KU SCHOOL OF ENGINEERING
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Abstract

Wheelchairs are an essential part of many people's lives. Within the United States alone, as many as 2.2 million people depend on them in their daily lives. For many, moving to and from the wheelchair itself can be a tiring, even dangerous part of their day. Wheelchair transfers put a large amount of stress on the veterans arms. The goal of this project is to reduce the difficulties of performing wheelchair transfers, pursued in changing three components of the common wheelchairs used by the Department of Veterans Affairs. This project will address the placement and storage of the transfer boards, the location and usability of the leg rest, and design and attach a seat lift system. The goal of this two semester project is to produce a turn key prototype to improve the transfer process for veterans. At the end of the second semester designs for all components and prototypes for the transfer board integration were completed. Designs for the lift system drive mechanism and structural integration and support, and the leg rest are complete with their prototypes still under construction and should be successfully completed in June.

Acknowledgements

This project would not have been possible without the assistance of the following parties:

First, the team would like to thank the faculty advisor Professor Thomas DeAgostino for all his guidance and support. Through weekly meetings and random office visits this project developed and the team was very excited to see where it has gone.

Thank you to the BREAK facilitator and technical advisor Dr. Kenneth Fischer for his expertise in engineering and this project. Through his input the team was able to revise and improve their concepts into efficient, practical designs.

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Lastly, the team would like to thank the previous capstone team, Anne Henselman, Katherine Hybl, and Jakob Yedo, for the work they put in last year. They provide a great springboard to get the team started, and hit the ground running.

Nomenclature

KU:	University of Kansas
BREAK:	Biomechanical Rehabilitation Engineering Advancement in Kansas
Leavenworth VA:	Dwight D Eisenhower Department of Veterans Affairs Medical Center in Leavenworth Kansas

Introduction

For many veterans with limited mobility wheelchairs provide the capacity to increase their independence. But there are still areas where improvements can be made. One aspect of the wheelchair that could be vastly improved is the process of transferring to and from the wheelchair by way of a transfer board. For standard wheelchairs the current process involves the user, or their attendant, placing the transfer board underneath the user's hip and then rocking and shuffling across the board to the new surface. Much of the time direct horizontal transfers are impossible due to elevation differences. Because of this the transfer process can be difficult, tiring, and at times even dangerous. A 2010 study done at Veteran Administration hospitals showed that approximately 31% of its participants experienced a wheelchair related fall, with 14% of participants suffering an injury as a result of the fall (Nelson, et al., 2010). The Dwight D Eisenhower Department of Veterans Affairs Medical Center in Leavenworth Kansas (Leavenworth VA) has partnered with the University of Kansas (KU) Biomechanical Rehabilitation Engineering Advancement in Kansas (BREAK) program to address this common problem.

This was the second year of this project. The original team researched and brainstormed designs to address the Leavenworth VA's concerns but were unable to complete a prototype. The 2017-2018 Capstone Team started from the former team's research, analyzing and altering the designs to best address the needs of the Leavenworth VA.

Problem

The three primary points of concern for the Leavenworth VA were the relative seat height when transferring, leg rest position while transferring, and transfer board storage. During the transfer processes it is rare that the wheelchair seat height is equal to the destination height (ie. going from the wheelchair to a car seat). This elevation difference can result in instability of the transfer board, and increased strain on the user.

The Leavenworth VA was a concerned about leg rest position due to the frequency with which they become a trip hazards. Most leg rests in use swivel to the side, but unless time is taken to either completely folded up the foot pedal or remove the leg rest entirely, they protrude off the main body of the wheelchair.

The Leavenworth VA's final point of concern was the accessibility of the transfer board while in storage. A common method of storing transfer boards is to hang the board off of the back of the chair. However, this location creates difficulties for users with a limited range of upper body motion, and other items frequently hung from the same location interfere with the accessibility of the board.

