DEPARTMENT OF
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UNIVERSITY OF WISCONSIN–MADISON

X-Chair: Autonomous Wheelchair Restraint Adaptations

BME 400

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Abstract

Moving the body has many benefits for almost all major organs and is beneficial for a number of bodily functions. Many wheelchair users however, are currently unable to achieve the health benefits of whole-body movement due to mobility limitations they encounter. Neuromuscular conditions inhibit the straightening of joints, limiting the overall mobility of the patient, and forcing them to stay in a seated position for the majority of the day. The cost of hiring a CNA or other licensed physical therapist is expensive and is typically not covered by health insurance for those affected by a permanent disability. The client, who has been diagnosed with Type II Spinal Muscular Atrophy (SMA), has requested a device to enable autonomous body movements, via their standing wheelchair, to further prevent atrophy of his muscles and aid in bodily functions. At present there are no compatible existing devices. The team has developed a design that uses motorized supports to effectively secure the client within their standing wheelchair, and allowing independent operation by the user. This design will allow the client to access and operate their standing wheelchair autonomously by enabling the user to position the restraints themselves, something previously unattainable. Due to conflicts with in-person meetings and additional challenges, the team was unable to fabricate a device prototype this semester. The team has composed detailed fabrication and testing plans for the upcoming semester to streamline the physical prototype development.

Table of Contents

I. Introduction

a. Problem Statement

The client is unable to safely enter and operate the standing wheelchair with the manufacturer included restraints. There are currently 3.3 million wheelchair users in the U.S. and within this population, there is a varying degree of upper and lower extremity mobility, ranging from full movement to none [1] . Without a large degree of mobility, many wheelchair users are unable to take advantage of the benefits of movement due to various mobility challenges they encounter.

Moving the body has many benefits for the brain, muscles, bones, joints, intestines, heart, lungs and other organs [2]. Movement is also beneficial for a number of bodily functions such as blood flow, digestion, muscle strength, and bone health [2]. Existing standing wheelchair supports enable users to enter the upright position, but they lack autonomous accessibility for the user. The restraints require strength and dexterity to position in place, that mobility limited users may not possess. The cost of hiring a CNA or licensed physical therapist is quite expensive and usually is not covered by health insurance for those affected by a permanent disability. The goal of this project is to develop a device that enables the wheelchair user the ability to secure themself within their standing wheelchair independently.

b. Impact

Approximately 75 million wheelchair users worldwide and 3.3 million wheelchair users in the United States utilize a wheelchair on a daily basis [1, 2]. Similar to the client, many wheelchair users could benefit from a device that would allow them to move themselves into otherwise unattainable positions. This provides the opportunity to move in positions such as prone or vertical that could help immensely in improving their quality of life.

c. Existing Devices

While there are no devices to aid in full body movement for certain wheelchair users, there are many devices and working systems that can be modified or repurposed to create a more capable device that can be widely used.

Inversion tables are an exercise machine that enable users to relieve pressure from their spine by inverting their body, along with strengthening core muscles. The table utilizes feet restraints allowing the user to place their feet between two pads, securing them safely to the table. The user is then able to invert their body for a period of time, alleviating pressure on the spine and providing an adequate stretch. The more that an inversion table is used by an individual, the longer the user can remain inverted, but they generally should not exceed an inversion period of 15 minutes [3]. There are a limited number of wheelchair user adapted inversion tables, but these inversion tables require a large amount of upper body strength to operate safely. The adapted inversion tables have a strap attached to the base of the table, limiting the rotation of the table to horizontal at rest. This allows the user to enter the table from their wheelchair, but also requires a large amount of upper body strength, seen in [4, Fig. 1]. It also has the potential to accidentally invert if the user's center of mass is too high up the table, and could lead to client injury by falling off the chair.

Figure 1: Wheelchair adapted inversion table with a strap to hold the table horizontal at rest [4].

Vibration plates and other vibration devices are mainly used to help massage sore muscles, and have numerous other positive impacts including the ability to increase bone density, increase muscle mass, improve circulation, and reduce joint and back pain [5]. By using a whole body vibration device for 15 minutes a day, multiple days a week, users can experience enhanced blood flow, decreased stress, along with other positive body benefits [6]. Full body vibration plates are also accessible for wheelchair users. By placing the users feet on a vibration plate for up to 10 minutes, this can aid in the circulation to lower extremities as well as enhance the flow of lymph fluids from the ankles towards the heart [7]. In addition to this, by placing the elbows on the knees during vibration the neck and shoulders will be relieved of pain and circulation of the upper body will improve [7].

II. Background

a. Research

Spinal Muscular Atrophy, otherwise known as SMA, is a genetic disease that affects voluntary muscle movement. The name "spinal muscular" stems from the fact that most voluntary muscle movement is controlled by nerves in the spinal cord. "Atrophy" is the progressive decline or shrinkage of the muscles as a result of them not remaining active. SMA is caused by a deficiency of the motor neuron protein called SMN (survival of motor neurons) and affects the motor neurons and muscle cells. Oftentimes the severity of SMA in patients is correlated with the age of onset. The age of onset is correlated with SMN proteins. There are three main types of SMN related SMA. Type I is the most severe with the earliest age of onset being at birth . Usually this group of patients only live several years. A ventilator and feeding tube may be required due to deficient respiratory and swallowing functions. Type II SMA can usually be seen in children between the ages of 8 to 16 months old. The child can typically sit without support. However, their proximal muscles are affected much sooner than distal muscles. The thighs, for example, become

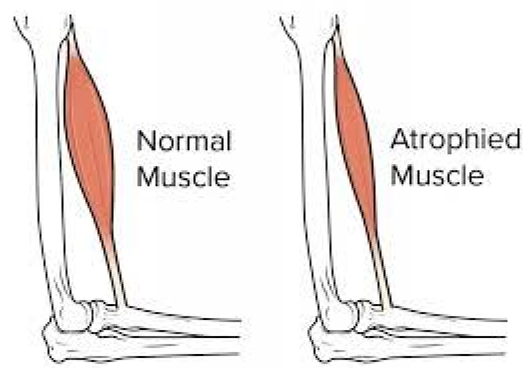

Figure [2]: Atrophied vs Normal Muscle [10]

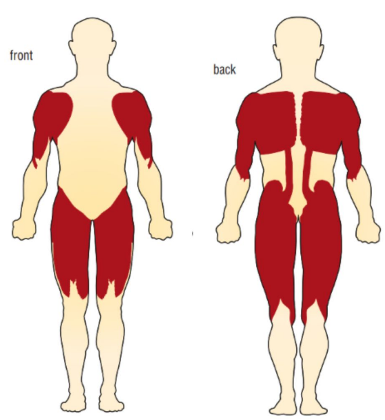

Figure [3]: The red regions are the proximal muscles which are affected first in patients with SMA [9].

weaker before the lower legs and feet. Legs generally weaken before the arms; hands remain the strongest. Children can benefit from physical therapy, braces, and a variety of other assisting devices. Type III is the least severe with the latest age of onset being after 18 months or the child has taken at least 5 independent steps. Many individuals with Type III SMA can walk until their 30s or 40s, although some may lose this ability in their teens. They may use canes or walkers, needing a wheelchair for longer distances. Some clinicians believe that a Type IV SMA exists that begins in adulthood, and has a lesser degree of Type III traits. SMN related SMA has been found to genetically affect chromosome 5. Non-SMN related SMA has a wide range of severities or effects. For example, the most distal parts of the body like the hands and feet could be targeted first. Patients with SMA often develop a curvature in the spine as a child that can lead to scoliosis. The child usually has to undergo spinal fusion surgery to fix the problem. Respiratory muscle weakness and swallowing muscle weakness, may also be experienced presenting great danger [8].

Exercising can help to improve range of motion, prevent contractures, strengthen muscles, maintain swallowing and respiratory muscles, strengthen posture, allow for greater blood circulation, and provide an overall benefit to the person's mental well-being [9]. The extent that an SMA patient can exercise is dependent on age, developmental stage, and neuromuscular involvement [10]. While aerobic exercise has evidence proving it to have a positive impact on patients, there is a lack of research indicating a positive impact as a result of strength training. The phenomena, "vicious circle of inactivity", is when a patient experiences loss of muscle strength, leading to inactivity, causing deterioration of cardiovascular health and increases in fatigue. This leads to more inactivity, leading to further loss of muscle strength [11]. Therapeutic exercise in SMA is used to improve function, range of motion, independence, and overall quality of life [12]. Functional exercise is the performance of movements that one would like to accomplish throughout the day. Rolling, reaching, and sitting are all functions that can help improve daily activities. Range of motion (RoM) is movement and flexibility of the joints. RoM is maintained through stretching and without stretching, these muscles get tight. When the tightness becomes permanent, this is called a contracture. Contractures can prevent normal movement and increase discomfort. Weight bearing is also beneficial for muscles and bones. Standing can improve bone strength, respiratory, and bowel functions. Devices are used to help a person achieve a standing position. Some standing aids help a person lie on their belly or their backs; these are called the prone position and the supine position respectively. Also proven to be beneficial is water therapy. Water therapy allows for your body to be lighter and easier to move due to buoyancy in the water [13].

b. Client Information

The client works as a senior programmer analyst in the Biostatistics and Medical Informatics Department at the UW - Madison School of Medicine and Public Health. They have been phenotypically diagnosed with Type II SMA and genetically diagnosed with Type III. They have been unable to walk throughout their life, and have used a wheelchair to assist with their movement for decades. The client has requested a design that enables them to move and exercise more easily, with autonomy being the most important criterion. Specifically, the ability to independently move between a seated and standing position is the task the team will address this semester.

c. Design Specifications

The device will be used by one individual on a daily basis, multiple times a day. The device must be in its forward, restraining position during the duration of operation, for up to 8 hours at a time. The device will need to prevent the user from being ejected out of the wheelchair when enduring non-flat surfaces, too fast of acceleration, and abrupt stops. The electrical components must not shock the user, and the device must have a manual override to prevent the user from being trapped in the chair. The mechanical restraints cannot injure the user while entering their position, and the leg restraints cannot apply an excessive force on the user while in the standing position. This device must function for a minimum of 3-5 years with potential daily use from the end user. The device must be stored in a dry environment to mitigate damage of the electrical components. The device adaptation must not impede the normal operation of the wheelchair. The restraints must provide a comfortable and secure hold on the user during operation. The device's esthetic must be appealing to the user and visually blend in with the other components of the wheelchair.

III. Preliminary Designs

a. The Inversion Table

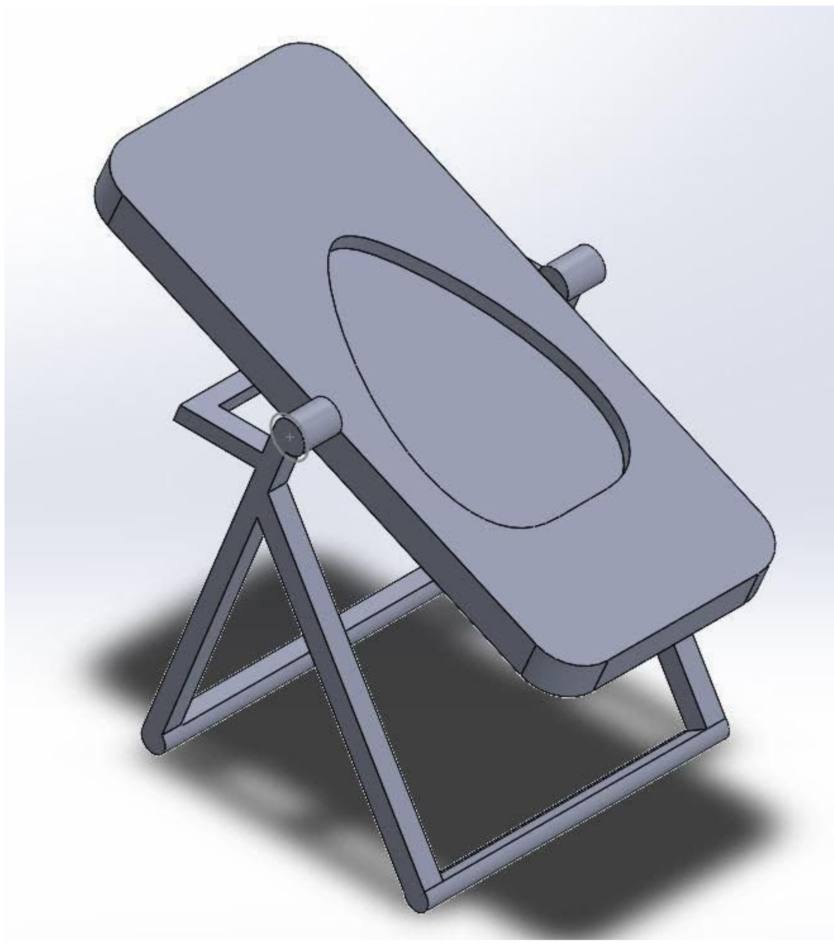

Figure 4: CAD model of the inversion table preliminary design

This design is a motorized inversion table that is rotated by a microcontroller during use. The device would be operated by a control panel that sends signals to the microcontroller, causing the device to reposition based on the user's input. As of now, the team is unsure if independent operation would be safe for the user, and has decided that a second person would be required to assist in applying the restraints and ensuring the user is safe during device operation. To allow the device to remain horizontal for entry, a locking mechanism would be engaged, and the table would rest on the rear horizontal support while the user enters. There would be an ergonomic indent in the chair that would fit the figure of the client to help support the client and increase the comfort during operation. The user would be secured in using a series of straps that would go across his/her body and tighten with the table to allow the user to safely rotate to a prone position. The horizontal support bar prevents the table from rotating further than the prone position as well as support the table while the user enters the device. The frame would be rigid and arranged to ensure the table is stable while rotation occurs.

b. The Pressure Cuff System

Figure 5: CAD model of the pressure cuff system preliminary design

This design incorporates pressure cuffs on both the leg restraints and the chest restraints to provide comfort and security for the user. The restraints would act similar to blood pressure cuffs and would inflate via a series of connected rubber bladders to various pressures. The leg restraints would be mounted to the wheelchair using the existing peghole for the current leg restraints to allow them to be removable and alleviate the need for permanent mounting on the wheelchair. The two leg restraints would be mounted onto a bar that would fit in the peghole, but each restraint would be completely enclosed, similar to how pictured in Figure 5 above. The restraints would only encompass a portion of the lower leg, from slightly below the knee to below the middle of the lower leg, and would be large enough the user could lower their entire foot through the opening while deflated for ease of use. The chest restraint would be secured to the chair using a strap that would encompass the back of the chair and would fit through the rear of the chest restraint. The restraint would be able to open to allow the client to enter the wheelchair and then would close via tightening a strap across the restraint. Due to the maximum angle of standing the client can reach within his wheelchair, the chest restraint will not have to bear as robust a load as the leg restraints and is more in place for added comfort and support during operation of the chair. The system would inflate with a portable air compressor that would be secured to the chair, and would be controlled by a panel of buttons located within arms reach of the user. The inflation and deflation would be adjusted by the buttons that would be connected to a microcontroller to allow variability in the level of inflation the user would like.

c. The Roller Coaster System

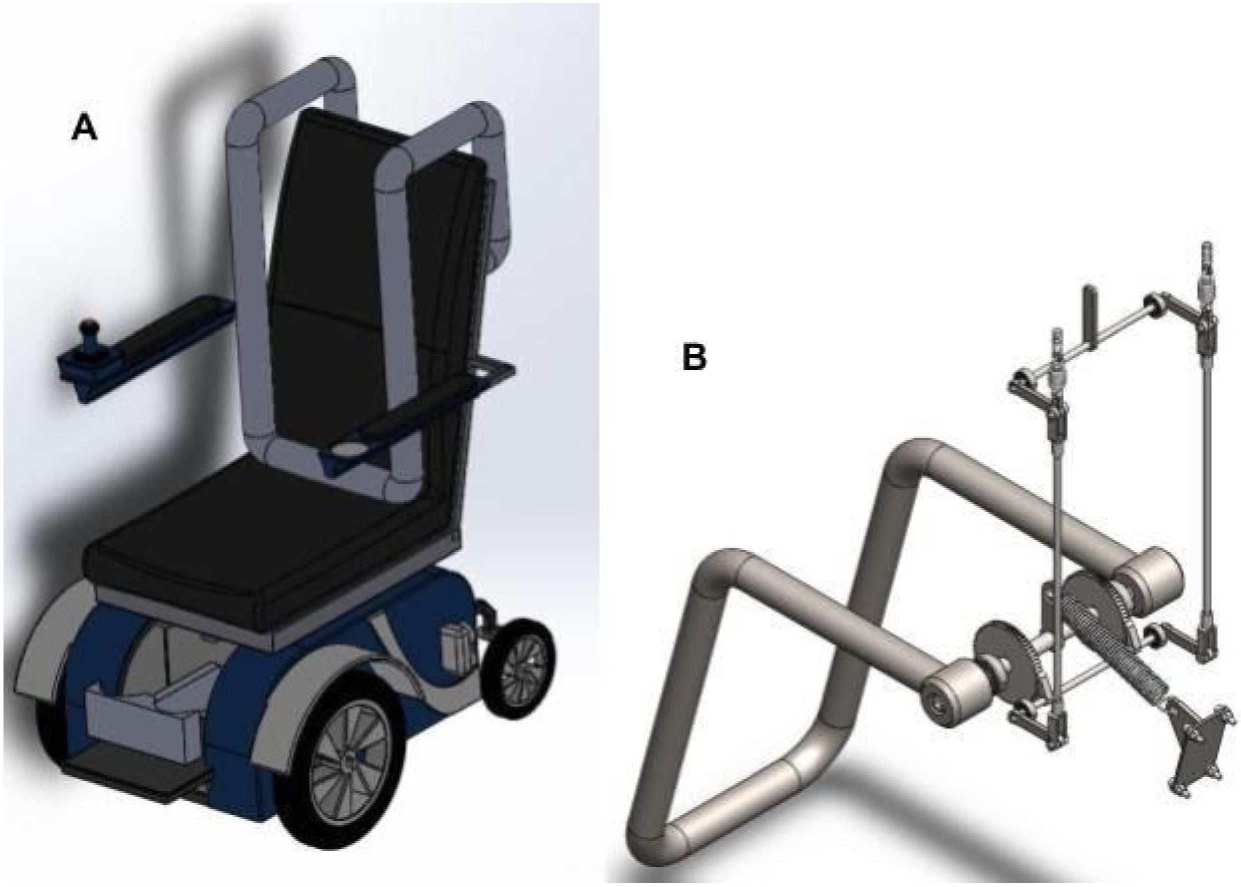

Figure 6: A) CAD model of the roller coaster system preliminary design. **B)** Ratchet system similar to what the chest restraint would utilize [14].

The Roller Coaster design consists of a system that is similar to the restraints on the "SUPERMAN: Ultimate Flight" ride at Six Flags Great America seen in Figure 7. As the over-the-shoulder restraint is pulled down tight to the user’s body, the leg restraints would simultaneously fold out from in between the legs to a position over the legs to prevent them from falling away from the chair. This synchronous, linked system would create a much easier restraint system for the user, as they would only need to worry about the upper restraint. The chest restraint would use a locking ratchet mechanism similar to the one shown in Figure 6B above. A lever would release the ratchet mechanism, and the spring-loaded system would return the chest restraint to resting position above the user. The leg restraints would also return flat against the bar protruding from in between the user's legs. This is a simple, well-known system that is employed on high intensity rides and attractions.

Figure 7: SUPERMAN: Ultimate flight roller coaster ride [15]

d. The Boa System

Figure 8: CAD model of the Boa System preliminary design.

