

# **Chapter 16**

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# WHEELCHAIR STAIR LIFT SYSTEM

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## INTRODUCTION

A wheelchair lift system was designed to transfer a client in a wheelchair from the main floor of his residence to his basement. A stairway must be available to other occupants of the house. The client remains in his wheelchair during the transport. Modification of the wheelchair has been minimized. The system required replacement of the existing steps. It includes a cantilevered platform, a chain driven lift, and two structural channels for support.

## SUMMARY OF IMPACT

The wheelchair lift system allows the client access to his basement. It conforms to ASME codes and standards.

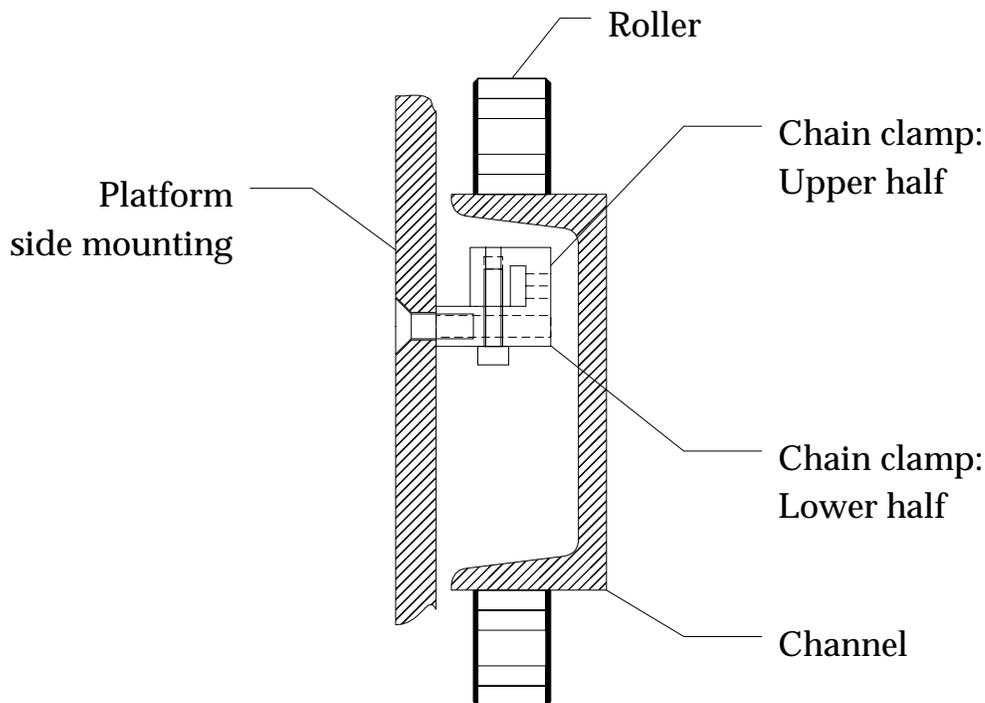


Figure 16.1. Schematic Illustration of the Wheelchair Lift System.

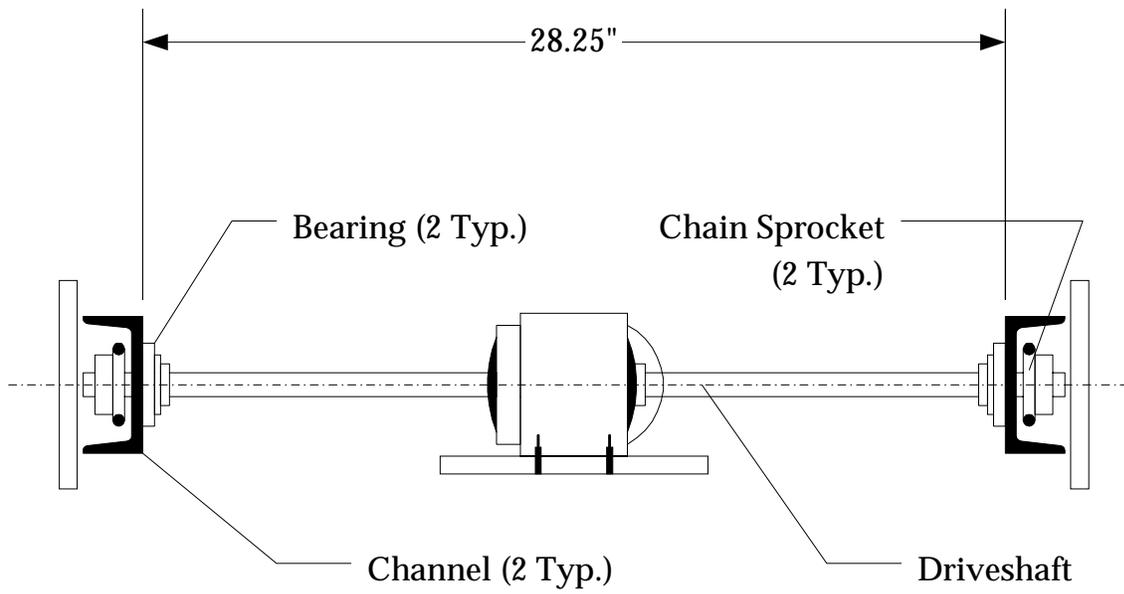


Figure 16.2. Components of the Drive System.