Solution Goals

The team's overall goal was to make the transfer process easier to complete either with, or without assistance; the specific goal was to provide a wheelchair prototype that addressed all three of the Leavenworth VA's points of concern. In order to address concerns about relative seat height the team designed a lift system controllable by the user, or an assistant, which would be able to match the height of a desired transfer destination. To consider the lift system successful, it had to be easy to use, safe, and able to match the height of a wide range of common transfer destinations such as beds, chairs, or car seats.

The goal for the leg rest system was to alter the design in such a way that the leg rest could be taken completely out of the way of wheelchair user as well as their assistants. This component was considered successful if it eliminated trip hazards for the staff and was easily stored and retrieved.

The goal for transfer board accessibility was to incorporate the storage of the transfer board in such a way that users with limited upper body range of motion could easily access it without it interfering with the daily use of the wheelchair. The transfer board integration would be considered successful if it was easy to access, use, and return to its storage, and did not interfere with the general use of the wheelchair.

Significance and Impact

While there were effective methods of transferring that worked, and could be adapted to fit the daily lives of most users, all users deserve the best care and equipment available. On average a wheelchair bound individual will have to complete 14 to 18 transfers per day (Tsai, et al., 2014). By improving this process strain put on the user's body, and their chances of injury could be decreased. Improper transfers can result in sores and blisters on the hands and thighs, or injurious falls. This project aimed to make complex transfers safer, easier, and more efficient for wheelchair users.

The Leavenworth VA serves approximately 36,000 veterans annually many of whom use wheelchairs either short, or long-term (US Department of Veterans Affairs). By achieving its goals, this project would be able to improve the lives of many veterans using wheelchairs, as well as their loved ones, and the staff of the Leavenworth VA.

Project

Overall Design Considerations

Some considerations that have been taken into account are the customer priorities, the ease of use, the ease of implementation, safety, cost, and overall effectiveness. The designs also needed to be mindful of the extent to which each component will interfere with the wheelchair's ability to fold for storage. These considerations are the same for all parts, though some were weighted differently. The goal of the team is to provide a turnkey design to the VA hospital that will incorporate all the components they feel merit improvement. In this way we hope to ease the implement, and speed the production and distribution of our resultant product.

Each components' final design was combined into a single CAD model to present and to ensure that interactions between designs were appropriate and fully understood. This model can be seen in Figures 1 and 2 on the next page. Special consideration had to be taken into account on how the lift system supports were mounted on the base wheelchair and how the armrest would attached to ensure they did not interfere with the guiding post.

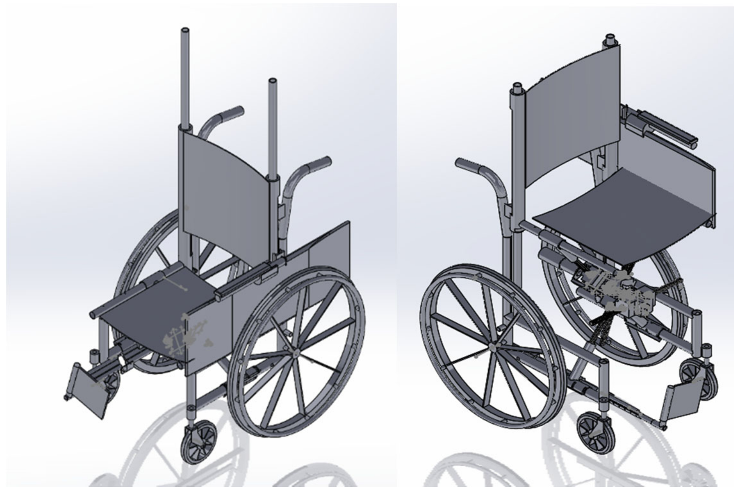


Figure 1 and 2: Comprehensive model with seat raised and lowered

Lift System Design

The Lift System could be separated into four separate subsystems, the drive mechanism, structural integration and support, the control system, and the motor and power source. As the drive mechanism largely informed the details of the other three, it is discussed first. The control system, and the motor and power source designs were delayed in order to support the advancement of the mechanical aspects of the project, and were subsequently shelved until such time as the established systems were fully realized.

