

ME 2145

Wheelchair Stair Assistant Term Project

FINAL REPORT

26/03/11

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INTRODUCTION

Wheelchairs assist the mobility of millions of people with physical disabilities; however, stairs remain an obstacle to most users. The goal of this project is to design and create a stair climbing wheelchair attachment that can be used with a large majority of folding wheelchairs the attachment would bring more accessibility to those who already own a wheelchair but are unable to access areas governed by stairs.

Ideally the full cost should be priced under \$3,200 the cheapest user independent stair climbing wheelchairs currently available [1]. To make the mechanism realistic it needs to be as light as possible while staying solid therefore a material such as titanium or aluminum would be used.

Safety is a major priority, so the design will include balance aids, guards to keep body parts out of mechanical areas and a large factor of safety applied to everything. The attachment should stay simple to use and robust enough to last for five years, whilst remaining accessible for serving temporary needs, such as a gymnast needing a year to heal a leg injury. To ensure it is functional for the user, the mechanism should not require more than 100-150lbs of lifting force to operate.

Testing on a small scale using a scaled down 3d printed model with realistic weight distribution will be done to test for balance and safety. The wheelchair would work in indoor environments only due to variety surfaces in an outdoor environment such as wet surfaces possible uneven surfaces and ideally on all indoor surface materials (wood, concrete, tile, etc.). A height and weight limit might be necessary to manage center of gravity effectively, and the user may have to be positioned in a certain way while climbing stairs for the chair to be operated in a safe manner.

REQUIREMENTS

Design requirements:

- Be a mechanism that attaches to any of the standard folding wheelchairs shown in “Wheelchair information” document [2].
- Must be driven through arm movement
- Must be safe.
- attachment should easily remove or be compact enough allowing the chair to fold up and fit into a car or stored easily.
- Must work for varying stair sizes.
- cannot impede normal wheelchair functions.
- Must climb **OR** descend a flight of stairs.
- Be independently operated

CONCEPTS

CONCEPT ONE

This concept uses 3 wheels that spin independently allowing for normal day-to-day travel on flat and inclined surfaces. The mechanism would be driven by a wheelchair push arm. The mechanism would likely be driven by a gear or belt system. For the wheelchair to climb stairs, the independent rotation of each wheel would be locked, and the whole wheel assembly would be rotating replicating the systems used in 3-wheel stair climbing cart [3]. This design is a mechanical complex that has the potential to be hard to drive and would consist of many moving parts. This design has the advantage of being tested in the real world with push carts.

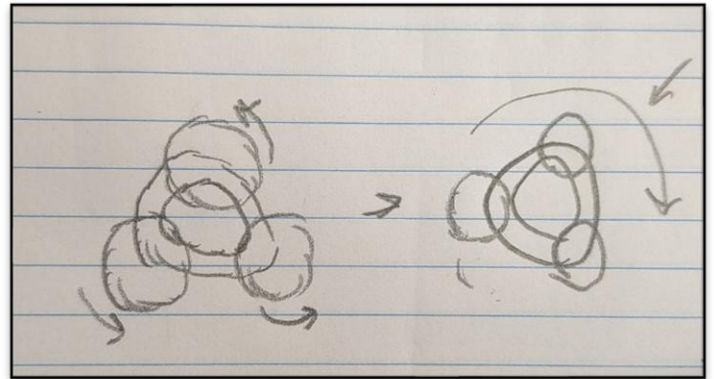


Figure 1: Concept 1 Drawing

CONCEPT TWO

To propel the wheelchair upstairs, this concept uses two pistons which would likely drive a rotating disk converting rotational energy into linear energy, replicating the motion of feet walking upstairs. Likely the mechanism be mounted to the back of the wheelchair, and the user would have to lie backwards to keep the center of gravity low whilst propelling upstairs. An advantage to this system is that it is separate from the wheel.

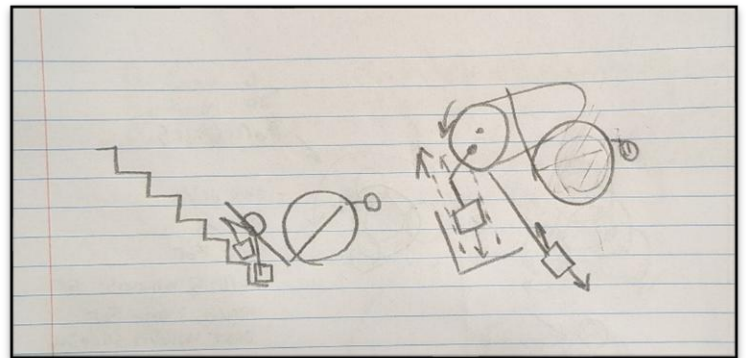


Figure 2: Concept 2 Drawing

Concept Three

This concept uses no mechanism and instead utilizes the shape of the wheel to propel the user upstairs, by cutting out in a specific shape, leaving openings for each step to slot in and push off. This design may require substantially large amounts of force to propel but has the advantage of being easy to manufacture and install.

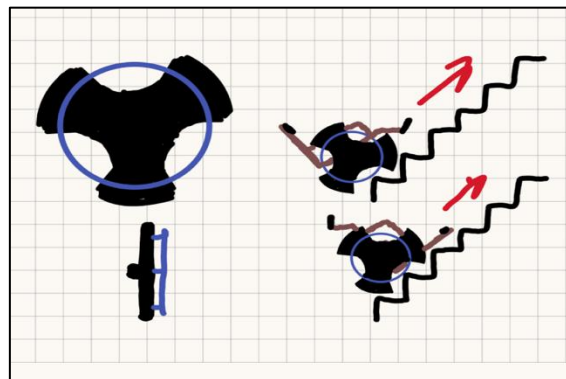


Figure 3: Concept 3 Drawing

Concept review

Concept one

Concept one took inspiration from stair dolly carts. It was deemed unfeasible by the group as it would be too complex and incredibly difficult for the gymnast to operate. The center of gravity would be positioned too high. In addition to this the individual wheel size would have had to be the height of a single flight of stairs (8 inches) with at most a 4-inch offset you would be riding 6 inches off the ground which is substantially shorter than a standard wheelchair.

Concept Two

Concept two is not short of flaws, there will be a major offset with the center of gravity, the mechanism will be clunky and heavy, there will be a lot of moving parts. However, the mechanism would be simplest to operate and allow the wheelchair to continue normal day-to-day operations with the least impact. Overall, the concept is promising but will most definitely have its flaws.

Concept three

Concept 3 did not consist of mechanisms, rather it used a special cut out shape to propel stairs in a somewhat similar fashion to concept one. This concept promised good results the major downside would be the force required to push upstairs. Also this claim cannot be backed with numbers without any gear ratios or any other way of reducing required force for movement it would be nearly impossible to propel and balance upstairs. A mechanism could be created that would turn a one-way pushing motion into rotational motion which may supply extra force but would come at the sacrifice of the user experience.

FINAL DESIGN

The design selected for the mechanism is concept two. This concept was chosen due to the simple nature of the mechanism consisting of 2 links, a slider, and a crankshaft. The crank shaft will be powered through a hand force geared up using a chain or a belt. This design was selected after evaluating the advantages and disadvantages of each concept, then determining which design offered the greatest attributes with the least drawbacks.

