BEACH WHEELCHAIR ATTACHMENT

FINAL DESIGN REVIEW

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Executive Summary

This document includes the problem that is under scrutiny, the background research towards finding a solution, the objectives, scope of the project, the planned overall design process, the preliminary design we have produced and analyzed, the critical design we have manufactured, the testing and results, and the final assessment of the produced design. The problem is lack of easy access and movement for wheelchair users on the beach. Other solutions and designs have been logged under background research. With this information, the scope of work was designed to meet all the needs specified and describe how the specifications will be measured. The overall process was undertaken to produce multiple designs which were then refined into a preliminary design to move forward with. A timeline for the project and analysis of the preliminary design have been specified. The critical design and manufacturing plan for the design are mentioned as well. The critical design is a wheel and lever ratchet mechanism that can be easily attached to any manual quick-release axle wheelchair. The design is a three-part assembly: the ratcheting hub and wheels are the first assembly, the second is the lever which attaches to the first assembly, and the third assembly is the separate front wheel ski mechanism to prevent sinking into the sand.

Chapter 1. Introduction

The Final Design Review (FDR) will allow our sponsor, Quality of Life Plus (QL+), to clearly see what we have produced with the results and recommendations for further iterations of the attachment. The document is broken down into 9 chapters: Introduction, Background, Concept Design Development, Objectives, Final Design, Manufacturing Plan, Design Verification Plan, Project Management and Conclusion and Recommendations. QL+, a Virginia-based nonprofit organization that provides opportunities for American veterans, asked for a beach wheelchair design for their challenger, Nathan. QL+ gives veterans (challengers) the ability to enhance their lives with the help of student-led teams. The organization wants to not only make life easier for veterans, but also more enjoyable. Nathan specifically wants a manual wheelchair attachment for daily and beach use with a discreet design. Our team, three Cal Poly engineering students, have made it our task to meet Nathan's needs and produce a design for a similar wheelchair to Nathan's that could potentially be used by others. The following sections will breakdown what products and technology already exist as well as which ideas we have chosen to move forward with.

Chapter 2. Background

The first research task was to find existing wheelchair designs for specific beach use. In detail, we researched all-terrain style wheelchairs. We also included the findings of several types of beach vehicles to analyze and see if some design or idea could be taken from them. Below are notes on each type of existing design that was found.

Ogo- The Ogo is a wheelchair system using similar Segway technology by allowing the user of the wheelchair to move his or her upper body to move the chair. The Ogo is displayed in Figure 1. A joystick can be used in place of the body movements for easier use. The design is discreet, however the cost places it out of easy access to most wheelchair users. Analysis of the wheelchair concludes that the wheels do not have enough surface area to move on sand as easily as we need. [1]

Figure 1. The Ogo chair fits most of our challenger's needs. [1]

Sand Rider- The Sand Rider is a typical beach wheelchair. The design uses large gray inflatable wheels (balloon wheels) for an increase in surface area to maneuver across sand. The Sand Rider requires assistance to push and the larger wheels and design can attract unwanted attention. [2]

Rip or Trackmaster chair- The Rip Chair and Trackmaster chair both incorporate a design of tracks to move over all types of terrain. The Rip Chair is significantly larger and less portable, designed more like a construction vehicle than the Trackmaster design. The Trackmaster is simpler in design, however is still quite large and noticeable. Both designs allow for easy maneuverability over sand. [3]

Sand Roller- The Sand Roller, in Figure 2, is one of the simplest designs we found. The increased width of the flat plastic wheels allows for the user to push the wheelchair manually without a high increase in force needed. The larger wheels make it harder to turn the chair; a third wheel in front accommodates this extra difficulty. The aesthetics are not very pleasing and can attract unwanted attention. [4]

Figure 2. The Sand Roller is a very effective wheelchair for travelling through sand manually, but lacks the necessary aesthetic value. [4]

Grit Freedom Chair- The Grit Freedom Chair is very discreet in style and aesthetics. An attached front wheel is included for added stability and control. The use of a lever drive system amplifies the force the user produces to make it easier to self-propel over grass, sand, and rough terrain; however, the force needed to exert to travel across sand is still very high and ineffective. [5]

Nudrive Air- NuDrive Air is a non-invasive approach similar to the Grit freedom chair. The attachment uses a lever system that reduces the force needed to self-propel by 40%. Unfortunately, the wheels are not modified to allow for all terrain application, specifically sand. [6]

All existing designs specified above that do not have figures attached to their description can be seen in Appendix A.

Several expired patents use a similar design to the Sand Rider beach wheelchair; one specific all-terrain wheelchair is modified to be manually operated using a lever system with three wheels. This three-wheel design has a flywheel that is used to create energy and transition that energy to rotational movement of the wheels. This, however, would be a heavy design and not accurate for the scope of our project. A similar design to the Rip or Trackmaster chair used a system of wheels and ratchets with tank tracks to increase surface area and mechanical output. The two patents mentioned, and more patent information can be seen in Appendix B.

Further analysis and research provided government specifications pertaining to wheelchair accessibility and building codes. The American Disabilities Act (ADA) specifications show that the width of an adult-sized wheelchair measured from the outside of the rear wheels is 26 inches, and the length from the back of the rear wheels to the front of the foot rests is 48 inches. The wheelchair would also need to traverse a ramp with a 1:12 slope ratio. ADA also requires that the minimum clearance width for a single wheelchair passage is 32 inches. [7], [8], [9]

Chapter 3. Objectives

The objectives chapter defines the specific scope of our project, the problem we have been given in more detail, the specific needs and wants of the user, analysis of the problem using a QFD (Quality Function Deployment), and several of the specifications we will be meeting. This section defines the foundation from where we have started, what we have designed and planned for the manufacturing stage.

3.1 Problem Statement

Nathan needs a way to get from the sidewalk to the beach as well as maneuver on the beach manually. Current designs are too expensive, hard to use, and attract unwanted attention. Specifically, it needs to be an attachment to a daily use wheelchair and used without excessive help from others.

We will be designing an attachment for a TiLite Aero Z wheelchair which is similar to Nathan's, to increase ease of use over sand. The attachment can then be modified to fit his specific chair in later production. Our goal is to make the attachment available to use for several different wheelchairs, allowing others to benefit from the design as well.

A boundary diagram seen in Figure 3 was used to narrow down the scope and focus of the project. This boundary diagram allows us to target the main problem and find a specific solution for Nathan in the confines of the boundary we have set up. The boundary diagram sets the area in which we are designing and creating our attachment. The dashed line represents the boundary of our scope, the area we are creating an attachment for. Specifically, we will be working with creating an attachment that pertains mainly to the lower part of a TiLite wheelchair similar to Nathan's wheelchair. Both the TiLite wheelchair we will be designing for and Nathan's wheelchair model can be seen in Figure 4. Ideally, the attachment can then be used specifically for Nathan's chair to go to the beach without Nathan having to transfer to a different wheelchair.

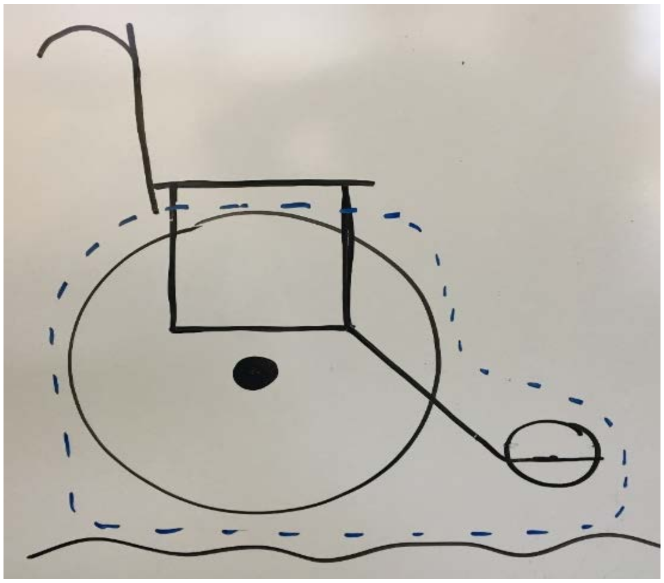

Figure 3: The Boundary Diagram for the scope of the project.

Figure 4a. TiLite ZR wheelchair. Nathan's specific wheelchair is weighted at 10 lbs and made of aluminum.

Figure 4b. TiLite Aero Z wheelchair. The wheelchair we will be modifying is similar in weight and material to Nathan's chair.

3.2 Needs and Wants List

To relate this project directly to Nathan, we discussed his needs and wants for the design. This input from the customer helps us to define the scope and whether certain wants are feasible. Below is a summarized list of what Nathan has specified.

Needs	Wants
· Reduce the difficulty to traverse sand	· Do not attract attention (looks like a standard manual wheelchair)
· Traverse hard and soft sand easily	· Operate his own chair without help from others
· Portable	· Not a separate wheelchair solution
· lightweight	· Move directly from his vehicle to the beach

3.3 QFD

The needs and wants were compiled using the Quality Function Deployment (QFD) method to identify the requirements and specifications of the project. QFD is a method designed to take customer input (desires, wants, needs) for a project or product and translate that input into engineering specifications and measurements. This way, general terms such as 'is safe' can be measured and specifically defined.

The specifications chosen for our project came from the customer's simple description of his needs. The customer wants to operate the device independently, including setup, which is why we specified that it be lightweight and portable. When considering possible solutions, we realized that making a device that does not draw a lot of attention from people will limit us when increasing the surface area of the wheels. With this limitation, we will most likely need to make it easier to travel in sand with the help of a power assist mechanism. The specifications are ranked on importance to our design. The most important specifications was our main focus during the design process. From the analysis of our QFD matrix (the full QFD can be seen in Appendix C), we have found that the most important specifications to meet are the force to move in soft sand and hard sand. Our focus will be meeting this specification by creating an attachment to the TiLite wheelchair.

From our background research we found preliminary ideas for attachments. The QFD contains a section for comparing existing designs to the specifications we will be measuring for our intended design. We compared 5 existing designs to analyze which current wheelchair is most similar to what we are trying to achieve. Of the five designs, The BT-X Beach wheelchair (similar to the Grit Freedom chair mentioned in Section 2) is most like what Nathan has specified as his wants and needs for the design. The BT-X Beach wheelchair in Figure 5 is not the best existing design for our most important specifications to meet though; this is due to the conflict between Nathan's want for the wheelchair to look normal and his need for it to travel easily on sand. The best existing design for meeting our most important specification requires an increase in surface area in contact with the sand. This means that the wheels need to be wider. Generally, wider wheels are less aesthetically pleasing. From our QFD we have concluded that the best solution is to first meet the specifications of traveling on sand, and secondly to meet the specification of discreetness.

Figure 5. The BT-X Beach wheelchair. From the results of our QFD, the BT-X Beach wheelchair is one of the main designs that met most of our criteria.

3.4 Specifications

In order to meet the specifications conceived using Nathan's wants and needs, we required a way to test our design. We established parameters, seen in Table 1, for our design to recognize that we met the specifications. Low risk (L) means it will be relatively easy to meet. Medium Risk (M) and High risk (H) will be harder to meet. Compliance is how we will show we have met our requirements. This is done through Testing (T), Analysis (A), and Inspection (I). To show we had met the lightweight and portability specifications, we created target dimensions and a weight target. For the specification of torque per travel in hard and soft sand, we defined a test measuring force that will be converted to a torque measurement. The requirements and target values all have maximum tolerance values, meaning our design must be less than or equal to the given values. For instance, the weight of the device cannot exceed 15 lbf. The force requirements and target values are based off the information Nathan has given us. He has specified what general range of force he must produce on various terrains.

Table 1. Specifications Table. A Specifications Table to define the testing done to meet our specifications from the QFD. Risk is the ability for us to meet the requirements

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Weight of device	15 lbf	Max	M	I
2	Length (overall)	30 in	Max	L	I
3	Width (overall)	30 in	Max	L	I
4	Height (overall)	30 in	Max	L	I
5	Force to move on sidewalk	5 lbf	Max	L	A, T
6	Force to move on grass	10 lbf	Max	M	A,T
7	Force to move in hard sand	10 lbf	Max	M	A, T
8	Force to move in soft sand	45 lbf	Max	H	A, T
9	Time to setup	5 mins	Max	M	T

The overall dimensions of the design will be determined by inspection to show we have met the requirements. Inspection means we will physically measure the dimensions to make sure they are within the target values.

The force to move was tested by pulling the TiLite wheelchair across the specified terrain with someone sitting in it while connected to a device that measures the force applied. Initial force calculations on the different sand grades has been measured based on testing. After taking the wheelchair to the beach, we measured and recorded the average pounds-force values. These values can be seen in Table 2. Original testing also showed us that the front wheels are an issue and require further design considerations. The main reason the wheelchair would get stuck was due to the front wheels being dug into the sand. In order to measure the force, the crane scale (a type of hand-held hook scale) had to be placed at an angle to partially pull the front wheels off the sand. This allowed us to measure the force without the front wheels getting stuck.

Table 2. Initial Force Testing Table. The wheelchair was taken to the beach in December to determine initial measurements for the force required to move the wheelchair on the beach. We found that it will be necessary to create some type of attachment for the front wheels

Type of Surface or Terrain	Average Pounds-force	Maximum Pounds-force
Soft Sand	57	69
Hard Sand	17	22

The force to move over various terrain values were based off of the tested values in Table 2. Nathan initially gave us values that he guessed were the amount that was required of him. We took these values, and the values we obtained from testing to create a benchmark and goal for our beach design. The values in Table 1 are about 30-40% less than the maximum values seen in Table 2. All the raw data from our preliminary testing can be seen in Appendix H.

The weight specification from Table 1 is a medium risk. Due to the current weight of Nathan's wheelchair, we want to make sure that the modification we make will not be substantially heavy. Nathan is a very active individual who usually sets up his wheelchair independently. We want to continue to allow Nathan to be independent and to still easily set up his wheelchair with the added weight of the attachment. Defining the weight of the attachment versus the weight of the overall chair allows us to focus on the device we are creating since the chair we are using is not an exact match to Nathan's chair.

Set up time and moving through hard sand are also medium risks. Nathan has described that moving through hard sand is still a struggle but is less of a struggle than that of moving through soft sand. We want to minimize set up time if there are any modifications to be added for specific beach use because Nathan has specified that the easier it is to move from his vehicle to the beach is better. The longer set up time might also deter other people from using our device because it will become more of a hassle than it is worth.

The force to move in soft sand is a high risk and is the main focus of our project. As discussed above in the needs list we received from Nathan, one of the most important requirements for our design is that it needs to be discreet. Discreet, in this case, means that it would not draw attention from other people passing by him on the beach any more than a standard wheelchair would. The problem with this requirement is that most wheelchair modifications that allow for effective sand travel are large and bulky. Generally, beach wheelchairs have something that increases the surface area, but increasing the surface area causes many of the chairs to look strange. Our design will have to meet his need for discreetness while still increasing the surface area in a nonobvious way, or by overcoming the need for surface area with a powered or mechanical assist. Because of these reasons, this will likely be the specification that is hardest to meet, but also one of the most important.

Chapter 4. Concept Design Development

The following is a discussion of the process we undertook to create designs and prototype. The Concept phase allowed us to construct a preliminary design to analyze further based off of the background research we had done in Chapter 2.

4.1 Development Process

With background research to guide us, we started by using different techniques for brainstorming. These techniques were used in 3 idea generation sessions where we sat down as a group to come up with concepts and ideas as possible solutions. The first session included writing down a list of everything we could think of as a solution for each function we were trying to design. The functions included aesthetics, traversing through sand, user independent, and how to attach. The second session involved taking the list from the first session and combining one idea from each function to create a system of different designs. The third brainstorming session involved using one of the designs from the second session and analyzing how it could be modified or changed to further fit our problem. The techniques of brainstorming and the results of the idea generation sessions can be seen in Appendix D. Based on the idea generation sessions, we moved on to concept model building. We combined several of our ideas into small models depending on which function we were trying to display. We focused on designing and showing the function of moving over sand since this is the focus of our design. Many of our designs we created were based on the idea sessions we had and the background research we had done. We selected the easiest and least invasive designs to develop for the models.

Figures 6, 7, and 8 are some of the models we built to visualize what our possible solutions are. Figure 6 is a design based off some of the current track wheelchairs mentioned in Chapter 2. Figure 7 is a new concept based on the testing we did. We found that the front wheels would constantly get stuck. A wheel with more surface area in the front would help eliminate that issue. Figure 8 is also a new concept using skis combined with a track-type wheel based on the background research and idea generation sessions we had done. Further designs and pictures can be seen in Appendix D.

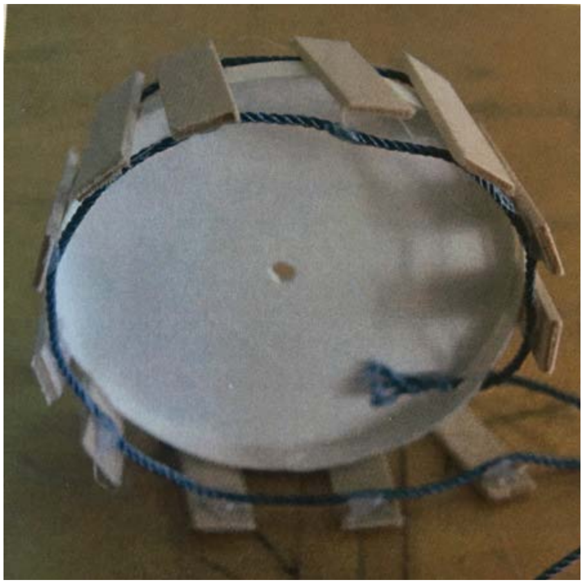

Figure 6. Rope Ladder Concept made of popsicle sticks were cut and attached with string to create a conceptual rope ladder track.

Figure 7. Roller Attachment Concept made from foam wrapped around a cylinder made of paper cups to show a roller mechanism in place of the two front wheels.

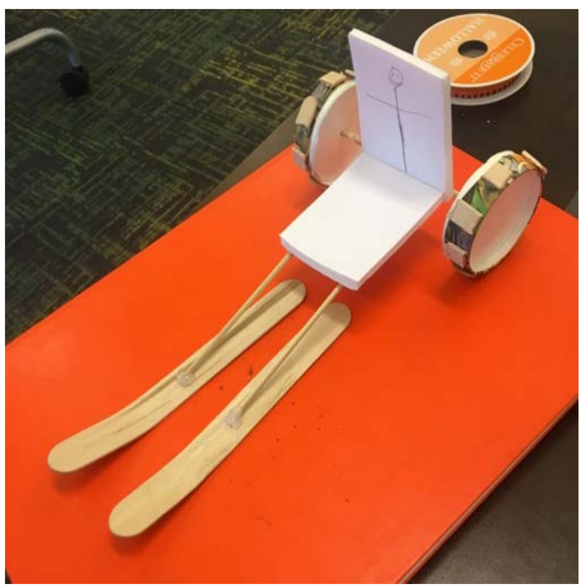

Figure 8. Popsicle stick Concept was used to turn popsicle sticks into skis and cut to be added as tread to the back tires.

4.2 Selection Process

After a first attempt at conceptualizing our ideas into actual models, we focused on selecting a specific design to further study and analyze. This design is what we chose to prototype and eventually alter and modify to come up with the design to move forward with.

We began the selection process by separating the different functions of our project: how to traverse across sand, how to attach the device, and how to use a mechanical assist as an attachment. Each team member took one of the functions and created a Pugh Matrix, seen in Table 3, 4, and 5. A Pugh Matrix is a table that helps evaluate products or designs against the criteria specified. For instance, the Pugh Matrix for how to attach the device had products or designs such as clamps, glue, hooks, etc. A datum must be chosen for each Pugh Matrix in order to compare the different ideas. The + signifies that the design is better than the datum for the specific criteria, the – means that the design is worse when compared to the datum, and the S signifies that the design is the same as the datum for that certain criteria.

We created three Pugh Matrices. The first one, seen in Table 3, was a Pugh Matrix for different types of mechanical assist options. Based on our beach testing, Nathans needs and wants, and the idea generation sessions we had, we knew that a mechanical assist would be necessary to incorporate into our design. The datum for Table 3 was chosen to be the levers with a geared hub. The criteria are based off the specifications in our QFD; however, they are not the same for each Pugh Matrix. The criteria for each Pugh Matrix are based on what each function is; for instance, the Pugh Matrix for mechanical assists would need to meet the criteria for physical advantage, but the traversing across sand Pugh Matrix would not.

Table 3. Pugh Matrix for Mechanical Assist. Pugh Matrix for the function of mechanical assist. The mechanical assists were narrowed down from the brainstorming session to a few reasonable systems. From the analysis, we concluded that the top two methods would be levers with a geared hub, and a hidden flywheel with hand crank.

Criteria / **Concept**	Levers with Geared Hub	Toggle switch/joystick with electric motor	Hidden flywheel with Hand Crank	Ogo type Segway chair
Reparability		-	S	-
Tediousness		+	-	+
Aesthetics		+	+	+
Lightweight		-	-	-
Minimal prep		S	S	+
Portable		-	+	-
Physical advantage		+	S	+
Daily Maintenance		-	-	-
∑ +		3	2	4
∑ -		4	3	4
∑ S	DATUM	1	4	0

∑ Total	0	-1	-1	0

From Table 3, we found that none of the other ideas proved to be better than the datum of levers and gears. The Segway type chair ranked about the same as the datum; however the technology of a Segway type chair is out of the scope of this project. We are designing an attachment and the design of Segway technology would be more of a permanent fixture to a new chair. The flywheel, although ranked worse than the levers and gears and Segway technology, was something we kept in mind for further ideas.

The second Pugh Matrix (Table 4) was a list of different ways of traversing across sand. For Table 4 the hollow roller under chair was used as the datum.

Table 4. Pugh Matrix for Traversing Across Sand. Pugh Matrix for the function of traversing across sand. The hollow roller under the chair was chosen as our datum to compare the rest of our ideas to. The Dyneema rope ladder ranked the highest in comparison to the datum. The short skis and hollow treaded wheel also scored well compared to the other designs.

Criteria	Dyneema Rope Ladder	Clear Telescoping Wheel	Hollow Roller Under chair	Short Skis	Hollow Treaded Wheel	Tank Track s	Hollow Ball Under chair
Lightweight	+	S	DATUM	+	S	-	S
Portable	+	S		-	S	-	S
All Terrain	S	S		S	+	+	S
Minimal Prep Assistance	+	S		S	S	-	S
Robust	S	-		S	+	+	S
Discrete	-	-		S	-	-	S
Ease of Movement	S	S		S	S	+	S
Independent	S	S		S	S	S	S
Sum +	3	0		1	2	3	0
Sum -	1	2		1	1	4	0
Sum S	3	6		4	4	1	8
Total	2	-2	0	0	1	-1	0

The tank tracks and telescoping wheel where both considered worse than the datum. The short skis and hollow ball under chair were considered to be ranked equally with the hollow roller under chair. The rope ladder and hollow treaded wheel were ranked highest and slightly better than the datum. The short skis, rope ladder, and hollow ball/wheel were chosen as the top designs for further design.

The third Pugh Matrix (Table 5) was a list of the different ways of attaching or fastening the design we will create to be attached to a daily use wheelchair. Clamps were used as the datum for Table 5.

Table 5. Pugh Matrix for Attaching and Fastening. Pugh Matrix of the function for attaching the device to the wheelchair.

Criteria	Clamps	Bolts	Springs	Magnetic	Press fit	Glue	Hooks	Weld or Embed	Retractable Pins	Clip (Buckle)
Lightweight	DATUM	s	s	+	+	+	s	+	S	s
Portable		s	s	+	+	+	s	+	S	s
Minimal Prep		s	+	s	+	+	s	+	S	s
Robust		s	-	S	+	-	s	+	s	+
Independent		-	S	S	S	S	s	S	S	S
Aesthetics		S	+	-	S	S	s	S	S	S
Reparability		S	-	-	-	S	s	-	-	S
Sum+		0	2	2	4	3	0	4	0	1
Sum-		1	2	2	1	1	0	1	1	0
SumS		6	3	3	2	3	7	2	6	3
Score		-1	0	0	3	2	0	3	-1	1

The press fit, glue and welding were by far the best options. We will look at these options for creating the attachment; however, because the device is going to be something that can be taken on or off, these methods will not be as useful. For attaching the device to the wheelchair, the best options clips, hooks or springs. We have many options and want to keep it broad so that we do not hinder our design process too much. Retractable pins, although ranked low, are already used for placing the normal wheelchair wheels on and off the wheelchair. Retractable pins have proven to work in the past and is something that will be considered for further designing.