The initial idea was to have a lift system that operated similar to that of a scissor lift in a car jack. A lead screw would be spun pulling the sides of the lift together making the seat raise. This design, however, lead to several issues. The first being there was a need for two inputs, one on both sides of the chair. Another flaw was that it created extreme inward moments at the back end of the seat if the user did not sit perfectly centered. This excess moment would cause severe stresses in the lift system as well as the frame. The final problem was that when the seat was lowered all the way, the seat sat an inch above the base height for the wheelchairs the system would be added to. Though small, this initial height raise could have caused issues for users that already had a difficult time getting in and out of the wheelchair. The considerations for the redesigned lift system, and the explanation of the analysis is shown below. Through the use of a decision matrix, the team's conclusion was to implement dual extending crossbars. The decision matrix for the lift system design is shown in Figure# in the appendix.

In order to have a properly working lift system the first design consideration was the rate at which the lift system would raise the user. For this a one half inch per second rate of lift was chosen. This seemed slow enough to ensure safety of the user while not taking too much time to complete the raise. With this being known the expansion rate of the lead screws could be calculated using related rates and was found to be .3 inches per second. Once the rate of lift was determined, the static forces loaded onto the wheelchair could be calculated using a distributed load of 600lb. This would allow the wheelchair to have a design factor of two as per the request of the V.A. With a load of 600lbs it was found that the compressive force acting on each lead screw is 6600 N. This would be the basis of all other structural calculations as this was the prescribed load that the wheelchair must hold. With the bearing load known, the specifications about the lead screws could be made. Knowing that the lead screw would be made out of steel, the minimal diameter of the screw could be calculated and was found to be .002m in diameter. With this being the main source of support a large design factor was chosen and the use of a .016m diameter lead screw will be used. In many lead screws of this dimensions a pitch of 2mm and 3mm can be found easily. In order to increase the friction to keep the lead screw as a self locking mechanism a 3mm pitch was chosen due to lack of options for this diameter of lead screw. Once the pitch was determined and the materials of the lead screw and the threads it will lock into were known the torque required to raise the seat was calculated and found to be 4.456 Ft*lb or 6.042N*m. This would be the basis of determining the necessary motor and gearbox combination. Another issue that arose was the thrust shoulder needed to disperse the load along a larger surface area to decrease pressure held by the gearbox. To do this, 3.3 mm was lathed off of the power screws as shown on the page 20 in Appendix 3. The power screws were then fitted with a thrust bearing sandwiched between two thrust washers and this was the acting shoulder. This served two purposes; one to disberse the load, and to also decrease the friction of the spinning power screw and the gearbox.

The crux of this lift system design was centered around the gearbox. It must take one input shaft and transmit rotation in two directions while also transmitting the rotation to the connected gearbox. This is shown in Figure 6. At first it was proposed to have each gearbox be an enclosed cube with the support being on the flat sides of the outside of the gearbox as shown in analysis page 3. With this design it was determined that the wall thickness would have to be 1.066” for aluminum and .5” for steel. Though this was an over simplified design it was proposed to decrease the open space in the interior of the gearbox. This lead to the current gearbox design shown in Figure 6. With this new gearbox design it was determined that a very specific size of gears must be used in order to give the necessary clearance for all of the shafts. The gear chosen was a 12 pitch, 15 tooth 20 degree pressure angle spiral bevel gear with a bore diameter of .5 inches. The analysis of gear loads is shown starting on Page 26. It was shown that the gears transmitted a tangential load of 71.44 lb, a radial load of 26 lb, and an axial load of 26 lb. While performing analysis on the gears, bending stress on the threads of the lead screw were calculated. It was found to be 38.65 N/mm which is well below yield stress of steel.