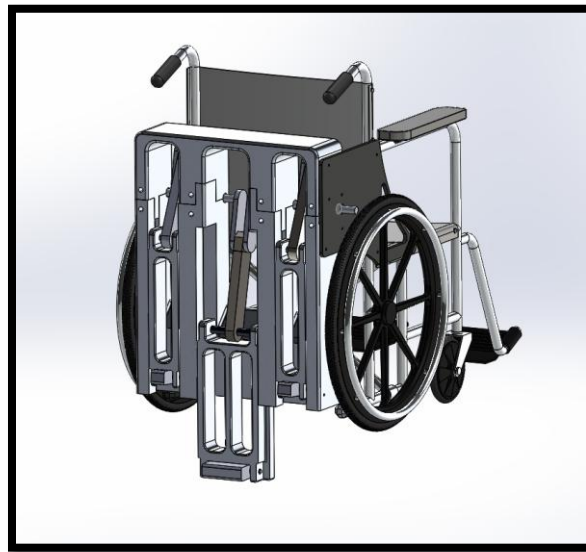


Figure 4: Milestone 2 CAD Model

The Mechanism Consists of:

Crank shaft - this will act as the crank in addition to the drive link of the mechanism.

Large link - this will consist of two parts, an upper and lower part allowing for the link to form around the Crank shaft.

Sliders - there will be 2 different types of sliders, a wide and narrow slider. These will be 180 degrees out of phase.

Feet - the feet will provide a retractable pushing surface for the chair.

Base block – the base block will house the whole mechanism and is made up of 2 parts.

Mounts – mount will be attached to both the base bock and the wheelchair (NOTE: there is a lower and upper mount lower not shown in photo).

Wheels/pulleys – there will be a wheel attached to the main drive wheel pf the chair and this will provide the pushing force, in addition to this a smaller wheel will be attached to this larger wheel, the smaller wheel will drive a wheel twice the size of its self this wheel that is being driven will provide the rotational force for the crank shaft.

Design synthesis

For the design synthesis, it was found that an average staircase height was 8 inches tall [4] therefore the slider must have traveled greater than or equal to 8 inches. That's why a travel distance of 9 inches was chosen as it leaves a solid inch for safety. In addition to travel distance, interference is considered by offsetting the point of rotation 3 inches up and to the left relative to the slider point of attachment at its maximum vertical position. Given all this information, the calculations done to obtain the link dimensions found; the driving link to be 4.24 inches and the pushing link to be 9.09 inches. The casing was then designed around the maximum and minimum positions of the links in the horizontal direction to ensure that they remain fully contained.

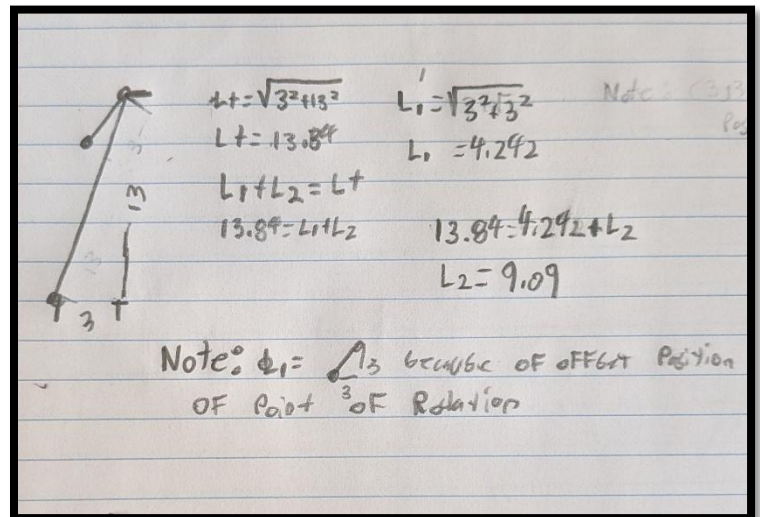


Figure 5: Calculations of Position Analysis of Mechanism

Mass of the overall chair was calculated using an estimate of the gymnast weight to be 200lbs, the wheel chair weight to be 50lbs. The weight of the Mechanisms was found by using multiplying the volume of the model with the density of aluminum 7075 which resulted in a weight of 141lbs. Using these values, the total downwards force was found by canceling out the normal force effect on the chair giving a total force acting parallel to the chair of 1229.835N.

UNB
SU

26/03/11 F.S. applied
here

$400N \times (0.608) = T$
 $T = 101.6 Nm$

assumed

$T_{out} = T_{in}$

Knowns Unknowns

$T_{in} = 101.6 Nm$ $T_{out} =$
 $T_{out} =$
 $T_{in} =$

assumption total
Aluminum = 200 lb
Chair = 50 lbs
Aluminum = 100 lbs

7.75 aluminum
2810 kg/m³

2 in x 26 in
(12.25) x (26.25) x (5.75 x 2.5)
(0.13) x (0.5334) (6464) = 0.0457 m³

2810 x 0.0457 = 128 kg assume for Volume
64 kg = 141 lbs

$W = 200 + 141 + 50 = 391 lbs = 1739.25 N$

$1739.25 N \times 0.645 = F_N$
1229.835 N

8

DESIGN CHALLENGES AND CHANGES

During the design phase it was observed that when the mechanism was placed on a staircase, no motion was transferred. The sliders were simply sliding along the stairs instead of pushing against them.

To solve this problem, feet were added to the bottom of the sliders. These feet utilize a ratcheting mechanism that allows a pushing force to be exerted in one direction while allowing the foot to collapse during the return stroke. The feet are forced into a position naturally perpendicular to the slider using a low-force torsion spring (90-degree spring), which serves only to return the feet to their default perpendicular orientation.

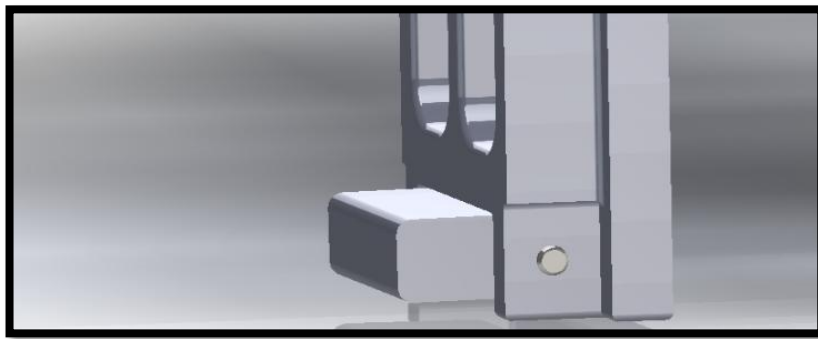


Figure 7: Feet positioning when $q = 0^\circ$

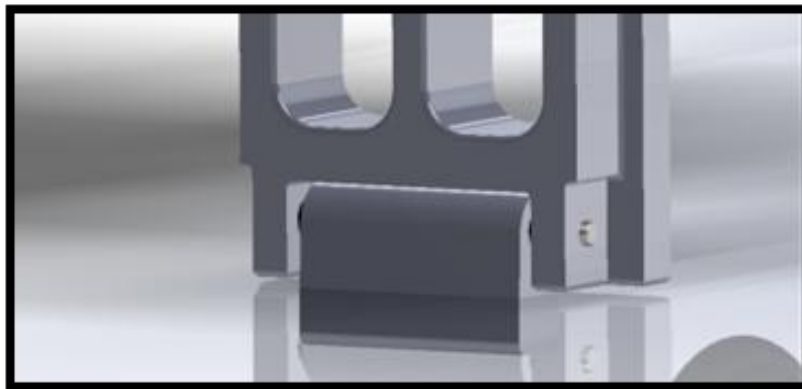


Figure 8: Feet positioning when $q = 90^\circ$

MOTION ANALYSIS

To analyze the motion of the climbing mechanism, the velocity of the crank and slider must be calculated. These calculations will determine whether the mechanism will operate at a practical and controllable speed during use. The mechanism is powered manually by the user. An input angular velocity of 10 rpm is assumed as this mechanism requires a long travel due to the torque advantage designed into it.

