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Union Advanced Educational Robot

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UNION COLLEGE

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A 2012 Senior Design Project

Erik Skorina

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Introduction

The ideal platform for educational robotics combines strong flexibility with high computational power and relatively low cost. Existing robots used in educational environments fall into two categories: simple robotics kits and commercial robotics development platforms. The first category ranges from simple devices like Parallax's Scribbler to the more comprehensive Lego NXT ecosystem. These robots are cheap, relatively easy to use, and (in the case of Lego or Vex systems) relatively flexible in the ability to add additional sensors and actuators. However, these systems lack the kind of processing power necessary to process video input in real time or to run more complicated control algorithms. In most cases, such functionality must be implemented through the use of a host computer, which imposes sharp limits on portability and autonomy. [1,2]

In contrast, commercial robots range from comparatively simple devices like Mobile Robots' Pioneer series all the way up to complete development platforms such as Willow Garage's PR2. These robots almost universally have on-board computers capable of video processing and navigation, and provide nearly complete sensor suites for use in development. However, these robots often trade flexibility for reliability, with limited means for expansion or component replacement. In particular, the popular Pioneer series robots are designed to last years in educational settings, but are relatively limited in their ability for expansion (particularly true when using the on-board computer). In addition, these commercial robots are not always affordable; while simpler systems like a Pioneer start at approximately $4000 US, more flexible and complex platforms range up to $400,000 US in the case of the PR2. These are by no means affordable for educational use, especially if multiple units are desired.[1,2]

Our project was the design and construction of a medium sized (approximately 40 kg when fully loaded) mobile robot for educational and research use. This robot was designed to provide a strong baseline chassis with sensors, actuators and necessary software to allow for easy integration with existing robotic equipment, software and curricula. In particular, it was designed for use in intermediate and advanced undergraduate robotics courses and undergraduate research projects in robotics. The following descriptions from professors in the Computer Science department illustrate the characteristics needed for this:

> An ideal teaching robot for me would be mobile, robust, and capable of running the Robot Operating System (ROS). Mobility is important because most interesting problems in AI and robotics appear when robots leave "staged" labs and enter the real world. Robustness is important not only for any number of obvious reasons (students will be driving this robot into walls a lot, and I would like it to last longer than a week), but also because I'd like to use this as a platform for embodied evolution (EE) which requires hours and hours of unsupervised robot learning. ROS is an extremely versatile programming environment for teaching robotics - it is simple enough that students can write a module in a matter of minutes, and complex enough to be used in very expensive industrial robot systems. – John Rieffel, CS

> I am interested in seeing a robotic platform designed at Union, for use in both research and teaching. One of my interests is in social robotics. For a robot to be social, it has several basic requirements. First it needs to be able to navigate in human-scale environments. This means that it requires sufficient sensing capability to be able to perform both localization and object avoidance. In turn, this requires a platform capable of controlled maneuvering, and carrying a payload (processing power) that can support the sensing required.
>
> Second, it needs to be a minimum height to promote social interaction, via voice or gesture. Again, to support these requirements, the platform should be able to support an appropriate payload, including microphones, speakers and the necessary processing power. The platform as proposed [our project] is extensible, such that adding components (an extending head, for example) should be possible.
>
> Toward the end of this academic year, I am proposing to develop, in conjunction with upper level students, a toolkit for creating voice interfaces. Ultimately, as a test of such a system, it would be useful to deploy an interface created using this toolkit on a roving platform [our project] capable of navigating the computer science department. This would be a great continuing platform to experiment with both fundamental robotics principles (control, navigation, etc.) and interaction in a unified manner. – Nick Webb, CS

In addition to hardware design, this project involved the creation of the necessary software for complete integration between the robot and existing production-quality robotics software such as Willow Garage's ROS (Robotic Operating System) and Microsoft's MRDS. It was intended to be less expensive than a Pioneer while offering superior mobility and flexibility. In addition, we made the robot accessible to everyone by using only open-source components whenever possible and by publishing the final plans on the Internet for anyone to use and adapt. Doing so allows other users, both at Union and at other schools, the ability to freely use and modify the design to suit their needs.

Design Requirements

Previous researchers have attempted to define the ideal features of an educational robot, with Weiss and Overcast[1] identifying the following criteria as essential: platform flexibility and extensibility, quality and durability of hardware, quality of documentation and teaching resources, availability of sample code, continuing developer activity, total system cost, SDKs available, and the available programming languages. This means that any good educational robot should provide as flexible a platform as possible without compromising cost, durability or ease of use. Especially important is that such a robot must come with the necessary sample code and documentation necessary to effectively teach using the platform, and that development (if possible) should be possible using standard SDKs and programming languages. Moreover, if possible, a robot should provide a high-level interface for development so that students do not spend too much time trying to control low-level hardware operation and instead can focus on high-level operation.

Existing work and the needs of our CS department customers have led to the following requirements:

- The robot must be capable of autonomous indoor navigation and movement, and must be able to easily pass through doorways.
- The robot must be able to use modern high-performance sensors like the Microsoft Kinect[3] in concert with computationally intensive navigation and localization software.
- The robot must have an equivalent level of maneuverability as an adult human (2 degrees of linear freedom, 1 degree of angular freedom, speed of 1.5 m/s)
- Minimal mechanical complexity.
- The robot must be capable of carrying a meaningful payload (~10 kg) and supporting it with the necessary power, data connections, and processing power.
- The robot must be extremely robust; it must be able to survive collisions, protect its electronic equipment from damage, and maintain performance during extended unsupervised operation.
- The robot must provide an accessible software platform that is *both* accessible and powerful, posing limited obstacles to use by novice student users without limiting the capabilities available to more advanced users.
- The robot must be as inexpensive and flexible as possible, using off-the-shelf components whenever possible to limit costs and ease fabrication. In addition, it must be easy to modify without the need of special tools.

Mechanical System

This paper will focus on the mechanical aspects of the final robot design. These systems consist of the Drive System, the side plates, the upper connectors, the frame, the bottom plate, and the bumpers. This paper will cover what each of these sections of the robot needed to accomplish, how they accomplished these goals, and any analysis of the final design, including problems with the design and ways it could be improved.

Frame

The purpose of the frame is to provide a durable, adaptable base for the robot. This base would have to retain structural integrity through all possible accidents the robot would be subjected to, while also allow for the addition of new components as our customers used it for different research projects. It would have to be large enough to hold all of the necessary electronic components while small enough to allow the robot to navigate easily in a human environment.

One inch thick 80/20 extruded T-slotted aluminum in a box configuration provides a durable base for our robot. The box that all the components fit inside is 18” by 18” by 6” tall. This frame is strong enough to ensure that it is one of the last parts of the robot that will fail (we have jumped up and down on it, and it has hardly flexed). In addition, the T-slotted nature allows components to be bolted at any place along its length, ensuring maximum adaptability.

Figure 1: Robot Frame made of 1" thick 80/20

Though additional components can be easily bolted onto frame using ¼-20 machine screws, the nuts must be slotted into the 80/20 from the end. As the ends of many of the pieces of 80/20 in the frame are blocked off, the frame must be partially disassembled (or at least loosened and deformed) in order to bolt new components into some of the places.

Drive System

The drive system of the robot was responsible for fulfilling the overall mobility goals of the robot, as well as be mechanically simple to reduce the maintenance requirements. To reiterate, the Robot was to have a maximum forward speed of greater than 1.5 m/s (a fast walk) and be able to travel in all directions to keep up with a human.

To accomplish these goals, we chose to use a set of 4 Mecanum wheels to drive the Robot, as shown in Figure 1. Mecanum wheels have smaller rollers on their outside face angled at approximately 45 degrees off of the path of the full wheel. This causes the resultant force of the wheel to not be directly forward, allowing a full set of Mecanum wheels to drive a vehicle in every direction and with any rotational velocity depending on the relative angular velocity of each of the individual wheels.

Figure 2: Mecanum Wheel

The drive system of the robot consists of 4 separate motors each directly connected to each of the 4 Mecanum wheels, as shown in Figure X. The motor is held in place by a bracket which is bolted to the extruded aluminum support piece. The output shaft of the Motor is then attached via a setscrew to the flexible shaft coupler. This allows the motor output shaft to be offset slightly from the axle depending on the imperfections of the physical parts. The other side of the shaft coupler is also attached via a setscrew to the axle, a rod of ¼" diameter chrome plated steel. The axle was held in place with bearing pressure-fit into brackets bolted to vertical pieces of extruded aluminum. A metal pin connects the axle to the wheel hub. As shaft coupling is flexable, the axle would normally be allowed shift side-to-side during operation of the robot. This was prevented using ¼" inner diameter PVC piping on the axle as spacer. These can press against the rotating parts of the bearings, meaning the friction they add is negligible.

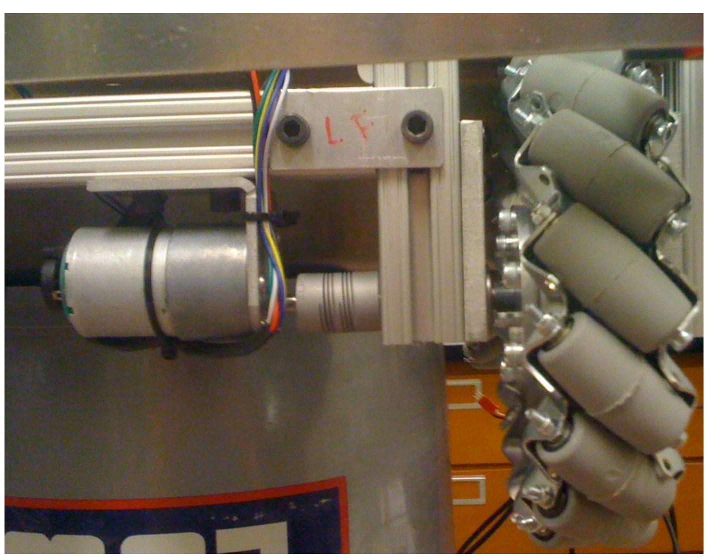


Figure 3: Drive System as Constructed

In its current configuration, all of the robot's mobility goals are met. In the wheels do not deflect side to side, and there is no chance of the wheels locking upon collision with the 80/20 supports, a problem that had cropped up during testing. That being said, there are still lingering alignment problems with the bearing not lining up perfectly. This is caused by imperfections in the cutting of the 80/20 support pieces and the bracketing process, and causes additional friction as the axles rub up against the inside of the 80/20 support pieces. This could be alleviated by drilling out the holes in the 80/20 even more. In addition, in the current configuration the axles stick out past the outside of the robot, providing opportunity for them to catch during a near miss with a short object.

Side Plates:

The purpose of the side plates was to protect to interior electronics of the robot while accommodating for all the necessary switches and the fan. These switches are necessary to turn the robot on and off, while the fan is necessary to provide airflow. These can be seen in Figure 4. In addition, they were to be easily removable to all the interior electronics of the robot to be accessed in case of maintenance.

To do this, we made the side plates out of 1/8" thick aluminum, each with a ¼" hole by each corner. This would allow them to be easily bolted on and removed from the 80/20 frame. In addition, the side plate in the back has several holes in it large enough to implant the switches controlling power of the robot, allowing it to be turned off as necessary. The Power plug, also located in the back, was attached to a separate plate which can be bolted to the back plate. This allows the back plate to be removed without unattaching the power wires.

Figure 4: Back Plate, showing Fan, Power plug, and switches.

While the back plate can be easily unbolted from the frame, the wires connecting the fan and switches to the back plate cannot be so easily undone. This makes removing the back plate from the robot a laborious process. Also, the aluminum used to protect the robot is probably stronger and

heavier than necessary. The performance of the robot could be improved slightly be replacing the material used with a plastic.

Upper Connectors:

The purpose of the Upper Connectors is to allow the AER to be adapted to whatever application it needs to be used for. This allows the robot to function in a multitude of settings and ensure that it will continue to be useful to our customers (the Computer Science Department) in the years to come.

To allow the largest variety of components to be attached to the top of the robot we installed a 1/8” aluminum plate on the top of the robot with evenly spaced ¼” holes covering the entire surface. This would maximize the number of options our customers would have when trying to attach additional components, as they could bolt everything necessary to these holes. This plate can easily be removed to while attaching add-ons to it, allowing work to be done without moving the entire robot.

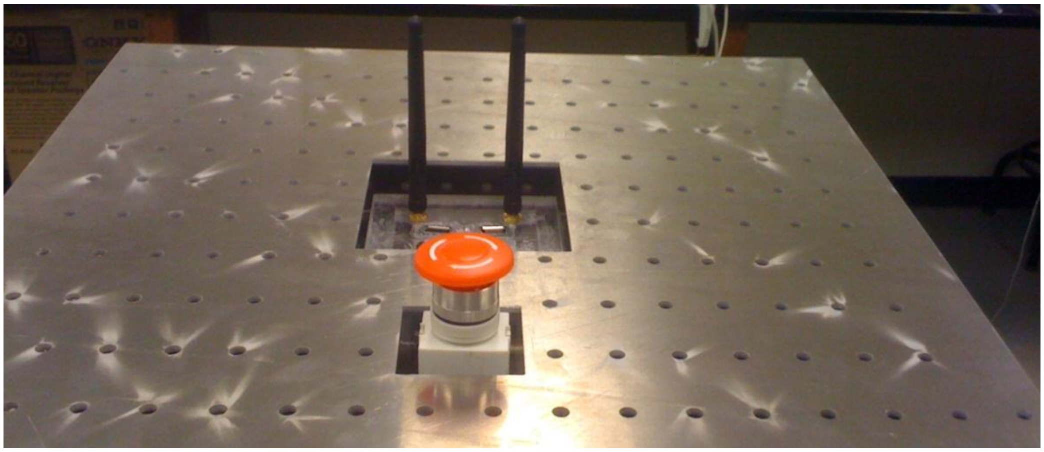


Figure 5: Top Plate, with Emergency Stop

In addition to providing hardpoints for additional components, we needed to provide power and a link to the computer as well. This would make it possible for our customers to easily plug their components into the top of the robot without having to wire them into the already complex electrical system. To do this we included 4 separate connectors (one power, 2 USB, and one Kinect) easily accessible on an acrylic panel recessed below the top plate. This panel was bolted to a sheet of acrylic blocking access to the robot from above. This acrylic served both to anchor the connector panel and to protect the electronics from debris (or water) falling through the holes in the top plate.