The various Pugh Matrices were combined using a morphological attribute chart (a way of selecting one option from each Pugh Matrix and combining them to come up with different designs) and input into a weighted decision matrix seen in Table 6. The weighted decision matrix is the analysis of the Pugh matrices. Five designs were chosen based on the Pugh matrices to compare; a rope ladder attached with hooks and driven by levers and gears, a hollow treaded roller with retractable pins driven by levers and gears, skis attached with clamps and driven by a flywheel, a rope ladder attached with clips and buckles driven by a flywheel, and a hollow ball under chair attached with magnets driven by levers and gears. The five designs were compared to each other to figure out the design that was most likely be the next step to prototype. Criteria from our needs and specifications in the QFD are graded for each of the five designs based on a scale from 0 (does nothing for the criteria) to 3 (perfectly matches what we want for a criteria). This number is multiplied to the weight of importance of each given criterion. The weight of importance is based on what we as a team have decided is the most important factors and criteria to consider. The score for each criterion are then added up to a total score at the bottom of the table. The result of the decision matrix was to prototype the design that used a rope ladder as the main attachment, connected with hooks, and using levers and gears as a mechanical assist.

Table 6. Weighted Decision Matrix. Weighted Decision Matrix based off the Pugh Matrices.

Concept / Criteria	Weights	Method of travel: Rope Ladder Attachment: Hooks Drive: Levers and Gears	Method of travel: Hollow Treaded Roller Attachment: Retractable Pins Drive: Levers and Gears	Method of travel: Skis Attachment: Clamps Drive: Flywheel	Method of travel: Rope Ladder Attachment: Clip/Buckle Drive: Flywheel	Method of travel: Hollow Ball Under Chair Attachment: Magnet Drive: Levers and Gears
Lightweight	3	2	1	1	1	2
Portable	3	3	2	2	2	1
Manual	2	3	3	2	2	3
All-Terrain	5	3	2	1	3	1
Minimal Assistance (beach prep)	2	3	2	1	3	3
Corrosion Resistant	4	2	2	3	3	2
Durability/ Robust	4	2	3	1	2	2
Discreteness (Appearance)	3	1	2	2	1	2
Ease of Movement (Power Per Push)	5	3	2	1	3	1
∑ +		76	65	47	72	53

The Rope Ladder design with hooks and levers and gears was the best one with our criteria. The rope ladder with the flywheel was our next design if the levers and gears did not work. The only issue with using a flywheel is the addition weight. Flywheels are pretty heavy and would decrease the portability and detachability of our design. The hollow treaded roller was third on the list. This design could be very versatile and can be created using treaded wheels or a smooth roller instead. It would also be more portable than using the rope ladder with the flywheel. Although the skis did not score well compared to the other designs, they can be implemented into the final design for extra support especially for the front wheels.

4.3 Preliminary Analysis

During our build day, we created a prototype and proof-of-concept to show the rope ladder design we chose in the process of the design matrix. The prototype is an easy way for us to see the general function we are trying to focus on, and to analyze materials for the specific design. From building the prototype, seen in Figure 9a and 9b, we were able to see where we needed to modify our original design and where we may run into problems.

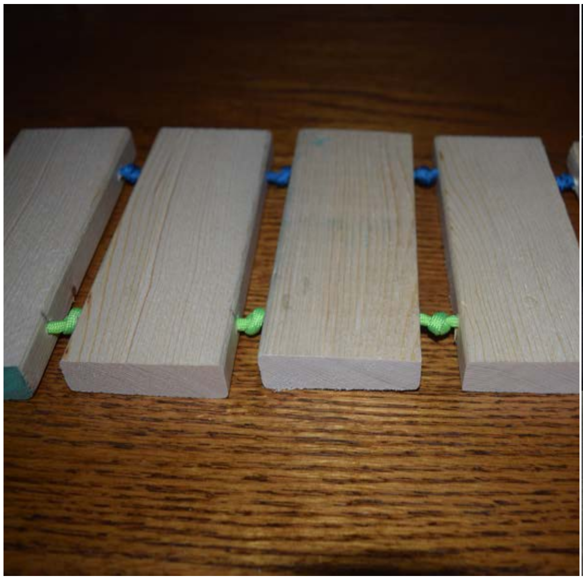

Figure 9a. Rope Ladder Prototype The first prototype is a rope ladder track attachment. It is made of wood and Paracord.

Figure 9b. Rope Ladder and TiLite wheelchair The rope ladder track attachment on the wheelchair.

4.4 Preliminary Design Concept

We created a SolidWorks model to show the changes we wanted to make and came up with a preliminary design based on our brainstorming, matrices, concept modeling, and prototype build day. The SolidWorks model, in Figure 10, shows the basic design of a rope ladder, how it would be attached to the wheel, and a preliminary design of a lever for a gear system. The ladder portion of the design would interfere with the chair of the wheelchair as seen in Figure 9b. The attachment to the wheel, clips to be pressed onto the wheel, we found to be too weak to hold the design together. The lever system for the gears was to be designed to be as noninvasive as possible. We would be using a design similar to the NuDrive Air seen in Appendix A and mentioned in Chapter 2 to allow for easy attachment and detachment. The NuDrive air is a lever mechanism that attaches and detaches to the wheel of the wheelchair. This way it can be placed on or off depending on what the user wants.

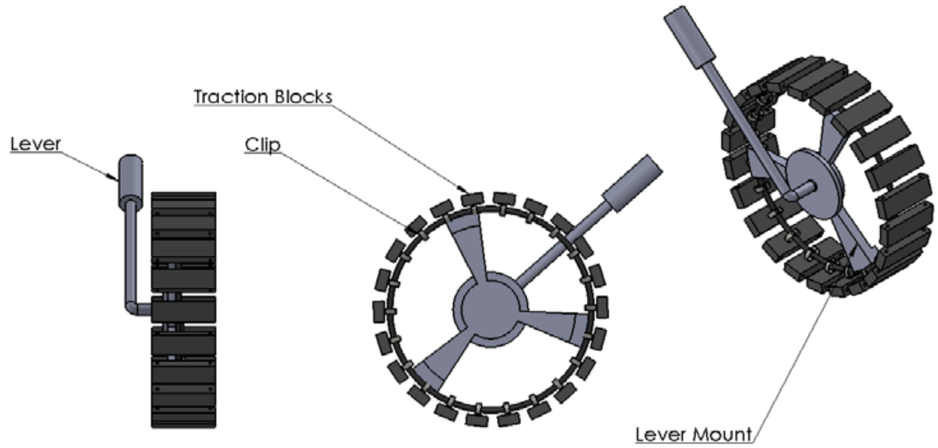

Figure 10. Initial Concept. The SolidWorks model for the rope ladder and lever system. Both are detachable and easy to place on and off. They act like chains for the snow.

The combination of the rope ladder system and the lever and gears system would make it easier to traverse across sand. The rope ladder system increases the overall traction of the wheel and increases the surface area; however, there is too much interference to the wheelchair for the design to work.

After receiving the wheelchair that we will be modifying, we have found that the rope ladder system had too many unsolved issues for it to be a design worth moving forward with. The rope ladder would be too flexible and a hassle to try and place each specific block on the wheels at a time, and the mechanism for keeping them on would not be strong enough from the force on the sand. The material would also be bulky and hard to move. With the rope ladder design, the wheel was too close to the seat of the wheelchair for the design to work. The results of this prototype were to continue modifying the existing design or take a step back to redesign our prototype. We began by looking back at our Pugh Matrices and Weighted Decision Matrix to come up with a new solution. The levers and gears increase the mechanical advantage of the system and can still be used for a new or modified design without the rope ladder system. We are still using an attachment to meet the goal of having one wheelchair to 'do it all' and not needing a specific new wheelchair just for beach use.

4.5 Revised Concept

Based on the information we had come up with in our Pugh Matrices and Weighted Decision Matrix, we found that going with levers and gears was still part of the plan. We moved from the rope ladder mechanism to a treaded wheel instead. The treaded hollow wheel was ranked third in our Weighted Decision Matrix and was concluded to be the next step to continue with.

Wheeling around in the wheelchair and doing more research helped inspire a new concept for our design based on our Weight Decision Matrix. This preliminary design, seen in Figure 11, uses several systems from different applications that should help solve our problem when combined. After deciding to extend the axle, we decided to also use a modified wheel design instead of the rope ladder to simplify the design and how it will be used daily. The quick release axle, mentioned as an attachment idea in the Pugh Matrix for attachments, is the same system as Nathan's and the TiLite wheelchair's system. The axle will just be longer to account for the wider wheel and the lever system. The lever has a ratchet system inside the hub, with a potential for a push release to allow for the wheelchair to move backward as well.

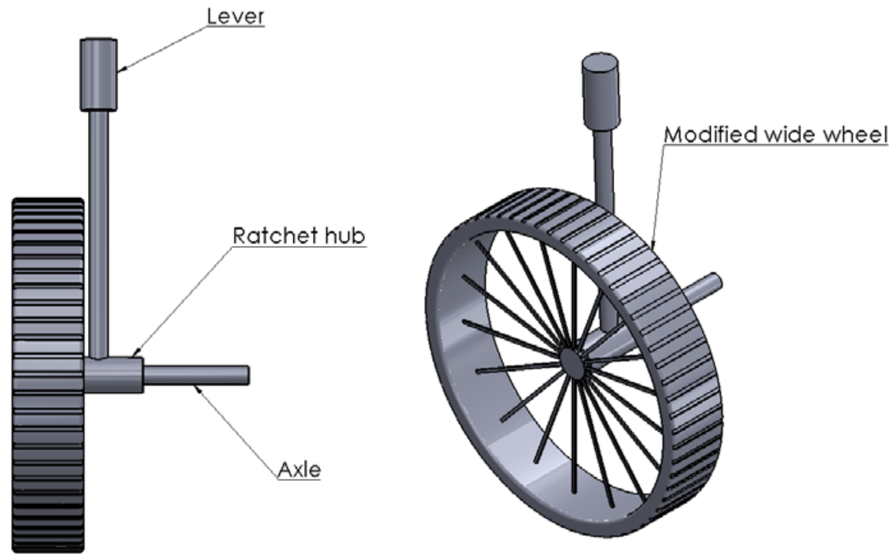

Figure 11. Preliminary Wheel Design. The preliminary design combines the original idea of a lever system with a longer axle and wider wheel.

The wheels in the preliminary concept were designed to be made of a light plastic material that is wider and lighter than the current wheels. This wheel design is based off of our background research with the Sand Roller wheelchair seen in Chapter 2.

Further research guided us to a company that makes double wheels (two bike-sized wheels attached to each other) called Melrose Wheelchairs [10] and have found research showing a wheelchair (the Hippocampe seen in Figure 12) using double wheels on the beach with no extra effort. We planned to design and create our own double wheels based on the design from Melrose Wheelchairs. This design would be easy to repair if it were to break than relying on a plastic wheel designed specifically for this attachment.

With the extended wheels, we also want to add a lever ratchet system for a mechanical assist just as in our initial concept. This would make it even easier to traverse across sand and allow the users hands to stay dry from the wet sand. The ratchet system would sit inside a hub, like the wheel system of a bike. A custom quick release axle length will be required for the extended wheels and ratchet system. The concept design drawing can be seen in Appendix E.

Figure 12. The Hippocampe wheelchair uses a dual wheel for the main wheels on each side. This has proven to work well in the sand.

4.6 Risks and Unknowns

It was determined that the most critical point in our hub design would be the ratcheting gear, because of this we did a gear tooth analysis. The analysis showed that our ratchet's teeth will be more than strong enough to withstand the forces they will encounter. A weight analysis was also necessary since it is important for us to keep our attachment from being too heavy. The hub should be roughly 4.57lbs which is acceptable, but we plan to try to optimize the design of the hub to decrease the weight. This weight calculation is based on our preliminary design and the Specifications Table, Table 1 in Chapter 3.

The other unknown is the use of an attachment for the front wheels. The wheels get stuck in the sand and are hard for the user to maneuver. We contacted a company called Wheelblades™ [11] that creates small skis for wheelchairs and strollers to use over snow and ice. Patrick, the inventor, told us that the Wheelblades™ have not been tested on sand. We have procured a set of Wheelblades**™** to test and have taken them to the beach to do a preliminary comparison. We found that they helped in keeping the front wheels from digging into the sand. They are not an exact solution. The front wheels turn due to the uneven ground and cause the Wheelblades**™** to turn sideways and get stuck in the sand. The Wheelblades**™** have been modified to be more usable on sand. We created a mechanism to stop the ability of the front wheels to turn, this will allow us to make sure the Wheelblades**™** will always be facing the right direction to be useful on sand. The final design can be seen in Chapter 5, the final design.

Overall this new design required more testing and prototyping to set the specifications; however, this new design is more feasible and a simpler mechanism than that of the rope ladder. Continued testing and prototyping solidified the design as a working concept and has brought us to the final design we have created.

Chapter 5. Final Design

This section will discuss the design we have finalized for manufacturing and all prototyping, and decision making we did to get to the design. After the Preliminary Design Review, we made some discoveries and insights on our design that have allowed us to fill in a lot of detail of the design that we previously did not know. Our final design contains a full design for manufacturing with no black boxes or missing information. After the Critical Design Review, we began the final stage of manufacturing and testing the attachment we created.

5.1 Structural Prototype

The structural prototype was the next prototype built after the preliminary prototype of the rope ladder. The structural prototype was to prove that our design would be manufacturable work for the scope of our project.

For our structural prototype, we manufactured a double wheel assembly from bike wheels to find out if the method we were planning to use to attach the rims would be effective. We began by removing the spokes from one of the rims so that the wheels could be close enough together to attach without interference from the hubs. We chose to use brackets made from sheet metal to connect the two rims. This was done by cutting the sheet metal into strips for brackets, drilling two holes in a small piece of sheet metal, and drilling a hole in each of the rims corresponding to the brackets. We then used two ¼” bolts to secure each bracket to the rims. After only 4 brackets were added to the rims, the assembly began to feel very strong; however, we plan to use 6 brackets instead of 4 for the final design.

Building this prototype gave us confidence in our chosen method of connecting the rims. The other option besides using brackets would be to weld the two rims together. This would be much more difficult to do consistently, and we were also concerned that the welding might warp the rims. Based on our prototype welding can be avoided by simply using the brackets to attach them.

Figure 13. The Double Wheel Prototype. The prototype is two bike rims attached by metal brackets. One rim has spokes while the other doesn’t.

The other part of our structural prototype was the hub assembly with a two-way ratcheting mechanism inside. To manufacture this as a prototype we used a 3D printer to create most of the parts. It took several iterations before we were able to figure out the correct tolerances to get all of our pieces to fit together. This showed us how important tolerances will be for the final design when it is made out of metal, although the tolerances will be different. This is because of the inherit differences between manufacturing something out of plastic with an additive process versus precision manufacturing something out of metal. We were able to build a working ratcheting device out of the 3D printed parts, but it only goes one way instead of both directions like we plan for our final design.

When assembling the parts, we realized how much of a design concern mounting the pawls will be, and we were able to make changes to the design based on what we learned. Another thing that was very apparent after assembly is that finding a way to transition from one ratchet to the next is paramount. We also learned that our design did have some extra space inside that can be minimized to save weight for the final product. This is also important because if we can make the hub narrower, this will allow for our custom axle pin to be shorter as well. Since the axle pin supports most of the weight of the wheelchair, we want to minimize its length to avoid large stresses in the pin. The prototype shown below has a cap with holes only to show what is going on inside.

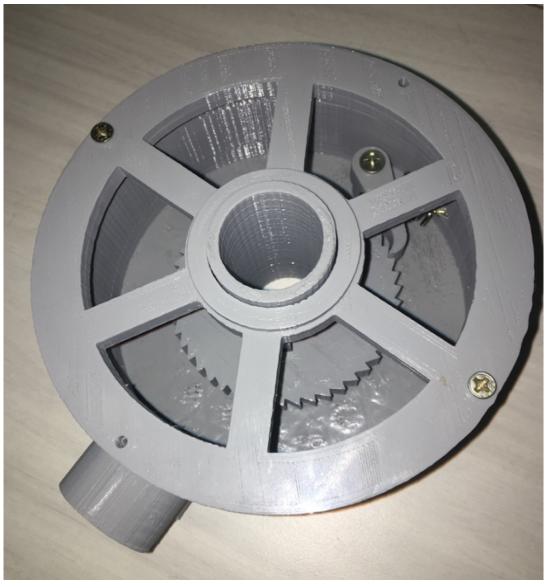

Figure 14. Ratcheting Hub Prototype. The prototype is a 3D printed model of our design. The prototype has viewing slots so that the internal mechanism can be viewed.

5.2 Overview of the Final Design

The final design for manufacturing is a more detailed version of the design we had prepared for the Critical Design Review (CDR) with a difference in the type of wheels and a more fleshed out version of the hub and ratchet mechanism. Figure 15 provides a SolidWorks model of the full design. The full assembly is split into 3 subassemblies; the double wheel assembly, the hub and lever assembly, and the front wheel assembly. The original design for Preliminary Design Review (PDR) was to have the hub and lever system as a separate part as the double wheels. After some discussion, we found that the separation was unnecessary and would only increase the time it takes to set the wheel attachment up. Therefore, the final assembled design will have two main components; the front wheel component and the back-wheel component. The final manufactured design can be seen in Figure 16. The complete drawing package can be seen Appendix F.

Figure 15. The Final Design

Figure 16. The Final Manufactured Design on the beach

5.3 Double Wheels Subassembly

The final double wheel design is based off the design we found on Melrose Wheelchair as mentioned in Chapter 4. The X-Wheels™ we found on their site were out of our price range and we were able to recreate a similar design and modify it for what we specifically need. A SolidWorks model of the double wheel subassembly can be seen in Figure 16.

Figure 17. The Double Wheel Subassembly the wheelchair uses a dual wheel for the main wheels on each side. This has proven to work well in the sand and be user friendly.

The double wheels are permanently attached to the hub system as one unit. This will limit the problems of assembly for the attachment. The lever can be screwed on and off so that the attachment can be placed on easier.

The double wheels are designed and assembled based off bike wheel rims specific to the size of the original wheelchair wheels (24”). The hub of the double wheels was manufactured based on the design we have created. The hub is a combination of a bike wheel hub and the inner sleeve we need to attach the ratcheting system to. Spokes are sized for the wheel and hub was manufactured. The tires were purchased and assembled to the double rims. The rims are attached using brackets that we manufactured from basic metal and cut in the Cal Poly machine shops. The design of the double wheels is minimal and effective to cut down on cost and difficulty. It is also an easy design to duplicate and repair in the event that it breaks. The simple design has proven to work in our structural prototype and in research done on the design.

5.4 Hub and Lever Subassembly

The hub and lever subassembly are based off the preliminary design we had created. The design is now all fleshed out with all the detail necessary to manufacture from 6061 aluminum. The hub and lever subassembly are pictured in Figure 17. The original inner sleeve design was going to be attached to a purchased hub on the double wheels; however, we ran into a problem with how to attach the inner sleeve to the hub. We solved this problem by designing the inner sleeve and hub as one piece instead of two separate parts. This allows us to be able to directly combine and assemble the double wheels to the hub and lever assembly. The inner sleeve can be seen in Figure 18. As mentioned above, now that the subassemblies will be combined into one assembly, there will be less worry of damage due to sand or parts disconnecting. The hub consists of two different rotations. The double wheel and inner sleeve rotate separately of the lever and outer sleeve. This separation of rotation allows the wheels to continue moving even when the lever does not. Otherwise, the lever would have to spin around 360° and would result in the lever getting stuck in the sand. The lever can be attached or detached for easy assembly.

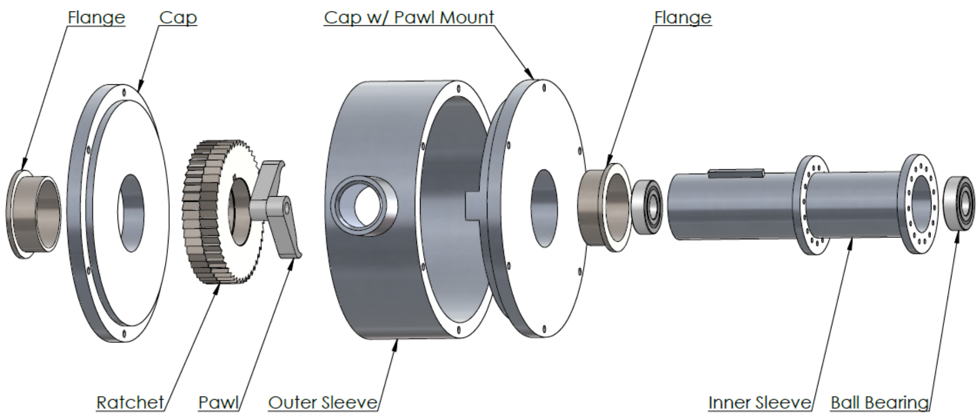

Figure 18. The Hub and Lever Subassembly

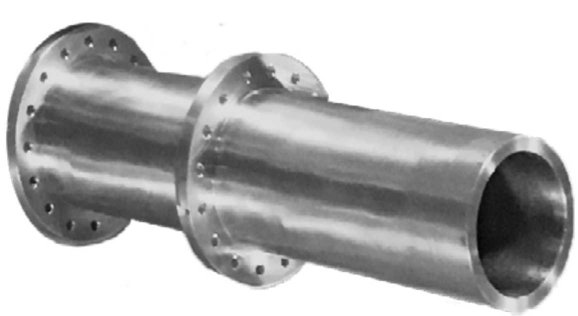

Figure 19. The Inner Sleeve The inner sleeve was designed to be a combination of a bike hub and a shaft for the ratchets to attach to. The Inner sleeve was manufactured by Cyclonetics Inc.

The hub consists of many different parts that are combined into one housing to keep the system sealed from outer damage or dirt and debris. The inner sleeve, has two ball bearings to allow the quick-release axle pin to move through the system to connect with the main body of the wheelchair. The axle pin is how the original wheelchair wheels are connected to the main body of the wheelchair. We have designed a longer axle pin to account for the extra distance needed for the ratcheting system in the hub. On the outer diameter of the inner sleeve (inside the outer sleeve but connected to the inner sleeve), the ratchet gears are attached using a key. The key can be broached to the right size we need for connecting the inner sleeve and ratchet gears. The gears will then rotate as the wheel rotates even if the lever is not being pushed. The inner sleeve sits inside the outer sleeve by using flange sleeve bearings to allow both the inner sleeve and outer sleeve to rotate as separate entities.

Inside the outer sleeve the pawls are attached. The pawls are the mechanism that engages the ratchets in order for the ratchets to click and rotate. The pawls will engage by the force of a locking spring plunger. We will only keep one pawl engaged at a time to move in one direction. It could be damaging to the pawls to engage both the forward and backward plungers at the same time. The lever is screwed on by outer threads on the lever and inner threads on the outer sleeve. The axle pin, of a custom length as mentioned previously, will slide into the hub of the double wheels, through the bearings in the inner sleeve portion, and connect into the main body of the wheelchair. A cap is placed on each side of the outer sleeve in order to keep all components inside. The caps also have a pin screwed in to them to slide the pawls in to place. Having the pawls move at a different time than the ratchets allows the wheels to continue to move while the lever is not moving. A second flange sleeve bearing is placed on the other end of the inner sleeve and the final cap encloses the system.

5.5 Front Wheels Subassembly

The front wheels were originally going to be assembled with Wheelblades**™**; however, we have found through testing that the Wheelblades**™** have a tendency to rotate and plow sideways through the sand causing much more resistance. We have decided that a modified version of the Wheelblades**™** that prevents rotation is the final front wheel assembly.

The design, seen in Figure 19, is a simpler solution to the front wheels. We have kept the Wheelblades**™** and have just attached a bar to connect both the left and right front wheels together. The bar would cause both wheels to rotate together and limit the amount of rotation. This design lowers the amount that the front wheels can rotate and will hinder the front wheels from turning sideways and getting stuck. The design is less invasive and easier to manufacture than finding a whole new solution.

Figure 20. The Front Wheel Subassembly A crossbar was added to limit the amount of turning that the front wheels can experience.

5.6 Stress Analysis and Weight

To start our testing, we took the wheelchair to the beach without any attachments and used a crane scale to measure how much force it took to pull the wheelchair across both hard and soft sand. We found that it was roughly 60lbs in soft sand and 20lbs in hard sand.

Once we received our Wheelblades™ we took them to the beach to be tested. At the beach, we discovered that they help to make it easier to move on the sand, until the wheels rotate about 90° so that the Wheelblades™ are sideways. When the Wheelblades™ become sideways they drag in the sand and make it harder to move. To fix this issue we locked the Wheelblades™ so that they only face forward.

After creating a SolidWorks model of the attachment, we were able to give it material properties which then allowed us to estimate the weight of the device. We found that one attachment by itself weighs about 4.57lbs which when double for the other attachment is 9.14lbs. 9.14lbs is under our max weight of 15lbs.

