Stair Chair

Product Design Specifications (PDS)

BME 200/300 Section 307

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Client

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Abstract

Stroke patients and other persons who have temporarily lost use of one leg have trouble going up multiple stairs. Electric stair lifts are the only solution available on the market and they are expensive and essentially permanent once installed. This is not practical for people who commonly need to traverse 3-5 stairs outside their homes for only 8-12 weeks until recovering full use of their legs. The current solution generally used involves slowly and meticulously scooting backwards up stairs, often requiring the assistance of another person. This paper outlines the design process of a device made to remedy this problem. The device is a freestanding apparatus consisting of a base platform, a ramp to bridge the stairs, and a winch and pulley system to raise and lower the platform. The user can crank themselves up to the level of the top of the staircase, and the device will lock in place so they can walk across the ramp into their homes and back before cranking themselves back down to ground level. Force requirements to raise the lift and base platform tilt angle were tested using a dynamometer and a level, respectively. Through this testing, the team concluded that at a full scale, the device will be both functional and efficient. This full scale model will include a winch fixed to the base platform and T-slotted bearings to stabilize the base plate.

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Introduction

Motivation

Stair negotiation is a major obstacle for individuals rehabbing temporary wounds to their lower extremities. Over a million Americans each year will be treated in emergency departments for complications from falls during ascension and descension of stairs [1]. Completely healthy older adults are at a greater risk for falls on stairs because of a lack of balance and have a greater risk for tripping [2]. 42.1% of stair related injuries are to lower extremities and older adult patients (>55) are more prone to fractures than their younger counterparts [1]. Most ankle fractures for these patients tend to lead to 6-12 week non weight bearing periods, where stair negotiation becomes even more of a challenge [3]. The motivation for this project is to create a device that allows the user to ascend and descend stairs during this temporary non-weight bearing period.

Competing Designs

While electric stair chairs do exist on the market in great numbers, they accomplish the same goal but for a different problem. A typical electric stair chair will cost at a minimum $2000 USD, a price that many individuals are not willing to pay for stair negotiation over a 6-12 week recovery window [4]. The market for these types of devices is typically arthritic elderly patients who require these lifts for the rest of their lives, making the price a more warranted investment [5]. This is not the market the team is looking to reach. The mechanically powered stair chair is instead targeted towards individuals within a 6-12 week recovery period, who need a temporary, inexpensive solution to stair negotiation, and not a bulky expensive device that is nearly useless after recovery.

Problem Statement

The team is creating a mechanically powered stair climbing device to help temporarily disabled patients at Encompass Rehabilitation Hospital with stair negotiation during their non-weight bearing period of recovery. Crutching up stairs is not feasible for elderly patients, and large electric stair climbing devices are beyond the budget of many patients. The device should be able to fit between 3-5 stairs and withstand average outdoor weather conditions in the state of Wisconsin.

Background

Physiology

To get a better understanding of the mechanical advantage the team would have to tune the track based designs for, research was done on the seated leg press one rep max of women in the 80-85 age group. The team decided to focus on this age group in particular per client's request, as he identified them as likely the weakest of the patients he sees. Tuning the device to the weakest user would ensure the device be usable for a wide range of patients. From a study conducted by Rosalia L. Parrino et al, there was a quantitative measure associated with one rep leg press strength per body mass [6]. A value of 1.72 (load/body mass) was determined and will be the team's initial value for tuning prior to possible testing.

Given the team's shift to a device mechanically powered by the arm of the user, further research was conducted to examine the power generated during an arm cranking movement by elderly women. This study considered the loss of arm strength and power with age for women and men, but given the clients inclination to tune the device to older women, we will look at the results for women. The study found a power output of 2148 kg/min for women at the age of 70, with a standard deviation of 599 [7]. The study also found no clear evidence that there was a significant loss of power in the 5 year span studied for women around the age of 70 [7]. The team can use this average power output for consideration on a possible winch and the necessary mechanical advantage for all users. Also considering the fact that older women (>70) can generate 45% of the power output that 20 year old women can, and that a 20 year old women on average can generate 86 Watts during an arm cranking exercise, the team has accepted values to base the winch placement and selection on [7][8].

Design Research

Given the novelty of the product, the team was not able to locate any codes or standards that directly related to the device. With this in mind, the team decided to turn its focus to general medical device standards issued by ISO and Wisconsin State Legislature for stair construction code. ISO 13485 is the standard of quality of medical devices throughout their lifecycle, and emphasizes process documentation and risk management for all devices to market [9]. With this in mind, the team will include two points of failure prevention in any design to market to fit within these guidelines, and also keep the LabArchives up to date for all of the design process. Per the Wisconsin State Legislature on stairs, any set of three or more risers must have a handrail. Any set of stairs must also be 91.4 cm wide and each riser may not exceed 20.32 cm in height between top to bottom [10]. With this in mind, the team must design a device that can fit within these sizes so that it is usable on all up to code stairs in the state of Wisconsin.

Client Information

Mr. Daniel Kutschera is a physical therapist at Encompass Rehabilitation Hospital in Fitchburg, Wisconsin. The client hopes to rent out this device to elderly patients with injuries to lower extremities as they recover.

Design Specifications

The device is a mechanically powered stair climbing device that can ascend and descend between 3-5 stairs and be used frequently for up to 26 weeks at a time. The device must also be able to withstand masses of up to 140 kg to account for the many different masses of individuals using the device. The max weight of the product should not exceed 30 kg to make sure it is easily able to be moved between home to home. The device must also have appropriate safety features, such as a seatbelt for users and a system to prevent total mechanical failure or sliding down the track. Given the teams to consider the device as rentable by durable medical equipment (DME), the expected life in service for the device should be around 5 years, like other DME devices (see Appendix A). The design is also a proof of concept, so that the team and our client Mr. Daniel Kutschera can decide if we want to explore the selected design further after creating a scale model.

Preliminary Designs

Design 1: Ratchet

The first design utilizes a ratchet system to get up the steps. The design includes a seat that rotates 360 degrees to make getting on and off easy and also a lap belt for safety. The user sits down facing down the steps and uses their good leg to ratchet themself up the steps with the seat locking in place along the way. To get down, a handbrake mechanism is in place to control the descent of the user. The seat glides along a continuous track in a clockwise direction.

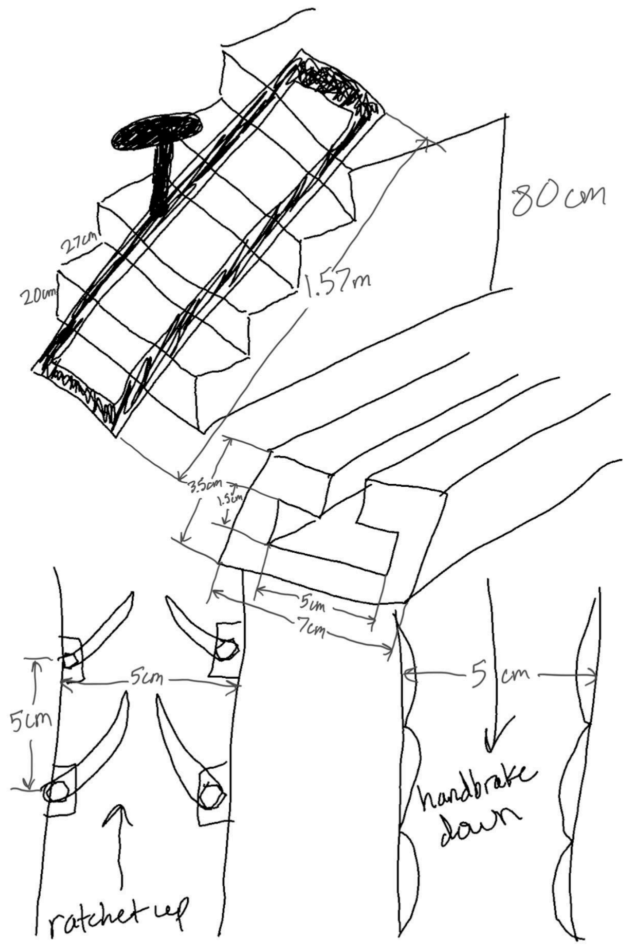


Figure 1: Ratchet Design

Design 2: Counterweight

The second design utilizes a counterweight to aid in both the ascent and descent of the stairs. The design also includes a swiveling seat to allow for easy entry and exit from the device and a lap belt for safety on the ascent and descent. Additionally, the seat is moving up and down on two tracks, with a third in the middle housing the counterweight. The seat and the counterweight are connected via a pulley system, and the counterweight would be adjusted in weight based on the user's weight. On the way up, the counterweight would be lowered, meaning less force would be required to move up the stairs. The user could either push themselves up with their working leg or use the railing to pull themselves up. On the way down, the counterweight would be raised, slowing the descent to make it both safe and quick.