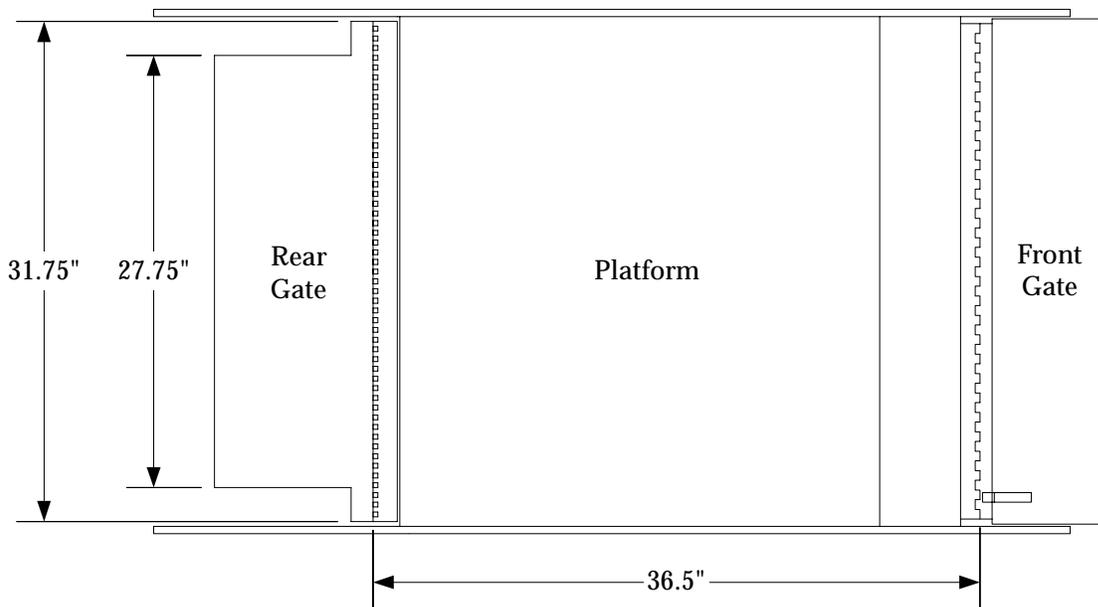


Figure 16.3. Platform with Front and Rear Gates.

## TECHNICAL DESCRIPTION

The design and development of the system consisted of four main parts: 1) replacement of existing steps, 2) design of a cantilevered platform to carry the wheelchair up and down, 3) design of a chain-driven lift to move the platform and the wheelchair up and down, and 4) design of a structural support system. Figure 16.1 shows a schematic illustration of the main components of the system and depicts the platform side mounting, the chain clamps, and the channel supporting system.

A steeper stairway was required, to provide clearance between the lift passenger and the existing header. This was a simple matter since the basement is unfinished. A stairway angle of 45° provides sufficient clearance. The width of the stairway was reduced to 27.5 inches to accommodate the platform support channels. The new steps did not meet current building codes. A "Non-conforming Permit" was obtained, given that the proposed configuration represented a structural improvement. The door at the top of the stairway was replaced because it opened toward the stairs, obstructing the placement of support channels between the doorjamb. A wider (36") door, aligned with the stairway opening in the floor, makes it possible for the 27" wheelchair to pass.

Two structural channels, below the platform, running parallel to the stairs, provide a support system. They are bound by the 35" opening in the main floor, allowing sufficient space for the wheelchair to pass. The platform that carries the wheelchair was cantilevered using rollers on either side. Each channel is lag bolted to the floor joists at the top of the stairs and to the concrete floor at the bottom of the stairs. The width of the platform was maximized so that it just fits through the opening in the main floor.

A chain-driven system provides a cost-effective means of moving a platform on rollers. The drive system is a brake motor flange mounted to a helical-worm gear drive with a hollow shaft output. Figure 16.2 illustrates the different components of this system, including a motor and a drive shaft. The motor, obtained from Boston Gear, is splash-proof, with an output of 39 RPM (yielding a chain speed of 28 ft/min w/17 tooth drive). The shaft has #40 chain drive sprockets at both ends. The chain has a load rating of 4300 lbs, 20 times the actual load.

The platform shown in Figure 16.3 has attached rollers that follow the support channels. It descends at

the same angle of the steps, 45 degrees. Safety gates at either end of the platform secure the wheelchair. Polyurethane rollers, used as followers, offer a smooth and quiet ride, are lightweight, low cost, and require no lubrication.

