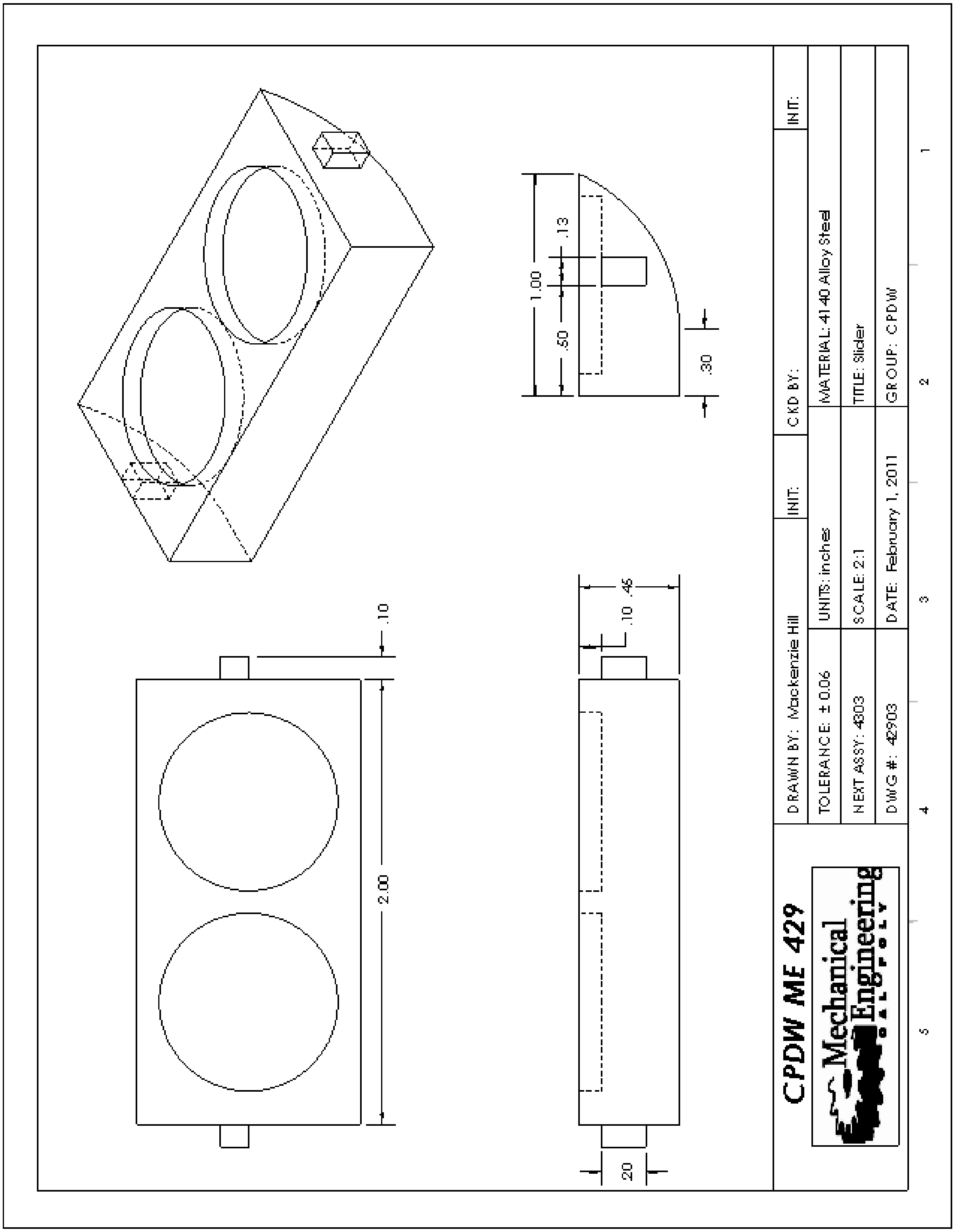


Figure 72: Detailed Drawing of Spring Slider

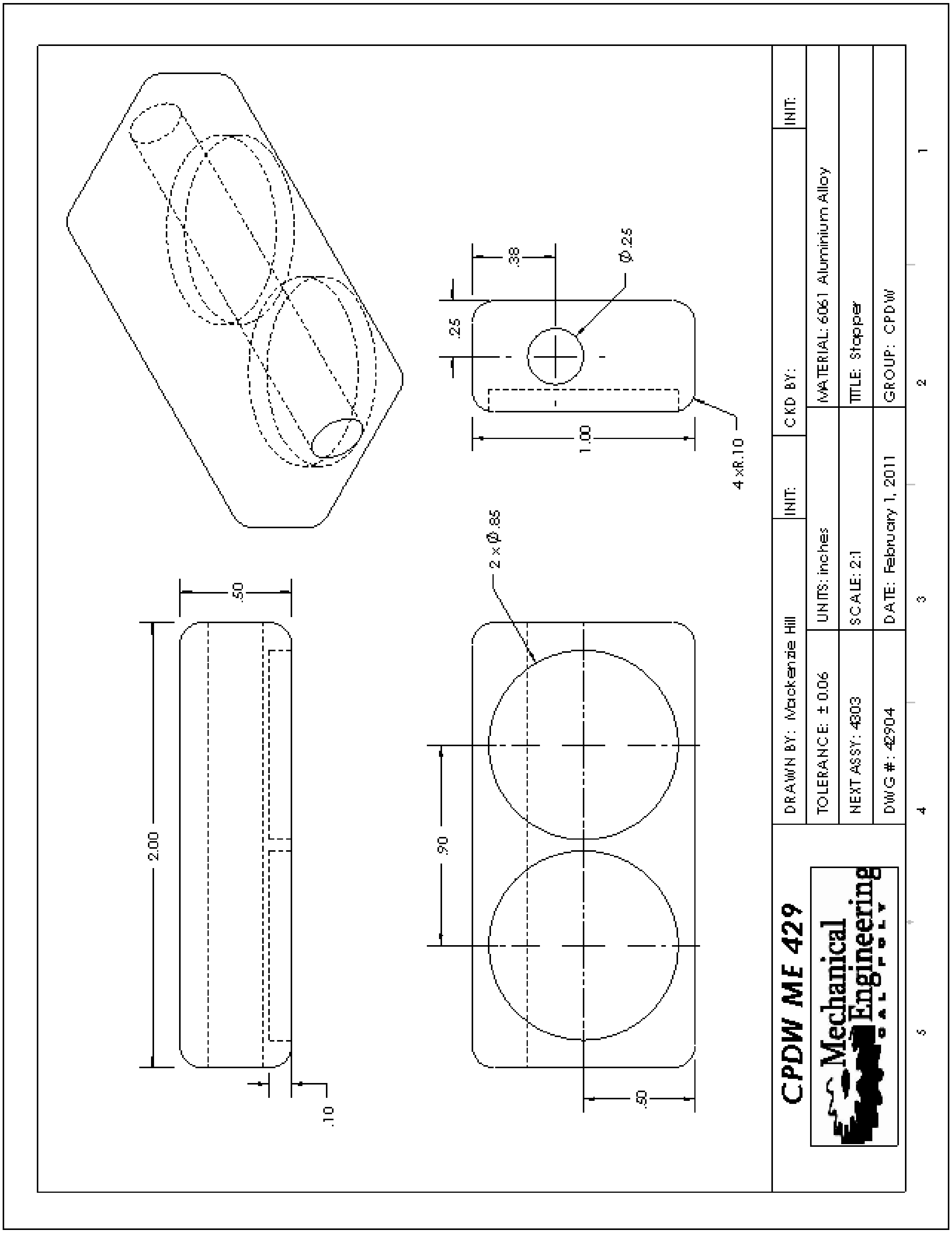


Figure 73: Detailed Drawing of Spring Stopper

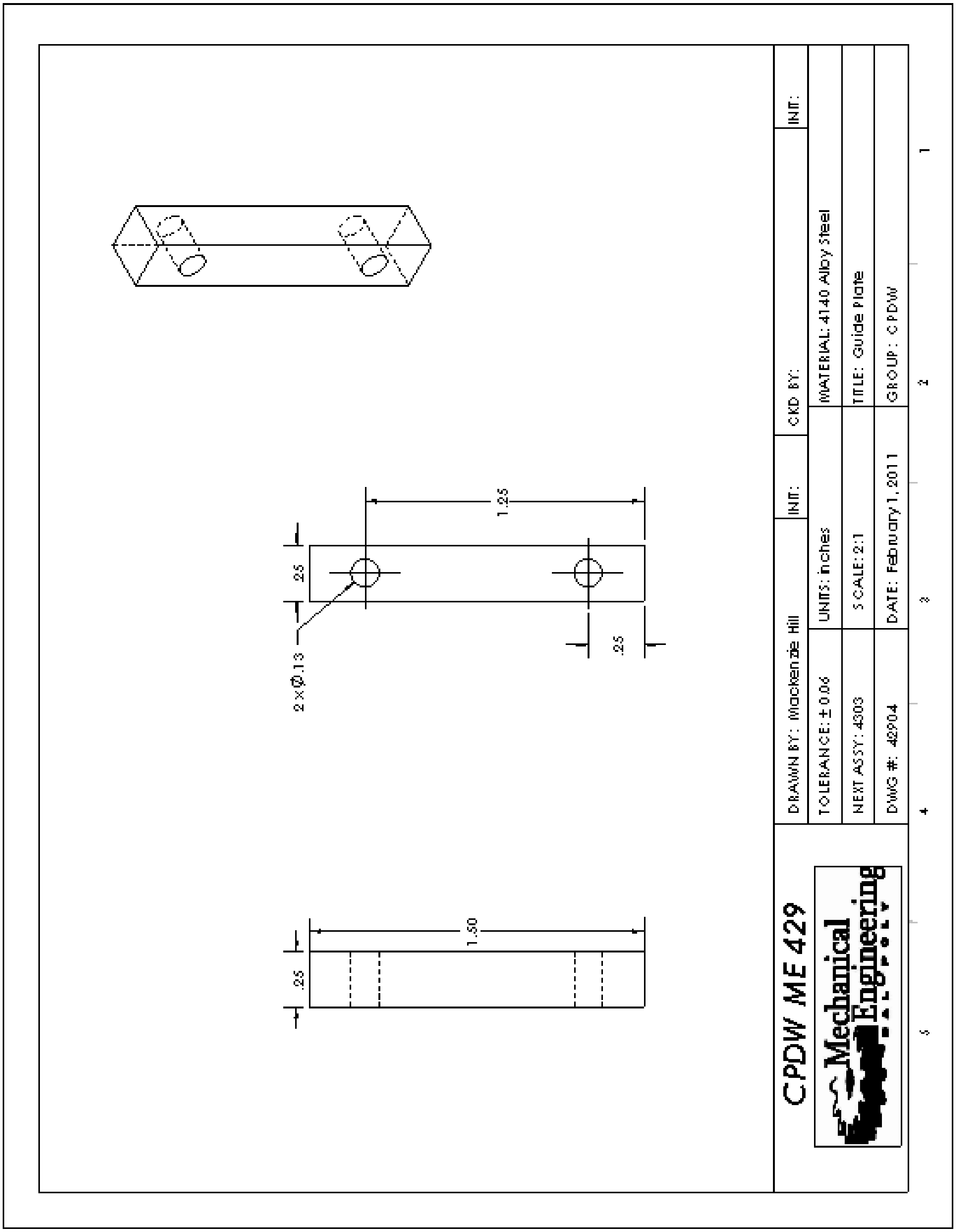


Figure 74: Detailed Drawing of Slider Guide

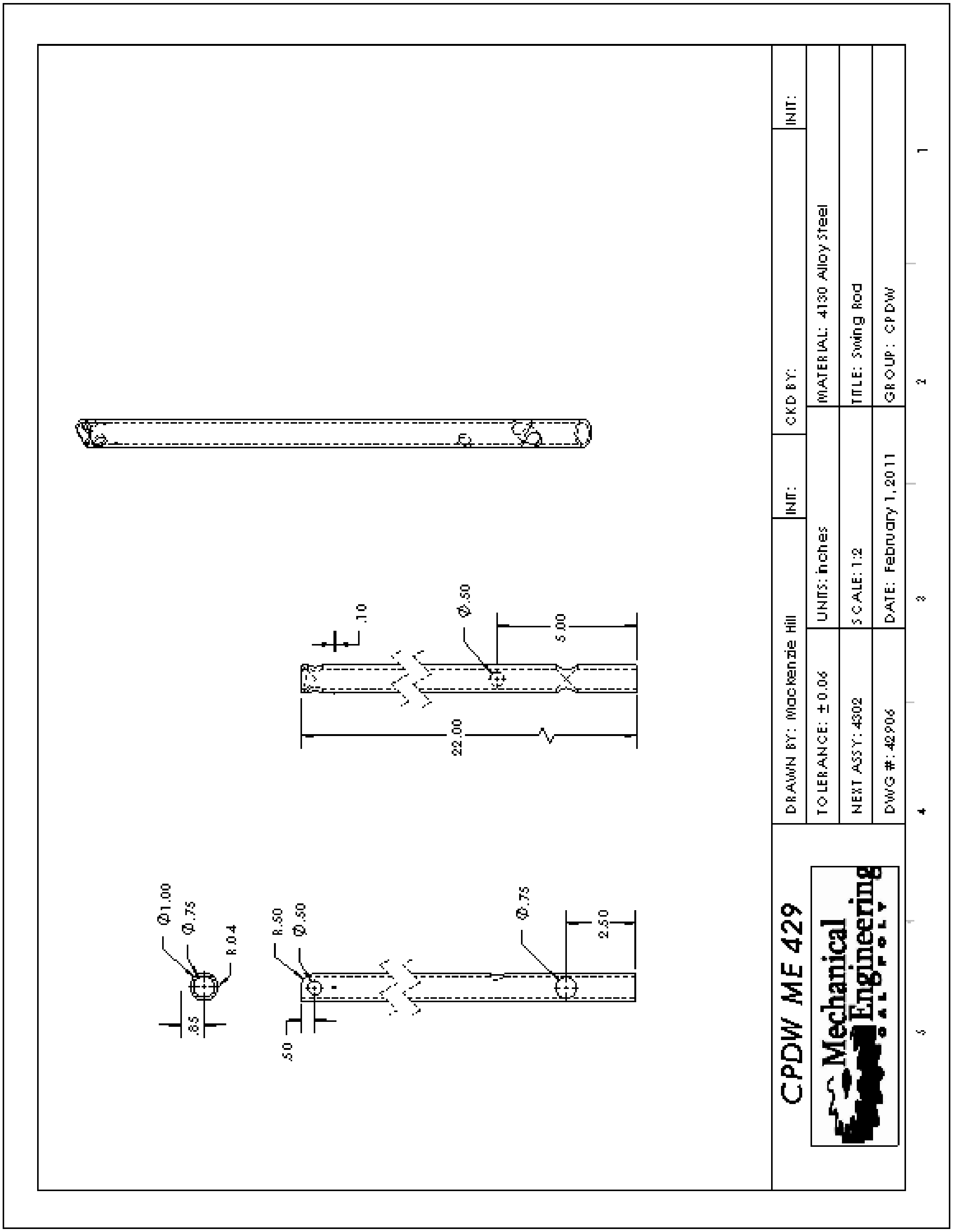