Gear tooth analysis was also done because if our gears fail, the whole mechanism fails. Using Equation 1 below we found that the yield strength of the gear was much greater than the load it experiences. To calculate the load the tooth was experiences we used a force P = 250lb and divided it by the width and thickness of the tooth which were 0.375" and 0.1819" respectively. We found that the load was 3665 psi which is much less than the yield strength of 31200 psi.

$$\tau = \frac{P}{\omega * t} < S_{Sy} \qquad (1)$$

Where ω is the width of the tooth, t is the thickness of the tooth, and P is the force applied to the tooth. S_{Sy} is the yield strength we are comparing our calculated tensile strength to. The hand calculation can be seen in Appendix H for a more in depth look at how the calculation was broken down.

Preliminary force to torque calculations were done to help us determine the amount of force we needed with the same amount of torque with and without the beach wheelchair attachment. The force was first determined from preliminary testing using Figure 21.

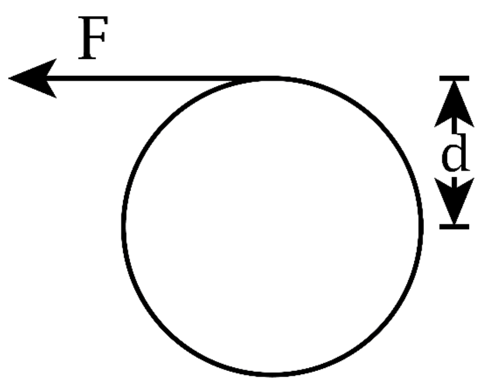

Figure 21. Force Diagram of Wheel The wheelchair torque per travel was based on the force provided and the distance the force was from the axle.

Using Equation 2 we were able to determine the Torque per distance from the axle of the wheel.

$$\tau = F * d \tag{2}$$

Where force is F and d is distance. With this equation we keep the torque the same and can either solve for the design parameters of force or distance from the axle. This gave us some room for designing. We chose a distance of about 1 ½ feet from the axle to give a comfortable height for the lever. With this lever position, the lever grips with your arms just at 90°. The torque was calculated to be 35 ft-lbs. Figure 22 shows the diagram for calculating the force and torque with the wheelchair attachment. To keep the torque the same, we calculate a force of 23 lb_f per wheel compared to 35 lb_f per wheel. This is a reduction of 12 lb_f for each side totally a reduction of 24 lb_f. Hand Calculations can be seen in Appendix H. The force analysis does not take into account the reduction in force from the front wheel assembly. This would decrease the amount of force needed even more, making our device even more efficient and useful. Testing shows a more realistic picture of what our attachment can do.

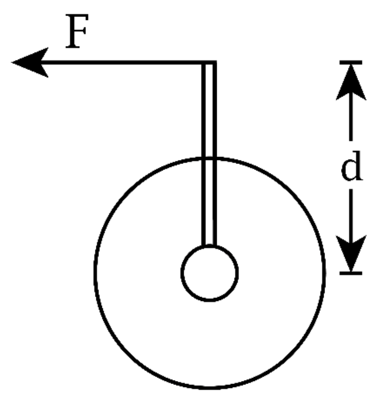

Figure 22. Force Diagram of Wheelchair Attachment The wheelchair torque per travel was based on the force provided and the distance the force was from the axle.

5.7 Cost Analysis and Breakdown

We created a list of all the parts and materials to purchase in order to manufacture the full beach wheelchair attachment. Table 7 presents all the parts, quantity of parts, and the total cost of the whole project. For the full List of parts, see Appendix G. All the parts are sized for the necessary dimensions and no more. The less material will limit the cost but also will keep our design from becoming too heavy.

Table 7. Cost Analysis. The cost analysis is split into separate components to show what parts are needed for what component. The quantity is either based in number of parts to order, or number of inches needed.

	Part	Vendor	Qty	Units	Cost	Total Cost
Wheel Assembly	Spokes	Bike Hub Store	72	# parts	$0.99	$71.28
	Custom Spoke	Bike Hub Store	72	# parts	$0.25	$18.00
	Innersleeve	Speedy Metals	2	# parts	$14.40	$28.80
	Ball Bearings	Mcmaster	4	# parts	$13.49	$53.96
	Ratchets	Mcmaster	4	# parts	$55.88	$223.52
	Key Stock	Mcmaster	1	# parts	$3.18	$3.18
	Rims	Niagra Cycle	4	# parts	$15.28	$61.12
	Tubes	Niagra Cycle	4	# parts	$4.50	$18.00

	Tires	Niagra Cycle	4	# parts	$9.78	$39.12
	Brackets	Home Depot	12	# parts	$1.00	$12.00
	nuts 1/4"	Home Depot	24	# parts	$0.07	$1.68
	bolts 1/4"	Home Depot	24	# parts	$0.11	$2.64
Hub Assembly	Pawls	McMaster Carr	4	# parts	$46.54	$186.16
	Outer Sleeve	Speedy Metals	2	# parts	$10.38	$20.76
	Flange Sleeve	McMaster Carr	4	# parts	$6.36	$25.44
	Cap	Speedy Metals	4	# parts	$12.91	$51.64
	Pawl Pin Collar	McMaster Carr	4	# parts	$1.07	$4.28
	Pawl Pin	McMaster Carr	1	# sets	$10.97	$10.97
	Locking Spring Plunger	McMaster Carr	4	# parts	$12.36	$49.44
	Hex Bolts	Miners	24	# parts	$0.35	$8.40
	Flanged End Cap	McMaster Carr	1	# feet	$22.21	$22.21
	Bearing Spacer	McMaster Carr	1	# feet	$12.64	$12.64
	Ratchet Spacer	McMaster Carr	0.5	# feet	$26.44	$13.22
	Set Screws for Ratchet Spacer	McMaster Carr	1	# sets	$10.31	$10.31
	Set Screws for End Cap	McMaster Carr	6	# parts	$0.33	$2.00
	Rod	McMaster Carr	1	# parts	$12.55	$12.55
Skis	bolts 1/4"	Home Depot	4	# parts	$0.11	$0.44
	nuts 1/4"	Home Depot	4	# parts	$0.07	$0.28
	Angle Bar	Home Depot	1	# parts	$5.37	$5.37
	FreeWheel		1	# parts	$0.00	$0.00
	Wheelblades	Wheelblades	2	# parts	$50.00	$100.00
Axle Pin	Axle Pin	McMaster Carr	2	# parts	$63.12	$126.24
Manufacturing	Inner Sleeve	Cyclonetics	2	# parts	$260.00	$520.00
	Outer Sleeve	Cyclonetics	2	# parts	$85.00	$170.00
	Caps	Cyclonetics	4	# parts	$85.00	$340.00
	Total Estimated Shipping and Tax					$150.00
		Parts Total	298.5	**Total Spent**		$2,375.65

To make purchasing and shipping easier, we have chosen the to use as little vendors as possible. The majority of our bike parts and wheel parts are coming from Niagara Cycle. All of our metal stock will be coming from Speedy Metals or McMaster-Carr. The table also gives a full list of how many of each part we need. This can be compared to our assembly drawings to show that all parts are accounted for. SKU numbers for each specific part can be seen in Appendix F in the Bill of Materials.

Our cost increased significantly when we decided to outsource our CNC parts to a company called Cyclonetics. We decided to outsource to them instead of manufacturing in house because the inner sleeves complicated geometry and tiny holes. Outsourcing also meant our parts would be of a higher quality. We learned from working with Cyclonetics that machinists will make parts exactly how you dimension them, so it is very important to make sure the drawings are perfect. We also outsourced our outer sleeves and caps to Cyclonetics.

5.8 Justification for Material, Geometry, and Components

Most of the metal components were manufactured from 6061 Aluminum. It is stronger than other aluminum compositions and is also easy to machine. Aluminum is a readily available material and less expensive than other metal composites. For the forces our device will undergo during normal operation, aluminum will work based on our calculations in the analysis section.

Some of the parts from McMaster Carr are made from steel. This makes some of the parts stronger and more durable. The pawls, for example, are steel.

The double wheels were designed to be assembled from bike parts because of the greater surface area that bike tires have over wheelchair tires. The bike tires and rims are also cheaper and easier to acquire than wheelchair wheels. Bike wheels come in many different sizes and shapes which allowed us to get a specific rim geometry ideal for this application. Wheelchair wheels also usually come assembled, but since our design incorporates a custom hub that requires full assembly of the wheels, bike parts were a more logical option. Due to the accessibility of bike parts, it would make repairing the double wheels easier if they were to break as well.

The geometry of our design was based on the critical dimension of the axle rod. The axle rod needs to be ½” in diameter to match the TiLite chair’s dimensions. We designed the inner sleeve to fit bearings that have an inner diameter of ½” to allow the axle rod to fit through. The bearings then dimensioned the inside diameter of the inner sleeve. A thickness was chosen based off the diameter. The bushings from McMaster Carr determined the outside dimension of the inner sleeve. The ratchets were then sized to the outer diameter of the inner sleeve. The outer sleeve and caps were dimensioned to give enough room for the ratchets and pawls to fit snuggly inside the outer sleeve. The size of the double wheels were determined based off the original size of the wheelchair wheels. Spokes were then cut down to size to fit from the inner sleeve to the double wheel spoke holes.

Originally the inner sleeve and hub of the double wheels were to be two separate parts connected together through some type of attachment process (welding or bolting). We realized that welding the parts together would compromise the strength of both the hub and the inner sleeve. After some discussion, we decided that creating the hub and inner sleeve as one part would be the best solution. This solved our issue of figuring out how to attach the inner sleeve and hub together. The new inner sleeve is a combination of both the inner sleeve and the hub of the double wheel system. The outer sleeve was enlarged to allow for room to switch from one pawl to the other in switching direction. The rest of the parts were designed for minimal size to limit the amount of extra weight of the attachment and unnecessary space.

5.9 Safety, Maintenance and Repair Considerations

Our Safety and Hazards Check is an in-depth discussion of all the safety concerns in our design. This form can be seen in Appendix J.

To account for safety concerns, we have limited the amount of moving parts in easy reach. This will limit the number of pinch points as well. From the structural prototype, we found that there were several sharp edges on the double wheel assembly. For the final design, we have manufactured our brackets with rounded edges and sized them to have no edges sticking out of the wheel assembly.

Using flange sleeve bearings, the inner parts of the hub will be sealed inside the outer sleeve. Having the hub sealed will make sure no dirt and debris can enter the ratcheting mechanism. There is still a possibility of sand, water, and dirt entering the hub. If the inside of the hub mechanism needs to be cleaned, the caps can easily be taken off by unscrewing the bolts. All inner pieces can be unscrewed and disassembled for cleaning.

If screws become stripped or broken, replacement fasteners can be found at a local hardware store. New axle rods can be bought from McMaster Carr in the event that the axle rod breaks. The drawing package can be used to find a local machinist to create an inner sleeve, outer sleeve or modified caps in the case that any of the parts break or become damaged. Melrose Wheelchairs also has a supply of double wheels that can be used in the event that the manufactured double wheels fail.

Overall, pinch points are the main concern and will be acknowledged by informing the user of where the pinch points are located and how to avoid contact with pinch points. Informing the user of how to best use the design will also make the attachment last longer due to it being properly used. The user manual in Appendix I describes the way to safely use the beach wheelchair attachment.

Chapter 6. Manufacturing Plan

6.1 Procurement

All vendors have been listed in Table 7. The majority of our bike parts for the double wheel assembly and lever system have been purchased from Niagara Cycle. All the stock metal we need for manufacturing have been purchased from Speedy Metals, and the hardware (fasteners, nuts, and bolts, etc.) have been purchased from Home Depot. The quick-release axle pins have been purchased from McMaster Carr. The bushings have also been purchased from McMaster Carr.

6.2 Manufacturing

Table 8 describes a timeline for the manufacturing that has been done along with the parts to be manufactured and how they have been processed.

Table 8. Manufacturing Breakdown. The parts that we will have to manufacture or modify are listed below along with how they will be manufactured and when they expected to be completed.

Part	Manufacturing Process	Expected Dates
Brackets	Cut, Drill, and Grind	2/18-2/24
Inner Sleeve	Outsourced	4/10-4/30
Ratchets	Mill	3/4-3/11
Outer Sleeve	Outsourced	4/10-4/30
Caps	Outsourced	4/10-4/30
End Flange	Lathe	5/9
Bushings	Lathe	5/1
Spacers	Lathe, Saw	5/10

The brackets used to hold together the two bike wheels have been made by taking sheet metal and cutting it into approximately 1”x3” rectangles using a sheet metal shear machine. After being cut, the pieces had two ¼” holes drilled at ½” from the center of the bracket. Finally, the brackets have been ground on a metal grinder to remove sharp edges. Once the brackets were made, we drilled ¼” holes into the rims so that the brackets could be attached to them.

Figure 23. Double Wheel Manufacturing Holes are being drilled into the rims so that brackets can be used to attach the rims to one another.

The inner sleeve, outer sleeve and both caps have been outsourced to a company in San Luis Obispo by the name of Cyclonetics Inc. After receiving the parts back, they were modified to incorporate mounts for the pawls and lever arm. To mount the pawl pin, we drilled a through hole in one cap, and drilled and tapped a matching hole in the other cap. One side of the pawl pin was threaded so that it screws in to one cap and fits into the other for support since the pawls mounted on it provide the driving force to the ratchets. We drilled and tapped three more holes in the outer sleeves as well. One hole was for the lever arm which is threaded on the bottom and simply screws into the outer sleeve to attach. The other two holes are for the locking spring plunger, and these holes are offset from the center line to align with the pawls on the inside.

Figure 24. All Parts all the parts pre-assembly

Figure 25. Outer sleeve on Mill The hole for the lever arm was drilled into the outer sleeve using a mill.

The ratchet gears and pawls have come prefabricated but not to the dimensions we require. The ratchets interior diameter was to small, so we used a mill to increase the diameter. We used the boring tool because the diameter was larger than any drill bits available at the on-campus shops.

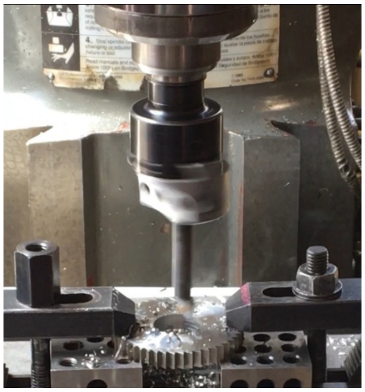

Figure 26. Boring Tool The inner diameter of our ratchets was increased using a boring tool on a mill.

To transfer force between the ratchets and the inner sleeve we are using a key. This required us to cut a keyway in the ratchets using a broaching tool, and we had to mill a slot in the inner sleeve for the other side of the key. We spoke with several faculty in the Industrial and Manufacturing Engineering (IME) department who helped us find an easy solution for broaching the ratchets. We needed a nonstandard sized broaching guide, so we designed and made a broaching guide on the mill and lathe to fit our ratchets exactly. An arbor press was used to take the broach and guide it through the ratchets to make a keyway. Key stock was then cut to size and ground down to fit in the keyway between the two parts. This process turned out to be difficult because of inconsistencies in the keyways on the ratchets. The key stock we ordered was too tall to fit in the keyway we were able to make, so ideally smaller stock would be ordered which would likely make this process much easier.

Some other small modifications were made to allow everything to properly fit together. The flanges were cut down to size on the lathe to make room for the ratchets on the inner sleeves. Spacers that were not originally in the design were cut to place inside the inner sleeves to locate the bearings, and to place on the outside of the inner sleeves to locate the ratchets. The spacers to locate the ratchets had holes drilled and tapped for set screws to set them in place.

Finally, a flanged end-cap was made on the lathe with set screw holes to keep all parts tight in the outer sleeve housing. Locking collars were also bought for the pawl pin to keep the pawls in place. Loctite was used crucial bolts and screws to keep them in place.

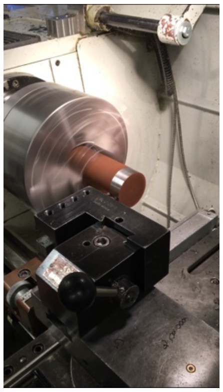

Figure 27. Flanged End-cap Stock The flanged end-cap was turned on a lathe from a large piece of stock steel.

6.3 Assembly

The assembly process starts with the double wheels. The rims are attached using six evenly spaced brackets, bolts, and nuts. Once they are secured, and adjusted to be concentric with each other, Loctite is used to lock the nuts in place. After the rims are attached to one another, the spokes are attached in a radial spoke pattern seen in Figure 28, connecting the rims to the inner sleeve. A radial spoke pattern is when none of the spokes cross each other in their attachment. A radial pattern is easiest to assemble and fix if the spokes are loose or need replacing.

Rim tape or rim strips is then attached to the inside of the rims, where the tire tubes will go. The rim tape provides a barrier between the spoke heads and bolts for the brackets in order to keep the tire tube from popping due to sharp edges.

The tire tubes are given a couple pumps of air and placed inside the tires before being situated on the wheel rims. This step provides help in easily attaching the tubes and tires to the rims without damaging the tire tubes. The tire tube air valve is aligned with the large hole on the rims and the tire and tube are slowly placed on each rim. Once one tire and tube are on one of the rims, the second tire and tube must be assembled by first attaching them to the side of the rim closest to the already assembled rim, tire, and tube. Aligning the treads on the tires to be offset helps with maintaining a tight fit between both tires.

Once both tires and tubes are together on the connected rims, the tubes can be fully inflated to their required psi reading.

Now that the double wheels are assembled, the next step is assembling the ratchet system. One of the flanges is placed on the inner sleeve until it sits close to the shoulder where the spokes are attached. Next, one of the caps is bolted on to the outer sleeve. The pawl pin is screwed in to the cap that has been attached. The cap and outer sleeve are then slid on to the flange and inner sleeve. A locking collar is placed on the pawl pin and tightened into place with setscrews. The two pawls are placed on the pawl pin inside the outer sleeve.

Figure 28. Assembled Double Wheels The double wheels are assembled with part of the hub assembled and the remaining parts to the right.

After the pawls are in place, the key is situated in the keyway. Two ratchets are then set in to the outer sleeve over the key making sure that the ratchets are going opposite directions and match up with the pawl it will be hitting. A spacer is added and tightened with a setscrew to keep the ratchets in place. Locking spring plungers are screwed into the designated holes on the outer sleeve. Loctite is applied to keep them in place. The final cap is then positioned on the outer sleeve to align with the pawl pin and screw holes. The cap is bolted down.

Once the ratcheting mechanism is assembled, the spacer is placed inside the inner sleeve to keep the bearings in place. A bearing is then placed on either side of the spacer inside the inner sleeve. The quick-release axle pin is slid through the inner sleeve and the bearings inside.

Figure 29. Assembled Double Wheel and Hub

The entire wheel assembly is attached to the wheelchair by inserting the quick-release axle pin into the axle of the wheelchair until it is locked into place. Once both wheel assemblies are attached to the wheelchair, the levers can be screwed into the outer sleeves.

The front wheel assembly can then be positioned in front of the two front wheels. The user can now roll the front wheels into the Wheelblades™ and secure them in place.

The beach wheelchair attachment is now ready to be used on the beach.

Chapter 7. Design Verification Plan

Below is a description of the testing that has been done to verify that we have come up with a working solution to the scope of our project.

7.1 Testing

To verify that our design will work, we have created a plan to test and analyze critical features of our design. The testing we have already completed include gear tooth and weight analysis as well as testing our Wheelblades™ at the beach. The schedule and results of these tests can be seen in Table 9.

Our gear tooth analysis showed that the yield strength of our gears is much greater than the load they will experience, so we are confident in the gears we have chosen. The weight analysis also showed that we were initially below our max weight.

Once the parts were manufactured and the design was modified to input other manufactured parts, a true weight analysis was taken. The metal was heavier than expected after manufacturing and increased the weight. Originally a hollow lever was used which kept the weight down, but the levers both broke during testing due to the threads not having enough material to grasp on to. We switched the design to solid metal levers which increased the weight of the attachment. This was a necessary change to the design. The total weight of the device exceeds our maximum allowable. The weight measurement was 20 lbs for the total attachment.

To test our device as a whole, we took the chair with the front and rear wheel attachments to Avila Beach. After initial success riding it on the beach only trying to see how it moved, we set up a couple different tests to quantitatively show whether or not our device meets the design requirements. To test the modified Wheelblades™ we measured the distance the chair went after five strokes with the levers. Figure 30 shows some of the testing we did. We did three trials without the Wheelblades ™ attached and compared the results to three trials with them.

Figure 30. Distance Testing on Soft Sand. Rope was used to measure how far the chair moves after five strokes with the levers.

The results show that they do improve performance by a small amount. A summarized version of the results is seen in Table 9. The full testing results can be seen in Appendix J.

Table 9. Summarized Testing Results

Test	Parameter	Results
Length Inspection	Change in Length [inches]	4
	Max Allowable Change in Length [inches]	10
Soft Sand Force	Average Force [lb_f]	36.0
Hard Sand Force	Average Force [lb_f]	9.7
Distance With Wheelblades™	Average Distance [inches]	56.4
Distance Without Wheelblades™	Average Distance [inches]	63.7

It is important to note that, objectively, moving with the Wheelblades™ is easier because the front wheels will not sink. The distance moved can be close without them if the user is consistently trying to pop a wheelie while pushing the levers. This movement is effective but not easy to do consistently, and the Wheelblades™ remove the need to do this at all. This test also showed that adding the crossbar was effective for stopping the Wheelblades™ from rotating which causes them to dig into the sand.

Another important thing to test was the amount of force required to move, so we used the same crane scale that we did for the preliminary testing of the unmodified chair. These test results are seen in Table 9. We tied rope to each of the levers to connect them and then attached the crane scale in the middle of the rope, this can be seen in Figure 31. With a person weighing roughly 140 lbs in the chair, we pulled repeatedly while filming the display of the scale. The person in the chair reset the levers after each pull so the test could continue. The results of this test showed that on soft sand the max force required was only 36 $lb_{f.}$ The force was also measured in hard sand to determine the final force to pull. The maximum force required was only 9.7 lb_f.

Figure 31. Force testing on soft sand. A crane scale was used to measure the force it takes to make one forward rotation.

7.2 DVPR

The Design Verification Plan Results (DVPR) is a table of the results of all the testing we have done throughout our design process. Table 10 is the design verification plan results. The specification number describes what test it is. For example, I1 stands for ‘Inspection 1’, whereas T1 stands for ‘Testing 1’. The acceptance criteria is the parameter we are testing for, usually the number given is a maximum and we are testing to make sure the results are lower than the maximum. The test stage column refers to when the test was taken. SP stands for structural prototype and FP is final prototype.

All tests were taken once and where designed for the whole system to be tested. Timing describes when in the year the test was taken and when the tests were concluded. Results are shown in the Test Results column. Quantity Pass and Quantity Fail determine whether or not we passed or failed our testing. The only test our final prototype failed was the weight inspection test. Notes describe the tests and the results we had concluded from them.

Table 10. DVP&R. The DVP&R contains the tests, inspections, and analysis we plan to perform on our device along with the respective results.

Senior Project DVP&R													
Date: 1/30/18		Team: Beach Wheelchair	Sponsor: Quality of Life +			Description of System: A ratcheted lever arm will be attached to double wheels					DVP&R Engineer: Jackson Cole		
TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES TESTED		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start	Finish	Result	Quantity Pass	Quantity Fail	
1	I1	Weight Inspection	Change in Weight < 15lb	Jackson Cole	SP	1	Sys	2/1/2018	2/6/2018	20 lbs		x	We had unplanned manufacturing that increased the weight of the device
2	I2	Length Inspection	Change in Length < 10 in	Jackson Wiley	SP	1	Sys	2/1/2018	3/15/2018	3 in	x		
3	I3	Width Inspection	Change in Width < 10 in	Abbey	SP	1	Sys	2/2/2018	3/6/2018	9 in	x		We have minimized the width as much as possible with our tolerance
4	I4	Height Inspection	Chang in Height < 10 in	Jackson Wiley	SP	1	Sys	2/15/2018	3/6/2018	0 in	x		The lever rods will be minimally high to ensure they do not go above the top of the wheelchair handles
5	T5	Force required to move in soft sand	Force < 45lbs	Jackson Cole	SP	1	Sys	2/2/2018	2/5/2018	57 lbs		x	Our structural prototype did not have our full assembly to test. The final design should pass this test.
					FP			5/3/2018	5/17/2018	25 lbs	x		The final design did well on the beach
6	T6	Force required to move on hard sand	Force < 10lbs	Jackson Cole	SP	1	Sys	2/2/2018	2/5/2018	17 lbs		x	Our structural prototype did not have our full assembly to test. The final design should pass this test.
					FP			5/3/2018	5/17/2018	9 lbs	x		The final desgin did well on the beach but we did not need the wheelblades on hard sand
7	T7	Time to set up	time < 5 mins	Jackson Wiley	FP	1	Sys	5/3/2018	5/17/2018	3 min	x		Set up is not easy alone but was still under 5 min

Chapter 8. Project Management

Before we began the designing phase of the project, we created Table 11 to determine when our most important deliverables are. The final design review (Expo) is where our work is put on display to visualize the process of the project. Table 11 describes the important milestones and deliverables mentioned above to summarize what we have done to finish the beach wheelchair attachment.