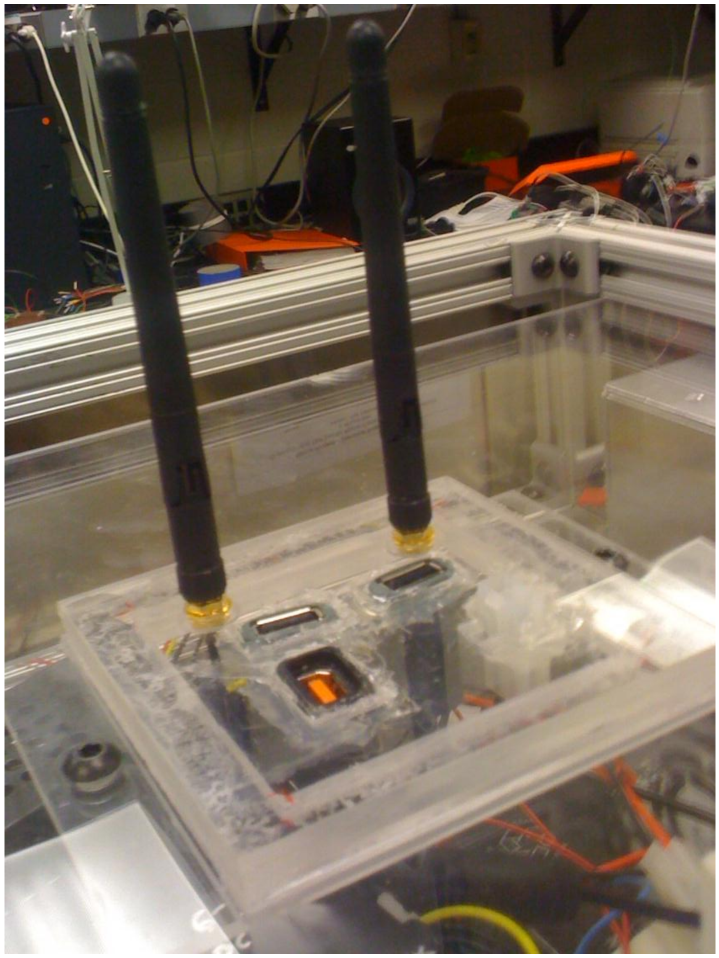


Figure 6: Electronic Connectors on the Top of the Robot

One problem with the ease of use of this configuration is that none of the holes on the top plate are threaded, which was impractical give their excessive quantity. This, coupled with the acrylic plate below it, means that it is impossible to bolt anything to the top plate without removing it. This can make it difficult to quickly add and remove components while the working with the robot. This could be circumvented by threading some of the hole, or by adding raised brackets that the additional components could be bolted to without removing the top plate.

Bottom Plate

The batteries are the largest and heaviest single part of the robot, together, they make up around 30-40% of the total mass of the robot. In order to ensure that the robot be as stable as possible, the center of mass would have to be as low as possible, which meant placing the batteries below the level of the bottom of the robot. This would ensure that they could be easily removed and prevent the robot from tipping over in the event that one of the components added by the Computer Science Department is tall and top-heavy.

We accomplished this by building the bottom plate of the robot out of 1/8" aluminum but folded downwards to form a channel that the batteries could rest in. was bolted in multiple places to the frame of the robot, ensuring that it was securely connected and would not fall off. In addition, the channels allow the batteries to be slid out and examined without needing to disassemble any other part of the robot. We put down a layer of foam to prevent the batteries from sliding around while the robot is in motion.

One problem with this configuration is that the batteries are completely exposed, as are the connectors that allow them to power the rest of the robot. The wires could get snagged on something, which could unattach one of the batteries, reducing the power available to the robot. In addition, the plate is a large and thus is difficult to bend. If this robot was to be produced on a larger scale, or anywhere with a less capable machine shop, it might be necessary to redesign this component for easier manufacturing.

Bumpers

The purpose of the pumpers is to provide a cushion for the robot in the event of a collision. As the robot could travel in all directions, there would have to be bumpers on all sides of the robot. In addition, the bumpers would have to include sensors that would inform the robot if it had collided with something, letting it know when it collides with something outside of the field of view of its sensor.

We created these bumpers out of bent 1/8" aluminum. The bumper brackets, one in each corner of the robot, were bolted to the 80/20 of the frame. Each bracket had two touch sensors bolted to it, with each sensor angled 90 degrees off of the other. Pieces of Velcro are glued to each lf the sensors, which can wrap around the plates of aluminum used as the bumpers. Thus, whenever the robot collides with anything, a sensor is tripped regardless of the angle that the collision came from. The Velcro allows the bumpers to be easily removed and, in the event that they catch on something while the robot is in motion, no permanent damage will happen as the bumper gets pulled off the robot.

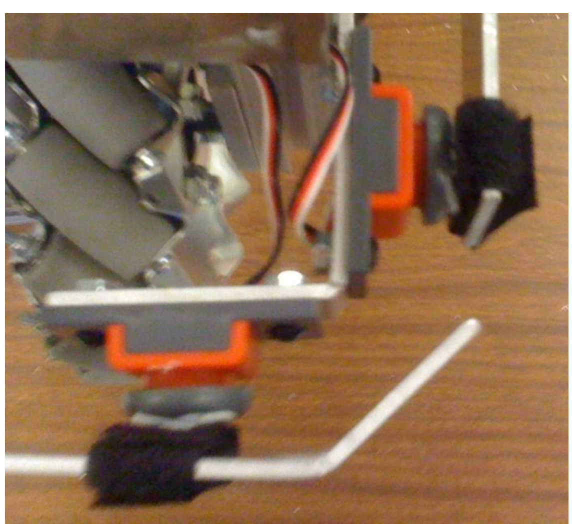


Figure 7: Bumper Configuration

Conclusion

In conclusion, the Drive System, Side Plates, Upper Connections, Frame, Bottom Plate, and Bumpers come together to form a durable, reliable, and adaptable body for the robot. These, combined with the electronic components of the robot, allow it to function as intended. It can travel at speed in excess of 1.5 m/s, and can move in all directions while maintaining the same heading. It has a dedicated port for a Microsoft Kinect, allowing it to sense its environment at a level beyond that of similar robots. It is durable, and has survived numerous collisions with solid surfaces without skipping a beat. In addition, the ROS drivers allow it to be easily controlled using ROS or a simple USB game controller. In addition, the total cost of the robot came out to around $3,000, making it cheaper than the current commercial robot in its size category. Overall, this project was a success.

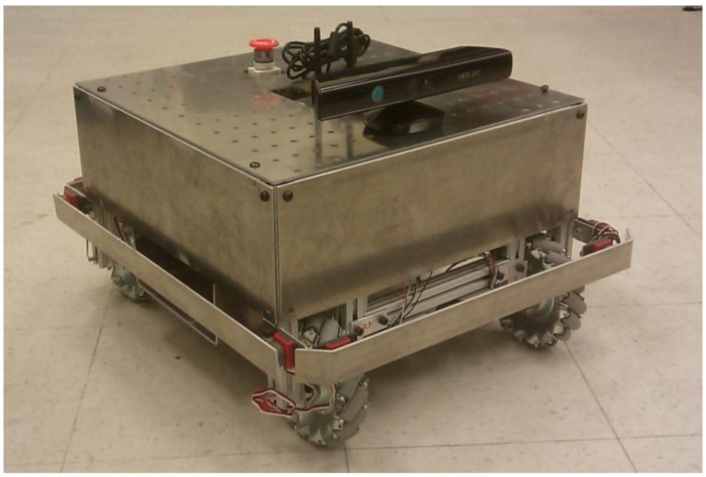


Figure 8: Final Product

Future Work

Though the project was a success, there is still more to accomplish. One of the current ongoing problems that relates to the performance of the robot is wheel slip. Wheel slip is when one or more of the wheels loses traction with the ground, causing it to spin without affecting the total motion of the robot. This results in a loss of accurate control of the robot by its control system until the wheel regains the necessary traction. The current configuration of the robot is capable of detecting wheel slip but is unable to do anything about it. This problem usually occurs when the robot is traversing uneven ground, particularly when passing over a threshold. Future work on the robot could be designing a system to reduce wheel slip.

One way that this could be done would be to incorporate suspension into the drive system. This would press the wheels against the ground even when inconsistencies in the floor surface would normally raise one wheel higher than the others. In addition, this would reduce the vibrations experienced by the robot during operation, lowering the chance of vibration damaging one of the other components.

References

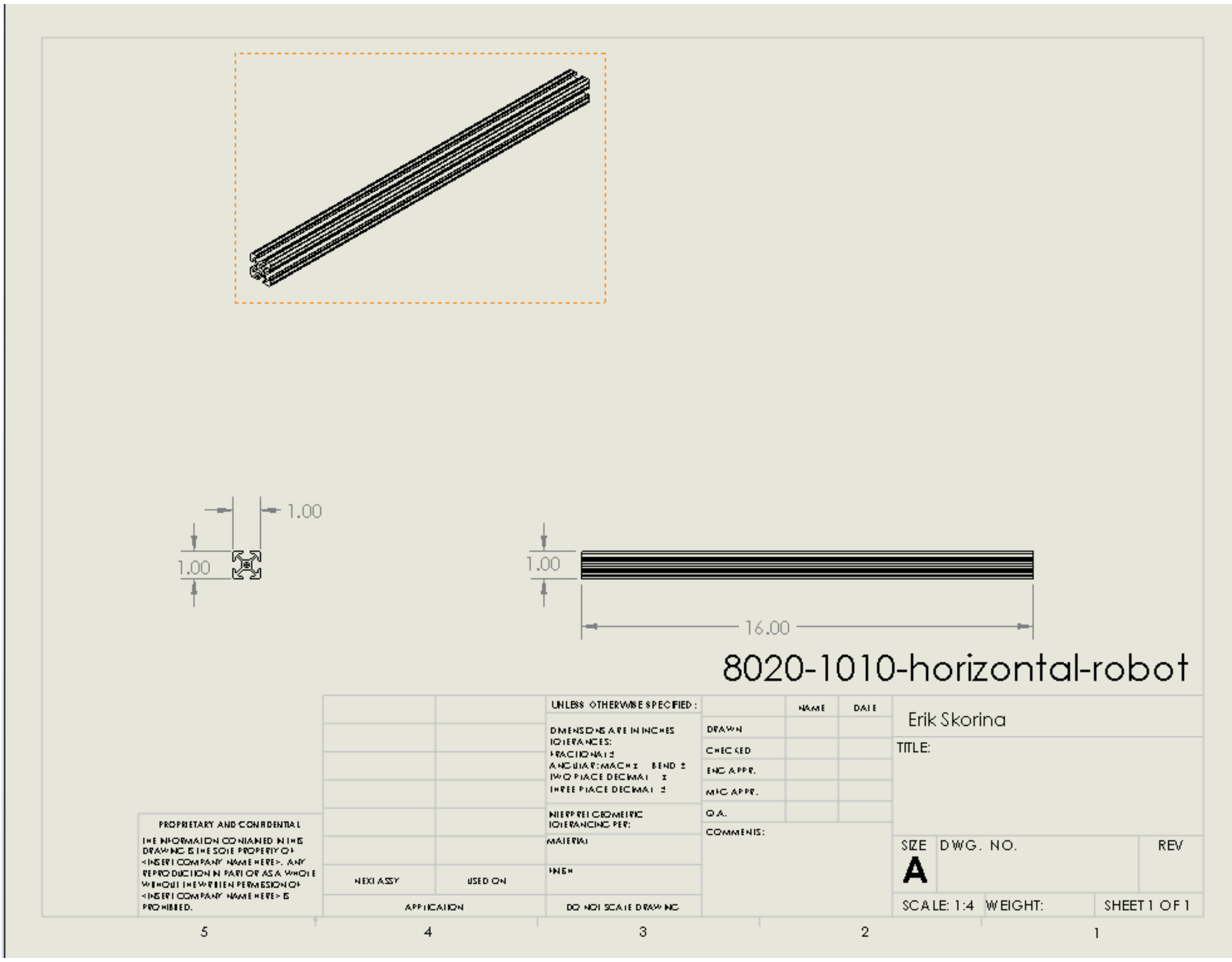
1. Richard Weiss and Isaac Overcast. 2008. Finding your bot-mate: criteria for evaluating robot kits for use in undergraduate computer science education. J. Comput. Small Coll. 24, 2 (December 2008), 43-49.
2. Anne-Marie Eubanks, Robert G. Strader, and Deborah L. Dunn. 2011. A comparison of compact robotics platforms for model teaching. J. Comput. Small Coll. 26, 4 (April 2011), 35-40.
3. http://www.microsoft.com/en-us/kinectforwindows/, Microsoft Corporation

