Danny's Recumbent Bike Accessibility Device

Final Design Report (FDR)

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Team

Recumbent Bike Transfers

By

Jack McAtee
jmcatee@calpoly.edu

Huy Nguyen
hnguy128@calpoly.edu

John Kulick
jkulick@calpoly.edu

Joseph Lee
jlee535@calpoly.edu

Sponsor

Barb Springer

QL+

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Executive Summary

The purpose of this document is to fully define our design solution and explain our manufacturing and testing results. Our project's goal is to find a way to allow Danny Knutson, a retired Navy pilot and incomplete quadriplegic with limited use of his arms and an impaired sense of balance, to enter and exit his recumbent tricycle without any discomfort for him or his aide. We completed multiple interviews with Danny, patent research, existing product research, and other technical literature research in order to fully understand the problem. We synthesized this information to create a concrete list of customer wants and needs, which led to a full list of specifications that were developed using the Quality Function Deployment technique. Key specifications from this list that our design will satisfy are as follows, but not limited to: the machine's range of motion both horizontally and vertically, level of comfortability to use, and force required by the user to operate. These specifications were accepted by our sponsor and we then began the ideation phase of the project. Once we had numerous concepts, we employed the use of a decision matrix to determine the best idea for our project. We then performed preliminary analyses, risk analysis, and cost analysis in order to further develop our concept. After completing further engineering analyses, we refined our design to meet the required specifications. We purchased all necessary components, designed the parts that must be manufactured in-house, and drew up a plan to modify ordered parts for assembly. After all parts were received and manufacturing was complete, we enacted a testing plan on the assembled device. With the device finalized, we traveled to Danny's home in Sacramento to install the device and complete our final testing. This document details this process and the results of the project.

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1. Introduction

Danny Knutson is a retired U.S. Navy Blue Angels pilot and Northrop Grumman employee who is now an incomplete quadriplegic due to past injuries. Danny suffered a spinal injury as a pilot, and then after a hit-and-run biking accident, he was left with paralysis in his right arm, balance issues, and limited movement of his legs. Danny enjoyed cycling before the incident and wanted to continue the activity to stay in shape. Using a recumbent trike, Danny can enjoy cycling again; however, getting in and out of his trikes is difficult and requires his wife to support him. As this task is very physically demanding, Danny needs an alternative method of getting in and out of his recumbent trike. As a senior project team of four Cal Poly San Luis Obispo mechanical engineering students working with our sponsor, Quality of Life Plus, we have been tasked with finding a solution for Danny.

2. Background

This section details the background behind our basic customer needs, existing design solutions/patents, and technical literature, all of which will aid us in our design process.

2.1. Customer

Through a video interview with Danny, we learned that he has two different project ideas: (1) a permanent device in his garage which would support him while getting in and out of the recumbent trike, and (2) a portable device which would provide the same function but based out of his car. Our team is responsible for the first project, getting Danny in and out of his trike while in his garage. The device can be mounted on the wall, ceiling, or be self-standing. Danny has two different trikes, an ICE Sprint X Recumbent Trike and a Catrike Expedition. Our device must be adaptable to both trikes. Through additional questioning, it became evident that a potential device would need to be easy and quick to use, balanced, comfortable, durable, and safe; these became our primary, general goals. We also compiled a list of specific goals, which includes allowing Danny to operate the device himself, making a device that has a small footprint and does not interfere with Danny's current garage setup, making the device aesthetically pleasing, low cost, and designing for a variety of weights so that the device can be replicated for other customers.

2.2. Existing Designs and Patents

Many solutions already exist to improve the mobility of disabled and elderly people, including the Invacare Reliant Lift, a Rifton Supine Stander, the Drive Medical Hydraulic Patient Lift, Etac Turner Pro, and the Hoyer Ascend Patient Lift, all depicted in Figures 1 and 2.

Drive Medical Hydraulic Patient Lift [1]

Rifton Supine Stander [2]

Figure 1. Existing Products that Partially Address the Problem at Hand.

Drive Medical utilizes a sling and hand-powered hydraulics to lift and lower individuals; however, the sling is meant to only transfer a person from one location to the next, not necessarily aid the individual in changing his or her body position. In the same way, Rifton's supine stander straps the user onto a padded backing, such that the body stays rigid while it is pivoted into a standing position. Both products would not be applicable to our problem since we require the manipulation of the user's body from a standing position to a seated position.

Etac Turner Pro [3] Invacare Reliant Lift [4] Hoyer Ascend Patient Lift [5]

Figure 2. Sit-to-Stand Devices that are Promising Solution Ideas.

To that end, several sit-to-stand devices are available on the market. Among these are the Etac Turner Pro, the Invacare Reliant Lift, and the Hoyer Ascend Patient Lift. Each of these functions through a similar concept: bracing the knees against a pad to fix the legs while the upper body is pulled up, using either the user's own upper body strength (as in the case with Etac's product) or a powered sling (like the Hoyer and the Invacare). Thus, the user can transition from a seated position to a standing position. However, with limited use of his arms, Danny does not possess the ability to safely and reliably carry his body weight. Therefore, the most useful products to draw inspiration from are the Hoyer and Invacare lifts because they are externally powered. The only necessary additions to these designs are ensuring the usage of the system does not interfere with the process of getting in and out of the trike and extending the range of motion such that the seated position is not at a normal right angle but at a recumbent angle.

Additionally, in our research we came across several relevant patents. Each patent details either a sit-to-stand device or a full body transfer lift, both of which utilize technology that could prove useful to the problem at hand. Patent numbers and descriptions are provided in Appendix A for reference.

Through the course of our ideation process, we continued to research existing products that we could incorporate into our design. We came across ceiling-mounted hoists used in the medical industry such as the Handicare C-450 ceiling lift. Devices like this one would be able to provide the vertical and horizontal range of motion we seek as well as provide the safety and robustness we desire. The Handicare C-450 will be discussed in more detail in Section 4 of this report.

2.3. Technical Literature

Existing technical literature provided additional insight into the subject. One major tool in designing a device which aids a repeated motion, such as sitting and standing, is a dynamic human model. Several dynamic human model examples were found through preliminary research which will help our team develop a model to represent Danny. One such model was developed to study human sitting and standing motion for the design of a support robot. The two-dimensional dynamic model consists of upper body, upper legs, lower legs, and feet, which are connected by rotational joints, and sitting/standing motions are assumed to be planar and bilaterally symmetric [6]. A similar dynamic model was developed by Abbas Fattah and his team in order to design a sit-to-stand assist device that is gravity-balanced: the machine is unpowered but keeps the body in a neutral or equilibrium position by using a variety of springs. Fattah's model is a three-degree-of-freedom system and assumes planar, symmetric motion as well [7]. These models will be useful in designing a device for Danny that supports a similar sitting/standing motion.

To create this model for Danny, one possibility is to use position sensors to track his movements. In a paper titled "Design and Simulation of a Simplified Mechanism for Sit-to-Stand Assisting Devices", Erika Ottaviano and her associates did just that, collecting experimental data by hooking up motion sensors to 20 volunteers and analyzing their sitting and standing motions. Due to the wide variety of motions based on different heights, weights, and gaits, an average trajectory pattern was developed, which encapsulates the majority of the test population. The results are presented in Figure 3 [8].

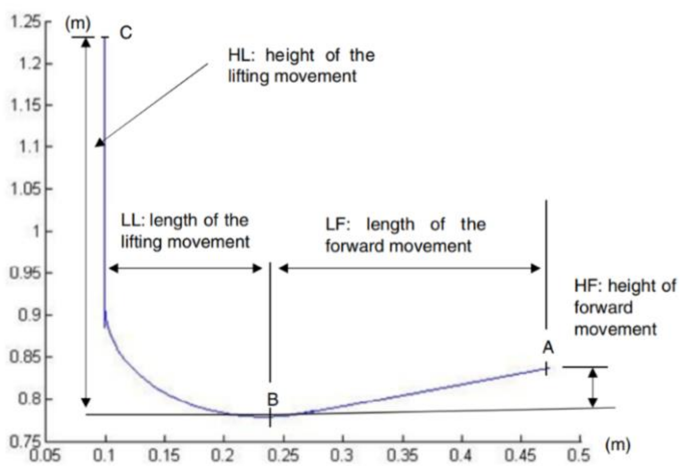

Figure 3. Required Trajectory Pattern for Ottaviano's Sit-to-Stand Assisting Device [8].

This trajectory pattern is a helpful visual aid and quantitative model for designing our device that will be based off Danny's average trajectory pattern as he gets into and out of his recumbent trike. Additionally, it would be helpful to measure the force required to lower and raise Danny. In a collaboration between several Japanese universities, Yoshiyuki Takahashi and others designed a "sit-to-stand assistance system," a moveable handrail for people with Parkinson's disease. In their analysis, the force imparted on the handrail by individuals with Parkinson's was measured and plotted, as seen in Figure 4 [9]. This handrail force data will be a useful example for collecting data for Danny when determining the force he exerts on the device.

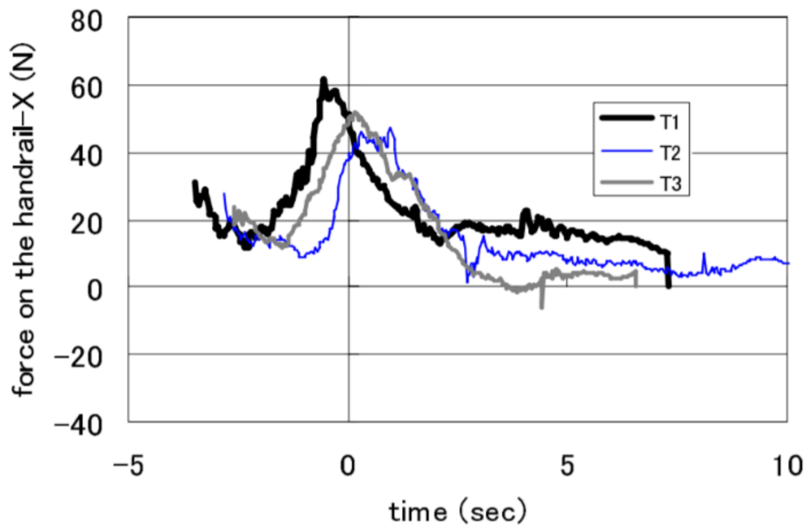

Figure 4. Force on the Handrail (Vertical Axis) for Individuals with Stage 4 Parkinson's Disease [9].

Another area of research focused on mechanisms used to accomplish similar goals to that of this project. Common mechanisms for lifting include the use of springs, hydraulics, pneumatics, and motors. An interesting example of using springs in a lifting device is described in a journal article about the development of a nonpowered lift for people in wheelchairs [10], depicted in Figure 5.

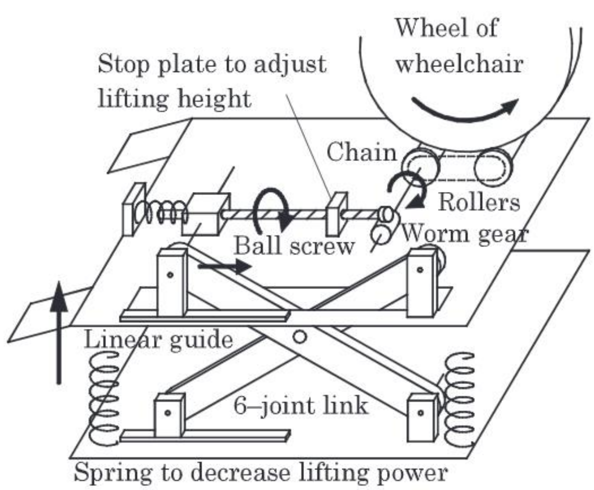

Figure 5. Mechanism of Nonpowered Lift Driven by Wheels of Wheelchair [10].

This device consists of a platform onto which the wheelchair user rolls, and two large rollers which are geared to springs. The rollers are operated by spinning the wheelchair wheels, and therefore the user lifts and lowers themselves by rolling the wheelchair. Although Danny's assistance device does not need to be nonpowered, this product is a good example of a simple mechanical design that could solve the problem presented.

2.4 Applicable Industry Codes, Standards, and Regulations

The following is a list of safety codes, standards, and regulations relating to our design project that can serve as guidelines as we design a solution. These are used in workplaces and situations involving lifting equipment and disabled patients.

2.4.1 OSHA [3182-3R-2009]

OSHA provides these guidelines to help prevent work-related musculoskeletal disorders specifically for nursing homes, but these are also helpful for similar work environments. For our project this OSHA standard helps gives us an idea for potential problems that can arise for our user or an aide when operating our potential device.

2.4.2 CFR [Title 21, Volume 8, Subchapter H—Medical Devices]

This regulation gives the identification and classification of a "Non-AC-powered patient lift," which is a potential type of device that we may use for the project.

2.4.3 Lifting Operations and Lifting Equipment Regulations 1998

The LOLER regulations are under the Health and Safety at Work etc. Act 1974. The regulations were set to prevent and reduce injury from lifting equipment in work environments. These help to set some benchmarks for acceptable factors of safety, loads, and positioning for our device to help minimize risk.

2.4.4 Manual Handling Operations Regulations 1992

These regulations help prevent work-related musculoskeletal disorders in workplaces. These regulations will help give us a guideline for how we can expect someone to use our device to prevent injuries outside the scope of what we are designing our device for.

2.4.5 ASME B30 Standard

This standard by ASME is intended to provide protection of life, limb, and property by prescribing safety requirements. This standard is applicable to lifting equipment, relevant technology for our project. The B30 Standard may help us set some factors of safety when designing our device.

3. Objectives

The following sections describe the development and description of the design criteria for our project.

3.1. Problem Statement

Following our interview with the end user we developed the following problem statement:

Danny Knutson, a 6'2" and roughly 230 lb retired Navy Captain and pilot, is an incomplete quadriplegic who enjoys riding his recumbent tricycle. He needs a way to safely and reliably get in and out of his trike without requiring excessive physical strain on whoever is aiding him. The solution is intended for home use and should be durable, balanced, and reasonably priced.

From this statement, we were able to develop a strong list of needs and specifications; the specifications are shown in Section 3.3.

3.2. Boundary Diagram

Figure 6 was created to further understand the scope of our project. As is seen in the picture, the device will be situated within Danny's garage and will not be moved after its first installation. However, the location of this device is not limited to a specific portion of the garage; rather, it is confined to a portion of the garage that has enough volume to accommodate the final design. The device is to be mounted to the ceiling and will interface with Danny as it aids him in and out of his trike, but will not interface with the wall, floor, or trike itself.

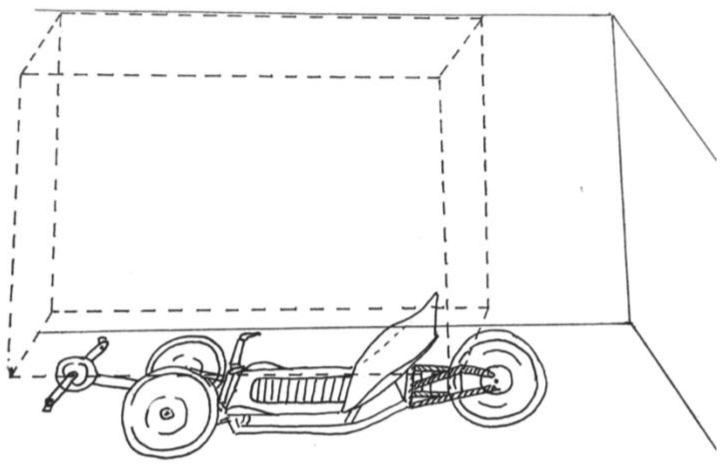

Figure 6. Boundary Diagram for Danny's Accessibility Device.

3.3. Quality Function Deployment (QFD)

Our team employed the Quality Function Deployment (QFD) technique in order to refine and translate our interpreted customer wants and needs into engineering specifications. This process utilizes a house of quality to help match the customer needs to the specifications and determined the effectiveness of current solutions. To do this, we assigned a correlation rating between the specifications and needs to determine the specifications' relevance to the needs. We also assigned an importance rating (1 being important and 5 not important) between 1 and 5 to determine the overall importance of our specifications and needs. The house of quality detailing this process is found in Appendix B which also contains a full list of wants and needs. The project's engineering specifications derived from this technique are shown in Table 1.

Table 1 lists all specifications by their description and provides additional information. The requirement column displays what measurable quantities our design will be held to and the adjacent column applies a tolerance to this quantity. The risk column categorizes how demanding the specification will be to meet: L meaning low risk, M meaning medium risk, H meaning high risk. The compliance column describes how each specification will be measured; either by I (inspection), T (testing), or A(analysis). The high-risk specifications are user operation and price to manufacture the project. User operation has been defined as a stretch goal, as it may be difficult to accomplish, and it is not essential to the function of the device. The overall price of our project could also be difficult to minimize, especially since we plan to incorporate the use of an existing, albeit expensive, medical device.

Table 1. Specification table for Danny's Trike Recumbent Accessibility Device.

Spec.#	Parameter Description	Requirement or Target	Tolerance	Risk	Compliance
1	Range of Motion (Vertical)	3.5 ft	±2 ft	L	I
2	Range of Motion (Horizontal)	3.5 ft	±0.5 ft	L	I
3	Volume	25 ft^3	+5 ft^3	L	I
4	Steps to Operate	5	±3	L	I
5	User Force to Lower/Raise	0.5 lb	±0.25 lb	M	T, A
6	Level of Comfortability (0-10)	8	-2	M	T
7	Time to Operate	3 min	±1 min	M	I
8	Max. Allowable User Weight	400 lbs	±50 lbs	L	T, A
9	Min. Factor of Safety of Components	3	-1	L	T, A
10	User Operated Raising/Lowering	Yes	N/A	H	I
11	Price to Manufacture	$3000	±$200	H	A
12	Works for Danny's Two Trikes	Yes	N/A	L	I

Below are descriptions for each specification:

Range of Motion (Vertical)

Vertical range of motion describes the distance the device can raise and lower Danny vertically. The goal is to provide enough vertical range of motion such that Danny can stand on the ground and sit in his trike while using the device.

Range of Motion (Horizontal)

The horizontal range of motion describes how far the device can move Danny forwards and backwards. This specification is crucial in helping position Danny's center of gravity in relation to his feet and must be accommodating enough to ease him comfortably from standing to sitting and vice versa.

Volume

The volume refers to the amount of space the mechanical device will occupy in the garage.

Steps to Operate

This relates to how many steps the user, Danny, must take to operate the device. Making the device as simple as possible is the goal because with less steps, it will most likely be easier for Danny to operate.

User Force to Lower/Raise

Requiring the user to exert some effort may be necessary for our solution, but we seek to minimize this amount of force input as much as possible to allow for better ease of use.

Level of Comfortability (0-10)
Ideally the device will be pain free for the user, but there may be some limitations. A certain allowable amount of pain, which is subjective for the user, is necessary when designing the device. The scale will be one through ten, with zero equivalent to extreme pain, and ten equivalent to completely comfortable.

Time to Operate
This specification refers to how long it will take for Danny to use the device, from the moment he enters the device to the time he exits it. Reducing the time to operate will allow for the user to have the most amount of time riding his trike or other activities.

Maximum Allowable User Weight
Our device will specifically be designed for Danny's current weight, but also will be usable for a range of weights should Danny's weight change in the future.

Minimum Factor of Safety of Components
This specification helps to measure the safety of the mechanism. For our device, it will be designed to withstand at least two times the expected mechanical stresses.

User Operated Raising/Lowering
Designing the device to allow the user to be as independent as possible is important. For our device, it is our goal to allow the user to control the device to lower and raise himself, instead of having someone else do it for him.

Price to Manufacture
This is the sum of the price of all the components, the price of assembly, and shipping costs.

Works for Danny's Two Trikes
Designing a device that works regardless of the type of trike is optimal. In this case, designing a device that will work with Danny's two trikes is our goal because it will make the device more versatile, depending on Danny's preference.

4. Concept Design
This section explains the ideation process we undertook in order to generate ideas for our design. This section also details our chosen concept, justifications for choosing it, preliminary analyses, and risk and cost analyses.

4.1 Ideation Process
After completing the problem definition and engineering specifications portion of our design, we were ready to begin the ideation process. The first task was to employ the functional decomposition technique; this allowed us to break up our design into specific functions that we would be able to brainstorm around. The main function that we identified for our design was the function of lowering and raising Danny. A list of secondary functions was also identified as follows: secure

feet to ground, support upper body, and secure trike. Each one of these functions were subjects for our brainstorming sessions, with an emphasis on raising and lowering Danny due to its integral part of our design. The methods we used to ideate for these functions included brainstorming and brainwriting. With ideas generated from these sessions, we were able to create small prototypes to aid in idea generation and refinement. After developing a full list of ideas, as seen in Appendix D, we then were able to refine the list. We selected the best ideas for each function and created Pugh matrices for the functions. These matrices can be found in Appendix E and were used as visual representations as to how our ideas compared to one another. This gave us added insight into the complications of our concepts and helped to further develop our ideas.

4.2 Refined Ideas for Combined Functions of Horizontal and Vertical Positioning

We used the Pugh matrices to compare our ideas to each other and identify the better ideas and eliminate the lesser ones. Figures 7 through 11 depict sketches of our top concepts after this process. Descriptions are provided beneath each figure.

4.2.1 Design #1

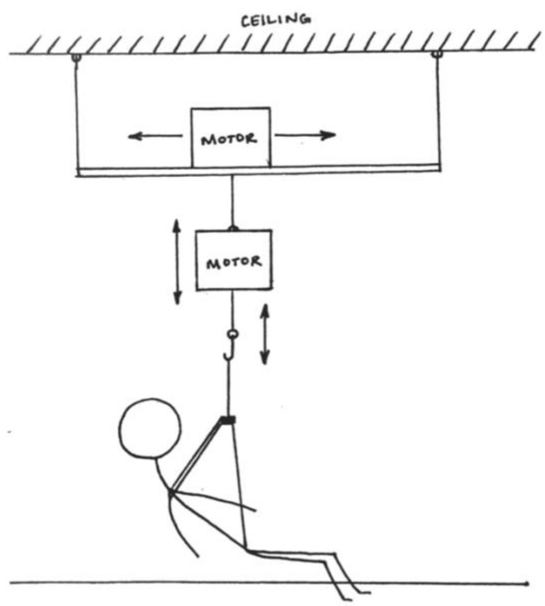

Figure 7. Sketch of Hoist and Motor Design.

The "hoist and motor" system would be a system mounted on the ceiling controlled by two motors that direct the system in the horizontal and vertical motion. A hoist providing vertical motion would be connected to a sling that would wrap around the back of the user and under the arms, coming together above the head to the lifting system. Horizontal motion is achieved by placing the hoist on a track and driving it with a motor.

4.2.2 Design #2

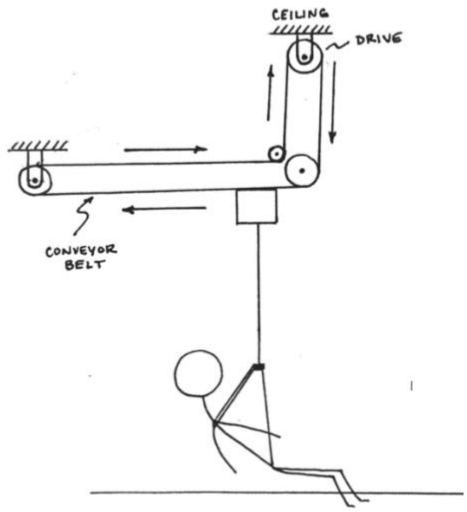

Figure 8. Sketch of Conveyer Belt Design.

The Conveyor Belt design would consist of a sling attached to a conveyer belt controlled by a motor that would travel in the shape of an "L." The "L" shape would allow an initial vertical motion and a final horizontal motion. This design would only have one motor, so the path of the motion would be restricted by the size and shape of the conveyer belt.

4.2.3 Design #3

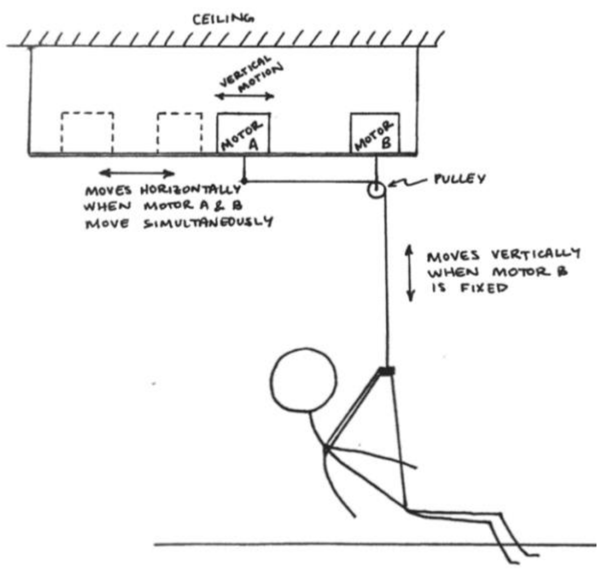

Figure 9. Sketch of Double Block System Design.

The Double Block system is comprised of two motor-driven blocks which translate horizontally on a rail. A cable attached to one block runs over a pulley fixed to the second block and connects to a sling. By alternating motion of the two motors with respect to each other, both vertical and horizontal motion can be achieved.

4.2.4 Design #4

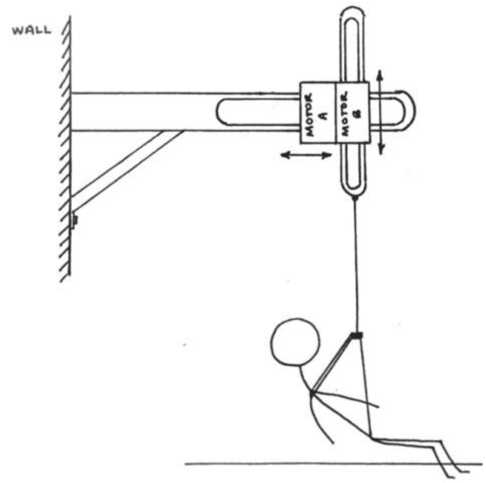

Figure 10. Sketch of Double Motor Design.

The Double Motor design consists of a horizontal beam with a vertical beam on the end, each controlled by a motor. This design would attach to the side wall instead of the ceiling, causing the system to use up more garage space than ceiling designs. A sling would be attached to the end of the vertical beam.

4.2.5 Design #5

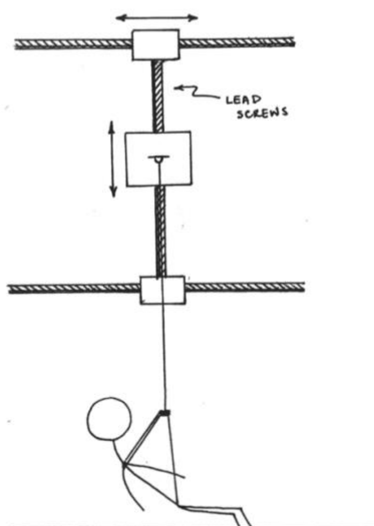

Figure 11. Sketch of Lead Screw Design.

The Lead Screw design utilizes a vertical lead screw in conjunction with two horizontal lead screws to maneuver a sling. The lead screws would have a smaller range of motion but allow for better precision and control.

The three secondary functions of supporting Danny's body, securing his feet to the ground, and keeping his trike in place, while necessary to the overall design, are not impactful enough to make strong differences between the above proposed systems. Refer to Appendix D to find Pugh matrices and rough sketches of ideas addressing these secondary functions. To support his body, we find that it might be best to use an underarm sling due to its simplicity, comfort, and thin profile, although other options such as a harness could potentially be used. A minimal way to secure his feet would be to brace them against a raised step, and other ideas that we can use are Velcro straps or foot clamps. To secure the trike, a variety of solutions would be effective, including pushing it back against a wall, using wedges as wheel stopper blocks, and actuating the trike's brakes. For all the secondary functions, we felt that each of the solutions mentioned above would satisfy our needs and that the choice of solution would have little to no bearing on the effectiveness of the overall design. Thus, our design comparison and decision process were focused on the main function, as detailed in the following section.

4.3 Design Decisions.

After we developed and refined our concepts, our next task was to determine the best concept for further development. In order to do this, we selected five of our ideas that were subjected to a weighted decision matrix, which can be seen in Table 2. This tool was used by assigning a 1-5

Table 2. Decision Matrix.

	Idea Number:	#1		#2		#3		#4		#5	
Weights	Engineering Specifications	Hoist and Motor		Conveyor Belt		Double Block		Double Motor		Lead Screw	
5	Range of Motion (Vertical)	5	25	2	10	5	25	3	15	3	15
5	Range of Motion (Horizontal)	5	25	2	10	5	25	3	15	3	15
4	Volume	4	16	3	12	3	12	2	8	3	12
4	Steps to Operate	3	12	5	20	3	12	3	12	3	12
3	User Force to Lower & Raise	5	15	5	15	5	15	5	15	5	15
5	Level of Pain to Use (0-10)	5	25	5	25	5	25	5	25	5	25
2	Time to Operate	3	6	4	8	3	6	3	6	2	4
1	User Weight Range	5	5	5	5	5	5	5	5	2	2
5	Min. Factor of Safety of Components	4	20	2	10	4	20	3	15	2	10
5	User Operated Raising/Lowering	5	25	3	15	5	25	5	25	5	25
3	Price to Manufacture	3	9	1	3	2	6	1	3	3	9
3	Works for Danny's Two Trikes	5	15	3	9	5	15	2	6	4	12
	Total Points: Unweighted/Weighted	52	198	40	142	50	191	40	150	40	156

score, 5 being excellent, to each concept based on how well it met our engineering specifications. Each specification was weighted 1-5, 5 being most important, and the weighted sum of all scores was calculated, yielding the highest score to be our selected concept.

4.4 PDR Concept

Our preliminary concept was the hoist and motor idea. Danny would be held upright in a torso sling, potentially with an additional waist support, and footholds on the ground would help to secure his feet as he was raised/lowered by the hoist and moved forwards/backwards along the ceiling-mounted rail. To secure the trike, it would be backed up against the wall of the garage. It is important to note that the decisions regarding how Danny, the trike, and Danny's feet are supported were very fluid—these decisions are subject to change depending on Danny's comfort. Figure 12 shows a SolidWorks CAD concept model of the raising and lowering system. At this point, we had tentatively selected a hoist and method of providing horizontal positioning.

The Handicare C-450 ceiling lift, pictured in Figure 13, is a patient lift used both in professional environments such as hospitals and assisted living facilities as well as personal in-home use. Because it is a medical device specifically designed to raise and lower humans, this product meets rigorous medical safety standards and is equipped with safety and comfort features such as soft start/stop, emergency lowering, an overspeed governor, built-in load limits, overcharge and overcurrent protection, and a slack strap sensor. In addition to the lift itself, the C-450 kit comes with a hand remote for user control of the lifting and lowering, which was necessary for our design. [11]

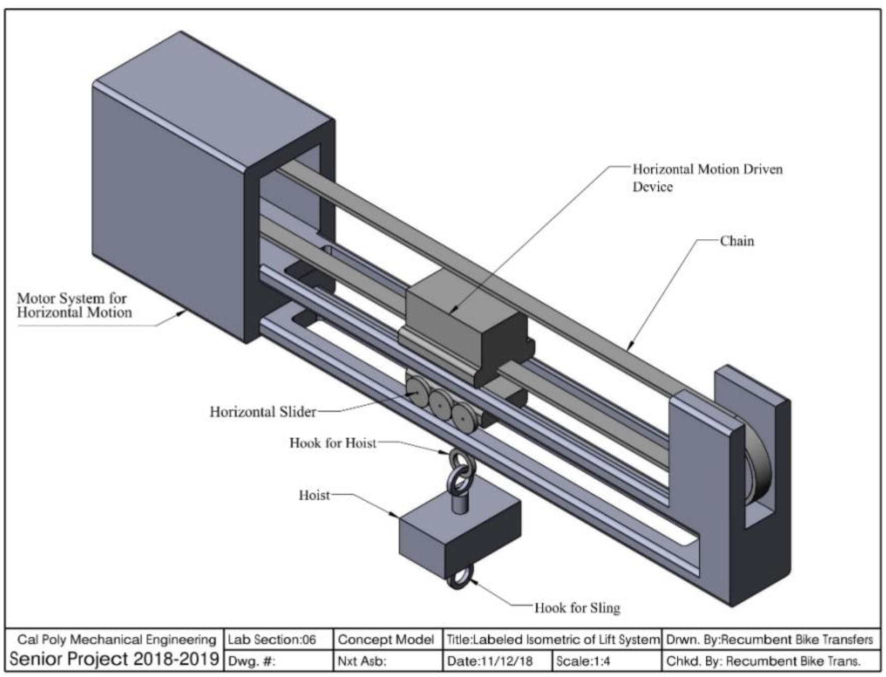

Figure 12. Labeled Diagram of Concept CAD Model.

For horizontal positioning, we proposed using a motor to drive a sprocket and chain loop, much like a garage door opening system. The chain would be attached to the C-450 and power its horizontal motion. We anticipated that the horizontal range of motion would only need to be about 2 feet. The exact method of mounting and assembling the components was yet to be decided.

Figure 13. Handicare C-450 Ceiling Lift [11].

4.5 Preliminary Analyses

Much of the needed preliminary analyses for this project was circumvented by the usage of the predesigned Handicare C-450 or similar human hoist. Thus, the preliminary analyses we focused on were specific to the function of the horizontal positioning system and Danny's comfort upon lowering. As our first analysis, we wanted to test the under-arm sling for comfortability and proof of function. We created a rudimentary prototype of the sling and lowering system by placing a hammock underneath the arms of the user and a rope looped around an overhead beam to allow the user to be lowered. The apparatus is shown in Figure 14 below.


Figure 14. Under-arm Sling Testing Apparatus and Concept Prototype.

Figure 14 also shows the trajectory of the user upon lowering. There were four main results determined from this test. First, we verified the fact that Danny needs to have his feet secured while being lowered, for maximum safety. Second, we determined that the horizontal positioning system will need no more than 2 feet of stroke, due to the ability of the user to lean into the downward motion and achieve a horizontal motion, as seen in Figure 14. Next, we decided that an additional hip support system might be necessary to support Danny's hips upon descent and ascent, so that his hips do not slouch and bring his torso forward. Finally, we found that when the lowering point is fixed, as was in our experiment, and the user leans back, the rope holding the user creates an angle with the vertical plane. This angle will cause the pivot point of the rope, the horizontal positioning system in our system, to see a horizontal force which will need to be counteracted. Appendix F details the derivation of the horizontal force that must be counteracted in the horizontal positioning system. We found that this force was around 100 lbs, which is a conservative estimate. At this point, we planned to implement a braking system that can resist this force so that Danny will only translate horizontally when he commanded it.

Additional calculations were made for deciding on the parameters to look for in a motor, as seen in Appendix F. In doing research on available motors, the Dayton 150 in.-lb DC Gearmotor stood out as a potential solution due to its high torque and low speed outputs [12]. As the design developed, the selected motor changed, but this motor gave us an idea of what was available and how much it would cost. The Dayton DC Gearmotor is shown in Figure 15.

Figure 15. Dayton 150 in.-lb DC Gearmotor [12].

