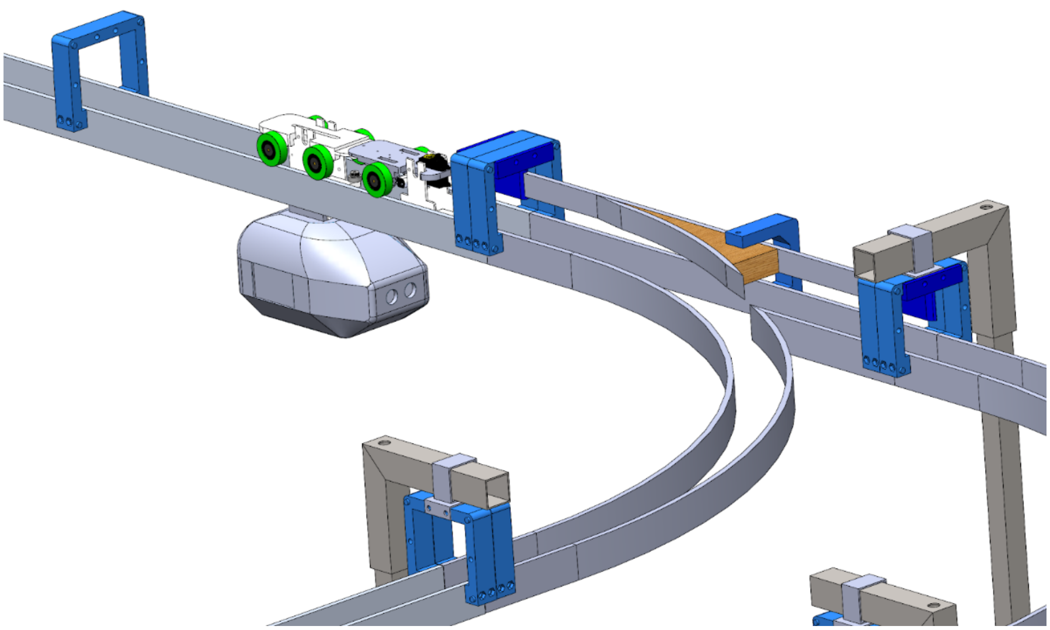
The Spartan Superway

A Solar Powered Automated Transportation Network



Small Scale Track Design and Manufacturing

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Abstract

The Small-Scale Track Design and Manufacturing team is responsible for creating a new double-rail system that envelops the older iteration of the track. By building this year's track from the ground up, the team focused its creative freedom towards the switching components and the modular design. There are four unique subassemblies that make up the track. These subassemblies are the straights, switches, curves, and the support structures. Once the Solidworks models were designed, the next focus was to find a way to manufacture everything.

Manufacturing methods that were used throughout this project include 3D printing, welding, drill pressing, metal bending, and grinding. The 3D printed bracket's design plays an integral role in this year's system because it creates track subassemblies that do not need to be disassembled. The railings that pair with the brackets are manufactured using the drill press and countersink bits. Some of the biggest challenges that this year's team had to overcome were utilizing some of the more advanced manufacturing techniques such as welding and bending to create the curved track sections and base supports.

Overall, this year's project is overall considered a success because it met all the goals set out by administration at the start of the semester. Moving forward, future teams should have at least one member who is adept at 3D printing to manufacture all the brackets and one member who is adept at TIG welding to manufacture the supports. The track works well in its current state, however, there are improvements that could be implemented with the track's turn sections, leveling system, and manufacturability.

Acknowledgments

Dr. Buford Furman & Eric Hagstrom:

- Provided scope of work for this year's team.
- Provided general guidance on fundamental design decisions for track.
- Oversaw progress throughout year to see if the team's direction was correct.

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- Provided recommendations for manufacturing issues which we eventually encountered.

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- Collaboration and advice on manufacturing components of the support.

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SPARTAN SUPERWAY

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Executive Summary

Spartan Superway needs a new small-scale track to showcase a new double rail track design. The previous iteration of the track focused on dual rail design with single rail segments. To improve the robustness of the previous design, Spartan Superway must utilize a double rail design. A double rail design provides a safety net to prevent the pod car from falling through the rail. Regarding the small-scale track, previous iterations were difficult to disassemble, transport and reassemble. The switch section is one of the most difficult sections to design. For a switch to exist and remain a passive element a gap in the track must be cleared. This proves problematic when the Spartan Superway project wishes to showcase development at fairs and events.

To develop a track that is easier to disassemble, transport and assemble a modular design was the primary focus. To remain modular the track focuses on having three main parts. A linear rail section, a turn section and a switch section. These three components are designed to be interchangeable. During assembly, the location of the sections can be switched around like a model train. To successfully cross the switch section a third rail design was implemented. This third rail is only necessary at the switching segments eliminating the overall number of components in the design. Having a third rail ensures that the bogie always remains in contact with two rails. To prevent issues in the future, a single hanger bracket design is used repeatedly throughout the design. This improves the design by reducing the number of spare parts that must be kept on hand if a section fails.

In terms of manufacturing two of the biggest hurdles faced were time management and manufacturing curved aluminum rails. Due to the large footprint of the project and the requirement that no components would be taken from the previous design proper time management was necessary to effectively compete the small-scale track. All the required materials that were needed to be purchased to begin fabrication were purchased over the first two weeks of the semester. Over the course of the next 8-10 weeks the support structure was built. This included drilling holes into all the steel components, preparing all the metal for welding by removing oil and beveling edges, welding various components, mixing/pouring concrete and bending sheet metal. While concurrently manufacturing the support structure, time was focused on 3D printing, producing some of the straight segments of the track and attempting to bend aluminum. Previously Spartan Superway outsourced bending aluminum. Due to cost a past engineering team designed and fabricated a means to produce bend aluminum track. Unfortunately, the bends produced this machine created rails that would not lie flat and had twists in the rails. Due to the new double rail design this is unacceptable. An inexpensive ring roller was purchased to accomplish bending the aluminum. This ring roller was able to bend the rail but was unable to bend them to the desired radii. The purchased ring roller inspired a homemade ring roller/slip roller to be quickly designed and prototyped to produce these segments of track. Over the course of the weeks 12-16 all the aluminum segments were rolled to shape to produce the switches and turns. During this time all the remaining straight sections were also assembled. Throughout the entire process an average of about 25 hours per week of 3D printing was required to complete the project in a timely manner. An average of about 16 hours per week with all members present and actively working was required to complete the project in its entirety.

The bogie has minimal issues maneuvering through the modular track. The gaps between the track's modular sections and the height differences of the track did not affect the bogie at all. The wheels of the bogie seem to absorb any of the impact from moving through these sections. Some binding occurred with the bogie in the switching sections of the track. This was mitigated by adjusting the track with the use of shims to bring the switch segment within tolerance. The leveling system of the track did not meet the intended design specifications as manufactured. To achieve the design requirement of 8.3 degrees of adjustment all that is needed is changing the length of the bolts in the leveling structure. Although the support structure did not meet this design requirement, the structure performed without issue.

The overall design of the small-scale track met all the desired requirements and outcomes as stated in the Design Requirements section. The bogie did not fall through the track and no portion of the track ever failed under load.

Introduction

Current options for public transportation do not alleviate road congestion. This is why citizens large metropolitan areas such as New York, Los Angeles, and San Jose suffer greatly from long commute times and increased air pollution within these areas. According to Barth and Boriboonsomsin (2008), “to reduce CO2 emissions in the future, transportation policy makers are planning on making vehicles more efficient and increasing the use of carbon-neutral alternative fuels”. Consequently, while more cars are being developed, fatalities and accident rates are also increasing. According to Fortune, “40,000 people died in motor vehicles crashes [in 2016], a 6% rise from 2015. [Meaning,] it would be a 14% increase in deaths since 2014, the biggest two-year jump in more than five decades.” (Korosec, 2017). Throughout the United States, vehicle manufacturers are improving their products to adapt the new autonomous driving technology. However, while alleviating the impact of carbon emissions, autonomous vehicles still contribute to the problems of congestion and accident rates. In addition, autonomous driving is still being researched and the technology is not ready to be released to the public. Therefore, a new transportation solution is necessary to alleviate the pressing concerns of congestion, emissions, and vehicular accidents.

Spartan Superway aims to be the remedy to these issues by creating a new paradigm in public transportation. Spartan Superway sets itself apart because of its self-sustainable and autonomous traits. Solar energy is used to power the entire system, which consists of multiple individualized van-sized pod cars that ride on a network of rails placed throughout the city. By utilizing solar energy, Spartan Superway can be part of the solution to emissions, while setting the standard for future self-sustainable public transportation systems. Since the Spartan Superway utilizes individual pod cars, users can treat Spartan Superway like a taxi or personalized bus. However, unlike conventional bussing systems, Spartan Superway allows users to save time due to the personalized nature of the design. Users can ride the pod cars to their intended location without having to stop every other block. Eventually, as Spartan Superway grows and is implemented throughout the city, an established transit network will be able to transport people efficiently and alleviate the everyday issues commuters face.

For such an ambitious project to be implemented, it must first go through development and troubleshooting cycles. Due to monetary and time constraints, it is best to tackle these issues when working with a smaller scale model. Currently, there are two small scale models and one full scale model in the Spartan Superway project. Over the past five years, students at San Jose State have worked on the Spartan Superway to address issues and create multiple models of the project. The small-scale model of the project has successfully completed a complex small-scale model with multiple pods running around the track simultaneously. The full-scale model has created a small subsection of the track which encompass the switch mechanism to demonstrate turn sections. The most recent progress comes from the half scale model, which is built to tackle challenges of coming into a station at a different level. This document is meant to encompass the progress of the 2017-2018 1/12th-scale track design and manufacturing team's progress with creating a newly designed track that aims to improve on the old design's shortcomings.

Objectives

The 2017-2018 Track and Manufacturing team focused on 4 main goals for the project to succeed this academic year. The first goal of this year's iteration of the track was to implement a double rail system into its design. Previous iterations of the track utilized a single rail system for its switching mechanism, this caused the bogie to sag and ultimately become unstable. In addition, if the bogie's switching mechanism did not activate correctly the bogie would fall from the track. By implementing a double rail design, this year's small-scale track team aims to eliminate these concerns.

In addition, incorporating a double rail system, another goal of this year's team was to create modular sections of the track. Utilizing modular parts allows faster assembly and disassembly times for the track. In addition, modularity allows changes and improvements to the track to be easily made.

The third goal for this year's design was to incorporate a leveling system for the supports of the track. When taking the project to different events, previous iterations of the track encountered problems of uneven terrain. When setting up the track, the uneven terrain causes binding and overall failure of the track. The leveling system aims to alleviate these problems.

Finally, the last goal for this year's track team is to allow members of the Spartan Superway to troubleshoot the track at events. Originally, this newly designed track, is created to encompass the old model. By incorporating clearance space between the new track and the old track, members are given extra space to troubleshoot between both track models.

Design Requirements and Specification

To produce a successful track model, the following specifications were created:

1. *Track Perimeter*: 200 inches long x 200 in
2. *Distance Between current and past track*: 30 inches
3. *Inner track width*: 2 inches
4. *Curve radii*: 25 inches
5. *Modular sections*:

a. 15 Straights: 48 in long

b. 4 Curved sections: 25-inch radii

c. 2 Switch Sections

d. 20 Support Structures with leveling systems

2. Ability to complete a 15% grade change

To meet the following design goals of the project, the following engineering specifications were made. The dimensions of the track were chosen because the new track design will encompass the 2016-2017 iteration of the track. With the specified gap between the two track systems, members of the team will be able to maneuver in between the two tracks at various project fairs in the Spring. The inner track width was determined by referencing the old track model. The radii of the curve were chosen to mirror the large-scale track dimensions. The full-scale track team is utilizing 30-meter radii, so we felt that a 25-inch radius would suffice. Modularity was a focus for this project because it increases the speed of assembly and disassembly, an issue previous iteration of the project had.

Literature Review

Public Railway Transport (PRT) systems have been in development since 1953. PRT systems consist of five key components:

- "On-demand, origin-to-destination service
- Small, fully-automated vehicles
- Exclusive-use guideways
- Off-line stations
- A network or system of fully-connected guideways" (Carnegie, 2007)

Currently, there are five versions of various PRTs that are currently operational around the world. One of them is in Morgantown, West Virginia. However, as cities increasingly grow dense, implementation of these transit networks have caught the eye of several congested cities. New Jersey, in comparison to West Virginia, is slowly facing "A rising tide of traffic congestion, [which] threatens to increase roadway gridlock, stifle the economy, and erode our quality of life in New Jersey" (New Jersey, 2008). In 2007, with hopes to address this issue, Jon A. Carnegie proposed the implementation of PRTs in New Jersey to the New Jersey Department of Transportation. However, there have not been any updates on the state of New Jersey and PRT systems.

One challenge that PRT systems face towards implementation is the lack of institutional framework support. The meaning behind this issue, as stated in Carnegie's proposal. Carnegie (2007) states that "there is minimal institutional infrastructure and expertise to support the specialized analysis, design, construction, and operations needed to implement PRT and ensure safety and security". However, since 2012, San Jose State University has played a part in trying to solve this issue by utilizing student manpower and inviting students from around the world to give valuable input and by creating a class out of the Spartan Superway project. With the addition of Spartan Superway into the senior project curriculum, students are now able to gain a deeper understanding with PRT systems, and aid with the research towards the plan of implementing this concept into the public.

Final Design

Hanger Bracket

The final iteration of the hanger bracket utilizes a Lego-like design to connect one track section to the next, creating a simple and easy to assemble track system. To mount brackets onto the rails, nut insertions were designed into each side of the hanger bracket, as shown with the yellow arrows in Figure 1. To connect the brackets together, the Lego like design is utilized on the four corners of the bracket's front and back faces, which are shown with the red arrows on Figure 1. These connections are further secured with the two nut insertions and a hole sized for an M5 bolt that are both placed on the bracket's back face. These features of the bracket are shown in Figure 1 and are displayed with the black arrows. The green arrows found on Figure 1 are designed to connect the bracket and the mounting sleeve that is part of the support structure.

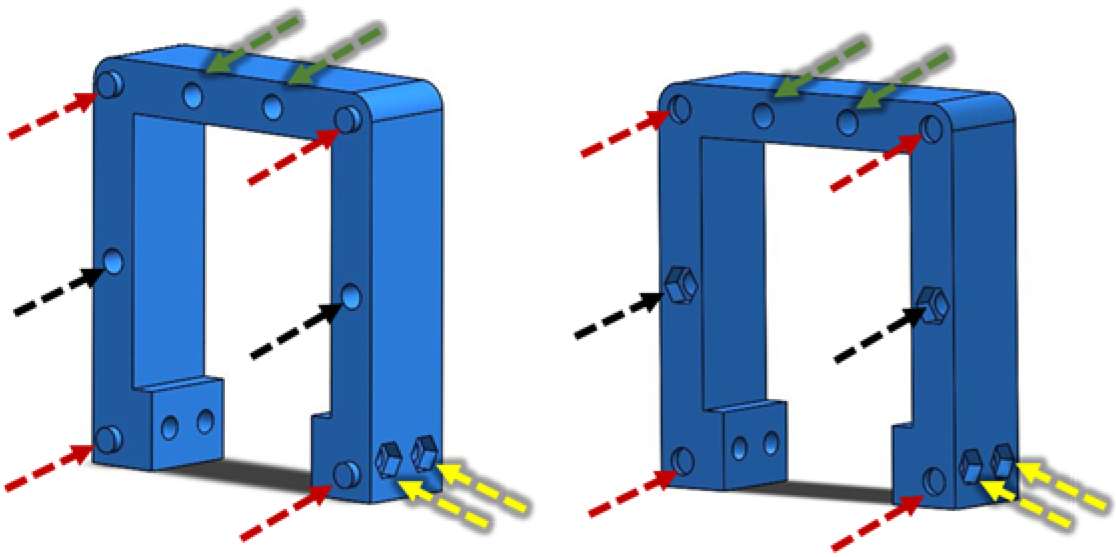


Figure 1 Hanger Bracket

Straight Section

The first modular section of this year's iteration of the track is the straight section. The track has 15 straight sections. This design, shown in Figure X, utilizes a foot-long aluminum flat bars so that the straight sections can be easily stored and transported. The rails are connected to the hanger brackets using nuts and bolts, in which the bolts are screwed in from the inside, Figure X. The straight section uses 3 brackets to prevent binding at the center, where the aluminum is most flexible. The track width this section, along with the entire track, is 1.5 inches. This provides enough clearance for the bogie, and it reduces the clearance gap at the switch section.

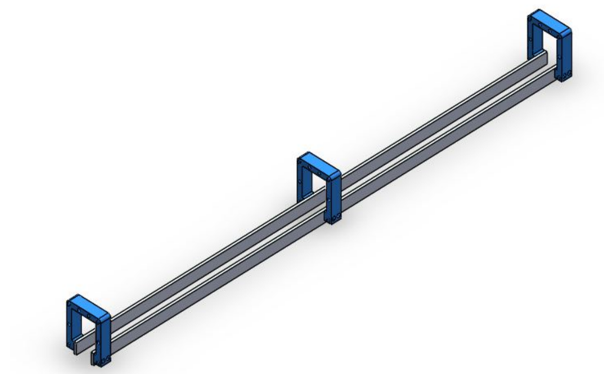


Figure 2 Modular Straight Section Final Design Switch Section

The switch section of the track is a combination of the other two modular sections: the straight and curve. Just like the curved section, the switch has a 25-inch turn radius. A third rail is required to support the bogie when it completes a switch because of the present clearance gap of the design. To support the third rail, as well part of the lower rails, special parts were designed and will be discussed below. In total there are 2 switch sections in the final design of this track.

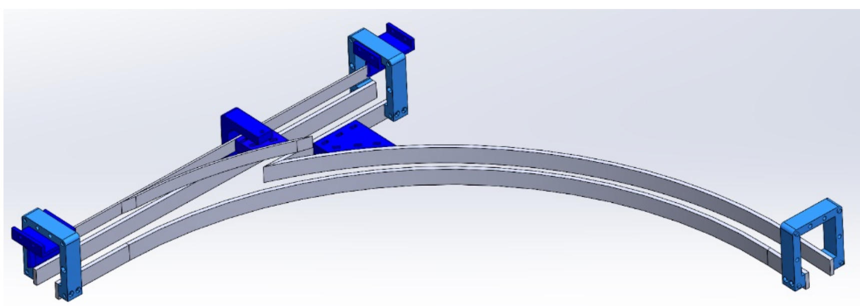


Figure 3 Modular Switch Section Final Design

Third Rail Attachment

The 3-D printed third rail attachment, shown in Figure 4, is designed to house the third rail of the switch section. The third rail attachment fits over two connected hanger brackets and is mounted using two 75mm M5 screws. To provide a smooth bogie transition onto the attachment, one of the attachment was grounded into a wedge shape. Lastly, the housing portion of the attachment was designed for a 0.75-inch rail, which allows enough space for the bogie to pass through. Drawings for this can be found in Appendix A.

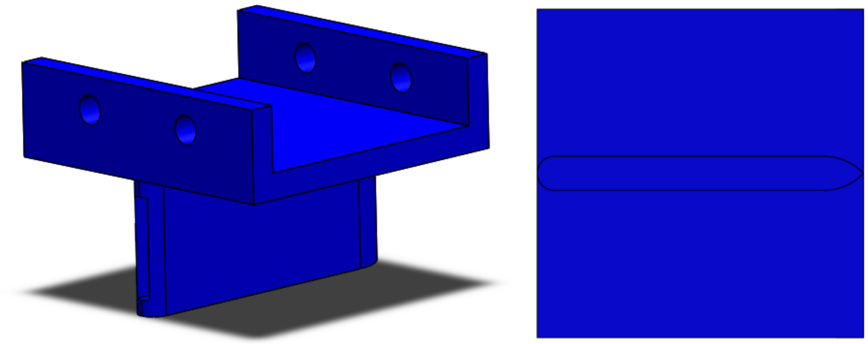


Figure 4 Isometric and Bottom View of Third Rail Support Sleeve

<u>Half Bracket</u>

The purpose of the 3-D printed half-bracket, shown below, is to to help stabilize the third rail of the switch section. It is mounted in the same fashion as the hanger bracket and utilizes a screw on the top to connect to the wedge. The half bracket uses a rib instead of a L-shape to provide more bracket support.

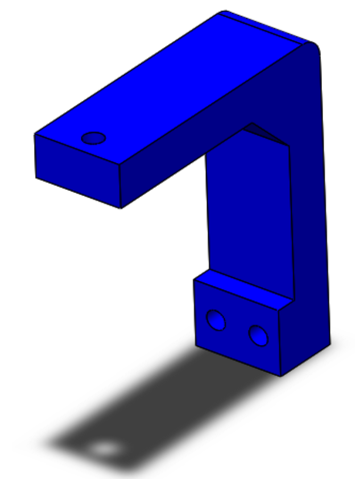


Figure 5 Half bracket component final design

<u>Wedges</u>

The 3-D printed wedges, Figure 6, are used to force the rails to keep their shape at the switch section. These wedges are useful in connecting the rails because it eliminates the need for welding the rails together; welding aluminum poses the problem of warping. Both wedges are connected using screws and nuts that insert into the pockets on each face. The wedge in Figure 6 is the third rail wedge, and it is connected to the half bracket using an M5 screw.

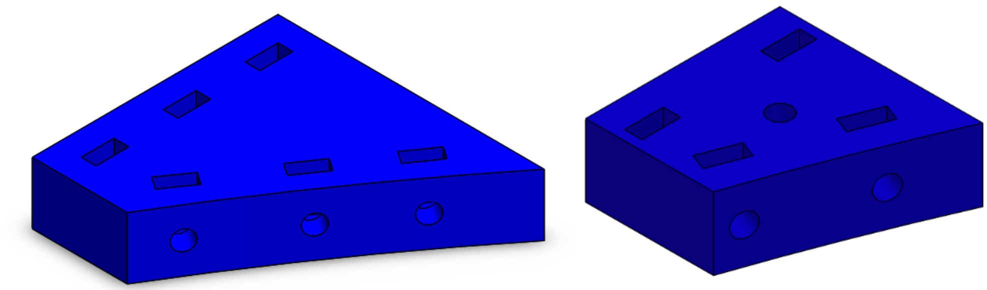


Figure 6 Bottom (Left) and Top (Right) switch section wedge design

<u>Curve Section</u>

The final modular section of the 2017-2018 track section is the curved section. The curve section has a 25-inch centerline turning radius and utilizes 2 hanger brackets. There are 4 total turn sections, used to round off the corners of the track.