Figure 75: Detailed Drawing of Rod Arm

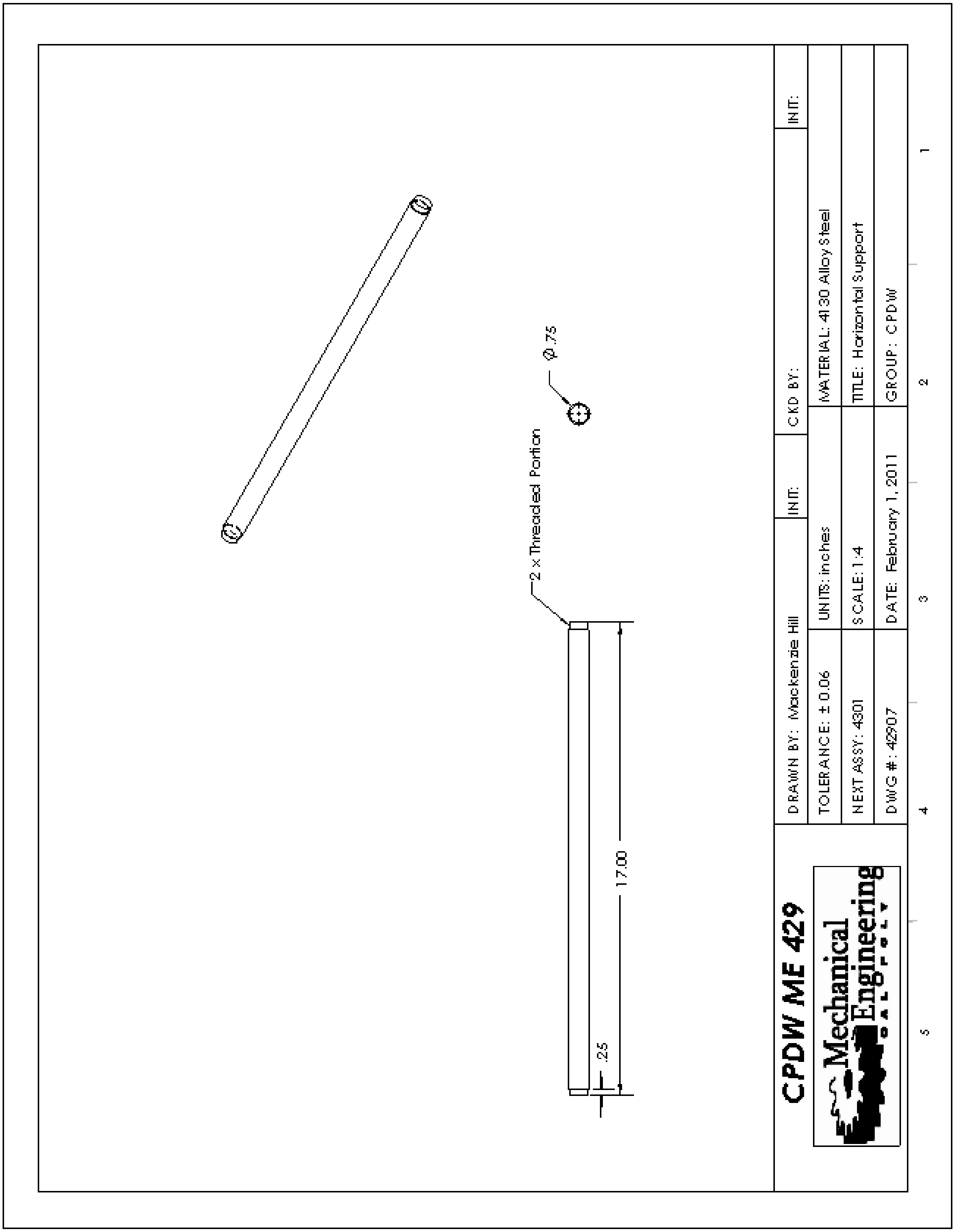


Figure 76: Detailed Drawing of Horizontal Support Rod

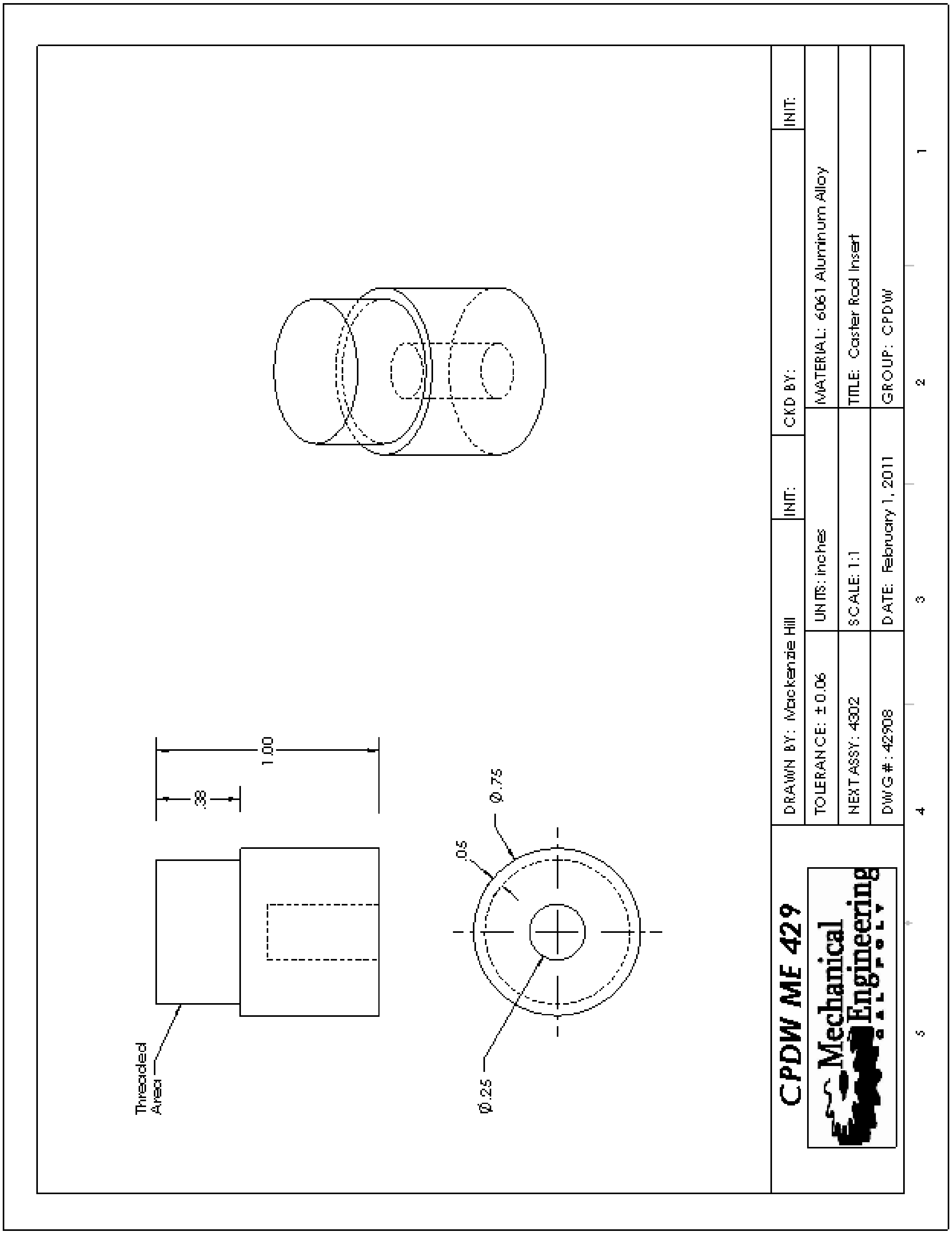


Figure 77: Detailed Drawing of Caster Insert

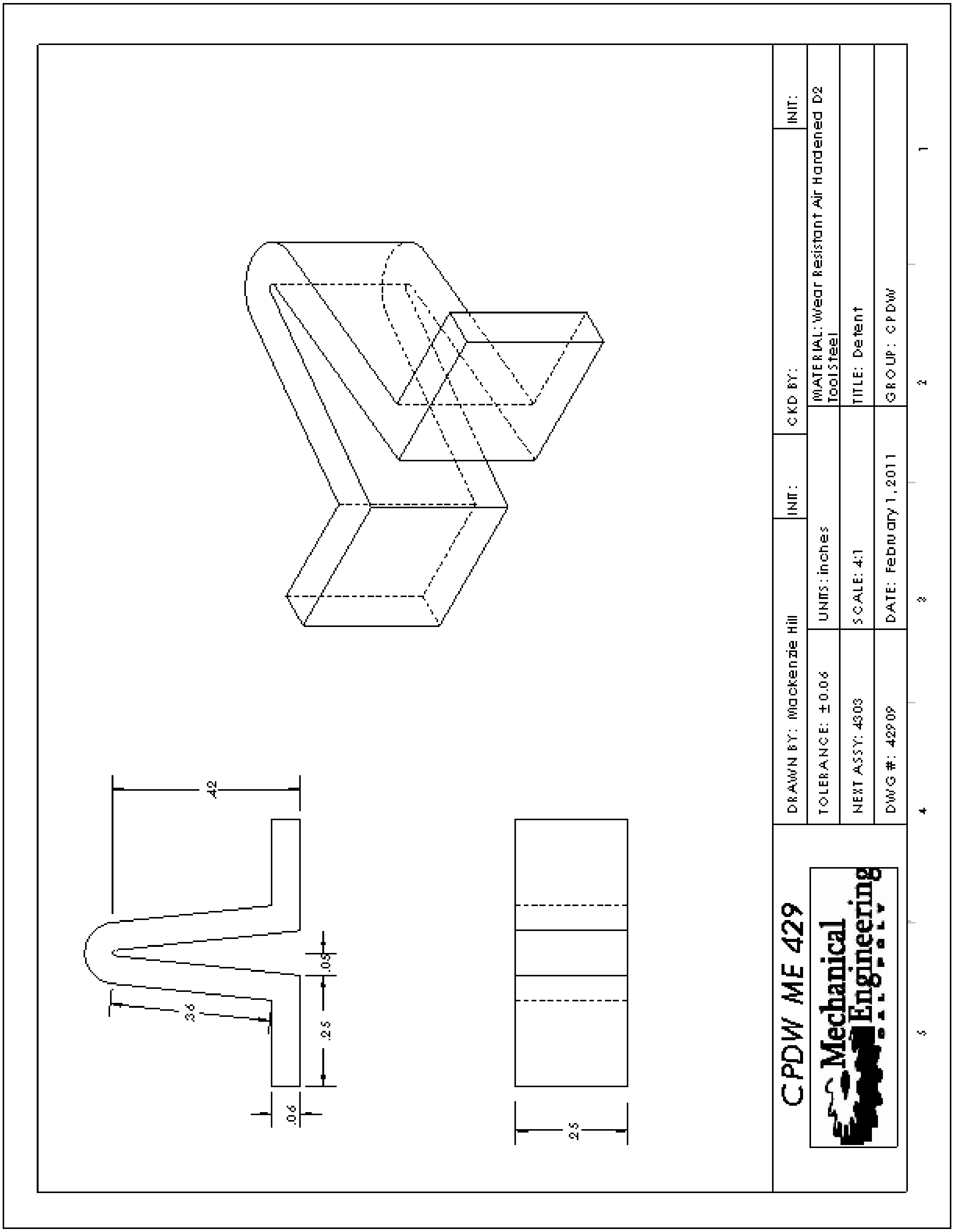


Figure 78: Detailed Drawing of Detent

Swing Dancer(s)

