

Design and Manufacturing Proposal for a
Stair-Climbing Wheelchair without an External Power Source

by

Alfredo Rivera
Timothy Studley

SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF SCIENCE
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

JUNE 2007

©2007 Alfredo Rivera. All rights reserved.
©2007 Timothy Studley. All rights reserved.

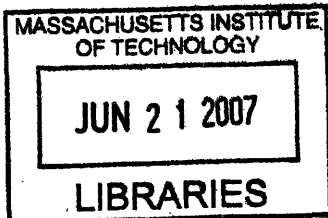
The author hereby grants to MIT permission to reproduce
and to distribute publicly paper and electronic
copies of this thesis document in whole or in part
in any medium now known or hereafter created.

Signature of Author: _____
Alfredo Rivera
Department of Mechanical Engineering
5/11/2007

Signature of Author: _____
Timothy Studley
Department of Mechanical Engineering
5/11/2007

Certified by: _____
Daniel Frey
Associate Professor of Mechanical Engineering
Thesis Supervisor

Accepted by: _____
John H. Lienhard V
Professor of Mechanical Engineering
Chairman, Undergraduate Thesis Committee



ARCHIVES

Design and Manufacturing Proposal for a
Stair-Climbing Wheelchair without an External Power Source

by

Alfredo Rivera
Timothy Studley

Submitted to the Department of Mechanical Engineering
on May 11, 2007 in partial fulfillment of the
requirements for the Degree of Bachelor of Science in Engineering
as recommended by the Department of Mechanical Engineering

ABSTRACT

With over two million wheelchair users in the United States, many buildings have struggled to provide accessible elevators and ramps for the disabled. The only other option for the disabled to ascend stairs is to purchase a high-tech battery-operated wheelchair with elaborate sensors and gyroscopes, which can cost around \$25,000. As a result, there is a high demand for a cheap and efficient way to climb stairs with a practical wheelchair. With the safety of the user as a main concern, it is the goal of this report to provide a light-weight, inexpensive stair-climbing wheelchair.

In order to significantly reduce cost of production, the wheelchair will not have any outside power source. The user's strength is the only means of energy for climbing. Our specific design relies on three critical modules: wheels with retractable spokes, a lock-in ratchet on the axle, and a seat-tilting mechanism. By focusing on integrating light-weight materials into the design, the force required to operate the wheelchair should be very manageable.

The next stages of manufacturing were determined and explicitly outlined. Using SolidWorks and previously developed components, a complete manufacturing proposal has been formulated. The production calls for two additional wheels with retractable spokes, two locking mechanisms of the main axle, and a tilt-in-space feature using gas springs. The final product should provide the disabled with a safe, reliable, and inexpensive wheelchair capable of ascending nearly any staircase.

Thesis Supervisor: Daniel Frey
Title: Associate Professor of Mechanical Engineering

Introduction:

The disabled currently have only one option for climbing stairs when elevators and ramps are not accessible: a battery-powered wheelchair with gyroscopes and sensors. Typically these types of wheelchairs are heavy, expensive, and difficult to maneuver. The most popular version is called the iBot (shown below in Figure 1), which was designed by Dean Kamen, the developer of the Segway scooter. The iBot is FDA (Food & Drug Administration) approved and guarantees user satisfaction. However, because this chair is equipped with high-tech sensors and gyroscopes, it is highly priced at around \$26,000. With an estimated two million wheel-chair users in the United States, only a very small proportion has purchased the expensive battery-powered wheelchair.



Figure 1: Independence iBot wheelchair in stair-climbing mode

Considering the majority of users are without this luxury, we believe there is a high demand for an inexpensive alternative. By eliminating the external power source and relying on the user as the energy input, a low-cost stair-climbing wheelchair is a realistic option.

The main difficulty in producing a working prototype is that the final product must be extremely safe. Companies and users do not want to invest in a product that

involves a high risk of failure. If anything were to happen to the wheelchair while it was ascending or descending a staircase, the consequences would likely be severe. A disabled person does not have the ability to control the chair once it begins to fall. With this in mind, many developers have either nixed the production of the wheelchair or resorted to safer high-cost alternatives. We hope that our prototype can be the first to break into this market by emphasizing its safety, low-cost, and light weight.

Background:

Professor Ernesto Blanco previously designed a wheelchair that used spring-loaded spokes on the wheels. His original idea relied on a series of motors as a power source. A miniature working model of Professor Blanco's design is shown in Figure 2.



Figure 2: Model of Professor Blanco's motorized stair-climbing wheelchair

However, he found that the estimated cost to produce the wheelchair with the motors was too high for the market demand. Because of this, his designs started to focus more on

users “pulling” themselves upstairs, and as a result, the safety and strength of the user became reoccurring issues.

In the summer of 2005, we undertook a UROP (Undergraduate Research Opportunity) with Professor Blanco, and with the help of another undergraduate student, we designed wheels with retractable, spring-loaded spokes. By incorporating our new spoke design into some of Blanco’s original ideas, we were able to start creating a new design that involved users pulling the spokes in order to ascend stairs.

This report will provide complete overviews of the components that we have already constructed, but will not go into tremendous detail regarding the production process. The main goal of this report is to provide an outline of the necessary steps in completing our current prototype. Due to time and budget constraints, along with the unexpected retirement of Professor Blanco, the final manufacturing stages of this project will need to take place at a later date. As a result, the bulk of this report focuses on the additional construction that needs to be done in order for the wheelchair to be a functional alpha prototype.

Design and Manufacturing Proposal:

The wheelchair we have designed includes four wheels with retractable spokes, two locking ratchet mechanisms on the main axel, and a tilting mechanism to facilitate the climbing process. The design relies on the user to scale up the stairs by pulling the spokes of the main wheels toward his/her body. The wheels’ spokes will catch the stairs one by one and propel to user backward up the staircase at an appropriate recline. The following manufacturing proposal will provide design parameters and production insight

for all of the critical modules. Precise SolidWorks drawings for these components are included in the Appendix, while the actual files are available on a data CD as well.

Front Climbing Wheels:

The main wheels of the wheelchair are extremely unique components and by far our most critical module. After being repeatedly altered over the past two years, the front climbing wheels are the basis for all other design considerations. The wheels feature spring-loaded spokes that retract when a normal force is applied to the rubber tip. Because the spokes are secured by two concentric aluminum guides, the spokes jam whenever a force is applied at an angle. This feature allows the wheel spoke to catch the edge of a step and then consequently retract as the rotation proceeds. The rubber tips provide an additional source of static friction on the stairs, which allows for a bit more stability while climbing. Early bench level testing on the wheel indicated that the spokes were capable of withstanding the weight of nearly 200 pounds when applied perpendicular to only one spoke. Figure 3 shows one of the retractable spoke wheels.



Figure 3: One of two large climbing wheels in stair-climbing mode

As for the wheels' ground use, the spokes also have the ability to remain retracted within the wheel's frame. A circular piece of delrin rotates with the spokes around the center of the wheel and holds the spokes in when the spoke-locking mechanism is initiated. Aluminum handles on the outer frame of both wheels allow the user to rotate the delrin pieces slightly in order to begin the latching sequence for the spokes.