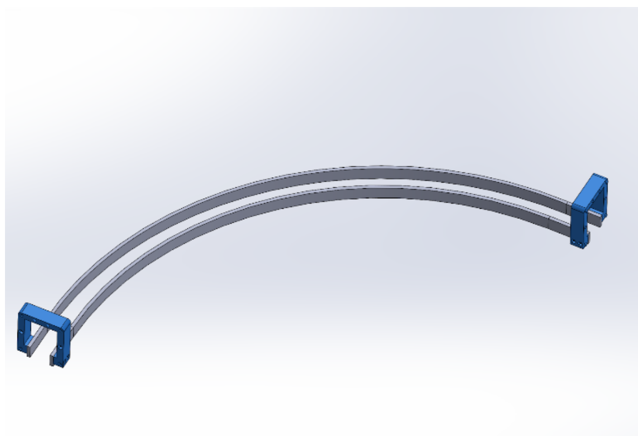


Figure 7 Modular Curve Section Final Design

<u>Jigs</u>

In addition to all the components on the track, our team used 3-D printed jigs, shown in Figure 8 to drill all the holes on the aluminum rails. The jig on the left is used for the ends of the rail, while the jig on the right is used for the center brackets on the straight sections of the track. The jigs are designed for 1 x 0.25-inch square flat bars. Dimensions for the jigs can be found in Appendix X.

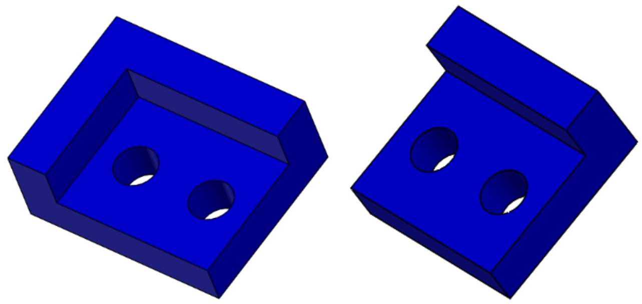


Figure 8 3-D printed jigs for ends of rail (left) and center of straight section (right)

While keeping the main theme of modularity in mind, the support systems were designed to assemble and disassemble quickly, while maintaining its functionality. The supports of this year's track consist of three sections that constitute the overall assembly. The bottom of the assembly consists of the leveling system and concrete slab as shown in Figure 9, highlighted by the red box. The leveling system consists of hot rolled steel flat-bar that is welded onto 16 gage square tubing. These steel bars have a cross section of 1.25" x .3" and has a ⅜" nut on the top of the bar. With ⅜"-16 x 2" bolts threaded through the four nuts on the corners of the support, it allows for a cheap and viable lead screw design that will level the support system when it is placed on uneven ground. 16 gage square tubing, with dimensions of 1.25" x 1.25" x 4", is placed in the center of the concrete slab and acts as a slot for the longer square tubing to fit through. The next part of the assembly is the 16-gage square tubing, with dimensions of 1" x 1" x 36", that acts to elevate the system. This is the middle section of the track, which is highlighted in blue, found in Figure 9. Finally, the top portion of the support is highlighted in black, found in Figure 9. Utilizing a sleeved design, the top part of the assembly adjusts height and is attached to the brackets of the track using a clamp design. This clamping action will be attached using a nut and bolt. The idea for this track attachment can be seen on Figure 9. The top assembly consists of two telescoping square tubes, one being 16 gage square tubing with dimensions of 1.25" x 1.25" and the other being an 11-gage square tubing with dimensions of 1.5" x 1.5" that is fitted on the outside. The 16 square tubing has a weld nut welded onto the part to create a height adjustment point on the track. The 11-gage square tubing is utilized to mount the brackets and track onto the support system. A 5/16"-18 x 2" is the bolt that is used up top of the track to change the height of the attached track.

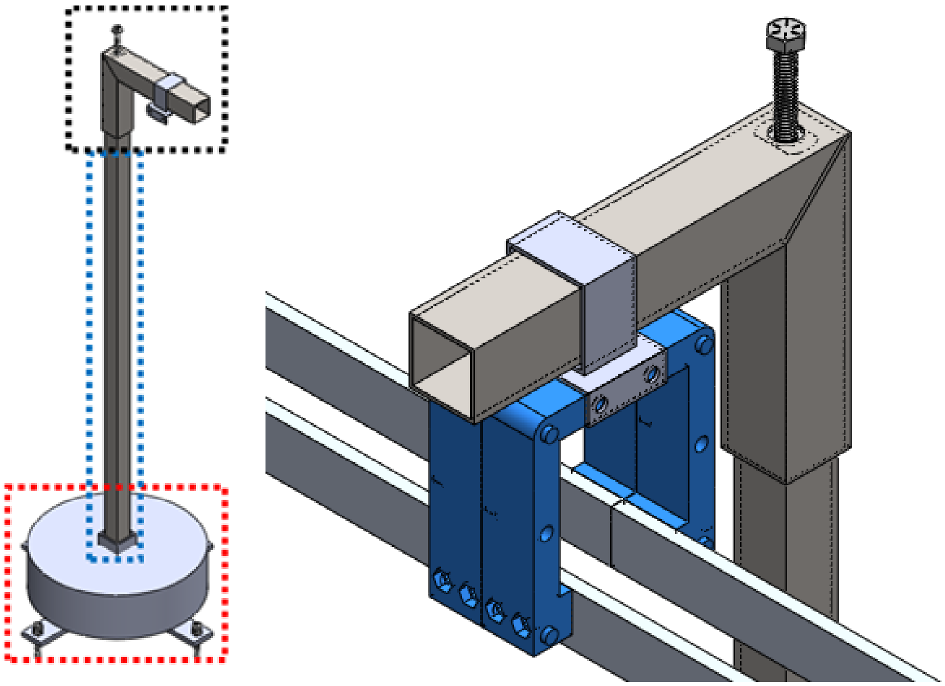


Figure 9 Full body assembly of the support structure (left) and the mounting sleeve attachment to the brackets (right).

Fabrication and Assembly

<u>3-D Printing</u>

The hanger bracket, half bracket, third rail attachment, wedges and jigs were all manufactured using 3-D printing. The team used a heavily modified Anet A8 3-D printer, with a 0.6 mm nozzle. The specifications for 3-D printing can be in Table 1. Great effort was taken to reduce the amount of time required to 3D print all the components.

All the 3D printed components were printed in ABS. This was one of the main changes from previous iterations of the small-scale track. PLA is easier to print and more environmentally friendly compared to ABS. To achieve the design specifications ABS was chosen. This choice was made since ABS is a stronger plastic compared to PLA. The added strength reduces the amount of material needed as well as the overall cost and printing time needed to complete the project.

To successfully print ABS the following print settings were used:

Table 1 3-D Printer settings

Setting Common to All Prints	
Nozzle Diameter	0.60 mm
Extruder Temperature (deg C)	205
Heated Bed Temperature (deg C)	100
Layer Height	0.300 to 0.3200
Cooling Fan	OFF
Build Surface	Generic form of "BuildTak" Made by Zonyee
Setting for Hanger Bracket, Half Bracket & Wedges:	
Top Solid Layers	4
Bottom Solid Layers	4
Outline/Perimeter Layers	6
Infill Percentage	55
Supports Required	None
Settings for All Other Parts:	
Top Solid Layers	3
Bottom Solid Layers	3
Outline/Perimeter Layers	2
Infill Percentage	25
Supports Required	From Build Platform Only

Modular Sections

For all the straight sections of the track, we first match 15 pairs of rails, so that each rail is about the same size. To create a straight, we first drilled 3 pairs of 7/32 inch holes at each end of the rails using the drill press (Figure 10), as well as the middle. The holes were positioned using the 3-D printed jigs. The holes were then counter-sunk, so that the M5 screws would be flush against the inside rails.

Once the rails have been correctly drilled, they are connected to the brackets from the inside to the outside, as seen in Figure 10.

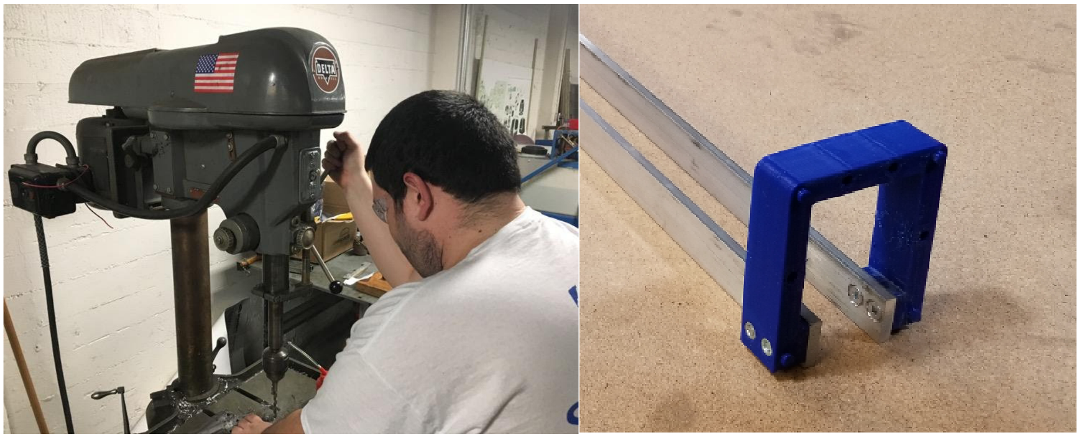


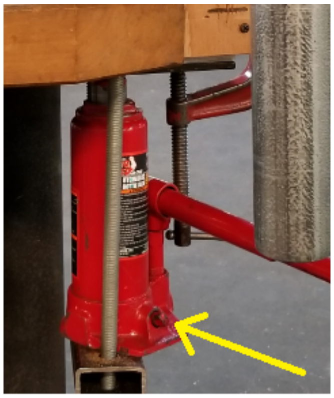
Figure 10 Drill pressing rails (Left) and bracket-rail connection (Right)

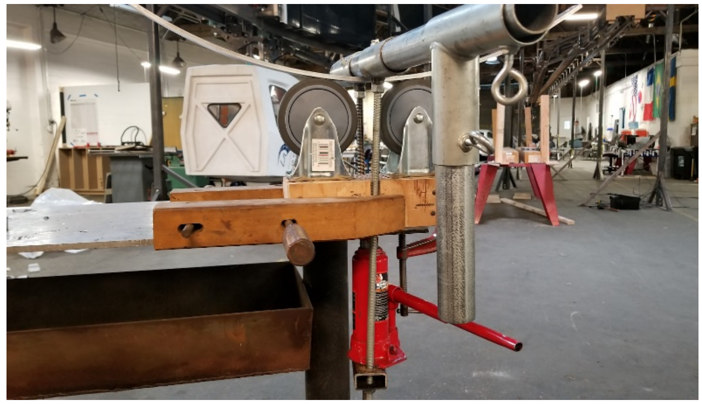
<u>Bending</u>

To bend the aluminum rails for this year's iteration of the track, our team used the bender in Figure 11. The steps to operate the bender is listed below:

<u>Steps:</u>

1. Load a rail in between bottom wheels and the circular tubing (Shown in Figure 1)
2. Ensure the pressure release valve is tightened (Figure 11)
3. Once rail is loaded on, crank the bottle jack until the rail contacts both wheels and the circular tubing
4. To begin bending, crank the bottle jack ¼ to ½ a crank
5. Begin turning the circular crank in either direction.
6. To ensure flatness, complete one pass in each direction.
7. Manually adjust rail back onto wheels, as bending will cause the rail to slide off the wheels.
8. Repeat steps 4-6 until desired radius is achieved
9. Release bottle jack by removing the crank and turning the pressure release valve (Figure 11) CCW





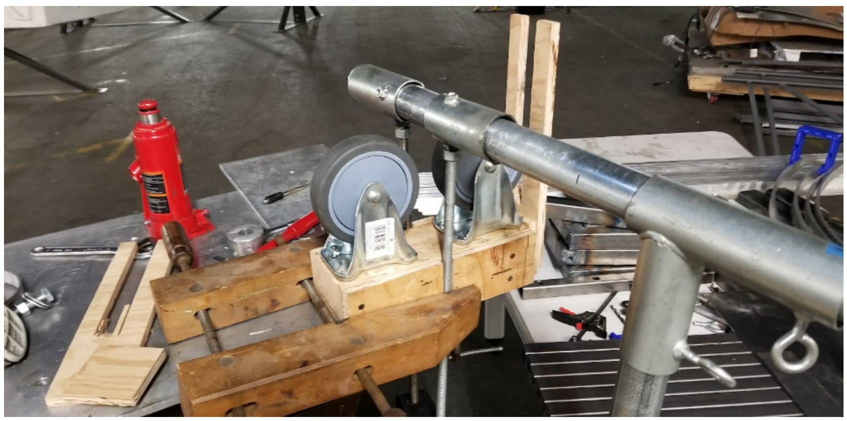


Figure 11 Pressure valve location (Top left), Rail inserted into bending machine (Top Right), Bending machine used for this project (Bottom)

Welding

Welding was utilized throughout the support structures. The Spartan Superway Design Center carries a TIG Welder in house and that was utilized to create all the necessary welds for this year's iteration of the track.

Manufacturing the Support Structures

To create the support structures of the track, TIG welding was utilized. A figure of the TIG welder is found in Figure 12. Before welding, please refer to the instructions on how to operate the welder, which can be found below in Appendix C. The following steps show how to prepare the metal for welding and create the entire support system.

Figure 12 The SSDC's TIG Welding machine

<u>Steps:</u>

1. Prepare the hot rolled steel flat bar.
   a. Using the grind wheel, the edges of the flat bar needed to be grinded off. This allows space for the filler metal to flow in, creating an easier weld.

Figure 13 Grinding off the marked portions with the grind wheel

   b. Drill hole a .5" diameter hole in the flat bar that is about .5" away from the edge

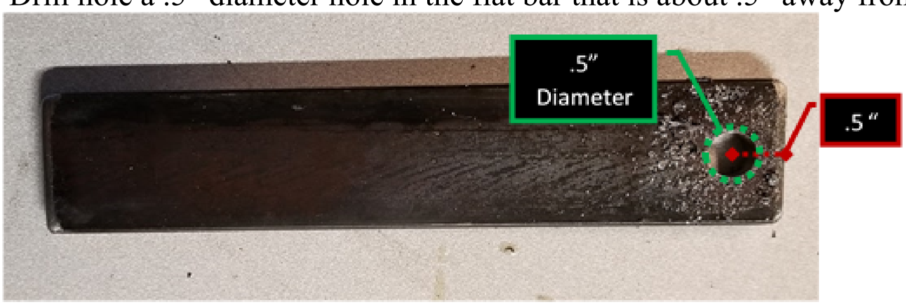


Figure 14 Drilling a hole through the hot-rolled steel flat bar

1. Prepare the top mounted square tubing
   a. Cut the square tubing in a 45-degree angle using the Miter saw in the shop

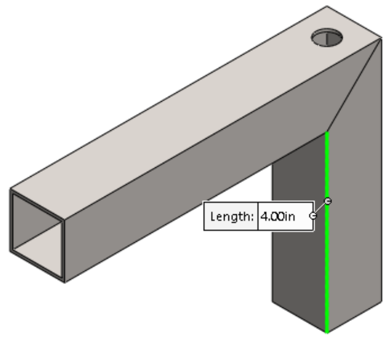


Figure 15 An isometric view of the top mounted square tubing.

b. Using the drill press, drill a hole .5” diameter hole about .5” away from the edge

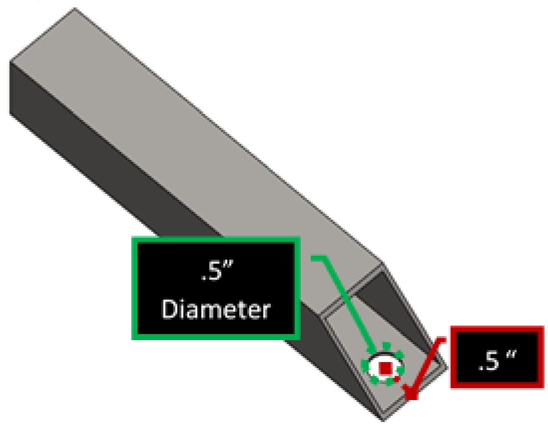


Figure 16 Drilling a hole through the square tubing with the following dimensions.

a. Weld the nuts above the steel flat bar so that the holes line up properly.
Tip: Use a set of four bolts that will get discarded to hold the nuts in proper place. Throw these bolts after completing all the necessary welds since they have most likely warped.
b. Weld the steel flat bar to all four sides of the 1.25” x 1.25” square tubing.
c. Repeat as needed
d. Refer to Figure 16, for clarification.

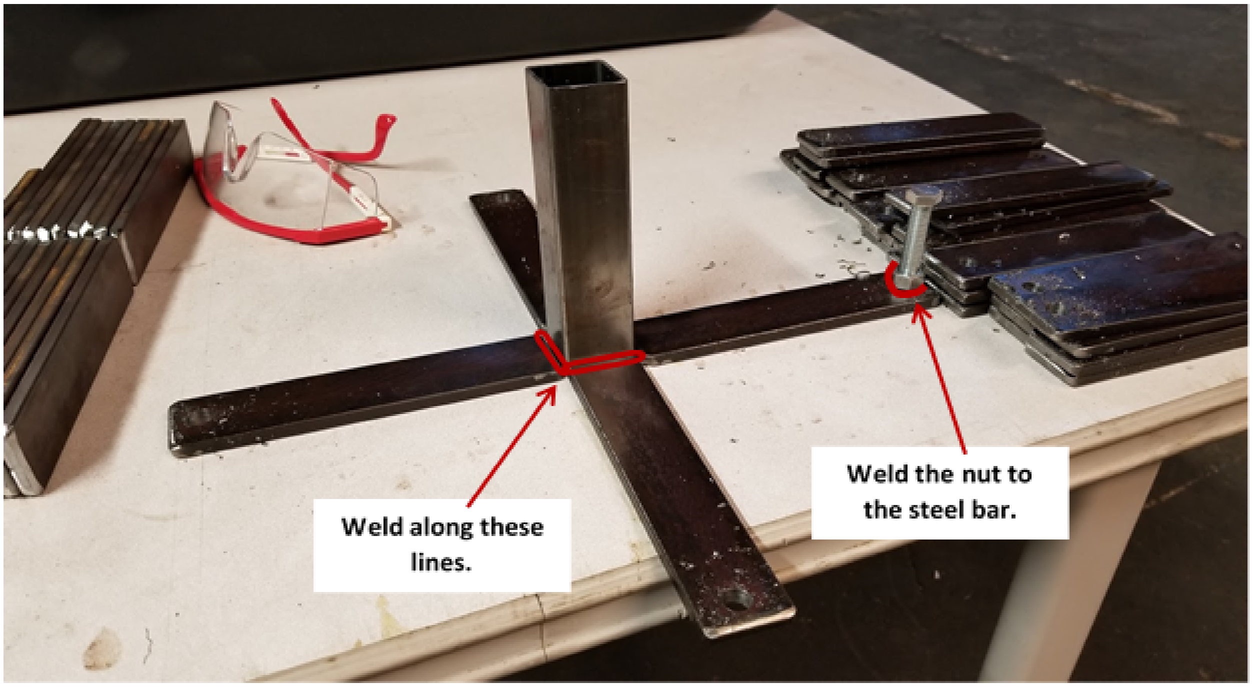


Figure 17Welding together the leveling system.

1. Pour concrete
a. Make cutouts for the hot-rolled steel flat-bar to fit through the 10" concrete forms
b. Follow instructions to mix the concrete
c. Pour concrete in the concrete forms and the bottom portion of the support system should look like Figure 18.

The choice to remove the concrete forms were ultimately for aesthetics, feel free to paint over the branding on the outside. Note that previous teams painted old bases.

Figure 18 Hardened concrete in the concrete forms

1. Weld the Top Mounted Square Tubing
   a. Weld the weld nut onto the drilled square tubing
   b. Weld the the square tubing with the weld nut with the other square tubing to create an "L" sleeve like design.

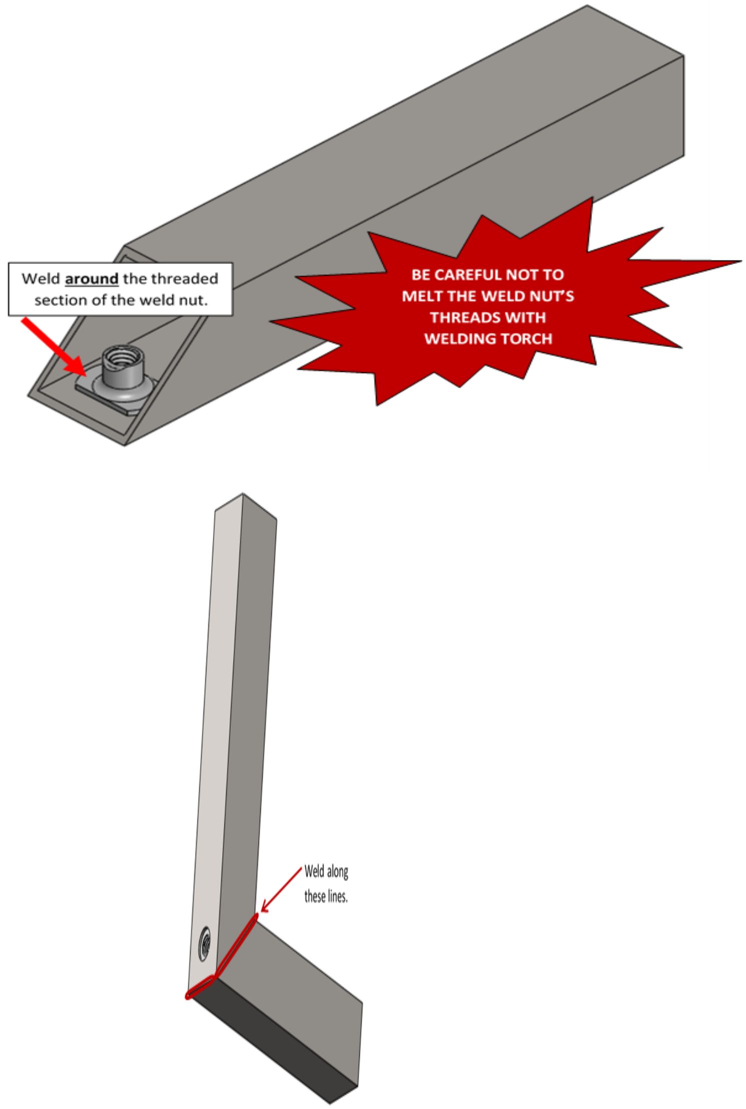


Figure 19 Graphics for welding the top mounted square tubing

1. Create the track attachments
   a. Get non-zinc plated sheet metal and cut into 1.5" x 3"
   b. Measure .5" lengthwise on both sides and bend the metal inwards at those points
   c. Tack weld four corners of the sheet metal to the 11-gage square tubing
   d. Put two brackets together and drill holes into the top two holes of the brackets to get the fourth image of Figure 20.