In the design of the gearbox it was imperative to know the shear stress put on the shoulder added to the power screw. First the shear stress was calculated and found that the shoulder thickness needed to be .31” in order to prevent yielding. In order to determine the diameter of the shoulder the shear stress on the gearbox was calculated to prevent shearing of the gearbox itself. It was determined that the diameter of the shoulder needs to be 1.1 inches in diameter.

It was suggested that there could be an out of plane torque. On last two pages of analysis the maximum torque placed on the system was calculated and the tension needed on each of the bolts holding the gearbox together was calculated. The maximum torque was calculated to be 312.386 N*m. Using this value, the force required on each bolt was calculated to be 2003.85 N. It was then thought that the threads of the bolt and the gearbox might not be able to hold this load with the prescribed diameter. With 2003.85 N on each bolt the thread stress was calculated to be 35 MPa. Using the stress for aluminum and this would be the material that would shear first, it was calculated that with the tension in each bolt of 2003.85N the bolts have a design factor 14.29.

The new design of gearbox also created a better location for bolting the two sides together and thus flanges were placed on each side of the gearbox with holes placed evenly along the flange. An unanticipated torque due to the gearboxes trying to bend the lead screws were the main source of tension in the bolts. The bolts chosen to hold this load was 18-8 Stainless Steel Socket Head Screw with a thread length of 16mm to give sufficient threads to engage the 18-8 Stainless Steel Nylon-Insert Locknut. These together would provide the necessary preload as well as be able to hold any unanticipated tensile loads.

With these design consideration in mind, an expansion of the lead screws of 5 inches on both sides yielded a 15 inch raise in the seat. This was sufficient to carry out the goals of the lift system as well as to fulfil the needs of the user.

The design of the lift system's structural integration and support subsystem was focused on three goals. Minimization of resistance to the vertical movement of the seat, maximization of support to the user, and elimination superfluous movement. This required the addition and modification of several parts.

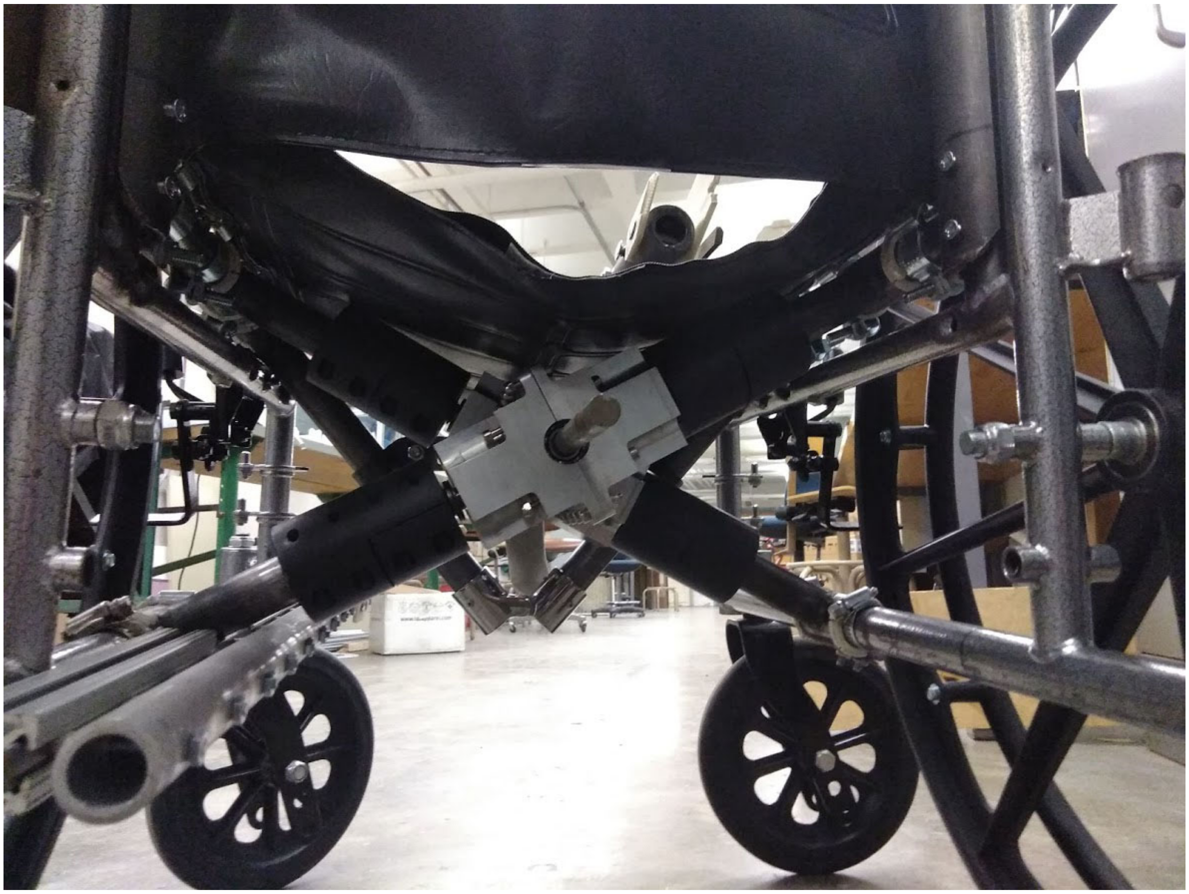
As many wheelchair users may lack significant torse strength, the ability of the back and arms of the wheelchair to lift with the seat was of utmost importance. To facilitate this a new assembly was created combining the seat and back supports. A vertical rail fixed to the frame of the wheelchair provided support while the seat was elevated. Around it a tube containing linear bearings to limit friction acted as the support to the fabric of the backrest as well as being the anchoring point of the seat bar and armrest.. The seat bars were cantilevered off of the bottom end of this vertical tube. The armrests, which were selected based on the transfer board integration system described below, were to be attached by welding.

