UTAH STATE UNIVERSITY

Transformable Wheelchair

AutoBots

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TEAM AUTOBOTS

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ABSTRACT

This report includes the development, design, and analysis of a transformable wheelchair. There was a need to design and build a wheelchair that transformed to be pushed, pulled, or self-propelled. This design meets the need of physically restricted wheelchair users who frequent simple hiking trails without needing to move to a secondary off-road capable device. Documentation for concepts, analysis, and completed design details follows.

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DESIGN SUMMARIES

For wheelchair users who desire to participate in recreational activities, such as hiking and camping, an additional wheelchair specialized for outdoor recreational use is necessary. A secondary wheelchair is often expensive and difficult to transport. Thus, the need arose to design a wheelchair for both every day and recreational use. Design requirements were outlined by the Assistive Technology Laboratory (ATL) and Center for Persons with Disabilities (CPD) for a lightweight transformable wheelchair. The scope of the design is for users who are 12 to 30 years of age, a maximum weight of 250 lb., having reasonable upper body and head control, with the use of both hands. This report contains the design requirements, conceptual design, trade studies, design analysis, testing, simulations, and final design package.

DESIGN REQUIREMENTS

The requirements set forth by ATL and CPD are as follows:

1. **Built for under $1500.** A prototype of the transformable wheelchair must be built for under $1500. Several materials and components may be obtained from the AT Lab, effectively reducing the cost of the prototype. Regardless, building the wheelchair with all new materials and components must not exceed budget limit.
2. **Parking Brake.** The design must include a parking brake wheelchair users can engage.
3. **Safety Harness**. An upper body safety harness must be included to maintain users in the wheelchair during off-road activities.
4. **Collapsible**. The wheelchair must be capable of folding up for storage and/or transportation.
5. **Maximum wheelchair weight of 75 lb.** The weight limit facilitates transport when collapsed and off-roading use.
6. **Maximum user weight of 250 lb.** Wheelchair must safely hold and transport a user up to 250 lb. on level and uneven terrain up to speeds of 4 miles per hour.
7. **Capable of traveling on a simple hiking trail.** The design must safely and comfortably allow users to take the wheelchair on a dirt walking trail of 2.5’ or more in width.
8. **Easily configured to be pushed, pulled, or self-propelled.** Prototype must allow a second party to push or pull wheelchair. Users must be able to propel themselves.

Two of the requirements were changed throughout the semester. The requirements listed above are the final requirements after the changes were made. The two changes were in the cost budget and the weight of the occupant. The Assistive Technology Laboratory supplied the initial $750 toward the project, which was the original budget. A few weeks into the semester, Dr. Hansen was able to contribute an additional $750 from a grant he acquired. It turned out that the additional $750 made an enormous difference, allowing the inclusion of many more desired wheelchair features.

The second change was in the weight of the occupant. The initial requirement given was 300 lb., in order to include most of the population. This requirement was reconsidered about half way through the design process, because it is excessively large. The change was justified with two different sources. First, Roger Serzen, an engineer at Sunrise Medical, was contacted and confirmed that the industry standard is to design to a 250 lb. passenger. Secondly, charts showing weight distribution curves were obtained. In nearly every case, the 95th percentile curve is below 250 lb. for the entire age range of the design scope. Some of the demographics show the 95th percentile curve far below 250 lb. Two of these charts are shown in Figure 1. They show height and weight percentile curves, by age, for Americans ages 2-20. Approximately half of our design scope age falls within this range. Additional charts are included in Appendix A.

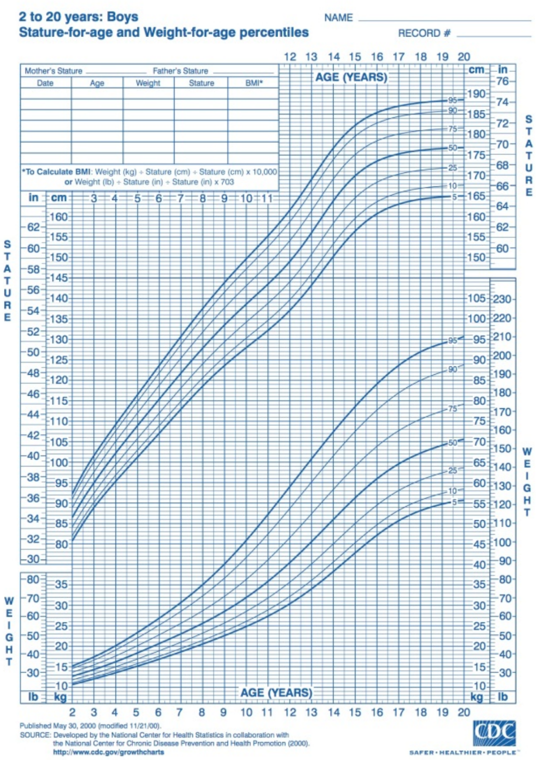


Figure 1.a. Boys in America ages 2-20

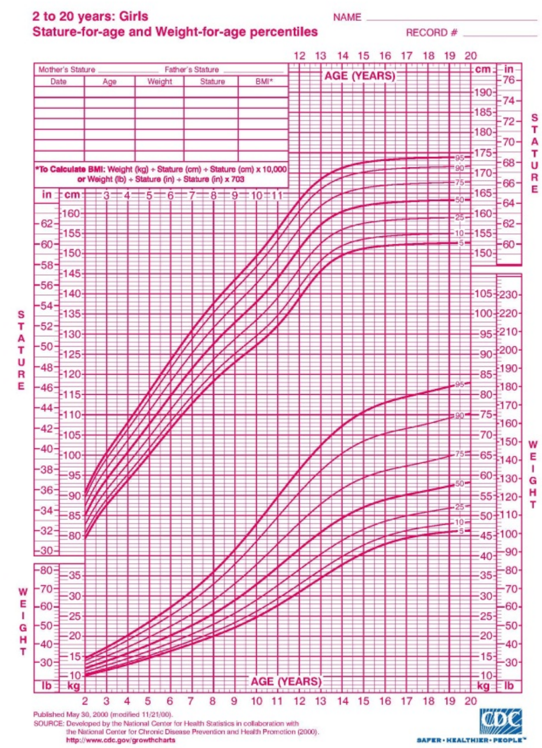


Figure 1.b. Girls in America ages 2-20

CONCEPTUAL DESIGN

The transformable wheelchair design process started with a conceptual design phase. In this process several solutions were theorized. (See Appendix B for conceptual pictures.)

FOLDING

The traditional folding technique for standard wheelchairs was considered first. While simple and fairly compact, this approach does not reduce the height of the wheelchair when collapsed. Adding a hinge like mechanism to the wheelchair back and leg rests enables users to fold the back rest down and the foot rests up into the collapsed seat between the two main tires. An entirely different approach is to fold the main tires themselves around the seat. One configuration folds the back rest down onto the seat with one tire folded on top and the other on the bottom. A second arrangement folds both main tires underneath the seat with the back rest collapsed into the seat. The latter options are more compact than the traditional method. Unfortunately, problems could arise when incorporating a brake, pulling, and suspension system.

PULLING SYSTEM

The pulling mechanism needs to be incorporated within the wheelchair, accessible by a second person. A push bar designed out of telescoping tubing could be pulled up, over the user, and extended out in front as a rickshaw handle. Telescoping a rickshaw handle out of the armrests or from below the seat base is an alternative. A detachable system could be stored behind or under the seat. A final option is to have a steel cable zip line attached to the base of the seat. While a zip line offers the ability to lock and unlock at a variety of lengths (e.g. ratcheting the wheelchair up a slope), the cable poses a safety risk to both the user and the person pulling.

The two main wheels will be in use while pulling (i.e. casters will be lifted off the ground). This results in a reclined position for the wheelchair. Consequently, the need for a stability wheel in the back was taken into account. The back wheel could fold down from the back rest, slide along a track on the back rest, or pivot an angle range on the back of the seat.

SUSPENSION

Full, partial, or seat suspension could be used to minimize vibrations felt by the wheelchair user. The full suspension entails a shock on the two main wheels, the two casters, and stability wheel. Partial suspension is more economical with only two shocks on either the main wheels or the casters. Shocks underneath the seat itself reduces vibrations felt whether in rickshaw position or on all four wheels.

TIRES AND BRAKES

Solid tires require minimal maintenance, but offer no shock absorption. Air filled tires, on the other hand, give a little while off-roading and risk becoming deflated and/or punctured. Foam filled tires are a good compromise between the two options. Tires with a tread are immediately preferred over slick tires for more traction. The standard parking brake on traditional wheelchairs would be insufficient for users needing to stop or slow themselves down while on a hiking trail, for example. Disc or rim brakes (commonly found on bicycles) were suggested. A lever system idea would potentially serve for both propulsion and braking. The lever would offer additional power in self-propulsion, and its clever gripping system could double as a brake. The lever idea did not make it past conceptual design, but drawings of the idea can be found in Appendix B.

CUSHION AND HARNESS

Viscoelastic or bonded foam cushions compress with spring-like and time dependent properties for the comfort of the user. Compartmentalized air cushions are most effective in reducing pressure points, but require air maintenance. A contoured seat facilitates postural stability and overall comfort.

A child's car-seat type harness stabilizes the user at the hips and torso, keeping the user from sliding down the wheelchair. A traditional lap belt requires fewer steps to secure, but presents limited security for the user. As a result, a variation harness was considered: a lap belt with optional shoulder straps, padded with neoprene wicking material for comfort and temperature/moisture control.

TRADE STUDIES AND PRELIMINARY DESIGN

The conceptual design phase successfully produced many ideas for each component of the wheelchair. Each of these ideas originated as a possible solution for how that particular component could meet or contribute toward meeting the requirements. In other words, each of the ideas from conceptual design meets the requirements. The only requirements in jeopardy at this point were the cost and weight budgets. In order to perform a trade study, overall designs of wheelchairs had to be compared. However, with several options available for each component, there were a myriad of possible combinations for complete wheelchair designs. In order to reduce the possibilities, some selections had to be made for individual components. These selections were made based on a 'good – better – best' system because each option would meet requirements. Criteria were determined for each component – quantitative as often as possible– which were used to rank the ideas. Trade studies were then performed for each component to determine the best option. In the comparative trade studies, key factors for that component are marked with an (*). The best choice for each particular factor is marked in blue. The rankings are then listed at the bottom of each study.

Utilizing trade studies, the optimal system from the conceptual designs was chosen. First, the frame material trade study (Figure 2.a.) ranked Aluminum, Chromoly, Titanium and Carbon Steel. Titanium was both sufficiently strong and light, but exceeded our budget. Aluminum was within our price range. However, an extremely large tube diameter was required in order to achieve high enough safety factors. Carbon Steel weight was beyond our maximum wheelchair weight limit of 75 lb. To satisfy cost, weight, and strength a combination of Titanium and Chromoly was considered.

Frame Material	Aluminum	Titanium	Chromoly	Carbon Steel
Density	.0972 lb/in3	.1616 lb/in3	.283 lb/in3	.283 lb/in3
Cost/ft	$1.82/ft	$20-30/ft	$5/ft	$1/ft
Strength	18 ksi	70-130 ksi	60 ksi	53 ksi
Strength/Density Ratio*	185	619	212	187
Choice	**2nd best**	**Best**	**3rd best**	**Worst**

Figure 2.a. Frame material trade study.

Next, the folding study (Figure 2.b.) showed that the classic (traditional) X style and the collapsing bars concept would be equally as easy to use. Ultimately it was decided that the classic X style would be the simplest to design and to manufacture, and therefore became the top choice.

Folding Study	Classic X	Collapsing Bars	Fold Under Wheels	1 over 1 under
Number of parts (total)	25	16	18	?
Number of specialized parts (excluding tubing and bolts)*	6	10	8	?
Number of holes drilled	6	0	2	?
Number of cuts and welds	6	6	4	?
Number of Steps to fold*	3	5	7	4
Choice	**Best**	**2nd best**	**3rd best**	**Worst**

Figure 2.b. Folding trade study.

The trade study on the braking system (Figure 2.c.) showed the disc brakes as the best option, assuming it would fit within the budget. Rim brakes were the next best option. The lever brake did not have enough definite information on it to justify selecting it. In deciding between the ideas for a pulling system, the telescoping poles concept quickly stood out as the favorite because of how easy and safe it will be to use and it doesn't have any loose parts. (See Figure 2.d.)

Brakes	Disc	Rim	Lever
Cost	Donation ($150)	$50	?
Wheels Detatchable*	Yes	No	Yes
Pressure-Sensitive Braking	Yes	Yes	No
Wheather Sensitive	Less	More	More
Weight	2.5 lb	1 lb	?
Choice	**Best**	**Worst**	**2nd best**

Figure 2.c. Brakes trade study.

Rickshaw Conversion	Telescoping	Folding	Detaching	zip line
Number of parts needed	~13	~17	8	6
Steps needed to move	~4	>10	>10	1
Stability (qualitative)*	Good	Bad	Good	Bad
Choice	**Best**	**Worst**	**2nd best**	**3nd best**

Figure 2.d. Rickshaw conversion trade study.

The seat cushion trade study (Figure 2.e.) showed the best cushion to be the air one. It is the most expensive of the options considered, but provides the best comfort and support. Similarly, the restraint was also selected based on comfort and ease of use for the passenger. This will best be provided by the lap and shoulder belt combination. The next best choice would be just a lap belt. (See Figure 2.f.)

Seat Cushion	Air	Mini-Air	Air and Foam	Foam
Skin break down prevention	high	low	high	low
Impact absorption*	high	high	low	low
Weight capacity	500 lbs	500 lbs	500 lbs	250 lbs
Weight	2.65 lbs	2 lbs	2 lbs	2 lbs
Cost	$332	$225	$285	$75
Choice	**Best**	**2nd best**	**3rd best**	**Worst**

Figure 2.e. Seat cushion trade study.

Safety Restraint	Lap belt	Lap & shoulders belt	Child car seat
Steps needed to fasten	1	2	3
Belt friction on skin	low	low	high
Restricts upper body motion*	no	yes	yes
Weight	1 lb	1.5 lb	1lb
Cost	$25	$65	$80
Choice	**2nd best**	**Best**	**Worst**

Figure 2.f. Safety restraint trade study.

Finally, in an off-road situation, tires become a worry. The standard slick tires on wheelchairs will not provide much traction and make the ride very bumpy. Air tires provide traction and shock absorption, but can go flat. Solid urethane tires have tread to increase traction, can't go flat, but still create a stiff ride. In the trade study (Figure 2.g.) it was determined that the solid urethane tires would be the best choice.

Tires	Air filled	Foam Filled	Solid
Can get flats*	Yes	No	No
Cost	$270	N/A	$210
Absorbs minor shocks	Yes	Yes	No
Available	Yes	No	Yes
Choice	**2nd best**	**Worst**	**Best**

Figure 2.g. Tires trade study.

Based off of the rankings of the component trade studies, four options were compiled for complete wheelchair designs. These four options were then compared against the requirements in a trade study (See Figure 2.h.). This time the options were viewed as 'meets/doesn't meet requirements' rather than the 'good-better-best' comparisons of the previous trade studies.

OPTION 1: This system features a titanium frame with classic wheelchair folding and solid tires. The suspension and disc brakes are located on the main wheels. Telescoping tubes are used to convert wheelchair into rickshaw position. In order to reduce pressure points, a compartmentalized air cushion is attached. A lap and shoulder belt is included for added safety on uneven terrain.

OPTION 2: This system incorporates all the same features as Option 1 in exception of the build material. Aluminum replaced the more expensive titanium frame.

OPTION 3: While Aluminum fit within the cost budget, it presented problems with strength requirements. Chromoly, a common wheelchair frame metal, was considered. The more economical build material allowed for financing a mini-compartment air cushion (offering highest pressure redistribution). Additionally, suspension was moved to the seat to offer full shock absorption. The folding was also changed to a collapsing configuration to further reduce volume of collapsed wheelchair.

OPTION 4: To meet both cost and weight requirements a mixture of Titanium and Chromoly considered. Remaining features in Option 1 were maintained.

Requirements	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Foldable	Yes	Yes	Yes	Yes
<75 lb.	Yes	No	No	Yes
Holds 300 lb.	Yes	Yes	Yes	Yes
Hiking Trail Capable	Yes	Yes	Yes	Yes
Pullable/ Pushable/Self	Yes	Yes	Yes	Yes
<$1500	No	Yes	Yes	Yes
Parking Brake	Yes	Yes	Yes	Yes
Harness/Belt	Yes	Yes	Yes	Yes

Key:	**Meets Crieteria**	**Doesn't Meet Criteria**

Figure 2.h. Overall trade study.

Option 4 was selected for the preliminary design of the wheelchair. This preliminary design is shown in Figure 2.i. Some of its features include a push-bar that telescopes out to form the rickshaw, disc brakes, solid tires, and a suspension system.

Figure 2.i. Preliminary Design

DESIGN ADJUSTMENTS

Unfortunately, issues arose with various details of the preliminary design and adjustments had to be made. Titanium is difficult to work with, and using two different materials would be complicated. This sparked the conversation about adjusting the requirement for weight of the occupant. The high weight requirement drove diameters and thicknesses high on the tubing. This in turn drove weight to be high and was the reason for needing to use titanium. The requirement was discussed and the change was justified, as demonstrated in the design requirements section of this report. Consequently, a frame built entirely of Chromoly was able to meet the requirements.

The next issue arose with the disc brakes. It was also found that disc brakes require special rims to connect to. These rims cost nearly $500 each, putting them way beyond the budget of this project. A solution was then determined for implementing rim brakes. Rim brakes are tricky for this particular design because of the suspension system. They need to remain stationary with respect to the wheels, and in this design the frame and wheels move relative to each other. An extension was added from the axle to the edge of the wheel. The brake calipers are mounted on this extension, and thus move with the wheels. Pictures of this are included in the Design Details section of the report.

DESIGN DETAILS

The final design of the wheelchair is shown in Figure 3.a. As shown, the overall look of the wheelchair is similar to those commonly used around the world. The new design essentially takes everything good about the current design and modifies it to include some special features. One of the more prominent and unique features is the push handle behind the wheelchair. Most conventional wheelchairs have two handles extending backward, whereas this design has a straight bar. Each unique feature or difference will be discussed by section.

Figure 3.a. Transformable wheelchair in everyday use configuration.

FRAME

The frame was chosen to look and perform as a conventional frame. Chromoly was chosen as the material to manufacture the frame from, in varying thicknesses. A wall thickness of 0.065 inches bends nicely an was chosen for the main frame structure, with 0.058 inch wall tubing chosen as a cheaper alternative where the thicker was not needed. Thinner wall thicknesses allow for a lighter design, but still provide the necessary strength needed. Chromoly was chosen for its strength, and relative cheapness in cost. It is also a standard material used for conventional wheelchairs and readily available. Chromoly has a resistance to rust, but it is still possible. Since the wheelchair may come in contact with water, everything will be power coated or otherwise painted.

In the process of cutting the weight down, unnecessary components from a traditional wheelchair were avoided. This led to a minimal, yet fully functional collapsing design. As expected, the wheelchair collapses horizontally for storage, as shown in Figure 3.b. The collapsed position allows for better storage capabilities while still allowing the wheelchair to roll.

Caster size and position were taken into consideration. A larger wheel diameter was chosen because this helps to overcome obstacles such as holes, bumps, and ridges. On many conventional wheelchairs, the castors tend to hit the back of the footrest or the rider’s actual foot when spinning around. Because of this issue and the larger chosen diameter, a wide stance was chosen. This greater separation between the set of casters helps with stability, and avoids collision with the footrests or actual feet. Figures 3.a. and 3.b. illustrate the size and position of the casters relative to the frame design.

Figure 3.b. Collapsed wheelchair.

DIMENSIONS

Figures 3.c. and 3.d. show the front and right side profiles, respectively. The width and height of the armrests, seat, and push handle is within standard ranges compared to conventional wheelchair design. When it comes to portability, Figure 3.e. shows the smallest rectangular prism that encloses the wheelchair. The dimensions of the prism are rounded up to be 37.5 inches long, 45.5 inches tall, and 12.25 inches deep. The chair may fit inside any car trunk, closet, or storage facility so long as the available space meets the specified dimensions as shown.

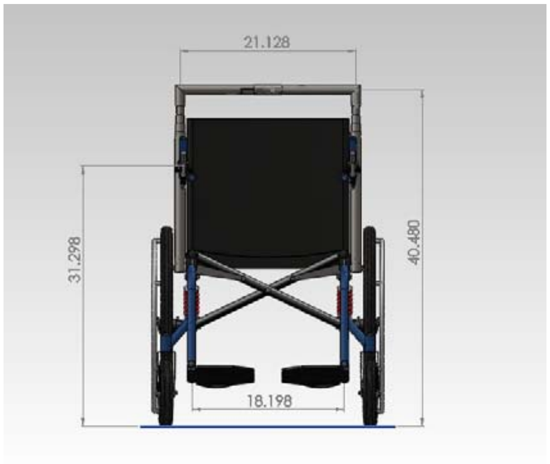


Figure 3.c. Dimensions (front view)

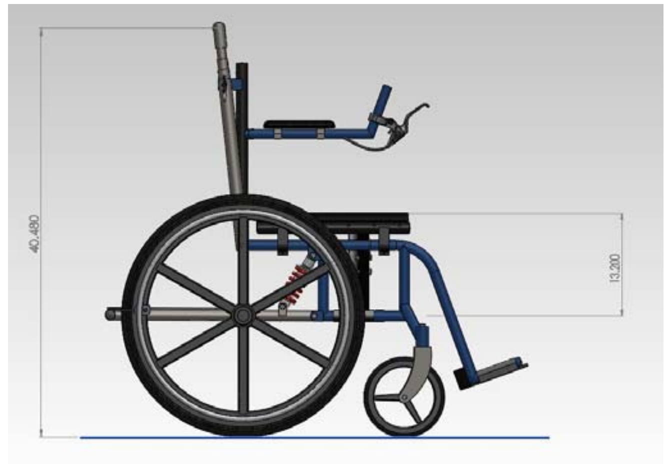


Figure 3.d. Side dimensions

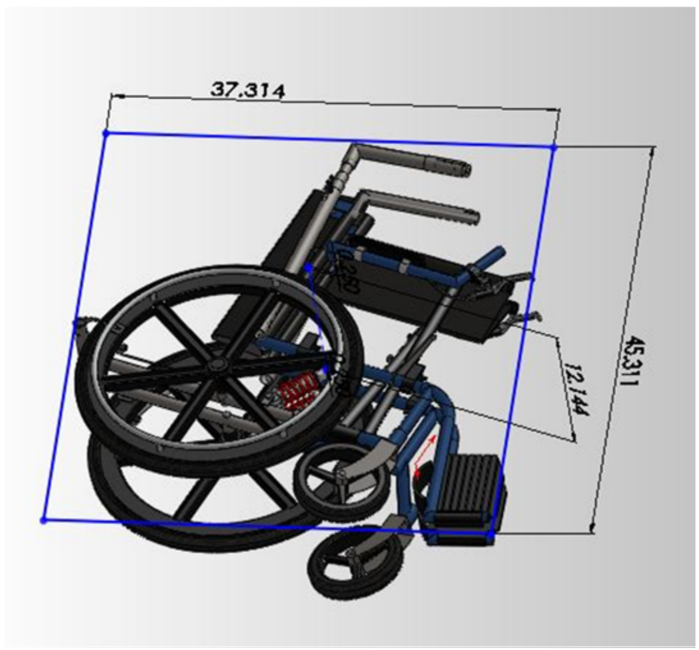


Figure 3.e. Collapsed wheelchair dimensions in inches.

PULLING SYSTEM

As noted previously, the pulling system makes for the most obvious and unique design change of the wheelchair. The pulling system involves the push handle, and a series of concentric tubes along the sides of the wheelchair. The whole push handle is able to extend upwards and swivel forwards into the position shown in Figure 4.a. When fully extended and locked into place, the user is then able to be pulled by a friend similar to a handcart or rickshaw. Because of the dual purpose in the push handle, it will be hereafter referred to as the push/pull bar.

Figure 4.a. Wheelchair in rickshaw position.

The push/pull bar's angle is secured and locked into place by quick release pins. These pins are able to secure the push/pull bar in either the pulling (extended) position, or the pushing (collapsed) position. There are two pins, one located on each of the largest tubing, attached via lanyard. The pins go through the bar(s) and the frame, securing its position. The length of the pulling system, and the distance it extends is locked into place by quick release spring pins. These pins secure the length when extended, and only extended. When the bars are retracted into the pushing position, the quick release pin not only secures the angle as stated previously, but goes through each concentric tube, securing them all into a collapsed state. Both pins are shown below in Figure 4.b.

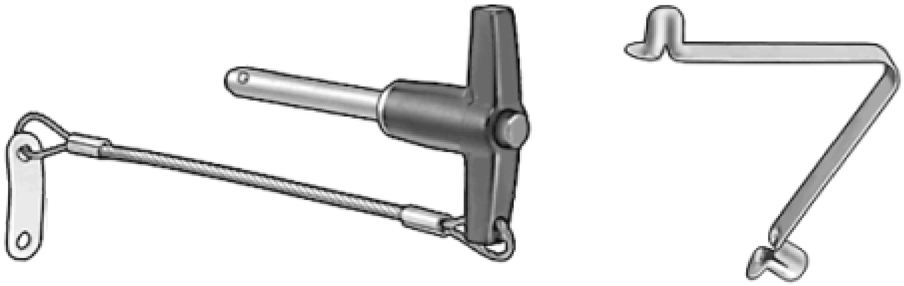


Figure 4.b. Quick release pin and quick release spring pin.