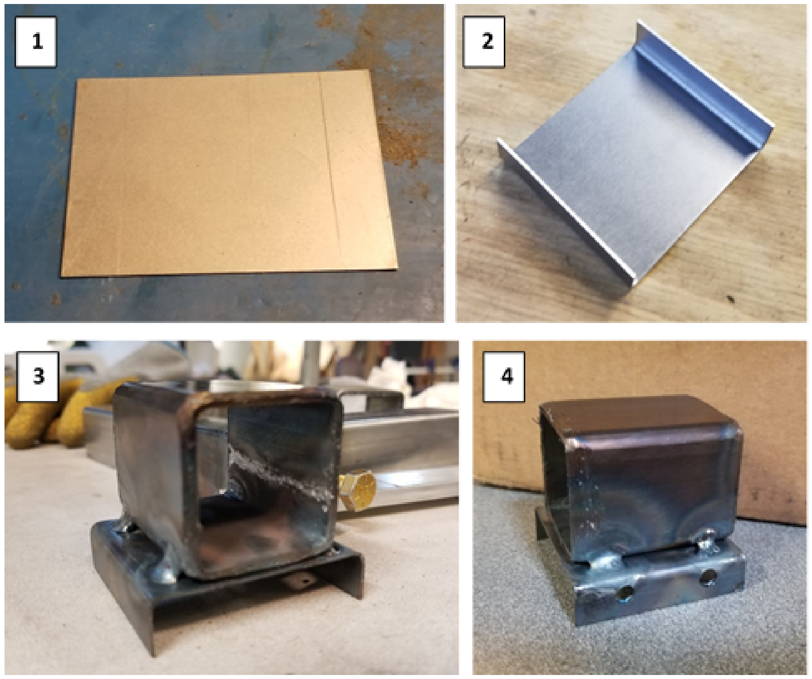


Figure 20 The different stages of creating the track attachments.

Assembly of the Track

To assemble the 2017-2018 track section, the following steps should be followed:

Supports
Refer to Figure X for each step

1. Place straight square tubing (BLUE) into the support base (RED)
   a. Make sure the holes line up
2. Fasten the support using ⅜'' bolt and nuts
3. Slide L-shaped square tubing (BLACK) over the top of the straight square tubing (RED)

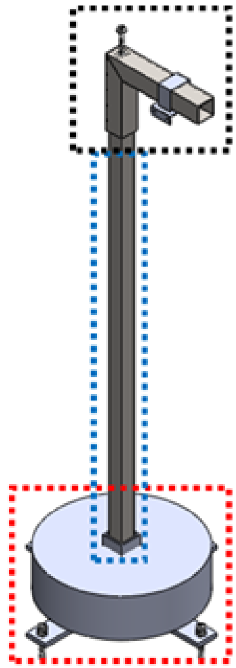


Figure 21 Support Section Assembly Guide

Modular Sections

1. Lay out the entire track on the floor in the configuration desired
2. Connect pairs of straight sections first
3. Insert bolts and nuts through the connection points shown in Figure 22 (black arrows)

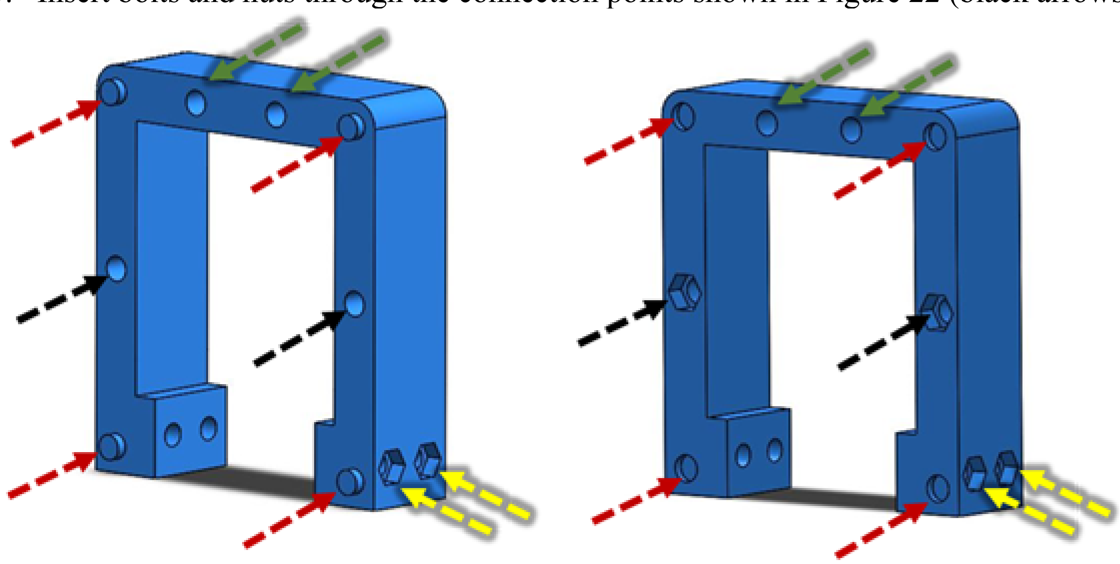


Figure 22 Hanger Bracket Mounting Diagram

1. Once connected, slide mounting sleeve over the two hanger brackets. Insert 15 mm screw through both the mounting sleeve and hanger brackets. Fasten everything with M5 nuts. The completed section should now look like Figure 23.

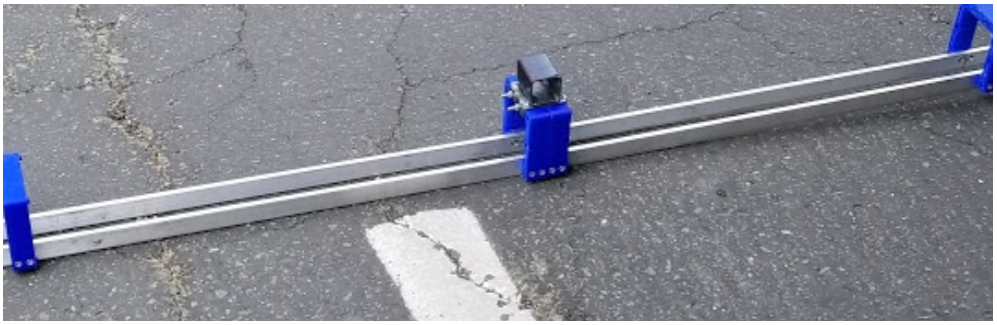


Figure 23 Mounting Sleeve Connecting two straight sections

1. Insert the mounting sleeve through the L-bar square tubing of the supports, shown below.

Figure 24 Modular section mounted onto supports

1. Once a section is mounted, continue adding desired sections to the mounted section.
   a. For sections connected off the ground, INSERT MOUNTING SLEEVES FIRST
   b. Mounting sections in this way requires AT LEAST THREE PEOPLE (**Figure 25)**
      i. Person one: Holds the section up
      ii. Person two lines up the mounting sleeves with hanger brackets
      iii. Person three: insert screws and fasten everything in place

Figure 25 Mounting modular straight section off the ground

1. Repeat step 6 for all curves and straight, until you only have **switch sections.**
1. Refer to *Mounting a Switch Section* for switch section attachment

<u>Mounting a Switch</u>

Refer to Figure 26:

1. Mounting brackets of this section is like the other modular sections
2. **HOWEVER**, third rail support sleeves must be mounted **OVER** mounting sleeve **BEFORE** inserting 15 mm M5 screw.

a. **CAUTION**: support **BOTH** third rail support sleeves while doing this. Failure to do so will cause the third rail support to **CRACK/BREAK**

2. Connect top wedge of the third rail to the half bracket using an M5 screw and nut

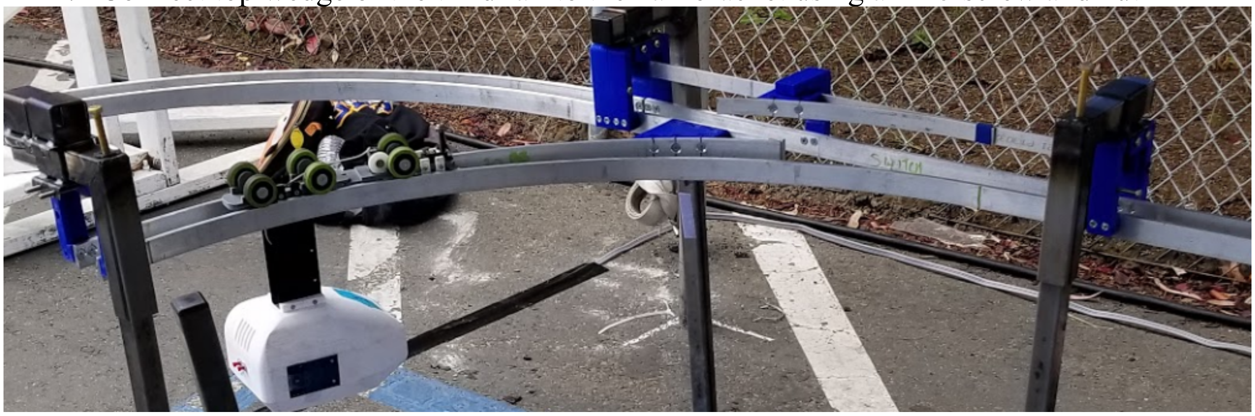


Figure 26 Assembly reference for mounting modular switch section

<u>Adjusting the Track</u>

With everything mounted, adjust the supports to ensure the bogie does not bind. This can be done in three ways (or combination of the three):

a. Move the support structures through translation

b. Adjust the leveling system until the rails are level

c. Adjust the height of screw located at the top of the entire support section

Analysis

To determine if the track designs would meet the project specifications, the following analyses was performed on each section.

Rails

The 6061 aluminum rails were designed to withstand the weight of 3 bogies, about 10 lbs total. This material has a yield strength of 42 ksi. To determine if the yield stress caused by this force would cause failure, FEA analysis was performed on SolidWorks.

Straight Section

For the straight section, both ends of 48-inch-long track were fixed, with 10 lb point load acting at the center of the rail, 24 inches; this location is where the rail would experience the most loading. This is shown in Figure 27. The simulation results show that the rail experiences a max deflection of 0.014 inches, with a von Mises Stress of 1.086 ksi; this resulted in a minimum safety factor of 7.3662. The minimal displacement of the rail instills confidence that the bogie should not experience derailment. A SF of 7.3 also shows that the rails will not experience fracture and can support the weight of additional bogies.

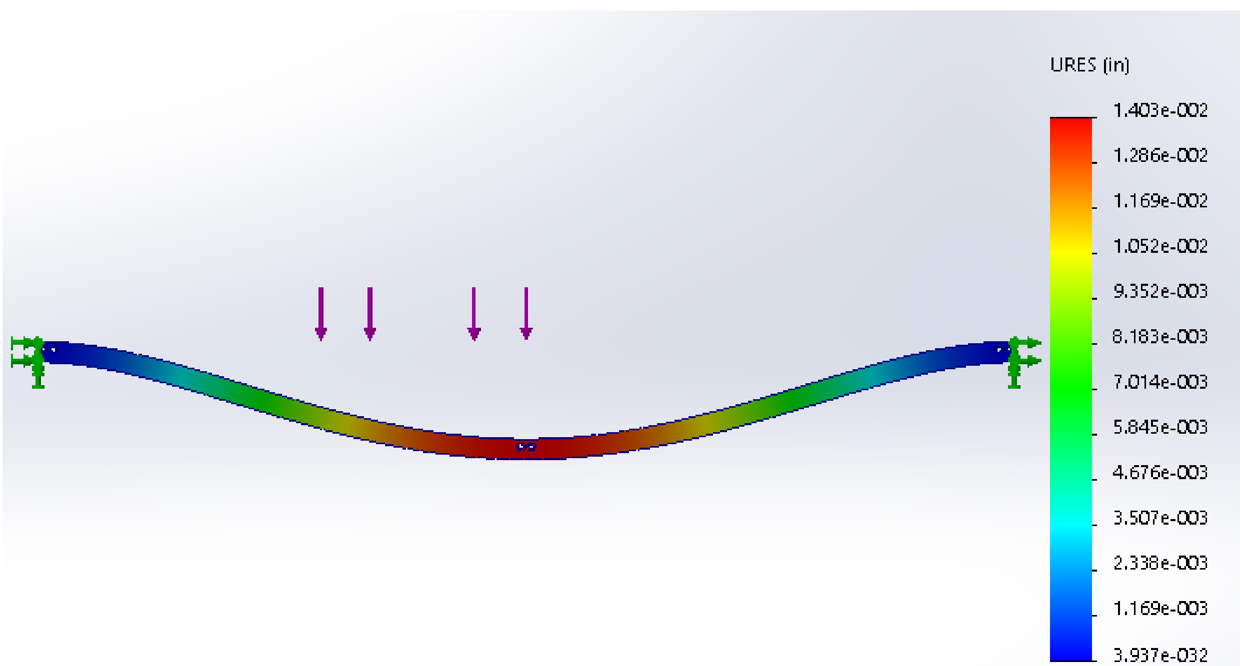


Figure 27 SolidWorks FEA results of straight rail

Curved Section

For the curved section, analysis was performed on the outer rail, due to the limitations of SolidWorks FEA. Just like the straight rails, both ends of the outer curve were fixed, with a 10 lb point force acting at the center of the curved rail. Referring to Figure 28, the max deflection of the rail was 0.02 inches, with a von Mises stress of 1.427 ksi and a minimum SF of 5.603. Again, much like the straight rails, the curved rails experiences little deflection. This rail should not experience any fracture or failure.

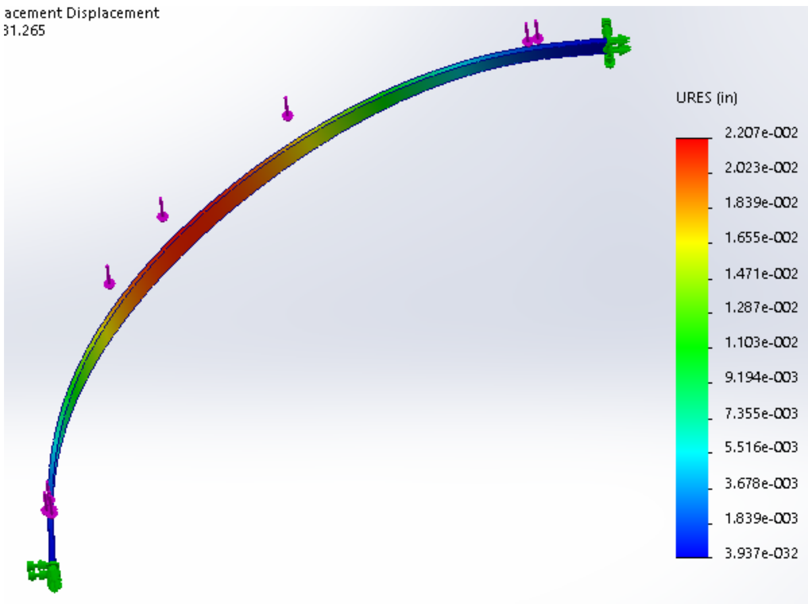


Figure 28 SolidWorks FEA results of outer curve rail

Switch Section

The main concern of the switch section is the portion circled in Figure 29. The switch and curved sections have been analyzed already, so they will be disregarded. With both ends of Figure 29 fixed and a 10 lb force acting on the rail, this portion of the switch experienced a max deflection of 0.006 inches, and a minimum safety factor of 9.3; thus, this section will not fail.

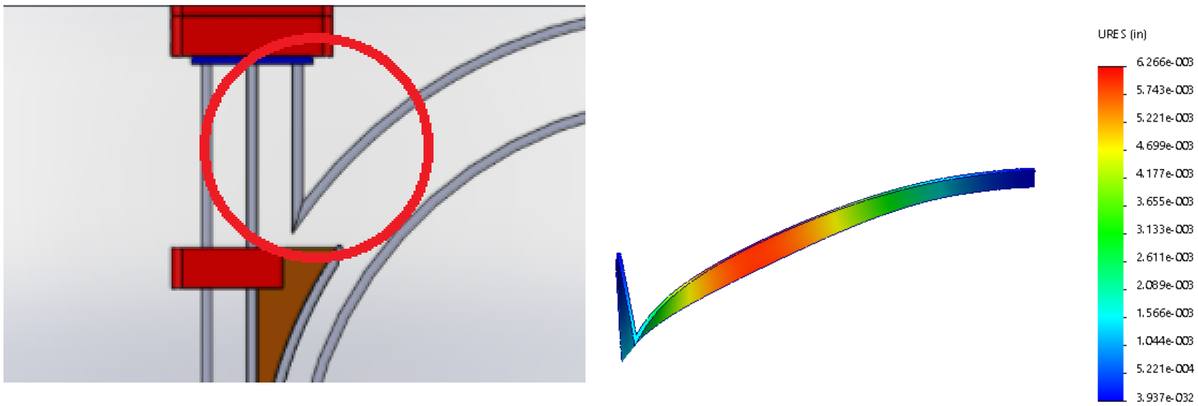
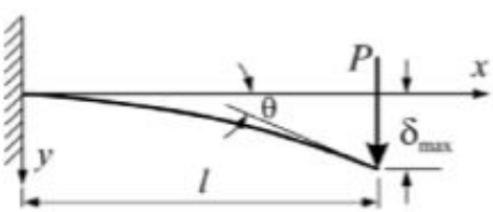


Figure 29 SolidWorks FEA results of switch rail

<u>Hanger Bracket</u>

To meet the 1.5-inch track width specification, the hanger bracket must be able to withstand any internal stresses from the aluminum rails. Two assumptions were made to find the necessary cross-sectional area of the bracket: the distance between hanger brackets was two feet, and the max deflection experienced by the bracket would be 0.25 inches. With these values, we also modelled the straight rail as a cantilever beam (Figure 30 details this calculation). Using these material properties and values, the calculated force would be the max force acting directly on the hanger bracket. Another assumption made to the bracket design was an assumed thickness of 1 inch; this thickness would provide enough room for the nuts and bolts required for this hanger design. The bracket must also have a max deflection of 0.05 inches to stay within the tolerances of our 1.5 track width specifications. Using all this values and assumptions, the required cross-sectional area was calculated and incorporated into the hanger bracket design. These calculations are shown in Appendix D. The stress caused by the bogies and rails vertically on the bracket were negligible.



$$\delta_{max} = \frac{Pl^3}{3EI}$$

Figure 30 Free Body Diagram for Cantilever Beam

<u>Third Rail Sleeve</u>

The third rail sleeve of the switch section (Figure 31) was designed to withstand the moment caused by bogies pressing on the third rail. This moment would cause bending stress and fracture of the housing, which would cause the bogie to drop through the clearance gap. For the SolidWorks FEA, a force of 10 lbs acts on the housing of third rail, as shown below. The material of the sleeve is Acrylonitrile Butadiene Styrene (ABS) plastic, which has a yield strength of 2683 psi. Results show that the max deflection of the housing was 0.01 inches (Figure 31), with a max Von Mises stress of 5.031 ksi and a minimum SF of 5.3. With these results, it can be concluded that the third rail sleeve will not fail.

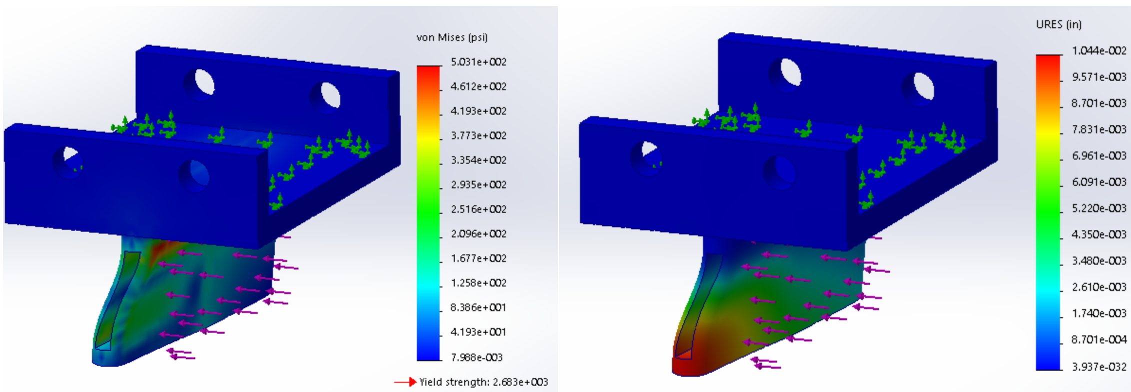


Figure 31 SolidWorks FEA results of third rail sleeve

Support Structures

To analyze the support structure, the team focused on analysis of the top-mounted square tubing. This component holds the most weight of the entire support structure because it carries the weight of the track, bogies, electronics for controls, and the cabin. Overall, if this part fails, the entire suspended system would fall. By utilizing SolidWorks Finite Element Analysis capabilities, this steel component was subjected to 15 pounds of load pointing downwards. The results show that the maximum deflection is .001" with a maximum von-mises stress reading of .002 psi and minimum safety factor of 35.5. These results show that our support structures excel at holding extra weight based on its design.

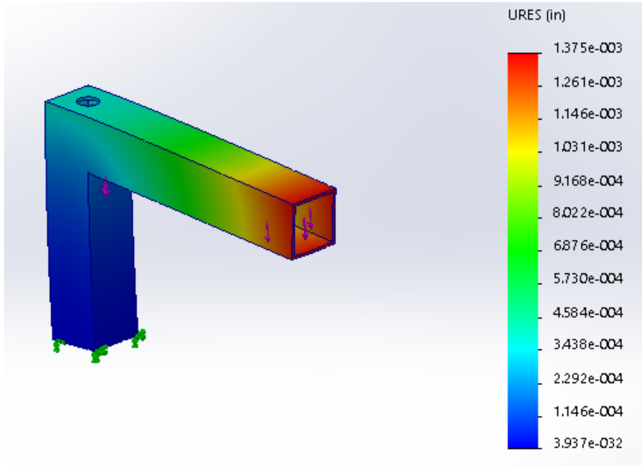


Figure 32 SolidWorks FEA results of top mounted square tubing of support

<u>Testing</u>

The first specification that we tested for the was the modularity of the track. Specifically, we tested whether the Lego-like design of the hanger bracket would work. As can be seen in Figure X, the brackets managed to fit together with very little wiggling. One problem that did arise however, was that the female side needed to be cleaned out. The female components had stray support structures left over from the 3-D printing process. Overall, with the brackets fitting together, the team had no problems shifting straights and curves around the track.

