Traffic Cone Setter

A Major Qualifying Project Report:
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Abstract

Currently, traffic cones must be placed by a worker off the side of a moving truck, which is a dangerous task, or by using very expensive equipment. The goal of this project is to create a mechanism capable of placing cones automatically and at a lower cost, allowing for broader implementation, thereby reducing the need for workers to be put in harm's way. This design pulls cones one at a time from the bottom of a stack while keeping the rest of the cones held in place. A slider-crank mechanism is used to actuate the device, and a spring-loaded mechanism is used to hold the cones in place. This device is an improvement over the alternatives because it costs less than other similar cone-placing devices, meaning this safer solution can be implemented very easily.

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Introduction

This project was completed as an MQP at Worcester Polytechnic institute. Our group developed a device for the Worcester Department of Public Works (WDPW) to use while conducting road work. In order to conduct road work, often a lane must be closed off to make room for the workers. This is usually done using a series of cones. Traditionally, a worker rides on the back of a truck and manually places cones down on the road in order to close off a lane. In order to place the cones the worker must lean over the side of the truck, which places them in potential danger. An average of 20,000 road workers are injured every year, and the most common source of injury and death in these environments is vehicles colliding with the traffic vehicles (FHWA, 2012). This poses a serious threat to those workers who are unbuckled and exposed. If traffic workers were able to stay safely buckled in the cabin of the truck as opposed to standing on the back, the number of severe injuries and deaths would be reduced.

The objective of this project was to create a device that could place cones completely autonomously. After discussions with representatives from the WDPW, it was decided that the most effective way to accomplish this would be to have a device that can be fixed to the side of a standard truck and drop cones off the side while the truck is driving. This would remove the need for a worker to be standing on the back of the truck, and instead allow them to stay in the safety of the truck cabin. To accomplish this, the team created a mechanism that utilizes a slider-crank linkage and retractable slides to drop cones one at a time from a large stack.

Background

Traditionally, traffic cones are manually placed on the road by someone leaning off the side of a truck. This is a very simple solution and is still widely used today, but it carries with it some inherent risks and places the person placing the cones in potential danger of being struck by passing vehicles or falling off of the truck and onto the road. As such, there are a few already existing solutions for expediting this process.

One such example is the Roadrunner, produced by Royal Truck & Equipment. As shown in Figure 1, the Roadrunner is a slide that can be attached to the side of a truck and guides cones as they are dropped.

Figure 1: The Roadrunner

The Roadrunner makes it so the person placing the cones does not need to lean out of the truck, they simply place the cone at the top of the slide and it is deposited down onto the road. This reduces the danger of the cone placer falling off the truck however, this process still requires a worker to stand on the back of the truck, leaving them exposed in the case of an accident. (Tech Insider, 2018).

Another cone placement mechanism exists that eliminates the need for a second attendant dropping the cones. The MnDOT AutoCone 500 Truck, or simply the Autocone, was developed by Centreville Manufacturing, Inc. and is able to run completely automatically.

As seen in Figure 2, the cones are stored in a rotating barrel with conveyor belts that push the cones towards the front of the truck. There, there is a 4 bar linkage arm that places the cones down onto the road. (Theiss & Ullman, 2017)

Figure 2: MnDOT AutoCone 500 Truck

As opposed to the Roadrunner which could simply be fixed to the side of an ordinary truck, the AutoCone is an entire vehicle by itself. As mentioned, it does not require a secondary person to feed cones into the mechanism, meaning the whole system can be operated by just a single driver. It can store up to 500 cones in the barrel, and is also capable of retrieving cones as well as placing them. Cones are moved to the front of the barrel using a conveyer system, and deposited onto the road using a linkage system. However, all of this added functionality comes at a high cost when compared to the very simple Roadrunner. Whereas the roadrunner can be affixed to most traditional trucks, the AutoCone requires an entire dedicated truck that cannot be used for other purposes. An ideal solution to this issue would be a mechanism that was capable of running completely or nearly automatically, while still remaining relatively small and inexpensive.

This project is a continuation of a previous project done in 2019 by Christopher Ferreira, Holly Gagnon, and Zachary Whitmore. The mechanism that they designed was based on a 4-bar linkage, seen in Figure 3. This uses a constant rotational input from a motor to move the arm in a set arc. On the end of the bar is a gripper mechanism that uses two rubber wheels to pick up and drop the cones. The whole gripper mechanism is attached to a pulley so that it can slide to the base of the arm to retrieve the cones and then down to the end to place them on the road.

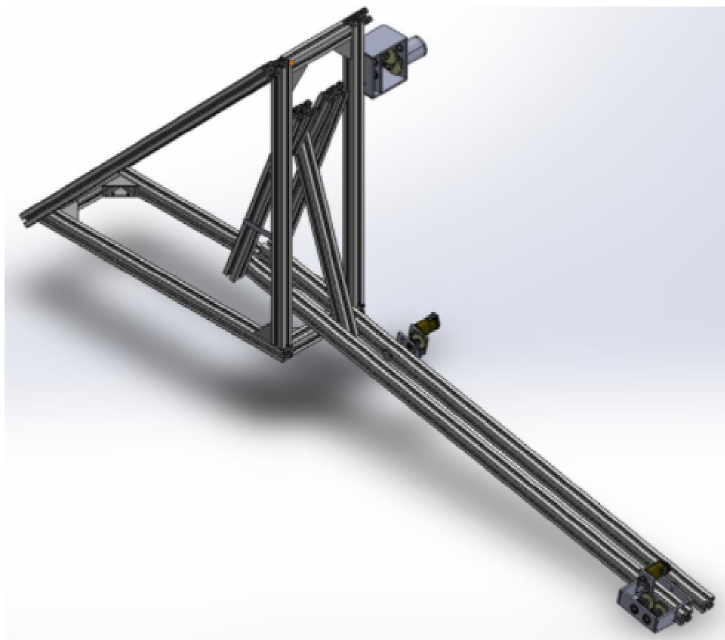


Figure 3: Four Bar Linkage Dropper

While this design could work for this device, our team ultimately decided not to continue pursuing this design due to the feed mechanism required to accompany this system. The nature of the linkage is that it repeats the same path each time a cone is placed. In order to function, a new cone needs to be placed in position each time a cone is dropped. The AutoCone mentioned above overcomes this by using the massive barrel system to place cones into position resulting in the high cost. Our team's solution seeks to remove the need for this bulky system.

Functional Requirements

After a meeting with James Kempton, a representative from the Worcester Department of Public Works, a list of functional requirements were generated based on his suggestions and desires for a product to automatically place cones. For this project, the intended constraints required a maximum size of a 5ft by 4ft footprint which includes the cone storage system. The design would be a maximum weight of 50 lbs, and the maximum amount of cones differs depending on the size of the truck. The design should be able to fit on the back of a variety of trucks along with room to hold at least 80 cones. The device must function according to the following list of requirements:

This device (must be):

- Able to Place cones a constant 20 ft apart
- Compatible with 10lb traffic cones, potentially adjustable for different sizes
- Fully automatic, no human input is required
- Able to be installed / removed in under 15 minutes using standard tools
- Able to be installed on either side of the truck
- Resistant to bumps and uneven surfaces
- Weather-resistant
- Corrosion resistant
- Cost: Under $1000
- Easy to operate by a single driver
- Have easy to replace components that can be replaced in under 10 minutes using standard tools
- Easy to Repair

Following these requirements would lead us to creating a device that can successfully complete each task consistently.

Design Concepts

Based on the functional requirements defined above, four conceptual designs were generated. The first of which is the Hydraulic Pusher, found in Figure 4.

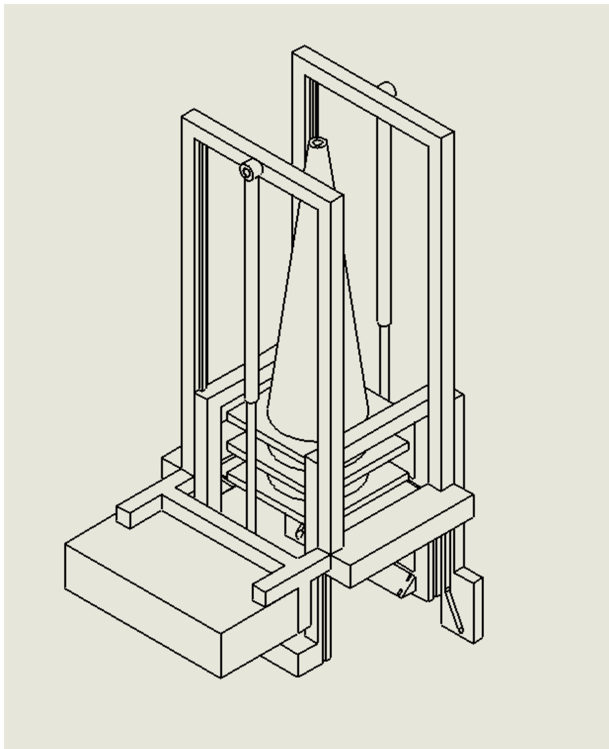


Figure 4: Hydraulic Pusher Sketch

This mechanism is primarily actuated by a pair of hydraulics which push a cone out of a stack of cones and onto the ground. It uses spring loaded catch mechanisms to hold and grab the cones. The hydraulics will be controlled from the cab and will have the option to place cones at a regular interval or to place cones individually.

The advantage to this design is that it is resilient. Hydraulics are resistant to bumps and jolts which might cause other mechanisms to jam. They are also excellent at resisting damage from weather conditions. Another advantage to this design is that it can be reprogrammed to drop at different intervals or to have a different dropping force.

The second conceptual design, labeled as the Clockwork Dropper, can be seen in Figure 5.

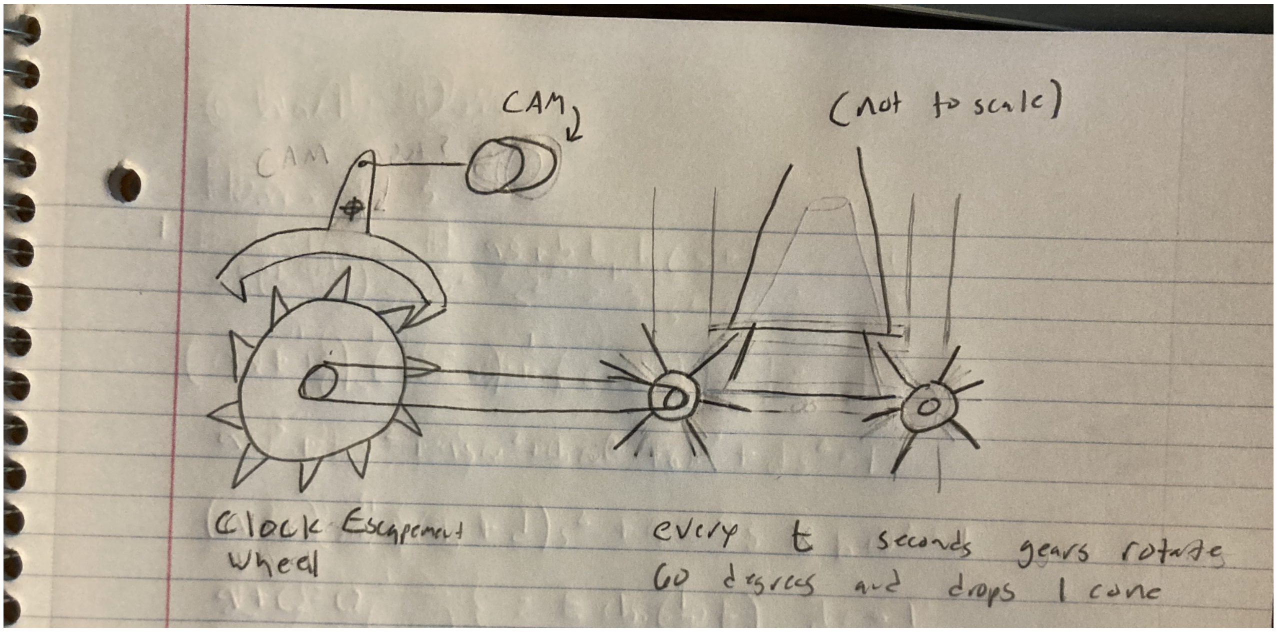


Figure 5: Clockwork Dropper Sketch

This mechanism functions similarly to a clock, turning a constant rotating motion into set impulses. The Clock Escapement wheel is attached to two sets of dropper gears. A rotating cam wheel locks and unlocks the escapement wheel at set intervals, causing the dropper wheels to make a periodic 1/6th rotation. This drops the cone on the bottom of the stack, but keeps the rest held in place

The advantage of this design is that it is purely mechanical, requiring no electronic components. The rotational input could potentially come from the rotation of the wheels, meaning when calibrated correctly the mechanism would always drop cones every 20 ft regardless of how fast the truck is moving. However, there are some potential problems with this design, namely that it relies solely on gravity to drop the cones. Because of their material there is potentially a great deal of friction between them, increasing the chance that a cone could get stuck and not drop when it was supposed to. Additionally, significant bumps in the road might knock the cones out of alignment and cause the system to jam.

The third conceptual design is an assisted dropping mechanism which can be seen in Figure 6.

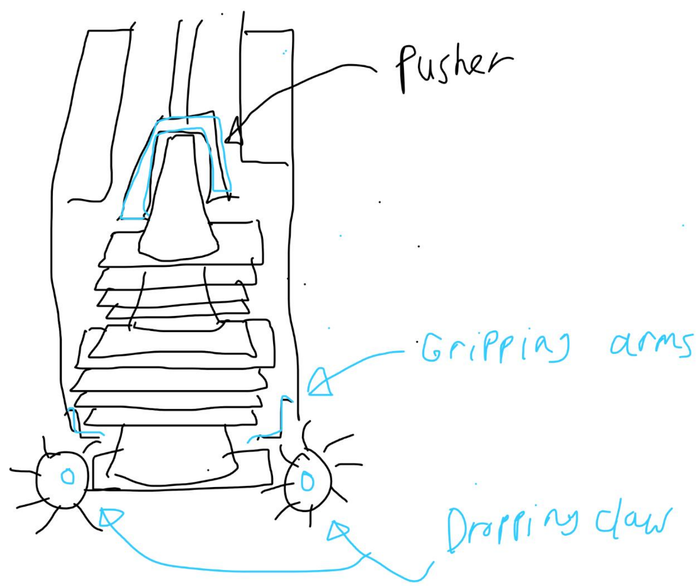


Figure 6: Assisted Dropper Sketch

This design works as a hybrid of the prior designs, focusing on using primarily gravity to control the flow of the cones while also including a shaped pushing system to push new cones into place. The system also features a set of rollers that will allow the cones to slide to the bottom of the mechanism and to the ground. The advantage of this system is that it automatically separates cones, and requires little power once the mechanism is started.

The design was made with a hope of finding a solution that uses as little energy as possible while also allowing the system to function without causing a malfunction if misaligned. However, while a system like this would possibly solve the problem, it was seen as an expensive and possibly heavy design that would be limited to a select amount of cones. Such a device would need a distinct amount of space to function as intended, potentially larger than what is required of this project. Additionally, the addition of the pushing piston will add significant cost to the device due to the added complexity.

The final design is a linkage arm, based on the design of the previous group to work on this project, Christopher Ferreira, Holly Gagnon, and Zachary Whitmore. The completed assembly can be seen in Figure 7 (Ferreira et al., 2019).

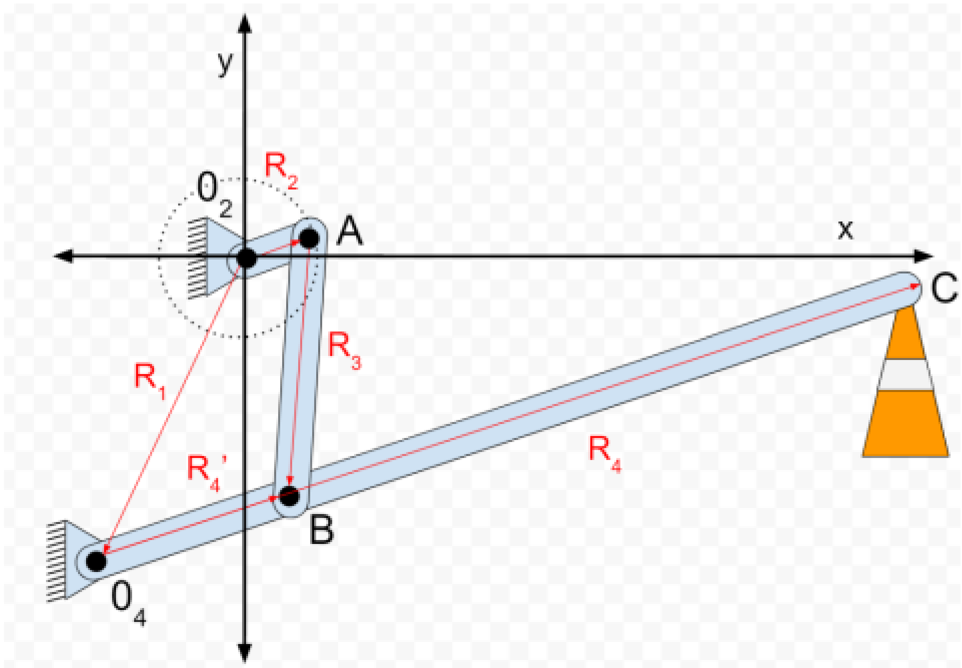


Figure 7: Linkage Mechanism

The previous team to work on this project has already done all of the relevant design and calculations for a mechanism like this, proving that it is indeed functional. However, the system does have some inherent limitations. Because it is based on a linkage, the point at which the gripper mechanism returns to grab the next cone is always at the same point relative to the truck. This makes retrieving cones from a stack impossible, as the pickup point will get lower and lower with each cone that is removed from the stack, and the mechanism has no way to compensate for that. This means that someone would need to manually replace each cone after the device picks it up, which goes against the functional requirement that the machine can be operated by a single driver. If this design were to be used, it would need to be modified so that it can compensate for the decreasing stack height.