The greatest challenge in designing the seat-backrest assembly was dealing with the moment created by the user during the initial stage of performing a transfer with a transfer board with the seat in an elevated position because at that point the entire weight of the user would, however briefly, be entirely maintained by the seat-backrest assembly on whichever side of the wheelchair the user was transfering from. It was found that under the conditions prescribed by the Leavenworth VA, this load would create a moment which could only be supported by designing the assembly with a robustness which resulted in a prohibitively excessive addition of weight to the base wheelchair. The vertical rail necessary to support this weighed in excess of twenty lbs on its own. In light of this, the decision was made to design the assembly around a 300 lb load applied to the forward most end of the seat bar, with individual parts having the capacity for greater loads where it was tenable.

The connection between the drive mechanism and the wheelchair frame and seat bars had the dual purpose of passing the load from the seat to the drive mechanism, and then to the frame, as well as housing the power screws when the seat was in an un-elevated position. This was achieved by using a solid clamping shaft coupling to lock the power screw's round nut to a length of hollow tubing of sufficient strength. The opposite end of this tube was then attached to the seat bar, or frame, with a small assembly sporting a supported sleeve bearings. This small assembly, referred to as the seat bar connector, was designed allow for the bearings to be easily replaceable, and was used in combination with the horizontal V-bar described below.

The last portion of the structural integration and support was referred to as the horizontal V-bar. It's purpose was to prevent lateral movement in the seat bars, and to ensure the wheelchair maintained a constant width. Positioned forward of the drive mechanism, the horizontal V-bar was designed to support a 600 lb load acting in either direction at the outer ends of its diagonal arms. Special attention was paid to ensuring that its positioning would not allow for any contact with the seat above it, and it was positioned as far back from the front of the seat as the drive mechanism would allow in order to avoid incidental contact with the user's legs. In order to prevent the need for extra steps while collapsing the wheelchair the horizontal V-bar was designed to be connected, by way of a web belt or canvas strip, to the center bottom of the seat sling. This was done in such a way that by lifting up on the fabric of the seat the horizontal V-bar will "unlock" allowing for the wheelchair to collapse.