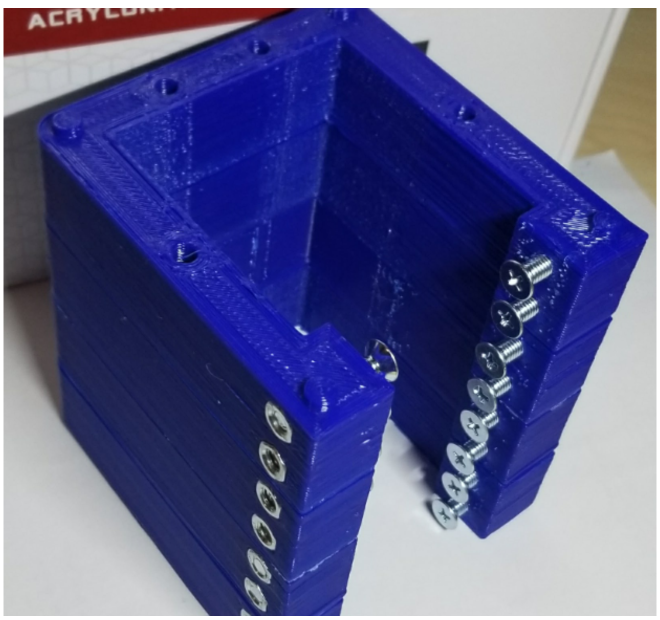


Figure 33 3-D Hanger Brackets Connecting like Legos

The second specification that the team tested was the inner track width of 1.5 inches. To do this, the team first tested the completed bogie on a straight section, as seen in Figure 34. The bogie did not bind at any point of the straight, so the team proceeded with manufacturing the rest of the straights.

Figure 34 2017-2018 Bogie Design Mounted on Straight Section

After the straight section, we tested the inner track width of the curved section. We did this by connecting a curved section onto the straight section. After ensuring that the curved section did not cause the bogie to bind, we proceeded to manufacture the other curved sections, as well as the switch section. Concentricity was a main concern for the team this year, so we fit the bogie into these manufactured sections before mounting them. The team did run into binding problems for one of the curves, so the issue was resolved by bending a new outer curve.

Figure 35 2017-2018 Bogie Design Mounted on Straight Section

For the switch section, there were a variety of concerns to test. First, the team had to ensure that the bogie's servo arm would fit through the brackets when the third rail sleeve was amounted. As seen in Figure 36, the arm had clearance of about ½ inch; the bogie should have no problems binding vertically. In addition, the servo arm maintains contact with the third rail, so there the bogie should not fall off the track; a problem with previous iterations of the track.

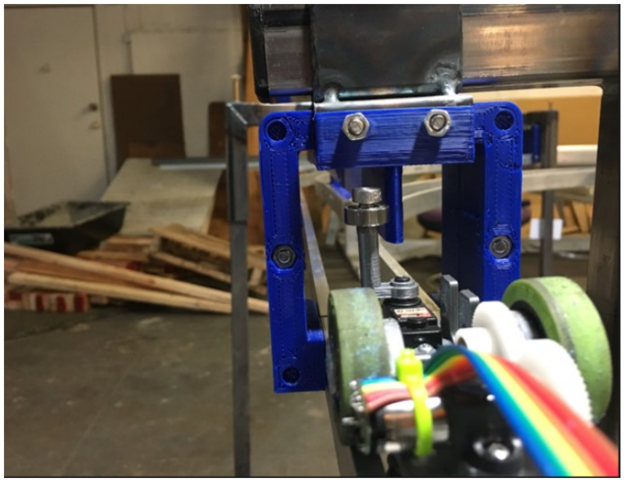


Figure 36 Servo Motor Clearance Testing

The next portion of the switch that was tested was the 6-inch clearance gap seen in the switch section design. The left side Figure 37 shows that the bogie wheels maintain contact with the double rail when performing a switch onto the straight rail. This is also true when the bogie makes a transition onto the curved portion, as seen on the right side of Figure 37

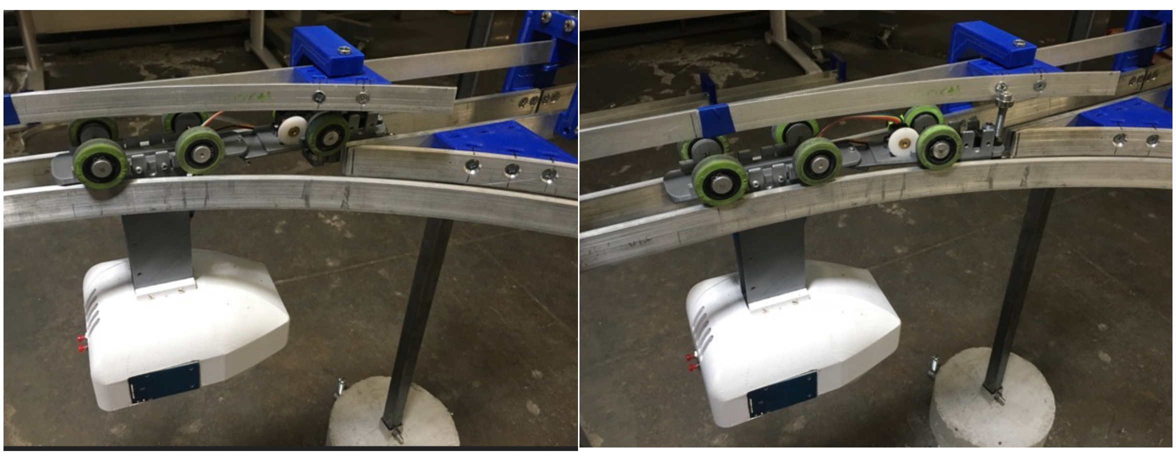


Figure 37 2017-2018 Bogie Design Passing Clearance Gap of Switch Section.

The final section to test for the track was the ability of the support leveling system, shown in Figure 38 below to achieve a 15% grade, or about 8.3 degrees. After drilling one bolt all the way through, the team measured a maximum angle of about 6.3 degrees. Although this measured angle did not meet the design specification, it can achieve the 15% grade by inserting bolts 2.5 inches or longer into the system.

Figure 38 Leveling system of the Support Section. This version can achieve a 6.3-degree incline

With each section of the track tested for design specifications, the only testing left was the to put the entire track together, Figure 39, to determine if any section of the track was causing the bogie to bind. While at the shop, the bogie ran flawlessly, but when the team reached Maker Faire, the switch section had tolerance issues. First, bogie wheels were colliding with the rails of one of the switch section; the curved portion was too tight, shifting the rails slightly right. On the other switch, the rails were a little too wide, so the bogie would occasionally fall through. With some minor support shifting, the issue was mostly resolved.

Figure 39 Completed Assembly of 2017-2018 Spartan Superway Track

Budget

The original budget for the entire project was estimated to be $1,443.87 USD as shown in Table 2 and Figure 40. The largest expenses were raw materials and hardware from Amazon, Midwest, Gorilla Metals/Metal Werx and McMaster. All the steel tubing and hot rolled flat bar stock was purchased from Metal Werx except for the 1.5-inch square tubing which was purchased from McMaster. All the aluminum was purchased from Midwest Steel Supply Co. Previous semesters utilized West Coast Aluminum (local vender). Due to the estimated wait time the Aluminum was purchased from Midwest since prices were comparable. Miscellaneous items such as tools, welding supplies and fabrication supplies were purchased from the remaining vendors. A complete breakdown of all purchases and cost can be found in Appendix X. Compared to the original bill of materials, additional items needed to be purchased to complete fabrication. Costs were reduced from the previous bill of materials by utilizing discounts and sales as frequently as possible. Overall, fabrication remained $55.05 USD under the proposed budget.

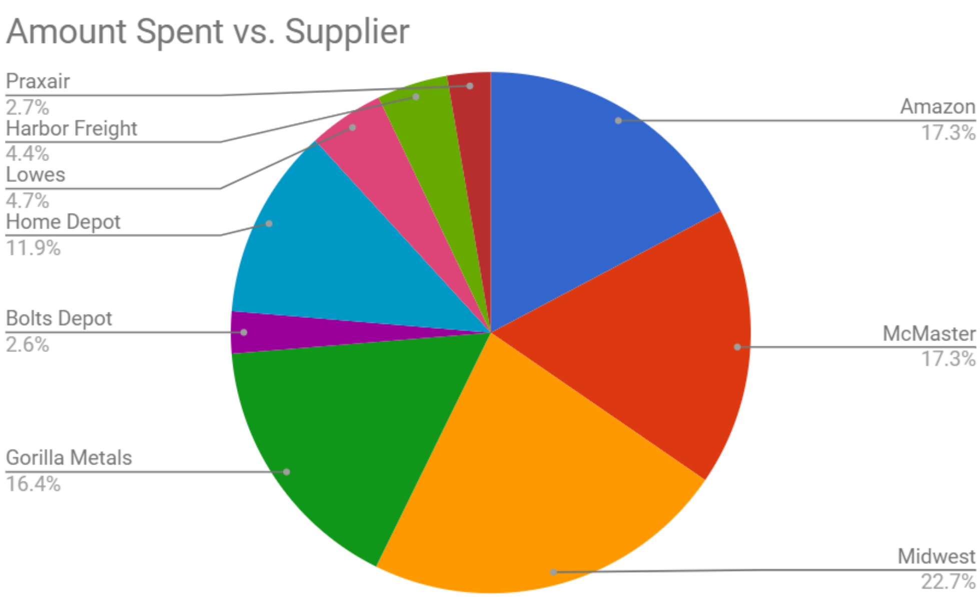


Figure 40 BOM Pie Chart

Table 2 BOM for the 2017-2018 Spartan Superway Track and Manufacturing

Order Total by Vendor:	
Supplier	Money Spent
Amazon	$ 239.88

McMaster	$ 240.27
Midwest	$ 315.25
Gorilla Metals	$ 228.33
Bolts Depot	$ 36.25
Home Depot	$ 164.86
Lowes	$ 65.32
Harbor Freight	$ 61.17
Praxair	$ 37.49
Total:	**$ 1,388.82**
Budget:	**$ 1,443.87**
Remaining:	**$ 55.05**

Results and Discussion

Successfully designing, manufacturing and testing the track proves that implementation of the double rail system into the Spartan Superway can be achieved. Translating all the progress of the Small-Scale Track and Manufacturing team to the full-scale model will propel the Spartan Superway project in the right direction.

After testing each section of the track, the following results were observed. First the bogie had minimal problems maneuvering each modular section of the track. Most of the sections stayed within the 1.5 ± 0.15 in inner track width. The only binding concerns were at the switch. The servo arm successfully contacted the third rail, and the third rail was able to support the weight of the bogies. The bogie was also able to transition through the 6-inch clearance gap of the switch section. The leveling system of the track failed to meet expectations, as the supports could only adjust 6.3 degrees, slightly below our desired specification of 8.3 degrees. This, however, can be solved by inserting 2.5 + inch long screws.

Overall all the designs met their safety requirements, the minimum safety factor for the entire track was 5.3. With this safety factor, and through testing the track, we confirmed that no portion of the track failed or would cause the bogie to drop on the ground.

Conclusions and Recommendations for Future Work

Overall, this year's project was a success. The track was built, and the bogie ran through without falling due to the double rail design. Modularity was a success as well, since three unique track components and a support structure that can be fully disassembled were created. By designing and manufacturing a leveling system in the support structure, uneven terrain did not stand in the way during Maker Faire. Although this iteration of the track only met 6.3 degrees of grade out of 8.3 degrees, this issue can be alleviated by utilizing longer bolts to further increase the capabilities of the leveling system.

Focusing the design on the hanger bracket revolutionized this year's track design by achieving modularity and by improving the strength of the previous brackets. The previous brackets did not help the old track because it caused binding and problems when the bogie passed through. This change had a hand in helping this year's model create modular subassemblies that sped up assembly and disassembly times during Maker Faire. However, throughout the year the team faced issues with manufacturing. The main issue that the team faced was creating concentric bends due to its effects of causing the bogie to bind and hinder its progress through the track. This setback held us back for a week, until the team figured out a different manufacturing method of creating a slip-roll.

Over the past year, this team spent the most time in the shop due to the overload of manufacturing work that needed to be completed throughout the semester. By following the older group members' advice, this team started early and started manufacturing in early February. Even with this early start, the last component wasn't completed until early May, just in time for the last presentation. This is also factoring that each team member spent at most two extra days in the shop, on top of the general Wednesday meeting, to shoulder the manufacturing load. Overall, this manufacturing pace is simply unsustainable and not recommended for future teams of three to partake in.

Improvements

Based on the work that this year's track team compiled, future teams can expand the track to their liking. By creating modular designs, it is easy to expand the track and include a new section altogether. However, this year's track system is not perfect and there are improvements that need to be made.

First, it is important to look at the manufacturing process for the support structures. The support structures proved to work as intended, however there were some sagging welds, poorly machined components, and a lot of manufacturing that needed to be put into creating this subassembly. Due to the need of keeping costs low, the team decided to manufacture everything in house. Because of this, the support structures had small flaws with every model made. Moving forward, future members of this project should investigate either outsourcing these components to ensure that they are properly manufactured or looking for an alternative design that allows the users to still change the height and level the system at its base. By designing for manufacturability and maintaining the fundamental functionalities of the supports in mind, future iterations of Spartan Superway's small-scale model will continue to progress.

Figure 41 The support structures holding up a small subsection of the track

Another manufacturing issue that needs to be improved from this year's model is the slip-roller or ring-roller. Figure X shows this mechanism. Future teams can be assigned into creating this tool and improving it with better materials and potentially flanged wheels to keep the metal on the same straight path. This is critical due to the potential of creating bowed bends that are not leveled. This is the main issue why this new slip-roller had to be manufactured. Creating a better functioning slip-roller allows Spartan Superway to create concentric bends in house and saves costs compared to outsourcing all the work.

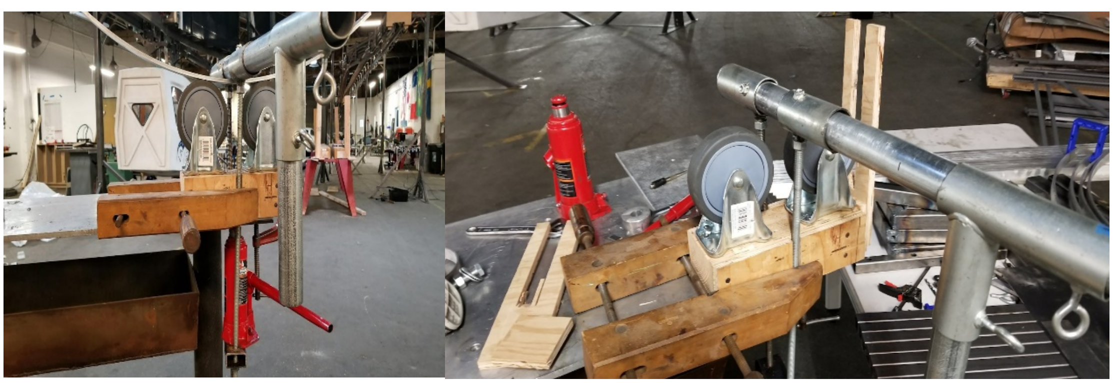


Figure 42 The slip roll used to create the curved sections of the track

This year's track consisted of three main track subassemblies, which are the switch, straight, and curves. However, moving forward different options could be explored to create "T styled intersections," or full intersections where bogies are able to make more complex decisions. At

Maker Faire in 2018, the middle of the track remained empty since the older model of the track was not taken. Therefore, filling this space up should be the next focus for the following year's teams.

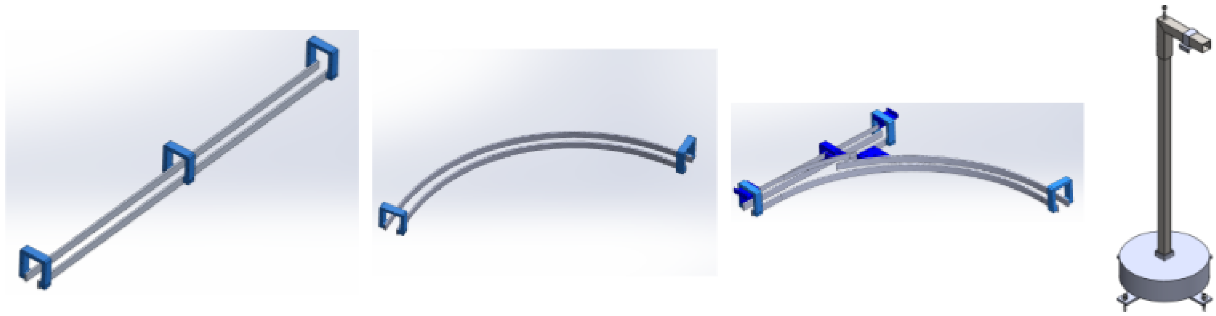


Figure 43 The three subassemblies of the track with the support structure

Furthermore, since this system is supposed to be solar powered, improvements should be made to accommodate a small-scale solar team. Previously, these solar panels were mounted onto the support structures as shown in Figure 44. Like the solar panel improvements, a charging bay should also be implemented into future iterations of the track. By adding a charging bay, Superway is presented an opportunity to fill in the middle portion of the track with a new subassembly that will add further functionality to the guideways.

Figure 44 The empty space in the track can be filled with more robust track components.

Another improvement that could be implemented into future track models could be implementing a better loading station than the one currently used. Currently, the entry point for the bogies lies on one straight section that has a flimsy hasp and lock assembly mounted on it with small screws. Referring to Figure 45 allows one to understand this section of the track. The issue with this design falls when the track is not perfectly square. When this occurs, the lock is subjected to strenuous loads and could potentially cause the part to fail later down the line.