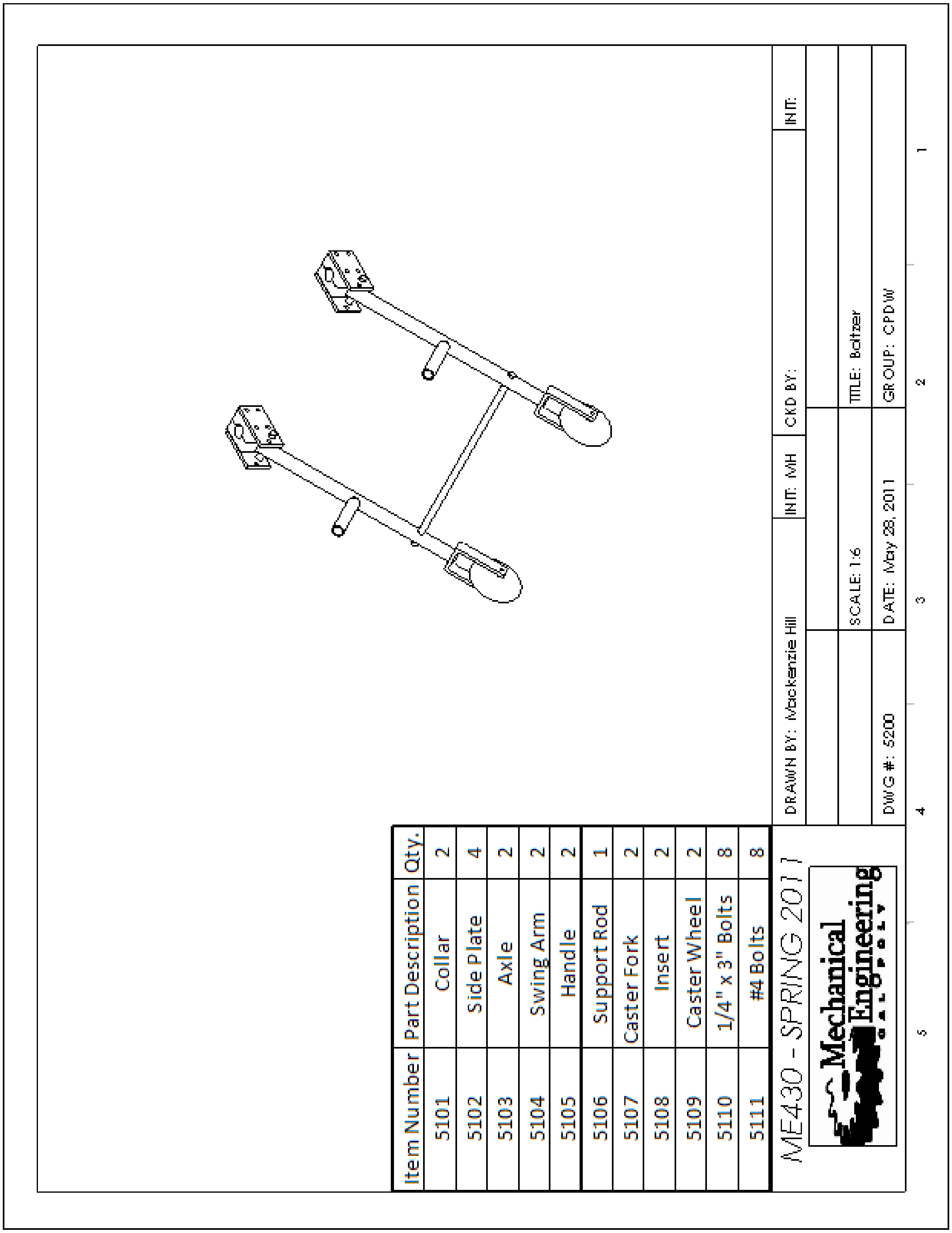


Figure 79: Detailed Drawing of Boltzer

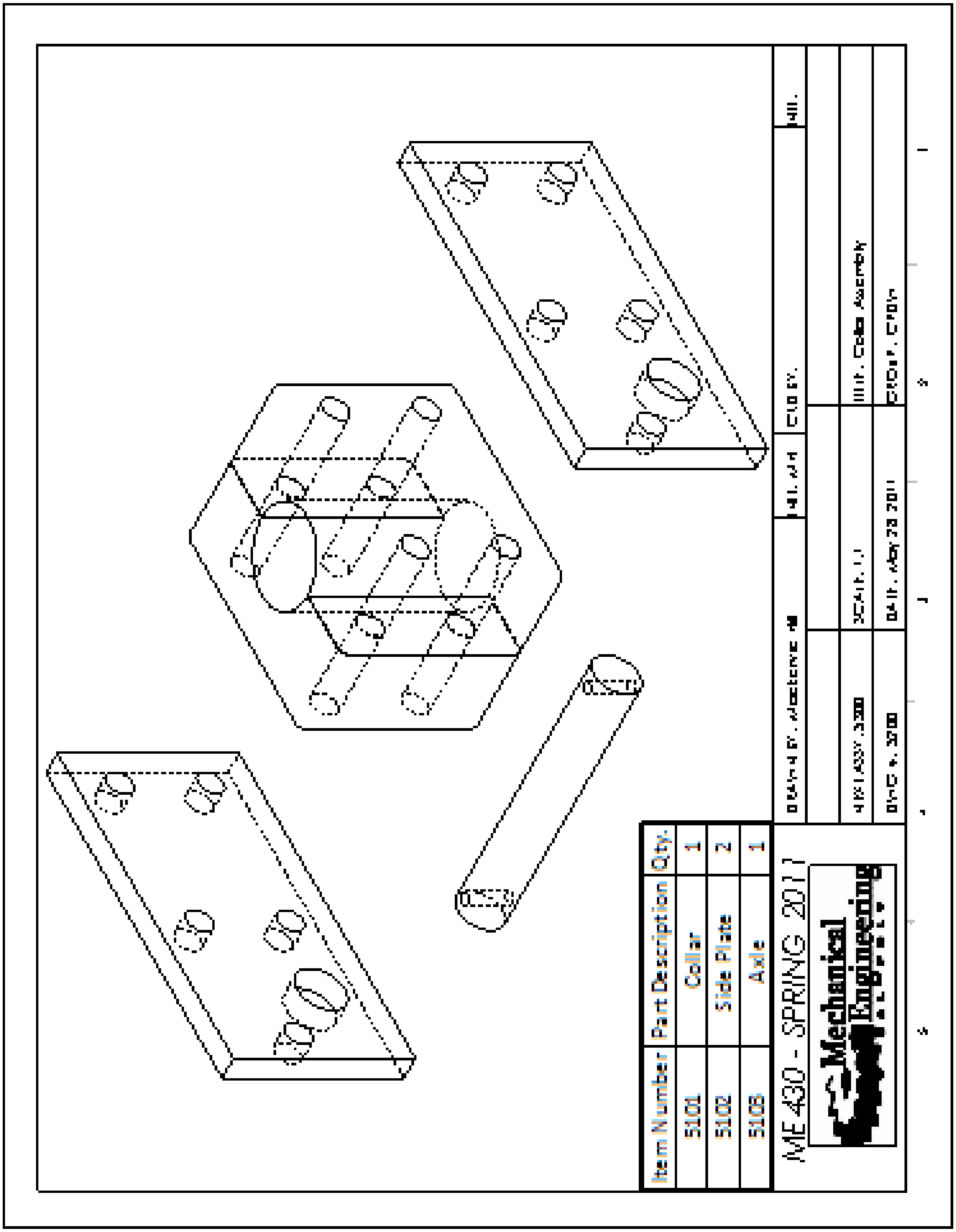


Figure 80: Assembly of Collar Attachment

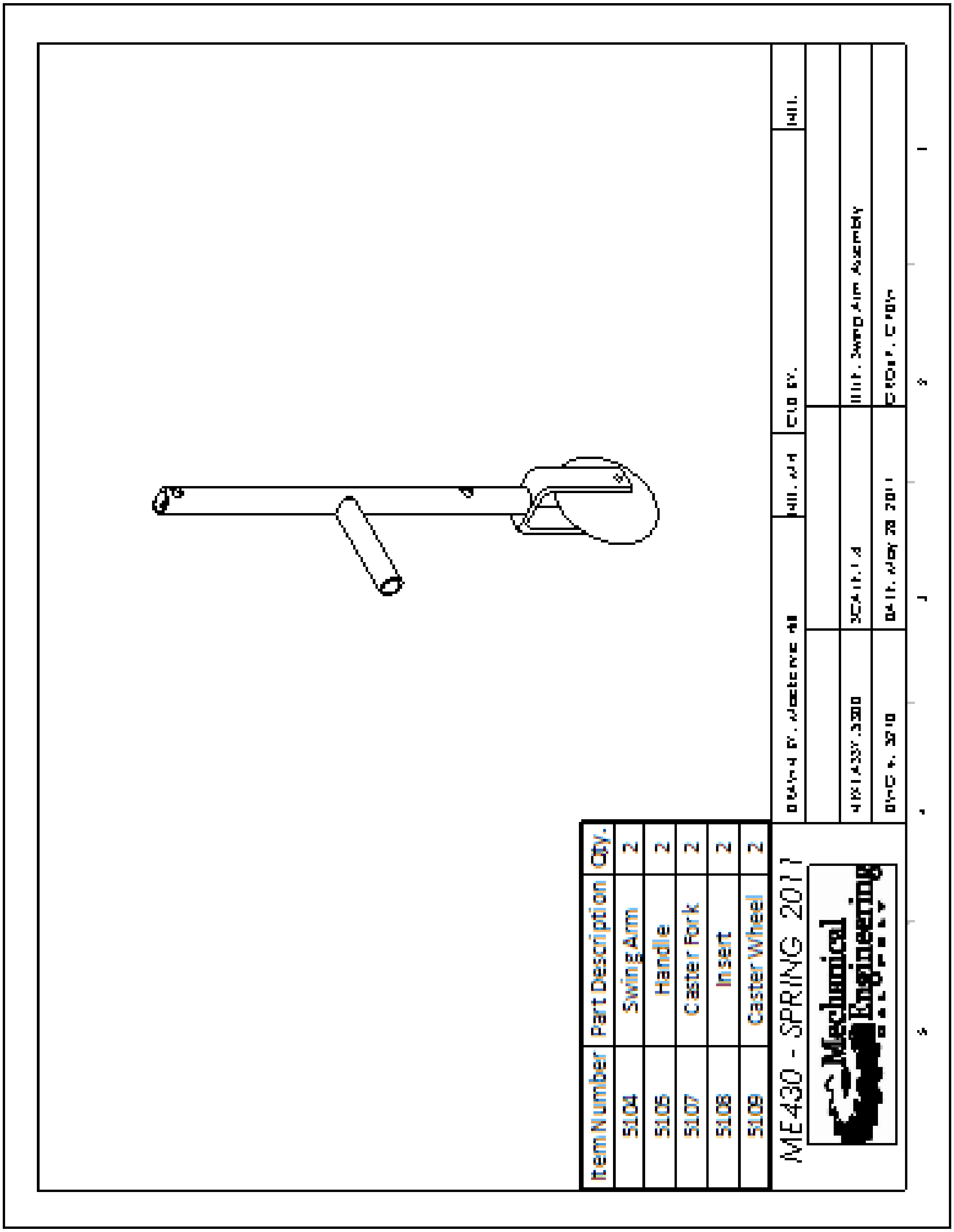


Figure 81: Assembly of Swing Arm Attachment

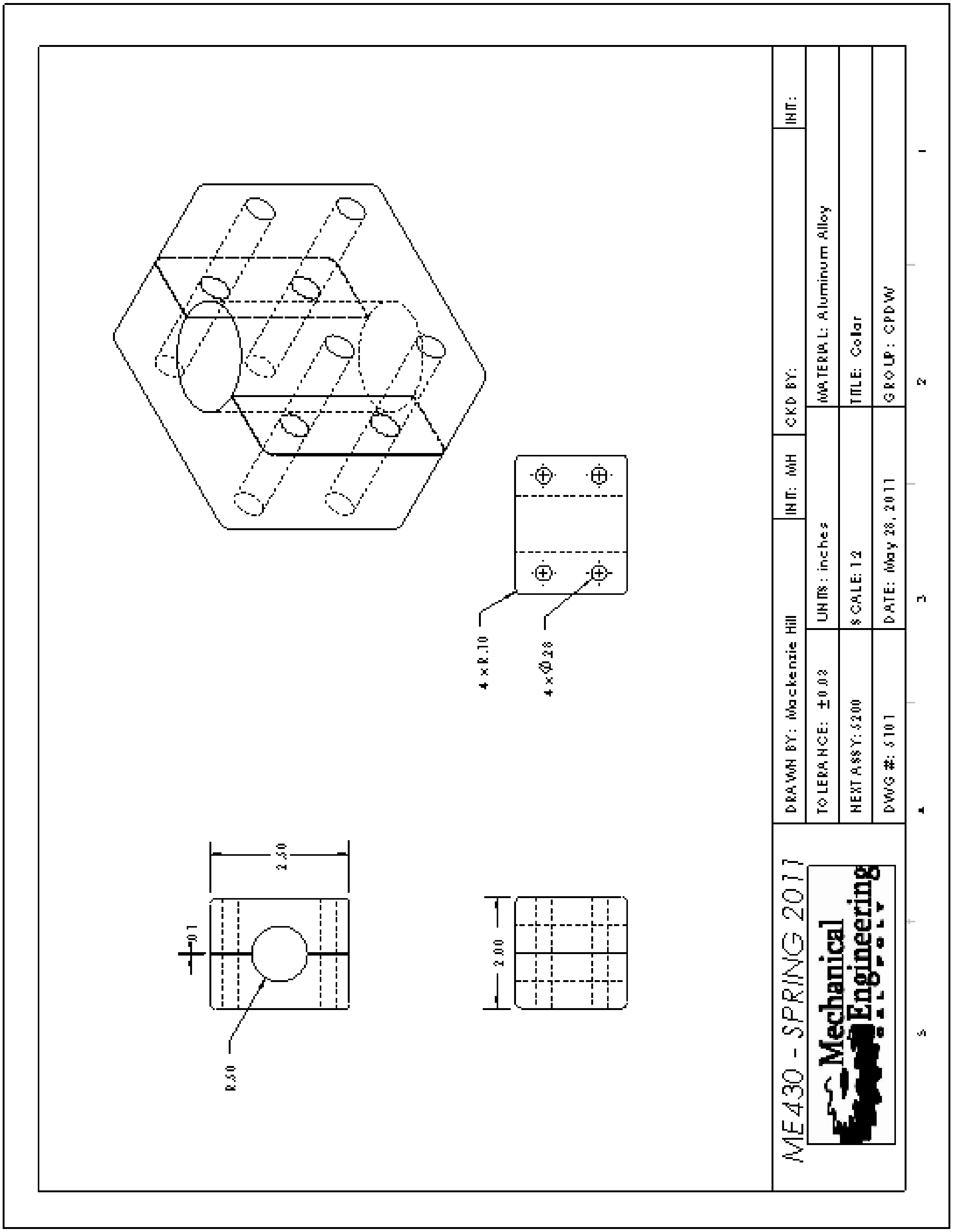


Figure 82: Detailed Drawing of the Collar

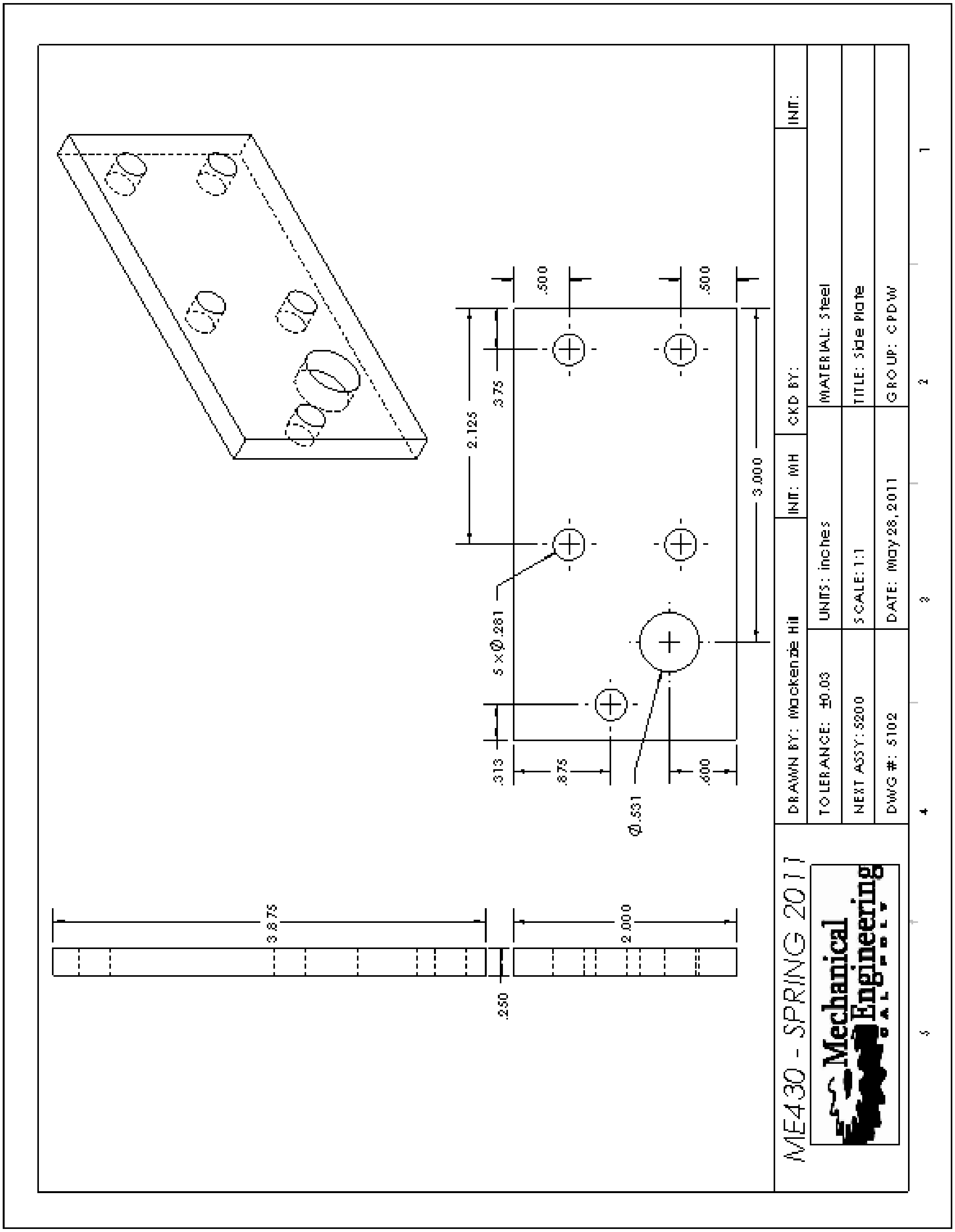


Figure 83: Detailed Drawing of the Side Plate

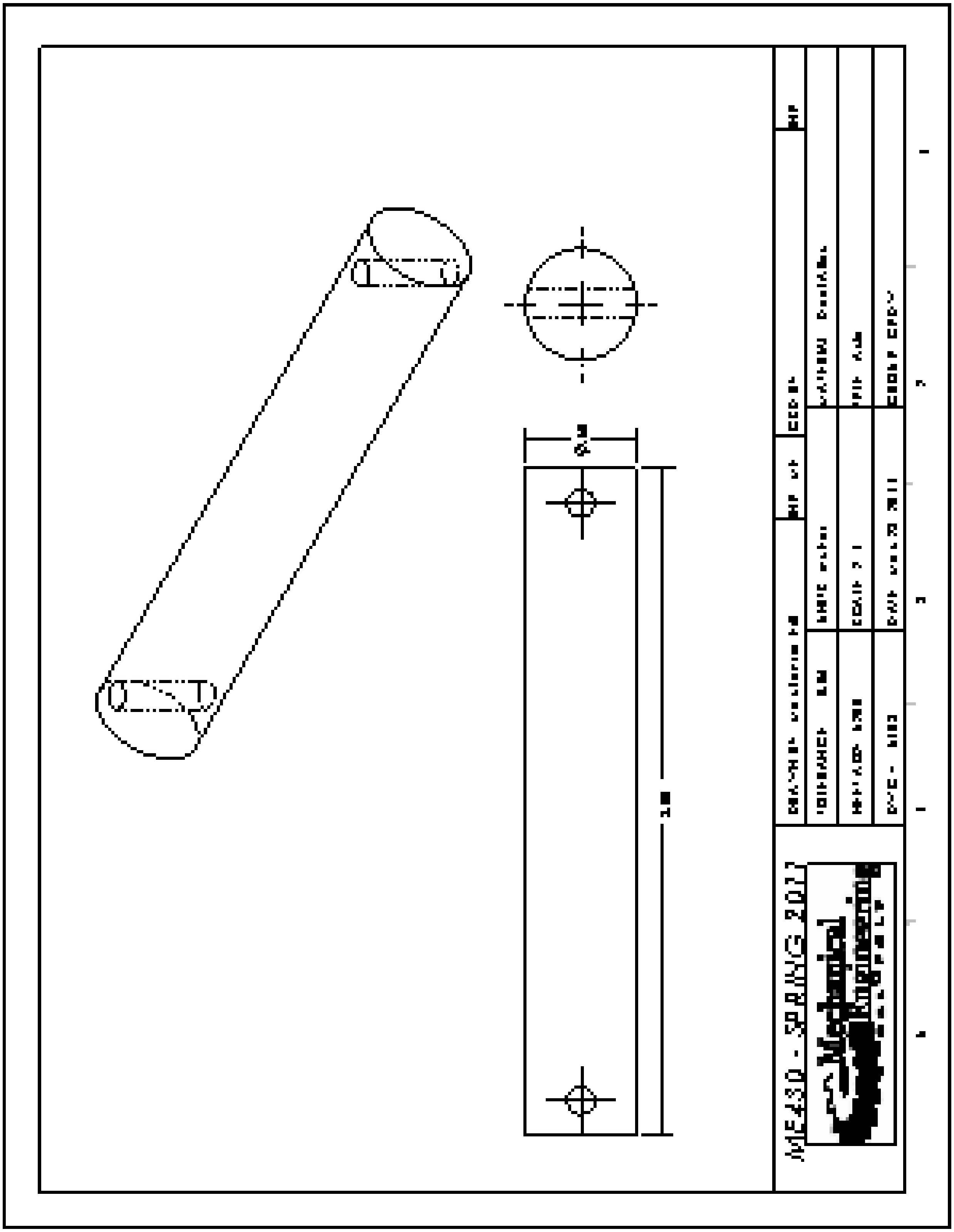


Figure 84: Detailed Drawing of the Axle

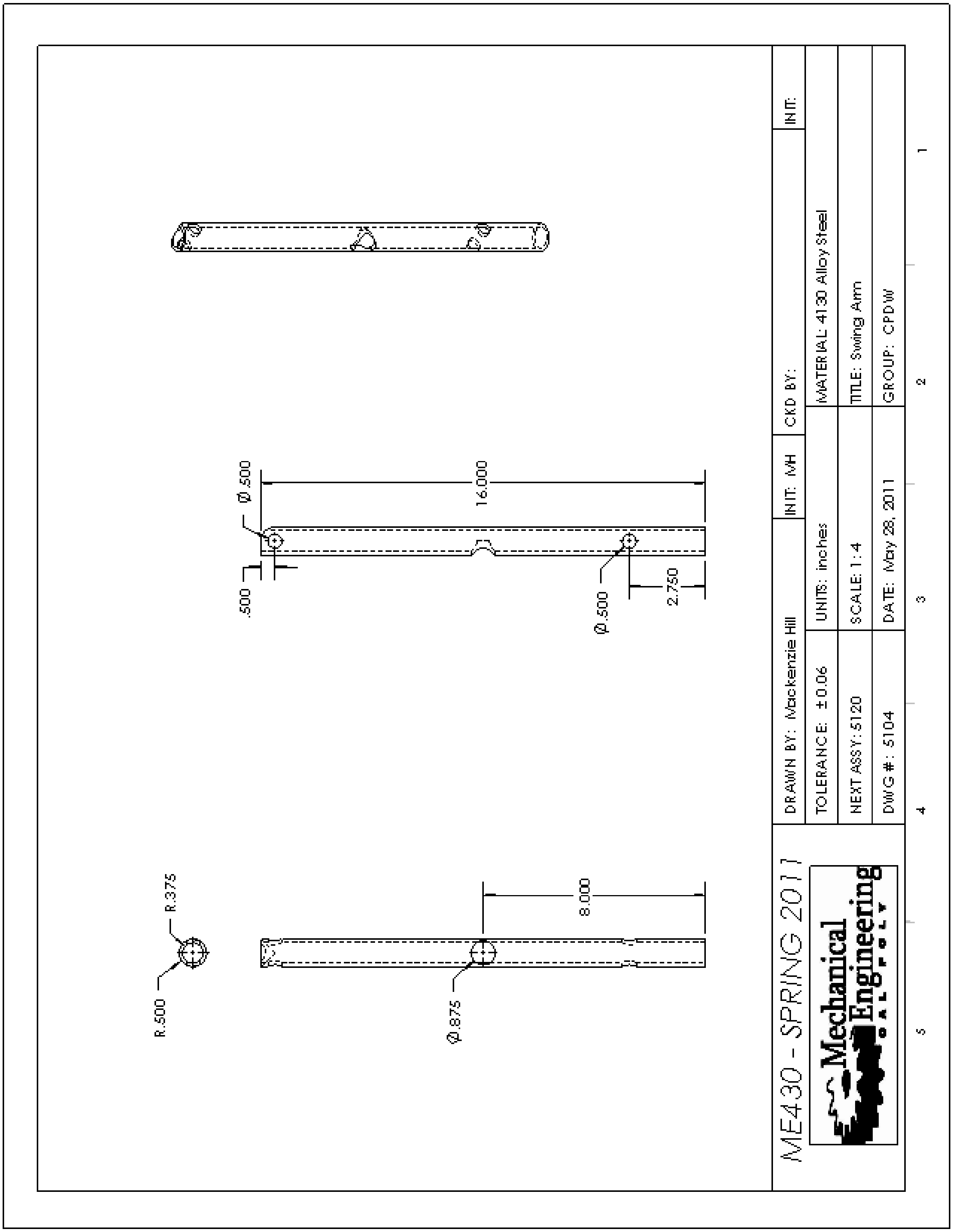


Figure 85: Detailed Drawing of the Swing Arm

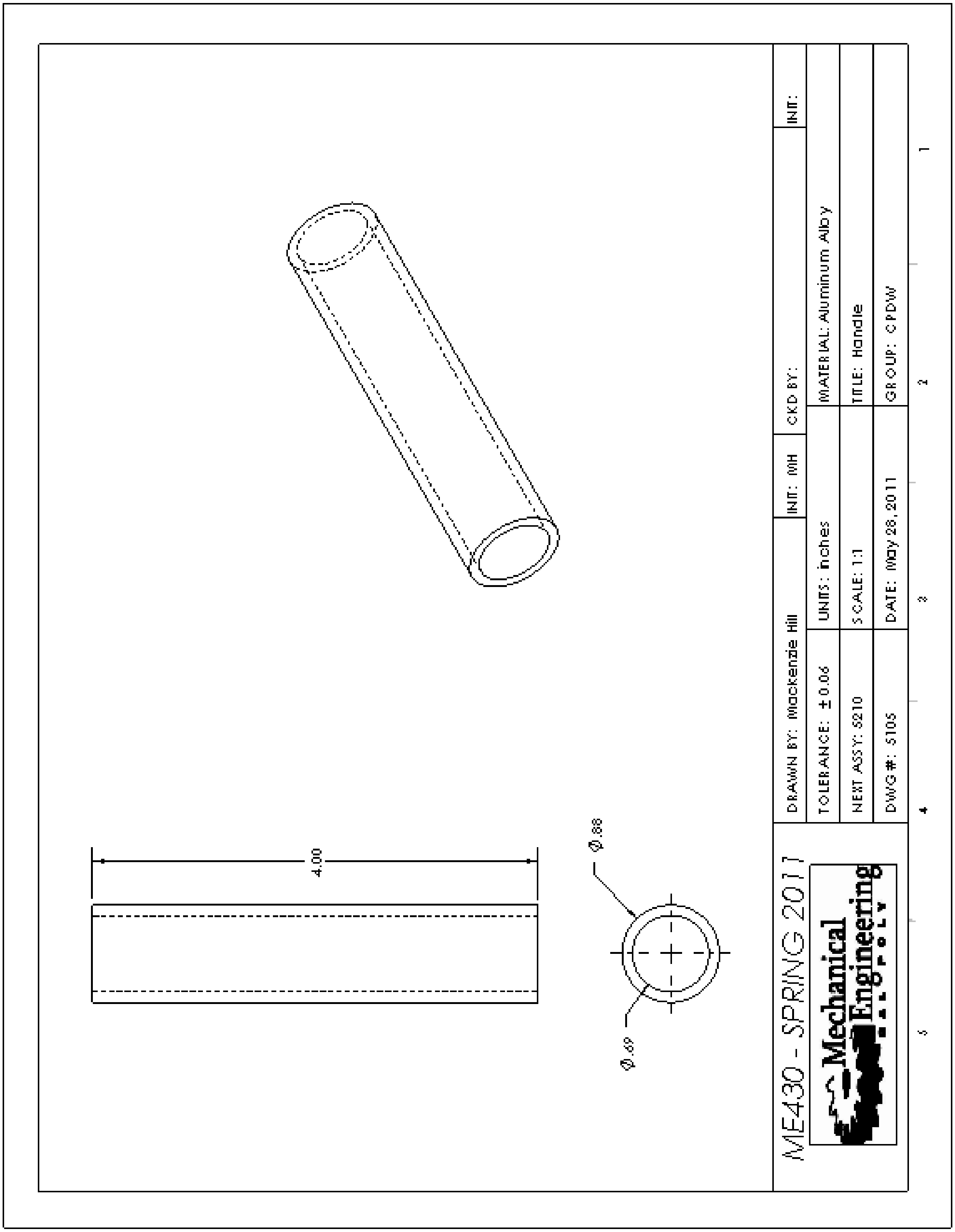


Figure 86: Detailed Drawing of the Handle Appendix C: Vendors

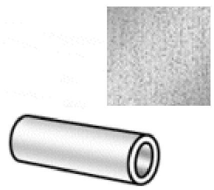
Appendix C: Vendor Information

Table 11: List of Vendors

List of Vendors	Contact Information						
Companies	Address	Email	Phone Number	Fax Number	Website	Hours	
McMaster-Carr	600 N County Line Rd.	chi.sales@mcmaster.com	630-833-0300	630-834-9427	http://www.mcmaster.com/#	M - F	7:00 am - 6:00 pm
	Elmhurst, IL 60126-2081		630-600-3600			Sat	7:00 am - 2:00 pm
Nashbar	6103 St Rt 446	custserv@nashbar.com	877-688-8600	877-778-9456	http://www.nashbar.com	M-Sun	7:30 am - 12:00am ET
	Canfield, Ohio 44406						
SpinLife	330 West Spring Str.	customerservice@spinlife.com	800-850-0335	614-564-1401	http://www.spinlife.com/	Not Listed	
	Suite 303						
	Columbus, OH 43215						
Quickie Wheel	SouthwestMedical.com, LLC	information@quickie-wheelchairs.com	800-236-4215	602-279-0952	http://www.quickie-wheelchairs.com/	M - F	8:00 - 5:00 MST