The platform is normally at the bottom of the steps, allowing the stairs to be used in the usual fashion. An open, spring loaded, pushbutton switch serves a call switch at the top of the stairs. The passenger controls the platform while in transit, using with a normally-open, three-position, spring-loaded toggle switch. The platform automatically stops when it arrives at the full up and down positions. Microswitches at both ends are used to open the proper electrical circuits. A spring retractable electrical cable reel provides power to the platform. A sensor plate that covers the underside of the platform, required by code, has several lever-actuated switches attached. If any switch is activated, power to the motor is cut, and the lift stops. The electrical circuit schematic for this control system is shown in Figure 16.4.

The 120 V AC reversible break-motor, operating at 0.5 hp and 1725 rpm, is geared at a reduction ratio of 45:1. This AC motor network includes 4 sets of safety sensor switches or microswitches located on the safety plate, at the rear gate, at the front gate, at the bottom of the stairway, and on the safety belt. The safety switches at the front gate and at the bottom of the stairway are in parallel and linked together with the rest of the safety switches in a cascade form. An override button feature is connected across and in parallel to all the safety switches. This allows the user flexibility and authority in making a decision against any warning signal triggered by the safety switches. On the other hand, the control system network runs on a separate independent DC power supply because the logic control unit and relays are incompatible with AC power supply characteristics.

Two parallel toggle switches are incorporated in the logic control unit. The one labeled "call box" is stationary and mounted at the top of the flight of stairs, while the other, labeled "control box" is on the platform. The signal from the DC power source is split in two when fed into the logic control unit. One goes through a buffer, while the other is channeled through an inverter. These two opposite signals then flow through two separate relays, located exactly between the motor and the AC source. Both of these relays are SPDT (Single-Pole-Double-Throw) contacts. The two relays act as the polarity flipping mechanism. The mo-

tor stage (which depends on the correct direction of rotation to run) operates as desired when the joystick toggle switch is pushed or pulled.

This project was budgeted at \$2,000. Total spending did not exceed \$300, as local businesses and friends of the client donated about \$1700. Contributions included: a motor and gear box, donated by Boston

Gear; materials donated by E & C Manufacturing and Art Iron Inc., both from Toledo, Ohio; machining of several parts, by Custom Machine & Tool from Palmyra, WI; and construction the new stairway, by the woodworking shop of Sylvania Southview High School.