Table 11. Design Process and Deliverables

Deliverable	Due Date
SOW	10/13
Ideation	10/19
Build Concept Models	10/24
PDR	11/14
Design Analysis	11/28
Build Prototypes	1/23
CDR	2/6
Manufacture	2/18-4/22
Hardware/Safety Demo	4/26
Testing	5/17
Expo	6/1

We spoke to Nathan prior to developing the problem statement in order to better understand the problem from the user's perspective. Following this discussion, we researched any existing design concepts that Nathan had mentioned as well as anything else we could find that might work. This included researching technologies and concepts not currently being applied to beach wheelchairs, but that could be adapted to help solve the problem. After gaining a good understanding of the problem travelling over sand, we developed a full list of needs and wants that the design should satisfy in the end. To determine whether we meet these in the end, we used a QFD to more clearly define these needs and wants as specifications that can be tested. Moving forward with a well-defined problem we began an ideation phase. This involved several brainstorming sessions with the whole team present to form concept ideas to build quickly and test. Each time we used a different brainstorming strategy to encourage formation of new ideas, even after discussing the same problem for multiple sessions. Several rough concept models were built to test these ideas quickly with foam core and wood. We then used a weighted decision matrix to narrow down the ideas generated to what we could build as a more functional prototype. From these models and other discussion, we chose a design to build as a prototype for the PDR. After building the prototype, however, we revised the concept based on issues that became evident.

The preliminary design was tested after we created a prototype. This prototype needed to prove the key functions of our design would work as expected on sand. Following this, we did a full analysis of the design to help choose materials for the critical design review. Analysis included all necessary stress calculations to assist with material selection. This was very important for selecting the most appropriate materials. A manufacturing plan with cost analysis was also created once material selection was complete. With these things done, we presented our finalized design at the CDR to receive approval to start manufacturing the final prototype.

After CDR, we began purchasing the parts to start the manufacturing process. The brackets were manufactured first, cut down to the size we had specified and drilled through with two holes each. They were grinded down to eliminate sharp corners.

A decision was made to outsource some of the harder parts to manufacture in order to get them to the exact dimensions necessary for our design. Cyclonetics Inc. was the machining company we outsourced to. They were very helpful in machining our caps, outer sleeves, and inner sleeves to the specifications we gave them. They also were helpful with design recommendations for future iterations.

While the main parts were being machined by Cyclonetics Inc., we began assembling the double wheels. The final design can be seen in Figure 32.

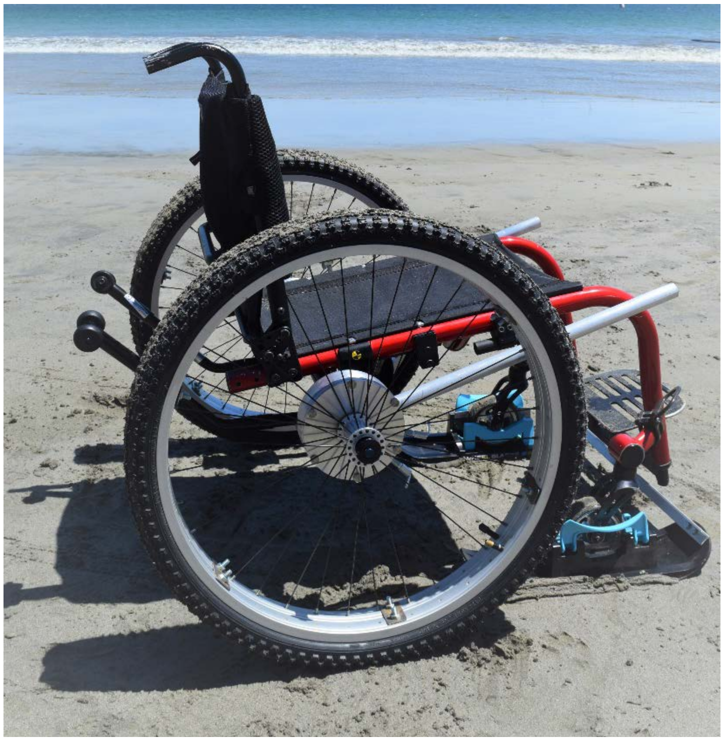

Figure 32. Final design on the beach. The wheelchair was tested and proven that our beach wheelchair attachment worked effectively in sand.

Our Gannt Chart with all the dates and plan for manufacturing can be seen in Appendix K.

Once we created our final product, we evaluated it to see if the specifications defined in our problems statement had been met. The main testing portion is taking force measurements on the wheelchair to see how much force is required on different parts of the beach. The final testing stage also includes weight calculations to determine if there is any unnecessary weight that we can modify for.

Chapter 9. Conclusions and Recommendations

The original scope of the project was to find a way to help Nathan travel in his chair on sand by modifying the wheels or using a power assist device. The scope of this project has been refined to creating an attachment for the TiLite wheelchair to more easily maneuver on sand. Modifying the wheels and a power assist are still part of our scope but have been designed for the TiLite in our possession. The best design for the TiLite wheelchair is a combination of large wheels and ratchet lever attachments along with an extension to the axle and a front wheel attachment to account for the front wheels digging into the sand. The final design has been manufactured and designed based on our research and testing.

Through manufacturing, we found some areas where the design could be altered to create a better attachment. For instance, the inner sleeve was not designed and manufactured to have inner shoulders to keep the bearings in place. This would be a good addition to the machining of the inner sleeve. To eliminate the use of spacers for the ratchets, the bushings need to be extended in length. The flanged end-cap can be eliminated in future iterations by drilling screws into the bushing to attach it to the outer sleeve and keep everything in place. Some of these alterations would also help reduce the weight of the device, especially eliminating the steel end-cap.

Overall our design proved to pass all force tests on the beach and greatly decreased the amount of effort required to move a certain distance. The beach wheelchair attachment proved to be a success for the scope of the project we had defined.

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Appendices

Figure 1.1 The Sand Rider wheelchair

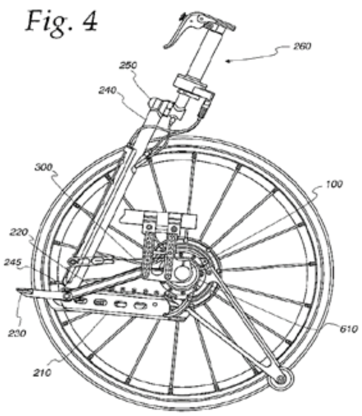
Figure 1.2 The Rip Chair

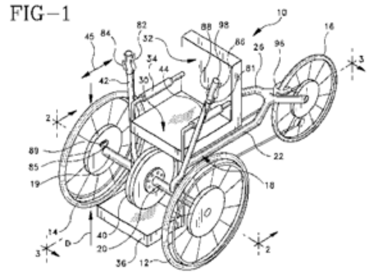
Figure 1.3 The TrackMaster Chair

Figure 1.4 The Grit Freedom Chair

Figure 1.5 The NuDrive

Figure 1 Extended Background Research for finding applicable and existing designs. We were able to analyze existing designs to figure out how to take the best parts of each one for our own design.





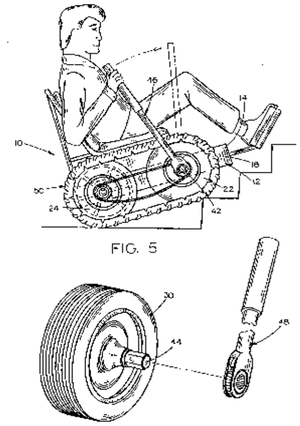
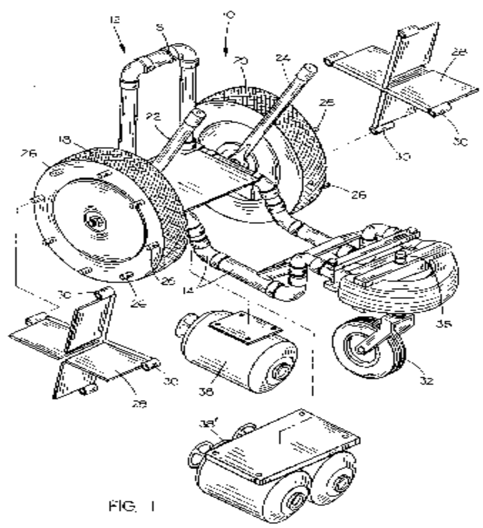


Figure 1.1 Patent US 20080073869 A1 is a drive system for a human powered vehicle. This system includes a drive lever, one way clutch, a neutral shifting system, and a brake. The shifter allows for multiple drive ratios.

Figure 1.2 Patent US 5826897 A. This patent is for a human powered vehicle that uses a rowing lever to power a flywheel. A transmission then transfers the energy from the flywheel to rotational movement.

Figure 1.3 Patent US 5020818 A. This design includes a pair mounted wheels on each side which are interconnected. A ratchet arm can be attached to increase torque as well as tank tracks.



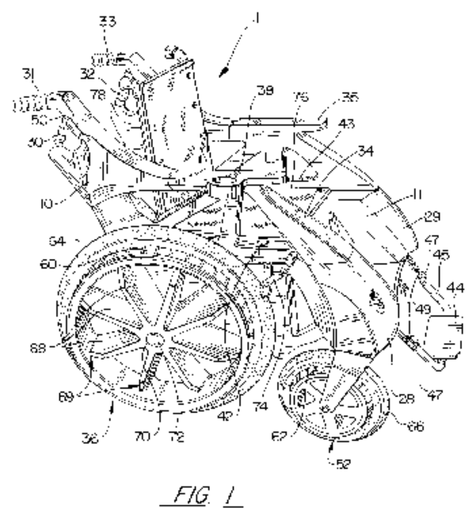


Figure 1.4 Patent US 5149118, An all-terrain wheelchair comprising a frame constructed of hollow members to allow chair to float in water. Design allows for attachments such as air tanks, paddles, and wheels.

Figure 1.5 Patent US 6073958 A. An all-terrain wheelchair for all outdoor use. This chair is made of hollow members and has horizontally ribbed wheels. This chair also can fold in half for storage.

Figure 1. Patent Information from background research. Five different Patents were found that pertained to the design we were trying to create. Many of the patents are expired; however, they all give information to help us on our design.

Existing Designs
1: Ogo
2: BT X Beach
3: fat tires
4: tank chair
5: flat wide tires

Nathan	Needs, Wants	Item No.	Importance	A: modification weight	B: overall width	C: overall length	D: overall height	E: Torque/Travel sidewalk	F: Torque/Travel soft Sand	G: T increase post beach	H: Torque/Travel Hard sand	I: time trials (setup)	J	1	2	3	4	5
	lightweight	1	3	9	1	1	1	3	3	3	3	1		2	4	3	1	3
	portable	2	3	3	3	3	3					1		4	5	1	1	1
	manual	3	2					9	9	9	9			1	5	3	1	5
	all-terrain	4	5					1	9	1	9			4	3	5	5	5
	minimal assistance (beach prep)	5	2	1	3	3	1					9		5	3	5	5	5
	durability/robust	7	4						1	9	1			3	4	2	5	2
	discreteness (appearance)	8	5		1	1	1							5	4	1	1	1
	ease of movement (power per push)	9	5	3	3	3		9	9	9	9			5	2	3	5	3
	easy to switch from deep to hard sand	10	5						3		3			4	3	4	5	4
	user controlled (independent)	11	3	1			3	3	3	3	3			5	5	1	5	1
		12																
		13																
		14																
		15																
	Targets			<= 10 lbs	30" max	30" max	30" max	10 lbs max	30 lbs	5% max	15 lbs max	5 minutes max						
	Weighted Importance			59	38	38	37	95	154	131	154	24			552			
	% Importance			11	7	7	7	17	28	24	28	4						

Figure 1. QFD analysis showed us that the most important measures to design for will be the torque per travel on hard sand and soft sand. These two criteria will let us know if our design will work or not. The target values are set based on the information given from Nathan. Importance of each need and want is based on input from Nathan and the overall scope of what we are trying to design.

Appendix D *[D] Concept Design Development-Brainstorming, Models, Pugh Matrices, and Weighted Decision Matrix*		Date 11-11-17

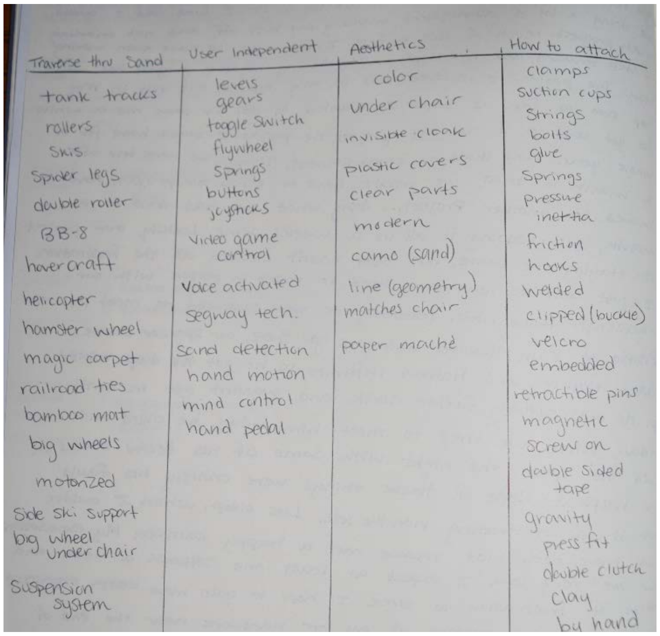


Figure 1. The first brainstorming session involved creating a list based on the specific functions we have. We wrote down ideas for each column; traversing through sand, user independence, aesthetics, and how to attach. We recorded all ideas even if they aren't plausible in order to gain more ideas.

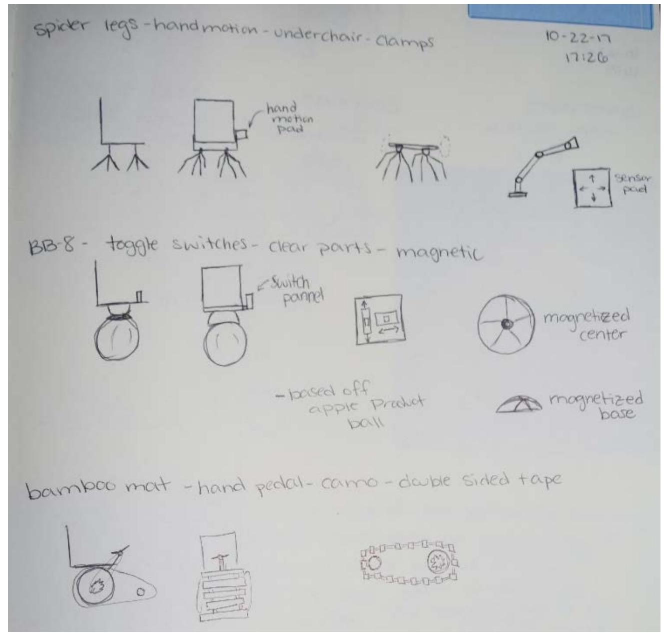


Figure 2. The second brainstorming session involved using the list of ideas from the first session. We chose an idea for each function to come up with ways to combine the different ideas. We each worked on 3 for 5 minutes each giving us a total of 15 ideas to start with. Three ideas are seen above.

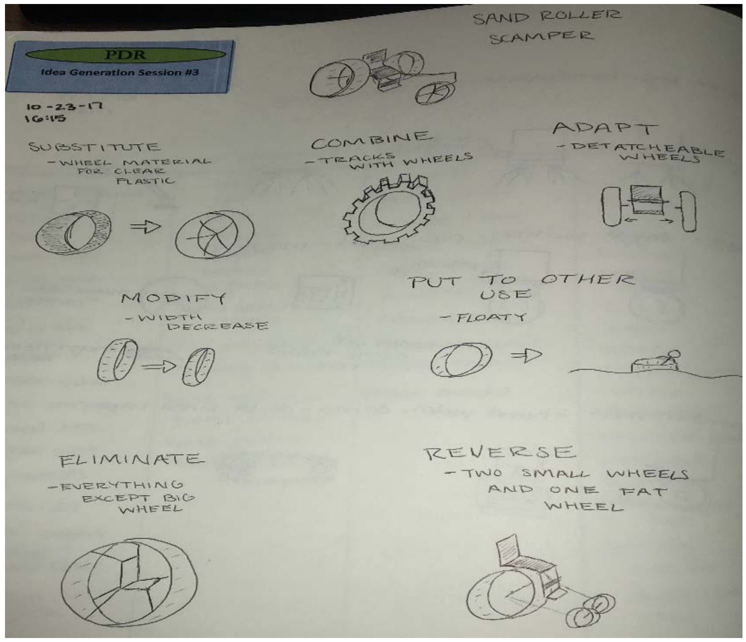


Figure 3. The third brainstorming session used a concept called Scamper. We took the Sand Roller existing design and applied the acronym, SCAMPER, to it. We Substituted, combined, adapted, modified, put to other uses, eliminated, and reversed the design.

Figure 4. A Flywheel drive system was one of the concepts we tried to incorporate in or model building. We don't know much about the technology, but know how it generally works.

Figure 5. A telescoping wheel was another of the design concepts we tried to visualize. This design would be hard to implement into an actual prototype.

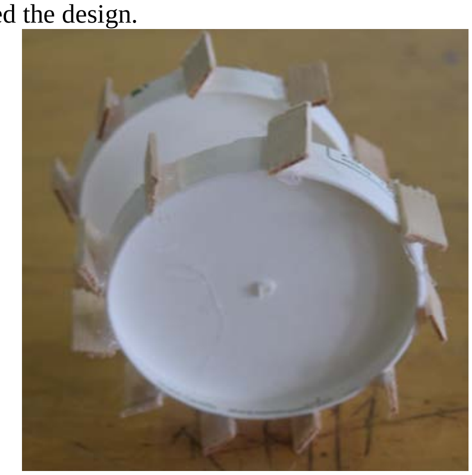


Figure 6. A treaded wheel was a simple design that we could modify in several different ways to get the prototype we wanted. The stress on the treads or 'scoops' would be too significant and hard to design for when prototyping.

Table 1. Pugh Matrix for the function of mechanical assist. The + signifies that the design is better than the datum for the specific criteria, the – means that the design is worse when compared to the datum, and the S signifies that the design is the same as the datum for that certain criteria. The mechanical assists were narrowed down from the brainstorming session to a few reasonable systems. The systems were compared to the levers with geared hub as our datum. From the analysis, we concluded that the top three methods would be levers with a geared hub, a toggle electric motor system, and a hidden flywheel with hand crank.

Criteria / **Concept**	Levers with Geared Hub	Toggle switch/joystick with electric motor	Hidden flywheel with Hand Crank	Ogo type Segway chair
Reparability	DATUM	-	S	-
Tediousness		+	-	+
Aesthetics		+	+	+
Lightweight		-	-	-
Minimal prep		S	S	+
Portable		-	+	-
Physical advantage		+	S	+
Daily Maintenance		-	-	-
∑ +		3	2	4
∑ -		4	3	4
∑ S		1	4	0
∑ Total	0	-1	-1	0

Table 2. Pugh Matrix for the function of traversing across sand. The + signifies that the design is better than the datum for the specific criteria, the – means that the design is worse when compared to the datum, and the S signifies that the design is the same as the datum for that certain criteria. The hollow roller under the chair was chosen as our datum to compare the rest of our ideas to. The Dyneema rope ladder ranked the highest in comparison to the datum. The short skis and hollow treaded wheel also scored well compared to the other designs.

Criteria	Dyneema Rope Ladder	Clear Telescoping Wheel	Hollow Roller Under chair	Short Skis	Hollow Treaded Wheel	Tank Tracks	Hollow Ball Under chair
lightweight	+	S	DATUM	+	S	-	S
portable	+	S		-	S	-	S
all terrain	S	S		S	+	+	S
minimal prep assistance	+	S		S	S	-	S
robust	S	-		S	+	+	S
discrete	-	-		S	-	-	S
ease of movement	S	S		S	S	+	S
independent	S	S		S	S	S	S
Sum +	3	0		1	2	3	0
Sum -	1	2		1	1	4	0
Sum S	3	6		4	4	1	8
Total	2	-2	0	0	1	-1	0

Table 3 Pugh Matrix of the function for attaching the device to the wheelchair. The + signifies that the design is better than the datum for the specific criteria, the – means that the design is worse when compared to the datum, and the S signifies that the design is the same as the datum for that certain criteria. Clamps were used as our datum to compare the rest of our attachments to. The press fit, glue and welding were by far the best options. We will look at these options for creating the attachment; however, because the device is going to be something that can be taken on or off, these methods will not be as useful. For attaching the device to the wheelchair, the best options clips, hooks or springs. We have many options and want to keep it broad so that we do not hinder our design process too much. This will allow us to make changes later on.

Criteria	Clamps	Bolts	Springs	Magnetic	Press fit	Glue	Hooks	Weld or Embed	Rectractible Pins	Clip (Buckle)
Lightweight	DATUM	s	s	+	+	+	s	+	S	s
Portable		s	s	+	+	+	s	+	S	s
Minimal Prep		s	+	s	+	+	s	+	S	s
Robust		s	-	S	+	-	s	+	s	+
Independent		-	S	S	S	S	s	S	S	S
Aesthetics		S	+	-	S	S	s	S	S	S
Reparability		S	-	-	-	S	s	-	-	S
Sum+		0	2	2	4	3	0	4	0	1
Sum-		1	2	2	1	1	0	1	1	0
SumS		6	3	3	2	3	7	2	6	3
Score		-1	0	0	3	2	0	3	-1	1

Table 4. Weighted Decision Matrix based off the Pugh Matrices. Each concept is graded based on a scale from 1 to 3. This number is multiplied to the weight of each given criteria. The score for each criterion are then added up to a total score at the bottom of the table. The Rope Ladder design with hooks and levers and gears was the best one with our criteria. The rope ladder with the flywheel was our next design if the levers and gears did not work. Although the skis did not score well compared to the other designs, they can be implemented into the final design for extra support especially for the front wheels.