4.6 Risk Assessment

Initially, the primary challenge associated with a lifting/lowering device for Danny was to guarantee his safety. Danny would be putting all his weight on the harness; therefore, safety was extremely important. One of the obvious safety considerations was the device being mounted on the ceiling: the mounting hardware and ceiling joists would need to be strong enough to support Danny's weight. This risk would be dealt with by implementing a safety factor of at least 2 on all ceiling-mounting materials. The more complicated safety issue deals with the hoist. The hoist also must be able to lift and lower Danny in a slow and controlled motion and include safety features for worse-case scenario events, such as a power outage. However, with the aid of the Handicare C-450 Ceiling Lift, this risk is mitigated. This lift is designed specifically for lifting and lowering people with disabilities, so the hoist is fitted with necessary safety features [11]. This allows the focus of the project to be on Danny's comfort, whereas using a homemade hoist would require much more time focused on keeping Danny safe.

With that said, the new challenge of the project was to make Danny as comfortable as possible while being lifted and lowered into this trike. Our concept design made some assumptions for how Danny would sit down and how his body would naturally be able to sit down. We expected that Danny's ability to stand and the support of the sling would allow for him to sit back and stand up with the help of the system, but at this point we were not sure; therefore, it was important to us that we leave plenty of time to run tests with Danny in order to create a device that would provide the most comfort possible.

4.7 Cost Analysis

After reviewing the components of the concept prototype, we estimated the price of all the components, as shown in Table 3. It is important to note that the hoist is the bulk of the total cost. It is the opinion of the team that the cost of the hoist is justifiable, given the hoist's abilities and safety features, as discussed in Section 4.4. Therefore, the proposed budget is $3000.

Table 3. Estimated Budget.

Component	Cost ($)
Hoist	2300
Motor, Sprocket, Chain	500
Support Materials	
Rail	50
Ceiling Fittings	50
Sling	100
Total	3000

4.8 Decisions, Changes, and Updates Made Since PDR

After consulting with several mentors, we decided to change our horizontal positioning system from a chain and sprocket to a lead screw and nut. This greatly simplified the challenge of joining the horizontal positioning system to the trolley, and in addition the safety of the design was improved. All other general aspects of the design remained the same. Also, final component selections were made to more fully define the assembly. This led to our Critical Design Review (CDR) iteration of the design. Subsequent iteration after the CDR resulted in our final design, which is described in detail below.

5. Final Design

This section fully explains our final design and justifies the design decisions that were made. In addition, we discuss the risks, maintenance considerations, and costs associated with our design.

5.1 Description of Design & Functionality

The final assembly, shown in Figure 16, is composed of three subassemblies: the horizontal positioning assembly, vertical positioning assembly, and the mounting assembly. All components will be referenced by their item numbers; see the exploded assembly in Appendix N for reference.

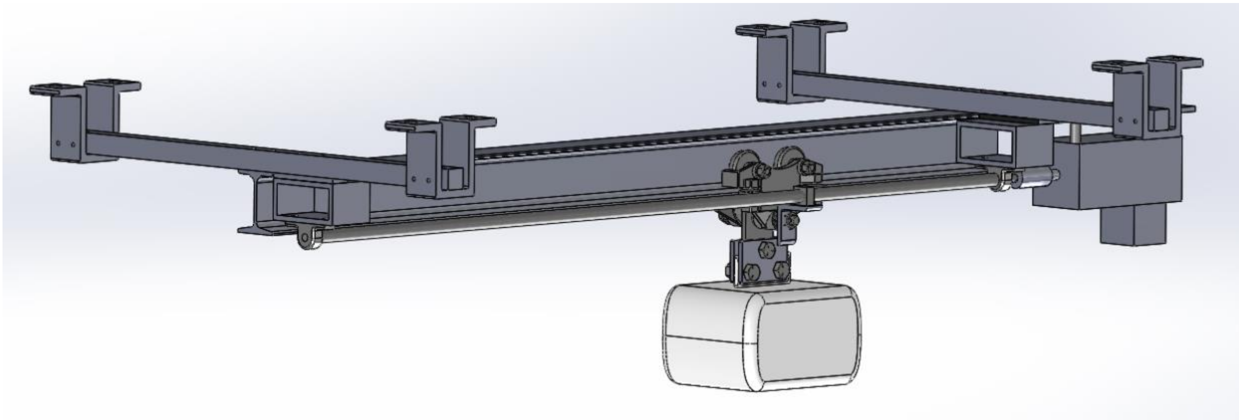

Figure 16. Final Assembly CAD Model.

5.1.1 Horizontal Positioning Assembly

The horizontal positioning assembly is responsible for horizontal motion, which is necessary for getting Danny backwards into and out of his recumbent trike. Horizontal motion is achieved through a lead screw system, in which a trolley over Danny's head is connected to a nut on a lead screw, and the lead screw is driven by a motor. Details of this assembly and the design choices made are discussed below.

5.1.1.1 Rail Assembly

The rail assembly consists of all driven components in the horizontal positioning system. These components are driven by the power assembly, which is discussed in the next section. Refer to Figure 17 for a CAD view of the assembly and for item numbers. The primary driven components are the trolley (Item No. 7), the trolley bracket (Item No. 9), the lead screw (Item No. 5), the lead screw nut (Item No. 6), the bearings (Item No. 4), as well as the I-beam bearing supports (Item No. 11) and primary I-beam (Item No. 2). The rail assembly utilizes a lead screw to transform angular motion from the motor to linear motion of the trolley. A lead screw system allows for precise control of position; additionally, the threads of the lead screw prevent Danny from moving forward or backward when the motor is not running, i.e. he will only move when desired. This benefit is the main reason a lead screw was chosen instead of a chain-and-sprocket design. With a chain-and-sprocket, a braking system for the motor is necessary to keep the motor position fixed when off. This is not necessary with a lead screw design.

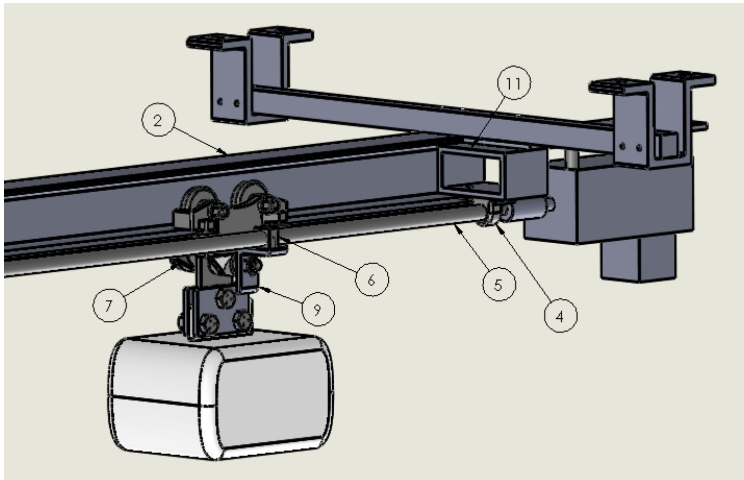

Figure 17. CAD view of Rail Assembly.

The trolley bracket connects the trolley to the lead screw nut and is depicted in Figure 18. This is an important component because the bracket must rigidly transmit motion in the horizontal direction; however, any downward force on the trolley must not be transmitted to the nut because this will put a shear force on the lead screw and may cause binding. Therefore, the bracket is rigidly secured to the trolley along the path of motion, but loosely screwed into the bottom of the nut. This way, the bracket can move subtly in the vertically direction, and any downward force on the trolley is not transferred to the lead screw nut.

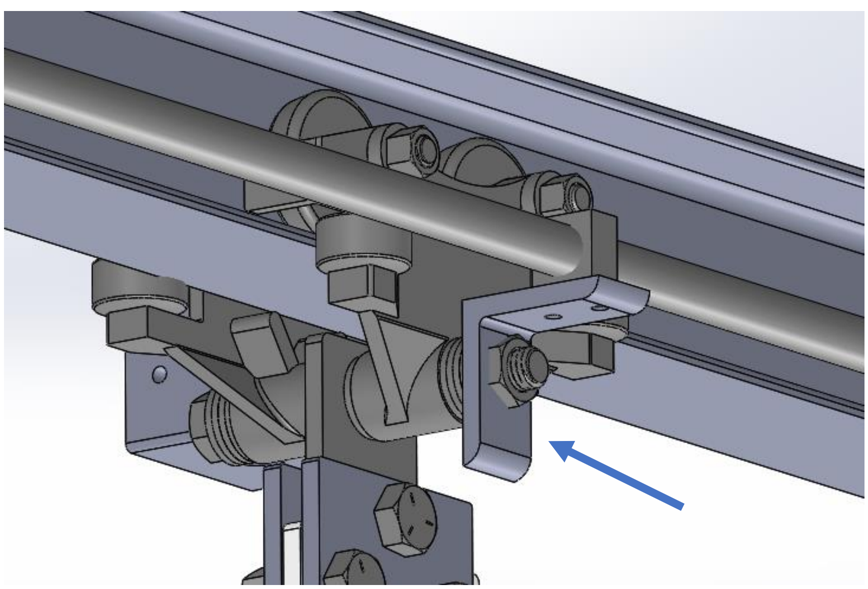

Figure 18. CAD view of Trolley Bracket, which pairs the trolley to the lead screw nut.

Our structural prototype, pictured in Figure 19 below, helped to verify the concept of the rail assembly, especially regarding the trolley bracket. The prototype proved that a lead screw design could reliably and safely move a load horizontally, and that a bent sheet metal bracket to connect the trolley to the lead screw could perform well. Additionally, we learned from this early build that ensuring the leadscrew is aligned with the bearings is difficult when mounting, and failure to align correctly results in binding during horizontal travel.

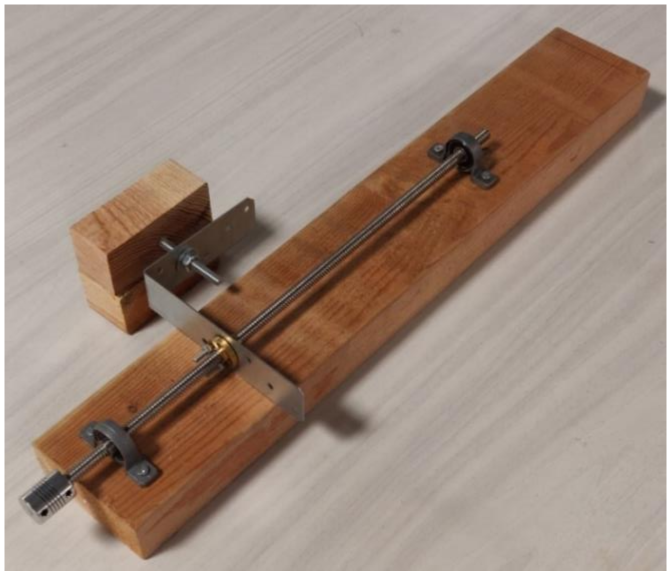

Figure 19. Structural Prototype.

The design was further verified through conservative hand calculations as explained next. These calculations are summarized in Table 4, and calculations are attached in Appendix K. Beam deflection analysis was conducted on the I-beam track, conservatively modeled as simply supported at both ends with a point load of 300 lb in the center, resulting in a maximum deflection of 0.03 in., which should not be enough to bind the lead screw if the trolley bracket functions the way it is intended to. For the lead screw, we calculated the critical load and critical speed for a ½ in. diameter, 3.5 feet long lead screw, and two fixed bearings. The resulting critical load was 1988 lbf, which is much more than the 180 lbf axial load we expect from the accelerating case calculation found in Appendix K. The resulting critical speed was 3000 rpm, which is more than the 1200 rpm we expect to run with our motor. For bearings, we selected 10 mm Boca Bearing Mounted Bearing based on the catalog ratings. Using its specifications, we calculated that the life of the bearing would be 10 years, expecting that the device is used for 15 minutes, 180 times a year. A bending failure analysis on the trolley bracket gave a factor of safety over 10 for 12-gauge sheet metal, assuming a worst-case scenario load of 180 lbf. The final design for the trolley bracket, however, used ¼ steel instead of sheet metal, since the sheet metal was too thick to bend with the equipment available in Cal Poly Machine Shops. Therefore, the final factor of safety for the trolley bracket was much larger.

Table 4. Summary of Design Calculation Results for Horizontal Positioning Assembly.

Part	I-Beam	Lead Screw		Bearings
Calculation	Max Beam Defl.	Crit. Load	Crit. Speed	Brg. Life
Units	[in]	[lbf]	[RPM]	[yr]
Theoretical	0.03	1988	3000	10
Expected Actual	-	180	1200	-

5.1.1.2 Power Assembly

The power assembly consists of the driving portion of the design; this includes the motor (Item No. 13) and coupling (Item No. 14), controller box assembly, and remote, as well as all limit switches and wiring. The motor was selected to have a full load of 6 in-lbf of torque which is slightly less than the conservative torque estimate shown in Appendix K; however, we believe is satisfactory given the conservative estimates made in our calculations. It operates at 12 VDC to provide electrical safety in Danny's home. The controller box allows the speed of the motor to be adjusted.

5.1.1.2.1 Controller Box

The controller box consists of the motor controller circuit board, a 12 VDC source, 24 VDC source, switching relays, wireless relays, circuit breaker, and a fan inlet and outlet for thermal management. The flow of current begins from an AC source on the wall of Danny's garage, which is then routed through the 12 VDC converter to supply 12 VDC to the motor controller. The motor controller then outputs 12 VDC to load poles on the relays. The relays then route the power to the opposite armatures of the motor to allow for switching of the motor polarity. In order to operate these relays, a 24 VDC signal is routed from the 24 VDC source, split, and two legs each are routed to their respective COM port on the wireless relays. The wireless relays are double pole relays and the 24 VDC signal is then routed from the normally closed terminal to the power poles of their respective relay. The wireless relays operate from a handheld wireless remote that allows power to flow from the normally closed ports, which sends a 24 VDC signal to the relay of choosing which allows power to flow to the armature of the motor. Only one relay can be energized at once and the prevention of this is twofold: when pressing both relay buttons at the same time, neither relay is activated, and a mechanical interlock between the two buttons prevents the relays from being activated at the same time.

To provide a secondary safety function, the return lines from the relays are additionally routed through limit switches to prevent the user from running the machine into the ends of the travel.

All components were selected so that they meet or exceed the operating voltage and current of the motor. The motor was sized with a conservative estimate of the required torque and will not operate at full speed, and thus will most likely not operate at its peak capability.

All of these components are mounted in a polycarbonate housing which is fan cooled and crossflow is obtained by also installing an inlet with a filter.

One of the main concerns with this design is the high current being drawn from the motor. The low, 12 V operation of the motor should allow the user to be safe from arcing, and the polycarbonate sealed enclosure should be enough to keep the user safe from electrical exposure. The controller box also has a fan to keep it cool when operating during hot summer days or for long durations. There should be no maintenance required for the motor or electronics due to the low usage of the product and high reliability of components. Refer to the drawing package in Appendix N for full wiring diagram.

5.1.1.2.2 Remote and Speed Control

The remote consists simply of a small plastic remote with four buttons, A, B, C and D. B moves the user back, and A moves the user forward. This remote is attached to the Handicare C-450's pneumatic remote by Velcro to allow the user to use both with ease. See Figure 20 for an image of both the remotes. Initially, we had hoped that the user would be able to operate both controls while using the device, but after testing it was deemed necessary that an aide would use the remotes.

Figure 20. Remotes, combined.

In addition to the remote, a small PVC enclosure hangs down from where the electrical enclosure is mounted. This enclosure contains a potentiometer and an on-off-switch. The on-off-switch interrupts the signal to the “low” wire on the potentiometer which allows for the motor to stop and operates as an emergency stop. The potentiometer controls the speed of the motor and may need to be adjusted given the different loading situations that the machine is under. That being said, it should be noted that clockwise rotation increases the speed and power of the motor and counter-clockwise decreases both.

The remote is only be subjected to an insignificant electrical load which is safe to handle without extra protection. Nonetheless, the signal switches are enclosed so they cannot come into electrical contact with the user. Also, the remote is designed so that the motor only runs when the switches are pressed, so that if the remote is to be dropped then the motor will stop. No maintenance is required, and repairs are only needed if wire terminals come loose.

5.1.2 Vertical Positioning Assembly

The vertical positioning system is responsible for vertical motion. The primary component of the vertical positioning assembly is the Handicare C-450 ceiling patient lift (Item No. 10). The C-450 is a medical hoist that has built-in safety features, such an over-speed governor, built-in load limits, and a slack tape sensor. Additionally, the C-450 is relatively lightweight, has a capacity of 450 pounds, and includes a hand remote. These features ensure comfortable and safe vertical movement for Danny. This assembly also contains a sit-to-stand sling, a foothold device, and a hanger bracket assembly. The sit-to-stand sling is an underarm sling from Proactive Medical (Part No. PTC 30131). Finding the best sling for Danny depended heavily on testing with Danny once the entire assembly was ready and mounted on the ceiling. The foothold device consists of a garage mat and two Velcro foot straps which prevent Danny’s feet from sliding forward when lowering. After testing with Danny, the foot straps were removed, since the mat itself was deemed enough.

5.1.2.1 Hanger Bracket Assembly

The hanger bracket subassembly (Item No. 8) is responsible for securing the Handicare C-450 lift to the trolley. Although Handicare sells a hook compatible with the C-300 unit, it was not adaptable to our trolley; therefore, a new part will be manufactured by the team. The hanger bracket assembly, shown in Figure 21, is a simple, robust design which consists of two bracket plates screwed together onto the Handicare handle and trolley tab.

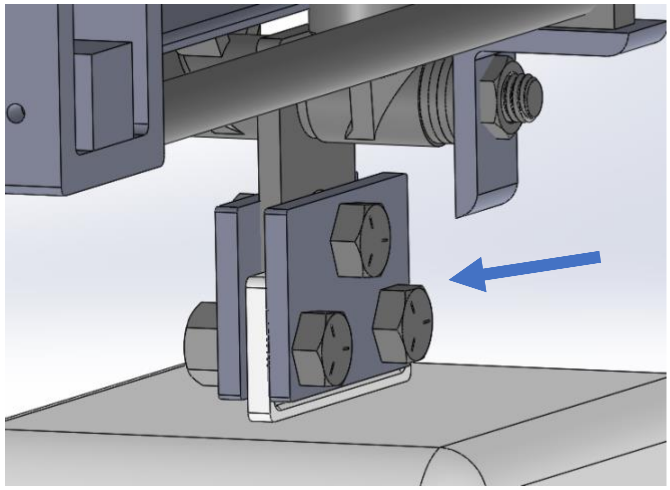

Figure 21. CAD view of Hanger Assembly, which pairs trolley and Handicare C-450.

Hand calculations analyzing the stress on the assembly were completed to ensure that each component meets a minimum factor of safety of 2. First, bending and axial stress analysis was completed on hanger bracket pieces. For each calculation, factors of safety were well over 2. The bracket thicknesses are intentionally much thicker than necessary to ensure that failure will not occur on the brackets themselves. Calculations for the brackets are presented in Appendix K. Next, bending stress analyses was completed on the top bolt. The factor of safety for bending failure came out to 3, which is satisfactory. Calculations for this analysis can be found in Appendix K. All calculations used conservative numbers to find maximum stresses; therefore, failure of the hanger bracket assembly is deemed to be not an issue.

5.1.3 Mounting Assembly

The mounting assembly is responsible for securing the entire final assembly to the ceiling of Danny's garage. This assembly consists of two lengths of 1" square steel beams placed on either end of the I-beam track (Item No. 1). A motor plate (Item No. 3), where the motor bolts to, is attached to the last support beam. Each support beam is slid through a U-bracket (Item No. 16) for adaptability in mounting to the ceiling joists. See Figure 22 for a depiction of each.

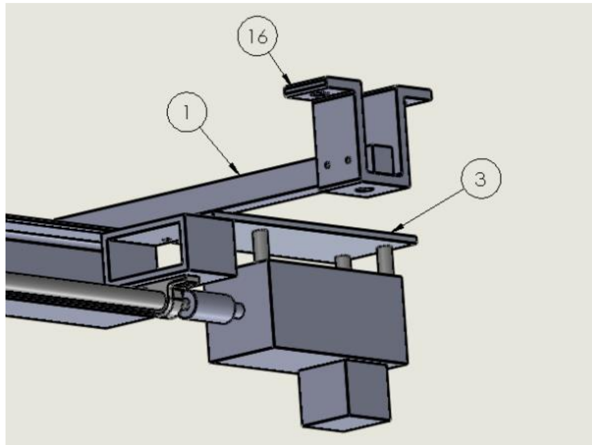

Figure 22. CAD view of Mounting Assembly.

Initially, 6061 aluminum was selected for its strength-to-weight ratio and popular use in structural applications, and a quick look at the S-N curve of this alloy showed that cyclic fatigue would not be an issue for well over 10 million cycles. However, we decided on using steel instead due to the higher strength and, therefore, superior loading capability. These beams have threaded holes to accept ¼”-20 bolts to locate and mount the I-beams and motor plate, as well as clearance holes for ¼”-20 bolts which are fastened onto ceiling brackets. The ceiling brackets are then drilled into the ceiling joists using ¼” lag screws. The reason for the ceiling bracket design is that we were not certain of the spacing of the ceiling joists in Danny’s garage. The use of brackets that slide along the support beams gave us much more flexibility with installing the device. The ceiling brackets also have four set screws each, which are used to locate the support beam within the bracket. The set screws also provided flexibility with the installation process.

Taking the extreme case of hanging 350 lbs from a single support beam, stress analysis showed that the support beams were well beyond the strength requirements, with a factor of safety against yielding of 4. Beam deflection analysis was conducted on the support beam to verify that the mounting system is stiff enough. The maximum deflection was 0.04 in., which would not be enough to affect the function of any subsystem. Another concern was that the I-beam track could rip out of the support beam if the threads in the tapped holes fail, but using a conservative thread max shear stress analysis, our factor of safety against thread failure was 2.6.

5.2 Safety, Maintenance, and Repair

Safety of the device is discussed in detail in a Design Hazard Checklist in Appendix E. The primary update concerning safety after the Preliminary Design Review (PDR) was the replacement of the 90V motor with a 12V motor. This decreased any risk of injury due to high voltage. Other major safety concerns dealt with failure of the structural components, resulting in the user falling or losing balance. This type of failure was corrected by using large factors of safety on structural components (4 on the support beams and 12 on the I-beam sections) and utilizing the Handicare C-450 lift which is rated for 450 lbs and has its own built-in safety features. Failure modes of the device are discussed in detail in a Failure Modes and Effects Analysis table in Appendix I. This table goes through critical potential issues with the device, as well as current and future corrective plans. Maintenance of the device should be minimal. The primary part that may need maintenance is the Handicare C-450, which needs to be charged between uses; this was mitigated by keeping the Handicare plugged-in and charging at all times. Maintenance of the motor and control system should only be necessary after 5-10 years of use, as long as the components are used as instructed.

5.3 Cost Summary

After determining all the raw materials and components to purchase, the total cost of our confirmation prototype was projected to be $2628. A breakdown is provided in Table 5, a detailed budget is provided in Appendix H, and an Indented Bill of Materials is in Appendix G.

Table 5. Confirmation Prototype Cost Estimate.

Components	Cost ($)
Lead Screw and Bearings	65
Handicare C-450	1850
Motor and Controls	467
I-Beam and Trolley	129
Mounting System	64
Sling	53
Total	2628

6. Manufacturing

6.1 Procurement Process & Final Budget Status

All parts and materials for the project were approved and purchased by the sponsor, QL+. Throughout the manufacturing process, as new parts were needed, the team contacted QL+ for approval and purchase. Vendors included McMaster-Carr, Ultimation, Amazon, Digi-Key, Automation Direct, Med Mart, Home Depot, and BettyMills. Automation Direct granted free supplying for the project, as a donation to QL+. The final budget status after installation and manufacturing is $3228 of the $3000 budget we had.

6.2 Lead Screw Modification

The Acme lead screw (Part No. RBT113) is 4 feet long, with 5/8”-8 threading. Modification was required so that the ends of the lead screw could be inserted into bearings on both sides and the motor coupling set screw could sit deeper into the shaft of the lead screw and transmit torque more effectively. The lead screw was first put on a lathe; each end was turned down to a diameter of 3/8” for a length of 3/8” on one end and 2” on the opposing end. A step was left at the end of the turned down portion for preventing axial movement. The ends were then deburred and cleaned. A slight flat was ground into the 2” long end using a disc sander, then a small 6.6mm diameter hole was drilled into the flat portion where the coupling’s set screw would sit in. During the lathing process, the lead screw deflected at one end, causing it to vibrate when spinning. It is recommended that for future production during this portion that one end of the leadscrew is supported to a neutral position. This is especially important if the lead screw has a smaller diameter or is longer. The modified lead screw inside the bearing and coupling is shown in Figure 23 below.

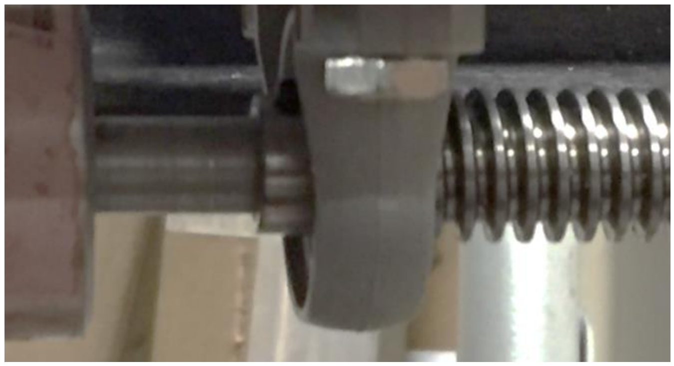

Figure 23. Lead screw modification so that the bearings could be fastened to each end.

6.3 I-Beam Modification

The 4-foot-long steel S3x5.7 I-beam (Part No. RBT111) was fixtured onto a mill table using toe clamps. A dial indicator was used to square the beam, and a ¾" diameter end mill was used to create 4 flats on both ends of the beam. Over each of these flats, a size F drill was used to create clearance holes for ¼"-20 bolts in the locations specified in the engineering drawing. The modification can be shown in Figure 24 below. The modification is on the upper side of the I-beam, where the bolt is inserted.

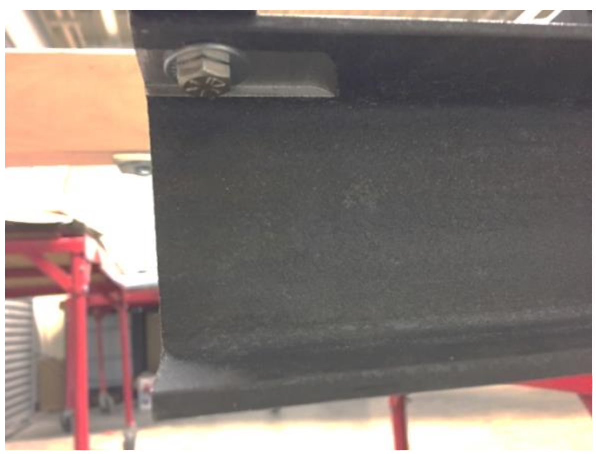

Figure 24. I-Beam modification for screw head to sit flat on flange.

6.4 Support Beam Modification

The support beams (Part No. RBT311) are 1 in x 1 in carbon steel. Two support beams, each 26 inches long, were cut from a 6-foot stock length using a cold saw. A number 7 drill bit was used to drill into the beams at specified locations along the beams. A ¼"-20 tap was then used to hand-thread each hole. All holes and cut edges were deburred and cleaned. The resulting support beams are shown below in Figure 25.

Figure 25. Carbon steel support beam cut to length.

6.4 Motor Plate

The motor plate (Part No. RBT116) was machined from an ¼ in by 4 in (2 ft long) 6061 aluminum plate that was purchased from McMaster Carr. The plate was cut to a length of 11 inches long using the vertical bandsaw. Then the plate was taken to a drill press, where six ¼”-20 clearance holes were drilled through the plate using a size H drill bit as per the engineering drawing, 2 for mounting the plate to the support beam and 4 to mount the motor. All holes and edges were deburred and cleaned.

6.5 Motor Spacers

4 aluminum cylindrical spacers (Part No. RBT119) were clamped into a vise using a V-block. A ½” end mill was used to face them down to a length of 1.18”, then the belt sander was used to slowly grind down the lengths to 1.14”, using a digital caliper to measure lengths between each sanding. One of the spacers are shown in Figure 26 below.

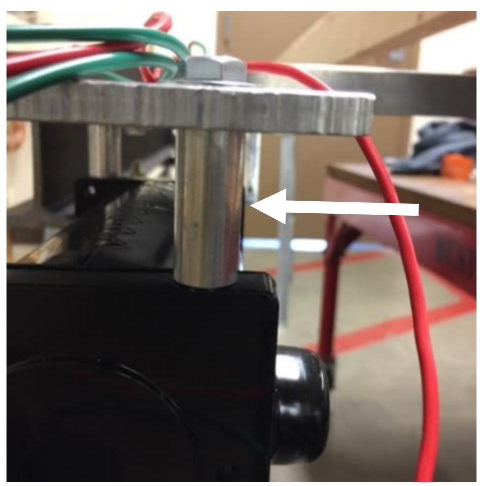

Figure 26. Aluminum cylindrical spacer to fasten motor concentrically with the lead screw.

6.6 Hanger Brackets

Two hanger bracket plates (Part No. RBT231) were machined from one 3”x12” ¼” thick 6061 Aluminum plates. Two 6-inch-long sections were cut from the stock piece using the vertical band saw. The pieces were then be taken to the drill press for holes. Both pieces were given clearance holes. Each part was clamped onto the drill press table and pilot holes were drilled in the three specified locations. Drill sizes were gradually increased until a 17/32" drill bit was appropriate, which is the final diameter of all three holes. Corners of the brackets were then ground down slightly so that edges are not sharp. Figure 27 shows the hanger brackets assembled.

Figure 27. Hanger bracket, securing Handicare hoist to trolley beneath the I-beam.

6.7 Trolley Bracket

The trolley bracket (Part No. RBT115) was machined out of 2 in x 2 in, 1/4 in thick and 1 ft long steel L bar. The L bar was cut to a 1 in length using the abrasive chop saw. The part was then taken to a drill press where a 9/16" hole was drilled on one leg of the L. On the other leg, two #7 holes were drilled. The holes and cut edges were deburred and cleaned. The trolley bracket can be seen in Figure 28 below, placed under the nut and lead screw.

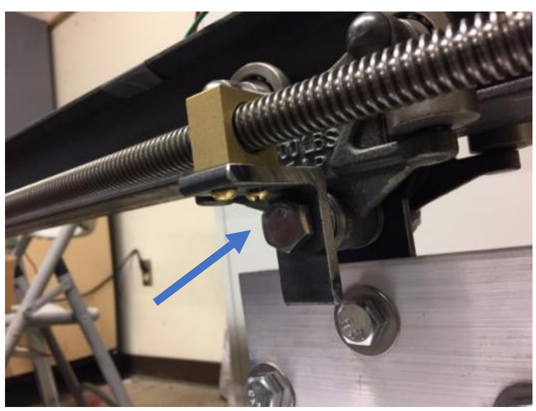

Figure 28. Trolley bracket connecting the lead screw nut to the trolley.

6.8 Bearing Supports

Two bearing supports (Part No. RBT118) were machined out of 2 in by 4 in (6 in long) rectangular stainless-steel tubing. The tubing was measured and cut to two pieces of 2 in long pieces using a vertical bandsaw. The ends were deburred and cleaned. Four pairs of holes were drilled at specified locations, two at the bottom and two at the top portions of the 4 in long side. The drilled holes were all size H for ¼ in-20 clearance holes. Figure 29 below shows one of the bearing supports.

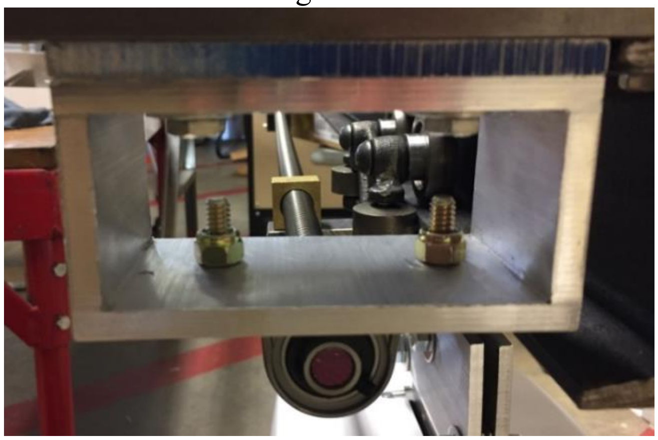

Figure 29. Bearing support, made of aluminum rectangular stock cut to length.

6.9 Spacer Plate

The spacer plate (Part No. RBT117) was cut out of the leftover aluminum from the motor plate, which was a ¼ in by 4 in (1 ft long) aluminum plate. A 2-inch-long piece was cut using a vertical band saw. The edge of the cut was cleaned and deburred. Two H sized ¼ in – 20 clearance holes were drilled using a drill press. The spacer plate is sandwiched between the bearing support and the support beam, so it is vital that the holes on each of these parts align, otherwise the bolt would not go through all three parts. For future production of this process, it is important to line up the holes by using precise measuring techniques or making a hole with the parts clamped together.

6.10 U-Bracket Modification

The U-brackets (Part No. RBT310) are used to mount our system to the ceiling of the user. Four 1 5/8” U brackets were modified to be able to hold and support our system. For each bracket, four holes were drilled and tapped. The holes were made using a drill press with a ¼”-20 tap hole drill bit. The holes were then hand-threaded using a ¼”-20 tap set. A problem that occurred during the drilling process was that the side that was being drilled deflected slightly but then went back to position when the drill was all the way through. This caused the edge of the hole to catch on to the drill bit and kick the vise up. This was extremely dangerous but was prevented using a heavier vise. It is recommended that for future production the bracket should have a wedge to support the ends of each bracket and a stable vise is used. The U-bracket holding the support beam is shown in Figure 30 below.

Figure 30. U-bracket, fixes to support beams using four set screws. A bolt set through the support beam end was added later to ensure the support beam does not slide out of the bracket.

6.11 Brass Nut Modification

The brass nut (Part No. RBT114) was modified with two 10-24 tapped holes with depths of ½” to be able to connect to the trolley bracket. The drill press was used to create two holes, which were then tapped by hand.

6.12 Limit Switch Trigger

A vertical piece of wood was epoxied to the trolley to move with the trolley. This enabled it to come into contact with the limit switches and stop the machine from traveling too far. This piece was later replaced with a Simpson Strong-Tie steel piece which had a pre-existing hole that fit over the trolley bolt and was easily secured with a nut. Figure 31 depicts the trigger evolution.