	505 W. Thomas Road						
	Phoenix, AZ 85013						

Appendix D: Vendor Component Specifications and Data Sheets

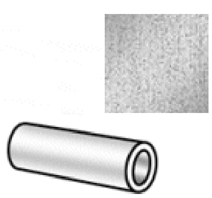
Swing Arm for Model #1



Part Number: 89955K8 $77.71 Each

Material	Easy-to-Weld Aircraft-Grade 4130 Alloy Steel
Alloy	4130
Finish/Coating	Unpolished (Mill)
Shape	Tubes
Tube Type	Round
Wall Thickness	.25"
Wall Thickness Tolerance	±15%
Length	6'
Length Tolerance	±1"
Inside Diameter	.5"
Outside Diameter	1"
Outside Diameter Tolerance	±0.005"
Tolerance	Standard
Temper/Condition	Annealed
Hardness	Rockwell C19-C26
Maximum Attainable Hardness	Rockwell C49
Yield Strength	75,000 psi
Specifications Met	Aerospace Material Specifications (AMS), Military Specifications (MIL)
AMS Specification	AMS -T-6736A
MIL Specification	MIL-T-6736B
WARNING	Hardness and yield strength are not guaranteed and are intended only as a basis for comparison.

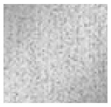
Connecting Rod/Axle

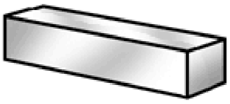


Part Number: 89955K26 $22.61 Each

Material	Easy-to-Weld Aircraft-Grade 4130 Alloy Steel
Alloy	4130
Finish/Coating	Unpolished (Mill)
Shape	Tubes
Tube Type	Round
Wall Thickness	.049"
Length	6'
Length Tolerance	±1"
Inside Diameter	.402"
Outside Diameter	.5"
Outside Diameter Tolerance	±0.005"
Tolerance	Standard
Temper/Condition	Half Hard
Hardness	Rockwell C19-C26
Maximum Attainable Hardness	Rockwell C49
Yield Strength	75,000 psi
Specifications Met	Aerospace Material Specifications (AMS), Military Specifications (MIL)
AMS Specification	AMS -T-6736A
MIL Specification	MIL-T-6736B