This system would utilize the already existing Boa lacing system. The Boa lacing system is made up of a small button mechanism and closed loop of wire. As the button is turned clockwise, it cinches and shortens the wires, tightening the loop. To loosen the system, the button is pulled up, and the tension in the wires is released.

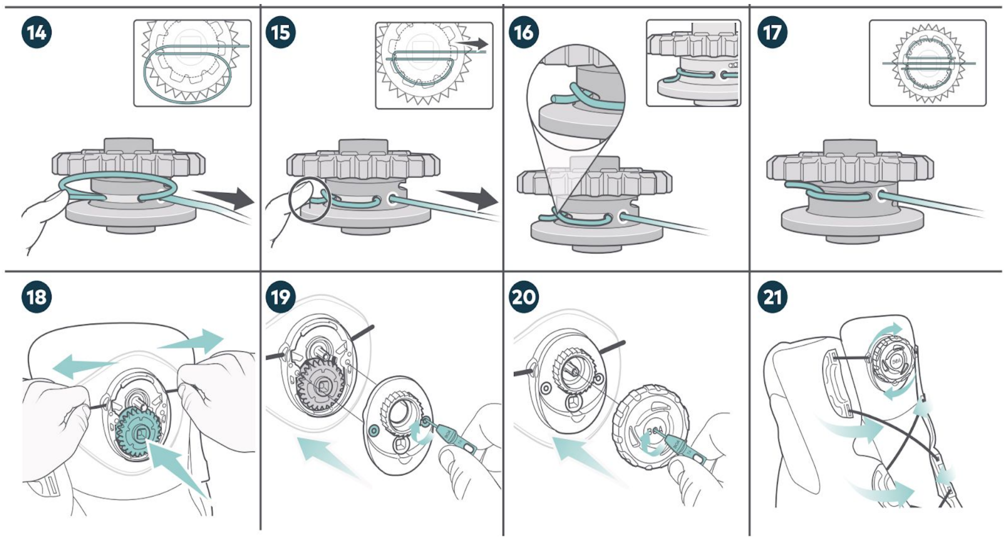

Figure 9: Example of the Boa lacing mechanism [16]

This button mechanism will be positioned within arms reach of the user on the wheelchair, and they can tighten the restraints to the desired setting. In a similar manner to the pressure cuff design, the leg restraints would use the existing support holder in the wheelchair to secure the support to the chair. Each restraint would be completely enclosed, but the Boa System would be connected between the two restraints for ease of use. The restraints would only encompass a portion of the lower leg, from slightly below the knee to below the middle of the lower leg. While the Boa System is completely released, the gap in the restraint would be large enough the user could lower their entire foot through. In order to acclimate to SMA patients with less dexterity and strength, a lever will be added to the button mechanism to give the user extra leverage when turning the mechanism.

IV. Preliminary Design Evaluation

a. Design Matrices

i. Adaptation vs. Inversion Design Matrix

Table 1: Design matrix comparing a standing wheelchair adaptation and inversion table against the following criteria.

Design Criteria	Standing Wheelchair Adaptation 	Inversion Table 
Safety (25)	20	15
Independence/Autonomy (20)	20	4
Ease of use (15)	12	6
Cost (15)	12	3
Comfort (15)	12	9
Stability(10)	8	6
Total (100)	84	43

Justification of Criteria

The first design matrix compares the idea of a standing wheelchair adaptation to the stand alone inversion table design.

Safety: The primary objective of this design is to create safe space for a user to be able to move/stand. For this reason, safety was weighted as the highest priority. The inversion table is a stand-alone device that will be flipping the user upside down while only being held by restraint straps. This puts the user in a higher risk of injury. The standing wheelchair adaptation is already built safely for the user and the adaptations to the wheelchair should only increase the safety of the wheelchair. Therefore, the standing wheelchair adaptation was thought to be more safe.

Independence/Autonomy: One of the client's biggest requirements was that this design be usable by him independently, so independence and autonomy were weighted the second highest. With the complexities of the inversion table design, the team thought the user may need a second person to help position the restraints to ensure the user is safe while using the design. The client is unable to use the standing function of his wheelchair by himself, but a wheelchair adaptation, such as a restraint system, will give him that option. Therefore, the standing wheelchair adaptation was graded higher than the inversion table.

Ease of Use: SMA patients have limited dexterity and strength, and because of this, the design must be easy to use. An adaptation on a wheelchair the user is already comfortable using will be much more comprehensive than a new, stand-alone device such as the inversion table. The standing wheelchair adaptation scored much higher than the inversion table.

Cost: The client gave the team a budget of approximately $2000 to work with. This is a number the team tried to stay under as much as possible. Therefore, a stand alone device that uses high torque motors and a microcontroller to control movement is relatively expensive compared to an addition to a standing wheelchair. A rough estimate of the cost of the inversion table ran up to approximately $720, compared to an adaptation that at most, cost less than \$500. These are only estimates, however the standing wheelchair adaptation is estimated to cost less and therefore, received a higher score.

Comfort: This device will be used multiple times throughout the day over a period of approximately eight hours and comfort is necessary for the user. The inversion table will use an ergonomic padding that will fit around the user. However, when inverted, the full weight of the user will be on the straps across their body and could become uncomfortable. The standing wheelchair is already designed for the user to be either sitting or standing for multiple hours at a time. The added restraints will have padding to ensure the user is not uncomfortable while tightening the restraints. Therefore, the standing wheelchair adaptation and inversion table were scored a 12 and 9 respectively, with the standing wheelchair adaptation being slightly higher.

Stability: Stability refers to the ability of the design to fix the user firmly to the device. Neither design was thought to be perfect, however, the wheelchair adaptation was graded slightly higher due to it being a small addition to an existing, functional device instead of completely stand alone. The inversion table idea is putting the user in a different position than the original idea was designed for, this could create stability issues.

ii. Chest Restraint Design Matrix

Table 2: Design matrix comparing the three proposed systems to implement for a chest area restraint against the following criteria.

Design Criteria- Chest Restraint	Boa System 	Pressure Cuff 	Roller Coaster Harness 
Safety (25)	25	20	25
Ease of Implementation (20)	20	16	12
Ease of use (15)	15	12	15
Cost (15)	15	12	6
Comfort (15)	12	15	9
Stability(10)	10	10	10
Total (100)	97	85	77

Justification of Criteria

The second design matrix evaluates the wheelchair adaptation designs being implemented as chest restraints.

Safety: The number one priority for this project is to design a system that can be used autonomously by the client in a safe manner. Therefore, the team ranked safety as the highest priority as any aspect of the design that puts the client at risk will not allow for autonomous use, as well as put the client in harm's way. The Boa system and the roller coaster harness earned the highest ratings in terms of safety because the Boa System is already used in heavy duty, high force and impact situations such as snowboarding. In terms of the roller coaster harness, the restraint provided by this is well known and used widely for the purposes of restraining people in a roller coaster, that exhibits a wide array of forces in all directions, and the design of such a restraint accounts for all of these factors. Therefore, this system appears to provide ample safety for the client.

Ease of implementation: Ease of implementation refers to the team's ability to implement the design and accounts for the necessary fabrication steps. A maximum rating means that the team has a good conceptual idea of how that system would be implemented into the final design, and the design is well within the team's ability to fabricate. The Boa System received a maximum score for this category because the team found detailed steps of how to put together a system, and overall it is a simplistic design that involves force of tension in stainless steel wires. In terms of the roller coaster system, this earned the lowest score because this system is the most difficult to implement in regards to the complexity of the fabrication process and the machining steps required to build the design.

Ease of use: This design matrix criterion refers to the client's ability to easily use the design for its intended purpose. The Boa System and roller coaster harness earned the maximum scores in this category. The Boa System implementation allows the client to tighten the chest restraint using the circular button. In terms of the roller coaster system, this criterion was evaluated with the thought that the client would reach up to pull the harness over his chest, similar to what is done by roller coaster riders. However, the team was able to meet with the client in person after the design matrix had already been evaluated, and the team developed a much clearer understanding of the client's limitations afterwards. The team recognized that it would be nearly impossible for the client to be able to reach above the shoulders to pull the harness down. As a result, the team would need to implement an electrical component that does this at the press of a button. This does not change the ease of use rating for the design, as this new implementation would account for the client simply pressing a button to bring the chest restraint down, and also pressing a button to release the restraint when ready to get out of the standing wheelchair.

Cost: Cost is an important factor to consider as the client has established a budget of $2000. The Boa System earned the maximum rating for cost because the component pieces to put together the Boa System are relatively inexpensive with the following cost breakdown: Boa components $10, nylon webbing $27, padding $10. These are the requirements for the chest constraint, and for the leg constraint the only additional cost would be a fracture boot for $55. Overall, these components in total are well within the budget and allow for extra components to be ordered for the purposes of testing. The pressure cuff system received a slightly lower score, as this system requires additional components that are at a higher cost. The roller coaster design earned the lowest rating for cost, as the increased complexity of the components would drive up the cost, as many would have to be outsourced for fabrication.

Comfort: The device must be comfortable for the client to use because it may be used numerous times throughout the day. The pressure cuff earned the highest rating because of the slight variability that is inherent to the design. That variability allows for the client to be set the inflation of the rubber bladders to the most comfortable setting. The other designs ranked slightly lower due to the lesser ability to customize the fit around the client.

Stability: This design criterion refers to the design's ability to fix the client firmly to the standing wheelchair. All 3 categories earned the maximum rating for this category because they are all building off of the standing wheelchair, and no individual design provides an advantage over the others.

iii. Leg Restraint Design Matrix

Table 3: Design matrix comparing the three proposed systems to implement for a chest area restraint against the following criteria.

Design Criteria- Leg Restraints	Boa System 	Pressure Cuff 	Roller Coaster Harness 
Safety (25)	25	20	25
Ease of Implementation (20)	20	16	12
Ease of use (15)	9	9	12
Cost (15)	15	15	6
Comfort (15)	12	15	12
Stability (10)	10	8	10
Total (100)	91	83	77

Justification of Criteria

The third design matrix evaluates the wheelchair adaptation designs being implemented as leg restraints.

Safety: Safety is the most important criteria for the client, as the device must be operable safely and autonomously by the client. The Boa System and roller coaster designs earned the highest rating for the safety category, as they provide a restraint mechanism that has proved to be sustainable in high force and high impact situations that go beyond the forces and impact that the final design will encounter.

Ease of implementation: The Boa System earned the highest rating out of the designs for this criterion because of its simplistic design and existing instructions on how to implement the device. The roller coaster design provides the most difficult implementation, as it requires the leg restraints to be integrated with the overhead restraint. This ensures the client does not need any additional controlling to trigger the leg restraint to come into place other than bringing the overhead restraint into position.

Ease of use: The roller coaster system won the highest rating in this category because it does not require the client to do anything to put it into place; this will automatically happen as the chest restraint is brought into position. The Boa System requires the client to either bend down to tighten the Boa System, or use a lever attached to a system that brings the cable up to the client's reach to tighten it. Either way, this is more than what is required for the roller coaster system.

Cost: The Boa System is the least expensive design due to the key components required being inexpensive. The pressure cuff requires additional components that are slightly more expensive than the Boa System. The roller coaster system requires the most expensive components, and thus earned the lowest score of the 3 designs.

Comfort: The pressure cuff system provides the highest level of comfort as it would allow the client to customize the level of inflation of the rubber bladders so that it is as comfortable. The other systems earned lower scores due to the lack of customization in comparison to the pressure cuff system.

Stability: Both the roller coaster system and the Boa system earned the maximum scores for this category as both are able to fix the user to the chair very well and pose no risks in doing so successfully. The ability to customize the pressure of the restraint leaves some lack in stability for the pressure cuff system resulting in it earning a lower score than the other two systems.

b. Final Design

i. Chest Support

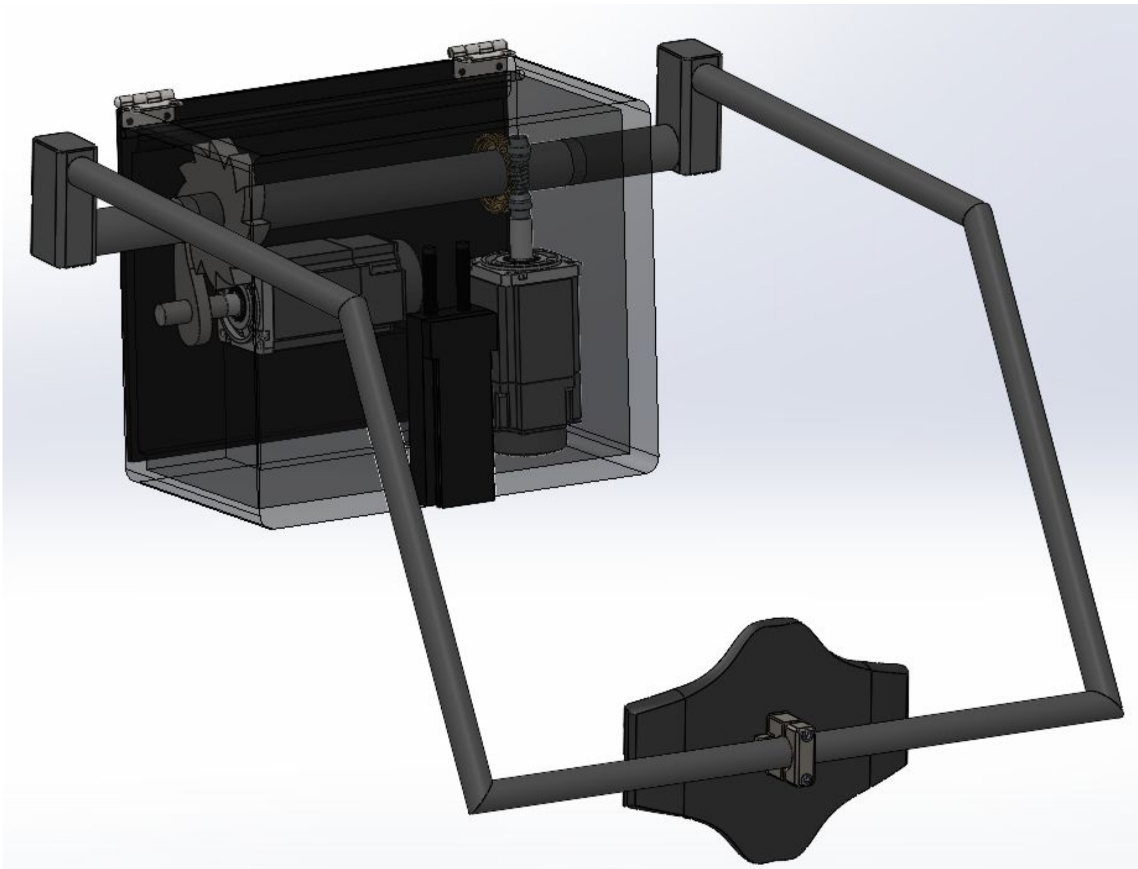

Figure 10: CAD model of the final design chest support component

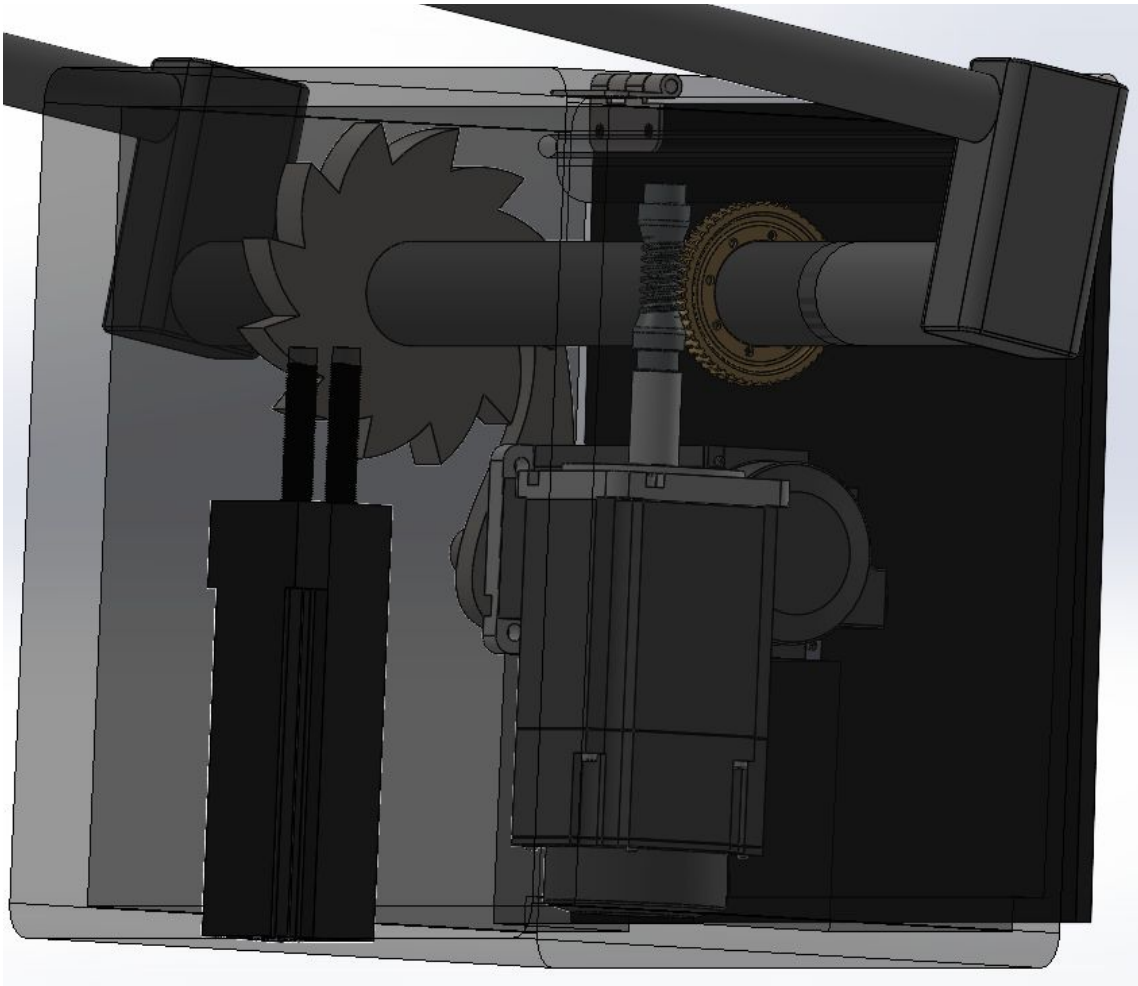

Figure 11: CAD model of the final design chest support from a zoomed in perspective

The final design is split into two main devices, the chest support and the leg support, that work together to secure the client in the wheelchair. The chest support is modeled after a roller coaster's support system, where a padded, metal bar comes over the shoulders of the client and secures them into place. When rotated into position, the bar is located at the same position as the manufacturer included chest support. The pad is secured to the overhead bar by a clamp that is mounted to the back of the pad, and is tightened with two bolts. The pad's position and angle are adjustable to ensure comfort for the user. The active components within the box are two servo motors, one a 360 degree, continuous servo motor and one a 180 degree, non-continuous servo motor. The continuous servo motor is the motor responsible for driving the overhead bar by using a worm gear/worm drive system. The worm gear is mounted onto the overhead bar and the worm drive is attached to the servo motor, with the two components's axes of rotation perpendicular. As the servo motor rotates, the worm drive rotates, this drives the worm gear, causing the bar to rotate. For each full rotation of the worm drive, the worm gear rotates by one single tooth, this increases the torque applied greatly and prevents backdrive of the bar in static conditions. To provide additional security during dynamic conditions, a ratchet locking mechanism is also used to prevent backdrive. There is a ratchet gear secured to the overhead bar that has one direction of rotation prevented by a pawl. The pawl is controlled by the 180 degree servo motor, rotating it's position to allow or prevent movement. When the locking mechanism is active, the pawl is rotated into position, blocking the ratchet gear from rotating backwards, but still allows forward rotation into the securing position. The motors are controlled by a nucleo microcontroller that uses pulse wave modulation signaling to control the position of the motors from user inputs. To rotate the bar, the user presses a button located on the arm rest, and the nucleo responds to the signal with the respective bar action or inaction.