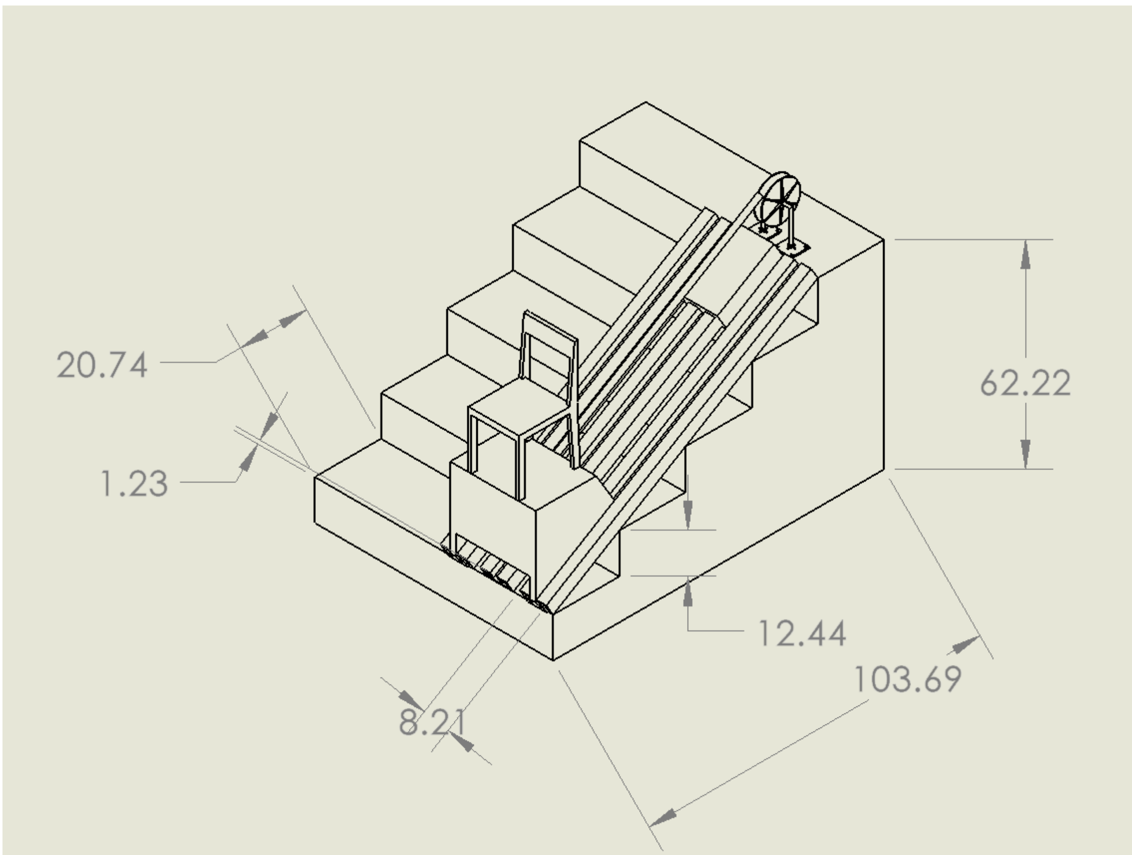


Figure 2: Counterweight Design

<u>Design 3: Hydraulic Pump Design</u>

The third design uses a hydraulic pump mechanism to raise and lower the user up the stairs along two tracks. The user pushes down on a pump similar to that of a barbershop chair, which causes the chair and the pump to slowly raise. The mechanical advantage could be easily adjusted by tweaking the radii of the hydraulic tubes, which would allow for different users of different weights and levels of strengths to all utilize the device. The hydraulic pressure would also slow the descent, keeping the descent safe but relatively quick.

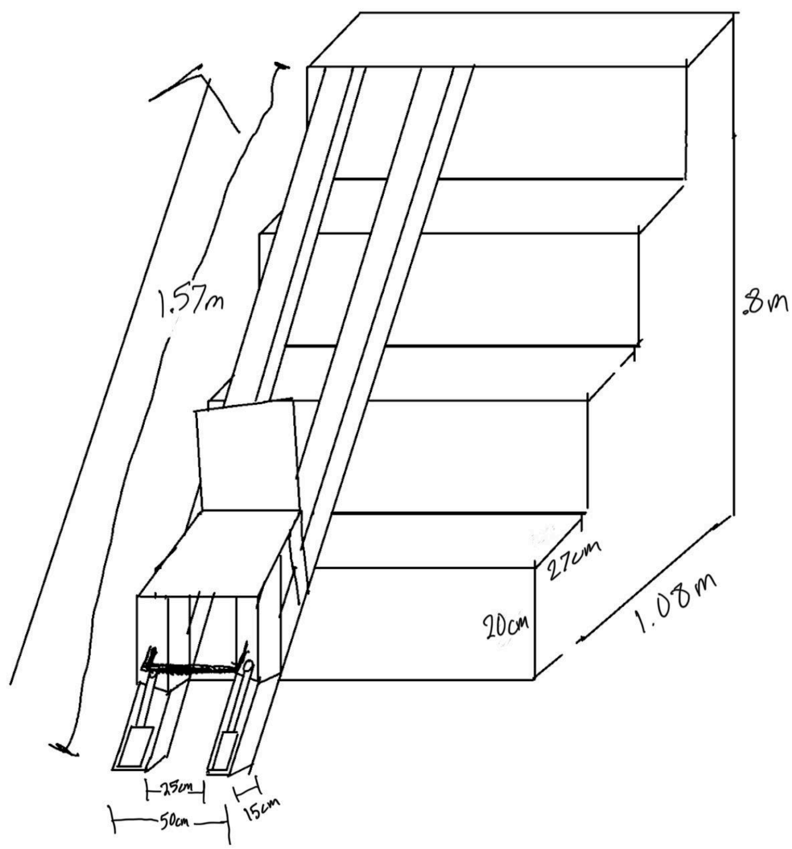


Figure 3: Hydraulic Pump Design

Design 4: Vertical Lift

The fourth design uses a winch system to raise and lower the user on a platform, allowing the user to either walk or wheel across the flat platform to get to the top of the stairs. The flat platform is connected via a hinge to the main platform, and locks into a flat position when the main platform is at the maximum height. The winch system is hand-powered, and can be adjusted to allow for users of different strengths to easily but relatively quickly raise themselves. This design is wheelchair compatible, allowing users to bring their wheelchair up with them, never having to switch between their wheelchair and another chair in the raising process. To descend, the user moves across the flat platform to the main platform, uses the winch to lower the platform, and then rides or walks off.