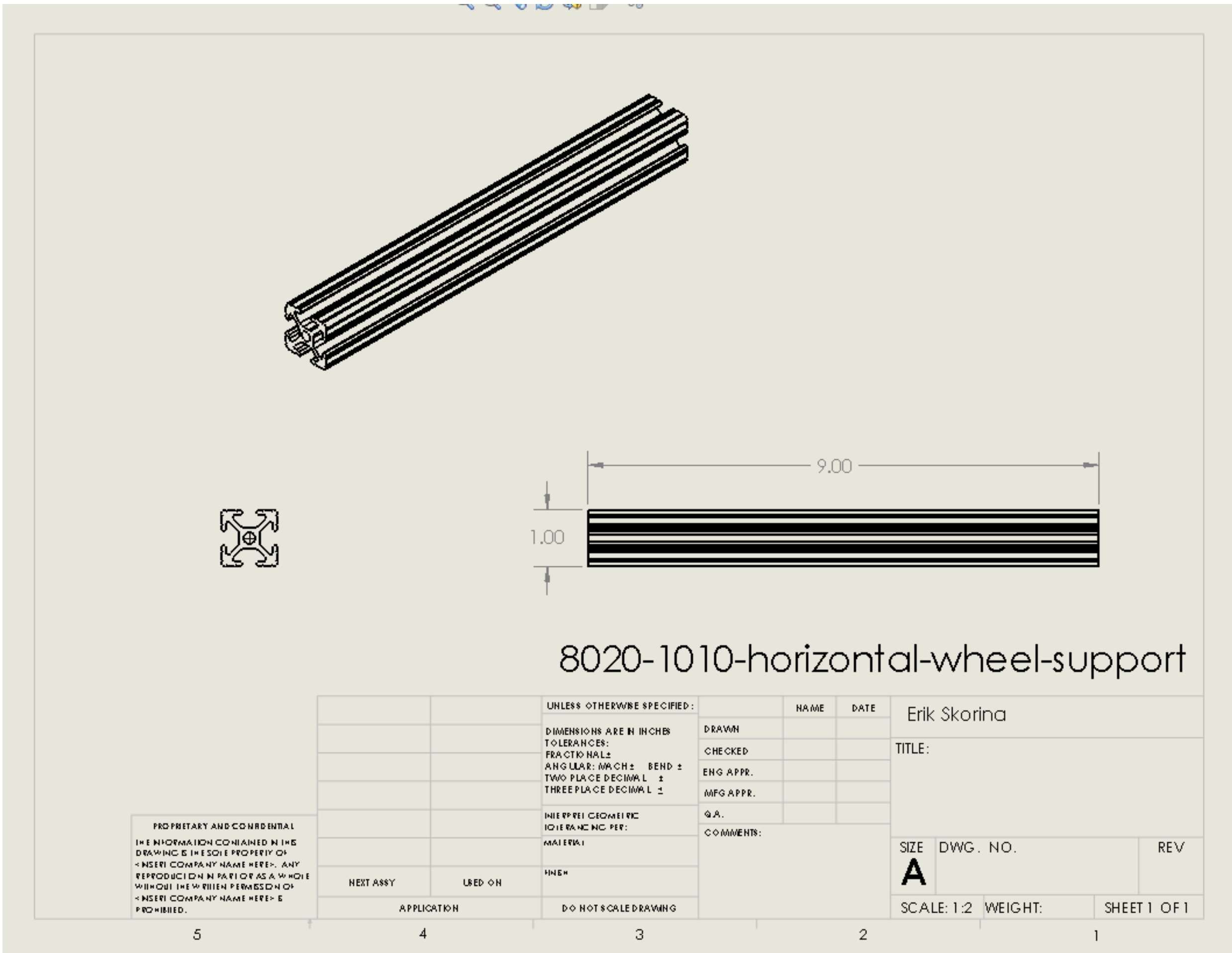
Mechanical Component List			
Item	**Description**	**Material/Part**	**Quantity**
Top Plate	18” by 18” plate with holes every inch to mount necessary attachments	1/8” Aluminum	1
Bottom Plate	18” by 18” plate that supports the electrical components	1/8” Aluminum	1
Side Plate	18” by 6” plate that protects on each of the robot’s 4 sides to protect the electronic components	1/8” Aluminum	4
Horizontal Body Support	16” beam that serves as the horizontal part of the body of the robot	10s 80/20 Extruded Aluminum	8
Vertical Body Support	10” beam that serves as the horizontal part of the body of the robot. Contains a hole on the bottom to let the Axle through	10s 80/20 Extruded Aluminum	4
Vertical Wheel Support	4” beam that supports the other side of each axle. Contains a hole to let the Axle through.	10s 80/20 Extruded Aluminum	4
Horizontal Wheel Support	9” beam that connects the two Vertical Wheel Supports and supports the two Motors on each side.	10s 80/20 Extruded Aluminum	2
Motor	Pololu Gearmotor that drives each wheel.	Pololu 37D mm Metal Gearmotor 67:1	4
Motor Bracket	Bended Aluminum that supports Motor and is bolted to Motor Support	1/8” Aluminum	4

Motor Bracket Support	Plate that is bolted to both Horizontal Wheel Support and Motor bracket.	1/4” Aluminum	4
Axle Coupling	Connects the Output shaft of the motor to the Axle. Allows for imperfections and fluctuations in the alignment of the two shafts	Helical Beam Shaft Couplings McMaster-Carr Item # 9861T529	4
Axle	5” shaft that is connected to the Hub and connects it to motor	McMaster-Carr Chrome-Plated Steel Shaft 1/4" OD	4
Hub	Connects the Axles to the Wheels	AndyMark 250 Hub	4
Wheel	Mecanum wheel that can drive the robot in any direction desired, and allows it to turn in place.	AndyMark 6" Mecanum Wheel	4
Bearing	Allows the Axle to rotate with minimum of friction.	McMaster-Carr Flanged Double Sealed for 1/4" ID 6384K342	8
Bearing Support	1” by 2” plate that supports the Bearing and connects it to the vertical supports	3/16” Aluminum	8
Support Bracket	1” by 2” plate that connects the Wheel support pieces to each other and to the frame of the robot	1/8” Aluminum	8
Body Bracket	Pre-Fabricated Corner Bracket used to bolt the body of the robot together	Drillspot Inside Corner Bracket, 2 Hole, For 10S	24
Nuts and Bolts	T-Nut and Screw compatible with 80/20 used to connect every bracket and plate to the 80/20 beams	Drillspot BHSCS & T-Nut, For 10s	As Needed
Bumper Support Bracket	6” by 1” bent aluminum bracket that the bumper sensors are bolted to, securing them and offsetting the front and rear bumpers from the body of the robot	1/8” Aluminum	4
Bumper	21.9” by 1.5” bent aluminum bumper to protect the robot from collisions coming from the front and back.	1/8” Aluminum	2
Side Bumper	20” by 1.5 “ plate to protect the robot from collisions on either side	1/8” Aluminum	2

Touch Sensor	Attached to the bumper to allow the robot to tell if it has collided with something	Sparkfun touch Sensor	8
Velcro	1.5” strip of two sided Velcro to the bumper sensors and used to attach the bumpers to the bumper sensors.	Velcro	16
Top Acrylic Plate	14” by 16” sheet of acrylic with a 4.25” by 4.25” hole in the center to protect the electronic components from objects falling through the top plate	1/8” Acrylic	1
Bottom Acrylic Plate	14” by 16” sheet of acrylic to keep the electronic components isolated from the conductive aluminum	1/8” Acrylic	1
Top Wire Mount	4” by 4” sheet with holes for the 4 plugins and the two wireless antennas. Fits on top, allowing the antennas to be easily screwed into the holes.	1/8” Acrylic	1
Lower Wire Mount	4” by 4” sheet with holes for the 4 plugins and two wireless antennas. Fits below the Top Wire Mount, gives more space for the lower parts of the antennas.	1/8” Acrylic	2
Wire Mount Big Hole	4” by 4” sheet with single 3” by 3” hole in the center. Allows wires from 4 plugins and two antennas to dangle down to the rest of the interior.	1/8” Acrylic	1
Bottom Wire Mount	5.5” by 4” sheet with single 3” by 3” hole in the center. Allows the wire mount column to be bolted to the underside of the Top Acrylic Plate.	1/8” Acrylic	1

Frame Components





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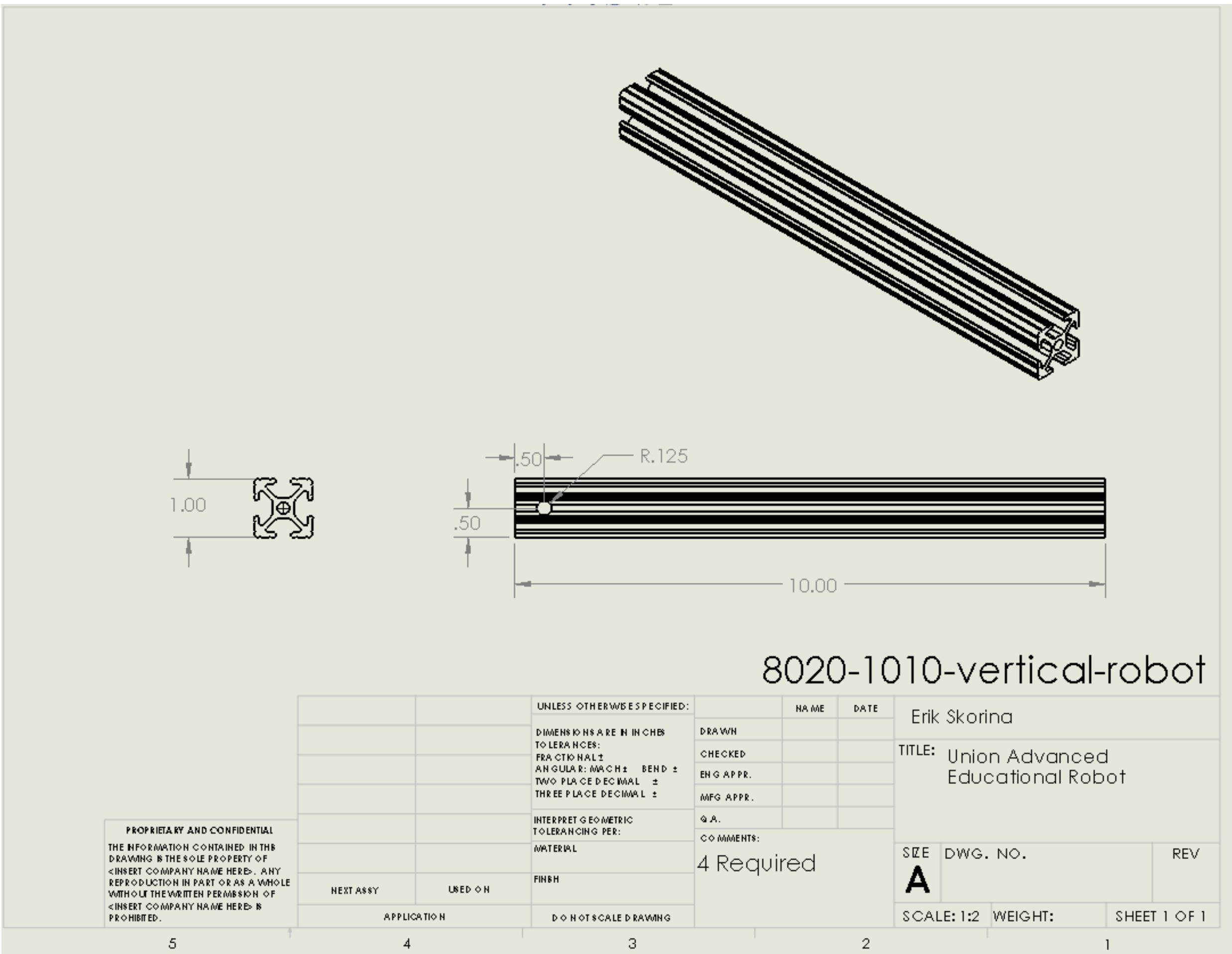

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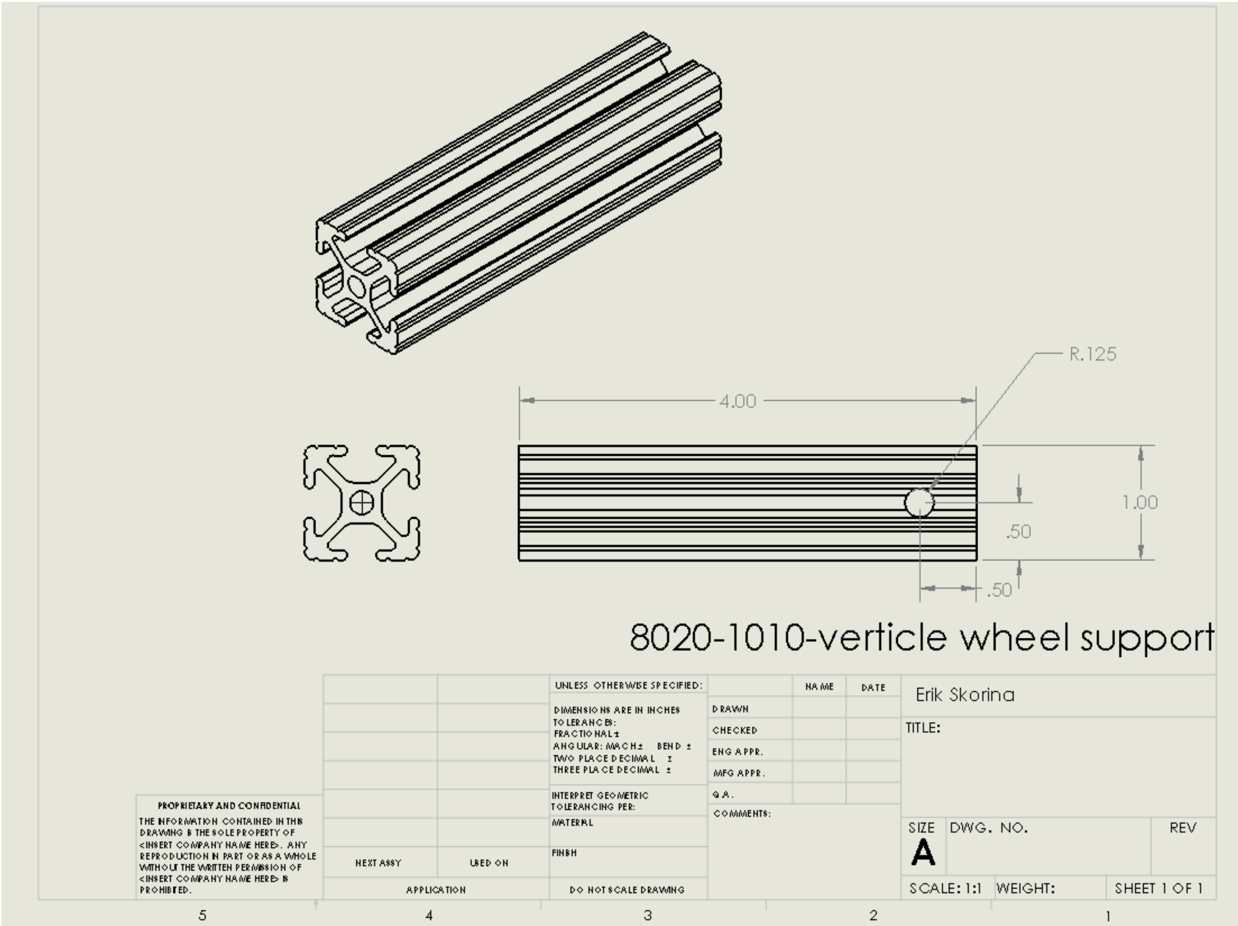
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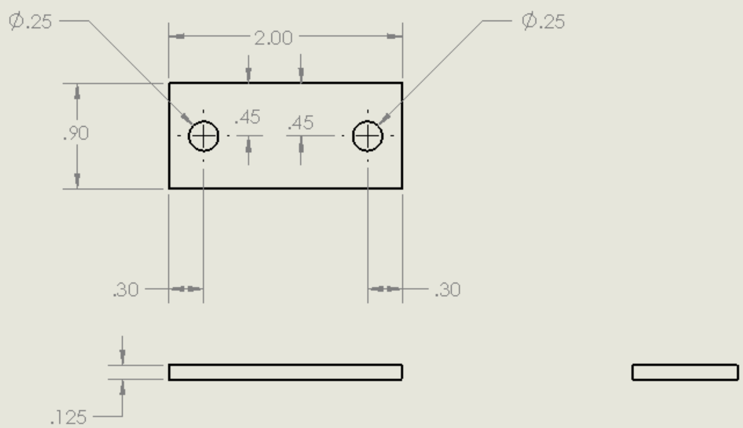