Design Selection

In order to select the best design to pursue moving forward, a decision matrix was created. The following grading criteria was utilized, based on the previously defined functional requirements: Footprint, Weight, Cone Dropping Consistency, Required Human Input, Installation Time, Bump Resistance, Weather Resistance, Corrosion Resistance, Expected Production Cost, Repair Time, and Assembly Time. Scales were created in order to quantitatively score each design on a scale of 1 to 10 for each category. These categories and bounds were all selected based on direct recommendations from James Kempton from the Worcester Department of Public Works. All of the criteria and grading scales can be found in Table 1.

Table 1: Grading Criteria and Scales

Criteria	Lower Bound	Upper Bound
Footprint	1 = 15ft^2	10 = 1.5ft^2
Weight	1 = 50 lbs	10 = 5 lbs
Tolerance (average error in distance between dropped cones)	1 = +/- 5 ft	10 = +/- .5 ft
Required Human Input (number of cones the mechanism can drop before it needs to be manually reloaded)	1 = 1 cone	10 = 10 cones
Installation time (expected)	1 = 10 minutes	10 = 1 minute
Bump Resistance	1 = Not Resistant	10 = Very Resistant
Weather Resistance (Haas, 2021)	1 = ip60	10 = ip68
Corrosion Resistance (how long the machine can operate before being significantly affected by corrosion)	1 = 1 year	10 = 10 years
Expected Production Cost	1 = $1000	10 = $0
Expected Repair Time	1 = 10 minutes	10 = 1 minute
Expected Assembly Time	1 = 30 minutes	10 = 3 minutes

As a note regarding the Required Human Input category, ideally a mechanism could drop 100 to 200 cones all on its own to truly require no human input for an extended period of time. However, holding this amount of cones would undoubtedly require some type of separate feeding mechanism that is outside the scope of this project. With that in mind, for simplicity's sake a score of 1 was defined as 1 cone and a score of 10 was defined as 10 cones for the maximum capacity.

Lastly, each category was weighted based on the overall importance. Bump resistance was chosen as the most important factor, as the mechanism needs to be able to reliably work on rough construction terrain without getting jammed. Assembly Time and Required Human Input were ranked at the bottom, since the mechanism will only need to be assembled 1 time, and as mentioned before a separate feeder mechanism will be required in order to hold large amounts of cones regardless of the design, so the number of cones it can hold at once is of less importance. The weighting matrix can be found in Table 2.

Table 2: Weighting Matrix

Bump resistance	0.15
Installation Time (expected, minutes)	0.1
Weather resistance (electronics ect)	0.1
Corrosion Resistance (rust and wear over time	0.1
Expected Production Cost ($)	0.1
Repair Time (minutes)	0.1
Weight (lbs)	0.1
Drop Cones 20 ft apart (expected tolerance)	0.075
Footprint (ft^2)	0.075
Assembly Time (minutes)	0.05
Required human input	0.05
Total	1

With these scales and weights in mind, the following design matrix found in Table 3 was generated, The final scores for each design can be found in the far right column.

Table 3: Weighted Design Matrix

Design Requirement >	Footprint (ft^2)	Weight (lbs)	Drop Cones 20 ft apart (expected tolerance)	Required human input	Installation Time (expected, minutes)	Bump resistance	Weather resistance	Corrosion Resistance	Expected Production Cost ($)	Repair Time (minutes)	Assembly Time (minutes)	
Grading Scale >	1 = 15 ft^2 10 = 1.5 ft^2	1 = 50 lbs 10 = 5 lbs	1 = +- 5 ft 10 = +- 0.5 ft	1 = 1 cone 10 = 10 cones	1 = 10 minutes 10 = 1 minutes	1 = very sensitive 10 = very resilient	ip60 = 0 ip68 = 10	1 = 1 year 10 = 10 years	1 = $1000 10 = $0	1 = 10 minutes 10 = 1 minute	1 = 30mins 10 = 3mins	
Linkage Design	2	7	5	1	8	3	4	5	7	10	1	8.875
Hydraulic Dropper	3	5	7	6	6	7	8	8	1	5	5	12.95
Clockwork Dropper	3	6	6	6	5	6	6	7	8	5	3	11.225
Assisted Dropper	4	6	7	7	5	5	6	7	5	7	3	11.175

Based on this design matrix the Hydraulic Dropper was selected as the best design, with a score of 12.95. It scored about average in most categories, but above average in Bump, Weather, and Corrosion resistance, making it the most resilient of the 4 designs. It did score far below average in the production cost, due in large part to the 2 hydraulic cylinders that are required in the design.

Synthesis and Analysis

Our team began our analysis with free-body diagrams of separate parts of the system. We broke the device into two important interactions. The interactions between the interaction between the hydraulics and the sliding mechanism, and the interaction between the device and the cones.

First is the interaction between the hydraulics and the sliding mechanism. Figure 8 below depicts the force interactions with the device. We used this free body diagram to balance the force of the hydraulics. The FBD depicts two scenarios, the first, on the left, depicts the active half of the device's operation where a cone is being pushed from the device. The second on the right depicts the return half of the device's operation where the catch is returning to its initial position. In both scenarios the hydraulic force needs to be balanced so that they provide enough force to move the device while not being too much force that it breaks the device. These FBDs would be used to find the ideal force of the hydraulics.

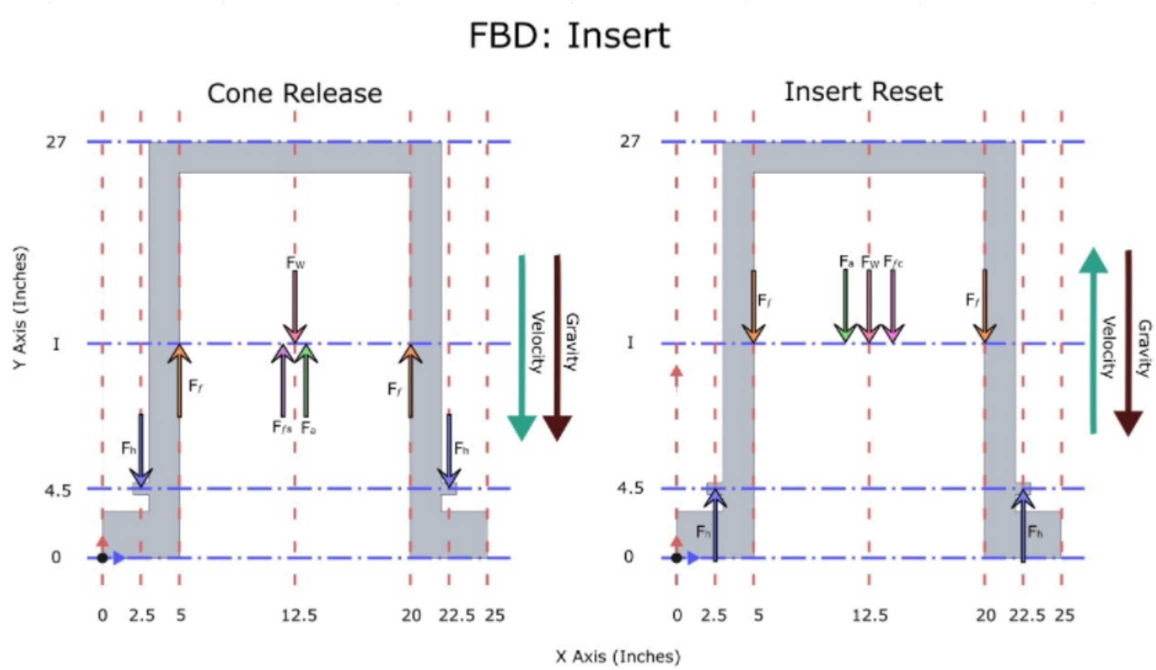
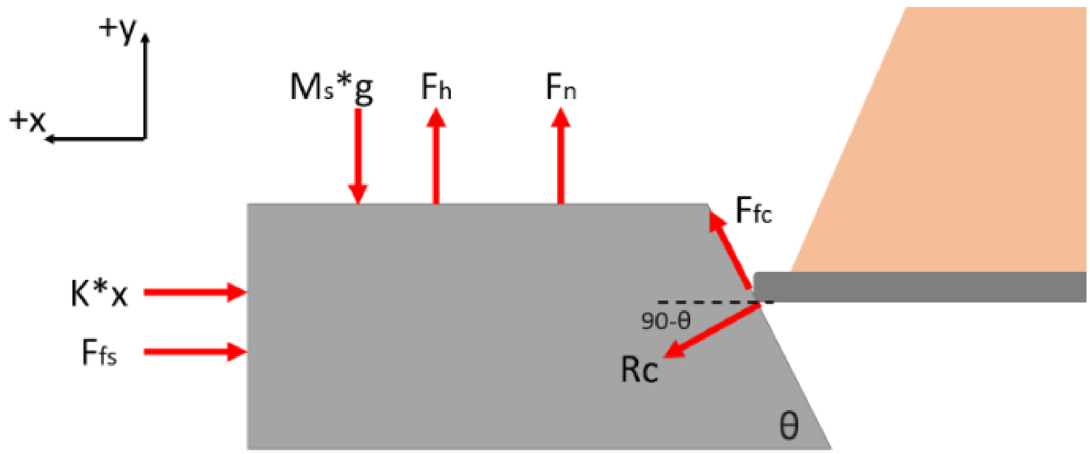


Figure 8: Free Body Diagram for the Insert

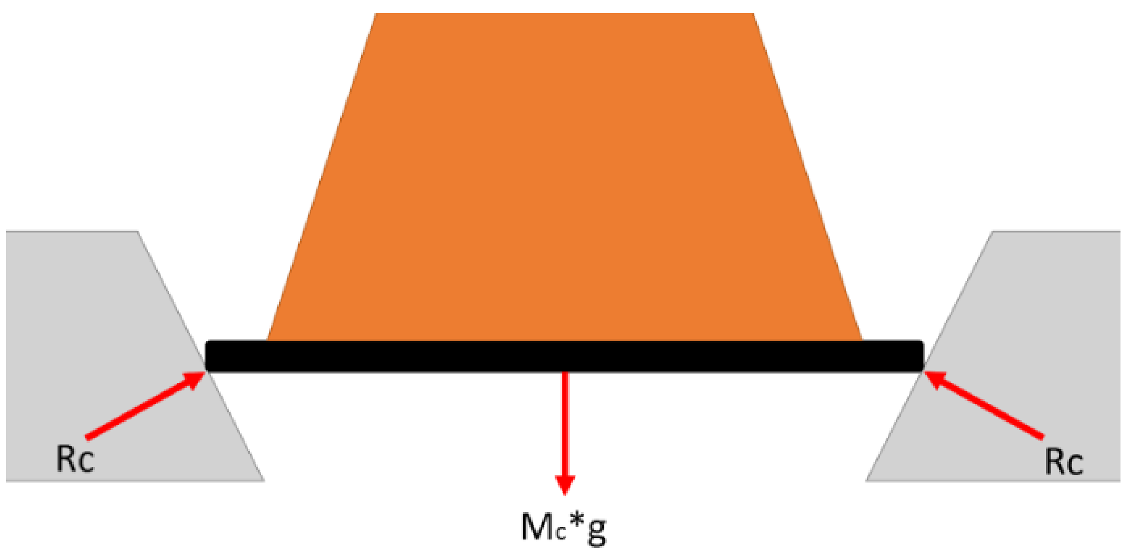
Lastly, free body diagrams were created to show the interaction between the slides and the cones, seen in figures 9 and 10.



$$\Sigma Fx = -K*x - F_{fs} + R_c*\cos(90-\theta) + F_{fc}*\cos(\theta) > 0$$

$$\Sigma Fy = -M_s*g + F_n - R_c*\sin(90-\theta) + F_{fc}*\sin(\theta) = 0$$

Figure 9: free body diagram and design equations for linear slide



$$\Sigma Fy = -M_c*g + 2*R_c*\sin(90-\theta) = 0$$

Figure 10: free body diagram and design equations for cones

These free body diagrams were primarily used to determine the necessary spring force for the return springs on the slides, and the angle of the slides themselves. The scenario shown above is when the insert is moving upwards to retrieve the cones, and the downward force of the cones is pushing the slides inward so that they can push down on the cone from above. The downward force of the cone decreases as the stack gets shorter, so this free body diagram shows the worst-case scenario where there is only one cone and the force pushing the slides in is at a minimum. If the force of the return springs exceeds the force of the cones pushing on the slides, then the slides will be unable to retract and the cone will not be dropped.

This free body diagram only shows the slides attached to the insert that push the cones down. The second set of slides that hold the cones in place when they are not being dropped were not modeled, as they will be pushed back by the sloped geometry of the insert itself. As long as the spring force is greater than the friction in the linear slides, they will be able to slide without issue.

Detailed Design Description

After choosing the hydraulic pusher design we began to make a detailed CAD model of the system in SolidWorks. Through the detailed design process we discovered a number of issues regarding our design. Our team worked through these issues during the detailed design process resolving a number of the problems with our design.

Table 4 shows all of the parts used in the final assembly, and the part number that they will be referred to as throughout the report.

Table 4: Bill of Material for Device Components

Part Number	Description	Number of Units	Price per Unit	Cost of Components
1A	80-20 Rail 1" (Single) - 14.5"	4	$10.72	$42.88
1B	80-20 Rail 1" (Single) - 16.5"	4	$10.72	$42.88
2A	80-20 Rail 1" (Double) - 4"	8	$3.81	$30.48
2B	80-20 Rail 1" (Double) - 12.75"	4	$15.39	$61.56
2C	80-20 Rail 1" (Double) - 14.5"	4	$15.39	$61.56
2D	80-20 Rail 1" (Double) - 19"	4	$15.39	$61.56
2E	80-20 Rail 1" (Double) - 48"	2	$34.73	$69.46
3	Large Wedge	2	$7.50	$15.00
4	Slide Frame 14.5"	2	$12.96	$25.92
5	Small Wedge	2	$7.50	$15.00
6	Slide Frame 16.5"	2	$12.96	$25.92
7	Spring 1.75” Uncompressed	6	$0.60	$3.60
8	Plastic Tube	6	$0.08	$0.48
9	Wooden Dowel	6	$0.06	$0.36
10	Motor and Gearbox	2	$31.86	$63.72
11	M4 Screw 13mm	8	$0.24	$1.92
12	Ball Joint Rod End	4	$4.07	$16.28
13	Connecting Rod	2	$7.62	$15.24
14	Crank Arm	2	$7.02	$14.04
15	Crank Hub	2	$5.31	$10.62
16	Set Screw ⅛”	4	N/A	N/A

17	M3.5 Bolt 13mm	8	$0.52	$4.16
18	M3.5 Hex Nut	8	$0.31	$2.48
19	80-20 Rail Slider 1”	4	$69.55	$278.20
20A	80-20 Screw 1/4"-20 1/2"	236	N/A	N/A
20B	80-20 Nut 1/4"-20	238	N/A	N/A
21	¼”-20 Screw 1”	8	$0.90	$7.20
22	Offset Bracket	10	$7.96	$79.60
23	Corner Bracket	4	$7.07	$28.28
24	3-Way Connector	4	$12.14	$48.56
25	Strait Bracket 1”x 2”	16	$8.16	$130.56
26	Strait Bracket 1”x 4”	10	$8.16	$81.60
27	Angled Bracket	8	$10.26	$82.08
28	Angled Bracket Extended	6	$18.59	$111.54
29	Gusset Bracket (Single)	36	$8.81	$317.16
30	Gusset Bracket (Double)	4	$13.45	$53.80
31	Strait Bracket 2”x4”	2	$12.44	$24.88
32	Square Bracket 2”x2”	16	$12.16	$194.56
33	Arduino Uno	1	$18.99	$18.99
34	L298N H-Bridge Motor Controller	1	$6.99	$6.99
35	BRINGSMART 12V 12rpm DC Worm Gear Motor	2	$29.99	$59.98
36	500 Ohm Potentiometer	2	$3.33	$6.66
		Total Cost of Components:		$2,115.76

*Both the 80-20 Screws (Part 20A) and the 80-20 Nuts (Part 20B) are excluded from the cost of the device. These components are included when ordering various brackets and connectors (Parts 22-32) from McMaster-Carr and therefore included in the price of the connector.

*The ⅛” set screws (16) are excluded from the cost of the device because they come included with the crank hubs (15).

The first time a part is referenced, the part number will be specified as (Part #), corresponding to that parts # in Appendix D. After all subsequent references to it, it will simply be referenced as (#). Subassemblies are referenced in a similar way only using letters instead of numbers. Each subassembly drawing and their corresponding reference letter can be found in Appendix B.

Our design uses four spring-loaded wedges to both hold up a stack of cones and to pull cones from the stack. Two of the wedges are mounted in the stationary wedge housings (E) which are rigidly mounted to the frame. These two wedges are the large wedge subassemblies (B) and are used to hold a stack of cones in place. The other two wedges are the small wedge subassemblies (A) and are mounted perpendicular to the large wedges (B). The small wedges (A) are mounted in the sliding wedge housings (F) which are actuated up and down by the crank-slider linkage (H). These two wedges are the small wedge assemblies (A) which are used to pull cones from the stack. The sliding wedge housings (F) translate 3" up and then 3" down. A diagram was created to show the actuation of the sliding wedge mechanism, seen in Figure 11, along with a description.