Concept / **Criteria**	Weights	Method of travel: Rope Ladder Attachment: Hooks Drive: Levers and Gears	Method of travel: Hollow Treaded Roller Attachment: Retractable Pins Drive: Levers and Gears	Method of travel: Skis Attachment: Clamps Drive: Flywheel	Method of travel: Rope Ladder Attachment: Clip/Buckle Drive: Flywheel	Method of travel: Hollow Ball Under Chair Attachment: Magnet Drive: Levers and Gears
Lightweight	3	2	1	1	1	2
Portable	3	3	2	2	2	1
Manual	2	3	3	2	2	3
All-Terrain	5	3	2	1	3	1
Minimal Assistance (beach prep)	2	3	2	1	3	3
Corrosion Resistant	4	2	2	3	3	2
Durability/Robust	4	2	3	1	2	2
Discreteness (Appearance)	3	1	2	2	1	2
Ease of Movement (Power Per Push)	5	3	2	1	3	1
∑+		76	65	47	72	53

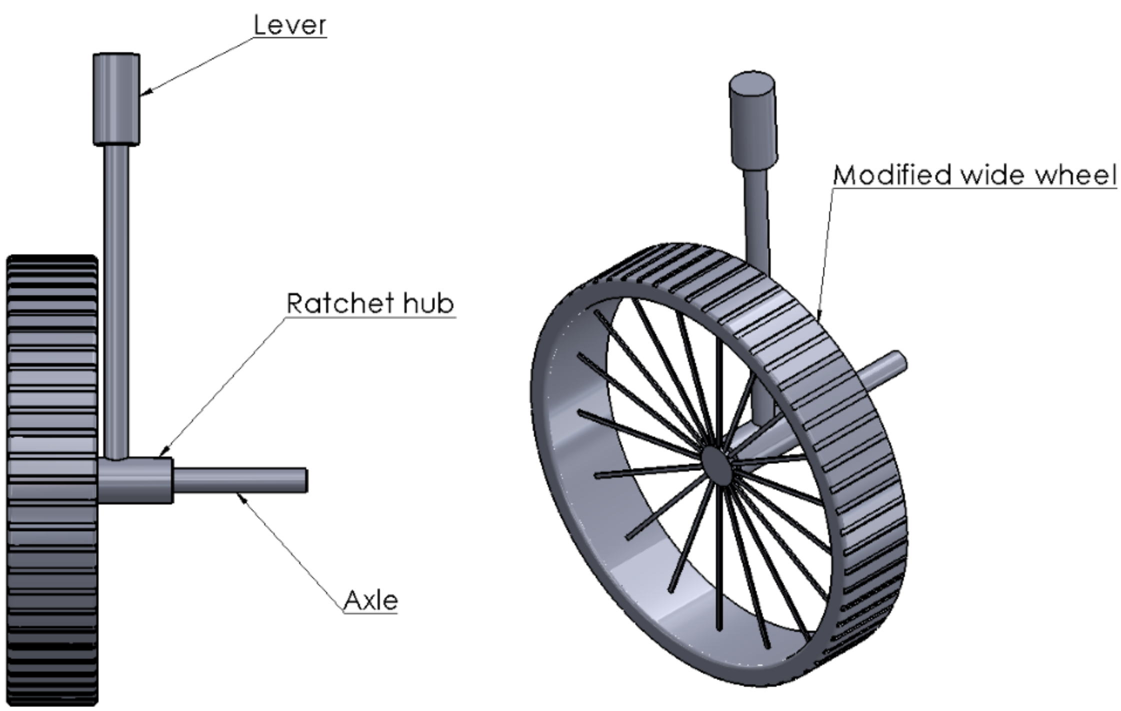
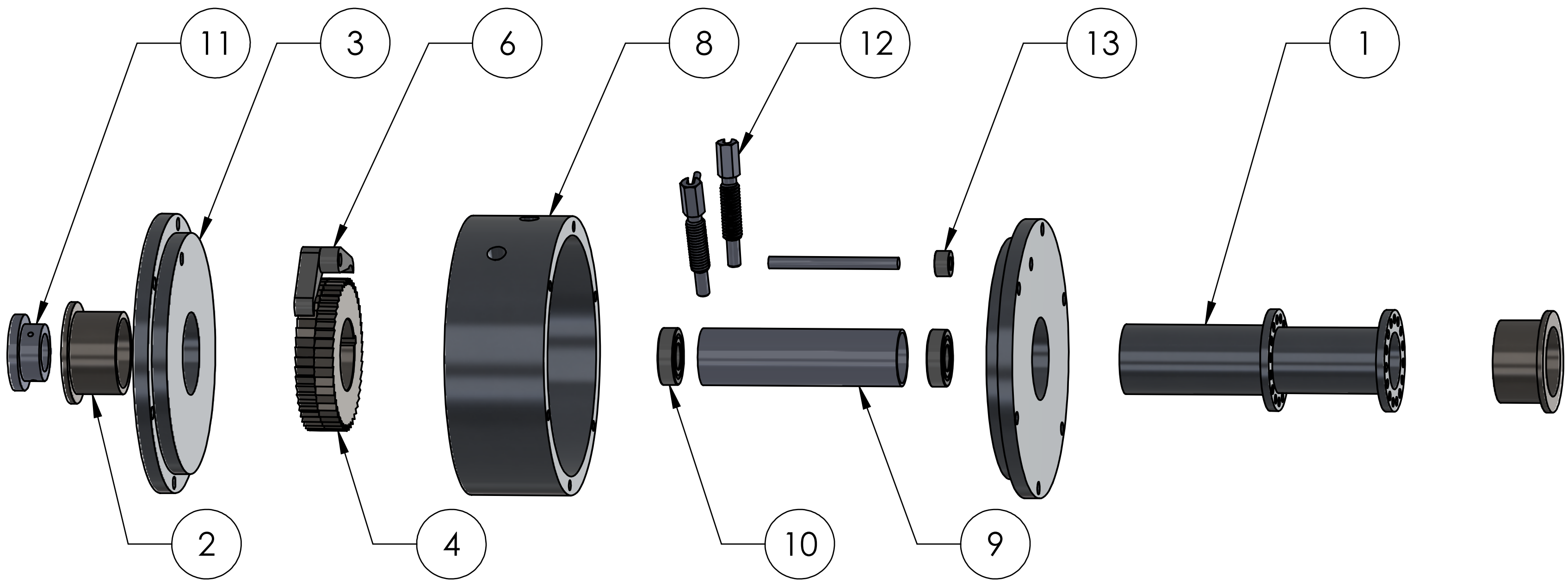


Figure 1. The Concept Design layout. This design was the first installment of the concept for modified wide wheels and a ratchet system. In this design there are a lot of unknowns and black boxes. The wheels are also based on creating plastic wheels instead of the new design of using bike wheels.

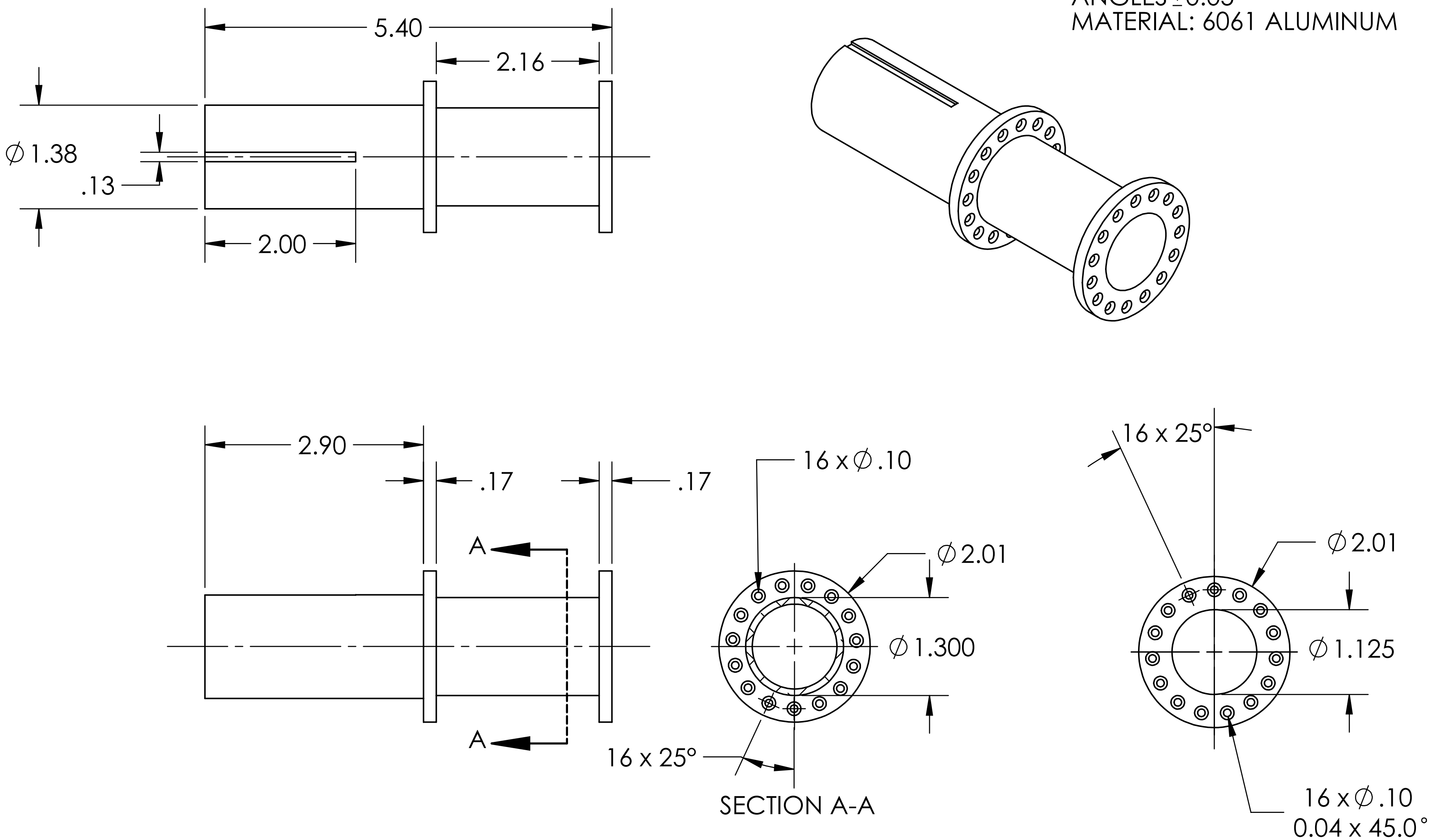
Indented Bill of Material (BOM)

Assembly Level	Part Number	Description	Vendor	Vendor Part Number	Quantity		Cost	Total Cost
		Lvl 0 / Lvl 1 / Lvl 2 / Lvl 3						
0	1000	Final Assy						
1	1100	Wheel Assembly						
2	1110	Wheelsmith DB14 Spokes	Bike Hub Store	DB14-BLK-240	72	# parts	$0.99	$71.28
2	1120	Custom Spoke Length	Bike Hub Store	CUSTOMSPOKE	72	# parts	$0.25	$18.00
2	1130	Innersleeve Assembly	Speedy Metals	t61r2x.5	2	per 6 inches	$14.40	$28.80
3	1131	Ball Bearings	McMaster Carr	2342K186	4	# parts	$13.49	$53.96
3	1132	Ball Bearing Spacer	McMaster Carr	9056K27	1	# feet	$12.64	
3	1133	Ratchets	McMaster Carr	6283K22	4	# parts	$55.88	$223.52
3	1134	Ratchet Spacer	McMaster Carr	9056K37	0.5	# feet	$26.44	$13.22
3	1135	Steel Machine Key Stock	McMaster Carr	98491A102	1	# parts	$3.18	$3.18
2	1140	Wienman Rims	Niagara Cycle	6019	4	# parts	$15.28	$61.12
2	1150	Q-Tubes	Niagara Cycle	214315	4	# parts	$4.50	$18.00
2	1160	CST Tires	Niagara Cycle	478721	4	# parts	$9.78	$39.12
2	1170	Brackets	Home Depot	57000	1	36x36 sheet	$21.98	$21.98
3	1171	Nuts 1/4"	Home Depot	49088	24	# parts	$0.07	$1.68
3	1172	Bolts 1/4"	Home Depot	800586	24	# parts	$0.11	$2.64
1	1200	Hub Assembly						
2	1210	Pawls	McMaster Carr	6283K32	4	# parts	$46.54	$186.16
3	1211	Spring Plunger	McMaster Carr	3403A14	4	# parts	$12.36	$49.44
2	1220	Outer Sleeve	Speedy Metals	t61r5.5x.5	2	per 2 inches	$10.38	$20.76
2	1230	Flanged Sleeve	McMaster Carr	6338K314	4	# parts	$6.36	$25.44
2	1240	Cap	Speedy Metals	61r5.5	4	per 1 inch	$12.91	$51.64
3	1241	Hex bolts	McMaster Carr	800586	24	# parts	$0.11	$2.64
2	1250	End Cap Stock Metal	McMaster Carr	8920K311	1	# feet	$22.21	$22.21
3	1251	Set Screw Shaft Collars	Home Depot	811938	3	sets of 2	$0.62	$1.86
2	1260	Alloy Steel Dowel Pin	McMaster Carr	98385A254	1	# sets	$10.97	$10.97
3	1261	Set Screw Shaft Collars	McMaster Carr	9414T6	4	# parts	$1.07	$4.28
1	1300	Lever						
2	1310	Lever Rod	McMaster Carr	8974K12	3	# feet	$5.59	$16.77
1	1400	Skis						
2	1410	WheelBlades	Wheelblades		2	# sets	$50.00	$100.00
2	1420	FreeWheel	FreeWheel		1	# parts	$0.00	$0.00
2	1430	Angle Bar Stock	Home Depot	80137	1	# parts	$5.37	$5.37
2	1440	Nuts	Home Depot	49088	14	# parts	$0.07	$0.98
2	1450	Bolts	Home Depot	800586	14	# parts	$0.11	$1.54
1	1500	Axle Pin	McMaster Carr	90985A431	2	# parts	$63.12	$126.24
Total					305.5			$1,182.80

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	1130	Inner Sleeve	1
2	1220	Flanged Bushing	2
3	1240	Cap	2
4	1132	Ratchet	2
5	1250	Pawl Pin	1
6	1210	Pawl	2
7	1133	Key	1
8	1220	Outer Sleeve	1
9	1132	Bearing Spacer	1
10	1131	Bearing	2
11	1250	Locking End Cap	1
12	1211	Locking Spring Plunger	2
13	1251	Set Screw Shaft Collar	1



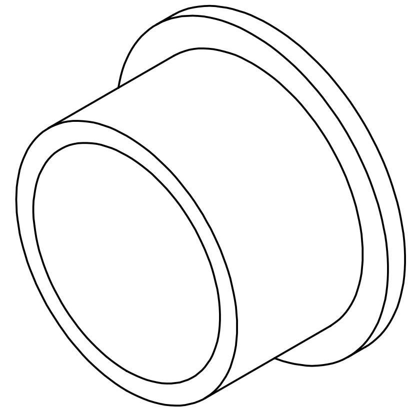
Cal Poly Mechanical Engineering ME 430 - Spring 2018	Lab Section:	Assignment #	Title: Exploded Hub Assembly		Drwn. By: Jackson Wiley
	Dwg. #:	Nxt Asb:	Date: 5/29/18	Scale:	Chkd. By: ME STAFF

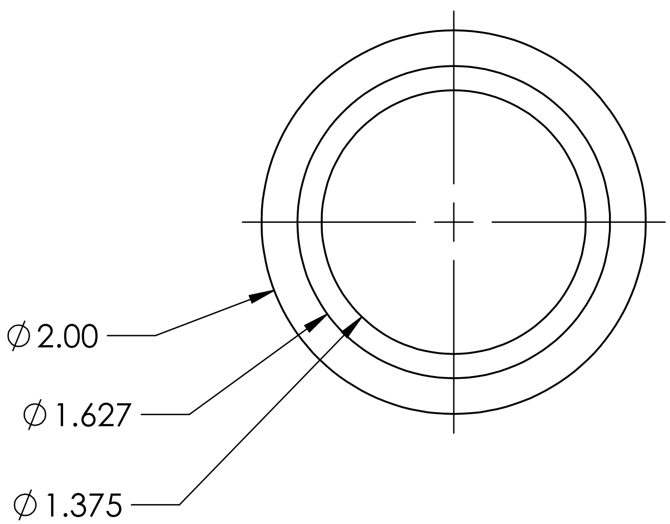


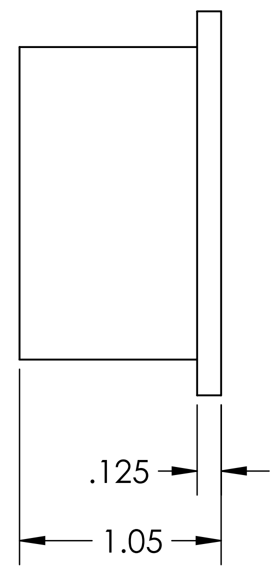
NOTES:
UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS IN INCHES
TOLERANCES:
X.XX ±0.05
ANGLES ±0.05°
MATERIAL: 6061 ALUMINUM

Cal Poly Mechanical Engineering	Lab Section:	Part#: 102004	Title:INNER SLEEVE	Drwn. By:JACKSON COLE
ME 429 - WINTER 2018	Dwg. #:	Nxt Asb:	Date: / Scale:1:2	Chkd. By: ME STAFF

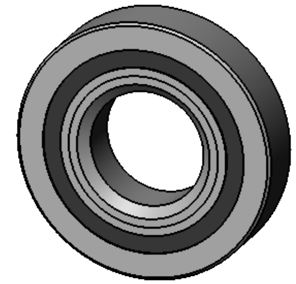
NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.05"
ANGLES ±0.05°
3. MATERIAL:
6061 AL







Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: Flanged Bushing		Drwn. By: Jackson Wiley
ME 430 - Spring 2018	Dwg. #:	Nxt Asb:	Date: 5/29/18	Scale: 1:1	Chkd. By: ME STAFF



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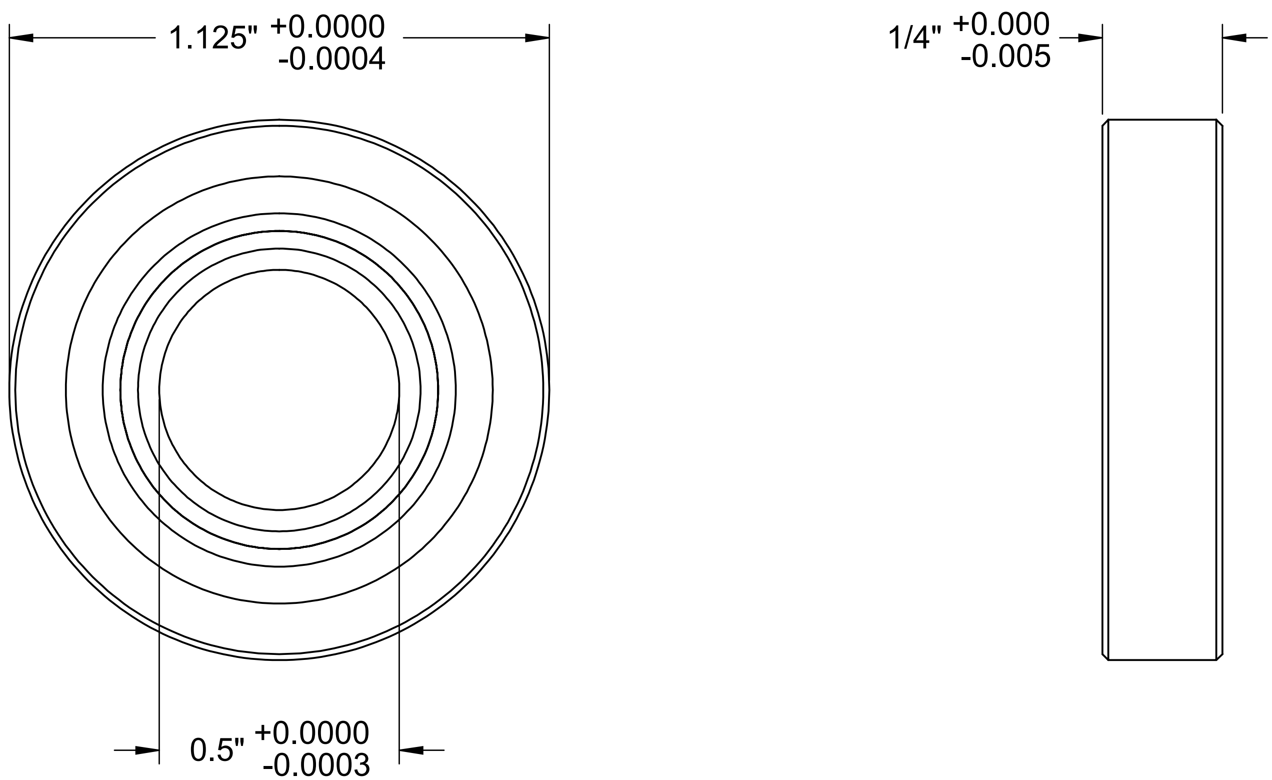


McMASTER-CARR® CAD

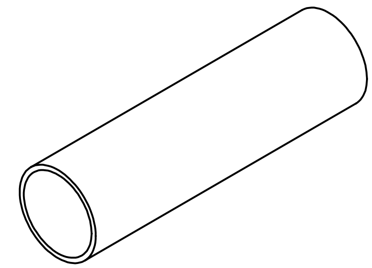
PART NUMBER **2342K166**

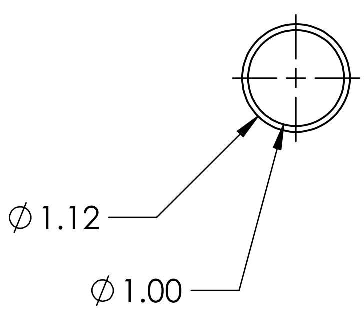
http://www.mcmaster.com

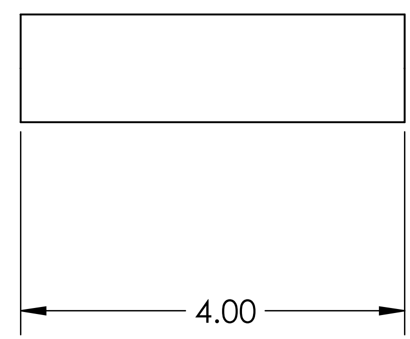
Information in this drawing is provided for reference only.

Permanently Lubricated Ball Bearing

NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.005"
3. MATERIAL:
6061 AL

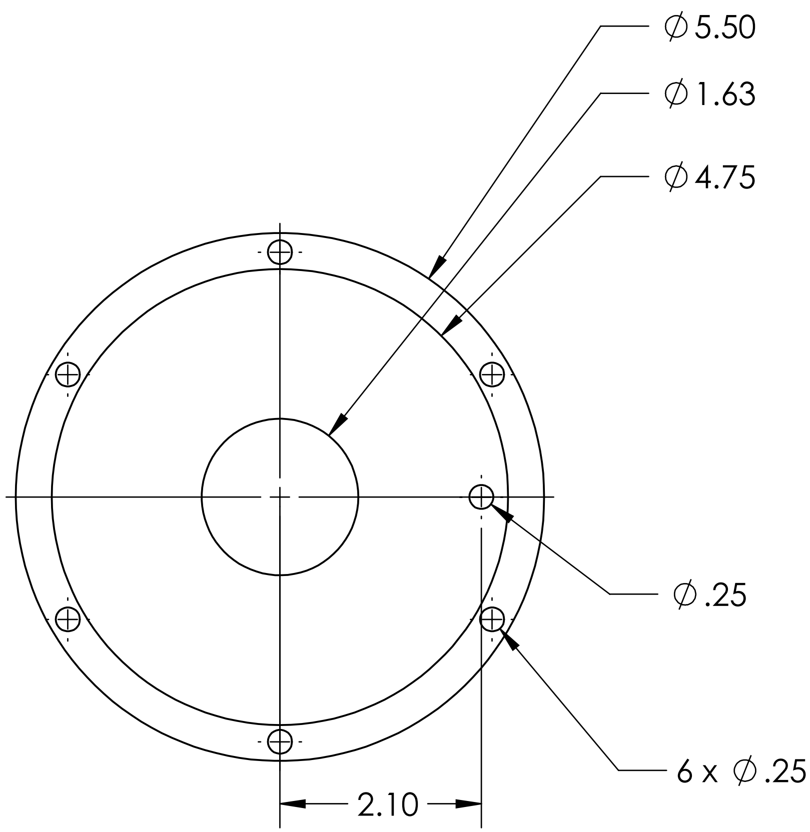


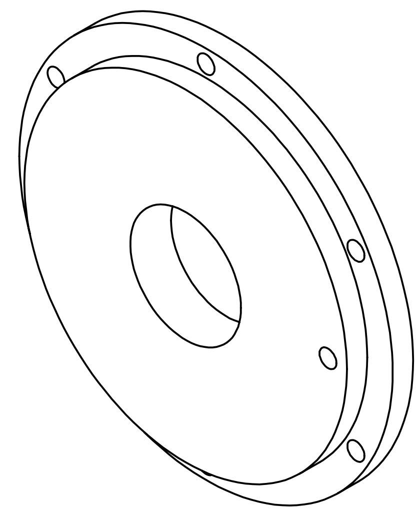


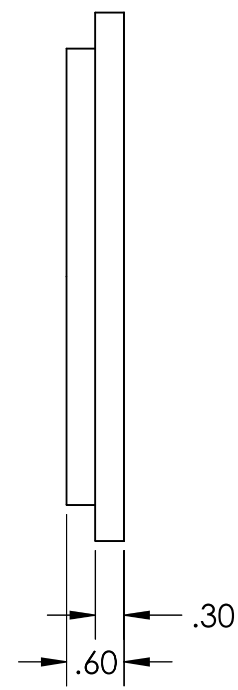


Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: Bearing Spacer	Drwn. By: Jackson Wiley
ME 430 - Spring 2018	Dwg. #:	Nxt Asb:	Date: 5/28/18 / Scale: 1:1	Chkd. By: ME STAFF