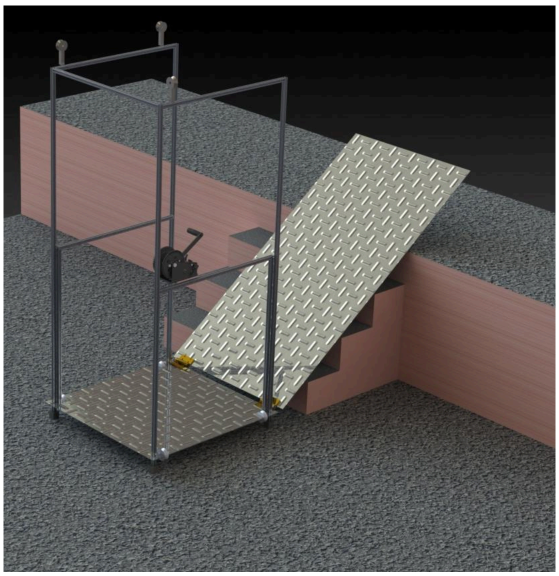


Figure 4: Vertical Lift Design at Lowered Position

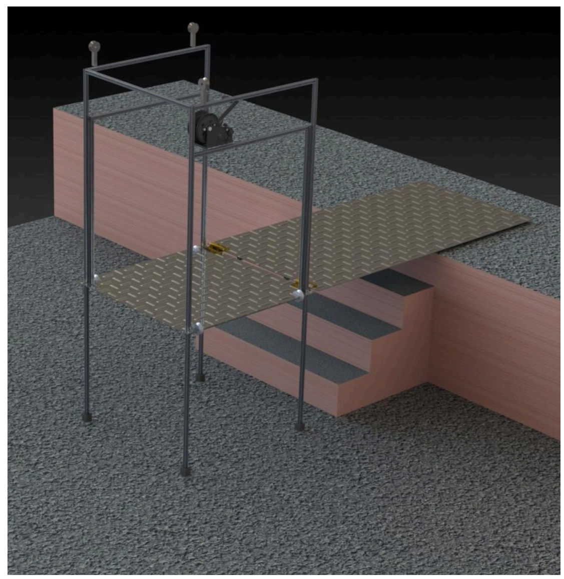


Figure 5: Vertical Lift Design at Raised Position [11]

Preliminary Design Evaluation

Design Matrix

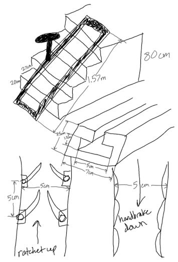
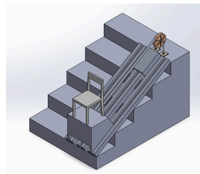
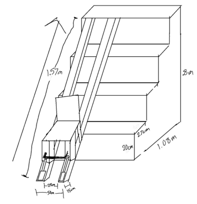
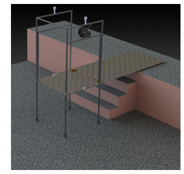
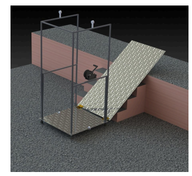
Design Criteria (Weight)	**Design 1: Ratchet** 		**Design 2: Counterweight** 		**Design 3: Hydraulic Pump** 		**Design 4: Vertical Lift**  	
Safety (25)	2/5	10	4/5	20	4/5	20	5/5	25
Efficiency/Ease of Use (25)	4/5	20	5/5	25	3/5	15	3/5	15
Adaptability (15)	3/5	12	2/5	6	2/5	6	5/5	15
Ease of Fabrication (10)	2/5	4	4/5	8	3/5	6	4/5	8
Weather (10)	3/5	6	4/5	8	3/5	6	4/5	8
Cost (10)	4/5	8	3/5	6	3/5	6	2/5	4
Weight (5)	5/5	5	1/5	1	5/5	5	1/5	1
Total Score (100)	**65**		**74**		**64**		**76**	

Table 1: Stair Chair Mechanism Design Matrix

Safety

The safety category refers to the risk of injury for a user while operating the stair chair. This category also considers the risk of worsening injuries through accidental mechanical output from the user's wounded lower extremity, either through slipping while operating the device, or total mechanical failure. Given the wide range of patients that the stair chair is hoped to be usable for, and the risks of mechanical failure, the team decided to weigh the safety category highest at 25. The vertical lift design won the safety category because the user never needs to move up and down an incline, which contributes to user safety. It also will have attached railings so that individuals will not roll off the lift as it raises.

Speed/Efficiency

The efficiency/ease of use category refers to how quickly the user can get from the bottom to the top of the stairs and how easily the chair is mounted and dismounted by the user. The team recognizes that an inefficient and slow device will not be worth using and that a device that involves significant mechanical output could limit the kind of patients who can operate the device. With this in mind, the team decided to weigh this category the second highest at a 20. The counterweight design won this category with a 5/5, earning this score for the ease of tuning the weight. The counterweight would also likely be the fastest of the options, making it much more efficient than slowly ratcheting up a track, or pumping a hydraulic chair.

Adaptability

The adaptability category refers to how much the device can be altered to fit the needs of the user. Whether the rails must be able to telescope to adjust to different amounts of stairs is one of the major considerations of this category. Also, how much tuning the device may need between patients is another consideration of this category. Given this, the team decided to weigh this category at a 10. The boat lift won this category with a 5/5 because the platform could feasibly raise to many different amounts of stairs, making it a lot more adaptable than the other track bound designs.

Ease of Fabrication

The ease of use fabrication category refers to the simplicity of designing and eventually creating a working prototype. One of the major considerations of this category is the amount of time the team has to work on the product, as well as the materials needed to complete the designs. With this in mind, there was a tie in this category between the counterweight and boat lift design, with a score of 4/5. Both designs scored highly in this category due to their large simple parts that can be fabricated by the team, as opposed to the smaller more intricate parts, especially in the ratchet mechanism.

Weather

The weather category refers to how well the design can survive extreme temperatures and severe weather conditions. The device must also be able to withstand general wear and tear from water and sunlight exposure for long periods. Since the device is meant to be usable year-round, and the winters are unpredictable in the Midwestern market, the team decided to weigh this category at a 10. The counterweight and boat lift designs tied in this category with a 4/5 mainly due to their adaptability to the cold weather conditions. The hydraulic design could fail with drastic changes in pressure, and the small ratchet mechanism could corrode after long exposure to rain and heat.

Cost

The cost category refers to how expensive the design is to fabricate and maintain. The major considerations of this category involve the complexity of designs, and also how long those designs can go between major costly repairs. Since keeping the design as inexpensive as possible was a major request from the client, the team decided to weigh this category equally with other client requirements such as the ability to withstand weather and be able to adapt to different amounts of stairs. The ratchet design won this category with a 4/5 in comparison to the larger more expensive mechanisms such as the boat lift, which would have to be purchased by the team, or a large hydraulic mechanism which would be expensive to fabricate.

Weight

The weight category refers to the weight of the device, and therefore how easy it is to set up on the stairs of each user. Since the device is temporary, it must weigh enough to prevent any tipping or sliding, but also be able to be moved between the homes of users with ease. While the weight category is an important factor to consider, the team decided that other categories were more deserving of strong consideration for the final design, and therefore weighed this category at just a 5. The ratchet and hydraulic pump design won this category with a score of 5/5 as their weight can be easily tuned by the types of materials and fluids used for the hydraulic design.

Proposed Final Design

The team has decided to move forward with the vertical lift design. It is the safest of all the designs which is very important since the users are primarily elderly stroke patients or individuals with physical disabilities. The safety comes from the elimination of various failure points such as the transition from wheelchair to an alternative chair, or a rapid descent. It is also the only design that allows the user to remain standing or seated in their wheelchair while getting over the stairs which will help with efficiency and make it easier to carry any cargo up the stairs. Additionally, the vertical lift design is the most adaptable because it only moves vertically and horizontally, and doesn't interact directly with the stairs. This would make it much easier to adjust to different staircase designs, as height is the only notable variable. It also does not require any interaction with a railing, allowing it to be implemented on staircases without railings and those that do not have a stable railing.