WARNING	Hardness and yield strength are not guaranteed and are intended only as a basis for comparison.

Collar

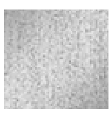




Part Number: 9008K531 $31.72 Each

Material	Multipurpose Aluminum (Alloy 6061)
Shape	Sheets, Bars, Strips, and Cubes
Sheets, Bars, Strips, and Cubes Type	Plain
Finish/Coating	Unpolished (Mill)
Edge Type	Square
Tolerance	Standard
Thickness	2"
Thickness Tolerance	±.024"
Length	12"
Length Tolerance	±1"
Width	2"
Width Tolerance	±.024"
Test Report	Without Test Report
Temper	T6511
Hardness	60-95 Brinell
Yield Strength	35,000 psi
Flatness Tolerance	Not Rated
Temperature Range	-320° to +300° F
Specifications Met	American Society for Testing and Materials (ASTM)
ASTM Specification	ASTM B221
WARNING	Hardness and yield strength are not guaranteed and are intended only as a basis for comparison.

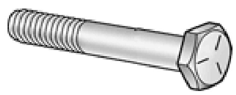
Side Plate for Model #1



Part Number: 8975K713 $15.39 Each

Material	Multipurpose Aluminum (Alloy 6061)
Shape	Sheets, Bars, Strips, and Cubes
Sheets, Bars, Strips, and Cubes Type	Plain
Finish/Coating	Unpolished (Mill)
Edge Type	Square
Tolerance	Standard
Thickness	1/4"
Thickness Tolerance	±.008"
Length	36"
Length Tolerance	±1"
Width	2"
Width Tolerance	±.024"
Test Report	Without Test Report
Temper	T6511
Hardness	60-95 Brinell
Yield Strength	35,000 psi
Flatness Tolerance	Not Rated
Temperature Range	-320° to +300° F
Specifications Met	American Society for Testing and Materials (ASTM)
ASTM Specification	ASTM B221
WARNING	Hardness and yield strength are not guaranteed and are intended only as a basis for comparison.