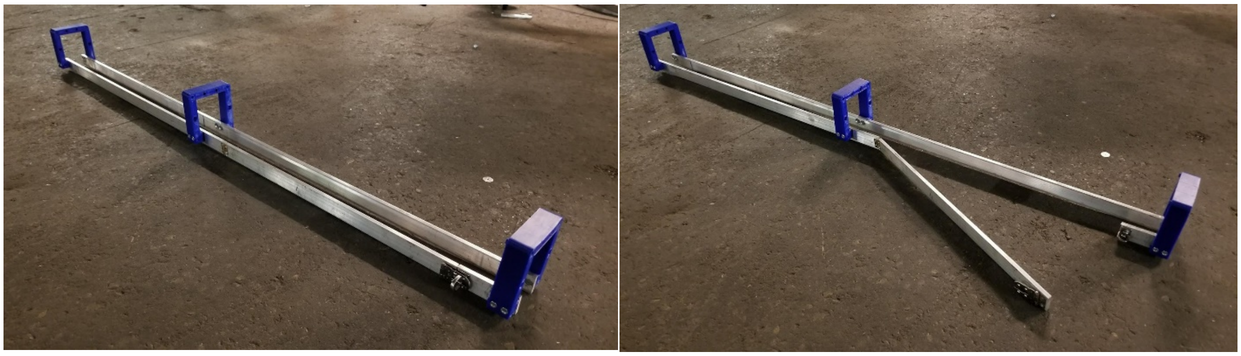


Figure 45 Straight Section with hinge to insert bogies

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Appendices

Appendix A: Engineering Drawings

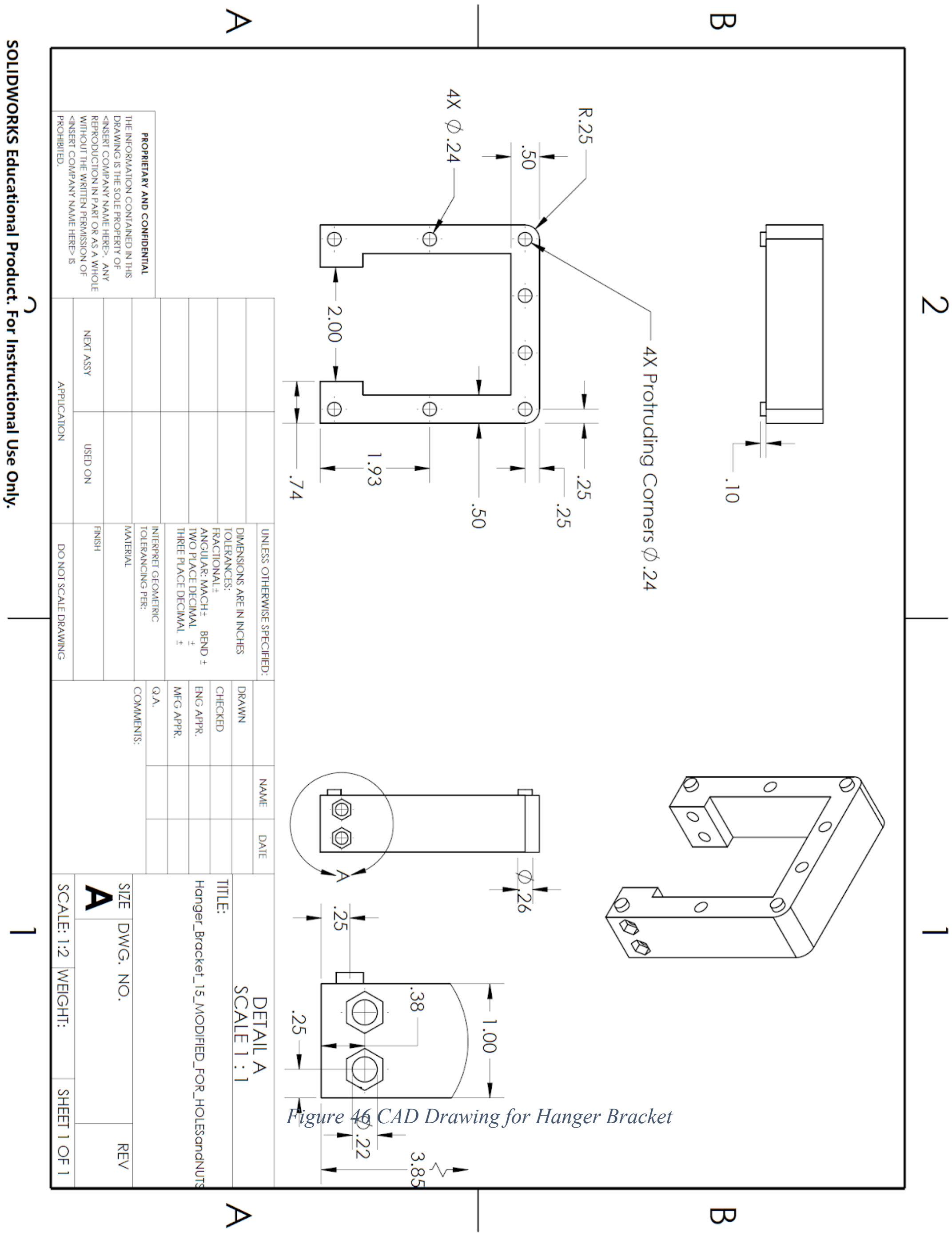


Figure 46 CAD Drawing for Hanger Bracket

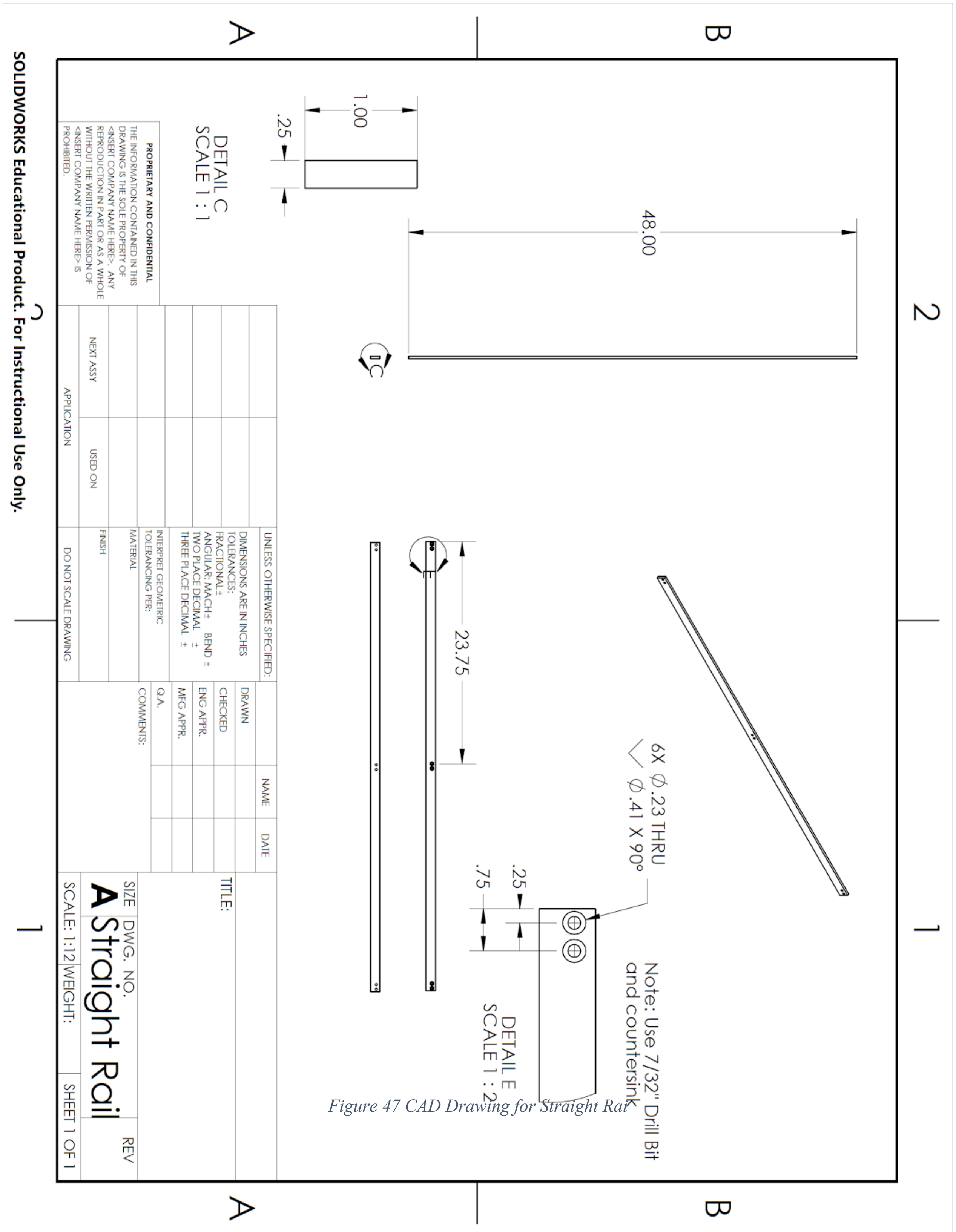


Figure 47 CAD Drawing for Straight Rail

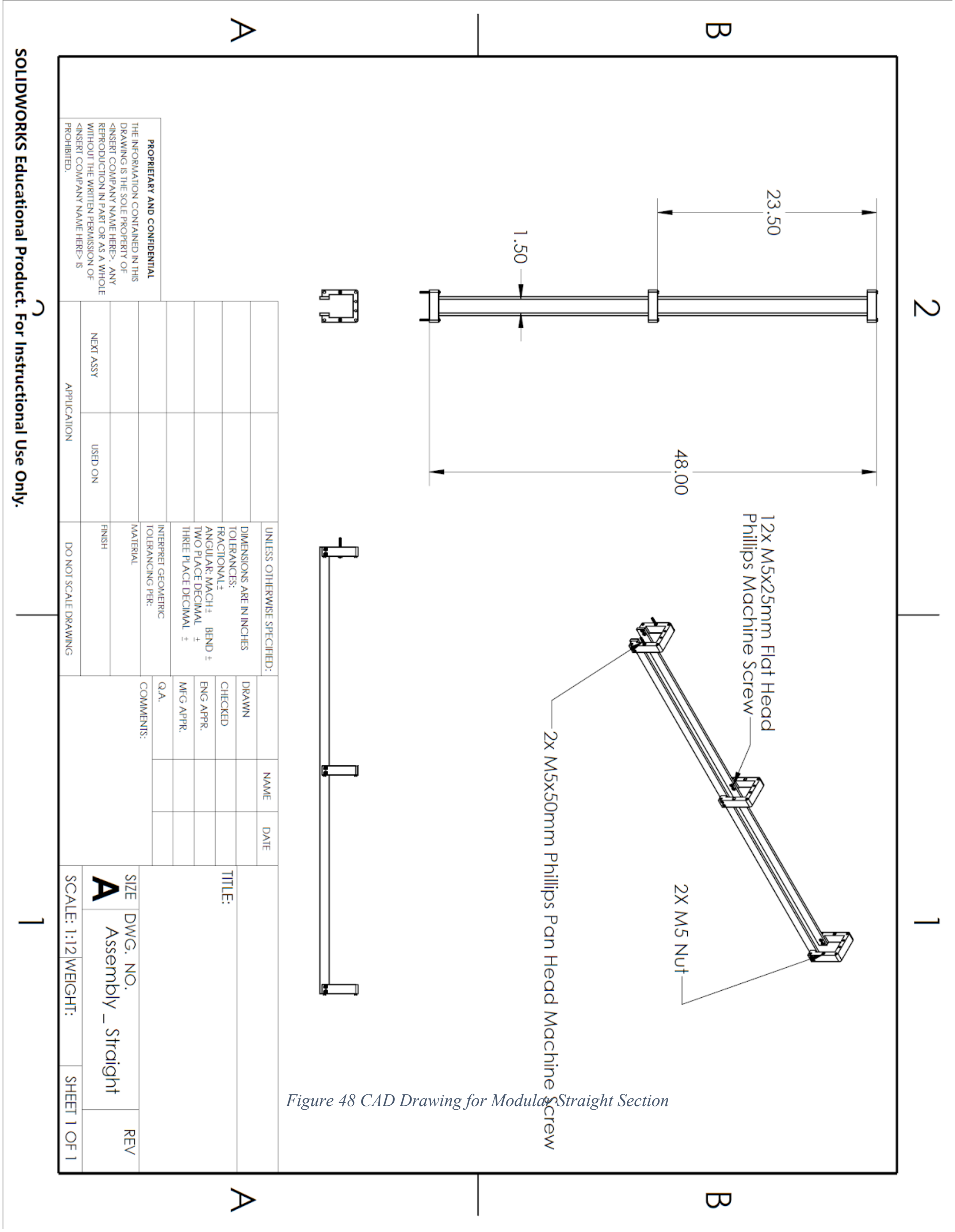


Figure 48 CAD Drawing for Modular Straight Section

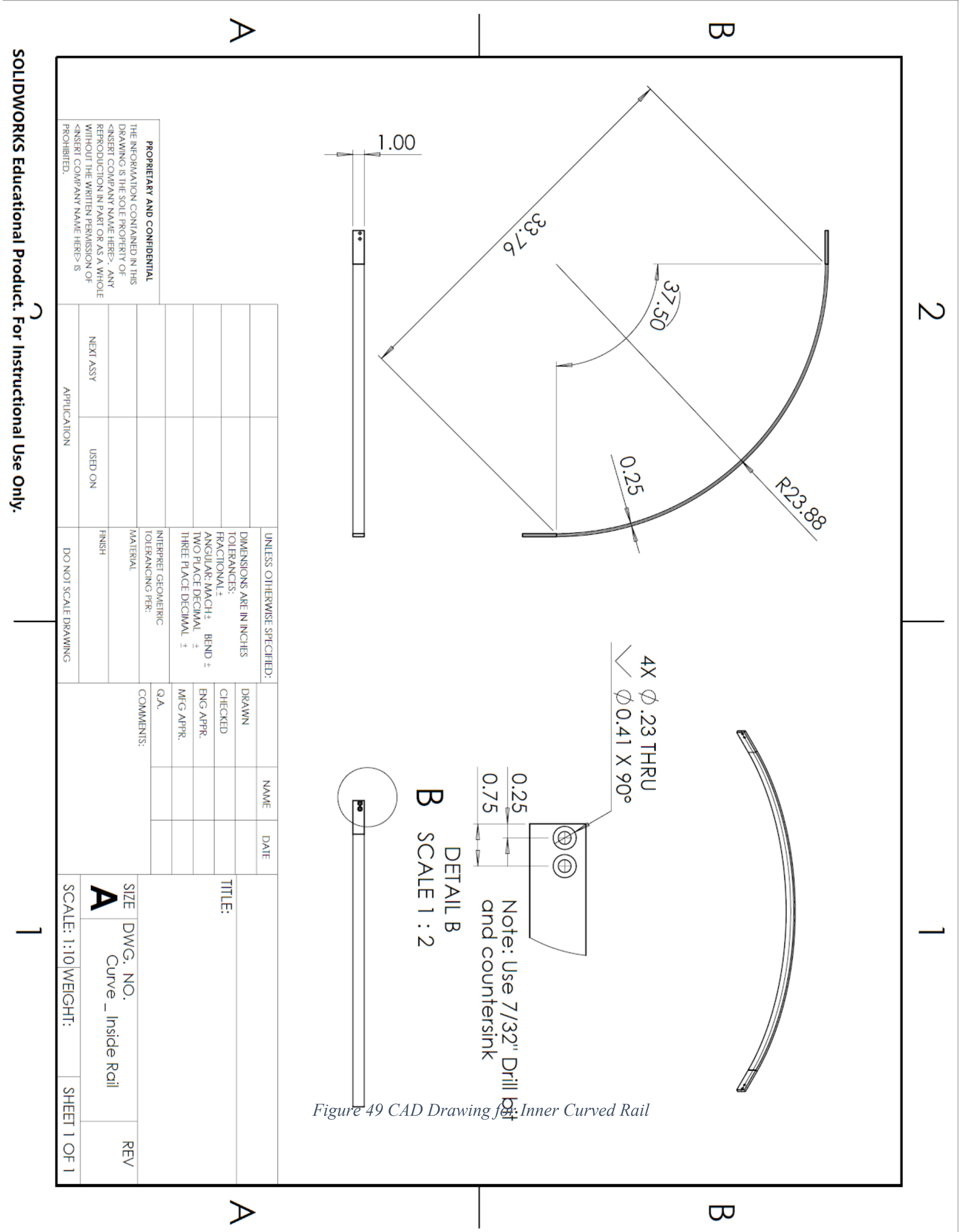


Figure 49 CAD Drawing for Inner Curved Rail

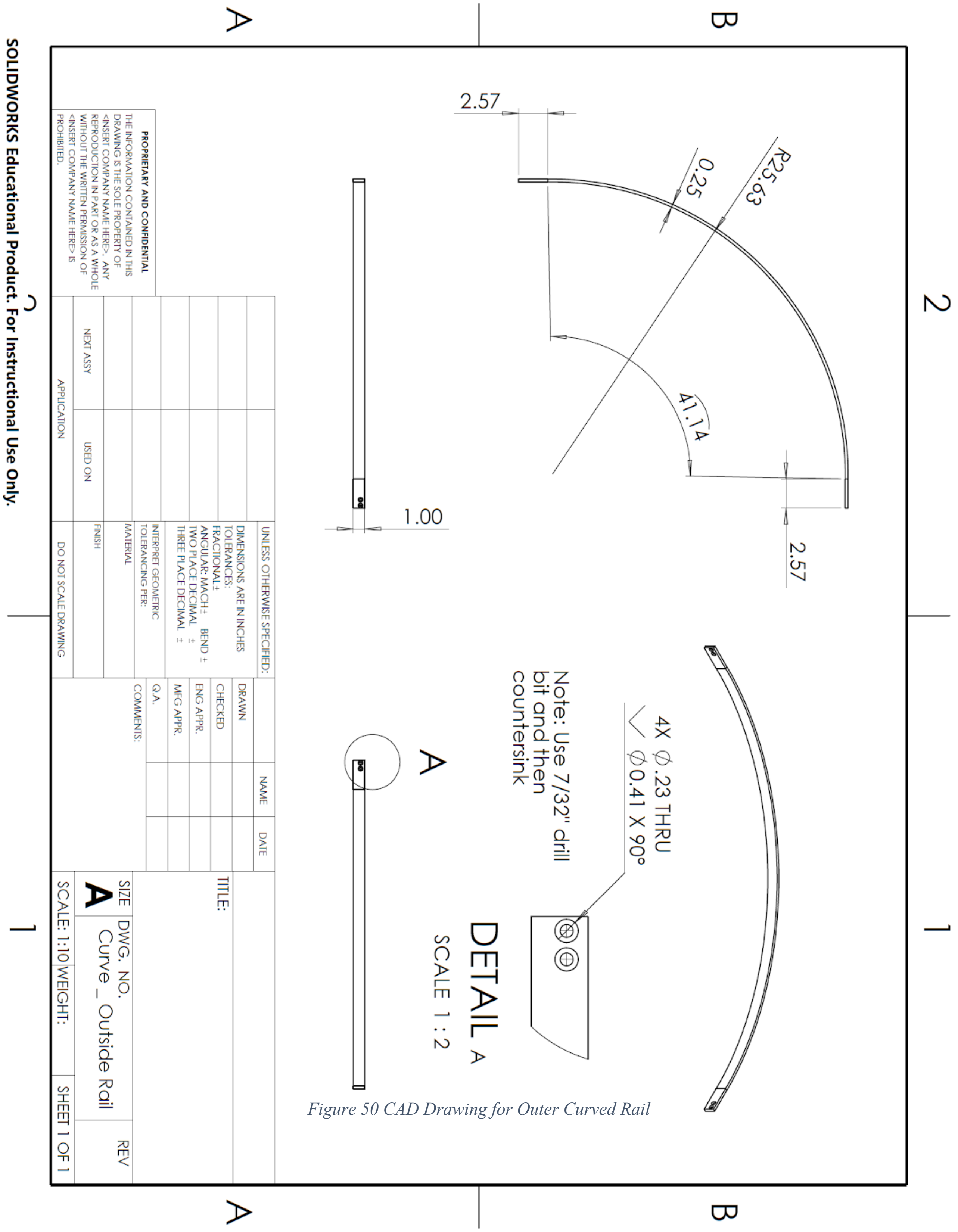


Figure 50 CAD Drawing for Outer Curved Rail

SPARTAN SUPERWAY

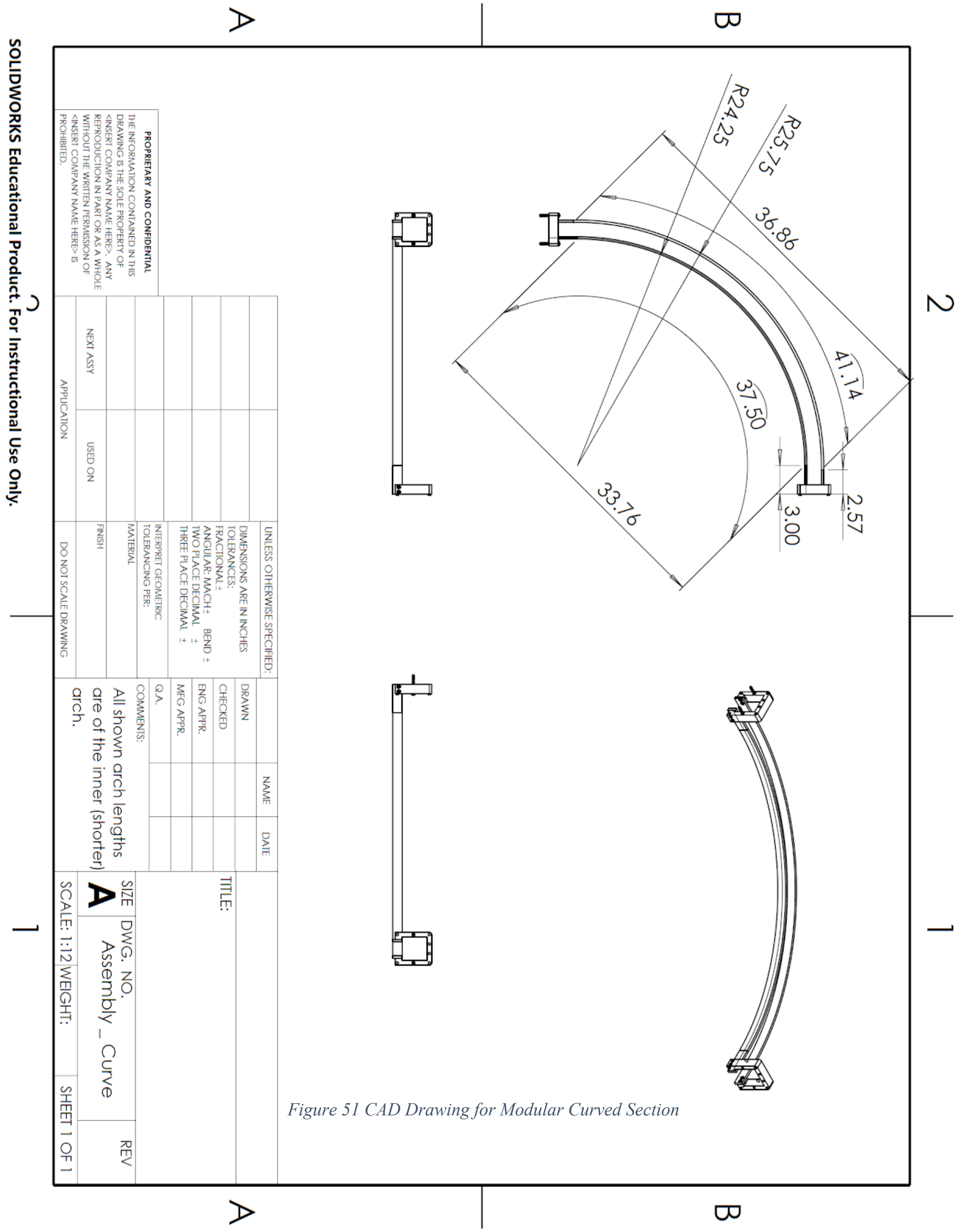


Figure 51 CAD Drawing for Modular Curved Section

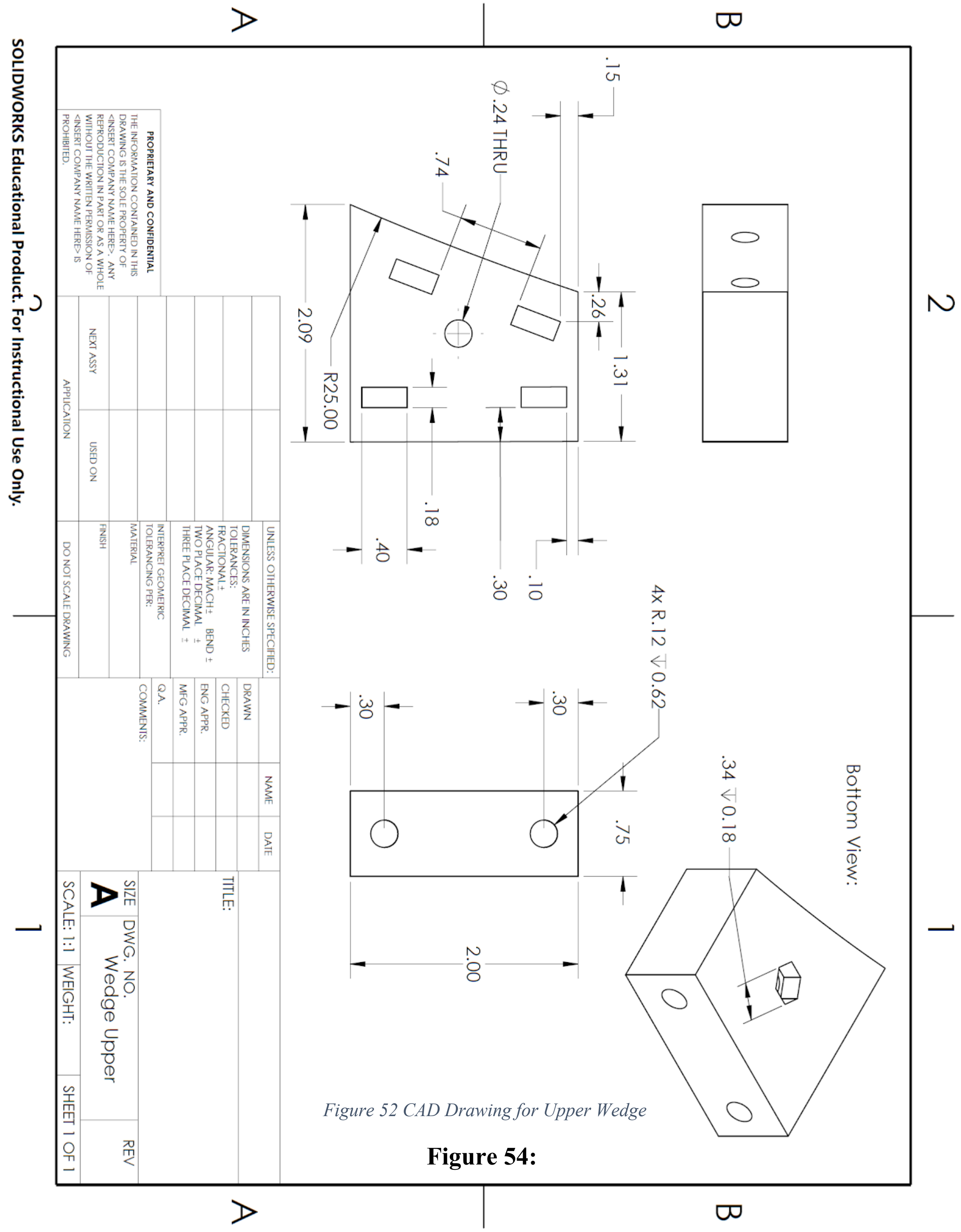


Figure 52 CAD Drawing for Upper Wedge

Figure 54:

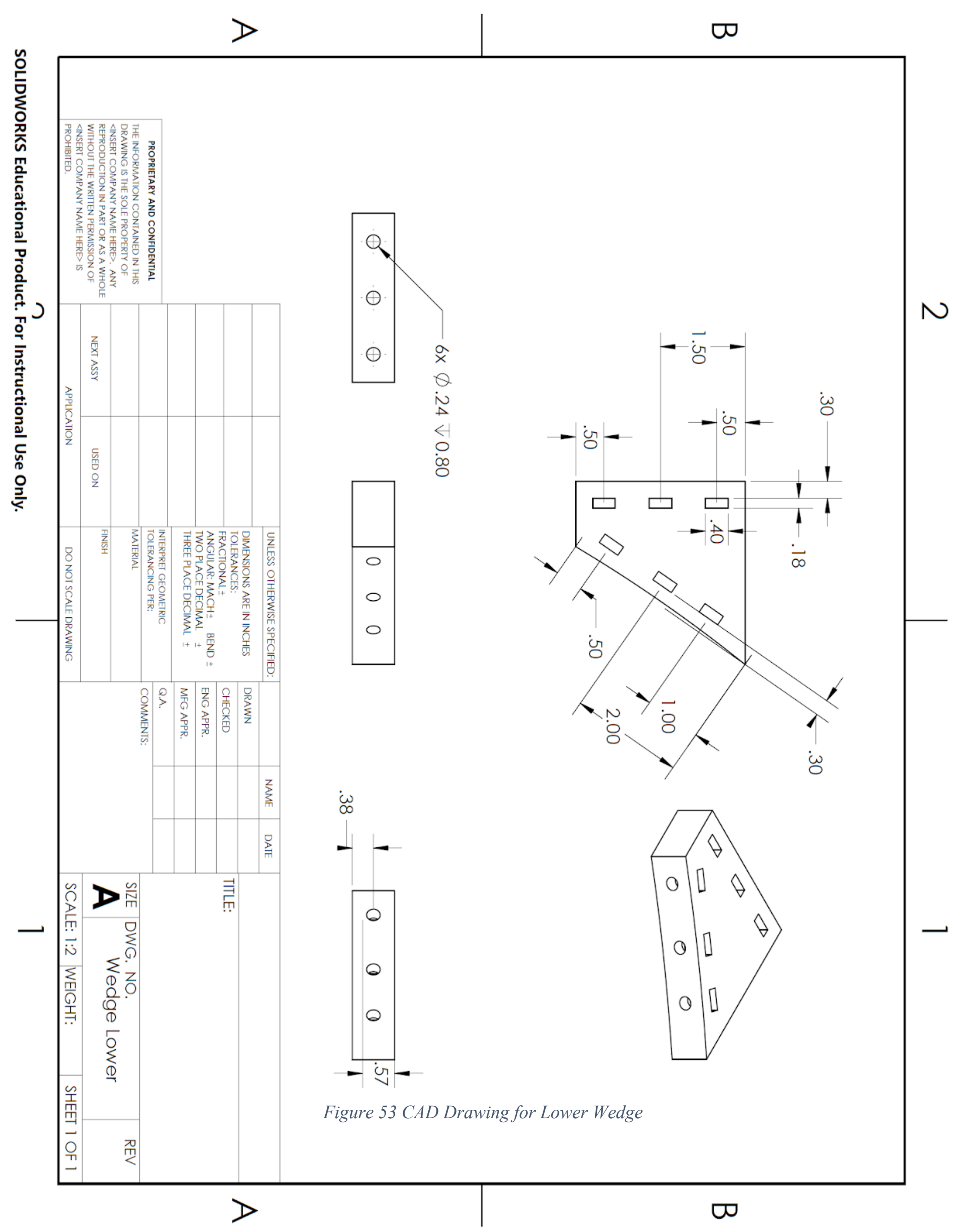


Figure 53 CAD Drawing for Lower Wedge

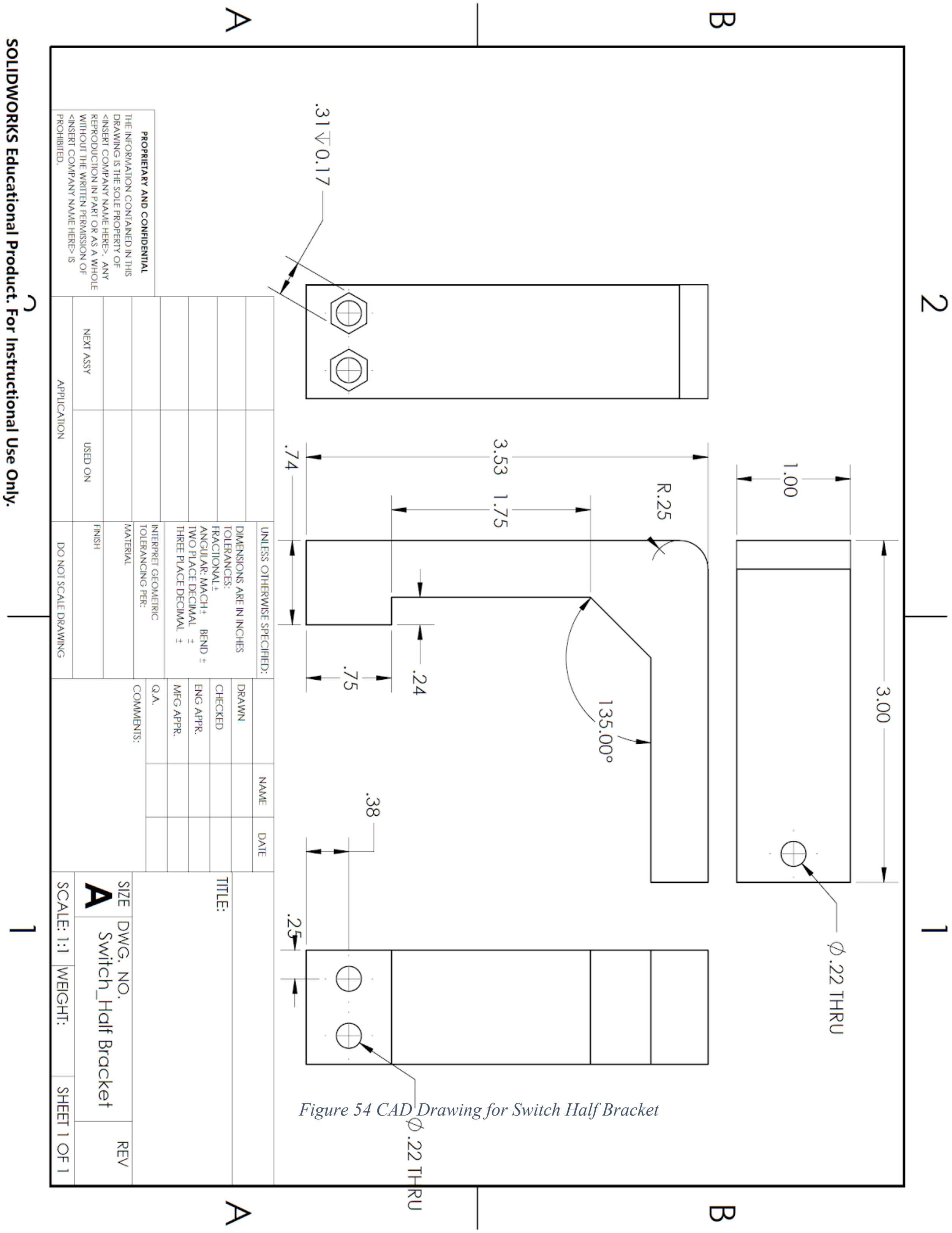


Figure 54 CAD Drawing for Switch Half Bracket

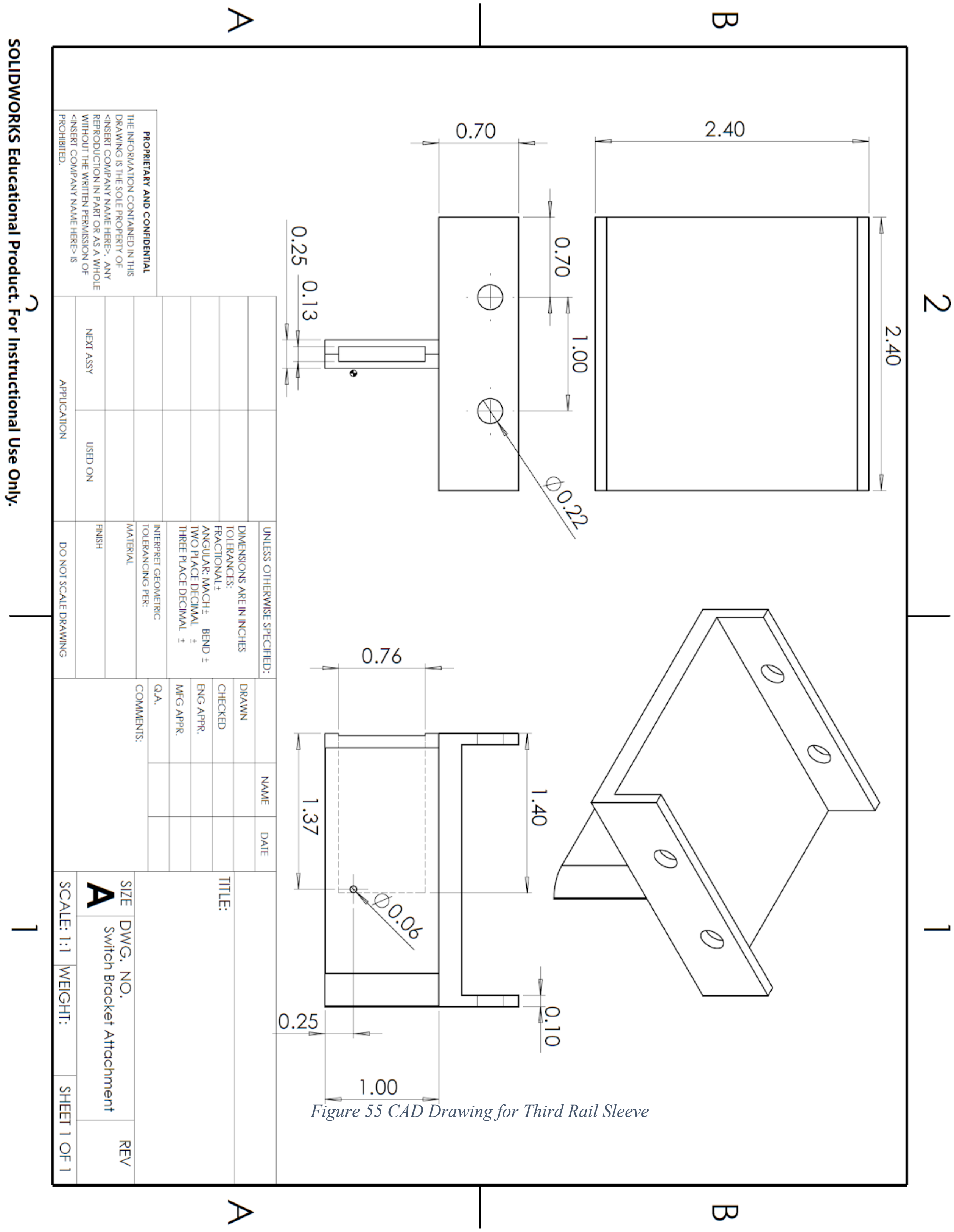


Figure 55 CAD Drawing for Third Rail Sleeve

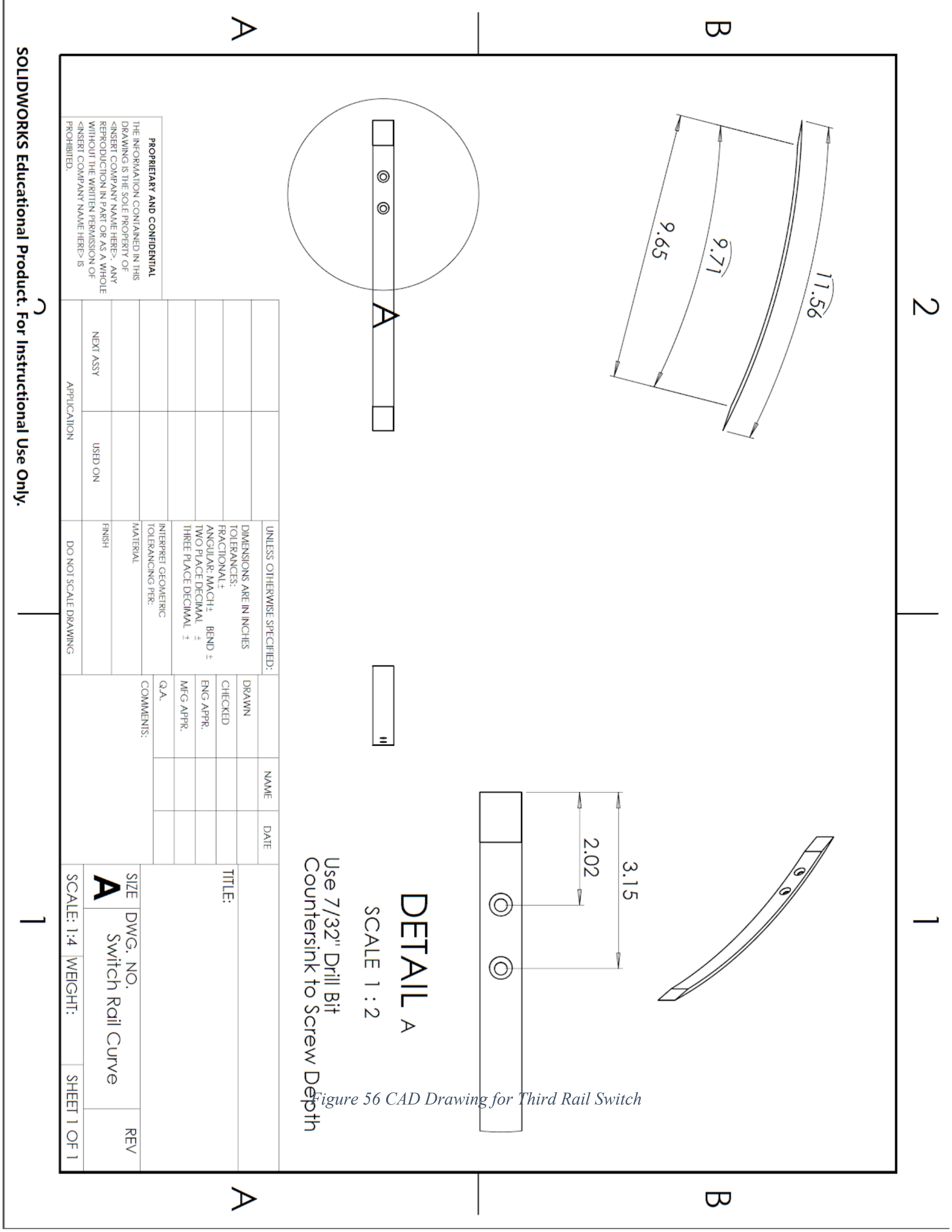


Figure 56 CAD Drawing for Third Rail Switch

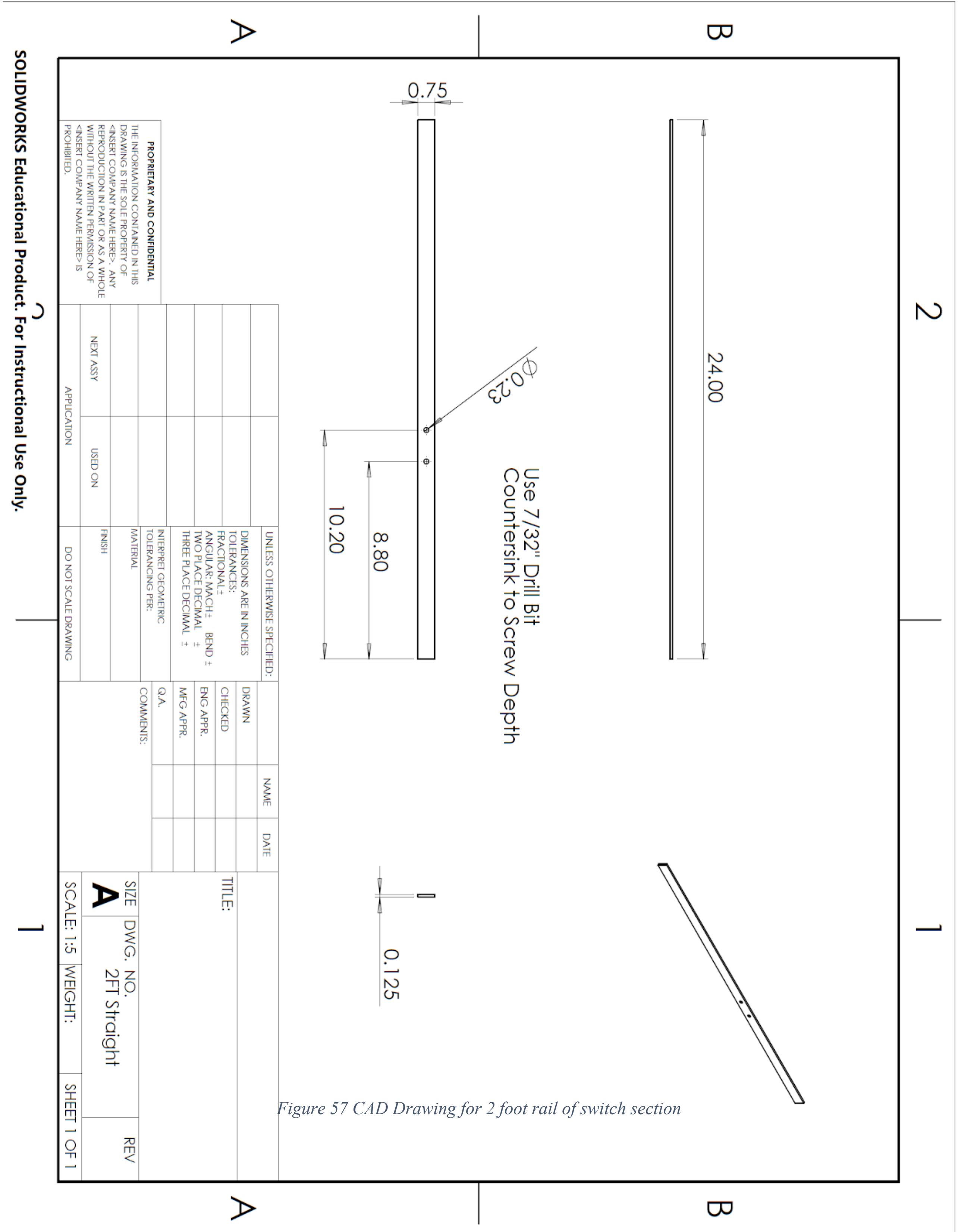


Figure 57 CAD Drawing for 2 foot rail of switch section

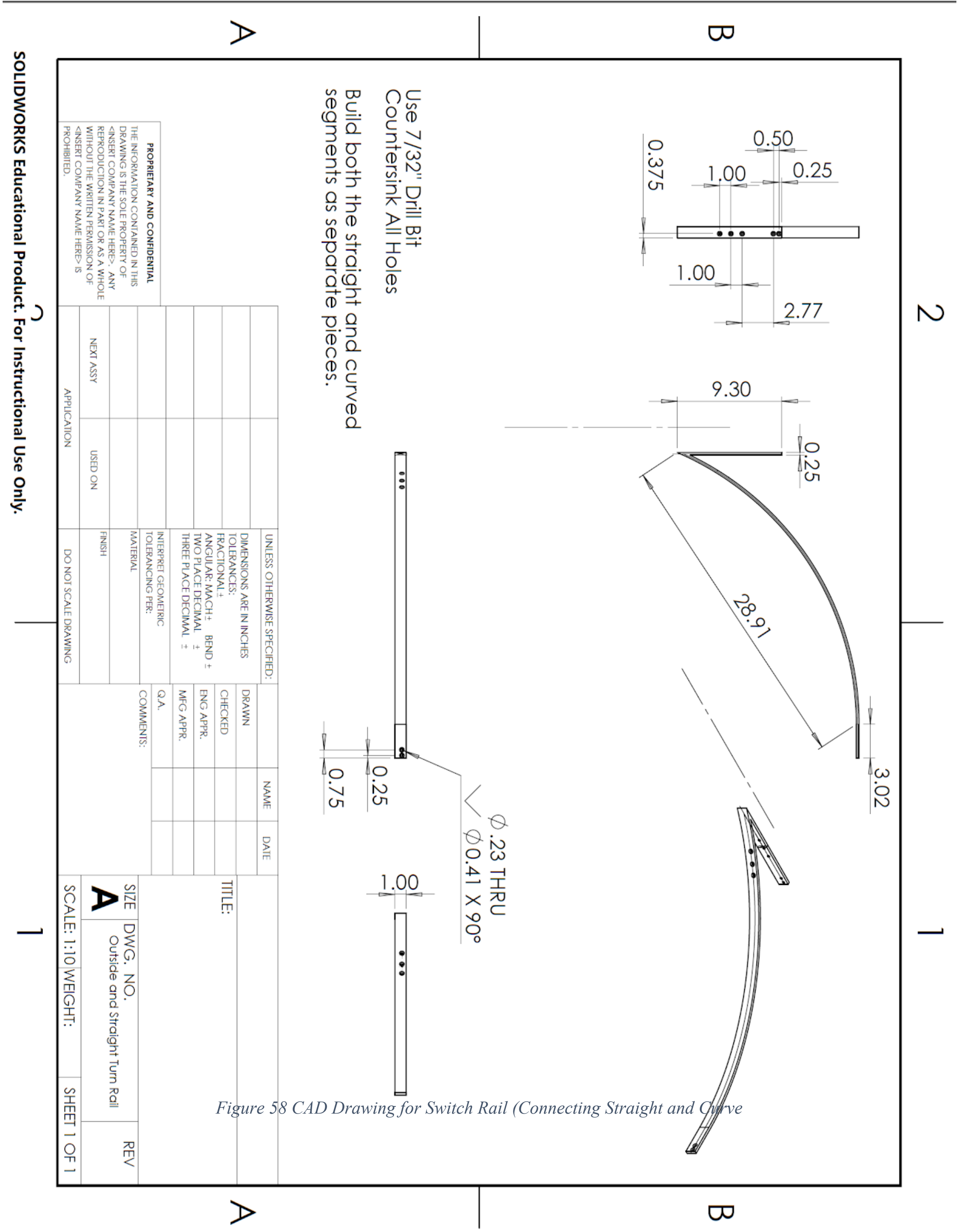


Figure 58 CAD Drawing for Switch Rail (Connecting Straight and Curve

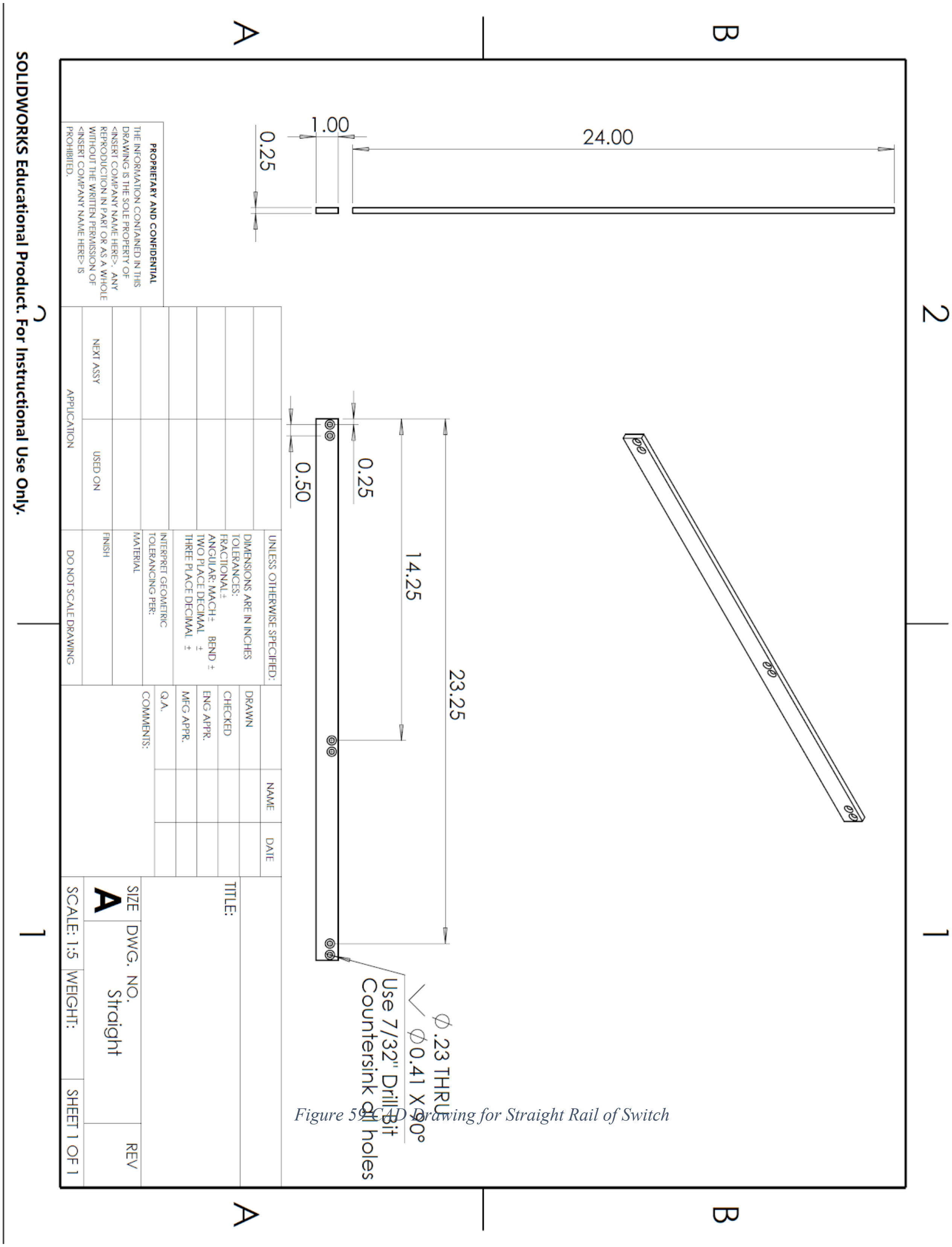


Figure 59 CAD drawing for Straight Rail of Switch

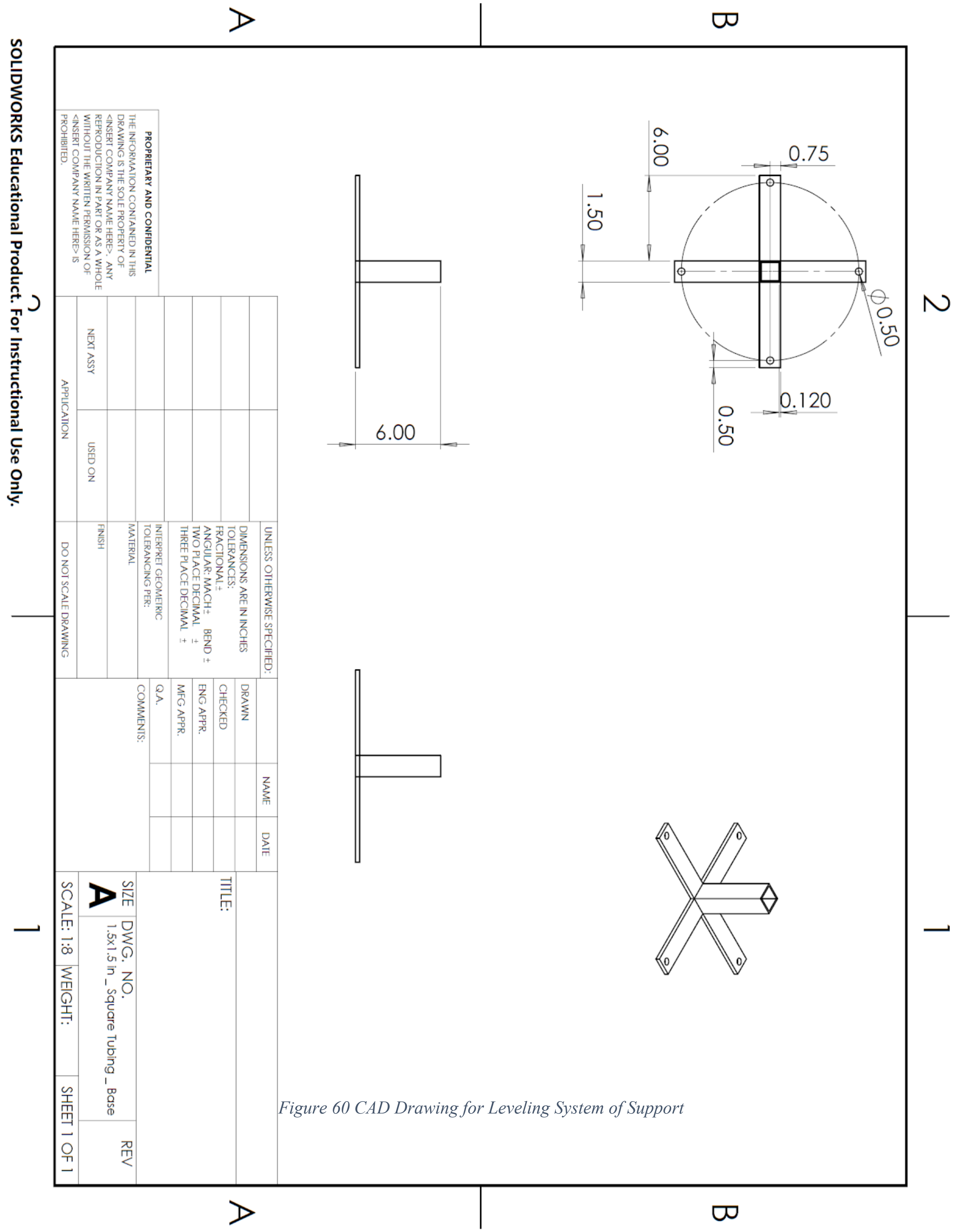


Figure 60 CAD Drawing for Leveling System of Support

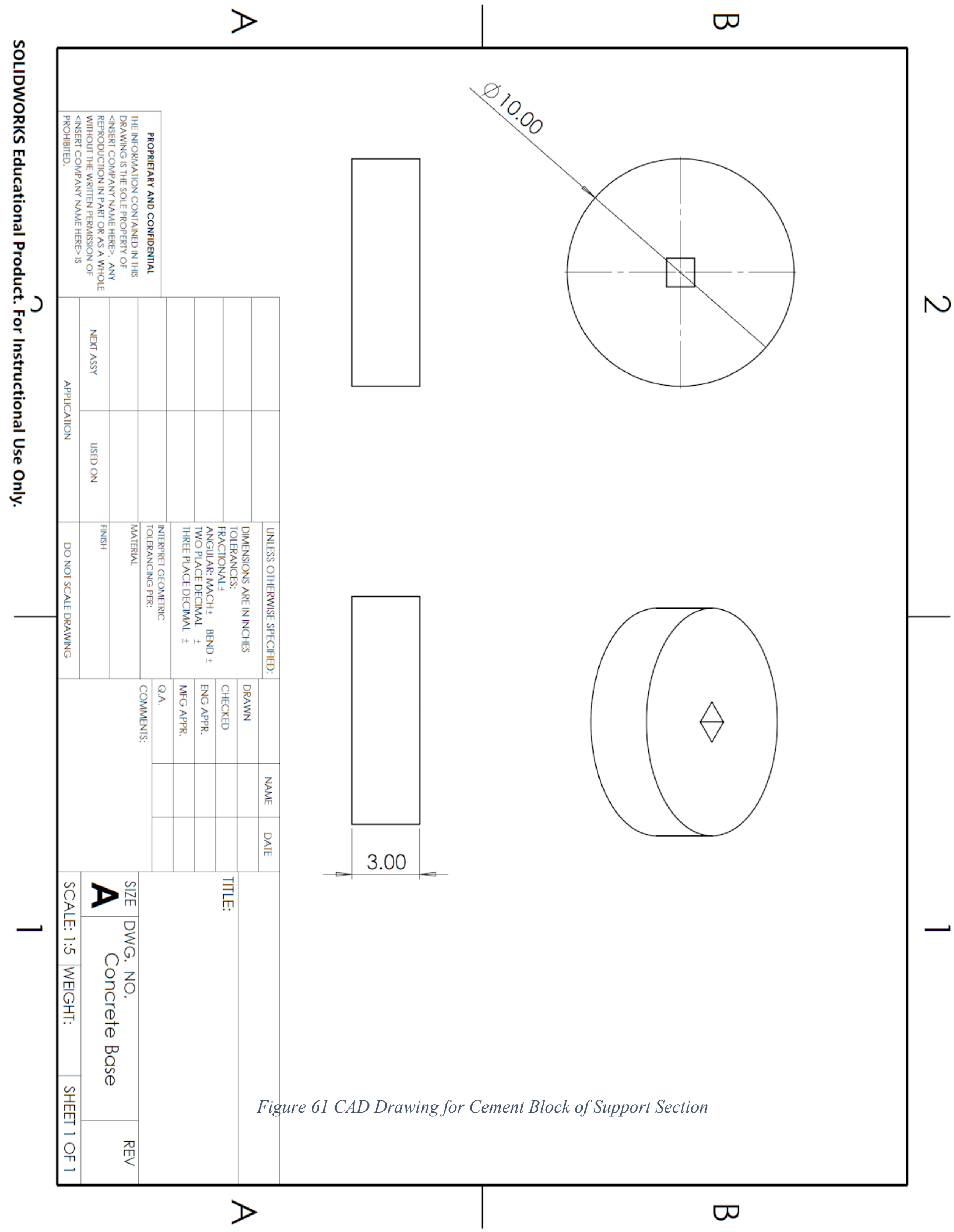


Figure 61 CAD Drawing for Cement Block of Support Section

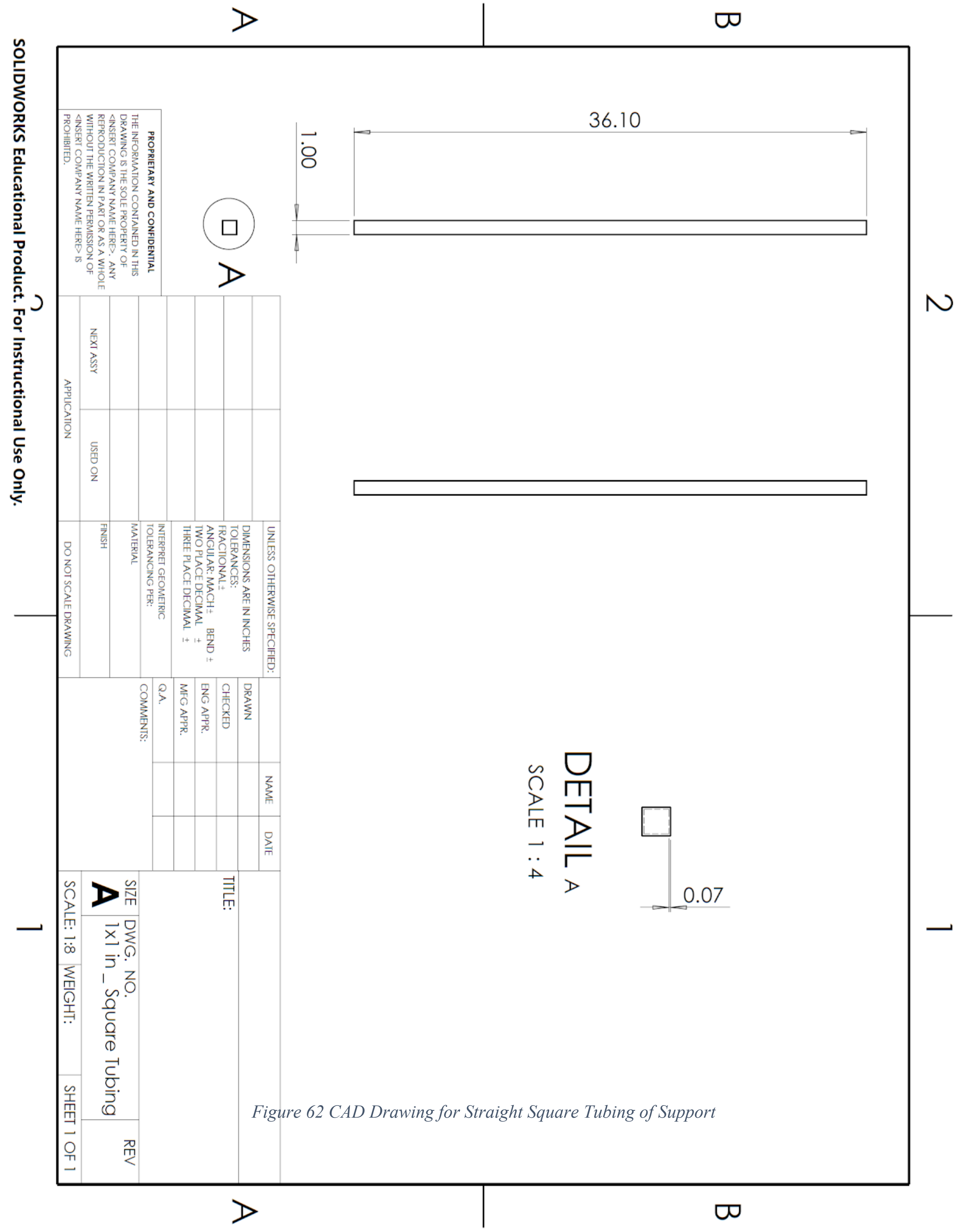


Figure 62 CAD Drawing for Straight Square Tubing of Support

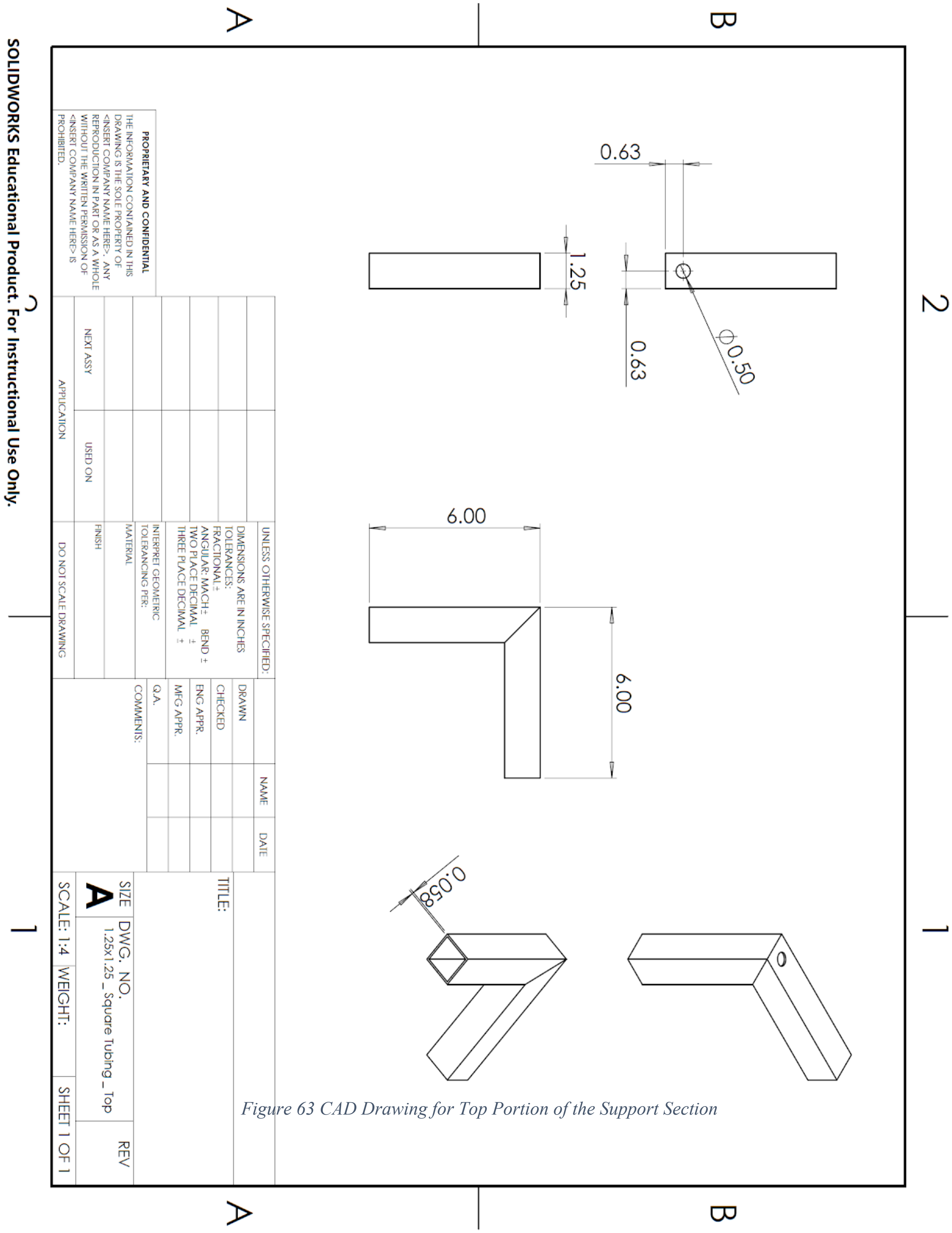


Figure 63 CAD Drawing for Top Portion of the Support Section