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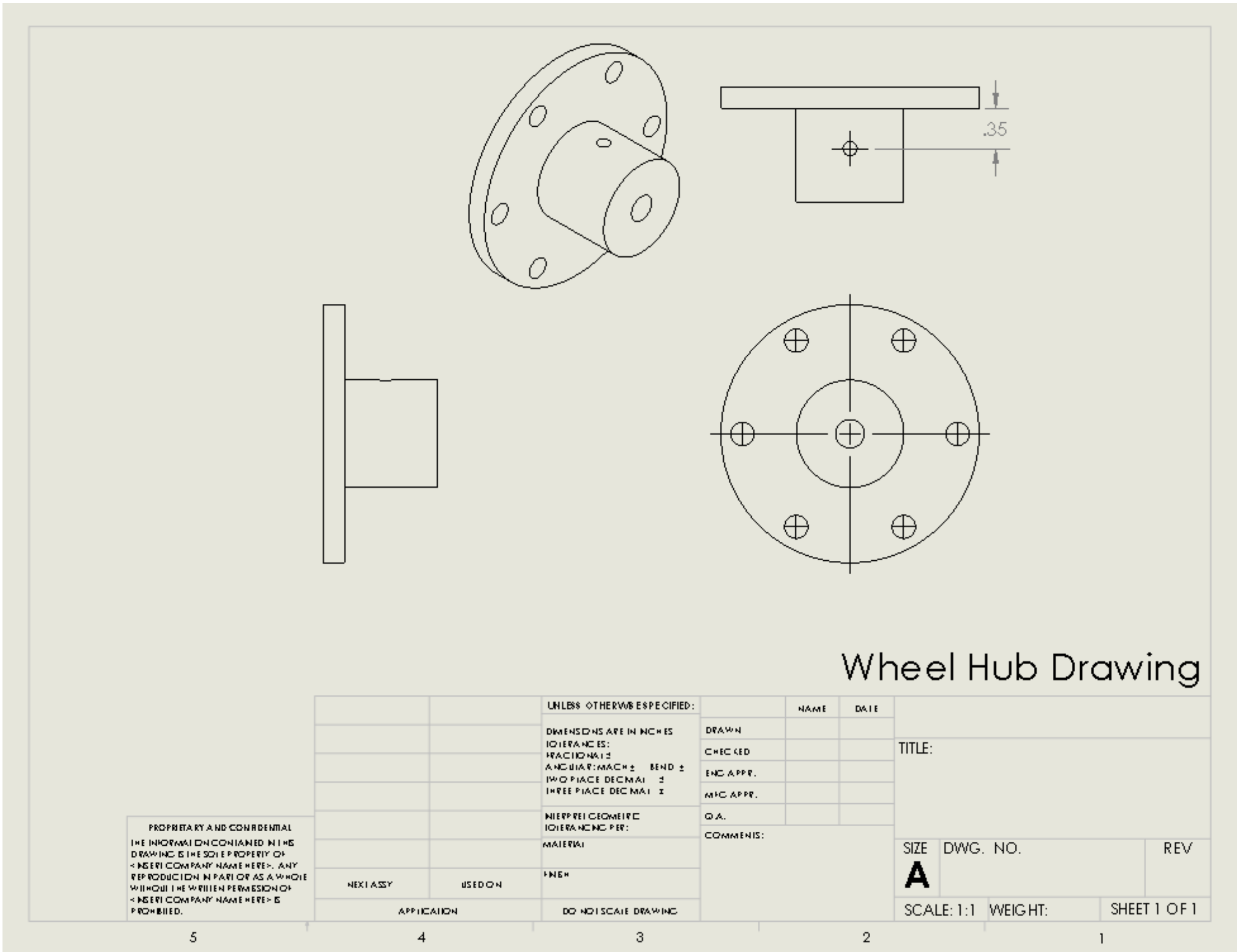
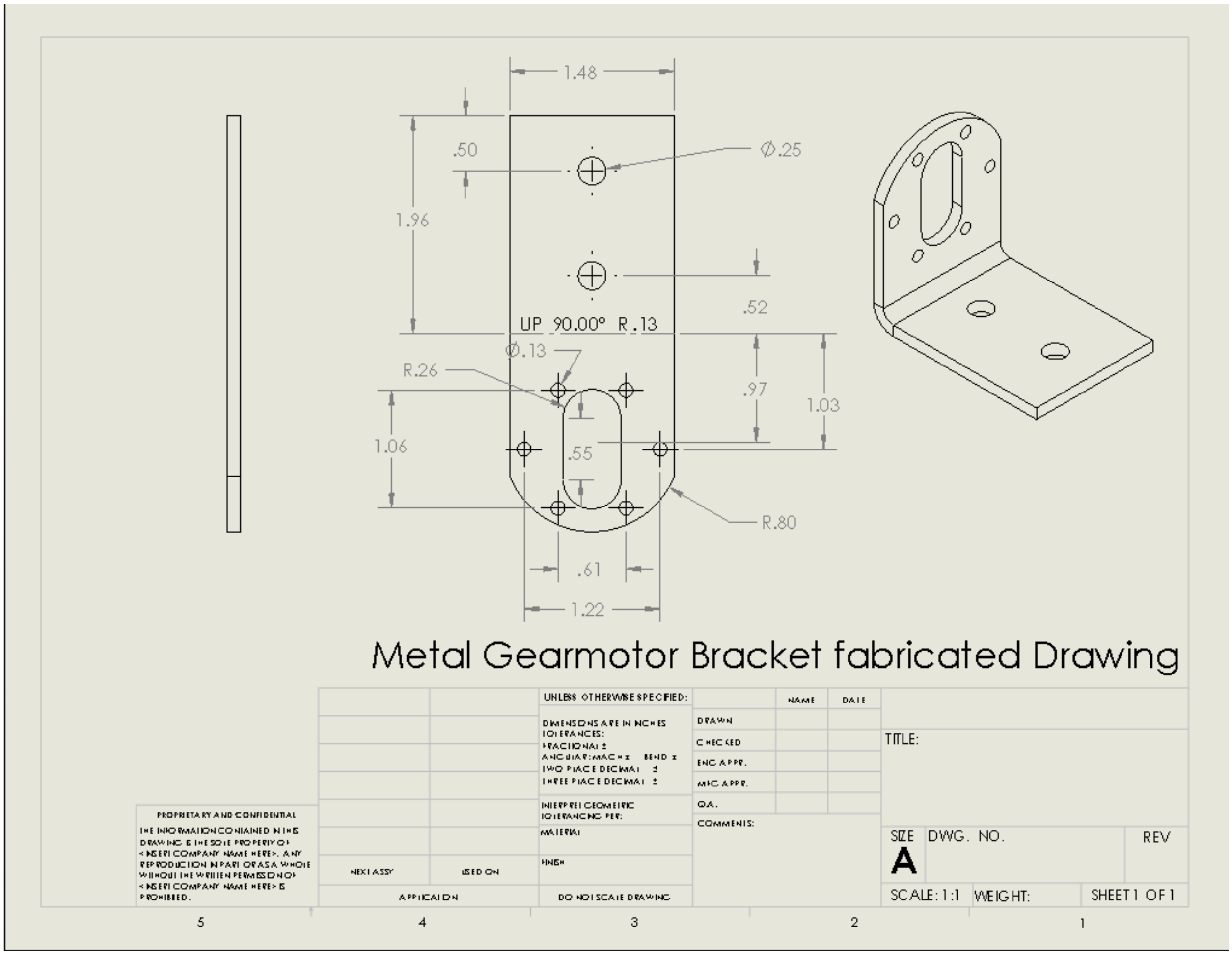
Drive System Components

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Ø.25
1.96
.52
UP 90.00° R.13
Ø.13
R.26
.97
1.03
1.06
.55
R.80
.61
1.22
Metal Gearmotor Bracket fabricated Drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
TITLE:
SIZE
A
DWG. NO.
REV
PROPRIETARY AND CONFIDENTIAL
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NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
5
4
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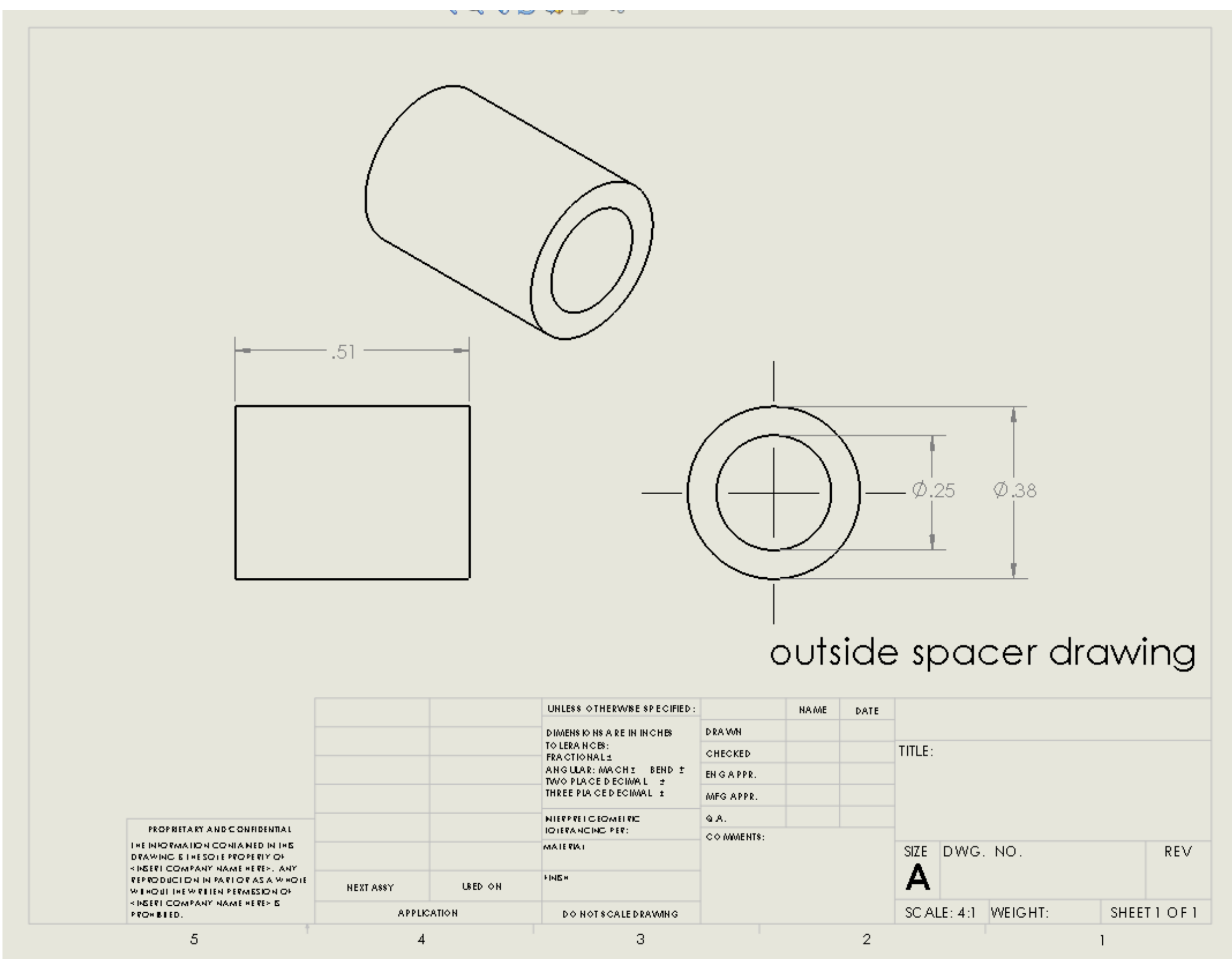