The bars are made from 4 sizes of Chromoly tubing, ranging from 1.25 inches in outer diameter, down to 0.875 inches. Each tube has a wall thickness of 0.058 inches which only allows a clearance of 0.009 inches between tubes. A low clearance will help keep the tubing rigid and straight when extended, yet still allow for enough room to bypass any frictional resistance.

Conventional wheelchairs have armrests in a vertical plane between the edge of the seat and the wheels. This allows for more sitting space and elbow room. Because of the movement of the push/pull bar as it swings back and forth between pushing and pulling configurations, an armrest in the conventional spot can get in the way. To overcome this, a rotating armrest was designed. As shown in Figure 4.c., the armrest rotates out of the way when the push/pull bar is moving past. When the push/pull bar is locked into either position, the armrest is free to rotate back to its original position. This allows the armrest to still be adjacent to the frame, providing more room to the user, and also allows the push/pull bar to rotate without restriction.

Figure 4.c. Rotating armrest during rickshaw conversion.

To still allow the wheelchair to collapse as shown in Figure 3.b., the push/pull bar must not be solid, and needs to be collapsible as well. The handle is able to separate in the middle, and rotate out of the way. The rotating handles are held in place by a series of spacers, shown in Figure 4.d. These spacers are positioned in a way to allow the handles to slide onto the extending tubing when in one position only. Once slipped on, and rotated into place, the spacers don't allow any motion except a 180° rotation. The spacers are further detailed in the drawing package (Appendix H) and are made out of Chromoly and will be fastened by welding to ensure a long lasting resistance to the loads it will experience.

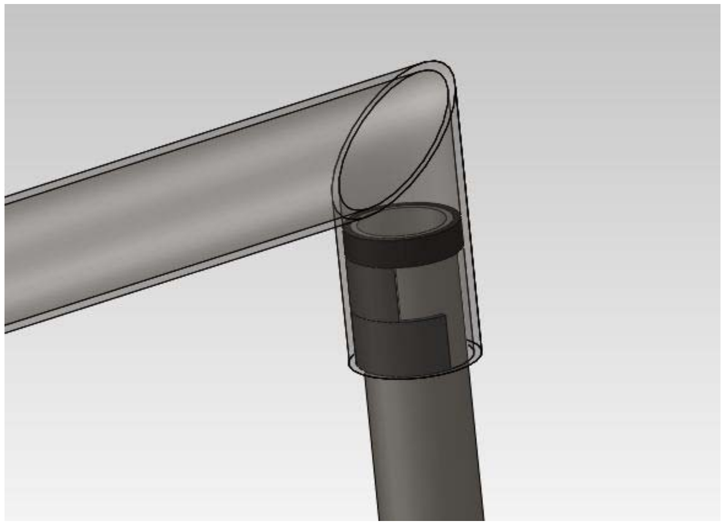


Figure 4.d. Push/pull bar rotating design.

The rotating handles of the push/pull bar would not work if there was no way to keep them from rotating when the wheelchair is not collapsed, and is needed to be pushed or pulled. To keep the handles in place, a center coupler was designed. This coupler keeps both sides of the handle from separating. Figure 4.e. shows the center coupler in the closed position. It is held in place by a series of grooves cut in the handle tubing, and a spring. The spring is attached to one cross bar of the coupler, and another crossbar of the right handle. When closed, the spring is in its natural position, so the closed position is where it's going to want to stay. To open the coupler to allow for the push/pull bar handle rotation, and the wheelchair's collapse, the center coupler is rotated 50° and pulled back. This puts the spring in tension but can be held in the open position by rotating back into another groove further down the handle and shown in Figure 4.f.

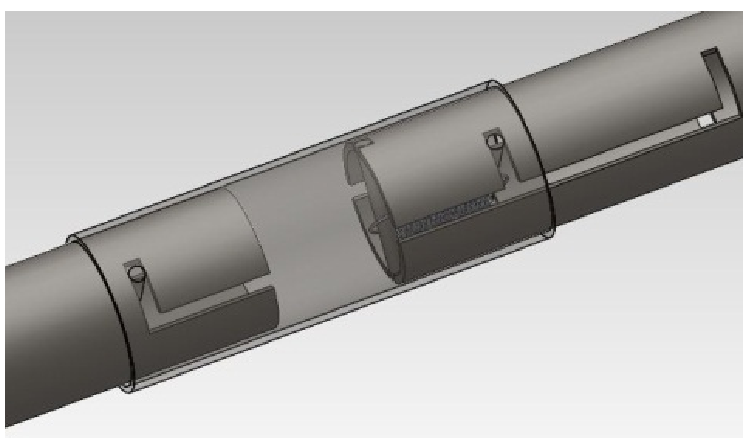


Figure 4.e. Spring loaded coupler in closed position.

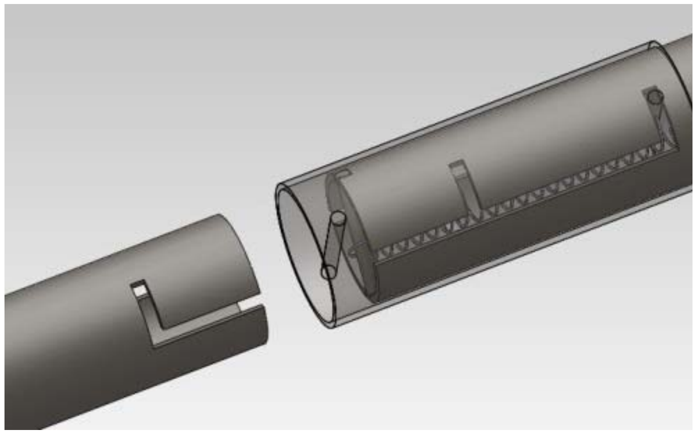


Figure 4.f. Spring loaded coupler in open position.

SUSPENSION

To keep the user from experiencing bumps and jostles when being pushed or pulled, a suspension system was design as a part of the wheelchair. This feature allows for shocks, when placed between the frame and a suspension bar, to absorb the motion created from rough or uneven terrain. The suspension bar, as shown in Figure 5.a., pivots about a bolt along the bottom edge of the frame. The wheel and axel are attached directly to the bar and as the wheels move, the bar pivots, and the shock compresses.


Figure 5. Right suspension coil.

To determine the desired specifications on the shock an analysis was done using concepts from Vibrations and Controls. Conditions were determined for a worst-case scenario, which is impact after a 1-foot drop with an occupant of maximum weight. This can be modeled as a second-order system with a step input. It was specified that under these conditions the chair should not bottom out and should have a settling time of approximately 0.75 seconds. Some main equations used for these include:

$$m\ddot{x} + c\dot{x} + kx = W \qquad \text{(E1)}$$

$$x(t) = \delta_{st} + e^{-\zeta\omega_n t}\left\{x_0 cos\sqrt{1-\zeta^2}\omega_n t + \frac{\dot{x}_0 + \zeta\omega_n x_0}{\sqrt{1-\zeta^2}\omega_n} sin\sqrt{1-\zeta^2}\omega_n t\right\} \qquad \text{(E2)}$$

$$t_s = \frac{4}{\zeta w_n} \qquad \text{(E3)}$$

These equations, along with the initial conditions were written into MathCad and graphed. The spring constant and damping coefficient were adjusted until a desirable match was found. The spring constant was also adjusted to match shocks that are available for purchase. Through this process, the ideal shock properties were determined. The graph of the response of the ideal shock is shown in Figure 5.b. The complete analysis is shown in Appendix C.

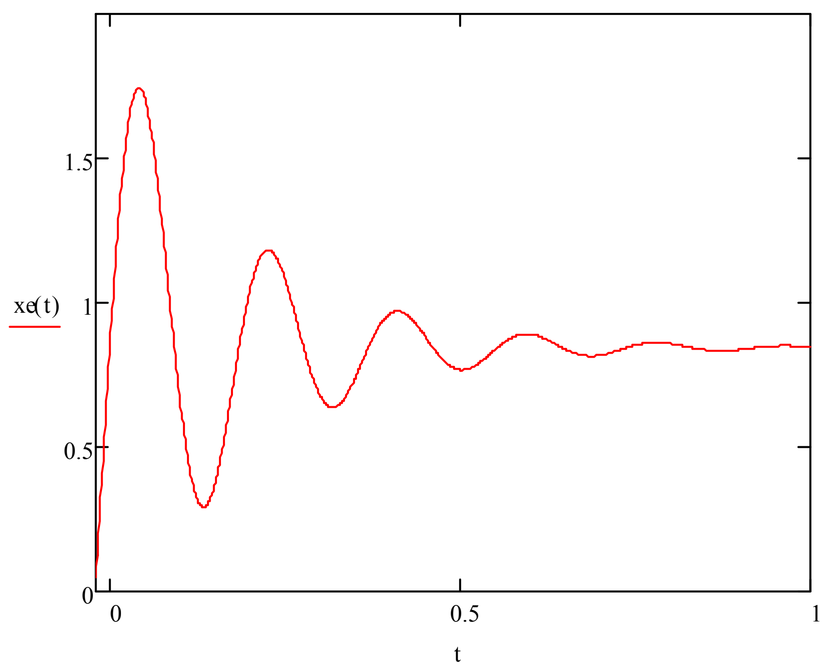


Figure 5.b. Response of the ideal shock under worst-case conditions

From the calculations of the shock response, it was determined that the ideal shock would have a spring constant of 500 lb./in, and a damping coefficient of 4.5 lb.*s/in. It was soon found that shocks with damping were beyond the budget of this project. This left the team with a decision between having no suspension or having a simple spring without damping. Both solutions have pros and cons. No suspension makes for a very bumpy ride when the passenger is off-road. It also creates very high impact forces in the worst-case scenario, and would likely require additional redesign on the frame. A spring without damping can oscillate for a long time and be annoying to the passenger. Ultimately a compromise solution was decided on. A 750 lb./in spring was selected in order to still provide some suspension, but not have large oscillations that annoy the passenger or eject them from the seat. At the critical design review, the team was informed that there is a pair of shocks with damping available for their use at the AT Lab. Those shocks will be used to build the prototype.

BRAKES

Brakes are nice to have for various reasons. When a user is going down a hill, it can be painful or hard to slow down the wheelchair by gripping the circular wheel push bars. Brakes had a good way to provide control and stability in downhill or uneven terrain. Additionally, if a user is being pulled by a colleague and something goes wrong, the user will want to know that he can stop his chair from going out of control.

As discussed during the explanation of design adjustments, the brakes were changed from being disc brakes to rim brakes. Because of the nature of the wheel moving up and down with the suspension system, a rim brake mounted to the frame is challenging to do. The best option is to mount the rim brakes to a portion of the frame that moves with the tires at all times. The only part of the frame that moves with the tires is the suspension bar. As described earlier, and shown in Figure 6.a., the suspension bar was lengthened so it would reach around the back of the tire. The rim brakes can be mounted on the end of the bar and move in tandem with the tires, experiencing no relative movement. However, there is a possible clearance issue between the rim of the wheels and the attached circular pushing bar. To compensate for a lack a clearance, slim brake pads are to be bought. This will keep the brakes working as intended without using more lateral space than needed. Examples of the anticipated purchased items are shown in Figure 6.b.

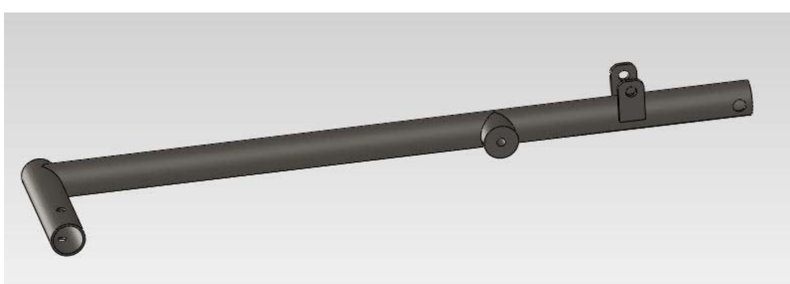


Figure 6.c. Suspension arm for brake system.

Figure 6.b. Rim brakes and thin brake pads

Parking brakes are necessary on any wheelchair for numerous reasons. For the same reasons cited above, a traditional parking brake attached to the body of the frame is impractical because of the way the wheels can move around, negating the effectiveness of such a device. A purchased set of locking brake handles will provide parking brake functionality. The same handles used to brake the wheelchair are also used to keep the wheels locked when desired. The brake handles are located on the armrest bar, as shown in Figure 6.c., providing easy access for both manual braking and activating the parking brake(s).

Figure 6.c. Locking brake handles and location on armrest bar

TIRES

As discussed in the trade study and conceptual design portions of this report, solid tires were selected for a couple of reasons. Solid tires provide the advantage of little to no maintenance, and never need to be filled with air. For a wheelchair that is to be used on a daily basis, as well as over rougher terrain, air free tires offer a high convenience. Tires with plenty of tread to handle a variety of terrain were selected as well. An example of the selected tire is shown below in Figure 7.a.

Figure 7. Solid tire with treads.

CUSHION AND HARNESS

The most requested seat cushion at the AT Lab for highly recreational wheelchair users is a compartmentalized air cushion. These cushions are ideal for minimizing pressure points and absorbing some vibrations on uneven terrain. The air cushion in Figure 8.a. is contoured to further promote the users comfort and postural stability. The cushion has a neoprene cover for wicking and breathable temperature control. Sown onto the cover are Velcro straps to secure onto canvas seating.

A Dynaform postural support harness will be adapted to become the variation lap and optional shoulder belt restraint (see Figure 8.b). The bottom left male and female connector will be switched to have the male piece on the shoulder harness. This enables the two bottom pieces to be connected together independently from the shoulder harness. Neoprene padding will be sown onto the bottom pieces that will function as an optional lap belt when the shoulder harness is not in use. When fully engaged, the shoulder harness will secure the user during recreational activities. All four harness straps will be sown onto the canvas seating.

Figure 8.a. Contoured compartmentalized air cushion.

Figure 8.b. Wheelchair harness.

SAFETY FACTORS

Safety factors in this analysis were analyzed at critical and high stress locations in the wheelchair. All safety factors are calculated against yield of the build material with conservative forces and geometries to ensure best possible performance. Cost and an ease of fabrication were also under consideration during design and analysis. A full stress analysis is found in Appendix C.

Table 1. Safety factors.

Member	Safety Factor
Axle	1.7
Caster Wheel Connection	11.1
Pulling Bar	1.9
Suspension Spring Bar	2.0
Spring Weld (under full braking)	6.9
Spring Weld (under vibration forces)	1.4

COST AND WEIGHT BALANCE

The cost required to build the designed wheelchair with all new components (i.e. actual cost in Table 1) is estimated at $1434. The AT Lab, however, is donating rims, casters, shocks, canvas, harness, foot and arm rests. Hence, the cost to build the prototype –including a contingency of $150- is approximately $1297. Funding from the ATL/CPD and a matching grant from Dr. Hansen totals to $1500. Both building and actual cost of the transformable wheelchair are within budget. The maximum allowable wheelchair weight is stated as 75 lb. With a Chromoly frame, air cushion, neoprene harness, shocks, arm and footrests, the estimated total weight is 67.8 lb. (see Table 2). A contingency of 4 lb. is been included in the estimated weight.

Table 2. Summarized cost and weight budget of transformable wheelchair.

	Part Count	Building Cost ($)	Actual Cost ($)	Weight (lb.)
Frame Subtotal	27	519	522	37
Frame Accessories Subtotal	32	58	171	4
Wheels and Seating Subtotal	35	527	699	21
Nuts/Bolts/Washers Subtotal	90	42	42	2
Contingency		150		4.0
Total	184	1297	1434	67.8

For a complete parts list and budget, see Appendix D.

As mentioned above, a contingency was included for both the cost and the weight. The allotted cost contingency is simply 10% of the total allowable cost. The weight contingency is slightly more complicated. The tubing for the frame must be purchased in full 20 ft. lengths. The amount of necessary tubing for each diameter was determined, and then each size of tubing was given a contingency. Since it is anticipated that there will be scrap or wasted tubing, the required lengths were given a generous 25% contingency. The weight contingency for the frame ends up being 6.75 lb. Because the frame contributes more than half of the weight of the overall design and already has a generous contingency, a smaller overall contingency was selected. The 4 lb. contingency is only 5.3% of the total allowable weight, but when combined with the 6.75 lb. frame contingency it comes to 14.3% of the total allowable weight. With these high contingencies and room to spare, there should be no question that this project will end up being under budget in both cost and weight.

TESTING AND SIMULATIONS

To better understand the design need and facilitate the development of conceptual designs, traditional wheelchairs from the AT Lab were simply tested on a variety of terrains and slopes. During the preliminary design phase, crude modifications were made with available components to simulate rickshaw assembly, theoretical measurements, forces and range of motion. A number of tests and simulations will be performed after the building stage to ensure ISO standard compliance.

CONCLUSION

The chosen transformable wheelchair design meets or exceeds all design requirements set forth by the ATL and CPD. A contingency has been included in the cost to build the prototype. Even with the contingency, the total cost is within the budget limit. Improved designs of the wheelchair would require an increase in funds. A set of disc brakes, for example, would cost approximately 2/3rds of the current budget. It has been proposed to design a kit to transform traditional wheelchairs into off-roading capable (i.e. simple hiking trails wide enough to accommodate a standard wheelchair). Compartments for electronics or accessory ports to clip/hang things from have also been suggested. The current transformable wheelchair has gone through a vibrations analysis, cost and weight budget. A complete drawing package has been rendered, and the design is ready for the building stage.

REFERENCES

Rao, S. S. (2011). *Mechanical Vibrations*. (5 ed.). New Jersey: Pearson Education, Inc.

References: ISO TC/193, ISO 7176-1, ISO 7176-3, ISO 7176-5, ISO 7176-13.