ii. Leg Support

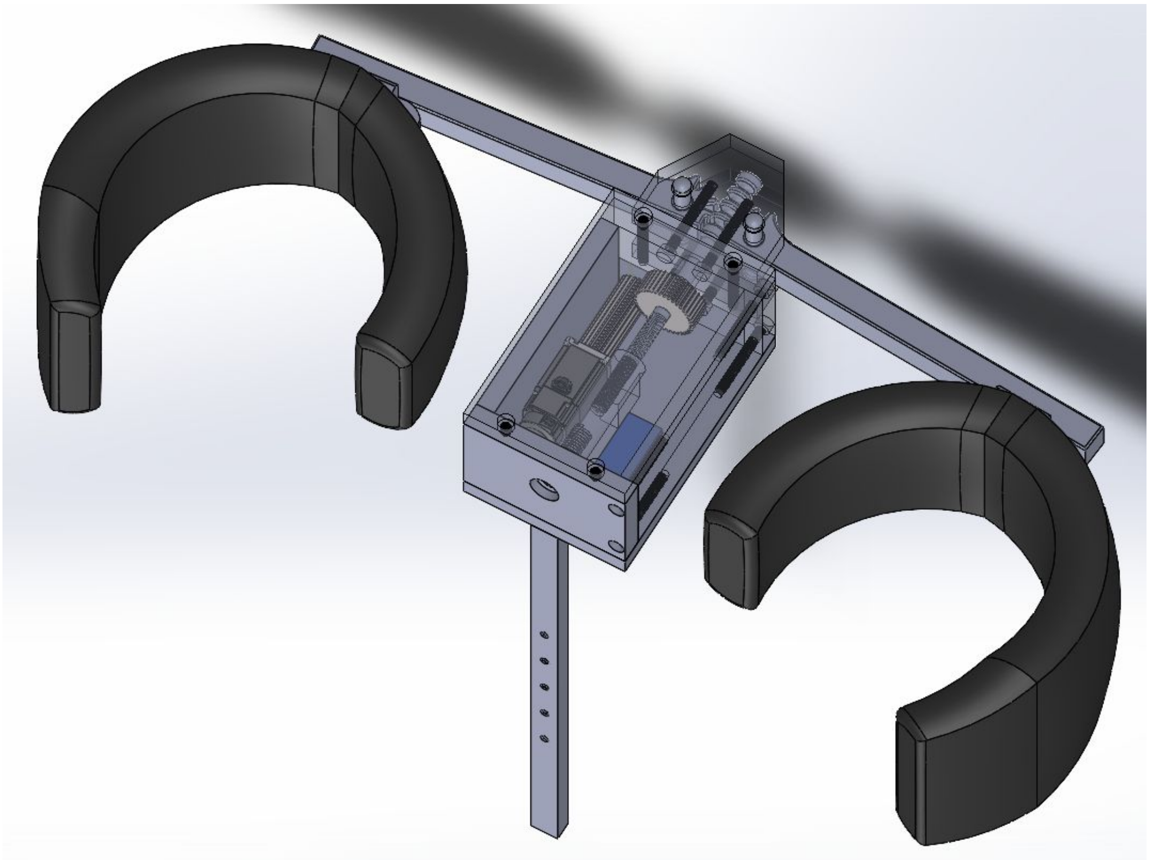

Figure 12: CAD model of the final design leg support component

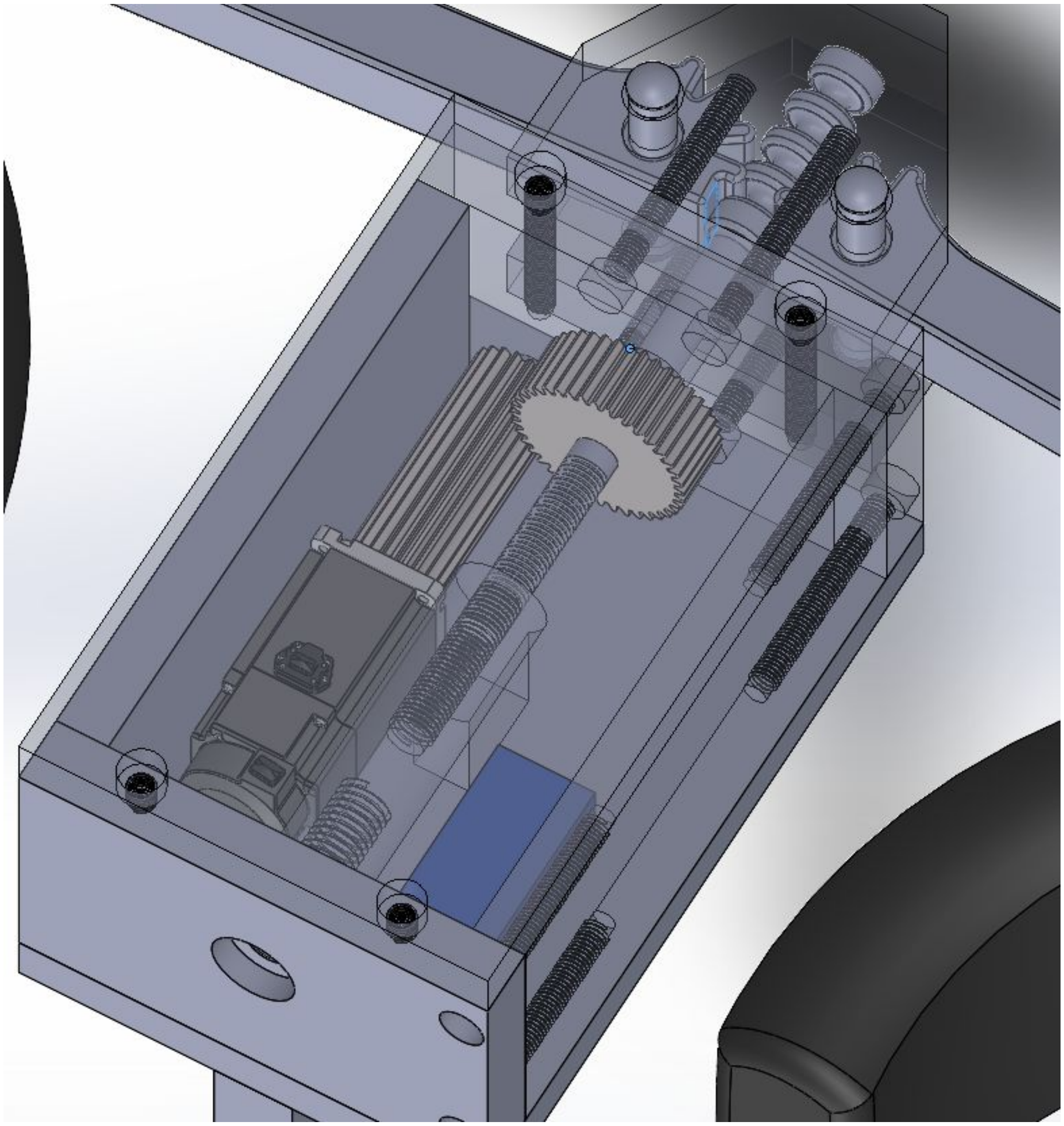

Figure 13: CAD model of the final design leg support from a zoomed in perspective

The leg support of the final design utilizes a driven rack and pinion system to reposition the support arms based on the user's needs. The leg support mechanism is modeled after a winged corkscrew mechanism where movement of the center bolt causes the arms to rotate in the opposite direction. When the client uses the device to secure themself, the support pads will end up in the same position as the manufacturer included supports. The pads on the support arms are held in place by a clamp with threaded bolts, allowing the pad's position to be adjusted. The support arms are mounted to the front of the leg support via pins through the support. The support arms have a series of teeth extending, that interlock with the threaded bolts's grooves, forming the rack and pinion system. The threaded bolt has a gear mounted to its middle region, and the lower end is threaded into a threaded support mounted to the back wall of the main compartment. The continuous servo motor drives a section of gear stock that is interlocked with the gear of the threaded bolt. When the mechanism is driven, the bolt is threaded into or out of the threaded hole, depending on the direction of the servo motor. As the threaded bolt moves toward the chair, the arms are rotated to extend outward, allowing the client to enter and exit the wheelchair. When the threaded bolt moves away from the chair, the arms are rotated into their position and secure the user. The leg support servo motors are also controlled using PWM signaling that is generated from user inputs measured by the nucleo microcontroller. To rotate the support arms, the user presses a button located on the arm rest, and the nucleo responds to the signal with either threading or unthreading the bolt to rotate the arms.

iii. Nucleo Code

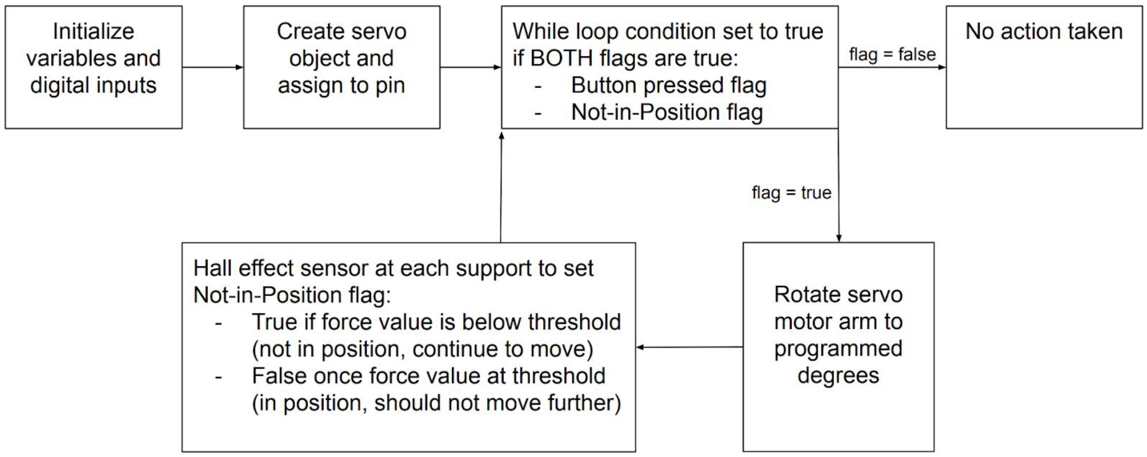

Figure 13: This code flowchart gives an overview of the steps taken in the code.

The code first initializes a boolean variable that tracks the positioning of the support. This boolean is set to true or false based on a hall effect sensor. The hall effect sensor will set boolean inPosition to true when the sensor reads that the support is in restraining position. The boolean will be set to false once the support is in the at rest position, behind the client's wheelchair. Based on the positioning of the support (in restraining position or at rest position) and whether the forward or backward buttons are pressed, will allow the support to move. The forward and backwards buttons are the digital inputs initialized at the beginning of the code. If the inPosition flag is set to true, and the forward button is pressed, then only the support will move from restraining to at rest. If the inPosition flag is set to false, and the backward button is pressed, then only the support will move from at rest to restraining. The servo motor arm is moved using the position() function, that is defined in the "servo.h" library.

V. Fabrication/Development Process

a. Materials

i. Chest Restraint Materials

The 80/20 extrusions are 20 mm x 20 mm profiles used for the framework of the design. The profile has a T-slot shape making it lightweight, as well as easy to fabricate. The extrusions are used for creating the chest restraint and box. The T-nuts used throughout the design can slide into the ends of the 80/20 extrusions. Five millimeter diameter screws are tightened into the T-nutes, securing L-brackets and angled connectors into place. These L-brackets and angled connectors are used to connect the chest restraint extrusions together. The L-brackets are also used to attach the extrusions of the box into place anywhere a 90 degree angle is formed. A steel sheet will be secured onto the framework, creating the backbone of the client's chest pad. Padding will be added to the steel sheet or other areas that may interfere with the client's body, ensuring maximum comfort. For the shaft assembly, a 20 mm x 500 mm shaft is needed in order to press fit the gears and bearing. The motors will power these gears and turn the shaft, ultimately rotating the restraint to an open or closed position. The worm drive system materials were selected to maximize the power transmission from drive to gear via friction. The cam gear, working as part of the ratchet system, is composed of hardened carbon steel, that helps reduce the wear the gear teeth undergo during loading. This is used to prevent back drive of the chest restraint. The bearing is used to hold the shaft up, while still allowing rotation of the shaft. A plastic or similar material will be used to cover the framework on all sides of the box. The plates will be customized, based on the color preference of the client. The 360 degree servo motor is a high torque continuous motor that is capable of driving the system by rotating the worm drive to turn the worm gear. The two hinges, as well as the latch and catch, will be used for closing the top plate shut onto the rest of the box. This will allow for easy serviceability. Appendix B can be seen for a material breakdown, description, and cost.

ii. Leg Restraint Materials

The leg support has a number of components and materials that are involved in its design. The leg support box, the leg support rod, the threaded bolt, and the support arms are all composed of steel plates. Steel was selected for it's material strength, corrosion resistance, and manufacturability, that all meet the design requirements. The leg pad base will be composed of a high density foam with the cover having gel inserts within a fabric cover. The high density foam and gel padding will help provide comfort and security for the user while operating the device. The gear mounted on the servo motor is fabricated from a length of carbon steel gear stock. The gear mounted on the threaded bolt is composed of brass. The material the gears are composed from is highly wear resistant and utilized specifically for applications such as this. The 360 degree servo motor is a high torque continuous motor that is capable of delivering a high enough torque to drive the system, with a factor of safety of two assumed. The one 180 degree servo motor is a servo motor with high enough torque to prevent backdrive of the ratchet system and rotate the shaft. The microcontroller selected for the project is a nucleo F303K8 due to its software capabilities and small size that allow it to be placed within the leg support. Appendix B can be seen for a material breakdown, description, and cost.

b. Methods

i. Chest support Fabrication

The chest support fabrication method can be broken down into a variety of assemblies, beginning with the chest support framework. The chest support extrusions should be cut to size. The extrusions that meet on an angle can be attached by an angled connector. The extrusions that meet at a 90 degree angle can be connected by a T-nut, L-bracket, and screw. The chest support pad will need to be machined to the client's desired design. Once it is secured into place, padding will be added for additional comfort. The shaft assembly should be created next. A flat will be milled on both ends of the cylindrical shaft. The pillow block bearings, cam gear, and worm gear will be press fit onto the shaft. For the side frames, the necessary extrusions are cut to size. Using the T-nut, L-bracket, and screws like before, the structure can be created. The side frames can then be connected to the bottom extrusions. Plates will then need to be added onto the framework to close it off. The bottom plate can be cut to size and then secured into place with screws, and preexisting T-nuts. The ratchet system and worm gear system will connect the gears to their motors, that will be mounted to the bottom of the box. The pillow block bearings will then be secured onto the side frames with T-nuts, washers, and screws. The shaft assembly can then be adjusted by height and rotation, as needed, in order to engage the gears. Power and electronics needed for running the motors will be connected. The side frames can then be connected to the top extrusions to finish the framework of the box. The front and back plates can be secured with T-nuts and screws. A hole should then be drilled on each side plate to fit the bearing. The side frames and top frames can then be assembled onto the framework. Two hinges, as well as a latch and catch can be mounted onto the top plate. The box should be fully assembled at this point and then can be mounted to the back of the wheelchair. As the final step, the chest support assembly can be connected to the shaft via customized connectors. A detailed step by step fabrication plan, along with labeled figures, can be found in Appendix C.

ii. Leg Support Fabrication

There are a number of components that need to be fabricated to assemble the leg support, beginning with the leg support box. The leg support plates should be cut to size and correct thickness. All but two of the plates have additional holes that need to be drilled and threaded. Once the plates have been cut and drilled correctly, the front plate, back plate, and non-drilled side plate are welded onto the base plate. The threaded support is lathed from a section of round stock, with the front and rear holes both drilled and tapped. The threaded support is secured to the back plate by threading a bolt through both components. The support bar should be cut to size and have the five threaded holes, drilled and tapped. The support bar is then welded onto the base of the leg support box. The front holder plates need to be machined to the correct dimensions and have both the through holes and the threaded holes incorporated. The front holder can be secured to the front plate with the use of 5mm x 0.8mm tap bolts threaded through the holes. The threaded bolt and support arm pieces need to be machined to the correct shape, and may require outsourcing to complete accurately. Then, machine the rack grooves, tap the opposite end of the bolt, and press fit the larger spur gear onto the middle region. A through hole will be drilled on each support arm head. Position the threaded bolt into the center hole of the front plate, and align the support arm teeth to form the rack and pinion. The threaded bolt must have the gear on the inner section of the box and is threaded into the threaded support. Once the support arms are aligned with the threaded bolt and the front holder through holes, using a nut and bolt the arms are secured to the device. The gear stock is cut to length and the center hole is drilled before mounting the stock to the continuous servo motor. The motor is placed within the support so the gears effectively interlock and transfer power. The nucleo microcontroller is secured in the back of the leg support. The electrical components are connected according to the software requirements. The side plate and top plate are secured into position adjacent to other plates using threaded bolts, beginning with the side plate. The leg pad holders are cut to size, and the threaded holes are drilled. The leg pads are fabricated to the client's specifications and the rear is attached to half of the leg pad holder. The leg pad is then mounted to the desired client position using the leg pad holders. As the final step, the nucleo circuitry is connected to the wheelchair's power source. A detailed step by step fabrication plan, along with dimensioned technical drawings, can be found in Appendix C.

c. Testing

Two testing protocols have been created to test the two components of the final design, the instrumentation and mechanical portions. The majority of testing for this device will be completed in the Spring 2021 semester after fabrication has been completed. The team was able to complete some of the testing for the code and will be able to use software to test mechanical aspects before fabricating.

The first protocol was made to test the functionality and verification of the code. The first test is to determine whether or not the code will rotate the motor in the correct direction. This test will follow a simple procedure. When the button is pressed to deploy the supports, the motor will be checked to make sure it is rotating in the correct direction. Then, the supports will be removed and the motor will be checked to determine that it is moving in the opposite direction. The next test will be to test how long the device takes to deploy and retract. This is being tested as the device should be able to move from one position to another within 30 seconds, however this is an evolving conversation that the team is discussing with the client.

The second testing protocol is aimed to verify mechanical stability, accuracy, performance, and comfortability of the entire device. The first test can be completed using SolidWorks Finite Element Analysis. This will allow the team to test force on specific parts of the chest and leg supports and receive feedback from SolidWorks. These results will then be used to create more specific tests for potential points of failure. Next, the locations of both the leg and chest supports in their deployed and relaxed positions will be measured. This test is to make sure the device does not have large variability in its final positions. This accuracy is important to ensure that the device will be effective. Finally, the team will create a user survey. The client will enter the wheelchair with the final device attached to it and deploy both supports to their restraining positions. Once supports are in their correct positions, the user will complete some of the daily activities that they would normally perform while in the wheelchair. While the user does this, verbal feedback will be given and recorded regarding comfort, range of motion for the arms, shoulders, and head, ease of use, and appearance of the device.