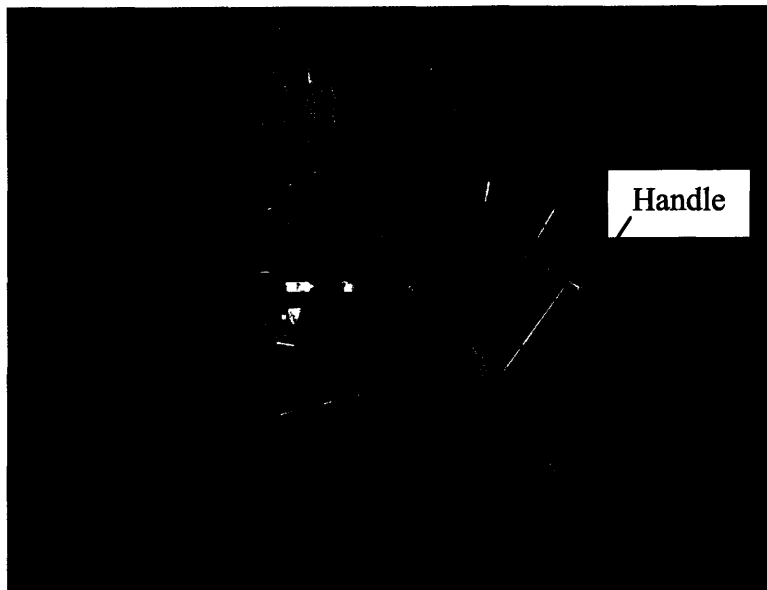


Figure 4: The wheelchair has initiated ground use, and as the user travels forward, the spokes will retract and stay inside the wheel.

Each spoke has a small triangular piece of delrin on its innermost end which acts as a latch. When the handles initiate ground use, the user moves forward in the wheelchair, and one by one the spokes begin to retract. A picture of the wheel with the spokes retracted inside the body of the wheel is shown in Figure 5.

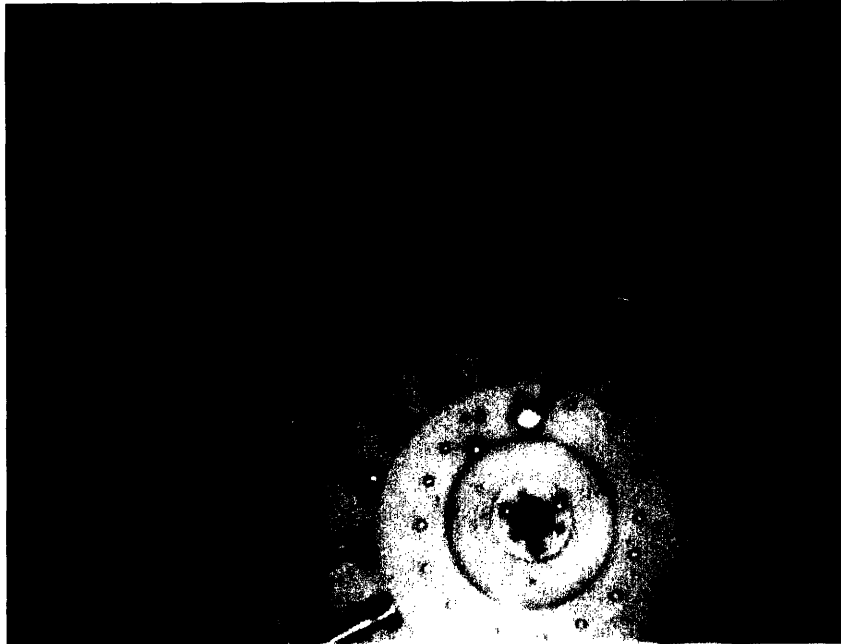


Figure 5: Spokes locked into the central delrin disk. A small rotation of the handle will send them out into climbing mode again.

The delrin triangles catch on the L-shaped slits of the center delrin component and allow the user to travel on level surfaces without the interference of the spokes.

Two circular pieces of lexan make up the frame of each wheel. The inner lexan rim is connected to a delrin axel within the wheel, while the outer rim is connected to its counterpart via 32 aluminum guides that were tightly fitted into slits on both sides. The photos of the wheels reveal various drill holes and cut sections on the lexan that were intended for other purposes but, in the end, were unnecessary.

There are, however, two important additions that need to be made to the wheel before it is considered complete. The circumference of each lexan frame needs to be fitted with a thin rubber “tire”, seen on most wheelchairs. This will provide increased static friction on the ground and on the stairs for increased control. An additional benefit of this addition is the grip it provides for the users as they drive themselves on level

surfaces. These hard rubber tires are sold by many manufacturers in many different sizes, and they simply snap on the frame. Four six-foot tires with quarter-inch cross-sections need to be purchased and snapped on. The only other modification to the main wheel is four tapped holes on the outer lexan pieces, which will be addressed below in the design of the wheel's ratchet locking mechanism.

Locking Ratchet on Axel:

In order to insure the safety of the user, the wheels need to be prevented from rolling forward during the ascent. With that in mind, the ratchet mechanism on the axel needs to be able to withstand a high amount of torque. We have purchased an industrial-strength ratchet (shown in Figure 6) from a car manufacturer.

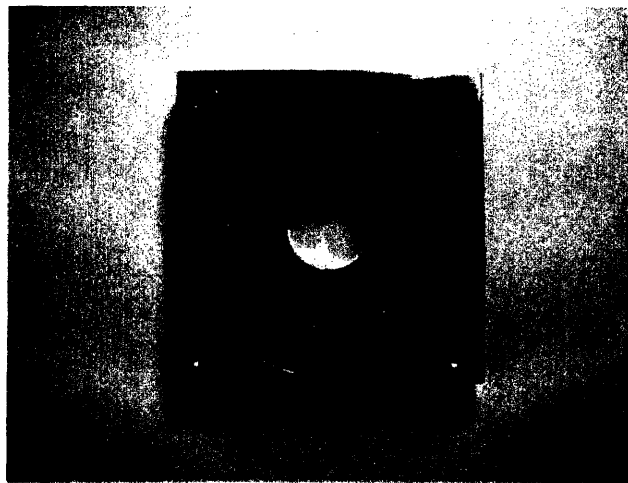


Figure 6: Industrial-strength ratchet used in car manufacturing. The center hexagon acts as a locking female piece.

The ratchet, which is used in most vehicles, prevents car seats from flying forward in the event of a high-speed car crash. Due to the nature of its use, it is unlikely that the ratchet itself would be the component to give out while climbing stairs.

The tricky concept inherent in this module is that the ratchet needs to be capable of being activated for climbing and deactivated for ground use. Otherwise, the user would be unable to drive forward on level surfaces. Our only option was to design a lock-in mechanism that can activate the ratchet at the bottom of a staircase.

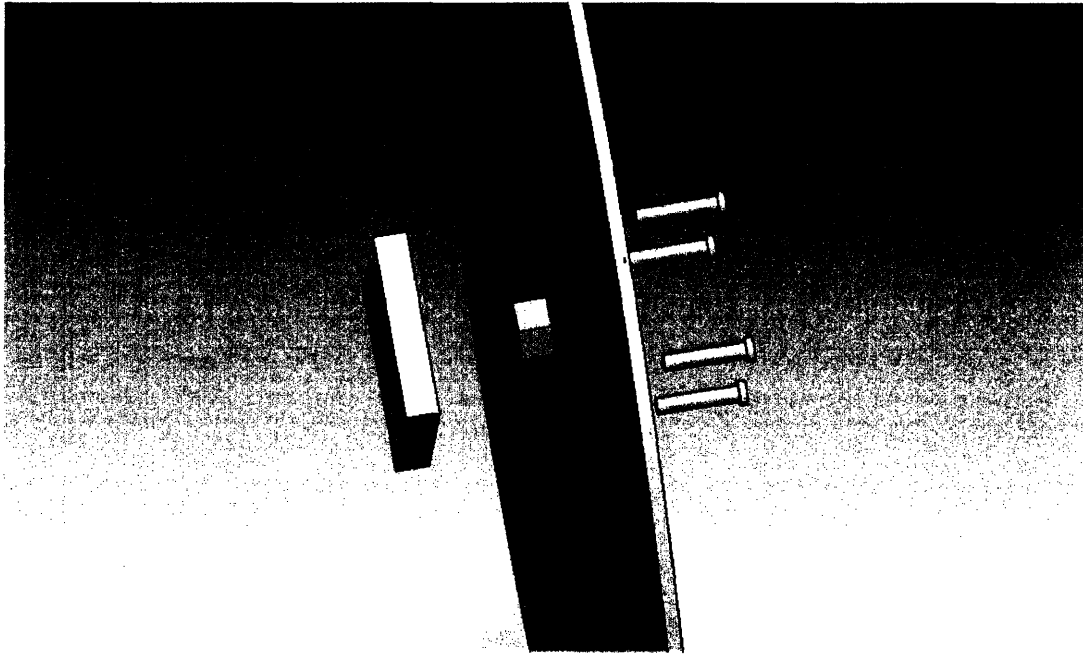


Figure 7: SolidWorks assembly screenshot of the wheel's outer lexan rim with the ratchet (left) and the sliding rods (right).