The final product/system did not function, as there appeared to be binding in the gearbox drive unit, which is shown below.



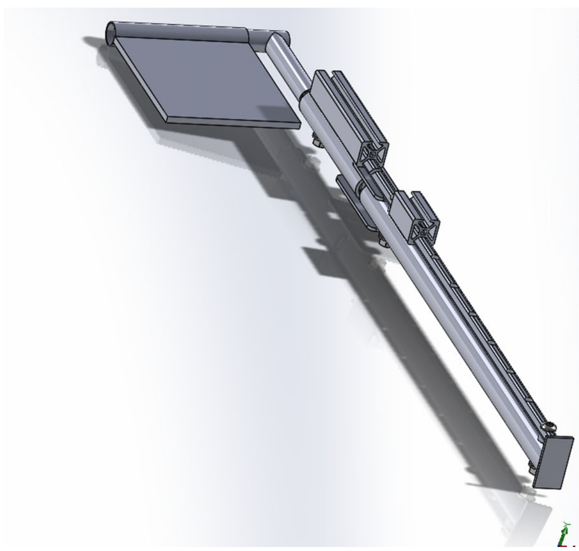
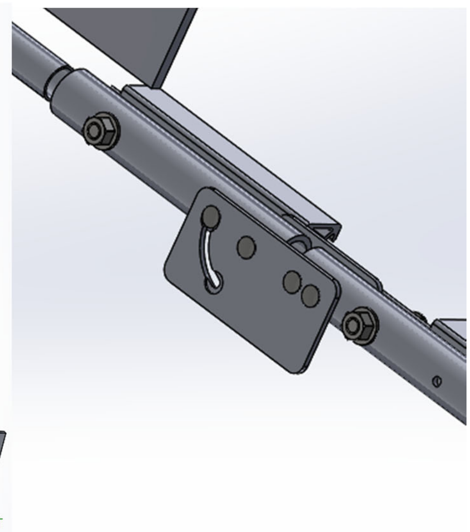
Leg Rest Design

For the leg rest design we wanted to keep the design simple and as functional as possible. We wanted to reduce the space the leg rest were talking up and still allow for the wheelchair to be folded completely. The new design had to be easy to use for both the user and the nurses, safe (with no or limited pinch points) and cost effective.

Our original idea was to move the connection point of the leg rest to underneath the seat and have the leg rest be able to retract or condense underneath the veteran. On the original wheelchair there was lower crossbar that would allow for any new rail or tubing to be added to it. With the current foldability of the chair we still had ample space to add the tubing. We considered 3 design option with the same relative operating design. The first was a rod system where the leg rest would slide on a rod and have a an elbow joint that would lower the foot paddles into place. The rod would run through a connection attached to the lower wheelchair tubing. The next idea was telescoping tubes that would collapse on themselves to save space underneath the seat. The outermost tube would have be welded or otherwise attached to the wheelchair tube. The final idea was to have the leg rest peddle already lowered on a sliding roller system. Based off of preliminary idea drawings and our decision matrix, we determined rod system was the most viable option.

The rod design uses a combination of 80/20 material in combination with steel tubing and the original foot pedal which allows the footrest to move up and underneath the wheelchair when in the up position. When in the down position it is in the same place that the current footrest is in. The 80/20 is attached to the bottom rail of the wheelchair using a set of screws and t-nuts using holes that are added to the original wheelchair. On the opposite side of the 80/20, a custom sliding t-nut is able to slide through the tracking system allowing the foot pedal to be in the both the normal down position and the new under the wheelchair position. This t-nut is attached with a series of screws to the steel tubing which makes the entire system slide through the tracks. The integral part to this design is the implementation of a 70 degree hinge that allows the footrest to lock in both the upright and down positions. A picture of this hinge can be seen below. A 3D printed prototype of this hinge was created during the semester. This new design should allow for nurses to aid the users in a safer and easier manor.