Fabrication

Materials

The base plates for the design were made out of aluminum diamond tread plate, one of the plates sized at 1x1 ft and 2x1 ft. The team decided on this material because of its strength and durability. It also has increased corrosion resistance and is considered to be economical as opposed to alternative materials [12]. To mount the base plates, the team purchased 4, 5 ft pieces of 20 mm x 20 mm aluminum extrusion for its resistance to debris buildup, and ability to introduce t-slotted nuts for fastening the pulleys. The team purchased 600 lb capacity single-groove pulleys from McMaster-Carr for the final design. The team also purchased surface mount hinges from McMaster-Carr. Both products purchased from McMaster-Carr were selected for their strength and also their ability to accept standardized fasteners that could be easily acquired from the Makerspace located in Wendt Commons. All fasteners used on the final design were purchased from the Makerspace. Both the corner brackets used for extra strength under the top extrusion and the HDF that was lasercut to create the stairs for the final design were purchased from the Makerspace.

Methods

To create the final prototype the team first used the miter saw at the Makerspace to cut the extrusion into the necessary sizes outlined in the full protocol in Appendix C. Once the pieces of extrusion were cut, the holes were tapped for M5 size screws and then fastened together to create the frame for the design. During the process of creating the frame, corner brackets were attached to the top parts of the connections for greater stability. Pulleys were then fastened to the top of the frame by using M4 size screws and t slotted nuts. Once the team completed the frame, the next step was to waterjet the aluminum base plate so that the extrusion could slide up and down within the frame and so that there were notches in the plate where the rope could connect to the bottom pulleys without rubbing on the base plate. The team did have to waterjet the aluminum base plate two times as the first hole size was not large enough to allow the extrusion to slide up and down without significant friction. Once the base plate was completely waterjetted, both the base and ramp plates were drilled through. The holes on the ramp plate were created to attach the hinges, and the holes on the base plate were also for the hinges, but also the pulleys that hung down off the underside. Once the prototype was complete, the team decided to fabricate stairs scaled to the same size of the prototype for demonstrations. The boxes generated by the laser cutter at the Makerspace were generated on the boxes.py software and then copy and pasted from Adobe Illustrator into the laser cutting software. Using the HDF purchased from the Makerspace, boxes were cut out and glued together to create the stairs used in the team's demonstrations and testing.

Final Prototype

The final prototype was constructed at a ⅓ scale to the proposed final design. The prototype was also constructed without a winch as the team determined testing the winch on a scale model would not yield useful results and could therefore be omitted to save cost. The prototype uses the vertical lift mechanism as proposed with the preliminary final design. In place of a winch, the rope is simply pulled to raise and lower the platform. This prototype allowed us to test the function of the mechanism without investing a large sum of money.

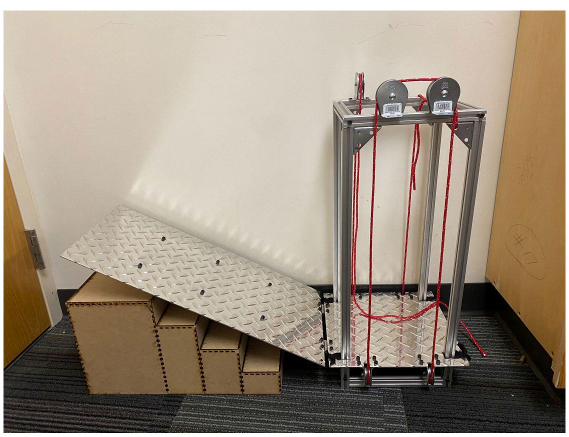


Figure 6: Final Prototype at Lowered Position

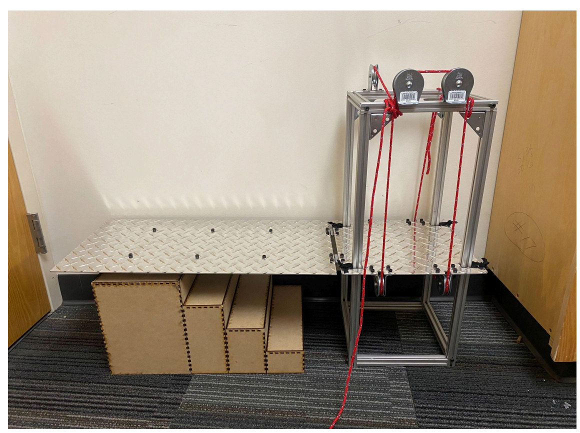


Figure 7: Final Prototype at Raised Position

Testing

Platform Tilt Angle Testing

Platform tilt angle testing was done to determine both the effect of nylon and weight on the tilt angle of the base plate. A greater tilt angle implies less balance, and subsequently more friction, which both increases the force requirement to raise, and decreases stability and safety of the device. This tilt angle was tested using a level on an iPhone, and the angle was measured at various points throughout the height of the lift. Three trials were performed with each weight, both with and without nylon.

Force Requirement Testing

Figure 8: Required Force Testing with Load of 7.5 kg with Inclusion of Nylon

Force requirement testing was performed to determine the input force required to raise varying loads up the height of the lift. The testing was performed first without nylon, and then with nylon added to the plate at the interaction point with the vertical extrusions. A dynamometer, or grip strength tester, was used to measure the input force, and load was varied using metal plates. The string was tied to the dynamometer, and it was then pulled and the force was recorded. The force was recorded at various points throughout the ascension to determine how this input force varied up the height of the lift. Three trials, both with and without nylon, were done at weight increments of 2.5 kg from zero kg up to 12.5 kg.

Results

Platform Tilt Angle Testing

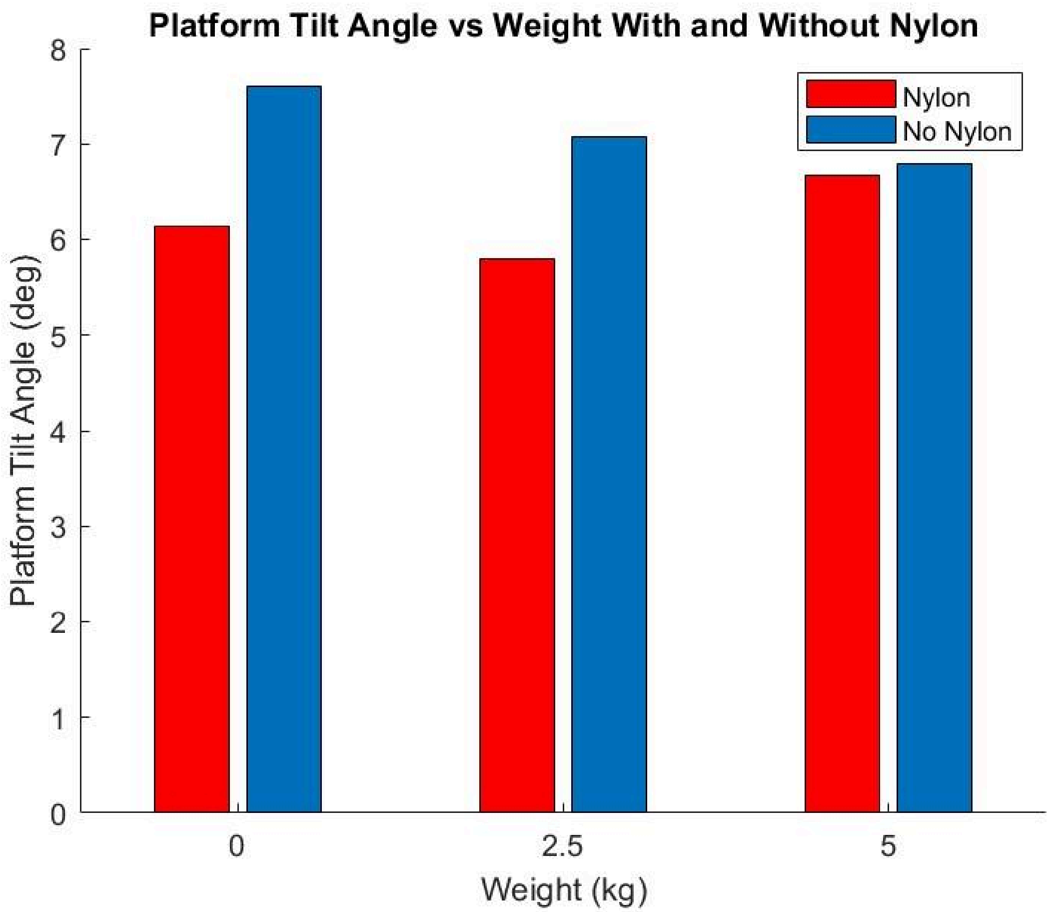


Figure 9: Average Platform Tilt Angle While Raising Platform With and Without Nylon