www.cdc.gov/growthcharts

http://www.halls.md/chart/height-weight.htm

APPENDICES

Appendix A: Weight Distribution Charts

Appendix B: Conceptual Designs

Appendix C: Analysis

Appendix D: Cost and Weight Breakdown

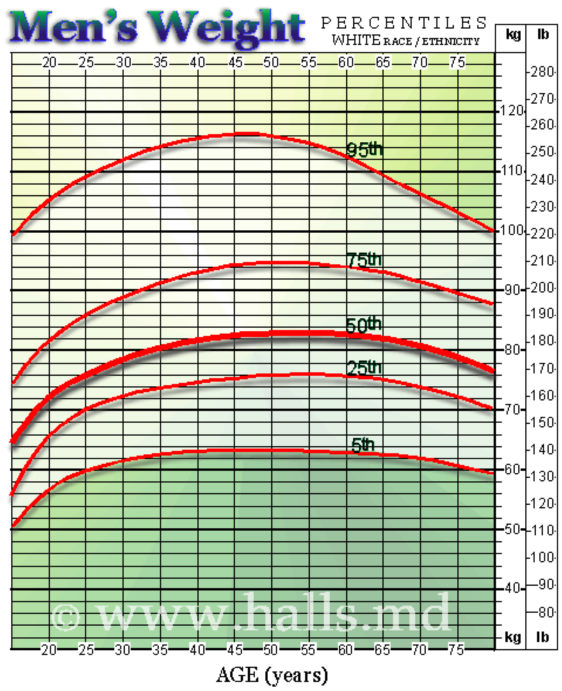
Appendix E: Product Links

Appendix F: Spring Schedule

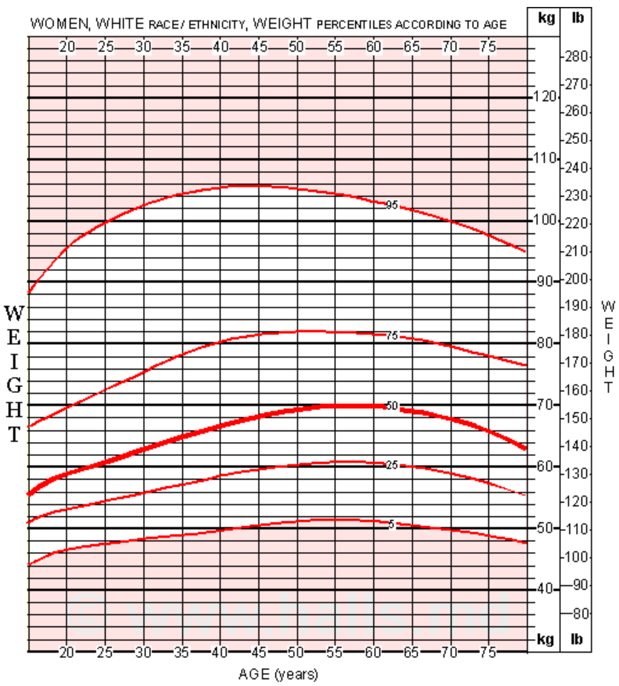
Appendix G: ISO Standards

Appendix H: Drawing Package

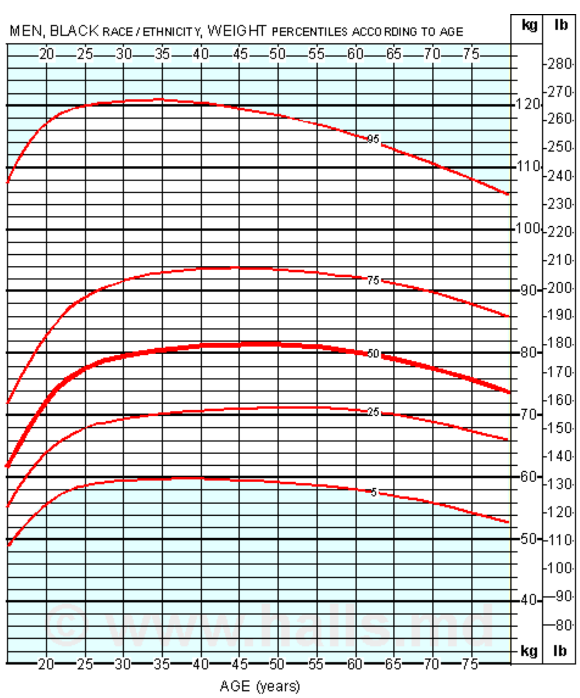
Appendix A: Weight Distribution Charts



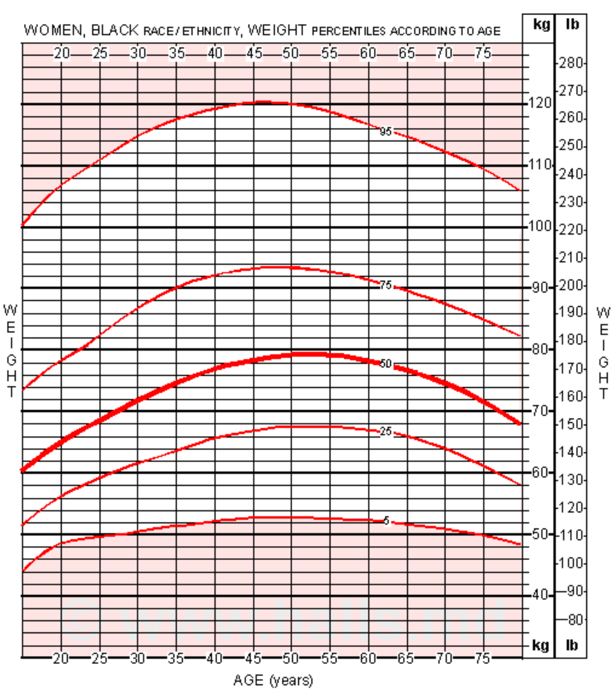
Weight of White Men



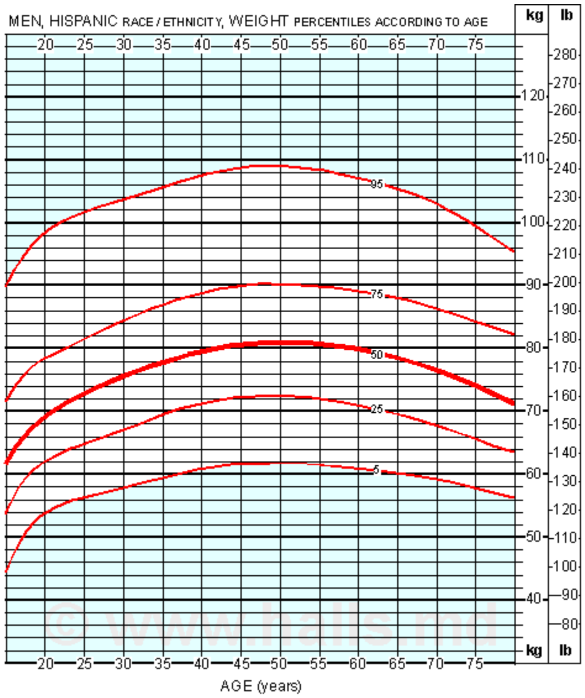
Weight of White Women

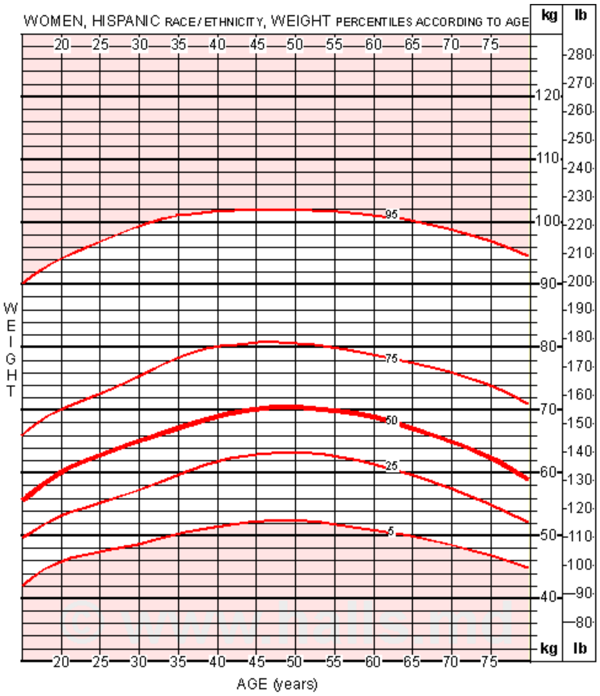


Weight of Black Men



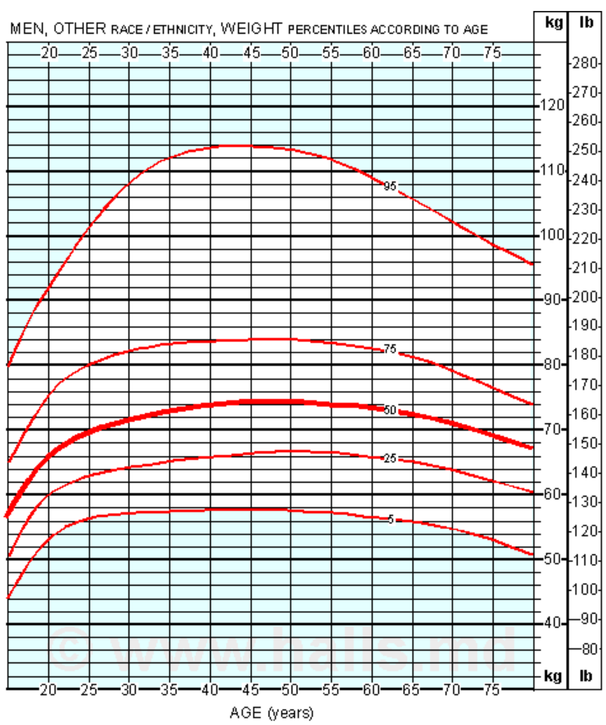
Weight of Black Women

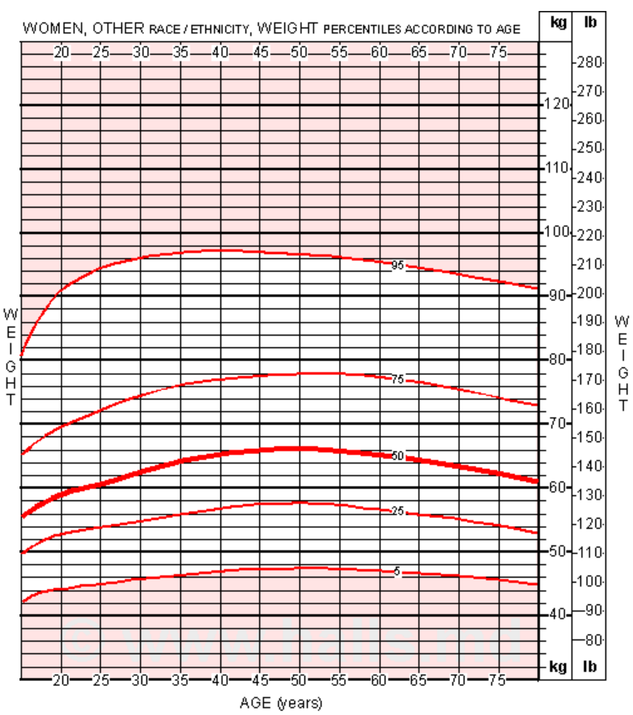




Weight of Hispanic Men

Weight of Hispanic Women





Weight of Men, Other Ethnicities

Weight of Women, Other Ethnicities

Appendix B: Conceptual Designs

Frame and Folding

Pulling System

Suspension

Tires

Cushion and Harness

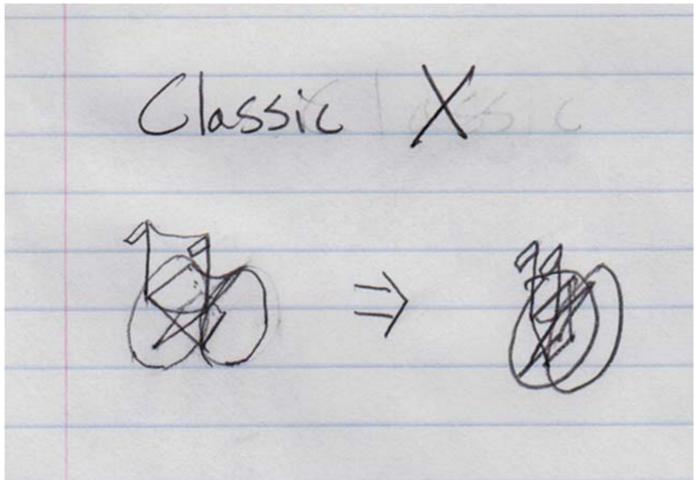


Figure 1.a. Classic (traditional) collapsing wheelchair.

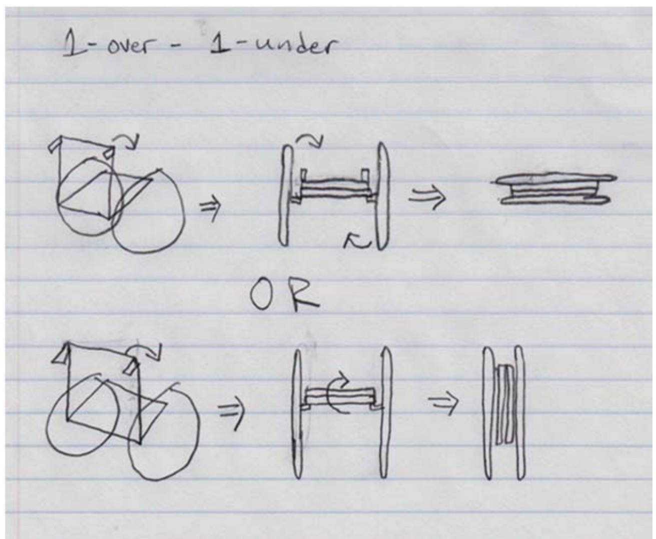


Figure 1.b. Collapsing seat back down then folding one wheel on top and the other on the bottom.

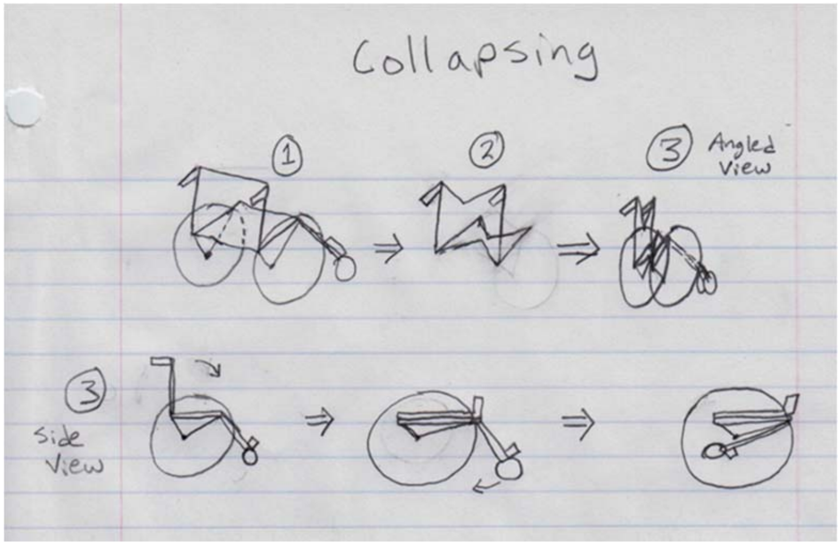


Figure 1.c. Collapsing cross bars in, back rest down and wheels up.

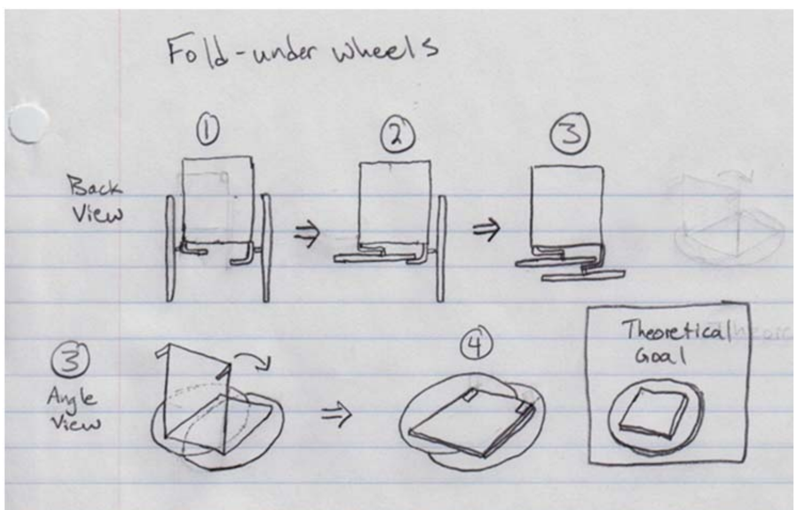


Figure 1.d. Fold wheels under and back rest down.

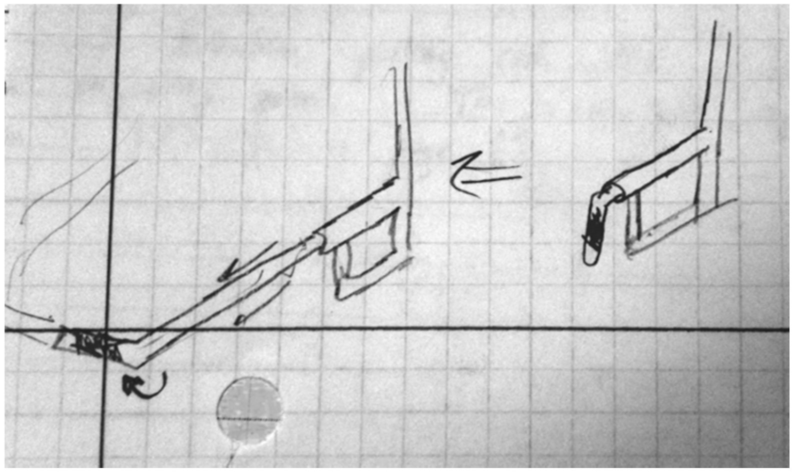


Figure 2.a. Rickshaw extension from arm rest.

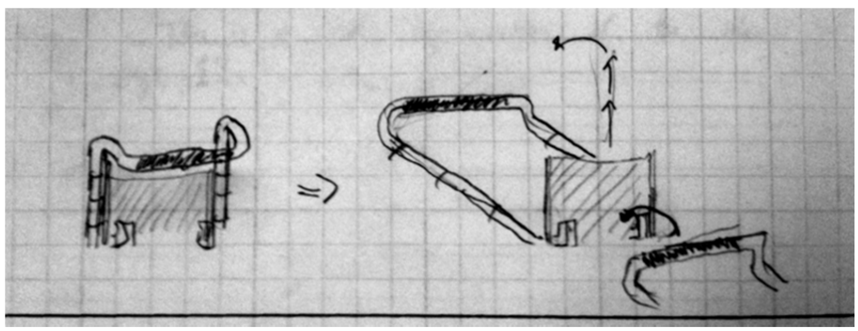


Figure 2.b. Rickshaw extension from push bar.

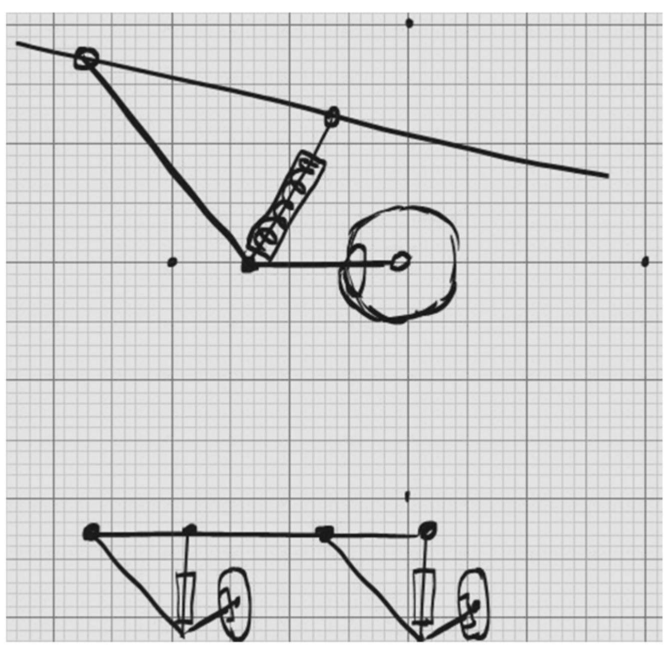


Figure 3. Suspension on front wheel casters.

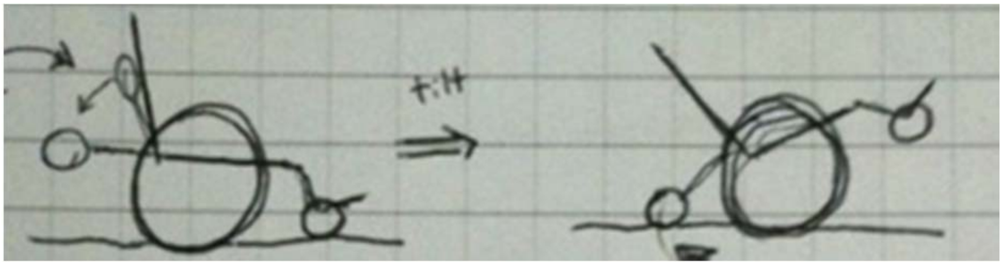


Figure 4.a. Third tire fold out from back rest for rickshaw position.

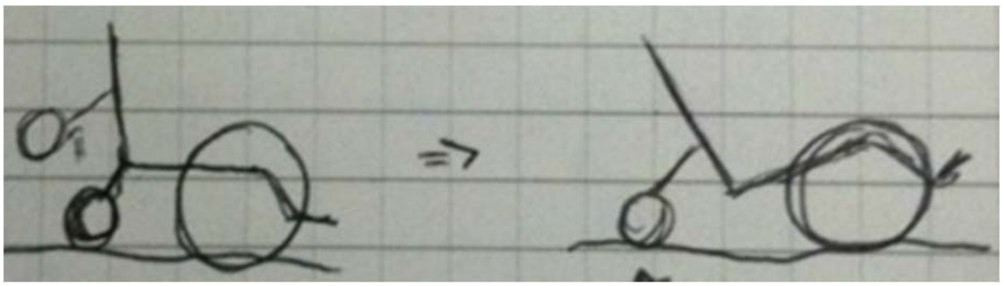


Figure 4.b. Third tire sliding along back to and from rickshaw position.

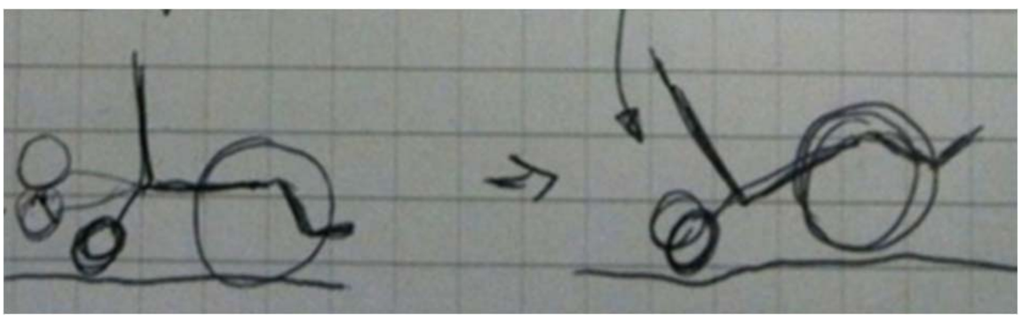


Figure 4.c. Third tire pivoting from back seat for rickshaw position.


Figure 5.a. Compartmentalized air cushion.

Figure 5.b. Foam and compartmentalized air cushion.

Figure 5.c. Foam cushion.

Figure 6.a. Shoulder and lap belt.

Figure 6.b. Car seat restraint.

Figure 6.c. Lap belt.

Appendix C: Analysis

Appendix B1: Mathematical Analysis

Appendix B2: Free Body Diagram

Appendix B3: Vibration Analysis

Appendix C1: Mathematical Analysis

Wheelchair Parameters

Analysis of Axle

In analyzing the axle a cantilever circular beam under forces due to the maximum weight was modeled. The dimensions were chosen such as to place all the stress in the bolt connecting the wheel to the frame.

$$Daxle := .375in$$

$$Iaxle := \frac{Daxle^4 \cdot \pi}{64} \quad caxle := \frac{Daxle}{2}$$

$$Laxle := 2.5in$$

$$\sigma axle := \frac{(Laxle \cdot Rbw) \cdot caxle}{Iaxle} = 34.492 \cdot ksi$$

$$n := \frac{Sy}{\sigma axle} = 1.74$$

Caster Wheel Arm

For the caster arm the normal stress and the stress of bending due to the offset from the frame were calculated as follows.

$$Lcw := 4in$$

$$\sigma cw := \frac{Rsw}{A} + \frac{(Rsw \cdot Lcw)c}{I} = 5.391 \cdot ksi \qquad n := \frac{Sy}{\sigma cw} = 11.13$$

Pulling Bar Stresses

Using a pinned-pinned circular beam at an angle to model the Pulling bar the stresses were calculated as fallows.

$$\theta rickshaw := 30deg \qquad cg := 9in \qquad Lrs := 4 \cdot 18in = 72 \cdot in$$

length to back of se

$$Dors1 := 1.25in \quad Dors2 := 1.125in \quad Dors3 := 1in \quad Dirs1 := 1.134in \quad Dirs2 := 1.009in$$

$$Dirs3 := 0.884in \quad Dors4 := .875in \quad Lsection := 18in \quad Dirs4 := .759in$$

$$I1 := \pi \cdot \frac{\left(Dors1^4 - Dirs1^4\right)}{64} = 0.039 \cdot in^4 \quad I2 := \pi \cdot \frac{\left(Dors2^4 - Dirs2^4\right)}{64} = 0.028 \cdot in^4$$

$$I3 := \pi \cdot \frac{\left(Dors3^4 - Dirs3^4\right)}{64} = 0.019 \cdot in^4 \qquad I4 := \frac{\left(Dors4^4 - Dirs4^4\right)}{64} = 3.974 \times 10^{-3} \cdot in^4$$

Sum of moments about pivot

$$Rpuller := \frac{(-Fy \cdot \cos(\theta rickshaw) \cdot cg)}{Lrs \cdot \cos(\theta rickshaw)} = 15.625 \cdot lbf$$

Sum forces in Y

$$Rwheel := -(Rpuller + Fy) = 109.375 \cdot lbf$$

$$\frac{\sin(\theta rickshaw)\cdot Rpuller}{A} = 0.041\cdot ksi$$ stress normal to pull bar is insignificant

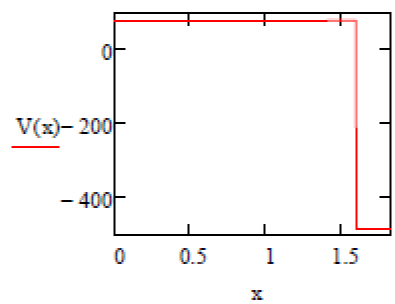
$ab := (Lrs - cg) = 1.6\,m$

$Lrs = 1.829\,m$

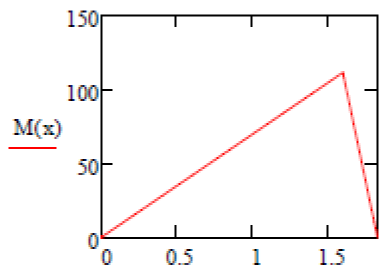
$V(x) := if[x < (Lrs - cg), Rpuller, (Rpuller + Fy)]$

$x := 0m, .001m .. Lrs$

Plots are in SI units due to bug in mathcad



$$M(x) := \int_0^x V(x)\,dx$$



$$\sigma max1 := \frac{M(Lrs - cg)\cdot\frac{Dors1}{2}}{I1} = 15.911\cdot ksi \qquad \sigma max2 := \frac{M(3\cdot Lsection)\cdot\frac{Dors2}{2}}{I2} = 17.103\cdot ksi$$

$$\sigma max3 := \frac{M(2\cdot Lsection)\cdot\frac{Dors3}{2}}{I3} = 14.717\cdot ksi$$

$$\sigma max4 := \frac{M(Lsection)\cdot\frac{Dors4}{2}}{I4} = 30.966\cdot ksi \qquad n := \frac{Sy}{\sigma max4} = 1.938$$

<u>Braking Stresses on Suspension Arm</u>

To model the stresses in the suspension arm due to maximum braking the weight of the rider along with the force of friction between rubber and asphalt were used to bend the beam calculations and safety factors are as fallows. Free body diagram in Appendix B2.