The angular velocity (ω) in rad/s of the crank is calculated using equation [1]:

$$\omega = \frac{2\pi(10)}{60} [1]$$

$$\omega = 1.05 \frac{rad}{s}$$

The crank length is 4.24” and when converted into meters is 0.1077m. The linear velocity of the crank pin is 0.113 m/s. This is the maximum velocity which occurs through the movement cycle (at $\theta = 90^\circ$). This was determined using equation [2], where r is the crank length in meters, and ω is the angular velocity in rad/s.

$$v_s = r\omega \sin(\theta) [2]$$

$$= (0.1077) (1.05) \sin(90)$$

$$v_s = 0.113 \frac{m}{s}$$

The time required for one push motion of the slider mechanism can be estimated using this velocity. 0.2286 is the length in meters of the slider mechanism. One extension stroke occurs in approximately 2.02 seconds. This value was determined using equation [3] where d is length of the slider mechanism in meters, and v_s is the max velocity of the crank pin in m/s. This is an acceptable speed as it is not too slow, is feasible, and safe.

$$t = \frac{d}{v_s} [3]$$

$$t = \frac{0.2286}{0.113}$$

$$t = 2.02$$

Design Advancements

To drive the wheelchair, a plate was mounted to the wheel using the same bolt pattern as the push bar. This is where a mount is attached and a gear shaft is placed into a socket, which translates the rotation of the wheel into the crank-slider mechanism.

To ensure that the crank-slider is not constantly working, an over-center mechanism was considered; however, due to complications, a spring-loaded pin is being implemented for the sake of simplicity. This will involve the user twisting and pulling the pin to disengage the climbing mechanism from the wheel drive.

To test this, a full scale 3d printed model was made of this motion transfer assembly.

The crankshaft's length was increased so that the pulley, which will drive the stair-climbing mechanism, can line up with the drive wheel. This is still using a ratio of 2:1.

The overall weight of the assembly has increased by a total of 40 lbs from the original estimate. This was expected and accounted for with the large factor of safety used in the force calculations from the previous milestone.

Modeling adjustments

Minor changes were made to the design for the modeling process, as tolerances were not included in the original design. This led to many of the 3D-printed parts not fitting correctly and interfering with the motion of the mechanism.

Scale model

The scale model is currently being 3D printed. The main components, such as the main block top and main block bottom, have been 3D printed at 25% scale. As of the writing of this document, the slider's feet and links are being 3D printed.



Figure 9: 25% scale of main block top and bottom

To simulate the proper weight distribution of the wheelchair, a 25% scale model of the wheelchair will be made, paired with a center of gravity offset were created. This offset would be achieved by positioning a weight in a specific location to obtain the same relative center of gravity. This approach would reduce printing time and provide a more accurate representation of the wheelchair's center of gravity.

Design Verification

To test the center of gravity as discussed in the verification plan, a material was assigned to each part of the assembly. A human model was placed into the CAD file and assigned the material "water," as the average density of a person is close to that of water.

The center of gravity was found to be located at, relative to the assembly's origin. It was determined that the center of mass is found to be in the middle of the wheelchair, alleviating the possibility that the center of gravity would be located too far back with the addition of the mechanism.

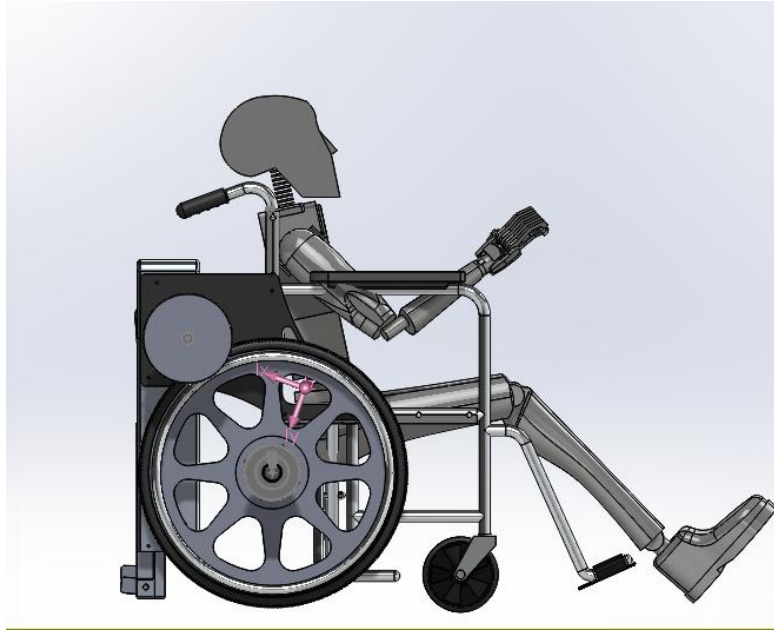


Figure 10: Human Model Paired With Mechanism

For testing, a set of scaled stairs were fabricated out of cardboard using dimensions of 8"x8" while being reduced by 25% in order to maintain accurate geometry. The mechanism is driven manually contrary to using a wheel since the rotation of the wheel is considered to be reliable due to the design of a simple pully system. Additional details on mechanism testing can be found in *Appendix A*.

To validate the motion transfer system and ensure that the mechanism does not work continuously, a spring-loaded pin will be used. The pin will be used as a locking mechanism within the motion transfer to help prevent unwanted or motion. Ideally, the pin engages with a slot in the mechanism which then restricts the movement. Moreover, when motion is wanted, the pin can be manually disengaged therefore allowing movement of the system. The entire motion transfer system will be 3d printed at full scale to verify that it operates correctly.

Force analysis

The total force being applied to the feet of the mechanism was calculated as 1229N, as seen in the figure. This was calculated by using the combined weight of the mechanism, the user, and the wheelchair with respect to gravity.

The total torque was determined by creating a chart of angles from 0 to 100 in increments of 20. By comparing this data with the drive link and the push link using the maximum function in Excel, the maximum torque was found to be 149Nm.

Both the total force and torque will be useful in future calculations to ensure all stresses are within the safe range for their respective materials.

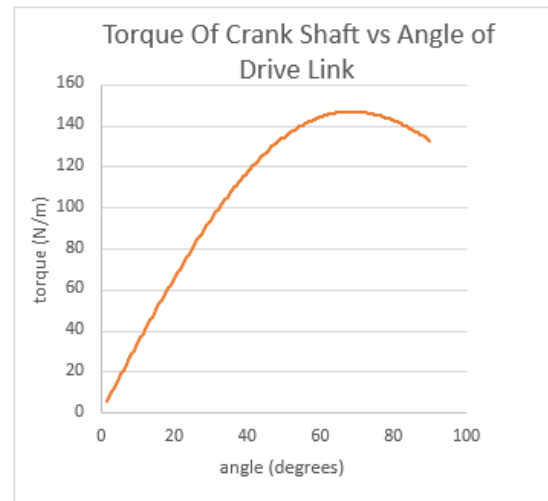


Figure 11: Plot of Torque vs Angle, q

Stress Analysis

The maximum stresses applied to the bolts which mount the mechanism to the chair was calculated to be 5.41 MPa, which is much lower than the allowable stress for an M5 bolt.

The bolts attaching the mechanism to the wheelchair experience a higher maximum stress of 8.65MPa, which is still rated to be safe for use.

Additionally, it should be noted if the 8.65 MPa is exerted on the hollow aluminum frame of the wheelchair, there is a possibility it will reach structural failure.

