IMPROVED PEDDLER FOR THE ANN ARBOR VETERANS AFFAIRS HEALTHCARE SYSTEM

Project 25

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Final Report

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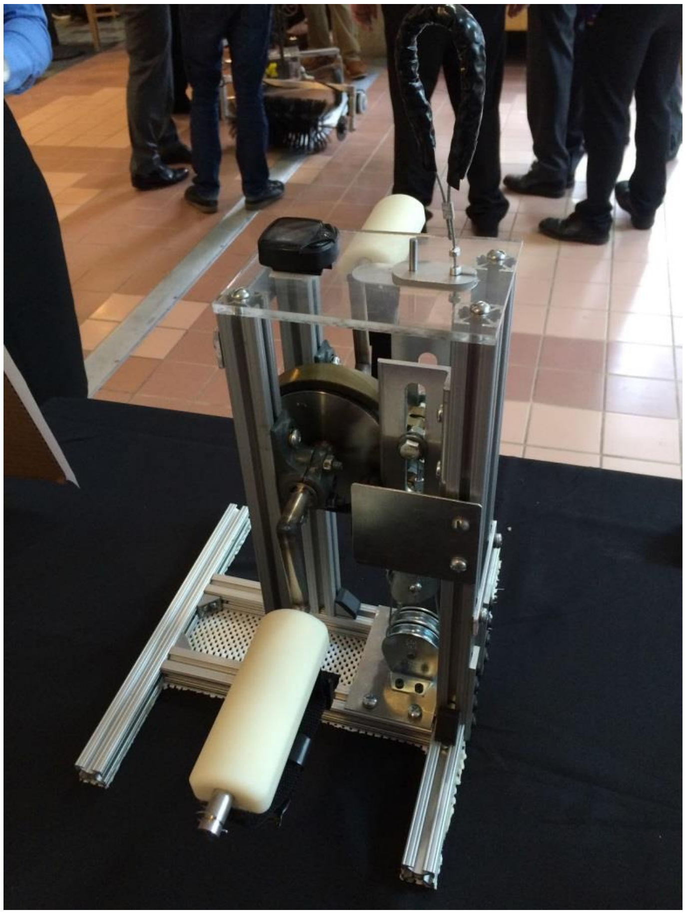

EXECUTIVE SUMMARY

The Ann Arbor Veterans Association (AAVA) has a Home Based Cardiovascular Rehabilitation (HBCR) program for patients who have experienced a significant cardiac event and live in areas far from the AAVA. A peddler sent home with veterans for this program has been identified as displeasing and uncomfortable to use; we have been tasked in redesigning the machine to fit the needs of healthcare professionals and alleviate the complaints expressed by users. The areas we have determined that need redesign are: application of pedaling resistance, pedal design, a time and distance display, and anchoring of the peddler during use - all while maintaining the ability to pedal with hands or feet and a relatively compact and lightweight peddler that will be portable for veterans of all ages. The concepts we have chosen to meet these needs are a band brake to apply resistance to a rotor, larger pedals, a bike computer, and increased coefficient of friction between the peddler and the surface.

Our final design incorporates these chosen concepts into a complete peddler which meets the key specifications. The pedal bar is similar to the original peddler, but with a rotor in the center which the band brake clamps around. The band brake is tightened by pulling up on a cable extruding from the top of the peddler; the cable is connected to the band brake through a system of pulleys which cut the required force needed to tighten the band brake by three quarters. The cable is held in place by a sliding aluminum door on the top panel of the peddler which closes beneath cable stoppers to create different resistance levels. The pedals are wider than the original peddler, incorporate a curved bottom for increased comfort when pedaling with hands, and utilize a sliding buckle strap for increased adjustability. We purchased a wireless bike computer which is placed on top of the peddler and receives information from a sensor placed next to the rotor, which picks up the rotation of a small magnet mounted in the rotor. This allows the bike computer to give a readout of speed and distance. In addition to the increased weight of our redesigned peddler, the frictional force between the peddler and the surface has been significantly increased through the addition of a vinyl mat to the bottom of the frame. The frame has been constructed primarily using angle brackets and square, t-slotted aluminum extrusions for ease of manufacturing, assembly, and adjustability.

After manufacturing, assembling, and doing some preliminary testing with our prototype we have developed some critiques to be implemented in future design iterations. These include using smaller pulleys to decrease the total weight and height of the peddler, adding more resistance settings, decreasing the weight of the rotor by removing material from the interior, changing the assembly of the pedal bar to eliminate the need for split bearings and decrease manufacturing costs from welding, improving upon the attachment of the pedal straps to the pedals, and building a housing around all of the moving parts to remove safety concerns. The peddler should also be tested by veterans for validation of the existing design changes through feedback on comfort, ease of use, likelihood to use as part of an exercise regimen, and overall comparative preference.

CONTENTS

PROBLEM DESCRIPTION AND BACKGROUND

Sponsor Background

The Ann Arbor Veterans Affairs Healthcare System (AAVA) provides healthcare services to United States of America veterans. It serves more than 65,000 veterans in a 15-county area of Michigan and Northwest Ohio. The main hospital campus is located in Ann Arbor, and there are community-based outpatient clinics in Toledo, OH and Jackson and Flint, MI [1]. The Veterans Health Administration (VHA) is the largest administration within the U.S. Department of Veterans Affairs. The VHA was created in its initial form during the Civil War and operates one of the largest healthcare systems in the world [2]. Together the VHA and AAVA work to provide state-of-the-art healthcare services and innovative in their work to meet veterans' changing needs.

Cardiovascular Disease & Exercise

Cardiovascular disease is recognized as the number one killer of Veterans in the United States of America [3], and is an identified priority condition targeted for improvement by the VHA [4]. Studies show that veterans are at nearly two times higher risk of having a new onset of heart disease compared with non-veterans [5]. The two most common types of cardiovascular disease in Veterans are Hypertension and Arteriosclerosis [6] and it has been observed that exercise lowers risks of death for those with cardiovascular disease [7]. There are two different forms of exercise: anaerobic and aerobic. Anaerobic fitness includes tasks that use energy without the use of oxygen. Anaerobic exercises are typically performed in quick, high intensity bursts lasting for short periods of time, for example, weight lifting and sprints [8]. Aerobic fitness, on the other hand, includes tasks that use oxygen to supply energy. Aerobic exercises are usually repetitive, low movement exercises that last for long periods of time, for example, walking, swimming, or cycling [8]. Since aerobic exercises use oxygen, it puts the lungs and cardiovascular system to use and helps strengthen the heart muscle [8]. Therefore, aerobic exercise is very important to help the cardiovascular system and improve cardiovascular conditions. In order for the aerobic exercises to be effective in improving cardiovascular health and Lipoprotein changes, it is recommended that one performs an aerobic exercise maintaining 40-49% of the maximum heart rate for 20 continuous minutes, 3-5 times per week for 12 weeks [9].

Cardiac Rehabilitation Programs

Cardiac Rehabilitation (CR) is a multidisciplinary program of therapy for patients with specific cardiovascular diagnoses, and due to its success in improving both morbidity and mortality from cardiac causes is a recommended program by the American Heart Association/American College of Cardiology guidelines [4]. Currently, approximately only one quarter of the USA VA facilities offer a CR program, and less than 10% of eligible veterans receive CR [4]. The main reason why so few veterans receive this aid is because of transportation difficulties and/or geographic barriers. The VA Ann Arbor Healthcare System (AAVA) has established a Home-Based Cardiac Rehabilitation Program (HBCR) in order to reach rural veterans who are eligible for CR support [4]. Patients must have a pre-existing cardiovascular disease to qualify for this program, which lasts 12 weeks (enough time for lipoprotein changes) [10]. The program begins with an in person meeting at the AAVA to meet with a nurse to establish the starting point and distribute components, followed by weekly phone calls between the patient and nurse to track progress. Veterans are sent home after their introduction meeting with a package including a peddler (Fig.

1), pedometer, resistance bands, automated blood pressure cuff, and an electronic scale. The nurse will also follow up after six months, and the patient will come in to the AAVA for an "exit" meeting after 12 months [11].

Figure 1: Current peddler used by the AAVA in the HBCR program

Problems and Stakeholder Complaints

Patients and nurses have complained about the current peddler and its functionality. Because of this dissatisfaction, we have been tasked with redesigning the current peddler to address patient and nurse needs and desires. The patients complain about the peddler sliding across the surface it is sitting on while they are peddling and they have expressed a desire to have some sort of measurement device on the peddler to track the time or distance of their workout [4]. Patients have complained that the adjustable resistance is not reliable and the nurses would appreciate a way to quantify how much resistance each patient is using. The foot strap on the current peddler only has two settings and is not very adjustable; some patients with larger shoes or swollen feet resulting from their cardiovascular disease have trouble operating the peddler with their feet because they do not fit [10]. Veterans have also complained about knee and hip pain caused by the peddler and have given feedback that sometimes the device does not feel fluid in its revolutions [4].

Benchmarks

There are multiple benchmark products that attempt to solve some of these problems. Drive Medical is a company that manufactures and distributes medical equipment and has a few options for portable exercise peddlers. Drive Medical offers a foldable exercise peddler with an electronic display (Fig. 2, p. 6)) which reports time, revolution count, revolutions per minute, and calories burned [12]. This peddler solves the complaints about wanting a way to measure time or distance.

Figure 2: Drive Medical folding exercise peddler with electronic display [12]

Another peddler offered by Drive Medical has a detachable handle that can be used to stabilize the user while he or she is pedaling with their feet (Fig. 3) [12]. The addition of the handle might make the peddler more comfortable for the user and can help prevent some knee and hip discomfort.

Figure 3: Drive Medical exercise peddler with handle [12]

Carex is another health care brand that supplies medical equipment. They offer three different types of pedal exercisers and one of these includes a digital display (Fig. 4) which reports time, repetitions, and calories burned [13].

Figure 4: Carex pedal exerciser with digital display [13]

Walmart provides a $20 folding cycle with a monitor from Gold's Gym that tells the user the time duration of their workout (Fig. 5) [14].

Figure 5: Gold's Gym folding cycle with monitor [14]

All of these peddlers address a lot of the complaints about measuring time or distance of the workout but they still lack highly adjustable pedals and a measurable resistance knob. All of the benchmark products have pedals and tension adjustments similar to the currently used HBCR peddler which needs to be modified to fit our patients' needs.

USER REQUIREMENTS AND ENGINEERING SPECIFICATIONS

After speaking with workers at the Ann Arbor Veterans Affairs Hospital, we were able to determine what exactly our sponsors are expecting to see in the final peddler. One of the key requirements to improve the design of the peddler is to prevent the peddler from sliding in the horizontal direction during use. The current peddler is not anchored to the surface being peddled on while in use, so many patients have to place it against a wall in order to be able to effectively use the machine, making them less inclined to use the peddler [11]. In order to prevent the mechanism from slipping, we must increase the coefficient of friction of the bottom surface where the peddler comes in contact with the floor. A second requirement provided by the sponsors is for the straps to be more adjustable to accommodate the variety of foot and shoe sizes of the patients [15]. The veterans all have different shoe sizes and types that they use while on the peddler and there aren't many options for adjusting the straps so they fit comfortably around each individual shoe. We are to maximize the range of allowable shoe sizes to allow as many different shoe sizes as possible.

The peddler is for at home use, so the sponsors are looking to have the machine be compact and lightweight so that the Veterans at home can easily move the peddler and it doesn't get in the way or collect too much clutter [10]. Therefore, we are looking to minimize the volume and the weight of the new peddler. The sponsors stated that they like the size and weight of the current peddler, so we are aiming to keep the new model within similar dimensions. Our goal is to have the volume be no larger than 4608 in^3 (16" wide, 24" long, 12" tall) which is the approximate volumetric space that the current peddler occupies; we aim to keep peddler weight no more than 10lbs, which is 2.3lbs more than the current weight and was chosen to be heavier to help keep the machine anchored on the ground.

The nurses working with the patients of the HBCR program have found that it can be difficult to program specific exercises for the patients because there is no way to track the resistance of the peddler or the distance and time traveled [10]. While they are looking to track these, they also do not want the machine to get over-complicated because they claim too many readouts will overwhelm the users and may also result in decreased usage [11]. In order to solve these issues, we are hoping to have 10 equally spaced numerical resistance settings, a digital output read of time (with resolution of 1 second) and distance (with resolution 0.1 mile) with a maximum of 4 user control buttons. We've determined having 10 resistance settings and 4 control buttons clearly labeled, as well as displaying only time and distance, is enough information to help the nurse and the user, but doesn't have too much information that it will overwhelm the operator.

Another part of the current peddler that the sponsor has praised is that it can be used as both a hand and a foot peddler. Since it allows for movement in both areas, it gives the patient a choice for what form of exercise they would like to do. With their current satisfaction of the peddler having 2 functions, we are aiming for the improved peddler to have 2 possible exercises as well.

The HBCR program provides patients with five different components under a $100 budget per veteran. The VA hospital is requesting that we are able to fit the peddler in their $100 per-patient limit and we have established a target value of $30 for the total cost of the improved peddler. After paying for the peddler, nurses at the VA have noticed that many veterans choose not to use it because it is uncomfortable and they get frustrated while using the machine. We are looking to improve comfort and minimize frustration for the veterans while using the peddler so that the veterans feel more motivated to use the machine and work to improve their health. We are aiming for veterans to achieve a 1 on a 1 (low) to 10 (high) scale of frustration and a 10 on a 1 (minimum) to 10 (maximum) scale of comfort. To ensure safety, edges shouldn't have sharp edges and there should be no exposed pinch points on the machine.

The final request that the sponsors suggested is to minimize the time of assembly. This component is more of a want than a need because the nurses are the ones that assemble the peddler for the veterans. We are aiming for the peddler to take no more than 15 minutes for the initial assembly time. The nurses need to be able to store multiple peddlers in their small storage closet, therefore, we figured to minimize the storage space we could have the peddler broken up into multiple pieces and would require assembly. Nurses are busy, and we do not want them to take too much time to assemble the peddler; therefore, we've determined that fifteen minutes is an appropriate assembly time.

Table 1 (p. 9) shows each user requirement and the corresponding engineering specification. Requirements have been prioritized; a higher number indicating a higher priority.

Table 1: User Requirements and Engineering Specifications by Priority

System	User Requirements	Engineering Specification	Priority	Source
Safety	Ensure that device is safe for veterans	Edges and corners have a fillet with radius > 0.125”	5	Sponsor
Function	Time of workout	Digital output of time including hours, minutes and seconds	4	Sponsor
		Start, stop and pause buttons to record time of workout		
	Able to use hands and feet	Dual purpose pedaling mechanism	5	Sponsor
	Measurable resistance	Qualitative/relative adjustable resistance measurement between 1-10	4	Sponsor
	Doesn't slide on surface when in use	Force of friction > horizontal force exerted by user	5	Sponsor
	Distance	Digital output of distance traveled to the .1 mi (or equivalent km)	3	Sponsor
		Reset button to reset distance traveled	3	
	Easy to use	A new user is able to use within 5 minutes with minimal instruction	3	Sponsor
	Easy setup	Initial assembly takes less than 15 minutes for a nurse or patient	2	Sponsor
Price	Low Price	Fits in $100 budget for HBCR package	5	Sponsor
Dimensions	Compact/small size (doesn't get in the way)	Max size = 16" Wide, 24" Long, 12" Tall	2	Sponsor
	Lightweight	Max weight = 10 lb	3	Sponsor
Ergonomics	Adjustable pedal straps	Fit various shoe types (width and height): Precise values to come	3	Sponsor
	Comfortable to use (including pedal/handle)	User able to maintain constant frequency of rotation at all resistance levels	3	Sponsor
		User able to use hands or feet with scale of comfort greater than 7 on a 1-to-10 scale (10 being most comfortable)	3	Sponsor

CONCEPT GENERATION

To develop the best form for our mechanism, a lot of brainstorming had to take place. We began by creating a functional decomposition (Fig. 6) in which we determined that the main purpose of our mechanism is to provide aerobic exercise for the user. To effectively provide aerobic exercise, the peddler needs to support the components, facilitate motion, preserve safety, promote comfort, and display feedback. We then broke each of these functions down into more specific sub-functions within each category.

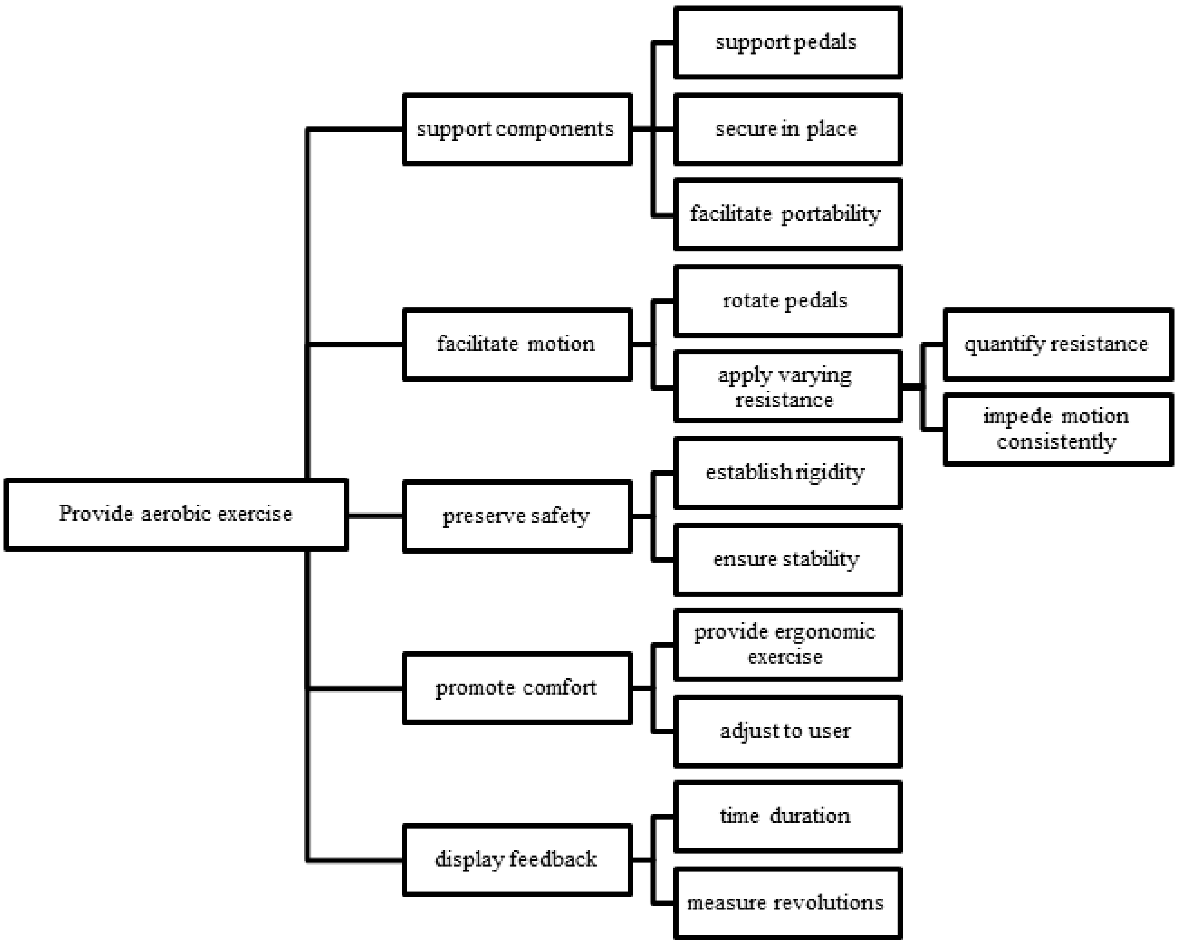

Figure 6: Functional Decomposition Chart

Once we had specific categories, we split up to work on our designs on our own. We all used different methods for our concepts, which included brainstorming, brain drawing (similar to doodling), and using creativity cards. After we all came up with our own separate ideas, we met up and shared our ideas, which helped us generate more ideas through combining concepts and working off of different designs.

To support the components of the peddler we need to create a frame. The purpose of the frame is to support the pedals, secure the mechanism in place, and facilitate portability. We generated different frame concepts (Appendix A, Fig. A1-A13) by brainstorming different ways that lightweight objects are held in place and by researching effective features in other peddler frames

[12,13,14]. One idea we generated for the frame style was a hinged A-frame (Fig. A13) to allow for easy storage, portability, and adjustable height. An encased solid unit with a solid base (Fig. A1) was another design we used to increase contact friction and secure the mechanism while giving a lot of room inside for resistance components. Another idea we brainstormed was to have a bar frame with a solid rectangular base (Fig. 7), similar to the already designed peddler in allowing for portability, but also improving contact friction. We also developed the idea for a notched base (Fig. 8) with an adjustable hinged frame that would keep the mechanism in place and allow for variable heights.

Anchoring is a key component to make the frame successful and secure it in place. Along with the notched base and increasing contact friction, we also thought of using suction cups (Appendix A, Fig. A8 and A9) or having an attached wedged stopper and/or having a separate friction pad to put underneath the mechanism to help anchor the peddler.

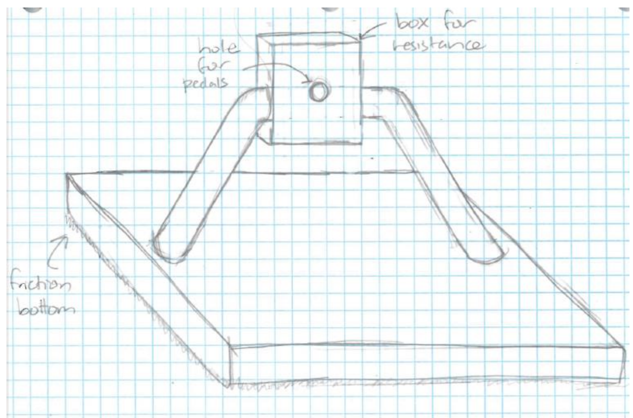

Figure 7: Bar frame with solid rectangular base

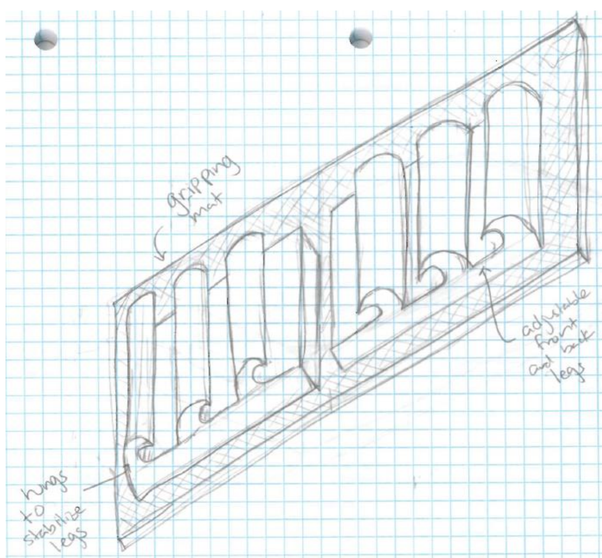

Figure 8: Notched base allowing for security and adjustability

To facilitate motion, the mechanism shall have rotating pedals and be able to apply varying resistance that can be quantified and impede motion consistently. We explored how different stationary bikes apply resistance, which helped us generate numerous ways that we may be able to use resistance on our peddler (Appendix A, Fig. A24-A28). Many stationary bikes we've researched as benchmark designs use a fan with air as their form of resistance, so we sketched that as one possibility (Fig. A24). Contact resistance is another common form used, so we thought that we could use a rotating disk with one single large brake pad (Fig. A26) that will come in contact with the disk to increase the resistance. We expanded on that idea and thought that we could also use contact resistance with multiple brake pads coming in contact with the disk at different locations to decrease/increase the resistance and allow for variability (Fig. 9). Using magnets is another way to quantify resistance, where moving the magnets closer to the disk allowing for higher resistance. Along with resistance, another important component of ensuring motion is the pedals. We based our new designs for the pedals off the already existing design and bike riding experiences. We thought that one pedal option is to use a bike pedal (Fig. A16) while another is to use a bike pedal top with a round handlebar bottom to allow for comfortable hand placement (Fig. 10).