All of the parts for the assembly have been purchased from both 80/20 and Mcmaster however the 80/20 parts have not arrived yet. Due to the lack of parts, the footrest will not be assembled however the parts necessary to complete the assembly have been ordered.

Figures 3 and 4: Leg Rest System

The final product work reasonably well, but was pretty complicated. Also the plastic prototype parts were easily (and quickly) broken. The system also needed some dimensional adjustments (shown below).

Transfer Board Design

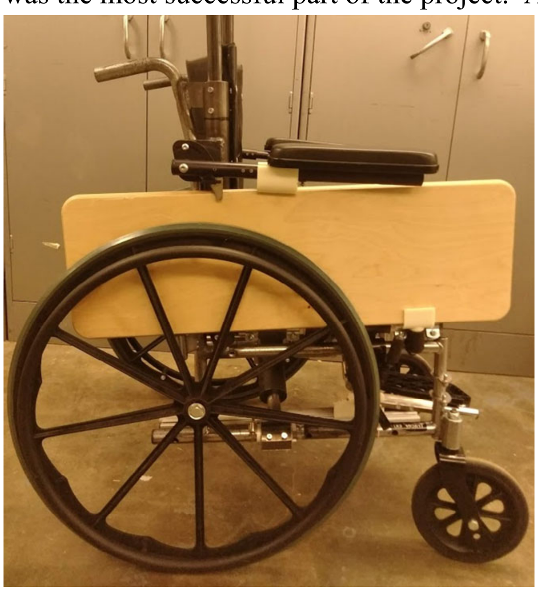
The Transfer Board is an essential part of the wheel chair design. It needs to be versatile in use, easily accessible, and not impede the function of either the lift system or the leg rest design. The veterans at the VA Hospital are very independent when it comes to transferring themselves from surface to surface, the transfer board needs to be something that the patient can use on their own, or with help from a healthcare professional. The transfer board need to be very versatile, meaning it needs to be able to transfer a patient to different surfaces at different heights and it needs to be able to transfer a patient at different angles relative to the wheelchair. meaning if a patient is trying to transfer to a different surface in a place with restricted space, such as a bathroom stall, and can not get a perfect 90 degree angle to the surface, then the transfer board needs to be able to rotate in some way in order to be effective. Another consideration to take into account is when changing the width of the wheelchair, it must still be able to fit through doorways and areas of restricted space, such as hallways. Research into the standards size of doorways, and what used to be the standard size of doorways was important to take into consideration when brainstorming ideas for the transfer board design. The standard size of a doorway is 36 inches [5]. However, there are doorways that get as small as 24 inches for bathrooms and closets. To meet ADA accessibility standards, door ways must be 32 inches in width. The width of a wheelchair is currently 26 inches [4]. In order to achieve this and not impede the other aspects of the wheelchair design, the team has come up with three different ideas for the transfer board. Before deciding on an idea, the team is researching current patents on transfer boards to make sure that there is no infringements on another's idea.

After discussions and design revisions at the beginning of the semester, the team concluded the best solution and integration for the transfer board would be to create a storage option that also increased transfer abilities. The design created a storage place for the transfer board under the armrest of the wheelchair. This design also allows for the armrest and transfer board to be used with or without lift of the seat. To do this the current armrests were replaced with *Quickie Zippie Wheelchair Parts Flip Up Padded Armrest* that allowed for armrest to be flipped up out of the way to slide the transfer board underneath. Two bottom and one top adapter was designed and 3D printed for this prototype. The adapters would act to sandwich the board in between the bottom base and the armrest. The adapters also ensured board alignment and continuous access to armrest latch. Mechanical drawings can be seen in Appendix 5 for the bottom and top adapters. A completed and revised prototype for the transfer board system can be seen in Figure 5 and 6.