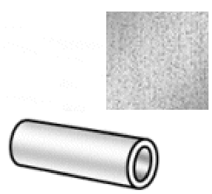
Bolts



Part Number: 91247A553 $8.07 per Pack of 50

Head Style	Standard Hex
Material Type	Steel
Finish	Zinc-Plated
Grade/Class	Grade 5
System of Measurement	Inch
Inch Thread Size	1/4"-20
Length	2-3/4"
Head Width	7/16"
Head Height	5/32"
Thread Length	Partially Threaded
Thread Fit	Class 2A
Thread Direction	Right Handed
Self-Locking Method	None
Rockwell Hardness	Minimum C25
Minimum Tensile Strength	120,000 psi
Specifications Met	American Society of Mechanical Engineers (ASME), Society of Automotive Engineers (SAE)
ASME Specification	ASME B18.2.1
SAE Specification	SAE J429
Screw Quantity	Individual Screw

Swing Arms and Handles #2



7767T23

Each ADD TO ORDER

In stock for $11.78

More About Steel Alloys

Material	General-Purpose Low-Carbon Steel
Finish/Coating	Unpolished (Mill)
Shape	Tubes
Tube Type	Round
Wall Thickness	.065"
Wall Thickness Tolerance	Not Rated
Length	6'
Length Tolerance	±6"
Inside Diameter	.87"
Outside Diameter	1"
Outside Diameter Tolerance	±.0035"
Tolerance	Standard
Hardness	Not Rated
Maximum Attainable Hardness	Not Rated
Yield Strength	Not Rated
Specifications Met	American Society for Testing and Materials (ASTM)
ASTM Specification	ASTM A513

Side plates for Model #2

8975K683

Each ADD TO ORDER

In stock for $20.26

More About Aluminum and Aluminum Alloys

Material	Multipurpose Aluminum (Alloy 6061)
Shape	Sheets, Bars, Strips, and Cubes
Sheets, Bars, Strips, and Cubes Type	Plain
Finish/Coating	Unpolished (Mill)
Edge Type	Square
Tolerance	Standard
Thickness	1/4"
Thickness Tolerance	±.008"
Length	36"
Length Tolerance	±1"
Width	2-1/2"
Width Tolerance	±.024"
Test Report	Without Test Report
Temper	T6511
Hardness	60-95 Brinell
Yield Strength	35,000 psi
Flatness Tolerance	Not Rated
Temperature Range	-320° to +300° F
Specifications Met	American Society for Testing and Materials (ASTM)
ASTM Specification	ASTM B221
WARNING	Hardness and yield strength are not guaranteed and are intended only as a basis for comparison.

Caster Fork for Model #1

Frog Legs
Ultra Sports Caster Forks Caster Fork

Model No. US456

List Price: $329.00

You Save -$69.00

Our Price: **$260.00**

Price includes FREE shipping!

Customize ▼

Image may show upgrades

Larger Image

Description | Return Info

Key Specs

- Weight: 2 lbs.

Features

- Available in 1" and 1.5" wide models.
- Available for 3", 4", 5" and 6" caster wheels.
- Fits most manual wheelchairs from manufacturers like Invacare, Quickie, E&J, Colours and more.
- Polymer shock absorber flexes to soften bumps and cut vibration.
- Easy replacement of existing rigid caster forks.
- Hinged pivot point allows you to roll up and over obstacles.
- Choice of axle position--for wheel size and seat height.
- Please specify caster housing to floor measurement and wheelchair model upon ordering.

Description

For the person really on the GO! Ultra Sports incorporate a lightweight stembolt for additional weight reduction on your chair. In many cases, this makes Ultra Sports shock absorbers lighter than the rigid forks they replace. But don't think for a second that you sacrifice anything in performance. The hollowed-out design is ten times stronger than an ordinary, solid stembolt inserted into your chair. The Ultra Sports Caster Forks are sold as a pair.

Caster

4 x 1" Light-Up Caster

Light-Up Clear Urethane Tire

5/16" Precision Bearing Bearing, 1" Hub Width

View Product Images

Product Features

- 1in Hub Width
- 5/16 Bearing
- Fits Invacare, Quickie, TiSport & Others

By: TAG
Item Number: RP183000
Unit of Measure: Each

Appendix E: Detailed Supporting Analysis

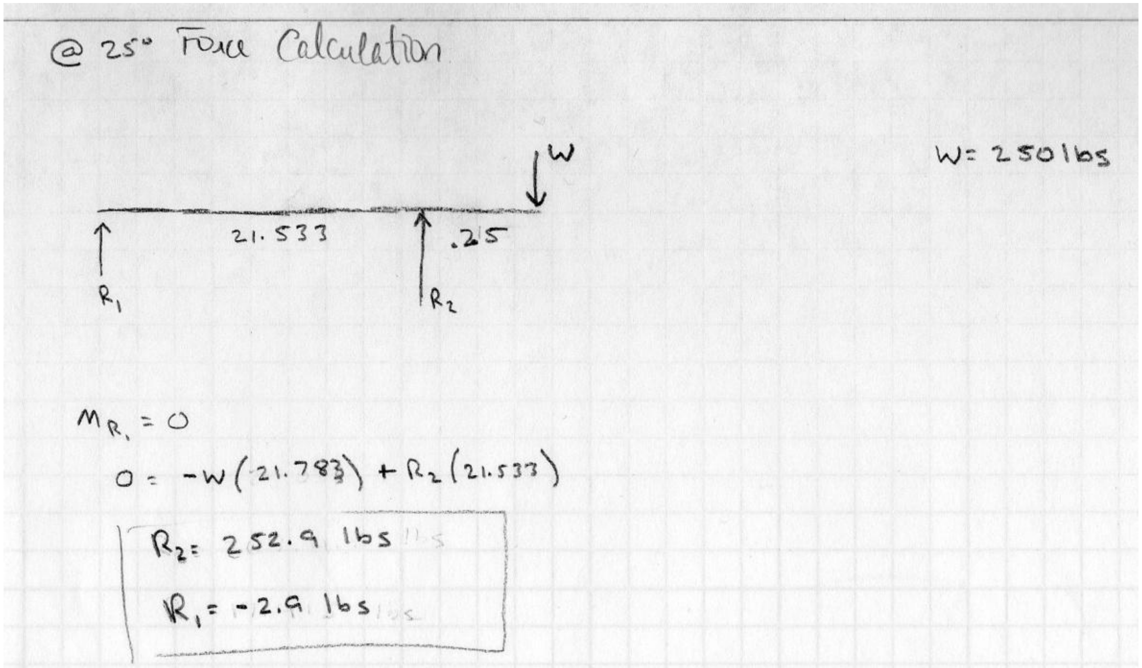


Figure 87: Analysis at 25°

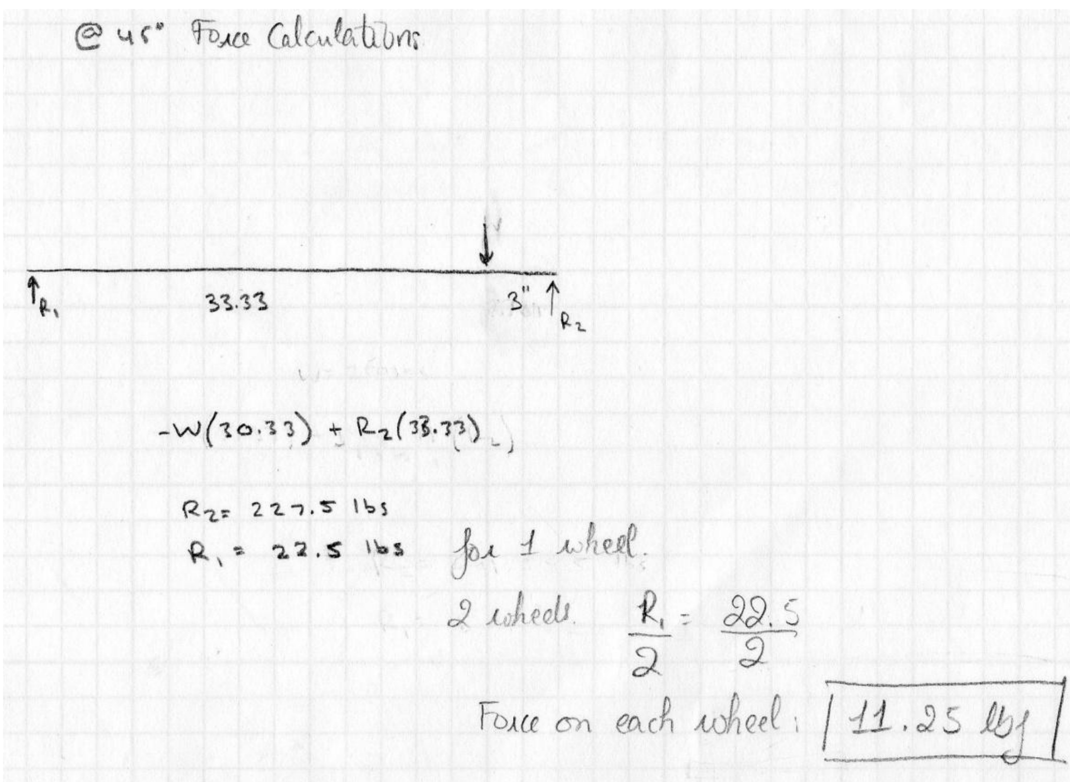
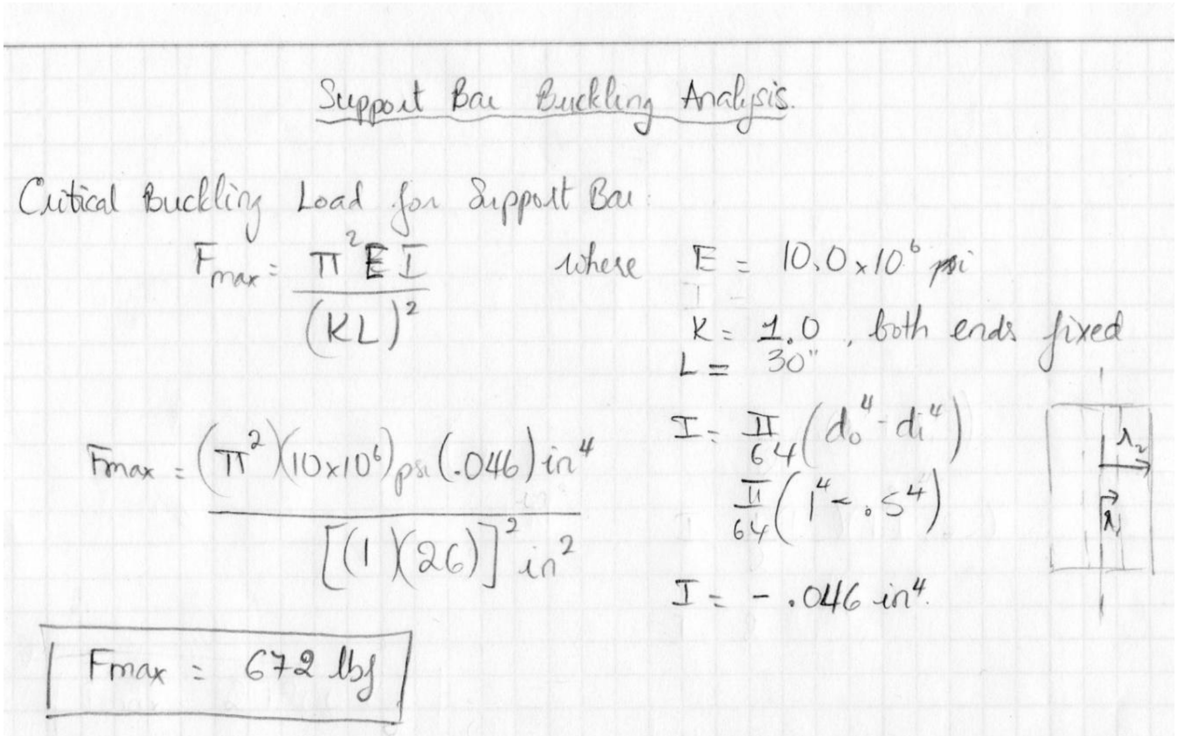


Figure 88: Analysis at 45°



Support Bar Buckling Analysis.