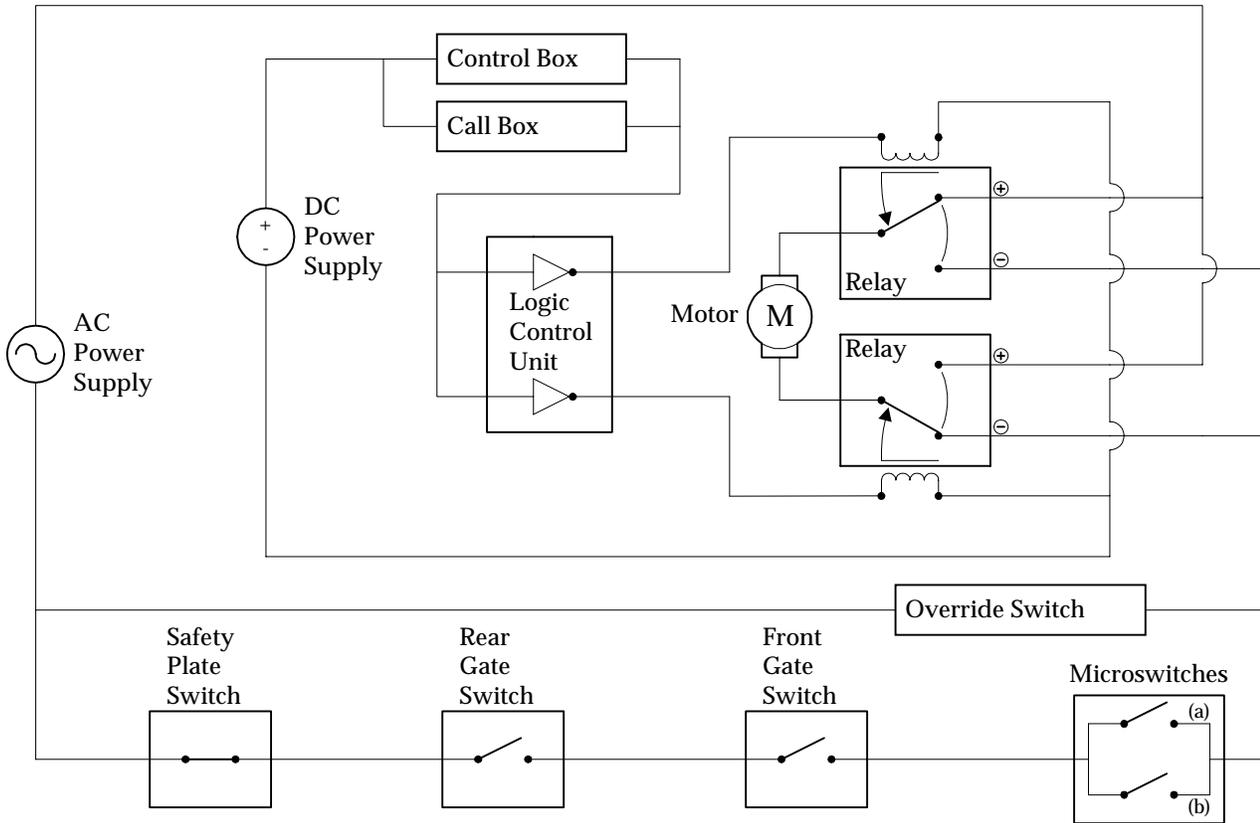


Figure 16.4. Schematic of the Electric Circuit for the Control System.

# FOLDING SHOWER/COMMUNE CHAIR

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## INTRODUCTION

A folding shower/commode chair facilitates travel for a person with tetraplegia. The prototype is lightweight and includes folding armrests, a transfer seat, and interchangeable cushions. It can be folded to be compact for travel and storage. The front legs rotate towards the back. The armrests disengage from the seat frame and rotate upward 90 degrees for chair access and downward 270 degrees for travel and storage. The seat frame folds upward against the back frame. The chair frame, seat frame, transfer seat, and armrest are aluminum. The seats, armrests, and back support cushions are made of Wolmanized plywood and covered with a layer of foam and vinyl for comfort.

Figures 16.5 and 16.6 illustrate the shower/commode chair, in both folded and unfolded positions.

## SUMMARY OF IMPACT

The shower/commode chairs being used at the Medical College of Ohio serve dual purposes. They can be put into a bathtub for an individual to sit down and take a shower, or they can be wheeled directly over a standard toilet or a space large enough for a receptacle to be placed underneath. Wheels with brakes allow the chair to move freely or lock in place. However, these chairs are too bulky for travel. For automobile travel, they must fold to a compact size.

## TECHNICAL DESCRIPTION

The criteria specified by the client were that the chair be compact and lightweight, have a strong back piece to support the user, have rigid armrests to provide support, something to prevent water from escaping onto the floor, and armrests for easy transfer from the wheelchair to the shower/commode chair and vice versa. To prevent pressure sores, the client requested that the seats be padded and interchangeable - one for



Figure 16.5. Unfolded Shower/Commune Chair .



Figure 16.6. Folded Shower/Commune Chair.

the commode and one for the shower chair. Wheels were not necessary.

The chair is 36 inches high and 18.5 inches wide, which allows it to fit inside a standard bathtub, and still fit over the largest commercial or residential toilet. When completely folded, its height and width do not change, but its depth decreases from 18 to 4 inches.

The chair frame was constructed from 7/8 inch 6061-T6 anodized black aluminum tubing, which offers good mechanical strength and is ideal for welding. It folds so that the back of the frame, made from bent aluminum tubing, remains rigid. The seat folds up toward the back. One of the front legs folds toward the front, the other toward the back. The armrests fold down.

The seat is connected to the back of the chair frame by a continuous aluminum hinge, which evenly distributes the load applied to the seat across the seat's back support. The front legs are connected to the back frame by horizontal tubes and sleeves which rotate about the back legs, locking in the open or closed position via pull ring spring plungers. With the spring plunger pin protruding through the rotating sleeve, it can be easily guided into two holes drilled in the back leg for the open and closed positions. By pulling on the ring handle and rotating the front leg, the ring may be released and the leg turned until it snaps into position.

The frame was connected using mechanical fasteners and welding. A back brace was used to provide the seat back support. A continuous hinge on the back brace allows the seat frame to be folded up. Aluminum angles, with leg dimensions 1 x 1 x 3/16 inches, were used for the back brace and the seat frame. The inside dimension of the seat frame is 18.5 by 16 inches.

Holes were drilled in the side angles of the seat frame, to allow the transfer board and armrests to lock in place. The armrest consists of two main parts, the pivoting arm and the leg. The arm is made of 1 x 1 inch channel, 1/8 inch thick. Mounted on the arm is a 1/2 inch vinyl-covered cushion placed over a piece of

wolmanized plywood. The leg, made of aluminum tubing (OD of 5/8 inches, wall thickness of 0.065 inches), rotates about a pivot on the arm. A plastic stopper and a handle are also mounted on the leg.

The armrest can be folded up along the back frame, allowing the user to transfer from a wheelchair to the shower/commode chair, and vice versa. The armrest can be folded by rotating it 270 degrees in the downward position so that the height of the folded chair will not exceed the height of the back frame. A transfer seat can be attached to the right or to the left side of the shower/commode chair. Its legs are adjustable to account for any height difference that may occur between the bathroom floor and the base of the bathtub.