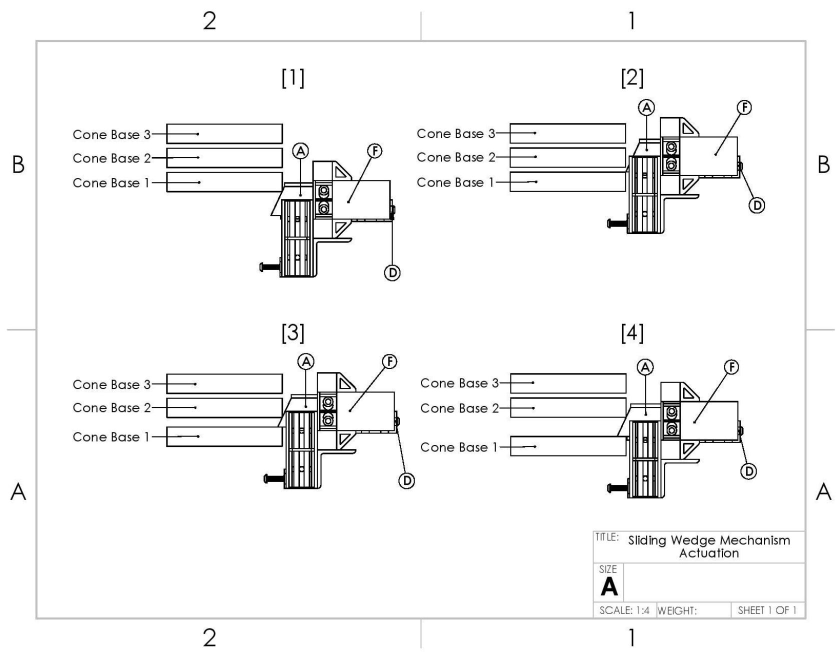


Figure 11: Drawing of Sliding Wedge Mechanism Actuation made with Solidworks

As the sliding wedge housings (F) translate upwards the small wedges (A) come into contact with the bottom of the first cone in the stack [1]. As the sliding wedge housings (F) continue to translate upward the wedges (A) are pushed back by the base of the bottom cone until they move above the base [2]. At this point the wedges (A) are pushed by springs (7) over the top of the base of the bottom cone in the stack [3]. Next the sliding wedge housings (F) translate downward pulling the bottom cone with them [4]. This cycle repeats for every cone that is deployed.

Another diagram was created to show the actuation of the sliding wedge mechanism, seen in Figure 12, which operates perpendicular to the stationary wedge mechanism. Similarly, this diagram also includes a description of the actuation of the mechanism.

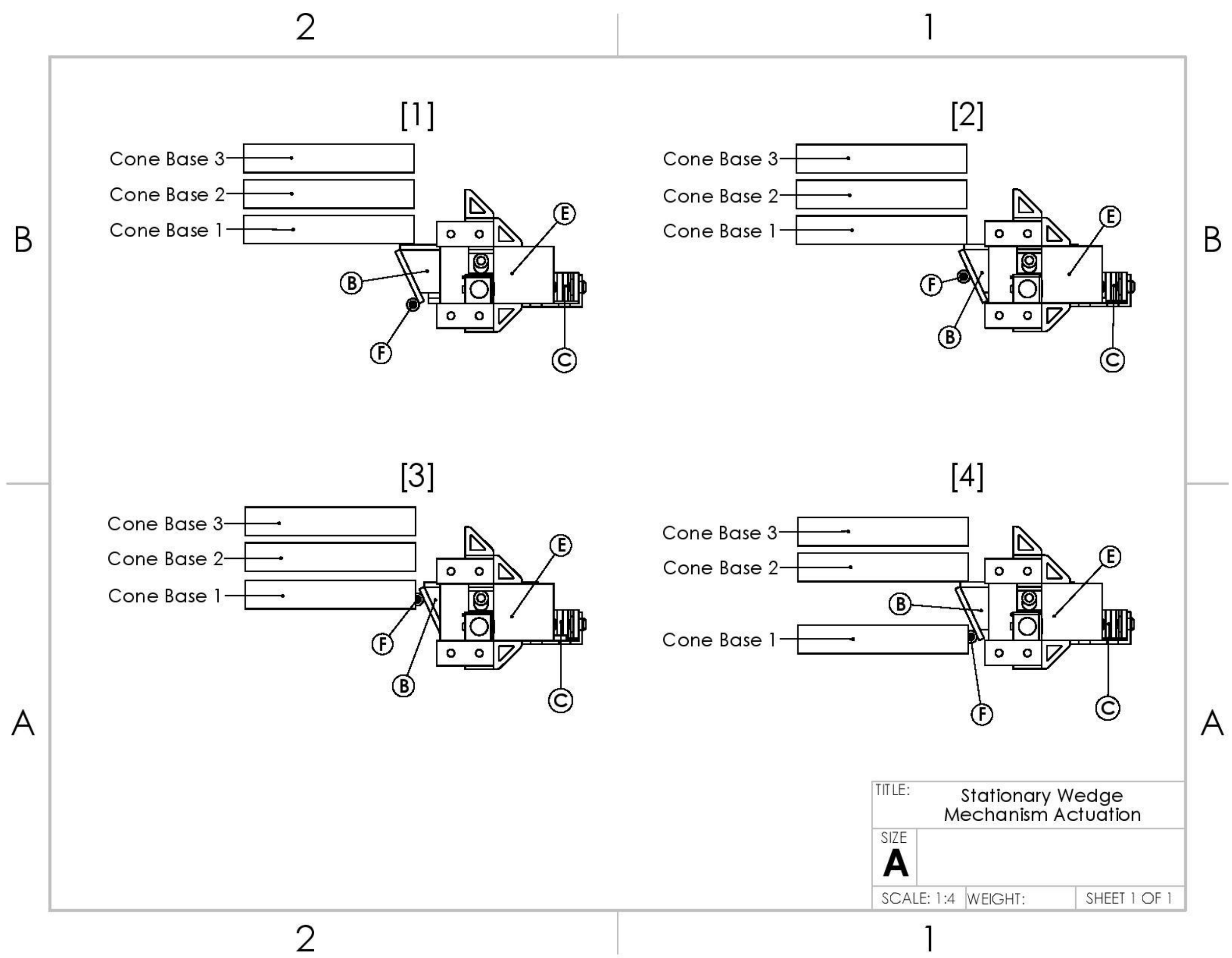


Figure 12: Drawing of Stationary Wedge Mechanism Actuation made with Solidworks

Simultaneously, when the sliding wedge housings (F) begin to translate upwards a set of four pegs come into contact with the large wedge subassemblies (B) [1]. These pegs push the large wedges (B) back into the stationary wedge housings (E) as the sliding wedge housings move upward [2]. At the top of the cycle the wedges have separated enough to allow the bottom cone to fall from the bottom of the stack [3]. As the device begins to translate back downward the slides are pushed back outward by a pair of springs (7) in order to catch the rest of the cones in the stack [4]. This cycle repeats for every cone that is deployed.

These wedges (A and B) are made from wood and have aluminum plates attached to the tops and bottoms. These wedges (A and B) are held in the wedge housings (E and F) simply by friction on the top, bottom, and sides. The plates reduce the friction by changing the contact from wood on aluminum to aluminum on aluminum. The wedges (A and B) also have aluminum plates attached to the angled face to reduce friction between the cone base and the small wedges (A), and between the large wedges (B) and the pegs on the sliding wedge holders (F). The springs (7) are glued both to the wedges (A and B) and into the spring housings (C and D) preventing the wedges (A and B) from falling out of the device.

The team changed the method used to actuate the sliding wedge housings (F) multiple times over the development of the device in order to simplify the design. The original design made use of a pair of hydraulic cylinders to actuate the sliding wedge housings(F). This design is briefly described in the Design Concepts section as the hydraulic pusher design. The hydraulics are a good method for operating the device because they are durable, high powered, and the trucks which would support the device include an onboard hydraulic system. The team chose to replace the hydraulic system with an electric motor driven system because WPI does not have the equipment for hydraulic systems which is expensive and complicated. By switching to a system which uses DC motors our team can use batteries to operate our device.

The use of electrical motors opens up the possibility of using a number of systems to actuate the device. One option is to use a lead screw or linear actuator. This option provides a lot of mechanical advantage, providing plenty of force to actuate the device, however they translate too slowly to achieve the desired drop rate. Another option our team considered was a rack and pinion system. This system would allow for faster actuation of the device however, two other problems exist with a rack and pinion system. One issue is that the motor would need to change directions every cycle of the device which is hard to control precisely and would add significant complexity to the electrical system. Another issue is that a rack and pinion system would impart a significant torque onto the sliding wedge housings (F) which would lead to increased friction and wear on the rail sliders (19). Finally, our team decided to utilize a crank-slider mechanism to actuate the device. This simplifies the system because the motors can run at a constant power setting while the device actuates up and down. Additionally, a crank slider mechanism mounted in the center of the sliding wedge housings (F) imparts only a small torque onto the wedge housings.

The whole device can be mounted onto a truck using the truck mounts (K), which are simply two long bars which can be clamped to the back of the truck in a variety of ways. The mounts (K) could be attached by using a set of U-bolts, a set of large clamps, dedicated bolts into the truck frame, or welded directly on. In order to design an exact mounting mechanism more details would need to be known about the frame of the truck.

This entire device was modeled in Solidworks. Drawings of each part in the device can be found in appendix A. Parts that were ordered from McMaster-Carr have drawings of each part available on their website. Any custom parts or parts ordered from other sources have been modeled in Solidworks and drawings were generated from the models. Drawings of the subassemblies that make up the device can be found in appendix B. Below is a drawing, seen in figure 13, showing the Solidworks Model of the full device assembly which includes the location of each subassembly in the device.

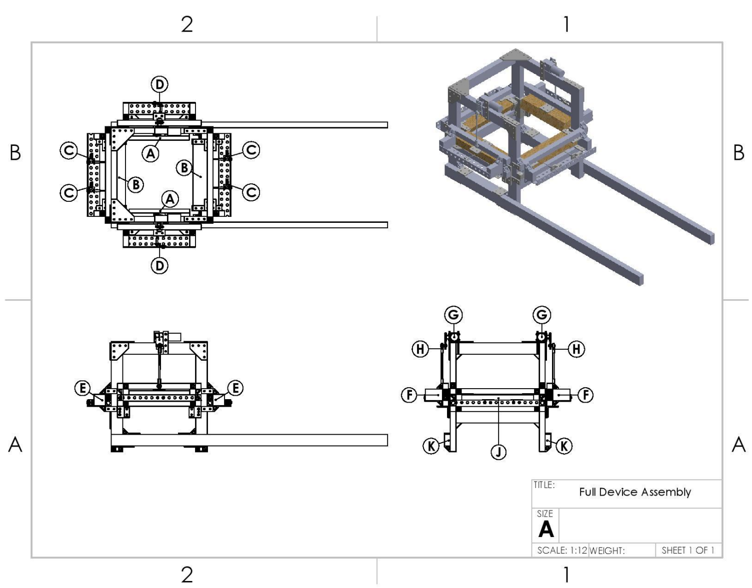


Figure 13: Drawing of Full Device Assembly made with Solidworks

Below that is a drawing of the full device assembly isometric, seen in Figure 14, which gives a closer look at the entire model.

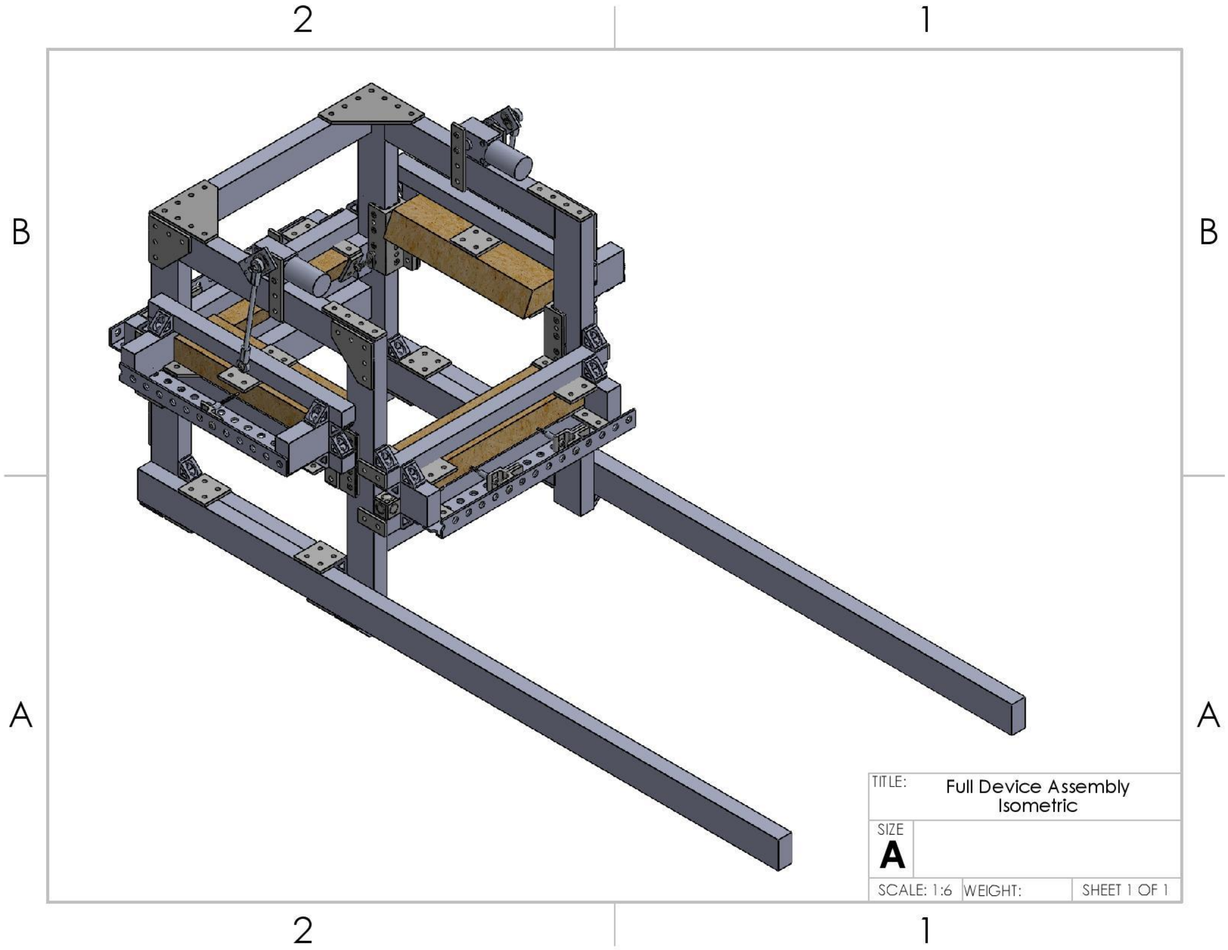


Figure 14: Drawing of Full Device Assembly Isometric made with Solidworks

Construction

1. Required Tools

As per the functional requirements, this assembly can be made using only standard tools. The following list is all the tools required to manufacture this specific prototype:

- 5/16th allen wrench
- 1/16th allen wrench
- 5.5mm wrench
- 6mm wrench
- Phillips head screwdriver
- Band saw
- Table saw
- Drill press
- Metal file

The majority of this assembly is made up of 80/20 material, which utilizes ¼” -20 fasteners and elongated nuts, as seen in Figure 15.

Figure 15: ¼” -20 fastener and elongated nut used for 80/20 components

It is important to note that this specific prototype used a great deal of scrap material that needed to be modified, and may not be the most optimal way to assemble such a mechanism.

Depending on the material available, some specifics of these instructions may need to be modified.

This assembly is made up of several distinct sub assemblies, as displayed in Figure 16.

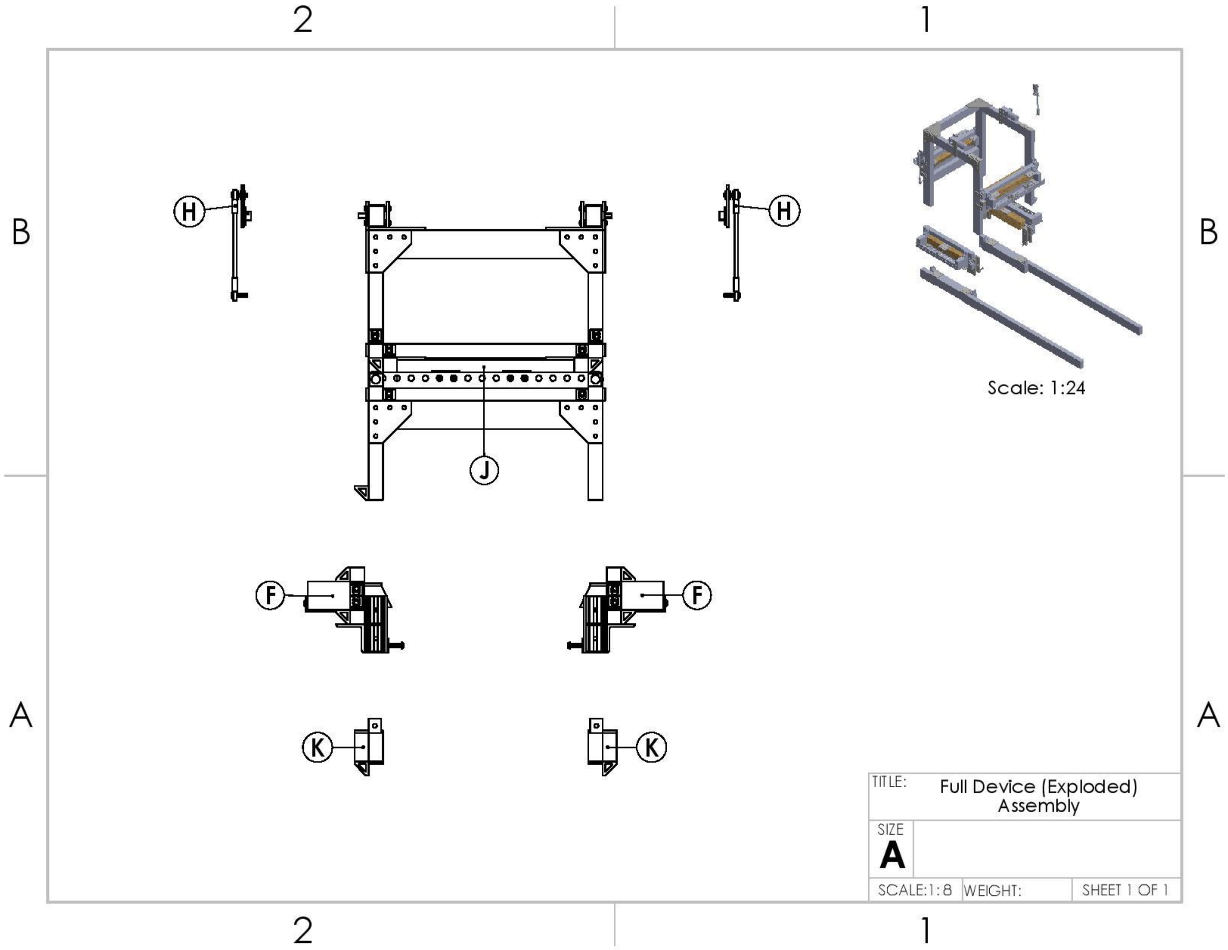


Figure 16: Drawing of Full Device (Exploded) Assembly made with Solidworks

The subsequent sections are a complete manual on how to assemble the prototype from this project.