$Ljointshock := 2.078in + .4215in \qquad Lshockaxle := 4.4995in \qquad Laxlebrake := 12in$

$$Rshock\_in\_y := \frac{-[(Ljointshock + Lshockaxle)\cdot Rbw + (Ljointshock + Lshockaxle + Laxlebrake)\cdot Ffriction}{Ljointshock}$$

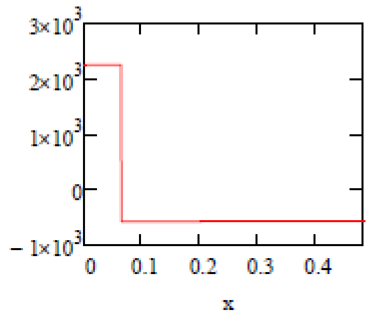
$Rshock\_in\_y = -634.361\cdot lbf$

$$Rshock := \frac{Rshock\_in\_y}{\cos(26.1316deg)} = -706.585\cdot lbf$$

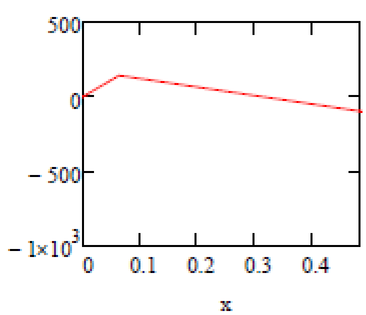
$Rshock\_in\_x := \sin(26.1316deg)\cdot Rshock = -311.204\cdot lbf$

$Rframejoint := -(Rbw + Ffriction + Rshock\_in\_y) = 505.79\cdot lbf$

$$Vy(x) := \begin{cases} -Ffriction & \text{if } x > (Ljointshock + Lshockaxle) \\ (Rframejoint + Rshock\_in\_y) & \text{if } x > (Ljointshock) \\ Rframejoint & \text{otherwise} \end{cases}$$



$$Marm(x) := \int_0^x Vy(x)\,dx$$



$$\sigma arm\_max := \frac{Marm(Ljointshock)\cdot c}{I} = 30.15\cdot ksi \qquad n := \frac{Sy}{\sigma arm\_max} = 1.99$$

<u>Shock Weld Stress(due to braking)</u>

Weld stresses were calculated using an estimated throat height of 1/8 in. and weld stress theory from Singley's Mechanical Engineering Design text. The calculations are as follows.

$$dweld := .4215in \qquad hweld := \frac{1}{8}in$$

$$Iu := \frac{dweld^3}{6} = 0.012 \cdot in^3 \qquad Athroat := 1.414 \cdot hweld \cdot dweld = 0.075 \cdot in^2$$

$$Iweld := .707 \cdot hweld \cdot Iu = 1.103 \times 10^{-3} \cdot in^4$$

$$\tau prime := \frac{Rshock\_in\_x}{Athroat} = -4.177 \cdot ksi$$

$$\tau doubleprime := \frac{\left(Rshock\_in\_x \cdot \frac{dweld}{4}\right) \cdot \frac{dweld}{2}}{I} = -0.33 \cdot ksi$$

$$\tau weld := \left(\tau prime^2 + \tau doubleprime^2\right)^{\frac{1}{2}} = 4.19 \cdot ksi$$

$$n := \frac{.577 \cdot 50ksi}{\tau weld} = 6.885$$

<u>Shock Weld Stress (due to vibration forces)</u>

Using the maximum deflection of the spring in the vibration analysis to compute the force on the weld the analysis was computed as fallows in similar fashion as above.

$$Rbw := 1125lbf$$

$$Rshock\_in\_y := \frac{-[(Ljointshock + Lshockaxle) \cdot Rbw]}{Ljointshock} = -3.15 \times 10^3 \cdot lbf$$

$$Rshock := \frac{Rshock\_in\_y}{\cos(26.1316deg)} = -3.509 \times 10^3 \cdot lbf$$

$$Rshock\_in\_x := \sin(26.1316deg) \cdot Rshock = -1.545 \times 10^3 \cdot lbf$$

$$\tau prime := \frac{Rshock\_in\_x}{Athroat} = -20.744 \cdot ksi$$

$$\tau doubleprime := \frac{\left(Rshock\_in\_x \cdot \frac{dweld}{4}\right) \cdot \frac{dweld}{2}}{I} = -1.637 \cdot ksi$$

$$\tau weld := \left(\tau prime^2 + \tau doubleprime^2\right)^{\frac{1}{2}} = 20.808 \cdot ksi$$

$$n := \frac{.577 \cdot 50ksi}{\tau weld} = 1.386$$

Appendix C2: Free Body Diagrams

Wheelchair full

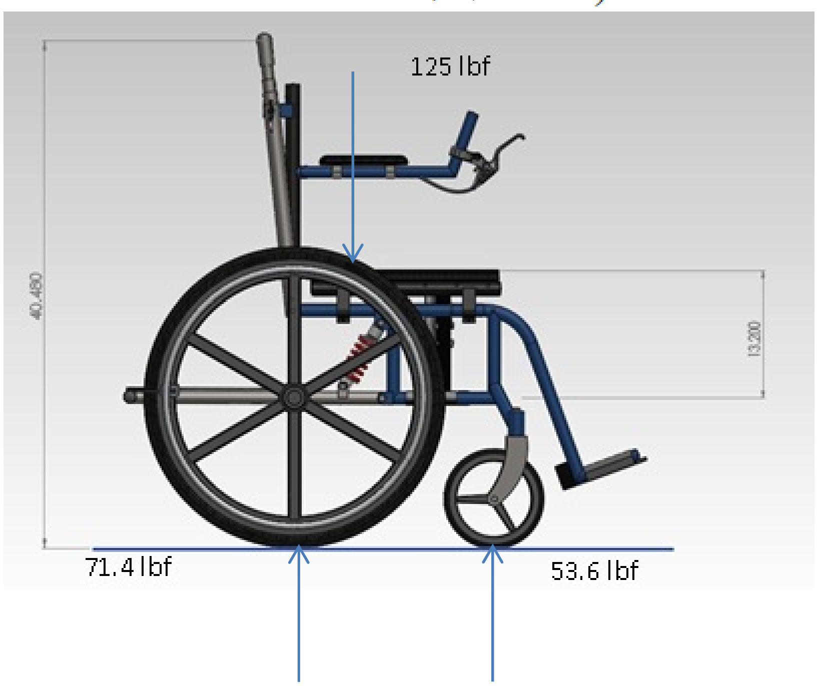
Summing moments about the axle and summing forces in the y-direction results in the following wheel reaction forces.

$$\sum M = 0 = 9\text{in}\cdot Fy + (12\text{in} + 9\text{in})\cdot Rsw$$

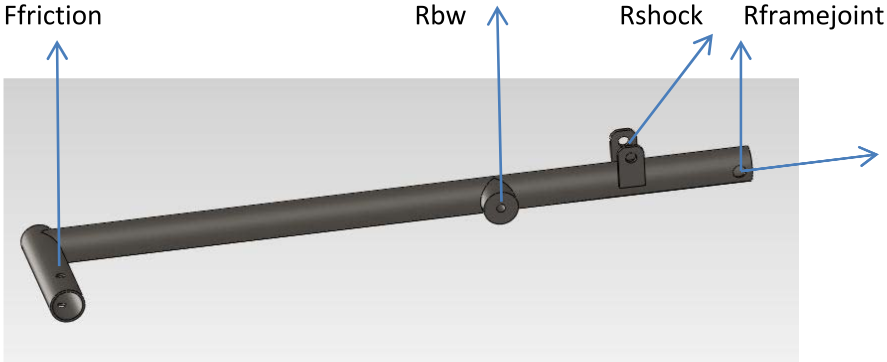
$$Rsw := \frac{9\text{in}\cdot Fy}{-(12\text{in} + 9\text{in})} = 53.571\cdot \text{lbf}$$

$$\sum Fy = 0 = Fy + Rsw + Rbw$$

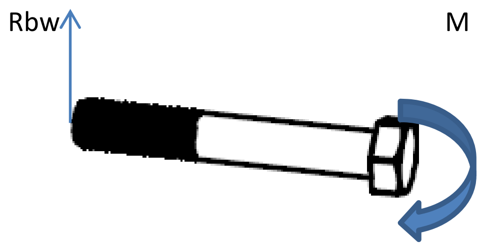
$$Rbw := -(Fy + Rsw) = 71.429\cdot \text{lbf}$$



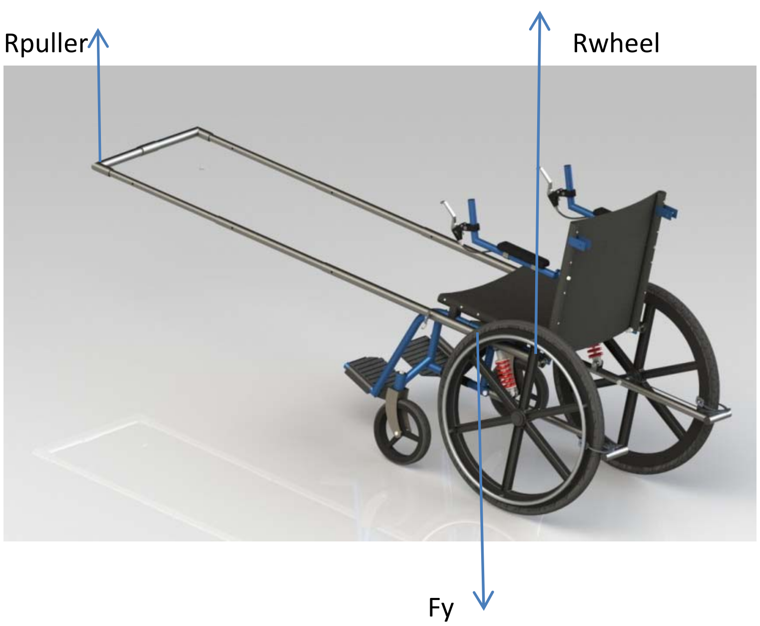
Suspension Arm



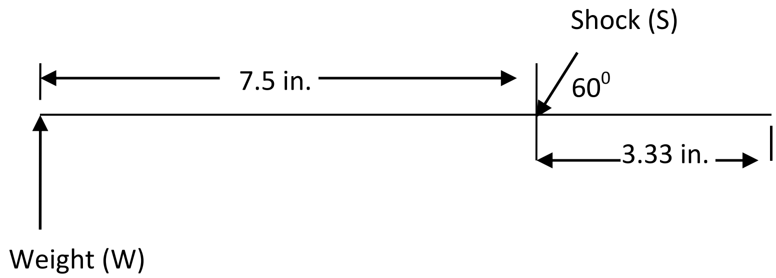
Axle



Pulling Arm



Appendix C3: Vibration Analysis



The vertical component of the shock force is defined as (V).

$$V = \frac{7.5}{3.3} W \qquad (1)$$

$$S = \frac{2}{\sqrt{3}} V \qquad (2)$$

Combining equations (1) and (2) yields:

$$S = \frac{3\sqrt{3}}{2} W$$

Weight of the occupant (250lbs.) $W_1 := 556.0277$ N

Wheelchair weight (75lbs.) $W_2 := \frac{333.62}{2} = 166.81$ N

Total weight $W_3 := W_1 + W_2 = 722.84$ N

Total mass $m := \frac{W_3}{9.81} = 73.68$ kg

Spring Constant $k := 131350\left(\frac{500}{750}\right)$ $\frac{N}{m}$ 131350 N/m is equivalent to 750 lbs/in

Damping Coefficient $c := 785$ $\frac{Ns}{m}$

Natural Frequency $\omega := \sqrt{\frac{k}{m}} = 34.47$ s^{-1}

Damping Ratio $\zeta := \frac{c}{2\sqrt{k \cdot m}} = 0.15$

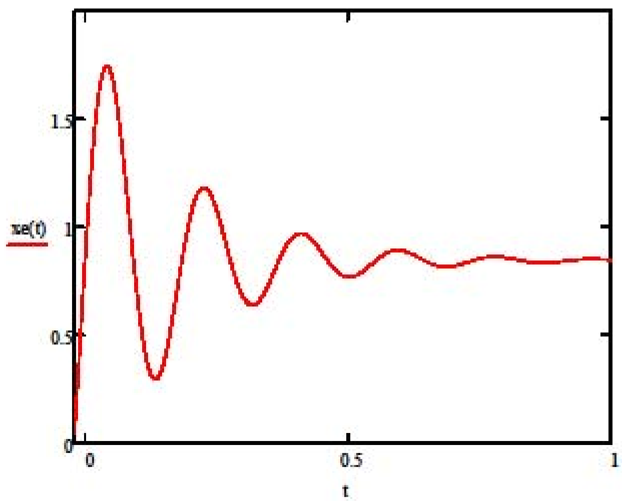
Static Deflection $xm_1 := \frac{3\sqrt{3} \cdot (W_3)}{2k} = 0.02$ meters $xm_2 := xm_1 \cdot 39.37 = 0.84$ in

Maximum Allowable Deflection (2in) $xmax = 2 \cdot .0254 = 0.05$ meters

Response (metric) $xm(t) := \frac{3 W_3 \sqrt{3}}{2k} + e^{-\zeta \cdot \omega \cdot t} \cdot \left(\frac{.985}{\sqrt{1-\zeta^2} \cdot \omega} \cdot \sin\left(\sqrt{1-\zeta^2} \cdot \omega \cdot t\right)\right)$

Response (english) $xe(t) := xm(t) \cdot 39.37$

Settling Time $st := \frac{4}{\zeta \cdot \omega} = 0.75$ sec



A minimum 500 lb/in shock will keep us from bottoming out, no matter what the damping is.
A damping coefficient of at least 785 Ns/m will give us a good settling time.

Appendix D: Cost and Weight Breakdown

Frame

Frame Accessories

Wheels, Shocks, and Breaks

Nuts, Bolts, and Washers

Frame:

Part	Count	Price Each ($)	Actual Cost ($)	Theoretical Cost ($)	Weight (lb.)	Feet Used
Tubing1 (1-1/4, 0.058)	1	96	96	96	4.428	**6**
Tubing5 (1-1/8, 0.058)	1	98	98	98	5.94	**9**
Tubing4 (1, 0.058)	1	98	98	98	9.69	**17**
Tubing (1, 0.065)	1	76	76	76	9.086	**14**
Tubing (7/8, 0.058)	1	151	151	151	4.554	**9**
Crossbar Guide	2	0.5	0.00	1.00	0.1	
Sheet Metal 1/8" (flanges)	16	0.1	0.00	1.60	2	
Solid bar	4	0.1	0.40	0.40	1	

Frame Subtotal	27		519.40	522.00	36.80

Frame Accessories:

Part	Count	Price Each ($)	Actual Cost ($)	Theoretical Cost ($)	Weight (lb.)
Locking Pins - 94748A237	2	23.83	47.66	47.66	0.2
Seat Bar Rest	4	1	0.00	4.00	0.05
Spring for RS center	1	1.61	1.61	1.61	0.004
Push-Button Spring Clips	6	1	0	4	0.1
Armrest	2	5	0.00	10.00	0.5
Footrest	2	15	0.00	30.00	3
Endcap 1" - 85985K23	10	0.09	0.90	0.90	0.05
Endcap 7/8" - 85985K21	2	0.08	0.16	0.16	0.01
Restraint	1	65	0.00	65.00	0.2
Paint	2	4	8.00	8.00	0

Frame Accessories Subtotal	32		58.33	171.33	4.11

Wheels and Seating:

Part	Count	Price Each ($)	Actual Cost ($)	Theoretical Cost ($)	Weight (lb.)
Tires	2	29.95	69.90	69.90	2.34
Rims	2	40	0.00	80.00	8
Bearing/Axle	2	2	0.00	4.00	0.5
Caster Wheels/Forks	2	36	0.00	72.00	3
Canvas	2	5	0.00	10.00	0.05
Cushion	1	332	332.00	332.00	2.65
Velcro Straps	4	6.01	0.00	6.01	0.05
Rim Brakes	2	20	40.00	40.00	0.7
Brake Pads	2	11	22.00	22.00	0.24
Brake Handles	2	21.13	21.13	21.13	1.0
Brake Cable	2	2	4.00	4.00	0.2
Zip Ties	10	0.757	7.57	7.57	0.0
Shocks	2	15	30.00	30.00	1.99

Wheels and Seating Subtotal	35		526.6	698.61	20.75

Nuts, Bolts, and Washers:

Part	Count	Price Each ($)	Actual Cost ($)	Theoretical Cost ($)	Weight (lb.)
Screw 8mm, 30mm (included shock connectors)	4	0	0.00	0.00	0
Screw 8mm, 40mm - 91310A541	4	0.37	1.48	1.48	0
Screw 3/8-16, 1.75" (Suspension Bar) - 99894A328	2	1.966	3.93	3.93	0.1
Screw 3/8-16, 2.5" (X) - 99894A352	1	1.51	1.51	1.51	0.075
Screw 3/8-16, 3.5" (RS Hinge) - 99894A376	2	5.4	10.80	10.80	0.2
Spacer 3/8 ID, 0.5" (RS Hinge) - 92825A241	2	0.384	0.77	0.77	0.01
Screw (Rotating parts) - 90604A539	4	0.22	0.90	0.90	0.08
Speed Nut (Rotating parts) - 90528A115	4	0.15	0.60	0.60	0.02
Screw 1/4-20, 1.5" (Helper bar) - 99894A123	2	1.08	2.16	2.16	0.1
Lock nut 1/4-20, 5/16" - 97135A210	4	0.1312	0.52	0.52	0.1
Screw 1/4-20, 2" (Armrest swivel) - 99894A150	2	1.512	3.02	3.02	0.15
Lock nut 3/8-16, 29/64" - 95615A140	5	0.082	0.41	0.41	0.1
Screw 6-32, 1.25" (Canvas) - 90403A155	18	0.14	2.52	2.52	0.75
Nut 6-32, 7/64" (Canvas) - 90480A007	18	0.02	0.36	0.36	0.3
Washer .14", .01" Wave (Canvas) - 99842A109	18	0.74	13.32	13.32	0.2

Nuts/Bolts/Washers Subtotal	90		42.31	42.31	2.2

Totals:

	Part Count	Actual Cost ($)	Theoretical Cost ($)	Weight (lb.)
Frame Subtotal	27	519	522	37
Frame Accessories Subtotal	32	58	171	4
Wheels/Brakes/Shocks Subtotal	35	527	699	21
Nuts/Bolts/Washers Subtotal	90	42	42	2
Contingency		150		4.0
Total	184	1297	1434	67.8

Appendix E: Product Links

Tires:
http://www.airfreetires.com/shopping/p-136-24-x-1-38-nu-teck-inyo-heavy-duty-540.aspx

Restraint:
http://www.hopupracing.com/mera4posebeh.html?productid=mera4posebeh&channelid=FROOG

Cushion:
http://www.spinlife.com/ROHO-Contour-Select-Air-Wheelchair-Cushion/spec.cfm?productID=72296

Shocks (this one is 750 lb/in but any shock with a minimum of 500 lb/in will work):
http://www.ebay.com/itm/New-Bike-MTB-Rear-Suspension-Shock-750LB.-IN-/370528059359?_trksid=p3284.m263&_trkparms=algo%3DSIC%26its%3DI%26itu%3DUCI%252BIA%252BUA%252BFICS%252BUFI%26otn%3D21%26pmod%3D360389046068%26ps%3D54

Disc Brakes:
http://accessibledesigns.com/disc.html

Quick Clamps:
http://www.google.com/products/catalog?q=quick+release+clamp&hl=en&client=firefox-a&hs=nLh&rls=org.mozilla:en-US:official&bav=on.2,or.r_gc.r_pw.,cf.osb&biw=1344&bih=920&um=1&ie=UTF-8&tbm=shop&cid=2707495008651282819&sa=X&ei=1o_CTpHnO8epiALBx_yGDA&ved=0CK8BEPMCMAI

Steel Tubing:
http://www.ipaco.biz/tube/index.htm

Rims – Disc Brake Style:
http://www.sportaid.com/spinergy-spox-sports-wheelchair-wheels-24-25-26-700c.html

Push-Button Clips (for easy pushing):
http://www.gandermountain.com/modperl/product/details.cgi?pdesc=CLAM_Rapid_Pole_Clip_Kit_w/RPS_Push_Button_1_1/4_8_pk_8442&i=448039&r=view&aID=504C8&cvsfa=2586&cvsfe=2&cvsfhu=343438303339&cID=GSHOP_448039

Rim Brakes:
http://www.google.com/products/catalog?q=bike+brakes&hl=en&client=firefox-a&hs=gIn&rls=org.mozilla:en-US:official&prmd=imvns&bav=on.2,or.r_gc.r_pw.,cf.osb&biw=1357&bih=857&um=1&ie=UTF-8&tbm=shop&cid=17845625860912468135&sa=X&ei=01XFTqHMDqeOigKh0ajPBQ&ved=0CJEBEPMCMAM

Spring for Rickshaw Center:
http://www.simsupply.com/p-18960-extension-spring.aspx

Brake Handles:
http://www.amazon.com/TerraTrike-Locking-Brake-Lever-Set/dp/B001FYAJ4C

Brake Cable:
http://www.google.com/products/catalog?hl=en&client=firefox-a&hs=LMs&rls=org.mozilla:en-US:official&q=brake+cable+bike&gs_upl=67006l67883l1l68124l5l4l0l0l0l0l286l889l0.1.3l4l0&bav=on.2,or.r_gc.r_pw.,cf.osb&biw=1357&bih=857&um=1&ie=UTF-8&tbm=shop&cid=15710618411582108740&sa=X&ei=BKLFTq_zNo3ZiALxkpn5BQ&ved=0CIUBEPICMAI

Thin Brake Pads:
http://www.buy.com/pr/product.aspx?sku=225629300&sellerid=30378622

Locking Pins for RS:
http://www.mcmaster.com/#pins/=f1c5fg

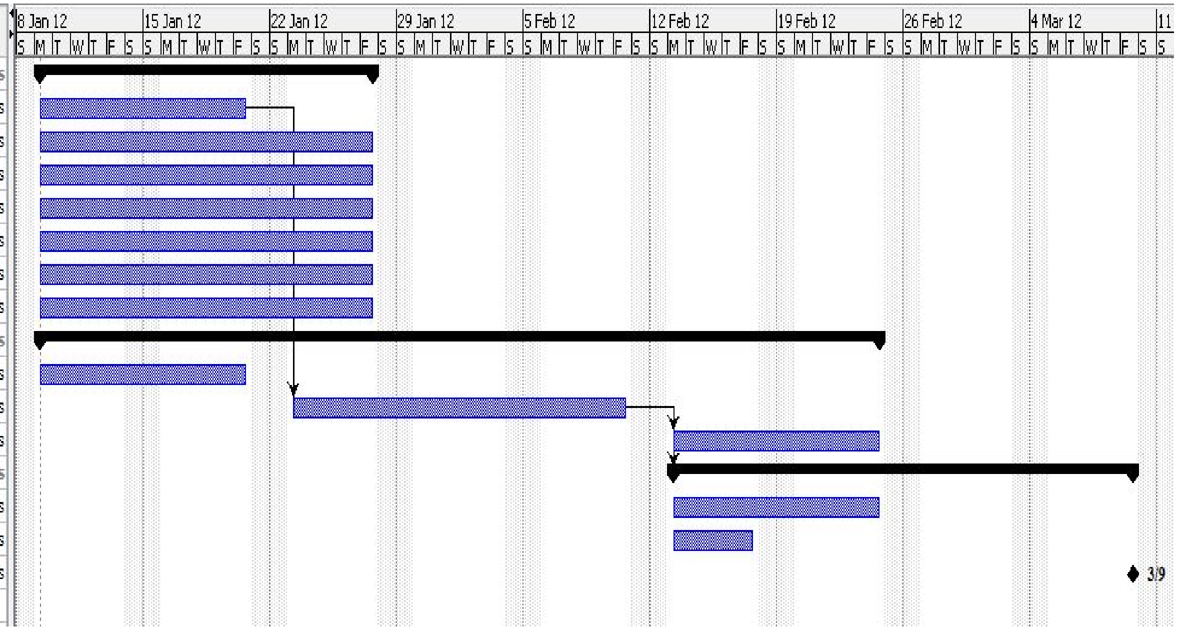
Bolts for suspension bar hinge:
http://www.mcmaster.com/#specialty-bolts/=f4y1jz

Bolt for X:
http://www.mcmaster.com/#specialty-bolts/=f4y3bq

Bolt for RS hinge:
http://www.mcmaster.com/#specialty-bolts/=f4y5rl

Appendix F: Spring Schedule

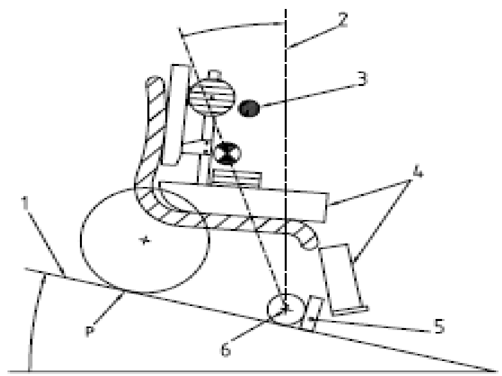
		Name	Duration
1		**Purchasing**	15 days
2		Tubing	10 days
3		Cushion	15 days
4		Brakes	15 days
5		Nuts and Botls	15 days
6		Shocks	15 days
7		Rickshaw Spring	15 days
8		Tires	15 days
9		**Manufacturing**	35 days
10		Sowing Canvas & Restraints	10 days
11		Build Frame	15 days
12		Assemble Components	10 days
13		**Presentation**	20 days
14		PowerPoint	10 days
15		Writing Associates	5 days
16		Class Presentation	0 days



Appendix G: ISO Standards

ISO Tests to be performed:

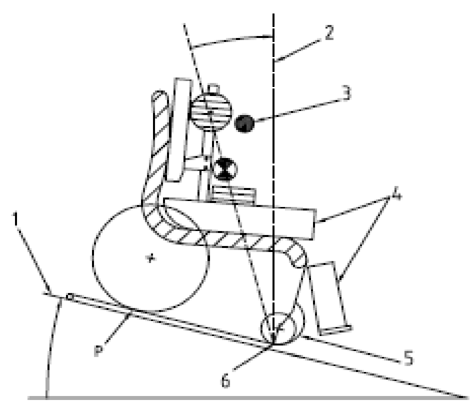
a. Forward stability when front wheels are unlocked.



Key
1 Test plane
2 Vertical
3 Tip restraint
4 Test dummy
5 Roll restraint
6 Axis of rotation

Figure 1 — Forward stability, front wheels unlocked

b. Forward stability, when front wheels locked.



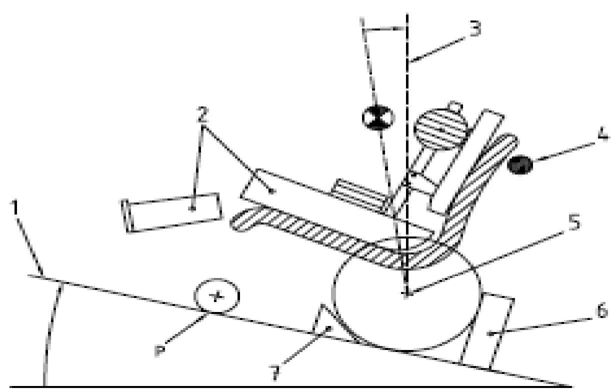
Key
1 Test plane
2 Vertical
3 Tip restraint
4 Test dummy
5 Flexible means
6 Axis of rotation

Figure 2 — Forward stability, front wheels locked

Table 1 — Forward stability

Adjustable wheelchair component	Least stable	Most stable
Rear-wheel position, fore-aft	Forward	Back
Castor attachment to frame, fore-aft	Back	Forward
Seat position, fore-aft	Forward	Back
Seat position, vertical	High	Low
Seat-back position, fore-aft	Forward	Back
Seat-back position, recline	Upright	Back
Seat position, tilt	Upright	Back
Elevating legrest position	Up	Down

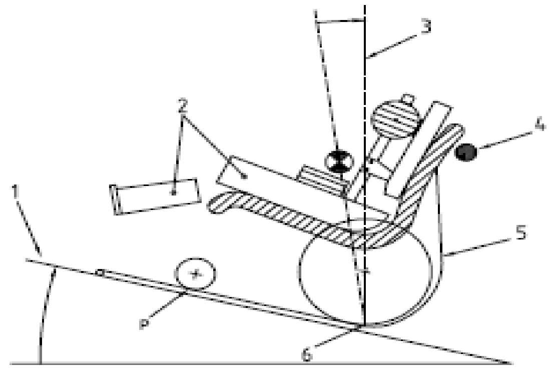
c. Rear stability, when rear wheels are unlocked.