VI. Results

All testing procedures will be carried out in the Spring 2021 semester. Testing that only required software can be conducted once all dimensions in SolidWorks are determined and set correctly. The team expects that the FEA testing will align with the estimated problematic areas described in the Sources of Error section of the report. The code validation protocol will be tested once materials arrive and the servo motor can be connected to the Nucleo. We expect the code to work accurately and efficiently 100% of the time. This includes correct movement of the servo motor and consistent time for the device to be fully activated. This semester, the team was able to write the code and test that it compiles. Theoretically, the team can determine that the code validation testing will all meet the set standards of success.

The results expected for the Beginning and End Location test is that the range of measurements will not exceed 25 mm. The team chose this range of locations to ensure that the device will accurately support the client when in use. The expected statements being asked on the survey are not yet determined. While the team believes that the device will exceed all expectations, they are prepared to make adjustments to the device in order for the client to have a typical range of motion, easily use the device, feel comfortable while using the device, and like the esthetics of the device when mounted on the wheelchair.

VII. Discussion

a. Sources of Error

Since the team did not reach the point of testing the final prototype this semester, this section will talk about potential problematic areas that the team may face during the testing phase. The first area of concern is the friction at the pin in the leg support. If the servo motor is unable to generate enough force to overcome this friction, a higher power motor will be required. Another concern is the shearing of the pinion teeth in the rack and pinion system. This is a physical safety mechanism to ensure dynamic system stability. The shearing of the teeth within the system could be a mode of failure, so it is important to confirm that it is working as expected. The potential backdrive of the chest support bar is something else we are keeping an eye on. This poses a danger to the user if there are any occurrences of backdrive, and there is a concern that the gears may drive backwards to some extent due to the onset of the force being applied to the chest support. Another source of error may be due to the dimensions used for the calculations. If the dimensions are not exact for the client's fit, and need some changes, the calculations will need to be adjusted to maintain accuracy.

VIII. Conclusions

a. Overview

Spinal muscular atrophy is a neuromuscular condition that hinders voluntary muscle movement. This semester the team was tasked with helping the client independently achieve the sitting to standing motion. Movement is beneficial for muscle strength, bone health, flexibility, posture, and a wide range of other bodily functions. The first design the team brainstormed was a stand alone device called the inversion table. However, it lacked autonomy so the focus shifted to developing a device that could be built off the client's existing standing wheelchair. Next, the team specifically focused on altering the chest and leg constraints on the client's standing wheelchair. The second set of proposed designs were based on a Boa System, roller coaster harness, and pressure cuff. The Boa System was determined to be the most promising for both the chest and leg constraints due to its highest rank in safety, ease of implementation, and cost. However, after meeting with the client in person, the team noticed numerous limitations, like the mobility of the client and the mounting locations available on the wheelchair, that required the team to pivot and integrate multiple systems.

The final integrated system is broken into two parts: the chest support and the leg support. The chest support consists of an automated roller coaster based chest restraint driven by a worm drive. The worm drive allows for a large torque reduction at the motor and inhibits back drive to ensure the support will not open under a load. The leg support is composed of a rack and pinion system that rotates support arms holding leg pads that close tightly around the client, holding him in the chair. Both systems include multiple safety features, both mechanically on the device, and in the code.

Due to extenuating circumstances this semester, the team was unable to fabricate these devices, but instead focused on developing detailed fabrication plans for each design and creating a materials list to be ready to order parts in the future. The team also spent time devising a testing plan to assess the code, functionality of the designs, and possible failure points in each design. Generating these plans has enabled the team to have precise goals they would like to achieve in the coming semester.

b. Future Work

The next step for this project will be to fabricate the chest and leg support designs. The team spent the last month creating detailed fabrication plans for each design so that when the materials arrive, they may begin building and assembling the device. The team has also looked into upgrading their UW-Madison TEAM LAB passes to get the MIG welding pass. This will allow them to weld components themselves without having to outsource the parts and wait for the finished product. In some cases, it was found to be easier to outsource parts to save time or because the part was too complex to make. The rack and pinion system is a very complex part that will be most cost effective if outsourced. Once the materials and components arrive, the team will fabricate and assemble the chest and leg support designs.

Once fabrication is complete, testing will need to be done to ensure the devices function properly and safely. A testing plan was also written this semester in order to save time in the future. A list of tests can be seen in the Testing section above. Additional tests will be created and performed once the team can assess the most efficient way to test factors like potential failure points in a cost effective manner.

One concern of the design is the potential for the user or anyone around them to accidentally open or close the supports by bumping the buttons. The team would like to add a secondary safety measure in the code that would require the user to press the button multiple times or hold it down for an extended period. Another possible idea the team has considered is a protective covering for the buttons that would not take away from the ease of use of the design.

When meeting with the client and observing them get into their standing wheelchair, the team noticed the client's struggle to properly position their feet and legs to stay on the foot plates. The team has already started strategizing possible adaptations to the wheelchair foot plates in order to better accommodate the client. A design matrix can be seen in the Appendix F and will be evaluated and acted upon in the coming semester.

To effectively determine the positions the supports are located at, the team would like to implement a few hall effect sensors for positional sensing. Hall effect sensors measure the magnetic flux that is applied to the sensor, and output a corresponding voltage. The team could attach permanent magnets to select positions on the device, so that while in a position, the magnet is applying a magnetic field to the sensor, causing a change in the voltage measured by the nucleo. The feedback from the hall effect sensor sets the position flag to true or false in the code, ensuring the safety measures operate effectively.

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X. Appendix

A: Product Design Specifications

Product Design Specifications

Autonomous Wheelchair Support Adaptations
Updated: December 1st, 2020

Team Members:
Benjamin Lawonn - Team Leader
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Function:

The client is unable to safely enter and operate the standing wheelchair with the manufacturer included restraints. There are currently 3.3 million wheelchair users in the U.S. and within this population, there is a varying degree of upper and lower extremity mobility, ranging from full movement to none [1] . Without a large degree of mobility, many wheelchair users are unable to take advantage of the benefits of movement due to various mobility challenges they encounter.

Moving the body has many benefits for the brain, muscles, bones, joints, intestines, heart, lungs and other organs [2]. Movement is also beneficial for a number of bodily functions such as blood flow, digestion, muscle strength, and bone health [2]. Existing standing wheelchair supports enable users to enter the upright position, but they lack autonomous accessibility for the user. The restraints require strength and dexterity to position in place, that mobility limited users may not possess. The cost of hiring a CNA or licensed physical therapist is quite expensive and usually is not covered by health insurance for those affected by a permanent disability. The goal of this project is to develop a device that enables the wheelchair user the ability to secure themself within their standing wheelchair independently.

i. Client requirements:

- Wheelchair support adaptations must allow autonomous use
- Must be able to secure user while at maximum standing position

- Cannot impede entry to wheelchair via ceiling lift
- Motorized to allow straightforward implementation

ii. Design requirements:

1. Physical and Operational Characteristics

A. *Performance requirements:* The device will be used by one individual on a daily basis, multiple times a day. The device must be in its active position during the duration of operation, for up to 8 hours at a time. The device's movement will be at the beginning and end of use and must hold in the restrained position during use and in the relaxed position when not in use. The device will need to prevent the user from being ejected out of the wheelchair when enduring non-flat surfaces, too fast of acceleration, and abrupt stops.

B. *Safety:* When designing the device, the mechanical and electrical hazards that could arise must be considered. The electrical components must not shock the user, and the device must have a manual override to prevent the user from being stuck in the chair. There should be a mechanical limit switch that disconnects the circuit to prevent over-rotation. The mechanical supports cannot injure the user while entering their position, and the leg supports cannot apply an excessive force on the user while in the standing position.

C. *Accuracy and Reliability:* The chest support must enter its designated position within +/- 25mm during 99% of the total number of uses. The leg support must enter its designated position within +/- 10mm during 99% of the total number of uses.

D. *Life in Service:* This device must function for a minimum of 3-5 years with potential daily use from the end user. Each use of the device is one cycle and may have multiple cycles per day. The average lifespan of a DC brushless motor is approximately 2-4 years, or around 20,000 hours of operation [17]. The expected lifespan of a Nucleo microcontroller is 10 years in service. [18]

E. *Shelf Life:* The device must be stored in a dry environment to mitigate damage of the electrical components. Under ideal storage and usage conditions the motor should operate for a projected 3-5 years. The device microcontroller will last a projected 10 years under proper storage conditions.

F. *Operating Environment:* The device may be used in a variety of temperatures ranging from -48 °C to 46 °C[19]. The device will also encounter varying humidities ranging from 30% to 83.8% [20][21]. Various weather including, but not limited to rain, lightning, snow, hail. The device may come in contact with dirt, dust, or mud during use.

G. *Ergonomics:* The device must not impede the operation of the wheelchair by the user. Additionally, the device must not leave painful or irritating marks or scratches on the subject. Therefore, no sharp edges or points may be present in the device. The supports must provide a comfortable and secure hold on the user during operation.

H. *Size:* The device must not exceed a width of 91.5cm and a height of 203cm during usage to allow movement through a standard door frame. The leg supports must have an opening space of at least 30cm of length and 12.5cm in width to allow the users feet to enter unimpeded.
I. *Weight:* The chest support and motor must not exceed a combined weight of 22.5kg to ensure the wheelchair will not tip over while the support is at rest. The leg support must not weigh more than 9.0kg to ensure the support can be removed if necessary and does not weigh excessively.
J. *Materials:* The device will be fabricated using aluminum or stainless steel due to the materials' properties and corrosion resistance. DC brushless motors will be used for powered components due to their longevity and performance. The Nucleo microcontroller will be used due to the longevity and simplicity of code implementation.
K. *Aesthetics, Appearance, and Finish:* The device's appearance must not stand out from the wheelchair it is attached to in order to be indistinguishable from the wheelchair. The device must be a neutral color and must not protrude excessively past the existing bounds of the wheelchair. The device's finish must be minimal to reduce attention drawn to the device.

2. Production Characteristics

A. *Quantity:* One device should be constructed for testing and usage purposes for the client.
B. *Target Product Cost:* The device should cost under the $2000 specified budget.

3. Miscellaneous

A. *Standards and Specifications:* Currently, there are no specific OSHA standards for a device similar to this. There are standards for safe patient handling and transferring that should be enforced when the client is moving from his chair to the device [22]. These standards also include solutions to maintain a safe environment for a patient. The FDA regulates medical devices that individuals use in their homes. This device would fall under the FDA's definition of a medical device, which states a medical device is "an instrument, apparatus, implement, machine ... or accessory which is … intended to affect the structure or any function of the body of man or other animals" [23]
B. *Customer:* The customer wishes to have a product that can increase his movement and blood flow. He wishes to autonomously operate his standing wheelchair to achieve an upright standing position. He does not like the feeling of being in the same position seated for a majority of the day, and hopes the design reduces that problem. The device must effectively operate over an extended period of time.
C. *Patient-related concerns:* The client and potential future users will need to be able to access the device using a ceiling lift or hoyer lift.
D. *Competition:* There are currently no devices on the market that fulfill the client's needs to autonomously implement the standing wheelchair restraints. The manufacturer included

restraints for the client's standing wheelchair secure the client in the chair, but lacked accessible controls for the client [24].

B. Material List

https://docs.google.com/spreadsheets/d/1YU2XxSeqkCOopelrGDzKCcGSy7Bj1SEvbfpkJvp7Jc0/edit?usp=sharing

Chest Restraint	Part Number	Description	Seller	Price	**Qty**	**Price x Quantity**	Link
Worm Gear							
Metric Worm Gears	57545K784	Metal Worm Gear, Bronze, 1.5 Module, 80:1 Speed Ratio	McMaster-carr	$76.68	1	$76.68	https://www.mcmaster.com/57545K784/
Worm							
Worm with round bore	57545K631	Steel Worm, 1.5 Module, 8 mm Shaft Diameter, 1 Start	McMaster-Carr	$23.47	1	$23.47	https://www.mcmaster.com/57545K631/

Chest restraint ratchet and pawl (cam gear)							
Ratchet and pawl system	6283K79	Metal Ratcheting Gear, 15 mm Face Width, 40 Teeth, 15mm Overall Width	McMaster-Carr	$59.91	1	$59.91	https://www.mcmaster.com/6283K79/
Motor for ratchet system							
Servo - Generic High Torque (Standard Size) ROB-11965 ROHS	ROB-11965	Digital Servo High Torque Gear High Torque, Control Angle 360° High Rotation, 20KG	SparkFun	$12.95	1	$12.95	https://www.sparkfun.com/products/11965
Motor for worm drive							

YANSHON Digital Servo High Torque Gear High Torque, Control Angle 360° High Rotation, 20KG	TD-8120MG	30 Kg-cm torque, 360 degree continuous servo motor	Amazon	$25.99	1	$25.99	https://www.amazon.com/Readytosky-Digital-Degree-Torque-Helicopter/dp/B07Z3VGZNP/ref=sr_1_3?dchild=1&keywords=360%2Bdegree%2Bhigh%2Btorque%2Bservo%2Bmotor&qid=1607420755&s=toys-and-games&sr=1-3&th=1
Extrusions							
20mm X 20mm T-Slotted Profile - Four Open T-Slots	20-2020	20mm x 20mm metric 20 series square T-slot profile with four	80/20 Inc	$0.16	276 in	44.16	https://8020.net/20-2020.html

		open T-slots					
T-nut							
M5 Slide-in Economy T-Nut Block	14122	The slide-in economy T-nut block is a fastening option that loads from the profile ends	80/20 Inc	$0.21	90.00	$18.90	https://8020.net/14122.html
Silver L-bracket							
20 Series 2 Hole - Inside Corner Bracket	20-4119	The 2 hole - inside corner bracket is an external fastening method that creates a 90 degree connection.	80/20 Inc	$2.85	22.00	$62.70	https://8020.net/20-4119.html
Screws							

Screws for T-nuts	13-5310	M5 x 10.00mm Button Head Socket Cap Screw (BHSCS)	80/20	$0.24	90.00	$21.60	https://8020.net/13-5310.html
Shaft							
Rotary Shaft	1482K36	1566 Carbon Steel, 20 mm Diameter, 500 mm Long	McMaster-Carr	$22.11	1.00	$22.11	https://www.mcmaster.com/1482K36/
Pillow Block Bearing							
Dry-Running Mounted Sleeve Bearing	2820T59	20 mm Shaft Diameter	McMaster-Carr	$35.87	2.00	$71.74	https://www.mcmaster.com/2820T59/
Washer							
Washer for pill block bearing	13-6040	5.39mm ID Washer	80/20 Inc	$0.25	4.00	$1.00	https://8020.net/13-6040.html
Screws for							

pillow block bearing							
Screws for pillow block bearing	13-5320	M5 x 20.00mm Button Head Socket Cap Screw (BHSCS)	80/20 Inc	$0.31	4.00	$1.24	https://8020.net/13-5320.html
Hinge							
20 Series 2 Hole - Standard Plastic Hinge	12075	The 2 hole - standard plastic hinge is made of fiberglass-reinforced black nylon with a stainless steel pin.	80/20 Inc	$2.55	2.00	$5.10	https://8020.net/12075.html
Latch and catch							
Double ball catch	12019	The double ball catch is comprised of a	80/20 Inc	$8.30	1.00	$8.30	https://8020.net/12019.html

		latch and a striker made of molded black fiberglass-reinforced nylon.					
Chest Pad Bracket							
20 Series 6 Hole - Rectangular Flat Plate	20-4166-Black	The 6 hole - rectangular flat plate is an external fastening method that requires no machining services.	80/20 Inc	$6.26	1.00	$6.26	https://8020.net/20-4166-black.html
Padding							
Super-Cushioning Ultra-Conformable Foam Sheet	86195K87	The foam allows for comfort by the user.	McMaster-Carr	$25.59	1.00	$25.59	https://www.mcmaster.com/86195K87/

Plastic Wall Sheets							
HDPE Panel: 4.5mm Thick, Black	65-2652	High density polyethylene (HDPE) panels are a strong, corrosion resistant option that provides durability and resists warping.	80/20 Inc	$36.60	1.00	$36.60	https://8020.net/65-2652.html
Bar Stock for Connectors							
Multipurpose 6061 Aluminum	9146T77	20 mm x 20 mm aluminum stock	McMaster-Carr	$11.21	1 ft	11.21	https://www.mcmaster.com/9146T77/
Flat Plate							
20 Series 4 Hole - Straight	20-4117-Black	The 4 hole - straight flat plate is	80/20 Inc	$5.50	2.00	$11.00	https://8020.net/20-4117-black.html

Flat Plate		an external fastening method that requires no machining services.					
Leg Restraint	Part Number	Description	Seller	Price	**Qty**	**Price x Quantity**	Link
Leg Restraint Gears (on motor)							
Gear rod stock	6847K11	32 pitch, 20 Teeth, 0.375" Pitch D, 1ft L, 1215 Carbon Steel	McMaster-Carr	$30.88	1	$30.88	https://www.mcmaster.com/6847K11/
Leg restraint Gears (on thread							

ed bolt)							
Metal Gear with Round Bore	7880K35	Metal Gear - 20 Degree Pressure Angle, Round Bore, 32 Pitch, 40 Teeth, 1.25" Pitch D	McMaster-Carr	$32.18	1	$32.18	https://www.mcmaster.com/7880K35/
Microcontroller							
NUCLEO-F303K8	497-15981-ND	STM32F303K8, mbed-Enabled Development Nucleo-32 STM32F3 ARM® Cortex®-M4 MCU 32-Bit Embedded Evaluation Board	Digi-Key	$10.99	1	$10.99	https://www.digikey.com/en/products/detail/stmicroelectronics/NUCLEO-F303K8/5428805?s=N4IgTCBcDaIHYFcDGAbApgewAQDMDMADHgNYAcIAugL5A

Motor for gear system							
Readytosky Digital 30KG Servo 360 Degree High Torque Metal Gear Servo Motor with 25T Servo Horn for RC Car Robot Arm Helicopter	TD-8120MG	Digital Servo High Torque Gear High Torque, Control Angle 360° High Rotation, 20KG	Amazon	$25.99	1	$25.99	https://www.amazon.com/Readytosky-Digital-Degree-Torque-Helicopter/dp/B07Z3VGZNP/ref=sr_1_3?dchild=1&keywords=360%2Bdegree%2Bhigh%2Btorque%2Bservo%2Bmotor&qid=1607420755&s=toys-and-games&sr=1-3&th=1
Limit swtich for leg and chest restraints							

SS-3GLP Limit Switch	SW764-ND	SWITCH SNAP ACTION SPDT 3A 125V	Digi-Key	$1.31	4	$5.24	https://www.digikey.com/en/products/detail/omron-electronics-inc-emc-div/SS-3GLP/664725?utm_adgroup=Switches&utm_source=google&utm_medium=cpc&utm_campaign=Dynamic%20Search&utm_term=&utm_content=Switches&gclid=CjwKCAiA8Jf-BRB-EiwAWDtEGv-V_jmsXK9r1wm4YvXYh86IL7uMP97eQ7sVNdvbRSrWAQZOVxU5DxoCSqMQ