The torque applied to the crankshaft results in a maximum stress of 103 MPa, which lies well within a safe range for our mechanism. This also provides a factor of safety of 4.5, insinuating that the shaft can

withstand the expected loading conditions without a high risk yielding. The resulting high factor of safety also results in a comfortable region for uncertainties like dynamic loading, stress concentrations and for possible imperfections within the material. The calculations for these results can be found in figure 12 below.

Overall, all components have been manufactured to focus on durability and reliability; while ensuring they can withstand high-stress operating conditions and maintaining a safe performance.

Stress Calculations

$F_{total} = 1229 \text{ N}$
 $\frac{1229 \text{ N}}{10} \leftarrow 10 \text{ bolts total on mounts}$
 $\frac{1229}{5}$
 122.9 N per bolt

$A_s = 14.22 \text{ mm}^2$ tensile ϕ For m5 bolt

$\sigma = \frac{P}{A} = \frac{122.9 \text{ N}}{14.22 \text{ mm}^2} = 8.65 \text{ MPa}$

$A_t = 14.22 \times 10^{-5} \text{ m}^2$

$\sigma = \frac{F}{A_t} = \frac{122.9 \text{ N}}{14.22 \times 10^{-5} \text{ m}^2} = 8,654,929.577 \text{ Pa} = 8.65 \text{ MPa} \checkmark$

max shear For m5 = 6816 N
 $122.9 < 6816 \text{ N}$

also a.b.i. 2 by 10 as 10 bolts

For crank shaft this is from graph
 $\tau_{max} = \frac{T \cdot (C)}{J} = \frac{149 \text{ Nm} \cdot (0.01905)}{\frac{\pi \cdot (0.01905^4)}{32}} = 109.85 \text{ MPa}$

$\sigma_r = 503 \text{ MPa}$
 $\frac{503}{109.85} = F.S. = 4.581 \checkmark$
 $> 2 \checkmark$

7075 yield

266mm
 5 Hole
 to on other side

Figure 12: Stress Calculations

Manufacturing considerations

The two main blocks which hold the whole mechanism will need the most attention during manufacturing.

Due to the large and chunky geometry, they will be possible to manufacture, although it will be very complex due to the internal pockets that exist in the parts. Fillets were added to assist with these pockets so that no sharp edges are needed to be manufactured.

The mechanism will be very sturdy, as everything was designed in an overkill sense where most materials are double or even triple the thickness they are required to be. The main area of concern for wear lies in the ratcheting mechanism, as constant use may wear down the teeth that are in contact with the drive from the wheel.

The only use of bearings in the model is on the crankshaft, whereas everywhere else will use bushings, as this allows for a more spread-out force and extremely low friction is not necessary.

Most parts will be made using either a CNC mill or lathe. The main blocks, links, and sliders will be made using a CNC mill, whereas the crankshaft will be manufactured using a CNC lathe due to its circular profile; the same goes for the pulleys and the drive system from the wheel. With large scale production, the blocks, links, and other parts have potential to be casted, which will also bring down production cost.

The mounts could be CNC milled, plasma cut, or water jetted as high tolerance is not necessary for this part and also have potential to be plasma cut if made slimmer in future iterations.

Bill of materials

Table 1: Mechanisim BOM

part name	file name	supplier	cost	quantity	cost total
bottom block	block bottom	https://www.xometry.com/quoting/home	2856.5	1	2856.5
block top	block top	https://www.xometry.com/quoting/home	1145.88	1	1145.88
long bushing	bushing long	https://www.xometry.com/quoting/home	0.5	2	1
crank shaft	crank shaft	https://www.xometry.com/quoting/home	418.39	1	418.39
link bottom	link bottom	https://www.xometry.com/quoting/home	60.58	3	181.74
link top	link top	https://www.xometry.com/quoting/home	22.52	3	67.56
narrow step	narrow step	https://www.xometry.com/quoting/home	24.03	2	48.06
wide step	wise step	https://www.xometry.com/quoting/home	417.15	1	417.15
upper mount	upper mount	https://www.xometry.com/quoting/home	317.4	2	634.8
small bushing	small bushing	https://www.xometry.com/quoting/home	0.5	4	2
small foot	small bushing	https://www.xometry.com/quoting/home	24.03	2	48.06
3313N39_High-Strength Steel Threaded Rod	3313N39_High-Strength Steel Threaded Rod	MC-MASTERCARR	6.39	4	25.56
3313N773_High-Strength Steel Threaded Rod	3313N773_High-Strength Steel Threaded Rod	MC-MASTERCARR	6.39	2	12.78
92949A877_18-8 Stainless Steel Button Head Hex Drive Screw		MC-MASTERCARR	0.58	4	2.32
total cost	5861.8				

The mechanism alone came out to a cost of \$5861.80 CAD. This is due to the custom CNC parts and the large size of the parts; a majority of these costs come from the top and bottom blocks. At a larger scale for production, casting would have potential to bring down these costs.

Table 2: Drive Mechanism BOM

part name	File name	supplier	cost	quant ity	cost total
crank pulley	large pulley	https://www.xometry.com/quoting/home	243	2	486
wheel drive	wheel drive	https://www.xometry.com/quoting/home	275	2	550
wheel drive mount	wheel drive mount	https://www.xometry.com/quoting/quote	55.8 1	2	111. 62
shaft insert	wheel dirve shaft insert	-	375	2	750
1/2 in. Hex ID 1.125 in. OD Shielded Flanged Bearing	bearing	https://www.studica.ca/en/bearing-12-inch-hex-bore-flanged-fr8zz-hexhd	4.96	2	9.92
Spur Gear Stock, 16 Pitch, 24 Teeth	Spur Gear Stock, 16 Pitch, 24 Teeth	https://www.mcmaster.com/products/spur-gear-rod-stock/	107. 11	2	214. 22
18-8 Stainless Steel Button Head Hex-Drive Screw, M5 x 0.8 mm Thread Size, 8 mm Long	18-8 Stainless Steel Button Head Hex-Drive Screw, M5 x 0.8 mm Thread Size, 8 mm Long	https://www.mcmaster.com/products/screws/thread-size~m5/rounded-head-screws-2~/stainless-steel-button-head-hex-drive-screws~/	17.8	1	17.8
		-			0
		-			0
total cost	2139.56				

The drive mechanism cost was found to be 1060.88. The total cost of the mechanism is therefore found to be \$6361.72 ± \$200 for additional hardware. Once more, due to the cost of the custom parts, this price could be cut in half, as both the left and right side of the wheelchair are being driven, which could be corrected by allowing the wheelchair to have a center axle so that forces from pushing can be spread through both wheels evenly

Safety concerns

Although the center of gravity was confirmed to be in a safe position, deemed from both the center of gravity of the CAD model and the 1/4 scale test, it is impossible to determine if the wheelchair is fully stable until real-world testing at a full scale is completed. More safety concerns lie with the belt and pulley system; as they are exposed, coverings should be made to cover these to prevent body parts or outside materials from entering the pulley system.

Balance remains a major concern, not only in terms of center of gravity but also the side-to-side balance. As this design only uses three feet, the user will have to be cautious to maintain a good side-to-side balance. The design mechanism tries to help this out by allowing the center foot to have a large surface area for balance.