2. Wedge Housings

The first step is to assemble the housing for the stationary slides. The sub-assembly drawing can be found in Appendix B, subassembly E.

Begin with a 16 ½ inch piece of 1x1 T-slotted framing (Part 1B). Connect a piece of 4 inch 1x2 T-slotted framing (Part 2A) at a 90 degree angle to the first bar using two angled brackets (Part 29), as shown in Figure 17. Repeat this same process on the other end of the bar, and then attach a second 16 ½ inch 1x1 T-slotted framing (1B) on top, using 2 additional angled brackets (29). Keep the bolts loose to allow for adjustment while constructing, and tigenten them all using the 5/32 allen wrench at the end.

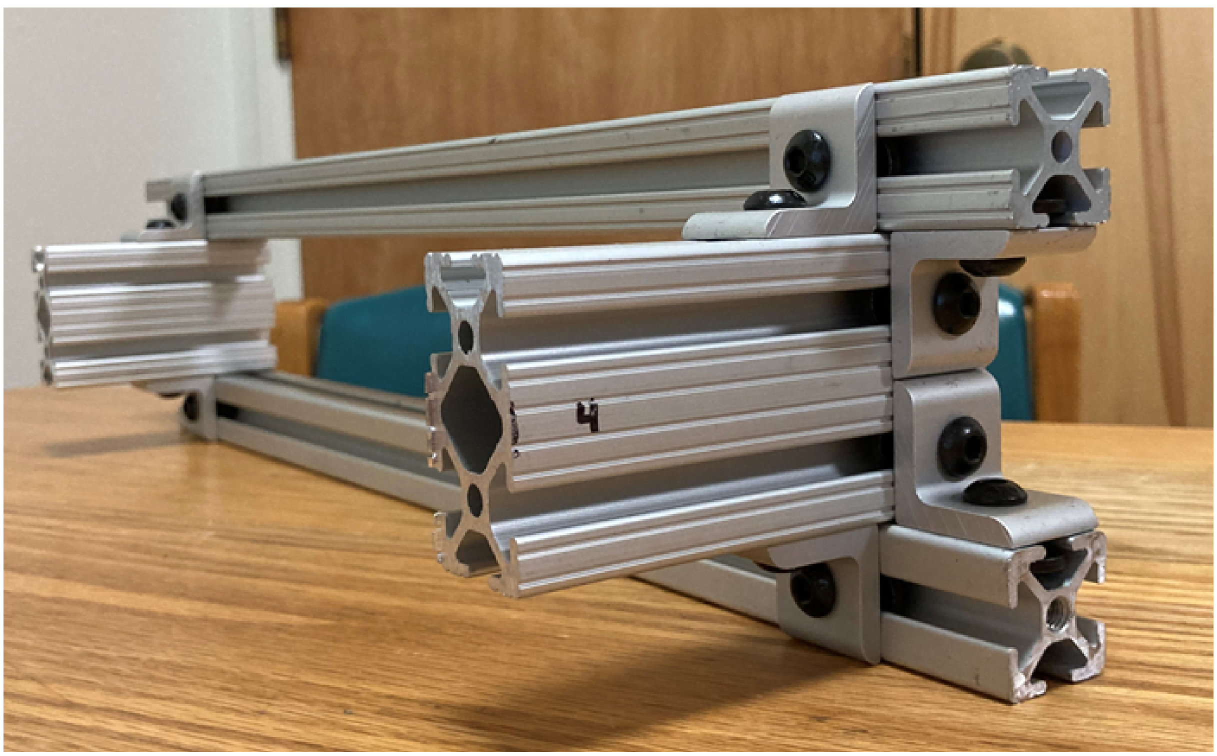


Figure 17: Stationary Wedge Housing Joints

Next, attach the Slider Frame (Part 6). In the case of this project a scrap piece of perforated steel bent at a 90 degree angle was used, but any piece of bent sheet metal will suffice. Using two ¼” -20 fasteners (Part 20A), affix the slider frame to the bottom of the bottom of the 1x2 T-slotted framing (1B), ensuring that they lie flush with the angled brackets (29) as shown in Figure 18.

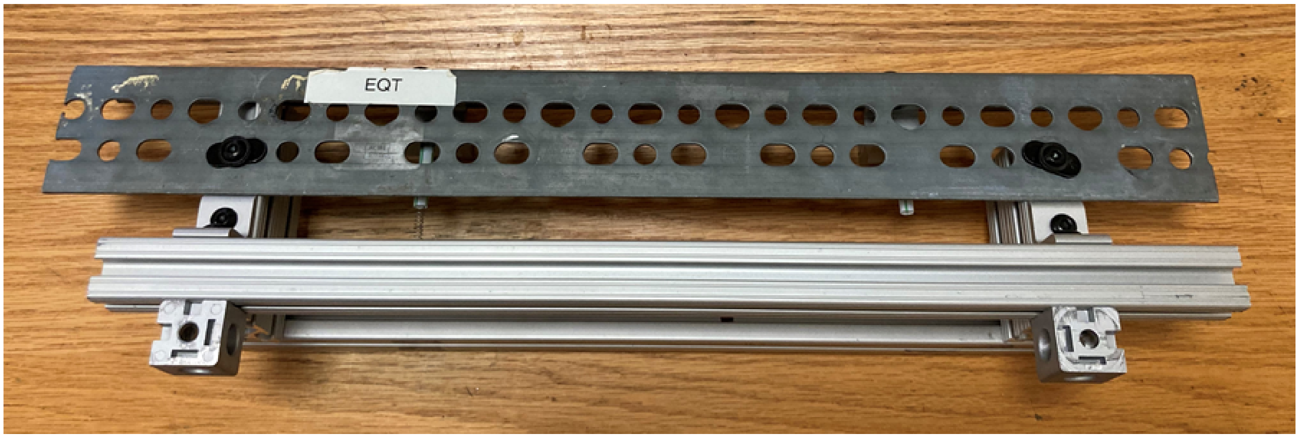
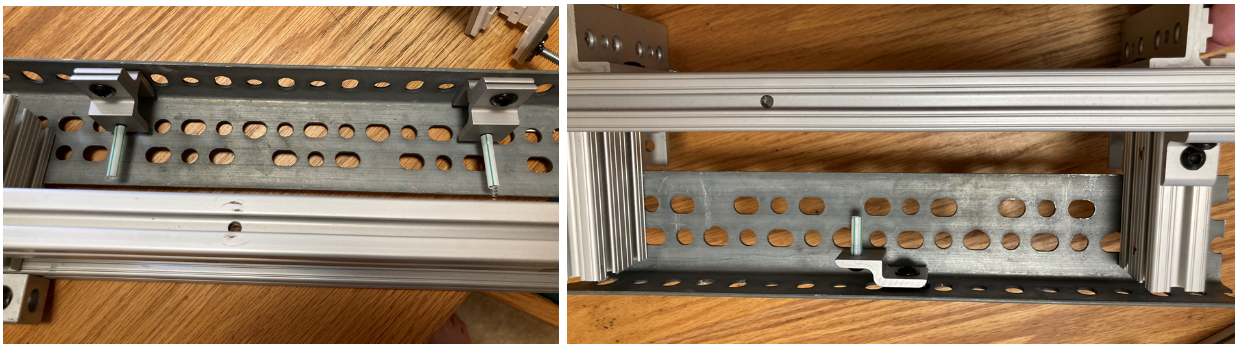


Figure 18: Slider Frame Attachments

Repeat this process 3 additional times to create all 4 of the wedge housings. The final step is to create the spring backings, which differ slightly between each housing. For this prototype Offset brackets (Part 22) were used as spacers, but future iterations could simplify this by making the 1x2 T-slotted framing (2A) and the slider frame (6) shorter. The subassembly for the single spring housing is in Appendix B, subassembly D, and the subassembly for the double spring housing is found in Appendix B, subassembly C. Affix a ¼” -20 bolt (20A) to each of these spacers and screw a 1 ½ inch threaded plastic tube (Part 8) to the end of it. This will help to constrain the spring, which will be discussed in section 6. Six of these spring-housing sub assemblies are needed. Two of the wedge housings contain two of these spring housings, spaced equidistant from the center, as shown in Figure 19a, and the other two only contain one where the tube is centered, as seen in Figure 19b.



(a) (b)

Figure 19: Spring-housing sub assemblies

3. Sliding Wedge Housings

Two of the wedge-housings are going to be fixed directly to the frame, but the other two need to move up and down. The sliding wedge housing sub assembly drawing can be found in Appendix B, subassembly F. Take the two wedge housings with two spring housings, shown in Figure 19a), and set them aside. They will not be needed until section 7.

Taking one of the left over wedge housings, attach one of the slides (Part 19) to it such that the bottom bar is connected to the second mounting hole from the top on the slides, as seen in Figure 20. Repeat this process for the opposite side.

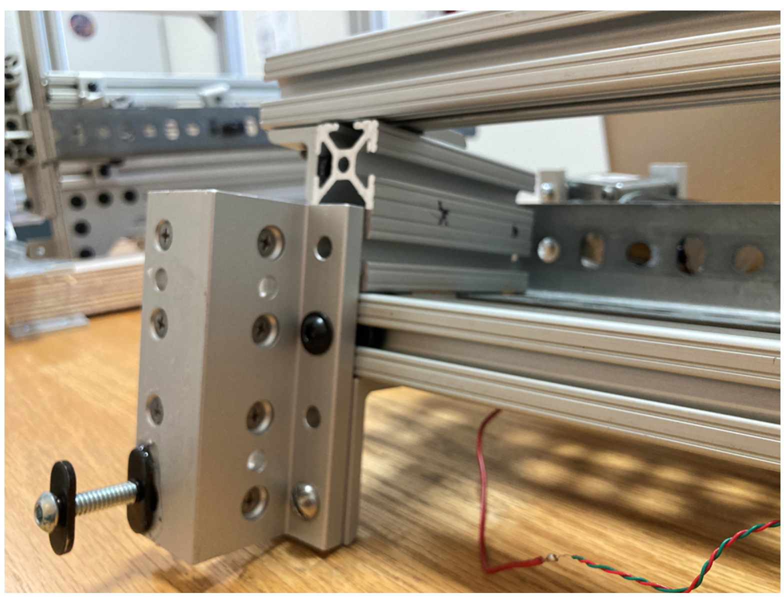


Figure 20: Slides

To better secure the slide, use a large angle bracket (Part 30) to connect the bottom bar of the wedge housing to the bottom mounting hole on the slide, as seen in Figure 21. Repeat this process for the opposite side.

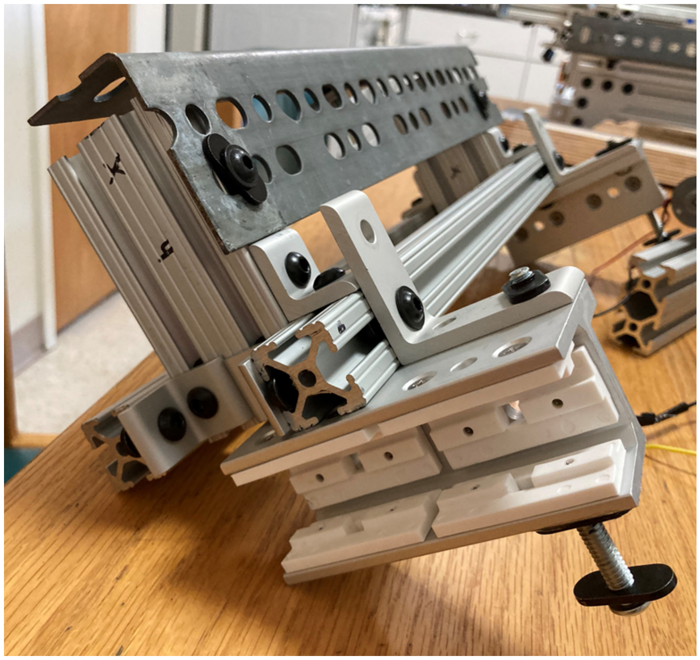


Figure 21: Angle brackets connecting the wedge-housing to the slides

The final step for the sliding wedge-housing is to attach the pins. Take a 1 ½ inch long ¼" -20 (Part 21) and screw an elongated nut (Part 20B) all the way to the end, such that it is flush with the head. A secondary nut (20B) may be used to secure it in place. Next screw a second elongated nut (20B) so that it is flush with the other end of the bolt. Lastly, use epoxy to secure the pins to the outside corners of the slides, as shown in Figure 22. Repeat this process bor the opposite side

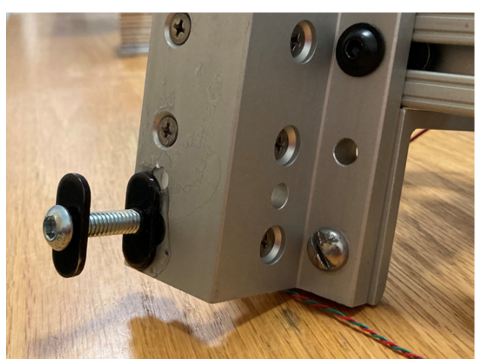


Figure 22: Pins

Repeat this entire process for the second wedge-housing. You should now have two wedge housings connected to sliders, and two wedge housings standing on their own.

4. Slider-Crank

The next step is to create the slider-crank sub-assembly, found in Appendix B, subassembly H.

First, connect two Ball Joint End Rods (Part 12) to either side of one of the Connecting Rods (Part 13), ensuring that the holes in the ball joints are facing the same direction, as shown in Figure 23. This will become the linkage arm of the slider crank.

Figure 23: Ball Joints (12) and Connecting Rod (13)

The next step is to create the Crank Arm (Part 14). This is one of the few parts in the assembly that needs to be custom-machined. The construction of this part requires a bandsaw to cut the stock to shape, and a mill or drill press to create the holes. See Appendix A for the detailed part drawing with dimensions.

Using four M3.5 bolts (Part 17) and M3.5 nuts (Part 18), attach the Crank Hub (Part 15) to the Crank Arm (14), as seen in Figure 24. Ensure that the bolts (17) are as tight to avoid any slippage in the crank arm.

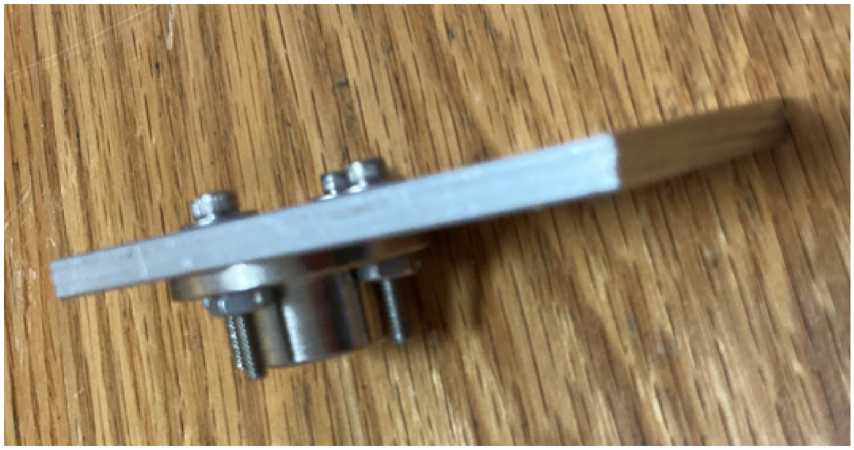


Figure 24: Crank Arm (14) and Crank Hub (15)

Next, connect the Linkage Arm to the Crank Arm (14) using a 1 ½ inch long ¼" -20 bolt (21), with an elongated bolt on each side of the crank arm as shown in Figure 25.

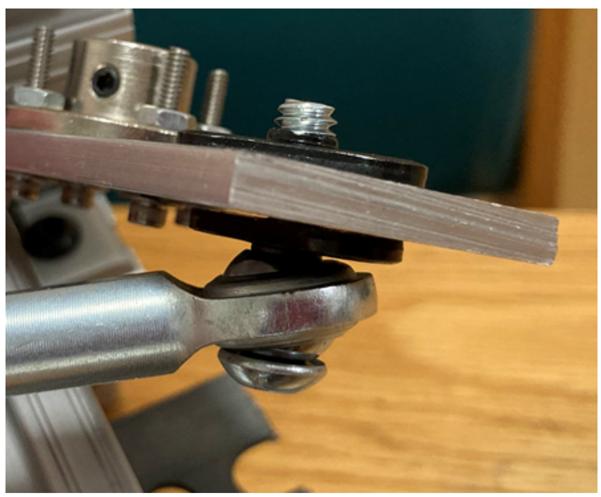


Figure 25: Joint between Linkage Arm and Crank Arm

Lastly, connect the free end of the Linkage Arm to the sliding wedge-housing in a similar manner to how it was attached to the crank arm, as shown in Figure 26. Ensure that the linkage arm is centered along the wedge-housing. In order to attach the arm one of the angled brackets may need to be removed temporarily.

Figure 26: Joint between Linkage Arm and Sliding Wedge Housing

Repeat this process for the other sliding wedge housing so that the 2 are identical.

5. Motor

The subassembly for the motor attachment can be found in Appendix B, subassembly G. Using two 1x4 Aluminum Plates (Part 26), affix one of the motors to the side of a 14.5 inch long 1x2 T-slotted framing (Part 1A). Keep the bolts loose for now so that the bars can be slid and adjusted. Next, insert one of the motors (Part 10) between these two plates (26) and bolt it into place. Use washers as spacers as needed, shown in Figure 27.