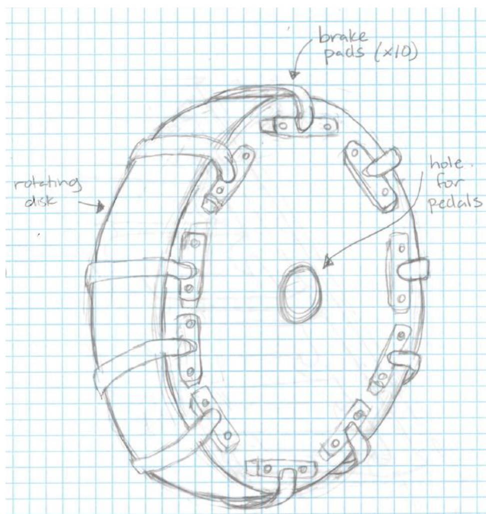

Figure 9: Disk with multiple contact resistance pads

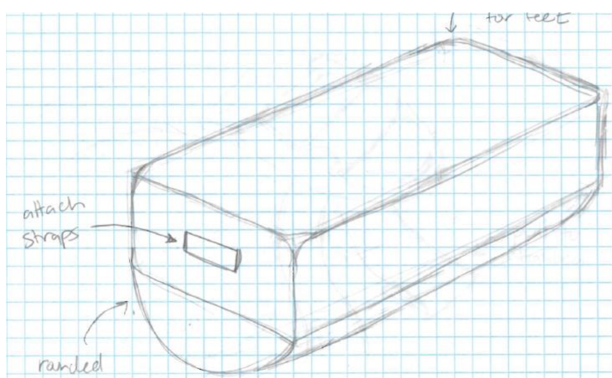

Figure 10: Pedal with flat top for feet and rounded bottom for hands

The peddler must be made as comfortable as possible to encourage veterans to use the mechanism and help improve their aerobic exercise. Two key ways to promote comfort in the design is to allow the mechanism to be adjustable for each patient and provide ergonomic exercise. One of the main components for adjustability is in the pedal straps. Everyday shoes are very adjustable to fit the different widths of people, thus, we examined different closure components of shoes to generate some ideas for our straps (Appendix A, Fig. A14-A23). Three ways that we thought we could secure the feet in place are with shoelaces, Velcro (Fig. A22), or an adjustable buckle strap (Fig. 11).

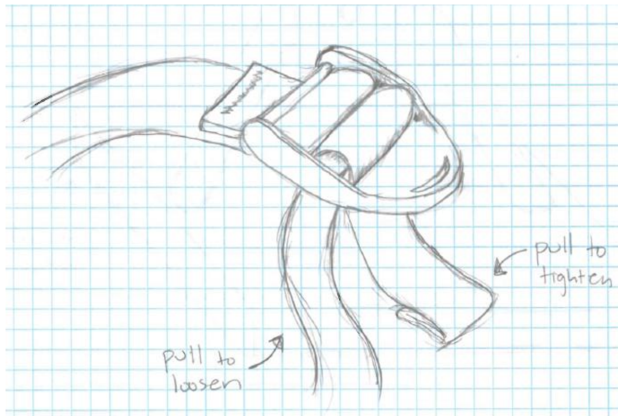

Figure 11: Adjustable pedal straps

One of the biggest complaints that veterans express is that they cannot determine how much resistance is being applied, how far they are going, or how long they have been peddling for; thus it is very important for this new model to be able to display feedback. The resistance feedback display should be incorporated with our resistance mechanism, and the time and distance by showing and calculating time of use and measuring the number of revolutions to output the distance moved. Within our concepts, we discovered that we could either display the distance in analog and the time digitally (Fig. A32), or have them both displayed digitally (Fig. A30-A31). In order to power the mechanism, we figured we can either have the peddler supply the power through its own kinetic energy, or it can be battery powered.

INITIAL CONCEPT SELECTION

We used Pugh charts to determine with which concepts to move forward. The concepts that we generated were not complete peddler solutions but rather individual component concepts. We created six separate Pugh charts corresponding to six different categories of design: anchoring, frame, pedal design, pedal straps, resistance (Appendix B, Tables B1-B5) and display. We then chose the best design from each of these categories to combine into our final peddler with extra consideration of how each winning concept works together with the others. Table 2 (p. 14) shows our Pugh chart for three different display ideas to show time and distance on the peddler. Weights are assigned to each design criteria from 1 to 10 with 1 being least important and 10 being most important. Rankings are then assigned to each concept idea from -3 to +3 with -3 being much worse than, 0 being equal to, and 3 being much better than the current peddler. The total score is calculated by adding up the products of ranking by the corresponding criteria ranking. The concept idea with the largest total is the winning design.

Table 2: Display Pugh chart

	Weight	Analog distance separate from digital time	Digital: Pedal Powered	Digital: Battery Powered
Display Time	8	3	3	3
Display Distance	7	3	3	3
Ease of Operation	7	2	3	2
Low Price	9	-3	-2	-1
Lightweight	7	-2	-1	-2
Ease of Assembly	3	-1	-1	-1
Manufacturability/Feasibility	9	-1	-3	-1
Total		**6**	**11**	**24**

Our highest scoring frame design was the bar frame with a rectangular base (Fig. 7, p. 11). The main advantage of this frame is that we believe it to be the most stationary while it is in use compared to the other frame ideas. The main disadvantage of this frame is that it will weigh more than the current peddler and we want to make sure we keep it within our weight constraint. Other frame ideas had lower scores because they were more difficult to manufacture and more expensive. The highest scoring pedals and straps were flat top pedals with a rounded bottom for hand and foot comfort with an adjustable “buckle” strap (Fig. 11, p. 13). This adjustable strap allows for many different sizes of foot or shoe sizes and is easy to manufacture. A disadvantage of these fully adjustable straps is that there may be a lot of extra material at tighter settings. The highest scoring display design is a battery powered digital display, which we believe to be cost efficient and relatively easy to manufacture (Appendix A, Fig. A30). Our Pugh chart concluded that the friction mat is the best concept idea for resistance but when taking this into consideration with our chosen frame design, we might not need any help with resistance in addition to the added surface area of the rectangular base. The highest scoring anchoring design was a friction mat, which will increase the coefficient of friction between the peddler and the surface it is on. The resistance selection was particularly difficult because of many options: magnets, a single caliper brake pad, multiple caliper brake pads, and a resistance fan. Two heavily weighted criteria for the resistance concepts were cost and durability. Magnets can be used for resistance and are very durable but the cost doesn’t correspond to our sponsor’s needs [16]. A single caliper brake pad is cost effective but not as durable as the magnets. We chose multiple caliper brake pads (Fig. 9, p. 12) for adjustable resistance so that individual pads will not wear out quickly and we keep the cost relatively low.

Analysis and testing on these concepts for each component (frame and base design, pedal design, feedback display, and resistance mechanism) will offer further insight into the best options for our redesigned peddler. Results from this analysis will guide future modifications or changes.

KEY DESIGN DRIVERS AND CHALLENGES

We analyzed our user requirements and engineering specifications and narrowed the list to determine our key design drivers. Our key design drivers are ease of use, reliability of resistance, no slip between the peddler and the surface that it is on, workout measurements, adjustable straps, and cost. These drivers are detailed in Table 3.

Table 3: Key Design Drivers

Driver ID	**Description**	**Importance**	**Design Driver Analysis**	**Validation**
Ease of Use	The resistance adjustment and electronic outputs must be easy for the patient to use and understand.	If it is NOT easy to use, the patients will not want to use the peddler and they will not receive the cardiovascular benefit.	Continue talking with current users to understand what improves ease of use.	Conduct a focus group to rate ease of use.
Reliability of Resistance	Aa set amount of resistance must be the same each time for each patient.	When patients choose a certain resistance level, it needs to be accurate so that they (and the nurses) can track progress.	Analytical model to determine forces.	Measure stresses in rotating bars at various levels to check consistency.
No Slip	Need to design a peddler that will not slip on the surface it is sitting on when it is in use.	If it is NOT stationary while in use, patients will have to push it up against a wall and may lose motivation to use the device.	Analytical model to determine coefficient of friction needed to avoid slip.	Test with different surfaces, resistance levels, and users to see if peddler slides.
Workout Measurements	Need to insure that the user receives feedback of time of workout and distance traveled.	Time of workout and distance traveled can help motivate the patients to peddle longer or "farther" while giving nurses better feedback of progress.	Search for current products that give similar output to incorporate in our peddler.	- Compare time readout to that of a stopwatch. - Count revolutions and calculate distance by hand to compare.
Adjustable Straps	Need to have pedal straps that can fit a large variety of foot or shoe sizes.	Patients may have health issues which lead to swollen extremities, and veterans may have large shoe sizes. If their feet do not fit, they will not use the peddler.	Conduct research to determine range of foot and shoe sizes.	Try out different shoe sizes to check fit.
Cost	The cost of the peddler must fit within the HBCR budget.	The HBCR program has a $100 budget for 5 items so the peddler must fit within the budget.	Find low cost alternatives for material and components.	Sum all components for total cost.

These design drivers can be tested and verified before final production through static and dynamic engineering fundamentals. The most challenging design drivers are the reliability of resistance and staying within budget. It is difficult to quantify cost because we do not have a good idea of how this product would be mass produced so we cannot know a realistic final system cost. We believe that the resistance will be difficult to manufacture and verify. Other challenges are likely to arise when we start the manufacturing process. Our group is not very experienced in electronics so creating the desired digital display may prove to be difficult. Manufacturing the frame and braking system will also be challenging. We have limited welding experience so we will likely sign up for training through the machine shop and search for guidance from other more experienced students.

INITIAL CONCEPT ANALYSIS AND DESIGN CHANGES

Mockup Construction

We constructed a mockup when we were still planning on using the two brake pad caliper resistance system. We constructed a mockup to prove our concept and discover if there are any problems that we overlooked during our concept generation and theoretical analysis process. The exterior can be seen in Figure 12 and the interior of the mockup can be seen in Figure 13 (p. 17). The housing in these pictures has cut out windows and it is lacking a top and bottom so that the resistance mechanism is visible. The final prototype will ideally have a fully closed housing which the user cannot reach inside.

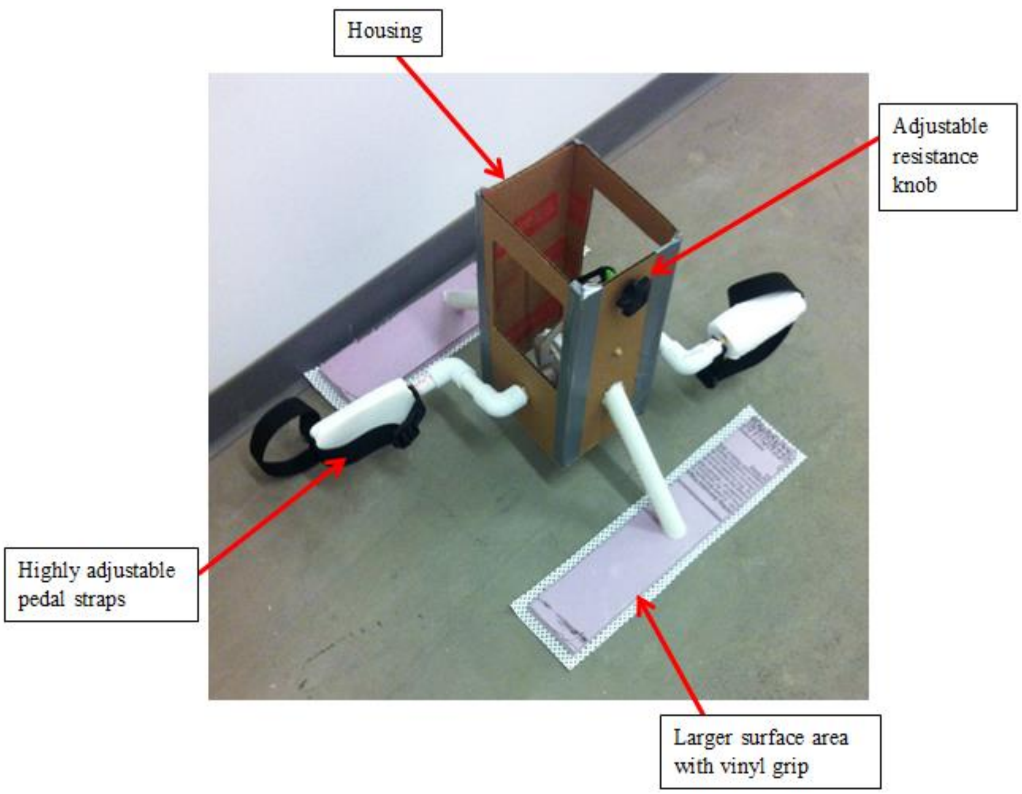

Figure 12: Exterior of mockup

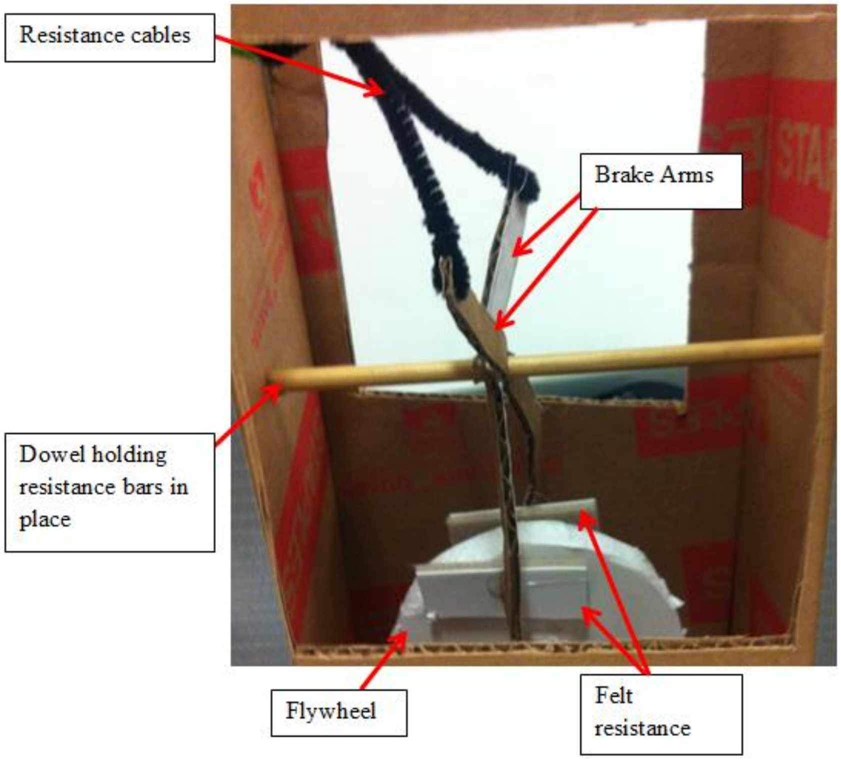

Figure 13: Interior of mockup

While constructing the mockup we came to the realization that the housing is very large and bulky and we want to generate some more concept ideas moving forward to minimize the size of the housing. We also realized that we have to be very meticulous when assembling the resistance system so that the resistance bars, dowel, resistance cables and adjustable resistance knob align properly. This was a major factor of what made us decide to switch to a band brake. The housing would not have to be as large for the band brake mechanism because there is not a larger caliper system jetting out on top of the rotor.

During the construction of our mockup we also became aware of potential difficulties regarding the assembly of our prototype. We constructed the friction system (brake arms, felt resistance pads and resistance cables) separately from the pedals, frame, and base and then joined them together in the final steps. The rotor must be mounted to the pedal bar before the corners are put in and before the pedals are installed. Since we were using PVC, we could break apart the 90 degree corners of the pedal bar to insert the rotor into the housing. In our final prototype, we will not be able to "break apart" the corners of the brake bar to get the sides of the housing in place. We would have to keep the brake bar straight until the housing is around it and then bend the corners afterwards which may be very difficult to manufacture. We then had to connect the sides of the housing after the pedal bar was properly positioned. If we weld the housing, this will have to be one of the final steps and it will occur after the entire resistance system is inside which gives us another reason to try to come up with more housing concept ideas.

After coming across these challenges, we met with a few more experienced manufacturers to get their input on the assembly of our peddler. We discussed with Professor Elijah Kannatey-Asibu Jr. in the Mechanical Engineering department at the University of Michigan. Kannatey-Asibu received his M.S. and Ph.D. in Mechanical Engineering from the University of California at Berkeley and currently teaches a class on manufacturing processes [17]. He suggested that we cut the pedal bars in half and weld them to either side of the rotor after we bend the bars. He also suggested making the housing in two pieces to then weld together around the resistance system. We also had multiple conversations Charlie Bradley who is an engineering technician in the University of Michigan mechanical engineering machine shop. He suggested that we cut each pedal bar into three pieces and then weld each corner because we do not have adequate machinery available to us to make consistent tight bends. This will give us much more flexibility in our assembly process.

Band Brake Selection

Our Pugh charts suggested that multiple brake pads would be the best form of resistance for our peddler. After moving forward with this and starting to plan the actual manufacturing of the system, we realized that this would be very difficult to manufacture because we would have to engage each brake pad at different times for different resistance settings. This would be challenging for us to manufacture with our current resources and we also realized that this design would be expensive. We held another brainstorming session to propose more resistance mechanisms that would be better suited for our peddler and decided on a dual-brake-pad caliper system as shown in Appendix C. We went forward with performing calculations for this design and when we got close to manufacturing, we realized that each small individual caliper component would be tedious to manufacture and the mechanism would be difficult to align. We predicted that alignment would be a major challenge and we decided that we needed to find a new resistance system.

We began talking with others who were more experienced with resistance and braking mechanisms. During a discussion with the University of Michigan Baja SAE racing team, they suggested that we use a band brake to provide resistance around the outside of a rotor. We had not come across band brakes in our previous research so we decided to research these further. A band brake applies constant resistance around the circumference of the rotor while the caliper mechanism has two brake pads on each side of the rotor; therefore, the caliper brake would wear much more quickly than the band brake. In addition, our caliper device has a lot of pieces that work together to provide the necessary resistance, while the band brake only has the band itself and the tightening mechanism. Having a lot of pieces makes manufacturing and alignment much more difficult and expensive. Therefore, based off of this information, we decided to use a band brake to apply varying resistance.

Band Brake Application Options

In determining how to tighten the band brake around the rotor, we had three potential designs. Our first idea was to have a lever mechanism (Fig. 14, 15, p. 19). For this mechanism, one end of the band is rigidly attached to the housing while the other end is attached to a lever that, when adjusted by the user, will pull the band closer to the rotor and increase the resistance. We would use a spring and 3D printed pieces in the handle of the lever to adjust the resistance and lock it into place in the housing.

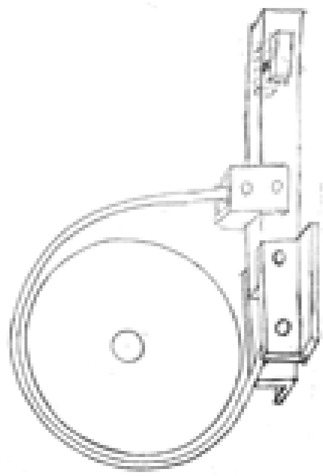

Figure 14: Rotor with band brake showing the lever mechanism

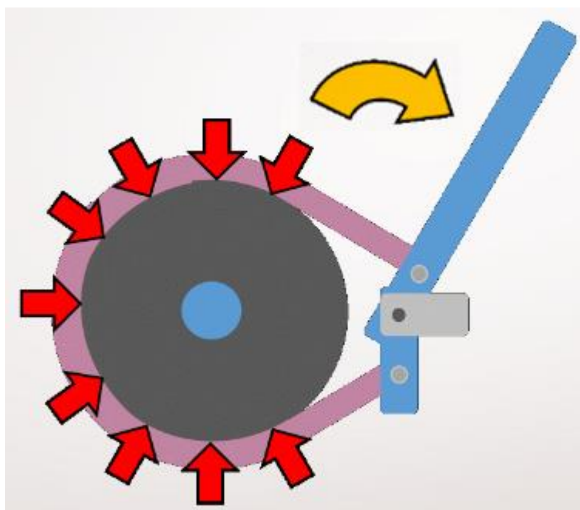

Figure 15: Diagram of functionality of lever mechanism [18]

Our second idea was to have a cable lock mechanism (Fig. 16, p. 20). One end of the band is rigidly attached to the housing, while the other end is attached to a slot by a shoulder screw. There is a wire wrapped around the screw at the slot that then comes out of the housing and is held in place with a cable lock (Fig. 17, p. 20). The user will have access to the cable, and as they pull the cable, the screw in the slot comes closer and tightens the band around the rotor, increasing resistance. On the cable will be different difficulty measurements so that the user can pull the cord through to have an idea of how hard they are working.

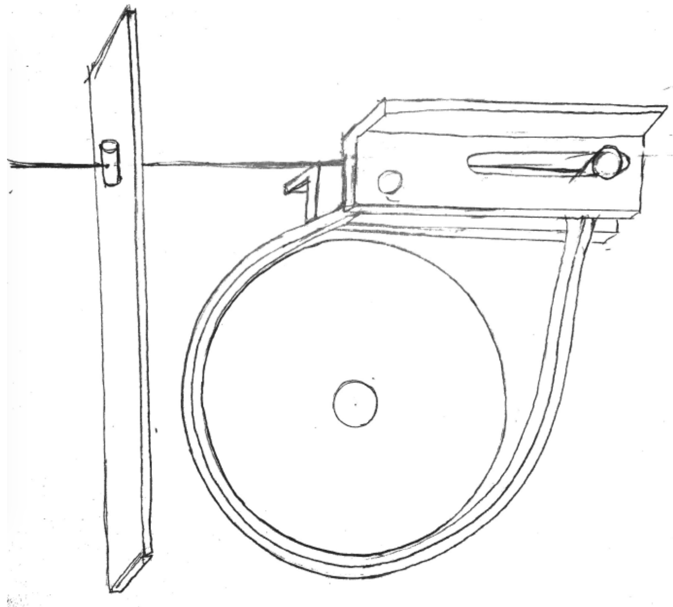

Figure 16: Rotor with band brake cable lock mechanism

Figure 17: Cable lock for cable lock mechanism [19]

Our final idea was to have a weight mechanism (Fig. 18, p. 21). For the weight mechanism, one end of the band brake is rigidly attached to the housing, while the other end is attached to a slot by a shoulder screw (which is vertical). There is a cable wrapped around the screw at the slot that then comes out of the housing toward the ground and at the bottom a solid weight is attached. Then, there are varying weights that can be added to the base weight to pull the band closer to the rotor and increase the resistance.

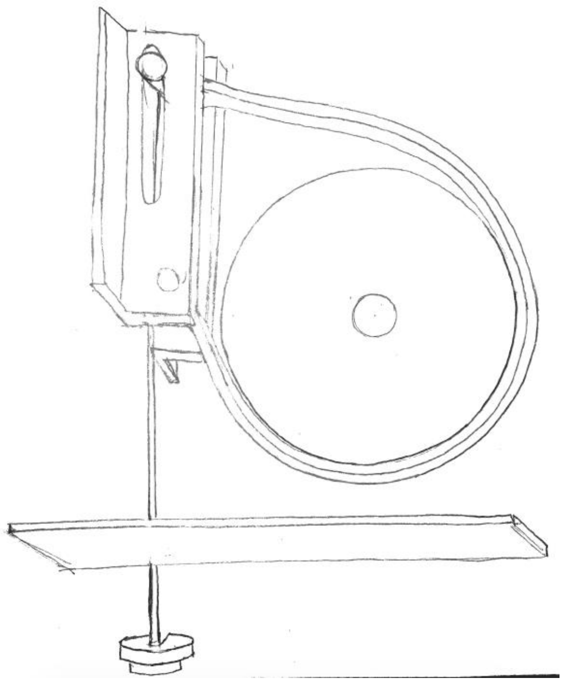

Figure 18: Rotor with band brake cable lock mechanism

ENGINEERING ANALYSIS

As previously mentioned, our key design drivers are ease of use, reliability of resistance, no slip, workout measurements, adjustable straps, and cost. Each of these drivers is very important to our peddler prototype. Reliability of resistance will be physically tested to verify and analyze. No slip requires engineering analysis in the form of theoretical modeling before we go forward with prototype production. We want to ensure that the resistance system will be operable by the user and that the peddler will not slip on the surface when it is in use.