The locking mechanism has been designed in SolidWorks to ensure it is manufactured with appropriate parameters. The mechanism involves the user manually activating the system by pushing the ratchets into the axels on the outside of both wheels. The ratchet slides on four one-inch long steel rods. The four holes on the ratchet corners will provide the means of the slide and will also be accompanied with delrin bearings in order to minimize the kinetic friction of the slide. The rods will fit tightly into the tapped holes in order to insure that the ratchet does not move freely during ascent or ground use.

The center of the ratchet is a hexagonal opening, which will act as the female piece when locked. The axel at the center of each main wheel has a corresponding male, hexagonal extrusion located on the outer side of each wheel.

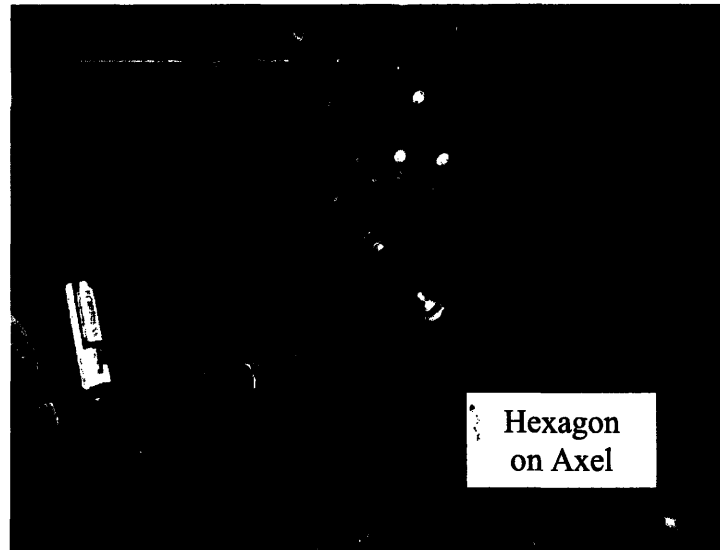


Figure 8: Close-up of the customized axel for the main climbing wheel

These hexagonal axel pieces are actually hexagon nuts, which means they need to be welded onto the axel after the main wheels have been permanently placed on the chair. The welding of the nut and the axel threads will insure that the ratchet never unscrews the male piece in this locking mechanism.

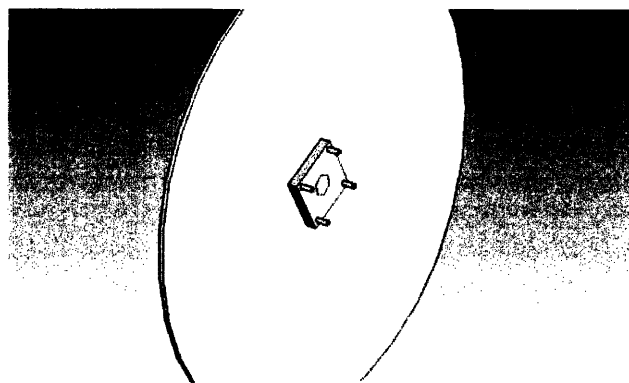


Figure 9: Ratchet mechanism locked into climb mode. The ratchet is pressed against the outer lexan rim.

When the ratchet is flush with the lexan frame, the main wheels are unable to rotate forward. The body of the ratchet rotates with the wheel, while the hexagon pieces interlock without rotation.

As a result of this new module, the main wheels need an additional modification. Four holes need to be drilled in the outer lexan frames. The slide rods will be inserted into these holes from the inside of the wheel frame. The holes are just under a quarter-inch in diameter. The inner side of the hole needs to be tapped again half way through the lexan with a 0.35 diameter drill. The rods, as detailed in Figure 10, are essentially acting as bolts; the top parts of the rods have a wider diameter to get stuck within the width of the lexan.



Figure 10: SolidWorks detail of one-inch long steel slide rod with a threaded hole in the end for a washer and screw.

The aforementioned central delrin wheel piece (which is flush to the outer lexan) will prevent the rod from moving inward during activation. Also, the outer end of the slide rod will have a flathead screw holding a washer in order to prevent the ratchet from being pulled out too far during ground use.

Rear Wheels:

To improve stability during stair climbing, our design includes two additional wheels located at the rear of the chair, on each side. These rear wheels will provide an extra two points of contact to improve balance while on stairs. The rear wheels have the same general design and assembly as the main wheels. The differences from the main wheels include the spoke length, lexan disk diameter, and the number of spokes (8).

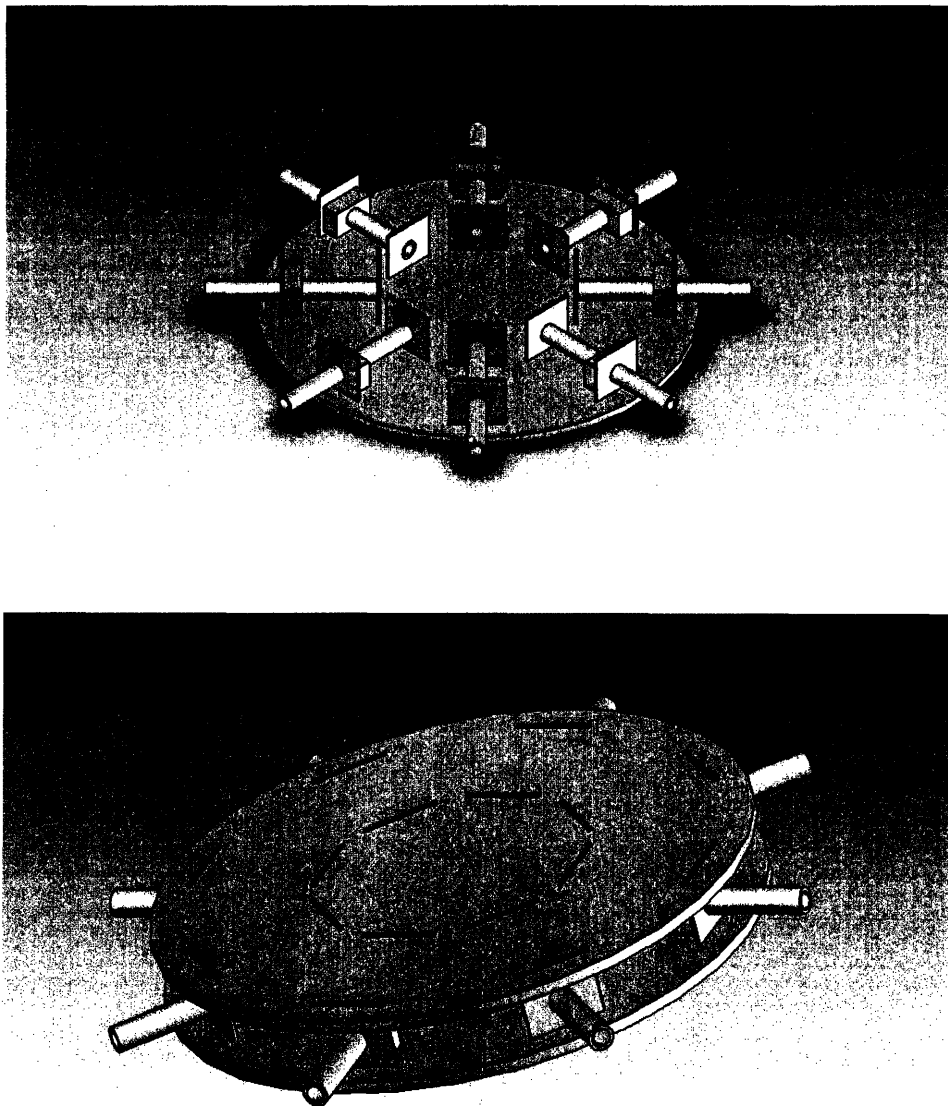


Figure 11: SolidWorks of the rear wheel: one is exposed (top) to show inner detail and the other (bottom) with both lexan rims fitted together.