Key
1 Test plane
2 Test dummy
3 Vertical
4 Tip restraint
5 Axis of rotation
6 Roll restraint
7 Wedge

Figure 3 — Rear stability, rear wheels unlocked

d. Rear stability, when rear wheels are locked.



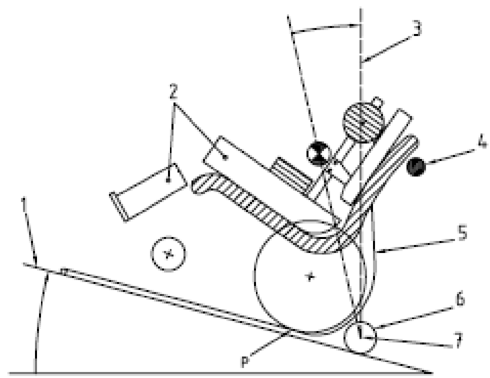
Key
1 Test plane
2 Test dummy
3 Vertical
4 Tip restraint
5 Flexible means
6 Axis of rotation

Figure 4 — Rearward stability, rear wheels locked

Table 2 — Rearward stability

Adjustable wheelchair component	Least stable	Most stable
Rear-wheel position, fore-aft	Forward	Back
Castor attachment to frame, fore-aft	Back	Forward
Seat position, fore-aft	Back	Forward
Seat position, vertical	High	Low
Seat-back position, recline	Back	Upright
Seat position, tilt	Back	Upright
Seat-back position, fore-aft	Back	Forward

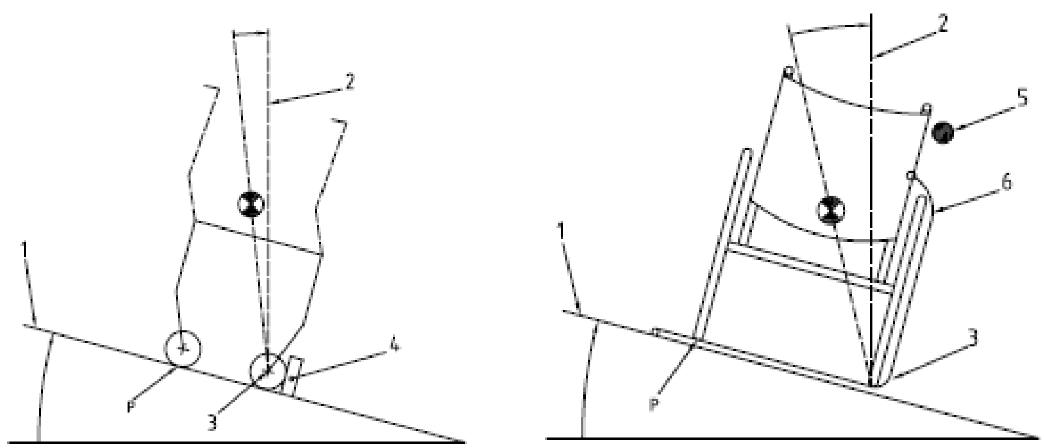
e. Rear anti-tip device stability.



Key
1 Test plane
2 Test dummy
3 Vertical
4 Tip restraint
5 Flexible means
6 Antitip device
7 Axis of rotation

Figure 5 — Rear antitip-device stability

f. Sideways Stability.



a) unlocked front wheels, front view

b) locked rear wheels, rear view

Key
1 Test plane
2 Vertical
3 Axis of rotation
4 Roll restraint
5 Tip restraint
6 Flexible means

Figure 6 — Sideways stability

Table 3 — Sideways stability

Adjustable wheelchair component	Least stable	Most stable
Rear-wheel position, camber	Narrowest track	Widest track
Castor attachment to frame, fore-aft	Back	Forward
Castor attachment to frame, inside-outside	Inside	Outside
Seat position, fore-aft	Forward	Back
Seat position, vertical	High	Low
Seat position, tilt	Upright	Back
Seat-back position, recline	Upright	Back

Test Report Tables:

Table 4 — Static stability test results

Stability direction		Tipping angle	
		Least stable	Most stable
Forward	Front wheels locked		
	Front wheels unlocked		
Rear	Rear wheels locked		
	Rear wheels unlocked		
	Antitip devices [a]		
Sideways	Left		
	Right		

[a] "least stable" and "most stable" refer to the positioning of the antitip devices (see 11.2.3 and 11.3.2).

Determination of effectiveness of brakes:

Table 1 — Maximum operating force

Means of operation	Operating force N
hand	60 ± 5
foot, push	100 ± 10
foot, pull	60 ± 5
finger	13,5 ± 2

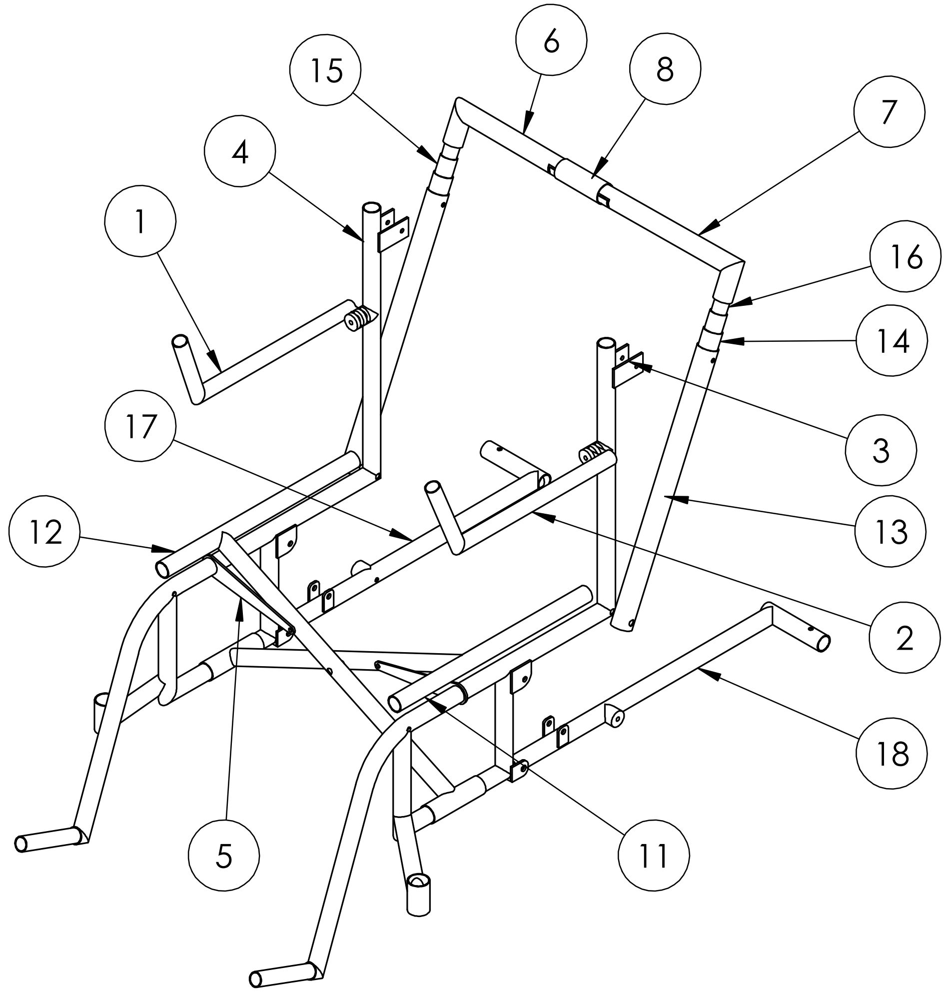
Table 2 — Results of running brake tests

Test plane inclination	Direction of travel		Normal operation	Reverse command	Emergency power off	Comments
Horizontal	Forwards	Min braking distance, m Max speed, m/s				
Horizontal	Reverse	Min braking distance, m Max speed, m/s				
3°	Forwards downhill	Min braking distance, m Max speed, m/s				
3°	Reverse downhill	Min braking distance, m Max speed, m/s				
6°	Forwards downhill	Min braking distance, m Max speed, m/s				
6°	Reverse downhill	Min braking distance, m Max speed, m/s				
10°	Forwards downhill	Min braking distance, m Max speed, m/s				
10°	Reverse downhill	Min braking distance, m Max speed, m/s				

Appendix H: Drawing Package

Drawing package begins on the next page.

PART NO.	BUILD-ONLY ITEMS	Build-only items/QTY.
1	Arm Bar Right	1
2	Arm Bar Left	1
3	Frame Left	1
4	Frame Right	1
5	Small Bar	2
6	Right Handle	1
7	Left Handle	1
8	Center Handle	1
9	Handle Spacer	4
10	Center Spring Bar	1
11	XBar 1	1
12	XBar 2	1
13	Bar A	2
14	Bar B	2
15	Bar C	2
16	Bar D	2
17	Spring Bar Right	1
18	Spring Bar Left	1
19	Spacer Ring	2



AUTOBOTS

TITLE: Assembly

	NAME	DATE
DRAWN	RML	12/10/11
CHK'D	BKS	12/13/11

DEBUR AND BREAK SHARP EDGES

REVISION 01

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

MATERIAL: 4130 Steel

FINISH: SEE DRAWINGS

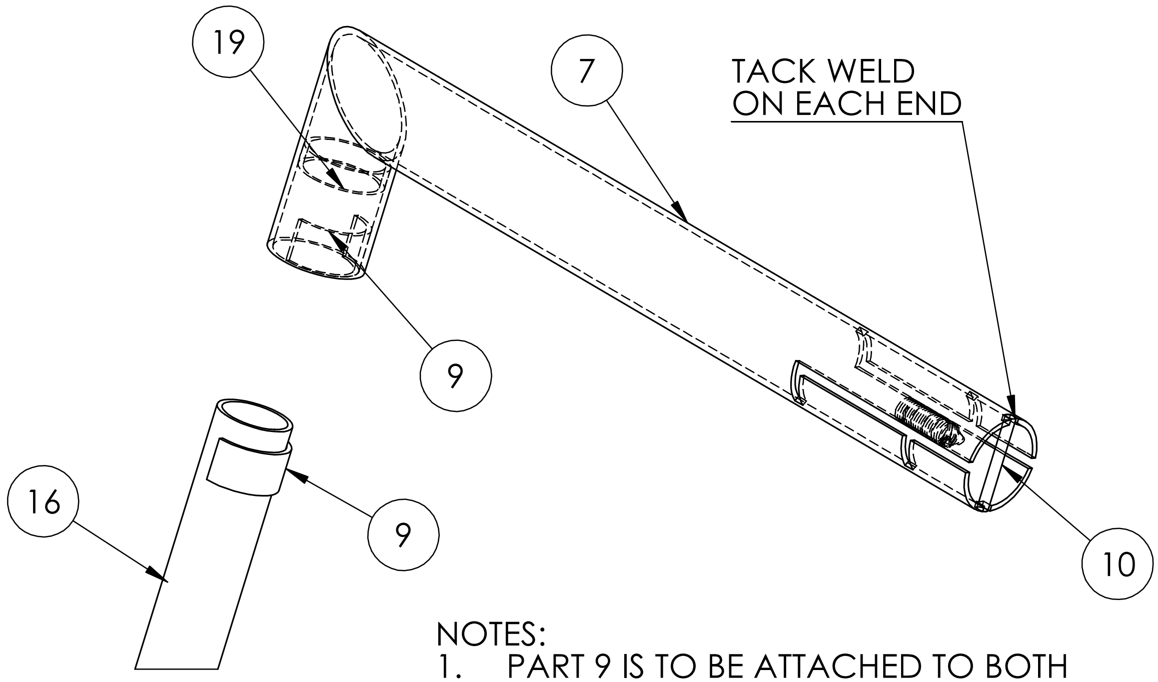
DWG NO. 0

A4

SCALE:1:10

SHEET 1 OF 5

PART NO.	BOUGHT / DONATED ITEMS	QTY.
20	1" End Cap	8
21	.875" End Cap	4
22	Brakes	2
23	Tires	2
24	Shock	2
25	Bearing/Axel	2
26	Spring	1
27	Footrest	2
28	Caster Wheels/Fork	2
29	Armrest	2
30	Stops	4
31	Cavas	2
32	Brake Handle	2
33	NUTS/BOLTS (SEE NOTE 3)	--
34	Spacer	2
35	Release Pin	2



NOTES:
1. PART 9 IS TO BE ATTACHED TO BOTH OF PART 16 AND TO THE INSIDE OF PARTS 6 AND 7 IN THE MANNER SHOWN ABOVE BY EITHER EDGE WELDS OR ADHESIVE.
2. PART 19 IS TO ATTACHED TO THE INSIDE OF PARTS 6 AND 7 IN THE MANNER SHOWN BY EITHER WELDS OR ADHESIVE
3. FOR NUT/BOLT PART NUMBERS, REFER TO APPENDIX C OF DESIGN REPORT.

	NAME	DATE		
DRAWN	RML	12/10/11	DEBUR AND BREAK SHARP EDGES	REVISION 01
CHK'D	BKS	12/13/11	MATERIAL: 4130 Steel	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

FINISH: SEE DRAWINGS

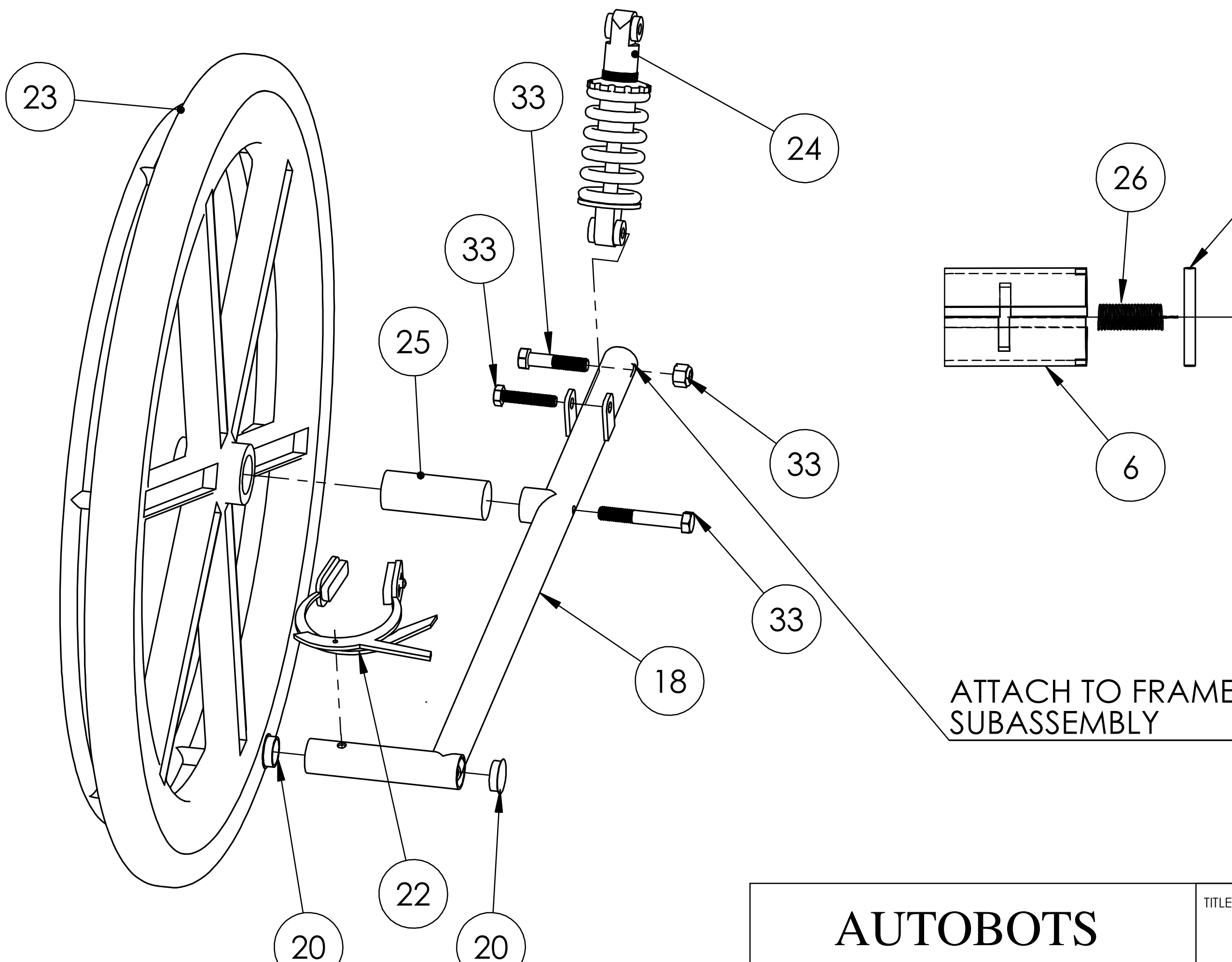
AUTOBOTS

TITLE: Assembly

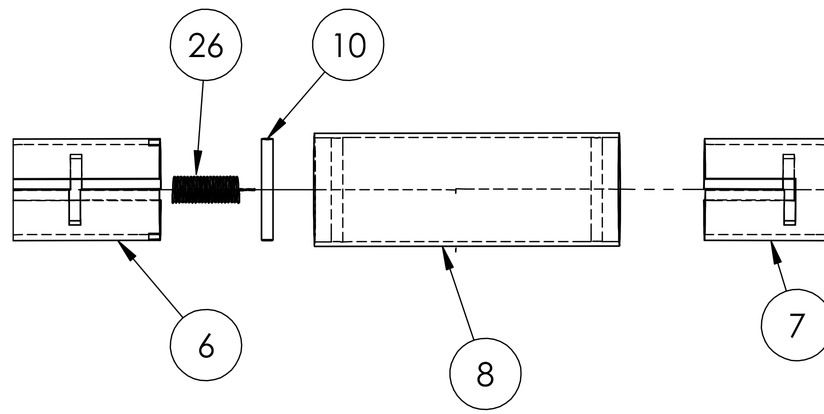
DWG NO. 0 A4

SCALE:1:10 SHEET 2 OF 5

SUSPENSION SUBASSEMBLY



CENTER HANDLE SUBASSEMBLY



AUTOBOTS

	NAME	DATE
DRAWN	RML	12/10/11
CHK'D	BKS	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: SEE DRAWINGS

TITLE: Assembly

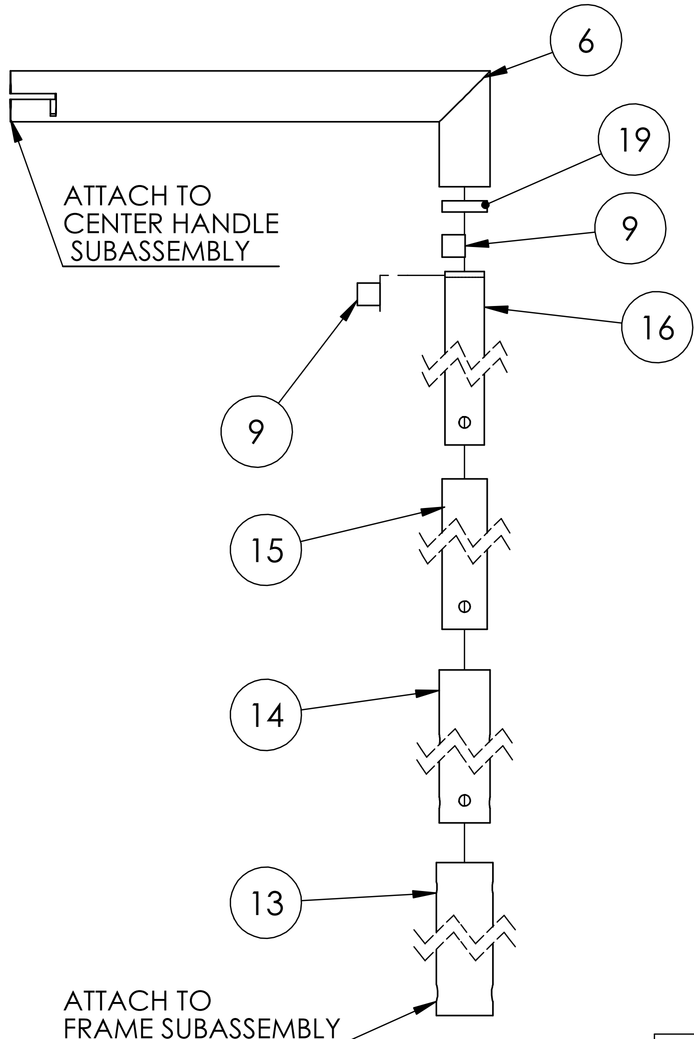
DWG NO. 0

A4

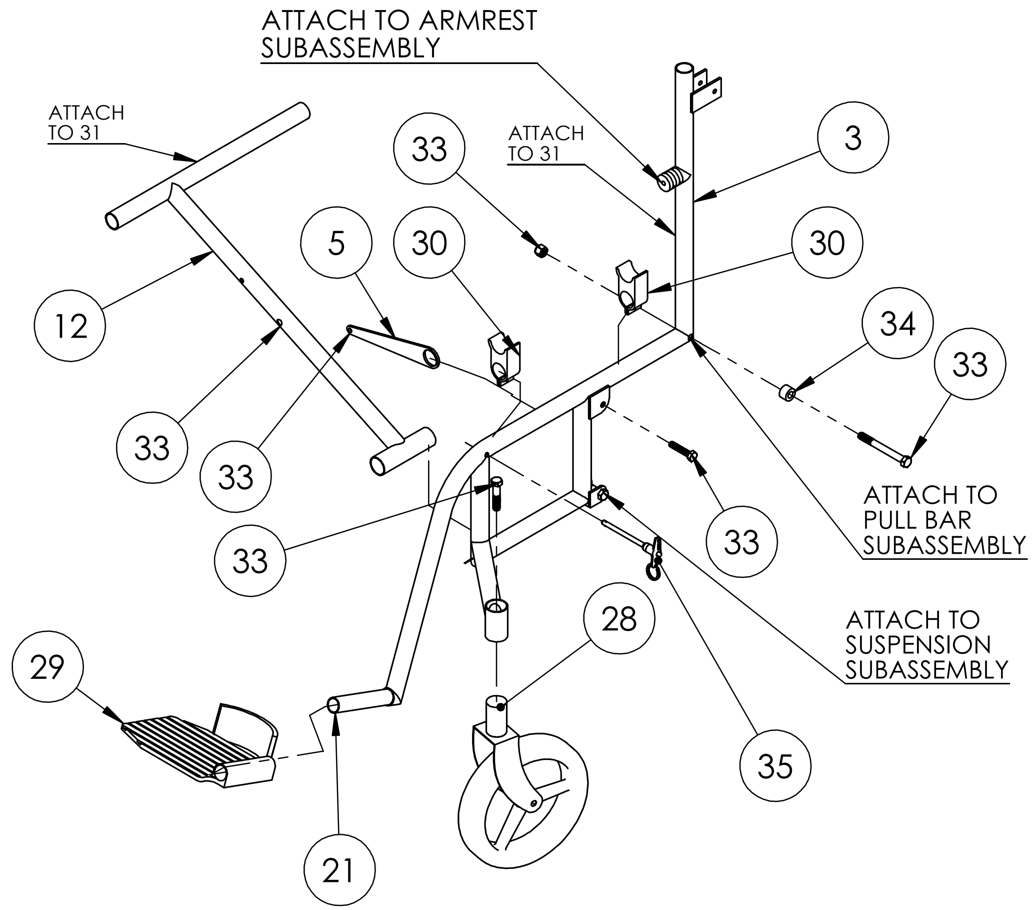
SCALE:1:5

SHEET 3 OF 5

PULL BAR SUBASSEMBLY

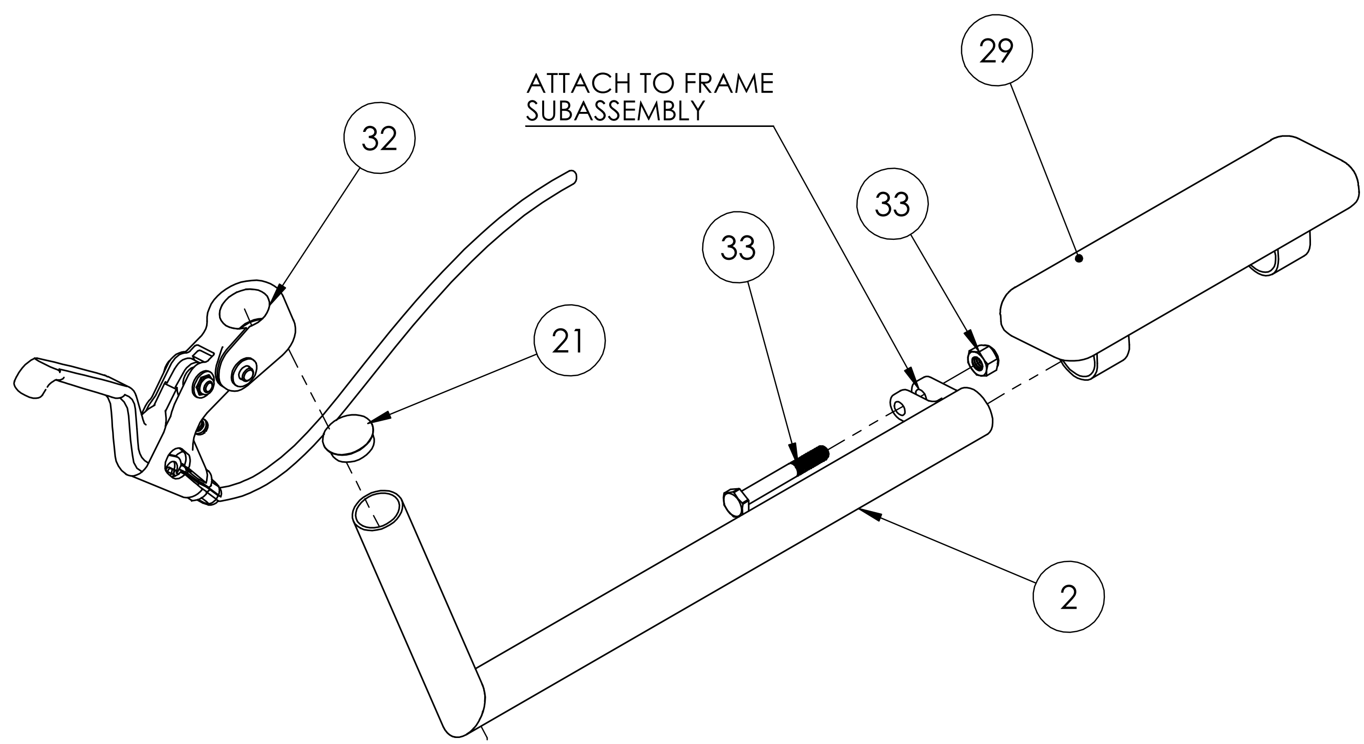


FRAME SUBASSEMBLY



AUTOBOTS				TITLE: Assembly
	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	RML	12/10/11		01
CHK'D	BKS	12/13/11	MATERIAL: 4130 Steel	DWG NO. 0 — A4
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES ANGLES ±2.0° 2 DECIMAL PL. ±0.01 3 DECIMAL PL. ±0.005			FINISH: SEE DRAWINGS	SCALE:1:5 — SHEET 4 OF 5