Testing of the Band Brake System

To empirically determine the force needed to move the band brake to different positions, we built two wooden test rigs to support the pedal bar (Figure 19, p. 22) and the brackets to hold the band brake around the rotor (Figure 20, p. 22). The support rig for the pedal bar and rotor had two top pieces that were screwed down onto the main supports around the central axis of the pedal bar, in similar locations as to where we plan to place bearings in our final prototype. The support rig for the band brake brackets allowed us to mount the two L-brackets in the proper locations for spacing of the band brake around the rotor. The bottom of the band brake is fixed in the brackets, and the top of the band brake can slide up and down in a slot to clamp around the rotor.

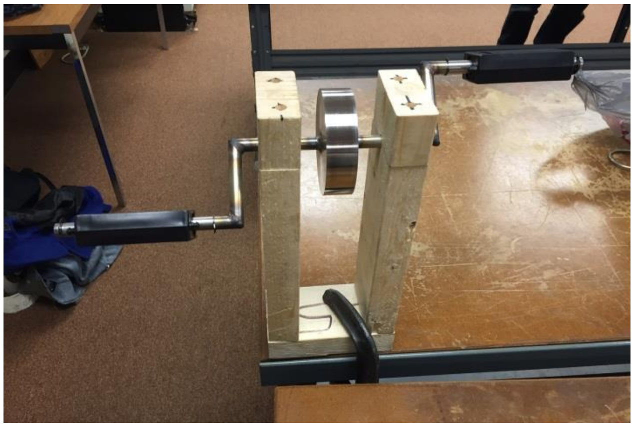

Figure 19: Support rig for pedal bar

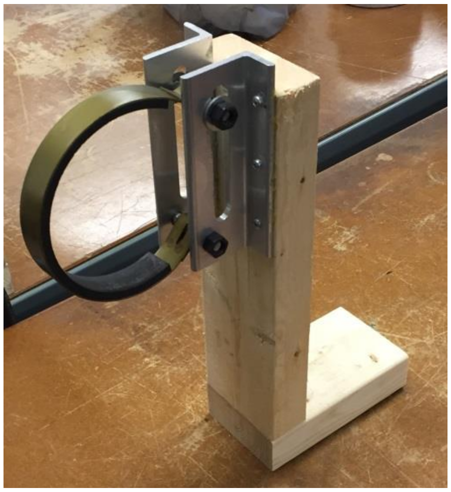

Figure 20: Support rig for band brake brackets

To tighten the band brake around the rotor, a cable is attached to the top of the band brake which can slide up and down in the slot. We attached weights to this cable to determine the force needed to achieve varying resistance settings when pedaling. The entire test rig is shown in Figure 21 (p. 23), with the cable running down between the tables and weights hanging from the end of the cable. The two wooden test rigs are held in place on the tables by C-clamps.

Figure 21: Test rig set-up with weights applied

We began with no weight applied and turned the pedals to feel what the system felt like with no resistance; we also made a mark on the cable in line with the bottom of the tables to use for length measurements. We then added small increments of weight until we felt that there was a noticeable change in the resistance when pedaling. We recorded the weight applied and the length the cable had extended from the initial length with no weight. We continued in this manner until we reached a setting that was incredibly difficult to pedal with hands and made our final length measurement (10.1 kg). We ended up with 5 different resistance settings in addition to the initial setting with no resistance applied. The results of our testing are shown below in Figure 22. We were limited in the weights we could apply by what we had available to us, so we could not test every single setting we would have liked. However, we feel that we now have a good idea of what we want the resistance settings to be and how much force we need to apply to reach those settings.

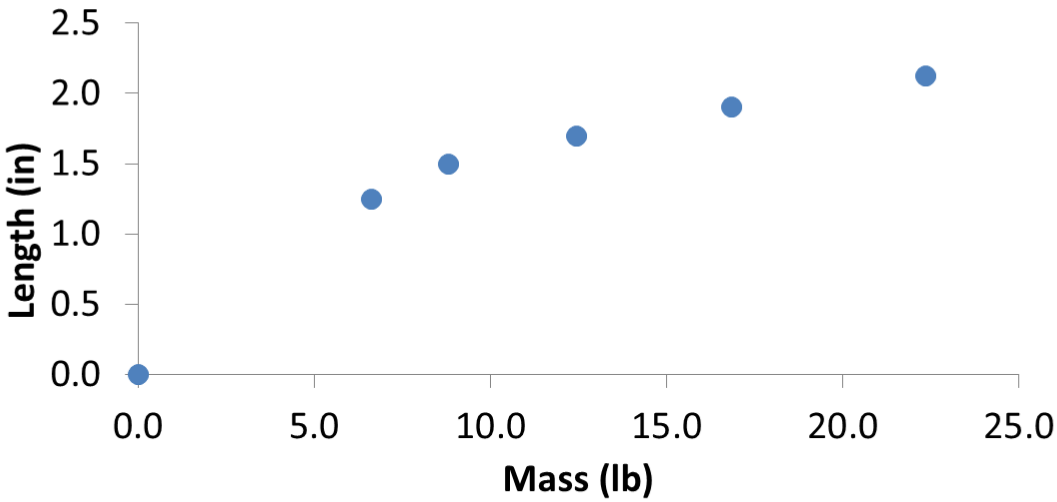

Figure 22: Relationship between applied weight and cable extension at various resistance settings

Pulleys
Our testing indicated that we would need approximately 22 lb applied to the band brake to achieve our maximum desired resistance. The average pulling strength of humans pulling from 30 degrees below their shoulders is 29 lb which is approximately the position that we can expect the peddler to be in during use [20]. Since this is simply the mean, we would like to accommodate for the possibility that patients fall outside of this average value. The older patients especially might have lower pulling strength capabilities. By applying pulleys, we can reduce the load that the patient has to apply to change resistance levels. Figure 23 shows the double pulley system that we have in place in our peddler to decrease the load by 75%.

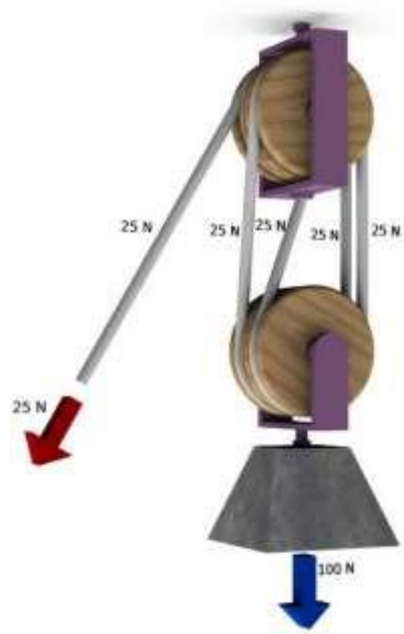

Figure 23: Double pulley system reducing load by 75% [21]

This figure depicts a load of 100 N which is reduced to 25 N by the double pulley system. When we use this same system on our peddler, it will make it so that the maximum load applied by the patient will be approximately 5.5 lb which is significantly less than the mean 29 lb pull strength.

Stability Analysis
An analysis was done on the frame to determine how much force would be required for the participants to exert in order to tip the peddler in the 3 different directions. One location that could cause tipping is around the lower right or left sides of the ground plane looking at the peddler from the front (L-bracket poles facing forward and the pedals exposed on both the right and the left side) (Fig. 24, p. 25). This tipping could occur if a lot of force is applied to the end of the pedal, outside of the base of the frame. Using equations 1 and 2 (p. 25), knowing that R=R1=, H=R2= and W=15.88 lbf, we solve for F to find that 17.63 lbf can be applied on the pedals at the location outside of the frame before tipping would occur.

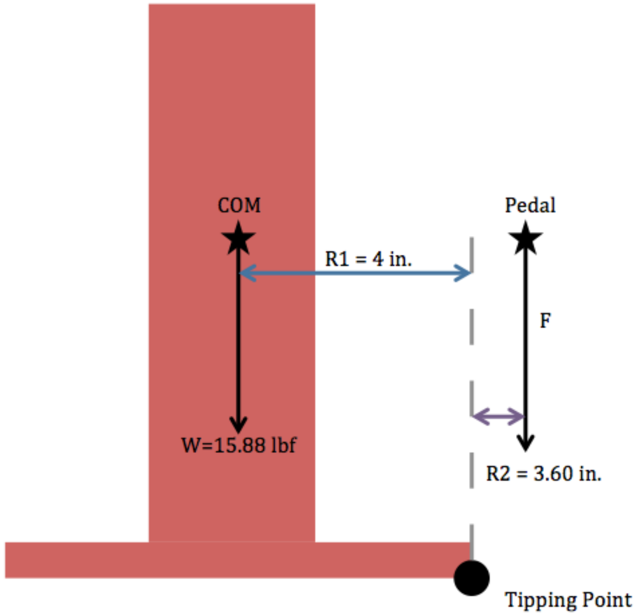

Figure 24: Front view of peddler for force analysis on outside of pedal

$$\Sigma \text{ Torque: } W*R-F*H=0 \qquad \text{(Eq. 1)}$$

$$F=W*R/H \qquad \text{(Eq. 2)}$$

Similarly, we performed a calculation on the back edges of the frame (with the pedals facing forward for analysis). When observing the back of the frame as the tipping point (Fig. 25), we solve for F in equations 1 and 2 above, knowing that R=4 in., H=8.5 in. and W=15.88 lbf, to determine that the maximum force that can be applied on the pedals in the forward direction is 14.95 lbf.

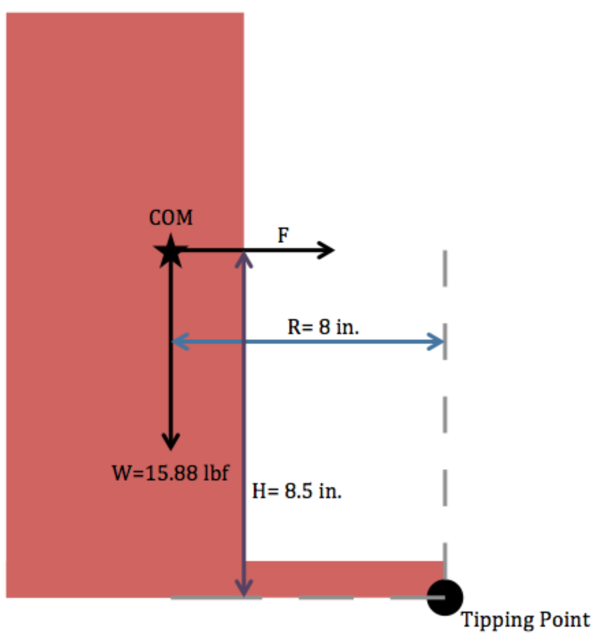

Figure 25: Side view of peddler for force analysis with back as tipping point

Base with Vinyl Mat

We analyzed the forces between the peddler's anchoring system and different surfaces on which it is used. First, we drew free body diagrams of one rubber foot of the current peddler; this diagram is shown in Figure 26, with F_N = the normal force, *mg* = the force of the weight of the peddler as a whole, and F_f = the force of friction resisting motion, F_{pedal} = the force imparted by the user. The diagram shows the forces imparted upon each of the four rubber feet when pedaling; when at rest, F_{pedal} and F_f are equal to zero.

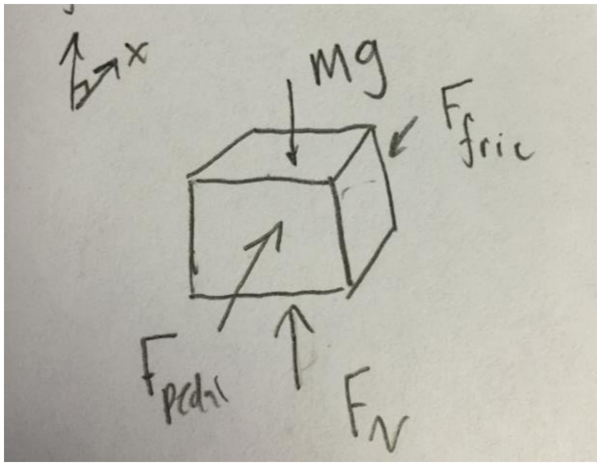

Figure 26: Free Body Diagram of Forces on Peddler Foot

From this analysis, and using Equation 3 and a coefficient of friction of 0.7 [22] for rubber on wood, we were able to determine that the force needed to overcome the force of friction and cause sliding is a mere 20.99 lbf assuming equally distributed force among the four rubber pads.

$$F_f=\mu*N \quad \text{(Eq. 3)}$$

Additionally we analyzed the new anchoring system that we have designed with vinyl lining on the underside of two rectangular plates. The free body diagram of this system is shown in Figure 27.

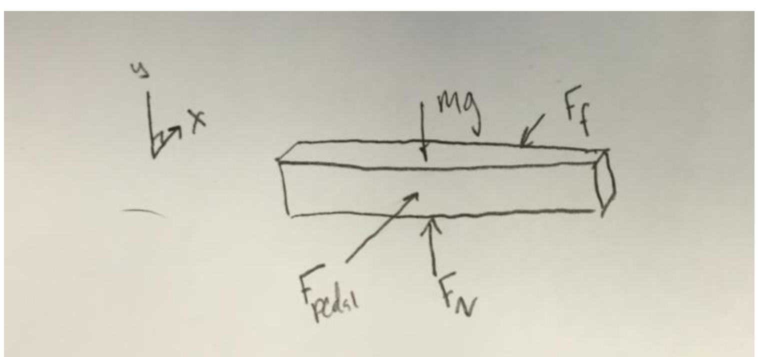

Figure 27: Free Body Diagram of Forces on Base with Vinyl Mat

Using a coefficient of friction of 0.63 for vinyl on wood [22], a force of 50 lbf from the user would cause the peddler to slip. Therefore the new, vinyl-lined design has been validated from this analysis.

CONCEPT DESCRIPTION

Band Brake

We have finalized complete concepts of all of the components of our peddler. The band brake is made of composites, and has a resistance pad lining the whole arc. As the ends of the arc are pulled together closely around the rotor, they apply more resistance and ultimately stop the wheel from spinning when enough force is applied (Fig. 28). However, in our prototype design, we will not need to stop the wheel as this is designed as a resistance mechanism rather than a braking system.

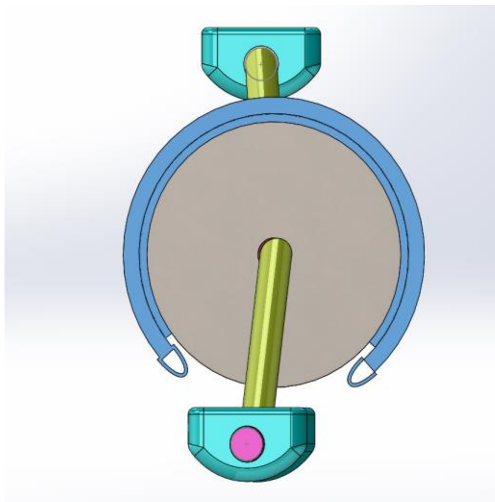

Figure 28: Rotor with band brake

Pedal Design

The pedal bar is rigidly attached to the rotor, so that as the pedals rotate, the rotor does as well. The pedal bar looks similar to the current peddlers pedal bar; instead of being bent, though, we decided to make the pedal bar into straight sections and then weld the pieces together because it will look a lot smoother and be easier to manufacture with the resources we are provided. As well, in order to rigidly attach the pedal bar to the rotor, we decided to individually weld each side of the pedals into the rotor (Fig. 29, p. 28). We determined the q-value (horizontal distance between the two pedals) to be 7 in. It is stated that the ideal q-value is small so that it is more similar to walking (when legs are close to each other) [23]. Based off of the 95% of men's hips and thigh dimensions [24], we were able to determine that the distance between 95% of men's feet is about 7 inches. We determined that 2.9 inches is an appropriate distance for the crank length (vertical distance between two pedals) based off of the current design peddler and research stating that the normal crank length for recumbent bikes is 17 cm (6.7 in) [24], but in order to prevent knee injuries, having a smaller crank length is better. The pedals have a rectangular top with width of 5", which was determined since 95% of males have foot breadth of 4.21 inches or smaller [24]. This value does not include shoes, and figuring shoes can add about 0.5" or more to either side, we determined 5" would be the best width. We determined that the pedal should have a flat top for use while foot peddling and then the bottom should be rounded for use while hand peddling (Fig. 30, p. 28). Each pedal has an adjustable strap attached on each end.

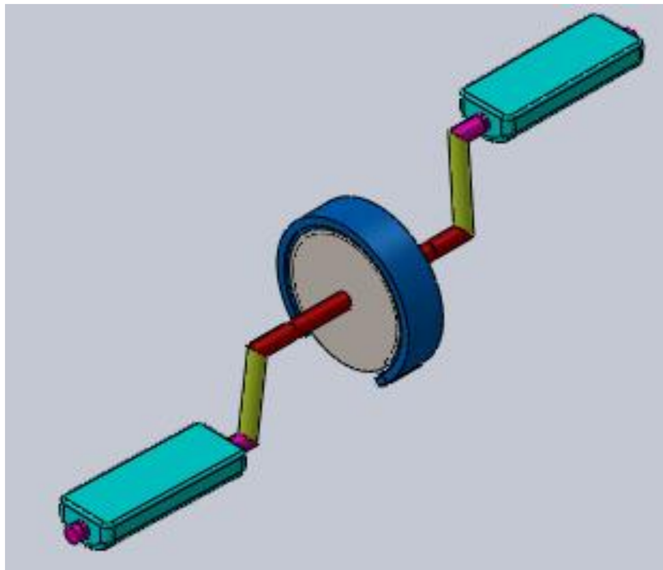

Figure 29: Band brake, rotor, and pedal bars with attached pedals

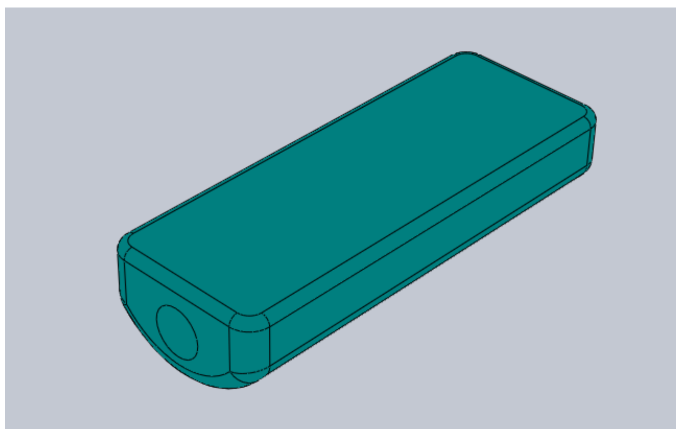

Figure 30: Pedal with flat top, rounded bottom and hole for pedal bar inserts

Bike Computer

Another major component of our mechanism is the digital display. We are using a battery powered bike computer with a magnetic sensor that displays the time, speed, and distance the user has gone while on the peddler. We have chosen to purchase a bike computer as opposed to designing one ourselves, as there are currently models that exist for relatively low prices which do exactly what we want. Pictured below in Figure 31 (p. 29) is the model of a bike computer, made by Arova, that we are using. The odometer works by having one magnetic sensor attached to the rotor and the other attached to the inside of the housing, and then as the rotor moves the sensor on the housing will track each revolution. Therefore, once the radius of the rotor is programed into the odometer, the odometer can determine and display the distance as well as the speed of the mechanism and duration of use.

Figure 31: Arova Wireless Cyclocomputer [25]

Base and Frame

Once we finished testing and determined that we are going to use pulleys and cable to tighten the band brake, we brainstormed some ideas for the base and frame. Some major factors we took into account was that we want the base and frame to be light, strong, inexpensive, and easy to assemble. We need the frame to be light because the rotor/pedal bar, and pulleys combined are already over our 10lb goal, thus, we also need the frame to be strong so that it can support those pieces without deflection. We were hoping to have the frame be inexpensive to decrease the overall price of our mechanism. After speaking with Charlie Bradley in the machine shop, he suggested that we look into using 80/20 aluminum. We looked into 80/20 T-slotted extrusion aluminum and determined that it is low in price and lightweight (about ⅓ the weight of steel [26]), with high strength (ultimate tensile strength of 38 ksi [26]), is relatively inexpensive and quite easy to assemble. Thus, we figured this is the perfect material to use to make our frame.

Once we determined the material, we had to figure out how to attach the pedal bar and rotor to the frame. We spoke with Charlie Bradley in the machine shop and he suggested using a split sleeve bearing to allow for easy rotation and assembly and to have something strong enough to hold the load. We did some research and discovered that the Babbitt Split Bearings from McMaster [27] would be perfect for our mechanism. The Babbitt Split bearing (Figure 32) come in a size allowable for ½" shaft diameter, is split to allow for easy assembly, can hold up to 800 lbs of dynamic loading and has a base mounting mechanism of 1 ⅜" - to allow for us to easily attach to the T-slotted aluminum extrusion.

Figure 32: Babbitt Split Bearing to be used to attach our pedal rod to our frame [27]

After we decided how to attach the pedal bar and after we chose what material to use for our base, we had to come up with a design for the frame that would support our mechanism. We determined the height of the two extrusions for the brackets and the height of the extrusions for the pedal bars based off of the best relative position determined from testing - where the rotor is centered within the band brake. We increased the height of the band brake and pedal bar to allow for more room for the pulleys to fit in. We then made a stable base connecting the pieces, and to try to prevent the frame from tipping, we decided to have some ground extrusion pieces extend out further. As well, while performing our tests, we noticed the wood holding the pedal bar and the band brake had a tendency to twist when under high loads, therefore, to prevent the tall pieces from moving, we added angle brackets for joint support and tall straight brackets to the extrusions holding the band brake. To ensure the tall brackets stayed at equal distance from each other for the whole length, we added an aluminum bar connecting the tall extrusions at the top location. Lastly, to attach the pulley to the frame, we decided to create a base plate using aluminum sheet metal and attach that to the t-slotted aluminum. Our frame is displayed in Figure 33.

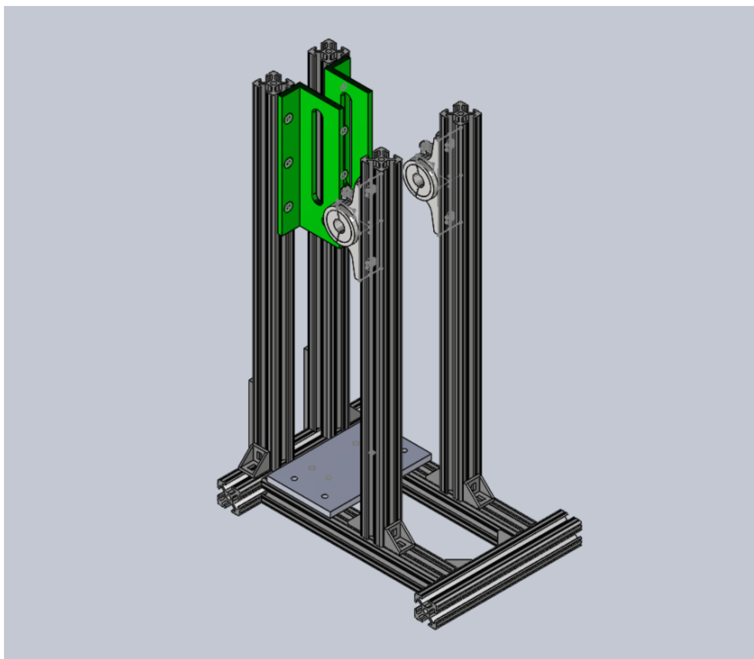

Figure 33: T-slotted aluminum frame with angled bracket and straight supports

Resistance Application

To apply resistance from the band brake to the rotor, we determined that a 1/16”-diameter cable would best translate force applied from the user to a force upon the band brake. Similar to our test rig, one open part of the band brake is anchored in place while the other opening is able to translate up or down to apply resistance to the rotor. We have designed our cable to wrap around the freely moving opening so that tension on the cable will add resistance to pedaling. The cable then enters a series of double pulleys: one suspended purely by the tension of the cable and one anchored to the bottom of the peddler’s frame; these pulleys reduce the amount of force needed to tighten the band brake around the rotor, creating an easier experience for the user when adding resistance.