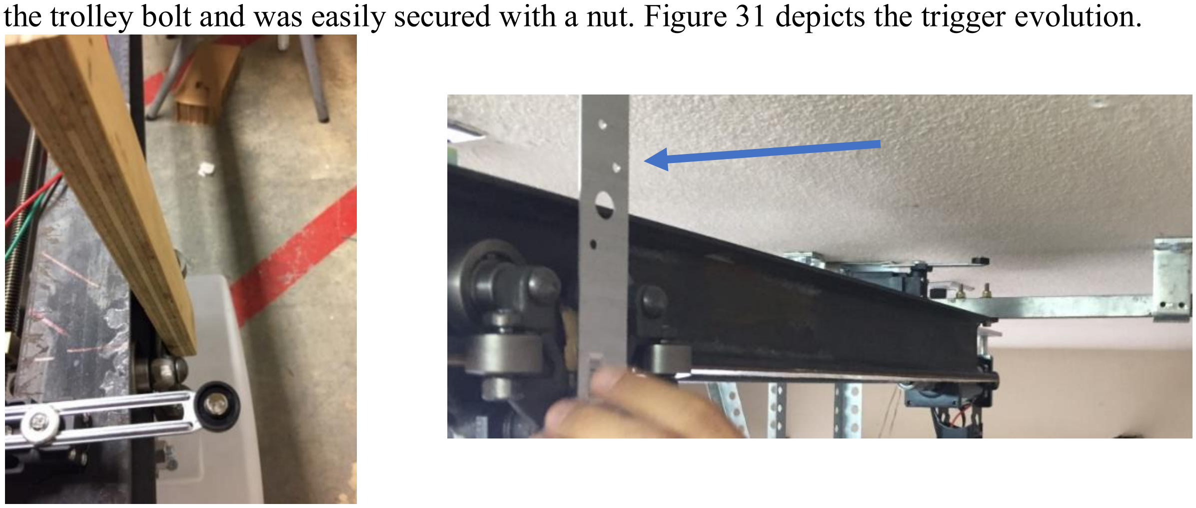

Figure 31. Limit switch trigger, initially a piece of plywood, but later replaced by a Simpson Strong-Tie steel piece.

6.13 Trike Mat

The trike mat, a 24” by 48” rug with a non-skid bottom, is the base for where Danny gets on the trike. Two 2” slits were cut using a box cutter 1’ from the long end of the rug. Velcro straps were then threaded though these slits to enable the user's feet to be secured to the rug. Figure 32 below shows the foot strap in position to secure the feet.

Figure 32. Velcro foot strap threaded through garage mat for foot securement.

6.15 Electrical Wiring

The electrical system within the controller box (RBT120) was originally wired system by system to avoid false wiring and danger. The relays were wired first in order to show that they would be able to be switched with the remote wirelessly. The motor was then connected to the 12-volt source to ensure proper wiring. Then, the motor was connected to the motor controller in order to test the velocity control aspect of the motor. Finally, the two systems were put together to allow full control of the motor. A 15 A circuit breaker was added between the 12V source and the motor controller for added protection. The wiring was done completely with 16 AWG wire, and junctions in wires were executed through jumped terminal barrier blocks. Screw terminal connections were executed using a spade terminal that was crimped onto bare wire, and if a spade terminal was not necessary the screw terminal was used to clamp down onto bare wire. Wire caps were used to connect the stock wires to our own wires for use in the control circuit. The electrical components were mounted to the controller box subpanel using small sheet metal screws. Figure 33 below shows the electric box with the correct wirings. Refer to the drawing package from wiring diagram.

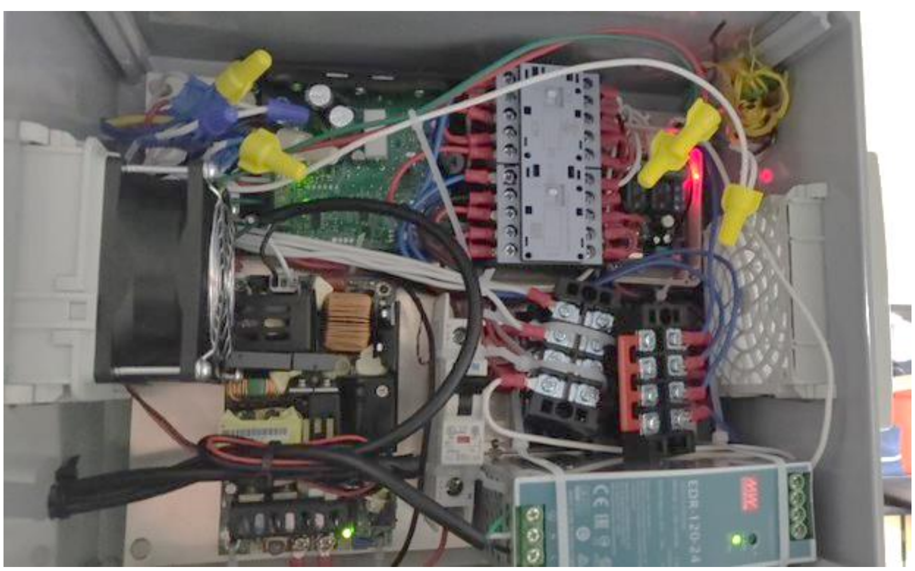

Figure 33. Electric Box.

6.16 Assembly

The assembly process was initially begun upside-down so that all the components could be laid out on a tabletop. First, 2 support beams (Part No. RBT311) were laid out, then the I-beam (Part No. RBT111) was fastened to the center of the support beams using ¼"-20 hex head bolts. The trolley was disassembled and washers were rearranged so that the trolley bolt went through the large hole of the trolley bracket (Part No. RBT115), which was situated between the washers and nut of the trolley and oriented such that the two small holes of the bracket were facing up. The trolley was then slid onto the I-beam while it was still easy to place on. Next, the motor plate (Part No. RBT116) was aligned on a support beam, with the cantilevered length extending to the outside of the assembly. On the other support beam, the spacer plate (Part No. RBT117) was aligned, with the extra length sticking out into the assembly. Then the bearing supports (Part No. RBT118) were fastened to the support beams on top of the motor and spacer plates using ¼"-20 bolts, with the extra lengths facing inward.

Following the assembly of the structural frame, the bearings, lead screw, and motor were mounted. First the brass nut (Part No. RBT114) was threaded onto the lead screw (Part No. RBT113). The two pillow block bearings were pushed onto the ends of the lead screw until they butted against the steps in the shaft, and the set screws were then tightened down onto the lead screw shafts. The bearings were then bolted to the bearing mounts, with the longer shaft of the lead screw towards the motor plate. The trolley was then positioned next to the nut so that the trolley bracket and nut could be fastened together with 10-24 bolts. Next, the coupling was fastened to the lead screw shaft by tightening the set screw into the shallow hole in the shaft. Once the coupling was secure, the motor shaft was inserted into the coupling and the four motor spacers were positioned underneath it. The motor was then fastened to the motor base plate using four 2-inch long ¼"-20 bolts through the spacers, and the set screw was tightened to secure the coupling onto the key of the motor shaft.

Two 8-foot-long 2"x4" wood beams were obtained to simulate ceiling joists, and the U-brackets (Part No. RBT310) were secured to the beams using 5/16" lag bolts and a hand drill with a socket bit, two on each beam spaced out the same distance as the support beams. The wood beams were then laid across two sawhorses so that the U-brackets aligned and the whole assembly was flipped upside-down and placed in the U-brackets. Set screws were then tightened onto the support beams through the U-brackets to lock the assembly in place.

On the side of I-beam now facing up, two limit switches were positioned and epoxied at each end of the I-beam so that the trolley could trigger the switches before crashing into the bearing mounts.

The hanger bracket assembly was put together next. Both hanger bracket plates (Part No. RBT231) were placed on either side of the trolley tab and Handicare C-450 mounting plate. Three ½" hex-head bolts were pushed through all the pieces, with two through the Handicare plate and one through the trolley tab. Nuts were threaded onto the other side of the bolts and tightened.

Finally, the wired connections between the control box (Part No. RBT120) and the motor and limit switches were made and plugged into power. Figure 34 shows our assembled prototype on a ceiling joist ready for testing.

Figure 34. Assembled recumbent trike transfer device mounted to mock ceiling joists.

7. Design Verification

The following sections explain how we confirmed that our confirmation prototype met all our design specifications. This section follows the Senior Project DVP&R table located in Appendix J. Each test description includes the method of verification that the design meets its specifications, how the test was performed, and the results.

7.1 Range of Motion (Vertical)

The vertical range of motion required is the change in vertical distance our device must allow for the user to get on and off the trike. The vertical range of motion is important in getting Danny in and out of the trike.

7.1.1 Range of Motion Test (Vertical)

The Handicare C-450 is designed to have 7.5 ft of vertical motion. The required vertical range of motion that we required was around 3.5 ft. A quick test of the Handicare C-450 device was performed to see how much range of motion it gives. The test was done in Cal Poly's Bonderson building. This simply required a measuring tape and space for the Handicare to operate. The result was 7 ft. 6 in. Therefore, the Handicare C-450 exceeds our needs for vertical range of motion. We learned from this test that the device would meet the expected range of motion, but also the only way the user would use all this vertical range of motion is if the user's garage is higher than the standard 10 ft. Table 6 below shows the results of the test.

Table 6. Table of Recorded Values for Horizontal and Vertical ROM.

Horizontal Range (ft' in.")	Vertical Range (ft' in.")
3' 5"	7' 6"

7.2 Range of Motion (Horizontal)

The horizontal range of motion required is the change in horizontal distance our device must allow for the user to get on and off the trike. The motion will be measured with a tape measure.

7.2.1 Range of Motion Test (Horizontal)

We expected the trolley to allow for roughly 3.5 ft of travel on the I-beam, which we confirmed from our analysis during the design. To confirm that our final prototype has this range of motion, we measured the trolley's travel distance by measuring the distance from the middle of trolley at one end of the beam to the other. The only equipment necessary was a tape measurer, and the test was conducted in Bonderson. The resulting horizontal range of motion was 3 ft. 5 in. We decided that this was acceptable because it fit within our acceptance criteria of -0.5 ft. We learned from this test that the expected horizontal range of motion will have to be close to the actual horizontal range of motion needed for the user. Table 6 above shows the results of the test.

7.3 Volume

The volume of our system is important because our design must be able to fit and operate inside the garage of the user.

7.3.1 Overall Volume Analysis

Our initial expected volume of the device was 25 ft^3. In addition to the CAD model's estimate of the volume, we took basic measurements of the final prototype to see that the volume of the device was within our expectations. Again, the only necessary equipment was a tape measure. After measuring the final prototype, the resulting volume was 18 ft^3.

7.4 Steps to Operate

The device is designed to allow the user to get on and off the trike. The number of steps to operate the device is important because the less steps required, the less complicated our device will be to use, and the more success the user will find using our device. For our device, it was decided that no more than 5 steps for each portion of sitting and standing to operate is optimal.

7.4.1 Steps to Operate Test

From preliminary analysis, it was hypothesized that the device would take 4 steps to operate, which is less than the target of 5 steps. We tested the device with the user to find how many steps our device requires for the user. Getting the sling onto the user will only be counted as one step, even if a helper is required for the user. The required equipment for this test was a video recorder and the location of the test was in the user's garage. Video recordings of Danny using the device for 3 trials demonstrated that it takes him on average 4.33 (round down to 4) and 5.67 (round up to 6) steps to operate for the sit-down and stand-up portions, respectively. The results are shown in Table 7 below. The results were acceptable because we found that as the user became more familiar with the device, he was able to find a more successful way to get to the desired position. In addition, the number of steps were within our acceptance criteria. In Figure 35 below, snapshots for the last trial were taken from the video we recorded. The first step, which is not included in the snapshots was getting on the sling. The next 3 steps for the sit-down portion are shown in Figure 35. Step two was moving horizontally back. The third step was moving horizontally and vertically. The fourth and final step was moving vertically down until the user was in the seated position. We learned from the test that our predicted path of motion did not match the actual and most comfortable motion for the user. We expected more periodic vertical and horizontal changes of directions. The test showed that the user's steps to operate would change frequently, in order to be more efficient and comfortable for the user.

Figure 35. *Top:* Danny starting to move horizontally *Middle:* Danny moving vertically *Bottom*: Danny completing the sit-down portion of operation.

Table 7. Steps to Operate Data for Sit-Down and Sit-Up.

Trial	Sit-Down Steps	Stand-Up Steps
1	5	7
2	4	5
3	4	5
Avg.	4.33	5.67

7.5 User Force to Lower/Raise

The device is designed for the user to put minimal force in the actions of getting off and on the trike. The gauge for verifying that the user force is acceptable will be a verbal response from the user, either pass or fail.

7.5.1 User Force to Lower/Raise Test

We expected that the remote of the device would be the only part of the device that the user will need force to operate. The remote was designed so that the user can hold the remote with one hand and operate the machine. After a complete run of both raising and lowering motions, the response from the user was that the user force was acceptable; however, the configuration of buttons on the remote was such that it was difficult for the user to access each button. Shown in Figure 36 below, Danny is attempting to use the device on his own. We found that during the last portion, he needed assistance balancing because he could not focus on handling the remote and balancing at the top at the same time. The result of this test, therefore, was that the remote needed modification for the user to use it independently. Instead, a helper was required to operate the remote.

Figure 36. User operating the remote required assistance to balance.

7.6 Level of Comfortability (0-10)

The level of comfortability includes the user's own scale of pain and discomfort. The pain for the user to operate the device is important because pain may obstruct the user to actually operate the device. It is optimal that our device is pain free to operate.

7.6.1 Level of Comfortability (0-10) Test

In order to gage how comfortable the user was when operating our device, we tested the device with the user after the device was installed. The test was conducted at the user's house. The test utilized a scale of 0-10, with 10 being that the device is pain free and comfortable to operate, and 0 being that the device cannot be operated by the user because of discomforts and pain. It was decided that a passing number would be 6. Our target for this device was 8, where for us this means that the only discomfort is getting used to the motion. There was no equipment necessary for this test besides the device itself. After testing with Danny and reviewing the footage of his 3 trials, we determined the ratings of his level of comfortability, on average, were 7 for the lowering into trike portion and 6.67 for raising out of trike portions. The results of the test are shown in Table 8 below. We found that as the trials proceeded the user and helper communication was improving. It was also evident that the user was becoming fatigued, which limited the amount of practice the user was able to partake in.

Table 8. Table of Ratings and Notes for Level of Comfortability Test.

Trial	Lowering into Trike		Raising out of Trike	
	Rating	Notes	Rating	Notes
1	5	Slack caused falling	6	Difficulty using the remote
2	8	Helper communication improvement needed	7	Bottom of sling catches on headrest
3	8	Helper use of remote shows improvement	7	Communication/ practice needed
Avg.	7	User fatigue evident	6.67	

7.7 Time to Operate

The time for the user to operate the device is separate for getting on and off the device, but our goal is that each portion of operating the device takes less than 3 minutes. It is important that the device does not take more time than this to operate because the user may be discouraged to use the device because it takes too long to operate.

7.7.1 Time to Operate Test

We measured the time in minutes it takes for the user to operate the machine. The test was conducted at the user's garage. This test was completed at the same time as the steps to operate test, because both require the user to do a full operation of the device. The equipment needed was the device itself and a video recorder. After re-watching the video, it was determined that the time to operate for lowering is 2 min. 16 s. and the time to operate for lowering is 1 min. 32 s. The times are shown in Table 9 below. It was evident that as the user became much more comfortable and communicated more efficiently the range of motion he desired, the time for the operation of the device became reduced drastically.

Table 9. Table of Recorded Times for Sit-Down and Stand-Up.

Trial	Sit-Down Time (s)	Stand-Up Time (s)
1	4:45	2:21
2	1:24	1:29
3	0:39	0:45
Avg.	2:16	1:32

7. 8 User Weight Range

The device is designed specifically for the user to operate, so it is necessary that it be able to handle at least the user's weight. We have targeted that the structure of the device will be able to handle 600 lbs, to obtain a factor of safety of around 2. The Handicare C-450 is rated for 450 lbs, so it was removed for this weight test.

7.8.1 Device Weight Capabilities Test

In order to test that the device structure could handle our expected loads, we tested the device without the Handicare C-450 attached. This test was conducted in Bonderson. We tested the structure by loading it with sandbags, beginning with 50 lbs, going up to 600 lbs in 50 lb increments. Equipment required for this test was twelve 50 lb sandbags, as well as rope and carabiners for attaching the sandbags to the I-beam. Additional equipment may be needed to have the device around 8 feet above the ground. For our test, we used 8' high cabinets. The weight of each sandbag was recorded for uncertainty purposes. The completion of the weight test demonstrated that the structure had at minimum a safety factor of 2.4, due to its capability of holding 600 lbs. The weights and observations are shown in Table 10 below. Figure 37 below shows the portion of the test at the maximum weight we tested.

Table 10. Device Weight Capabilities Test Recorded Data with Observations.

Weight	Observations
50	No deflection
100	
150	
200	
250	
300	Some deflection in wooden beam
350	
400	
450	
500	No deflection in I beam
550	
600	Device shows no sign of deflection or problems

Figure 37. System with 600 lbs loaded.

7.9 Minimum Factor of Safety of Components

The factor of safety is important to prevent failure for our parts. The higher the factor of safety, the more likely the device would not fail.

7.9.1 Factor of Safety Analysis

The Handicare C-450 comes with a built-in factor of safety that is certified for medical patient lifts. All other parts were designed with a factor of safety greater than 3. This was done through analysis and testing resulted in a safety factor slightly greater than 2. Our team thought that because our calculations were extremely conservative from the start, a factor of safety of 2 would be reasonable. The factor of safety of 2 fell within the acceptance criteria we had set.

7.10 User Operated Raising/Lowering

One of the problems which resulted in a need for this device was that the user needed assistance from a helper in order to get on and off the device. Because of this, it is important that our device allows the user to operate the device as independently as possible, or if there is a helper, the helper is not required to aid the user in any strenuous way.

7.10.1 Observations of Amount of Help Needed

Our original plan was that user would only need help getting on the sling before operating the device. After familiarizing the user with the device, we had the user operate the machine with a helper, so the test was conducted at the user's home. During both getting on and off operations, we counted the number of instances the user felt the need of a helper. It was decided that our device was meeting the specifications because the user indicated that he would always have a helper. Table 11 shows our recordings of the test. Having the helper control the remote allowed him to move more efficiently and safely. Figure 36, from Section 7.5.1 shows instances of the user operating the device and needing assistance. For the sit-down portion, where the user moved backwards and down, the user was able to operate the device on his own. The first snapshot shows the user holding the remote with both hands, where the right hand was used to hold and stabilize the remote, and the left hand was used to press the buttons. During the stand-up portion of operation, which included the left and right motions, the second snapshot shows the helper holding the strap of the sling, but this was simply a precautionary measure. Even though the user was able to operate all the range of motions on his own, there were some problems we did see when the user used the remote on his own. The third snapshot shows the helper firmly pressing against the sling. This was because when he started to stand up, he had trouble balancing because both his hands were on the remote and therefore could not grab his walker. This was one of the reasons it was best that the helper operated the remote.

Table 11. Pass/Fail Table of User Force to Lower/Raise.

Range of Motion	Pass/Fail
Up	Pass
Down	Pass
Left	Pass
Right	Pass

7.11 Price to Manufacture

The targeted price to manufacture our device is $3000.

7.11.1 Final Prototype Cost Analysis

Our final prototype cost was $2,547.07. This cost did not include cost for equipment for testing, unused parts, travel/lodging, etc., which totaled $3,228.26. When considering our budget, which was $3,000, our final prototype was within the budget. However, if we consider unexpected fees like the rental vehicle and lodging costs, we did not stay within our budget. Because the targeted price to manufacture would not include these fees, we feel that our final prototype was successful in being within budget.

7.12 Works for Danny's Two Trikes

The user has two trikes he uses. By making the device compatible with both trikes, it will allow for the user to use the device for both trikes and potentially other trikes.

7.12.1 Trike Compatibility Test

This test was conducted at the user's garage and the test confirmed that our device is compatible with both user's trikes. The device was tested using both trikes and he was able to successfully transfer in and out of both trikes. We passed this criterion with flying colors. Figure 38 below, shows both trikes in position for operation. The image on top shows Danny's bigger trike, the Expedition from Catrike. The image below shows Danny's smaller trike, the Sprint X from Icetrike. The image below also shows the trike on top of training equipment, which we did not design anything for, but does not cause any problems when operating our device.

Figure 38. Danny's two trikes in operating position.

8. Project Management

The following sections detail the design process, what worked well, and what we would do differently for future design projects.

8.1 Project Progress and Timeline

Below is a summary of the progress our team has made towards completing the project:

Our team formed during the "Team Building" phase. During this portion each member of the team chose to work on this project, and we all became comfortable working together. Next, we performed "Customer/Need Research" on what our user's and sponsor's needs were by interviewing the end user, Danny. After understanding the scope of the needs, we conducted technical research, where we researched standards/regulations and literature reviews that will aid in our design. The team also searched for existing solutions and patents relating to the needs specified by Danny. We then synthesized our research and customer interview to determine a formal problem statement and list of specifications.

We have completed the "Conceptualization" stage of the design process. Our team used many techniques to help generate creative and effective ideas including but not limited to set-breaking, brainstorming, check lists, attribute lists, and morphological analysis. We selected the best idea for further consideration by using a weighted decision matrix. We then performed various preliminary analyses, created an estimated cost for the project, and identified risks associated with our preliminary concept.

After settling on a concept design, we performed design analysis and detailed design/analysis, which led us to a rough Bill of Materials/CAD model. This led to a new design, a structural prototype plan, analyses/tests we did/planned to do, and design verification for the design.

Our next step was our structural prototype, where we ordered small scale parts for the horizontal position assembly, which included a lead screw, flange nut, bearings/housings, and a coupler. We took what we learned from testing our structural prototype to improve our design and come up with a final design. With this final design, we came up with a Manufacturing plan, a CAD model for our whole system, and a Design Verification Plan. We then did a risk assessment using a software called Design Safe, where the risk assessment is located in Appendix L.

We then began manufacturing our confirmation prototype. During manufacturing, there were small changes to our final design because of different parts used. After the completion of the confirmation prototype, we had a Confirmation Prototype Sign-off. From this, we were advised to design a way to make our device safe for earthquakes. After modifying our device to account for earthquake safety, we installed our device in the user's home. More tests were conducted at the user's home. After installment, we completed the Operator's Manual, located in Appendix M, after considering all the results from testing with the user. For the Project Expo and QL+ we made a video, which shows the project's process and results.

Our next steps are to send the Operator's Manual to the user, submit this FDR to QL+ and our advisor, and participate in the Project Expo.

8.2 Gantt Chart

Our team employed the use of a Gantt chart to help organize the deliverables and tasks needing completion in the future. This chart is organized by milestone and has intermediate tasks assigned to group members with due dates. This tool will allow us to stay on track throughout the year. Please see the full Gantt chart attached in Appendix C.

8.3 Project Management Reflection

Overall, the process drawn out for us by the project advisors was very thorough and effective. The constant deliverables and design reviews kept all parties updated on the status of the project and ensured that we stayed on track with each deadline. The timeline was also flexible enough that it allowed us to spend more time on certain phases of the project, like manufacturing, than other senior project groups.

There were some phases of the project, however, that could have used more planning beforehand. Due to the project stretching a whole school year, the final deliverable deadline always seemed to be a long-term goal, and often during the first two quarters of the project, other classes and projects were prioritized. As a result, much of the important work was completed in the third quarter. If we were to repeat the project, we would wrap up the design phase much earlier, leaving more time for manufacturing and fine-tuning the final product.

8.4 Process Takeaways

The overall process of the project worked well. Careful management, which included frequent updating and checking the Gantt chart, constant communication with our sponsor, and adapting to problems, allowed the team to have success with the project. However, there are some things that the team would do differently for project management if there were another design project. We would try to make Gantt chart updating a group task rather than the task of one person. This would allow the whole group to be aware of all the important dates and tasks, rather than relying on one group member for dates and tasks. We would also change and add tasks during the completion of our Confirmation Prototype. We would add in-person meetings with our user, do testing with our user before permanently installing the device, and determine the date of installment much sooner. Having these tasks would have allowed us to make more polished changes and make design changes to fix any problems the user had with the device.

9. Conclusions & Recommendations

The purpose of the Final Design Review (FDR) document is to provide a thorough description of the development of our final product, from the problem definition phase through final testing and installation.

9.1 Project Reflection

In our initial Scope of Work (SOW) document, we proposed a problem statement, which was approved in October 2018. The statement, also stated in this report in Section 3.1, is as follows:

Danny Knutson, a 6'2" and roughly 230 lb retired Navy Captain and pilot, is an incomplete quadriplegic who enjoys riding his recumbent tricycle. He needs a way to safely and reliably get in and out of his trike without requiring excessive physical strain on whoever is aiding him. The solution is intended for home use and should be durable, balanced, and reasonably priced.

In this FDR report, we describe our final deliverable which serves to solve the problem as stated. As demonstrated in Section 7: Design Verification, according to our specifications, the final deliverable successfully addressed this problem statement. The device safely aids Danny in getting in and out of his trike, with limited physical effort. The device fits in the desired area of the user's garage and meets our volume specifications. However, the device has room for iteration and improvement.

Even though there were complications that reduced our horizontal range of motion, like the placement of the limit switches, electrical box, and the slight misalignment of the leadscrew causing the motor to stall when too close to one side, the device still meets our planned horizontal range of motion. The stalling was fixed by having a higher potentiometer level, which was not a problem for the way the user wanted to move. During the manufacturing of our device, there were many instances where the device was taken apart and reassembled. During the early assemblies and testing, the leadscrew was positioned in a way that there was no stalling even at a low potentiometer level. However, we tested the motor under a 250 lbf hanging load which then showed the stalling of the device at a certain area of the screw, which was deemed insignificant. As stated before, with the increased load during actual usage, it was not insignificant and required increasing the potentiometer power. What we would do differently to prevent the misalignment is to have tighter tolerances in the horizontal positioning system. With tighter tolerances, it would reduce the amount of misalignment, making it almost negligible. We should have also loosened our system and repositioned it while loaded to align it as best as we could before tightening it down fully.

The one specification that was not met was user operated lowering and raising. This was due to the remote not being best suited for Danny's dexterity. During testing with Danny, we found that Danny had to hold the remote with both hands while operating the device. When operating, he was unable to quickly go the direction he desired because the vertical and horizontal motion buttons were not easily accessible for him. This resulted in the helper handling the remote during operation. If a subsequent prototype were to be made, we would put greater focus on the ergonomics of the remote to ensure that Danny could operate it with ease. This would require testing with Danny what he can and cannot do with one hand and designing something that will match his dexterity level. The failure of the remote assembly to be easily operated by Danny meant that our reach goal of the device being completely user operated was not met. However, since Danny will always have an aide with him when using the device, it is not a major issue, as the aide can operate the remote for him.

Another change we would make if we were to repeat the project is to work more closely with Danny to ensure that the device is built precisely to Danny's garage. Lacking a preliminary visit to Danny's house, we relied on the device being adaptable to any environment. This allowed us to adapt to the ceiling structure, ceiling height, and garage-door placement that we encountered during our visit; however, it would have been more efficient to have visited Danny before entering the design phase and design for a specific space on his garage ceiling. With our ceiling attachment brackets, the initial direction that Danny wanted the device to be oriented would have required adding joists to the ceiling structure. Knowing the exact joist positions and the layout of the garage would have allowed us to optimize the way our device was installed into the user's garage. The final position and direction of the device was satisfactory because we were able to mount our electrical box to the garage door opener rails already installed in his home. This allowed for a more efficient installation and setup, however, if we had seen Danny's garage before designing, the installation process would have been more straightforward and the location of the device in his garage would be best suited for his needs.

Another improvement if we had to do the project over again is having more direct interaction with the user. We had great communication with Danny via phone interviews and email. The direction of the project was clear, but there were instances we had to do some testing on ourselves and making assumptions. For Danny's movement during the operation of the device, it would have been helpful to see how Danny would sit down and stand up with similar contact points our device would allow with the user. We did to a mock test with ourselves to try to mimic how the user would move but testing with the user showed that he would have a much more directly diagonal motion rather than the repeated "up" and "down" motions we thought we would incorporate. Another test with Danny before designing was already discussed above, the section about the remote and one hand use. If we had mock remotes and had tested with Danny to see what he could and could not do, we may have been able to design a better remote, or design a remote that the aide would use, rather than designing a remote for Danny but having the helper use the remote instead.

There were many things that we would have done differently, but overall the project was a success. We had some unforeseen problems, like the area of installment for our device, specific boundary of operation for our device, and the placement of our device on the joists, but we were able to have a design that could adapt to these unforeseen circumstances.

9.2 Next Steps

The next step in the process is to allow Danny and his wife to practice with the device and get comfortable with the remote, sling, trike positioning, and horizontal speed. Within the span of 4 test runs, Danny and his wife were progressively improving the way they communicated during the operation of the device, so we are confident that they can quickly perfect the process. The horizontal speed is adjustable, but once they find a speed that works best, the speed potentiometer can be stowed away. We received another sling after returning from our visit to Danny's house, so we will mail it to him, and he can decide which he prefers. We hope the recumbent transfer device will have a lasting impact on Danny's ability to exercise and improve his quality of life.

Appendix A – Patent Table
Appendix B – QFD
Appendix C – Gantt Chart
Appendix D – Pugh Matrices
Appendix E – Design Hazard Checklist
Appendix F – Preliminary Analysis
Appendix G – Indented Bill of Materials
Appendix H – Project Budget
Appendix I – Failure Modes and Effects Analysis
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Appendix L – Risk Assessment
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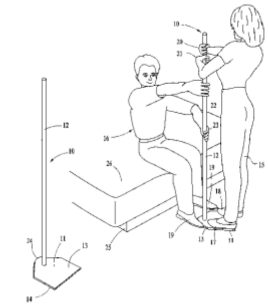
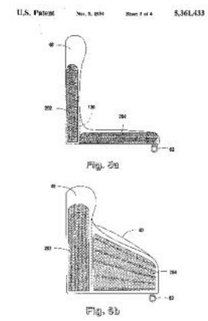
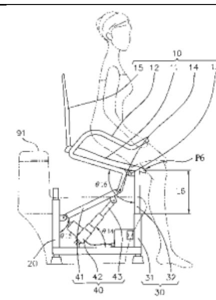
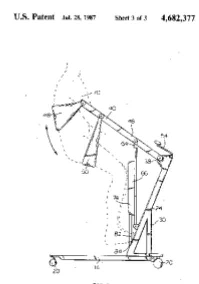
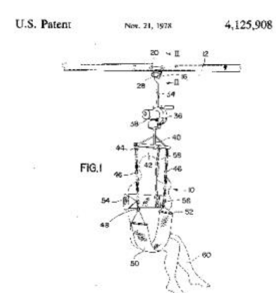
Appendix A. Patent Table

Patent Name	Patent No.	Description	Diagram
Movable stand to assist a person from a lying or sitting position to a sitting and/or standing position	US6615432B1	• User grips pole to help pull himself up. • Pole must be secured with the body weight of an assister.	
Pneumatic sit/stand assistance device utilizing sequential inflation for stabilizing effects	US5361433A	• Seat inflates to move user's center of gravity towards the feet	
Sit/stand assistance device	US8556347B2	• Powered pistons tilt the seat upright	
Device for transferring immobile persons	US4682377A	• Crane-like sling system • Portable	
Invalid transfer lift	US4125908A	• Sling system • Winch provides vertical movement • Ceiling-mounted rail provides horizontal movement	

Appendix B. QFD

Correlations	
Positive	+
Negative	–
No Correlation	

Relationships	
Strong	●
Moderate	○
Weak	▽

Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼

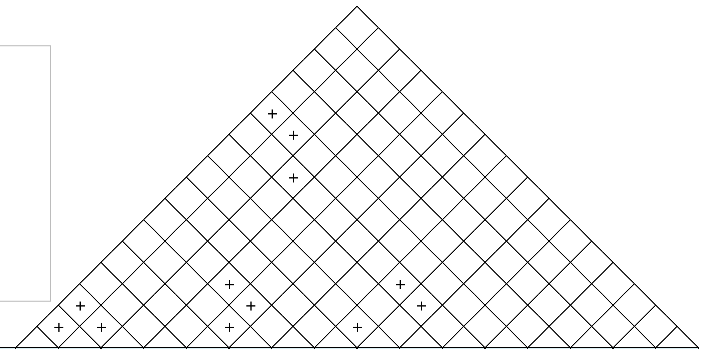
QFD House of Quality

Project:

Team 65 Mount/Dismount Recumbent Bicycle

Revision Date:

10/17/18

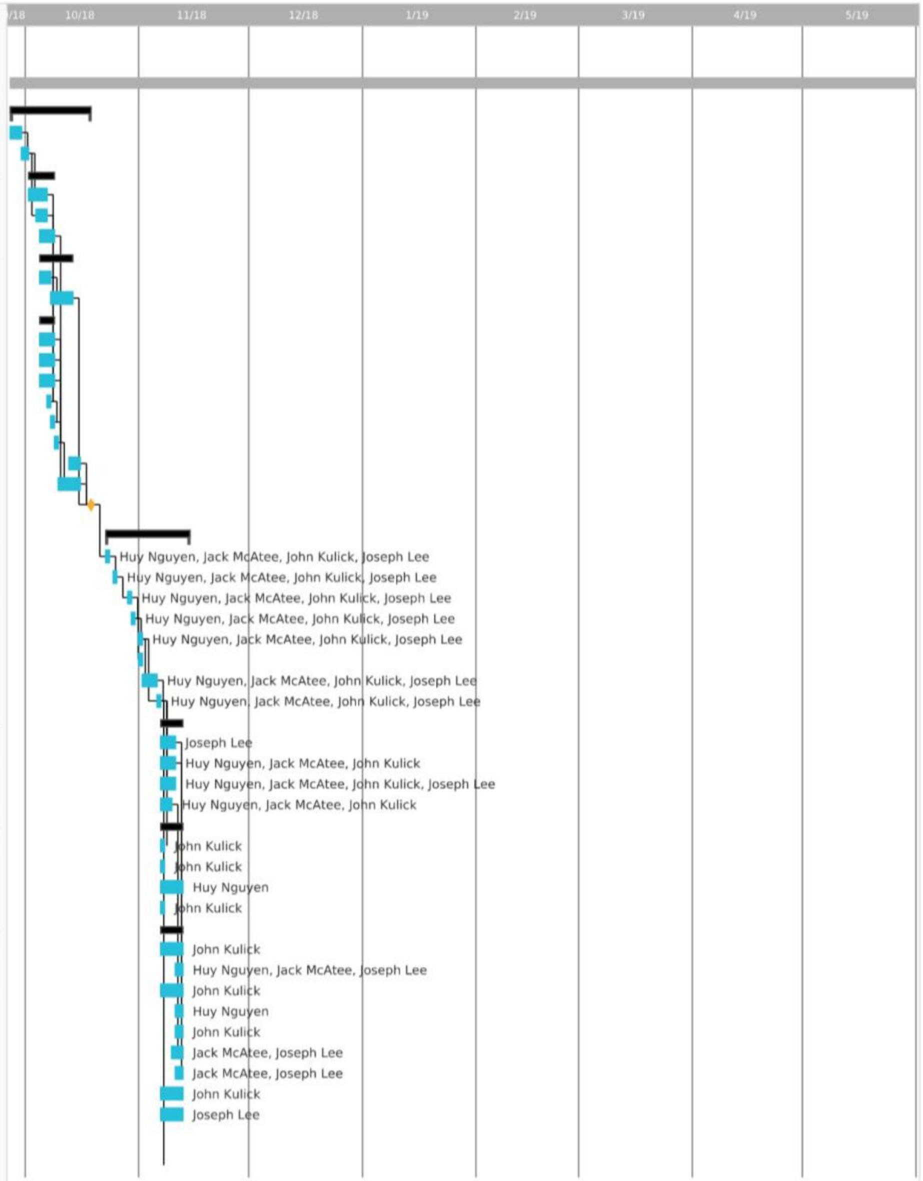


								Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16						
	WHO: Customers							Direction of Improvement	▲	▲	▼	▼	▼	▼	▼	◇	◇	◇	▼	◇					NOW: Curr. Products					
Row #	Weight Chart	Relative Weight	Danny	QL+	People with other Disabilities	Helper/Aide	Maximum Relationship	WHAT: Customer Requirements (Needs/Wants) / HOW: Engineering Specifications (Tests)	Range of Motion (Vertical)	Range of Motion (Horizontal)	Volume	Steps to Operate	User Force to Lower & Raise	Level of Pain to Use (0-10)	Time to Operate	User Weight Range	Min. Factor of Safety of Compor	User Operated Raising/Lowerin	Price to Manufacture	Works for Danny's Two Trikes					Invacare: Model No. RPS S350-	*Pneumatic sit/stand device (infl*	*Drive Medical: Hydraulic Patien*	*Etac Turner Pro*	*Hoyer Ascend Patient Lift*	Row #
1		9%	6	8	7	8	9	Independent Raising and Lowering	●	●		○	●	▽	▽	▽	▽	●	▽	○					3	4	1	1	3	1
2		5%	2	7	5	2	9	Small Footprint	●	●	●					▽			○						2	5	3	5	1	2
3		9%	8	9	7	7	9	Durable	○	○	▽	○	▽			○	●		○						4	4	3	4	5	3
4		8%	7	7	7	5	9	Comfortable	●	●	▽		○	●	○	▽	○	○	○						4	4	1	1	4	4
5		12%	10	10	10	10	9	Balanced	●	●			▽	▽		▽	▽								2	1	1	1	3	5
6		12%	10	10	10	10	9	Easy to use				●	●	○	●	▽		○		▽					3	5	2	3	2	6
7		6%	5	4	5	6	9	Quick to use	○	○		●	○	▽	●	▽		▽		▽					2	5	3	5	1	7
8		2%	1	3	2	1	3	Not an eye sore			○								○						3	2	1	3	2	8
9		6%	6	4	6	3	9	Does not interfere with current garag	○	○	●														3	4	4	4	3	9
10		12%	10	10	10	10	9	Safe	○	○		○	○	●	○	●	●	○	●	▽					4	1	2	1	5	10
11		6%	4	8	8	2	9	Adaptable to heavier weights or differ	●	●	○	▽	○		▽	●	○	▽	○	○					5	1	2	1	3	11
12		5%	5	6	6	1	9	Low cost	○	○	○					○	○	▽	●						1	5	4	5	1	12
13		7%	10	7	8	1	9	Adaptable to different trikes	○	○	▽	●	○		▽	▽	▽	○		●					3	1	2	0	3	13
14		0%																												14
15		0%																												15
16		0%																												16

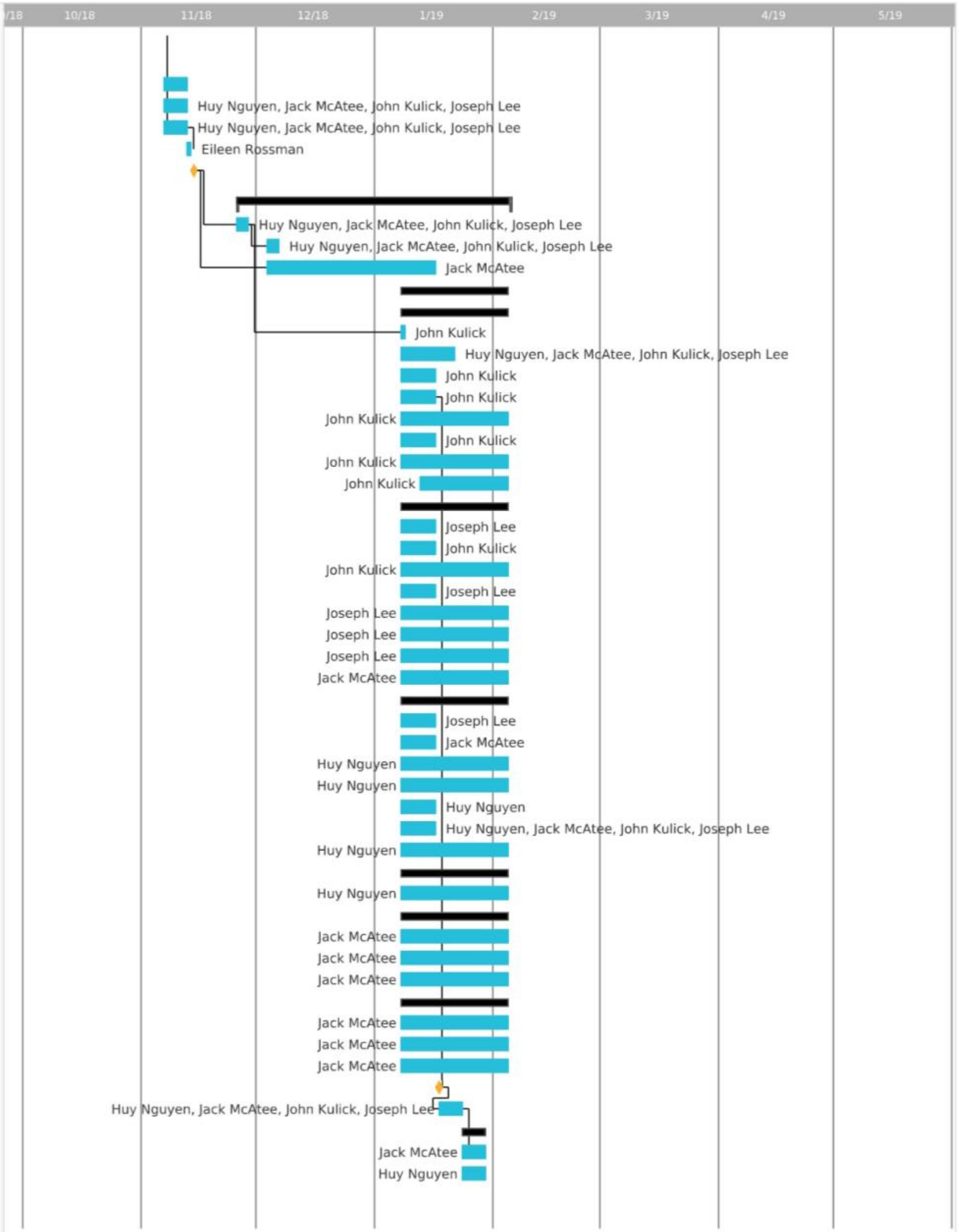
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	HOW MUCH: Target Values	3.5 ft	3.5 ft	100 ft^3	5	0.5 lb	0	3 min	80-400 lb	3	YES	$800	YES				
	Max Relationship	9	9	9	9	9	9	9	9	9	9	9	9				
	Technical Importance Rating	496	496	157.2	330.3	331.1	243.7	248.2	269.3	280.3	216.5	255.1	143.1				
	Relative Weight	14%	14%	5%	10%	10%	7%	7%	8%	8%	6%	7%	4%				
Curr. Products	Invacare: Model No. RPS S350-1	4	0	1	2	4	3	3	4	3	5	1	3				
	Pneumatic sit/stand device (inflation)	5	0	4	3	1	1	3	5	3	0	5	1				
	draulic Patient Lift with 6-Point Cradle	4	0	4	4	0	2	2	5	4	0	5	2				
	Etac Turner Pro	3	0	1	5	1	1	5	5	4	0	5	0				
	Hoyer Ascend Patient Lift	4	0	4	1	5	4	1	2	2	5	1	3				
	Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Appendix C. Gantt Chart

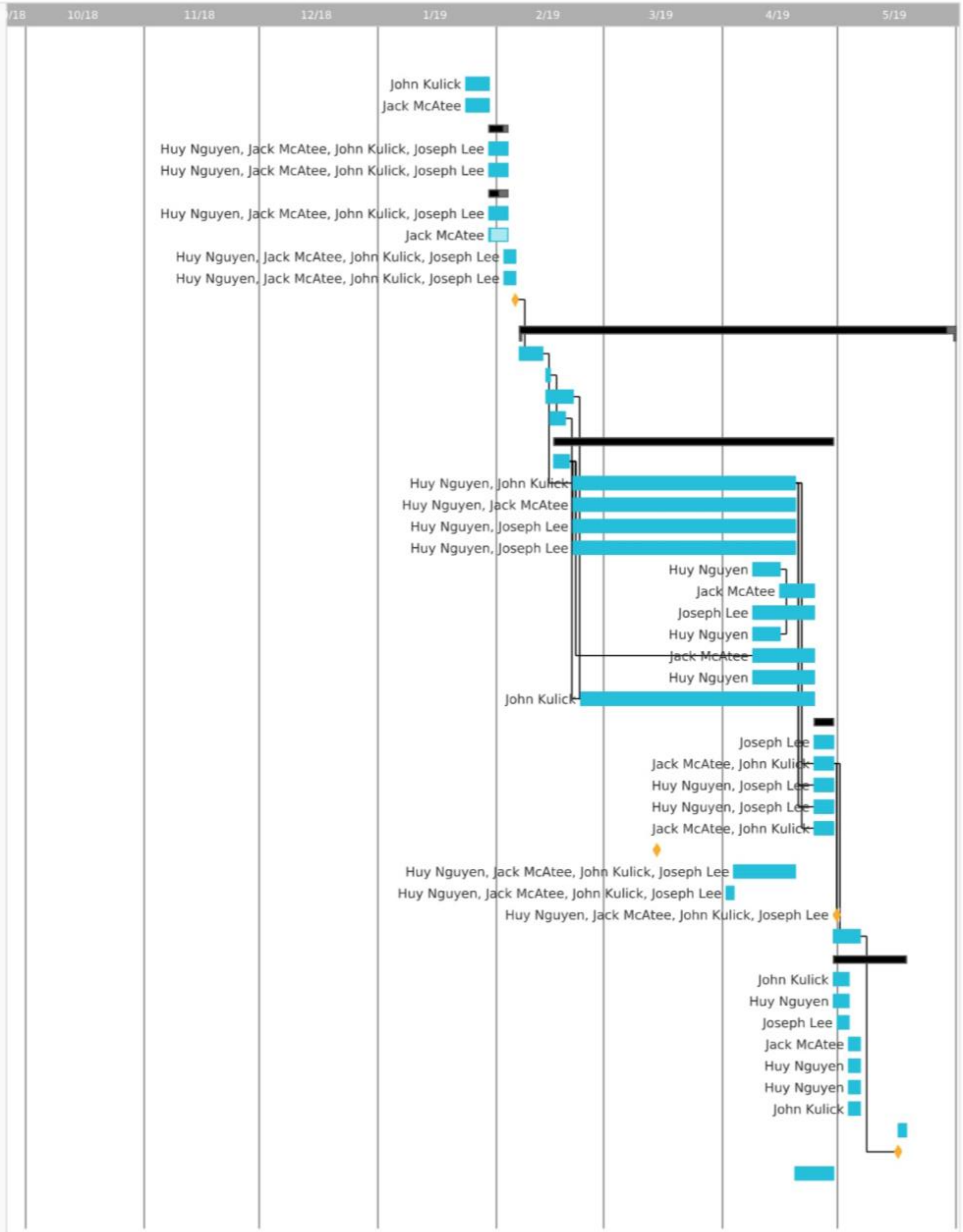
Team 65 Recumbent Bike T...	start	end	0h	99%
Problem Definition	**09/27/18**	**10/18/18**	**0h**	**100%**
Choose Project	09/27	09/29	0	100%
Meet Team	09/30	10/01	0	100%
Perform Customer/Need Research	**10/02/18**	**10/08/18**	**0h**	**100%**
Interview Sponsor	10/02	10/06	0	100%
Interview Users	10/04	10/06	0	100%
Online search for customer compla...	10/05	10/08	0	100%
Perform Technical Research	**10/05/18**	**10/13/18**	**0h**	**100%**
Develop Search Criteria	10/05	10/07	0	100%
Perform Literature Search	10/08	10/13	0	100%
Perform Product Research	**10/05/18**	**10/08/18**	**0h**	**100%**
Online search for current products	10/05	10/08	0	100%
Ask sponsor/users about currrent p...	10/05	10/08	0	100%
Patent search for similar products	10/05	10/08	0	100%
Write Problem Statement	10/07	10/07	0	100%
Write Customer Needs/Wants List	10/08	10/08	0	100%
Perform QFD	10/09	10/09	0	100%
Create Initial Project Plan	10/13	10/15	0	100%
Write Scope of Work	10/10	10/15	0	100%
Scope of Work Milestone	10/18	10/18	0	100%
Conceptualization	**10/23/18**	**11/14/18**	**0h**	**100%**
Ideation Session 1	10/23	10/23	0	100%
Ideation Session 2	10/25	10/25	0	100%
Ideation Session 3	10/29	10/29	0	100%
Create Concept Models	10/30	10/30	0	100%
Refine Ideas	11/01	11/01	0	100%
Ideation Session 4	11/01	11/01	0	100%
Pugh Matrices	11/02	11/05	0	100%
Concept Selection	11/06	11/06	0	100%
Develop Design for PDR	**11/07/18**	**11/12/18**	**0h**	**100%**
Concept CAD	11/07	11/10	0	100%
Preliminary Analyses	11/07	11/10	0	100%
Proof Of Concept Prototype	11/07	11/10	0	100%
Cost Analysis	11/07	11/09	0	100%
Format Report	**11/07/18**	**11/12/18**	**0h**	**100%**
Abstract Edited	11/07	11/07	0	100%
Introduction Edited	11/07	11/07	0	100%
Background Edited	11/07	11/12	0	100%
Objectives Updated	11/07	11/07	0	100%
Concept Design Chapter	**11/07/18**	**11/12/18**	**0h**	**100%**
Description of Process	11/07	11/12	0	100%
Sketches and Desc. of Ideas	11/11	11/12	0	100%
Decision Matirx Discussion	11/07	11/12	0	100%
description of chosen concept	11/11	11/12	0	100%
preliminary analyses	11/11	11/12	0	100%
costs	11/10	11/12	0	100%
risks	11/11	11/12	0	100%
Project Management Updated	11/07	11/12	0	100%
Conclusion Updated	11/07	11/12	0	100%



Made changes to errors from SOW	11/07	11/12	0	100%
added appendices	11/07	11/12	0	100%
Create Presentation	11/07	11/12	0	100%
Grade Presentation	11/13	11/13	0	100%
Preliminary Design Review	11/14	11/14	0	100%
Detail Design	**11/26/18**	**02/05/19**	**0h**	**99%**
Safety/FMEA/Analysis	11/26	11/28	0	100%
DFMA	12/04	12/06	0	100%
Keep Asking About Handicare	12/04	01/16	0	100%
Analysis	**01/08/19**	**02/04/19**	**0h**	**100%**
Select Motor & Electronics	**01/08/19**	**02/04/19**	**0h**	**100%**
Email Mello	01/08	01/08	0	100%
Talk to Mello: about bearings & ...	01/08	01/21	0	100%
Select Motor	01/08	01/16	0	100%
Figure out control system	01/08	01/16	0	100%
Select Switch	01/08	02/04	0	100%
Select Potentiometer	01/08	01/16	0	100%
Select Wire	01/08	02/04	0	100%
Select Limit Switches	01/13	02/04	0	100%
Lead Screw Selection	**01/08/19**	**02/04/19**	**0h**	**100%**
Critical Speed Calcs	01/08	01/16	0	100%
Torque Calcs	01/08	01/16	0	100%
Self Locking Calcs	01/08	02/04	0	100%
Buckling Calcs	01/08	01/16	0	100%
Bearing Selection	01/08	02/04	0	100%
Bearing Life	01/08	02/04	0	100%
Bearing Mounting Component Se...	01/08	02/04	0	100%
Nut Selection	01/08	02/04	0	100%
Overhead Rail Design	**01/08/19**	**02/04/19**	**0h**	**100%**
CAD Model of Assembly	01/08	01/16	0	100%
Stress calcs on rail	01/08	01/16	0	100%
Stress calcs on aluminum suppor...	01/08	02/04	0	100%
Fastener Stress Calcs	01/08	02/04	0	100%
Select Rail	01/08	01/16	0	100%
Select Trolley	01/08	01/16	0	100%
Sling Selection	01/08	02/04	0	100%
Foothold Design	**01/08/19**	**02/04/19**	**0h**	**100%**
Design It	01/08	02/04	0	100%
Trolley Screw Interface	**01/08/19**	**02/04/19**	**0h**	**100%**
Design Shape	01/08	02/04	0	100%
Select Fasteners/ Calculate	01/08	02/04	0	100%
Detailed CAD	01/08	02/04	0	100%
Hook Design	**01/08/19**	**02/04/19**	**0h**	**100%**
Design Shape	01/08	02/04	0	100%
Stress Calculations	01/08	02/04	0	100%
Detailed CAD	01/08	02/04	0	100%
Interim Design Review	01/17	01/17	0	100%
Structural Prototype	01/18	01/23	0	100%
Detailed Dwg Package	**01/24/19**	**01/29/19**	**0h**	**100%**
Trolley Screw Interface Dwg.	01/24	01/29	0	100%
I Beam Cut Dwg.	01/24	01/29	0	100%



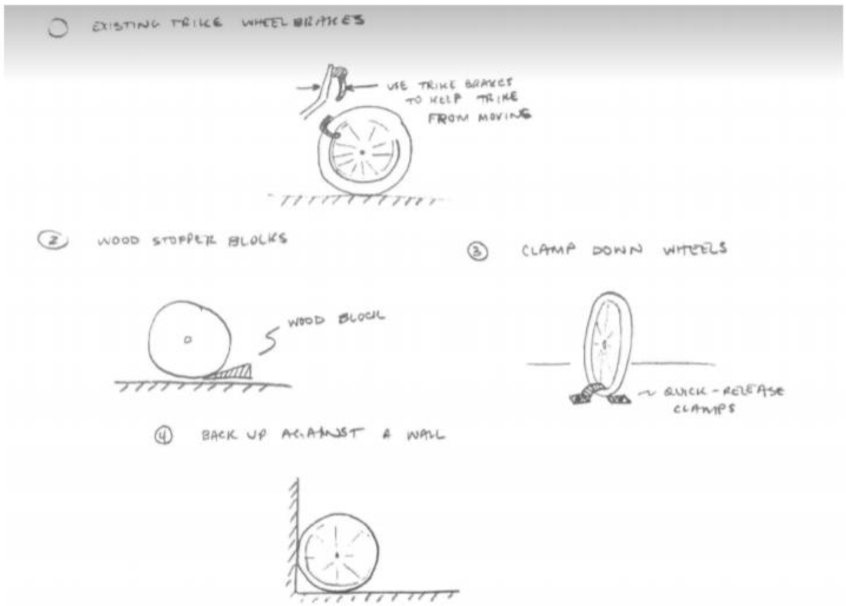
Wiring Diagram	01/24	01/29	0	100%
Hook	01/24	01/29	0	100%
Manufacturing Plan	**01/30/19**	**02/03/19**	**0h**	**77%**
Fabrication	01/30	02/03	0	100%
Assembly	01/30	02/03	0	100%
Procurement	**01/30/19**	**02/03/19**	**0h**	**54%**
Bill of Material Refinement	01/30	02/03	0	100%
Order Parts through QL+	01/30	02/03	0	7%
Format Report	02/03	02/05	0	100%
Cost Analysis	02/03	02/05	0	100%
Critical Design Review	02/05	02/05	0	100%
Manufacturing	**02/07/19**	**05/31/19**	**0h**	**98%**
Send purchase list to sponsor	02/07	02/12	0	100%
Meeting with Jim	02/14	02/14	0	100%
NSPE PRESENTATION	02/14	02/20	0	100%
Order Electronics	02/15	02/18	0	100%
Manufacture Device	**02/16/19**	**04/29/19**	**0h**	**100%**
Parts Arrive	02/16	02/19	0	100%
Turn Lead Screw	02/21	04/19	0	100%
Cut Support Beams to Length	02/21	04/19	0	100%
Drill and Tap Support Beams	02/21	04/19	0	100%
Face and Drill I Beam	02/21	04/19	0	100%
Manufacture Motor Mounting	04/09	04/15	0	100%
Manufacture Trolley Bracket	04/16	04/24	0	100%
Manufacture Foothold	04/09	04/24	0	100%
Manufacture Bearing Mounts	04/09	04/15	0	100%
Manufacture Hanger Bracket	04/09	04/24	0	100%
Modify Celing Brackets	04/09	04/24	0	100%
wire motor	02/23	04/24	0	100%
Mounting	**04/25/19**	**04/29/19**	**0h**	**100%**
Order Sling	04/25	04/29	0	100%
Mount Nut on screw	04/25	04/29	0	100%
Mount Screw on Bearings	04/25	04/29	0	100%
Mount I beam on supports	04/25	04/29	0	100%
mount motor and plate and such	04/25	04/29	0	100%
Manufacturing & Test Review	03/14	03/14	0	100%
Operators Manual	04/04	04/19	0	100%
Test Plan	04/02	04/03	0	100%
Confirmation Prototype Review	04/30	04/30	0	100%
Finalize Manufacturing	04/30	05/06	0	100%
Testing	**04/30/19**	**05/18/19**	**0h**	**100%**
Test 5 System Weight Test	04/30	05/03	0	100%
Test 6 Lag Bolt Weight Test	04/30	05/03	0	100%
Test 1 Motion Test	05/01	05/03	0	100%
Test 2 Steps to Operate	05/04	05/06	0	100%
Test 3 User Force to Lower/Raise	05/04	05/06	0	100%
Test 4 Level of Comfortability	05/04	05/06	0	100%
Test 7 Time to Operate	05/04	05/06	0	100%
Take to Danny	05/17	05/18	0	100%
Test Results Review	05/16	05/16	0	100%
Manufacturing Section Report	04/20	04/29	0	100%



Test Section Report	04/30	05/15	0	100%
Expo Poster	05/25	05/30	0	0%
Video	05/25	05/30	0	0%
Deliver and Test to Danny	05/17	05/30	0	100%
Expo	05/31	05/31	0	100%

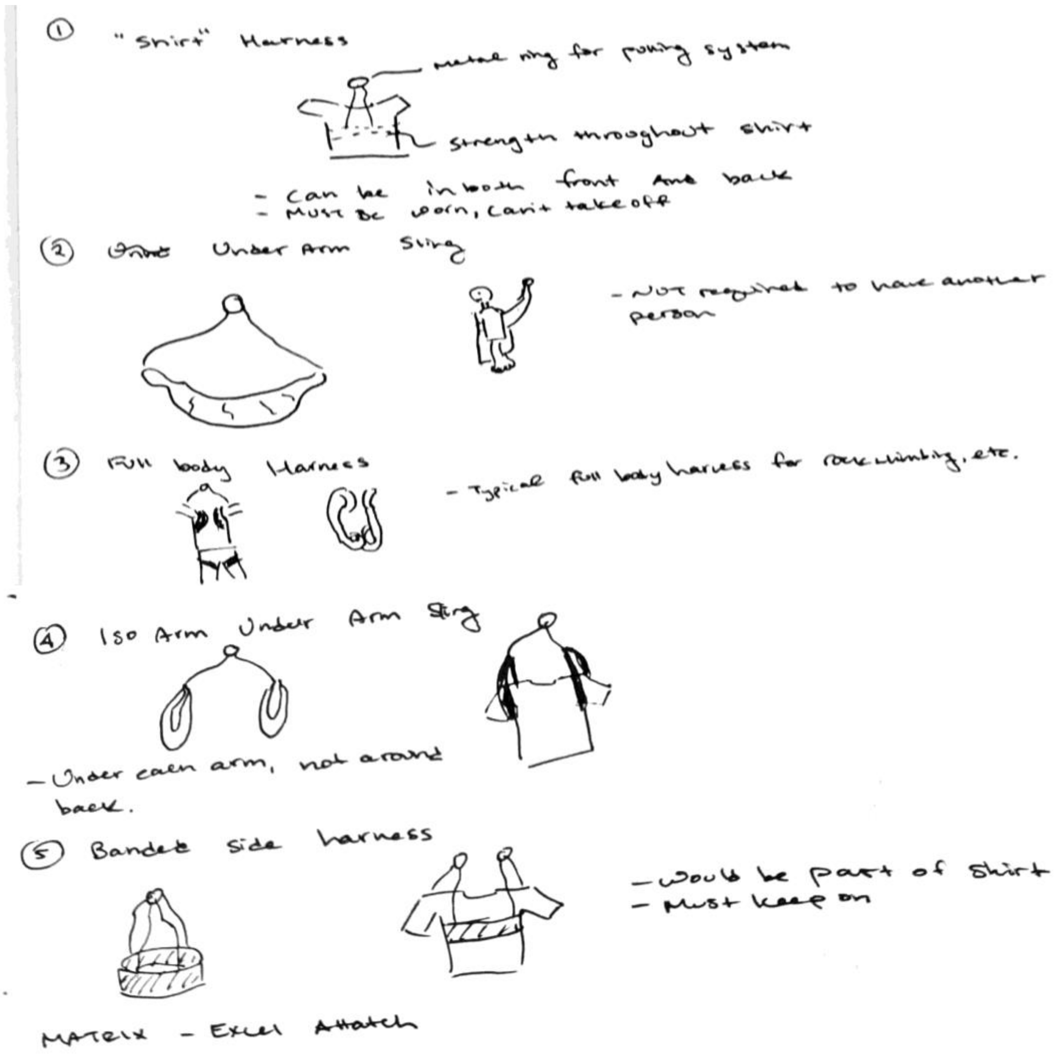
Appendix D. Pugh Matrices

Secure Trike				
Criteria/Concepts	Existing Trike Wheel Brakes	Wood Stopper Blocks	Clamp Down Wheels	Back wheels up against wall
Set Up/Tear Down Time	s	-	-	+
Cost	s	+	-	+
Safety	s	-	+	-
Footprint	s	-	-	s
Ease of Use	s	-	-	+

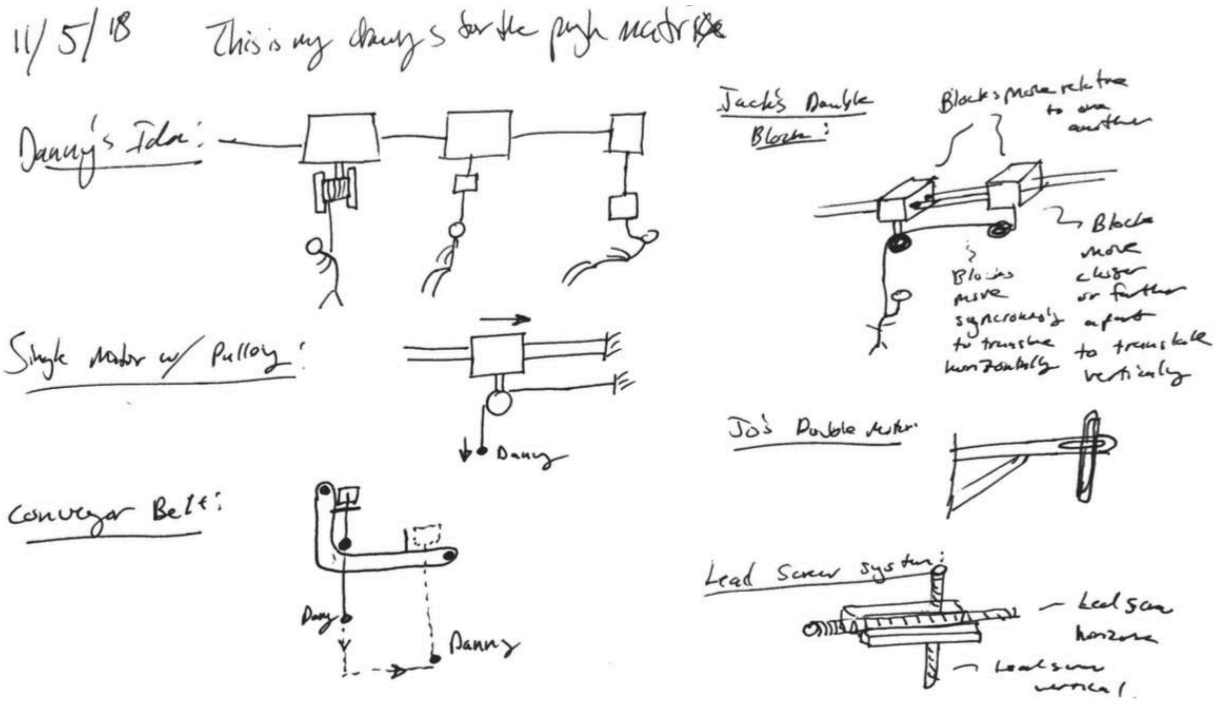


FUNCTION : SECURE DANNY'S FEET.

CRITERIA / IDEAS	DATUM BIKE CLIP-IN	VELCRO STRAPS	FLYPAPER	RAISED STEP	BELT BUCKLE	"VISE" GRIP
COMFORTABLE	S	—	—	S	—	—
EASY TO USE/ QUICK TO USE	S	—	S	+	—	—
RELIABLE/ REPEATABLE	S	S	—	—	S	S
EASY TO INSTALL	S	+	+	+	+	S



Support Body					
Criteria\Concepts	1. Shirt Harness (Always On)	2. Under Arm Sling	3. Full Body Harness	4. Iso Arm Under Arm SLing	5. Banded Side Harness (cant take off)
SetUp/Tear Down Time	s	+	-	s	s
Cost	s	-	-	+	s
Safety	s	s	+	s	+
Amount of Supp.	s	s	+	s	+
Comfort	s	s	-	-	s
Ability to Balance	s	s	+	+	+
Durability	s	+	s	-	s



Lift/Lower User	Datum					
Criteria\Concepts	Danny's Idea	Single Motor w/ Pulley	Conveyor Belt	Jacks Double Block Idea	Jo's Double Motor	Lead Screw System
Cost	s	+	-	-	-	-
Speed	s	+	-	+	s	-
Range of Motion	s	-	-	s	-	+
Controllability	s	-	-	-	s	+
Footprint	s	-	-	-	-	-
Safety	s	-	-	+	-	-
Power	s	+	+	s	-	s

Criteria\Concepts	Danny's Idea	Single Motor w/ Pulley	Conveyor Belt	Jacks Double Block Idea	Jo's Double Motor	Lead Screw System
Cost	+	+	-	s	-	-
Speed	-	+	-	s	s	-
Range of Motion	s	-	-	s	-	-
Controllability	+	-	-	s	-	+
Footprint	+	+	-	s	-	-
Safety	-	+	-	s	-	+
Power	s	-	+	s	-	+

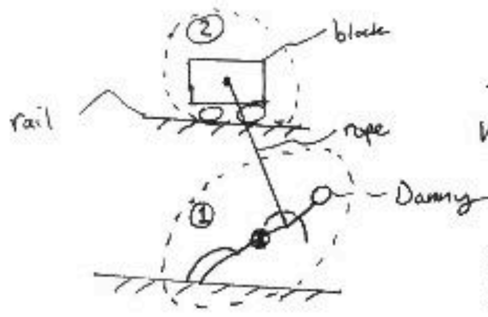
Appendix E. Design Hazard Checklist

Y	N	
■	□	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
□	■	2. Can any part of the design undergo high accelerations/decelerations?
■	□	3. Will the system have any large moving masses or large forces?
□	■	4. Will the system produce a projectile?
■	□	5. Would it be possible for the system to fall under gravity creating injury?
■	□	6. Will a user be exposed to overhanging weights as part of the design?
■	□	7. Will the system have any sharp edges?
□	■	8. Will any part of the electrical systems not be grounded?
□	■	9. Will there be any large batteries or electrical voltage in the system above 40 V?
□	■	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
□	■	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
□	■	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
□	■	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
□	■	14. Can the system generate high levels of noise?
□	■	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
■	□	16. Is it possible for the system to be used in an unsafe manner?
■	□	17. Will there be any other potential hazards not listed above?

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
1.Spinning lead screw with motor, translating trolley that can pinch, sling that can cause pinching	The lead screw, motor, and trolley will be too high for the user to have any direct interaction with, unless he or she is elevated (not including the system's elevation mechanism). The sling will have padding and be made of a polyester material to prevent pinching in the underarms and the connection point with the pulley.	2/26/19	2/26/19
3. The user with a weight range from 80 to 400 lbs, will be moved vertically and horizontally, who can fall if the system fails, causing injury.	The system will have a certain factor of safety to be able to handle this weight range and more.	2/26/19	2/26/19
5.The system will be mounted on the ceiling, where if the mounting isn't stable, the system can fall, causing injuries to the user.	The system will be screwed into metal beams that will be screwed into the ceiling joists in the garage. The mounting system will be designed to be able to handle at least two times the weight of the whole system and the user.	2/28/19	5/19/19
6.The system will be mounted on the ceiling, where if the mounting fails, the user can sustain severe injuries. The user is also strapped with a sling, where if the sling fails, the user can sustain severe injuries.	Refer to Hazard Description #5 for mounting system. The sling will be selected to withstand a least two times the weight of the user.	2/28/19	2/28/19
7. The lead screw and trolley may have rough surface or pinch points, which can cause injury if they come in contact a person.	Refer to Hazard Description #5. The system will be mounted on the ceiling, so the user should not have direct contact with the system, besides the sling, unless if the system falls.	3/5/19	5/19/19
16. The system can be used as a swing, or something to hang on to for reasons the system was not designed for.	There will be warning labels to warn the user that the system is to only be used for the designed purpose.	3/5/19	5/19/19
17. The user may lose balance, causing the user to swing uncontrollably.	The user's feet will be secured, allowing the user to always have two points of secure connection, the feet and upper body.	3/5/19	5/19/19

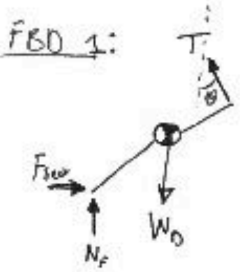
Appendix F. Preliminary Analysis

Sketch:



N_F = Floor Normal Force
θ = Angle between vertical and rope
T = Tension in rope
W_D = Danny's Weight
N_R = Rail Normal Force
F_f = Force of friction on block
F_B = Force at Breaking System.
F_{feet} = Force on feet.