ARM REST SUBASSEMBLY



AUTOBOTS

	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	RML	12/10/11		01
CHK'D	BKS	12/13/11	MATERIAL: 4130 Steel	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

FINISH: SEE DRAWINGS

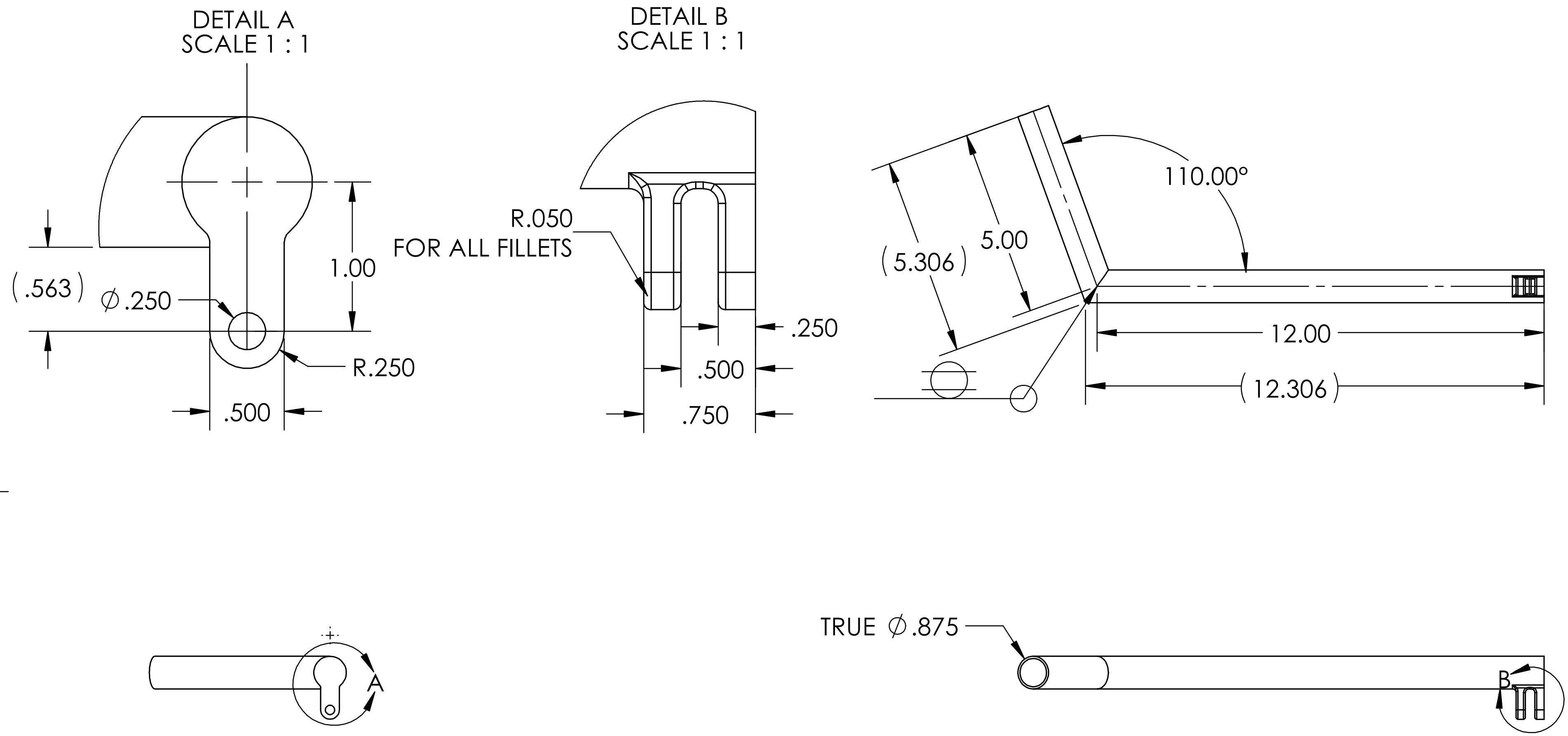
TITLE: Assembly

DWG NO. 0

A4

SCALE:1:5

SHEET 5 OF 5



NOTE:
ALL TUBING IS .875 INCH O.D.
.058 INCH THICKNESS

AUTOBOTS

	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	BKS	12/10/11		01
CHK'D	RML	12/13/11	MATERIAL: 4130 Steel	

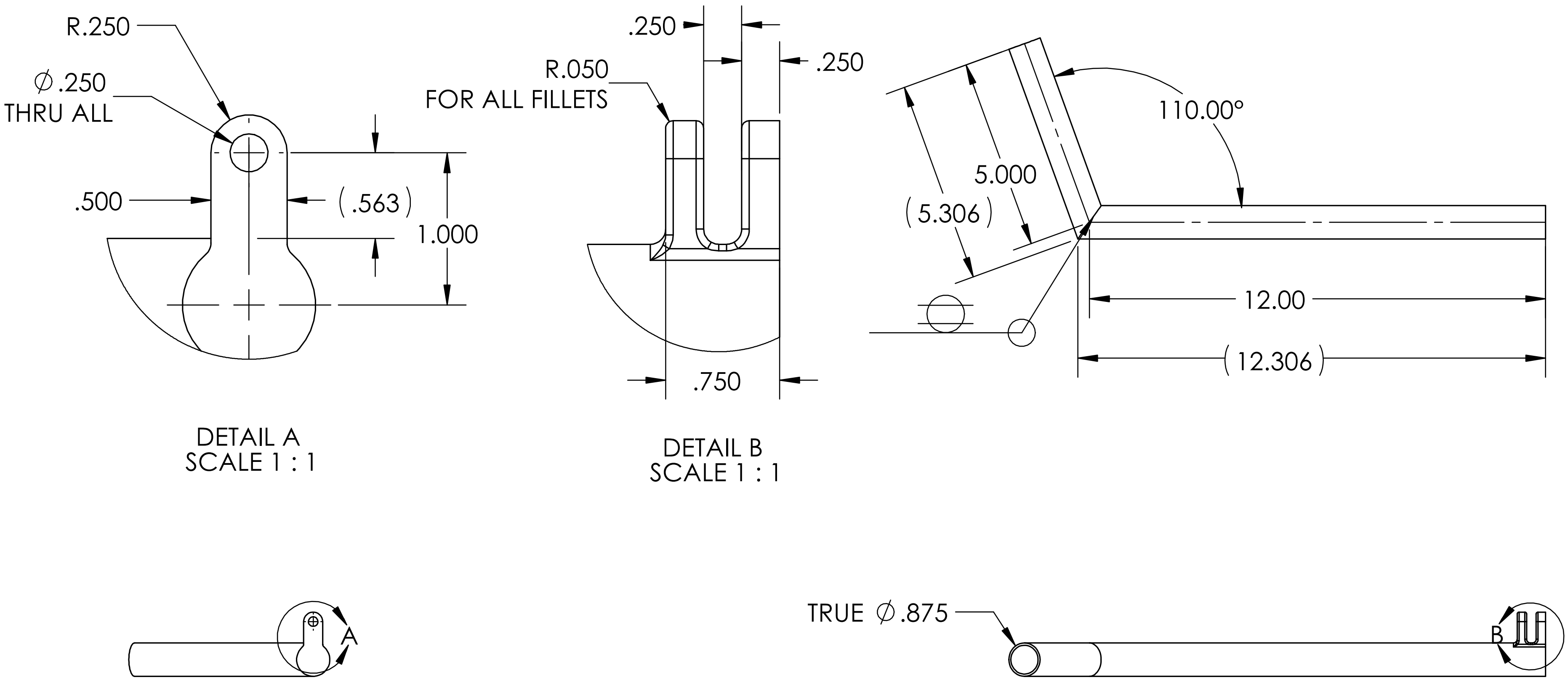
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

FINISH: POWDERCOAT

TITLE: Arm Bar Right

DWG NO. 1 — A4

SCALE:1:5 — SHEET 1 OF 1



NOTE:
ALL TUBING IS .875 INCH O.D.
.058 INCH THICKNESS

AUTOBOTS

	NAME	DATE
DRAWN	BKS	12/10/11
CHK'D	RML	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND
BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

TITLE: Arm Bar Left

DWG NO. 2

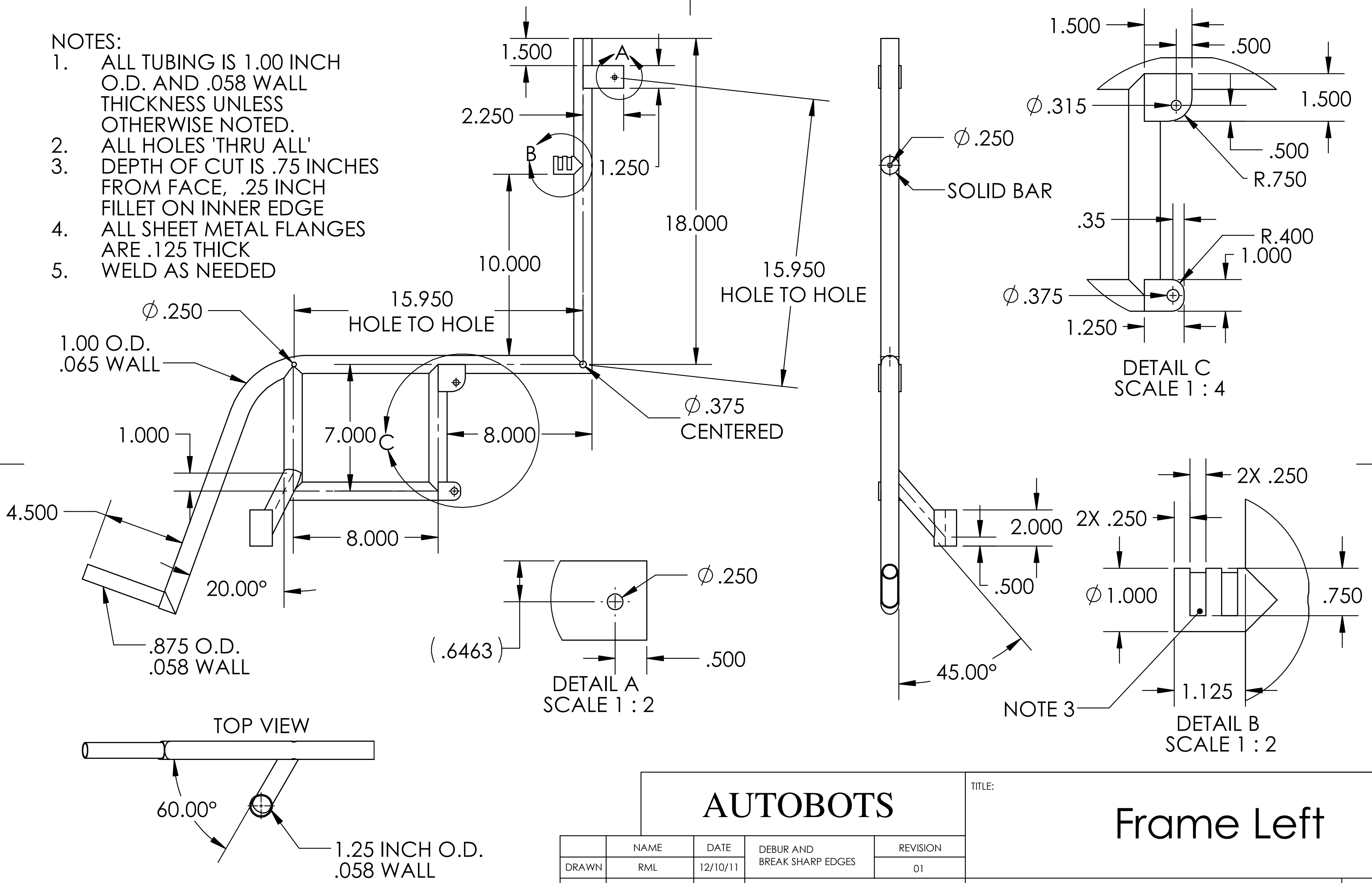
A4

SCALE:1:5

SHEET 1 OF 1

NOTES:

1. ALL TUBING IS 1.00 INCH O.D. AND .058 WALL THICKNESS UNLESS OTHERWISE NOTED.
2. ALL HOLES 'THRU ALL'
3. DEPTH OF CUT IS .75 INCHES FROM FACE, .25 INCH FILLET ON INNER EDGE
4. ALL SHEET METAL FLANGES ARE .125 THICK
5. WELD AS NEEDED



AUTOBOTS

TITLE: Frame Left

	NAME	DATE
DRAWN	RML	12/10/11
CHK'D	BKS	12/13/11

DEBUR AND BREAK SHARP EDGES

REVISION: 01

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

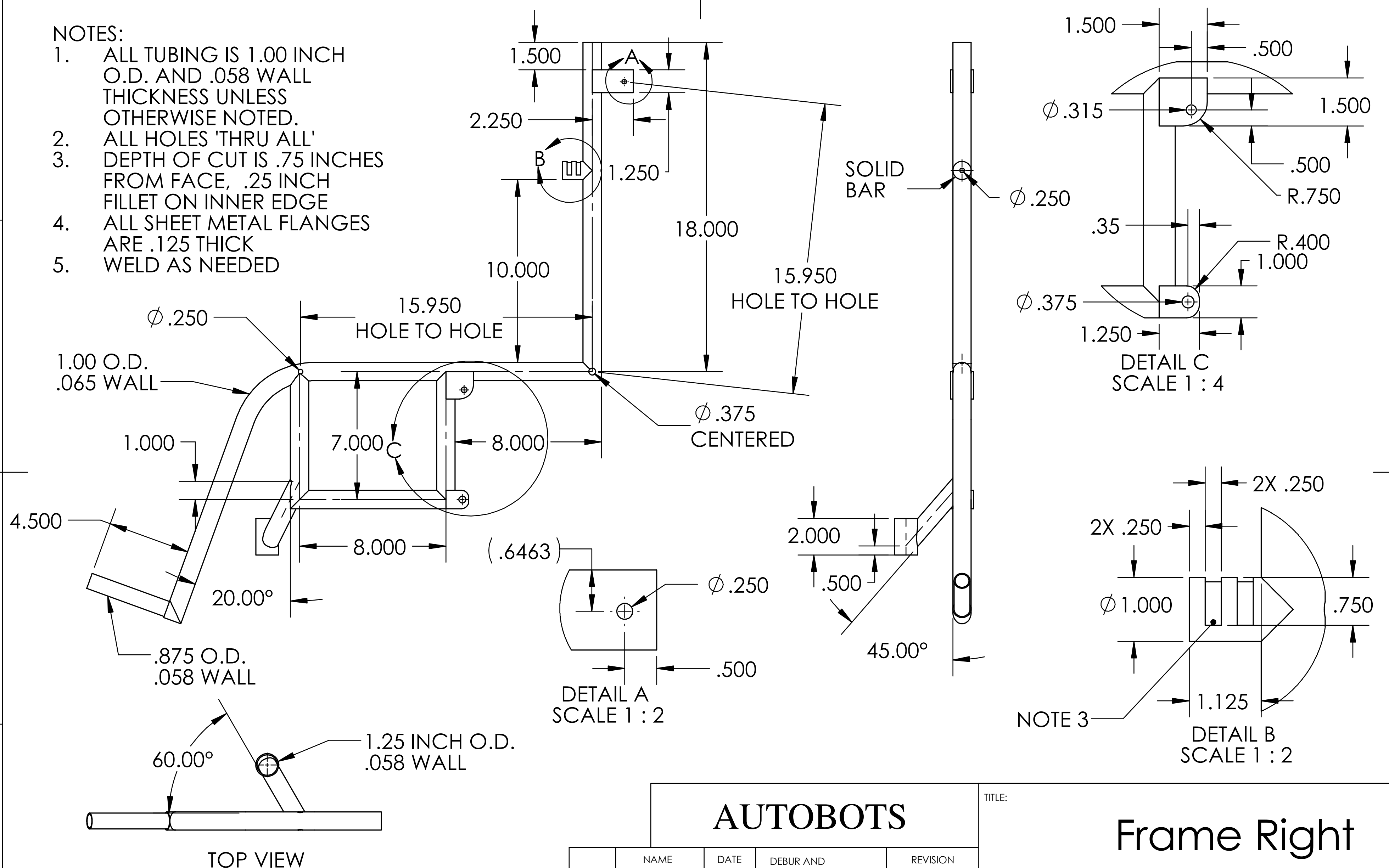
DWG NO. 3

A4

SCALE:1:7

SHEET 1 OF 1

NOTES:
1. ALL TUBING IS 1.00 INCH O.D. AND .058 WALL THICKNESS UNLESS OTHERWISE NOTED.
2. ALL HOLES 'THRU ALL'
3. DEPTH OF CUT IS .75 INCHES FROM FACE, .25 INCH FILLET ON INNER EDGE
4. ALL SHEET METAL FLANGES ARE .125 THICK
5. WELD AS NEEDED



AUTOBOTS

	NAME	DATE	
DRAWN	RML	12/10/11	DEBUR AND BREAK SHARP EDGES — REVISION 01
CHK'D	BKS	12/13/11	MATERIAL: 4130 Steel

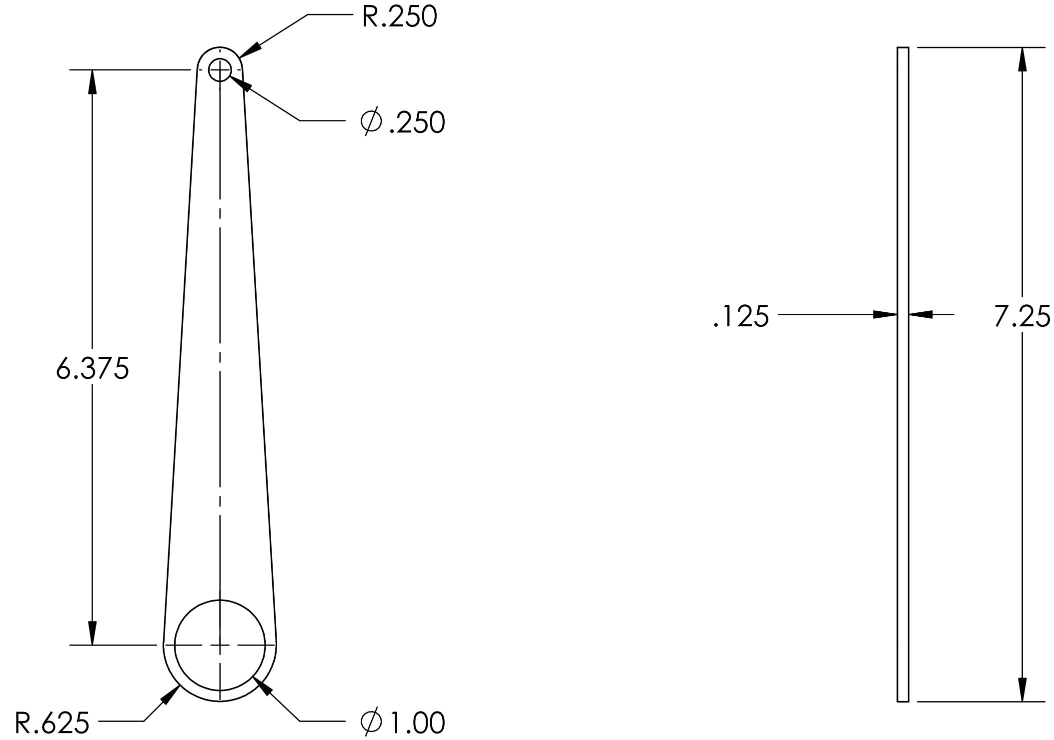
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

FINISH: POWDERCOAT

TITLE: Frame Right

DWG NO. 4 — A4

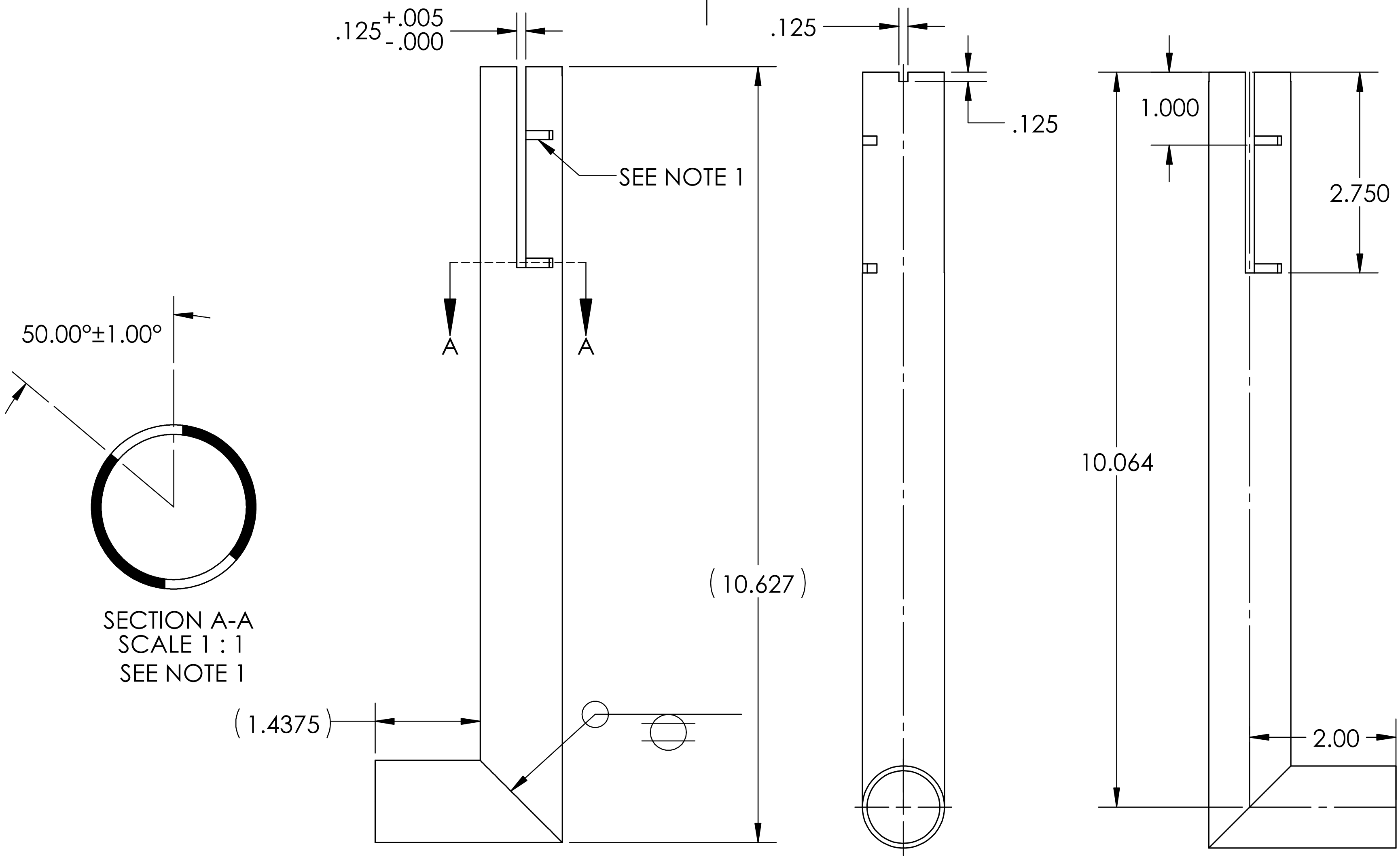
SCALE:1:7 — SHEET 1 OF 2



AUTOBOTS

	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	RML	12/9/11		01
CHK'D	BKS	12/13/11	MATERIAL: 4130 Steel	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES ANGLES ±2.0° 2 DECIMAL PL. ±0.01 3 DECIMAL PL. ±0.005			FINISH: POWDERCOAT	