Assembly information

The assembly of the mechanism was designed to be easily put together:

1. Place the spring in the designated spring hole. Then, attach the feet to the sliders. Insert the bushing into the foot, then insert the foot into the screw-in threaded axle and apply Loctite to the ends.
2. Once the feet are attached, insert them into the side step and both narrow steps. Insert the steps into the bottom block.
3. Once the steps are inserted into the blocks, place the crankshaft in the semicircle that separates the top and bottom. Then, place the top half of the block in.
4. Secure the top and bottom portions of the block using 1-inch bolts and a bumper and screw them into the block.
5. Once the top and bottom blocks are connected, attach the link top and link bottom together around the crankshaft. Then, screw and insert a 1/2-inch bolt into the link hole on the side of the link. Do this four times for each section of the crankshaft.
6. Once the link is assembled around the crankshaft, push the bushing into the hole of the bottom link. Arrange spacers for the small and wide steps, screw the threaded rod in, and apply Loctite.
7. With the assistance of another person, pick up the mechanism and mount it into the wheelchair using the mount plate. It might be helpful to support the mechanism with a box underneath. Use M5 screws to secure the mechanism into place.
8. Attach the pulley to the crankshaft of the mechanism.
9. Unscrew the wheelchair push bar. Align the hole of the wheel mount to the hole which previously attached the push bar. Once aligned, screw the push bar back into place.

10. Attach the axle mount to the wheel mount and insert the spur gear stock into the slot. It is recommended to use some form of adhesive at this step.
11. Place the pre-assembled ratchet pulley onto the spur stock. Insert the bearing into the ratcheting pulley and screw a 0.5-inch bolt into the threaded hole of the spur stock. Be sure to use Loctite.
12. Attach the pulley.

Appendix A

Verification plan

Table 3: Verification plan table

Engineering requirements	Verification procedure	Expected result
Wheelchair balance	A 3D printed model will be produced in which weight can be inserted to verify that the wheelchair is stable for daily use.	The wheelchair should be able to remain stable on various inclines up to 20 degrees.
Climbing test	A scaled-down chair model will be created to test the wheelchair's mechanism to see if it can climb.	The mechanism should climb stairs and remain stable.
Center of gravity	The center of gravity can be checked when proper mass properties are assigned to each component in CAD and a placeholder human can be loaded into the file.	The center of gravity should be positioned low and to the center of the wheelchair.

Center Of Gravity test

Additional C.G test

To confirm that the center of gravity was in a good position, additional tests were done with the 1/4 scale 3D printed model. With a center of gravity offset, it was found using the 3D printed mass of the mechanism that the climbing mechanism was able to stay stable at rest and whilst climbing.

Stair climbing test

A 1/4 scale 3D printed model was 3D printed and assembled. Fishing weights were attached to the wheelchair to replicate the center of gravity of the wheelchair with a person sitting in the chair for accurate stair climbing testing. A 1/4 scale 8-inch rise run scale staircase was made using cardboard. The stair climber was then layered flat on the stairs, and the crankshaft was operated by hand.



Figure 13: Scale Model Testing

Appendix B

User Manual:

What this does:

This attachment helps you go upstairs using your wheelchair. It works by connecting to your wheels and using your pushing motion to lift you step by step.

Wheel attachment:

The system uses a wheel-lock attachment that connects to your wheel

When attached, your wheel motion is transferred to the climbing system

This is what allows the chair to move upward instead of just rolling

Before using it:

Make sure the attachment is securely connected to your wheelchair

Check that the wheel-lock attachment is engaged (this allows the system to work with your wheels)

Make sure nothing is loose or damaged

Use only on dry, indoor stairs

How to go upstairs:

- Roll up to the bottom of the stairs
- Lean back slightly to stay balanced
- Begin pushing your wheels using the crank

The system will:

- Grip the step
- Lift you up one step at a time
- Keep a steady and controlled push until you reach the top

How to attach to system:

- Line up the attachment with the side of your wheel
- Slide the mount into place
- Secure it using the locking pin
- Make sure it feels firm and doesn't move

How to detach system:

- Hold the attachment steady
- Pull out the locking pin
- Slide the attachment away from the wheel
- Store it safely when not in use

After Climbing:

Once you're back on flat ground, remove or disengage the wheel attachment

Your wheelchair will return to normal movement

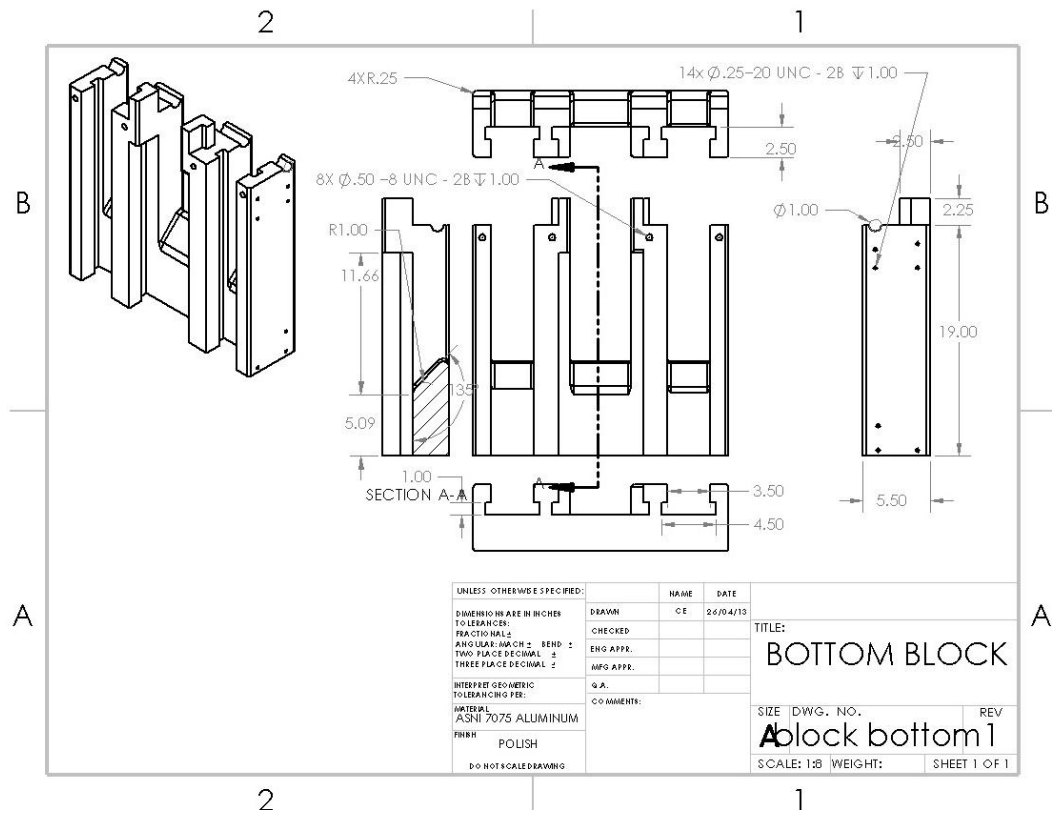


Figure 14: Block bottom drawing

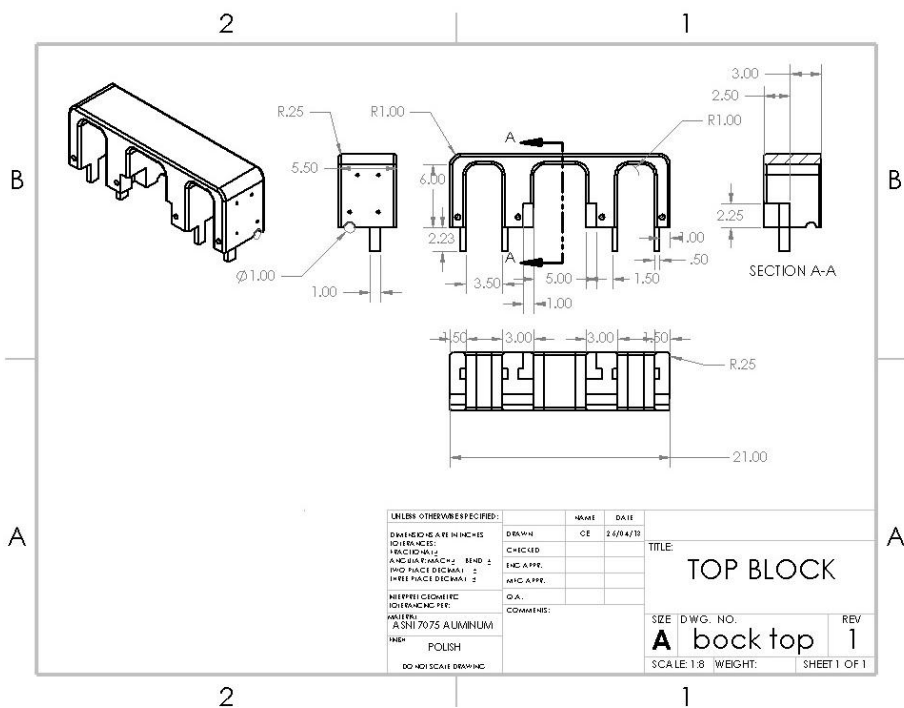


Figure 15: Block top drawing