FBD 1:



$+\uparrow \sum F_y: \quad N_F + \cos\theta T - W_D = 0$

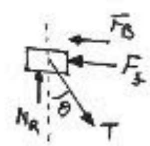
Assume: θ is small $\rightarrow$ $\cos\theta \approx 1$ (nonconservative estimate)

$N_F \approx 0$ (conservative estimate)

$\rightarrow \quad T - W_D = 0$

$$\boxed{T = W_D}$$

FBD 2:



$\xrightarrow{+} \sum F_x: \quad T\sin\theta - F_f - F_B = 0$

Assume: $F_f \approx 0$ (conservative estimate)

$\theta \approx 30°$ (from testing)

$F_B = T\sin\theta$

$F_B = W_D \sin\theta$

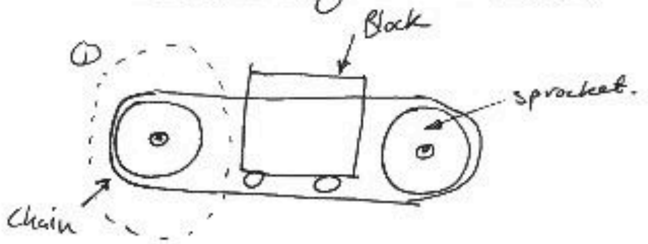
$= (220\text{ lb})(\sin(30°))$

$= 110\text{ lb}$

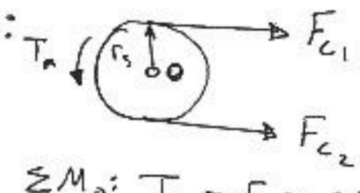
Motor Required Torque:

T_m = Motor Torque
F_c = Force of Chain
r_s = sprocket radius
V = linear speed of chain

Sketch:



FBD ①:



Assume: F_{c2} is slack ≈ 0

ΣM_o: $T_m - F_{c_1} r_s = 0$

$T_m = F_{c_1} r_s$

$T_m = (110\ lb)(1.5\ in)$

$\boxed{= 165\ in\text{-}lb}$ ✓

$V = r_s \omega$

$V = (1.5\ in)\left(37\ \frac{rot}{min}\right)\left(\frac{1\ min}{60\ sec}\right)$

$= 0.925\ in/s$ ✓

Indented Bill of Material (BOM)

Recumbent Bike Transfer Device

Vendor PN	RBT PN	Description					Vendor	Qty
		Lvl0	Lvl1	Lvl2	Lvl3	Lvl4		
	RBT0000	Final Assy						
			Horizontal Positioning Assy					
				Rail Assy				
	RBT111				3 in. I-Beam S3x5.7 Track		Ultimation	1
9792					Jervis-Webb I-Beam Trolley		Ultimation	1
	RBT113				5/8"-8 Leadscrew, 4 ft.		McMaster-Carr	1
	RBT114				5/8"-8 Brass Square Nut		McMaster-Carr	1
PN 887480136616					Brass Screws		Home Depot	2
	RBT115				Trolley Bracket		McMaster-Carr	1
KP000					Pillow Block Bearing 3/8"		McMaster-Carr	2
97135A210					Hex Head Steel 1/4-20 Bolts, 1 1/4 le		McMaster-Carr	8
AAA					1/4 " Washer		Home Depot	16
97135A210					1/4-20 Steel Locknuts (pack of 25)		McMaster-Carr	4
AFD					1/4" X 2" Hex Head Bolt		Home Depot	4
	RBT116				Motor Plate		McMaster-Carr	1
	RBT117				Spacer Plate		McMaster-Carr	1
	RBT118				Bearing Support		McMaster-Carr	2
	RBT119				Motor Spacer		McMaster-Carr	4
52427801005					Gorilla Construction Adhesive 9 oz		Home Depot	1
813952014571					1/4 2x4 MDF		Home Depot	1
	RBT120			Power Assy				
MTPM-P25-1JK40					12V 1/6 HP Motor		AutomationDirect	1
H12106HF-6P-P10					Controller Box		AutomationDirect	1
GSD1-48-20C						Motor Controller	AutomationDirect	1
EPP-400-12						12 V Power Supply	Digikey (Meanwell)	1
SVH-41T-P1.1						JST 16AWG Solderless Cri	Digikey	2
387700104						JST Plastic Connector	Digikey	1
CWC016-00-40L03						Relays	AutomationDirect	2
BIC0						Interlock	AutomationDirect	1
FAZ-D15/1-NA						Circuit Breaker	AutomationDirect	1
018803-00						24 V Fan	AutomationDirect	1
69706709770122						Surge Protector	Home Depot	1
88700020290						Junction Box 4x4x2	Home Depot	1
118800-30						Filter	AutomationDirect	1
					Remote			
202U						Wireless Relays	Solidremote	1
TX-134						Wireless Remote	Solidremote	1
EDR-120-24						24 V Source	Meanwell	1
AP2R31W02					Limit Switch		AutomationDirect	2
6408K12					Flexible Shaft Coupling Iron Hub witl		McMaster-Carr	1
6408K12					Flexible Shaft Coupling Iron Hub witl		McMaster-Carr	1
6408K73					14000 rpm Buna-N Rubber Spider fo		McMaster-Carr	1
207-1205R24					16 Gauge Wire		Home Depot	2
32076075019					22-18 AWG SPADE TERMINALS		Home Depot	1
WT51					Wire Caps		Home Depot	2
BC74098					4 Lug Terminal Blocks		Amazon	6
887480030280					M4x16 Zinc Bolts		Home Depot	4
887480036688					Lock Nut Nylon Insert Zinc		Home Depot	6
032076021047					20/10A on/off Screw Toggle Switch		Home Depot	1
032167000586					PB 50 3oz		Home Depot	1
			Vertical Positioning Assembly					
330050				Handicare C450			MedMart	1
PTC 30131				Sit to Stand Sling, XL, 27.5" x 55.5"			Proactive Medical	1
091111150487				3/4" EMT Conduit x 5'			Home Depot	1
0000-268-517				Handy Link Chain Zinc #135x1'			Home Depot	1
PN 066296089983				Rubber Mat			Home Depot	1
B07541ZRYY				Foot Straps			Home Depot	1
	RBT230			Hanger Bracket Subassembly			--	1
	RBT231				Bracket Plate		McMaster-Carr	2
AYB					1/2" Hex Head Bolt, 1" Length		Home Depot	3
PN 887480035421					1/2" Nut		Home Depot	3
PN 887480035421					1/2" Washer		Home Depot	6
			Mounting Assy					
B107-22A	RBT310			1 5/8" U Bracket			B-LINE	4
	RBT311			End Support Bar			McMaster-Carr	2
94105A539				1/4-20 X 3/4 Set Screw			McMaster-Carr	16
97135A210				Hex Head Steel 1/4-20 Bolts, 1 1/4 length			McMaster-Carr	4
ARK				5/16 Hex Lag Screws, 2.5" length			Home Depot	8
AKC				5/16 x 2 Steel Washer			Home Depot	8
								122

Appendix H. Budget of Total Project and Only Confirmation Prototype

RBT Part No.	Item	Vendor	Vendor Part No.	Quantity	Cost	Ttl Cost	Purchased By	Date Purchased	RBT Part No.2
RBT231	6061 Aluminum 1/4" x 3" (1 ft long)	McMaster-Carr	8975K87	1	$8.10	$8.10	QL+	2/21/2019	RBT231
RBT115	Low-Carb Steel 90 deg (1/4" thick, 2" x 2", 1 ft)	McMaster-Carr	9017K694	1	$10.22	$10.22	QL+	2/21/2019	RBT115
RBT311	1215 Carbon Steel 1" x 1" (6 ft long)	McMaster-Carr	4416T47	1	$59.02	$59.02	QL+	2/21/2019	RBT311
RBT113	Carbon Steel Acme Lead Screw, Right Hand, 5/8"-8 Th	McMaster-Carr	98935A915	1	$12.21	$12.21	Team	2/26/2019	RBT113
RBT114	360 Brass Acme Square Nut, Right Hand, 5/8"-8 Thre	McMaster-Carr	95270A119	1	$10.52	$10.52	Team	2/26/2019	RBT114
NU	Bearing Housing for 5/8" Wide and 0.812" OD Bearin	McMaster-Carr	2829N3	3	$13.80	$41.40	Team	2/26/2018	NU
NU	3 in. I-Beam S3x5.7 Track (6 ft long)	Ultimation	9792-S3-6	1	$89.00	$89.00	QL+	2/21/2019	NU
-	Jervis-Webb I-Beam Trolley							2/21/2019	-
RBT111	3 in. I-Beam S3x5.7 Track (4 ft long)	Ultimation	S3-4A	1	$19.20	$19.20	QL+	2/21/2019	RBT112
NU	1/2"-10 Leadscrew, 4 ft.	McMaster-Carr	98935A912	2	$10.00	$20.00	QL+	2/21/2019	NU
NU	1/2"-10 Brass Square Nut	McMaster-Carr	95270A114	2	$7.10	$14.20	QL+	2/21/2019	NU
NU	Shielded Ball Bearing 3/8"	McMaster-Carr	60355K45	2	$6.48	$12.96	QL+	2/21/2019	NU
NU	Bearing Housing	McMaster-Carr	2829N2	3	$9.02	$27.06	QL+	2/21/2019	NU
-	Boca Bearing 10mm Mounted Bearing	Amazon	KP000-10MM	2	$9.95	$19.90	Team	2/28/2019	-
-	Hex Steel 1/4-20, 1 1/4 length (pack of 10)	McMaster-Carr	92620A545	2	$3.14	$6.28	QL+	2/21/2019	-
-	1/4-20 Steel Locknuts (pack of 25)	McMaster-Carr	97135A210	1	$3.56	$3.56	QL+	2/21/2019	-
-	12V 250W AC/DC Converter	Digi-Key	1866-1655-ND	1	$82.41	$82.41	Team	2/25/2019	-
RBT120	12V 1/6 HP Motor	Automation Direct	MTPM-P25-1JK40	1	$0.00	$0.00	Donation	2/21/2019	RBT120
RBT120	Motor Controller	Automation Direct	GSD1-48-20C	1	$0.00	$0.00	Donation	2/21/2019	RBT120
-	Vertical Lift	Med Mart	330050	1	$1,800.00	$1,800.00	QL+	2/1/2019	-
RBT120	IEC miniature contactor	Automation Direct	CWC016-00-40L03	2	$23.00	$0.00	Donation	2/28/2019	RBT120
RBT120	Interlock	Automation Direct	BICO	1	$3.00	$0.00	Donation	2/28/2019	RBT120
RBT120	Wireless Remotes and Relays	Amazon	-	1	$17.99	$17.99	Team	2/28/2019	RBT120
RBT120	Circuit Breaker	Automation Direct	FAZ-D15-1-NA-SP	1	$19.50	$0.00	Donation	2/28/2019	RBT120
RBT120	24 V Fan	Automation Direct	018803-00	1	$0.00	$0.00	Donation	4/28/2019	RBT120
RBT120	Filter	Automation Direct	118800-30	1	$0.00	$0.00	Donation	4/28/2019	RBT120
-	5/16" x 2-1/2" Lag Screw	Home Depot	ARK	12	$0.42	$5.04	Team	4/28/2019	-
-	1/4 " Washer		AAA	16	$0.12	$1.92	Team	4/28/2019	-
-	5/16 x 2 Steel Washer	Home Depot	AKC	8	$0.18	$1.44	Team	4/28/2019	-
-	1/4" X 2" Hex Head Bolt	Home Depot	AFD	4	$0.24	$0.96	Team	4/28/2019	-
-	Alloy Steel Flat-Tip Set Screws Black Oxide, 1/4"-20 T	McMaster-Carr	94105A539	1	$8.40	$8.40	QL+	4/11/2019	-
RBT118	6061 Aluminum Rectangular Tube, 1/4" Wall Thickne	McMaster-Carr	6546K29	1	$25.39	$25.39	QL+	4/11/2019	RBT118
RBT119	Aluminum Unthreaded Spacer, 1/2" OD, 1-1/2" Long	McMaster-Carr	92510A771	5	$3.57	$17.85	QL+	4/11/2019	RBT119
RBT 116,117	6061 Aluminum, 1/4" Thick x 4" Wide, 2'	McMaster-Carr	8975K514	1	$10.59	$10.59	QL+	4/11/2019	RBT 116,118
-	14000 rpm Buna-N Rubber Spider for 1-23/64" OD Fl	McMaster-Carr	6408K73	1	$3.72	$3.72	Team	3/15/2019	-
-	Flexible Shaft Coupling Iron Hub with Set Screw, 1-63	McMaster-Carr	6408K12	1	$6.25	$6.25	Team	3/15/2019	-
-	Flexible Shaft Coupling Iron Hub with Set Screw, 1-63	McMaster-Carr	6408K12	1	$6.25	$6.25	Team	3/15/2019	-
RBT310	1 5/8" U Bracket (Pack of 4)	Ebay	B107-22A	1	$21.75	$21.75	Team	4/11/2019	RBT311
-	Rubber Mat	Home Depot	PN 066296089983	1	$18.97	$18.97	Team	4/24/2019	-
NU	Foot Straps	Amazon	B07541ZRYY	1	$8.99	$8.99	Team	4/15/2019	NU
NU	2x4	Home Depot	PN 750298153253	2	$2.97	$5.94	Team	4/24/2019	NU
-	Brass Screw	Home Depot	PN 887480136616	1	$1.18	$1.18	Team	4/24/2019	-
RBT120	4 Lug Terminal Blocks	Amazon	BC74098	2	$10.91	$21.82	QL+	4/24/2019	RBT121
NU	4 Lug Terminal Blocks	Digi-Key	WM5761-ND	8	$3.63	$29.04	QL+	3/20/2019	NU
RBT120	JST 16AWG Solderless Crimp Terminal	Digi-Key	455-1319-1-ND	27	$0.09	$2.34	QL+	3/20/2019	RBT120
RBT120	JST Plastic Connector	Digi-Key	455-1184-ND	3	$0.14	$0.42	QL+	3/20/2019	RBT120
-	1/2" Hex Bolts	Home Depot	AYB	3	$0.53	$1.59	Team	4/29/2019	-
-	1/2" Nuts & Washers	Home Depot	PN 887480035421	1	$3.96	$3.96	Team	4/29/2019	-
RBT120	Junction Box 4x4x2	Home Depot	88700020290	1	$7.09	$7.09	Team	5/13/2019	RBT120
RBT120	Surge Protector	Home Depot	69706709770122	1	$6.47	$6.47	Team	5/13/2019	RBT120
-	1/4 2x4 MDF	Home Depot	813952014571	1	$7.42	$7.42	Team	5/13/2019	-
-	Handy Link Chain Zinc #135x1'	Home Depot	0000-268-517	1	$2.04	$2.04	Team	5/13/2019	-
-	Gorilla Construction Adhesive 9 oz	Home Depot	52427801005	1	$7.97	$7.97	Team	5/13/2019	-
RBT120	1/2" Plastic Kwik Clip	Home Depot	32076898045	1	$3.28	$3.28	Team	5/13/2019	RBT120
RBT120	22-18 AWG SPADE TERMINALS	Home Depot	32076075019	1	$7.32	$7.32	Team	5/13/2019	RBT120
-	3/4" EMT Conduit x 5'	Home Depot	091111150487	1	$3.85	$3.85	Team	5/13/2019	-
-	PB 50 3oz	Home Depot	32167000586	1	$3.98	$3.98	Team	5/13/2019	-
NU	Metric Set Screw 6x10	Home Depot	887480138887	1	$0.82	$0.82	Team	5/13/2019	NU
NU	Metric Set Screw 4x5	Home Depot	887480137682	1	$0.60	$0.60	Team	5/13/2019	NU
RBT120	16 AWG Wire 24'	Home Depot	48243001309	3	$6.13	$18.39	Team	5/13/2019	RBT120
RBT120	Zip Ties	Home Depot	4715409150398	1	$9.21	$9.21	Team	5/13/2019	RBT120
RBT120	20/10A on/off Screw Toggle Switch	Home Depot	032076021047	1	$4.49	$4.49	Team	5/13/2019	RBT120
RBT120	Lock Nut Nylon Insert Zinc	Home Depot	887480036688	6	$0.47	$2.82	Team	5/13/2019	RBT120
RBT120	M4x16 Zinc Bolts	Home Depot	887480030280	4	$0.87	$3.48	Team	5/13/2019	RBT120
Travel	Gas	Shell	N/A	1	$64.48	$64.48	Team	5/18/2019	Travel
Travel	Rental Car	Avis	N/A	1	$518.42	$518.42	Team	5/18/2019	Travel
Travel	Hotel	Days Inn	N/A	1	$98.29	$98.29	Team	5/18/2019	Travel
Totals:					$2,547.07	$3,228.26	$3,000.00		
					FP	ALL			

Senior Project DVP&R

Date: 02/03/2019	Team: RBT	Sponsor: QL+	Description of System: Device for sit and stand motion.	DVP&R Engineer: Joseph Lee

TEST PLAN										TEST REPORT			
Item No	Specification #	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	SAMPLES		TIMING		TEST RESULTS			NOTES
						Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	
1	1,2	**Test #1: Range of Motion (Vertical and Horizontal)** Ensure the assembly can achieve the necessary horizontal and vertical motion to bring the user from a standing to recumbent position and vice versa. Target is to have at least 3.5 feet of travel in both horizontal and vertical directions.	Vertical: - 0.5 ft Horizontal: -0.5 ft	ALL	FP	1	C	4/30/2019	5/7/2019	Vert: 7' 6" Horiz: 3' 5"	Vert: 4' 6" Horiz: 4"	NA	The resulting device was built the way it was designed, resulting in the necssary range of motions in vertical and horizontal directions.
2	4	**Test #2: Steps to Operate** The device is expected to take at most 5 steps to operate. We will test our final design on the user to see how many steps it takes to use our design.	+ 3 steps	ALL	FP	1	Sys	5/18/2019	5/19/2019	Down: 4 (4.33) Up: 6 (5.67)	Down: 4 Up: 2	NA	As the user became more familiar and communicated more efficiently, the number of steps to operate the device was reduced.
3	5	**Test #3: User Force to Lower/Raise** The goal is for the user to apply force only from the hand to operate the system. We will test this with the user and see what he thinks. We will have the user operate the device with the remote. If he is able to easily operate the device with the remote, it will be a "pass."	Pass/Fail	ALL	FP	1	Sub	5/18/2019	5/19/2019	Pass	NA	NA	The user is able to press each button finem, but struggles to use the remote during operation. It was decided that the helper using the device in communication with the user was best.

4	6	**Test # 4: Level of Comfortability (0-10)** The goal for the device is not only to provide vertical and horizontal positioning of the user, but to do it comfortably. As the comfortability of the device will largely depend on the physical parameters and abilities of the user, this testing will most likely require iteration. The foothold location, sling positioning/length, and horizontal motor speed will be adjustable to account for this. The test results will be verbal feedback from the user.	-2	ALL	FP	1	Sys	5/18/2019	5/19/2019	Lower: 7 Raise: 6.67	Lower: 1 Raise: .67	NA	It was evident that as the trials went on, the user was finding it easier to use the device in communication with the helper. This resulted in increased comfort as the trials went on. It was also noted that the user seemed to fatigue as the trials went on.
7	8, 9	**Test #6: Device Weight** Capabilities Test (Max Weight Capacity and Min. Factor of Safety of Components) The device will be designed for users up to 300 lbs., with the capabilities of up to 400 lbs., although this will not be recommended. The device without the Handicare C-450 will be tested by loading with sandbags, beginning with 50lbs., going up to 600 lbs. In 50 lb. Increments. The goal of this test will be to determine weight capabilities of the device.	Pass/Fail	All	FP	1	Sub	4/30/2019	5/7/2019	Pass	NA	NA	The device showed no sign of yield or deflection. This confirms that the device at least has a FOS of 2.4 and is able to hold the weight of the desired user weight ranges.
	7	**Test #7: Time to Operate** The user will be expected to be accompanied by some helper when using this device. We will test how long it takes for the user to operate the device when getting on and off the trike. We will first allow the user to get familiar with how our device works and how to operate it. We will then time how long it takes for the user to operate the device, which we are targeting to be around 3 minutes,	+ 1 min	ALL	FP	1	Sys	5/18/2019	5/18/2019	Down: 2:16 Up: 1:32	Down: 1:44 Up: 2:28	NA	The time significantly decreased as the user became more familiear and comfortable with communicating with the helper.

Appendix K. Design Analyses and Hand Calculations

Lead Screw Calculations

2/4/19 "LEAD SCREW FINAL DESIGN"

$$C_s = F(4.76\times10^6)\frac{d}{L^2}$$

$$P = F(14.03\times10^6)\frac{d^4}{L^2}$$

$d = \frac{1}{2}$ in → $\frac{1}{2}$-10 ACME LEAD SCREW

$L = 3.5$ ft

F = ~~1000 lb~~ 4 (FIXED-FIXED) for P & 2.23 for C_s

$$C_s = 2.23(4.76\times10^6)(\tfrac{1}{2}\text{ in})/(12\times3.5\text{ in})^2$$

$$\boxed{C_s = 3008.73 \text{ rpm}}$$

$$P = 4(14.03\times10^6)(1/2)^4/(12\times3.5)^2$$

$$\boxed{P = 1988.379 \text{ lb}}$$

Bearing Calculations

BEARING CALCS.

R6-2Z BALL BEARING

EXPECTED $F_R = 0 \sim 50$ lb (CONSERVATIVE)

$F_a = 200$ lb

$L_{10} = (C_r/P)^3 \times 10^6$ Rev. — ball bearings

$C_r = 749$ lb

FOR P

$P = XF_r + YF_a$

$X = 0.56$

$Y = 1$

$P = 0.56(50) + 200$ lbf

$P = 228$ lbf

$L_{10} = (749/228)^3 \times 10^6$

$L_{10} = 3.5 \times 10^7$ rev

LIFE AT 1200 rpm

$3.5 \times 10^7 \text{ rev} \cdot \frac{1}{1200 \frac{rev}{min}} = 29166.67 \text{ min}$ or 486 hr.

USAGE

20 min → 180 times yr

(20 min)(180) = 3600 min use per year

$\frac{29166.67}{3600} =$ 8 years of use → 3600 min/yr

15 min → 180 times yr

$\frac{29166.67}{2700} =$ 10.8 years of use → 2700 min/yr

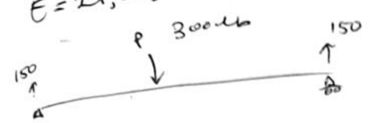
I-Beam Deflection Calculations

Bt 1/17/19 "Beam Deflection Calcs"

S3x5.7 $L = 6$ ft

$I_x = 2.52 \text{ in}^4$

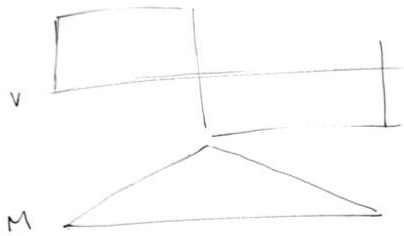
$E = 29{,}000{,}000$ psi



$$Y_{max} = \frac{PL^3}{48EI}$$

$$Y_{max} = \frac{300(6 \times 12 \text{ in})^3}{48(29{,}000{,}000)(2.52)}$$

$Y_{max} = .032"$



$$\sigma = \frac{My}{I}$$

$$\sigma = \frac{(150 \times 12 \times 3 \text{ lb}\cdot\text{in})(1.5 \text{ in})}{2.52 \text{ in}^4}$$

$\sigma = 3214.3$ psi

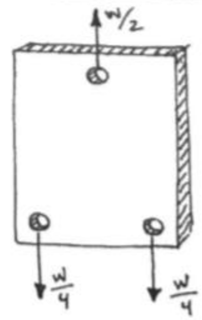
Yield point = 36 ksi

Yield >> σ, so not big deal

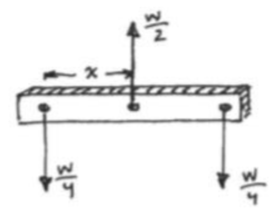
$$FS = \frac{36}{3.214} = 11.2$$

Hanger Bracket Stress Calculations

STRESS ANALYSIS ON HANGAR BRACKET :

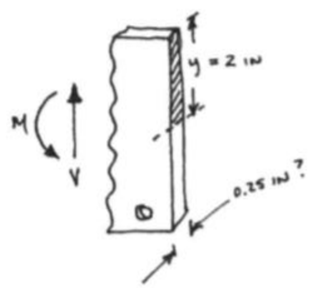


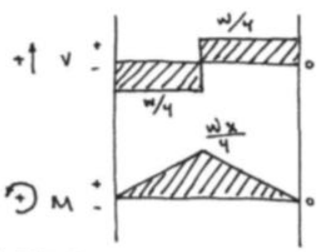
MODEL AS $\Longrightarrow$ SIMPLE BEAM



WHERE $W = W_{HOIST} + W_{DANNY}$

BENDING : $\sigma = \frac{-My}{I}$





SOLVE FOR PLATE THICKNESS, GIVEN THE FOLLOWING:

$W_{HOIST} = 5$ lb

$W_{DANNY} \cong 250$ lb

$h = 4$ in

$b = ?$

$x = 1$ in

$\sigma_{y,AL} = 35$ ksi (FROM MCMASTER CARR)

$\sigma_y = \frac{My}{I}$

AND

$I = \frac{1}{2} b h^3$

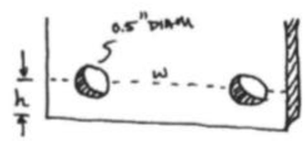
$M = \frac{Wx}{4}$

$$\sigma_y = \frac{\left(\frac{Wx}{4} y\right)}{\frac{1}{2} b h^3} = \frac{(255 \text{ lb})(1 \text{ in})(2 \text{ in})}{4 \cdot \frac{1}{2} \cdot (b)(4 \text{ in})^3} = 35 \times 10^3 \frac{\text{lb}}{\text{in}^2}$$

SOLVING FOR THICKNESS, $\boxed{b = 0.000114 \text{ in}}$

⇒ BENDING STRESS NOT A PROBLEM!

TEST FOR STRESS CONCENTRATIONS ON HOLES :



WIDTH = 3 in − 2(0.5 in DIAM) = 2 in

$h = 0.5$ in

$\frac{h}{w} = 0.25$, $\frac{d}{w} = 0.25$ in

FROM SHIGLEY'S FIG A-15-12 : $K_t = 6 = \frac{\sigma_{max}}{\sigma_o}$

AND $\sigma_o = \frac{F}{A}$

$$\Rightarrow \sigma_o = \frac{W}{lt} = \sigma_y$$

$$32 \times 10^3 \frac{\text{lb}}{\text{in}^2} = \frac{255 \text{ lb}}{(3 \text{ in})\, t} (6) \quad \Rightarrow \quad \text{THICKNESS } \boxed{t = 0.016 \text{ in}}$$

→ 1/4" PLATES WILL BE MORE THAN PLENTY...

STRESS ANALYSIS ON BOLTS

BENDING

$\sigma_y = \frac{-My}{I}$

WHERE $I = \frac{\pi D^4}{64}$

$\sigma_y = 32 \times 10^3 \frac{lb}{IN^2}$

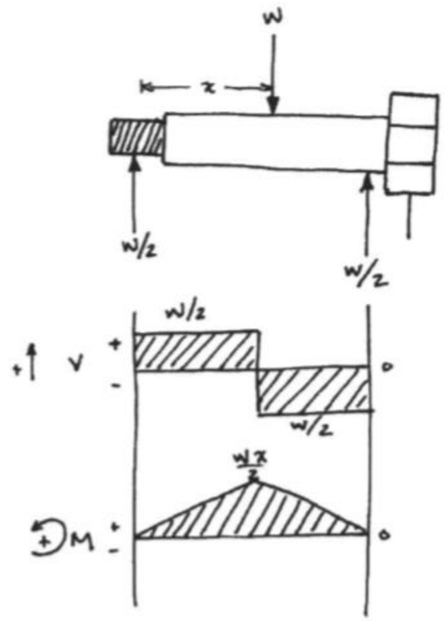
$\sigma_y = \frac{\left(-\frac{Wx}{2}\right)\left(\frac{D}{2}\right)}{\frac{\pi D^4}{64}}$

$= \frac{-64 W x}{2 \cdot 2 \pi D^3}$

$32 \times 10^3 \frac{lb}{IN^2} = \frac{-64 (200\ lb)(\frac{1}{2}\ IN)}{2 \cdot 2 \cdot \pi (D)^3}$

$\Rightarrow D_{MIN} = 0.2895\ IN$

FOR $x = 1/8''$, $D_{MIN} = 0.172\ IN$



Thread Stress on Support Beam

THREAD STRESSES

LOOKING AT 1st ENGAGED THREAD, WHICH TAKES 0.38 OF LOAD. LOAD SHOULD BE HALF OF TOTAL WEIGHT (ASSUME CONSERVATIVELY 400 LB)

$\sigma_x = \frac{6(0.38F)}{\pi d_r (1) p} = \frac{6(0.38)(200\ lb)}{\pi (0.25\ in)(1/20\ in)} = 11{,}610\ psi$

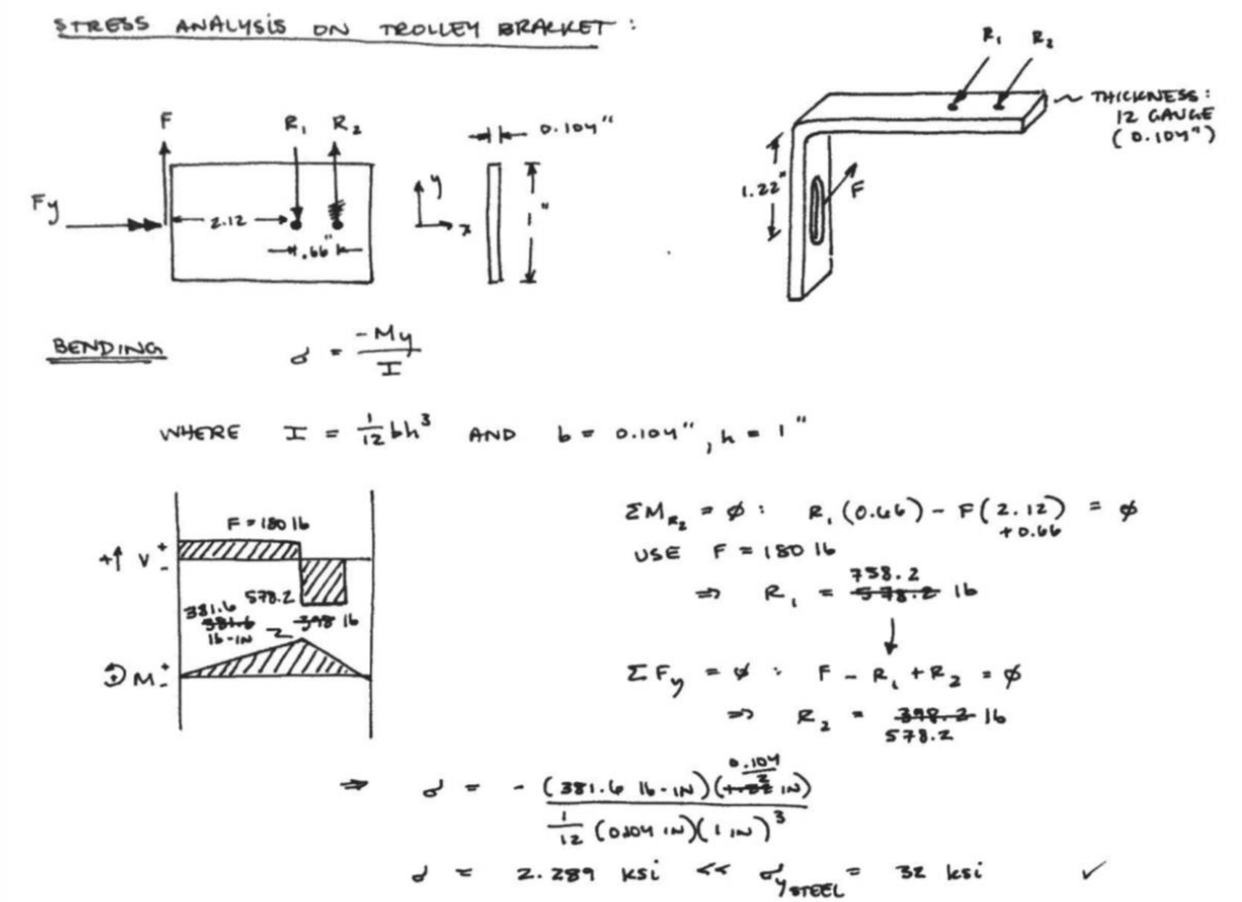
$\sigma_y = -\frac{4(0.38F)}{\pi d_r^2} = \frac{-4(0.38)(200\ lb)}{\pi (0.25\ in)^2} \approx -1550\ psi$

MAX SHEAR STRESS

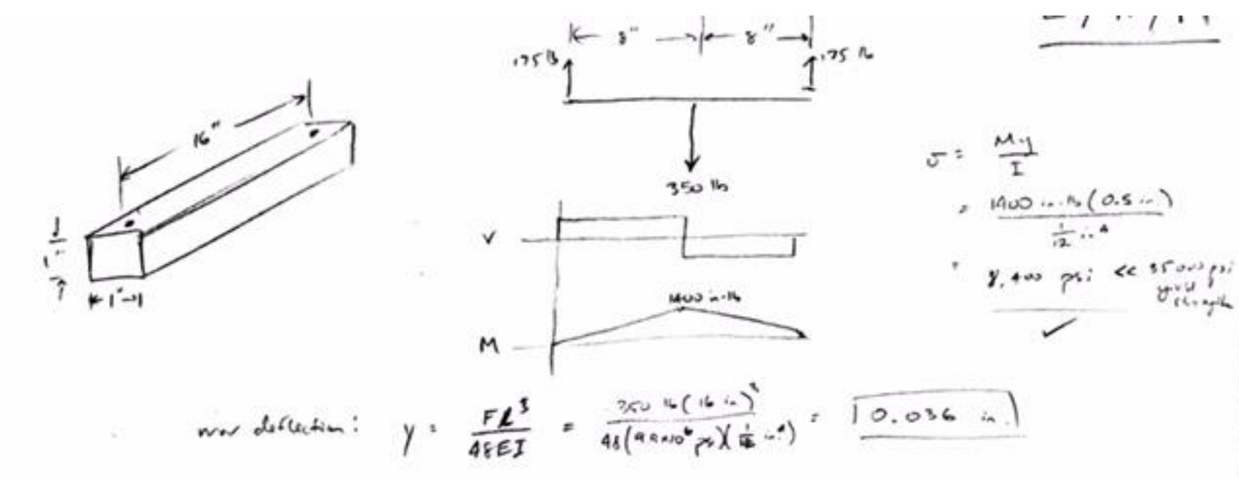
$\tau_{MAX} = \frac{\sigma_x - \sigma_y}{2} = \frac{11610 + 1550}{2} = 6580\ psi$

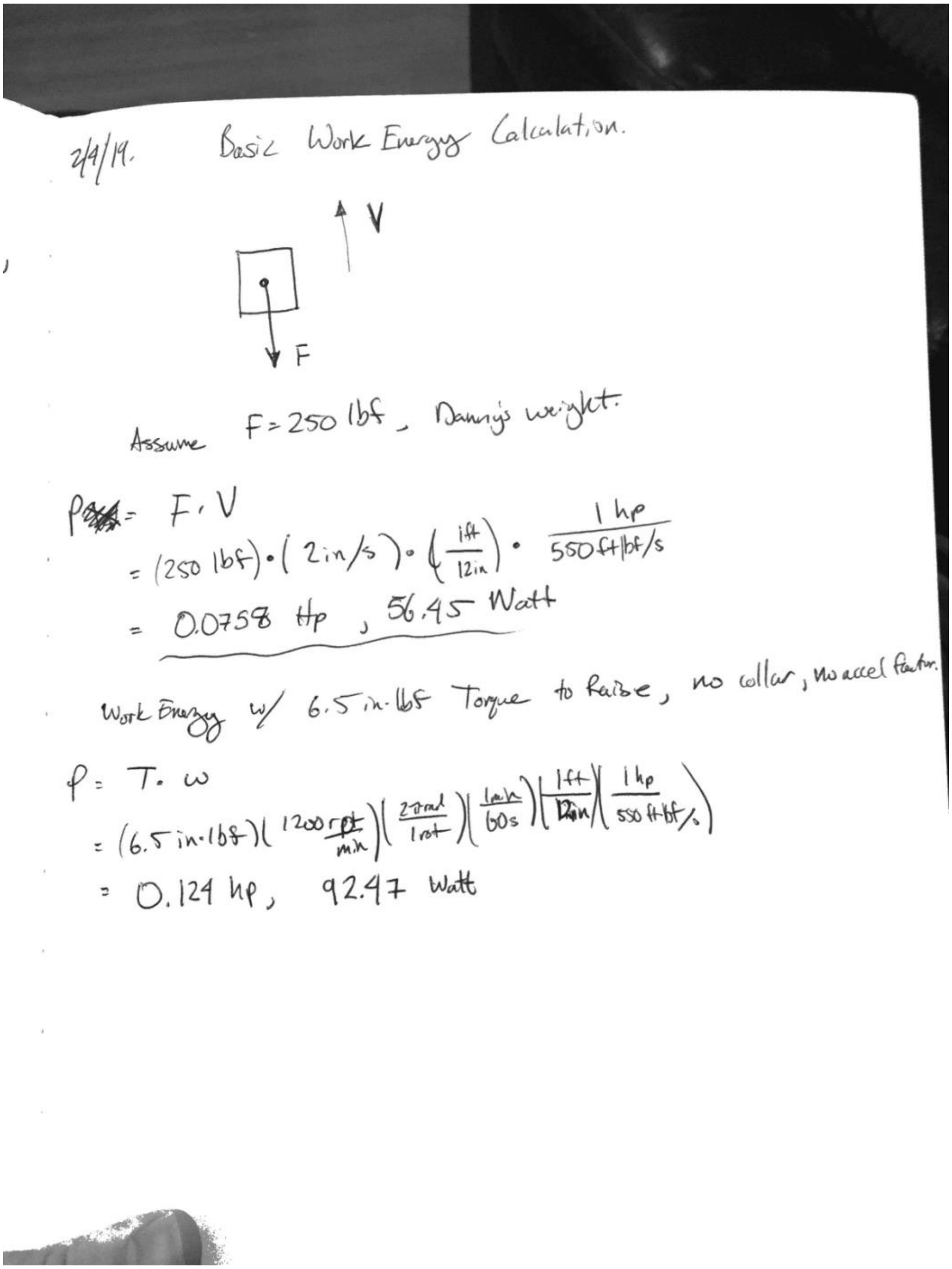
COMPARE TO $S_y/2 = \frac{35000}{2} = 17500\ psi$ ✓ F.S. = 2.6

Trolley Bracket Stress Calculations



Support Beam Deflection Analysis





2/4/19. Basic Work Energy Calculation.