.51
Ø.25
Ø.38
outside spacer drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
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MFG APPR.
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NEXT ASSY
USED ON
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DWG. NO.
REV
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WEIGHT:
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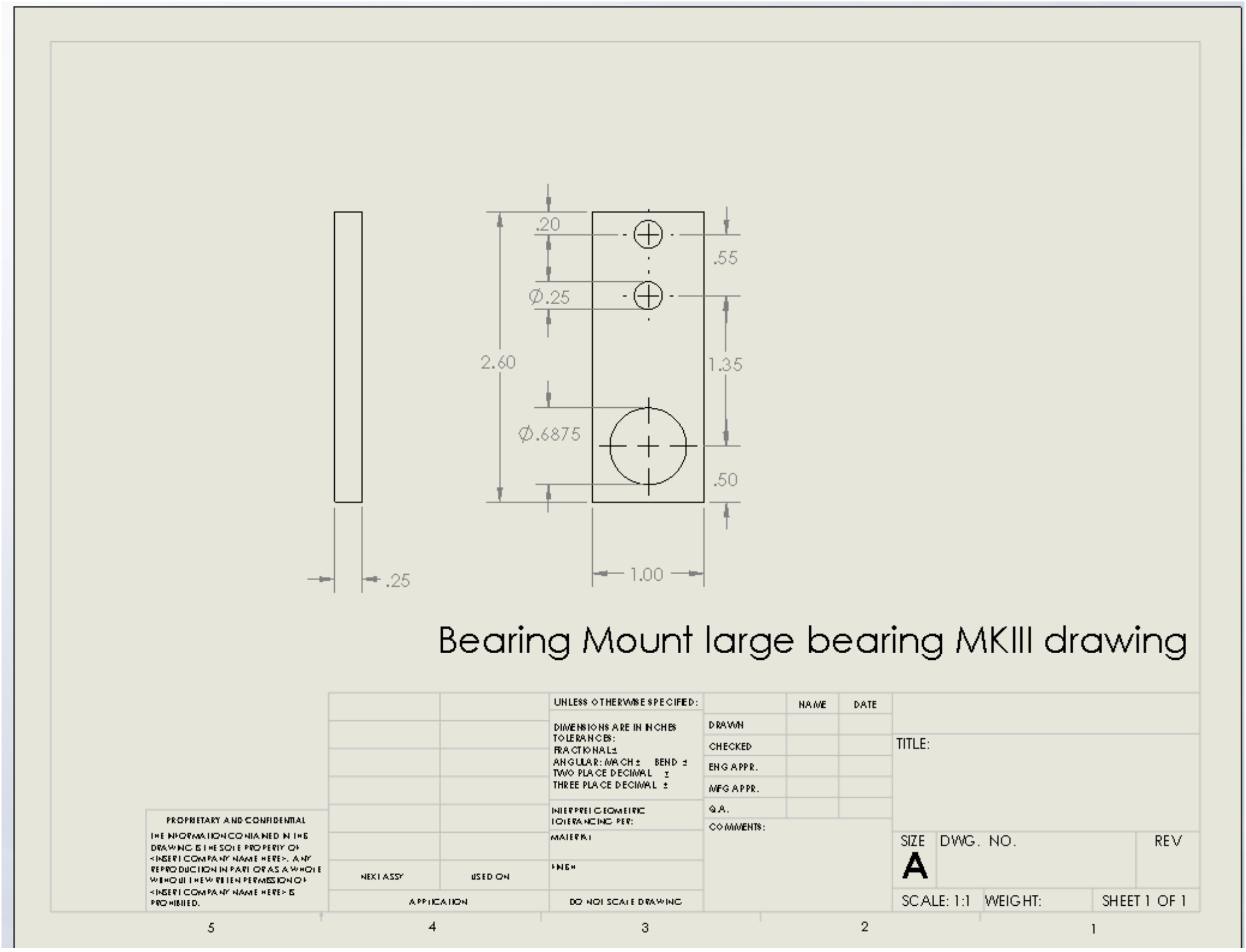
.20
.55
Ø.25
2.60
1.35
Ø.6875
.50
.25
1.00
Bearing Mount large bearing MKIII drawing
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
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DO NOT SCALE DRAWING
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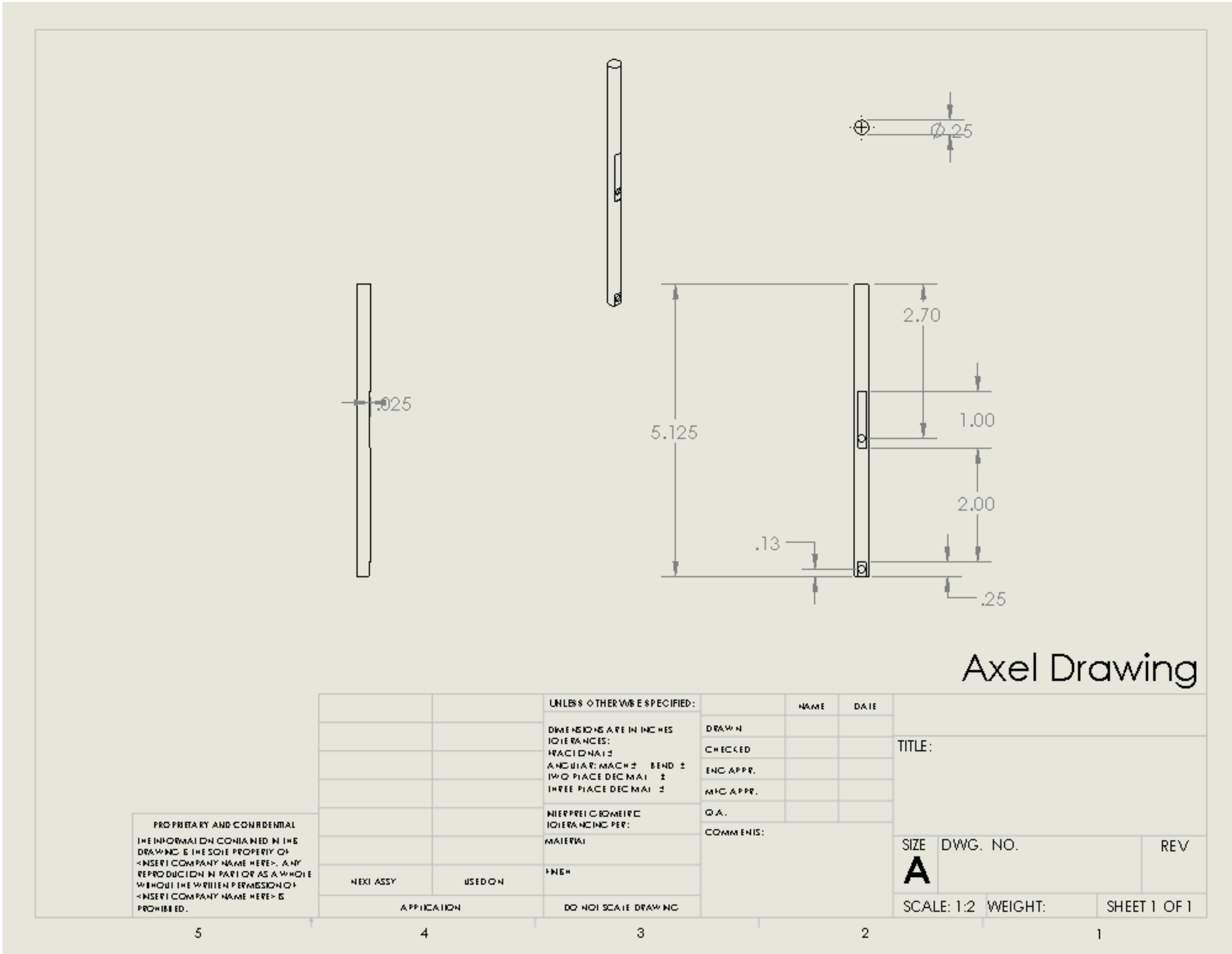
Ø.25
2.70
.025
5.125
1.00
2.00
.13
.25
Axel Drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
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MFG APPR.
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COMMENTS:
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NEXT ASSY
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APPLICATION
DO NOT SCALE DRAWING
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SHEET 1 OF 1
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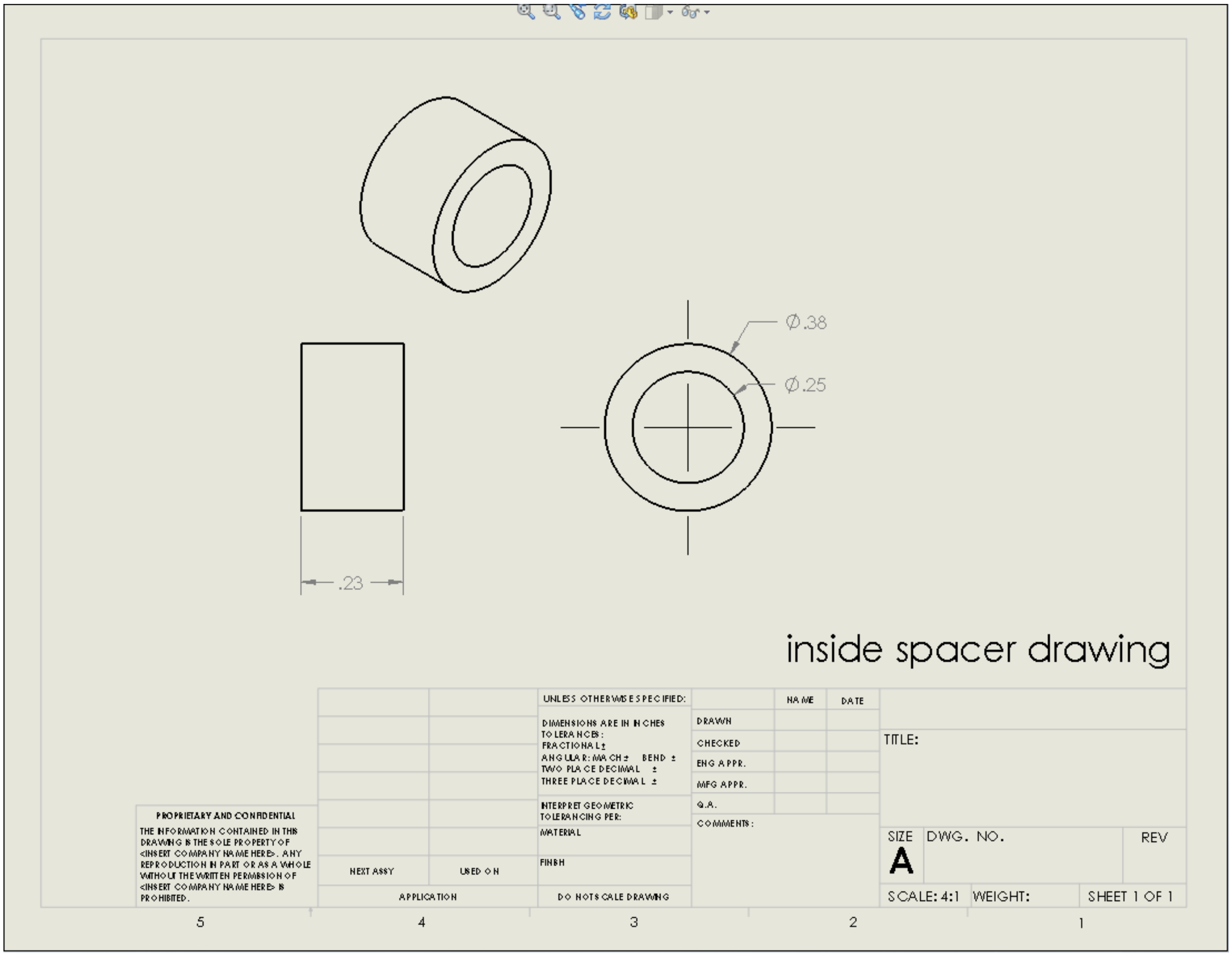
Ø.38
Ø.25
.23
inside spacer drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
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NEXT ASSY
USED ON
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DO NOT SCALE DRAWING
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SIZE
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REV
SCALE: 4:1
WEIGHT:
SHEET 1 OF 1
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4
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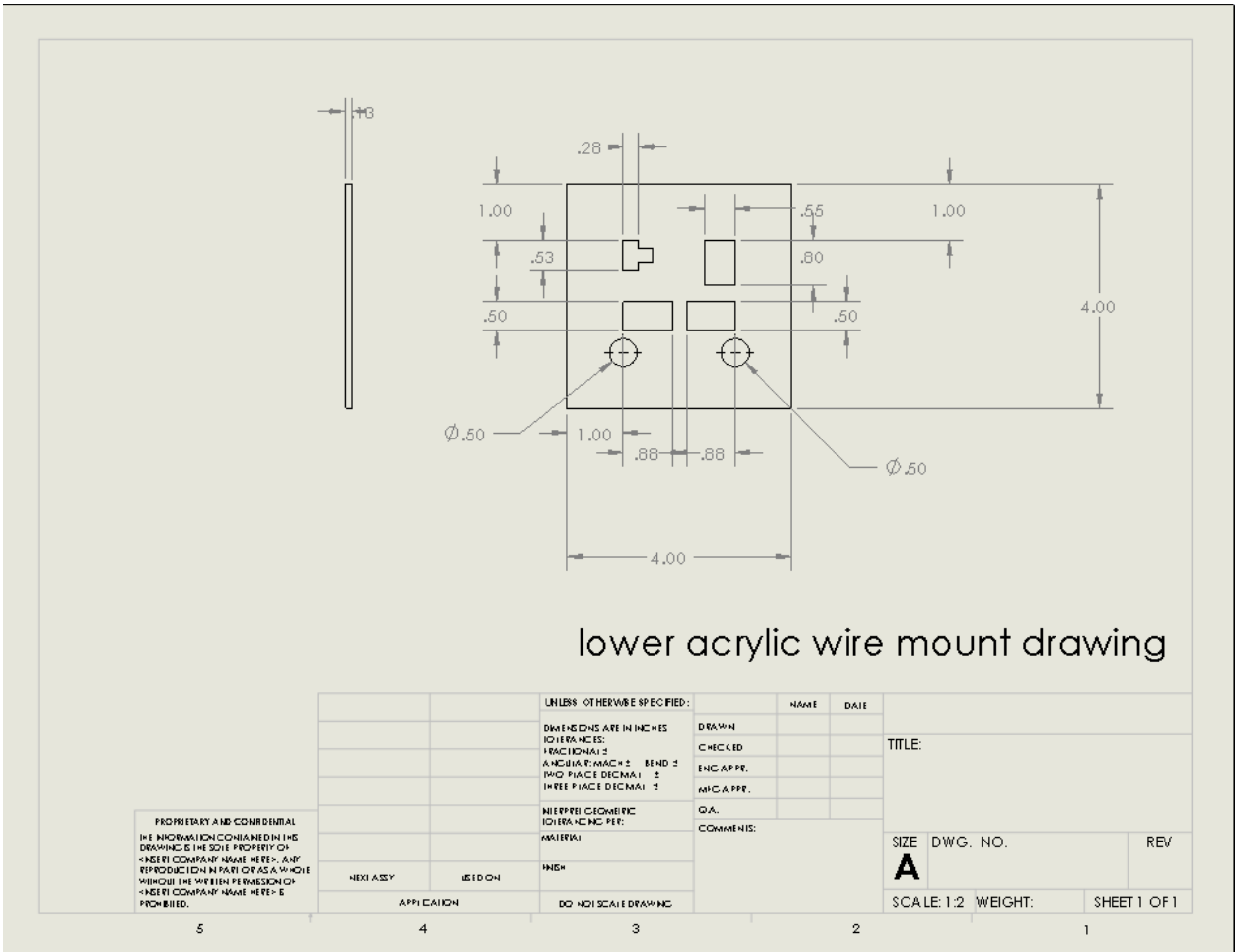
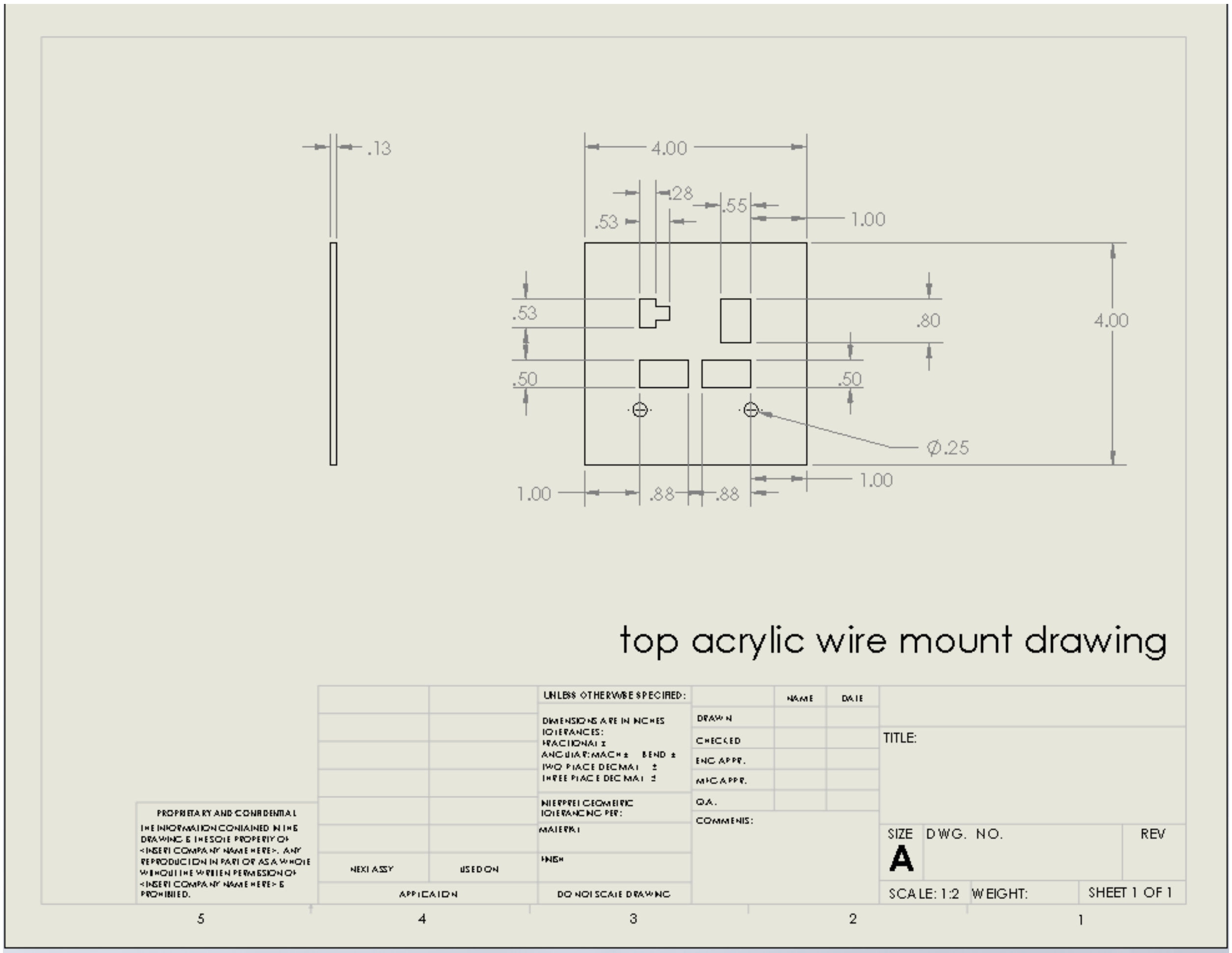
2
1