Four water resistant cushions were designed: a shower seat cushion, a commode seat cushion, a transfer seat cushion, and a backrest cushion. Also, two armrest cushions were added to provide padding for the armrests. All of the cushions were constructed by wrapping marine vinyl around a piece of open cell foam and Wolmanized plywood. The open cell foam provides soft padding on top of the plywood, which provides support. An elliptical hole was centered on the commode seat cushion. In order to prevent water from spilling from the bathtub, the transfer seat cushion tilts to an angled position, channeling any water that runs onto the transfer seat back into the bathtub.

All design calculations conform to the structural strength specifications of the American with Disabilities Act (ADA). The total weight of the main chair is 20.7 lbs., the weight of its frame being 7.2 lbs. and the weight of its cushions 13.5 lbs. The total weight of the transfer seat is 6.9 lbs., the weight of its frame being 3.2 lbs. and the weight of its cushion 3.7 lbs. The total combined weight of the chair, the transfer seat and cushions is 27.6 lbs. The cost for parts was \$600. Construction of the chair was done at Bionix Development Corporation in Toledo, Ohio, and at the University of Toledo Mechanical, Industrial and Manufacturing Engineering machine shop.

# GRASS FUNCTIONING WHEELCHAIR TIRE ASSEMBLY

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## INTRODUCTION

A universal castor enables patients in wheelchairs to traverse various types of terrain while retaining maneuverability. The design incorporates a wide tire to increase maneuverability on soft surfaces and a raised center to retain chair performance on hard surfaces. Computer controlled machining was used to machine the tires since they incorporated a series of large radii in their profiles. Large radii create a smooth transition between the various surfaces on the tires, improving function by reducing the perpendicular forces that oppose turning, and by introducing a vertical force component that promotes a sliding effect to improve turning.

## SUMMARY OF IMPACT

The client is an active person with paraplegia who uses a wheelchair that has the tendency to sink into the soil and tip over. A new tire/wheel assembly was designed and manufactured to maintain the current wheelchair maneuverability on hard surfaces while improving it on softer terrain. The new tire showed an improvement in supporting the load by exhibiting a decrease in the sinking depth from 2" to 0.5". Improvements in the turning and transition movements on dry lawn surfaces were also achieved.

## TECHNICAL DESCRIPTION

With the original wheelchair tire assembly, the front tires were sinking into the soil as client traversed his lawn. Forward movement was difficult and turning nearly impossible. The main problem was to prevent the front wheels from sinking into the soil. This could be achieved either by shifting the center of mass so that less weight would be put on the front tires, or by increasing the surface area of the tire to provide better weight distribution. Because increasing the contact area of the tire would cause a decrease in maneuver-

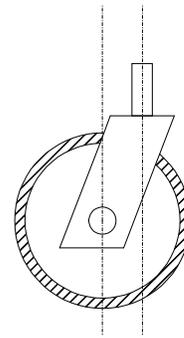


Figure 16.7. Total Castor Assembly.

ability on hard surfaces, the goal was to increase surface contact on soft surface, while minimizing surface contact on hard surfaces. Wide tires that distribute the weight over a larger area are available in the market, but result in reduced maneuverability on hard surfaces. Figure 16.7 shows a schematic of the total assembly. It includes a tire assembly, a fork, and an axial shaft. The tire assembly shown in Figure 16.8 in-

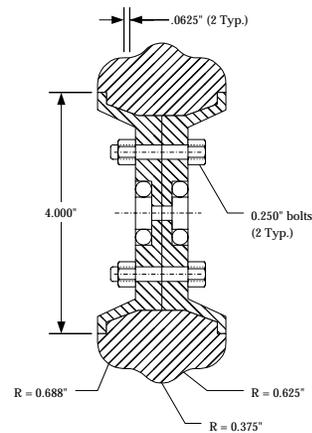


Figure 16.8. Tire Assembly.

cludes a three-piece tire/rim assembly in which the two-rim section is made of polypropylene and the tire is made of polyethylene. Polypropylene was selected for its hardness, rigidity, and low reactivity. Polyethylene was selected for low reactivity, good wear resistance, and sufficient stiffness. The tire assembly turns inside a fork made of 1 in. thick stainless steel plates. The tire assembly is also mounted on a 5/8 in. diameter stainless steel shaft using 2 radial bearings (shown in Figure 16.8), each having 2 seals. Each bearing is rated at 500 lbs. The width of the new tire was chosen as 3 inches as opposed to the 1.25 in. width of the original manufacturer tire. The commonly used Bearing Capacity Equation was used to calculate the required area to support the weight of the client and his wheelchair. The trial and error method was then used to determine the sinking depth that produced the calculated support area; this depth was estimated as 2.0" for the manufacturer tire and 0.5" for the new wide tire. Reduced sinking caused a reduction in the side forces that oppose turning.