The cable feeds upward through an acrylic plated mounted on the peddler’s frame. The plate contains a slot for implementation of a slider (Figure 34, p. 31).

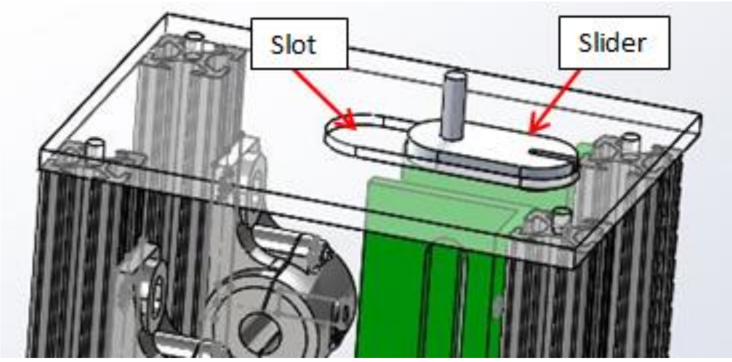

Figure 34: Top of peddler with metal slider

The slider has been designed to allow for cable adjustment (to apply more/less resistance from the band brake) through a small slot within the slider itself. The cable maintains its position with the use of small stoppers clamped to the cable at pre-set positions determined during our testing. The stoppers cannot pass through the slot of the slider, so the pedaling resistance level is maintained without the user's need to constantly hold the cable. The user can comfortably adjust the resistance using a textured, looped section of cable. This system allows the user to maintain a quantifiable resistance level without discomfort and without constant need for readjustment.

Figures 35 and 36 show our peddler at two different settings. The images show that when the stoppers are at a tighter setting, the band brake clamps down around the rotor with larger contact.

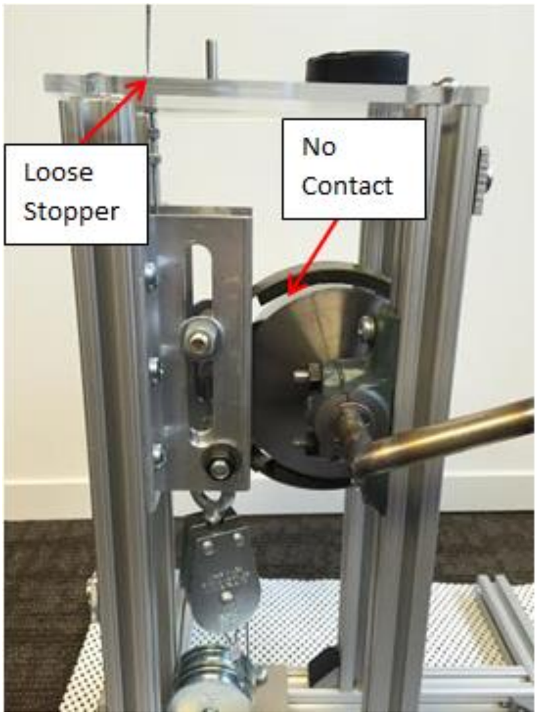

Figure 35: Peddler at loose resistance setting

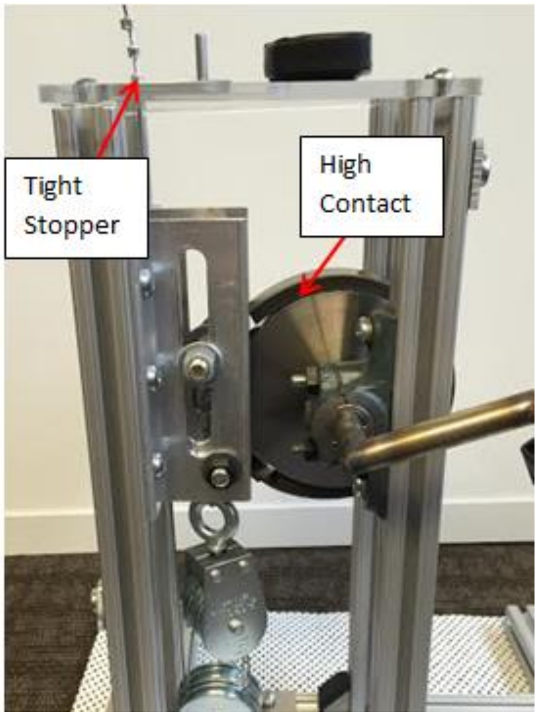

Figure 36: Peddler at high resistance setting

RISK AND FAILURE MODES EFFECTS ANALYSIS

Risk Probability and Impact

We made a risk probability and impact chart to assess various hazards that may arise when our peddler is in use (Table 4). We came up with four main hazards that could arise: electrical shock, overheat, pinch, and slip and fall.

Table 4: Risk Probability and Impact Chart where level is determined by the severity of the type of injury caused by the risk with 1 being first aid only, 2 being an injury causing time off work, and 3 being a disabling injury.

Hazard	Hazardous Situations	Likelihood	Impact	Level	Technical Performance	Schedule	Cost	Action to minimize hazard
Electrical Shock	If the electrical display screen malfunctions or breaks, the patient could be shocked from broken or exposed wires, water exposure, or exceeding amounts of current.	Low	Serious	3	Disabling of time/distance display, but primary function of device will remain intact	Able to meet key dates Slip <1 month	Small budget increase: <5% increase	Add insulation/casing and ensure the display has a low current
Overheats	The rotating pedal shaft can overheat and the patient could be burned by touching it immediately after long use.	Medium	Moderate	2	Minimal or no technical performance change	Able to meet key dates Slip <1 month	Small budget increase: <5% increase	Select components with low output heat dissipation
Pinch	When using the device, the patient could be pinched from the rotating pedals.	Medium	Moderate	1	Minimal or no technical performance change	Minimal or no impact	Minimal to no cost impact	Ensure that there are no pinch points
Slip and fall	Peddler can slip across the surface it is being used on and the patient could unexpectedly fall and injure themselves on impact.	Medium	Low	3	Reduction in coefficient of friction of resistance pads resulting in a higher risk of the hazard reoccurring.	Able to meet key dates Slip <1 month	Small budget increase: <5% increase	Ensure that there is a high friction force between the peddler and the surface that it is resting on so that it doesn't slip when in use.

Electrical shock could come about from having the electrical readout of distance and time of the workout. The likelihood of this risk occurring is very low but the impact would be serious if it were to occur. In order to minimize this hazard, we will add insulation where we believe it necessary to shield from electrical shock and also ensure that the display device has a low current. Overheating could arise from excessive friction between the felt pads and the aluminum rotor. If this spinning device overheats, it could burn the user if they come in contact with it. We believe that overheating has a medium likelihood with moderate impact to the user. In order to reduce this risk we plan to insulate the housing around the spinning rotor to keep the majority of the heat inside the device so that is no burn hazard. The current peddler gets hot to the touch when pedaling for long periods of time at high resistance levels and we believe this to be a risk to the user. The rotating pedals introduce the risk of pinch points where the user could get caught in the rotating device. Pinching is a medium likelihood risk with moderate impact to the user. We would like to reduce the amount of pinch points on the peddler to the best of our ability. The final hazard that we have discussed is slip and fall, meaning the peddler may slip out from under the user and then that user could fall off of the chair he or she is using and risk injury. Slipping is a problem that veterans have often complained about so we see this as having a medium to high likelihood of happening with low impact to the user. We plan to minimize this hazard by introducing a large coefficient of friction between the base of the peddler and the surface that it is being used on.

Failure Modes Effects Analysis

In addition to our risk probability and impact chart, we conducted failure modes effects analysis (FMEA). Failure modes included in Table 5 (p. 34) are related to the frame, pedals, and disk and the failure modes seen in Table E1 (Appendix E) are related to the brake pads, friction mat, and display. In these tables, severity of effect is rated on a scale of 1-10 with 1 being no noticeable effect and 10 being affecting safe operation without warning. Probability of occurrence is rated on a 1-10 scale with 1 being highly improbable and 10 being very high: failure all but guaranteed. Detection is rated on a scale of 1-10 with 1 being almost certain detection and 10 being almost no chance of detection prior to release to customers. The risk priority number (RPN) is then calculated by multiplying the severity by the occurrence by the detection. The RPN will then vary from 1-1000 with and RPN of 1 meaning failure is highly unlikely to occur, an RPN of less than 30 is reasonable, and an RPN of greater than 100 meaning failure is almost certain to occur.

Table 5: Failure modes effects analysis for frame, pedal, and disk items

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity of Effect	Potential Causes of failure	Occur within year	Current Design Controls	Detection	RPN	Recommended Action
Frame	Support components	Material deformation		4	Improper manufacturing/ material selection	3	Choose strong material and method of manufacture	2	24	Research materials and pick one with high fracture toughness
	Stability	Slip away from user	Prohibits user pedal motion	5	Anchoring devices fatigue	2	Test and Validate Method	2	20	Perform calculations to ensure proper mass distribution
Pedals	Provides user surface to propel with feet or hands	Pedals fall off	Prohibits user pedal motion	8	Improper manufacturing	1	Test and Validate Method	3	24	Research ways to properly secure pedals even after much use
		Pedals fracture	Prohibits user pedal motion	7	Improper manufacturing or material selection	3	Perform material strength calculations	3	63	Research pedal materials that are not brittle
	Secures feet while in use	Strap breaks or becomes unattached	Creates unstable pedaling surface	3	Improper manufacturing or strap fatigue	2	Test and Validate Method	3	18	Learn about strength of strap materials
Disk	Allow pedal movement	Disk becomes misaligned	Prohibits user pedal motion	6	Forceful use of device; improper manufacturing	2	Test and Validate Method	6	72	Research ways to track and ensure alignment
	Supply location to apply resistance	Does not rotate with pedals	Unable to apply resistance	6	Improper manufacturing	1	Test and Validate Method	2	12	Research adhesive methods
		Does not contact brake pads	Unable to apply resistance	6	Prolonged use; improper manufacturing	2	Design brake pads/system with proper dimensions	3	36	Determine proper tolerances

The failure mode with the highest RPN was the disk function of allowing pedal movement with a potential failure mode of becoming misaligned. This failure has an RPN of 72 which is a bit higher than the reasonable value of 30 but still below 100 which means failure is almost certain to occur. If this failure does occur, it will prevent the peddler from being used properly and it would be difficult to detect because it is located inside the housing. We believe that a RPN of 72 is acceptable for our highest risk failure mode.

VALIDATION

We have made a validation plan (Table F1, Appendix F) to make sure that our final prototype meets the user requirements that our sponsor outlined. This validation plan will be carried out after our peddler is manufactured so that we can prove that it is an improvement from the currently used peddler.

A few of our validations will come from giving our new peddler to various users and having them complete a survey comparing the new peddler to the currently used one. This will give us feedback on the less mathematically quantifiable user requirements such as easy and comfortable to use. After we gather information from our validation process, we can make minor adjustments or suggest further improvements to the Ann Arbor VA if they would like to improve the peddler even further.

We conducted validation testing to determine how much torque has to be applied to turn the pedals at each resistance setting and to verify that with increasing settings there is an increased torque required to pedal. The data we collected can be seen in Figure 37.

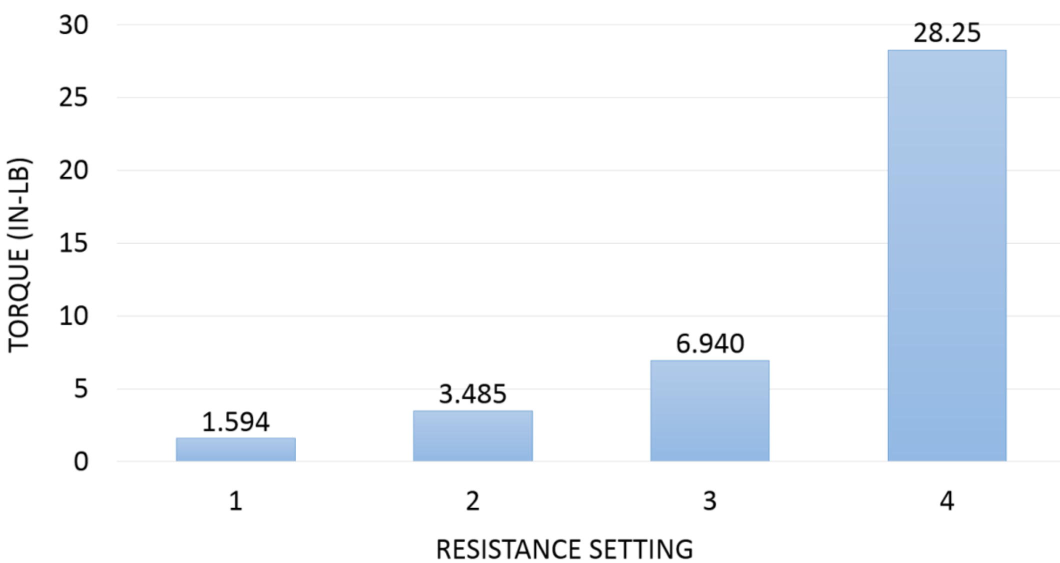

Figure 37: Torque testing at different resistance settings

The torque of 28.25 in-lb corresponds to 9.56 lb of force applied by the user. The minimum force to tip the peddler is 14.95 lb (Stability Analysis p. 24). This shows that at the maximum resistance setting, the peddler will not tip over.

We set our weight, size and display specifications at the beginning of our project and to validate that we met these requirements, we measured the final values as seen in Table 6 (p. 36). We were a bit over our desired weight, but this increased weight also increases the coefficient of friction between the peddler and the ground when it is in use so there was some trade off in that category. Our size was within our original constraints except for the height. The bike monitor that we installed gives all the display characteristics that we specified.

Table 6: Verification of weight, size and display

	Desired Specification	Actual
Weight	10 lb	15.88 lb
Size	16” wide 12” tall 24” long	13” wide 17” tall 10” long
Display	time distance speed	hr, min, sec miles mph

Due to patient confidentiality and time restraints, we were not able to survey veterans to compare the qualitative characteristics of the new peddler to those of the old peddler. We suggest that this should be done in future work so that the survey results can be used to validate the improvement on sliding on ease of use, comfort during use for hands and feet, fluidity of peddling, and quality of friction between the peddler and the surface on which it is being used.

DISCUSSION

After putting our peddler together and doing some validation testing, there are some aspects that could benefit from some adjustments. Looking at the resistance mechanism, we used pulleys to minimize the force needed to apply the band break. However, the pulleys we found weighed quite a bit and were very large, making the whole height of our mechanism longer. Finding pulleys made of a lighter material and of smaller radius would allow the band brake to work in the same manner, but would help bring down the weight and size of the mechanism as a whole. The resistance settings are set using small metal stoppers, held in place by a ¼” aluminum door. Only 4 resistance points could be set and this is largely due to the limitation of the space between the stoppers from the thickness of the door. We would suggest decreasing the thickness of the aluminum door to allow for more stoppers to be applied, ultimately increasing the number of resistance settings.

The rotor we used is made out of steel, adding a large mass to our peddler. While a large mass is beneficial to give a more realistic peddling feel, the overall mass could be reduced some. Some ways that mass can be reduced is by turning down the inside of the wheel that is not in contact with the band brake, or using a different material for the wheel, such as aluminum. The pedal bars are welded to the rotor, making split bearings necessary for assembly. Split bearings are quite expensive, bringing up the overall cost of our piece. The peddler’s price could benefit if, rather than welding the pedal bars to the rotor, they were tapped and screwed in, this way, regular sleeve bearings could be used and a lighter material, such as aluminum, could be used for the rotor.

The pedal bars, made from multiple pieces welded together, can become expensive with all of the manufacturing and welding. We did not have the right resources to bend the steel in an effective manner, but this would be a cheaper and more precise process to create the pedal bars. After attaching the new pedals and e-clips to the pedal bars, we noticed that the straps attached to the pedals extruded too much, hindering pedal rotation when both e-clips were attached. As well, the end of the pedal bar is exposed on the outside of the pedal, creating a snag point. To allow for smooth rotation of the pedals and to ensure that they stay within the e-clips, the pedals could be redesigned so the e-clips are located inside of the pedal, within a notch, and a cap at the end is placed at the end of the bar to prevent any snagging. The pedals material is very smooth and could cause feet to slip while in use, which could be improved by adding grooves, increasing friction. The straps for the pedals are held down by a small bit of vinyl material that often gets caught if too much adjusting occurs. The strap holders could be made more robust by using a stronger and more rigid material, such as flexible plastic. As well, the straps are attached to the pedals simply with hot glue, which is not the most secure method and after too many rotations they come off. We would suggest adding a place to secure the straps - such as slots in the ends of the pedals - and then sewing the straps together through the slots in the pedal or finding smaller E-retaining rings to block the pedals without rubbing the pedal straps.

When building our peddler, we left the inside open to show our new resistance mechanism set up. A protective housing made out of heat resistant plastic could be added around the resistance system to prevent pinch points while not significantly increasing the weight. Along with increasing comfort for the mechanism, handles could be added to the outside of the housing to allow for easier and more comfortable transport. Lastly, the bike computer that is mounted on the top of the peddler could be attached to an angled bracket on top of the peddler so that it is easier to read while peddling.

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APPENDIX A: CONCEPT GENERATION

Frames/Secure in Place:

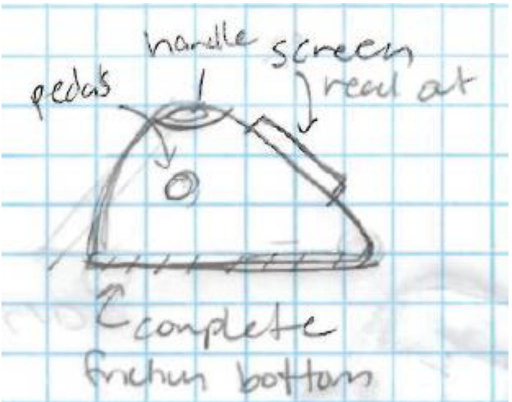

Figure A1: Solid encased unit with rectangular friction base

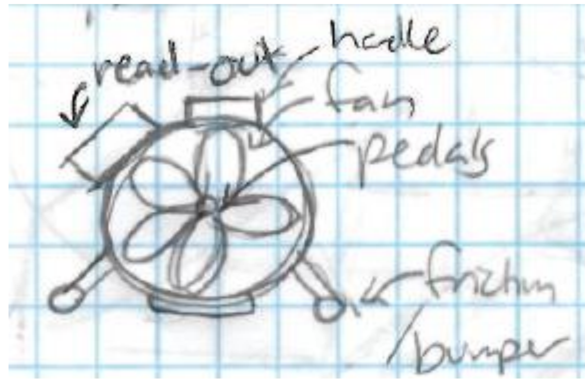

Figure A2: Fan with friction bumpers

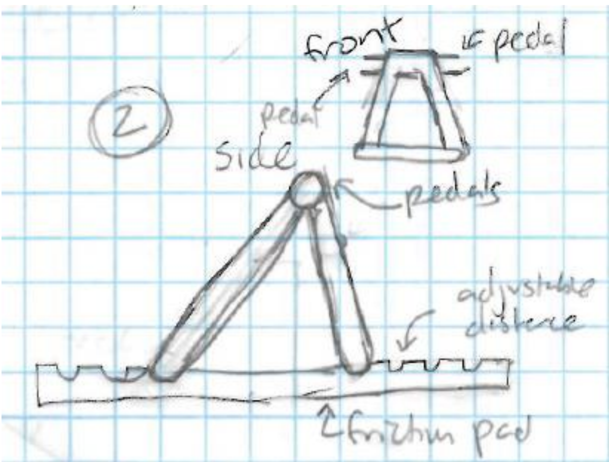

Figure A3: Adjustable hinged bracket with rungs and friction pad base

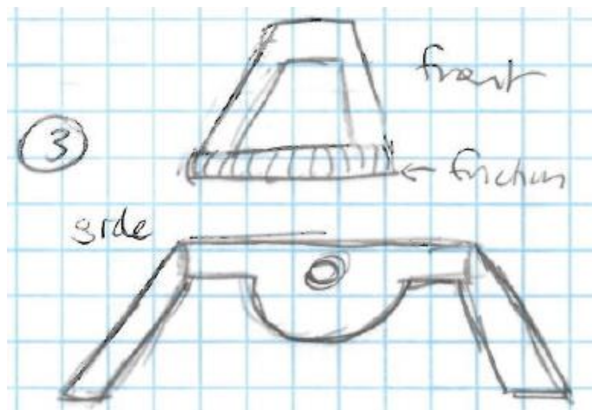

Figure A4: Flat angular base with solid line of friction

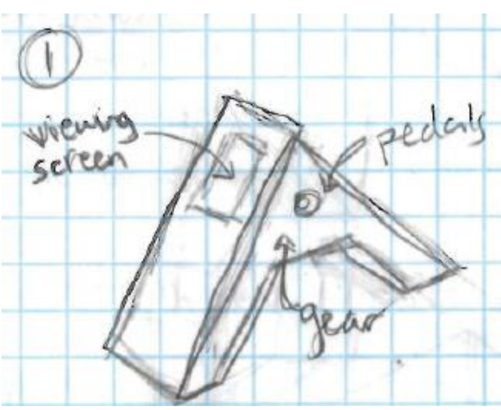

Figure A5: Solid A-frame

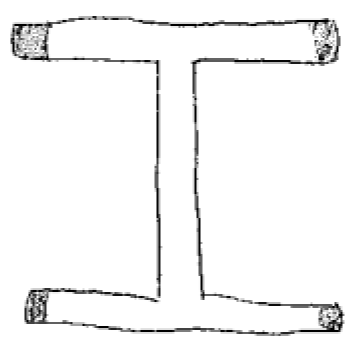
Figure A6: I-frame featuring rubber stoppers at four corners