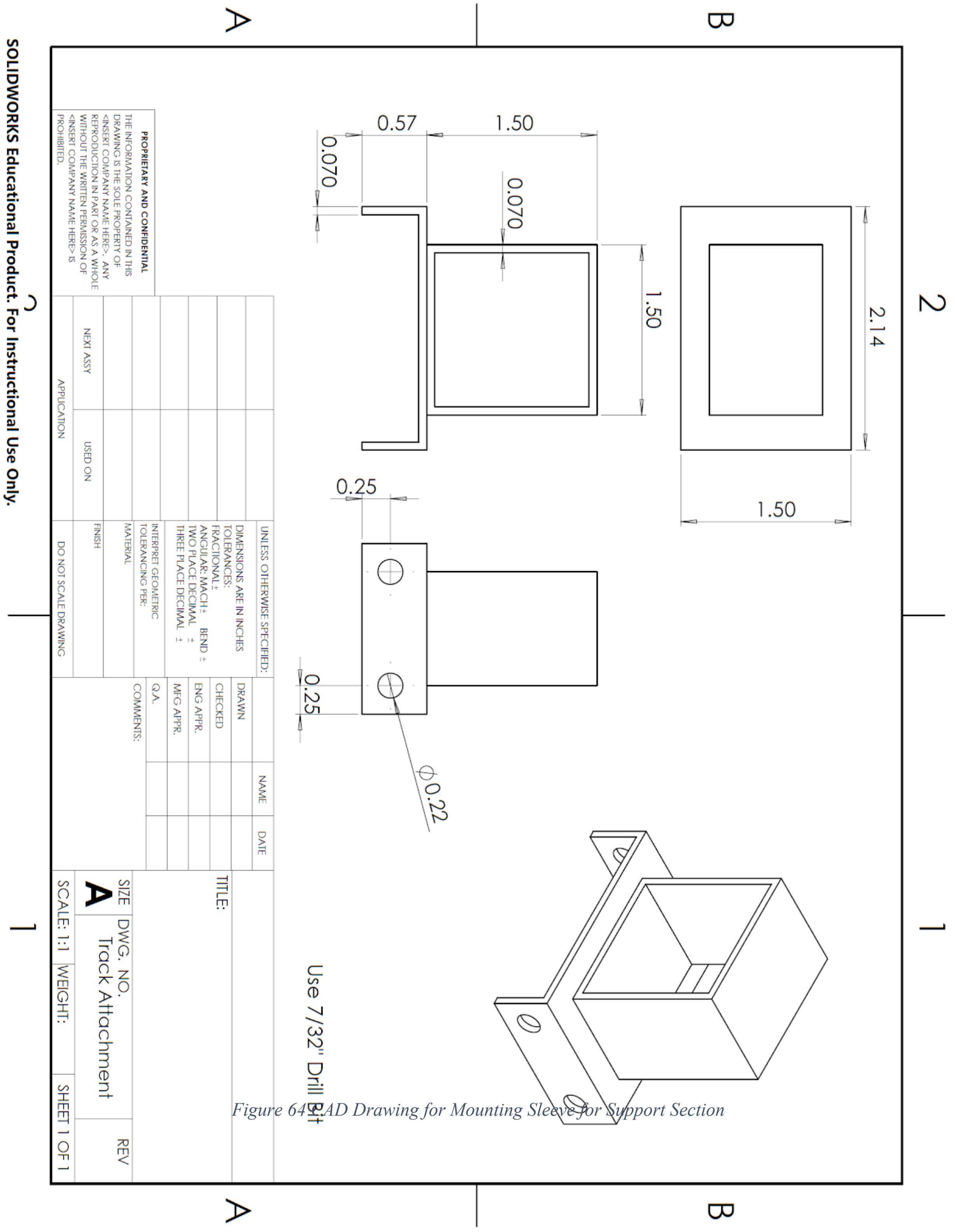


Figure 64 CAD Drawing for Mounting Sleeve for Support Section

Appendix B: Bill of Materials

Table 3 2017-2018 Small Scale Track and Manufacturing Completed BOM

2017-2018 Small Scale Track and Manufacturing Team Actual Purchases				
Total	**$ 1,388.82**			
Budget	**$ 1,443.87**			
Remaining	**$ 55.05**			
Supplier	**Description**	**Quantity**	**Unit Cost (include taxes)**	**Cost**
MCMASTER-CARR				
Order 1	Steel Phillips Rounded Head Screw (50mm/2 inch) - 25 per package	5	$ 7.00	$ 35.00
	Zinc-Plated Steel Hex Nut - 100 per package	4	$ 2.69	$ 10.76
	Steel Phillips Flat Head Screws - 100	3	$ 7.20	$ 21.60
	Zinc Yellow Chromate Plated Hex Head Screw 5/16-18 (50)	2	$ 8.84	$ 17.68
	Steel Narrow-Base Weld Nut (50)	1	$ 9.50	$ 9.50
	Rotating-Eye Padlockable Hasp	2	$ 11.00	$ 22.00
	Unfinished Brass Surface-Mount Hinge with Holes	2	$ 1.43	$ 2.86
	Sales Tax	1	$ 10.75	$ 10.75
	Shipping	1	$ 7.05	$ 7.05
			TOTAL	**$ 137.20**
Order 2	Square Tube 1.5*1.5*36	1	$ 21.22	$ 21.22