Assume $F = 250$ lbf , Danny's weight.

$$P = F \cdot V$$

$$= (250\ \text{lbf}) \cdot (2\ \text{in/s}) \cdot \left(\frac{1\ \text{ft}}{12\ \text{in}}\right) \cdot \frac{1\ \text{hp}}{550\ \text{ft lbf/s}}$$

$$= 0.0758\ \text{Hp},\ 56.45\ \text{Watt}$$

Work Energy w/ 6.5 in·lbf Torque to Raise, no collar, no accel factor.

$$P = T \cdot \omega$$

$$= (6.5\ \text{in} \cdot \text{lbf})\left(1200\ \frac{\text{rot}}{\text{min}}\right)\left(\frac{2\pi\ \text{rad}}{1\ \text{rot}}\right)\left(\frac{1\ \text{min}}{60\ \text{s}}\right)\left(\frac{1\ \text{ft}}{12\ \text{in}}\right)\left(\frac{1\ \text{hp}}{550\ \text{ft lbf/s}}\right)$$

$$= 0.124\ \text{hp},\ 92.47\ \text{Watt}$$

Lead Screw Self Locking

1/31/19 Self-Locking Calculations

eq (8-3) Shigley's. for ½"-10 ACME Screw

$$f > \frac{l}{\pi d_m}$$

$l = \frac{1}{10}$ in

$d_m = \frac{.5'' + .4''}{2} = .45''$

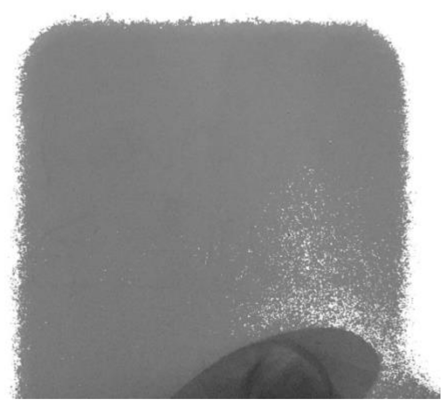
$$0.08 > \frac{\frac{1}{10}''}{\pi \cdot .45''}$$

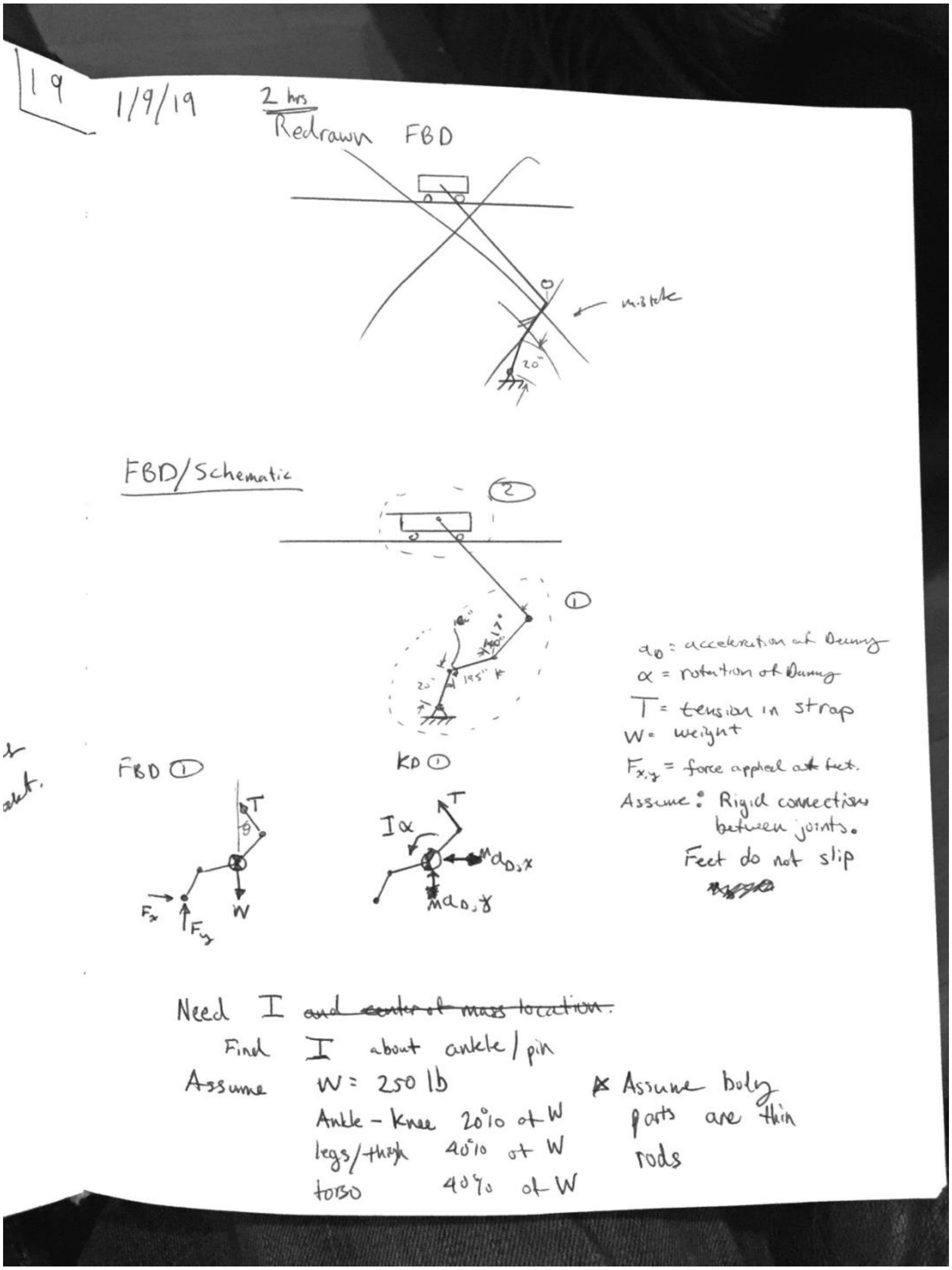
$f_{min} = 0.08$

$0.08 > 0.0707$

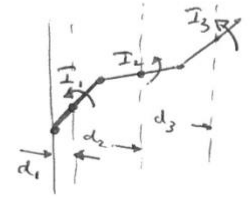
Self-locking ✓

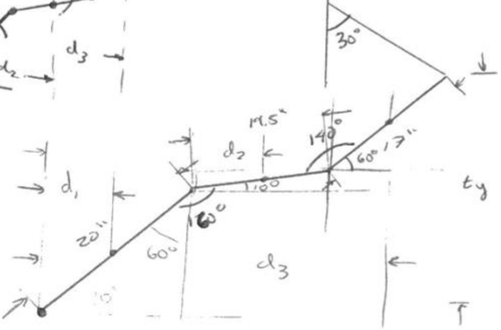
* 0.08 friction coefficient is on the low end.




19
1/9/19
2 hrs
Redrawn FBD
mistake
20°
FBD/Schematic
2
1
20°
145°
a_D = acceleration of Dummy
α = rotation of Dummy
T = tension in strap
W = weight
$F_{x,y}$ = force applied at feet.
Assume: Rigid connection between joints.
Feet do not slip
FBD 1
T
θ
W
F_x
F_y
KD 1
Iα
T
$Ma_{D,x}$
$Ma_{D,y}$
Need I ~~and center of mass location.~~
Find I about ankle / pin
Assume W = 250 lb
Ankle - Knee 20% of W
legs/thigh 40% of W
torso 40% of W
Assume body parts are thin rods

need distances, d





$M_{dummy} = \frac{250\,lbf}{32.2\,ft/s^2} \cdot \frac{slug\,ft/s^2}{1\,lbf}$

$= \frac{250}{32.2}$ slug

$= 7.76$ slug

$m_1 = .20\,(7.76$ slug$)$

$= 1.55$ slug

$m_2 = m_3 = .4\,(7.76$ slug$)$

$= 3.11$ slug

$d_1 = 10'' \cos 30° = 8.66''$

$d_2 = \cos 10° \frac{14.5''}{2} + \cos 30°\, 20'' =$ ~~30.~~ $26.92''$

$d_3 = \cos 60° \frac{17''}{2} + \cos 10°\, 14.5'' + \cos 30°\, 20'' = 40.77''$

$\bar{I} = I_1 + I_2 + I_3$

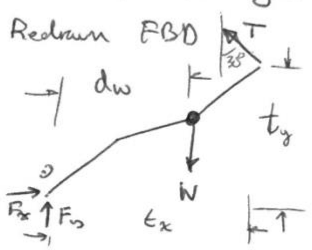
$= \frac{1}{12}(1.55\,slug)(20'')^2 + 1.55\,(8.66'')^2 + \frac{1}{12}(7.76\,slug)(14.5'')^2 + 7.76\,slug\,(26.92'')^2 + \frac{1}{12}(7.76\,slug)(17'')^2 + 7.76\,slug\,(40.77'')^2$

$= 167.9$ slug inch^2 + 5869.5 slug inch^2 + 13085.5 slug inch^2

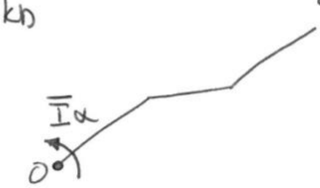
$= 19122.87$ slug inch^2

Further assumptions:
CG @ hip
$\alpha = 2\pi$ rad/s^2

Redrawn FBD



kD



$\circlearrowleft \Sigma M_o:\; W d_w - \sin 30° T t_y - \cos 30° T t_x = -\bar{I}\alpha$

$$T = \frac{W d_w + \bar{I}\alpha}{\sin 30°\, t_y + \cos 30°\, t_x}$$

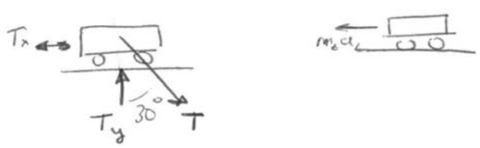
$$\ell_y = \sin 30^\circ(20") + \sin 10^\circ(14.5") + \sin 60^\circ(17")$$
$$= 28.1"$$
$$\ell_x = \cos 30^\circ(20") + \cos 30^\circ(14.5") + \cos 60^\circ(17")$$
$$= 42.71"$$

$$d_w = \cos 30^\circ(20") + \cos 10^\circ(14.5")$$
$$= 36.52"$$
$$T = \frac{250\ \text{lbf}(36.52") + 19122.87\ \text{slug inch}^2 * \frac{1\text{ft}}{12\text{in}} * 2\pi \frac{\text{rad}}{s^2}}{\sin 30^\circ(28.1") + \cos 30^\circ(42.71")}$$

$$= 375\ \text{lbf.}$$

Assume: $M_t \approx 0$

FBD ②



7")^2.

$$\Sigma F_x:\ T_x - \sin 30^\circ T = 0$$
$$T_x = \sin 30^\circ T$$
$$= 187.5\ \text{lbf}$$

$$\Sigma F_y:\ T_y - \cos 30^\circ T = 0$$
$$T_y = \cos 30^\circ T$$
$$= 325\ \text{lbf.}$$

1/10/19

Getting rough estimate for Torque Required.

Using 3/8" - 10 lead screw

assume $\alpha = \frac{29}{2}^{\circ}$

$f = 0.08$ ← Shigley's pg. 411

$$T_R = \frac{F d_m}{2}\left(\frac{l + \pi f d_m \sec\alpha}{\pi d_m - f l \sec\alpha}\right)$$

$$d_m = \frac{0.375" + .235"}{2}$$

$$= 0.305"$$

$F = 187.5$ lbf

$l = 0.1"$

$$T_R = \frac{(187.5\text{ lbf})(0.305")}{2}\left(\frac{0.1" + \pi(0.08)(0.305")(\sec(14.5^{\circ}))}{\pi(0.305") - (0.08)(.1")(\sec(14.5^{\circ}))}\right)$$

$= 5.4$ in-lbf   * 6.5 inlbf w/ 1/2" lead screw

Add collar friction.

Assume: $d_c = \frac{5}{8}"$

$$T_c = \frac{F f_c d_c}{2}$$

$$= \frac{(187.5\text{ lbf})(.08)(\frac{5}{8}")}{2}$$

$= 4.6875$ in-lbf

$T_T = 10.1$ in-lbf. ← required to lift w/ collar bearing.

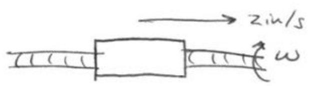
* 11.2 w/ 1/2" lead screw

Add 50% for acceleration factor since torque calcs assume no acceleration.

$T_T = 15.2$ in-lbf

Need to decide a good speed.

from Handcare — $2 in/s$



$V = \omega p$ ~ pitch

$$\omega = \frac{2 in/s}{0.1 in/rev} * \frac{60 s}{1 min}$$

$$= 1200 rpm$$

$$P = T\omega$$

$$= 15.2 in\, lbf * 1200 \frac{rot}{min} * \frac{1 min}{60 s} * \frac{2\pi}{1 rot} * \frac{1 ft}{12 in} * \frac{1 hp}{550\, ft\, lb/s}$$

$$= 0.289\ hp$$

$$= 0.3\ hp$$

w/o acceleration factor

$$P = 0.2 hp$$

Appendix L. Risk Assessment

designsafe Report

Application: RBT Transfer Device
Description: Device that moves
Product Identifier: Model 1
Assessment Type: Detailed
Limits: Complete
Sources: RBT Team
Risk Scoring System: ANSI B11.0 (TR3) Two Factor

Analyst Name(s): Joseph Lee, Huy Nguyen, John Kulick, Jack McAtee
Company: RBT
Facility Location: Cal Poly, San Luis Obispo, CA 93407

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

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-1-1	passer-by / non-user walk near	mechanical : head bump on overhead objects User/Tester is misusing device and passer-by/non-user gets too close to device.	Moderate Remote	Negligible		Moderate Remote	Negligible	
1-2-1	passer-by / non-user misuse	mechanical : cutting / severing While leadscrew is spinning, touching the leadscrew	Moderate Remote	Negligible		Moderate Remote	Negligible	
1-2-2	passer-by / non-user misuse	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Likely	Medium	warning label(s) /Not Applicable	Moderate Unlikely	Low	Action Item [5/11/2019] Joseph
1-2-3	passer-by / non-user misuse	mechanical : pinch point Pinch points in sling and Handicare hook	Moderate Unlikely	Low		Moderate Unlikely	Low	
1-2-4	passer-by / non-user misuse	mechanical : unexpected start Remote buttons pressed on accident	Moderate Likely	Medium	warning label(s) /Not Applicable	Moderate Unlikely	Low	Action Item [5/11/2019] Huy
1-2-5	passer-by / non-user misuse	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Remote	Negligible		Moderate Remote	Negligible	
1-2-6	passer-by / non-user misuse	electrical / electronic : shorts / arcing / sparking Wiring/Cords severed	Serious Remote	Low		Serious Remote	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
1-3-1	passer-by / non-user observe / watch	mechanical : head bump on overhead objects User/Tester is misusing device and passer-by/non-user gets too close to device.	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-1-1	RBT Team first use / test	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-1-2	RBT Team first use / test	mechanical : pinch point Pinch points in sling and Handicare hook	Minor Remote	Negligible		Minor Remote	Negligible	
2-1-3	RBT Team first use / test	mechanical : unexpected start Remote buttons pressed on accident	Minor Likely	Low		Minor Likely	Low	
2-1-4	RBT Team first use / test	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-1-5	RBT Team first use / test	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Serious Likely	High	supervision /Not Applicable	Serious Unlikely	Medium	Action Item [5/18/2019] Joseph
2-1-6	RBT Team first use / test	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Unlikely	Low		Moderate Unlikely	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-1-7	RBT Team first use / test	electrical / electronic : lack of grounding (earthing or neutral) Equipment not all grounded during assembly	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-1-8	RBT Team first use / test	electrical / electronic : shorts / arcing / sparking Wiring/Cords severed	Serious Remote	Low		Serious Remote	Low	
2-1-9	RBT Team first use / test	electrical / electronic : improper wiring Wiring in design done incorrectly	Serious Unlikely	Medium	supervision /Not Applicable	Serious Remote	Low	Complete [4/25/2019] John /The wirings were checked with EE professors/saftey personnel and tested to see it worked as designed.
2-1-10	RBT Team first use / test	electrical / electronic : overloading Exceeding specified weight the device can handle may cause device failure	Moderate Likely	Medium	warning label(s) /Not Applicable	Moderate Remote	Negligible	Action Item [5/11/2019] Jack
2-1-11	RBT Team first use / test	electrical / electronic : overvoltage /overcurrent Improper assembly of Power Assembly may cause motor to fail or not operate the way it is expected to do so	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-1-12	RBT Team first use / test	electrical / electronic : power supply interruption Cutting electricity output, incorrect assembly of Power Assembly	Minor Remote	Negligible		Minor Remote	Negligible	
2-2-1	RBT Team normal use	mechanical : cutting / severing While leadscrew is spinning, touching the leadscrew	Serious Remote	Low		Serious Remote	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-2-2	RBT Team normal use	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-2-3	RBT Team normal use	mechanical : pinch point Pinch points in sling and Handicare hook	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-2-4	RBT Team normal use	mechanical : unexpected start Remote buttons pressed on accident	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-2-5	RBT Team normal use	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-2-6	RBT Team normal use	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-2-7	RBT Team normal use	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-3-1	RBT Team aggressive use	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-3-2	RBT Team aggressive use	mechanical : pinch point Pinch points in sling and Handicare hook	Moderate Remote	Negligible		Moderate Remote	Negligible	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-3-3	RBT Team aggressive use	mechanical : unexpected start Remote buttons pressed on accident	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-3-4	RBT Team aggressive use	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Remote	Negligible		Moderate		
2-3-5	RBT Team aggressive use	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Unlikely	Low	In-process Jack
2-3-6	RBT Team aggressive use	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-3-7	RBT Team aggressive use	electrical / electronic : shorts / arcing / sparking Wiring/Cords severed	Serious Remote	Low		Serious Remote	Low	
2-4-1	RBT Team maintenance / lubrication	mechanical : pinch point Pinch points located in hook, connections to parts, screws, wheels of trolley, and spinning lead screw	Moderate Unlikely	Low		Moderate Unlikely	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-4-2	RBT Team maintenance / lubrication	mechanical : unexpected start Remote buttons pressed on accident	Moderate Likely	Medium	special tools or fixtures, other design change /Not Applicable	Moderate Unlikely	Low	Complete [4/27/2019] John /The remote was designed so that the buttons are very clear and the chance of pressing buttons on accident is reduced.
2-4-3	RBT Team maintenance / lubrication	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Likely	Medium	warning label(s) /Not Applicable	Moderate Unlikely	Low	Action Item [5/11/2019] Huy
2-4-4	RBT Team maintenance / lubrication	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-4-5	RBT Team maintenance / lubrication	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-4-6	RBT Team maintenance / lubrication	electrical / electronic : shorts / arcing / sparking Wiring/Cords severed	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-5-1	RBT Team repair tasks	mechanical : pinch point Pinch points located in hook, connections to parts, screws, wheels of trolley, and spinning lead screw	Moderate Unlikely	Low		Moderate Unlikely	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-5-2	RBT Team repair tasks	mechanical : unexpected start Remote buttons pressed on accident	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-5-3	RBT Team repair tasks	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-5-4	RBT Team repair tasks	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-5-5	RBT Team repair tasks	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-5-6	RBT Team repair tasks	electrical / electronic : shorts / arcing / sparking Wiring/Cords severed	Serious Unlikely	Medium	warning label(s) /Not Applicable	Serious Unlikely	Medium	Action Item [5/11/2019] John
2-5-7	RBT Team repair tasks	electrical / electronic : improper wiring During assembly, wiring of motor, control box, etc.. may be done incorrectly, causing problems with the Power Assembly	Moderate Unlikely	Low		Moderate		
2-6-1	RBT Team trouble-shooting / problem solving	mechanical : unexpected start Remote buttons pressed on accident	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Unlikely	Low	In-process Huy

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-6-2	RBT Team trouble-shooting / problem solving	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Unlikely	Low		Moderate		
2-6-3	RBT Team trouble-shooting / problem solving	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Unlikely	Low	In-process Jack
2-6-4	RBT Team trouble-shooting / problem solving	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-6-5	RBT Team trouble-shooting / problem solving	electrical / electronic : shorts / arcing / sparking Wiring/Cords severed	Serious Remote	Low		Serious Remote	Low	
2-6-6	RBT Team trouble-shooting / problem solving	electrical / electronic : improper wiring During assembly, wiring of motor, control box, etc.. may be done incorrectly, causing problems with the Power Assembly	Minor Likely	Low		Minor Likely	Low	
2-6-7	RBT Team trouble-shooting / problem solving	electrical / electronic : overloading Exceeding specified weight the device can handle may cause device failure	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-7-1	RBT Team cleaning	mechanical : pinch point Pinch points located in hook, connections to parts, screws, wheels of trolley, and spinning lead screw	Moderate Unlikely	Low		Moderate Unlikely	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-7-2	RBT Team cleaning	mechanical : unexpected start Remote buttons pressed on accident	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-7-3	RBT Team cleaning	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Remote	Negligible		Moderate		
2-8-1	RBT Team assemble	mechanical : pinch point Pinch points located in hook, connections to parts, screws, wheels of trolley, and spinning lead screw	Moderate Likely	Medium	gloves /Not Applicable	Moderate Unlikely	Low	On-going [Daily] Joseph /Whenever parts that had sharp edges were being machined or put together, gloves or other safety precautions were taken
2-8-2	RBT Team assemble	mechanical : unexpected start Remote buttons pressed on accident	Moderate Unlikely	Low		Moderate		
2-8-3	RBT Team assemble	mechanical : product instability If some parts are missing or not assembled correctly, it may make the device not perform the way it was intended or cause injury to user.	Moderate Likely	Medium	supervision /Not Applicable	Moderate Remote	Negligible	
2-8-4	RBT Team assemble	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Unlikely	Low	TBD John

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-8-5	RBT Team assemble	electrical / electronic : shorts / arcing / sparking Wiring/Cords severed	Moderate Unlikely	Low		Moderate		
2-8-6	RBT Team assemble	electrical / electronic : improper wiring	Moderate Likely	Medium	supervision /Not Applicable	Moderate Unlikely	Low	Complete [4/18/2019] John /The wirings were checked with EE professors/saftey personnel and tested to see it worked as designed.
2-9-1	RBT Team disassembly	mechanical : pinch point Pinch points located in hook, connections to parts, screws, wheels of trolley, and spinning lead screw	Moderate Likely	Medium	gloves /Not Applicable	Moderate Unlikely	Low	On-going [Daily] Joseph /Whenever parts that had sharp edges were being machined or put together, gloves or other safety precautions were taken
2-9-2	RBT Team disassembly	mechanical : unexpected start Remote buttons pressed on accident	Moderate Remote	Negligible		Moderate		
2-9-3	RBT Team disassembly	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Unlikely	Low	Action Item [5/9/2019] Jack
2-10-1	RBT Team storage	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Minor Remote	Negligible		Minor Remote	Negligible	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
2-10-2	RBT Team storage	mechanical : unexpected start Remote buttons pressed on accident	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-10-3	RBT Team storage	electrical / electronic : water / wet locations If device gets wet, this make cause the device to fail.	Serious Remote	Low		Serious Remote	Low	
2-11-1	RBT Team misuse	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Unlikely	Low	Action Item [5/9/2019] Joseph
2-11-2	RBT Team misuse	mechanical : unexpected start Remote buttons pressed on accident	Moderate Unlikely	Low		Moderate Unlikely	Low	
2-11-3	RBT Team misuse	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Remote	Negligible		Moderate Remote	Negligible	
2-11-4	RBT Team misuse	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Unlikely	Low	Action Item [5/9/2019] Jack
2-11-5	RBT Team misuse	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-1-1	Danny/User first use / test	mechanical : crushing If all safety precautions fail and device falls down, user may get injured	Catastrophic Remote	Low		Catastrophic Remote	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-1-2	Danny/User first use / test	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Likely	Medium	standard procedures /Not Applicable	Moderate Remote	Negligible	Action Item [5/9/2019] Jospeh
3-1-3	Danny/User first use / test	mechanical : unexpected start Remote buttons pressed on accident	Moderate Unlikely	Low		Moderate Unlikely	Low	
3-1-4	Danny/User first use / test	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-1-5	Danny/User first use / test	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Unlikely	Low		Moderate Unlikely	Low	
3-1-6	Danny/User first use / test	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-1-7	Danny/User first use / test	electrical / electronic : lack of grounding (earthing or neutral) Equipment not all grounded during assembly	Moderate Unlikely	Low		Moderate Unlikely	Low	
3-2-1	Danny/User normal use	mechanical : crushing If all safety precautions fail and device falls down, user may get injured	Catastrophic Remote	Low		Catastrophic Remote	Low	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-2-2	Danny/User normal use	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-2-3	Danny/User normal use	mechanical : pinch point Pinch points in sling and Handicare hook	Moderate Unlikely	Low		Moderate Unlikely	Low	
3-2-4	Danny/User normal use	mechanical : unexpected start Remote buttons pressed on accident	Serious Remote	Low		Serious Remote	Low	
3-2-5	Danny/User normal use	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-2-6	Danny/User normal use	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-3-1	Danny/User agressive use	mechanical : crushing If all safety precautions fail and device falls down, user may get injured	Catastrophic Remote	Low		Catastrophic Remote	Low	
3-3-2	Danny/User agressive use	mechanical : drawing-in / trapping / entanglement Sling has straps that can get tangled up with user	Moderate Unlikely	Low		Moderate Unlikely	Low	
3-3-3	Danny/User agressive use	mechanical : pinch point Pinch points in sling and Handicare hook	Moderate Remote	Negligible		Moderate Remote	Negligible	

Item Id	User / Task	Hazard / Failure Mode	Initial Assessment Severity Probability	Risk Level	Risk Reduction Methods /Control System	Final Assessment Severity Probability	Risk Level	Status / Responsible /Comments /Reference
3-3-4	Danny/User agressive use	mechanical : unexpected start Remote buttons pressed on accident	Moderate Unlikely	Low		Moderate Unlikely	Low	
3-3-5	Danny/User agressive use	mechanical : head bump on overhead objects The combination of getting too close to Handicare and swinging uncontrollabley can cause unintentional collision with user and device	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-3-6	Danny/User agressive use	mechanical : product instability Loose parts (fasteners/connections), misuse of device, and unfamiliarity of device may cause uncontrollable swaying when using the device	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-3-7	Danny/User agressive use	electrical / electronic : energized equipment / live parts Wiring/Cords severed	Moderate Remote	Negligible		Moderate Remote	Negligible	
3-3-8	Danny/User agressive use	electrical / electronic : overloading Exceeding specified weight the device can handle may cause device failure	Moderate Likely	Medium	warning label(s) /Not Applicable	Moderate Remote	Negligible	Action Item [5/11/2019] John

Appendix M. Operator’s Manual

Operator's Manual

Recumbent Bike Transfer Device

Created By

Recumbent Bike Transfer Team

for

Danny and Karen Knutson

I. Safety Warnings

- Make sure that there are no other large electrical loads connected to the same circuit as the device as this may overload the house's electrical system.

- Keep hands, hair, and loose clothing away from rotating machinery as it may get caught and cause injury.

- Make sure to remove device from power when opening the electrical box.

- Beware of potential tripping hazards such as the sling.

II. Remote Operation

The remote to operate the device combines pneumatic action with electronics. Vertical motion is achieved using the large grey pneumatic buttons. Horizontal motion is achieved using the small black electronic buttons.

Figure 1. Remote

- To move up, press and hold the grey "up" button as shown in the figure above. To move down, press and hold the grey "down" button.

- To move forward (towards the garage door), press and hold the black "A" button. To move backwards (towards the house), press and hold the black "B" button.

Caution: The forwards/backwards movement has some lag, i.e. once the "A" or "B" button is released, the motor will continue to spin for about half a second. NEVER quickly switch between forwards and backwards movement, as this could stress and eventually damage the motor. Instead wait for horizontal motion to completely stop before switching directions.

III. **Operating Procedure:** Lowering

A. Powering on Equipment

1. Ensure the Handicare and the power strip are plugged in.

Figure 2. Power strip with connections

2. Switch the power strip to "ON" using a broom handle. This powers the motor and electronics box.

3. Ensure the emergency switch is in the “ON” position.

Figure 3. Emergency switch location

B. Trike Placement

1. Wheel the trike underneath the device, with the front facing the garage door.
2. Align the axle of the front wheels with the blue tape markers on the garage floor.

Figure 4. Trike positioned in accordance to blue tape markers

C. Foot Placement

Stand over the trike and position feet as close to the front axle as possible.

D. Securing Sling

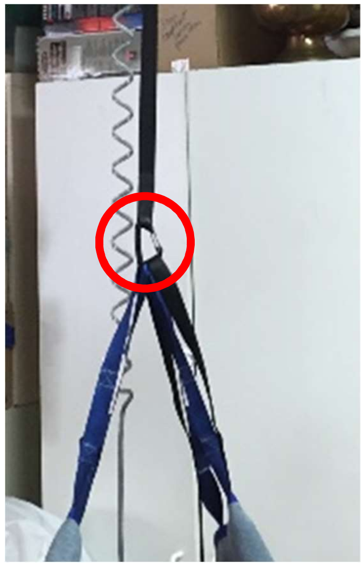


Figure 5. Carabiner connecting sling and Handicare strap

1. Use the grey "down" remote button to lower the Handicare strap and carabiner until it approximately reaches the user's chest level. Attach one end of the sling to the carabiner. Wrap the sling around the user's back and position it closely under the armpits. Attach the other end to the carabiner.
2. To ensure secure, snug support use the grey "up" remote button to slightly lift the user and begin transferring weight to the sling.

Caution: Make sure to have some kind of support, i.e. one hand on the walker to avoid losing balance.

E. Transfer Motion

Under the user's direction, use the grey "down" and "B" remote buttons to make the user go down and back, respectively, until seated in the trike.

***** IMPORTANT *****

Always strive to keep the strap connected to the hoist as vertical as possible. If the strap is at an angle with the weight of the user on the hoist, it is possible the motor may not be able to move the user horizontally.

Figure 6. Strap Position

F. Removing Sling

1. Press the grey “down” button to provide extra slack on the sling. It will be necessary to pull down on the Handicare strap to keep it taut as it lowers to provide more slack.
2. Remove the sling ends from the carabiner. Lean the user forward and slip the sling out between the seat and the user’s back.
3. Press the grey “up” button to lift the carabiner above the user’s head. User is now free to pedal out from under the device.

IV. **Operating Procedure:** Raising

A. Powering on Equipment

1. Ensure the Handicare and the power strip are plugged in.
2. Switch the power strip to “ON” using a broom handle. This powers the motor and electronics box.
3. Ensure the emergency switch is in the “ON” position.

B. Trike Placement

Return the trike to its home position, aligning the front wheel axle to the blue tape markers on the garage floor.

C. Foot Placement

Remove feet from trike pedals and position feet on the floormat as close to the front axle as possible.

D. Securing Sling

Use the grey "down" remote button to lower the Handicare strap and carabiner until it approximately reaches the user's chest level. Attach one end of the sling to the carabiner. Wrap the sling around the user's back and position it closely under the armpits. Attach the other end to the carabiner.

E. Transfer Motion

Under the user's direction, use the grey "up" and "A" remote buttons to make the user go up and forward, respectively, until user is standing erect.

***** IMPORTANT*****

Refer to Figure 6 and the Transfer Motion section of the Lowering instructions. Make sure to keep the strap as vertical as possible to ensure that the motor is able to translate the user horizontally.

Caution: When the user is nearly standing, it is very easy to lose balance. Make sure to stabilize the user as the standing position is reached.

F. Removing Sling

1. Press the grey "down" button to provide extra slack on the sling. It will be necessary to pull down on the Handicare strap to keep it taut as it lowers to provide more slack.
2. Remove the sling ends from the carabiner and slip the sling out from under the user's arms. User is now free to walk out from underneath the device.