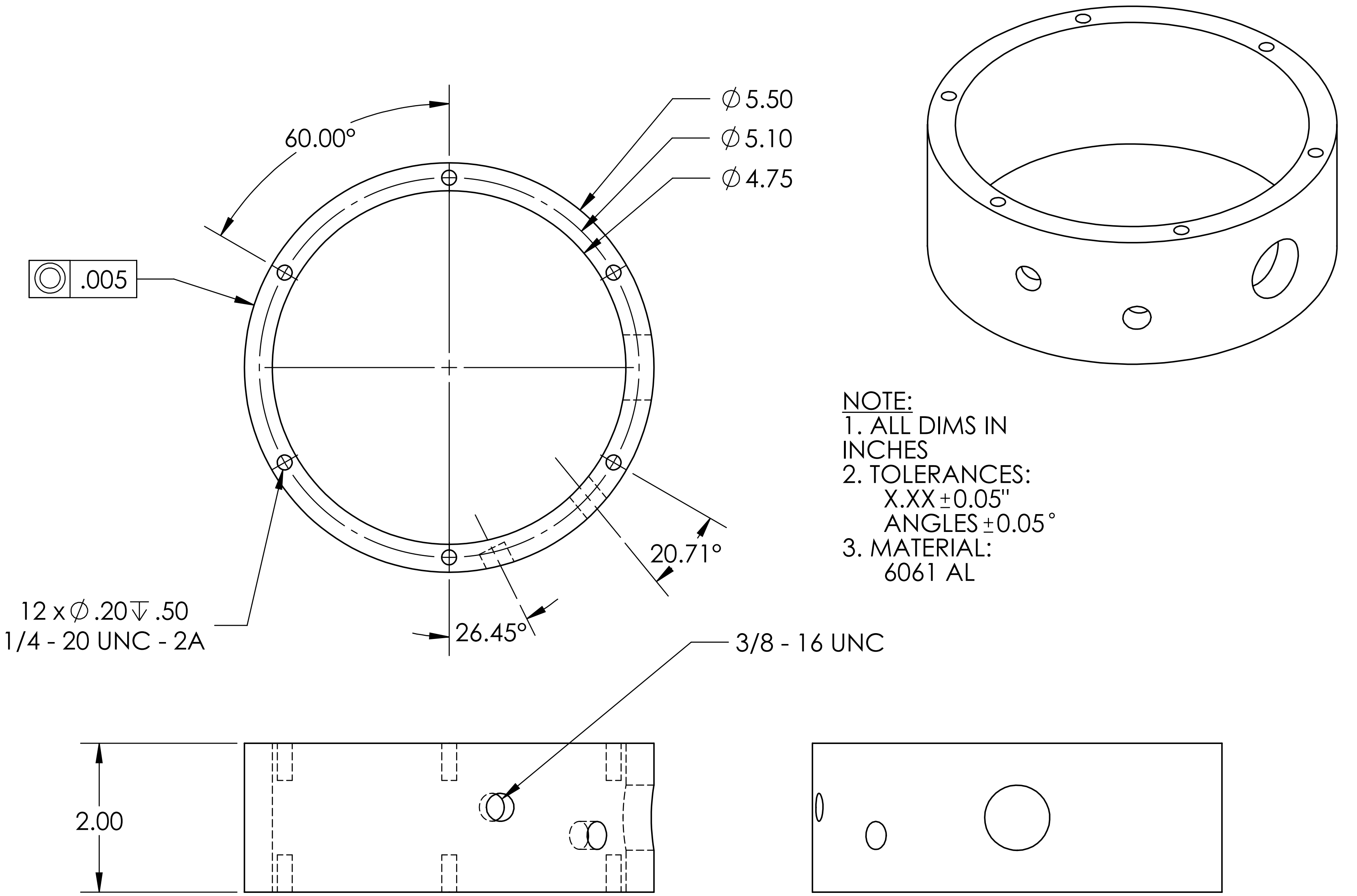
NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.05"
ANGLES ±0.05°
3. MATERIAL:
6061 AL







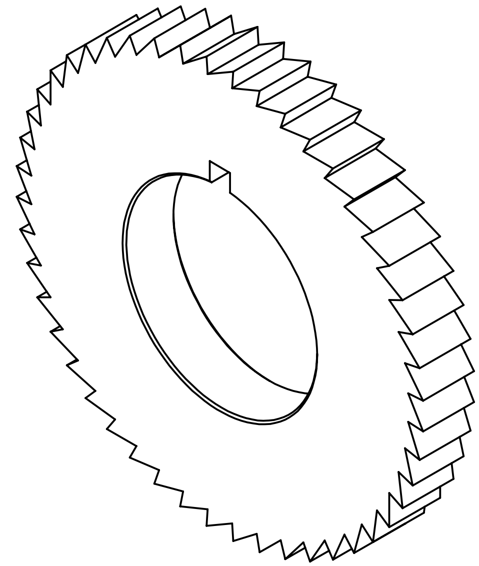
Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: Cap w/ through hole		Drwn. By: Jackson Wiley
ME 430 - Spring 2018	Dwg. #:	Nxt Asb:	Date: 5/28/18	Scale: 1:2	Chkd. By: ME STAFF

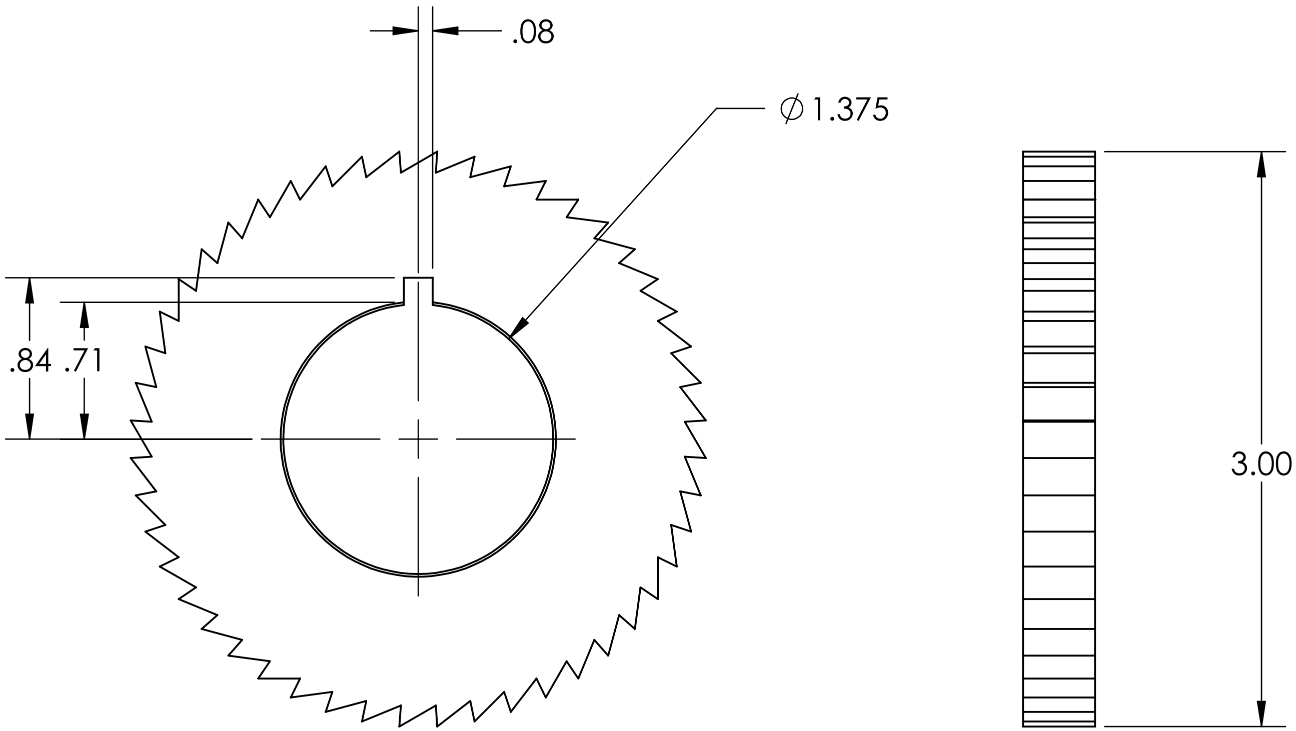


NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
   X.XX ±0.05"
   ANGLES ±0.05 °
3. MATERIAL:
   6061 AL

Cal Poly Mechanical Engineering	Lab Section:	Part#: 102006	Title: Outer Sleeve		Drwn. By: Jackson Wiley
ME 429- Winter 2018	Dwg. #:	Nxt Asb:	Date: 2/8/18	Scale: 1:2	Chkd. By: ME STAFF

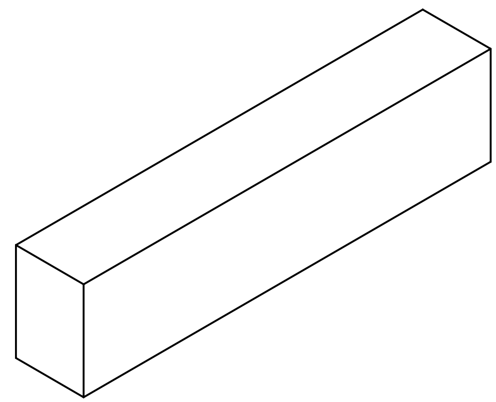
NOTE:
UNLESS OTHERWISE SPECIFIED
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.05
3. MATERIAL:
STAINLESS STEEL
4. RATCHET WILL BE PURCHASED. ONLY MODIFICATIONS ARE THE INNER DIAMETER AND KEYWAY.

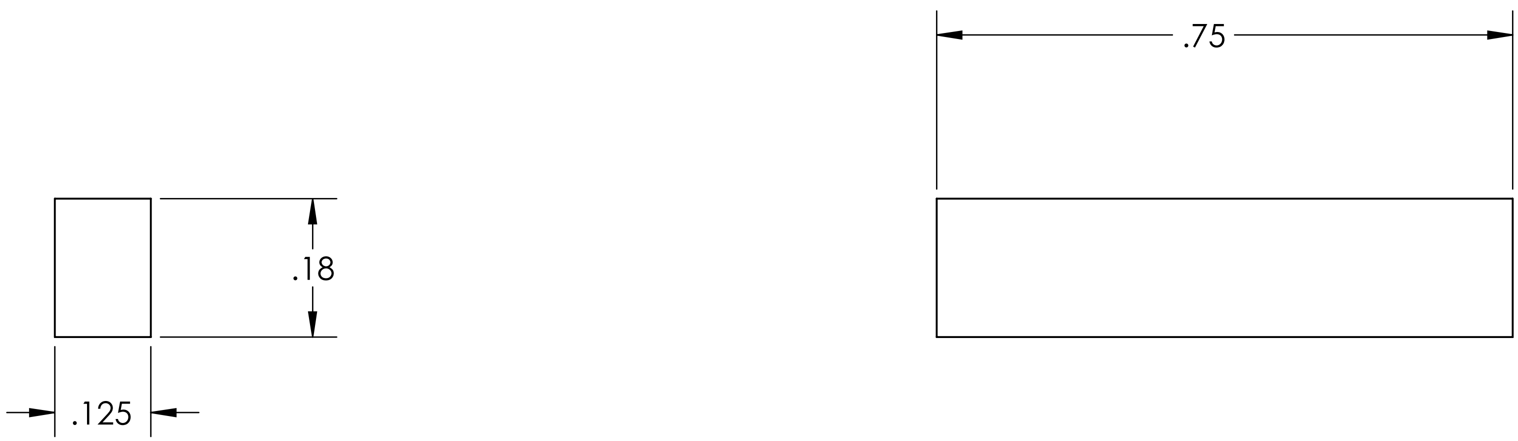




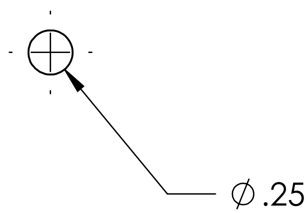
Cal Poly Mechanical Engineering ME 429 - Winter 2018	Lab Section:	Part#: 103003	Title: Ratchet		Drwn. By: Jackson Wiley
	Dwg. #:	Nxt Asb:	Date: 2/8/18	Scale: 1:2	Chkd. By: ME STAFF

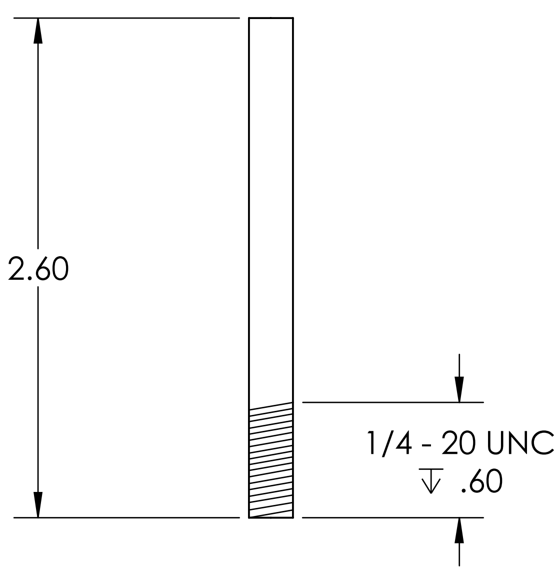
NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.05"
ANGLES ±0.05°
3. MATERIAL:
HARDENED STEEL





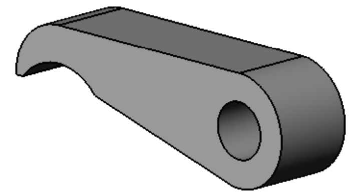
Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: Key		Drwn. By: Jackson Wiley
ME 430 - Spring 2018	Dwg. #:	Nxt Asb:	Date: 6/1/18	Scale: 4:1	Chkd. By: ME STAFF

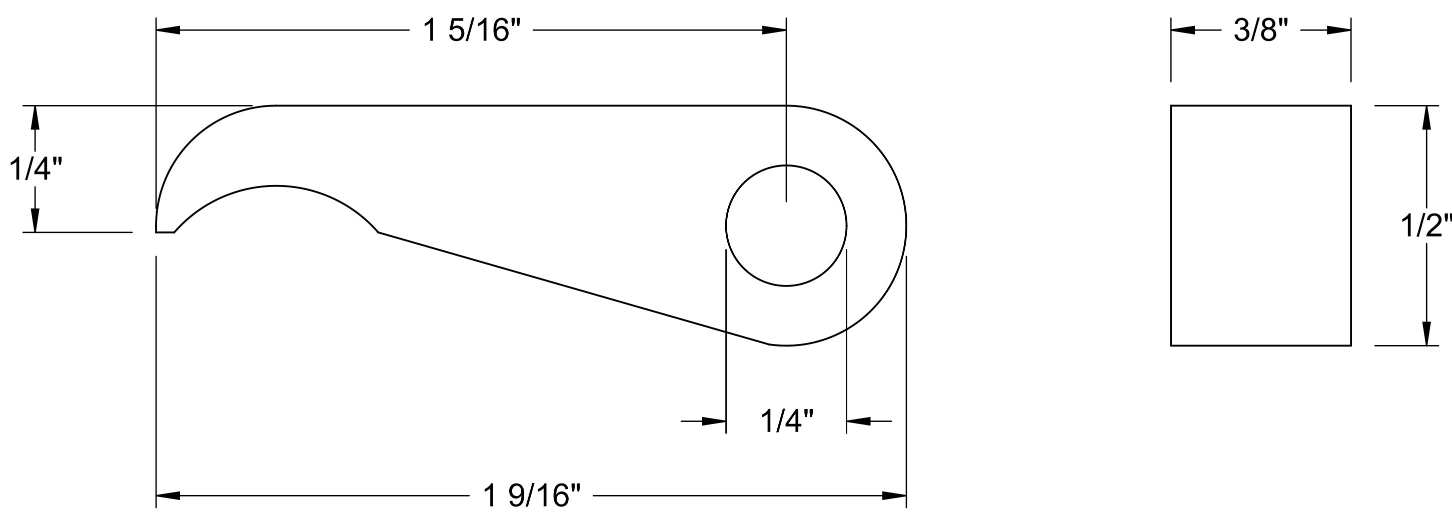




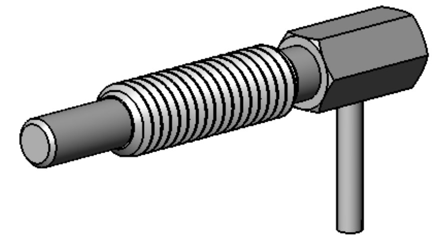
NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.005"
3. MATERIAL:
HARDENED STEEL

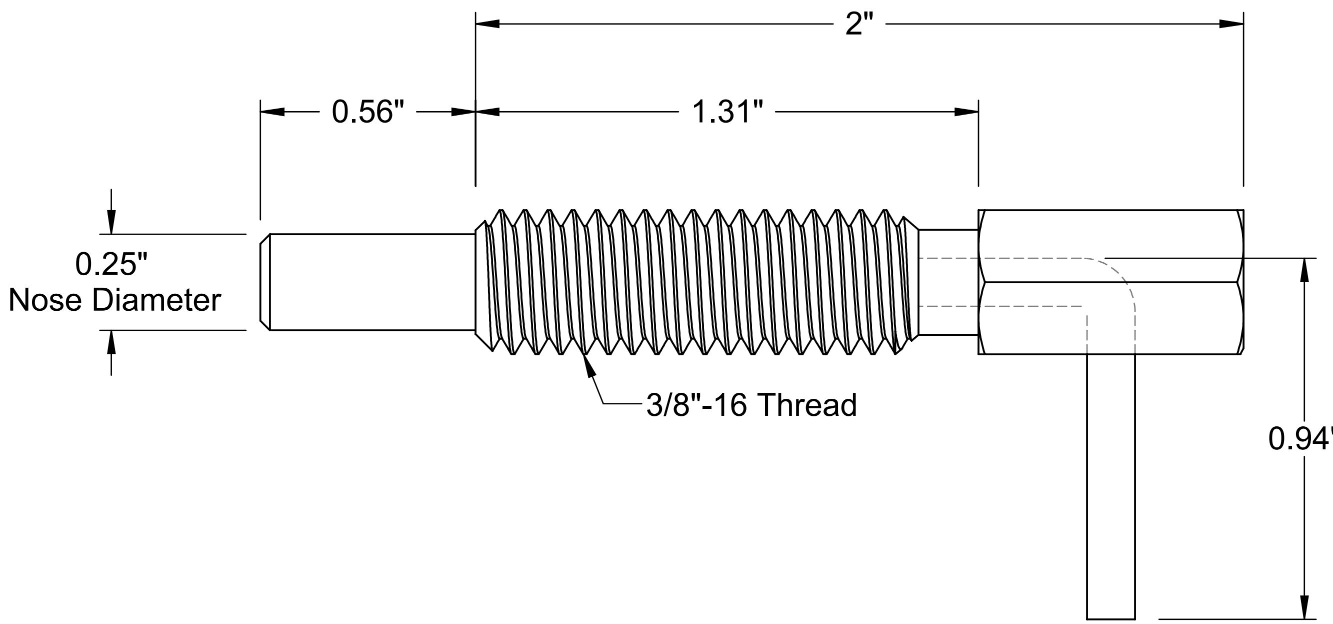
Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: Pawl Pin	Drwn. By: Jackson Wiley
ME 430 - Spring 2018	Dwg. #:	Nxt Asb:	Date: 5/28/18 · Scale: 1:1	Chkd. By: ME STAFF



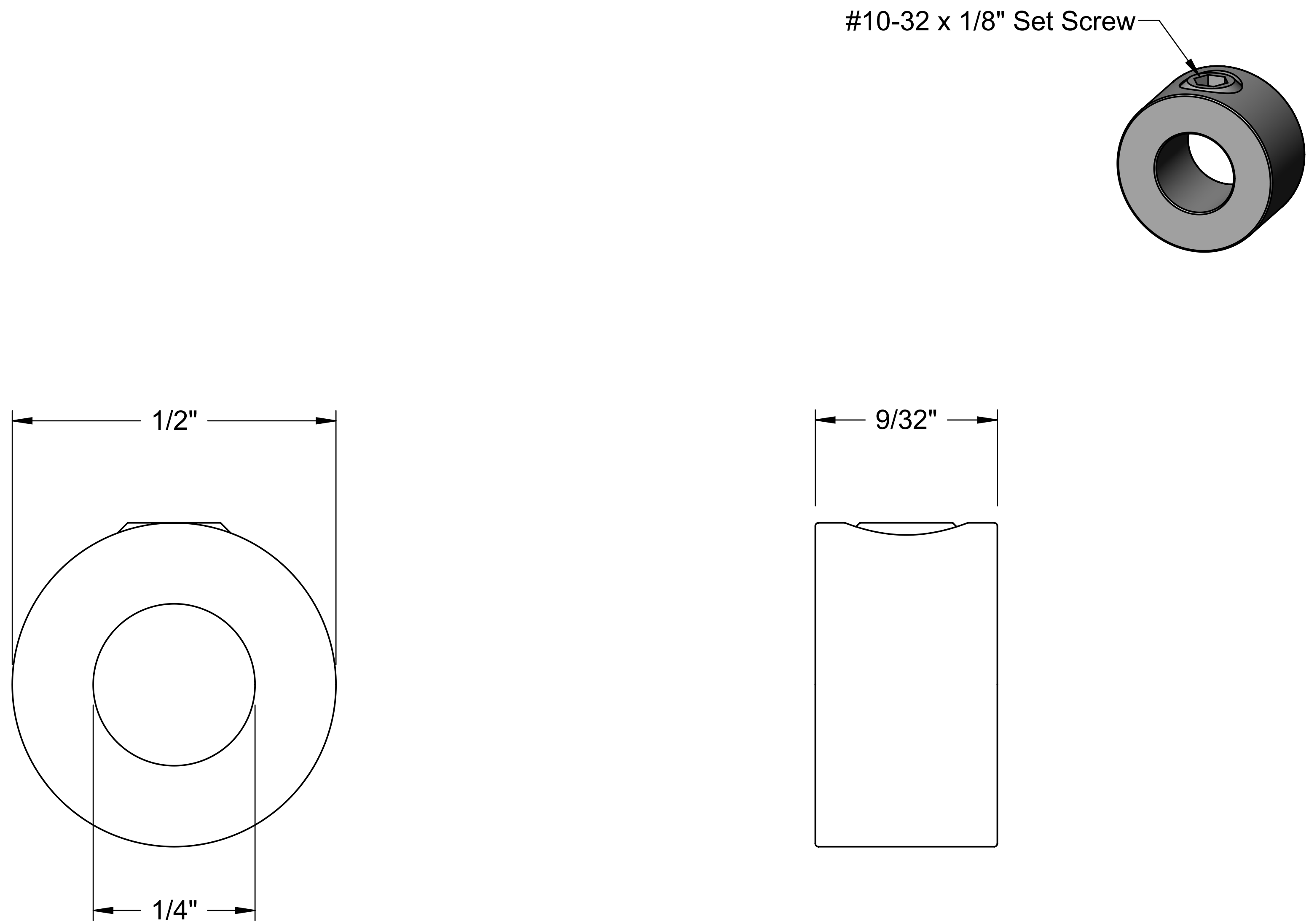


McMASTER-CARR® CAD	PART NUMBER	6283K32
http://www.mcmaster.com © 2015 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Pawl for Ratcheting Gears	





McMASTER-CARR® CAD		PART NUMBER	3403A61
http://www.mcmaster.com		Retractable Spring Plunger with Locking Nose	