	Square Tube 1.581.5*12	1	$ 11.67	$ 11.67
	Screws	5	$ 4.17	$ 20.85
	Square Plugs	1	$ 12.29	$ 12.29
	Square Plugs	1	$ 9.26	$ 9.26
	Hex Nut	1	$ 5.76	$ 5.76
	Sales Tax	1	$ 7.30	$ 7.30
	Shipping	1	$ 14.72	$ 14.72
			Total	$ 103.07
Midwest Steel and Aluminum	6061 Flat Aluminum Bar (0.25 x 1 x 48)	65	$ 3.79	$ 246.35
Partial Refund	Shipping	1	$ 81.10	$ 81.10
	Discount	1	$ (12.20)	$ (12.20)
			Total	**$ 315.25**
Gorilla Metal/Metal Werx	Square Tube 1x1x.065*36 (20)	1	$ 72.00	$ 72.00
	Square Tube 1.25*1.25*.065*5 (20)	1	$ 17.00	$ 17.00
	Square Tube 1.25*1.25*.065*12 (20)	1	$ 38.00	$ 38.00
	Flat Bar 1.25*.25*6 (80)	1	$ 62.00	$ 62.00
	Cutting Fee	1	$ 20.00	$ 20.00
	Sales Tax	1	$ 19.33	$ 19.33
			TOTAL	**$ 228.33**
Bolts Depot				
	Tap Bolts 3/8-16*2 (50)	2	$ 10.45	$ 20.90

	Hex Nuts Grade 5 3/8-16 (100)	1	$ 3.40	$ 3.40
	Shipping	1	$ 11.95	$ 11.95
			TOTAL	**$ 36.25**
Amazon				
Order 1	Hatchbox ABS Filament Blue (1kg per roll)	7	$ 21.99	$ 153.93
	Sales Tax	1	$ 14.21	$ 14.21
			TOTAL	**$ 168.14**
Home Depot				
Purchase 1 on 2/6/18	Sakrete	13	$ 3.90	$ 50.70
	TAX	1	$ 4.56	$ 4.56
			TOTAL	**$ 55.26**
Home Depot				
Purchase 1 on 2/12/18	Acetone 1 Gal	1	$ 15.27	$ 15.27
	6" Grinding Stone	1	$ 7.47	$ 7.47
	TAX	1	$ 2.10	$ 2.10
			TOTAL	**$ 24.84**
Lowes				
Purchase 1 on 2/6/18	All Purpose Plastic Tray	1	$ 13.97	$ 13.97
	4MIL Plastic	1	$ 13.88	$ 13.88
	QUIKFORM (Round Tubing)	2	$ 15.97	$ 31.94
	TAX	1	$ 5.53	$ 5.53
			TOTAL	**$ 65.32**

Harbor Freight				
Purchase 1 1/30/18	Ring Roller	1	$ 69.99	$ 69.99
	Discount 20%	1	$ (14.00)	$ (14.00)
	TAX	1	$ 5.18	$ 5.18
			TOTAL	**$ 61.17**
PRAXAIR				
Purchase on 3/1/18	Tungsten 1/16*7	1	$ 24.74	$ 24.74
	Tig ROD 1/16*36 (1 lb)	1	$ 9.57	$ 9.57
	Sales Tax	1	$ 3.18	$ 3.18
			TOTAL	**$ 37.49**
Home Depot				
Purchase 1	Sheet Metal 1*2	1	$ 10.98	$ 10.98
	Sales Tax	1	$ 1.02	$ 1.02
			Total	**$ 12.00**
Purchase 2	Sheet Metal 1*2	1	$ 10.98	$ 10.98
	Marker	1	$ 0.97	$ 0.97
	Sales Tax	1	$ 1.11	$ 1.11
			TOTAL	**$ 13.06**
SIMS				
	Useable aluminum	1	$ 12.00	$ 12.00
	Useable SS	1	$ 5.00	$ 5.00

	Tax	1	$ 1.57	$ 1.57
			Total	**$ 18.57**
Amazon				
Order 1	Hatchbox ABS	1	$ 21.99	$ 21.99
	Sales Tax	1	$ 2.03	$ 2.03
				$ 24.02
	Hatchbox	1	$ 18.99	$ 18.99
	Adhesion Sheets	1	$ 26.30	$ 26.30
	Sales Tax	1	$ 2.43	$ 2.43
				$ 47.72
Home Depot				
5/9/18	Machine Screws	1	$ 2.36	$ 2.36
	Hex Bolts	1	$ 6.97	$ 6.97
	Tax	1	$ 0.86	$ 0.86
			Total	$ 10.19
Home Depot				
5/4/18	Milwaukee 20 Piece Set	1	$ 14.88	$ 14.88
	Organizer Box	1	$ 8.97	$ 8.97
	Orange Safety Paint	1	$ 4.47	$ 4.47
	Sales Tax	1	$ 2.62	$ 2.62
			Total	$ 30.94

Appendix C: How to TIG Weld

SPARTAN Superway's Guide to TIG Welding

Assumed that material being welded is steel *Consult Welder's Manual for other material*

BOLDED & UNDERLINED TEXT: Pay attention to these directions

ITALICIZED TEXT: extra information to elaborate on concepts.

A. ***PREPARATIONS BEFORE WELDING***

1. Wear proper clothing

a. Wear **long sleeved non-synthetic clothing (shirt + pants)** to prevent sunburns
The welder emits harsh UV light to one's skin and will cause sunburns if left uncovered. Synthetic materials may melt into your skin.

b. Put on the **welding gloves** and **welding mask** found near the welder

1. **Prepare your materials properly** and ensure it is free of: **oil**, **moisture**, **dirt**, **and other impurities**.

b. Impurities INCLUDING ZINC PLATING cause porous welds that lack strength and increase possibilities of failure in components.

a. Utilize the metal-wire brush or grinder in the shop to properly clean material.

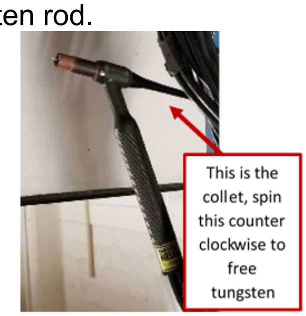
1. Select the proper tungsten diameter

a. Refer to the welder's manual for proper diameter for a given current range.

1. Sharpen tungsten electrode.

a. If the tungsten rod is dull:

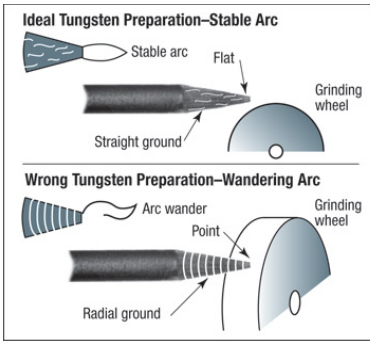
1. Turn the collet found in the back of the welding torch to free up tungsten rod.

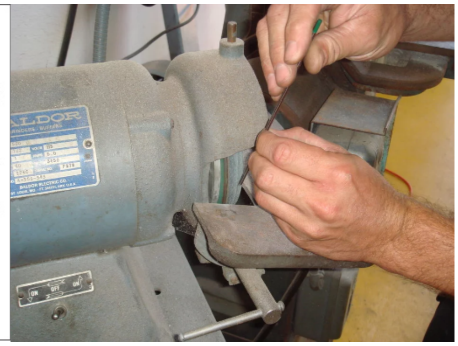


1. The tungsten rod should come out of the collet rather easily, so
DO NOT YANK OUT THE TUNGSTEN ROD
(it might break in the welding torch)

1. Take the tungsten rod to the grinding wheel.

1. Sharpen the tungsten rod **in the same orientation as the image below** and rotate as needed to create a pointed edge.





1. After the tungsten rod has been sharpened to a point, secure the tungsten rod back into the welding torch.
a. Insert the rod back into its intended space in the welding torch with the pointed tip exposed.
b. Adjust the height of the tungsten rod within the welding torch assembly.
c. Tighten the collet and ensure that the tungsten rod is secure.

   e. Throughout the welding process, the tungsten rod might start to get dull. If this is the case, ***<u>refer to section A.3.a</u>***

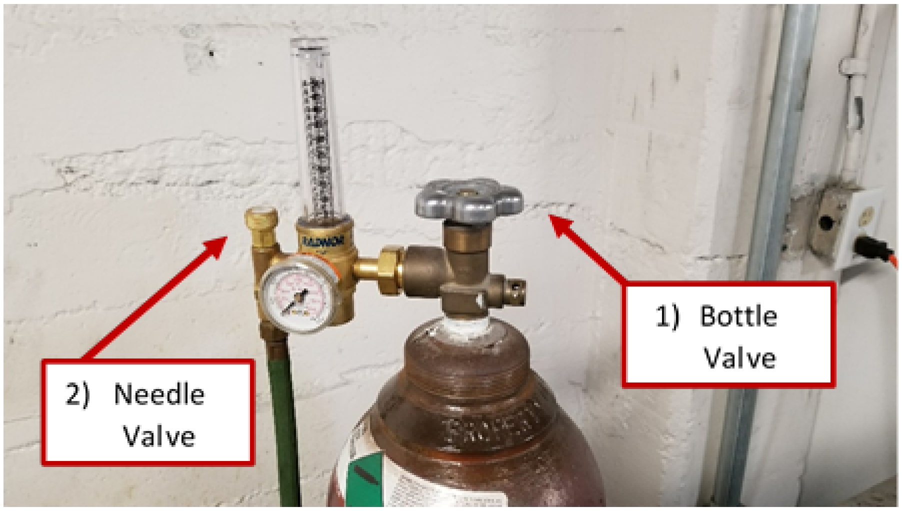
1. Clamp the ground clamp on workpiece or a clean metal surface at the edge of the table.
****do not clamp ground clamp onto painted/insulated surface****
****Ideally, clamp the ground clamp directly onto the work****

B. Setting up the Welder

1. Turn the Argon Gas on.

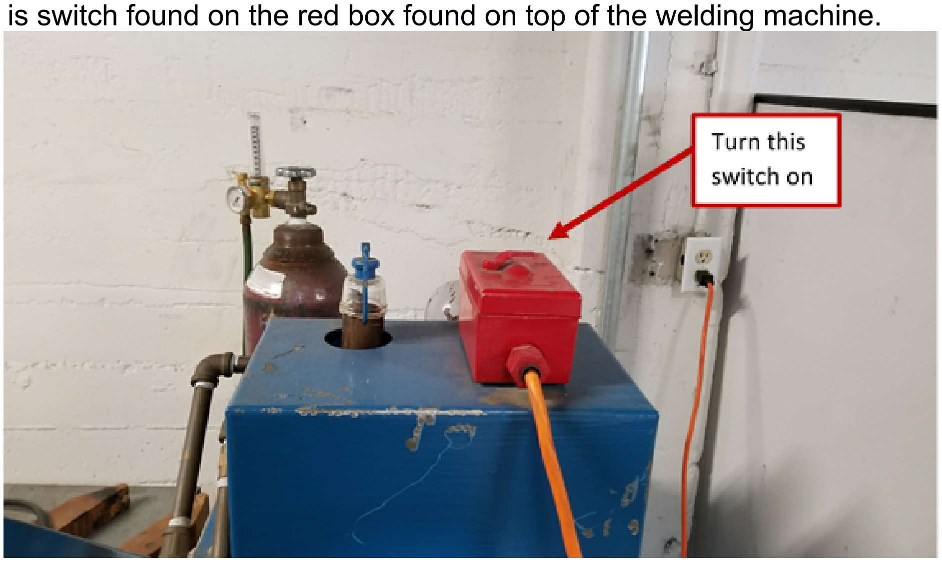
a. Turn the **bottle valve <u>counterclockwise</u>** about 1 full revolution
Adjust the **needle valve** until within range of **<u>15 to 20 cubic feet per hour</u>**.

1. *Without the proper **<u>argon</u>** gas coverage, the area welded is susceptible to contamination.*
2. ***<u>Contamination</u>** creates rusting which will degrade parts.*



1. Start the Welder's Water Cooling System

a. This is switch found on the red box found on top of the welding machine.



b. The user should hear the water cooling system turn on.

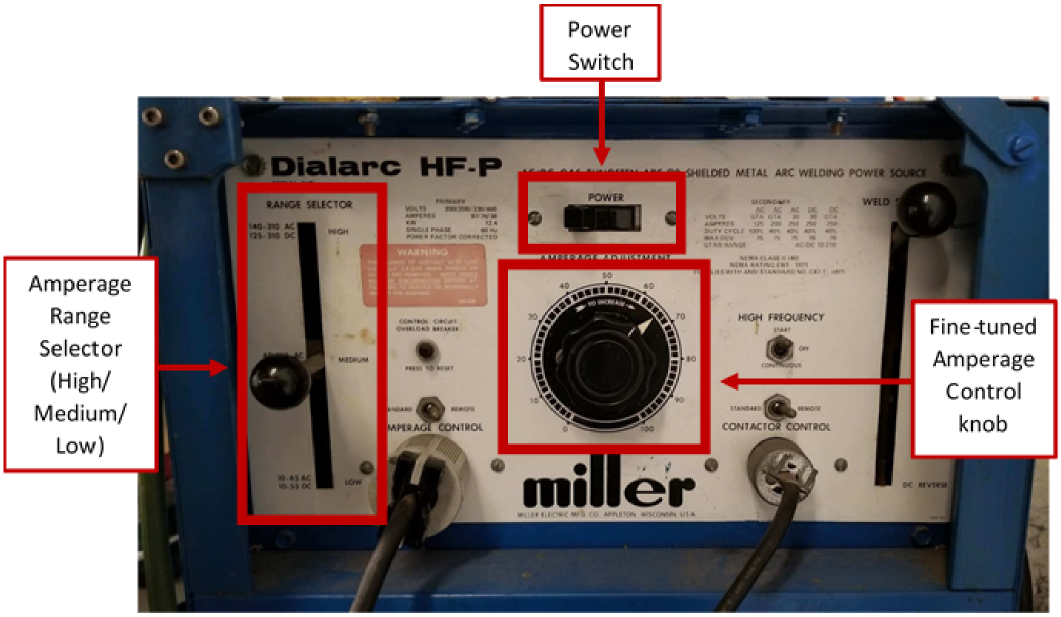
a. ***Ensure that there is enough water in the cooling tank***

The pump leaks about a gallon per hour

1. Select the correct settings necessary for your weld.

a. The figure below shows the face of the welder.

The descriptions found below the image show their functions.



1. ***The power switch** is used to turn on the welder.*

a. ***<u>DO NOT</u> turn the welder on unless gas and water cooling are on!***

2. ***Amperage Range Selector***

a. *Used to control the desired amperage range based on users' needs*

2. ***Fine-Tuned Amperage Control Knob***

a. *Based on the Amperage Range Selector selected, this knob fine tunes the amperage range for more precise current output.*

b. ***Example:***

If the amperage range selector is set to high (140-310 AC) and fine-tuned amperage control knob is set to 100%, the maximum current output is 310 AC.

If the amperage range selector is set to high (140-310 AC) and fine-tuned amperage control knob is set to 50%, the current output is 225 AC.

Etc.

c. *When welding, the foot-pedal is used to further control the current. The minimum is 30% of maximum current output.*

a. *To understand what current the user needs to select, utilize websites such as: https://www.millerwelds.com/resources/weld-setting-calculators/tig-welding-calculator*
Or Google: "selecting amperage for TIG Welding"

b. *Set the desired settings for the welding machine.*

1. ***Don't feel pressured to select the correct settings the first time around!***
   One can edit these settings while the machine is on or in between welds.
   DO NOT CHANGE while welding.

2. **Turn on the welder by flipping the power switch.**

a. Refer to previous image.

2. **Untangle welding torch cable from welding machine.**

1. Find a chair and get situated with the welding torch, filler metal, and foot-pedal.

a. PRO TIP: have enough slack on welding torch cable so the excess cables can go over opposing shoulder of welding torch. This setup is preferable so that the weight of cables don't play a factor during welding. See figure below for clarification.

C. Start TIG Welding:

1. Get situated

a. Move the foot-pedal near your feet at a comfortable position.

b. With the welding torch in your dominant hand, grip it like a pen.

1. PRO TIP: I found this grip works well for me:

c. Grab the filler metal and hold it comfortably with the left hand.

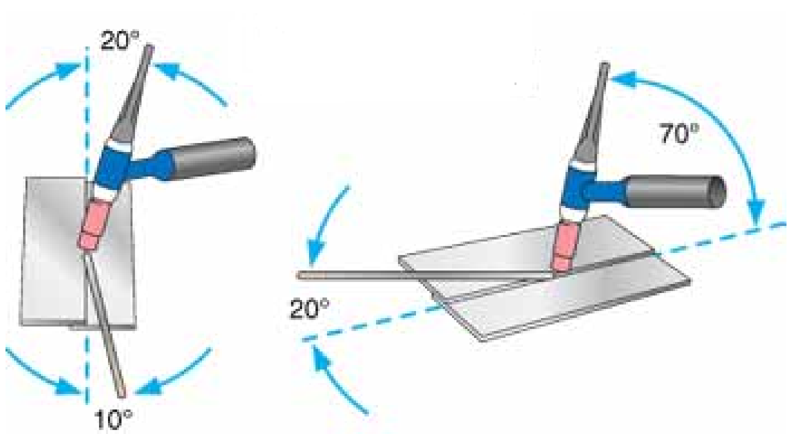
a. Ensure that the workpiece is fully secured

Without doing this, the welded parts could sag or warp.

1. **Establish an arc (with the proper settings selected)**

a. Hover the welding torch (exposed tungsten) near the steel.

1. Maintain about a 1/16” of space between the steel and the tungsten tip of the welding torch.
   The welder should hum quietly to let the user know the proper height is established. If the welder makes more noise, the user is keeping the welding torch too far away from the workpiece.
   ****Careful not to touch the tungsten onto the molten metal workpiece****
2. Refer to the figure below for proper orientation of the welding torch.



b. Press down on the foot-pedal about 50% to strike the arc and form a weld pool.
   The idea is to quickly dump heat and current into the metal to start the weld pool

1. Create a weld pool & weld along the desired weld-line.

a. Once the arc is established and weld pool is formed, ease off or press harder on the foot-pedal to control current.

CHECK: *if the metal starts to burn or melt, too much current is being outputted. Ease off the foot-pedal.*

b. Maintain the weld pool

c. Move the welding torch down the weld-line while making small circular motions

Ensure that the welding torch is maintained at the same distance throughout weld.

d. Slowly add filler metal into the molten pool as needed

1. When finished with the weld:

a. Completely release the foot-pedal to end the arc.

b. Keep the welding torch near the weld puddle for about 8 seconds

The argon gas continues to flow to protect the weld

C. Summary:

1. The steps to welding:

a. Establish an arc

b. Create the weld pool

c. Add filler metal into the pool

DO NOT *add filler metal into the arc*

d. After completing weld, end arc and ***keep welding torch near weld puddle***

Because argon gas protects the weld until puddle cools

2. To practice:

a. Grab steel found near the small-scale workspace and bring it to the welding table. This piece will be utilized for practicing!

b. With just the welding torch, start an arc onto the test metal.

c. Create clean lines

1. Try to keep height of the welding torch relative to the steel consistent.

d. Once comfortable with creating clean lines, add in the filler metal to new weld.

E. Cleaning Up

1. Ensure that the tungsten is sharpened properly for the next user.
2. Wrap the welding torch's cable in a figure eight. Wrapping it this way prevents tangles.
   Refer to the following figure:

1. Turn off the Welder's power switch.
1. Turn off the Welder's water cooling system.
1. Turn the argon gas valve fully clockwise until there is no gas flow.
1. Take any scrap material from the welding table with you.

Appendix D: Calculations

Table 4 Stress Calculations for Hanger Bracket

Force estimated using inherent beam deflection		
Assumed maximum aluminum deflection	0.25	in
Distance between hangar brackets	24	inch
Youngs modulus of 6061 aluminum	10000	ksi
Area moment base value	1.5	in
Area moment "h" value	0.25	in
Area moment	0.07031	in^4
Estimated force	0.03815	lbs
Minimum cross-sectional area to minimize vertical beam deflection given a one inch "base"		
Thickness of hangar bracket	1	in
Estimated youngs modulus of abs	210	ksi
Thickness of "hollow" hanger bracket	0.09	inch
Total length of hangar "beam"	3.35	in
Max deflection of Hangar	0.05	in
Equal to "I"	0.01359	
Assuming Solid Cross Section the minimum required height is:	0.16309	in
Vertical yield of half hangar bracket modeled with point force at base (fixed at top)		
Number of hangar brackets to divide load	3	
Pound mass of single track section	1.7	lbs
Pound mass of bogies	40	lbs
Yield Stress *calculated using solid cross section	126.1083	psi
Maximum allowed yield stress	2683	psi
Factor of safety	21.2754	