In addition, the rear wheels do not require the spokes to be locked inside the body of the wheel at any time. Thus, no locking mechanism for the spokes is required, but the spokes should still be spring loaded to employ the same method of stair climbing as the main wheels. Detailed dimensions and assembly diagrams of the rear wheels can be found in the SolidWorks files that have been included with this document. They should be made using the exact same processes and materials as the main wheels.

The same ratchets that are used on the main wheels will be applied to the rear wheels. The rear wheels are only used during stair climbing, thus they only need to rotate in one direction. As an added safety feature, the application of the ratchets here will also resist the chair from rolling down the stairs. Since the ratchets are applied to the rear wheels at all times, they can be incorporated into the center of the wheels. By mounting the ratchets inside the lexan disks, we can save space and avoid a complicated system like the one used on the main wheels.

The rear wheels should be attached to the chair frame using the same tubular steel the frame itself is constructed of. Two 8-inch long pieces of tubular steel should be welded to the frame at a 60 degree angle, so that the rear wheels are angled upwards when the chair is flat. This angle will allow the rear wheels to have the proper contact with the staircase when the chair is tilted for stair climbing.

The approximate connection points for the 8 inch steel tubes are shown in Figure 12 below.

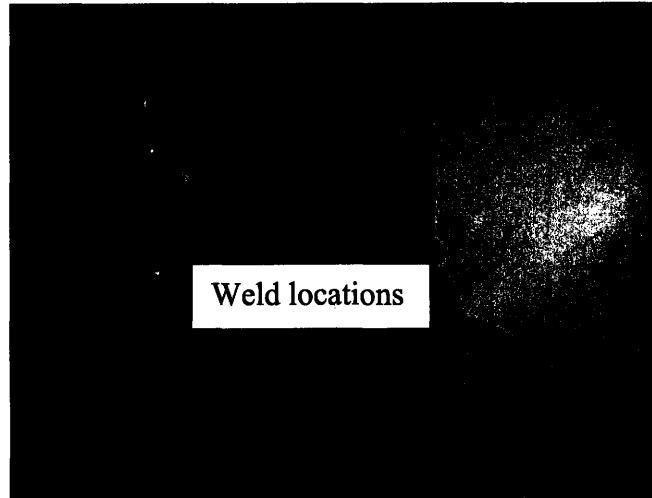


Figure 12: Weld locations are shown for the tubular steel add-ons for the additional rear, climbing wheels to be connected.

There should be a 90 degree bend at the end of each of the 8 inch tubular steel pieces. At the bend, the tubes extend an additional 3 inches inward. The 3 inch extensions will serve as mounting locations for the rear wheels. These extensions should be hexagonal in shape, so that they pass through the center of the ratchets mounted inside the rear wheels. The ratchets will allow smooth rotation in the desired direction and resist rotation down the stairs.

Tilting Mechanism:

At the beginning of the project, we identified a reclining seat mechanism as a key design parameter. The wheelchair user's center of mass must be transferred back during stair climbing. This is to reduce the required force for climbing and to eliminate the uncomfortable sensation of leaning down the stairs while climbing. The system we have

designed calls for the aid of a care giver to set the chair into a reclined position. The user still climbs the stairs without any external help, but assistance is needed to recline the chair and then return it to normal position at the top of the stairs.

The wheelchair frame should resemble that of a typical wheelchair. Only a few modifications need to be made to incorporate the reclining mechanism we have designed. We have shown where the necessary modifications need to be on a standard wheelchair in the descriptions and diagrams below.

The first modification involves creating pivot points at the locations where the bottom seat intersects the seat back. This location is shown in Figure 13.

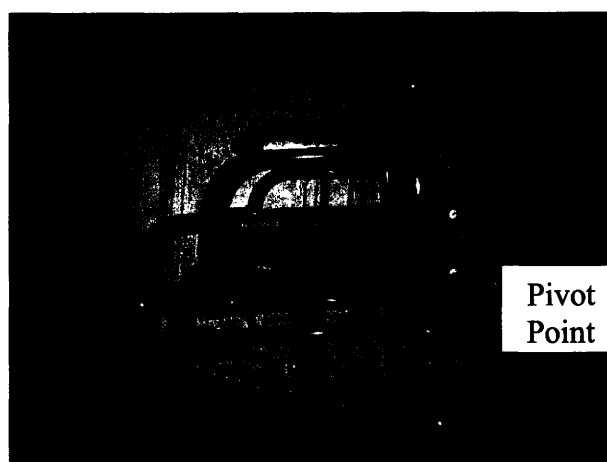


Figure 13: Side view of wheelchair depicting the pivot point for the proposed tilting mechanism.

A pivot on each side of the chair at this location will create a clamshell effect. The black pipes that support the seat bottom and the blue pipes that support the seat back will remain connected perpendicular to each other forming a seat structure. The armrests will also remain fixed to the seat structure. The blue pipes below the seat bottom will remain stationary, while the seat structure will be free rotate back. The pivot joint can be made using a U - shaped piece of tubular steel for the bottom part of the joint and straight piece

of tubular steel coming down from the seat structure. The straight piece will fit inside the middle of the U – shaped tubular steel. A pin driven through the entire assembly will provide the connection, but allow the required rotation. Some sort of bearings should be used to ensure smooth operation and to limit wear from rubbing at the joint.

This alteration essentially cuts the chair frame in half, with the only connection points being the pivot locations at the back of the chair, on each side. There should be a “stopper” on each side of the chair at the front, which the seat structure will rest on during normal use. The location of such a stopper is shown in Figure 14.

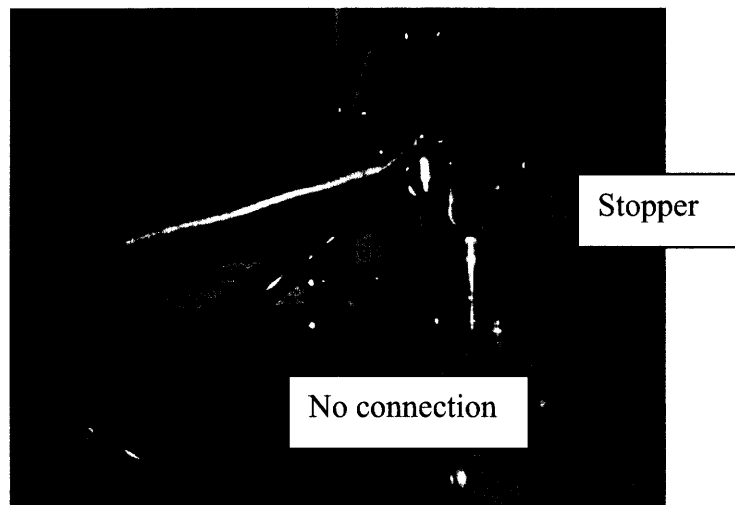


Figure 14: Front view of the wheelchair depicting the dynamics and location of the tilt stopper.