							AvD_BwE
Total Price						$651.79	

C. Fabrication Plans

Solidworks drawings of components for leg restraints

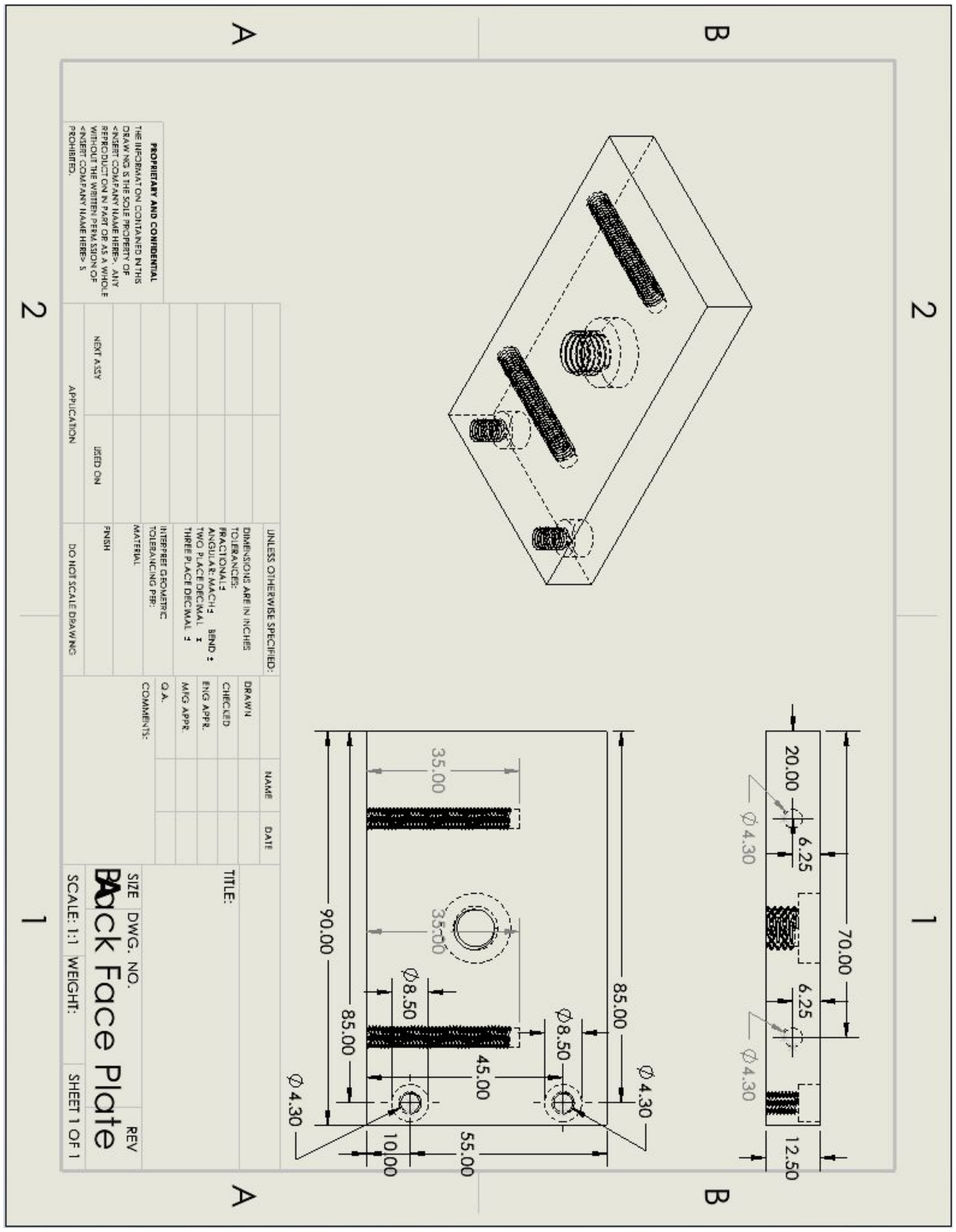

Figure 14: Back face plate drawing

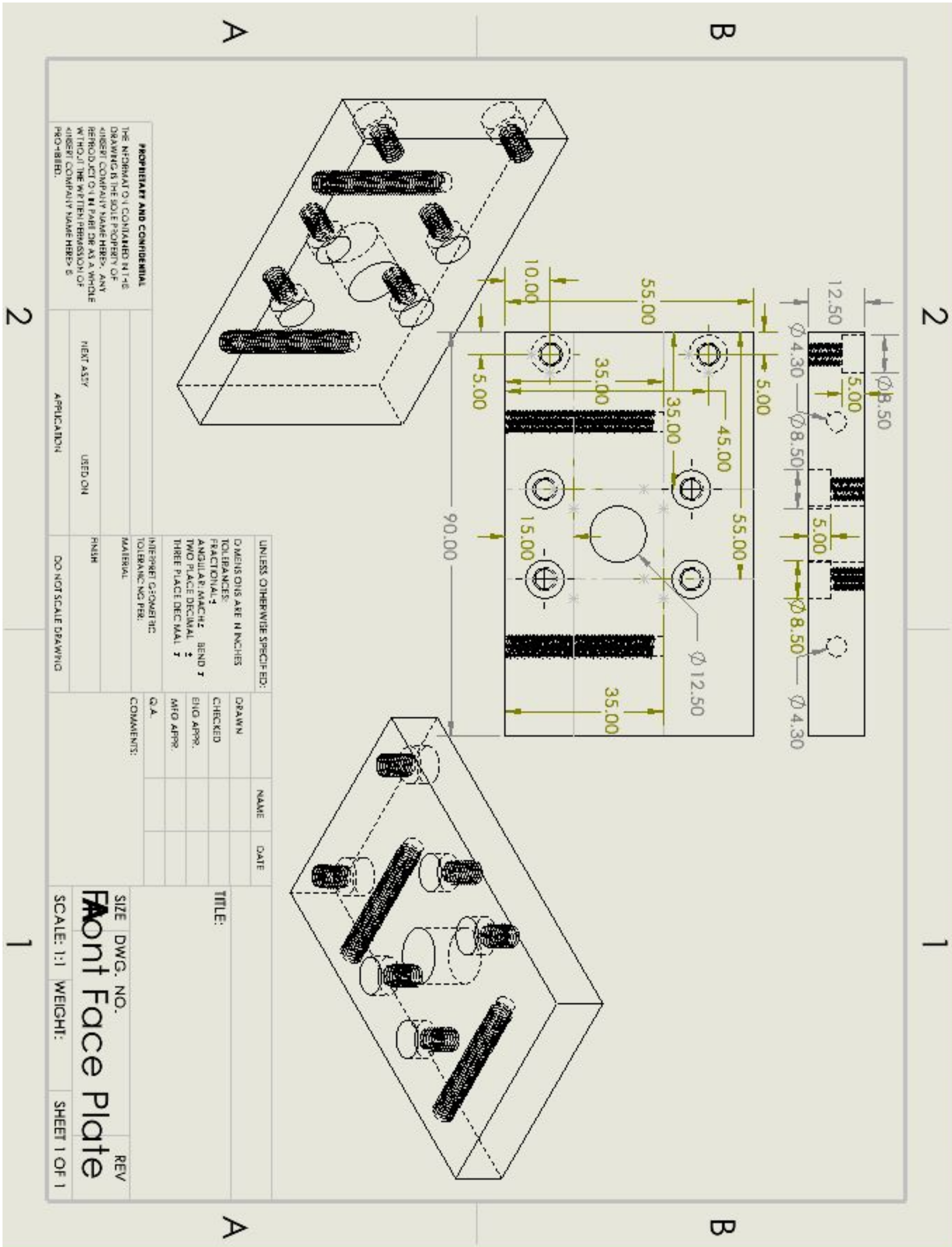

Figure 15: Front face plate drawing

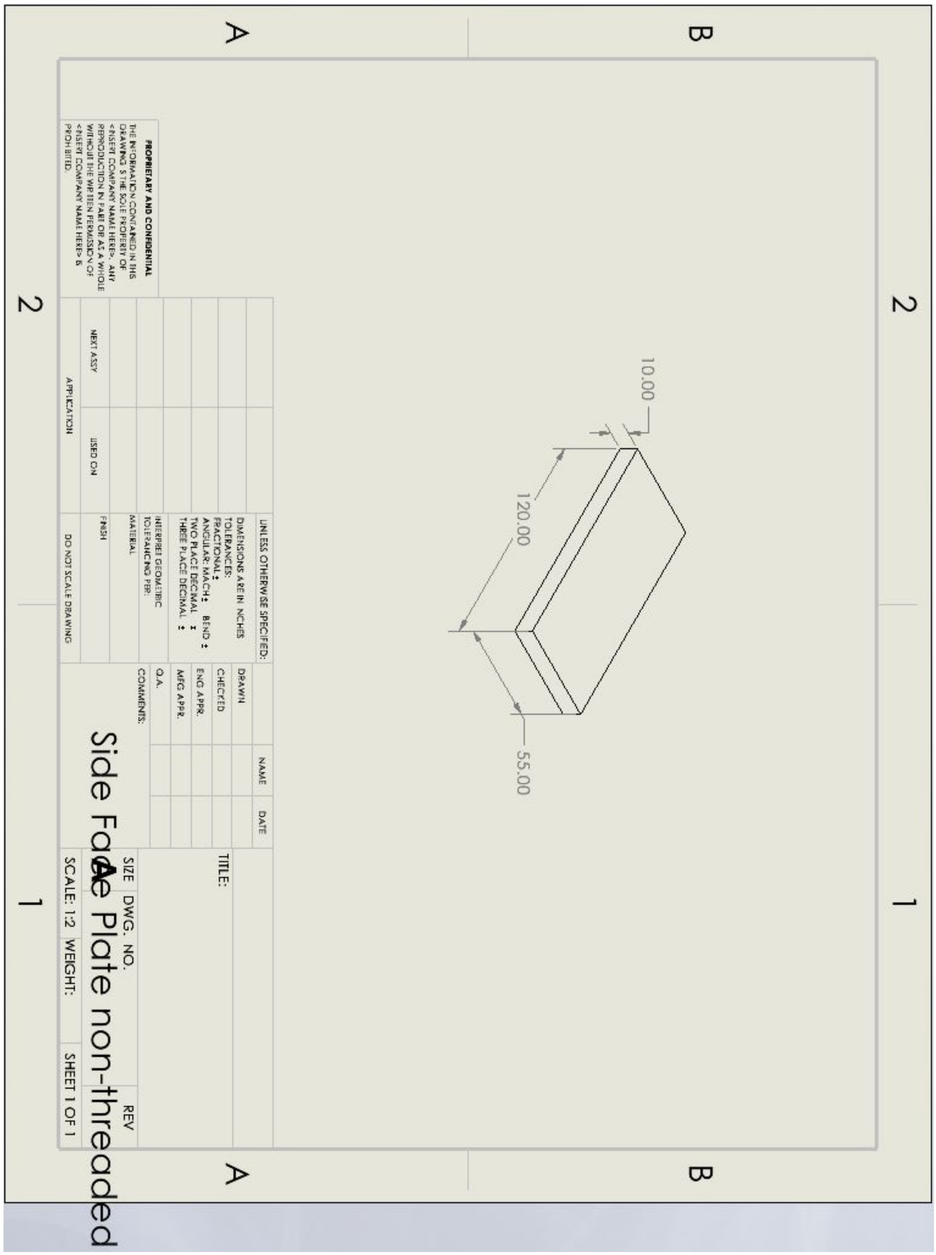

Figure 16: Non-threaded side plate drawing

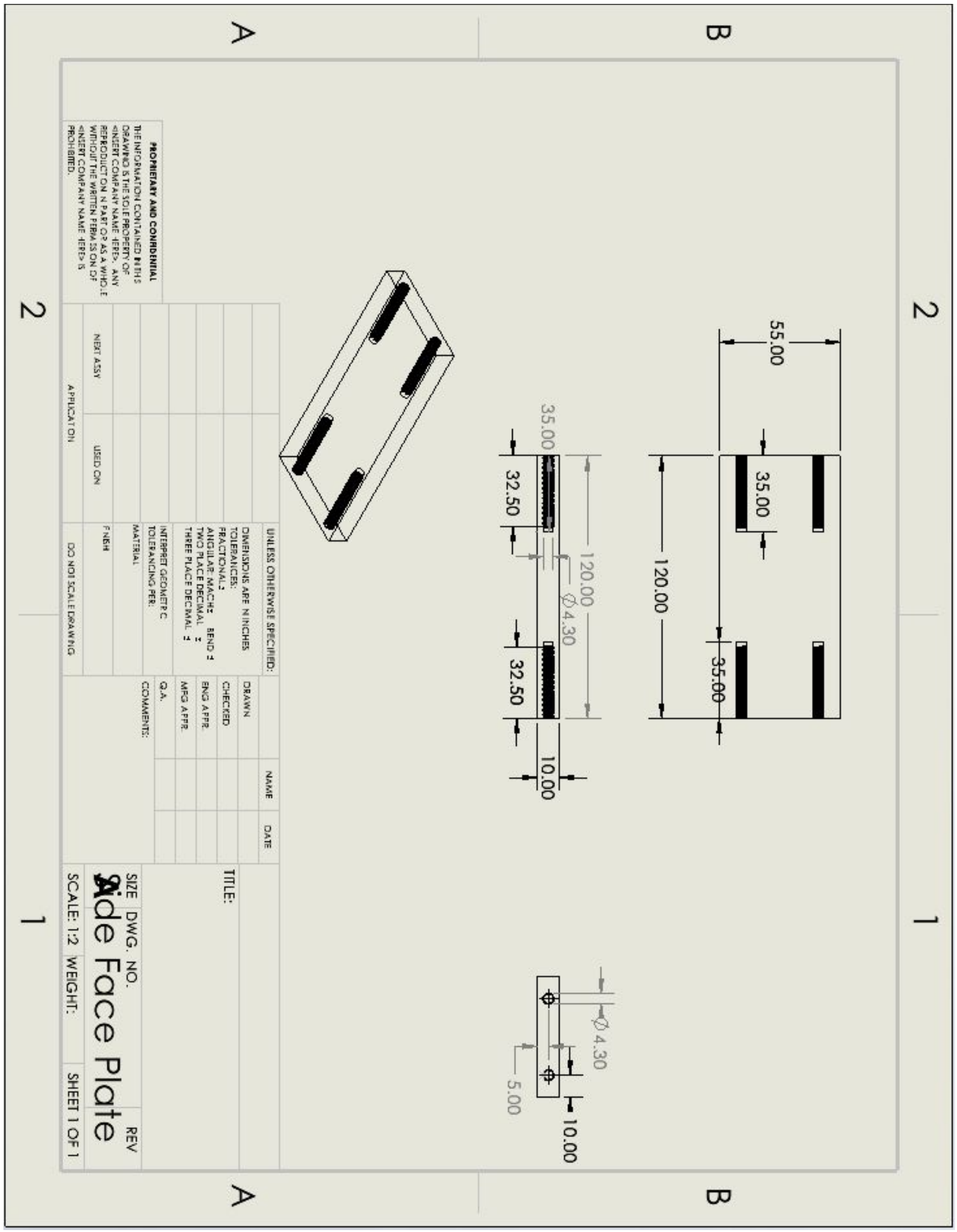

Figure 17: Threaded side plate drawing

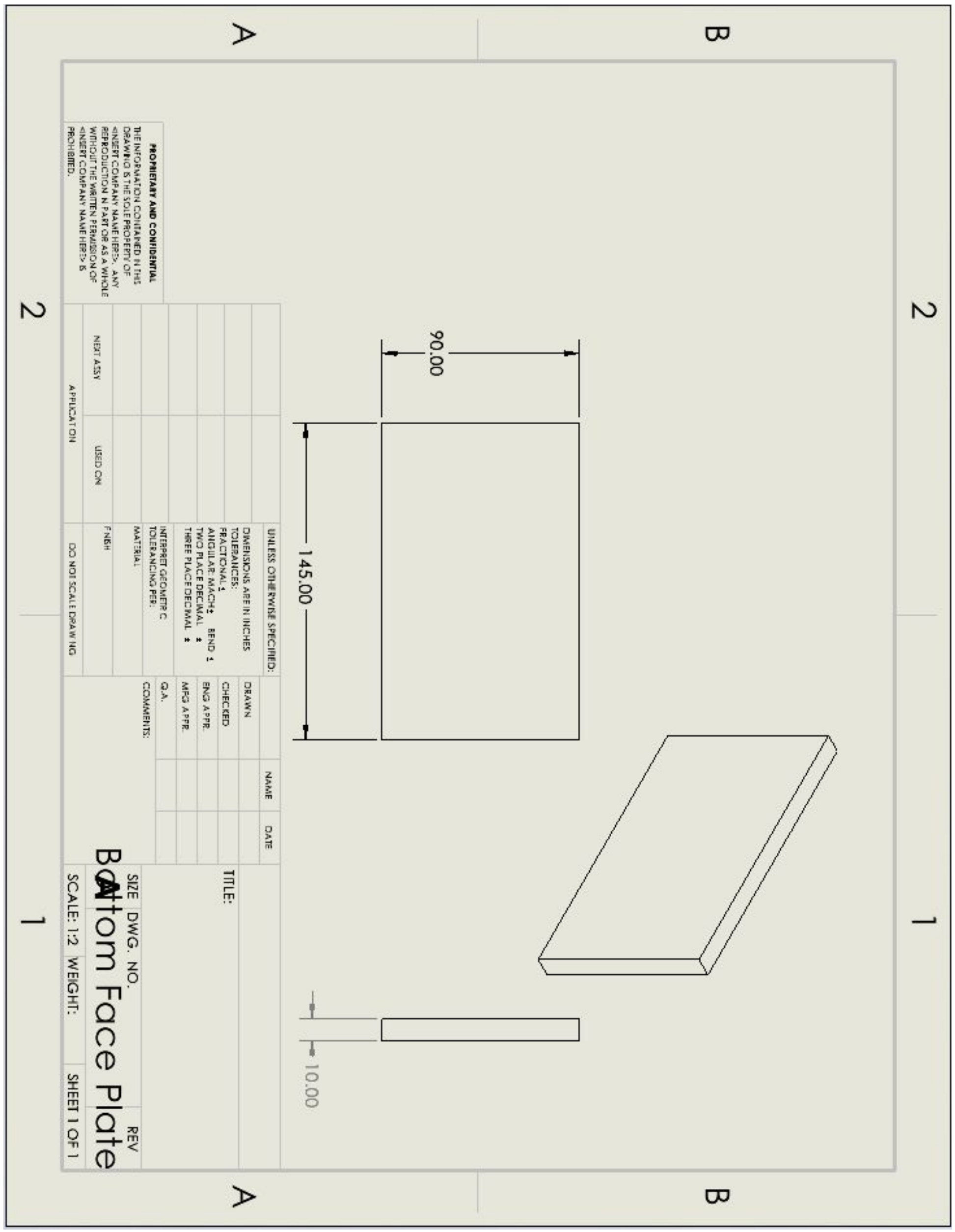

Figure 18: Bottom face plate drawing