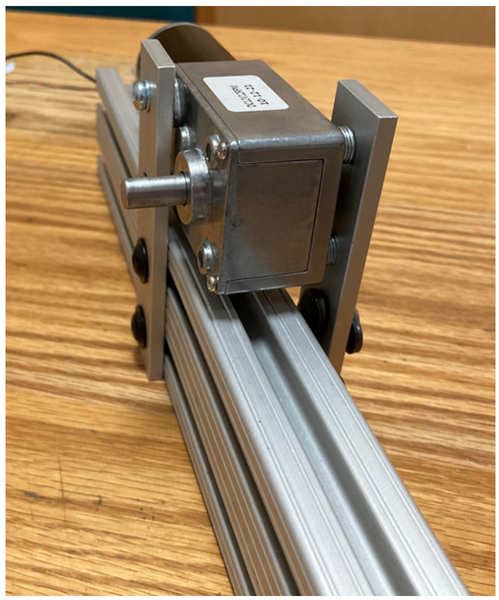


Figure 27: Motor Attachment

To complete the entire slider-crank assembly, connect the crank hub (15) to the shaft of the motor using the included set screws (Part 16). Repeat this process for both sides. The entire slider-crank sub assembly should now look like Figure 28.

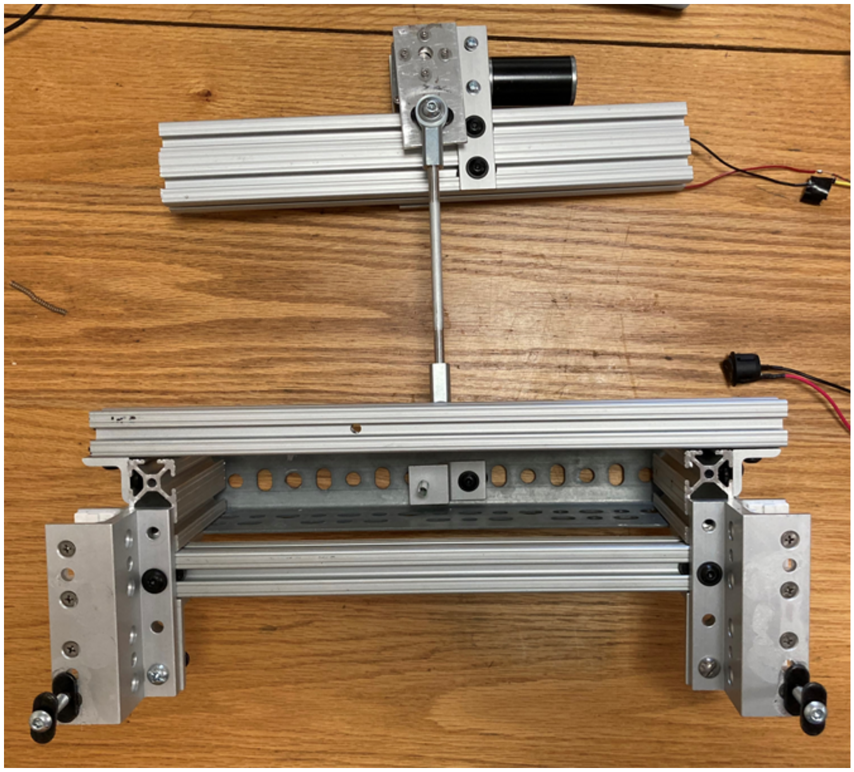


Figure 28: Slider Crank Sub Assembly

6. Wedges

The next step is to create the wedges. There are two different sized wedges, so begin with the Small Wedge (5). The Small Wedge subassembly can be found in Appendix B, subassembly A.

First, create the wedge-shape out of plywood, using a tablesaw to make the necessary cuts. The detailed drawing and dimensions can be found in Appendix A, part 5. Next, connect the extended corner brackets (Part 28) to the bottom of the wedge using wood screws and a 2x4 straight bracket (Part 31) to the top. The heads of the screws may need to be ground down to ensure the surface of the plates is completely smooth, as shown in Figure 29.

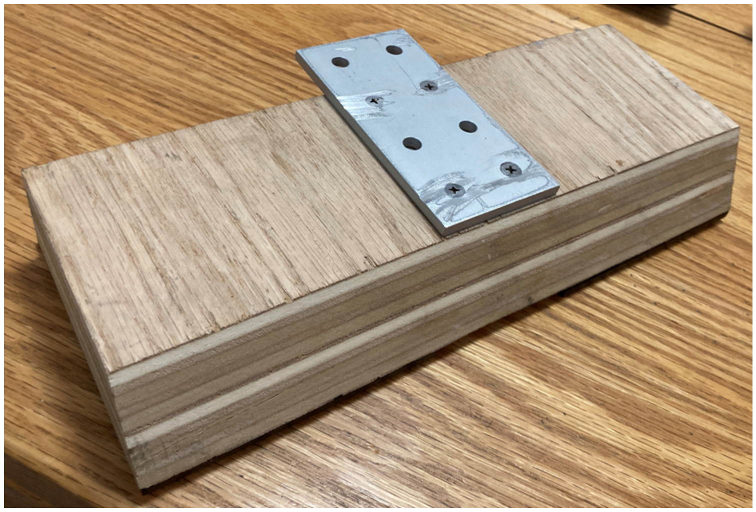


Figure 29: Small Wedge Plates

Lastly, hammer a wooden spike (Part 9) into the back of the wedge, such that it lines up with the plastic tube (8) when the wedge is inserted into the sliding wedge-housing. Cut the wooden spike (9) such that it extends 1 inch from the back of the slide (5). Place one of the springs (Part 7) over the wooden spike, as shown in Figure 30.

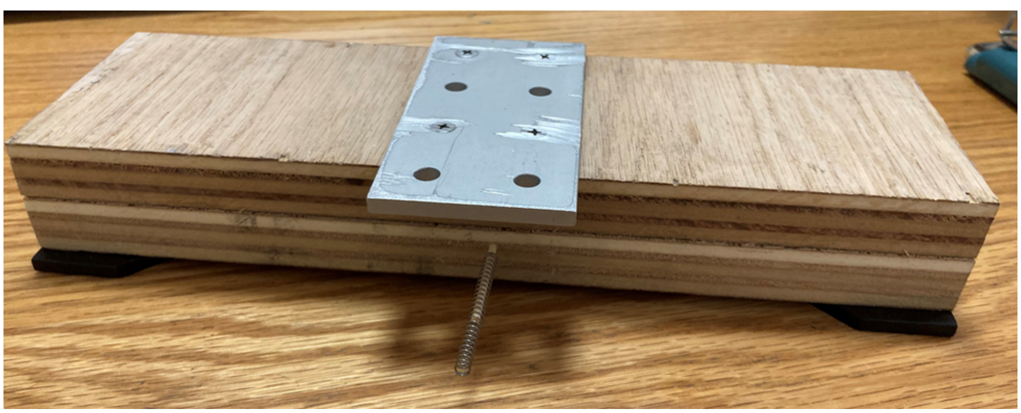


Figure 30: Small Wedge Spring

The larger wedge (Part 3) has a very similar manufacturing process. The sub assembly drawing is found in Appendix B, subassembly B.

First, create the wedge-shape out of plywood, using a tablesaw to make the necessary cuts. The detailed drawing and dimensions can be found in Appendix A, part 3. Next, connect a 2”x2” bracket (Part 32) and a 1”x4” bracket (26) to the bottom of the wedge (3), such that the 2”x2” bracket (32) is on top of the 1x4 bracket (26), and the wedge (3) is on top of both of them. Next connect a 1x2 bracket (Part 25) and 2x2 (32) bracket to the top of the wedge (3). Lastly, connect a 1”x2” bracket (25) to the sides of each of the slanted components of the wedge (3). It is important to note that this configuration was chosen based on the available plates that the team had access to while manufacturing, and simply using 1”x4” brackets (26) throughout could be simpler, and including some form of roller slides would be more ideal to reduce friction. The heads of the screws may need to be ground down to ensure the surface of the plates is completely smooth, as shown in Figure 31.

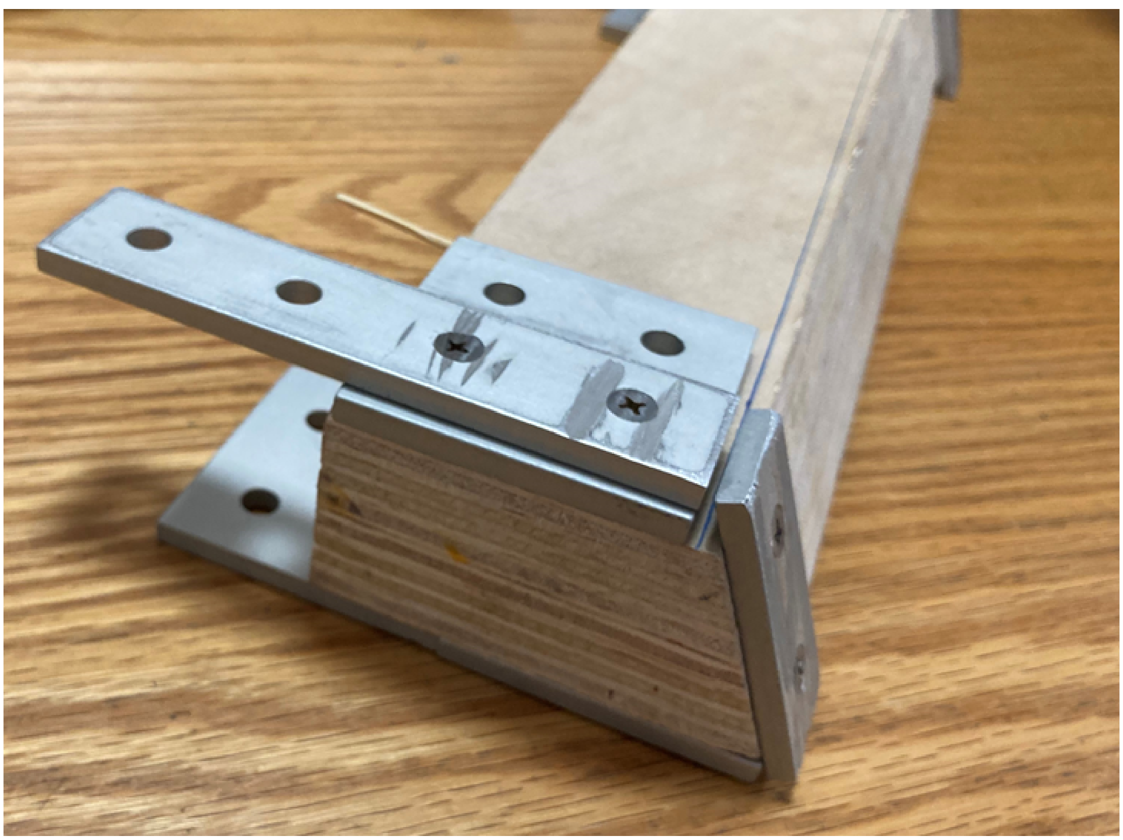


Figure 31: Large Wedge Plates

Lastly, hammer two wooden spikes (9) into the back of the wedge (3), such that it lines up with the plastic tubes (8) when the wedge assembly is inserted into the wedge-housing. Cut the wooden spike (9) such that it extends 1 inch from the back of the slide (3). Place one of the springs (7) over each of the wooden spikes (9), as shown in Figure 32.

*Figure 32: Large Wedge Spring*s

Insert all of the wedge assemblies into their corresponding housings, ensuring that the springs (7) lie inside the plastic tubes (8) and the wedges are able to retract and return freely.

7. Frame

The final step is to assemble the frame and connect all of the parts together. The assembly of the frame is shown in Appendix B, subassembly J.

First, use two small angled brackets (29) to connect a piece of 1x1 14.5 inch T-slotted framing (1A) to two 19 inch 1x2 T-slotted framing (2D) to create a U-shape. (in the case of this assembly a 1x2 bar was used for the bottom simply because there was extra, but it is not necessary). Use a square to ensure that the two parallel pieces are perfectly straight, as any misalignment will introduce a lot of friction in the slides.

Next, carefully slide the sliding wedge housings from section 3 onto the vertical bars, and connect the 14.5 inch bar (1A) with the motor (10) affixed to it to the top of the bar to the top of the two vertical bars (2D) using two corner brackets (Part 22), as shown in Figure 33.

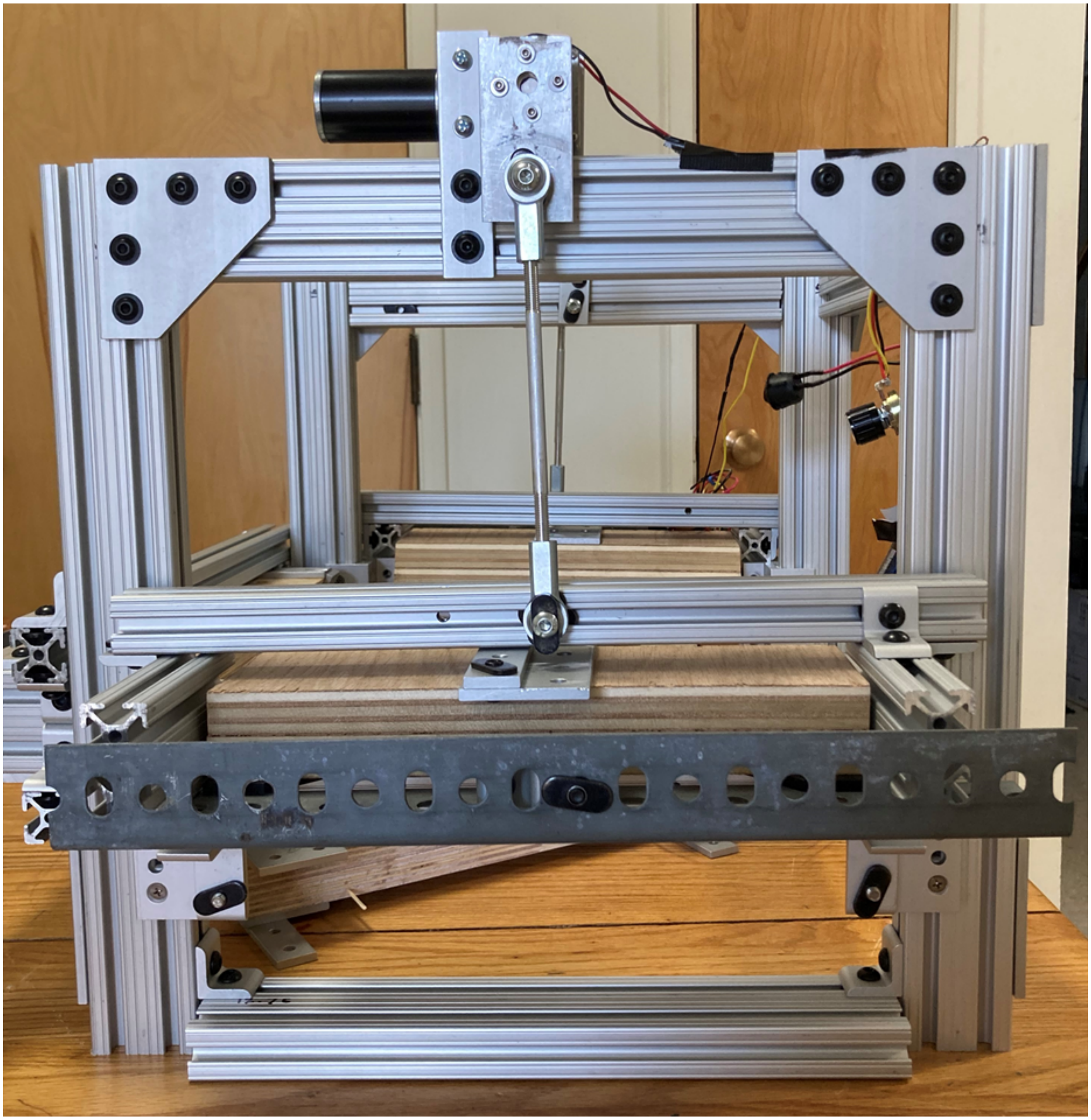


Figure 33: Frame for Sliding Portion

Ensure that the slider-crank operates smoothly before tightening all of the bolts down. If the slide is not smooth, ensure that the two rails are perfectly parallel. This makes up one side of the box. Repeat this same process to make the other side.

Next, use two large angled brackets and a 14.5 inch 1x2 T-slotted framing to connect the two sides together, as shown in Figure 34. Repeat this same process for both sides so the base is now a complete square.

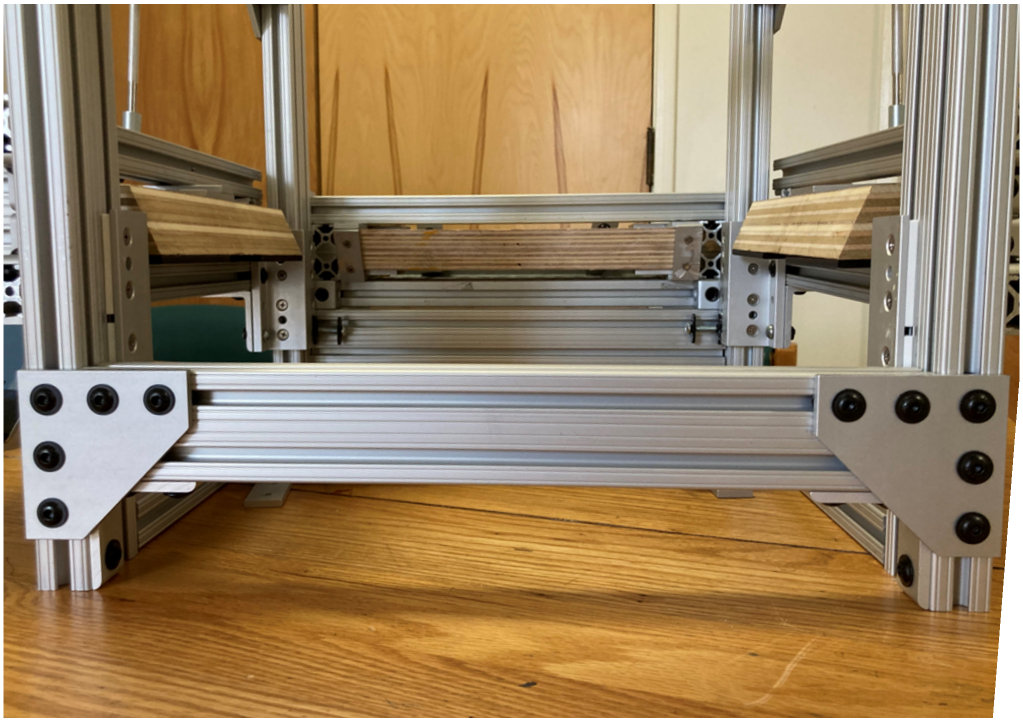


Figure 34: Base Connecting Bars

Take the four 3-way joints (Part 24) and file down the nubs such that each side is completely flat, shown in Figure 35.