Figure A7: Foot pad with smaller contact points for added friction

Figure A7: Foot pad with many small contact points for added friction

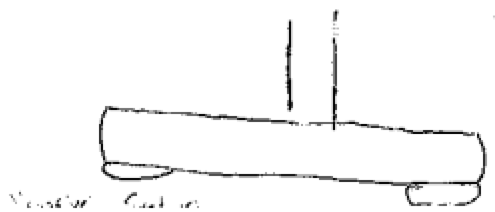

Figure A8: Frame design with suction cups at each of four corners

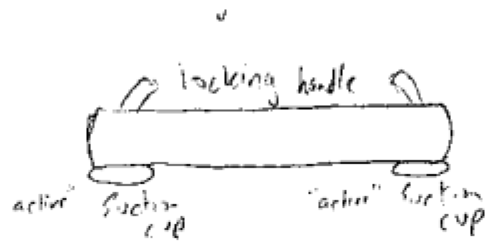

Figure A9: Frame design with locking suction cups at each of four corners

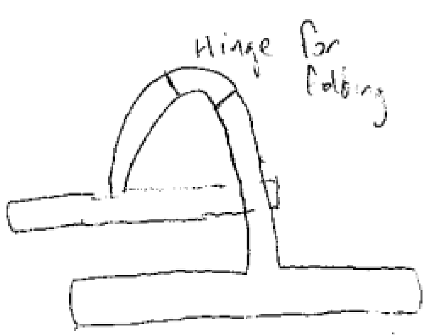

Figure A10: Frame design with a hinge at to change height

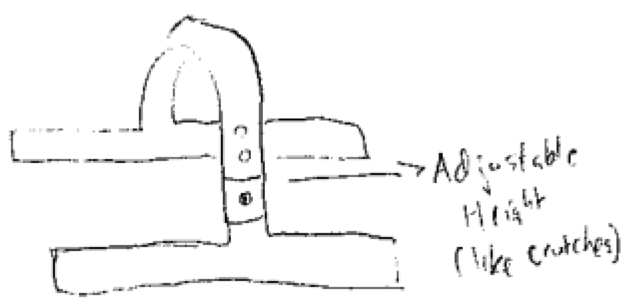

Figure A11: Frame with adjustable notches middle for folding and easy storage

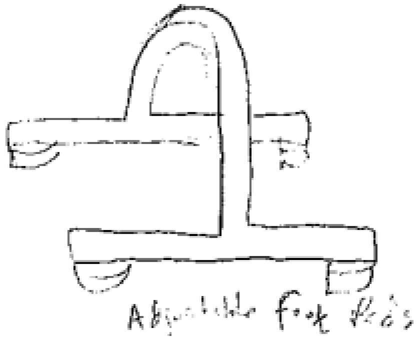

Figure A12: Frame with adjustable foot pads to change height

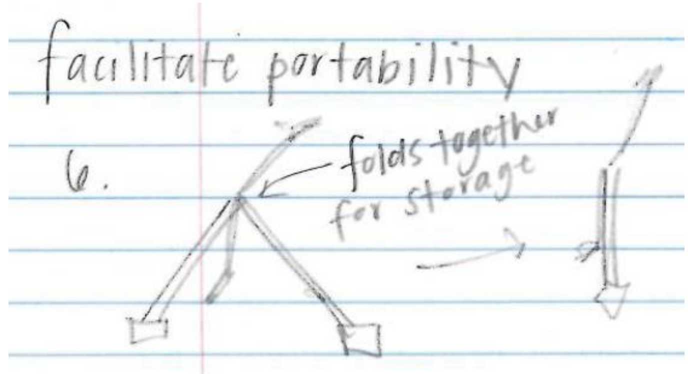

Figure A13: Hinged/foldable frame

Pedals:

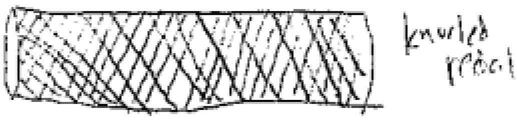

Figure A14: Knurled, Flat Pedal

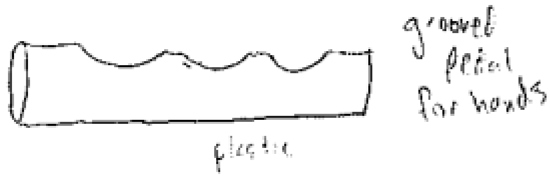

Figure A14: Plastic Pedal with Grooves for hands

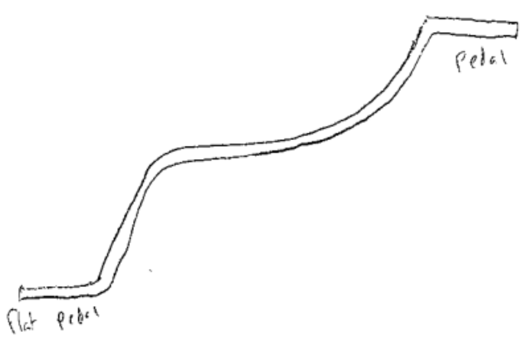

Figure A15: Full pedal design featuring flat pedals

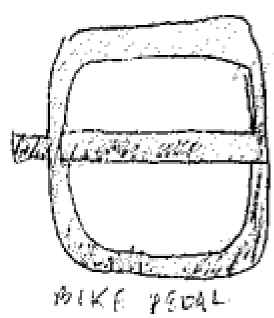

Figure A16: Standard Bicycle Pedal

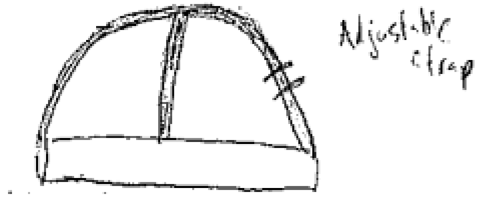

Figure A17: Flat pedal with adjustable strap

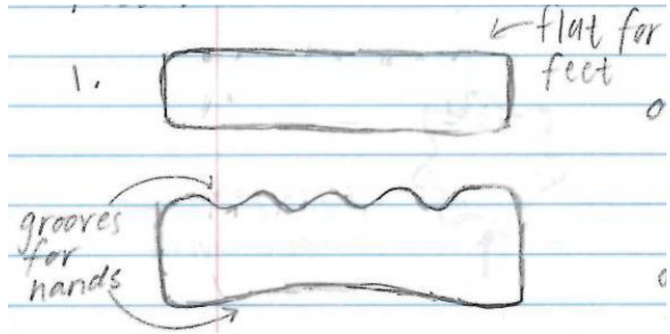

Figure A18: Pedal with top flat and bottom grooved

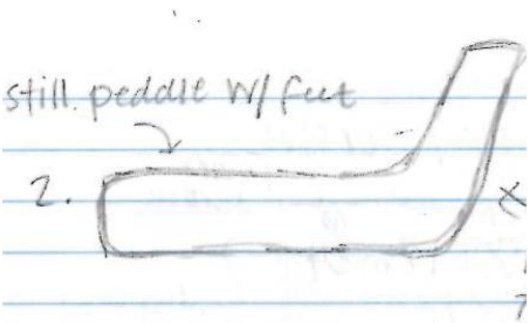

Figure A19: Pedal with flat base and curved side for handle

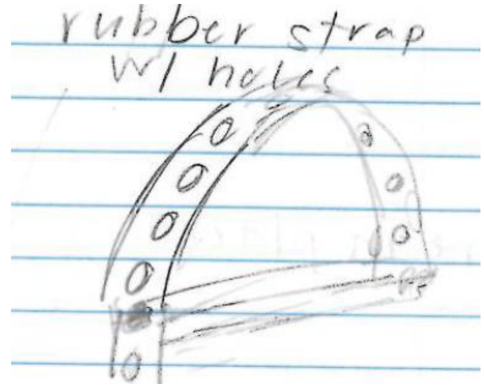

Figure A20: Rubber straps with holes for adjusting foot size

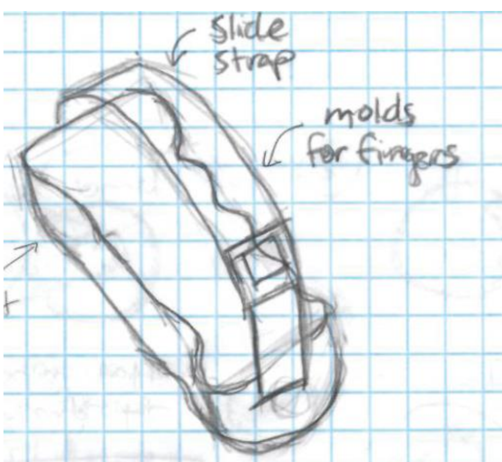

Figure A21: Flat top and rounded bottom with molds for fingers and slide strap foot security

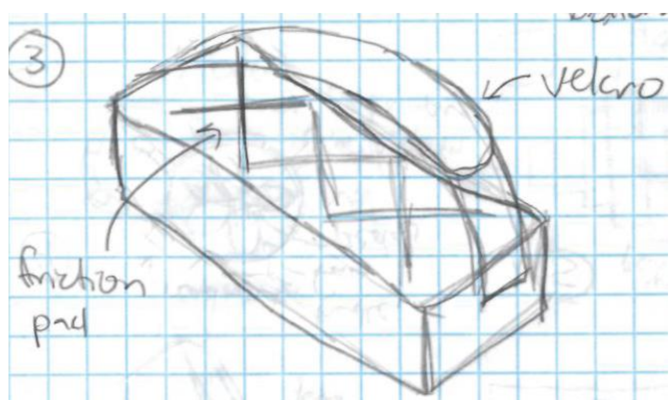

Figure A22: Friction pad on top for feet and Velcro secure system

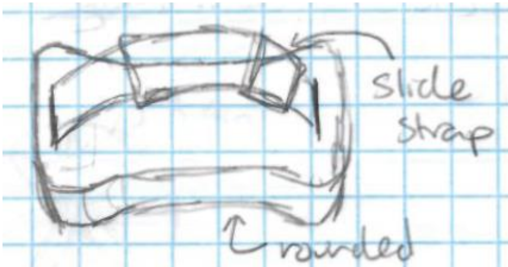

Figure A23: Rounded bottom and flat top with slide strap

Resistance:

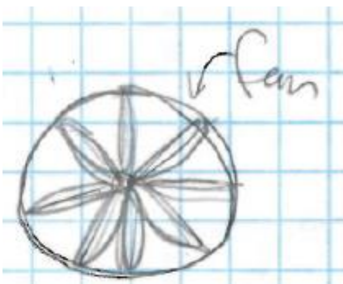

Figure A24: Fan resistance

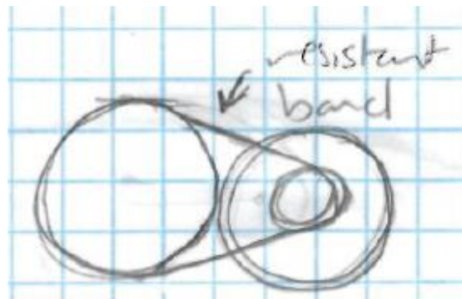

Figure A25: Resistance band resistance

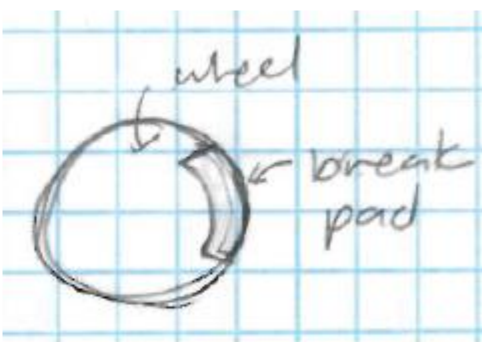

Figure A26: Single brake pad for resistance

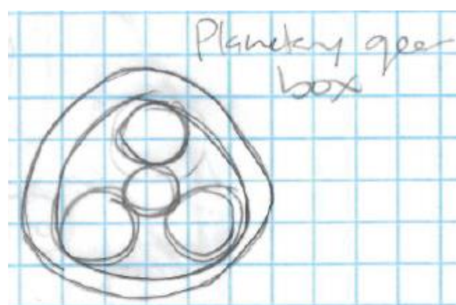

Figure A27: Planetary gearbox for resistance

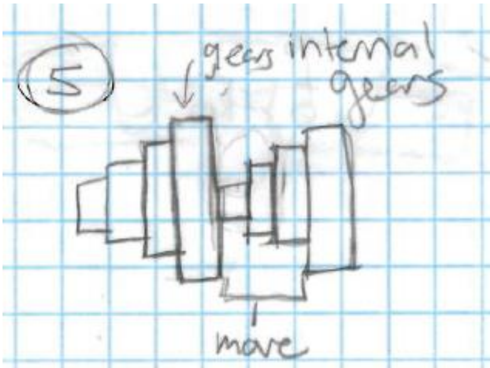

Figure A28: Internal gears for resistance

Display Feedback:

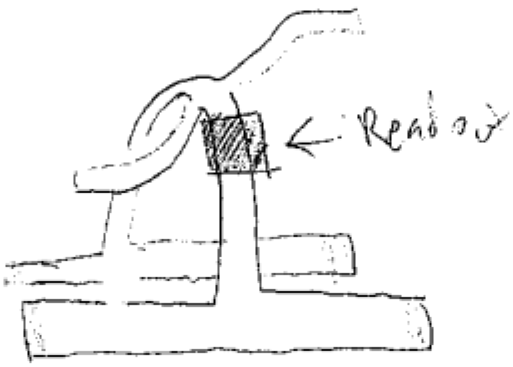

Figure A29: Position for digital time and distance readout

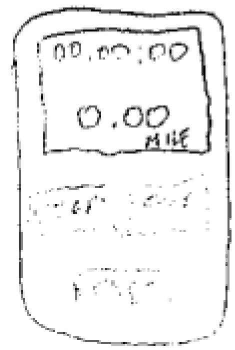

Figure A30: Digital readout with "stop," "start," and "reset" buttons

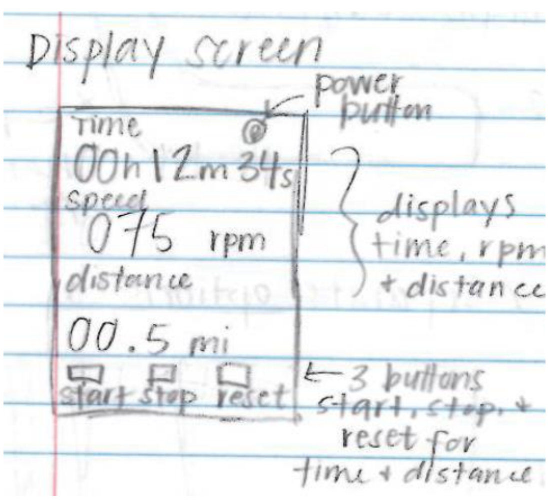

Figure A31: Display screen with power button, start, stop, reset and displaying time, rpm and distance

Figure A32: Analog distance readout similar to analog odometer on car dashboard

APPENDIX B: DESIGN SELECTION

Table B1: Anchoring Pugh Chart

	Weight	Separate Friction Mat	Large Bottom Surface Area	Weight Distribution	"Passive" Suction Cups	"Active" Suction Cups	High Friction Feet Grips	Connected "Stopper"
Stationary During Use	10	2	1	1	1	2	1	2
Ease of Operation	7	0	0	0	-1	-1	0	0
Low Price	9	-2	0	0	0	0	0	0
Compact Size	5	-1	-1	0	0	0	0	-1
Lightweight	7	0	-1	-3	0	0	0	0
Manufacturablility/ Feasibility	9	3	1	0	-1	-1	0	1
Total		**24**	**7**	**-11**	**-6**	**4**	**10**	**24**

Table B2: Frame Pugh Chart

	Weight	Notched adjustable centerpiece (crutches)	A-frame	Hinged for folding/ storage	Notched base (pool chair)	Fan with short legs off frame	Encasing unit with rectangular base	Bar frame with rectangular base
Stationary During Use	10	-1	0	-1	1	0	3	2
Ease of Operation	7	-1	0	-1	-1	0	0	0
Low Price	9	-1	0	0	-1	-2	-2	-1
Compact Size	5	0	-1	3	-1	-1	-1	0
Lightweight	7	0	-1	0	0	-1	-2	-1
Comfortable during Operation	7	2	0	0	2	0	0	0
Ease of Assembly	3	-1	0	-1	-1	0	0	0
Manufacturablility/ Feasibility	9	-1	1	-1	-1	-1	0	0
Durability	8	0	0	-1	-1	0	0	0
Total		**-24**	**-3**	**-22**	**-17**	**-39**	**-7**	**4**

Table B3: Pedal Design Pugh Chart

	Weight	Typical Bike Pedal	Flat on top, rounded with finger grooves on bottom	Flat pedals with side handlebars	Two different sets of pedals/handles to change out	Pedals with knurling
Multiple forms of exercise	10	0	0	0	0	0
Ease of Operation	7	0	2	3	3	1
Low Price	9	0	-1	-2	-3	-1
Compact Size	5	0	0	-1	-1	0
Lightweight	7	0	0	-1	0	0
Comfortable during Operation	7	0	2	3	3	1
Ease of Assembly	3	0	0	-1	-2	0
Manufacturablility/ Feasibility	9	0	-2	-3	-2	-1
Durability	8	0	0	0	-1	0
Total		**0**	**1**	**-18**	**-14**	**-4**

Table B4: Pedal Straps Pugh Chart

	Weight	Velcro	Tied Laces	Adjustable Buckle Strap	Rubber Strap with Multiple Holes
Multiple forms of exercise	10	0	0	0	0
Ease of Operation	7	2	-2	-1	0
Low Price	9	2	2	0	0
Compact Size	5	2	2	2	0
Lightweight	7	2	3	2	0
Pedal Size Inclusivity	6	2	3	3	0
Comfortable during Operation	7	-3	-2	0	0
Ease of Assembly	3	0	-1	0	0
Manufacturablility/Feasibility	9	2	2	2	0
Durability	8	-3	-2	-1	0
Total		**41**	**38**	**45**	**0**

Table B5: Resistance Pugh Chart

	Weight	Fan	Single Brake Pad (varying pressure)	Multiple Brake Pads (Add with tension)	Internal Gears	Pressurized fluid resistance	Resitance Band(s)	Planetary Gearbox	Magnet
Apply Resistance	9	3	2	3	3	1	1	2	3
Quantifiable Resistance	9	-2	1	2	2	1	1	2	2
Low Price	9	-2	-1	-2	-3	-2	-1	-2	-3
Compact Size	5	-1	0	0	0	0	0	0	0
Lightweight	7	-1	0	0	0	0	0	0	-1
Comfortable during Operation	7	2	0	0	0	0	0	0	0
Manufacturablility/ Feasibility	9	-1	2	1	-2	-3	1	-1	-1
Durability	8	2	0	0	1	1	1	1	3
Total		**0**	**36**	**44**	**8**	**-19**	**26**	**17**	**26**

APPENDIX C: INITIAL CONCEPT ANALYSIS

Resistance Concept: Caliper

One of our initial resistance designs we carried through with until we encountered the brake band was a caliper resistance mechanism. For this plan, we were going to have 2 felt pads applying varying forces to an aluminum rotor (one pad on each side) in order to have varying resistances. We examined various types of material used for contact resistance with stationary bikes [16] and two of the main materials that are used are felt and leather. After examining the materials specifically, we learned that leather requires a lot of upkeep in terms of constant lubrication [28], so we figured felt would be the best option. The felt brake pads were each going to be connected to a brake arm, where the end of each brake arm is connected to a firm wire wrapped around a spool (Fig. C1, below). The spool would have a small section to wrap the wire around and a large hand knob on the other end for the user to be able to turn with their hand and adjust the resistance. The resistance mechanism would be mounted inside of housing through a dowel and the overlapping hole in the center of the two brake arms. The hand knob would be accessible from the outside of the housing, while the winding spool would stay inside of the housing.

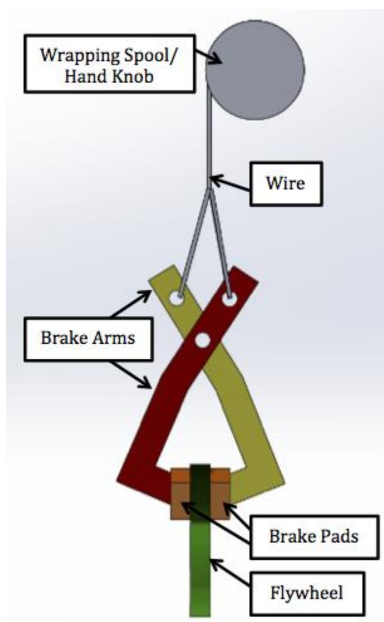

Figure C1: Resistance mechanism

Resistance Engineering Analysis: Caliper

During primary analysis of the resistance system, we wanted to determine what the dimensions of the adjustment knob would be compared to the dimensions of the cable spool holding the tension in the resistance system to apply force to the brake pads. We decided that at the maximum resistance setting, 80% of the maximum leg force applied by the user should be impeded by friction. Figure C2 (p. 52) shows a rough free body diagram of the resistance system including the friction force (F_f) located 1.75 inches away from the rotating axis pointing in the opposite direction from the force exerted by the leg (F_l) acting 2.375 inches from the rotating axis.

$$0.8*F_l*2.375in=F_f*1.75in \quad \text{[Eq. C1]}$$

$$F_f=\mu*N \quad \text{[Eq. C2]}$$

We assume that the friction force is equally split between the two brake pads. We also assume that the brake arms have equal length on either side of the pivot point so that the normal force on the brake pads is equal to the tension in the cable.

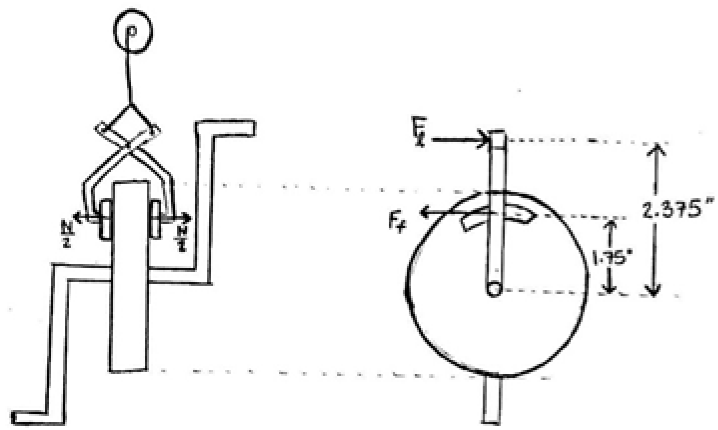

Figure C2: Analysis of resistance system

Figure C3 (below) shows a zoomed in sketch of the resistance knob attached to the cable spool. We need to ensure that the user has enough strength in their wrist and forearm (we designate the force exerted by the hand as F_h) to twist this knob to tighten the device to the calculated maximum friction. We assign the radius of the handle to the variable r_h and the radius of the cable spool to r_c.

$$F_h*r_h=N*r_c \quad \text{[Eq. C3]}$$

$$r_h/r_c=N/F_h=1.086*F_l/(F_h*\mu) \quad \text{[Eq. C4]}$$

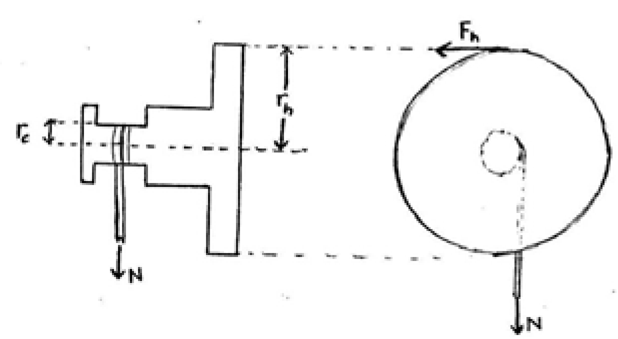

Figure C3: Analysis of resistance adjustment knob attached to cable spool

We conducted research to find values for μ, F_l, and F_h. We wanted to find the 95th percentile for the leg force applied by humans and the 5th percentile for hand force applied by humans to account for the worst case scenario. We used a coefficient of friction of 0.27 which was found as the coefficient of friction between straw fiber and aluminum [29]. We could not find a coefficient of friction between felt and aluminum but we took this value as an approximation. We then found the maximum force exerted by a male's legs by taking the standard values for leg press strength as a fraction of body weight [30] and combining it with the 95th percentile weight of males [31] to get a final F_l of 280.8 pounds of force. We found the 95th percentile of twisting hand torque similar to our application [32] and converted that to find the force F_h to be 45.6 pounds of force.

$$r_h/r_c=1.086*280.8lbf/(45.6lbf*0.27)=24.77 \qquad \text{[Eq. C5]}$$

This ratio of handle radius versus cable spool radius is very high. It implies that if there was a spool with a diameter of 0.5 inches then the hand knob would have to be 12.4 inches in diameter.

This theoretical modeling was relatively quick and it told us that the dimensions of our resistance knob and spool will not work out in the way that we would like it to. From here, we conducted similar calculations in the opposite order to start with a desired r_h/r_c ratio. If we want to change the forces in this system, we will have to change the dimensions of the brake bars so we can no longer assume that the normal force on the friction pads is equal to the tension in the cable. Instead we introduce an additional tension force (T) as shown in Figure C4 (below). In this figure, L_1 is the distance between where the cable is attached to the brake arm and the pivot point of the brake arm and L_2 is the vertical moment arm of the normal force with respect to the pivot point.