As seen in the above figure, before adding nylon, the average platform tilt angle decreased with added weight, but after more than 5 kg was added, friction greatly prevented movement. With the inclusion of nylon, the tilt angle decreased by nearly one degree on average and was minimized with 2.5kg. The angle did begin to increase when more weight was added due to the overall instability of the base plate. The space between the holes of the base plate and the aluminum extrusions allowed for tilt, which was exacerbated with both lower friction and higher weights. Much of this platform tilt would be remedied further by the use of T-slot bearings to hold the base plate level to the extrusions and more precise machining of the holes in the plate. Additionally, better placement of the pulleys to offset the weight of ramp on one side of the plate would eliminate much of this tilt.

Force Requirement Testing

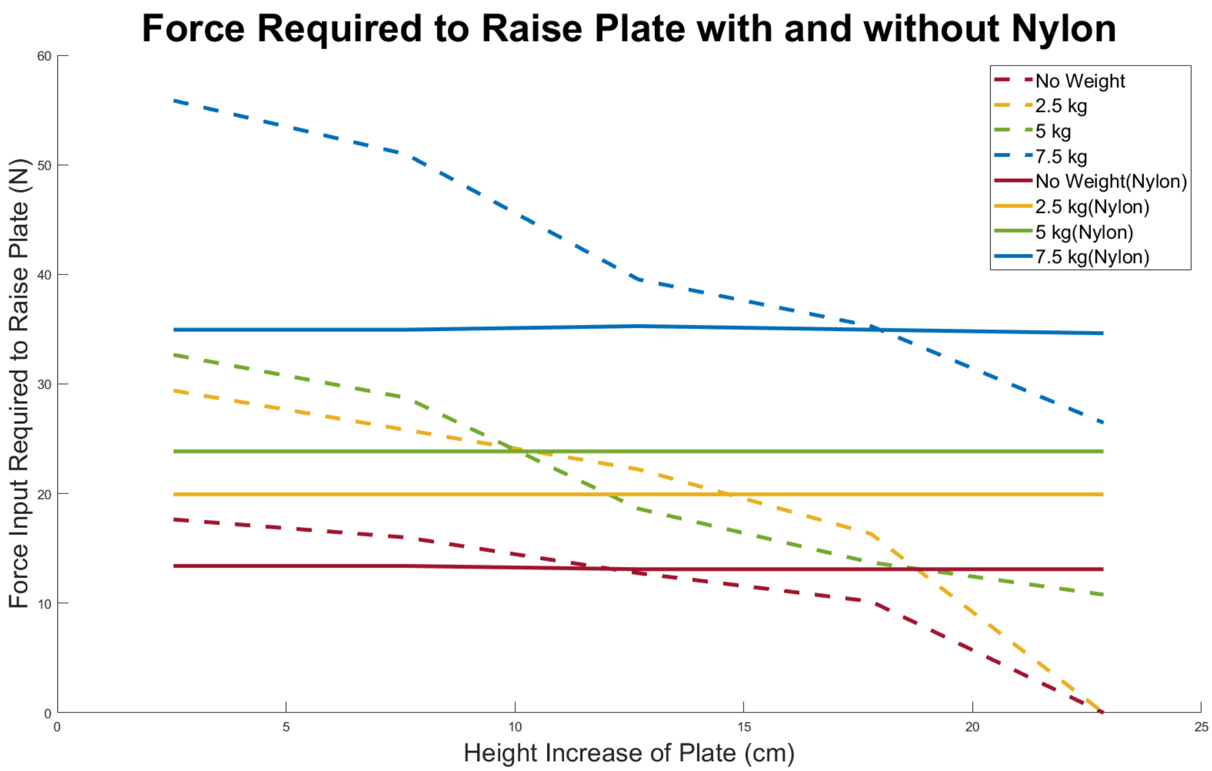


Figure 10: Force Required to Raise Lift with and without Nylon

The above figure shows the force required to raise the stair lift at various points throughout its ascension. As is clear on the graph, before the inclusion of nylon, there was a clear decrease in required force throughout the duration of the lift, with the initial measurement point having the highest force. This demonstrates a high static coefficient of friction from the two aluminum objects (the base plate and the aluminum extrusions) interacting with one another. The force often dropped very low at the top of the lift due to this friction now resisting the downward movement of the platform rather than the upward movement. With the inclusion of pieces of nylon at the interaction point between the aluminum pieces, the required force remained nearly constant throughout the ascension. This qualitative piece of information is very important for the functionality of the device, as a smooth ascent is vital in a good chair lift product. Additionally, the lower initial force requirement decreases the maximum power output that must be done by the individual using the device.