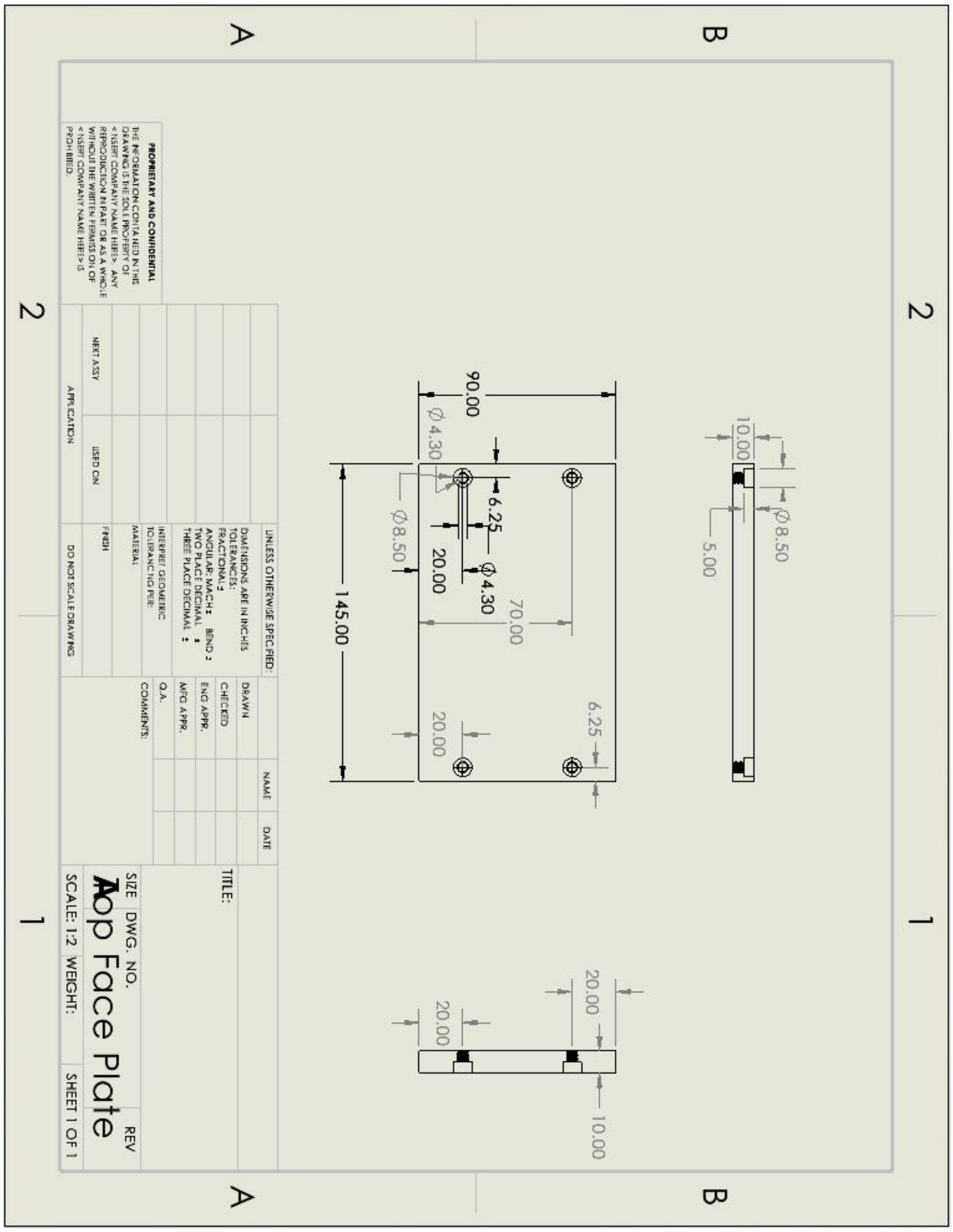

Figure 19: Top face plate drawing

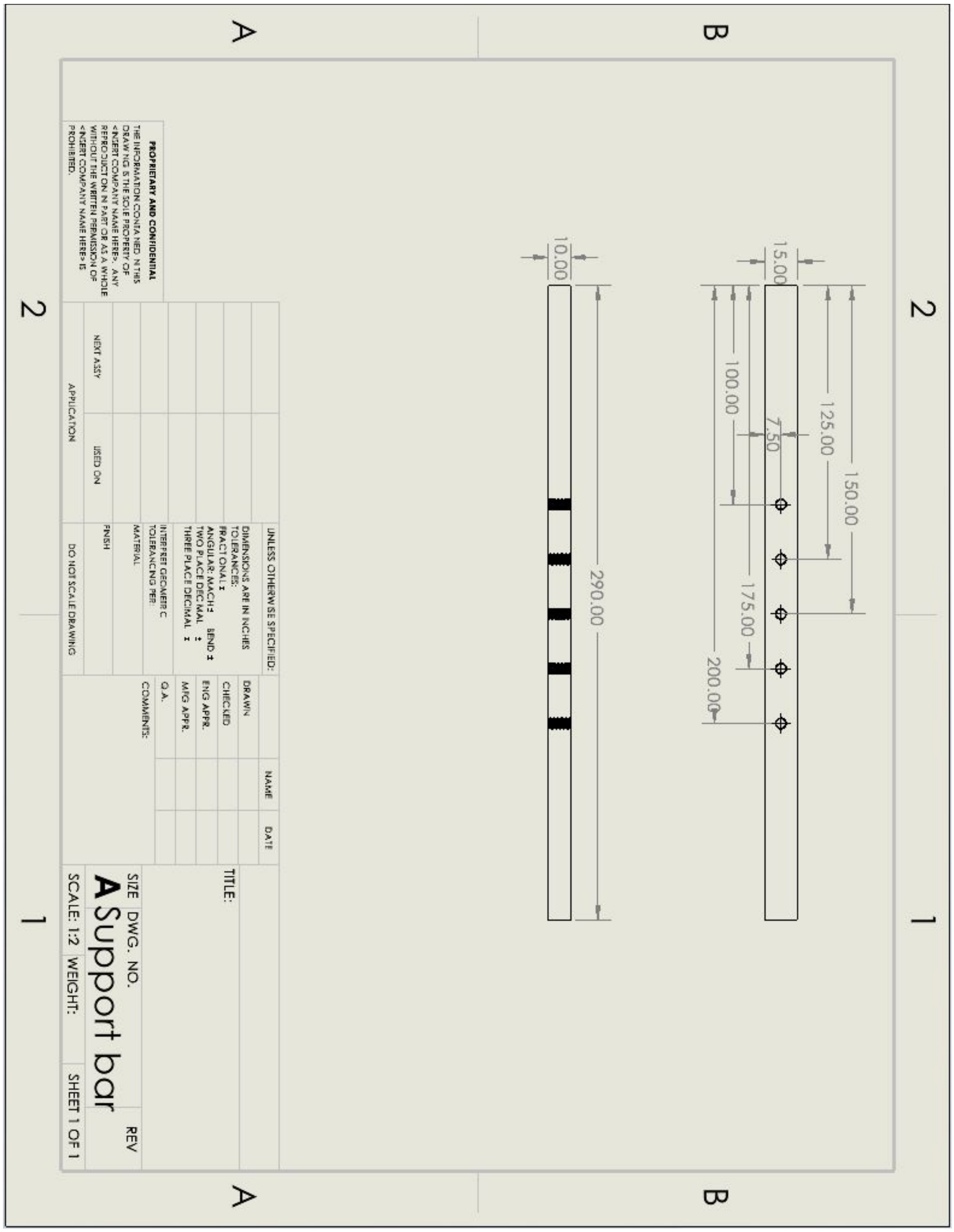

Figure 20: Support rod drawing

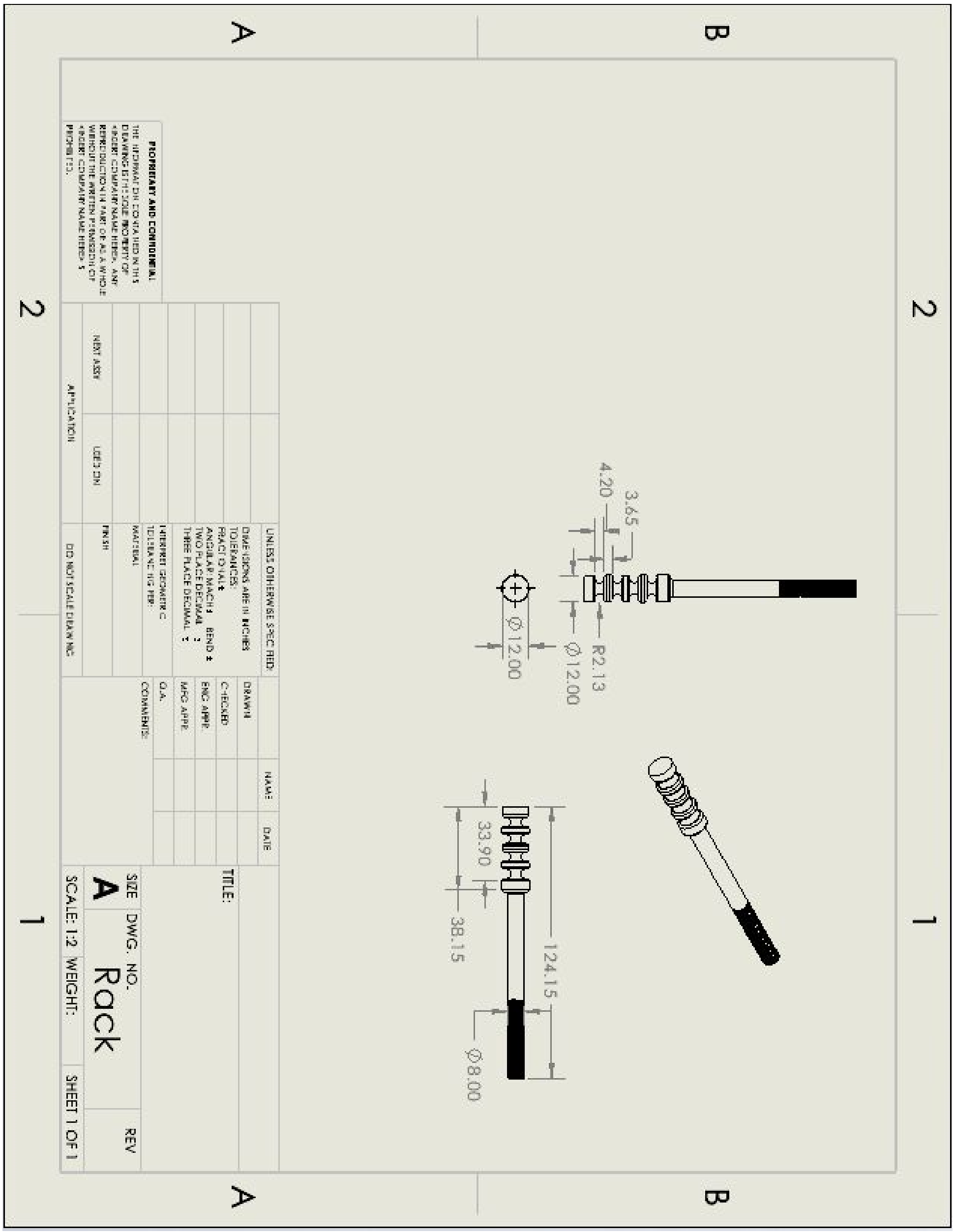

Figure 21: Threaded Bolt drawing

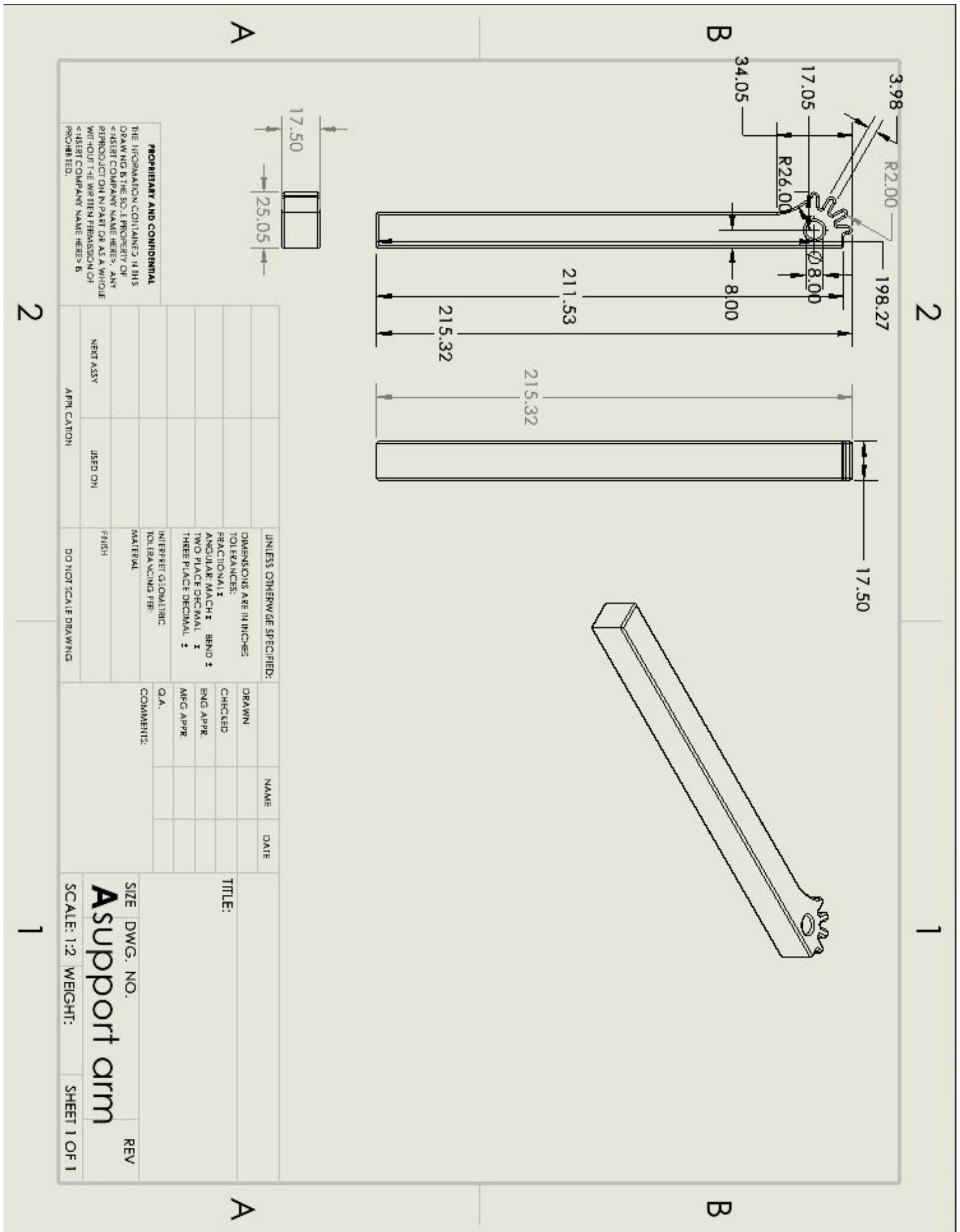

Figure 22: Support arm drawing

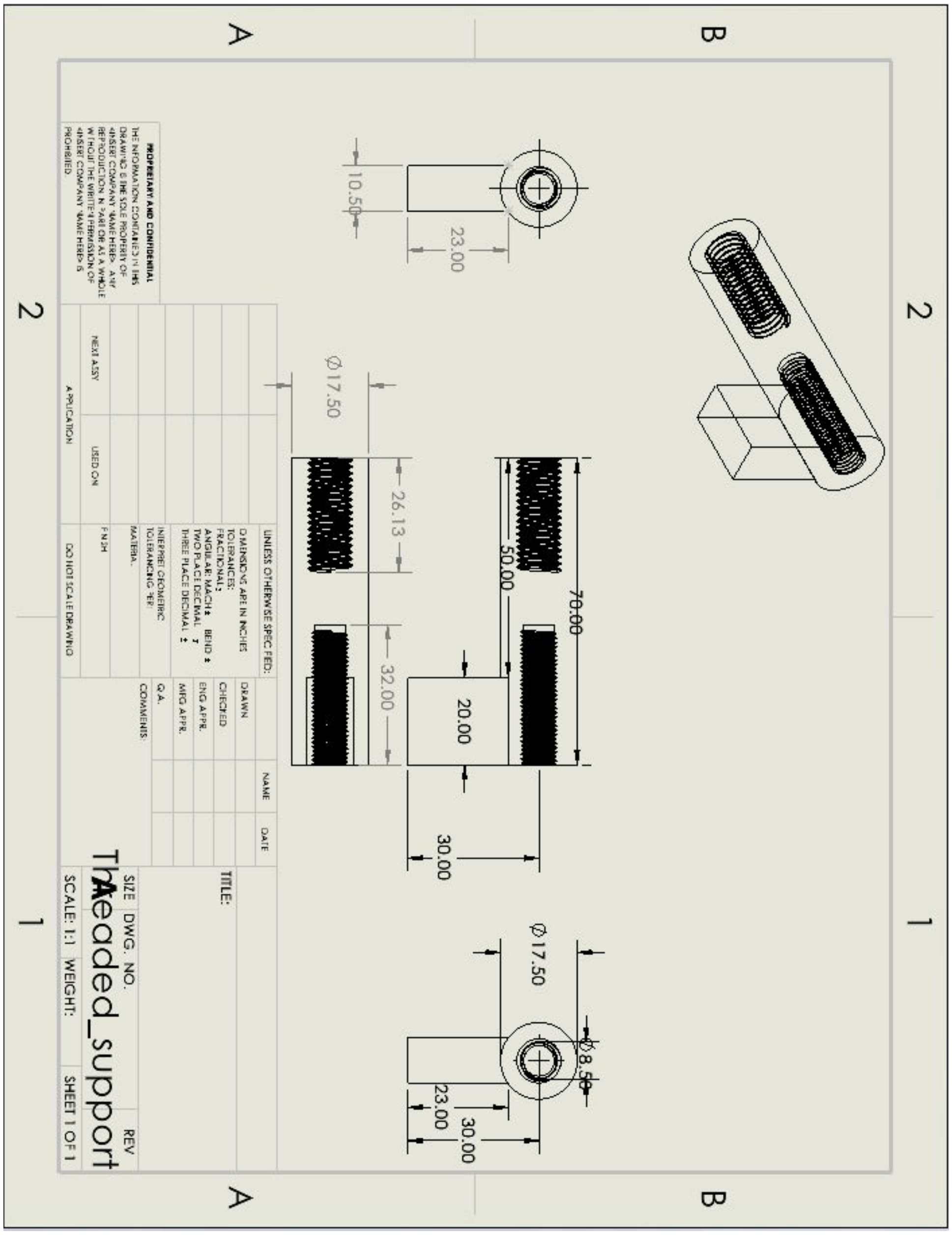

Figure 23: Threaded support drawing

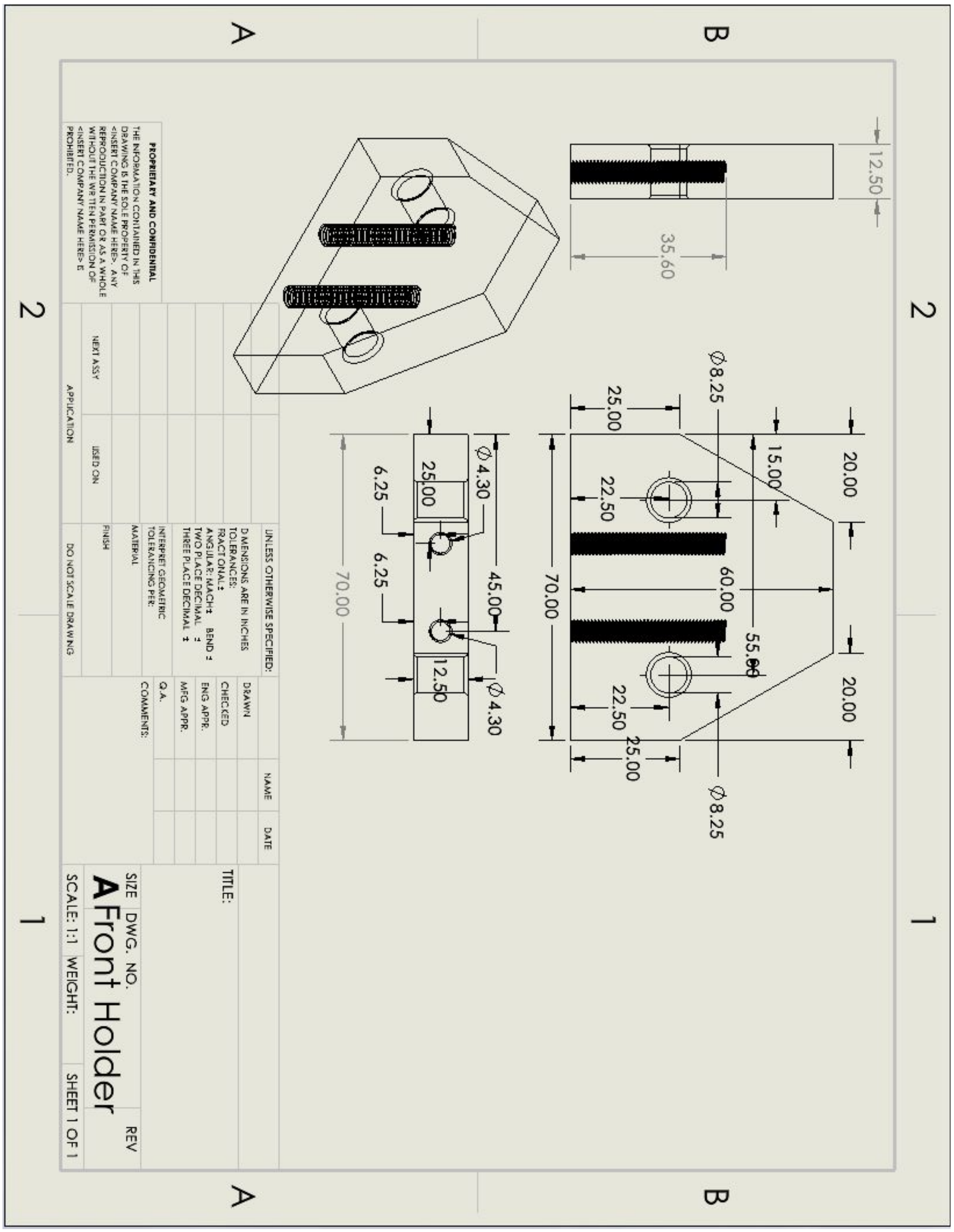

Figure 24: Front holder drawing

For all coordinate systems, the bottom, left corner of the plate is assumed to be the origin (0mm, 0mm).