Critical Buckling Load for Support Bar:

$$F_{max} = \frac{\pi^2 E I}{(KL)^2}$$ where $E = 10.0 \times 10^6$ psi

$K = 1.0$, both ends fixed

$L = 30"$

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right)$$

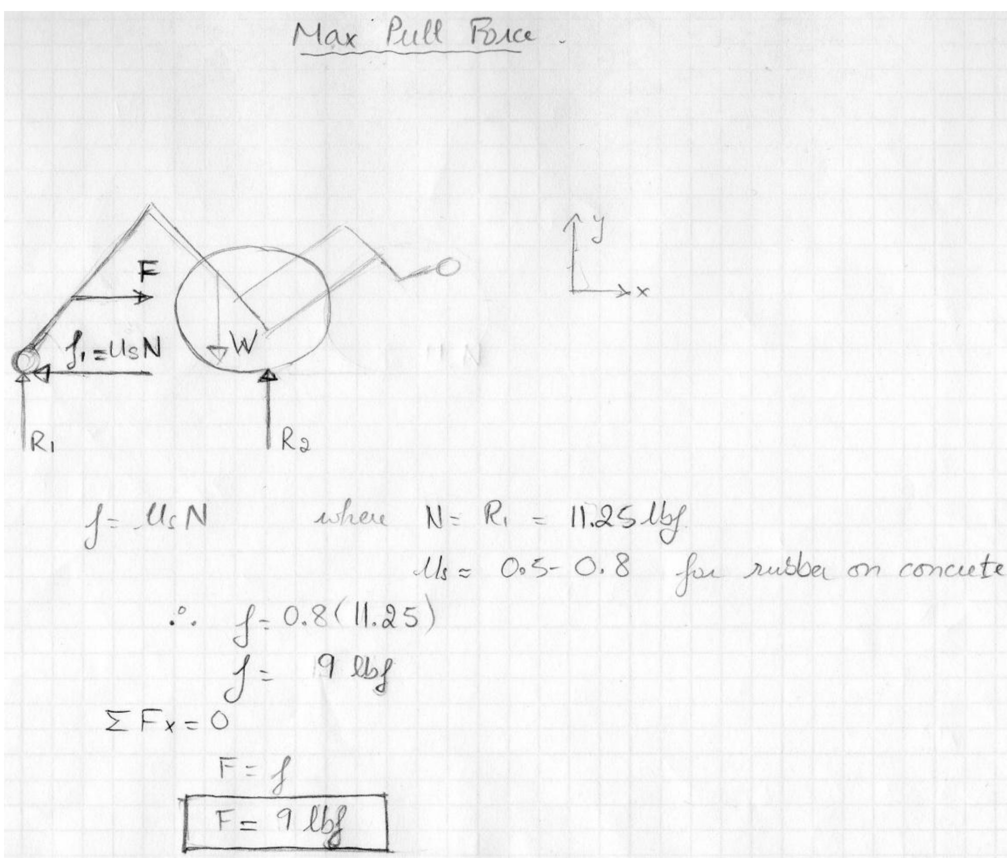
$$\frac{\pi}{64}\left(1^4 - .5^4\right)$$

$$I = -.046 \text{ in}^4$$

$$F_{max} = \frac{(\pi^2)(10 \times 10^6)_{psi}(.046) \text{ in}^4}{[(1)(26)]^2 \text{ in}^2}$$

$$\boxed{F_{max} = 672 \text{ lbf}}$$

Figure 89: Buckling Analysis



Max Pull Force.

$f = \mu_s N$ where $N = R_1 = 11.25$ lbf

$\mu_s \approx 0.5 - 0.8$ for rubber on concrete

$\therefore \; f = 0.8(11.25)$

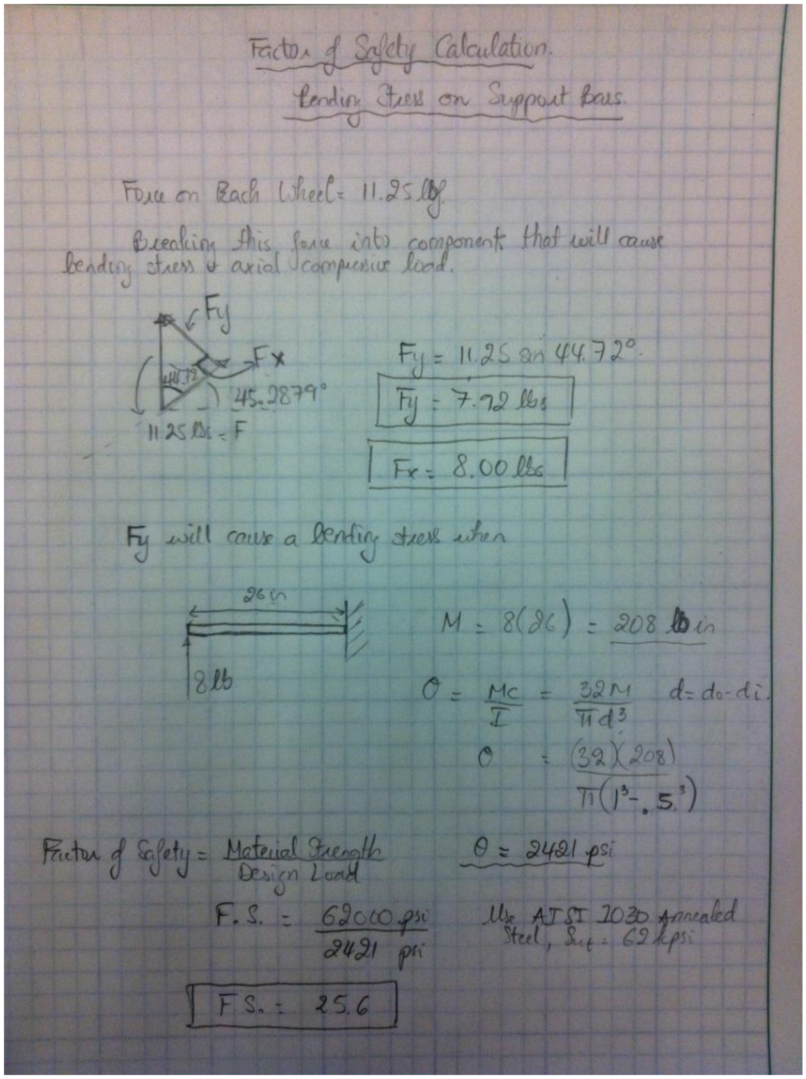
$f = 9$ lbf

$\Sigma F_x = 0$

$F = f$

$$\boxed{F = 9 \text{ lbf}}$$

Figure 90: Max Pull Force Analysis


Factor of Safety Calculation.
Bending Stress on Support Bars.

Force on Each Wheel = 11.25 lbf

Breaking this force into components that will cause bending stress & axial compressive load.

F_y

F_x

45.2879°

11.25 lbs = F

$F_y = 11.25 \sin 44.72°$

$\boxed{F_y = 7.92 \text{ lbs}}$

$\boxed{F_x = 8.00 \text{ lbs}}$

F_y will cause a bending stress when

26 in

8 lb

$M = 8(26) = \underline{208 \text{ lb in}}$

$\sigma = \frac{Mc}{I} = \frac{32M}{\pi d^3}$ $d = d_o - d_i$

$\sigma = \frac{(32)(208)}{\pi(1^3 - .5^3)}$

$\underline{\sigma = 2421 \text{ psi}}$

Factor of Safety = $\frac{\text{Material Strength}}{\text{Design Load}}$

F.S. = $\frac{62000 \text{ psi}}{2421 \text{ psi}}$

Use AISI 1030 Annealed Steel, S_{ut} = 62 kpsi

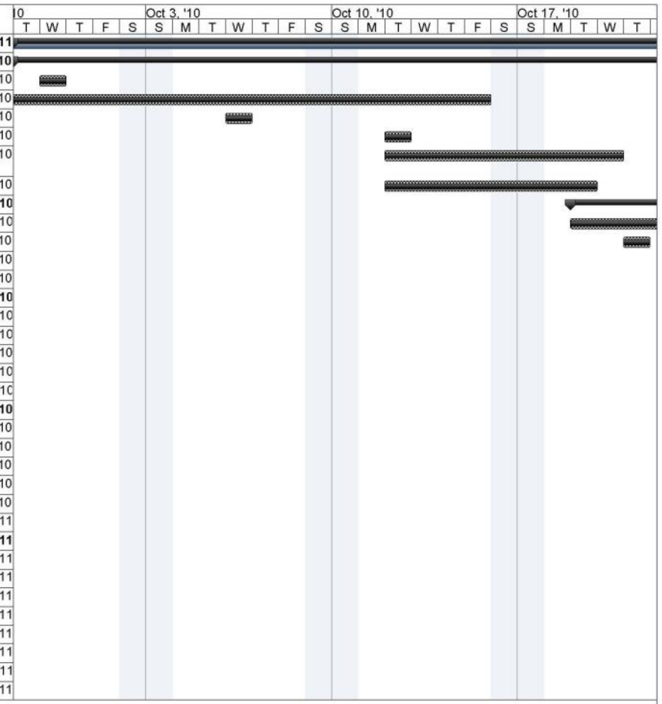
$\boxed{\text{F.S.} = 25.6}$

Figure 91: Factor of Safety Analysis

Appendix F: Project Timeline

Table 12: Gantt Chart

ID		Task Name	Duration	Start	Finish
1		**Senior Project**	**178 days**	**Tue 9/28/10**	**Thu 6/2/11**
2	✓	**Design Process**	**54 days**	**Tue 9/28/10**	**Fri 12/10/10**
3	✓	Write Introduction Letter to Sponsor BTB	1 day	Wed 9/29/10	Wed 9/29/10
4	✓	Coordinate Meetings and Getting Information for Sponsor	14 days	Tue 9/28/10	Fri 10/15/10
5	✓	Meet with Kinesiology Team	1 day	Wed 10/6/10	Wed 10/6/10
6	✓	BTB Sponsor Meeting	1 day	Tue 10/12/10	Tue 10/12/10
7	✓	Gather and Creates Customer Specifications and Engineering Specifications	7 days	Tue 10/12/10	Wed 10/20/10
8	✓	Writing Project Proposal	6 days	Tue 10/12/10	Tue 10/19/10
9	✓	**Generate Ideas for Models**	**31 days**	**Tue 10/19/10**	**Tue 11/30/10**
10	✓	Brainstorming	31 days	Tue 10/19/10	Tue 11/30/10
11	✓	Morphological Analysis	1 day	Thu 10/21/10	Thu 10/21/10
12	✓	Alternative Action	1 day	Tue 10/26/10	Tue 10/26/10
13	✓	Scamper	1 day	Tue 10/26/10	Tue 10/26/10
14	✓	**Conceptual Model**	**26 days**	**Tue 10/26/10**	**Tue 11/30/10**
15	✓	Sketch Ideas	26 days	Tue 10/26/10	Tue 11/30/10
16	✓	Meet to Discuss Ideas	1 day	Tue 11/2/10	Tue 11/2/10
17	✓	Build Foam Models	5 days	Tue 11/2/10	Mon 11/8/10
18	✓	Get Critique on Models	1 day	Tue 11/9/10	Tue 11/9/10
19	✓	Decision Matrix after feedback	3 days	Tue 11/9/10	Thu 11/11/10
20	✓	**Conceptual Design Report**	**20 days**	**Wed 11/10/10**	**Tue 12/7/10**
21	✓	Preliminary SolidWorks Models	11 days	Tue 11/23/10	Tue 12/7/10
22	✓	Write Conceptual Design Report	17 days	Wed 11/10/10	Thu 12/2/10
23	✓	Analysis	13 days	Tue 11/16/10	Thu 12/2/10
24	✓	Conceptual Design Report and Status Meeting With Sponsor	1 day	Tue 12/7/10	Tue 12/7/10
25	✓	Make Adjustments Based on Feedback	3 days	Wed 12/8/10	Fri 12/10/10
26	✓	Project Update to Sponsor	3 days	Tue 1/4/11	Thu 1/6/11
27	✓	**Detailed Design Model**	**21 days**	**Tue 1/4/11**	**Tue 2/1/11**
28	✓	Finalize SolidWorks Models (CAD drawings)	11 days	Tue 1/4/11	Tue 1/18/11
29	✓	Student Presentations	6 days	Tue 1/18/11	Tue 1/25/11
30	✓	Analysis	7 days	Tue 1/18/11	Wed 1/26/11
31	✓	Order/ Receive Parts	14 days	Thu 1/27/11	Tue 2/15/11
32	✓	Finalize Design and Write Report	20 days	Tue 1/4/11	Mon 1/31/11
33	✓	Design Report	1 day	Tue 2/1/11	Tue 2/1/11
34	✓	Final Design Review to Sponsor	1 day	Fri 2/11/11	Fri 2/11/11
35	✓	Project Update to Sponsor	1 day	Thu 3/10/11	Thu 3/10/11



Project: gantt updated
Date: Tue 5/31/11

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

Page 1

ID		Task Name	Duration	Start	Finish
36		**Manufacturing and Test Review**	**68 days**	**Mon 2/28/11**	**Wed 6/1/11**
37	✓	**Manufacturing**	**66 days**	**Mon 2/28/11**	**Mon 5/30/11**
38	✓	**Prototype Building: Swing Dancer**	**39 days**	**Mon 4/4/11**	**Thu 5/26/11**
39	✓	Caster and Caster Forks	1 day	Thu 5/26/11	Thu 5/26/11
40	✓	Side Plate	2 days	Mon 4/4/11	Tue 4/5/11
41	✓	Connecting Rod	2 days	Wed 4/6/11	Thu 4/7/11
42	✓	Collars	29 days	Fri 4/8/11	Wed 5/18/11
43	✓	Swing Arms	2 days	Fri 5/6/11	Mon 5/9/11
44	✓	Handle	2 days	Thu 5/19/11	Fri 5/20/11
45		**Testing**	**3 days**	**Fri 5/27/11**	**Tue 5/31/11**
46	✓	Analysis	11 days	Mon 3/14/11	Mon 3/28/11
47		Model Modifications	15 days	Thu 5/12/11	Wed 6/1/11
48	✓	Project Update to Sponsor	1 day	Mon 4/4/11	Mon 4/4/11
49	✓	**Hardware Demo**	**2 days**	**Fri 5/6/11**	**Mon 5/9/11**
50	✓	Prepare Presentation	2 days	Fri 5/6/11	Mon 5/9/11
51	✓	Project Update to Sponsor	1 day	Tue 5/10/11	Tue 5/10/11
52		Senior Project Design Expo XII	1 day	Thu 6/2/11	Thu 6/2/11

10 T W T F S | Oct 3, '10 S M T W T F S | Oct 10, '10 S M T W T F S | Oct 17, '10 S M T W T

Project: gantt updated
Date: Tue 5/31/11

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

Page 2

Appendix G: Installation Guide/User Manual

Statement of Disclaimer

Since this project is a result of a class assignment, it has been graded and accepted as fulfillment of the course requirements. Acceptance does not imply technical accuracy or reliability. Any use of information in this report is done at the risk of the user. These risks may include catastrophic failure of the device or infringement of patent or copyright laws. California Polytechnic State University at San Luis Obispo and its staff cannot be held liable for any use or misuse of the project.