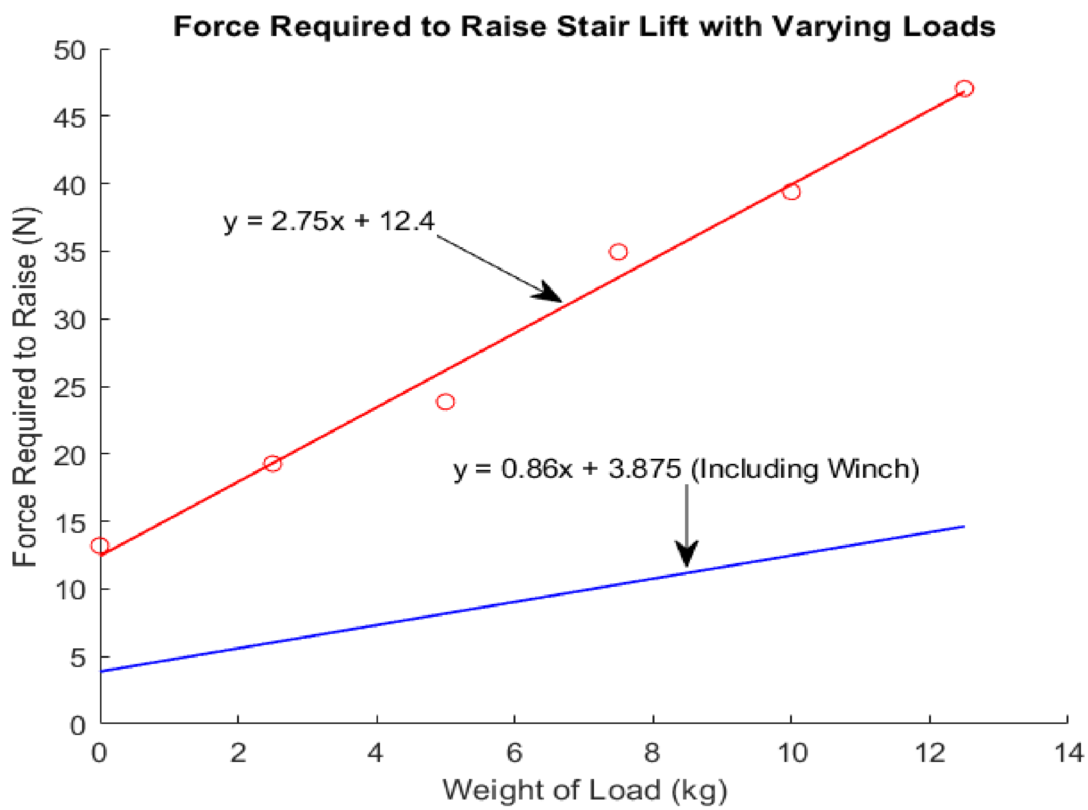


Figure 11: Force Required to Raise Lift with Nylon at Varying Loads

The above figure includes points that represent the average force required to raise the lift at varying loads. These average force values increased linearly with an increase in load, and this linear increase is approximated with the equation shown above the red line. This means that at this scale, a 1 kg increase in load corresponds to a 2.75 N increase in required force. The value of 12.4 N as the y-intercept represents the force required to lift just the weight of the device itself. An additional line was added to the graph, showing the effect that a winch would have on the force requirement of the device, decreasing force requirement by 3.2 times due to the gear ratio of the winch. Although theoretical, and at a scale level, this information allows us to make estimates for the power needed to raise the platforms for individuals of different weights. For example, if we scaled down both the mass and power output of an average elderly woman by ⅓ to match the scale of the device, she would be able to raise the device in 10 seconds at 10% of her maximum power output potential. The team believes these values to be adequate to prove the efficacy of this concept and for a full scale prototype to be created to test these values and their accuracy.

Discussion

The results of testing reveal that further improvements to the design are needed to keep the apparatus level and in turn, safe. Assuming the scale model could carry the maximum load of 300 kg, 262 Newtons of force would be required to move the platform at a steady rate. With the minimum expected power output by the user being 2148 kg/min, a 300 kg load could be raised to the height of 3-5 stairs in 2-3 seconds.

Ethical considerations have been made since the inception of this project to ensure that people with mobility issues can use the device safely. Some slight modifications must be made to allow for wheelchair users; a small ramp as well as a plate over the gap created by the hinges. Another consideration that would have to be made is the placement of the winch for people of different handedness that are wheelchair bound. The winch should be easily swappable so that both left and right handed people can easily operate it.

The results of testing show that the design has promise, but some changes would be made moving forward with the project. Firstly, the base plate should be attached to the vertical frame using either linear rails or bearings. This change would fix the plate in place and keep it from twisting which was a major issue with our prototype. Secondly, future designs would need to include safety features such as railings and multiple modes of failure to ensure the device passes all standards. The current design leaves the pulleys underneath the base plate resting on the base extrusions. An improved model would include some rings around the vertical rods to catch and support the moving platform at an appropriate level.

The holes in the base plate are wider than the extrusions leading to inconsistent and loose movement which is a source of error when testing applied forces and relevant angles. Another source of error in testing is human use. Humans are unable to identically replicate trials when testing. During use, the weights on the platform often slide slightly off center. The movement was minimized during trials, but when the weights were more than 3 centimeters from the center, there was a large impact on the observed platform tilt angle. It is unlikely that these sources of error caused found values to be significantly inaccurate or uncertain.

Conclusions

The team was tasked with designing and creating a proof of concept for a device that assists discharged patients from the Encompass Rehabilitation Hospital with stair negotiation. The device is meant for a range of 3-5 risers and is mechanically powered. To fulfill this request, the team created an adaptable ⅓ scale design devised of aluminum diamond tread mounted to aluminum extrusion powered by a pulley system that can lift the aluminum base plate by pulling on the rope, using the hand as a makeshift winch for the scale model.

The team found that this scale model was representative of what the full scale model could look like, and also the loads applied to the scale model during our testing were congruent with the expected loads on a full scale design. The team also found that including the nylon in the holes that the plate slid up and down on made for constant force application to lift the model. Laser cutting the stairs was a cheap and effective way to represent the usefulness of the prototype. With this in mind, there are a few problems with the design that are worth looking further into. Firstly, the team would like to introduce some type of bearing onto the bottom of the base plate so that there would no longer be the tipping caused by the unevenness of the distribution of weight on the base plate. Also, in a full scale model, the winch must be selected so that it can be manriding and therefore useful in the final design. The team would also look into adding a ramp to the bottom so that the design could be used by individuals in wheelchairs. Lastly, the team could rethink the pulley system as another means to help with the distribution of weight being lifted, to prevent tipping of the device.

References

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Appendix

Appendix A: Product Design Specifications

Function

The main function of this device is to transport non-weight-bearing patients both up and down an outdoor staircase consisting of 3 to 5 stairs. It should also allow for easy access into and out of the device for the patient. The device should be an inexpensive alternative to electric stair lift systems, as well as being resistant to conditions that come with Wisconsin winters. Additionally, the device should be light, but sturdy enough to withstand frequent use across eight to ten-week windows when patients are non-weight bearing.

Client requirements

- The client requests a proof of concept for a mobile stair chair that non-weight bearing patients of his can use to travel up and down between 3 to 5 stairs
- The device should be free-standing to make the device accessible for patients that do not have sturdy rails leading up to their residences
- The device must be durable enough to withstand heavy use during eight to ten-week windows
- The device must be reusable once a patient no longer needs to use it to travel up and down stairs
- The chair must be able to swivel and support up to 140 kilograms
- Given the old age of some of the patients, the ratchet system should not require more mechanical power than an 80-year-old could output with one leg
- The chair must have a seat belt attachment to keep patients secure as they use the device

Design requirements

1. **Physical and Operational Characteristics**
    a. *Performance requirements*

The device will be used frequently during largely eight to ten-week spurts, but should also be able to withstand up to twenty-six weeks of frequent use for patients that remain non-weight-bearing for longer. The device should also be capable of holding up to 140 kg.

b. *Safety*

The chair should have an attached seat belt to keep patients from falling off during use. The device should also have stable legs that keep it from tipping over, as it will be a freestanding unit. A ratchet system will be used on the rails to prevent patients from accidentally sliding down five steps while attached to the device. The chair will also be able to be sanitized easily as it will be made from plastic. Given the originality of the idea, there are limited standards to be concerned with beyond ISO 13485, the standard of quality for medical devices [1].

c. *Accuracy and Reliability*

The device should be able to ratchet up the stairs without enduring significant wear and tear that could render it unusable. The attached seat should swivel without much force, allowing a patient to twist the seat and get off of the chair once they have reached the top of the stairs.

d. Life in Service

The assisted stair chair is built with the assumption that it will be rented out by DME (durable medical equipment) rental companies. That being said, it will deteriorate from transport, installation, patient use, removal, and cleanings. Altogether the assisted stair chair can expect a lifetime of 5 years as compared with other DME [2].

e. Shelf Life

Due to the metal component of the assisted stair chair, the device should be stored in a dry, climate-controlled environment to prevent corrosion. Additionally, the device should be protected from high pH conditions, salt, and other corrosive materials.

f. Operating Environment

The assisted stair chair should be able to withstand routine weather conditions as well as tougher conditions. It should be able to withstand temperatures between -18°-52°C and should be able to function within the normal atmospheric pressure range between 751-767 mmHg [3]. Additionally, the assisted stair chair should be able to handle outdoor conditions such as dirt, snow, rain, humidity, and other common conditions.

g. Ergonomics

The stair chair should be accessible to a wide range of individuals, specifically those with limited strength in one leg. The force required to raise the chair should be feasible for all, meaning a force of 20 kg should be able to cause upward motion [4]. Additionally, the plate should be reachable for all users from a seated position, and getting onto and off of the chair should be seamless regardless of height.

h. Size

Staircases in Wisconsin must be at least 91.44 cm wide [5], so the stair chair should be able to accommodate staircases of that width and greater. This means that the product should be able to be installed and function within that 91.44 cm range without causing discomfort for the user. With a wider staircase, room should be made to the side of the product to allow for walking.

i. Weight

Because the individual will be propelling both themselves and the product up the staircase, the weight of the product should be minimized, with a maximum product weight being 30 kg. This maximum weight is adjustable if added weight allows for more mechanical advantage. An ideal weight is from 10-15 kg, and there is no concern with a minimum weight, as long as the product can withstand the performance requirements stated earlier. The track portion of the product does not have weight requirements.

j. Materials

The material for the chair portion should be a strong and durable yet relatively lightweight plastic, with metal included where needed to strengthen the product. The rails for the device will likely be made out of some aluminum alloy, given the material's high strength-to-weight ratio, excellent corrosion resistance, and high ductility that allows them to be shaped without damage to the material [6]. Additionally, a fabric cover could be included to keep the product out of the elements.

k. Aesthetics, Appearance, and Finish

The finish on the product should be a texture that is not overly slippery to prevent injuries. As far as color, many stair lifts come in a cream, beige, or light gray color [7] to not draw attention to the product. A neutral color such as those will be the initial goal for the product but can be expanded on with additional time.