The tire profile, shown in Figure 16.9, incorporates a bell-raised center to maintain the present maneuverability on hard surfaces. The raised center has smooth sloping radii with no sharp edges. The purpose of the radii is to minimize the perpendicular contact of opposing forces while turning in soft surfaces when the raised center is embedded in the soil. By avoiding normal contact there is a vertical force component that reduces resistance and induces sliding over the soil instead of soil displacement. This sliding effect further enhances turning ability on soft surfaces. Treads were omitted to reduce friction.

Computer numerically controlled (CNC) machining was employed to manufacture the tires. All components were manufactured at the Mechanical Engineering machine shop, including the CNC machining.

To analyze the characteristics and the effectiveness of the design, subjective and objective data were collected through a series of test runs using the prototype. During each run, the forces required to initiate the movement are directly measured using a series of linear spring scales attached to the drive wheels. After the run is complete, the operator fills out a questionnaire, using a 1 to 10 scale, 10 being excellent and 1 being poor. Tests were conducted on concrete and on dry lawn. Five types of maneuver were evaluated: 360 degrees right and left turns, forward and reverse motions of 10 feet, and forward to reverse motion.

During the right (left) turn test, the wheelchair was positioned on the test surface with the right (left) wheel brake in the on position. With the chair stationary, a force is applied to the left (right) rear tire to create the 360 degrees turning motion. During the forward (reverse) motion test, the wheelchair is positioned on the test surface and moved forward (reverse) 2 to 3 feet to align the front wheels with the rear wheels. With the chair stationary, equal forces are applied to both rear tires simultaneously to create a 10 ft forward (reverse) motion. During the forward to reverse motion test, the wheelchair is positioned on the test surface and moved forward 2 to 3 feet to align the front wheels with the rear wheels. With the chair stationary, equal forces are applied to both rear tires simultaneously to create a reverse motion that continues until the front tires are realigned with the rear tires.

Test results indicate improvements on dry lawn surfaces over the standard tire in turning and transition movements. The rigidity of the tire material causes damage to the interior flooring, so a material change is recommended.

The cost of all material is \$225.

# HAND POWERED BIKE

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## INTRODUCTION

The purpose of this project was to build a hand-powered bike for a client with quadriplegia. A Joyrider, an adult tricycle, was adapted to allow the client to transfer power to the rear wheel via hand pedaling. A constant velocity (CV) joint was employed and added to the bike to accomplish this task. The adaptation of the tricycle also included developing a driving system, consisting of a driving shaft attached to the CV joint, a transmission shaft, a sprocket, and a chain. Reconfiguring the pedaling system required the use of custom-made U-shaped handgrips, a footrest, and a specially designed fork. The original fork was replaced because it was not suitable for driving the bike with the pedals on top of it. The adapted bike, including its seat and footrest, functions much like a wheelchair.

## SUMMARY OF IMPACT

A patient with a spinal cord injury has no control over most of his muscles, from the chest down. He has good arm movement, but limited gripping power in his hands and fingers. Before his injury, the client had been an avid road biker and wanted to get back into the sport. Most of the bikes on the market for people with physical challenges have front wheel drive, which did not work for the client. The front tire would slip, making it difficult to operate while going uphill or riding on loose stones. Another problem in available designs is that they require the rider to lean during turns. Without control over his trunk muscles, the client cannot drive them.

The client tested the adapted tricycle, which met most of the design objectives.

## TECHNICAL DESCRIPTION

There are few rear-steering tricycles. One disadvantage associated with them is that, in turning aside to avoid an obstacle, the rear wheels often foul and hit the obstacle, even when the front wheel has cleared



Figure 16.10. Bike Before Adaptation.

and passed it. An adult tricycle, the Joyrider tricycle, manufactured by the Trailmate Corporation, was purchased and adapted (Figure 16.10.). Its low center of gravity reduces the risk of tipping, while its frame allows for easy modifications. The bike is rated at 250 lbs.; the client weighs 230 lbs. The seat was ideal: it has a high back support, and allows for easy transfer from a standard wheelchair.

The adaptation process required a CV joint to power and steer the purchased tricycle. The center of the CV joint houses the driving shaft that transmits power from the rider to the tricycle. This joint, donated by Dana Corporation, has a maximum turning angle of 80 degrees. Its inner race turns while transmitting power to the outer race, with a gear and a chain attached. A mounting mechanism was attached and fixed to the frame of the tricycle to hold the outer race.

The Joyrider comes equipped with a coaster brake that allows the rider to reverse the pedaling motion for braking. The bike also has a caliper brake attached to the front wheel, normally used as a stopping brake. Since the coaster brake is being applied for stopping in this adaptation, the caliper brake can be used for parking. The lever that actuates the caliper brake is a

pull and release device. A self-indexing device was employed to lock the caliper in place.

A custom made u-shaped handgrip is used to transfer power from the patient's arms to the back wheel. This grip was designed to accommodate the client's limited gripping ability. It has front and back pads. The front pad is ergonomically designed so that the hand forms comfortably to it. The back pad helps to hold the rider's hand up against the front pad. The handgrip is oriented vertically instead of horizontally, as it would be in most bicycle pedaling systems, because the vertical orientation allows for more natural placement of the hands throughout the cycling motion.