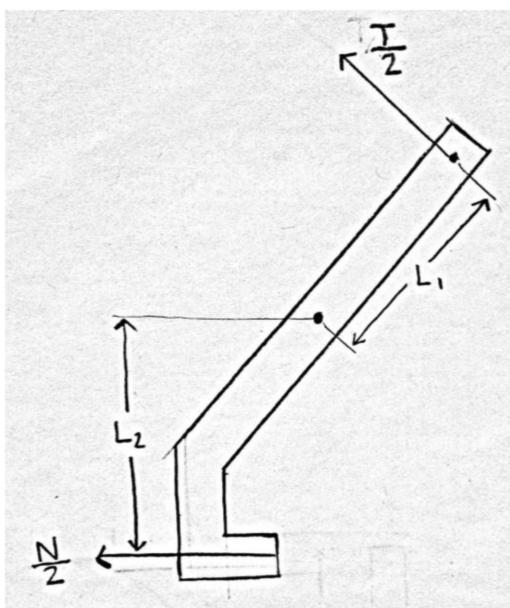

Figure C4: Forces in brake arm

The brake arms will each experience the same N/2 and T/2 forces and will have identical dimensions but one will be the mirror of the other. We can now introduce another equation in our calculations.

$$L_1*T/2=L_2*N/2 \qquad \text{[Eq. C6]}$$

And Equation C3 (p. 52) now becomes:

$$F_h*r_h=T*r_c \qquad \text{[Eq. C7]}$$

We decided that a reasonable r_h/r_c ratio would be 4. Using equations C1, C2, C6 and C7, we can find that L_1/L_2 is 6.19. We believe that this is achievable.

APPENDIX D: MANUFACTURING PLANS, DRAWINGS AND BILL OF MATERIALS

Table D1 is our Bill of Materials that shows all of the parts that we purchased (in stock) and machined. We have created manufacturing plans and drawings for all of the pieces that we fabricated. The manufacturing plans and corresponding drawings give step-by-step instructions on how we fabricated each individual piece.

We purchased a band brake and bicycle computer for immediate implementation into our prototype; these components required no further machining. We also purchased raw stock for the rotor (which was already sized for our needs), pedal bars, frame, and housing. We have used the lathe to drill out the center of the rotor, cutting the pedal bar pieces to size, and creating the grooves in the pedal bars. One challenge in manufacturing the disk we faced was holding the disk in the lathe to drill the center.

In creating 45-degree angle cuts in our pedal bar pieces to prepare them for welding, we used a digital protractor to measure a 45-degree angle at which the correctly-sized pedal rods were held in the vise of a mill. We used a ¾ inch, 4-flute endmill to remove material in multiple passes after advising from the machine shop staff. This proved to be challenging, as manual adjustment of the raw stock before milling was moderately inaccurate.

We 3D printed both of the pedals (Fig. D1). Some pros of using 3D printing are that it is easy to use, quick, and we can do complex geometry. However, 3D printing can be finicky and the resolution may not be ideal. For a conceptual prototype, though, we have determined this to be the best method for plastic components such as our pedals.

We used the lathe to turn the rotor to size and insert the center holes for the pedal bars to be welded to. As well, we are using the lathe to cut all of the pieces for the pedal bar to length and insert notches for the E-clips. (Fig. D3-D5).

We cut the 80/20 Aluminum stock pieces to length on a horizontal band saw. We cut the acrylic top plate on a laser cutter and we cut the sliding door on the water jet.

Table D1: Bill of Materials

Part #	Component	Qty	Stock Dimension	Supplier/ Manufacturer	Material	Part Number	Price ($)
1	Ground Pulley	1	2" pulley dia. for 3/16" cable	McMaster-Carr	Steel	3099T44	11.78
2	Hanging Pulley	1	1 1/2" pulley dia, for 3/16" cable	McMaster-Carr	Steel	3099T23	15.32
3	Cable	3.5'	1/16" wide cable	Lowe's	Galvanized Steel	348161	0.84
4	Pedal	2	5" x 1 3/4" x 1 1/2"		ABS Plastic	-	-
5	Pedal strap	60"	1" wide	Jo-Ann Fabrics	Nylon	8600371	3.99
6	Pedal buckle/strap adjusters	2	1.5" x 1.25"	Jo-Ann Fabrics	Plastic	8589616	1.99
7	Disk	1	4" diameter, 1 1/4" long	McMaster-Carr	316 Stainless Steel	9260K5	67.97
8	Band Brake	1	4", 7/8" wide	Ebay/Manco	Composite	-	17.99
9	Display	1	1.8" x 1.8" x 0.5"	Amazon/AROVA	Plastic	-	13.96
10, 11, 12	Pedal rod	3'	1/2" diameter	McMaster-Carr	304 Stainless Steel	89535K15	15.13
13	Cable Stoppers	4	.25" dia, 1/8" thick	Lowe's	Aluminum	348525	1.05
14	Cable sleeves	4	3/8"x1/4"	Lowe's	Aluminum	348525	1.05
15	Magnet	1	0.25" diameter, 0.125" long	McMaster-Carr	Magnetized	D1044	0.5
16	E-type Retaining Ring	6	For 1/2" shaft	McMaster-Carr	Stainless Steel	98408A138	6.44
17	L- Bracket	1'	1" x 2" legs, 3/16" thick	McMaster-Carr	6061 Aluminum	8982K92	5.46
18	Dowel pin	1"	3/16" dia	MEX50 Assembly Room	Steel	-	-
19, 24	Pulley Plate, Sensor Bracket	1	1/16" thick x 3"x8"	MEX50 Assembly Room	6061 Aluminum	-	-
20	Top Locking Plate	1	1/4" thick acrylic	McMaster-Carr	Acrylic	4615T27	6.63

Part #	Component	Qty	Stock Dimension	Supplier/ Manufacturer	Material	Part Number	Price ($)
21	Door	1	1/4" thick x 2"x1"	McMaster-Carr	6061 Aluminum	8975K596	1.72
22, 23	Brackets	8.25"	1/8" thick, 1" wide	MEX50 Assembly Room	6061 Aluminum	-	-
25	Frame	9'	1" 80/20 Aluminum	McMaster-Carr	80/20 Aluminum	47065T101	26.38
26	90 Degree 80/20 Brackets	10	1" x 1"	McMaster-Carr	Aluminum	47065T216	55.1
27	Screw for 90 degree brackets	20	1/4-20 3/8" long	McMaster-Carr	Stainless Steel	-	-
28	T-slot nut for 90 degree bracket	20	1/4-20 thread	McMaster-Carr	Stainless Steel	-	-
29	Split mounted sleeve bearings	2	For 1/2" diameter rod	McMaster-Carr	Cast Iron	6359K32	112.62
30	4" x 1" plate for T-slot frame	2	4" x 1"	McMaster-Carr	Aluminum	47065T259	13.48
31	T-slot nut	26	1/8" thick x 1" x 3/4"	80/20 inc.	Stainless Steel	3382	10.77
32	1/4-20 1/2" Screw	30	1/4-20 1/2"	MEX50 Assembly Room	Stainless Steel	-	-
33	3/8" dia, 2" long bolt	2	3/8" dia, 2" long	MEX50 Assembly Room	Stainless Steel	-	-
34	3/8" dia Nut	4	3/8" dia	MEX50 Assembly Room	Stainless Steel	-	-
35	3/8" Washer	4	3/8"	MEX50 Assembly Room	Stainless Steel	-	-
36	1/8" dia Screw, 1/4" long	4	1/8" dia, 1/4" long	MEX50 Assembly Room	Stainless Steel	-	-
37	1/8" Nut	4	1/8"	MEX50 Assembly Room	Stainless Steel	-	-
38	1/4" Washer	16	1/4"	MEX50 Assembly Room	Stainless Steel	-	-
39	Vinyl mat (also used on handle)	1	1' x 13"	Lowe's	Vinyl	174006	6.97
40	Electrical Tape	2'		MEX50 Assembly Room	Vinyl	-	-
						Total	**397.14**

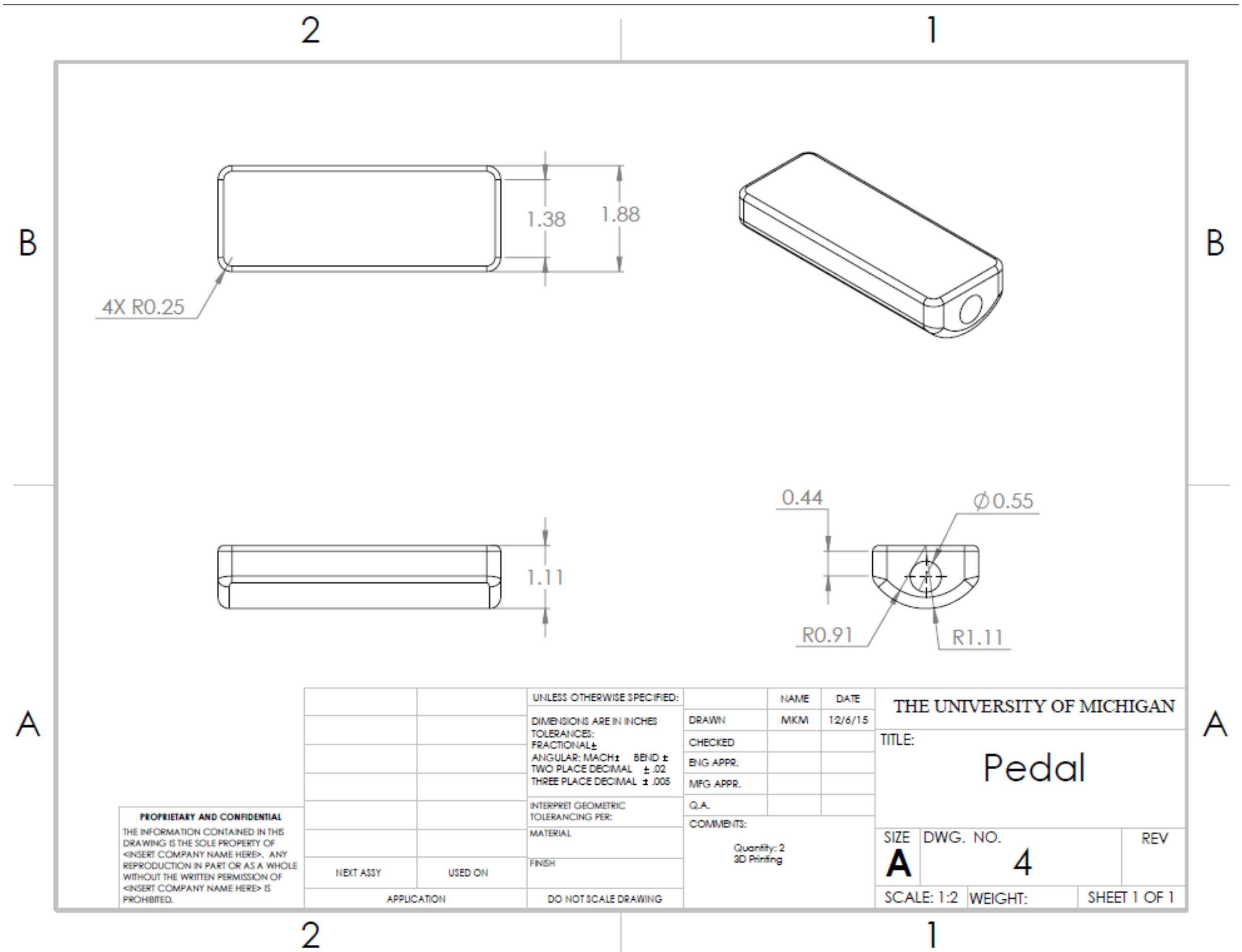

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Figure D.1

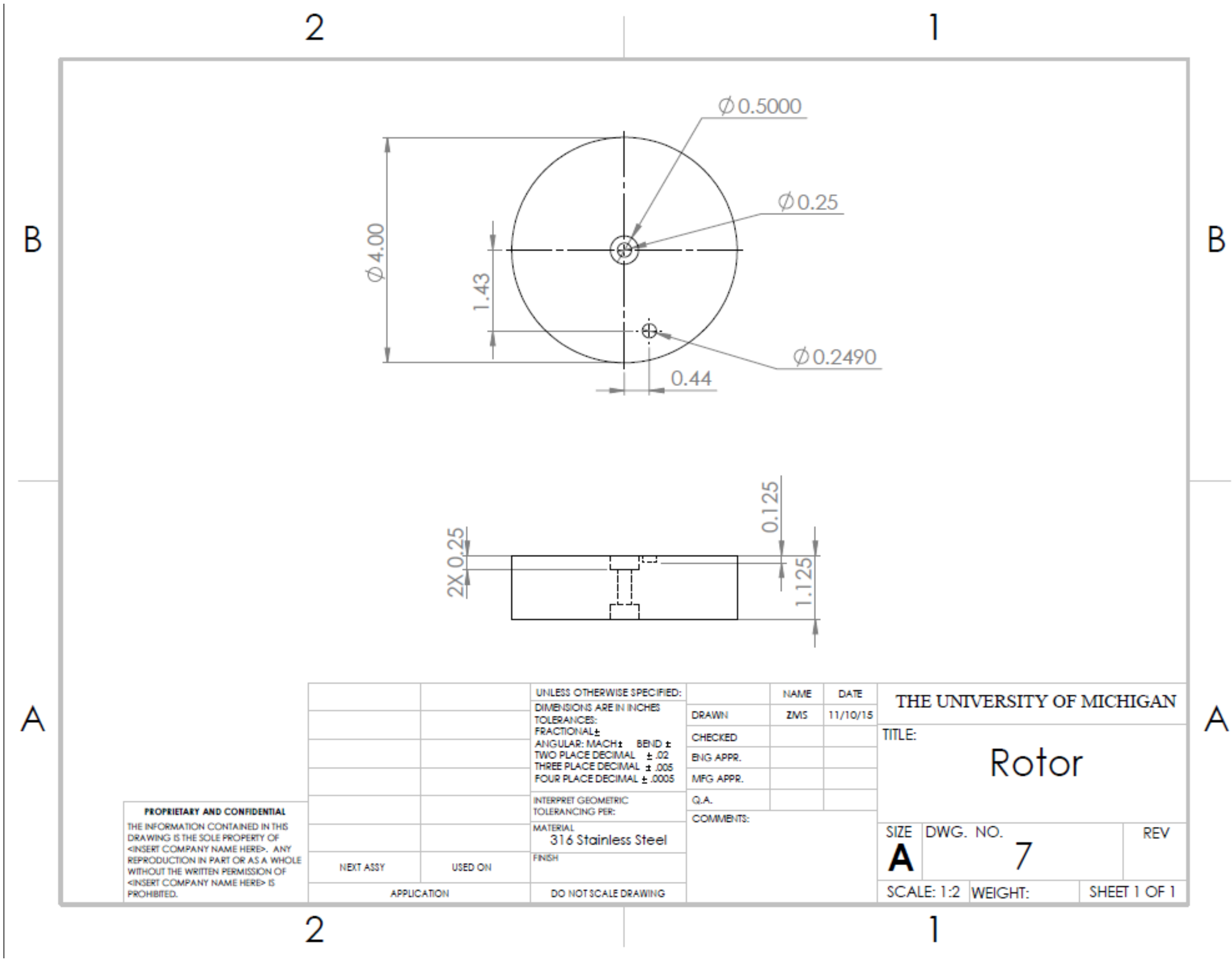

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Figure D.2

Manufacturing Plan

Part Number and Name: 7- Disk

Revision Date: 11/10/2015

Part Name: Disk Brake

Team Name: Team 25

Raw Material Stock: 316 Stainless Steel Rod 4" Diameter, 1 1/4" long

Step #	*Process Description*	*Machine*	*Fixtures*	*Tool(s)*	*Speed (RPM)*
1	Hold part in lathe				
2	Turn face down 1/16"	Lathe			<1000
3	Centerdrill the hole	Lathe		Center drill	<1000
4	Drill hole to 1/4"	Lathe		1/4" drill bit	<1000
5	Drill hole 31/64" at a depth of 1/4"	Lathe		31/64" drill bit	<500
6	Ream hole to 0.5" at a depth of 1/4"	Lathe		0.5" reamer	100
7	Turn piece around, measure rod thickness and hold the other side in the lathe	Lathe		Caliper	
8	Turn face down until rod width is 1.125", measuring with caliper	Lathe		Caliper	<1000
9	Drill hole 31/64" at a depth of 1/4"	Lathe		31/64" drill bit	<500
10	Ream hole to 0.5" at a depth of 1/4"	Lathe		0.5" reamer	100
11	Bring piece to mill. Install drill chuck. Find datum lines for X and Y.	Mill	Vise	drill chuck and edge finder	<900
12	Centerdrill the hole	Mill	Vise	Center drill and drill chuck	<1200
13	Drill hole to 15/64" and 0.125" deep	Mill	Vise	15/64" drill bit, drill chuck	<850
14	Ream hole to 0.2495" and 0.125" deep	Mill	Vise	0.2495" reamer, drill chuck	100
15	Clean up work station and return tools				

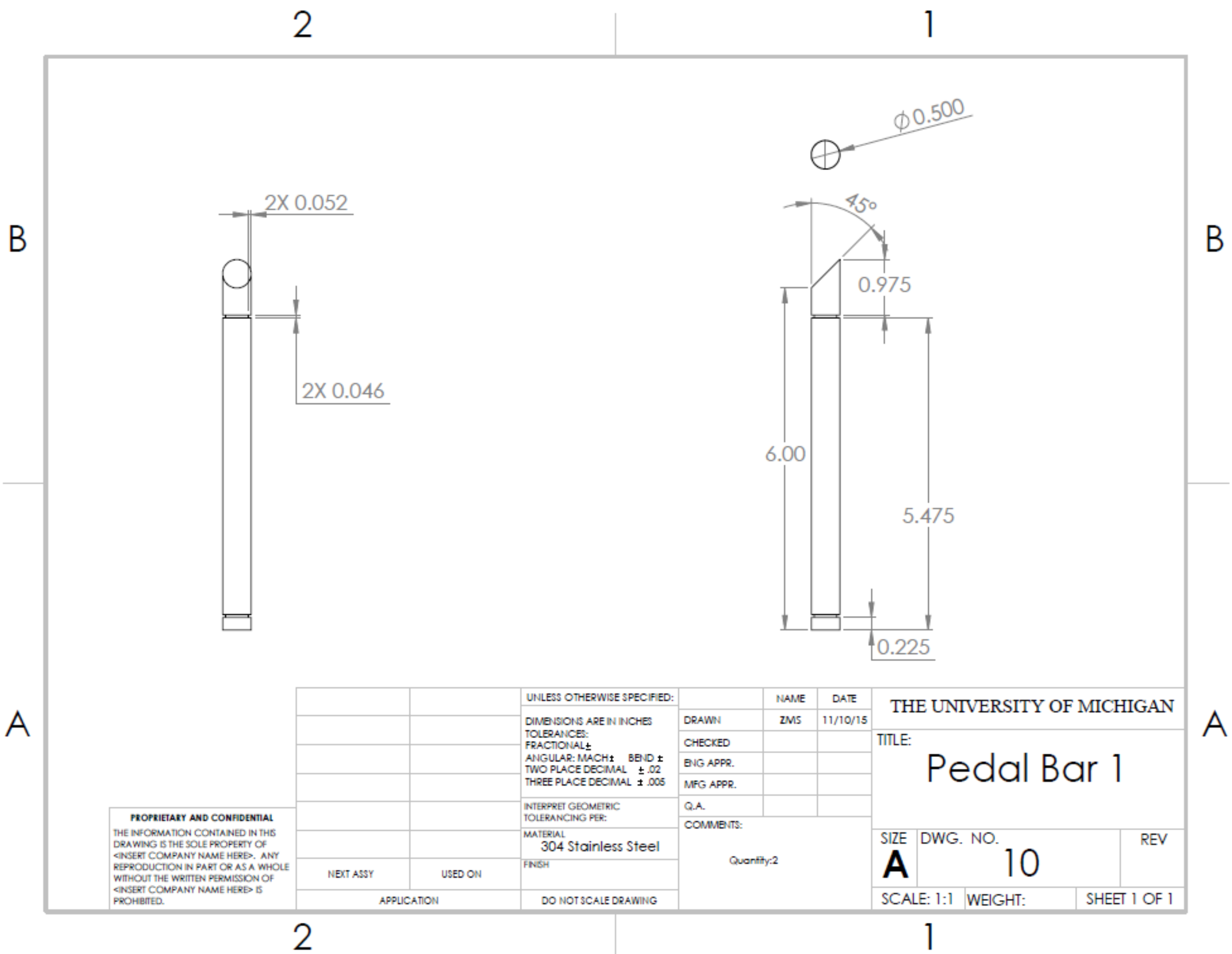
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Figure D.3

Manufacturing Plan

Part Number and Name: 10 - Pedal Rod 1 Revision Date: 12/6/2015

Team Name: Team 25

Raw Material Stock: 304 Stainless Steel Rod, 1/2" diameter, 3 ft long

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to approximate size	Band Saw			
2	Break edges by hand			File	
3	Hold part in Lathe	Lathe			
4	Turn piece down to exact length - 6 3/4"	Lathe			<1000
5	Change tool to one with thickness of 0.035"				
6	From the edge, measure in 0.260" and create a .052" deep groove with the 0.035" tool	Lathe		0.035" thick tool	<1000
7	Move in to 0.275" and create a .052" deep groove with the 0.035" tool	Lathe		0.035" thick tool	<1000
8	Take piece out of lathe and turn it around	Lathe			
9	From the edge, measure in 1.260" and create a .052" deep groove with the 0.035" tool	Lathe		0.035" thick tool	<1000
10	Move in to 1.275" and create a .052" deep groove with the 0.035" tool	Lathe		0.035" thick tool	<1000
11	Take piece to mill and install in vise at 45 degree angle so the notch that is 1.25" from the edge is the one to be cut	Mill	Vise		
12	Cut down edge at 45 degree angle, measure length of piece inbetween to make sure that it's final length is 6.5"	Mill	Vise	3/4 inch 4-flute endmill, collet, calipers	<850
13	Clean up workspace and return tooks				

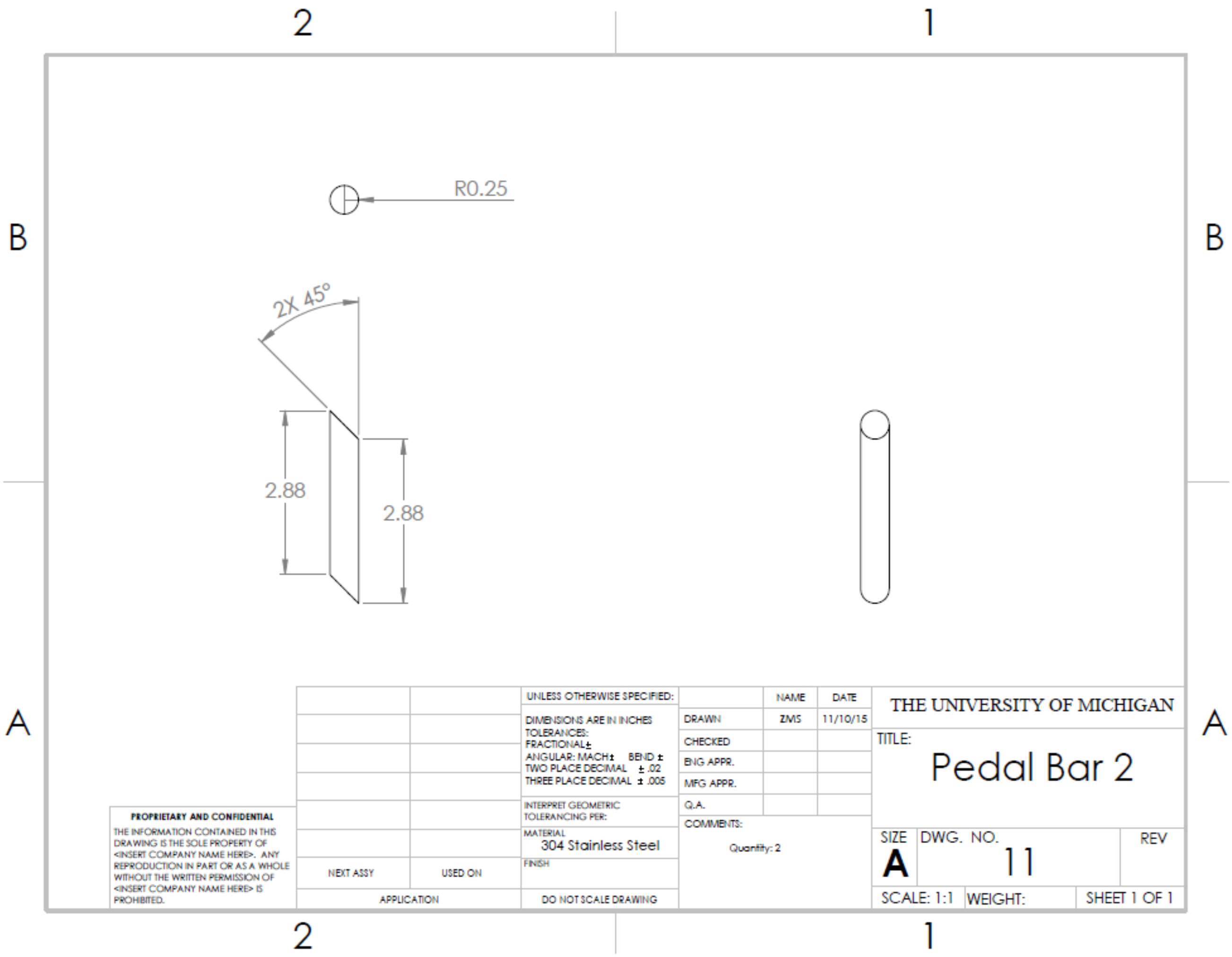
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Figure D.4