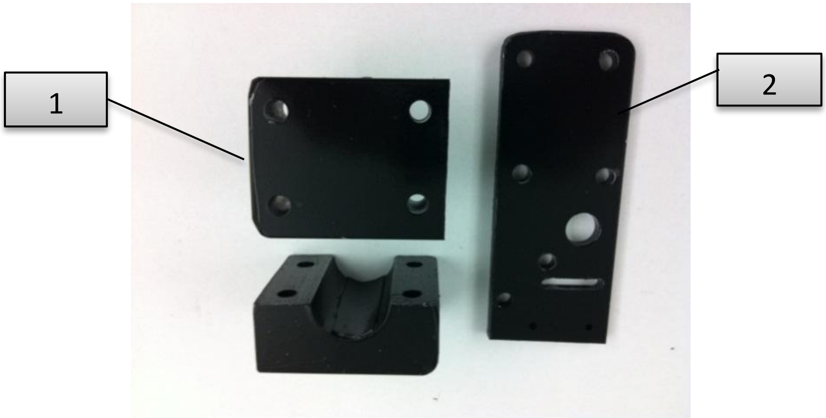
List of all Subsystems

Table 13: List of Pieces

Assembly	Part	Material	Geometry	Quantity
Collar				
	Sidewall(M)	6061 Aluminum Alloy	4.5" x 2" x .25"	4
	Collar (M)	6061 Aluminum Alloy	2" x 2" x 2"	2
Swing Arm				
	Swing Arm (M)	4130 Alloy Steel	Length: 16", OD: 1", ID: .5"	2
	Axle (M)	4130 Alloy Steel	Length: 3", OD: .5", ID: .402"	2
	Connecting Rod (M)	4130 Alloy Steel	Length: 16.5", OD: .5", ID: .402"	1
	Caster Wheel (Q)	Rubber	4" x 1"	2
	Caster Fork (S)	Aluminum		2
	Handles	Steel	Length: 4” , OD .75”	2
Miscellaneous				
	Bolts (M)	Zinc-Plated Steel Grade 5	36" x 2" x .25"	10
	Screws (H)	Zinc	#4 –40 x ¾ “	8
	Nut (A)	Steel	¼” Coarse Thread	10
Total				35

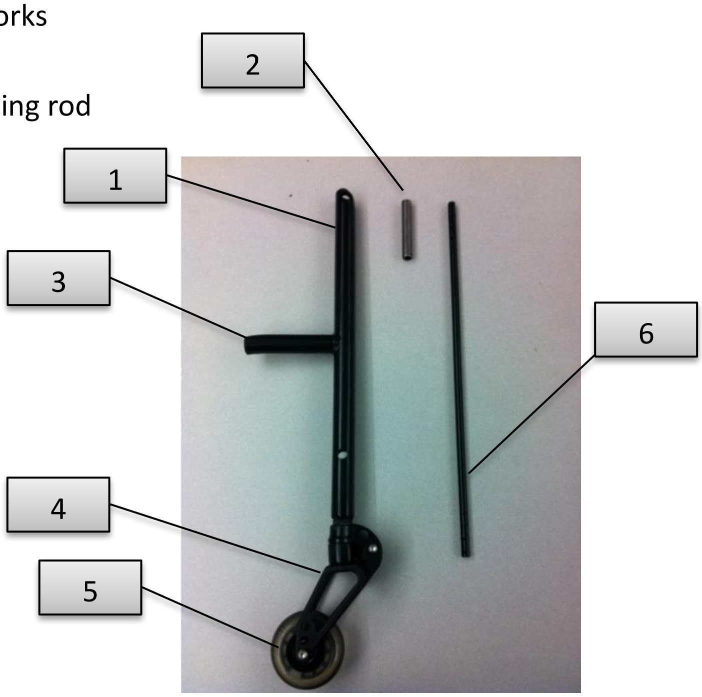
Collar Subsystem:

1. (2) collars
2. (4) side plates



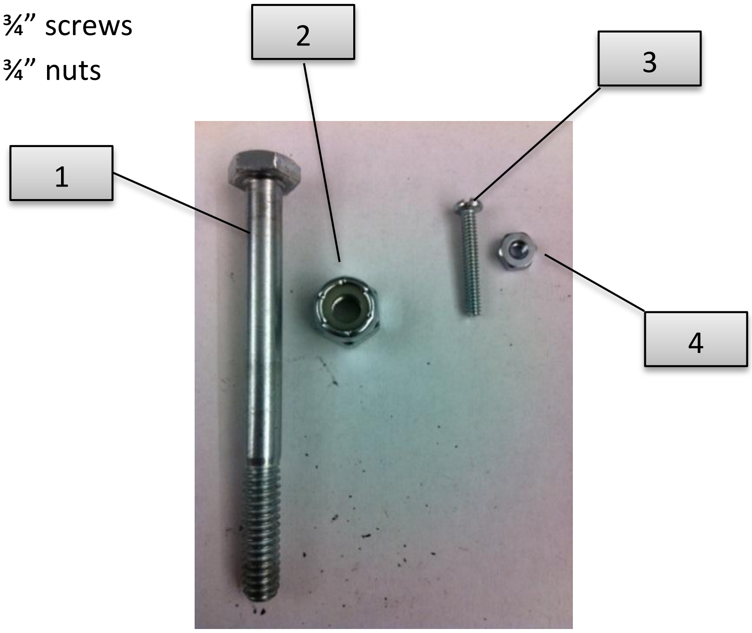
Swing Arm Subsystem:

1. (2) swing arms
2. (2) axles
3. (2) handles
4. (2) caster forks
5. (2) casters
6. (1) connecting rod



Miscellaneous Parts:

1. (10) ¼” bolts
2. (10) ¼” nuts
3. (8) #4-40 x ¾” screws
4. (8) #4-40 x ¾” nuts



Installation Procedure

Using the parts listed above; piece together the attachment using the procedure shown below

Table 14: Step by Step Installation Procedure

Step #	Procedure
1	Remove chair backing to expose chair frame
2*	Attach (1) collar to (2) sidewalls using (5) ¼"bolts and (5) ¼" nuts, don't tighten the bolts, leave them loose
3	Slide (1) axle through the side plates, going through (2) copper spacers and (1) swing arm
4	Insert (2) #4-40x3/4" screws into the axle holes & tighten with nuts
5**	Slide the collar onto the chair frame then tighten the bolts, be sure not to over torque the device
6	Connect the connecting rod through the 2 holes on the swing arms. Then insert (2) #4-40x3/4" screw and tighten with nuts
7	Repeat steps 2-6 for the other side of the chair frame
8	Reattach the chair backing

Notes: *Make sure all fillet pieces are facing the same direction and the axle holes are at the bottom

**Make sure the collar is on straight when installing it onto the frame and the top of the collar shouldn't be more than 30" measured from the ground up

Pictures of Installation: Step-By-Step

Step 1: Remove chair backing to expose chair frame

Figure 92: Wheelchair without seat backing

Step 2: Attach (1) collar to (2) sidewalls using (5) ¼"bolts and (5) ¼" nuts, don't tighten the bolts, leave them loose

Figure 93: Collar Subsystem

Step 3: Slide (1) axle through the side plates, going through (2) copper spacers and (1) swing arm

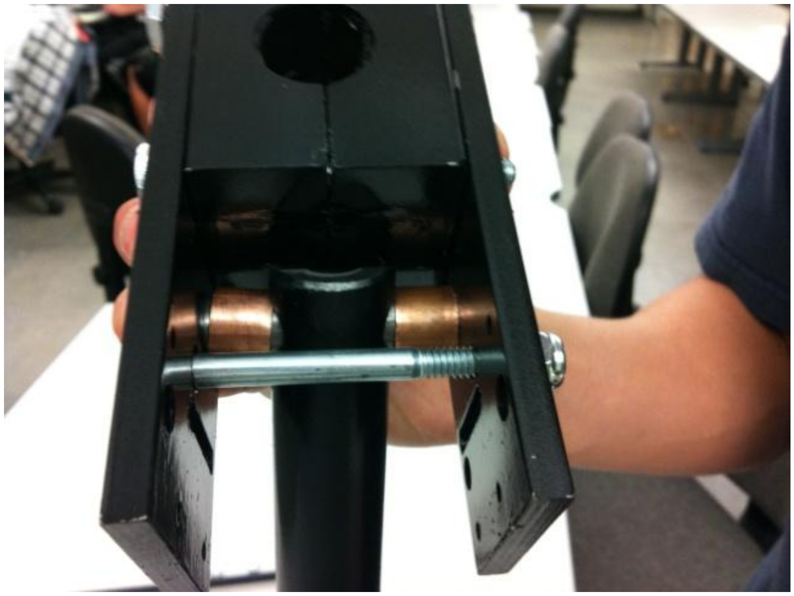


Figure 94: Axle with copper spacers and swing arm

Step 4: Insert (2) #4-40x3/4" screws into the axle holes & tighten with nuts

Figure 95: Side view of #4-40 x 3/4 " screw in axle

Step 5: Slide the collar onto the chair frame then tighten the bolts, be sure not to over torque the device

Figure 96: Collar Assembly attached to Wheelchair Frame

Step 6: Connect the connecting rod through the 2 holes on the swing arms. Then insert (2) #4-40x3/4" screw and tighten with nuts

Figure 97: Attachment with Connecting Rod

Step 7: Repeat steps 2-6 for the other side of the chair frame

Step 8: Reattach the chair backing

Figure 98: The Swing Dancer completely assembled

Operational Procedure

As with every device, there are procedures that must be followed to make sure the device is used how it was intended. While using the Swing Dancer, it is important that these steps be followed for a fun, yet safe experience.

1. While in the upright position, the user needs to roll forward using an extra amount of force than normally necessary to roll forward. While pushing forward, lean back in the chair. This should cause the wheelchair to start falling backwards into a wheelie position.
2. The most important step during this process is to keep rolling the wheels **forward** during this entire procedure. If the user decides to pause or roll backwards, the swing arms may not fully activate and proceed to roll back under the user instead of extending outwards. This will cause the user to fall backwards and could result in serious injury.
3. Once the swing arms are fully extended, the user is able to roll forward or backwards at whatever speeds they please. Due to the wheels being locked in a straight orientation, it is not possible to turn.
4. To get back to the upright position, roll forward with the same amount of force it took to pop a wheelie. In one fluid motion, stop the wheels from rolling forward causing the wheels to brake. This will cause the user's forward momentum to lean the chair forward until gravity naturally takes over and the chair will fall forward into an upright position
5. An alternative solution to getting into an upright position is to reach behind and grasp the handles on the swing arms. While leaning as far forward in the chair as possible, pull the handles towards your body. This will force the chair towards the upright position until gravity takes over and sets the front wheels back onto the ground and the chair is in an upright configuration.

For a better idea of the operational procedure, please see the pictures provided below.

Step 1: Push Forward while Leaning Backwards

Figure 99: Engaging Swing Arms by Forward Motion

Step 2: Fully Engage Swing Arms

Figure 100: Continue Rolling Forward

Step 3: Pop-a-Wheelie

Figure 101: Enjoying the Wheelie Position with Swing Arms Fully Engaged

Step 4: Return to Upright Position (Method #1)

Figure 102: Roll Forward With Extra Force

Figure 103: Stop Wheel with Hands to Force Chair Forward

Step 5: Return to Upright Position (Method #2)

Figure 104: Grasp Handles and Pull In while Leaning Forward

Figure 105: Continue Leaning Forward until Chair is in Upright Position