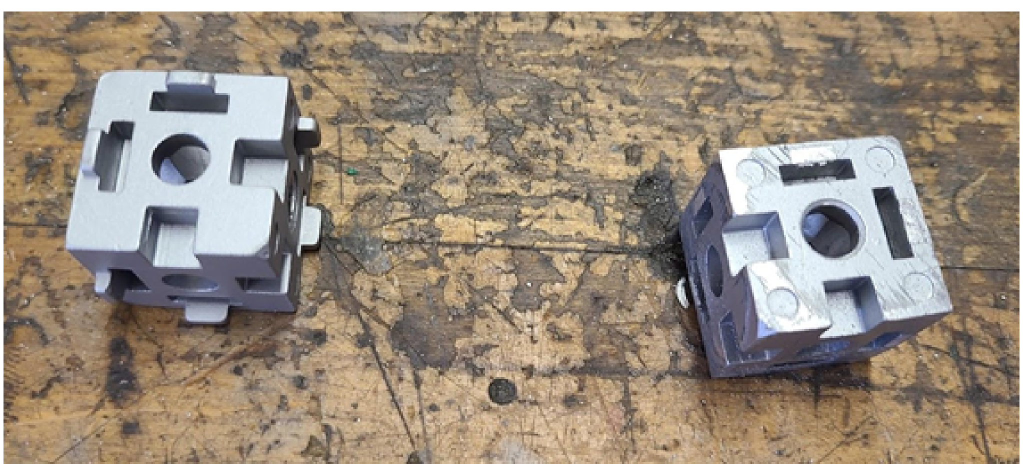


Figure 35: Filed 3-way joints

Using the 3-way joints (24), connect the two remaining wedge housings to the frame, as shown in Figure 36.

Figure 36: 3-way joins that connect the wedge housings to the frame

Lastly, attach the final piece of 14.5” 1x2 T-slotted framing (1A) to the frame above one of the stationary wedge housings, as shown in Figure 37. Leave the other side open, as it is needed to insert cones into the system.

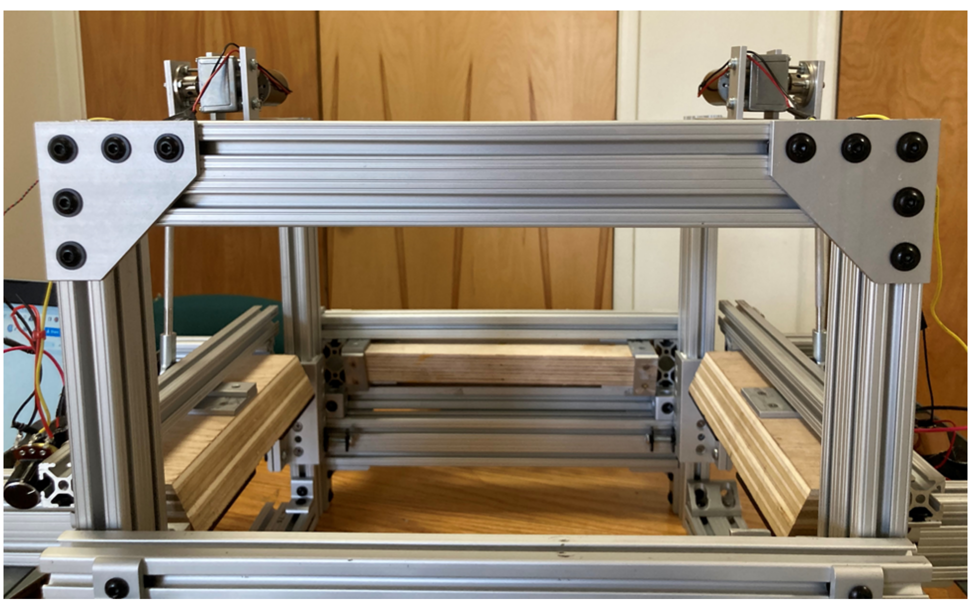


Figure 37: Final Connecting Bar

The final assembly should look like Figure 38. This picture includes the electronics, which will be discussed further in depth in the next section.

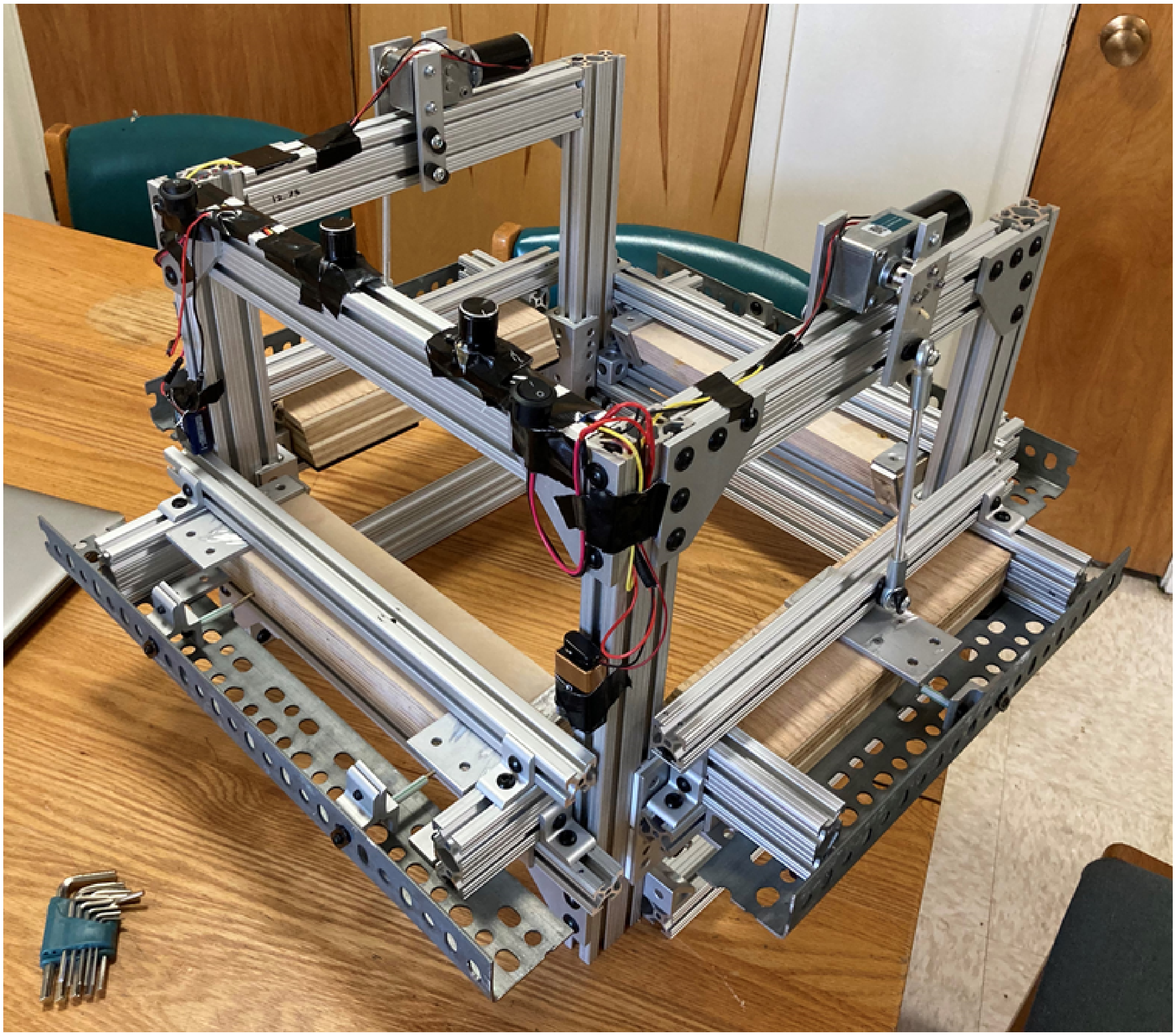


Figure 38: Completed Assembly

8. Electronics

For this design of the dropper, we needed a way to consistently power and control the motors so they did not desynchronize while in use. Desynchronization of the motors would cause problems for the dropper, misaligning the cones and most likely leading to a jam. For this process, multiple methods were utilized to ensure the device worked. The first method utilized an XL6019 DC Step-Up converter, a device utilized to amplify the output voltage of a given power source, seen in Figure 39.

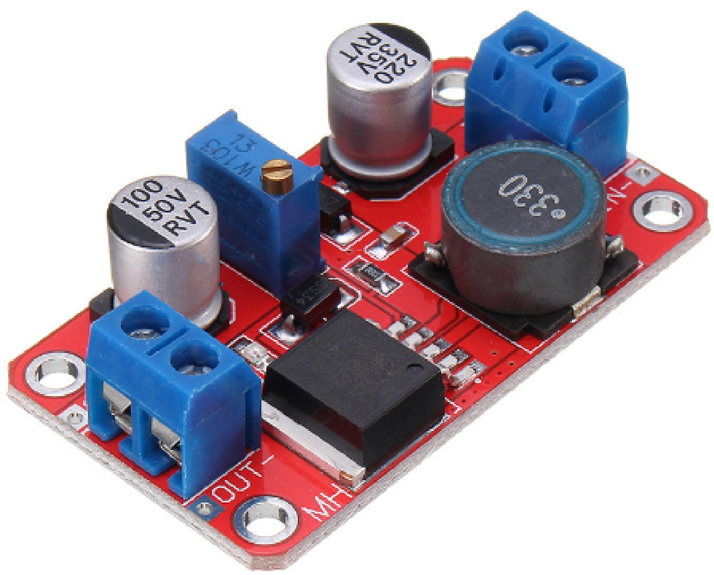


Figure 39: Physical view of the XL6019 DC Step-Up converter

In this case, a 5v 700mAH rechargeable battery was used. While this battery is definitely not enough to power the 12v DC motors alone, adding the DC step-up converter allows for consistent power transfer. While using this method alone would provide plenty of power, the system was also intended to work with 500-ohm potentiometers to control the power going into the motors, seen in Figure 40. A circuit diagram of this component can be found as part 36 in Appendix A.

Figure 40: Physical View of a 500 Ohm Potentiometer

These components would have been prepared similarly to the way they are presented in the circuit schematic displayed in Appendix C.1. However, during testing, we discovered the module would retain mass amounts of heat if left on over time, and likely would be unsafe for continuous use. Additionally, the device was incapable of consistently sending power to both motors evenly, so this idea was discontinued.

Following this, we proceeded to a secondary option which proved much safer. This method utilized an Arduino Uno, potentiometers, the same 5v power source, and an L298N H-Bridge module. The Arduino Uno module, seen as part 33 in Appendix A, is a common microcontroller utilized in several versatile projects. This microcontroller holds hundreds of libraries of code for programming and relies primarily on C and C++ formatted code via the Arduino IDE. Utilizing this allows for easy control of the H-bridge module. This module allows for a safer method of converting 5VDC voltage to 12VDC voltage and splits it evenly between the motors. In this system, the potentiometers would be utilized to control the motors via a mapping system so that no values used are wasted. A diagram of this version of the electronics can be found in Appendix C.2. Unfortunately, while this method was preferred to any other alternative, the H-Bridge module still could not provide enough power to both motors, and this idea was also retired.

With little time remaining before the presentation, we had to utilize 9v batteries to power the motors in place of a dedicated power source. While the system was still less than required for the motors, it would prove enough to show that the concept is sufficient, and could possibly work given enough time and effort into finalizing a design. A circuit diagram of this model can be found in Appendix C.3.

As one final note, the ideal design for the electronics control systems would utilize either a 12 volt battery, or would be linked directly to a truck battery to power all of the necessary systems, and everything would be controlled using the second method of a microcontroller with an L298N H-Bridge, resulting in little need for human input.

Testing & Results

The team calculated the speed that is required to fulfill our design requirement of dropping cones every 20' off of a truck traveling at 10 MPH. Taking 10 MPH over 20' per cone we calculated that the device must drop cones at a rate of 0.733 cones/second. Each cone requires 1 rotation, therefore the motor speed that is required to achieve this design requirement is 44.0 RPM. Initially our design utilized a pair of AM-255 12VDC motors to actuate the crank-slider mechanism. During initial testing we discovered that these motors could not support enough torque to move the slider crank through the full cycle. We estimated the torque required to actuate our device by assuming the crank arm (14) to be a 1.5" cantilever beam with the weight of one of the sliding wedge housings (F), 6.16 lbs, at the end and added 20% to account for energy loss. The result is ~177.41 oz-in of torque is required to actuate each crank-slider and move each sliding wedge housing (F). To compensate for this, we swapped the AM-255 12VDC motors out for a pair of BRINGSMART 12V 9rpm DC Worm Gear Motors, which can provide 972.12 oz-in of torque but only rotate at 9 RPM under load. These motors did work better, but it was here that another issue arose. Due to restrictions for the venue where we would be presenting this project, we were not allowed to use an external power supply or powerful battery. This is the reason why we attempted to make the system work with only a pair of 9v batteries. However, as anticipated, these did not supply enough power to the motors to get through the full cycle.

From this test we learned two valuable pieces of information. The first is that, in order for this system to actually function, the manufacturer would need to invest in some more powerful motors and/or gearbox that has enough torque to move the slides at the desired speed. The second is that power is a potential concern. However, in a real world application this system would be running off of a truck battery, which should be able to supply more than enough power. However, more research is required to identify the specific power needs.

Unfortunately, because we were not able to fully power the motors, we were unable to test the mechanism's cone-dropping abilities. The motors require a push to get all the way around, and move far too slow to work. The retracting slides are open for far too long, allowing all the cones to drop out at once. However, in our motor tests we were able to confirm that the pin and spring mechanism does function exactly as intended, which shows that this is a successful proof of concept.

Conclusions and Recommendations

While the prototype developed in this project was not successful in fulfilling all of the functional requirements, it does serve as a valid proof of concept that can be built upon moving forward. In terms of successes, the prototype developed fits within the size and weight requirements specified at the beginning of the process. The testing of the pin mechanism and slider crank shows that it should in theory be able to drop cones one at a time if the slider crank is able to move at the desired speed. As for failures and areas to be improved in the future, the assembly time was far longer than originally desired, but the installation time should still remain relatively quick. Since the mounting mechanism was never fully implemented or tested, the exact installation time is something that still needs to be determined. Cost is a challenge to estimate, as many of the materials used were borrowed and repurposed from other projects. However, it is safe to assume that, based on our bill of materials, it is at least $1000 over the desired $1000 budget. In order to reduce this, we recommend using more custom components as opposed to the 80/20 framing. These components could combine the frame pieces with the brackets, reducing the number of fasteners significantly. This will likely not only reduce the cost, but also the complexity, part count, and the number of threaded fasteners drastically, which will in turn also help to reduce the assembly time.

The tests with the motors showed that a stronger motor/gearbox is required to achieve both the torque and speed required to drop the cones at the desired rate. More research needs to be done in order to identify the ideal motor and gearbox setup, as well as the power requirements.

Because of time constraints we were not able to do any extensive strain testing to estimate the lifespan of such a mechanism, which is something that should definitely be investigated further in the future.

After testing and evaluating the prototype, we have come up with the following list of recommendations for any future iterations of this design:

- Put the sliders on rails with wheels like a drawer
- Use leaf springs instead of coil springs to reduce complexity of the component
- Find a stronger material to make the slides out of while not increasing the weight(a custom hollow component?)
- Reducing the system to one motor and gearbox that can power both crank mechanisms will simplify the electronics and eliminate the risk of desynchronization.
- A more robust and developed electrical system (preferably made by an ECE or Robotics major)
- A separate cone-feed mechanism is necessary to be able to dispense large amounts of cones at once
- There are two different styles of cones, some with thin bases and some with thicker bases. Our mechanism was designed with thin bases in mind, so some modifications might need to be made to make it compatible with both cone types
- The device requires over 18v in order to function effectively. Many tests during the process have shown that a 9v battery alone cannot power the motors efficiently, and two 9v sources only gave limited power to each motor based on how often the motors stalled. It would be best to use a dedicated power supply, or a 24V battery to power both motors efficiently. Alternatively, reducing the system to only one motor as mentioned earlier would mitigate the power issue.
- The motors utilized were high torque 9 RPM motors with a reduction ratio of 1:670, very slow in comparison to the deployment vehicle, but more than enough for this project. However, this motor also requires a lot of power to function at max speed. For future reference it would be best to use a faster motor, or a high speed motor with a powerful gearbox to allow for rapid deployment, and reduce stall.

In summary, this design will theoretically be able to function as desired and drop cones off of a truck. However, more work is required to fully realize it as a functional mechanism. We recommend that any future team to work on this project focuses their efforts on solving the power issues to allow for full testing, and investigating ways to reduce the cost and complexity with some custom-made framing pieces, and making it compatible with different sizes of traffic cones to make it more versatile.