i. Leg Restraints

Steel plates

1. From steel plates cut a series of six metal plates, these will form the exterior walls of the leg restraint box.
    a. Two plates machined to 120mm x 55mm x 10mm (sides)

    b. Two plates machined to 90mm x 55mm x 12.5mm (front & back))
    c. Two plates machined to 145mm x 90mm x 10mm (top & bottom)
2. On one of the 145mm x 90mm x 10mm plates, drill 4 - 4.3mm diameter through holes. With the 90mm edge as the base and the 145mm edge as the height, place the 4 through holes centered each at (20mm, 6.25mm), (20mm, 138.75mm), (60mm, 6.25mm), and (60mm, 138.75mm).
    a. With an 8.5 mm diameter counterbore, counterbore the two previous four holes 5mm deep on the respective side it was drilled.
3. On one of the 120mm x 55mm x 10mm plates, drill two - 4.3mm diameter, 35mm depth holes. With the 10mm edge as the base and the 55mm edge as the height, place the two holes centered at (5mm, 10mm) and (5mm, 45mm).
4. Repeat step 3 on the opposite 10mm base 55mm height face of the same 120mm x 55mm x 10mm plate
5. On one of the 90mm x 55mm x 12.5mm plates, drill two - 4.3mm diameter, through holes. With the 90mm edge as the base and the 55mm edge as the height, place the two holes centered at (85mm, 10mm) and (85mm, 45mm).
    a. With an 8.5 mm diameter counterbore, counterbore the previous two holes 5mm deep on the respective side it was drilled.
    b. On the same 90mm x 55mm x 12.5mm plates, drill two - 4.3mm diameter, 35mm deep holes. With the 90mm edge as the base, the 10mm as the height, place the two holes centered at (20mm, 6.25mm) and (70mm, 6.25mm).
6. On the other 90mm x 55mm x 12.5mm plates, two - 4.3mm diameter, through holes and one - 12.5mm through hole. With the 90mm edge as the base and the 55mm edge as the height, place the two 4.3mm holes centered at (5mm, 10mm) and (5mm, 45mm), and the 12.5mm hole centered at (45mm, 30mm).
    a. On the opposite 90mm base 55mm height face of the same 90mm x 55mm x 12.5mm plate, drill 4 - 4.3mm diameter, through holes. With the 90mm edge as the base and the 55mm edge as the height, place the 4 holes centered at (35mm, 20mm), (35mm, 40mm), (55mm, 20mm) and (55mm, 40mm). With a 9 mm diameter counterbore, counterbore each hole 5mm deep.
    b. With an 8.5 mm diameter counterbore, counterbore the previous six holes 5mm deep on the respective side it was drilled.
    c. On the same 90mm x 55mm x 12.5mm plate, drill two - 4.3mm diameter, 35mm deep holes. With the 90mm edge as the base, the 10mm as the height, and with the previous four holes counterbore coincident to the ground, place the two holes centered at (20mm, 6.25mm) and (70mm, 6.25mm).
7. With an 8.5 mm diameter counterbore, counterbore all previous holes 5mm deep on the respective side it was drilled.
8. Tap each 4.3mm hole with m2x0 8 end tap.
9. Welding
    a. Use the non-drilled 145mm x 90mm x 10mm plate as the base with the 145mm and 90mm edges coincident to the ground.
    b. Take the 90mm x 55mm x 12.5mm plate with only two holes, and position it on top of the base plate. Align the 90mm outer edges of the plates together, the 55mm edge perpendicular to the base plate, with the 10mm edges flush with the edges of the plate.

Orient the counterbore holes on the side facing away from the rest of the plate. Weld the plates together.

c. Take the other 90mm x 55mm x 12.5mm plate and position it on top of the base plate. Align the plate similarly to the previous plate, but on the opposite edge. Weld the plates together. Orient the four counterbore holes towards the inner section of the plate and the opposite plate. Weld the plates together.
d. Take the non-drilled 120mm x 55mm x 10mm plate and align it between the two welded plates. The plate should be aligned so the outer 55mm edges are flush, the 10mm face is flush with the base plate, and the plate is on the side that does not have any holes on the welded plates. Weld the plates together.

Support bar

1. Machine a bar of steel with dimensions 290mm x 15mm x 26mm
2. Drill 5 - 4.3mm diameter, 15mm depth holes. With the 15mm edge as the base and the 290mm edge as the height, place the holes centered at (7.5mm,100mm), (7.5mm,125mm), (7.5mm,150mm), (7.5mm,175mm), (7.5mm, 200mm).
3. Tap each hole with m2x0 8 end tap

Front holder

1. Machine two plates of steel with dimensions 70mm x 60mm x 12.5mm
2. On both plates, with the 70mm edge as base and 60mm edge as height, make two 30 degree cuts. The first cut starts at (0mm, 25mm) and ends at (20mm, 60mm) and the second cut starts at (60mm, 25mm) and ends at (40mm, 60mm).
3. With the same orientation as the previous step, drill two 8.25mm diameter through holes on each plate. Place the 2 holes centered at (15mm, 22.5mm) and (55mm, 22.5mm).
4. On both plates, drill two 4.3mm diameter, 35mm depth holes. With the 70mm edge as base and the 12.5mm edge as the height, place the 2 holes centered at (25mm, 6.25mm) and (45mm, 6.25mm).
5. Tap each hole with m2x0 8 end tap

Support arm

1. Machine a block of steel to 55mm x 25mm x 215mm
2. Drill an 8mm diameter through hole on the block of steel. With the 25mm edge as the base and the 55mm edge as the height, center the hole at (17mm, 37mm).
3. Use a CNC mill to fabricate the circular pattern of the pinion arms. The circular pattern is centered around the hole, with a pattern diameter of 15.05mm. There are 4 pinion arms in the 90 degree area they are present in. The width of each arm is 4mm and there is a 30 degree angle between each pinion arm.
4. Mill the flats of each edge on the support arm.
5. Repeat steps 1-4 for the second support arm.

Threaded bolt

1. Lathe a rod of steel round stock to a 12mm diameter and length of 125mm
2. Lathe one end of the rod to an 8mm diameter for a length of 84mm.

3. Fabricate the rack groves on the 12mm diameter end of the threaded bolt
4. Tap the 8mm end of the rod with 5mm x 0.8 tap for 42mm

Leg pad & clamp

1. Customize the leg pad based on the client's desired shape.
    a. Utilize manufacturer included restraints until customized restraints are fabricated

Assembly

1. Take welded component and attach threaded support to back plate using a 35mm 10mm x 1

ii. Chest Restraints

***The 80/20 extrusion in this fabrication plan is a 20 mm profile and will refer to it as "2020 ext"*

***All T-nuts used throughout the fabrication plan are the same*

***All L-brackets used throughout the fabrication plan are the same, except the color will be different based off whether it is inside or outside of the box due to cost differences*

***All screws used throughout the fabrication plan are the same, unless otherwise noted*

1. Assemble chest restraint
    a. Cut 2 380 mm 2020 ext (1).
    b. Cut 2 340 mm 2020 ext (2).
    c. Cut 1 300 mm 2020 ext (3).
    d. Secure (1) and (2) as seen in Figure 1 with an angled connector.
    e. Insert a T-nut (A) into (2).
    f. Attach an L-bracket (B) as per the orientation seen.
    g. Use screws (C) to attach the L-bracket loosely to the T-nut.
    h. Insert a T-nut into (3).
    i. Use the same L-bracket to connect the T-nut and (3).
    j. Align (3) with the bottom edge of (2).
    k. Tighten all screws into the L-bracket.
    l. Repeat steps 1e-l for the opposite side.
    m. Machine a sheet (4) per the design in Figure 2, to be refined by the client's design at a later date.
    n. Secure sheet with bracket to (3).
    o. Add padding.

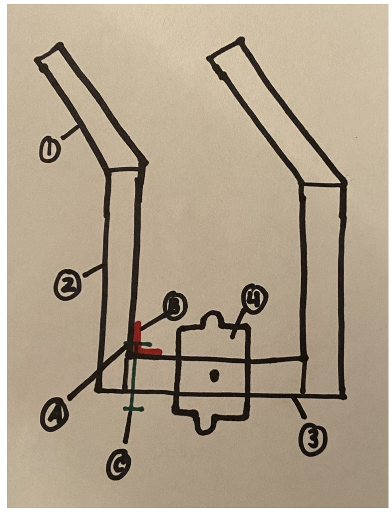

Figure 1: Chest restraint assembly reference

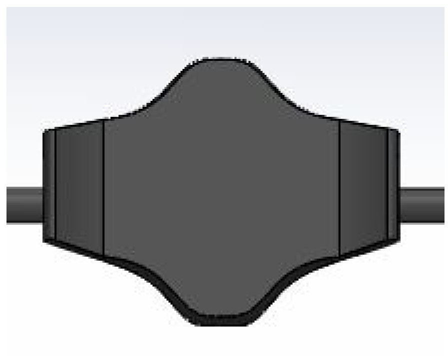

Figure 2: Solidworks drawing of the sheet used for the chest restraint

2. Create shaft assembly
    a. Mill a flat 1.35 mm in depth and 15 mm in length onto one end of a 20 mm diameter and 500 mm length cylindrical shaft as seen in Figure 3.
    b. Repeat step 2a onto the opposite end of the shaft.

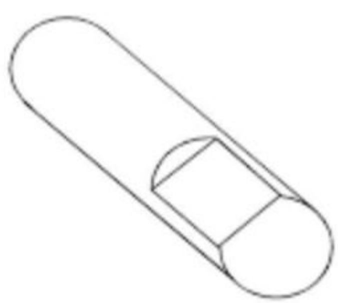

Figure 3: Mill flat onto shaft

    c. Press fit pillow block bearing onto shaft 105 mm from end #1.
    d. Press fit cam gear 130.8 mm from end #1 of the shaft.
    e. Press fit gear for worm drive 157.4 mm from end #1 of the shaft.

f. Press fit pillow block bearing onto shaft 105 mm from end #2.

3. Assemble left and right side frames
    a. Cut 4 2020 ext (1) (seen in Figure 4) to 250 mm length. These are the vertical extrusions.
    b. Cut 6 2020 ext (2) to 155 mm in length. These are the horizontal extrusions.
    c. Insert one T-nut (A) into the left vertical extrusion (1).
    d. Attach a L-bracket (B) as per the orientation seen in Figure 4. Use screw (C) to attach the L-bracket loosely to the T-nut
    e. Insert a T-nut into the bottom horizontal cross piece (2).
    f. Use the same L-bracket to connect the T-nut and bottom cross piece.
    g. Align bottom cross piece with the bottom edge of the left vertical support and tighten all screws into the L-bracket.
    h. Insert two additional T-nuts to the opposite side of where the L-bracket was applied for the bottom extrusion. Do this for the top side of the middle extrusion assembly too. Also, do this for the outer side of the top and bottom cross member extrusions. These are needed for a later step.
    i. Repeat 3c-g for the 5 other L-brackets per their specified extrusion using Figure 4 for positioning reference.
    j. Repeat steps 3c-i for the other side frame.

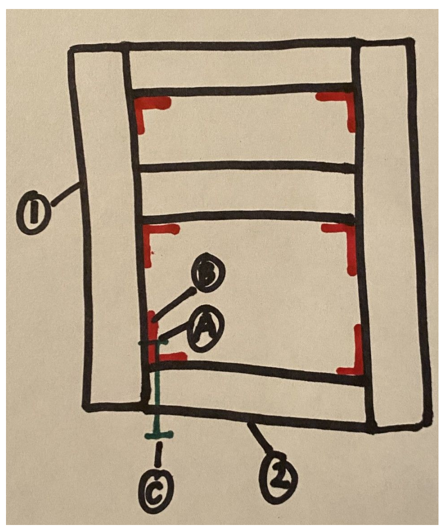

Figure 4: Side frame assembly reference

4. Connect side frames to ONLY bottom cross member extrusions
    a. Cut 4 300 mm 2020 ext to length (3). 2 will be used later for the top cross member extrusions.
    b. Insert one T-nut (A) into the left vertical extrusion (1) to the side adjacent of the original T-nut seen.
    c. Attach a L-bracket (B) as per the orientation seen in Figure 5.
    d. Use screws (C) to attach the L-bracket loosely to the T-nut.
    e. Insert a T-nut into the bottom extrusion (2).

f. Use the same L-bracket to connect the T-nut and bottom extrusion.
g. Align bottom extrusion with the bottom edge of the left vertical support and tighten all screws into the L-bracket.
h. Insert three additional T-nuts to the opposite side of where the L-bracket was applied for the bottom cross member extrusion. Insert three additional T-nuts to the outer side of the bottom cross member extrusion too. These are needed for a later step.
i. Repeat steps 4b-h to connect another bottom cross member extrusion to the same side frame.
j. Repeat steps 4b-i to connect both bottom cross member extrusions to the other side assembly (3).

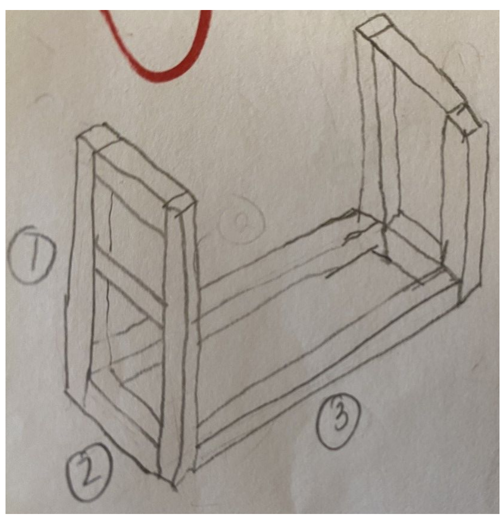

Figure 5: Side frames with bottom cross member extrusions reference

5. Attach bottom plate
   a. Fabricate plate 300 mm x 180 mm with holes and opening per Figure 6.
   b. Flip assembly shown in Figure 5 upside down and roughly align all the T-nuts and the extrusion with the location of the holes from the bottom plate. Insert and

loosely tighten all 10 screws into the T-nuts until all are aligned. Then thoroughly tighten.

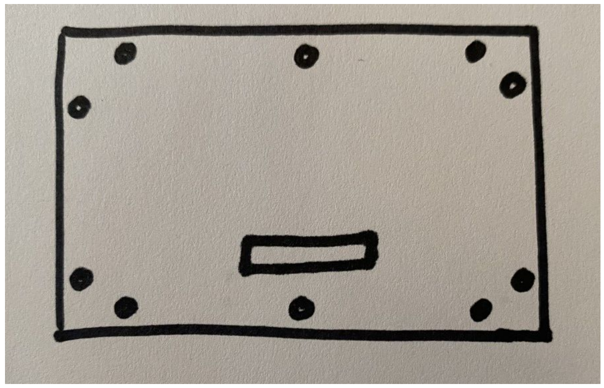

Figure 6: Bottom plate drawing

6. Attach ratchet system motor to bottom plate.
7. Attach worm gear system motor to bottom plate.
8. Install shaft assembly
    a. Use a washer and screw on each side of the pillow block bearing to secure into T-nuts.
    b. Repeat step 8a for pillow block bearing on other side support.
    c. Slightly loosen all 4 L-bracket screws on vertical extrusions of the side supports to adjust height of the middle side supports in order for cam gear and worm gear to interact with motors.
    d. Rotate the shaft as necessary to engage gears.
    e. Tighten all 4 screws previously loosened to secure the shaft in place.
9. Connect power and electronics to motor
10. Connect side frames with top cross member extrusions
    a. Insert one T-nut (A) into the left vertical extrusion (1) to the side adjacent of the original T-nut seen.
    b. Attach an L-bracket (B) as per the orientation seen in Figure 7.
    c. Use screws (C) to attach the L-bracket loosely to the T-nut.
    d. Insert a T-nut into the top extrusion (2).
    e. Use the same L-bracket to connect the T-nut and top extrusion.
    f. Align top extrusion with the top edge of the left vertical support and tighten all screws into the L-bracket.
    g. Insert three additional T-nuts to the top cross member extrusion, needed for a later step.
    h. Repeat steps 4a-f to connect another top cross member extrusion to the same side frame.
    i. Repeat steps 4a-g to connect both top cross member extrusions to the other side assembly (3).

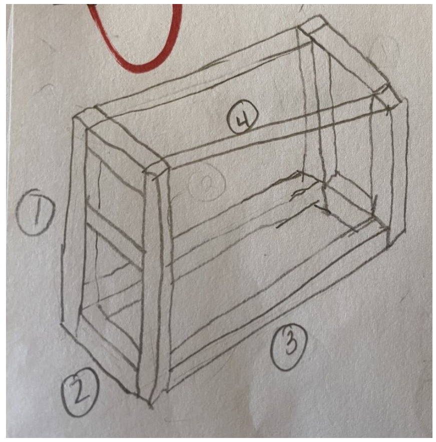

Figure 7: Side frames with top cross member extrusions reference

11. Attach front and back plates with screws and T-nuts
    a. Fabricate plate 300 mm x 250 mm with holes per Figure 8.
    b. Roughly align all the T-nuts and the extrusion with the location of the holes from the bottom plate. Insert and loosely tighten all 10 screws into the T-nuts until all are aligned. Then thoroughly tighten.
    c. Repeat for the other plate.