V. Troubleshooting

- Make sure the power is on and plugged in.
- In the event the motor fails to run, turn the potentiometer knob clockwise (higher number results in more power).
- Make sure that when the potentiometer is in the zero position, the knob provides some resistance when attempting to turn the knob counter clockwise past zero. The potentiometer is able to turn past 10 as well, with some resistance, which changes where the maximum power

point is with respect to the paper dial. To best ensure that the paper dial lines up with the power characteristics of the potentiometer, turn the knob clockwise past 10 and complete one revolution until the potentiometer rests on 10 and turning counterclockwise results in very little resistance.

- Make sure that the E-stop switch next to the potentiometer is switched to “on”
- Make sure “A” and “B” on the remote are the buttons that are being pressed and that they are not being pressed at the same time.
- Ensure the buttons are being held down for at least 2 seconds
- If the button does not work initially, try again as it may not work the first time
- Make sure the strap connecting the user to the hoist is not at a steep angle and is as vertical as possible.
- If the issue is not resolved, have an electrician open the box and perform the following checks in order.
    - Ensure the circuit breaker is flipped so that red is shown on the breaker
    - Check all screw terminals on the components for loose wires
        - If any are found loose, tighten with a small flathead screwdriver
    - Ensure that the LED’s are lit on the 2 DC sources as well as the wireless receiver when the box is powered on
        - If one or more of these LED’s are not lit ensure that the wires powering the devices are properly connected
    - With the power on, attempt to turn the motor on, either in forward or reverse.
        - If there is a loud click and you can see the relay switch move, then there is a faulty connection in the motor power connections (red and black wires). Turn the power off and check the wire caps in the top left of the box as they are most likely the culprit. Next, check the wire caps underneath the junction box of the motor. Next, check the connections in the potentiometer enclosure. If it still does not work, ensure that all other wires are properly connected.

- If there is not a loud click and the relays cannot be seen operating, the first step is to check the wire caps in the top left and make sure they are connected well. Ensure that the wires are connected to the limit switches properly. If this does not work, make sure all the blue and white wires are connected properly.

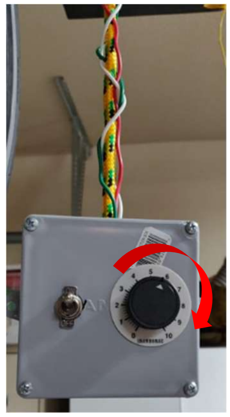


Figure 7. Potentiometer knob location

- In the event of an electrical outage or a sudden power loss to the Handicare during transfer, pull down on the red emergency strap on the bottom of the Handicare. This will allow for manual lowering of the sling.

Figure 8. Emergency Strap on Handicare

VI. Maintenance

Minimal maintenance is required to maintain the device.

It is recommended to tighten the fasteners every 6 months as a precaution against loosening.

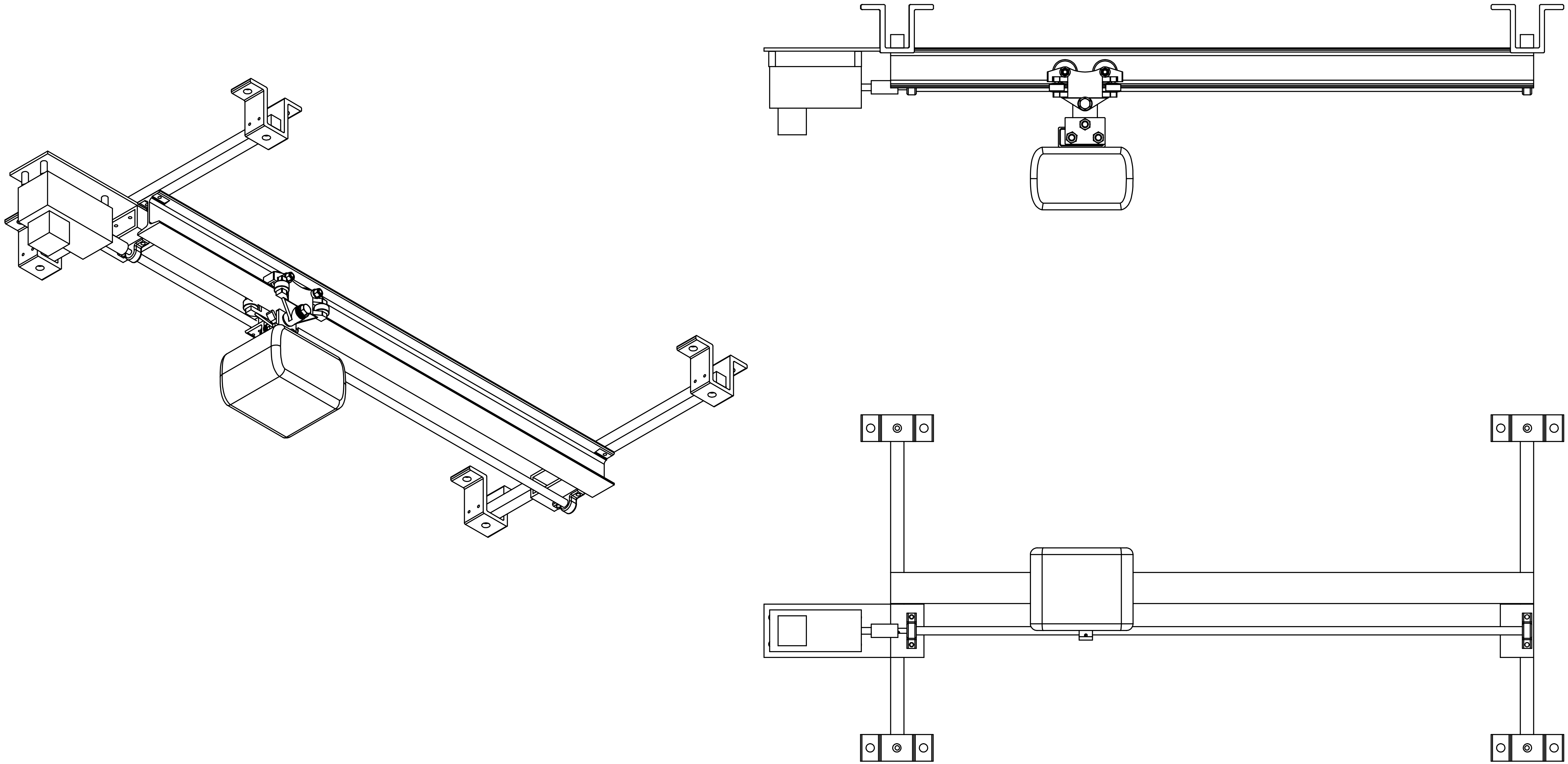
It is also recommended to lubricate the lead screw every 6 months to keep it rotating with minimal resistance and noise.

Should the black button remote run out of battery, it can be easily removed from the Handicare remote via Velcro. The battery can be replaced by separating the remote into two halves. Then simply re-assemble the two halves and stick the remote back onto the Handicare remote.

The sling strap may start to fray. In the case where the fraying becomes excessive, the sling should be replaced.

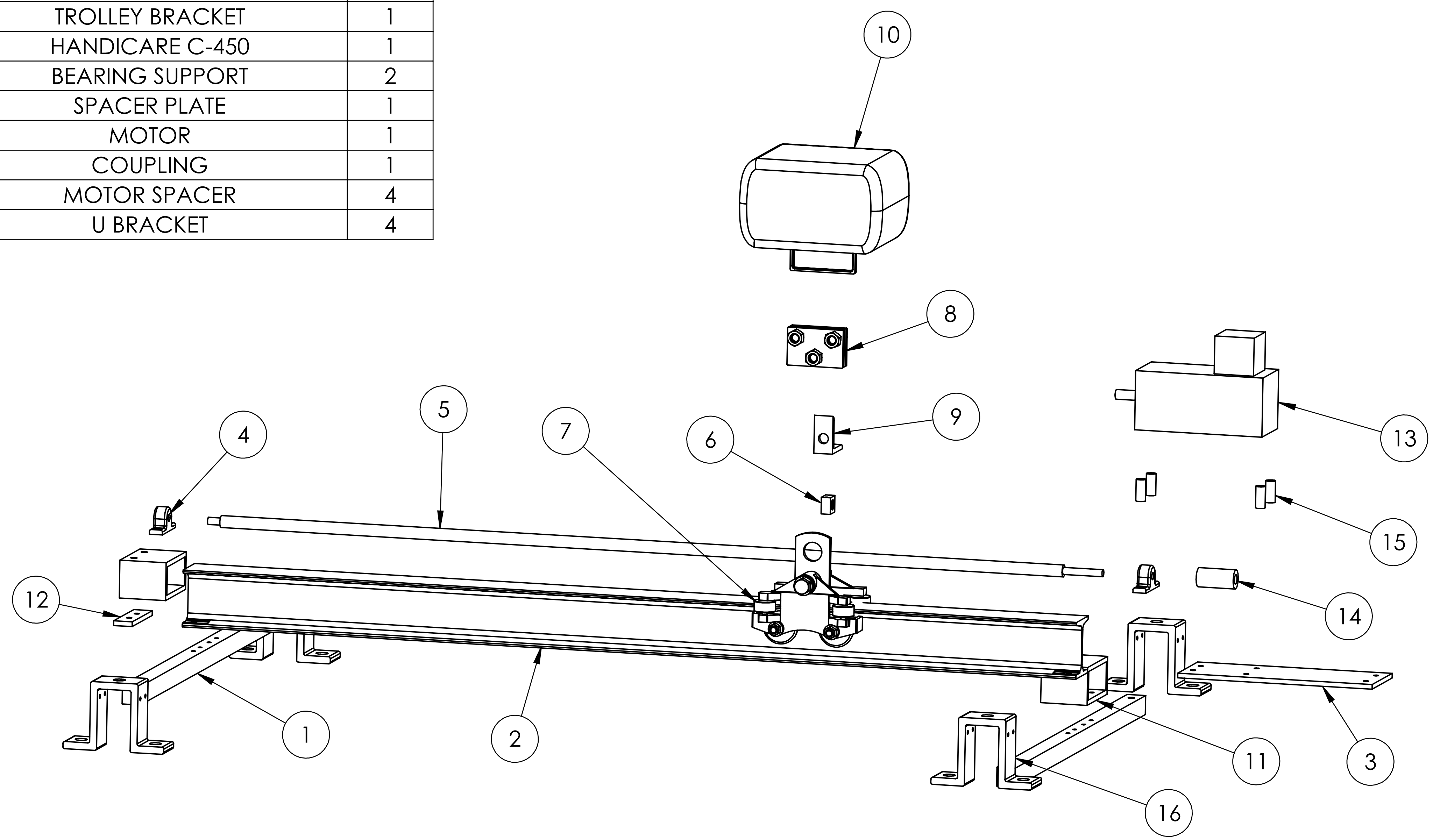
Appendix N. Drawing Package

RBT0000	Final Assembly
RBT0001	Exploded Final Assembly
RBT111	I Beam
RBT113	Lead Screw
RBT114	Brass Square Nut
RBT115	Trolley Bracket
RBT116	Motor Plate
RBT117	Spacer Plate
RBT118	Bearing Support
RBT119	Motor Spacer
RBT120-1	Wiring Diagram
RBT120-2	Power Subassembly
RBT230	Hangar Bracket Subassembly
RBT231	Bracket Plate
RBT310	U Bracket
RBT311	End Support Bar



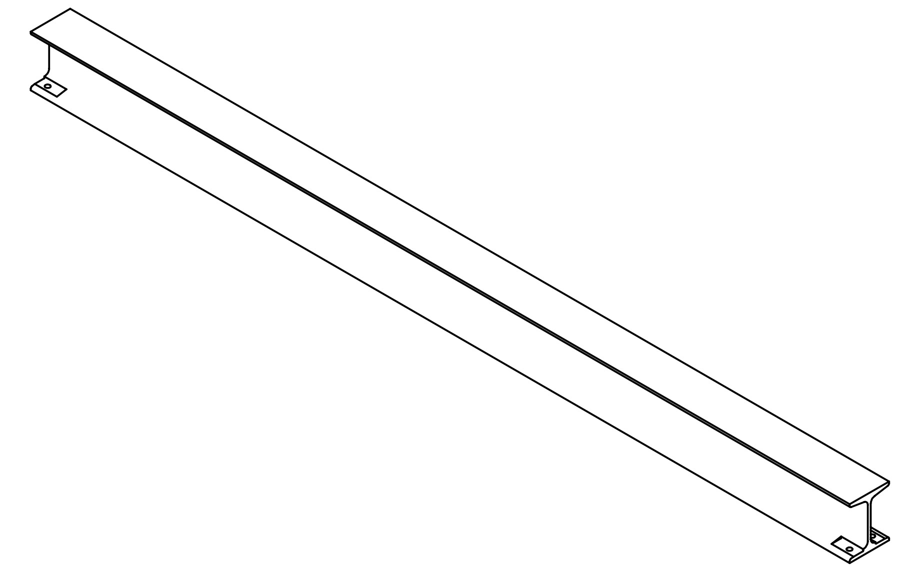
Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: FULL ASSEMBLY		Drwn. By: HUY NGUYEN
ME 430 - SPRING 2019	Dwg.#: RBT0000	Nxt Asb: RBT0000	Date: 5/30/19	Scale: 1/8	Chkd. By: ME STAFF

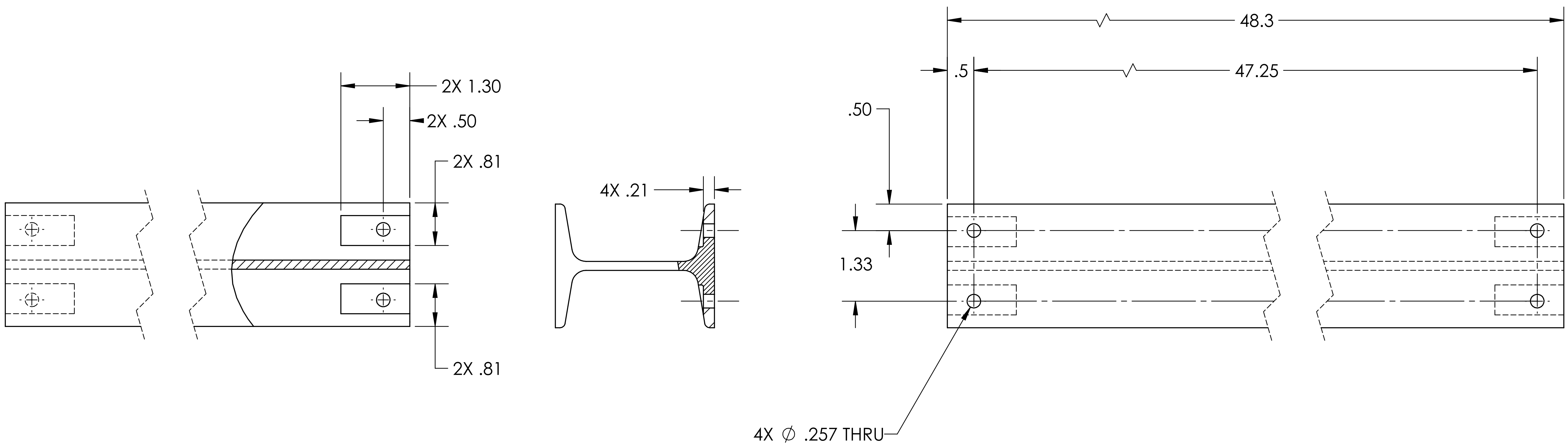
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	RBT311	END SUPPORT BAR	2
2	RBT111	I BEAM	1
3	RBT116	MOTOR PLATE	1
4	KP000	BEARING	2
5	RBT113	LEAD SCREW	1
6	RBT114	BRASS SQUARE NUT	1
7	9792	TROLLEY	1
8	RBT230	HANGAR BRACKET SUBASSEMBLY	1
9	RBT115	TROLLEY BRACKET	1
10	330050	HANDICARE C-450	1
11	RBT118	BEARING SUPPORT	2
12	RBT117	SPACER PLATE	1
13	MTPM-P25-1JK40	MOTOR	1
14	6408K12	COUPLING	1
15	RBT119	MOTOR SPACER	4
16	RBT310	U BRACKET	4



Cal Poly Mechanical Engineering ME 430 - SPRING 2019	Lab Section: 06	FDR PACKAGE	Title: EXPLODED ASSEMBLY		Drwn. By: HUY NGUYEN
	Dwg. #: RBT0001	Nxt Asb: RBT0000	Date:5/30/19	Scale:1/7	Chkd. By: ME STAFF

NOTES
1. MODIFY PART NO. S3-6 FROM ULTIMATION
2. MATERIAL: A36 STEEL S3 X 5.7 I-BEAM
UNLESS OTHERWISE SPECIFIED:
3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. INSIDE TOOL RADIUS .03 MAX
6. TOLERANCES:
   1. X.X = ±.1
   2. X.XX = ±.01
   3. X.XXX = ±.005





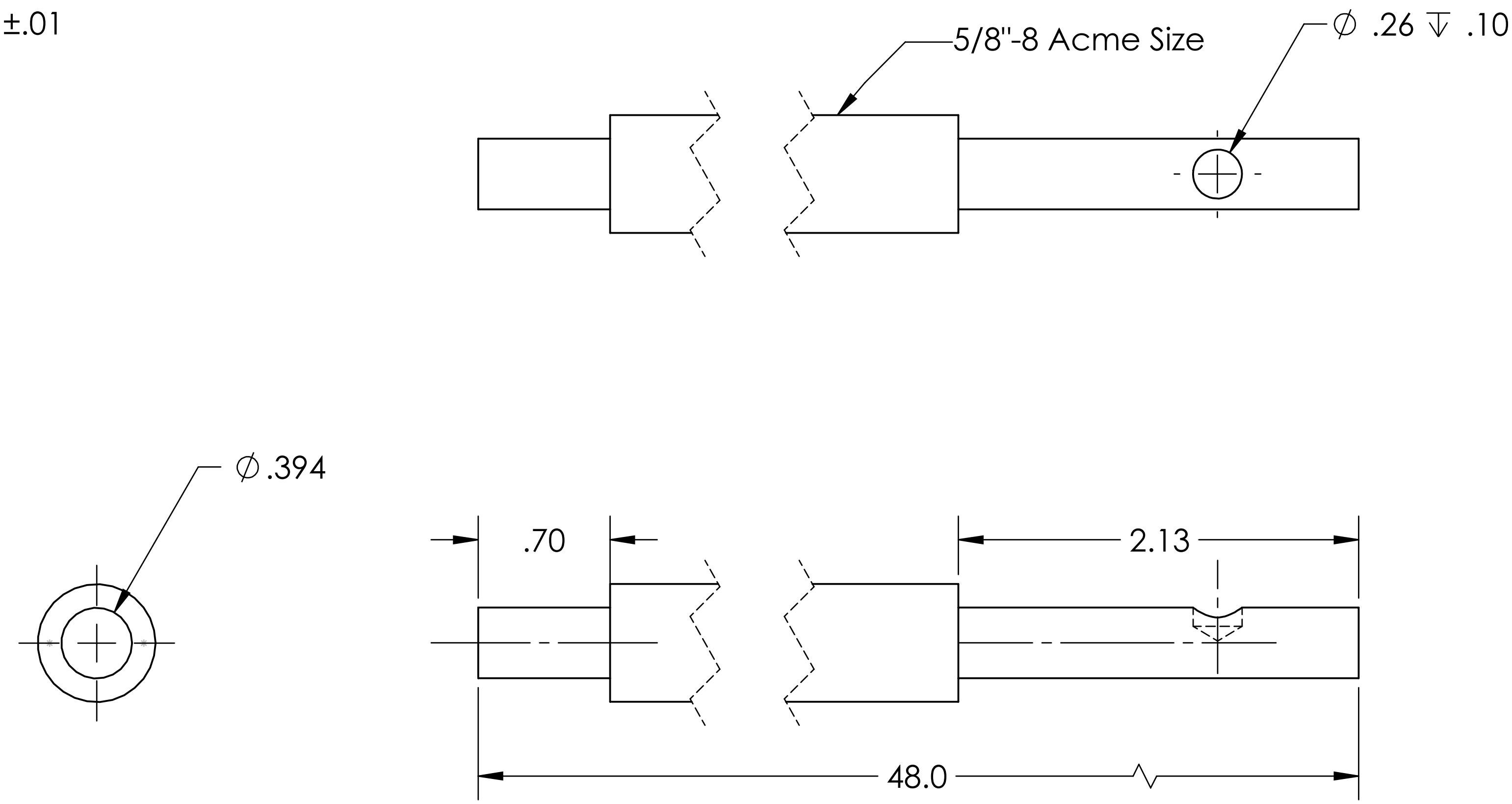
Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: I-BEAM	Drwn. By: HUY NGUYEN
ME 430 - SPRING 2019	Dwg. #: RBT111	Nxt Asb: RBT0000	Date: 1/31/19 / Scale: 1/2	Chkd. By: ME STAFF

NOTES

1. MODIFY PART NO. 98935A912 FROM MCMASTER-CARR
2. MATERIAL: CARBON STEEL

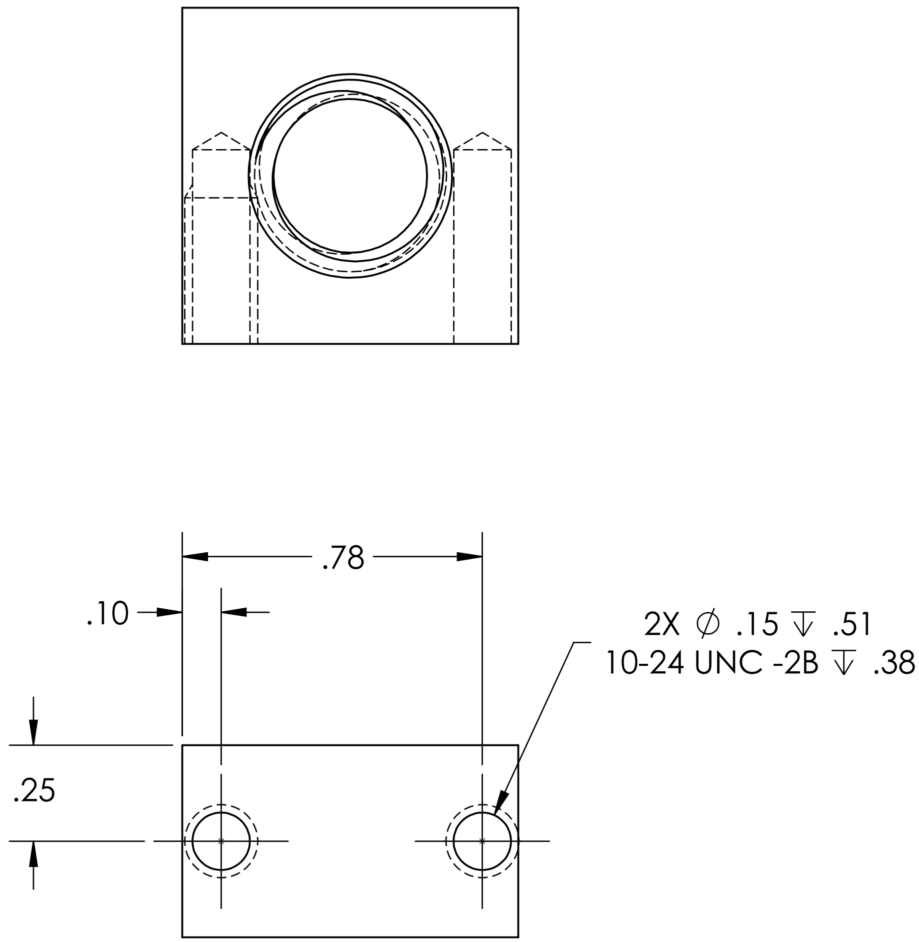
UNLESS OTHERWISE SPECIFIED:

3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. TOLERANCES:
   1. X.X = ±.1
   2. X.XX = ±.01

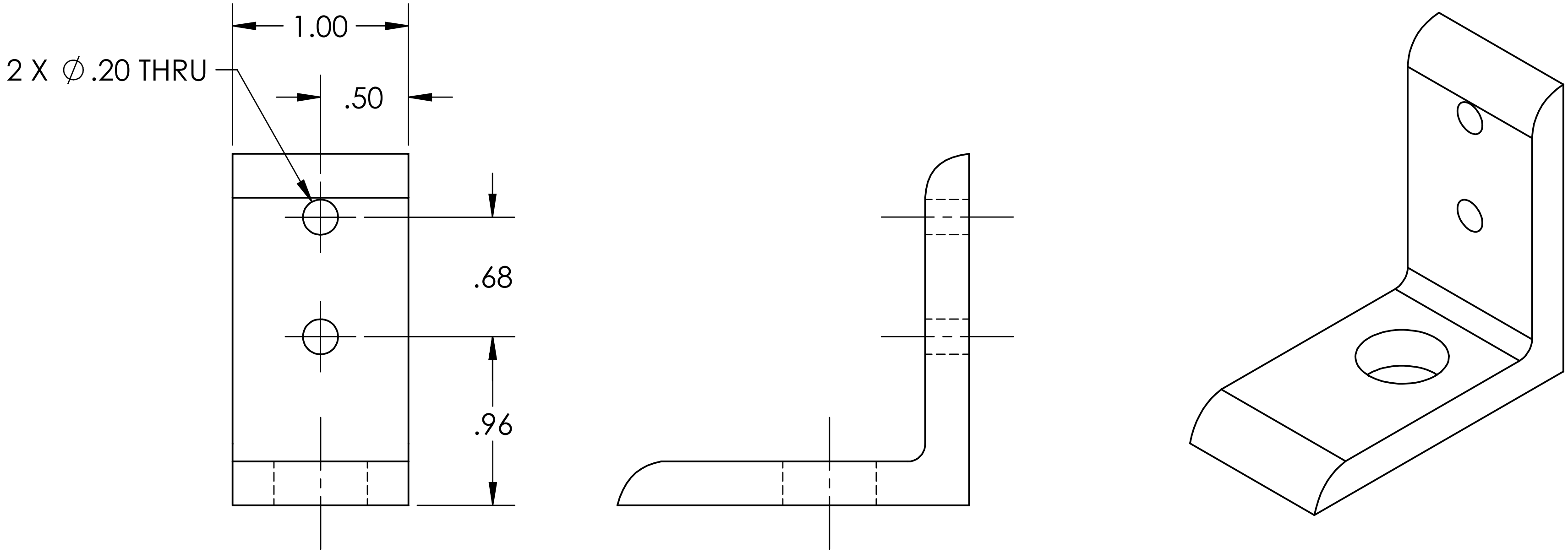


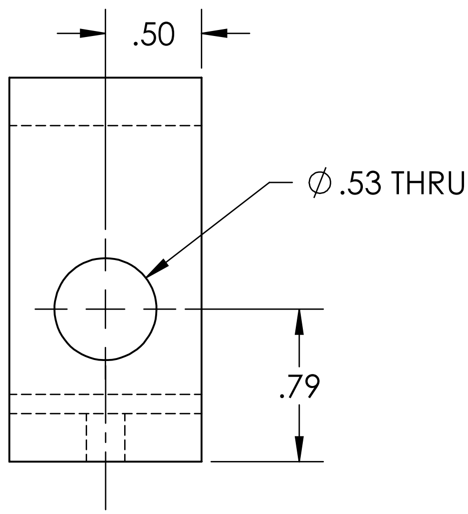
Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: 5/8"-8 LEADSCREW	Drwn. By: JOSEPH LEE
ME 430 - SPRING 2019	Dwg. #: RBT113	Nxt Asb: RBT0000	Date: 5/29/19 · Scale: 1/1	Chkd. By: ME STAFF

NOTES
1. MODIFY PART NO. 95270A119 FROM MCMASTER CARR
2. MATERIAL: 360 BRASS
UNLESS OTHERWISE SPECIFIED
3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. TOLERANCES:
X.X = ±.1
X.XX= ±.01



Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: 5/8"-8 BRASS SQUARE NUT	Drwn. By: HUY NGUYEN
ME 430 - SPRING 2019	Dwg. #: RBT114	Nxt Asb: RBT0000	Date: 5/29/19 Scale: 2/1	Chkd. By: ME STAFF



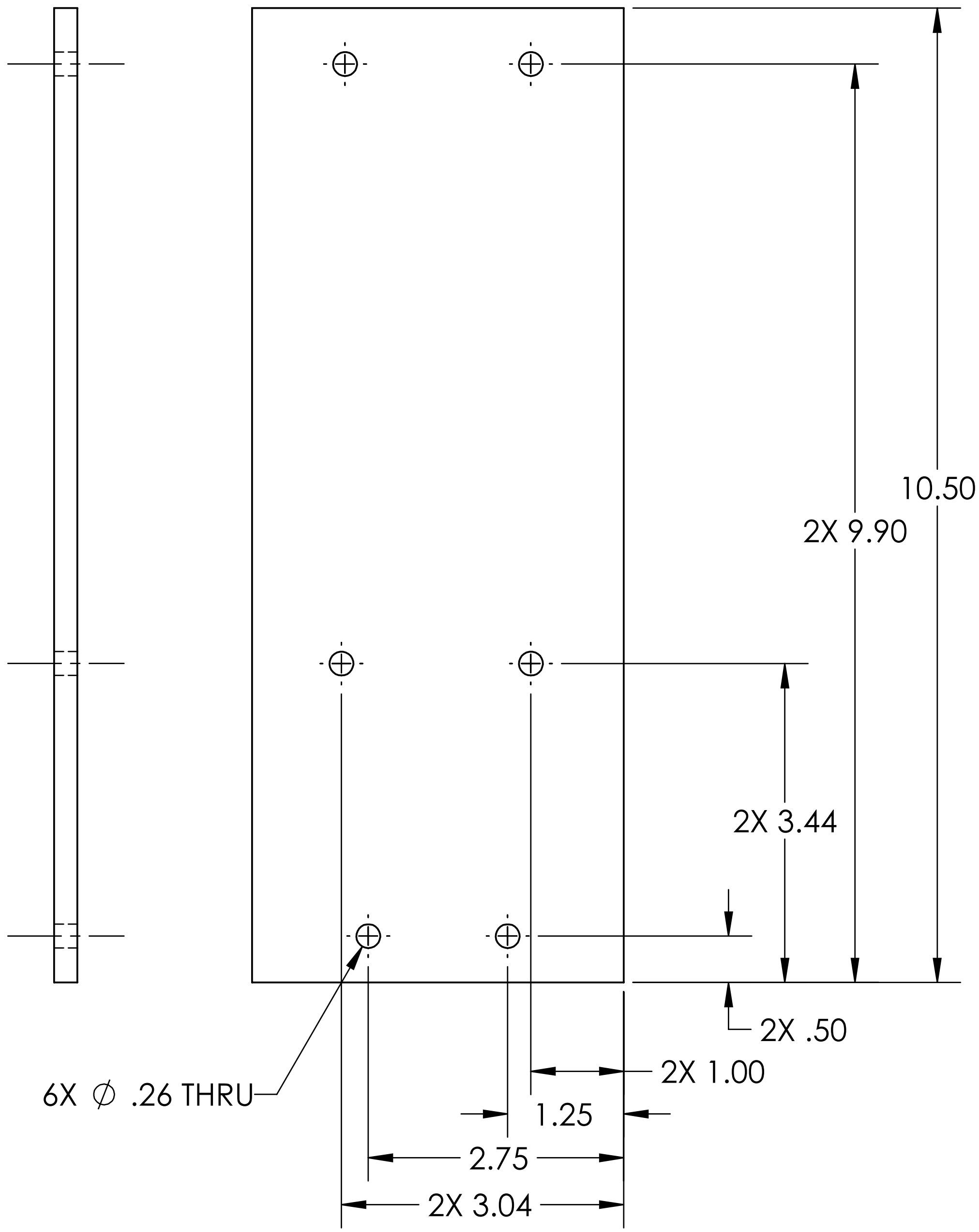


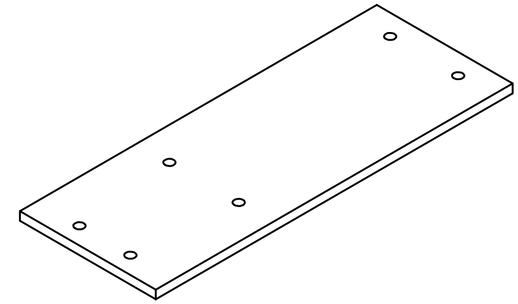
NOTES
1. MODIFIED PART NO. 9017K694 FROM MCMASTER CARR
2. MATERIAL: LOW CARBON STEEL

UNLESS OTHERWISE SPECIFIED:

3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. INSIDE TOOL RADIUS .03 MAX
6. TOLERANCES:
   1. X.X = ±.1
   2. X.XX = ±.01

Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: TROLLEY BRACKET		Drwn. By: JACK MCATEE
ME 430 - SPRING 2019	Dwg. #: RBT115	Nxt Asb: RBT0000	Date: 5/30/19	Scale: 1/1	Chkd. By: ME STAFF





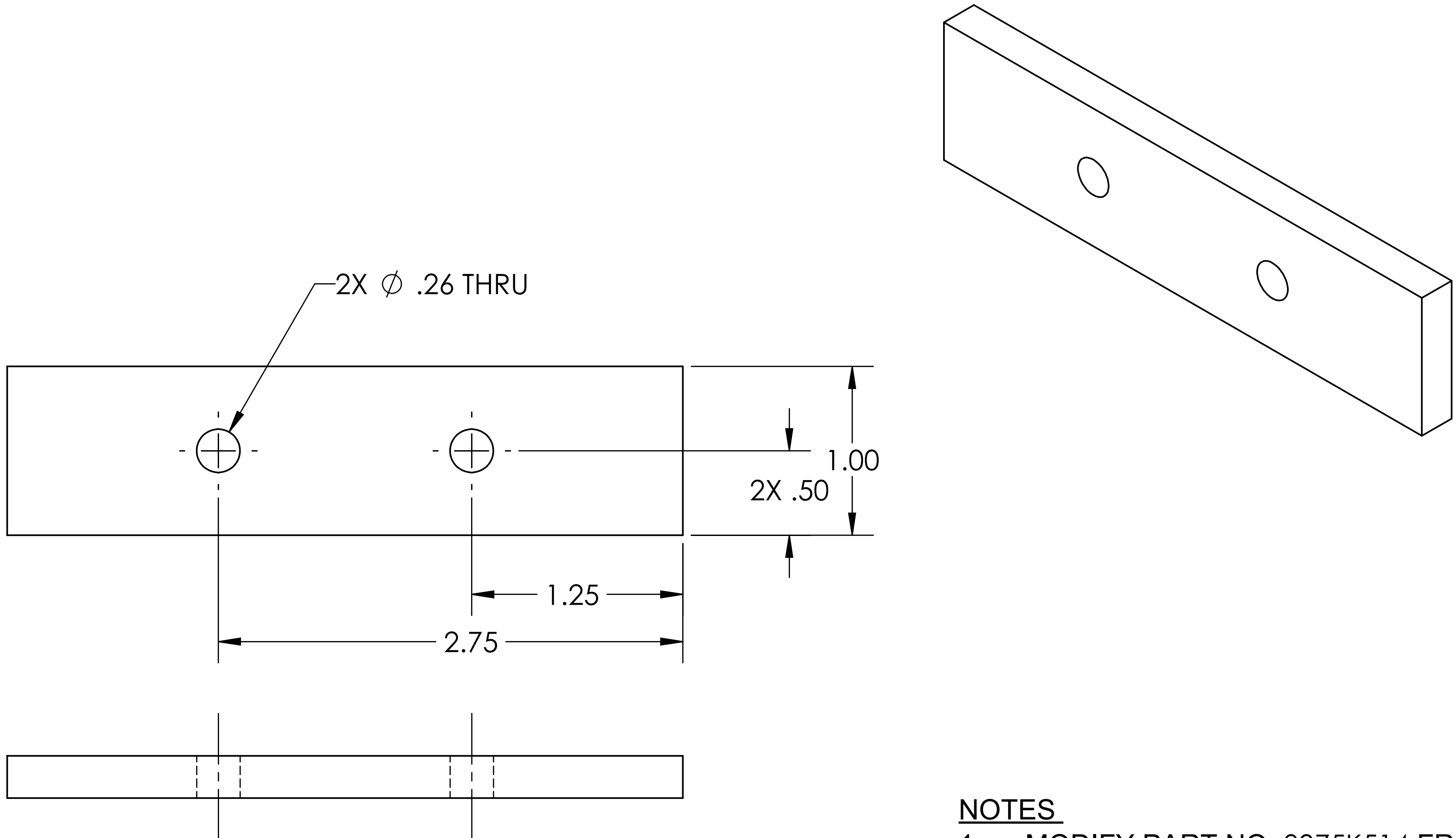
NOTES

1. MODIFY PART NO. 8975K514 FROM MCMASTER-CARR
2. MATERIAL: 6061 ALUMINUM

UNLESS OTHERWISE SPECIFIED:

3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. TOLERANCES:
   1. X.X = ±.1
   2. X.XX = ±.01

Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: MOTOR PLATE		Drwn. By: JACK MCATEE
ME 430 - SPRING 2019	Dwg. #: RBT116	Nxt Asb: RBT0000	Date: 5/06/2019	Scale: 1/2	Chkd. By: ME STAFF



NOTES

1. MODIFY PART NO. 8975K514 FROM MCMASTER-CARR
2. MATERIAL: 6061 ALUMINUM

UNLESS OTHERWISE SPECIFIED:

3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. TOLERANCES:
   1. X.X = ±.1
   2. X.XX = ±.01

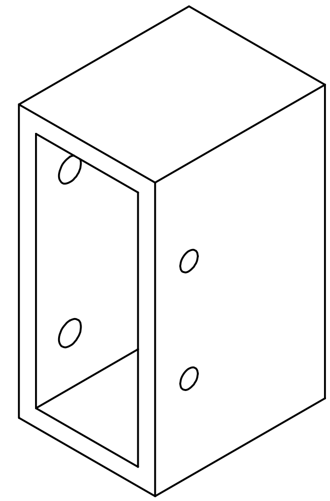
Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: SPACER PLATE		Drwn. By: JACK MCATEE
ME 430 - SPRING 2019	Dwg. #: RBT117	Nxt Asb: RBT0000	Date: 5/06/2019	Scale: 1/1	Chkd. By: ME STAFF

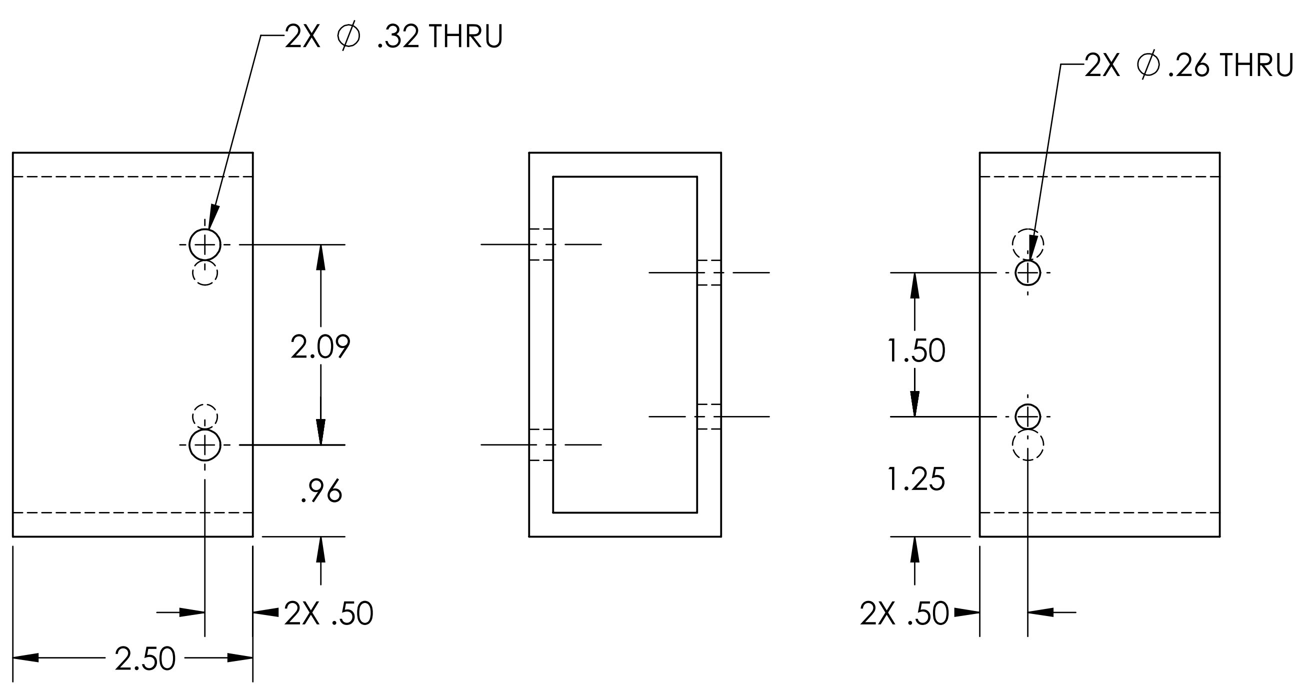
NOTES

1. MODIFY PART NO. 6546K29 FROM MCMASTER-CARR
2. MATERIAL: 6061 ALUMINUM

UNLESS OTHERWISE SPECIFIED:

3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. TOLERANCES:
    1. X.X = ±.1
    2. X.XX = ±.01





QUANTITY: 2

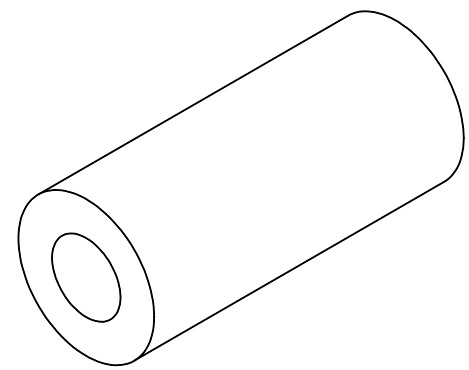
Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: BEARING SUPPORT	Drwn. By: JACK MCATEE
ME 430 - SPRING 2019	Dwg. #: RBT118	Nxt Asb: RBT0000	Date: 5/6/2019 · Scale: 1/2	Chkd. By: ME STAFF

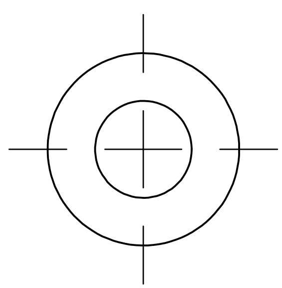
NOTES

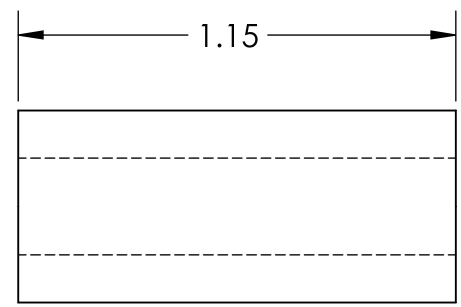
1. MODIFY PART NO. 92510A771 FROM MCMASTER-CARR
2. MATERIAL: ALUMINUM

UNLESS OTHERWISE SPECIFIED:

3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. TOLERANCES:
    1. X.X = ±.1
    2. X.XX = ±.01

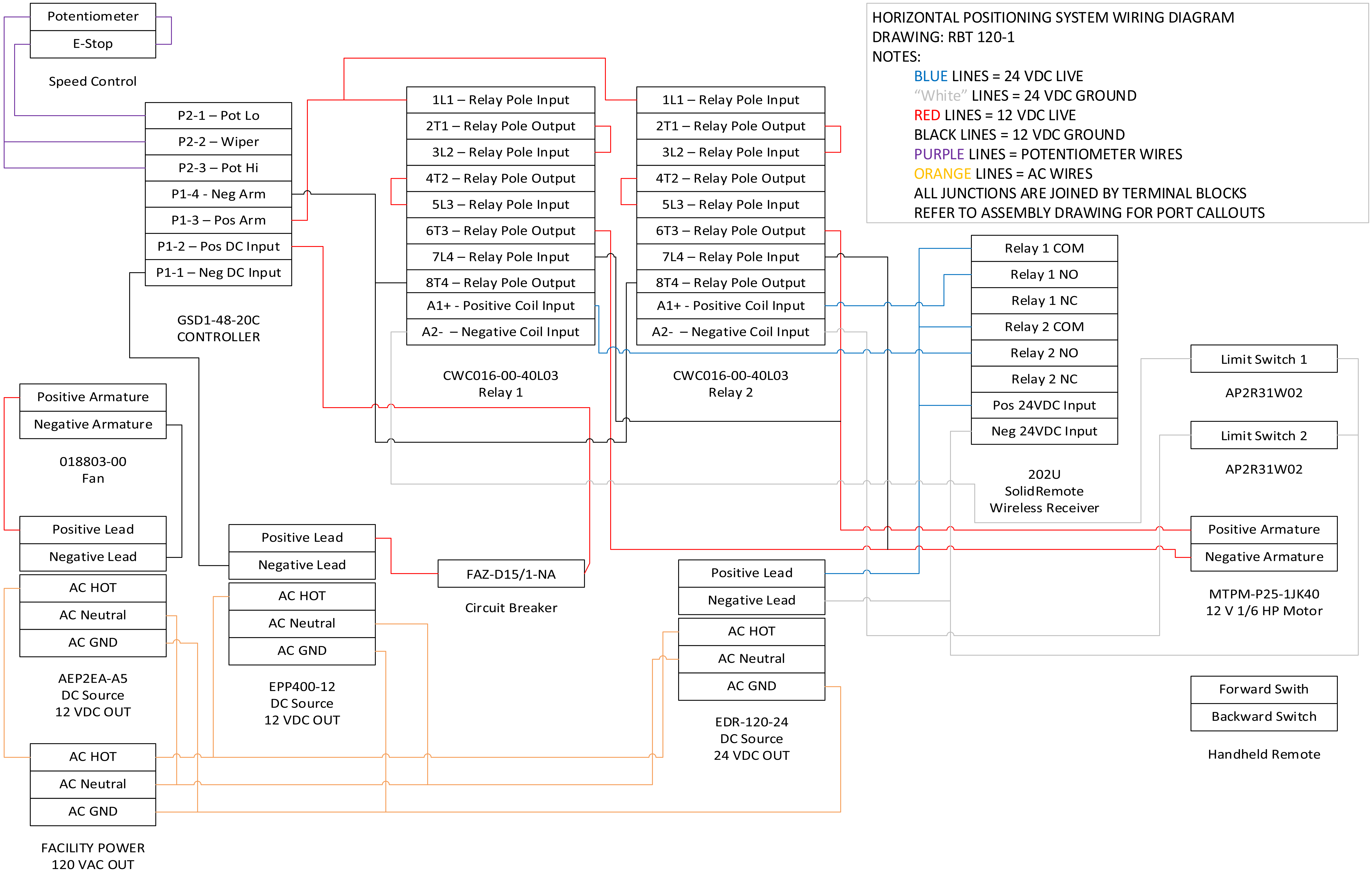


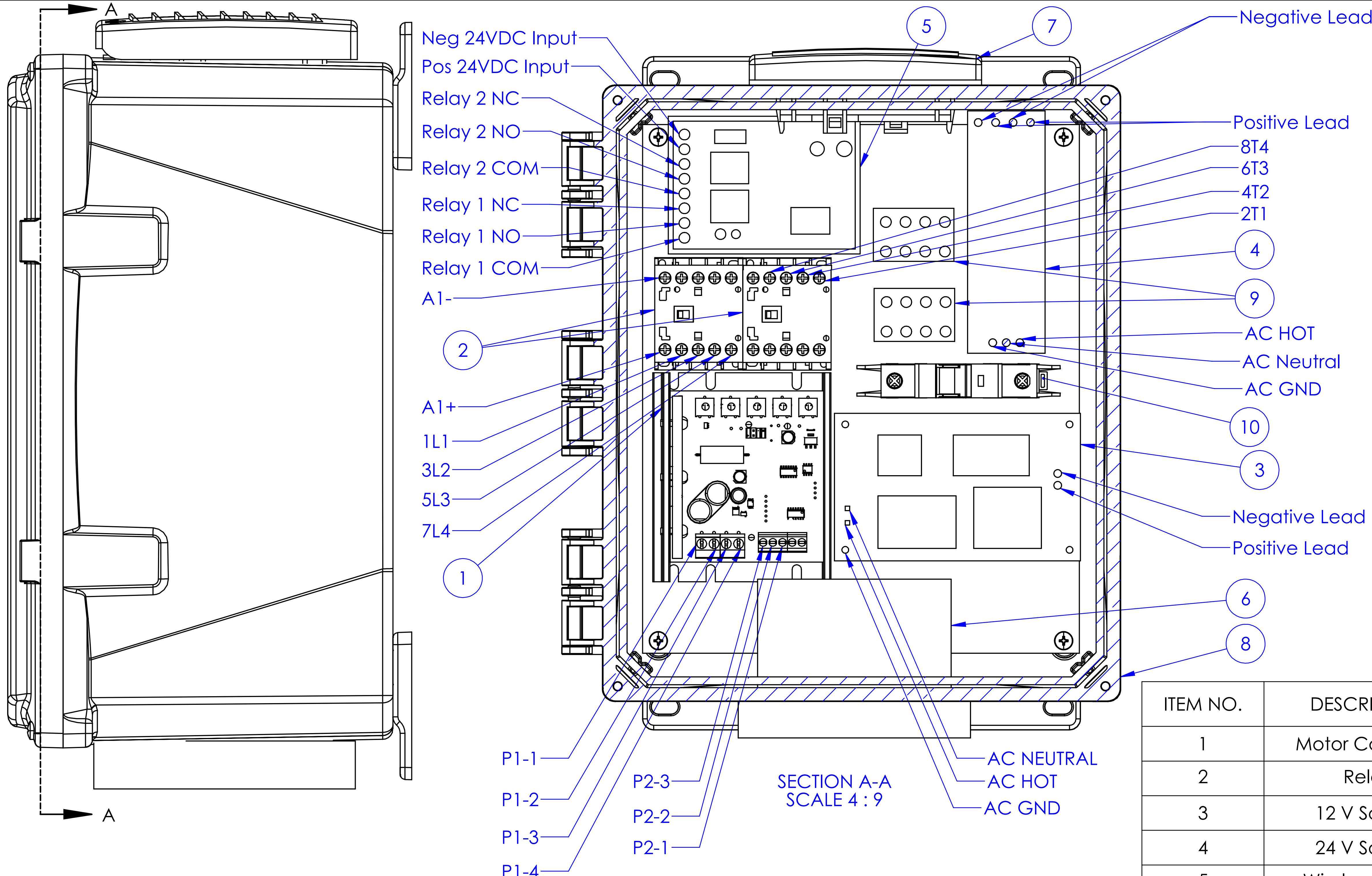




QUANTITY: 2

Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: MOTOR SPACER		Drwn. By: JACK MCATEE
ME 430 - SPRING 2019	Dwg. #: RBT119	Nxt Asb: RBT0000	Date: 5/06/2019	Scale: 2/1	Chkd. By: ME STAFF


HORIZONTAL POSITIONING SYSTEM WIRING DIAGRAM
DRAWING: RBT 120-1
NOTES:
BLUE LINES = 24 VDC LIVE
"White" LINES = 24 VDC GROUND
RED LINES = 12 VDC LIVE
BLACK LINES = 12 VDC GROUND
PURPLE LINES = POTENTIOMETER WIRES
ORANGE LINES = AC WIRES
ALL JUNCTIONS ARE JOINED BY TERMINAL BLOCKS
REFER TO ASSEMBLY DRAWING FOR PORT CALLOUTS
Potentiometer
E-Stop
Speed Control
P2-1 – Pot Lo
P2-2 – Wiper
P2-3 – Pot Hi
P1-4 - Neg Arm
P1-3 – Pos Arm
P1-2 – Pos DC Input
P1-1 – Neg DC Input
GSD1-48-20C
CONTROLLER
1L1 – Relay Pole Input
2T1 – Relay Pole Output
3L2 – Relay Pole Input
4T2 – Relay Pole Output
5L3 – Relay Pole Input
6T3 – Relay Pole Output
7L4 – Relay Pole Input
8T4 – Relay Pole Output
A1+ - Positive Coil Input
A2- – Negative Coil Input
CWC016-00-40L03
Relay 1
1L1 – Relay Pole Input
2T1 – Relay Pole Output
3L2 – Relay Pole Input
4T2 – Relay Pole Output
5L3 – Relay Pole Input
6T3 – Relay Pole Output
7L4 – Relay Pole Input
8T4 – Relay Pole Output
A1+ - Positive Coil Input
A2- – Negative Coil Input
CWC016-00-40L03
Relay 2
Relay 1 COM
Relay 1 NO
Relay 1 NC
Relay 2 COM
Relay 2 NO
Relay 2 NC
Pos 24VDC Input
Neg 24VDC Input
202U
SolidRemote
Wireless Receiver
Limit Switch 1
AP2R31W02
Limit Switch 2
AP2R31W02
Positive Armature
Negative Armature
018803-00
Fan
Positive Lead
Negative Lead
AC HOT
AC Neutral
AC GND
AEP2EA-A5
DC Source
12 VDC OUT
Positive Lead
Negative Lead
AC HOT
AC Neutral
AC GND
EPP400-12
DC Source
12 VDC OUT
FAZ-D15/1-NA
Circuit Breaker
Positive Lead
Negative Lead
AC HOT
AC Neutral
AC GND
EDR-120-24
DC Source
24 VDC OUT
Positive Armature
Negative Armature
MTPM-P25-1JK40
12 V 1/6 HP Motor
Forward Swith
Backward Switch
Handheld Remote
AC HOT
AC Neutral
AC GND
FACILITY POWER
120 VAC OUT



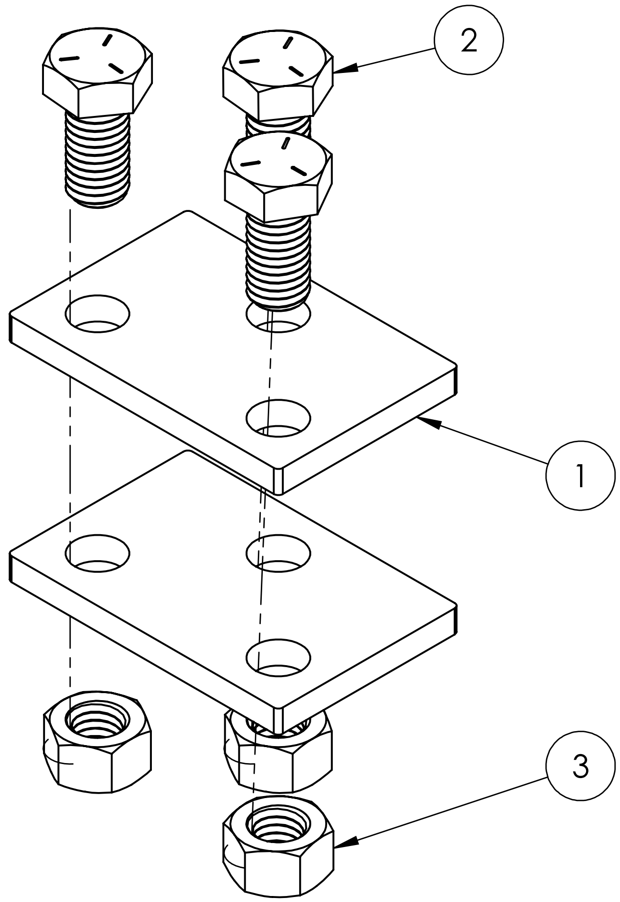
SECTION A-A
SCALE 4 : 9

NOTES
1. INTERPRET ABBREVIATIONS PER ASME Y14.38
2. REFER TO DWG RBT120-1 FOR WIRING
3. COMPONENTS NOT SHOWN HAVE SIMPLE CONNECTIONS AND SHOULD BE COMPLETED PER RBT120-1.

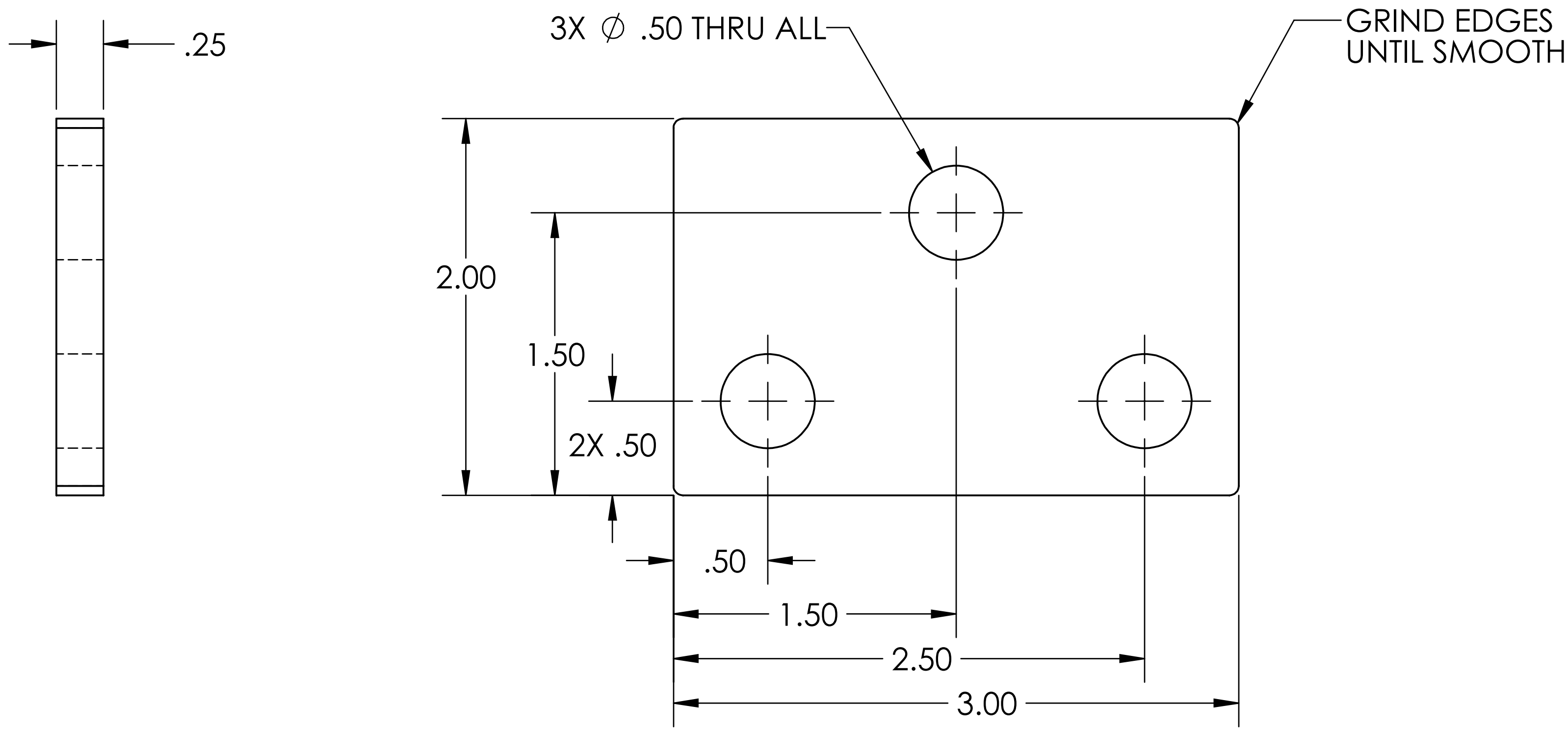
ITEM NO.	DESCRIPTION	DWG/PART NUMBER	QTY.
1	Motor Controller	GSD1-48-20C	1
2	Relay	CWC016-00-40L03	2
3	12 V Source	EPP-400-12	1
4	24 V Source	EDR-120-24	1
5	Wireless Relays	202U	1
6	24 V Fan	018803-00	1
7	Filter	118800-30	1
8	Controller Box	H12106HF-6B-P10	1
9	Terminal Block	BC74098	6
10	Circuit Breaker	FAZ-D15/1-NA	1

Cal Poly Mechanical Engineering	Lab Section:06	FDR PACKAGE	Title: POWER ASSEMBLY		Drwn. By: JOHN KULICK
ME 430 - SPRING 2019	Dwg. #: RBT120-2	Nxt Asb: RBT0000	Date: 5/31/19	Scale: 1/2	Chkd. By: ME STAFF

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	RBT231	BRACKET PLATE	2
2	92865A712	1/2" BOLT	3
3	95462A033	1/2" HEX NUT	3



Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: HANGAR BRACKET SUBASSEM.	Drwn. By: HUY NGUYEN
ME 430 - SPRING 2019	Dwg. #: RBT230	Nxt Asb: RBT230	Date: 5/30/19 Scale: 2/3	Chkd. By: ME STAFF

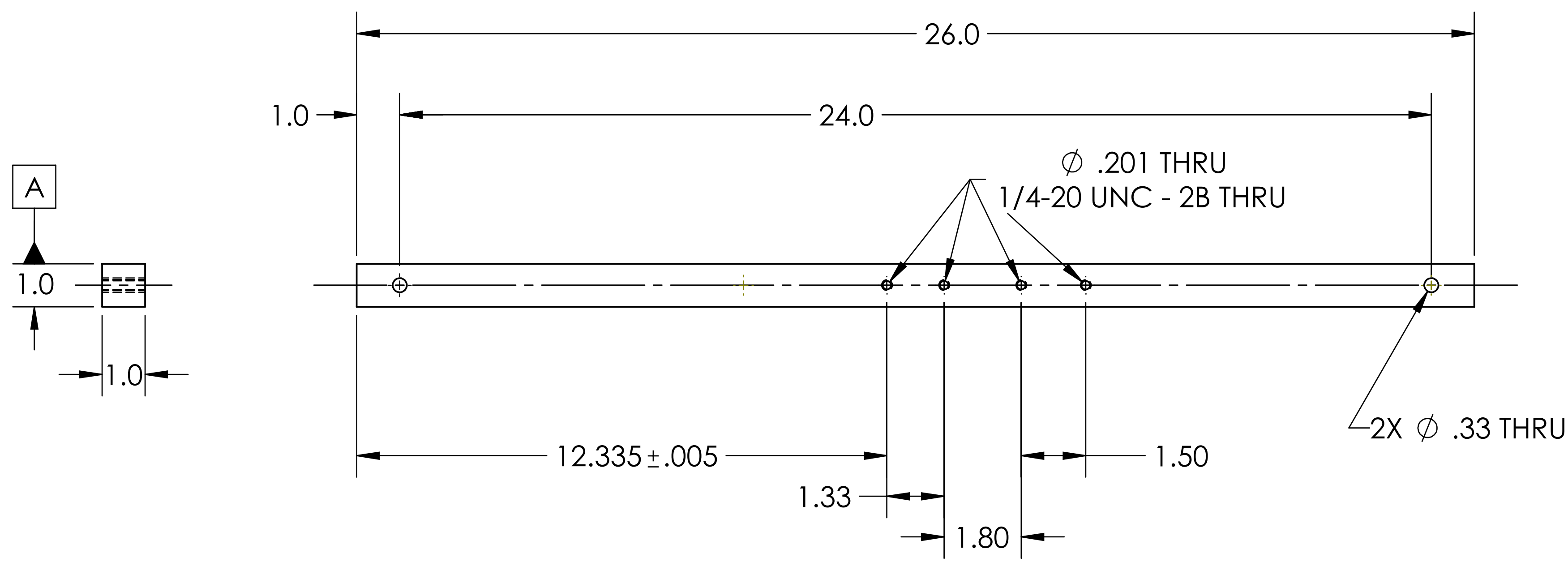


NOTES
1. MATERIAL: 6061 ALUMINUM
UNLESS OTHERWISE SPECIFIED
2. ALL DIMS. IN INCHES
3. BREAK SHARP EDGES .03 MAX
4. TOLERANCES:
X.X = ±.1
X.XX=±.01

QUANTITY: 2

Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: BRACKET PLATE		Drwn. By: JACK MCATEE
ME 430 - SPRING 2019	Dwg. #: RBT 231	Nxt Asb: RBT230	Date: 5/29/2019	Scale: 1/1	Chkd. By: ME STAFF

NOTES
1. MATERIAL: 6061 ALUMINUM
UNLESS OTHERWISE SPECIFIED:
2. ALL DIMS. IN INCHES
3. BREAK SHARP EDGES .03 MAX
4. TOLERANCES:
   1. X.X = ±.1
   2. X.XX = ±.01



QUANTITY: 2

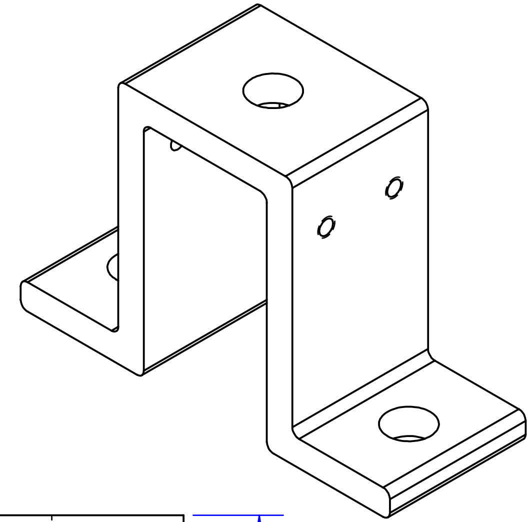
Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: END SUPPORT BAR	Drwn. By: HUY NGUYEN
ME 430 - SPRING 2019	Dwg. #: RBT311	Nxt Asb: RBT0000	Date: 5/29/19 / Scale: 1/4	Chkd. By: ME STAFF

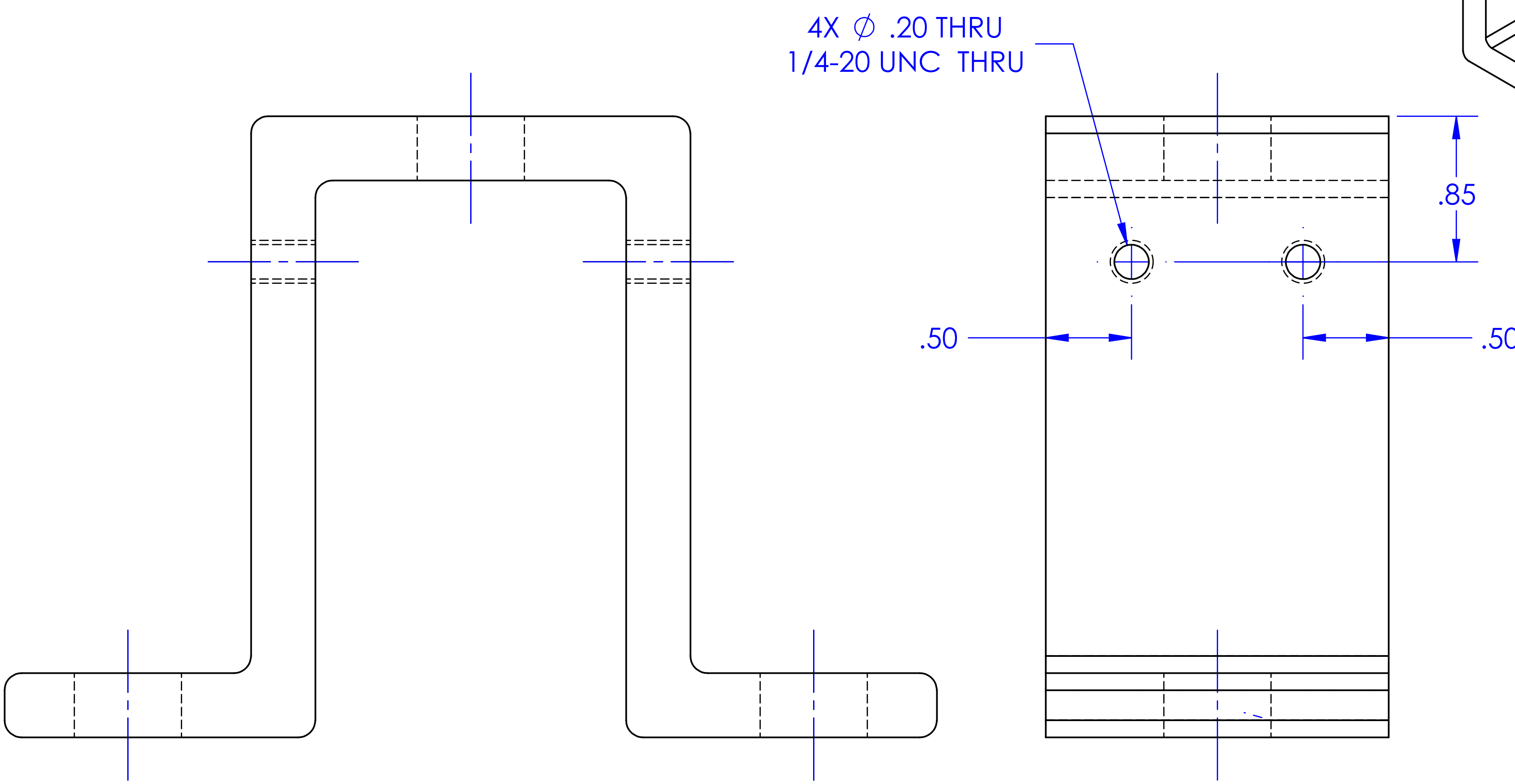
<u>NOTES</u>

1. MODIFY PART NO. B107-22A FROM B-LINE
2. MATERIAL: STEEL

UNLESS OTHERWISE SPECIFIED:

3. ALL DIMS. IN INCHES
4. BREAK SHARP EDGES .03 MAX
5. TOLERANCES:
    1. X.X = ±.1
    2. X.XX = ±.01





QUANTITY: 4

Cal Poly Mechanical Engineering	Lab Section: 06	FDR PACKAGE	Title: U BRACKET		Drwn. By: HUY NGUYEN
ME 430 - SPRING 2019	Dwg. #: RBT310	Nxt Asb: RBT0000	Date: 5/29/19	Scale: 1/1	Chkd. By: ME STAFF