At this stage the chair frame has the ability to tilt back and shift the user’s weight back during stair climbing. The next components will ensure the seat remains locked in the desired recline position throughout the duration of the ascent.

We have decided to use locking gas springs to secure the chair in a tilted position. One gas piston on each side of chair will allow the seat structure to tilt backwards and

also permit a smooth descent back to the normal seat position. We recommend the flexible version of the locking gas spring produced by International Gas Springs. This product offers adjustable force option and can be manufactured to any size specification. The locking mechanism operates when the plunger rod is depressed by opening a valve in the piston. When the plunger rod is released the valve closes and the passage of oil or gas is prevented, locking the piston in that position. This allows the piston to be locked into any position, thus allowing the user to recline to any desired angle. A sample of some of the various gas springs offered by International Gas Springs is shown in Figure 15.

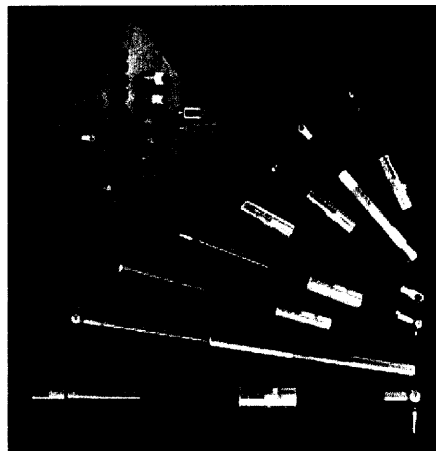


Figure 15: Sample gas springs suggested for the tilting mechanism

The gas springs can be fitted with ball joint ends, and the corresponding mounting brackets are also available from International Gas Springs. The ball joint ends allow the gas spring the freedom to extend during the tilt without being bent. A detailed drawing of the 90 degree mounted brackets can be found in the Appendix.

One set of brackets should be connected to the lower base of the frame and the others to the bottom of the seat structure. These locations are indicated in Figure 16.

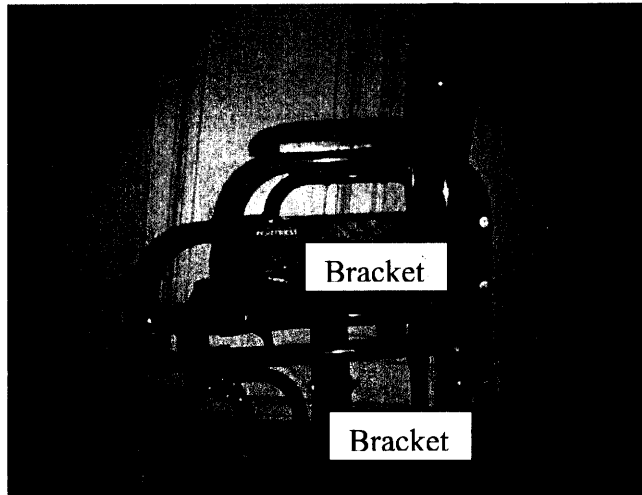


Figure 16: Bracket locations for the gas spring

The brackets should be soldered so that the actual connection points for the gas springs are toward the inside of the chair frame. This allows the gas springs to extend and contract without interruption and keeps the moving parts out of the way, while still allowing access to the locking mechanisms.

As stated above, a care giver is required to physically tilt the seat structure back while the user activates the locking mechanism at the desired angle. When stair climbing is complete, the user can simply release the locking mechanism and the gas springs will allow a smooth descent back to the normal seating position.

Analysis:

The following breakdown will provide insight into our design considerations and material selections for the various components.

Front & Rear Climbing Wheels:

The delrin used in the climbing wheels is an acetyl resin engineering plastic invented and sold by DuPont. It is especially useful in this application due to its very low coefficient of friction and its superior durability. When the user initiates the stair-climbing mode and activates the spokes on the front wheels, the user needs to apply enough force to the handle in order to overcome the force of 16 spring-loaded spokes. The triangular delrin pieces slide against the slits of the central delrin disk. The delrin-on-delrin movement significantly reduces the potential friction involved in this activating motion. Previous designs used triangular aluminum pieces on an aluminum disk, which made it nearly impossible to pull the handle. When the central disk was changed to delrin, the frictional force was still too high, and the aluminum triangles were cutting into the delrin. The two linking delrin pieces was the most efficient and durable option.

As for the rims on the wheels, the material needed to be extremely durable. The original plan called for Plexiglas, but we were afraid it might give way under the large amounts of stress. The best option was to use lexan, a highly durable polycarbonate resin thermoplastic. Using lexan allowed us to create 32 slits for aluminum guides without sacrificing any of the material integrity.

The size of the rims is roughly 23 inches in diameter, the same size as traditional main wheels on wheelchairs. With the rim size and common staircase dimensions

determined, the minimum number of spokes in the wheel was calculated to be 16. More spokes could have been incorporated for increased control, but it was important to maintain the minimum to help reduce the weight for climbing and eliminate the unnecessary force of additional springs on the handle rotation.

Although our original bench-level experiments indicated each spoke could hold nearly 200 pounds at a time, it is important to note that no single spoke will experience such a load. Because the wheelchair has four points of contact on the stairs, the weight of the user and structure will be distributed among them. The front wheel spokes will experience a higher force than the rear spokes due to the lower center of gravity. An additional benefit of having four climbing wheels is that the user has more control and is more likely to remain straight throughout the ascent.

The number of spokes in the rear wheels was halved as a result of the reduced wheel diameter. As mentioned with the front wheel, the minimum number of spokes needed would also correspond to the optimum. However, the reduction of weight was the main reason for deciding on the minimum number. Because the rear wheel spokes do not need to be retracted for ground level use, the spring-loaded torque levels did not play a factor in this decision.

Ratchet Use on Climbing Wheels:

As mentioned above, the type of ratchet used for the main and rear climbing wheels is extremely durable and one of the strongest ratchets commercially available. Its unique design ensures that the ratchet will not give out, no matter how much the user

weighs. While the ratchet itself leaves little uncertainty, the modules designed around it may have their faults.

The manufacturing and installation of the slide rods for the main wheels are vital for the success of the lock-in mechanism. The ratchet must be able to slide in and out of the hexagonal nut on the axle, and the repeatability of this movement is essential for prolonged use. If the rods are not exactly parallel to themselves and perpendicular to the wheel, then the ratchet will not connect to the axle as desired. This defect would also increase friction within the four outer holes of the ratchet and thus create more difficulty in moving the ratchet. In an attempt to reduce this friction and minimize jamming, delrin bearings need to be purchased and inserted into the ratchet holes. Similar to the main wheels, a delrin bearing on delrin rod would be ideal for smooth transitions, but considering the rods may experience high levels of torque, we decided that steel rods were our best option for such a thin member. Because of the small size of the rods, the weight and cost of the steel are relatively negligible as compared to the other steel components.

The integration of the ratchets in the rear climbing wheels is a much more manageable task. Because it does not need to be locked in and out, the ratchet can be rigidly connected to the new added frame of the wheelchair. The addition of the extra ratchets in the rear, however, definitely adds a good deal to the overall cost and weight of the prototype. Since the rear wheels do not experience as great of a force on the spokes, the resulting torque is lower, and therefore, the ratchets could be replaced by smaller, slightly weaker ratchets for both rear wheels.

Tilting Mechanism:

The tilting mechanism relies on the pivot points and gas springs. Our design for the pivots is simple but effective. The durability of the pivot relies mostly on the pin that connects the U – shaped tubular steel with the straight piece that extends from the seat structure. This connection must be able to withstand the constant weight of the user. Due to the nature of the connection, the pin that runs through the assembly will be under substantial loads and must be able to resist deformation. We recommend using tubular steel of higher strength than that of the rest of the frame and a solid steel pin with diameter of at least 0.5 inch. The points of contact between the pin and the tubular steel should have a relatively low coefficient of friction to ensure smooth operation and limit wear on joint. A plastic coating or sleeve may be applied to the steel pin to act as a bearing.