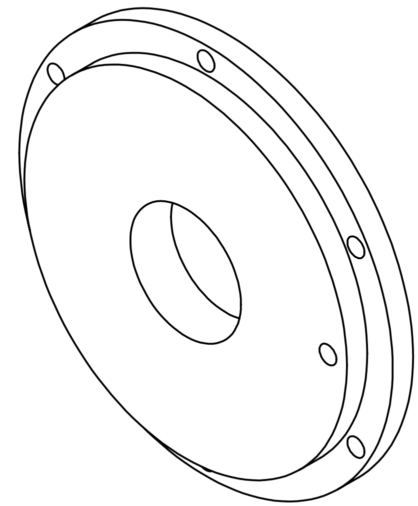


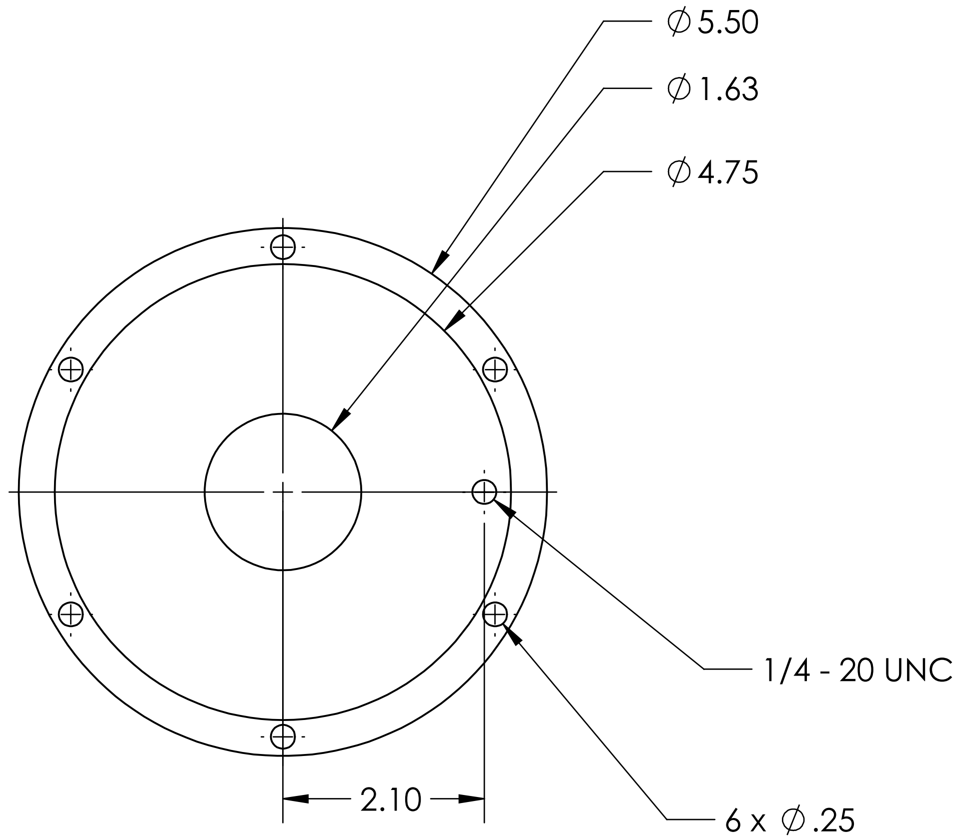
McMASTER-CARR® CAD

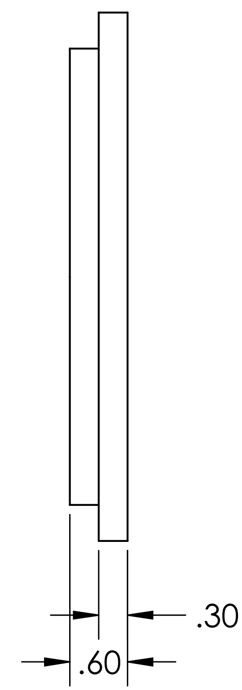
PART NUMBER 9414T6

Set Screw Shaft Collar

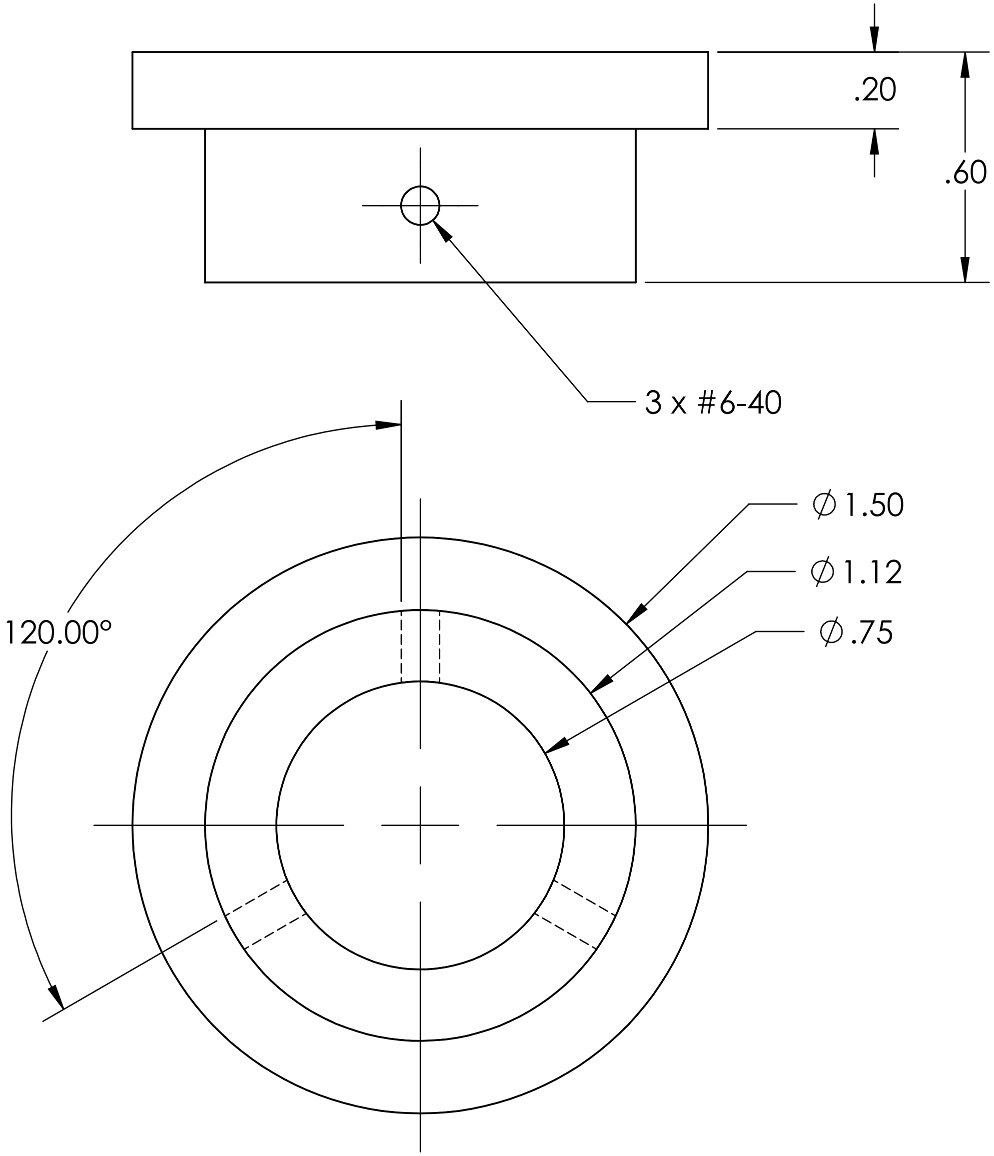
NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.05"
ANGLES ±0.05°
3. MATERIAL:
6061 AL

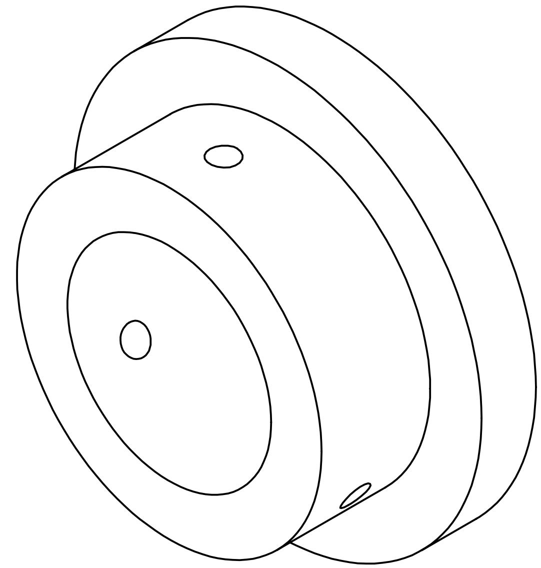






Cal Poly Mechanical Engineering ME 430 - Spring 2018	Lab Section:	Assignment #	Title: Cap w/ threads	Drwn. By: Jackson Wiley
	Dwg. #:	Nxt Asb:	Date: 5/28/18 / Scale: 1:2	Chkd. By: ME STAFF





NOTE:
1. ALL DIMS IN INCHES
2. TOLERANCES:
X.XX ±0.05"
ANGLES ±0.05°
3. MATERIAL:
STEEL

Cal Poly Mechanical Engineering	Lab Section:	Assignment #	Title: End Cap		Drwn. By: Jackson Wiley
ME 430 - Spring 2018	Dwg. #:	Nxt Asb:	Date: 5/29/18	Scale: 2:1	Chkd. By: ME STAFF

Table 1. The Full list of all the parts to be purchased. The quantity shows how many of each part we need. The bolded items are the most expensive and the most necessary for our design.

	Part	Vendor	Qty	Units	Cost	Total Cost
Wheel Assembly	Spokes	Bike Hub Store	72	# parts	$0.99	$71.28
	Custom Spoke	Bike Hub Store	72	# parts	$0.25	$18.00
	Innersleeve	Speedy Metals	2	# parts	$14.40	$28.80
	Ball Bearings	Mcmaster	4	# parts	$13.49	$53.96
	Ratchets	Mcmaster	4	# parts	$55.88	$223.52
	Key Stock	Mcmaster	1	# parts	$3.18	$3.18
	Rims	Niagra Cycle	4	# parts	$15.28	$61.12
	Tubes	Niagra Cycle	4	# parts	$4.50	$18.00
	Tires	Niagra Cycle	4	# parts	$9.78	$39.12
	Brackets	Home Depot	12	# parts	$1.00	$12.00
	nuts 1/4"	Home Depot	24	# parts	$0.07	$1.68
	bolts 1/4"	Home Depot	24	# parts	$0.11	$2.64
Hub Assembly	Pawls	McMaster Carr	4	# parts	$46.54	$186.16
	Outer Sleeve	Speedy Metals	2	# parts	$10.38	$20.76
	Flange Sleeve	McMaster Carr	4	# parts	$6.36	$25.44
	Cap	Speedy Metals	4	# parts	$12.91	$51.64
	Pawl Pin Collar	McMaster Carr	4	# parts	$1.07	$4.28
	Pawl Pin	McMaster Carr	1	# sets	$10.97	$10.97
	Locking Spring Plunger	McMaster Carr	4	# parts	$12.36	$49.44
	Hex Bolts	Miners	24	# parts	$0.35	$8.40
	Flanged End Cap	McMaster Carr	1	# feet	$22.21	$22.21
	Bearing Spacer	McMaster Carr	1	# feet	$12.64	$12.64
	Ratchet Spacer	McMaster Carr	0.5	# feet	$26.44	$13.22
	Set Screws for Ratchet Spacer	McMaster Carr	1	# sets	$10.31	$10.31

	Set Screws for End Cap	McMaster Carr	6	# parts	$0.33	$2.00
	Rod	McMaster Carr	1	# parts	$12.55	$12.55
Skis	bolts 1/4"	Home Depot	4	# parts	$0.11	$0.44
	nuts 1/4"	Home Depot	4	# parts	$0.07	$0.28
	Angle Bar	Home Depot	1	# parts	$5.37	$5.37
	FreeWheel		1	# parts	$0.00	$0.00
	Wheelblades	Wheelblades	2	# parts	$50.00	$100.00
Axle Pin	Axle Pin	McMaster Carr	2	# parts	$63.12	$126.24
Manufacturing	Inner Sleeve	Cyclonetics	2	# parts	$260.00	$520.00
	Outer Sleeve	Cyclonetics	2	# parts	$85.00	$170.00
	Caps	Cyclonetics	4	# parts	$85.00	$340.00
	Total Estimated Shipping and Tax					$150.00
		Parts Total	298.5	**Total Spent**		$2,375.65

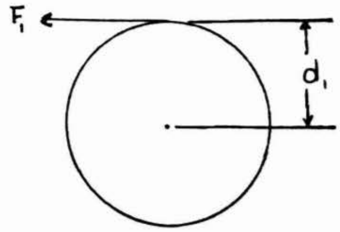
Table 1. Initial Analysis from the first beach day. We tested the wheelchair force going through hard sand and soft sand to create a baseline for what we want the design to achieve. The maximum and average values are in red.

	Soft Sand lbf	Hard Sand ibf
	56	21
	62	22
	59	19.6
	61	19.8
	50	15.9
	57.3	16.9
	46.7	16.9
	49	16.9
	52	16.9
	69	16.7
	65.8	16.5
	56.2	16.7
	56.8	16.9
	52	17.7
	48.8	17.6
	53.1	17.8
	49.8	17.6
	55.7	17.8
	53.1	17.8
	51.7	17.8

		60.6	18.9	
		62.1	17.1	
		60.3	17.1	
		61	17.4	
		65.2	17.4	
		61.1	17.4	
		62.3	17.1	
			16.9	
			16.9	
			16.7	
			16.9	
			16.9	
			13.8	
			14.4	
			14.9	
	Average	56.94814815	17.3314286	

Force to Torque Calculations

Pre-Wheelchair Attachment



Full Force = 70 lbf in soft sand

$F_1 = \frac{70\ \text{lbf}}{2}$ per wheel

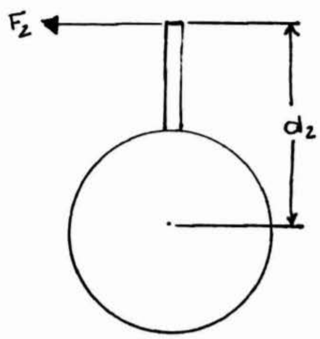
$\underline{F_1 = 35\ \text{lbf}}$

$\underline{d_1 = 1\ \text{ft}}$ (24" diam. wheels)

$\tau = F \cdot d$

$\tau = 35\ \text{lbf} \cdot 1\ \text{ft}$

$\underline{\tau = 35\ \text{ft-lbf}}$



$35\ \text{ft-lbf} = F_2 \cdot d_2$

$d_2 = 1\ \text{ft} + 1\frac{1}{2}\ \text{ft}$

$\underline{d_2 = 2\frac{1}{2}\ \text{ft}}$

$F_2 = \frac{35\ \text{ft-lbf}}{2\frac{1}{2}\ \text{ft}}$

$\underline{F_2 = 14\ \text{lbf}}$

<u>Full force = 28 lbf in soft sand</u>

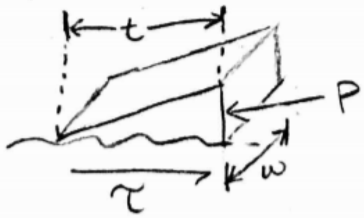
* ANALYSIS SHOWS THAT WITH LEVER ARM, FORCE REQUIRED TO MOVE IN SOFT SAND DECREASES BY 42 lbf.

Gear Tooth Analysis

Assumptions:

- treat ratchet tooth similar to spur gear tooth
- assume all stress is shear based on direction of force from the pawl
- assume force on lever is 30 lbs (probably larger than what our device will experience)

Ratchet Tooth



$t = 0.1819''$

$w = 0.375''$

$$\tau = \frac{P}{wt}$$

$$\tau < \frac{S_{sy}}{SF}$$

$S_{sy} = 31200$ psi (stainless steel)

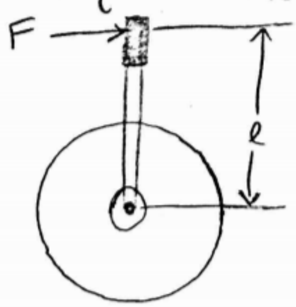
$\ell = 25''$

$F = 30$ lb

$T = F \cdot \ell$

$T = 30(25'')$
$= 750$ in-lb

Wheel w/ lever attached to find torque on ratchet



Find force on tooth from torque and radius of the ratchet

$r = 3''$

$$P = \frac{T}{r}$$

$$= \frac{750 \text{ in} \cdot \text{lb}}{3 \text{ in}}$$

$P = 250$ lb

3" ratchet

$$\tau = \frac{250}{(.1819)(.375)}$$

$= 3665$ psi

$$3665 < \frac{31200}{SF}$$ ✓

$SF = 8.5$

User Manual: Beach Wheelchair Attachment

This user's manual incudes instructions for product use and important safety information. Read this manual completely including safety warnings before using the product.

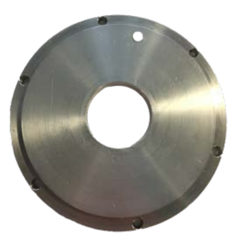
> Note: This manual is specified for wheelchairs with Quick-release axle rod wheel attachments. The user is assumed to know how to operate a Quick-release axle rod.

Overview of Parts

Figure 1 shows all parts that make up the Beach Wheelchair Attachment. This will act only as a guide for maintenance and repair to allow the user to become familiar with the attachment.

Quick-release axle rod

Bearing Spacer



Cap

Flanged End-Cap

Ratchet

Locking Spring Plunger

Pawl Pin

Key

Bearing

Figure 1. The full inventory of parts in the assembly

Figure 2 shows all the parts placed together in subassemblies. These subassemblies will be more applicable to what the user will be interacting with and repairing if necessary.

Assembled Double Wheels and Hub

Disassembled Double Wheels and Hub

Wheelblades™

Figure 2. The combined subassemblies that the user will be interacting with. The subassemblies are the front wheel assembly, the double wheel assembly, and the lever.

Assembling the Attachment

Warning: The user must be carefully supported in the wheelchair while attaching the double wheel assembly. If not properly supported the user could tip over. Only experienced users should attach wheels alone.

Warning: Both locking rotation pins must be disengaged during assembly.

As seen in Figure 2, the subassemblies include the double wheels, the front wheels, and the lever.

First, the user will detach their normal wheelchair wheels from the wheelchair. This will be done by using the quick-release mechanism to pull out the axle rod and release the wheels from the wheelchair. The user can then place their normal wheelchair wheels and axle rods aside for later reattachment.

Second, the user will grab the right double wheel assembly and one extended quick-release axle rod to place on the right side of the wheelchair, where the original wheelchair wheels were attached. The user will then place the extended quick-release axle rod through the hub of the double wheel and out the other side of the outer sleeve.

The user will then push down on the button of the extended quick-release axle rod in order to slide the double wheel into the axle of the wheelchair, just as is normally done on the user's regular wheelchair wheels.

Note: Check that the quick-release axle rod is fully engaged by moving the wheels towards and away from the wheelchair. If resistance is met, the Quick-release axle rod is in place.

Third, the user will repeat the second step for the left side of the wheelchair. After step 3, both double wheel assemblies should be attached.

Fourth, the user will place each lever into the designated hole located on the outer sleeve on each double wheel subassembly. The user will then screw in the levers tightly.

Note: It is easiest to attach the levers by rotating the lever holes to face upwards.

Fifth, the user will engage the forward locking spring plunger by pushing up then rotating the l-handle until it slides down the shaft of the locking rotation pin.

Caution: When changing direction with the locking rotation pins, be sure to disengage both locking rotation pins (the forward and backwards motion pins on one side of the wheelchair) before switching direction. When disassembling the beach wheelchair attachment, disengage both locking rotation pins.

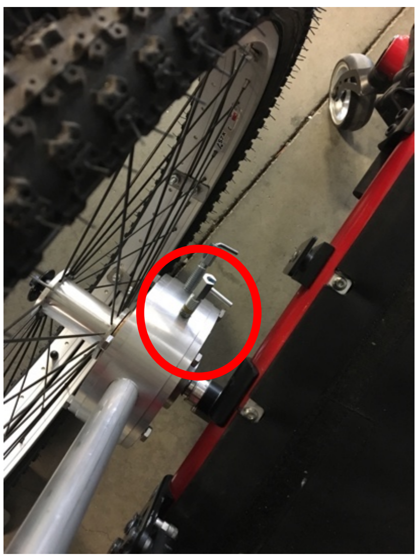
Sixth, the user, if not already near the sand, will then sit in the assembled wheelchair and move towards the beach. Once on the sand, the user will place the front wheel assembly directly in front of the front wheels. The user will then wheel forward into the front wheel assembly and tighten the stirrups around the front wheels.

Using the Attachment

Caution: When changing direction with the locking rotation pins, be sure to disengage both locking rotation pins (the forward and backwards motion pins on one side of the wheelchair) before switching direction. When disassembling the beach wheelchair attachment, disengage both locking rotation pins.

After the attachment is assembled and attached to the wheelchair you are able to move forward by first engaging the locking rotation pin for forward motion. By pushing both levers forward simultaneously and then pull them back to their upright position the user will move forward. This motion is repeated to continue forward motion.

For backwards motion, you first disengage the locking rotation pin for forward motion. Then engage the locking rotation pin for backwards motion on each wheel on the outer sleeves. Repeat the same simultaneous motion used to move forward.



To change directions, you have a few options.

Option 1. To turn right the user can keep both levers engaged for forward motion, but only push with the left lever. This will allow the user to slightly turn to the right while continuing to move forward the whole time.

Option 2. The user can also turn right by switching the right lever to engage in reverse and keeping the left lever engaged to move forward. At this point, pushing forward with the left lever and pulling back with the right lever will rotate the chair sharply to the right. The user would then have to switch the right lever back to engage in the forward direction before continuing to move.

Turning left can be accomplished in the exact same way by pushing only with the right lever, or by engaging the left lever in reverse and then pushing both levers in opposite directions

Trouble-shooting and Maintaining the Attachment

If the lever is stuck in one position or does not engage, then:

- Check the levers to make sure that they are both completely screwed in
- Check both locking spring plungers to ensure they are not both engaged at the same time

Warning: Do not engage both locking rotation pins at the same time on the same side. Doing so may cause damage to the beach wheelchair attachment. Only one locking rotation pin should be engaged at a time on each side.

- Check both locking spring plungers to ensure they are not both disengaged
- Look for debris in the wheels that might be blocking the wheels from moving
- If nothing is visibly blocking the device, the ratcheting hub can be disassembled to inspect for debris. See the next section for instructions to do this.

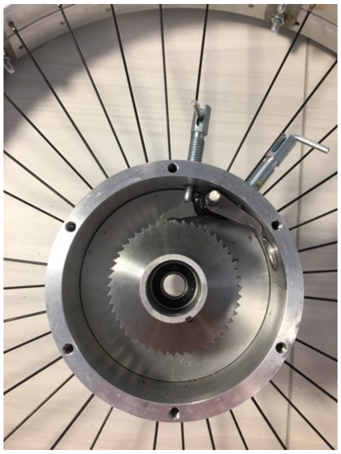
To inspect the hub:

Warning: The user must not sit in the wheelchair while inspecting the hub.

Caution: The ratchets inside the hub are sharp and can cause damage to hands if the user is not careful

- Remove the levers from the outer sleeves
- Remove the rear wheels from the wheelchair using the quick-release axle rod

- The hub will then be free from the chair to inspect
- Use an allen wrench (5/64**)** to unscrew the set screws from the flanged locking collar.
- Slowly and carefully remove the flange locking collar from the hub
- Remove the flanged bushing from the hub
- Remove the 6 screws from the inside cap of the hub and remove the cap



- Remove anything inside the device that may be blocking rotation
- Visually inspect the pawls to make sure they are undamaged
- Check to make sure the keyway and key stock are in place

<u>Replacing or repairing tires and tubes:</u>

If one or more of the tires develops a leak or goes flat, they can be changed in the same way as a bike tire. First, the wheel needs to be removed using the quick-release axle rod if it is still attached to the wheelchair, then both tubes should be deflated on the tire that needs to be repaired. Using bike tire levers, pry the tire over the rim and remove it. The tube can then be repaired or replaced. If you need more assistance on repairing a tire please refer to iFixit.

> **Note**: The outside edges of the tires must be taken off first to take off the inside edges from the rims. To place back on the rims, the inside edge of the tire must first be placed inside the rim.

Tightening Spokes and making tires true:

In order to make sure the wheels are moving straight; the spokes may need to be tightened or loosened. A spoke wrench is needed to adjust the spokes.

Safety Hazards:

Pinch Points

Pinch points are places and locations where hands can be injured from moving parts. The locations of all these pinch points are documented in figures below.

Tipping

Tipping can be caused by assembling the wheelchair improperly, turning too quickly in the chair, or turning while going at a high speed. If the double wheels are not correctly assembled (axle rod not in all the way, the double wheels attached with the lever on the outside rather than the inside), they can cause a hazard for tipping. Turning too sharply or at a high speed can abruptly change the moment and direction of speed that can lead to tipping. Tipping can also occur near strong ocean waves. The user must be cautious when near the ocean tide to be aware of the hazard of tipping.

Overuse

Users should be aware that while the device does decrease the amount of effort required to move, it can still be tiresome. Since the device can be tiresome we recommend that the user is aware of their capabilities and gradually become comfortable with the beach wheelchair attachment before traveling far distances on the beach.

Test Procedure: Length inspection

Length inspection only requires the measurement of the additional length acquired from the front wheel attachment.

Location and Equipment:

The test will be performed at a location with access to measuring equipment (the QL+ lab) after finalization of the front wheel attachment

The test will only require the use of a tape measure to determine the initial and final length measurement

Safety Procedures:

Minimal safety measures are required for using a tape measurer. Be aware of pinch points when retracting the tape measure.

Planned Data Collection and Documentation:

We will only need the initial length of the Aero Z Wheelchair in our possession and the final length after adding the front wheel attachment to determine the change in length.

The measurements will be added to our DVP to reach a conclusion about or design specifications. We will be minimizing the length added in order to keep the design as non-invasive as possible.

Tasks:

No list of tasks are required for this test.

Test Documentation:

Length of wheelchair without attachment [inches]	36
Length of wheelchair with attachment [inches]	40
Change in length measurement [inches]	4
Design Specification Change in length measurement [inches]	10

Test Procedure: Force Required on soft sand (final)

Location and Equipment:

The test will be performed at a nearby beach preferably with very find sand (Avila Beach will be used to maintain with our preliminary test data). The location for this test will be at the same location as the original data was taken.

The test will require the use of a crane scale and rope or paracord to attach the crane scale to the levers.

Safety Procedures:

User in chair must be cautious and aware of their feet while operating the wheelchair. User of the crane scale must be aware of over extending themselves in pulling the crane scale for testing.

Planned Data Collection and Documentation:

We will measure the force it takes to push the wheelchair with one lever swing over multiple swings. The data will be collected for several trials to find an average measurement.

The measurements will be calculated into torque measurements to compare to the preliminary test measurements. The final measurements will be added to our DVP.

Tasks:

1. Take the wheelchair to the beach
2. Attach the levers, double wheels, and outer sleeve to the wheelchair
3. Attach the front wheel assembly to the wheelchair
4. Tie rope or paracord around the top of the levers
5. Attach the crane scale to the rope or paracord
6. Have someone weighing approximately 130-150 lbs sit in wheelchair
7. Place another person in front and pull the crane scale until the levers are in the forwardmost position
8. A third person records the highest force measurement he sees on the crane scale
9. Repeat steps 7-8 for at least 5 pulls for 3 trials

Test Results

Trial 1	Force [lb_f]	Trial 2	Force [lb_f]	Trial 3	Force [lb_f]		
Pull 1	37.9	Pull 1	40.3	Pull 1	34.8		
Pull 2	41.6	Pull 2	30.1	Pull 2	38.3		
Pull 3	34.1	Pull 3	42.3	Pull 3	28.8		
Pull 4	43.1	Pull 4	42.1	Pull 4	29.2		
Pull 5	39.2	Pull 5	27.8	Pull 5	31.1		
Average	39.2	Average	36.5	Average	32.4	Total Average	36.0

Test Procedure: Force Required on hard sand (final)

Location and Equipment:

The test will be performed at a nearby beach with very fine sand (Avila Beach to maintain with our preliminary test data). The test will be preformed at the beach where the original testing was performed.