Carbon steel with yield strength of 120,000 psi was used for the driving shaft, which has a length of 8 inches. A force of 100 lbs on each pedal was estimated. The pushing and pulling forces on the pedals, along with the weight of the rider's arms and other bike parts (the CV joint, the chain and the sprocket) will bend and twist the shaft. The maximum bending moments and maximum torques acting on the shaft were estimated. A 0.80-inch shaft was selected corresponding to a factor of safety of 3.

The fork of the bike as purchased could not be used because it was not suitable for driving the bike with the pedals on top. A new fork was designed and built. It was welded to the lower part of the original fork after the upper handlebars were removed, as shown in Figure 16.11. Three tubes with two different tubing sizes were used for the new fork: two tubes with an OD of 1.05 in., a thickness of 0.109 in., and a length of 11.5 in., and one tube with an OD of 1.66 in., a thickness of 0.134 in., and a length of 8.25 in. All tubes are made of ASTM structural steel tubing with a minimum tensile strength of 58,000 psi. The two longer tubes were welded to two upper steel plates that hold the flange bearings of the driving shaft. These two tubes were then welded together to a steep plate to form a U-shaped part. The third and shorter tube was welded from its top to the U shaped part, forming the new fork.

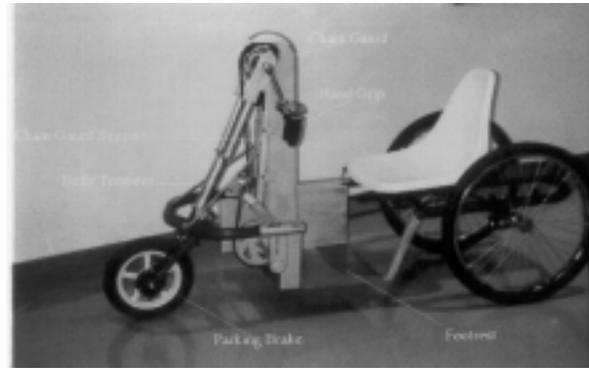


Figure 16.11. Bicycle After Adaptation.

The CV joint and the driving shaft were fabricated at Dana Corporation, Toledo, Ohio. The original upper part of the fork, handlebars, chain guard, and feet pedals were first removed from the original bike. The new fork was then welded to the lower part of the original fork. The CV joint and the driving shaft were mounted with flange bearings to the steering shaft at the top of the U shape part of the new fork. The custom-made handgrips were then attached to the crank arms that were fixed to the end of the driving shaft.

A transmission shaft was mounted where the original crank had been. The same diameter of 0.625 inches was used for this shaft, the length of which is 21 inches. The transmission shaft was made from stainless steel, with a yield strength of 40,000 psi. A custom made footrest, welded to the main frame, was attached in place of the foot pedals after the pedaling system was reconfigured. A chain guard was added to protect the rider, and a bully tensioner was used as a chain guide. All fabricated components are painted silver.

The costs of all parts, including the purchased Joy-rider, totaled \$550.

# HAND ASSIST

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## INTRODUCTION

An electrically controlled handgrip and release orthotic was designed for a client with quadriplegia due to a fifth cervical spinal cord injury. The prototype employs a forward/reverse switch to control power. An electric lead routes this signal into an independent motor which then powers an orthotic affixed to the hand that lacks muscle control. A rack and pinion, attached to the brace, are used to produce hand motions. The motor rotates the pinion that pushes the rack unit, creating a moment about the patient's metacarpal joint. This moment rotates the fingers, which are splinted together such that they move as one unit, enabling the hand to grasp an object. An important feature is the maximization of the range of grasp, and the minimization of the fixture size for aesthetic purposes.

## SUMMARY OF IMPACT

This prototype was developed for a patient with quadriplegia, who wanted to grip and release one of his hands to be able to drink from a glass, write and pick up objects. The device uses the patient's intact motor ability in the biceps and shoulder muscles, and is powered via a simple forward/reverse switch. The working prototype enables the patient to hold a variety of cup sizes and bring them to his mouth in proper orientation. The simple switch allowed him to control finger rotation.

## TECHNICAL DESCRIPTION

Criteria for the prototype were that it have three integrated functions: finger manipulation, forearm rotation, and maintenance of a rigid wrist. First, it would have to manipulate the fingers in a grasping motion. Secondly, it would have to splint the wrist to orient it

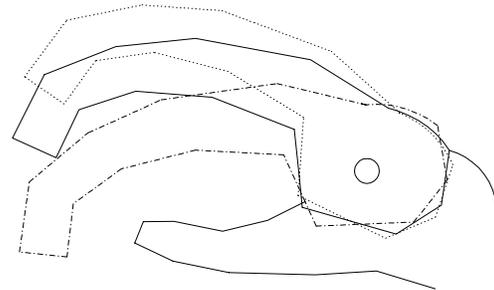


Figure 16.12. Claw Design Concept.

for the grasping position. Thirdly, it would have to reorient the forearm, rotating it about 90 degrees toward the body.