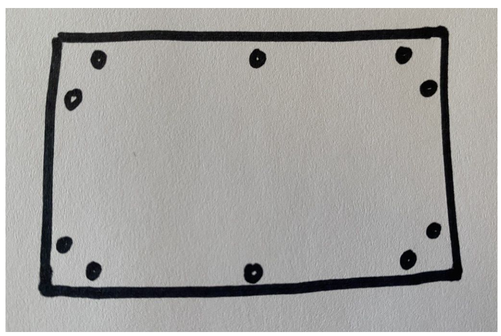
Figure 8: Front and back plate drawing

12. Create hole in side plates for shaft assembly
    a. Locate the side plate and mark where the center of the shaft is.
    b. Drill out a hole that has roughly a 25 mm diameter, the size of the bearing.
        i. Hole for the bearing should not be pre-drilled. Will be done once everything else is assembled.
    c. Repeat for the other side plate.
13. Attach left and right side plates
    a. Fabricate plate 180 mm x 250 mm with holes per Figure 9.
    b. Roughly align all the T-nuts and the extrusion with the location of the holes from the bottom plate. Insert and loosely tighten all 8 screws into the T-nuts until all are aligned. Then thoroughly tighten.
    c. Repeat for the other side plate.

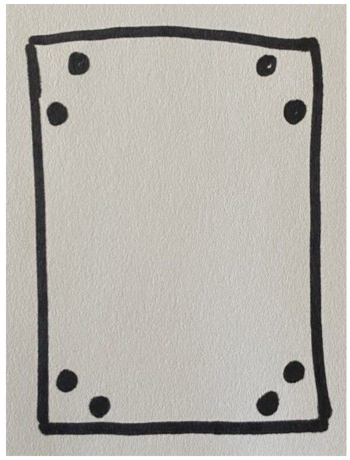

Figure 9: Side plate drawing

14. Attach top plate
    a. Create hole 80 mm x 20 mm in the top plate for headrest.
    b. Attach two hinges 75 mm from both ends of the top plate. Details are shown in Figure 10.

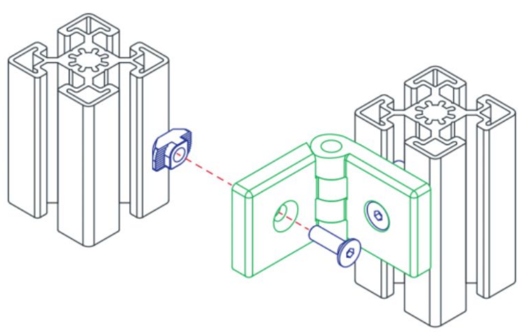

Figure 10: Details on how to attach hinge

    c. Attach latch and catch centered on the opposite end of the hinges. Details are shown in Figure 11.

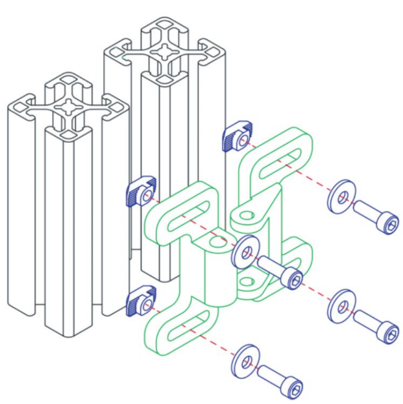

Figure 11: Details on how to attach catch and latch

15. Mount box onto the wheelchair.

    a. Bolt the headrest mount to front of the box
    b. Slide headrest mount into manufacturer included slot on the back of the wheelchair
16. Connect chest restraint assembly to shaft ends.
    a. Fabricate custom made connector.
    b. Insert connector aligning set screw opening with flat of shaft.
    c. Tighten connector to shaft with set screw.
    d. Repeat steps 16a-b for the other side.
    e. Attach chest restraint to connector using flat plate and 4 screws.
    f. Repeat Step 16e on the other side.
17. Test the rotation of the chest restraint assembly. Adjust as necessary by loosening the connector set screws until the shaft can rotate to the fully open position and then retighten the set screws on the connector.
    a. Insert connector onto top of chest restraint
    b. Repeat step 15 for opposite end of shaft and chest restraint
        i. Needs to be thickened by ½ an inch on two sides so that you can tap a hole where you can insert a set screw to connect to shaft restraint and chest assembly

D. Testing Plan

i. Code Testing

Autonomous Wheelchair Restraint Adaptations to Measure Code Accuracy and Reliability: Code eValidation Testing

I. <u>Parties Present for Testing / Data Analysis</u>

**By signing below the individual acknowledges that all test protocol instructions were followed directly and any deviations were recorded below properly. Additionally, singing below signifies that all information contained herein is accurate to the best of the reporting party's knowledge.*

Name	**Email**	**Signature**	**Date** (MM/DD/YYYY)

Ben Lawonn			
Jonathon Murphy			
Naman Patel			
Marissa Harkness			
Jenna Warden			

II. Date(s) of Testing:

Date Started: (MM/DD/YYYY)	**Date Completed:** (MM/DD/YYYY)

III. Problem Statement

The client is unable to safely enter and operate the standing wheelchair with the manufacturer included restraints. There are currently 2.7 million wheelchair users in the U.S. [1] and within this population, there is a varying degree of upper extremity mobility, ranging from full movement to none. Without a large degree of mobility, many wheelchair users are unable to take advantage of the benefits of movement due to various movement challenges they encounter.

Moving the body has many benefits for the brain, muscles, bones, joints, intestines, heart, lungs and other organs[2]. Movement is also beneficial for a number of bodily functions such as blood flow, digestion, muscle strength, and bone health[3]. Existing standing wheelchair supports enable users to enter the upright position, but they lack autonomous accessibility for the user. The restraints require strength and dexterity to position into their slots, that mobility limited users may not possess. The cost of hiring a CNA or licensed physical therapist is quite expensive and usually is not covered by health insurance for those affected by a permanent disability. The goal of this project is to develop a device that enables the wheelchair user the ability to secure themself within their standing wheelchair independently.

IV. **Testing Rationale and Goals:**

The scope of this test protocol is to verify the accuracy of the compiled code for the Nucleo F3030K8. Based on product design specifications, the code must perform correctly and move the chest and leg supports into position in under 30 seconds.

V. **Check Box Verification: Criteria**

By checking the “Verified” checkboxes below, the reporting party confirms that the step was completed and/or all criteria for that step were met and/or exceeded. To check a box, right click and replace the box with the symbol shown below:

❏ No Check
✓ Check Completed

VI. **Materials Required:**

Item:	**Quantity:**
Nucleo F303K8 Microcontroller	1
Motor	3
Chest Support	1
Leg Support	1
Permobil #F5 Corpus VS wheelchair	1
Laptop / device to run the code and receive output data	1
Laptop / device to collect functionality reports and times for retracting	1

VII. Wheelchair Supports Nucleo Code Functionality Testing: Setup

Step #	Instructions	Protocol Deviations (is applicable)	Verify Step Completed as Described (if necessary)
1.	Connect the Nucleo to any circuitry necessary and to the laptop / device containing the code to be run		❏ Verified Initials:
2.	Next, push and hold the forward button and ensure the motor is moving CCW		❏ Verified Initials:
3.	Then, push and hold the backward button and ensure the motor is moving CW		❏ Verified Initials:
4.	Now, flip the button switch (N/A)		❏ Verified Initials:
5.	Push and hold the forward button and check that the motor is NOT moving		❏ Verified Initials:
6.	Push and hold the backward button and check that the		❏ Verified Initials:

	motor is NOT moving		

** Add pictures of buttons for forward and backward restraint movement

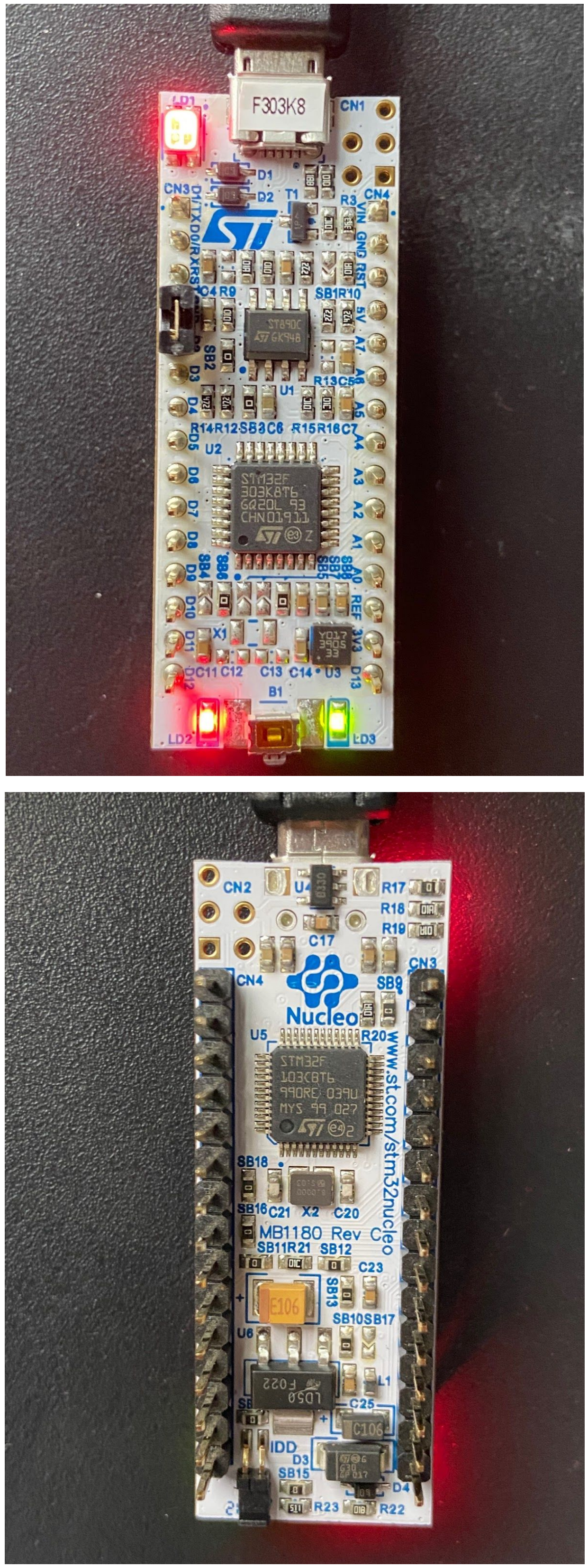

Figure 10: The Nucleo F303k8 microcontroller.

VII. Wheelchair Supports Nucleo Code Time of Execution: Setup

Step #	Instructions	Protocol Deviations (if applicable)	Verify Step Completed as Described (if necessary)
1.	Connect the Nucleo to any circuitry necessary and to the laptop / device containing the code to be run		❑ Verified Initials:
2.	Start timer and push forward button to move the chest support into position simultaneously		❑ Verified Initials:
3.	Stop timer when chest support reaches its final position		❑ Verified Initials:
4.	Record timer data in excel spreadsheet		❑ Verified Initials:
5.	Reset timer and restart timer and push backward button to move the chest support into the relaxed position simultaneously		❑ Verified Initials:

6.	Stop timer when chest support reaches the relaxed position		❏ Verified Initials:
7.	Record timer data in excel spreadsheet		❏ Verified Initials:
8.	Repeat steps 2-7 for the leg support		❏ Verified Initials:

** Add photos of buttons again with chest and leg restraints in relaxed and engaged position.

VIII. <u>Wheelchair Supports Limit Switch Verification: Setup</u>

Step #	Instructions	Protocol Deviations (if applicable)	Verify Step Completed as Described (if necessary)
1.	Connect the Nucleo to any circuitry necessary and to the laptop / device containing the code to be run		❏ Verified Initials:
2.	Push and hold the forward button so that the chest restraint goes beyond the maximum range dictated by a limit switch		❏ Verified Initials:
3.	Record in excel spreadsheet if the		❏ Verified Initials:

	restraint stops moving once the limit switch is hit		
4.	Repeat steps 2-3 for the leg restraints and record outcomes in excel spreadsheet		❑ Verified Initials:

** Add pictures of limit switch here

References

[1] "Disabled People in the World in 2019: facts and figures," Inclusive City Maker, 24-Oct-2019. [Online]. Available: https://www.inclusivecitymaker.com/disabled-people-in-the-world-in-2019-facts-and-figures/. [Accessed: 28-Sep-2020].

[2] "Wheelchair Users," Physiopedia. [Online]. Available: https://www.physio-pedia.com/Wheelchair_Users#:~:text=In the United States of,new wheelchair users every year.&text=However, they all need an appropriate wheelchair. [Accessed: 28-Sep-2020].

[3] "For Approximately How Many Minutes Should I Invert on My Inversion Table?," PacGym, 26-Apr-2020. [Online]. Available: https://www.pacgym.com/approximately-many-minutes-invert-inversion-table/. [Accessed: 06-Oct-2020].

ii. Mechanical Testing:

Autonomous Wheelchair Restraint Adaptations to Test Mechanical Components

I. <u>Parties Present for Testing / Data Analysis</u>

**By signing below the individual acknowledges that all test protocol instructions were followed directly and any deviations were recorded below properly. Additionally, singing below signifies that all information contained herein is accurate to the best of the reporting party's knowledge.*

Name	**Email**	**Signature**	**Date** (MM/DD/YYYY)
Ben Lawonn			
Jonathon Murphy			
Naman Patel			
Marissa Harkness			
Jenna Warden			

II. Date(s) of Testing:

Date Started: (MM/DD/YYYY)	**Date Completed:** (MM/DD/YYYY)

III. Testing Rationale and Goals:

The scope of this test protocol is to verify the mechanical stability, accuracy, performance and comfortability of the entire device. This testing is to be completed after the Code Validation Testing.

IV. Check Box Verification: Criteria

By checking the "Verified" checkboxes below, the reporting party confirms that the step was completed and/or all criteria for that step were met and/or exceeded. To check a box, right click and replace the box with the symbol shown below:

❏ No Check

✓ Check Completed

V. Materials Required:

Item:	Quantity:
Nucleo F303K8 Microcontroller	1
Motor	3
Chest Support	1
Leg Support	1
Permobil dF5 Corpus VS wheelchair	1
Laptop / device to run the code and receive output data	1
Laptop / device to collect functionality reports and times for retracting	1

VI. Wheelchair Supports SolidWorks Finite Element Analysis (FEA): Setup

Step #	Instructions	Protocol Deviations (is applicable)	Verify Step Completed as Described (if necessary)
1.	Open the model to be tested in SolidWorks		❑ Verified Initials:
2.	Under “Simulation” tab, select “New Study”		❑ Verified Initials:
3.	Chose “Static” study and click green check mark		❑ Verified Initials:

4.	In menu at left, right click "Mesh" then select "Create Mesh"		❑ Verified Initials:
5.	Adjust sliding bar to finest mesh possible and then click the green check mark		❑ Verified Initials:
6.	Make sure the applied material is "ABS" (Under "Apply Material" select "ABS" and then click "Apply")		❑ Verified Initials:
7.	Chose the geometry that best fits this model		❑ Verified Initials:
8.	Select the bottom face of the model to fix and click the green check mark		❑ Verified Initials:
9.	In menu at left, right click on "External Loads" and select "Force"		❑ Verified Initials:
10.	Select edge to be viewed		❑ Verified Initials:
11.	Select "Selected Direction"		❑ Verified Initials:

12.	Select the edge perpendicular to the edge first selected		❏ Verified Initials:
13.	Under “Force” apply a force to be tested		❏ Verified Initials:
14.	Check the force direction, select reverse direction if it is incorrect		❏ Verified Initials:
15.	Click the green check mark		❏ Verified Initials:
16.	Under the top menu, select “Run This Study”		❏ Verified Initials:
17.	Note the simulated maximum deflection		❏ Verified Initials:
18.	In menu at left, under “Results”, select “Strain”		❏ Verified Initials:
19.	Repeat all steps for leg restraint		❏ Verified Initials:

*** Add figures to show how this process was completed when it is completed.

VII. <u>Wheelchair Supports Beginning and End Location: Setup</u>

Step #	**Instructions**	**Protocol Deviations (is applicable)**	**Verify Step Completed as Described (if necessary)**

1.	When chest and leg restraints are in their resting positions, measure the closest point to the chair. Record this measurement in the data table provided.		❏ Verified Initials:
2.	Deploy the restraints to their active positions		❏ Verified Initials:
3.	Using the same point as measured before, measure that point to a chosen point on the chair. Record this measurement in the data table provided.		❏ Verified Initials:
4.	Repeat steps 1-3. Record all measurements.		❏ Verified Initials:
5.	Determine the minimum, maximum, and average distances measured for each of the four measurement categories		❏ Verified Initials:
6.	The range should not exceed 25 mm		❏ Verified Initials:

** Add pictures showing where measurements were taken in both positions for the chest and leg restraints.

VIII. Wheelchair Supports Range of Motion Survey

Step #	Instructions	Protocol Deviations (is applicable)	Verify Step Completed as Described (if necessary)
1.	Have user enter chair and deploy both restraints		❏ Verified Initials:
2.	Have user complete typical daily tasks		❏ Verified Initials:
3.	Have user verbally ask for adjustments to be made		❏ Verified Initials:
4.	Have user fill out survey ranking each category as well as verbal feedback		❏ Verified Initials:
5.	Have one person take notes on the adjustments made and the final comments regarding the survey		❏ Verified Initials:

** Add pictures showing adjustments and users range of motion while using the device

** Surveys will be created at the beginning of the Spring 2021 semester along with results tables

References

[1] "Disabled People in the World in 2019: facts and figures," Inclusive City Maker, 24-Oct-2019. [Online]. Available: https://www.inclusivecitymaker.com/disabled-people-in-the-world-in-2019-facts-and-figures/. [Accessed: 28-Sep-2020].

[2] "Wheelchair Users," Physiopedia. [Online]. Available: https://www.physio-pedia.com/Wheelchair_Users#:~:text=In the United States of,new wheelchair users every year.&text=However, they all need an appropriate wheelchair. [Accessed: 28-Sep-2020].

[3] "For Approximately How Many Minutes Should I Invert on My Inversion Table?," PacGym, 26-Apr-2020. [Online]. Available: https://www.pacgym.com/approximately-many-minutes-invert-inversion-table/. [Accessed: 06-Oct-2020].

E. Nucleo Source Code

```
#include "Servo.h"
#include "mbed.h"

//inPosition flag: T = restraining position; F = at rest position
bool inPosition = false;
DigitalIn Dforward(D5);
DigitalIn Dbackward(D6);
DigitalIn hallEffect(D7); //Feedback from Hall effect sensor sets inPosition to T or F
Servo myservo(A5);

int main(){

  while(1){
    if(hallEffect == 1){
      //sensor reads that support is in restraining position
      inPosition = true;
    }
    else{
      inPosition = false;
    }
```

```
        //In at rest position and forward button is pressed
        if(inPosition == false && Dforward == 1){
            //move support into restraining position
            myservo.position(3000);
        }
        //In restraining position and backward button is pressed
        else if(inPosition == true && Dbackward == 1){
            //move support backwards into at rest position
            myservo.position(-3000);
        }
        else{}
    }
}
```

F. Foot Plate Design Matrix

Table 1: Design matrix of three possible foot plate design ideas. This will be finished by the team in the future Spring 2021 semester.

Testing	Original Design 	Thigh Pads 	Enlarged Footplates 
Safety (25)			
Ease of Implementation (20)			
Ease of use (15)			
Cost (15)			
Comfort (15)			
Stability (10)			
Total (100)			