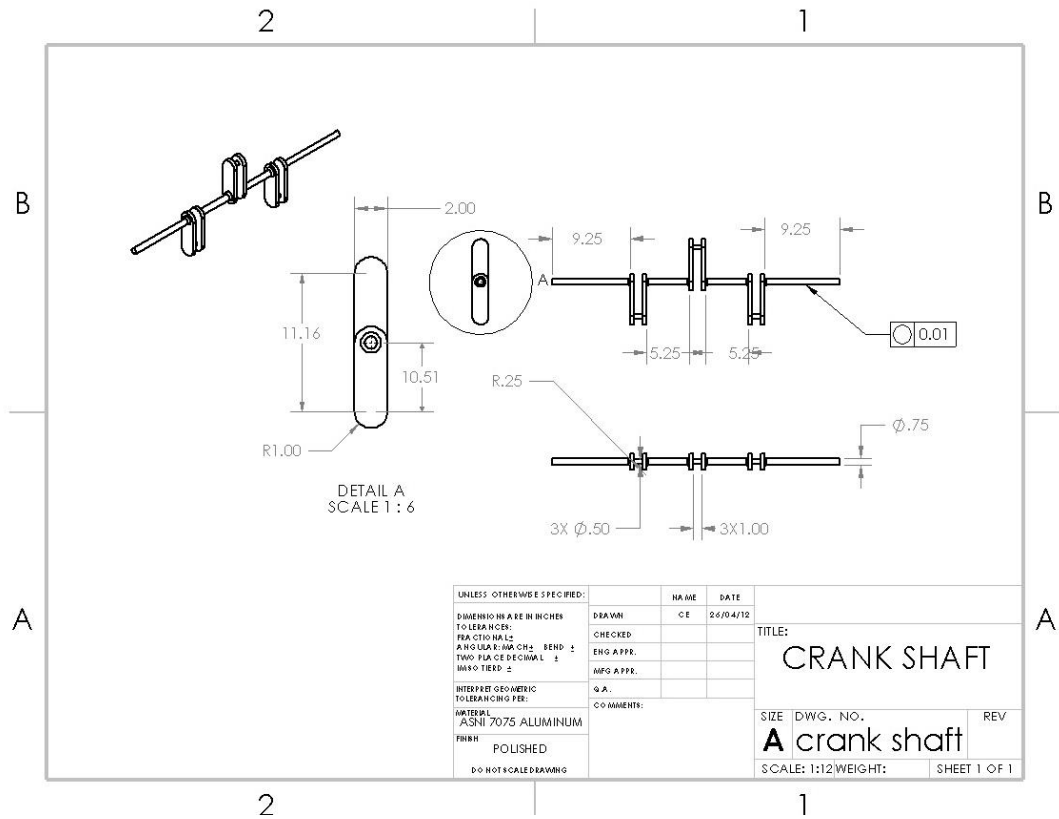


Figure 16: Crank shaft drawing

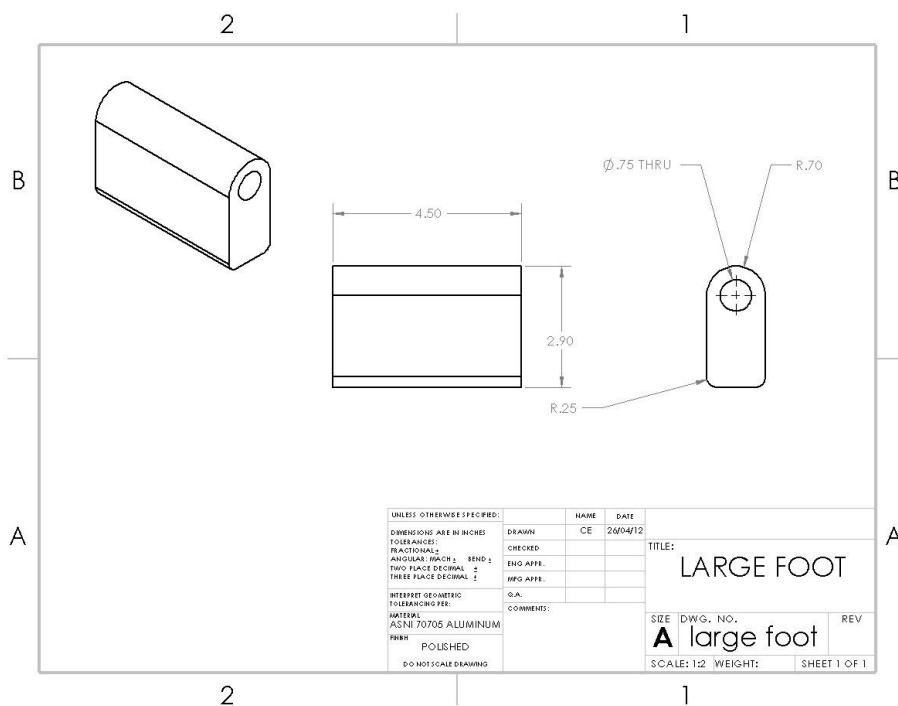


Figure 17: Large foot drawing

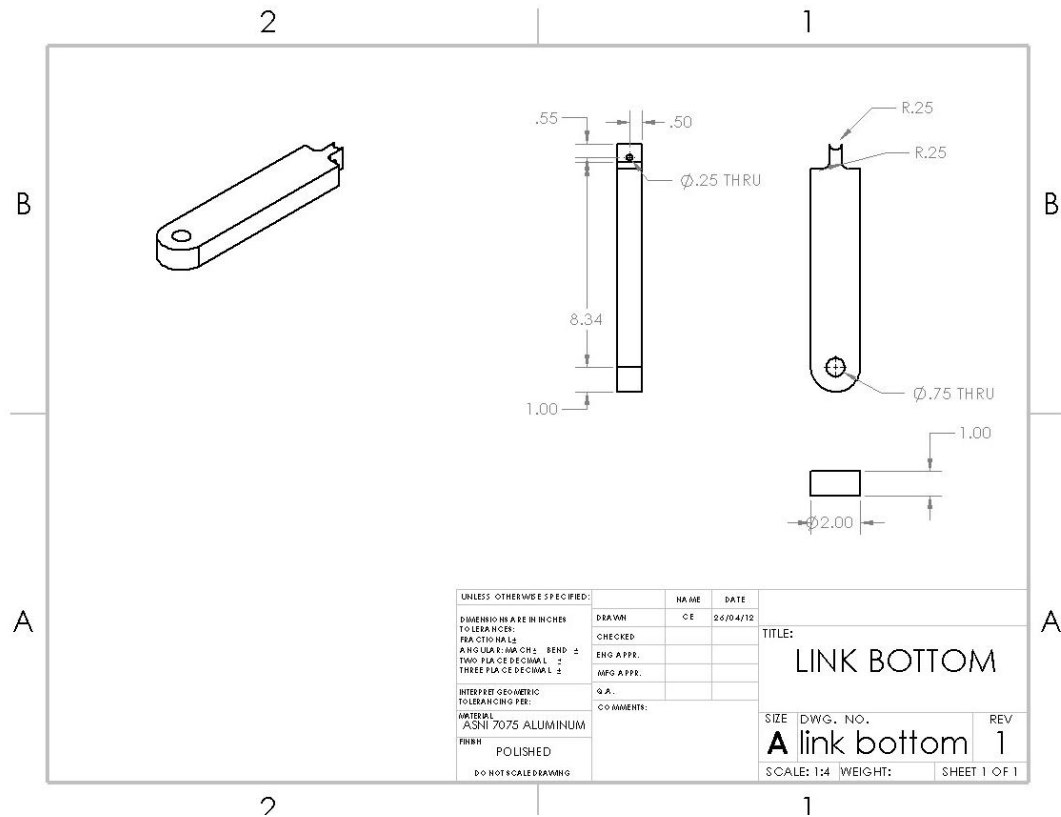


Figure 18: Link bottom drawing

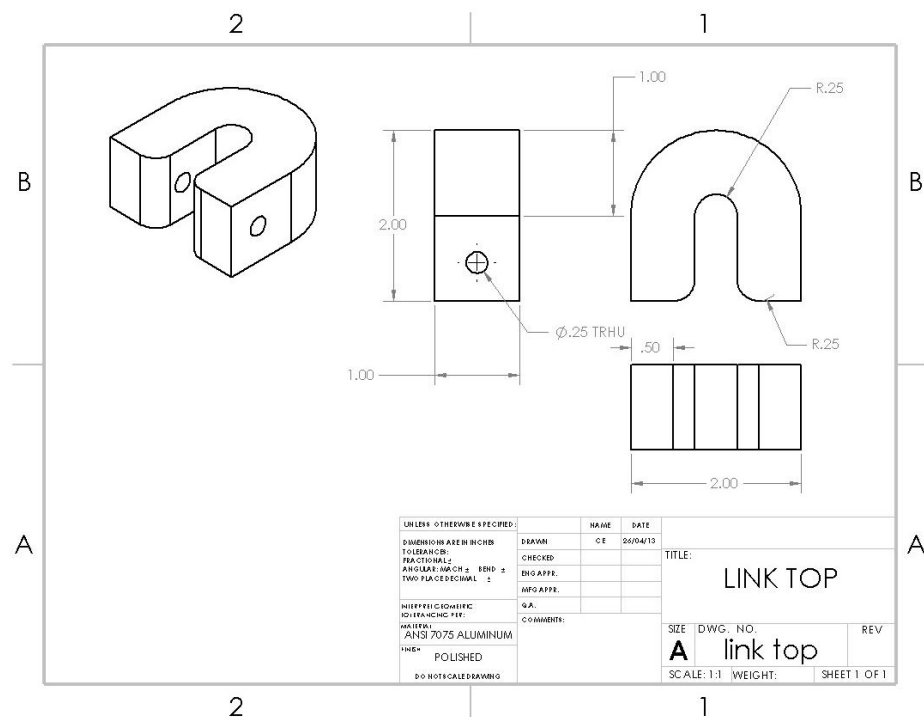


Figure 19: Link top drawing