By using the gas springs by International Gas Springs, we have allowed the user to recline to any angle. There is certainly an optimal range of tilt where the chair will climb stairs most effectively, but that is partially determined by the weight and strength and of the user and the incline of the staircase. The reclining feature has the main purpose of shifting the center of mass of the user towards the top of the stairs, but also puts the user in a more comfortable position while on the stairs. We have estimated that the most common angle of tilt for stair climbing will be between 45 and 60 degrees. The versatility of the gas springs allows the user to recline to a position that he/she feels most comfortable with and that is most appropriate for the set of stairs at hand. It is important to note that the user will require assistance to get the chair in a tilted position. Another individual must tilt back the seat structure using the regular handles, while the user locks

the gas springs in the desired position. When the climb is complete the user can unlock the gas springs and the chair will slowly return to its normal position without the need for external assistance.

Discussion & Conclusions:

We have outlined a detailed design of a wheelchair that would be capable of climbing stairs. The chair is designed to be versatile enough to be used as a normal wheelchair, but is also able to climb a variety of staircases. It is important to note that our design is intended for a niche market of the handicapped community. The user must possess the upper body strength that will enable him/her to operate the chair. In several basic benchmark tests, we found that the force required to pull on the spokes is rather substantial. However, the feat of climbing stairs without the aid of any external power seems possible using the wheelchair we have designed. If an active handicapped individual with the necessary strength were seeking more freedom from their wheelchair, but did not have the budget to purchase the high priced motorized stair-climbers, then our design may be a feasible solution. While we realize that there may not be a place in a commercial market for our design, we are pleased to have accomplished our initial goal. Being able to compete on a commercial level with the advanced technology used in motorized stair climbing chairs like the iBOT was not a priority of this project. The goal was to conduct a case study in mechanical design in hope of producing the plans for a chair that had the capabilities of much more expensive chairs, at a fraction of the price. The chair does have the capability to climb a wide variety of stairs by employing a purely

mechanical system. It does so using widely available and relatively inexpensive materials and processes.

We faced many difficulties in trying to maintain the goal of a design with only mechanical systems. There were several areas where a motorized or electronic solution would have been a better solution. For example, the tilting mechanism could have employed the use of a motorized piston to recline the chair. This method would have eliminated the need for an individual to help the user set the desired tilt. The piston could have easily controlled with an electric switch equipped on the arm rest of the chair. In addition, both the main and rear wheels could have benefited from being driven by a powerful electric motor, thus making the chair plausible for a wider range of users. Pursuing features like these would have made the design much more appealing from a marketing perspective. While looking to better technology to improve this design has its merits, such an endeavor would significantly increase the cost of materials and manufacturing for this device. Our main ambition was to complete the design while considering the issues of cost and manufacturability. When one considers that the cost of the iBOT, the best known stair climber, is on the order of \$30,000, it seems possible that many of the fundamental ideas of our design can be applied to produce a more efficient chair. Combining the retractable spoke wheels and reclining seat method with sophisticated motors and electric controls could give rise to a commercially competitive stair climbing wheelchair.

References:

Blanco, Ernesto. Professor of Mechanical Engineering at the Massachusetts Institute of Technology (Retired). Advised us from June 2005 – March 2007.

Castro, Sebastian. 2008 Undergraduate at Massachusetts Institute of Technology. Conducted research with us June – September 2005.

“Delrin.” *Wikipedia*. Wikipedia Foundation Inc. 30 April 2007
<<http://en.wikipedia.org/wiki/Delrin>>.

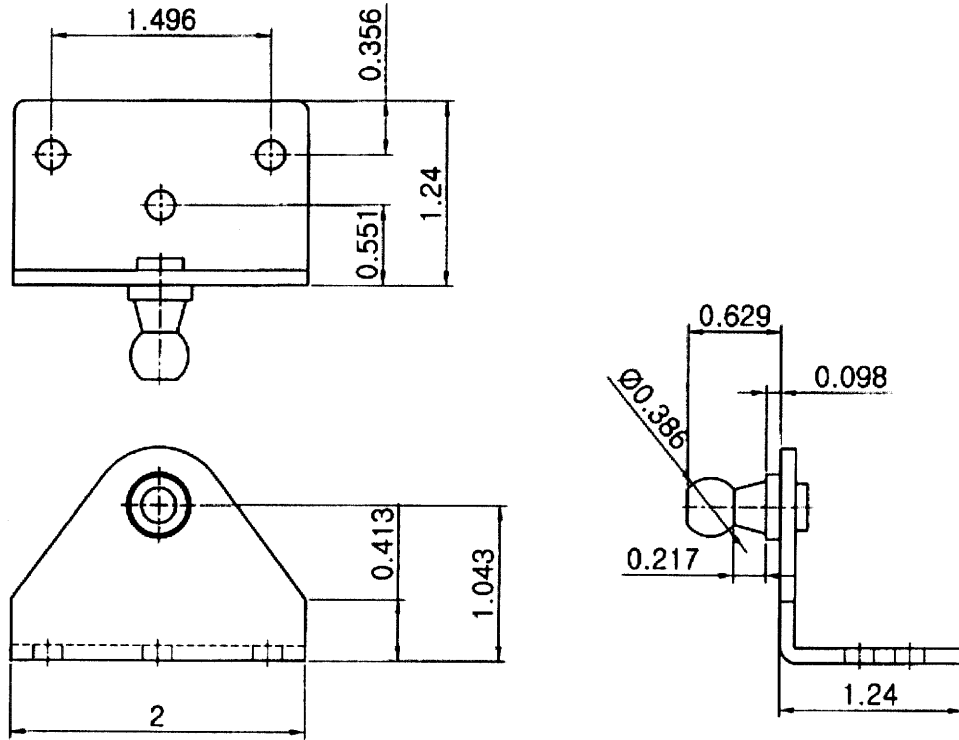
iBOT Mobility Systems. Independence Technology LLC. 20 October 2007.
<www.ibtotnow.com>.

International Gas Springs. International Gas Springs, Inc. 27 March 2007.
<www.internationalgassprings.com>

“Lexan.” *Wikipedia*. Wikipedia Foundation Inc. 30 April 2007
<<http://en.wikipedia.org/wiki/Lexan>>.