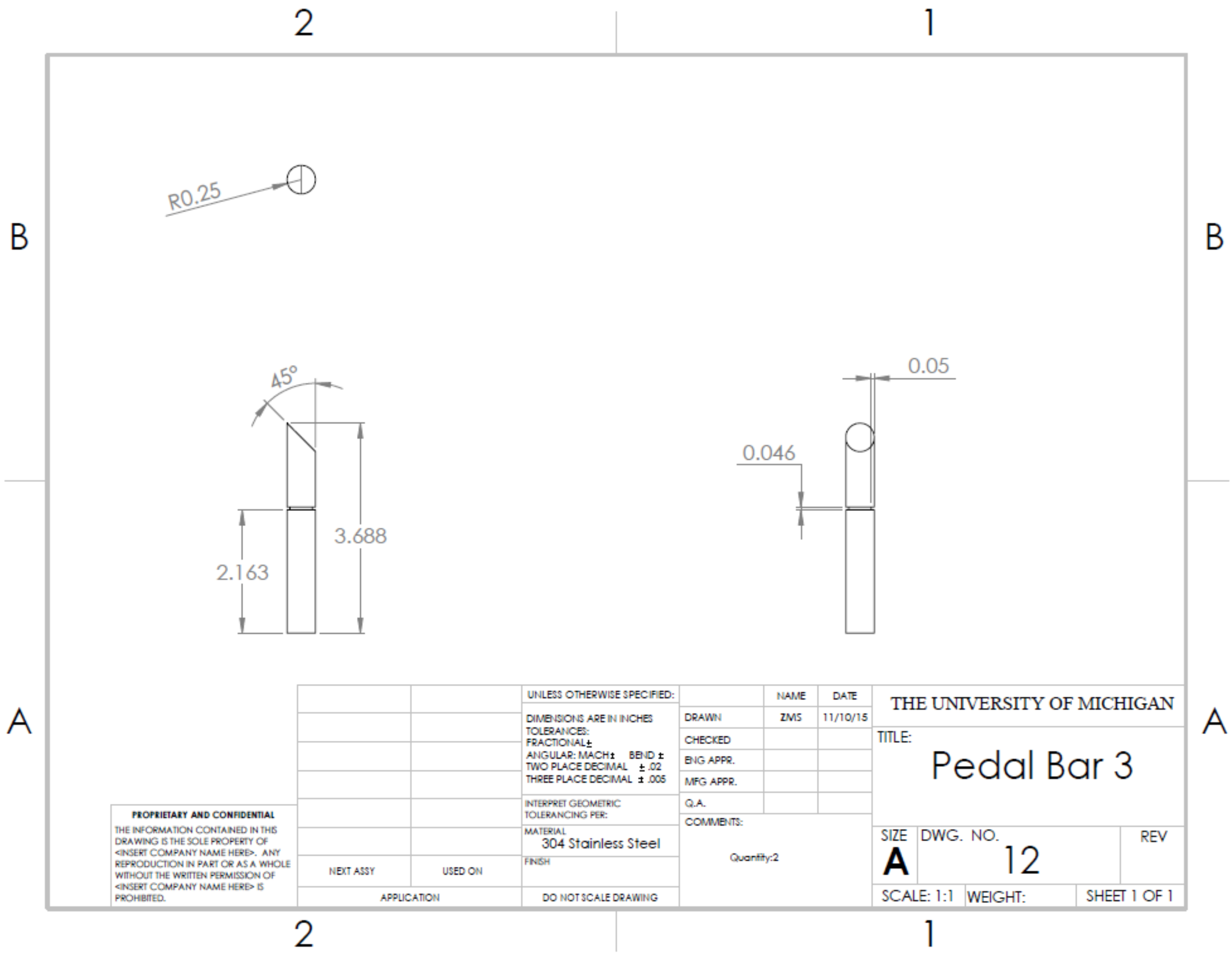
Manufacturing Plan

Part Number and Name: 11 - Pedal Rod 2 Revision Date: 12/6/2015

Team Name: Team 25

Raw Material Stock: 304 Stainless Steel Rod, 1/2" diameter, 3 ft long

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to approximate size	Band Saw			
2	Break edges by hand			File	
3	Take piece to mill and install in vise at 45 degree angle	Mill	Vise		
4	Cut down edge at 45 degree angle	Mill	Vise	1/4th inch 4-flute endmill, collet	<850
5	Turn piece around so that the 45 degree angle is flat on the bottom, and hold piece in vise	Mill	Vise		
6	Cut down edge at 45 degree angle. Measure and cut until the length from corner to corner is 3.375"	Mill	Vise	1/4th inch 4-flute endmill, collet, calipers	<850
7	Clean up workspace and return tooks				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INTERPRET GEOMETRIC TOLERANCING PER:
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Figure D.5

Manufacturing Plan

Part Number and Name: 12 - Pedal Rod 3 Revision Date: 12/6/2015

Team Name: Team 25

Raw Material Stock: 304 Stainless Steel Rod, 1/2" diameter, 3 ft long

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to approximate size	Band Saw			
2	Break edges by hand			File	
3	Hold part in Lathe	Lathe			
4	Turn piece down to exact length - 3.95"	Lathe			<1000
5	Change tool to one with thickness of 0.035"				
6	From the edge, measure in 1.77" and create a .052" deep groove with the 0.035" tool	Lathe		0.035" thick tool	<1000
7	Move in to 1.785" and create a .052" deep groove with the 0.035" tool	Lathe		0.035" thick tool	<1000
8	Take piece to mill and install in vise at 45 degree angle so the notch that is 2.16" from the edge is the one to be cut	Mill	Vise		
9	Cut down edge at 45 degree angle, measure length of piece inbetween to make sure that it's final length is 3.69"	Mill	Vise	1/4th inch 4-flute endmill, collet, calipers	<850
10	Clean up workspace and return tooks				

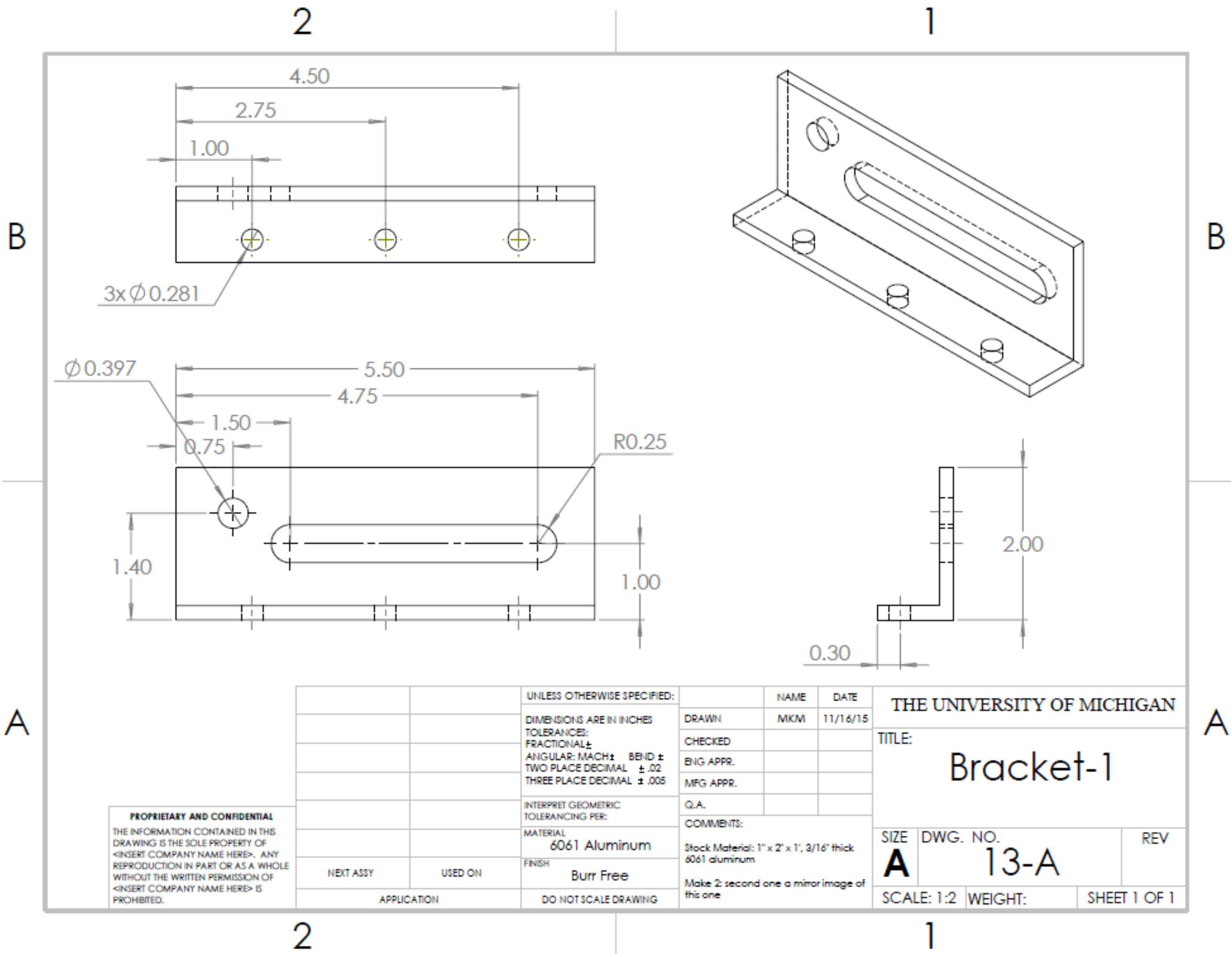
4.50
2.75
1.00
3x∅0.281
∅0.397
5.50
4.75
1.50
0.75
R0.25
1.40
1.00
2.00
0.30
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ± .02
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
Burr Free
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
MKM
11/16/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Stock Material: 1" x 2" x 1', 3/16" thick 6061 aluminum
Make 2: second one a mirror image of this one
THE UNIVERSITY OF MICHIGAN
TITLE:
Bracket-1
SIZE
A
DWG. NO.
13-A
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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Figure D.6

Manufacturing Plan

Part Number and Name: 13 - Bracket

Revision Date: 11/16/2015

Team Name: Team 25

Raw Material Stock: 6061 Aluminum 1" x 2" with 3/16" wall thickness

Step #	*Process Description*	*Machine*	*Fixtures*	*Tool(s)*	*Speed (RPM)*
1	Cut part to approximate size	Band Saw			300
2	Break edges by hand			File	
3	Install piece in vise and cut piece to length (5.5")	Mill	Vise	1/4th inch 2-flute endmill, collet	<1000
4	Find X and Y datum	Mill	Vise	Drill chuck and edge finder	<900
5	Centerdill the hole on the 1" side	Mill	Vise	Drill chuck and center drill	<1000
6	Drill the hole to size and chamfer	Mill	Vise	Chamfer and number 2 drill bit	<1200
7	Centerdill the next hole	Mill	Vise	Drill chuck and center drill	<1000
8	Drill the hole to size and chamfer	Mill	Vise	Chamfer and number 2 drill bit	<1200
9	Centerdill the final hole on the 1" side	Mill	Vise	Drill chuck and center drill	<1000
10	Drill the hole to size and chamfer	Mill	Vise	Chamfer and number 2 drill bit	<1200
11	Take piece out of mill and turn it to drill holes on 2" leg	Mill	Vise		
12	Find X and Y datum	Mill	Vise	Drill chuck and edge finder	<900
13	Centerdrill the hole	Mill	Vise	Drill chuck and center drill	<1000
14	Drill the hole to size	Mill	Vise	X drill bit	<1200
15	Cut out slot	Mill	Vise	1/2" 2 flute endmill and collet	<1000
16	Clean up area and return tools				

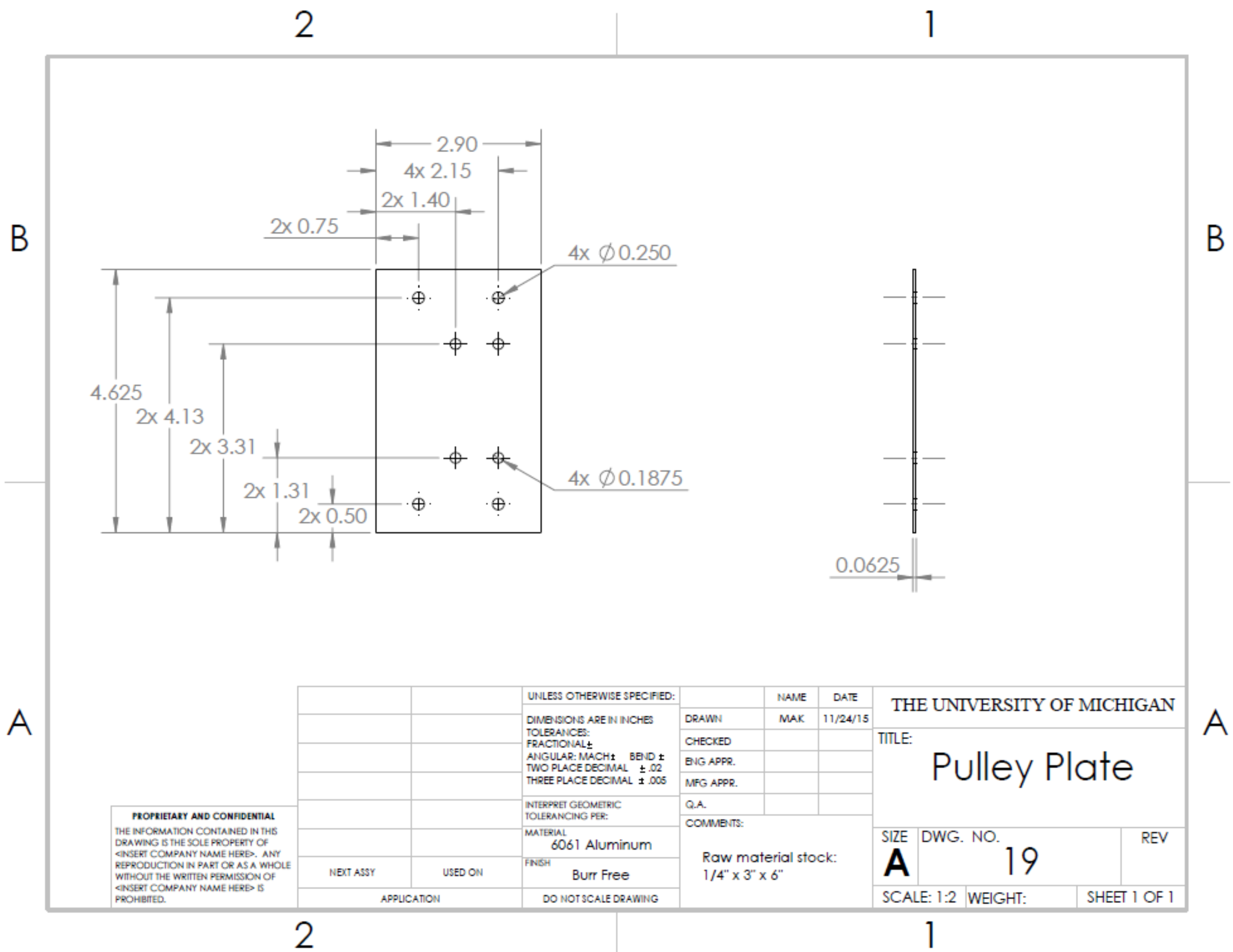
2.90
4x 2.15
2x 1.40
2x 0.75
4x ∅0.250
4x ∅0.1875
4.625
2x 4.13
2x 3.31
2x 1.31
2x 0.50
0.0625
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ± .02
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
Burr Free
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MAK
11/24/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Raw material stock:
1/4" x 3" x 6"
THE UNIVERSITY OF MICHIGAN
TITLE:
Pulley Plate
SIZE
A
DWG. NO.
19
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
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Figure D.7

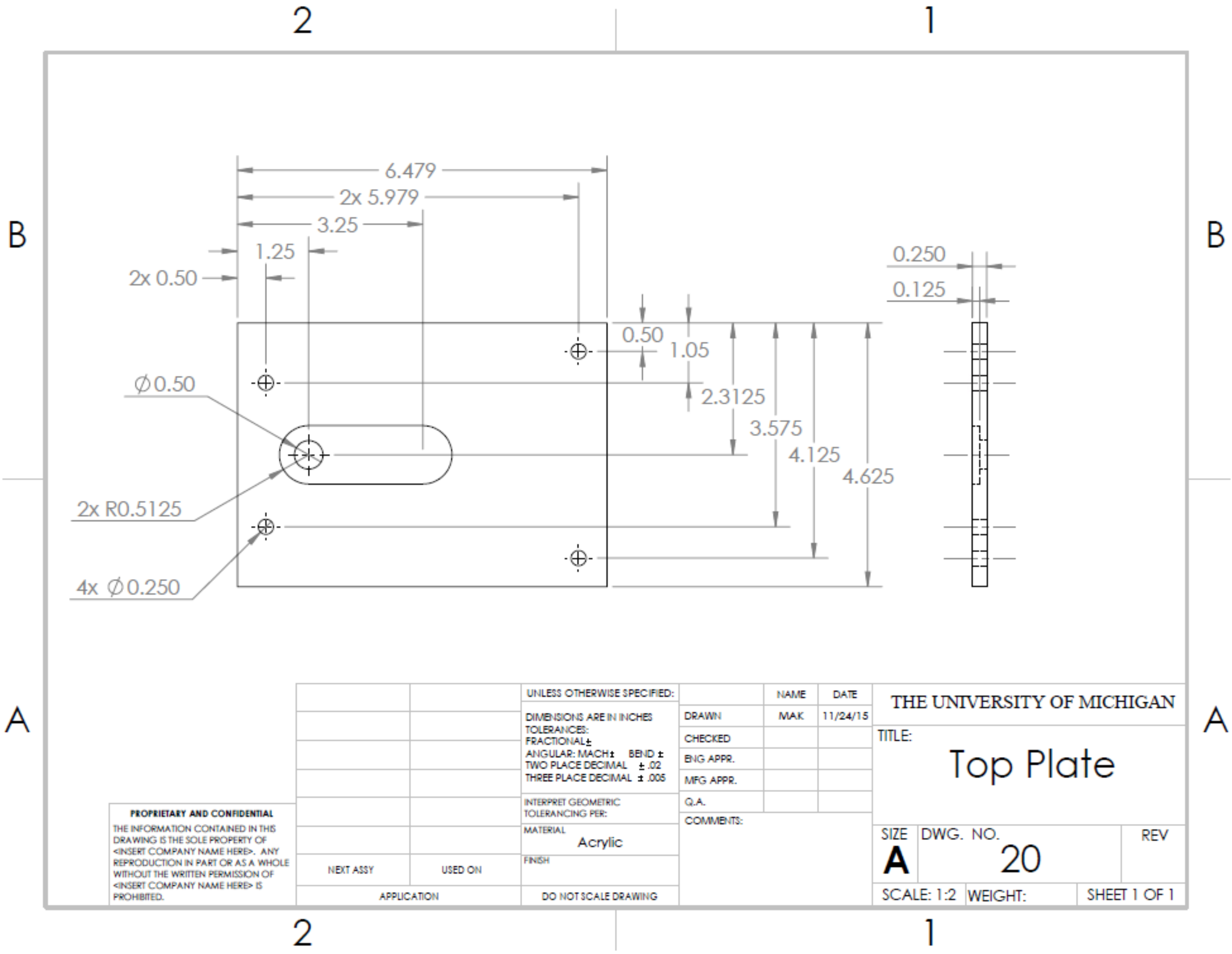
Manufacturing Plan

Part Number: 19
Part Name: Pulley Plate
Team Name: Team 25

Revision Date: 12/6/2015

Raw Material Stock: 1/4" x 3" x 6" 6061 Aluminum

Step #	***Process Description***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to size.	Band Saw			300
2	Break edges by hand.			File	
3	Locate points for the holes and center punch			Center punch and caliper	
4	Center drill and drill holes to appropriate size	Drill press		Center drill and 1/4" and 3/16" drill	
5	Break edges by hand.			Deburring tool	
6	Clean work station and return tools				



2
1
B
A
6.479
2x 5.979
3.25
1.25
2x 0.50
0.250
0.125
0.50
1.05
Ø0.50
2.3125
3.575
4.125
4.625
2x R0.5125
4x Ø0.250
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Acrylic
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MAK
11/24/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
THE UNIVERSITY OF MICHIGAN
TITLE:
Top Plate
SIZE
A
DWG. NO.
20
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
USED ON
APPLICATION
PROPRIETARY AND CONFIDENTIAL
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Figure D.8