2. **Production Characteristics**

a. Quantity

Client is seeking a proof of concept item.

b. Target Product Cost

Production cost will be determined once the feasibility of the product is determined through proof of concept.

3. **Miscellaneous**

a. Standards and Specifications

Standards are limited due to the novelty of the product. Related standards include:

i. ADA §405 - ADA Standards for ramps. [8]
ii. S. Hrg. 111-1138 - Hearing before the Senate Subcommittee on Employment and Workplace Safety of the Committee on Health, Education, Labor and Pensions - discusses patient lifting standards. [9]
iii. FDA CFR Title 21, Volume 8 §850.5150 - FDA standard on powered chair lifts. [10]
iv. ASME A18.1-2017 - American Society of Mechanical Engineers standard on safety for powered chair lifts. [11]
v. ISO 13485 - international standard on quality and safety of medical devices. [2]
vi. Premarket Notification 510(k) - “A 510(K) is a premarket submission made to FDA to demonstrate that the device to be marketed is as safe and effective, that is, substantially equivalent, to a legally marketed device.” Premarket Notifications can only be used for Class I and II devices. There is no classification for the proposed device, however the powered chair lift is classified as a class II device. [12]

b. Customer

The client intends to rent out the apparatus to patients at the Encompass Health Rehabilitation Hospital of Fitchburg. Patients are typically older people with short term mobility issues, most often with one usable leg.

c. Patient-related concerns

Since the device is intended for short term use, comfort is not necessarily prioritized. Safety is important to address since patients are already dealing with injuries. The device should require little effort to use.

d. Competition

Current solutions for ascending and descending stairs with a mobility issue include electric stair lifts, wheelchair lifts, wheelchair ramps, and elevators. The goal of this project is to provide a cheaper, temporary, and more practical solution than these alternatives. Few stair assist devices exist that are portable, lightweight, and safe. One dubbed the "Step by Step" is another UW Madison BME design project that Daniel Kutschera was involved in [13].

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Appendix B: Finance Table

Item	Description	Manufacturer	Mft Pt#	Vendor	Date	QTY	Cost Each	Cost Total	Link
Category 1									
Surface-Mount Hinge	Hinges for connection of base and ramp plates.	McMaster - Carr	1798A31	McMaster - Carr	11/1	2	$9.62	$19.24	https://www.mcmaster.com/products/hinges/
Pulley	Pulley for ropes to hoist design.	McMaster - Carr	3099T34	McMaster- Carr	11/1	8	$11.89	$95.12	https://www.mcmaster.com/products/pulleys/pulleys~/mounted-pulleys-for-wire-rope-for-lifting/
Silver Anodized Aluminum—Grooved Rail Texture	Extrusion for support and framework.	McMaster - Carr	47065T101	McMaster - Carr	11/1	4	$28.93	$115.72	https://www.mcmaster.com/47065T101-47065T413/
Diamond Tread Aluminum ⅛ inch Baseplate (1x1 and 1x2)	Material for base and ramp plates	Metals Depot	P418	Metals Depot	11/1	2	$18.92 (1x1) $32.84 (1x2)	$51.76	https://www.metalsdepot.com/aluminum-products/aluminum-diamond-plate
Hardware (screws, brackets, nuts)	Used to fabricate the final design	UW Makerspace		UW Makerspace	12/2	1	$16.78	$16.78	
HDF	Used to make the stairs for the final design	UW Makerspace		UW Makerapce	12/2	1	$4.48	$4.48	
							TOTAL:	**$303.02**	

Appendix C: Fabrication Protocols

Full Prototype

1. Cut the 20:20 aluminum extrusion to length (around 16 inches 4x for the height wise ones) (6x 8.4 inches, 2x 10 inches) (cut two to 18 inches for ramp plate)
2. Water-jet the aluminum base plates to create holes for the extrusion to run through (the cuts on the base plate should be 1 inch in from each side) (cuts will be about .8 inch side length squares)
3. Cut a notch into each side of the base plate to prevent the rope from rubbing on the metal
4. Tap the extrusion holes for fasteners
5. Fasten the extrusion together at the bottom with offset screws (see the figure below for details)

6. Fasten the top plates across
7. Attach 8 brackets (2 per piece of extrusion) for further stability
8. Use the hinges to attach the two plates

Water Jet

1. Download ProtoMax Make software
2. Program cuts into software
    a. The holes should be 1 inch inset from each corner and be 90x90mm
    b. The pulley slots should be 1 inch inset from the holes and go 1 inch in to the plate
3. Place plate into waterjet and secure with clamps
4. Fill waterjet until water just covers top of material
5. Run the program.

Laser Cut

1. Use boxes.py to generate the boxes needed for the laser cutting files
2. Take the files generated from boxes.py and select the thickness of the material to ensure that the material will be cut through completely
3. Download these files as .dxf and move them adobe illustrator for final processing before putting the wood into the laser cutting machine
4. Set the scope to 255 on the red in RGB to ensure the corners are defined by the laser cutting software
5. Copy and paste these drawings into the laser cutting software and ensure the laser is on material for the entire size of the wood
6. Once the corners are established on the software, allow the process to run
7. Once the boxes are cut out of the wood, pull the small pieces off and use a mallet to attach the panels of wood together
8. Once all four boxes have been put together, use wood glue to attach the boxes to create the final stairs

Metal Fabrication

1. Cut the extrusion using a chop saw into 6 8.4 inch pieces, 2 10 inch pieces, 2 22 inch pieces and 4 24 inch pieces
2. Tap the holes in the 8.4 inch pieces of extrusion and in the 10 inch pieces of extrusion so they can be attached for the top and the bottom of the frame
3. Screw the extrusion together to create the base, this will be made from connecting the 24 inch pieces and the 8.4 inch pieces
    1. Attach two 8.4 pieces on opposing sides that are above the screw hole for the bottom to create the base
4. Drill a hole through two of the pulleys to attach the t slotted fasteners and the screws
5. These pulleys will be the ones to hang off the sides and must be tight to the extrusion
6. Attach the pulleys onto the bottom with holes drilled through the base plate (these pulleys will be close to the notches in the base plate)
7. Drill through the ramp plate to attach the bottom pieces of extrusion that are meant for support (there will be three screws on each extrusion evenly spaced)
8. Drill through the base plate to attach the hinges and use a nut on the end to make sure the screw is fully attached

Appendix D: Testing Protocols

1. Place test weight on base plate and secure with tape

2. Place level on top of weight to record tilt angle

3. Pull rope using force meter

4. Record tilt and force at 1,3,5,7 & 9 in above bottom of plate

5. Repeat protocol for 0, 5, 10, and 15 lbs

Appendix E: Raw Data and MATLAB Code

Raw Data

Angle Data:

angle with no weight								
Trial	Weight (lbs)	0	1	3	5	7	9	←Height Raised (in
1	0	0	6	7	6	6	6	
2	0	0	6	6	6	6	6	
3	0	0	6	7	6	6	6	
	average	0	6	6.666666667	6	6	6	6.133333333
angle with weight centered								
Trial	Weight (lbs)	0	1	3	5	7	9	←Height Raised (in
1	5	0	6	6	6	6	5	
2	5	0	6	6	6	6	5	
3	5	0	6	6	6	6	5	
	average	0	6	6	6	6	5	5.8
angle with weight centered								
Trial	Weight (lbs)	0	1	3	5	7	9	←Height Raised (in)
1	10	0	9	7	7	6	6	
2	10	0	7	7	7	6	6	
3	10	0	6	7	7	6	6	
	average	0	7.333333	7	7	6	6	6.6666666