Upper Connectors Components




.13
4.00
.28
.55
.53
1.00
.53
.80
4.00
.50
.50
Ø.25
1.00
.88
.88
1.00
top acrylic wire mount drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
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DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
NEXT ASSY
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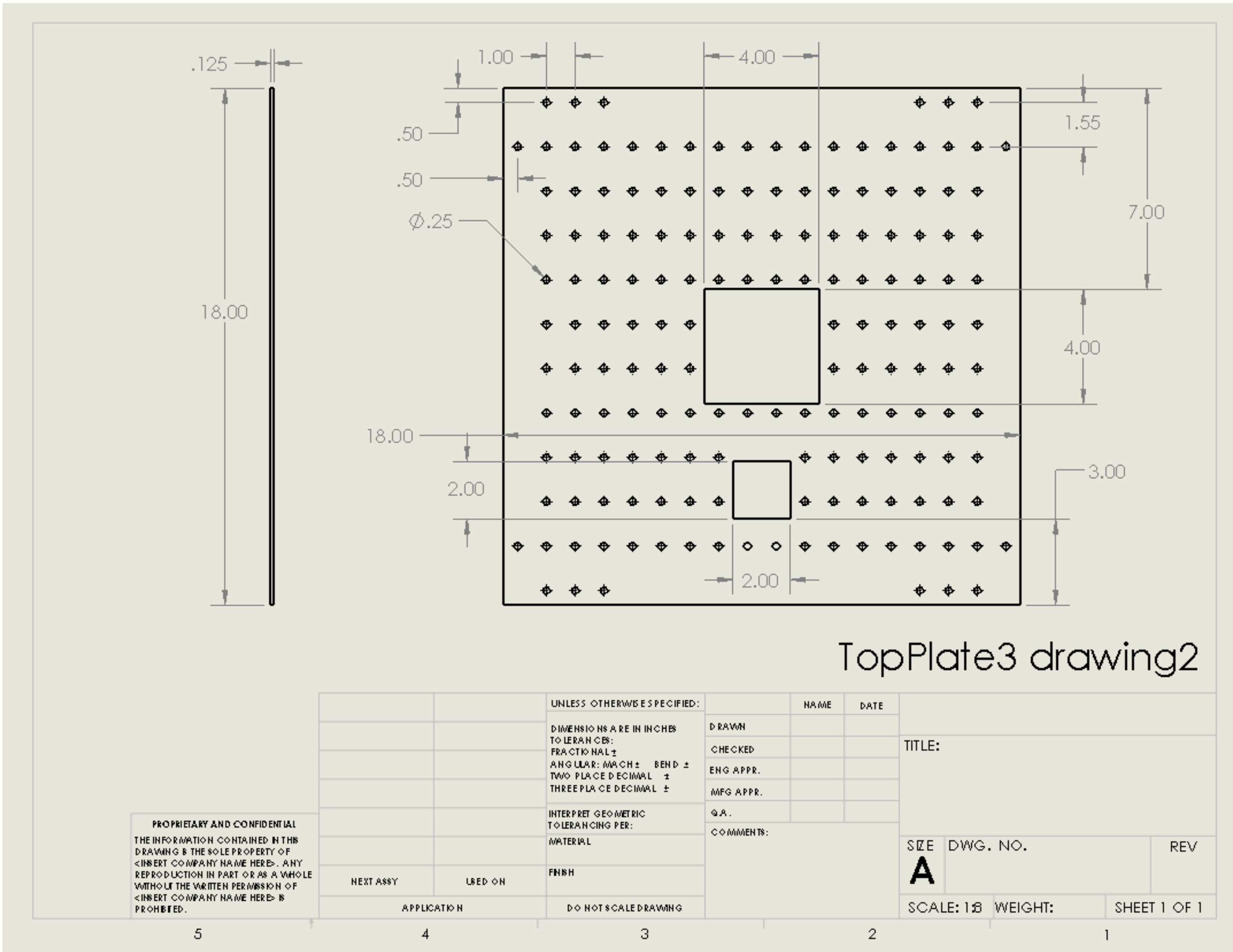

.125
18.00
1.00
4.00
.50
.50
⌀.25
1.55
7.00
4.00
18.00
2.00
3.00
2.00
TopPlate3 drawing2
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NEXT ASSY
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NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
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COMMENTS:
TITLE:
SIZE
A
DWG. NO.
REV
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1
PROPRIETARY AND CONFIDENTIAL
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5
4
3
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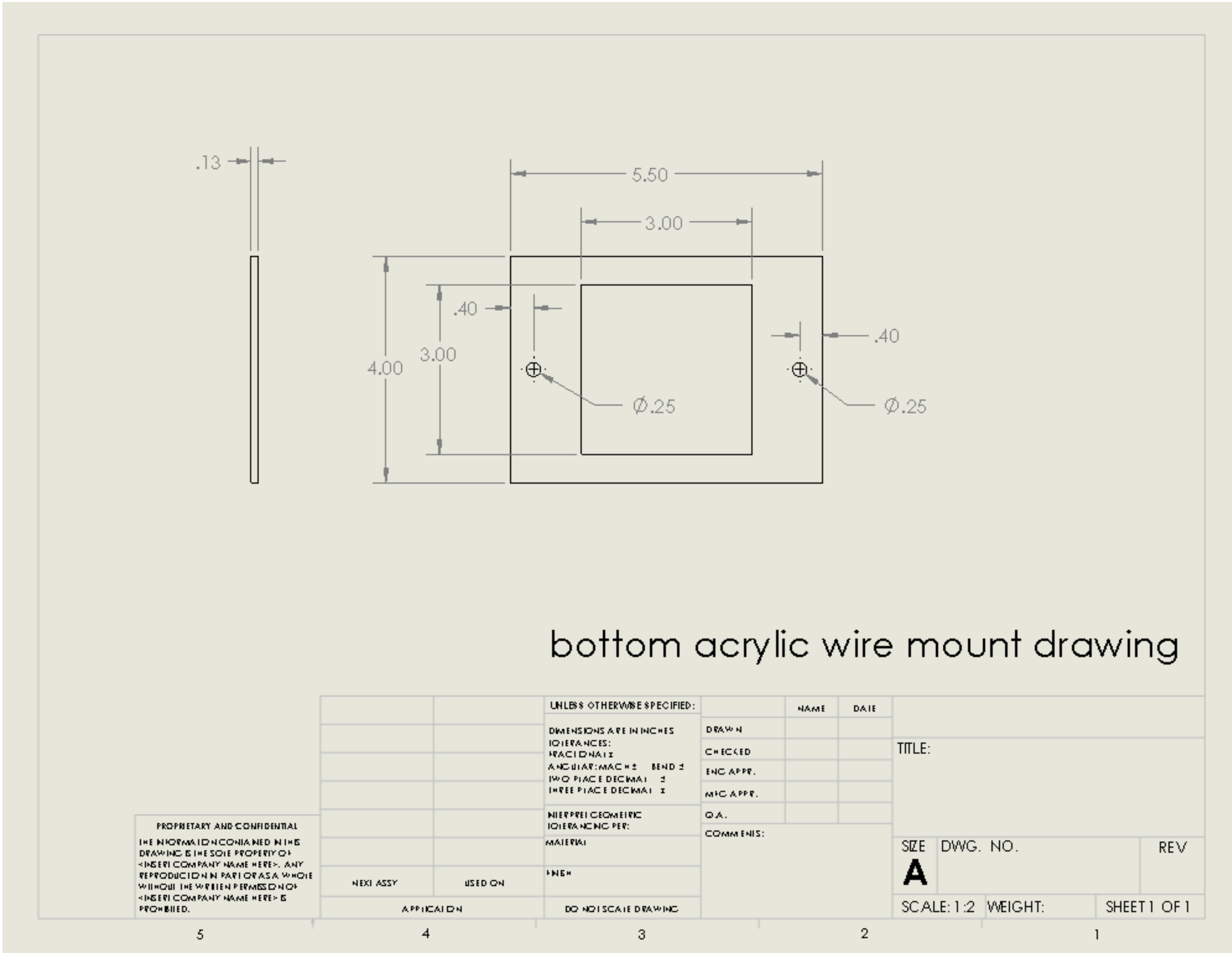
1


.13
5.50
3.00
.40
3.00
4.00
.40
Ø.25
Ø.25
bottom acrylic wire mount drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
NEXT ASSY
USED ON
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DO NOT SCALE DRAWING
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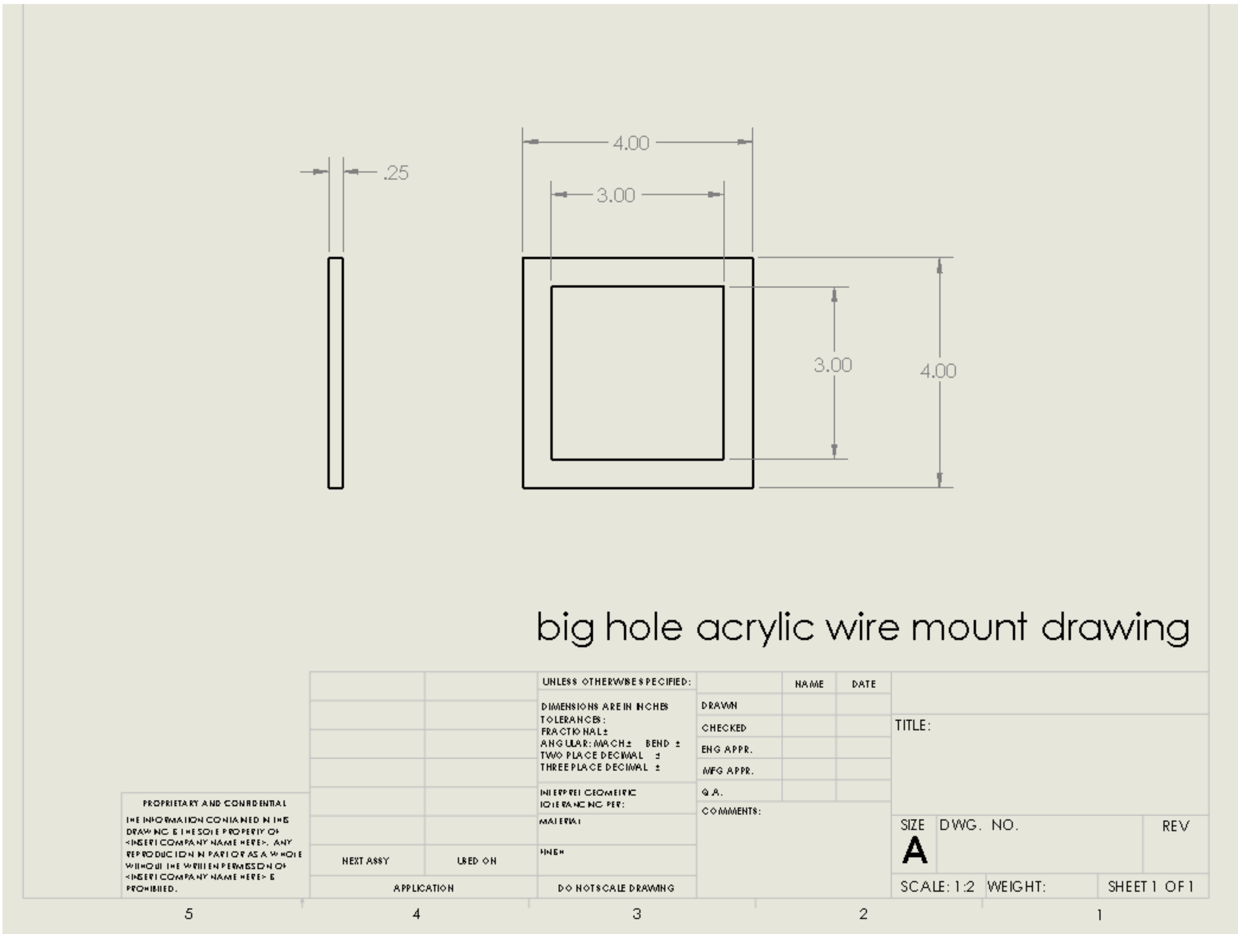