Manufacturing Plan

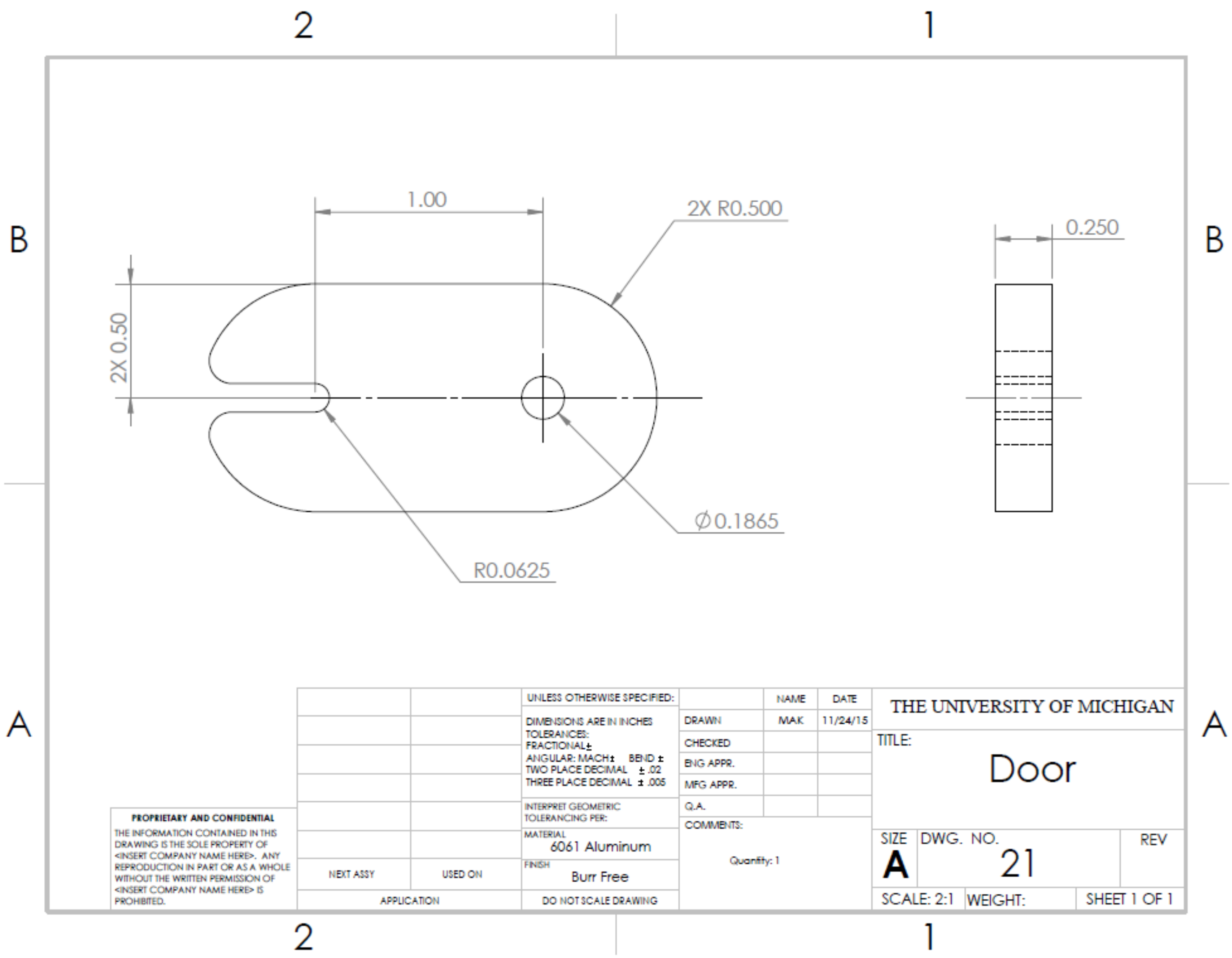
Part Number: 20 Revision Date: 12/6/2015

Part Name: Top Plate

Team Name: Team 25

Raw Material Stock: 1/4" x 6" x 12" Acrylic plate

Step #	***Process Descripti***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Put piece in laser cutter to cut to size and add holes	Band Saw			300
2	Break edges by hand.			File	
3	Hold part in vise.	Mill	Vise		
4	Use endmill to form slot to .125" deep removing .020" per pass.	Mill	Vise	1" 2-flute endmill, collet	<1000
5	Remove part from vise and file edges			File	
6	Clean work station and return tools				


2
1
B
A
1.00
2X R0.500
2X 0.50
R0.0625
∅0.1865
0.250
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
Burr Free
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MAK
11/24/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Quantity: 1
THE UNIVERSITY OF MICHIGAN
TITLE:
Door
SIZE
A
DWG. NO.
21
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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USED ON
APPLICATION

Figure D.9

Manufacturing Plan

Part Number: 21 Revision Date: 11/24/2015
Part Name: Door
Team Name: Team 25

Raw Material Stock: 1/4" x 3" x 6" 6061 Aluminum

Step #	***Process Descripti***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to size	Water Jet			
2	Break edges by hand.			File	
3	Hold part in vise.	Mill	Vise		
4	Use edge finder to find X and Y datum			Drill chuck and edge finder	<900
5	Center drill and then drill hole	Mill	Vise	Center drill, drill chuck, 5/32" drillbit	<1000
6	Ream hole	Mill	Vise	drill chuck, .1865" reamer	100
7	Clean work station and return tools				

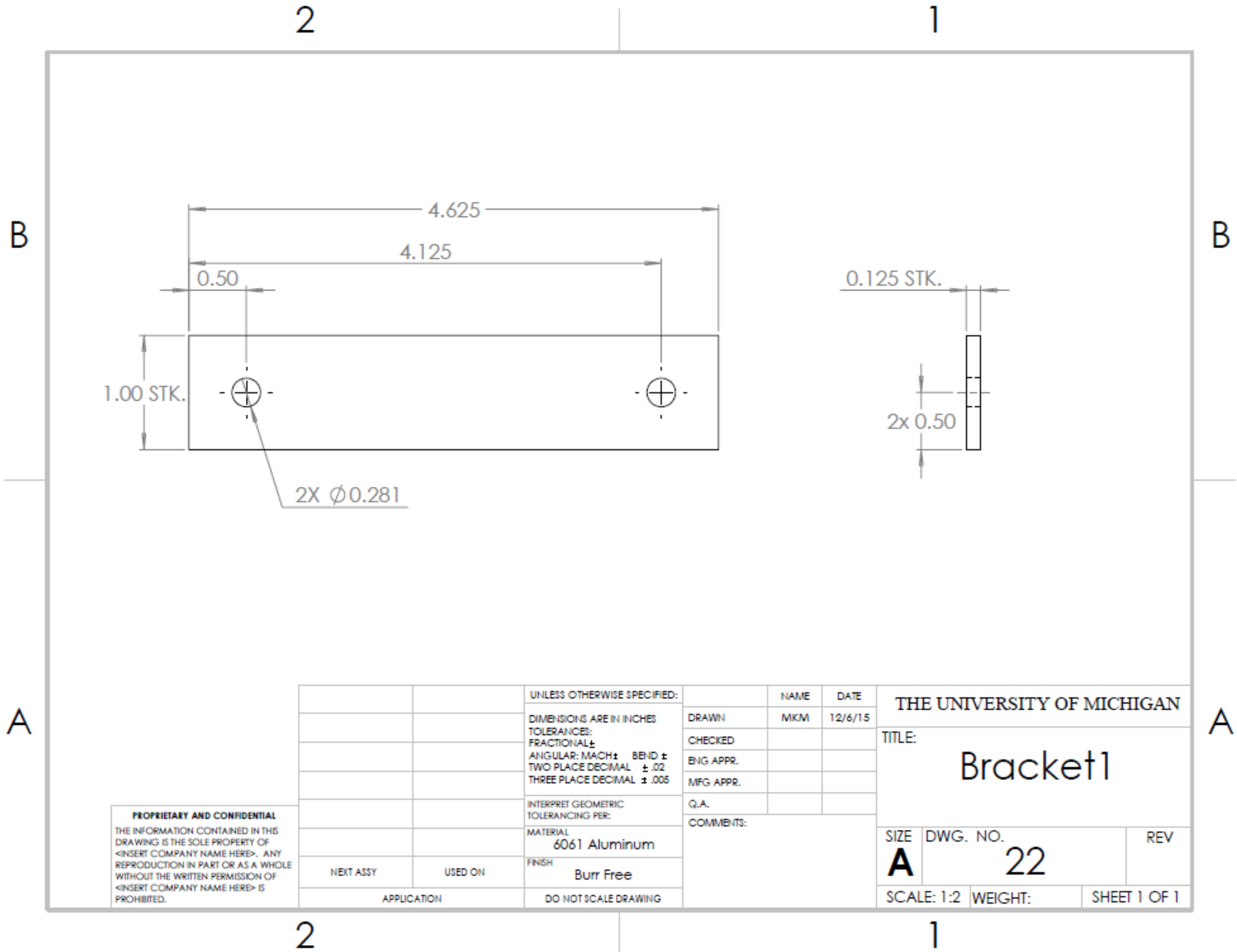
4.625
4.125
0.50
1.00 STK.
2X Ø0.281
0.125 STK.
2x 0.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
Burr Free
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
MKM
12/6/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
THE UNIVERSITY OF MICHIGAN
TITLE:
Bracket1
SIZE
A
DWG. NO.
22
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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Figure D.10

Manufacturing Plan

Part Number: 22

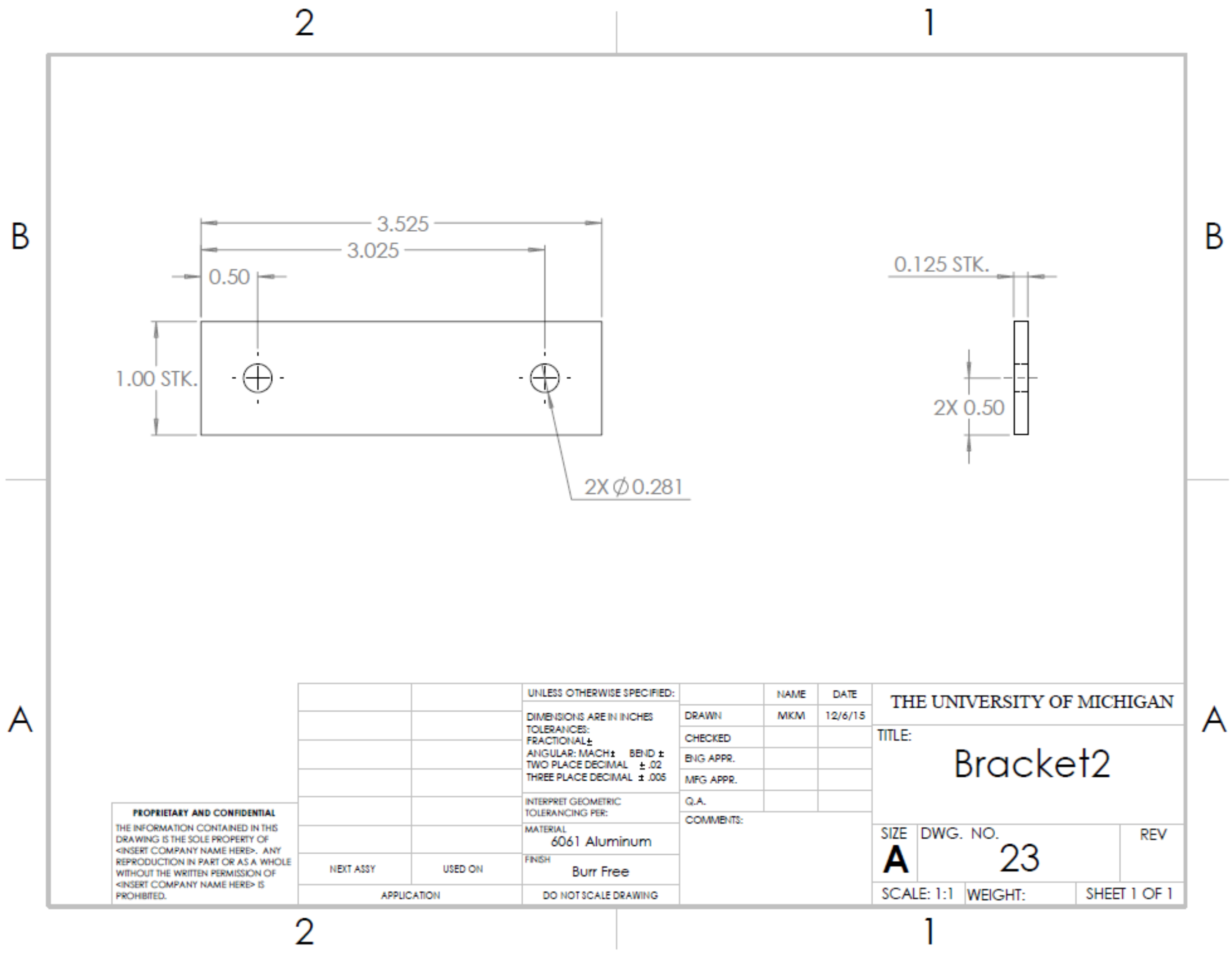
Revision Date: 12/6/2015

Part Name: Bracket 1

Team Name: Team 25

Raw Material Stock: 1/8" thick 6061 Aluminum

Step #	***Process Descripti***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to length	Band Saw			300
2	Break edges by hand.			File	
3	Locate points for the holes and mark			Caliper	
4	Center drill and drill holes to appropriate size	Drill press		Center drill bit and 9/32" drill bit	
5	Break edges by hand.			Deburring tool	
6	Clean work station and return tools				


2
1
B
A
3.525
3.025
0.50
1.00 STK.
2X ∅ 0.281
0.125 STK.
2X 0.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ± .02
THREE PLACE DECIMAL ± .005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
Burr Free
DO NOT SCALE DRAWING
NAME
DATE
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MKM
12/6/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
THE UNIVERSITY OF MICHIGAN
TITLE:
Bracket2
SIZE
A
DWG. NO.
23
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
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Figure D.11

Manufacturing Plan

Part Number: 23 Revision Date: 12/6/2015
Part Name: Bracket2
Team Name: Team 25

Raw Material Stock: 1/8" thick 6061 Aluminum

Step #	***Process Descripti***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to length	Band Saw			300
2	Break edges by hand.			File	
3	Locate points for the holes and mark			Caliper	
4	Center drill and drill holes to appropriate size	Drill press		Center drill bit and 9/32" drill bit	
5	Break edges by hand.			Deburring tool	
6	Clean work station and return tools				

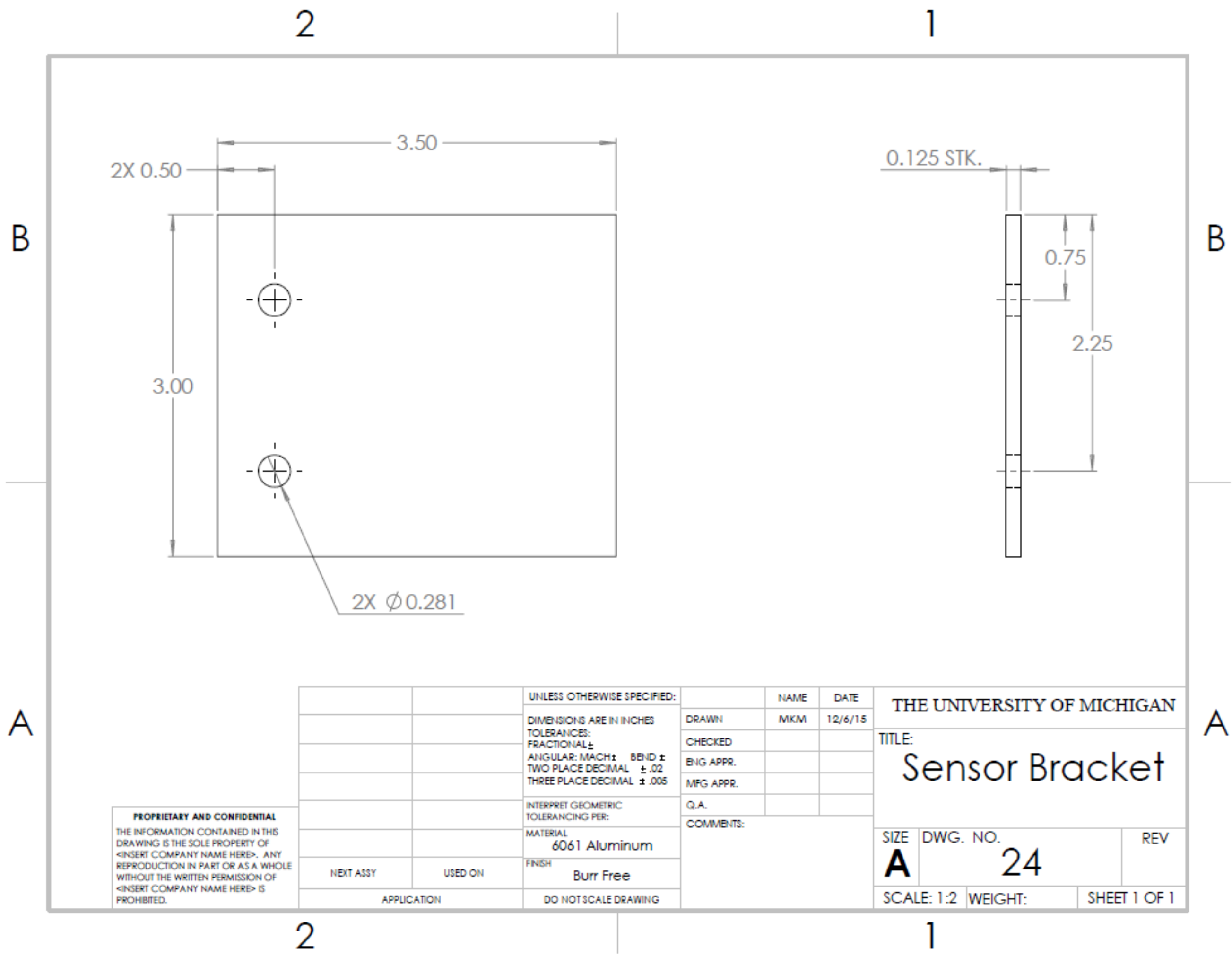
3.50
2X 0.50
0.125 STK.
0.75
2.25
3.00
2X ⌀0.281
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
6061 Aluminum
FINISH
Burr Free
DO NOT SCALE DRAWING
NEXT ASSY
USED ON
APPLICATION
NAME
DATE
DRAWN
MKM
12/6/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
THE UNIVERSITY OF MICHIGAN
TITLE:
Sensor Bracket
SIZE
A
DWG. NO.
24
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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Figure D.12

Manufacturing Plan

Part Number: 24

Part Name: Sensor Bracket

Team Name: Team 25

Revision Date: 12/6/2015

Raw Material Stock: 1/16" thick 6061 Aluminum

Step #	***Process Descripti***	***Machine***	***Fixtures***	***Tool(s)***	***Speed (RPM)***
1	Cut part to size	Band Saw			300
2	Break edges by hand.			File	
3	Locate points for the holes and center punch			Caliper and punch	
4	Center drill and drill holes to appropriate size	Drill press		Center drill bit and 9/32" drill bit	
5	Break edges by hand.			Deburring tool	
6	Clean work station and return tools				

APPENDIX E: RISK ANALYSIS AND FMEA

Table E1: Failure modes effects analysis for brake pad, friction mat, and display items

Item	Function	Potential Failure Mode	Potential Effects of Failure	Severity of Effect	Potential Causes of failure	Occur within year	Current Design Controls	Detection	RPN	Recommended Action
Brake Pad	Cause friction to create resistance	Overheating of pad or disk	Could burn user	10	Excessive or prolonged use at one time	1	Test and Validate Method	3	30	Learn about heating points of the disk and brake pad material
		Fatigues	Unable to apply resistance properly	5	Excessive or prolonged use	2	Test and validate materials	2	20	Research brake pad material
Friction Mat	Anchors device on surface while in use	Fatigues	Prevents proper anchoring of device	3	Excessive or prolonged use	2	Test and validate materials	3	18	Research friction mat material
		Slip	Prevents proper anchoring of device	4	Surface causes insufficient friction	1	Test friction coefficients and perform force calculations	2	8	Research friction mat material
Display	Shows user time and distance	Batteries lose capacitance	Prevents display of user feedback	6	Incorrect programming of display device	2	Provide backup batteries	2	24	Include On/Off button to conserve battery life
		Becomes uncalibrated with disk rotation	Displays inaccurate user feedback	6	Incorrect programming of display device	1	Test and Validate Method	5	30	Test calibration of display after multiple separate use sessions
		Electric short	Prevents display of user feedback; causes shock to user	10	Improper electronic wiring; improper housing assembly	1	Ensure proper wiring and housing	6	60	Quality check all electronic connections and housing positions

APPENDIX F: VALIDATION PLAN

Table F1: Validation Plan

System	User Requirements	Validation
Function	Time of workout	Demonstrate time readout. Compare with separate stopwatch to verify.
		Demonstrate functionality of digital readout
	Able to use hands and feet	Demonstrate ability to use with hands and feet
	Measurable resistance	If we have enough time: attach strain gauges to the pedal bar to measure strain in bars during the different resistance settings.
		If we don't have enough time: have multiple users pedal at the different resistance settings and give feedback on quality of resistance
	Doesn't slide on surface when in use	Give prototype to multiple users on multiple surfaces to verify that peddler does not slide
	Distance	Demonstrate distance readout
		Demonstrate distance readout
	Easy to use	Give prototype to unexperienced user and time how long it takes them to use correctly
	Easy setup	Plan what is assembled in the factory and what is assembled by the customer.
Price	Low Price	Estimate cost of material of total prototype
Dimensions	Compact/small size (doesn't get in the way)	Measure final prototype
	Lightweight	Weigh final prototype
Ergonomics	Adjustable pedal straps	Demonstrate adjustable pedal straps
	Comfortable to use (including pedal/handle)	Give prototype to multiple users and get feedback on fluidity of rotation
		Give prototype to multiple users and get feedback on comfort

AUTHORS

Kate Huizenga

Kate is from Grand Rapids, MI and will graduate with her B.S.E in Mechanical Engineering from Michigan in May of 2016. She interned at Bradford White in Middleville, MI the summer after her freshman year where she worked in the research and development lab with a heat pump water heater. The summer after her sophomore year she interned at Steelcase in Grand Rapids researching 3D printing and potential company benefits from using additive manufacturing. Kate returned to Steelcase the summer after her junior year where she worked on various cost saving projects resulting in over $125,000 cost savings per year and implemented over 50 requested engineering and quality changes to improve part design and manufacturing processes. Kate is a member of the Women's Club Water Polo Team on campus which has won the Big Ten Championship Tournament 7 years in a row and has placed in the top 4 at the National Collegiate Club Championship for the past 6 years. She has held positions of treasurer and fundraising chair for her water polo team during her first three years participating.

Michelle Kleinau

Michelle is from Bay City, MI, and will graduate from the University of Michigan in May 2016 with a B.S.E. in Mechanical Engineering, a minor in International Programs in Engineering, and a specialized study in Sustainable Engineering. After her sophomore year, she spent six weeks studying abroad in San Sebastian and Pamplona, Spain, taking classes in microrobotics and Spanish language, culture, and industry. This past summer she interned at Moeller Manufacturing Co. in Wixom, MI, working as a process engineer to make process updates and develop manufacturing plans for a number of turbine engine parts. Michelle is a member of three engineering societies on campus: Tau Beta Pi, Pi Tau Sigma, and The Epeians, having held leadership roles in each and currently serving as the chapter president of Pi Tau Sigma. Michelle is also a member of the Michigan Club Softball team, a chair for the SWE/TBP Fall Career Fair, and actively participates in her sorority, Pi Beta Phi.

Kelly McKee

Kelly is from Cleveland, Ohio and will be graduating in May 2016 from the University of Michigan with a B.S.E in Mechanical Engineering. After her sophomore year, she spent six weeks in New Hampshire studying literature and then interned with Thermolift, a startup company in Ann Arbor, enhancing the design of an at home heating and cooling system using the Vuillmiere cycle. This past summer Kelly worked for Walsh Construction Company at Ann Arbor Wastewater Treatment Plant as a commissioning intern where she developed performance test scripts and implemented tests for wastewater processing equipment and determined quantitative permissible water levels and flow rates to appropriately test the equipment. In her free time, Kelly enjoys exercising, drawing and exploring the outdoors. She works for Outdoor Adventures at the University of Michigan's as a gear manager and trip leader where she fixes, keeps track of and organizes gear and leads students on backpacking and kayaking trips throughout the state of Michigan. Kelly is also involved in her honors fraternity, Phi Sigma Pi, and sorority, Zeta Tau Alpha.

Zachary Snyder

Zachary was born and raised in Nashville, Tennessee and is a senior studying Mechanical Engineering with a specialized study in Sustainable Engineering at the University of Michigan. Zachary is a member of the University of Michigan Supermileage Team, which aims to build a vehicle capable of driving at more than 3,000 miles per gallon. After his sophomore year, he interned at Novita Technologies (Hendersonville, TN), completing projects in operations and in mechanical design. This past summer he interned at the Texas A&M Transportation Research Institute (College Station, TX) studying older driver behavior. Zach has presented his older driver research findings at both the Texas A&M Transportation Institute and the University of Michigan Transportation Research Institute. In his free time, Zach enjoys playing and watching sports, being active outdoors, reading, and cooking. A second-generation Wolverine, he loves attending every Michigan football and basketball game.