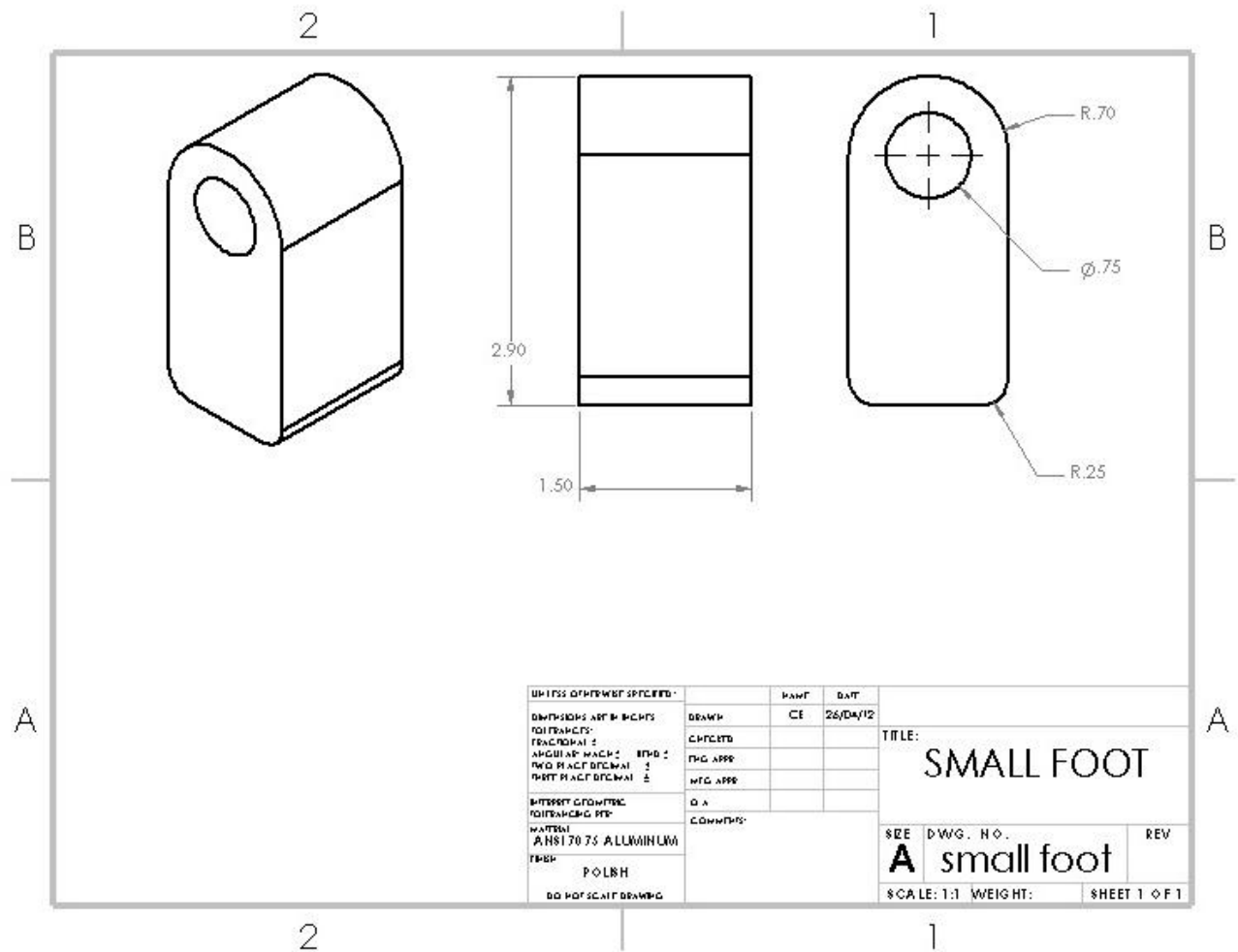


Figure 21: Small foot drawing

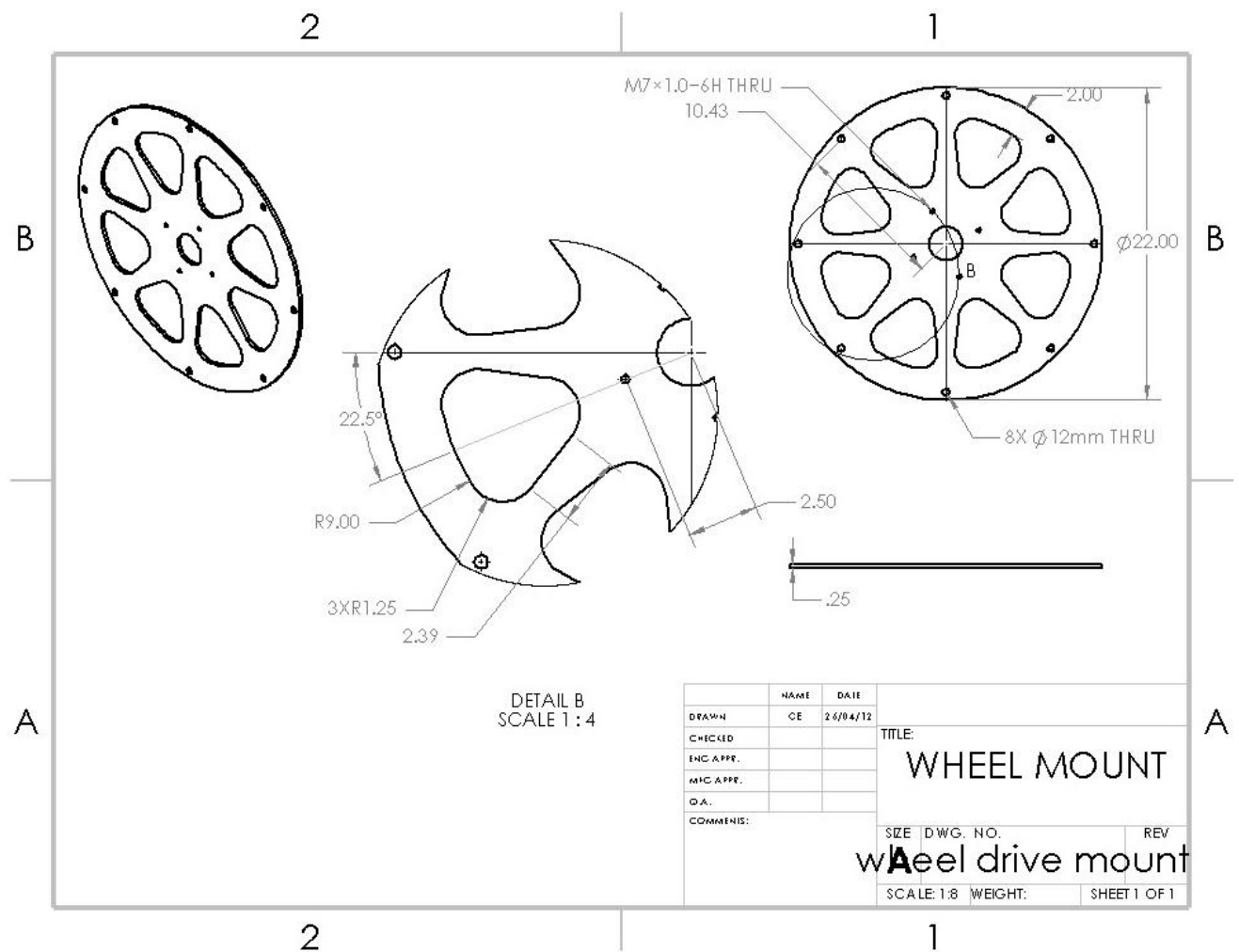


Figure 23: Wheel mount drawing

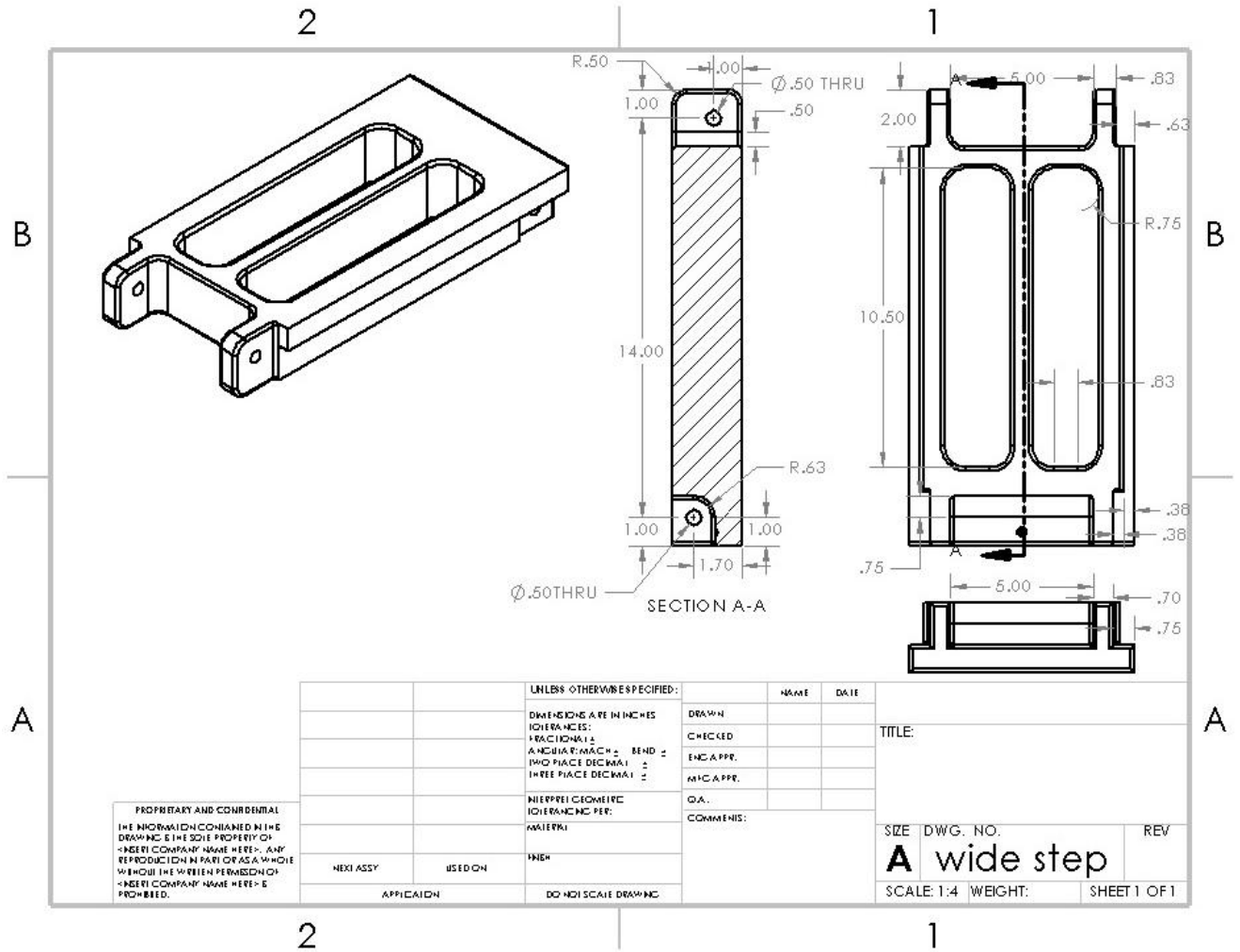


Figure 24: Wide step drawing

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