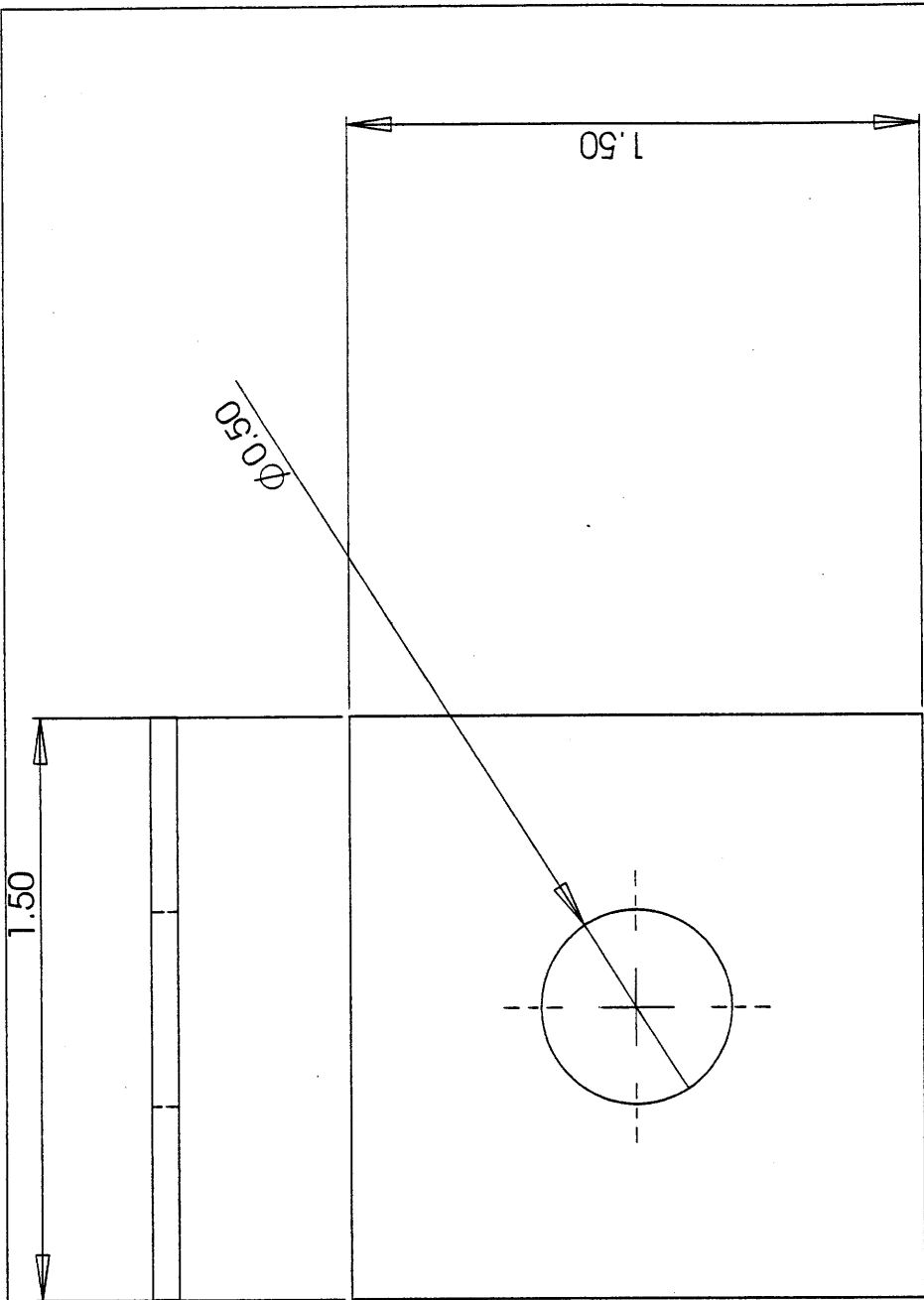
Appendix:

Mounted Brackets for Tilting Mechanism



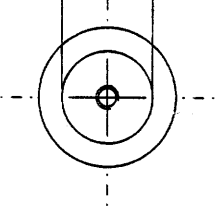
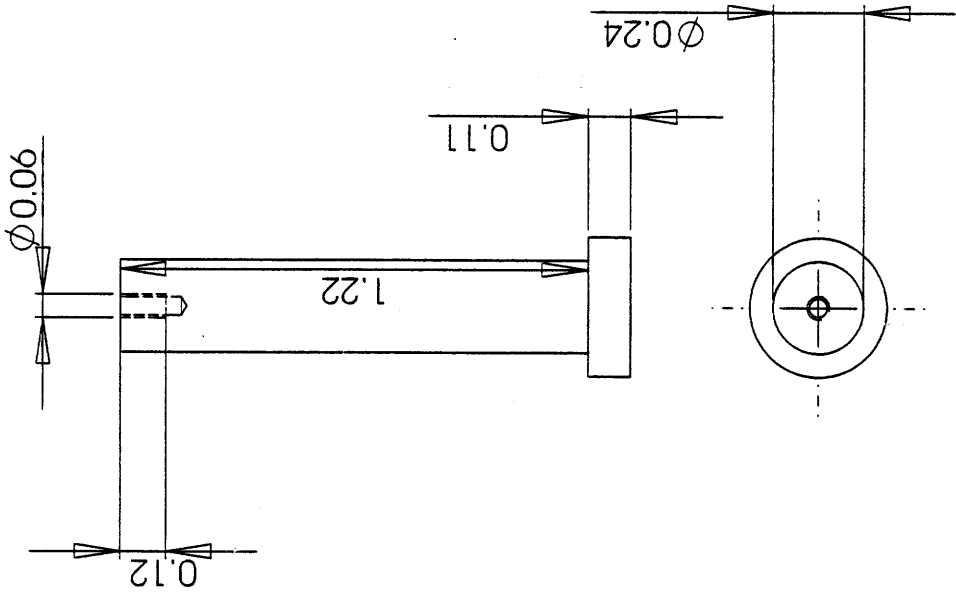
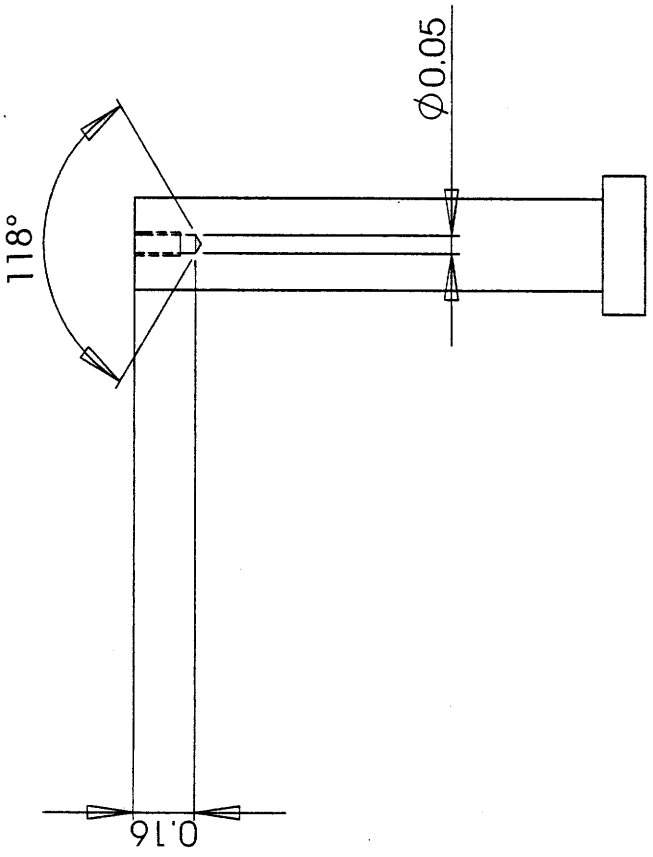
[Values expressed in inches]

SolidWorks Drawings:



0.07

<p>PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.</p>		<p>UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±</p>		<p>INTERPRET GEOMETRIC TOLERANCING PER: MATERIAL FINISH</p>		<p>DO NOT SCALE DRAWING</p>			
<p>DRAWN</p>	<p>CHECKED</p>	<p>ENG APPR.</p>	<p>MFG APPR.</p>	<p>Q.A.</p>	<p>COMMENTS:</p>	<p>DATE</p>	<p>NAME</p>		
<p>TITLE:</p>							<p>SIZE A</p>	<p>DWG. NO. Aluminum Guide</p>	<p>REV</p>
<p>APPLICATION</p>							<p>SCALE: 2:1</p>	<p>WEIGHT:</p>	<p>SHEET 1 OF 1</p>
<p>NEXT ASSY</p>	<p>USED ON</p>	<p>4</p>	<p>3</p>	<p>2</p>	<p>1</p>	<p>5</p>	<p>1</p>		



PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

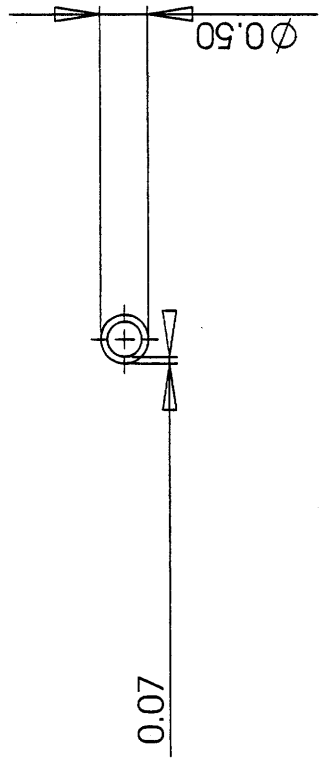
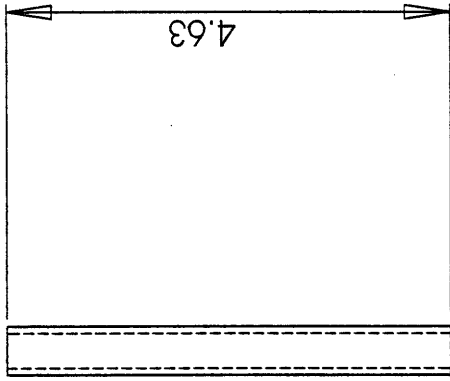
UNLESS OTHERWISE SPECIFIED:		DRAWN		NAME		DATE	
DIMENSIONS ARE IN INCHES		CHECKED					
TOLERANCES:		ENG. APPR.					
FRACTIONAL ±		MFG APPR.					
ANGULAR: MACH ± BEND ±		Q.A.					
TWO PLACE DECIMAL ±		COMMENTS:					
THREE PLACE DECIMAL ±							
INTERPRET GEOMETRIC TOLERANCING PER:							
MATERIAL							
FINISH							
NEXT ASSY		USED ON					
APPLICATION		DO NOT SCALE DRAWING					

TITLE:

SIZE DWG. NO. REV

A Slide Rod

SCALE: 2:1 WEIGHT: SHEET 1 OF 1



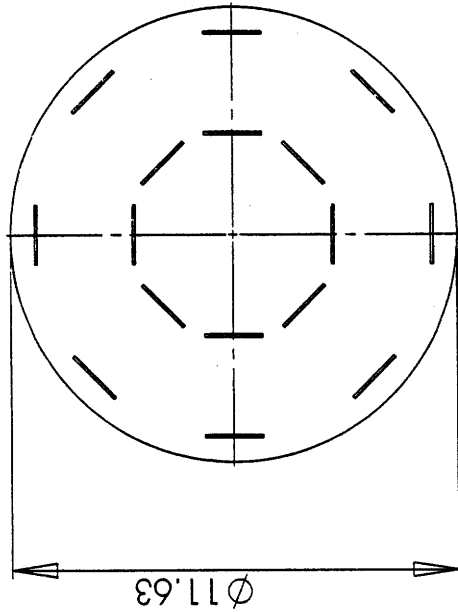
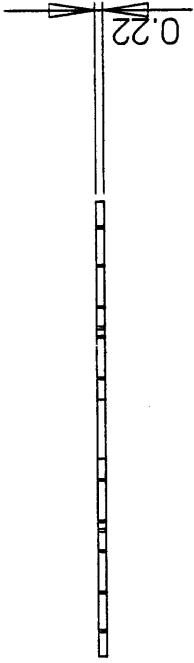
PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES		DRAWN	
TOLERANCES:		CHECKED	
FRACTIONAL \pm		ENG APPR.	
ANGULAR: MACH \pm BEND \pm		MFG APPR.	
TWO PLACE DECIMAL \pm		Q.A.	
THREE PLACE DECIMAL \pm		COMMENTS:	
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL			
FINISH			
NEXT ASSY	USED ON		
APPLICATION			

TITLE:

SIZE **A** DWG. NO. **Tube** REV

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



UNLESS OTHERWISE SPECIFIED:		DRAWN		NAME		DATE	
DIMENSIONS ARE IN INCHES		CHECKED					
TOLERANCES:		ENG APPR.					
FRACTIONAL ±		MFG APPR.					
ANGULAR; MACH ± BEND ±		Q.A.					
TWO PLACE DECIMAL ±		COMMENTS:					
THREE PLACE DECIMAL ±							
INTERPRET GEOMETRIC TOLERANCING PER.							
MATERIAL							
FINISH							
NEXT ASSY							
USED ON							
APPLICATION							
DO NOT SCALE DRAWING							

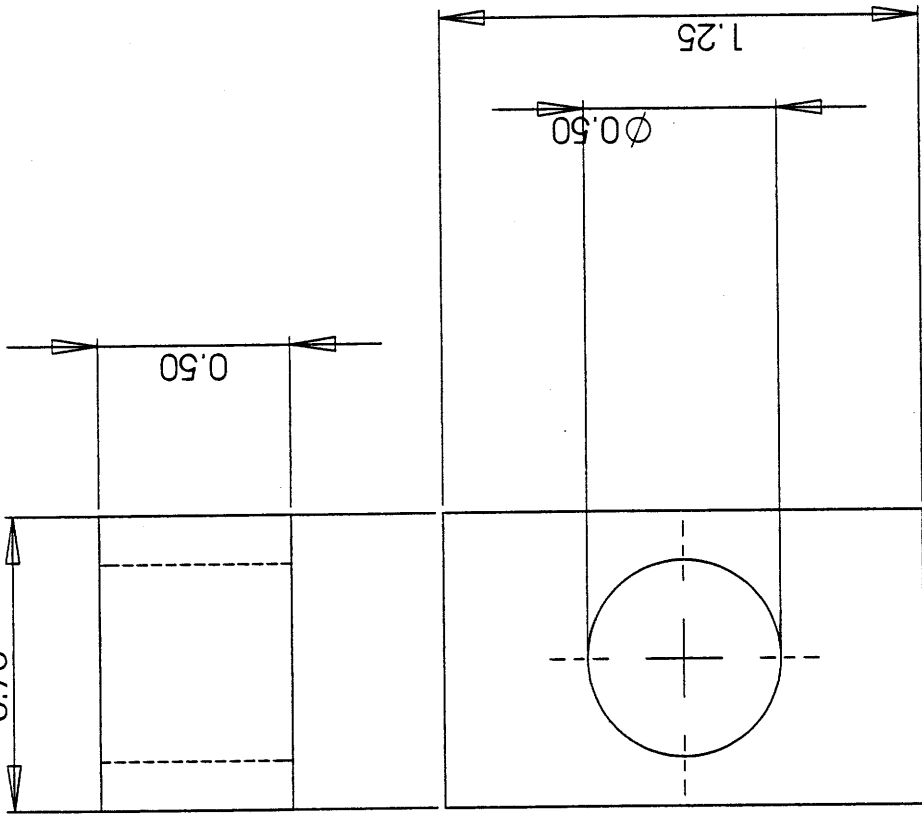
TITLE:

PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS
 DRAWING IS THE SOLE PROPERTY OF
 <INSERT COMPANY NAME HERE>. ANY
 REPRODUCTION IN PART OR AS A WHOLE
 WITHOUT THE WRITTEN PERMISSION OF
 <INSERT COMPANY NAME HERE> IS
 PROHIBITED.

SIZE **A** DWG. NO. **Wheel with Slits** REV

SCALE: 1:5 WEIGHT: SHEET 1 OF 1

0.75



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES		DRAWN	
TOLERANCES:		CHECKED	
FRACTIONAL ±		ENG APPR.	
ANGULAR: MACH ± BEND ±		MFG APPR.	
TWO PLACE DECIMAL ±		Q.A.	
THREE PLACE DECIMAL ±		COMMENTS:	
INTERPRET GEOMETRIC TOLERANCING PER:			
MATERIAL			
FINISH			
DO NOT SCALE DRAWING			
APPLICATION			
NEXT ASSY		USED ON	

TITLE:

PROPRIETARY AND CONFIDENTIAL
 THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

SIZE	DWG. NO.	REV
A	Wooden Piece	
SCALE: 2:1	WEIGHT:	SHEET 1 OF 1