.25
4.00
3.00
3.00
4.00
big hole acrylic wire mount drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
PROPRIETARY AND CONFIDENTIAL
NEXT ASSY
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APPLICATION
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WEIGHT:
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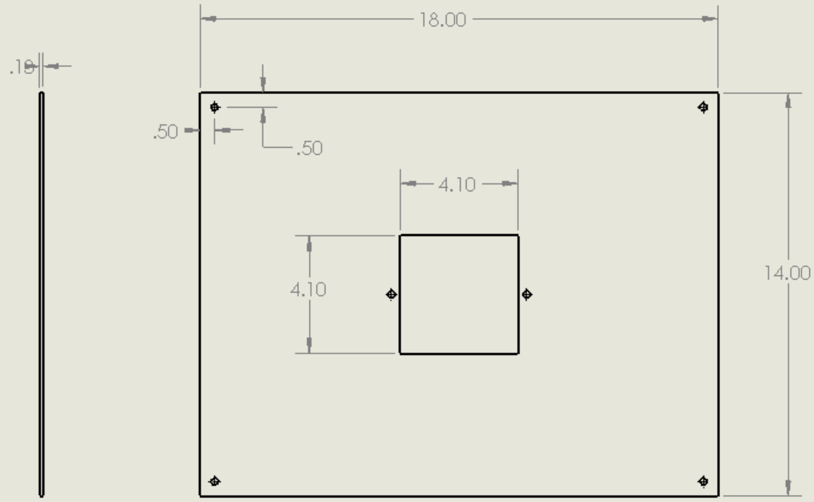

lower top plate acrylic 3 drawing

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
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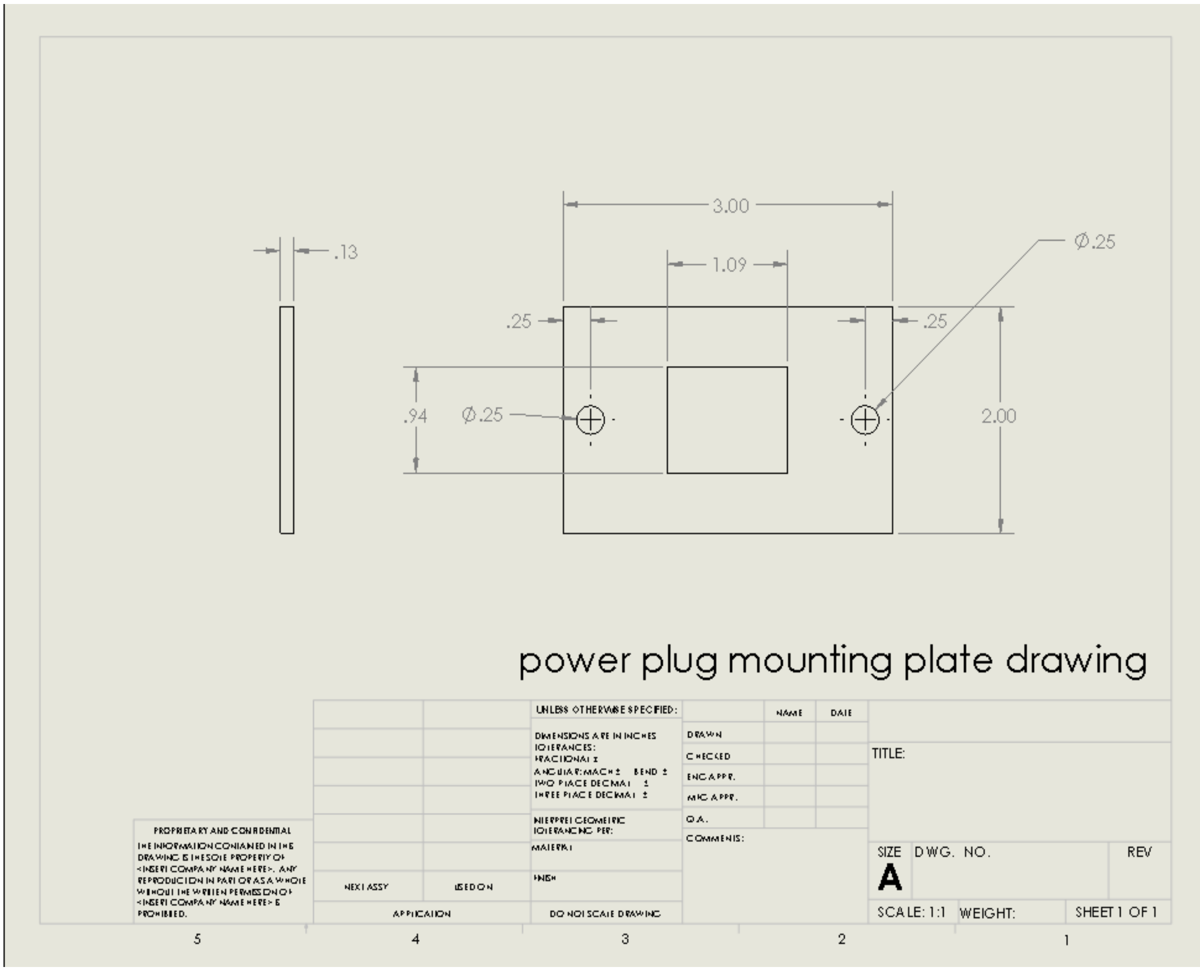
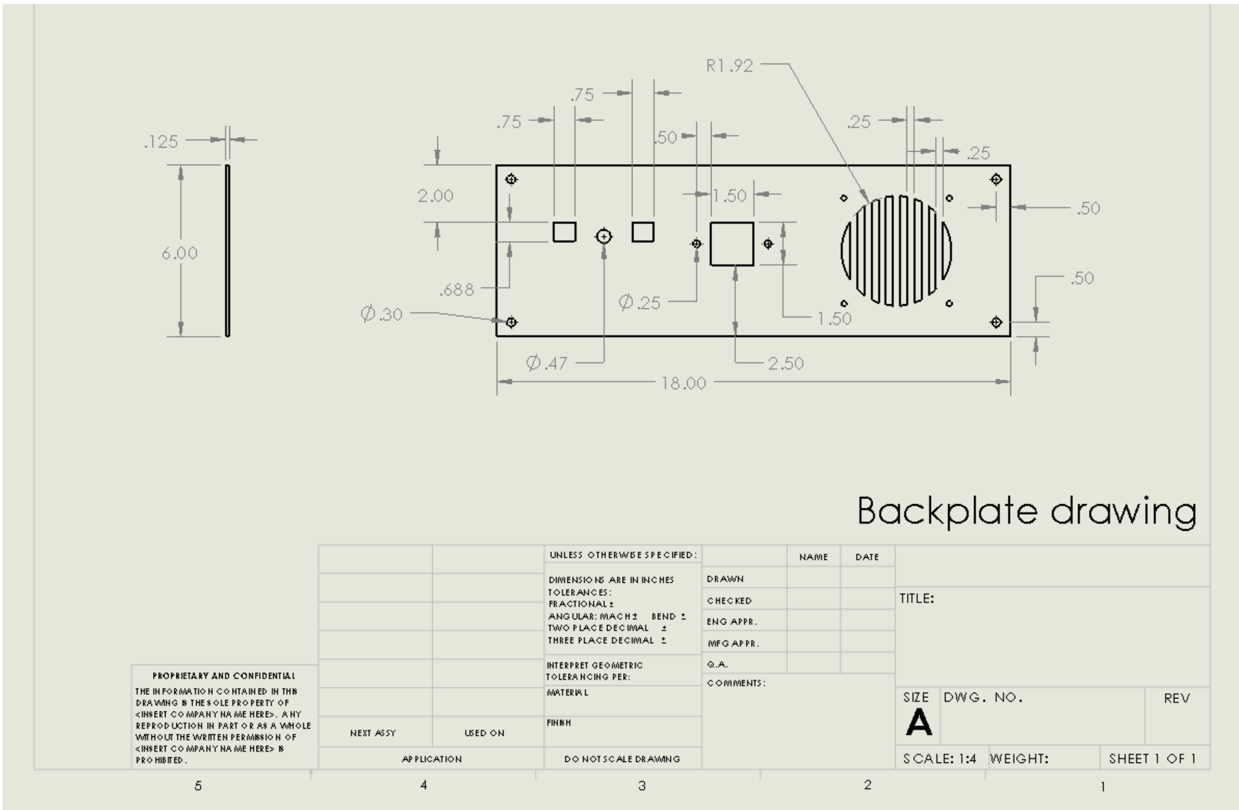
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. · REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:8 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1

Side Plate Components





.125
6.00
R1.92
.75
.75
.50
.25
.25
2.00
1.50
.50
.688
Ø.30
Ø.25
1.50
.50
Ø.47
2.50
18.00
Backplate drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
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NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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WEIGHT:
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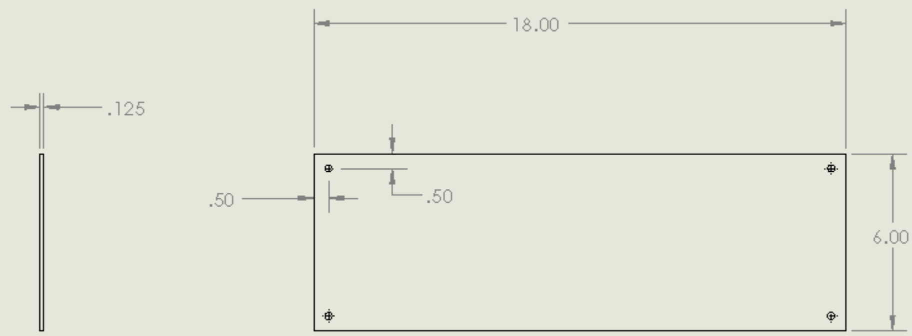


sideplate

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

Erik Skorina

TITLE:

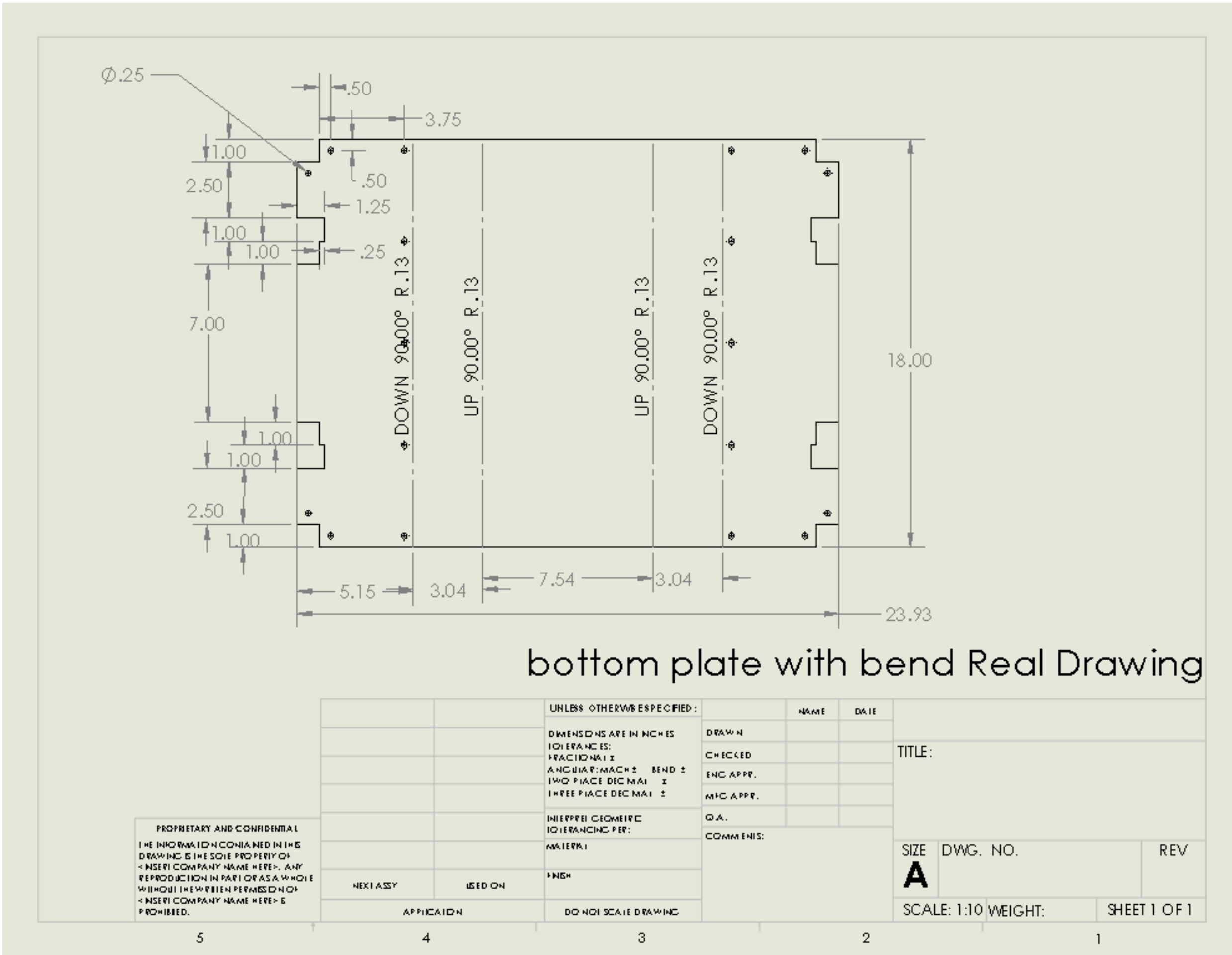
SIZE A | DWG. NO. | REV

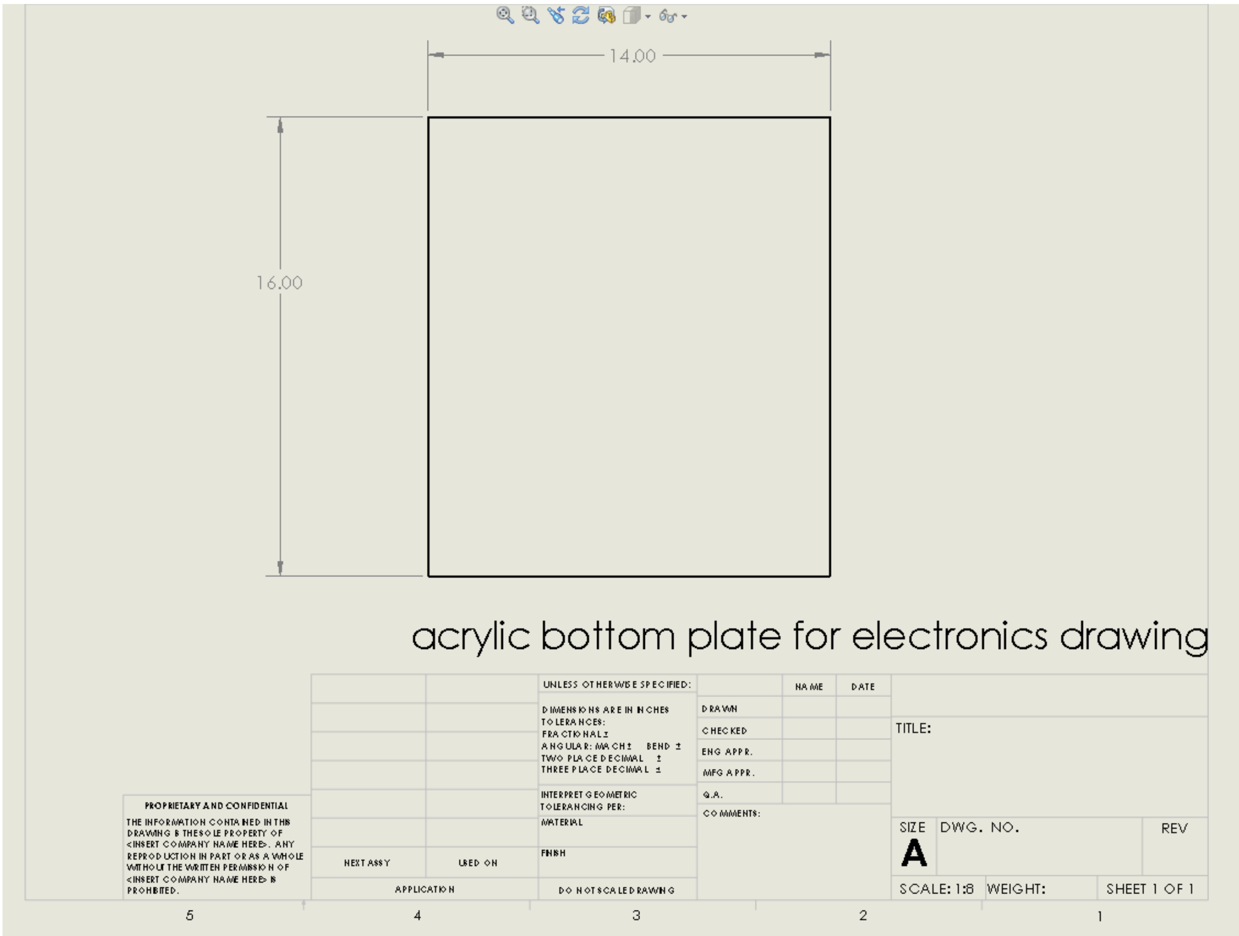
SCALE: 1:4 | WEIGHT: | SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

5 4 3 2 1

Bottom Plate Components




14.00
16.00
acrylic bottom plate for electronics drawing
UNLESS OTHERWISE SPECIFIED:
NAME
DATE
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
NEXT ASSY
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SIZE
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DWG. NO.
REV
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1
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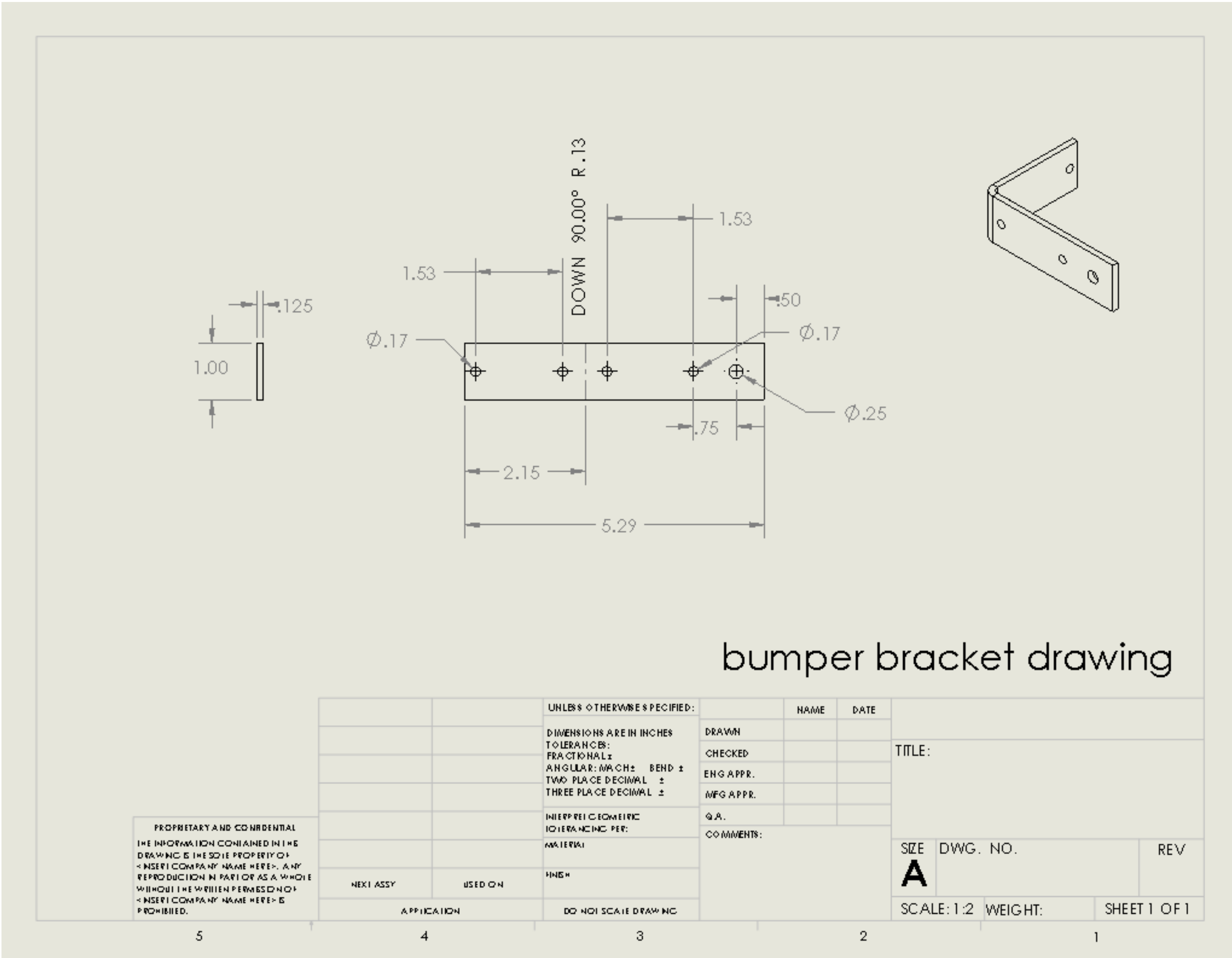
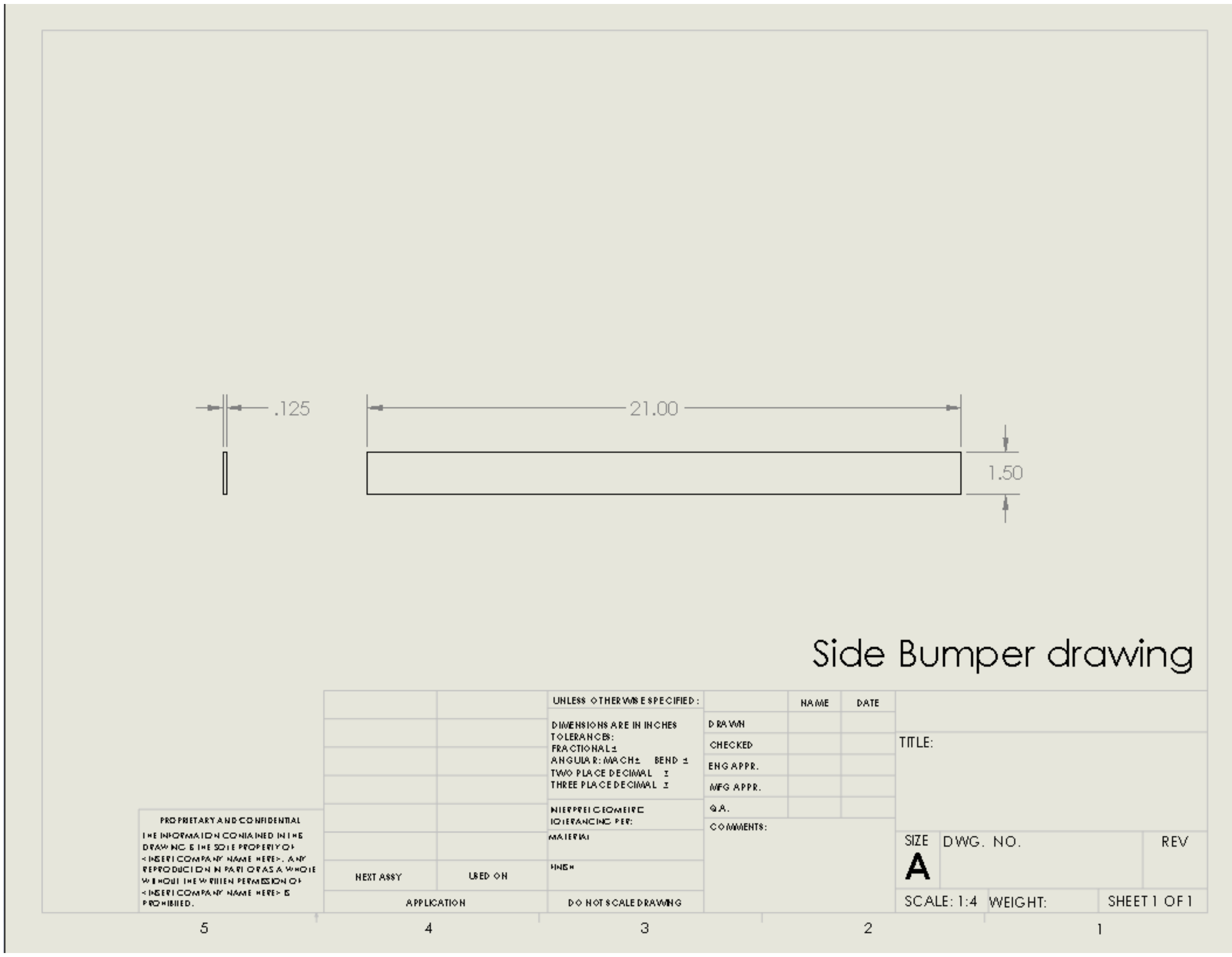
Bumper Components

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21.00
1.50
Side Bumper drawing
UNLESS OTHERWISE SPECIFIED:
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FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
SIZE
A
DWG. NO.
REV
SCALE: 1:4
WEIGHT:
SHEET 1 OF 1
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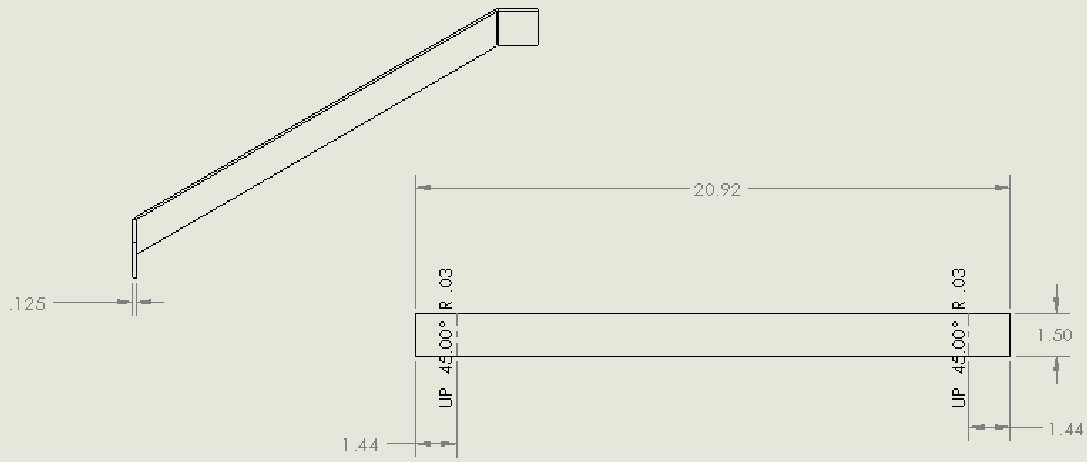

bumper2 drawing

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

SIZE A DWG. NO. REV

SCALE: 1:4 WEIGHT: SHEET 1 OF 1

NEXT ASSY USED ON

APPLICATION

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5 4 3 2 1