The test will require the use of a crane scale and rope or paracord to attach the crane scale to the levers.

Safety Procedures:

User in chair must be cautious and aware of their feet while operating the wheelchair. User operating the crane scale must be aware of over exerting themselves while taking measurements.

Planned Data Collection and Documentation:

We will measure the force it takes to push the wheelchair with one lever swing over multiple swings. The data will be collected for several trials to find an average measurement.

The measurements will be calculated into torque measurements to compare to the preliminary test measurements. The final measurements will be added to our DVP.

Tasks:

1. Take the wheelchair to the beach
2. Attach the levers, double wheels, and outer sleeve to the wheelchair
3. Attach the front wheel assembly to the wheelchair
4. Tie rope or paracord around the top of the levers
5. Attach the crane scale to the rope or paracord
6. Have someone weighing approximately 130-150 lbs sit in wheelchair
7. Place another person in front and pull the crane scale until the levers are in the forwardmost position
8. A third person records the highest force measurement he sees on the crane scale
9. Repeat steps 7-8 for at least 5 pulls for 3 trials

Trial 1	Force	Trial 2	Force	Trial 3	Force		
Pull 1	12.5	Pull 1	9.0	Pull 1	8.3		
Pull 2	12.7	Pull 2	8.8	Pull 2	11.2		
Pull 3	9.9	Pull 3	9.8	Pull 3	9.4		
Pull 4	9.0	Pull 4	7.7	Pull 4	10.7		
Pull 5	10.7	Pull 5	7.9	Pull 5	7.8		
Average	10.9	Average	8.6	Average	9.5	Total Average	9.7

Test Procedure: Force Required on hard sand-Distance

Location and Equipment:

The test will be performed at a nearby beach with very fine sand (Avila Beach to maintain with our preliminary test data). The test will be preformed at the beach where the original testing was performed.

The test will require the use of a crane scale and rope or paracord to attach the crane scale to the levers.

Safety Procedures:

User in chair must be cautious and aware of their feet while operating the wheelchair. User operating the crane scale must be aware of over exerting themselves while taking measurements.

Planned Data Collection and Documentation:

We will measure the distance the wheelchair travels with one lever swing over multiple swings. The data will be collected for several trials to find an average measurement.

The testing will include testing with the double wheels and with Wheelblades™ and testing with the double wheels without the Wheelblades™.

The final measurements will be added to our DVP.

Tasks:

1. Take the wheelchair to the beach
2. Attach the levers, double wheels, and outer sleeve to the wheelchair
3. Attach the front wheel assembly to the wheelchair
4. Have someone weighing approximately 130-150 lbs sit in wheelchair
5. Have them push the levers from the upright position to the lowest comfortable lever position forward
6. Measure the distance traveled and record
7. Repeat steps 5-6 for at least 3 pulls
8. Take off the Wheelblades™
9. Repeat Steps 4-6 for at least 3 pulls

Without Wheelblades™		With Wheelblades™		Difference Between Pulls [inches]
Trial 1	Distance [inches]	Trial 2	Distance [inches]	
Pull 1	61.5	Pull 1	55.2	6.3
Pull 2	62.0	Pull 2	54.8	7.2
Pull 3	67.7	Pull 3	59.2	8.5
Average	63.73	Average	56.4	7.33

Test Procedure: Time to Set Up

Location and Equipment:

The test will be performed at any open location (Avila Beach to maintain with our preliminary test data) preferably where previous testing has been located.

The test will require the use of a stopwatch or timer.

Safety Procedures:

User must be aware of pinch points while assembling wheelchair for the beach. User also must be aware of the surrounding area to ensure they do not endanger any people walking by.

Planned Data Collection and Documentation:

We will measure the amount of time it takes to add all attachments to the wheelchair to prepare the wheelchair for beach use. We will also measure time it takes to disassemble the beach attachments.

The measurements will be added to our DVP and analyzed to see where improvements can be made.

Tasks:

1. Take the wheelchair to a testing location
2. Start Timer
3. Attach the levers, double wheels, and outer sleeve to the wheelchair
4. Attach the front wheel assembly to the wheelchair
5. Stop Timer
6. Record set up time
7. Start Timer
8. Disassemble wheelchair
9. Stop Timer
10. Record take-down time
11. Repeat Steps 1-10 for at least 3 trials

Time to Set up [minutes]	
Trial 1	0:03:42
Trial 2	0:03:28
Trial 3	0:03:15
Average	0:03:28

Appendix K [K] Gantt Chart

Date 05-31-18

Task	%	Start	Due	Assigned
Problem Statement	100%	Start	Due	Assigned
Conduct customer interviews	100%	Sep 29, 2017	Oct 4, 2017	click to assign
Develop needs/wants list	100%	Oct 2, 2017	Oct 5, 2017	click to assign
Benchmark competitive designs	100%	Sep 29, 2017	Oct 4, 2017	click to assign
Research patents	100%	Oct 9, 2017	Oct 11, 2017	Abbey Scholle, Jackson Cole, Jackson Wiley
Research applicable industry codes/regulations	100%	Oct 9, 2017	Oct 11, 2017	Abbey Scholle
Task | Milestone | Group of Tasks				
Scope of Work	100%	Start	Due	Assigned
Introduction	100%	Oct 11, 2017	Oct 12, 2017	Abbey Scholle
Abstract	100%	Oct 11, 2017	Oct 12, 2017	Abbey Scholle
Background	100%	Oct 12, 2017	Oct 12, 2017	Abbey Scholle
Populate QFD	100%	Oct 6, 2017	Oct 11, 2017	Abbey Scholle
Project Management	100%	Oct 12, 2017	Oct 12, 2017	Jackson Cole
Table of deliverables	100%	Oct 9, 2017	Oct 9, 2017	Jackson Cole
Objectives	100%	Oct 12, 2017	Oct 12, 2017	Jackson Wiley
Specifications Table	100%	Oct 10, 2017	Oct 11, 2017	Jackson Wiley
Conclusion, References, Attachments	100%	Oct 12, 2017	Oct 12, 2017	Abbey Scholle, Jackson Cole, Jackson Wiley
Task | Milestone | Group of Tasks				
	0%	Start	Due	Assigned
Task | Milestone | Group of Tasks				
PDR Presentations	100%	Start	Due	Assigned
Ideation friday at noon	100%	Oct 19, 2017	Oct 20, 2017	Jackson Cole
ideation sunday	100%	Oct 22, 2017	Oct 23, 2017	Jackson Wiley
Ideation monday after 4pm	100%	Oct 23, 2017	Oct 23, 2017	Abbey Scholle
shopping list for concept model	100%	Oct 26, 2017	Oct 31, 2017	Abbey Scholle, Jackson Cole, Jackson Wiley
Build Concept Model	100%	Nov 2, 2017	Nov 7, 2017	Abbey Scholle, Jackson Cole, Jackson Wiley
Review Design	100%	Nov 10, 2017	Nov 13, 2017	click to assign
PDR Presentations	☑	Nov 14, 2017	Nov 14, 2017	click to assign
PDR Sponsor Presentation	100%	Nov 15, 2017	Nov 17, 2017	click to assign
Concept Design Development	100%	Nov 10, 2017	Nov 13, 2017	Abbey Scholle, Jackson Cole, Jackson Wiley
Apendices	100%	Nov 10, 2017	Nov 13, 2017	Abbey Scholle
Decision Matrices	100%	Oct 26, 2017	Oct 31, 2017	click to assign
List of Figures	100%	Nov 1, 2017	Nov 6, 2017	Jackson Wiley
List of Tables	100%	Nov 1, 2017	Nov 13, 2017	Abbey Scholle
Table of Contents	100%	Nov 1, 2017	Nov 6, 2017	Jackson Cole
power point presentation	100%	Nov 1, 2017	Nov 6, 2017	click to assign

▾ Edit Scope	100%	Start	Due	Assigned
Introduction	100%	Oct 27, 2017	Nov 13, 2017	Jackson Cole
Background	100%	Oct 27, 2017	Nov 13, 2017	Jackson Cole
Objectives	100%	Oct 27, 2017	Nov 13, 2017	Abbey Scholle
Project Management	100%	Oct 27, 2017	Nov 13, 2017	Jackson Wiley
Conclusion	100%	Oct 27, 2017	Nov 13, 2017	Jackson Cole
Task | Milestone | Group of Tasks				

▾ Further Research	100%	Start	Due	Assigned
CAD Model	100%	Nov 7, 2017	Nov 9, 2017	click to assign
Analysis on will it work	100%	Nov 7, 2017	Nov 13, 2017	click to assign
further research tire chains	100%	Nov 7, 2017	Nov 13, 2017	click to assign
further research track systems	100%	Nov 7, 2017	Nov 13, 2017	click to assign
further research, levers	100%	Nov 7, 2017	Nov 13, 2017	click to assign
Task | Milestone | Group of Tasks				

▾ CDR	100%	Start	Due	Assigned
CDR	☑	Feb 6, 2018	Feb 6, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
email about wheelblades	100%	Nov 28, 2017	Nov 30, 2017	Abbey Scholle
email about x wheels	100%	Nov 28, 2017	Nov 30, 2017	Abbey Scholle
find another retailer of x wheels	100%	Nov 30, 2017	Dec 6, 2017	Abbey Scholle, Jackson Cole
beach testing preliminary	100%	Dec 2, 2017	Dec 8, 2017	Abbey Scholle, Jackson Wiley
CAD model of wheelchair	100%	Dec 11, 2017	Dec 29, 2017	Abbey Scholle, Jackson Wiley
CAD model of product	100%	Dec 30, 2017	Jan 11, 2018	Abbey Scholle, Jackson Wiley
design of ratchet hub	100%	Dec 5, 2017	Dec 15, 2017	Jackson Cole, Jackson Wiley
analysis of ratchet hub	100%	Dec 25, 2017	Jan 12, 2018	Jackson Cole
pre-analysis of force on wheelchair	100%	Dec 1, 2017	Dec 13, 2017	Abbey Scholle
research on outsourcing	100%	Dec 11, 2017	Jan 6, 2018	Jackson Cole
calculations for length of axle	100%	Dec 22, 2017	Jan 12, 2018	Abbey Scholle
design and analysis of lever	100%	Dec 11, 2017	Jan 6, 2018	Jackson Wiley
part/material selection	100%	Jan 15, 2018	Jan 18, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
manufacture plan	100%	Jan 19, 2018	Jan 22, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
design verification plan	100%	Jan 19, 2018	Jan 22, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
build structural prototype	100%	Jan 16, 2018	Jan 22, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
planned testing of prototype	100%	Dec 11, 2017	Jan 24, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
beach testing prototype	100%	Jan 25, 2018	Feb 6, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
write CDR	100%	Jan 23, 2018	Jan 27, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
presentation for CDR	100%	Jan 29, 2018	Feb 2, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley
practice presentation of CDR	100%	Feb 3, 2018	Feb 6, 2018	Abbey Scholle, Jackson Cole, Jackson Wiley

Manufacturing	100%	Start	Due	Assigned
finalize measurements	100%	Feb 9, 2018	Feb 13, 2018	click to assign
order parts	100%	Feb 14, 2018	Feb 21, 2018	click to assign
purchase fasteners	100%	Feb 19, 2018	Feb 22, 2018	click to assign
manufacture brackets	100%	Feb 22, 2018	Feb 24, 2018	click to assign
Cyclonetics CNC parts	100%	Apr 2, 2018	Apr 11, 2018	click to assign
Mill outer sleeve	100%	Apr 12, 2018	Apr 21, 2018	click to assign
Shorten bushings	100%	Apr 9, 2018	Apr 21, 2018	click to assign
modify ratchet and pawls	100%	Apr 9, 2018	Apr 16, 2018	click to assign
assembly double wheels	100%	Apr 2, 2018	Apr 9, 2018	click to assign
assemble hub	100%	Apr 27, 2018	May 15, 2018	click to assign
assemble lever	100%	Apr 30, 2018	May 15, 2018	click to assign
assemble front wheel attachment	100%	Apr 23, 2018	Apr 28, 2018	click to assign

Task | Milestone | Group of Tasks

Testing	100%	Start	Due	Assigned
Test on grass	100%	May 19, 2018	May 25, 2018	click to assign
Force test on soft sand	100%	May 19, 2018	May 25, 2018	click to assign
Force test on hard sand	100%	May 19, 2018	May 25, 2018	click to assign
Distance test on soft sand	100%	May 19, 2018	May 25, 2018	click to assign

Task | Milestone | Group of Tasks

Hazard Mitigation	100%	Start	Due	Assigned
excessive force from user	100%	May 19, 2018	May 25, 2018	Abbey Scholle
crushing risk for user	100%	May 19, 2018	May 25, 2018	Abbey Scholle
pinch points for user	100%	May 19, 2018	May 25, 2018	Jackson Wiley
instability for user	100%	May 19, 2018	May 25, 2018	Jackson Wiley
misuse for user	100%	May 19, 2018	May 25, 2018	Jackson Wiley
excessive force for user	100%	May 19, 2018	May 25, 2018	Jackson Cole
duration for user	100%	May 19, 2018	May 25, 2018	Jackson Cole
tipping over for user	100%	May 19, 2018	May 25, 2018	Jackson Cole
pinch point for user	100%	May 19, 2018	May 25, 2018	Jackson Cole
entanglment of clothing or hair for user	100%	May 19, 2018	May 25, 2018	Jackson Cole
tripping for passerby	100%	May 19, 2018	May 25, 2018	Jackson Cole

Task | Milestone | Group of Tasks

designsafe Report

Application: Beach Wheelchair Team
Description:
Product Identifier:
Assessment Type: Detailed
Limits:
Sources:
Risk Scoring System: ANSI B11.0 (TR3) Two Factor

Analyst Name(s): Jackson Cole, Abbey Scholle, Jackson Wiley
Company: QL+
Facility Location:

Guide sentence: When doing [task], the [user] could be injured by the [hazard] due to the [failure mode].

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	operator normal operation	ergonomics / human factors : excessive force / exertion	Minor Likely	Low	other warning, instruction manuals	Minor Unlikely	Negligible	TBD [5/10/2018] Jackson Cole
1-1-2	operator normal operation	ergonomics / human factors : posture	Serious Remote	Low	other warning, instruction manuals	Serious Remote	Low	TBD [5/10/2018] Abbey Scholle
1-1-3	operator normal operation	ergonomics / human factors : repetition	Moderate Likely	Medium	instruction manuals	Moderate Unlikely	Low	TBD [5/10/2018] Jackson Wiley
1-1-4	operator normal operation	ergonomics / human factors : duration	Minor Likely	Low	instruction manuals	Minor Unlikely	Negligible	TBD [5/10/2018] Jackson Cole
1-1-5	operator normal operation	noise / vibration : equipment damage	Serious Remote	Low	fixed enclosures / barriers	Serious Remote	Low	TBD [5/10/2018] Abbey Scholle
1-1-6	operator normal operation	mechanical : pinch point	Moderate Unlikely	Low	warning label(s), instruction manuals	Moderate Remote	Negligible	TBD [5/10/2018] Jackson Wiley
1-2-1	operator basic trouble shooting / problem solving	slips / trips / falls : tip over	Serious Remote	Low	warning label(s)	Serious Remote	Low	TBD [5/10/2018] Jackson Cole

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-2-2	operator basic trouble shooting / problem solving	ergonomics / human factors : excessive force / exertion	Minor Unlikely	Negligible		Minor Remote	Negligible	TBD [5/10/2018] Abbey Scholle
1-2-3	operator basic trouble shooting / problem solving	material handling : instability	Moderate Unlikely	Low	instruction manuals	Moderate Remote	Negligible	TBD [5/10/2018] Jackson Wiley
1-3-1	operator misuse	mechanical : pinch point Improper hand placement	Moderate Unlikely	Low	warning label(s), instruction manuals	Moderate Remote	Negligible	TBD [5/10/2018] Jackson Cole
1-3-2	operator misuse	mechanical : crushing Improper hand placement	Serious Unlikely	Medium	warning label(s), instruction manuals	Serious Remote	Low	TBD [5/10/2018] Abbey Scholle
1-3-3	operator misuse	mechanical : drawing-in / trapping / entanglement Loose clothing or hair	Serious Unlikely	Medium	warning label(s), instruction manuals	Serious Remote	Low	TBD [5/10/2018] Jackson Wiley
2-1-1	team members set-up or changeover	ergonomics / human factors : lifting / bending / twisting	Moderate Unlikely	Low	instruction manuals	Moderate Remote	Negligible	TBD [5/10/2018] Jackson Cole
2-1-2	team members set-up or changeover	material handling : instability	Moderate Remote	Negligible		Moderate Remote	Negligible	TBD [5/10/2018] Abbey Scholle
2-1-3	team members set-up or changeover	material handling : excessive weight	Minor Unlikely	Negligible		Minor Remote	Negligible	TBD [5/10/2018] Jackson Wiley
2-1-4	team members set-up or changeover	mechanical : pinch point	Moderate Likely	Medium	warning label(s), instruction manuals	Moderate Unlikely	Low	TBD [5/10/2018] Jackson Cole

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-2-1	team members parts replacement	ergonomics / human factors : excessive force / exertion	Minor Unlikely	Negligible		Minor Remote	Negligible	TBD [5/10/2018] Abbey Scholle
2-2-2	team members parts replacement	ergonomics / human factors : lifting / bending / twisting	Minor Unlikely	Negligible		Minor Remote	Negligible	TBD [5/10/2018] Jackson Wiley
2-2-3	team members parts replacement	material handling : instability	Moderate Remote	Negligible		Moderate Remote	Negligible	TBD [5/10/2018] Jackson Cole
2-2-4	team members parts replacement	mechanical : pinch point	Moderate Unlikely	Low	warning label(s), instruction manuals	Moderate Remote	Negligible	TBD [5/10/2018] Abbey Scholle
2-2-5	team members parts replacement	mechanical : crushing	Serious Unlikely	Medium	warning label(s), instruction manuals	Serious Remote	Low	TBD [5/10/2018] Jackson Wiley
3-1-1	passer by / non-user walk near machinery	slips / trips / falls : trip	Serious Unlikely	Medium		Serious Remote	Low	TBD [5/10/2018] Jackson Cole
3-1-2	passer by / non-user walk near machinery	mechanical : pinch point	Moderate Unlikely	Low	warning label(s), instruction manuals	Moderate Remote	Negligible	TBD [5/10/2018] Abbey Scholle
3-1-3	passer by / non-user walk near machinery	mechanical : crushing	Serious Unlikely	Medium	instruction manuals	Serious Remote	Low	TBD [5/10/2018] Jackson Wiley

Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

												Action Results			
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality
front wheels/not getting stuck	chair gets stuck/sinks	chair gets stuck	8	1) too narrow 2) too rough	1) large surface area 2) smooth surfaces	2	take to the beach	2	32						
front wheels/hold user weight	wheels break	chair falls forward	9	1) uneven 2) too thin	1) keep original wheels	1	take to the beach stress test	1	9						
	wheels bend	chair unstable	6	1) uneven 2) too thin	1) keep original wheels	2	take to the beach	3	36						
	wheels crack	chair stuck	8	1) uneven 2) too thin	1) keep original wheels	1	take to the beach	3	24						
front wheels/reduce effort	gets stuck	increases effort	7	1) too rough 2) too rigid	1) large surface area 2) smooth surfaces	2	take to the beach	1	14						
	gets stuck	effort so high=stuck	8	1) too rough 2) too rigid	1) large surface area 2) smooth surfaces	2	take to the beach	1	16						
	user too tired	doesn't reduce effort	6	1) too rough 2) too rigid 3) too thin	1) large surface area 2) smooth surfaces	2	take to the beach	4	48						
back wheels/not getting stuck	chair sinks	gets stuck	8	1) too thin 2) too slick 3) too heavy	1) large surface area 2) gripped surfaces	2	take to the beach	1	16						
	effort not working	gets stuck	8	1) too thin 2) too slick 3) too heavy	1) large surface area 2) gripped surfaces	2	take to the beach	2	32						
	too much effort	gets stuck	8	1) too thin 2) too slick 3) too heavy	1) large surface area 2) gripped surfaces	2	take to the beach	3	48						
back wheels/hold user weight	wheels break	sharp edges, getting stuck	9	1) too thin 2) too weak	1) large surface area 2) stress analysis	1	take to the beach stress test	1	9						
	wheels bend	gets stuck, unstable	8	1) too thin 2) too weak	1) large surface area 2) stress analysis	2	take to the beach	3	48						

Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Action Results: Actions Taken	Action Results: Severity	Action Results: Occurence	Action Results: Criticality
back wheels/reduce effort	chair sinks	gets stuck	8	1) too thin 2) too heavy	1) large surface area 2) stress analysis	2	take to the beach	2	32						
hub lever system/not getting stuck	doesn't provide forward momentum	gets stuck	8	1) teeth too thin 2) lever too weak 3) too much friction	1) sealed effectively 2) stress analysis	5	take to the beach	1	40						
	cant move different directions	tips over	9	1) cable too weak 2) teeth too thin 3) ratchet not sealed	1) sealed effectively 2) stress analysis	5	take to the beach	1	45						
hub lever system/ reduce effort	doesn't provide mechanical advantage	too much effort	6	1) lever too weak 2) teeth to thin 3) bearings too much friction	1) sealed effectively 2) stress analysis	5	take to the beach	4	120	design for sealed system with easy disassembly					
axle system/hold users weight	breaks	chair collapses, user injured	9	1) too thin 2) too weak	1) stress analysis	1	take to the beach stress test	1	9						
	bends	chair unstable	6	1) too thin 2) too weak	1) stress analysis	2	take to the beach	3	36						
	cracks	chair unstable	6	1) too thin 2) too weak	1) stress analysis	1	take to the beach	3	18						
general / maintain appearance	surface gets damaged	doesn't look good	3	1) too fragile 2) too corosive	1) material analysis	4	take to the beach	4	48						

Design Failure Mode and Effects Analysis

Product: ______________________________ Prepared by: ______________________________

Team: ______________________________ Date: ________________ (orig)

												Action Results			
System / Function	Potential Failure Mode	Potential Effects of the Failure Mode	Severity	Potential Causes of the Failure Mode	Current Preventative Activities	Occurence	Current Detection Activities	Detection	Priority	Recommended Action(s)	Responsibility & Target Completion Date	Actions Taken	Severity	Occurence	Criticality

Appendix J: Design Hazard Checklist	Sheet No. J– 1/2	Date 02-9-18

DESIGN HAZARD CHECKLIST

Team: Beach Wheelchair Team Advisor: Sarah Harding Date: 11/9/17

Y	N	
☑	☑	1. Will the system include hazardous revolving, running, rolling, or mixing actions?
☐	☑	2. Will the system include hazardous reciprocating, shearing, punching, pressing, squeezing, drawing, or cutting actions?
☐	☑	3. Will any part of the design undergo high accelerations/decelerations?
☐	☑	4. Will the system have any large (>5 kg) moving masses or large (>250 N) forces?
☐	☑	5. Could the system produce a projectile?
☐	☑	6. Could the system fall (due to gravity), creating injury?
☐	☑	7. Will a user be exposed to overhanging weights as part of the design?
☑	☐	8. Will the system have any burrs, sharp edges, shear points, or pinch points?
☐	☑	9. Will any part of the electrical systems not be grounded?
☐	☑	10. Will there be any large batteries (over 30 V)?
☐	☑	11. Will there be any exposed electrical connections in the system (over 40 V)?
☐	☑	12. Will there be any stored energy in the system such as flywheels, hanging weights or pressurized fluids/gases?
☐	☑	13. Will there be any explosive or flammable liquids, gases, or small particle fuel as part of the system?
☐	☑	14. Will the user be required to exert any abnormal effort or experience any abnormal physical posture during the use of the design?
☐	☑	15. Will there be any materials known to be hazardous to humans involved in either the design or its manufacturing?
☐	☑	16. Could the system generate high levels (>90 dBA) of noise?
☑	☐	17. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, or cold/high temperatures, during normal use?
☐	☑	18. Is it possible for the system to be used in an unsafe manner?
☐	☐	19. For powered systems, is there an emergency stop button?
☐	☑	20. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Appendix J: Design Hazard Checklist	Sheet No.	J– 2/2	Date 02-9-18
Description of Hazard	**Planned Corrective Action**	**Planned Date**	**Actual Date**
Pinch points for assemble or disassemble	Inform the user and minimize the number of pinch points	11/28	06/01/18
Exposed to salt water and sand	Use environmentally resistant material that does not degrade	11/28	06/01/18