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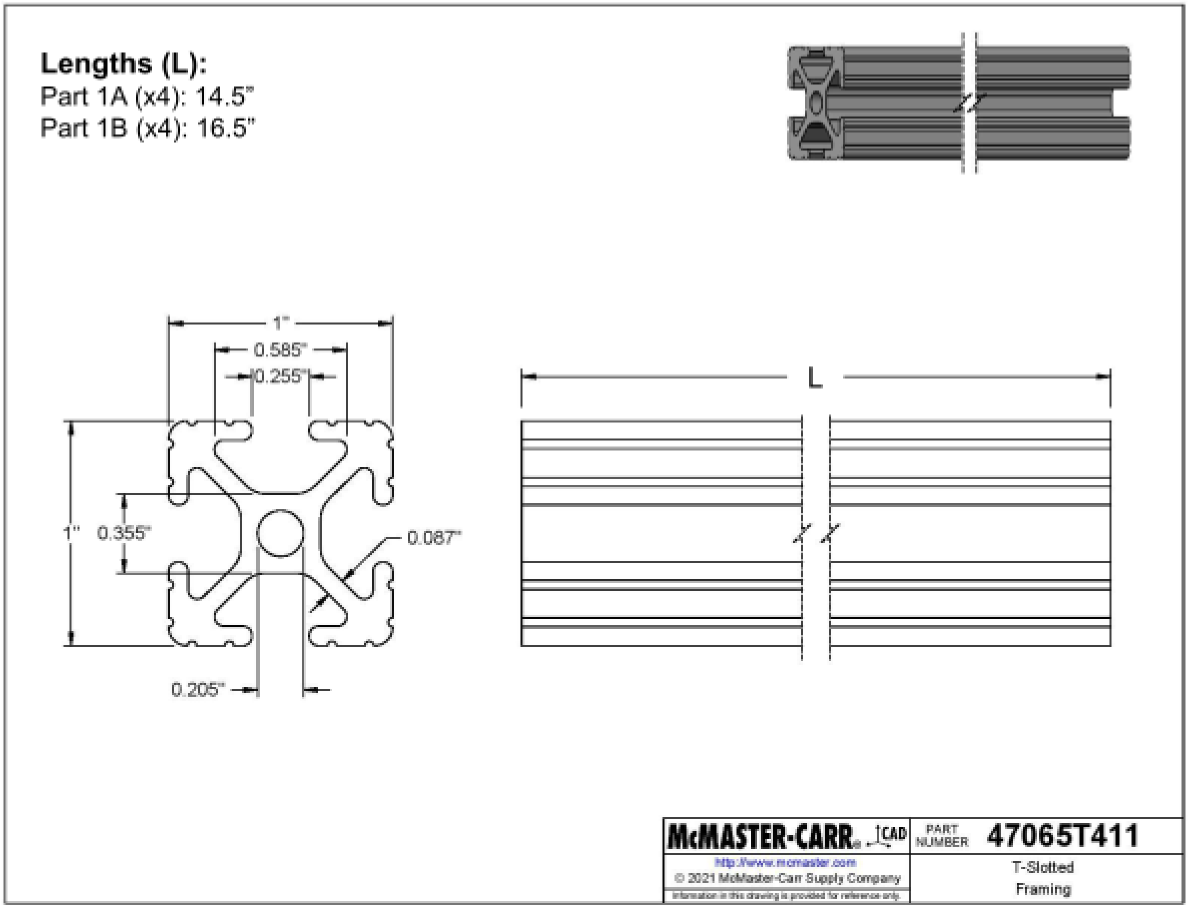
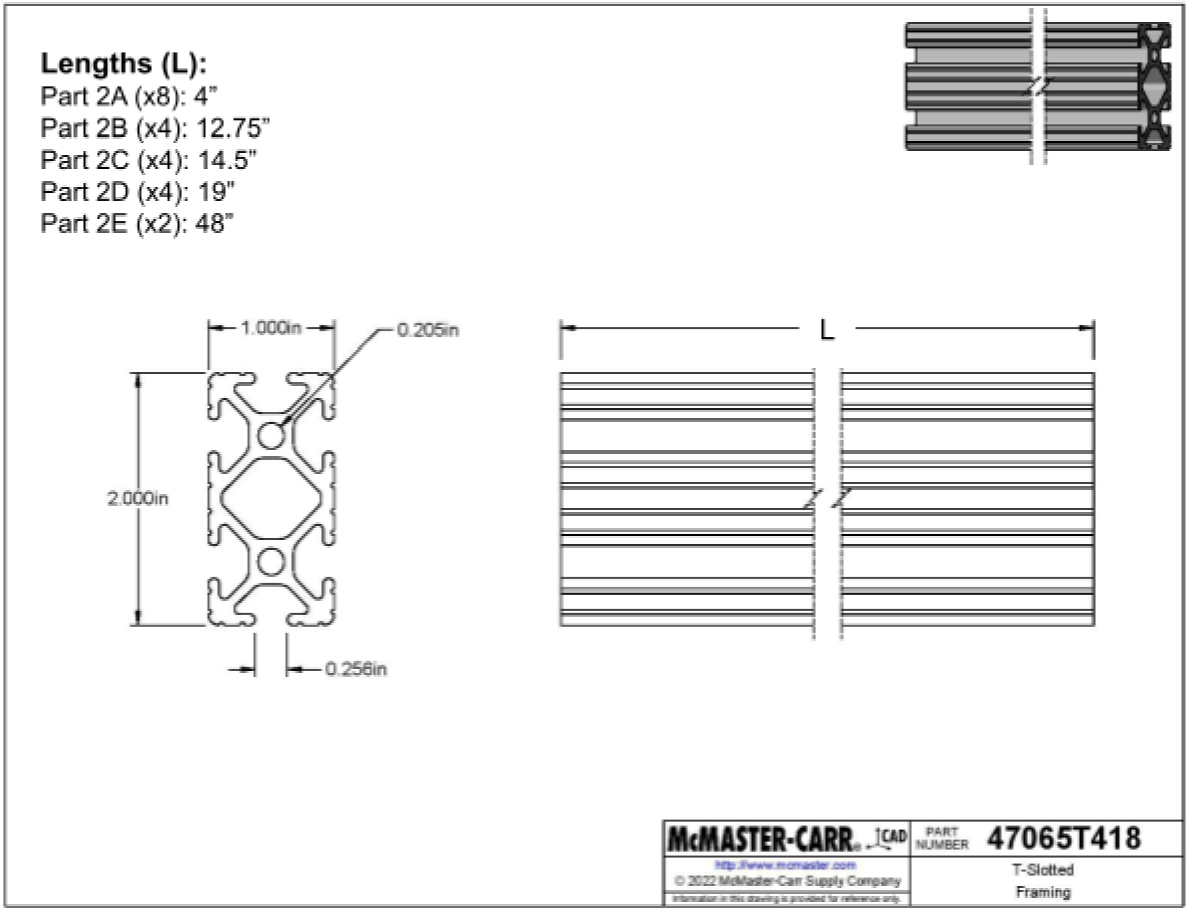
Appendices

Appendix A - Part Drawings

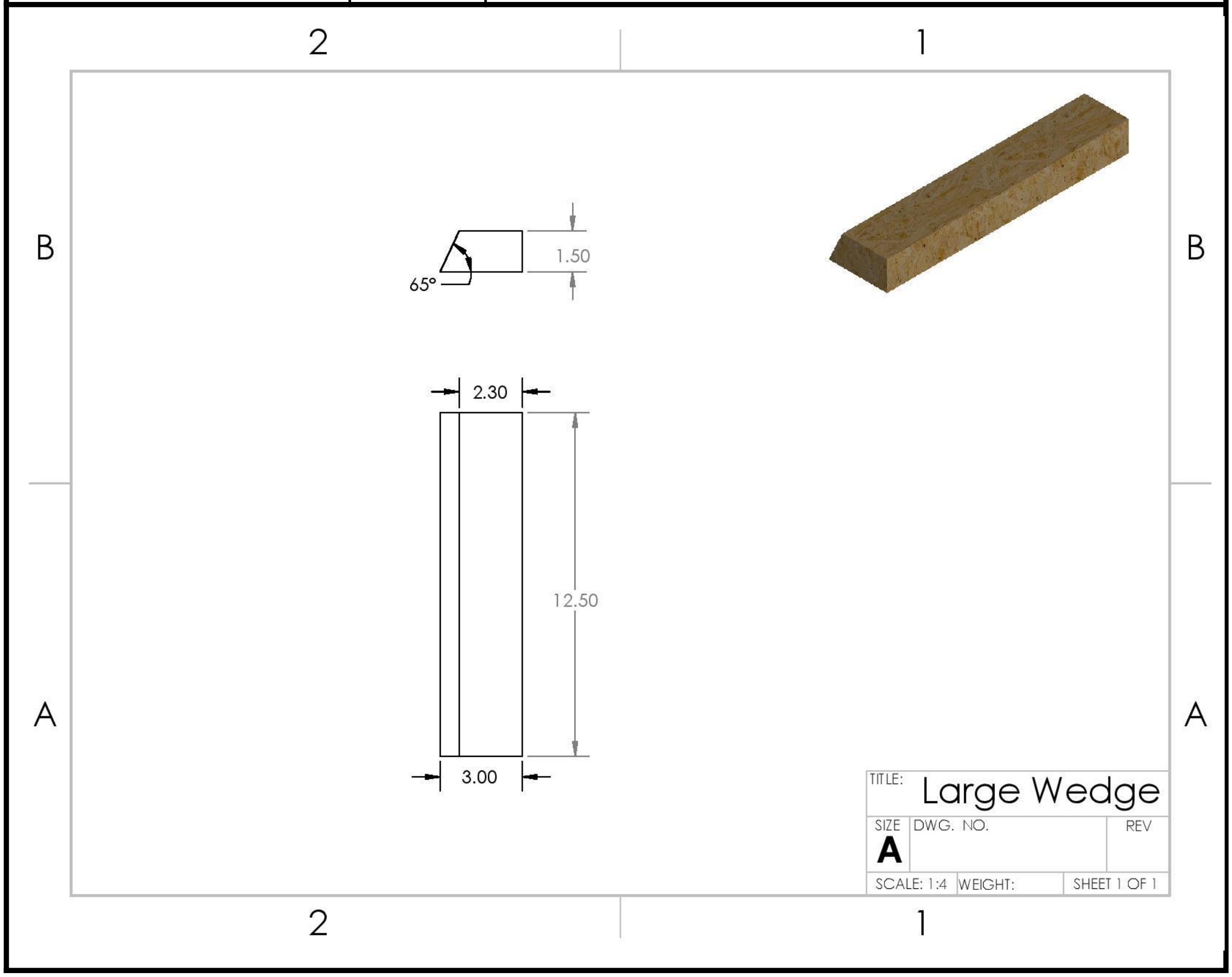
Part Number:	1	80-20 Rail 1" (Single)



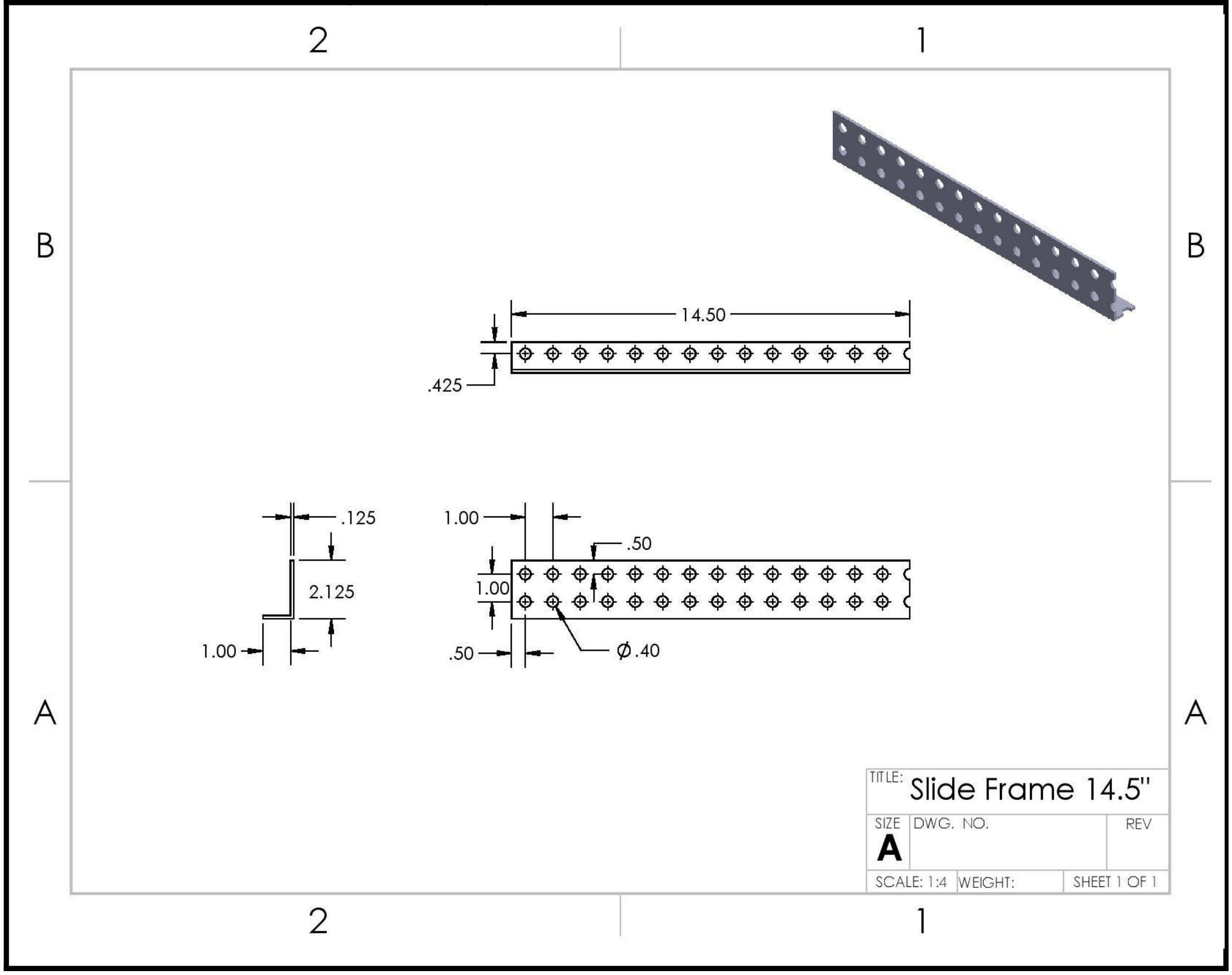
Part Number:	**2**	80-20 Rail 1” (Double)