Figure 5 and 6: Transfer Board Prototype showing overview and board alignment

Based off of the first prototype the top adapter needed to be adjusted and modified to better interface with the transfer board. Because the front and back bottom holders on the wheelchair were not the same diameter the back bottom adapter needed to be sanded down to fit into the holder. Future modification and improvement could include manufacturing both the top and bottom adapters out of injection molded plastic. For this to be done post printing modifications need to be taken into account. For the proof of concept prototype the armrest were attached as the manufacture designed them to be, screwed in through the backrest tubing, but for the comprehensive prototype the armrest will have to be modified and welded onto the backrest. This is to allow for the backrest and armrests to move with the lift system and not interfere with the guiding support rods.

While this modification was designed and prototyped to be a part of the comprehensive model, the transfer board integration design could also be produced separately and sold as a kit to modify any commercial wheelchair. This would allow any wheelchair to be more user friendly and accessible. This was the most successful part of the project. Additional images/drawings are shown below.



Conclusion

The wheelchair design consisted of three component groupings, the lift system, disappearing footrest, and integrated transfer board. The team completed the detailed design of the lift system, footrests, and transfer board integration. The lift system changed from the design created by the first team to an extending cross bar lift system with a central gearbox. The lift system drive mechanism was an original design Craig Cunningham took lead designer on, with input from all team members and BREAK faculty facilitators. The footrest pivoted from the original design to a design that Greg Keller took lead designer on, with input from both Sarah Bethel and Mitch Mastenbrook. The transfer board integration system was designed by Ashley Shepherd, with input from Sarah Bethel. Carl Holz was team leader, the main source of communication between faculty members, the VA hospital, and coordination between different organizations, oversaw project record keeping, and designed the liftsystem structural integration and support with input from Craig Cunningham. Team members anticipated finishing a complete prototype, incorporating all three components groupings, with a turnkey design presented to the leavenworth VA in June.

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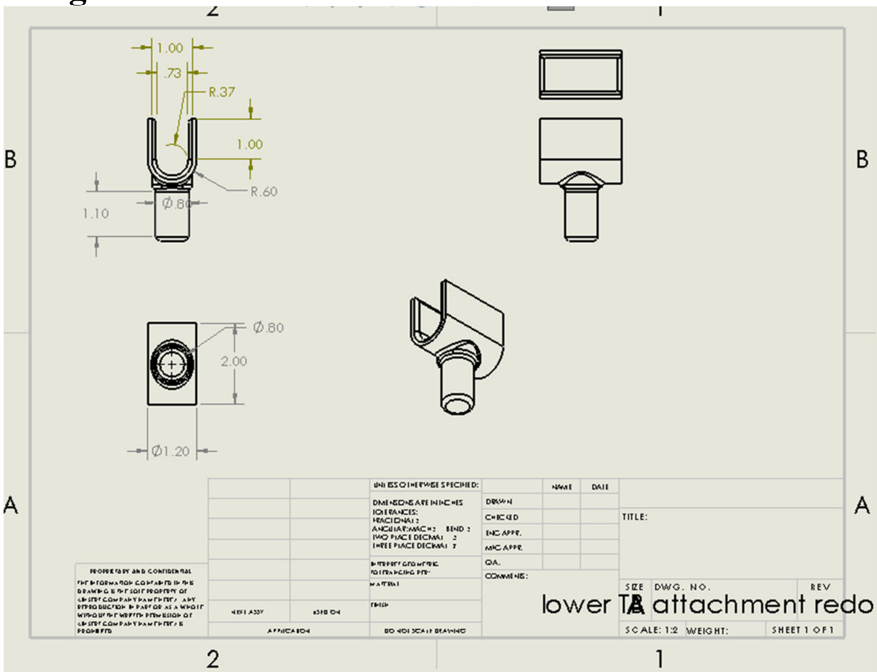
Integrated Transfer Board Lower Part/Holder



Integrated Transfer Board Upper Part/Holder