The design of the Hand Assist was based on a conventional amputee myoelectric arm. Almost every amputee arm utilizes a claw-type device that emulates fingers and pivots about a single point. Figure 16.12 shows this claw design, which maintains the natural curvature of the fingers, and induces a rotation about the metacarpal joint. This design allows for finger manipulation while maintaining a rigid wrist. The correct forearm orientation is accomplished through the use of a splint.

When the patient's hand was held in the desired grasping position, his thumb joint was immobile and was in a posture not conducive to grasping. Thus, it became necessary to build an artificial thumb, or a prop that would react against the force of the rotating digits, as shown as part E in Figure 16.13. It was important that the device not induce more than 0.68 psi of pressure on the patient's skin, to prevent skin irritation and inflammation. A prefabricated fully padded aluminum brace was incorporated.

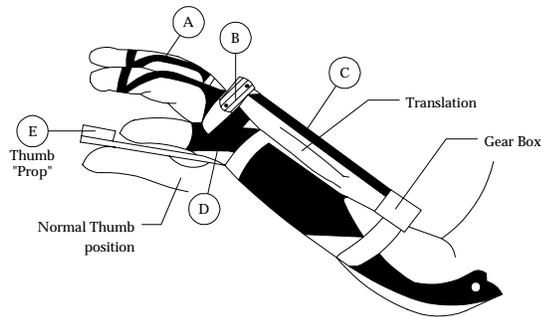


Figure 16.13. Final Design of the Handgrip.

The final design incorporated a switch, mounted on the patient's wheelchair and controlled with his shoulder motion. An attached 9.6 V battery allows current to flow to a single motor. This motor is able to turn either way, and thus induce the pushing and pulling of a rack that forces a moment arm at the metacarpal joint of the user.

The final prototype is shown in Figure 16.14. It includes four main parts: a finger fixture (part A), a moment linkage (part B), a grasp inducing rack (part C), and a brace fixture (part D). The electric assembly includes: 1) a two way toggle switch featuring spring return to neutral position, with reed contact due to small amperage of circuit, 2) a pushbutton enclosure for the toggle switch, 3) a micro motor with gear reduction assembly, 4) a stainless steel motor enclosure with hinge attached, and 5) a 9.6 volts DC rechargeable battery with recharger.

The finger fixture (part A) consists of flexible plastic finger rings that are connected to each other so that the fingers move as a unit. A lower digit stabilizer, made of aluminum, is connected to the moment arm, and a single aluminum extension across the middle finger ring holds the flexible finger rings to the lower digit stabilizer. The moment linkage (part B) is made of aluminum. It was machined to be made thin enough to float inside the slot of the rack, compensat-

ing for the angular rotation of the arm versus the desired translation of the rack. The grasp inducing rack (part C) is made of brass and purchased from Ohio Belting & Transmission Co. The mechanism allows the motor power to be transformed to a moment arm about the metacarpal joint.

The motor has a gear head reducer that lowers the rotational speed of the motor to approximately 14 RPM. The pinion is made of 5/8" steel wire that was machined to the spindle specifications. The rack is long enough so that the motor and pinion are near the elbow. The housing of the rack unit is mounted on a brace; this was required to stabilize, support, guide and protect the rack. The base brace (part D) is a padded single-spine prefabricated aluminum brace with nylon Velcro adjustment straps. No break was allowed in the brace fixture, to ensure wrist complete immobility. The brace fixture is used to mount the finger fixture and the wrist rack, and provides a mounting place for the motor, racks and gearbox. A Velcro upper arm harness, attached to the base brace, controls the client's forearm pronation/supination. This allows the client to grasp a wide range of object sizes. The thumb prop, made of aluminum, is affixed to the upper portion of the forearm fixture. A spongy rubber covering, glued onto the prop area, is used for raised friction and padding.

The cost of parts is about \$600.

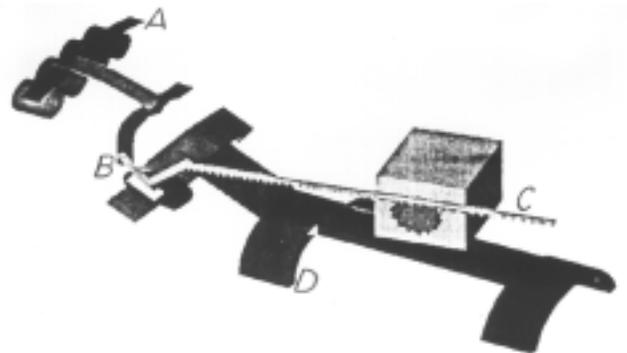


Figure 16.14. Final Hand Assist Prototype.