TITLE: Small Bar		
DWG NO. 5		A4
SCALE:1:2	SHEET 1 OF 1	



NOTES:
1. CUT SLOT DOWN TO SPECIFIED DISTANCE, THEN ROTATE AROUND CIRCUMFERENCE 50 DEGREES
2. ALL TUBING IS 1.125 INCH O.D. AND .058 WALL THICKNESS

AUTOBOTS

	NAME	DATE
DRAWN	RML	12/10/11
CHK'D	BKS	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

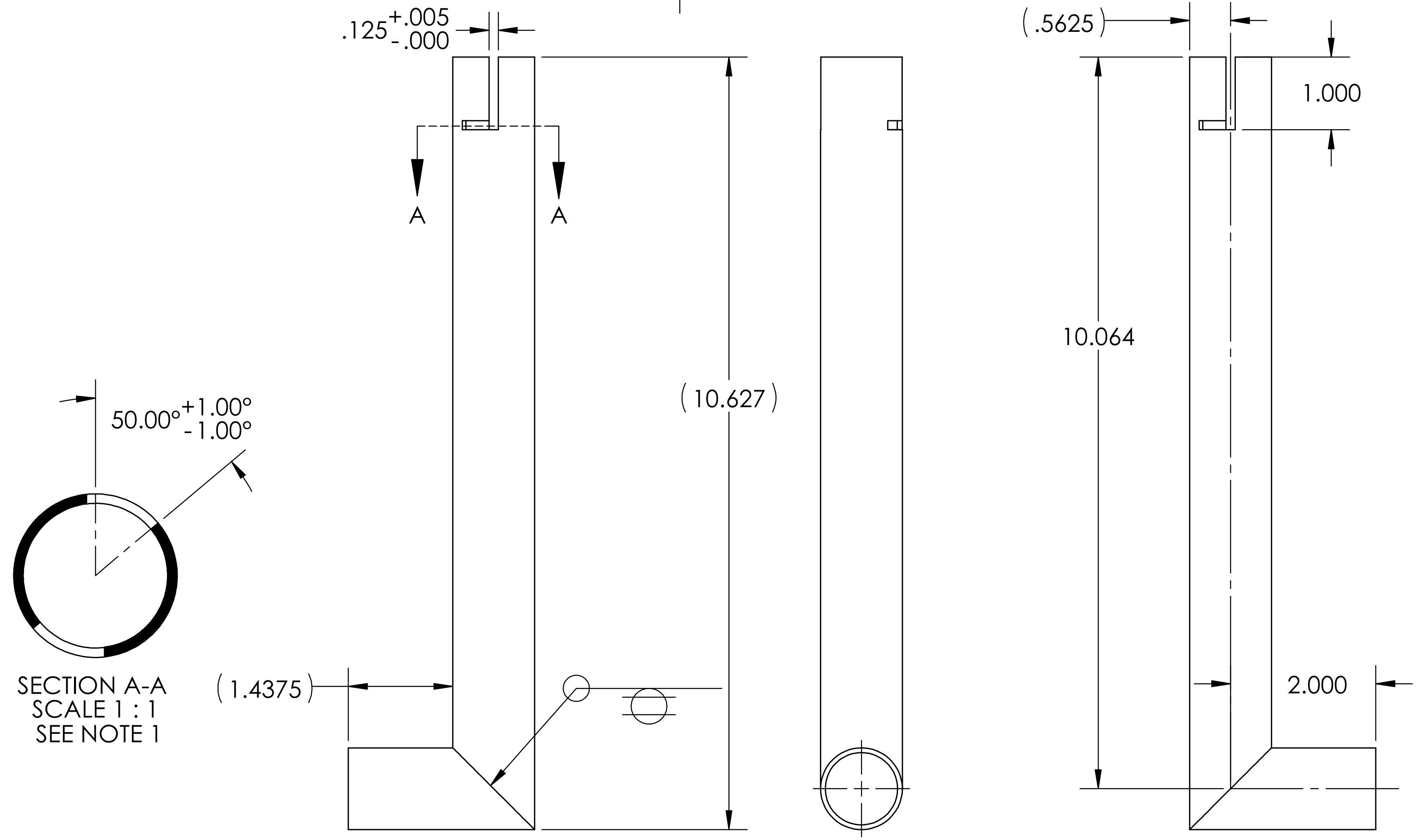
TITLE: Right Handle

DWG NO. 6

A4

SCALE:1:2

SHEET 1 OF 1



NOTES:
1. CUT SLOT DOWN TO SPECIFIED DISTANCE, THEN ROTATE AROUND CIRCUMFERENCE 50 DEGREES
2. ALL TUBING IS 1.125 INCH O.D. AND .058 WALL THICKNESS

AUTOBOTS

	NAME	DATE
DRAWN	RML	12/10/11
CHK'D	BKS	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

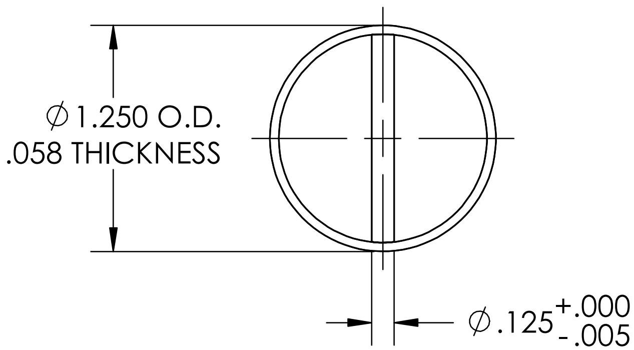
TITLE: Left Handle

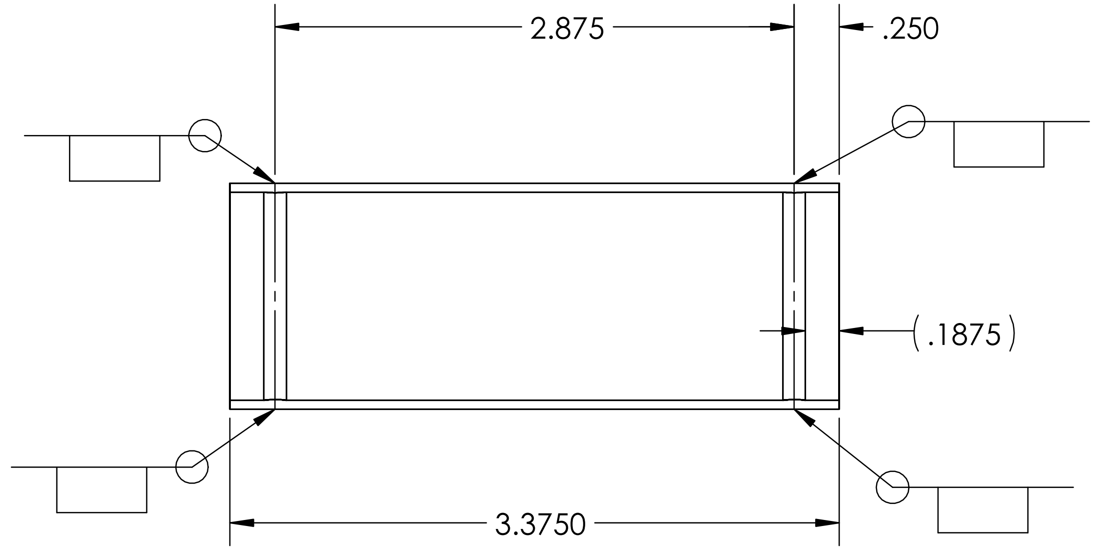
DWG NO. 7

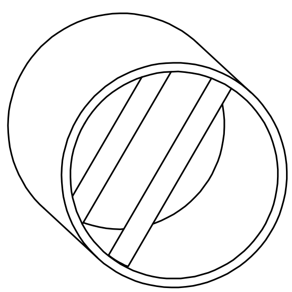
A4

SCALE:1:2

SHEET 1 OF 1







NOTES:

1. THE TWO CROSSBARS ARE SOLID
2. MAY USE SAME MATERIAL AS PART 10

AUTOBOTS

	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	BKS	12/10/11		01
CHK'D	RML	12/13/11	MATERIAL: 4130 Steel	

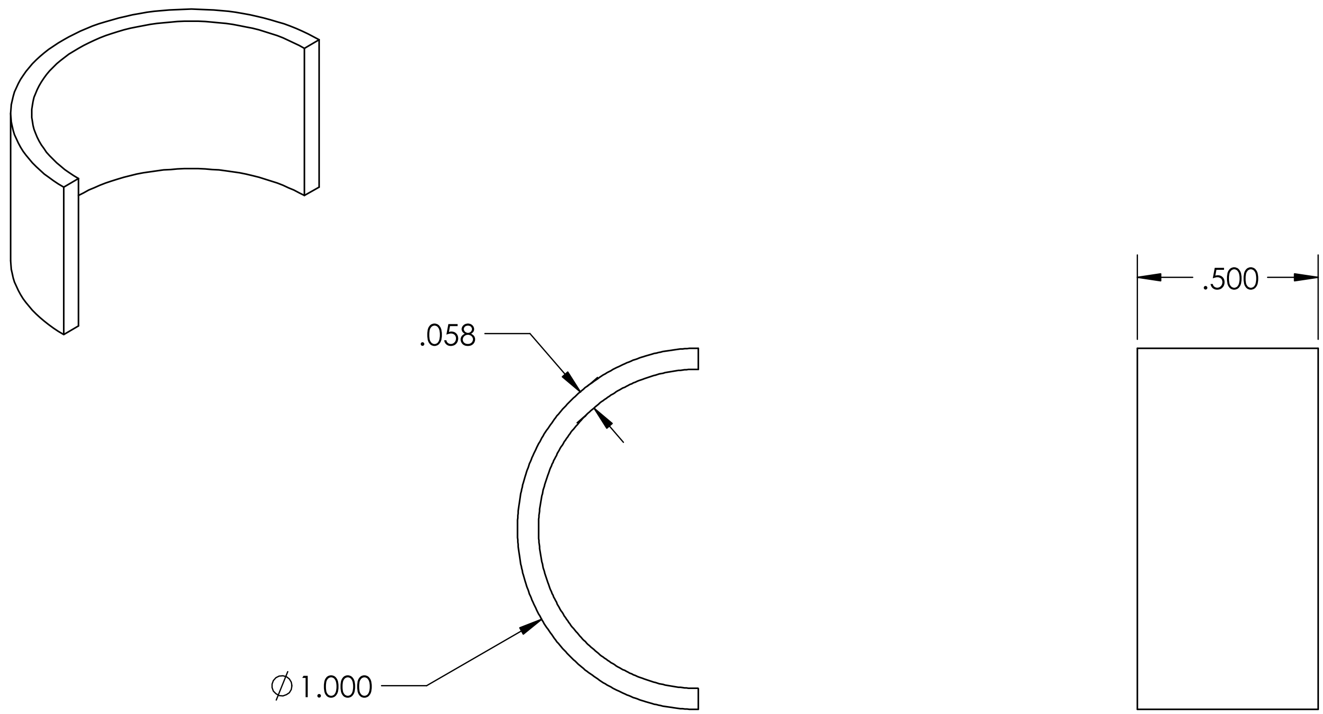
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

FINISH: POWDERCOAT

TITLE: Center Handle

DWG NO. 8 — A4

SCALE:1:2 — SHEET 1 OF 1



AUTOBOTS

TITLE: Handle Spacer

	NAME	DATE
DRAWN	RML	12/10/11
CHK'D	BKS	12/13/11

DEBUR AND BREAK SHARP EDGES

REVISION: 01

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

MATERIAL: 4130 Steel

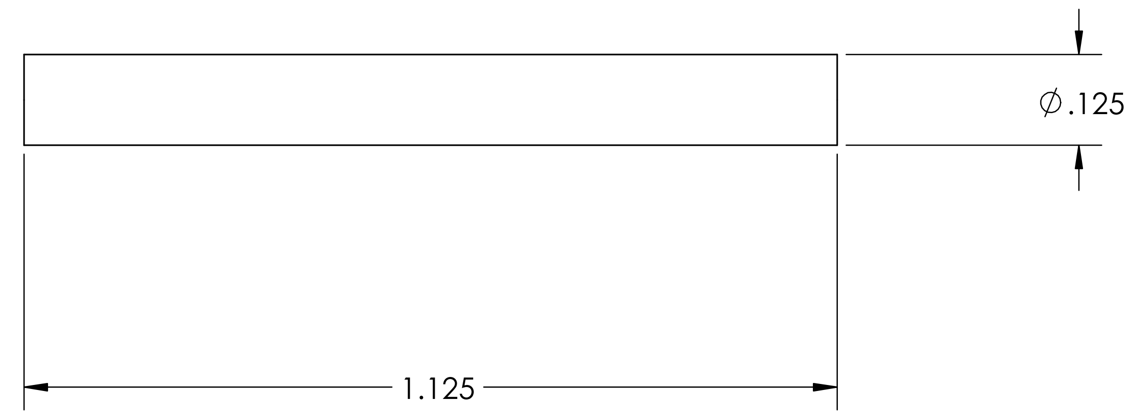
FINISH: POWDERCOAT

DWG NO. 9

A4

SCALE:2:1

SHEET 1 OF 1



NOTE:
USE .125 O.D. SOLID BAR

AUTOBOTS

TITLE: Center Spring Bar

	NAME	DATE
DRAWN	BKS	12/10/11
CHK'D	RML	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

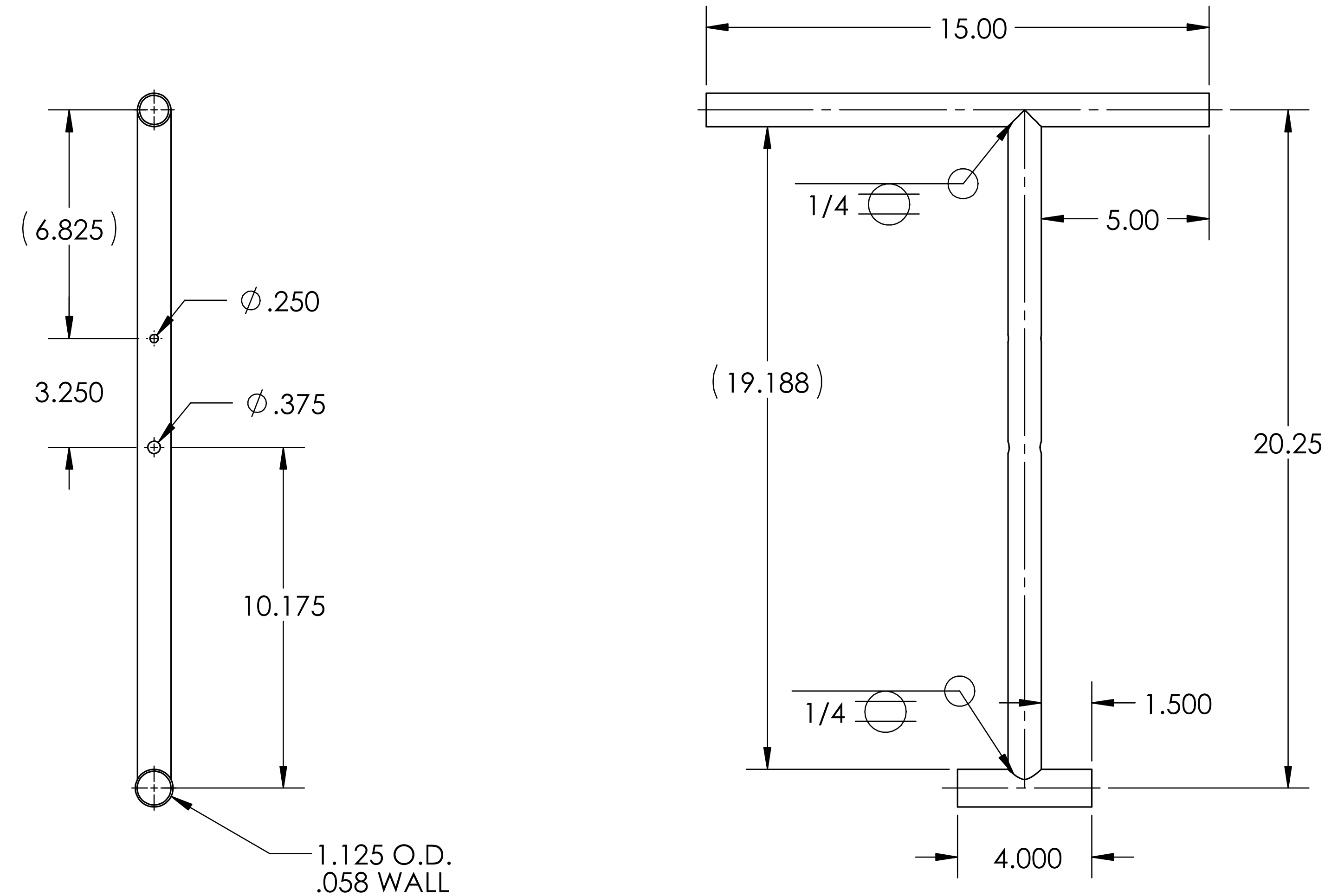
FINISH: POWDERCOAT

DWG NO. 10

A4

SCALE:2:1

SHEET 1 OF 1



NOTE:
ALL TUBING 1.00 O.D. WITH .058 WALL THICKNESS UNLESS OTHERWISE STATED

AUTOBOTS

	NAME	DATE
DRAWN	RML	12/10/11
CHK'D	BKS	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

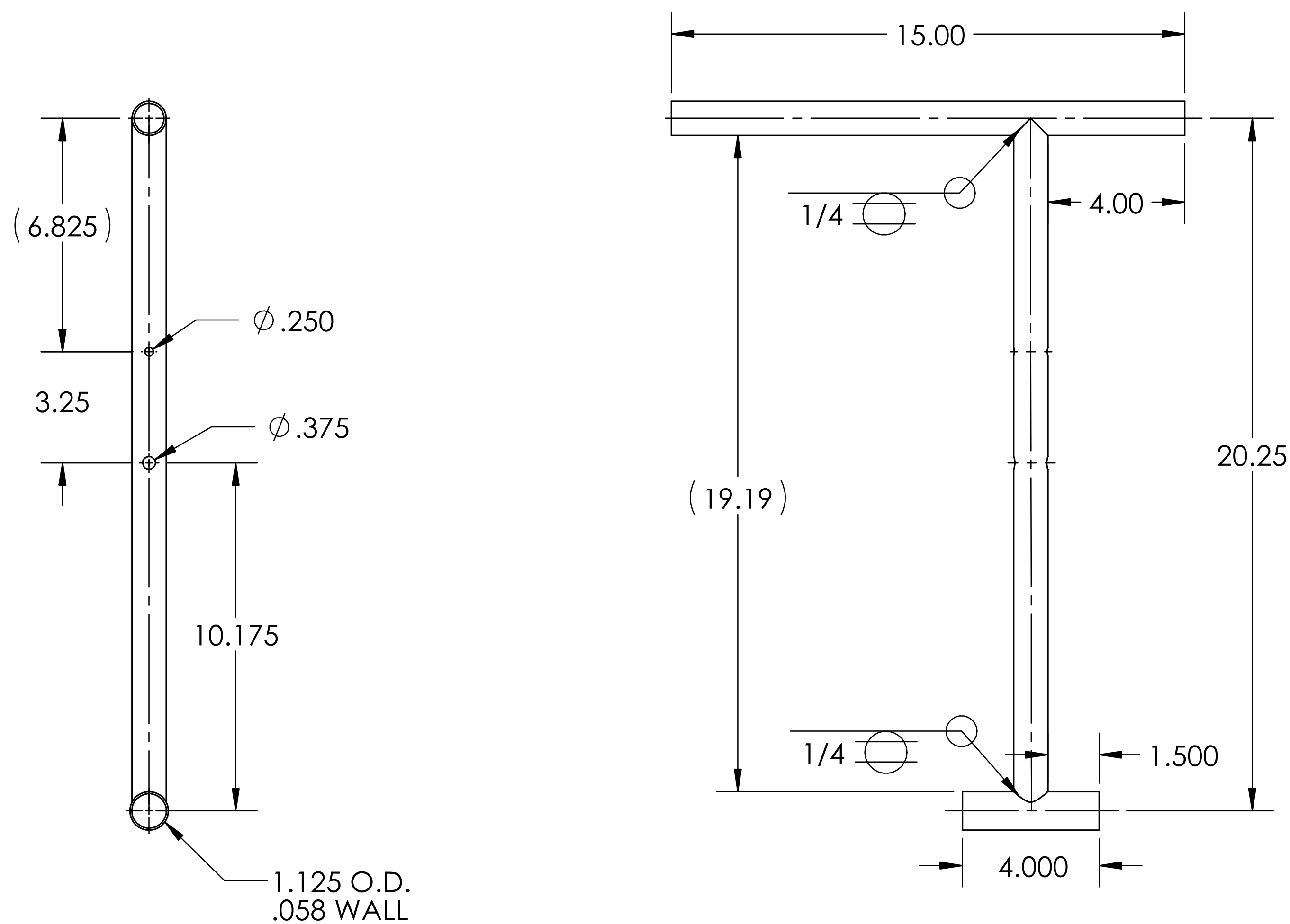
TITLE: XBar 1

DWG NO. 11

A4

SCALE:1:5

SHEET 1 OF 1



NOTE:
ALL TUBING 1.00 O.D. WITH .058 WALL
THICKNESS UNLESS OTHERWISE STATED

AUTOBOTS

TITLE: XBar 2

	NAME	DATE
DRAWN	RML	12/9/11
CHK'D	bks	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

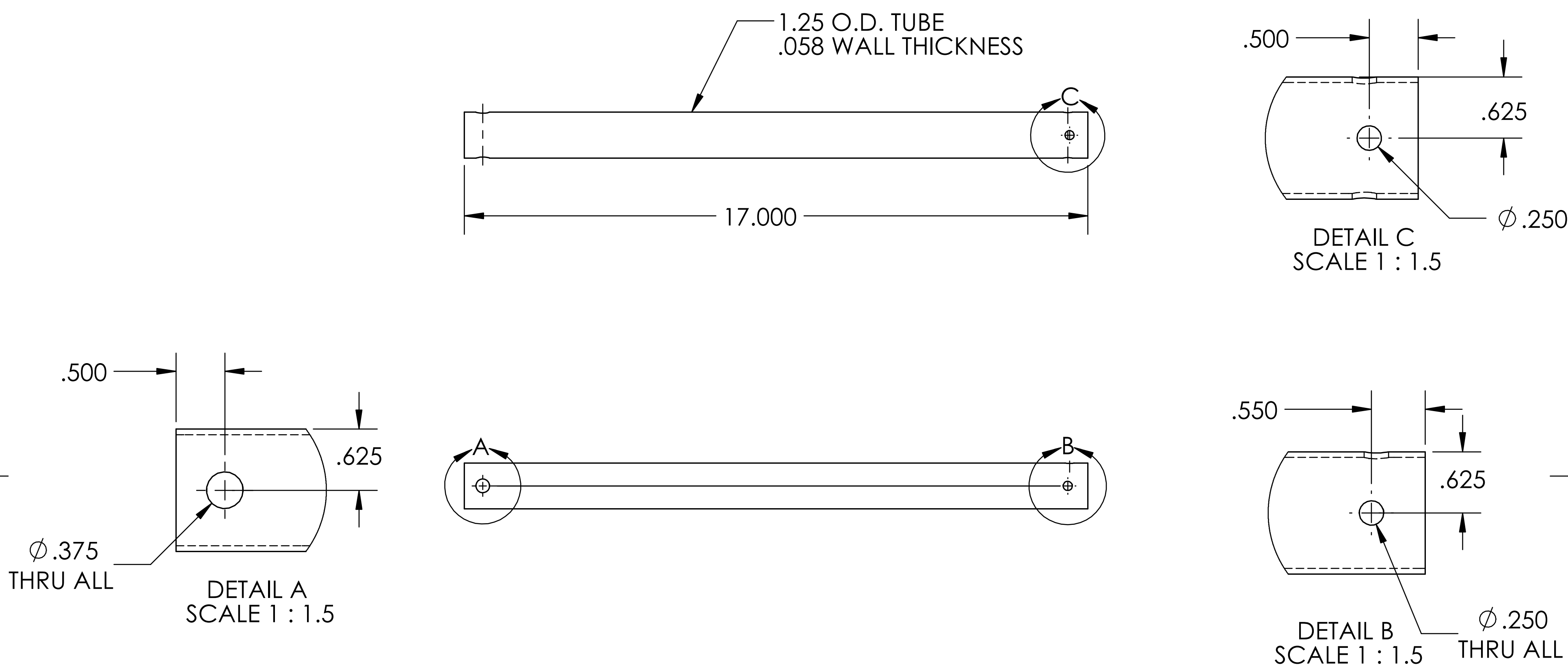
FINISH: POWDERCOAT

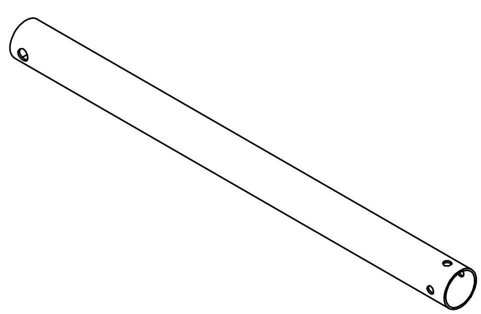
DWG NO. 12

A4

SCALE:1:5

SHEET 1 OF 1





AUTOBOTS

	NAME	DATE
DRAWN	BKS	12/10/11
CHK'D	RML	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