			333						67

angle with no weight and no nylon								
Trial	Weight (lbs)	0	1	3	5	7	9	←Height Raised (in
1	0	0	8	8	8	7	7	
2	0	0	8	8	8	7	7	
3	0	0	8	8	8	7	7	
	average	0	8	8	8	7	7	7.6
angle with 5 lbs and no nylon								
Trial	Weight (lbs)	0	1	3	5	7	9	←Height Raised (in
1	5	0	9	8	8	7	7	
2	5	0	8	8	7	7	7	
3	5	0	6	7	6	6	5	
	average	0	7.666666667	7.666666667	7	6.666666667	6.333333333	7.066666667
angle with 10 lbs and no nylon								
Trial	Weight (lbs)	0	1	3	5	7	9	←Height Raised (in
1	10	0	6	7	6	6	5	
2	10	0	8	8	8	7	7	
3	10	0	7	7	6	6	8	
	average	0	7	7.333333333	6.666666667	6.333333333	6.666666667	6.8

Force Requirement Data without Nylon:

	Weight (lbs)	**Trial**	**Deflection of Platform (° from flat)** **Avg Force Required to Lift (kg)** **At Height Above Base (in)**					
			0	**1**	**3**	**5**	**7**	**9**

	0	**1**	**0** **0**	**8** **1.7**	**8** **1.8**	**8** **1.4**	**7** **1.0**	**7** **0**
	0	**2**	**0** **0**	**8** **1.9**	**8** **1.5**	**8** **1.3**	**7** **1.1**	**7** **0**
	0	**3**	**0** **0**	**8** **1.8**	**8** **1.6**	**8** **1.2**	**7** **1.0**	**7** **0**
	5	**1**	**0** **0**	**9** **2.9**	**8** **2.4**	**8** **2.3**	**7** **1.8**	**7** **0**
	5	**2**	**0** **0**	**8** **3.1**	**8** **2.7**	**7** **2.1**	**7** **1.5**	**7** **0**
	5	**3**	**0** **0**	**6** **3.0**	**7** **2.8**	**6** **2.4**	**6** **1.7**	**5** **0**
	5	**DOES NOT LIFT**						
	5	**1**	**0** **0**	**7** **6.4**	**7** **5.3**	**-8** **5.0**	**DOES NOT EXCEED 5 in**	
	5	**1**	**0** **0**	**7** **5.4**	**8** **5.0**	**7** **4.9**	**8** **5**	**7** **2.4**
	10	**1**	**0** **0**	**6** **3.4**	**7** **2.6**	**6** **1.5**	**0** **1.3**	**5** **1.1**
	10	**2**	**0** **0**	**8** **3.5**	**8** **3.2**	**8** **2.2**	**7** **1.6**	**7** **1.3**
	10	**3**	**0** **0**	**7** **3.1**	**7** **3.0**	**6** **2.0**	**6** **1.3**	**8** **.9**
For 15 lbs, only force was measured								
	15	**1**	**0**	**5.3**	**5.1**	**3**	**3.1**	**2.1**
	15	**2**	**0**	**5.7**	**5.0**	**4.3**	**3.6**	**2.5**
	15	**3**	**0**	**6.1**	**5.5**	**4.8**	**4.1**	**3.5**

Force Requirement Data with Nylon:

force with no weight							
Trial	Weight	0	1	3	5	7	9
1	0	1.3	1.3	1.3	1.3	1.3	1.3
2	0	1.4	1.4	1.4	1.4	1.4	1.4
3	0	1.4	1.4	1.4	1.3	1.3	1.3

force with weight centered

Trial	Weight	0	1	3	5	7	9
1	5	2.1	2.1	2.1	2.1	2.1	2.1
2	5	2.1	2.1	2.1	2.1	2.1	2.1
3	5	1.9	1.9	1.9	1.9	1.9	1.9

force with weight centered

Trial	Weight	0	1	3	5	7	9
1	10	0	2.4	2.4	2.4	2.4	2.4
2	10	0	2.4	2.4	2.4	2.4	2.4
3	10	0	2.5	2.5	2.5	2.5	2.5

force with weight centered

Trial	Weight	0	1	3	5	7	9
1	15	0	3.5	3.5	3.5	3.5	3.5
2	15	0	3.6	3.6	3.6	3.6	3.6
3	15	0	3.6	3.6	3.7	3.6	3.5

force with weight centered

Trial	Weight	0	1	3	5	7	9
1	20	0	3.9	3.9	3.9	3.8	3.8
2	20	0	3.6	3.6	3.6	3.6	3.6
3	20	0	4.6	4.6	4.6	4.6	4.6

force with weight centered

Trial	Weight	0	1	3	5	7	9
1	25	0	4.8	4.8	5	5.2	5.2
2	25	0	4.1	4.1	4.7	4.7	5
3	25	0	4.4	4.5	4.9	5.3	5.3

MATLAB Code

Code for Figure 9:

```
avg_nylon_0lbs=6.133333333;
avg_nylon_5lbs=5.8;
avg_nylon_10lbs=6.666666667;
avg_nonylon_0lbs=7.6;
avg_nonylon_5lbs=7.066666667;
avg_nonylon_10lbs=6.8;
data=[6.133333333,7.6;5.8,7.066666667;6.666666667,6.8];
weights=['0kg','2.5kg','5kg'];
bar(data)
%Axis labels, title, and legend added manually
```

Code for Figure 10:

```
figure(1);
hold on;
plot(Heights,noNylon(1,:),'Color','#A2142F','LineStyle','--','LineWidth',3);
plot(Heights,noNylon(2,:),'Color','#EDB120','LineStyle','--','LineWidth',3);
plot(Heights,noNylon(3,:),'Color','#77AC30','LineStyle','--','LineWidth',3);
plot(Heights,noNylon(4,:),'Color','#0072BD','LineStyle','--','LineWidth',3);
plot(Heights,nylon(1,:),'Color','#A2142F','LineWidth',3);
plot(Heights,nylon(2,:),'Color','#EDB120','LineWidth',3);
plot(Heights,nylon(3,:),'Color','#77AC30','LineWidth',3);
plot(Heights,nylon(4,:),'Color','#0072BD','LineWidth',3);
xlabel('Height Increase of Plate (cm)','FontSize',20);
ylabel('Force Input Required to Raise Plate (N)','FontSize',20);
title('Force Required to Raise Plate with Varying Loads','FontSize',30);
lgd = legend('No Weight','2.5 kg','5 kg','7.5 kg','No Weight(Nylon)','2.5
kg(Nylon)','5 kg(Nylon)','7.5 kg(Nylon)');
fontsize(lgd,15,'points');
```

Code for Figure 11:

```
figure (2);
hold on;
scatter(weight,forceRequired,"o","r");
p = polyfit(weight,forceRequired,1);
px = [min(weight) max(weight)];
py = polyval(p,px);
plot(px,py,'LineWidth',1,'color','r');
f=@(x) .86*x + 3.875;
fplot(f,[0,12.5],'LineWidth',1,'color','b')
xlabel("Weight of Load (kg)");
ylabel("Force Required to Raise (N)");
title("Force Required to Raise Stair Lift with Varying Loads");
x=[.4 .5];
y=[.7 .62];
x2=[.6 .6];
y2=[.4 .3];
ylim([0,50]);
annotation('textarrow',x,y,'String','y = 2.75x + 12.4');
annotation('textarrow',x2,y2,'String','y = 0.86x + 3.875 (Including Winch)');
```