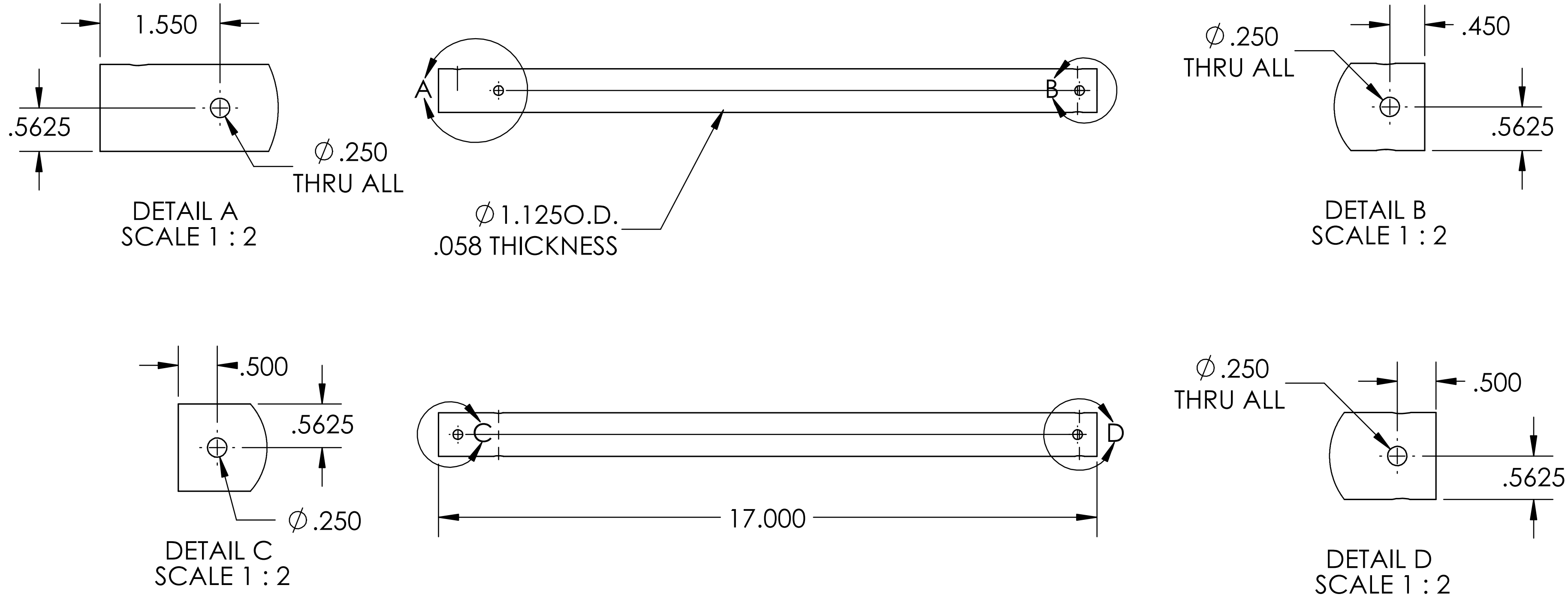
TITLE: Bar A

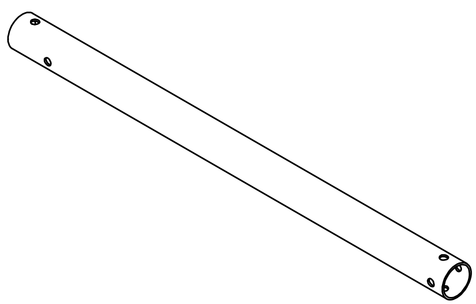
DWG NO. 13

A4

SCALE:1:5

SHEET 1 OF 1

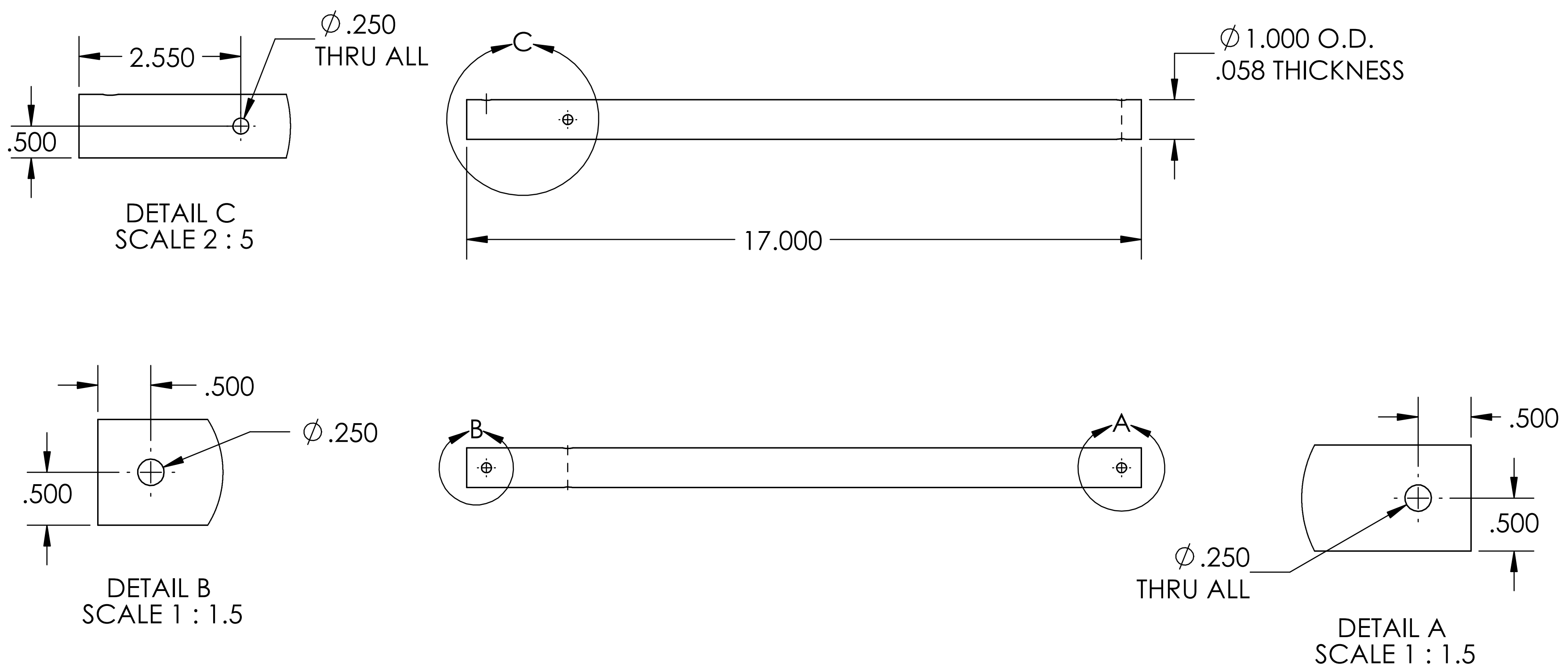


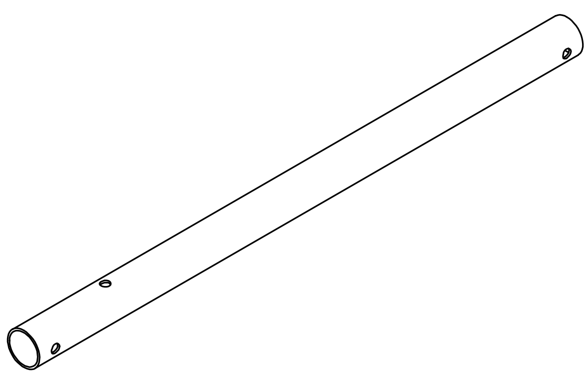


AUTOBOTS

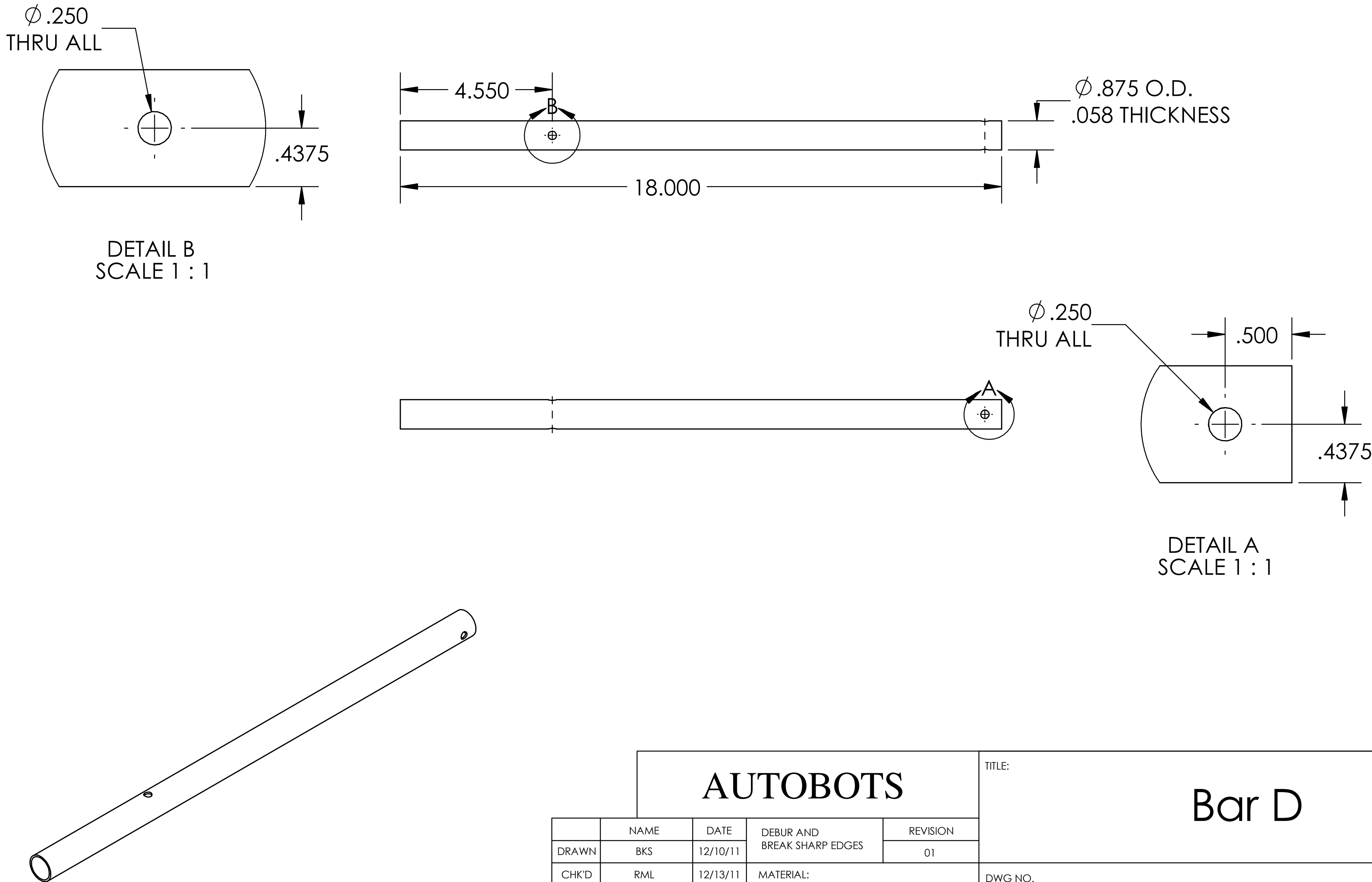
	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	BKS	12/10/11		01
CHK'D	RML	12/13/11	MATERIAL: 4130 Steel	
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES ANGLES ±2.0° 2 DECIMAL PL. ±0.01 3 DECIMAL PL. ±0.005			FINISH: POWDERCOAT	

TITLE:	Bar B	
DWG NO.	14	A4
SCALE:1:5	SHEET 1 OF 1	





AUTOBOTS			TITLE:	Bar C
	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	BKS	12/10/11		01
CHK'D	RML	12/13/11	MATERIAL: 4130 Steel	DWG NO. 15 — A4
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES ANGLES ±2.0° 2 DECIMAL PL. ±0.01 3 DECIMAL PL. ±0.005			FINISH: POWDERCOAT	SCALE:1:5 — SHEET 1 OF 1



AUTOBOTS

	NAME	DATE
DRAWN	BKS	12/10/11
CHK'D	RML	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

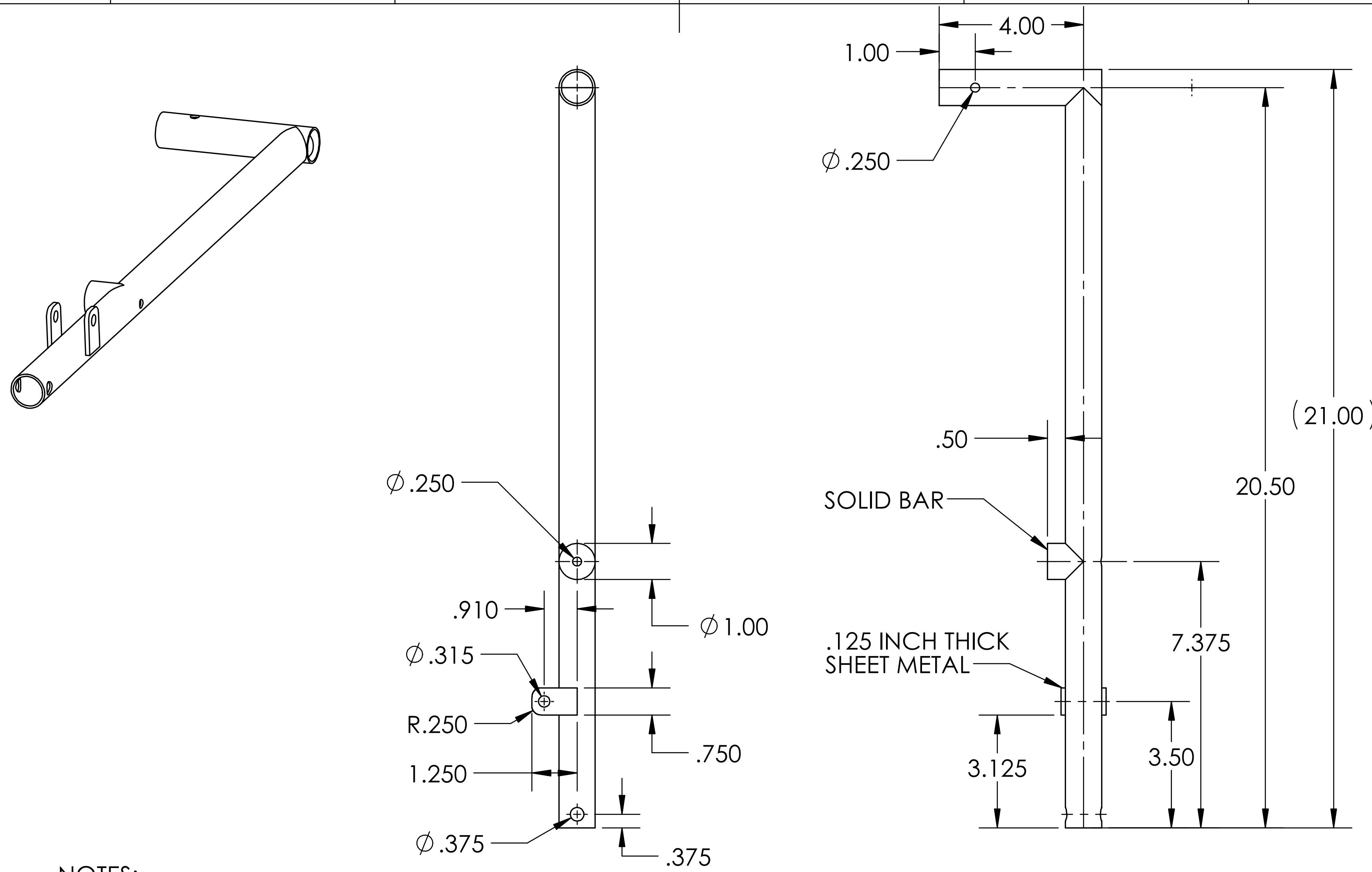
TITLE: Bar D

DWG NO. 16

A4

SCALE:1:5

SHEET 1 OF 1



NOTES:
1. ALL TUBING IS 1.00 INCH O.D. AND .065 WALL THICKNESS
2. ALL HOLES 'THRU ALL'

AUTOBOTS

TITLE: Spring Bar Right

	NAME	DATE
DRAWN	RML	12/11/11
CHK'D	BKS	12/13/11

DEBUR AND BREAK SHARP EDGES

REVISION: 01

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

MATERIAL: 4130 Steel

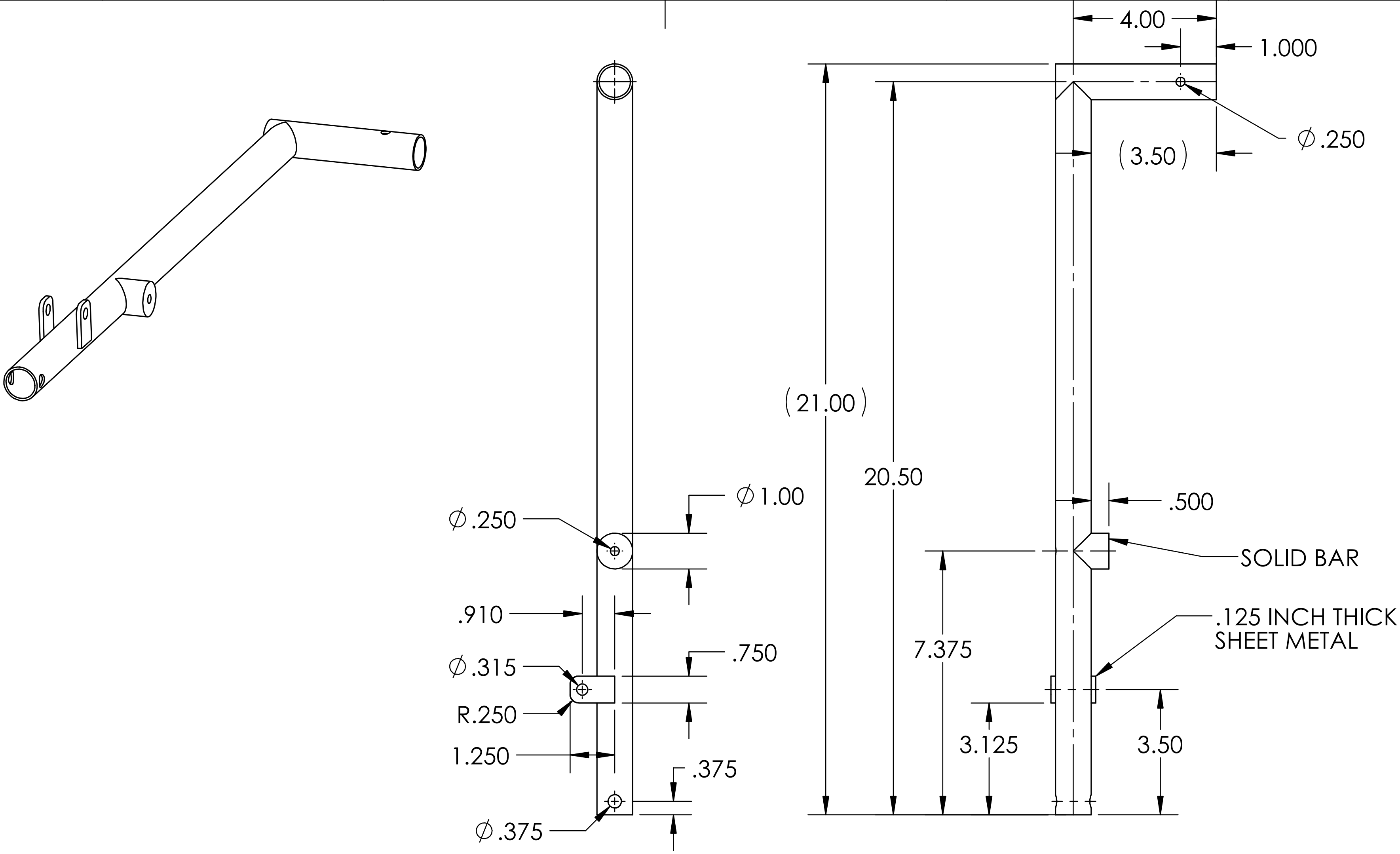
FINISH: POWDERCOAT

DWG NO. 17

A4

SCALE:1:4

SHEET 1 OF 1



NOTES:
1. ALL TUBING IS 1.00 INCH O.D. AND .065 WALL THICKNESS
2. ALL HOLES 'THRU ALL'

AUTOBOTS

	NAME	DATE
DRAWN	RML	12/11/11
CHK'D	BKS	12/13/11

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

DEBUR AND BREAK SHARP EDGES

REVISION: 01

MATERIAL: 4130 Steel

FINISH: POWDERCOAT

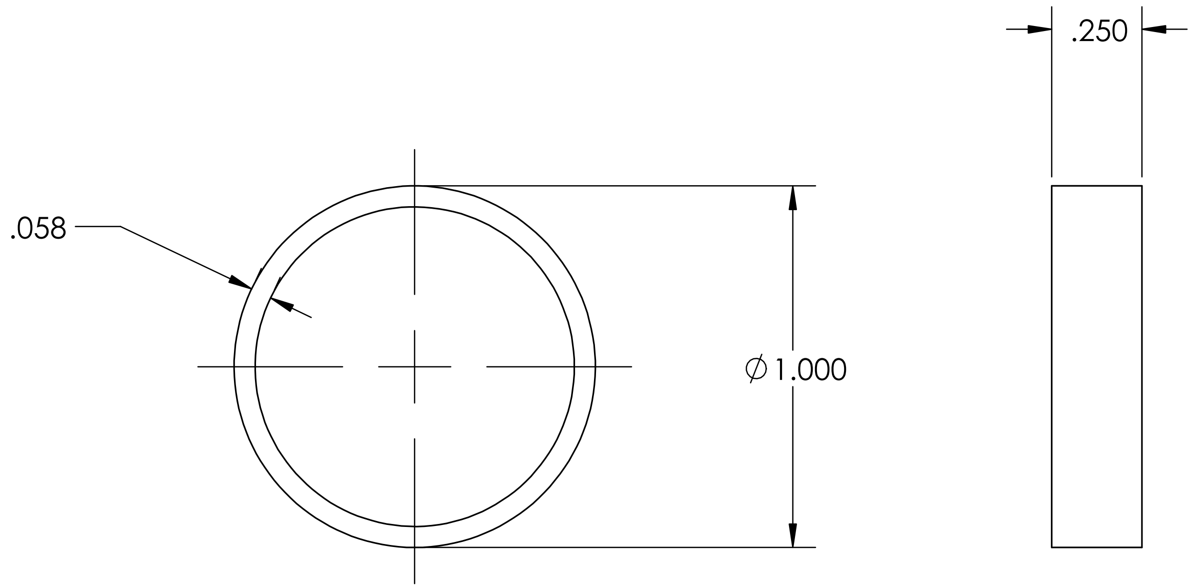
TITLE: Spring Bar Left

DWG NO. 18

A4

SCALE:1:4

SHEET 1 OF 1



AUTOBOTS

	NAME	DATE	DEBUR AND BREAK SHARP EDGES	REVISION
DRAWN	RML	12/10/11		01
CHK'D	BKS	12/13/11	MATERIAL: 4130 Steel	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
ANGLES ±2.0°
2 DECIMAL PL. ±0.01
3 DECIMAL PL. ±0.005

FINISH: POWDERCOAT

TITLE: Spacer Ring

DWG NO. 19 A4

SCALE:2:1 SHEET 1 OF 1