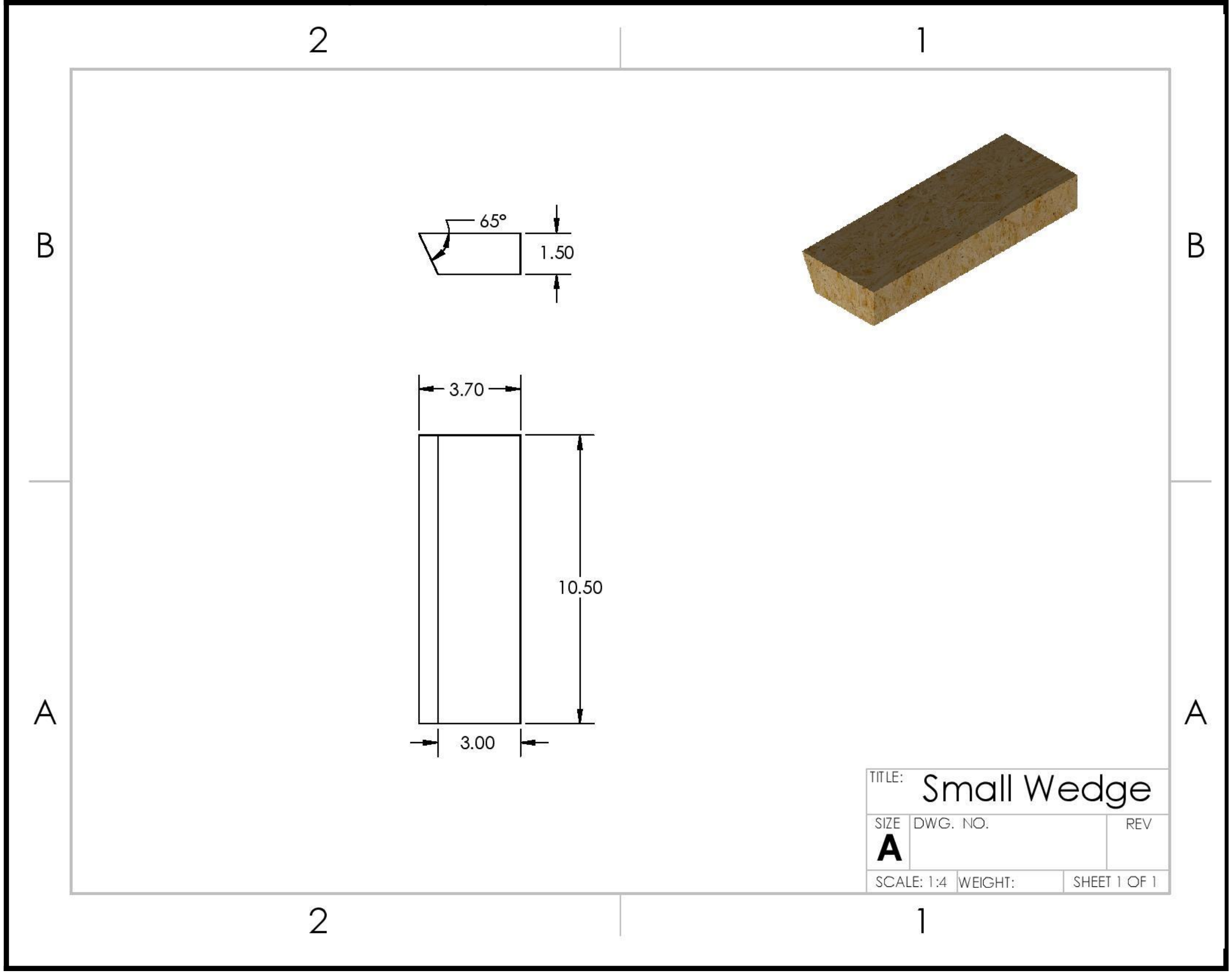
Part Number:	3	Large Wedge



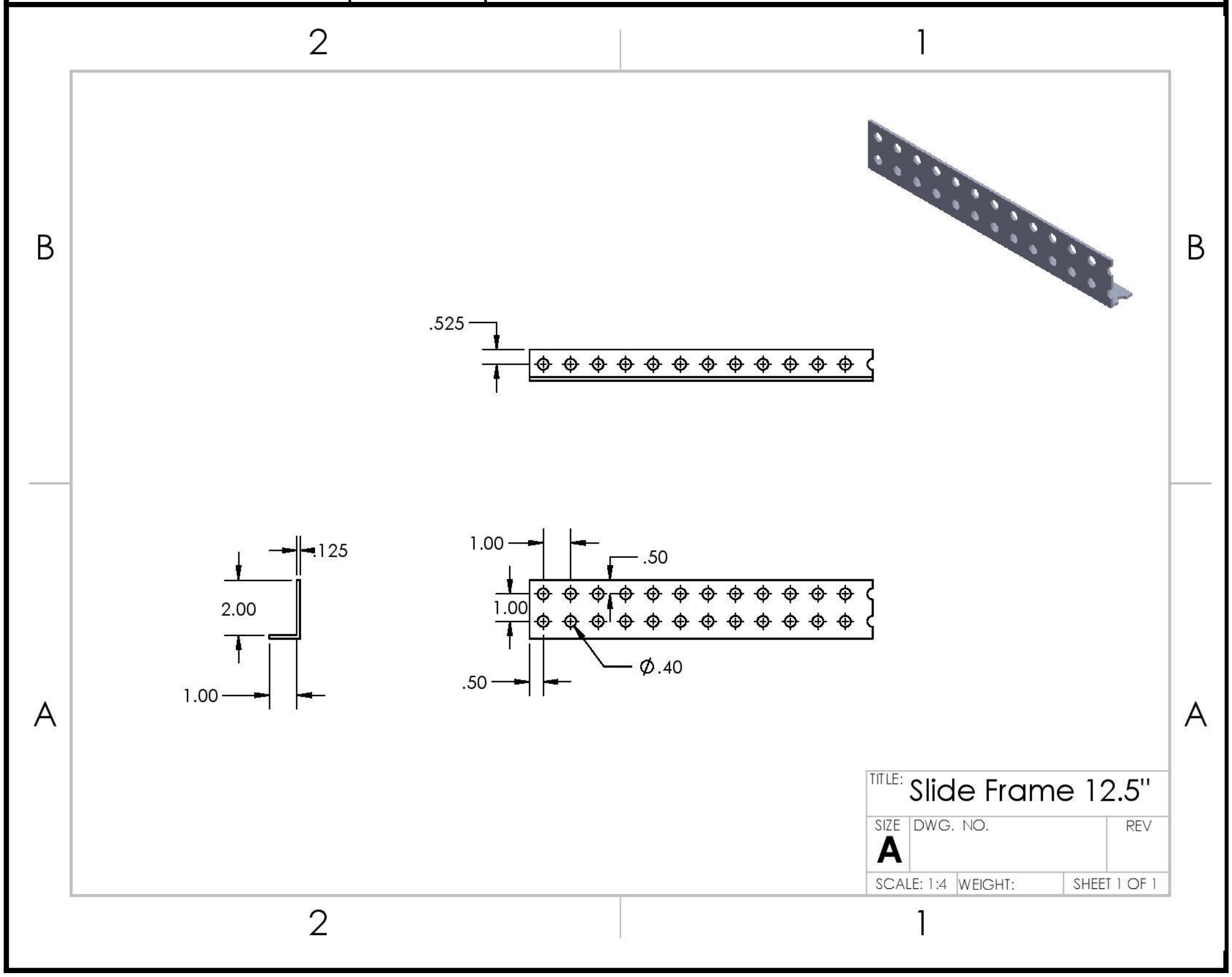
Part Number:	4	Slide Frame 14.5”



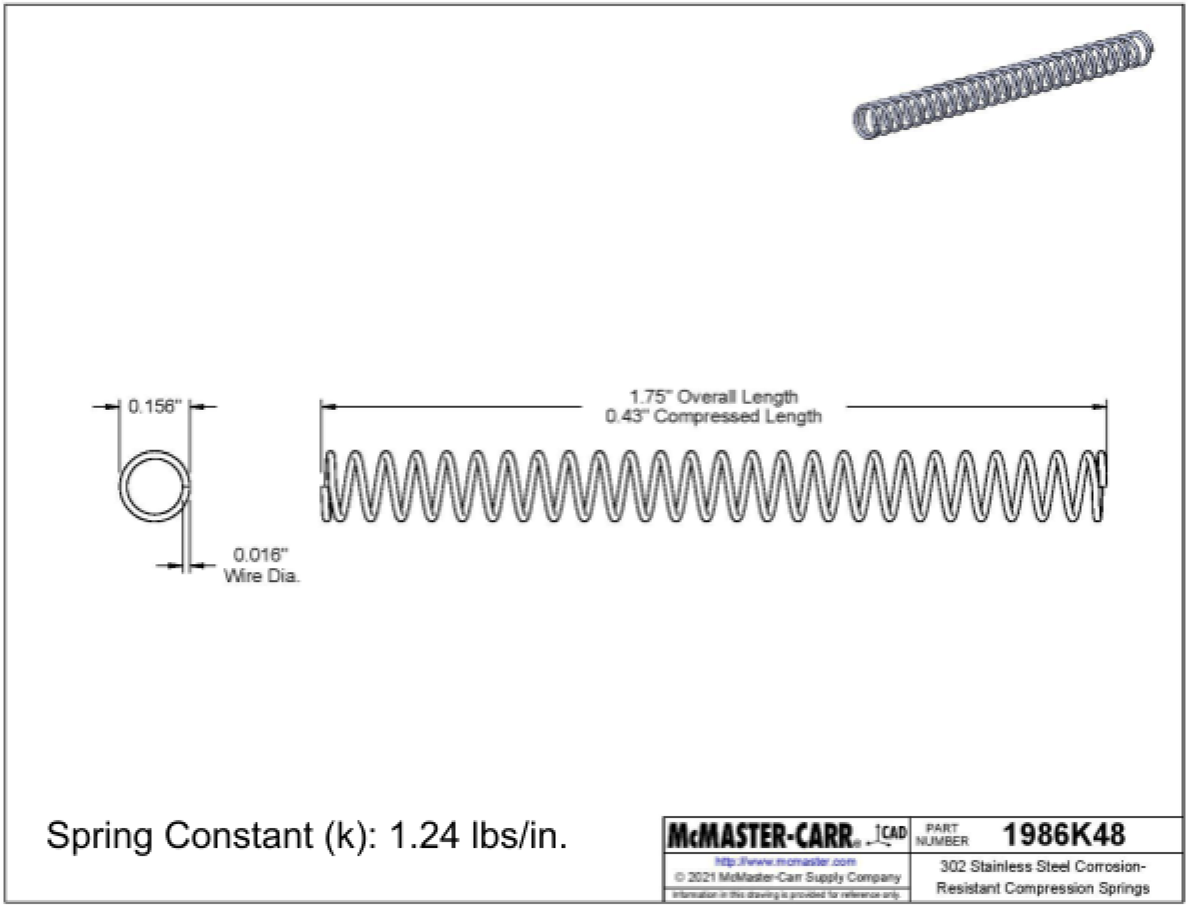
Part Number:	5	80-20 Rail (Single)



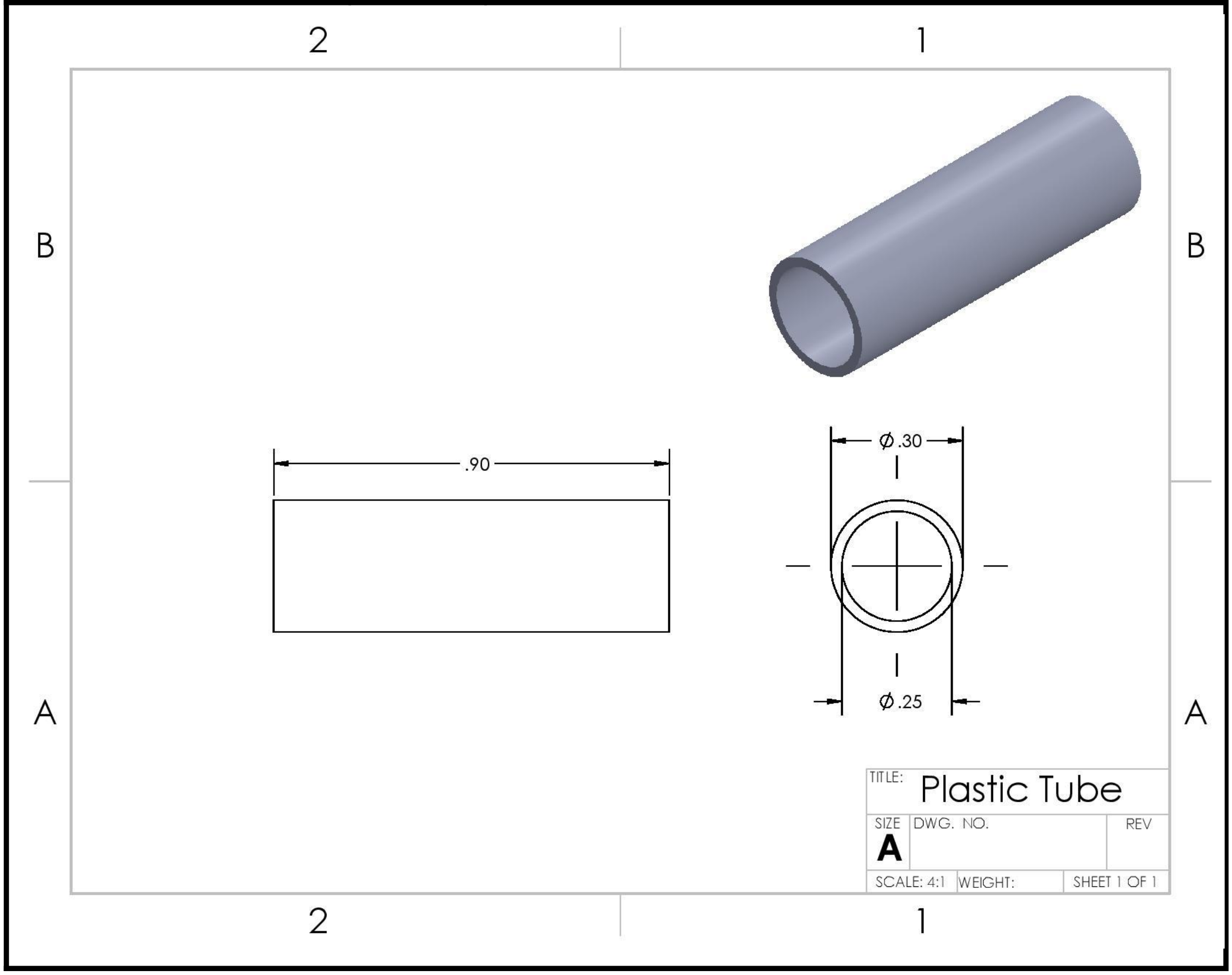
Part Number:	6	80-20 Rail (Single)



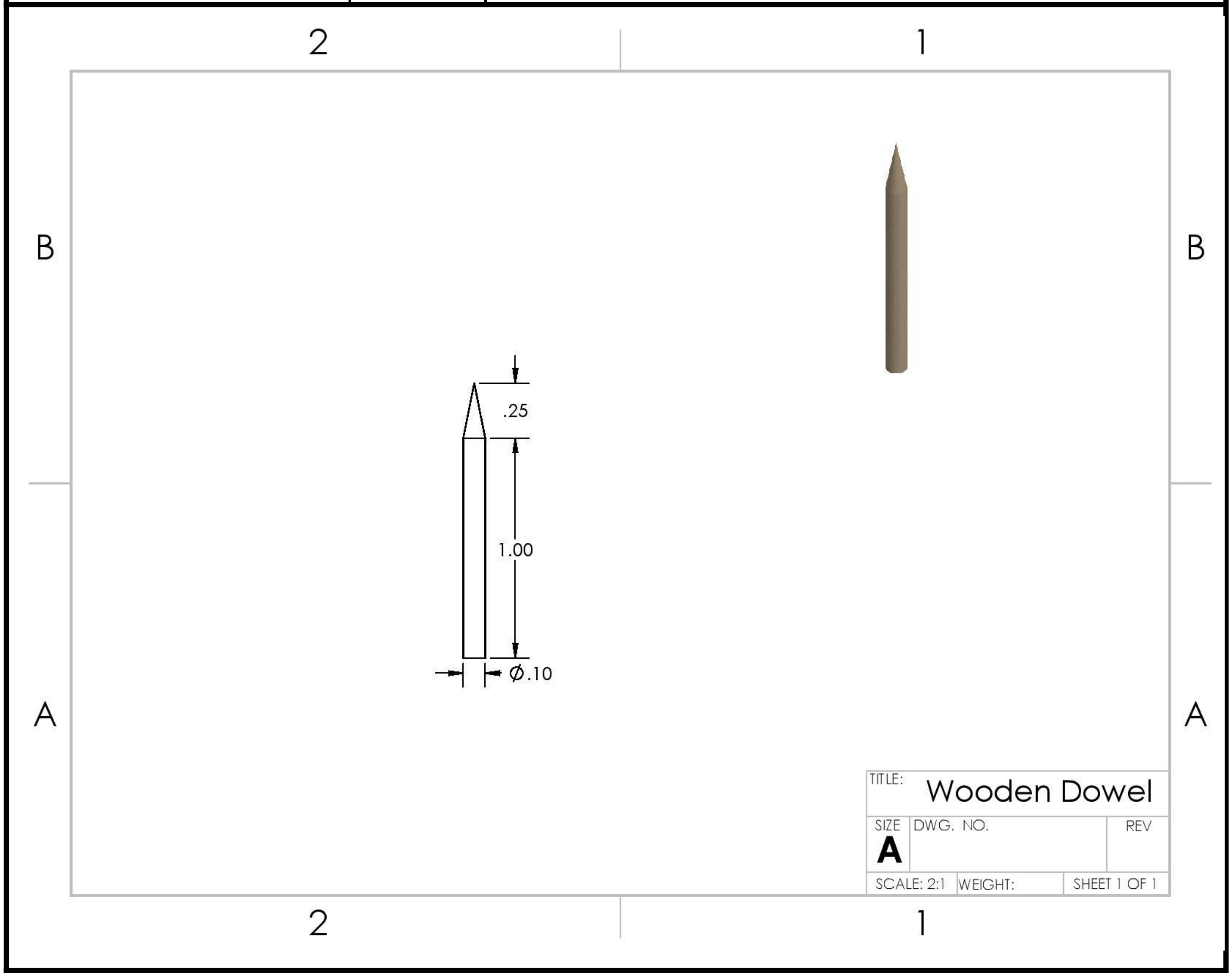
Part Number:	**7**	Spring 1.75” Uncompressed



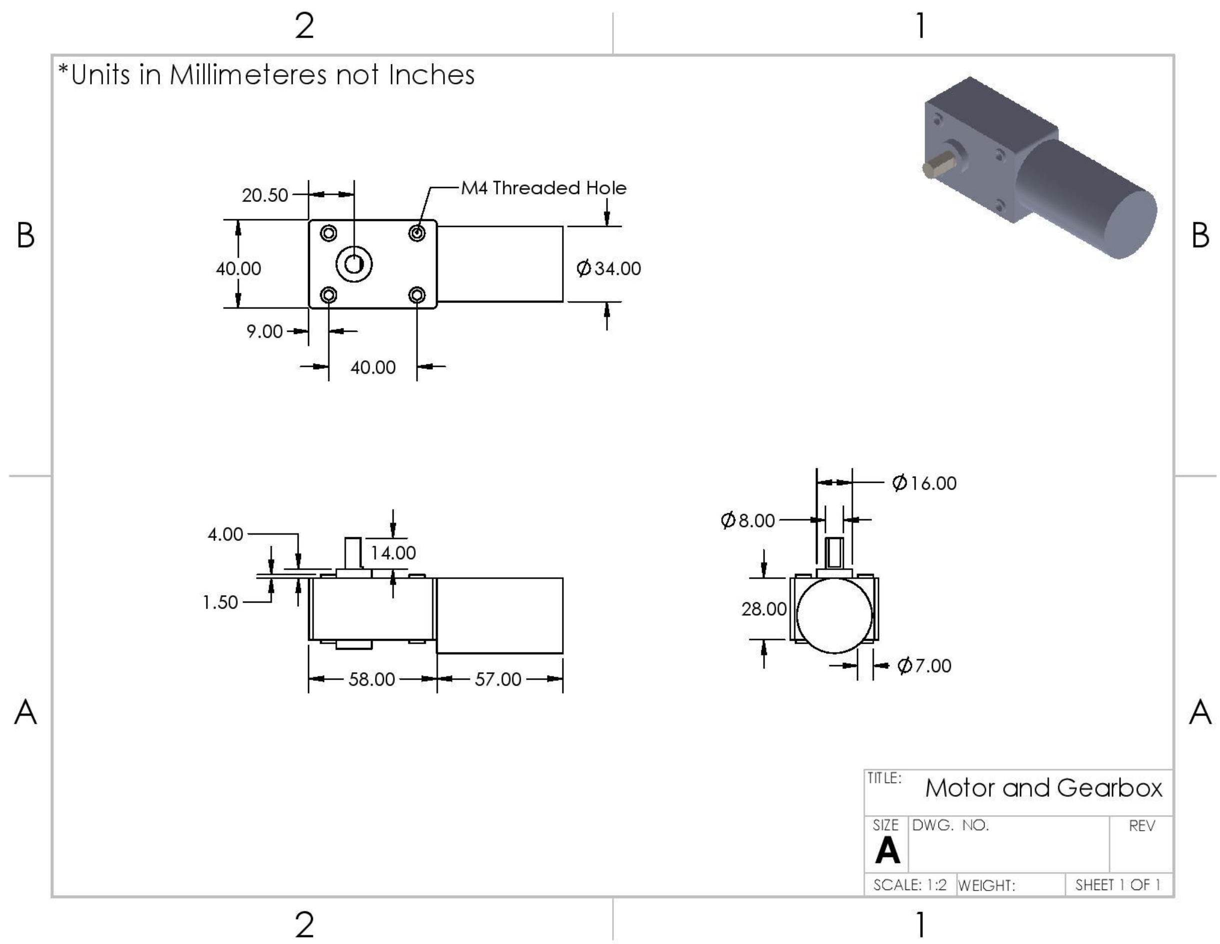
Part Number:	8	Plastic Tube



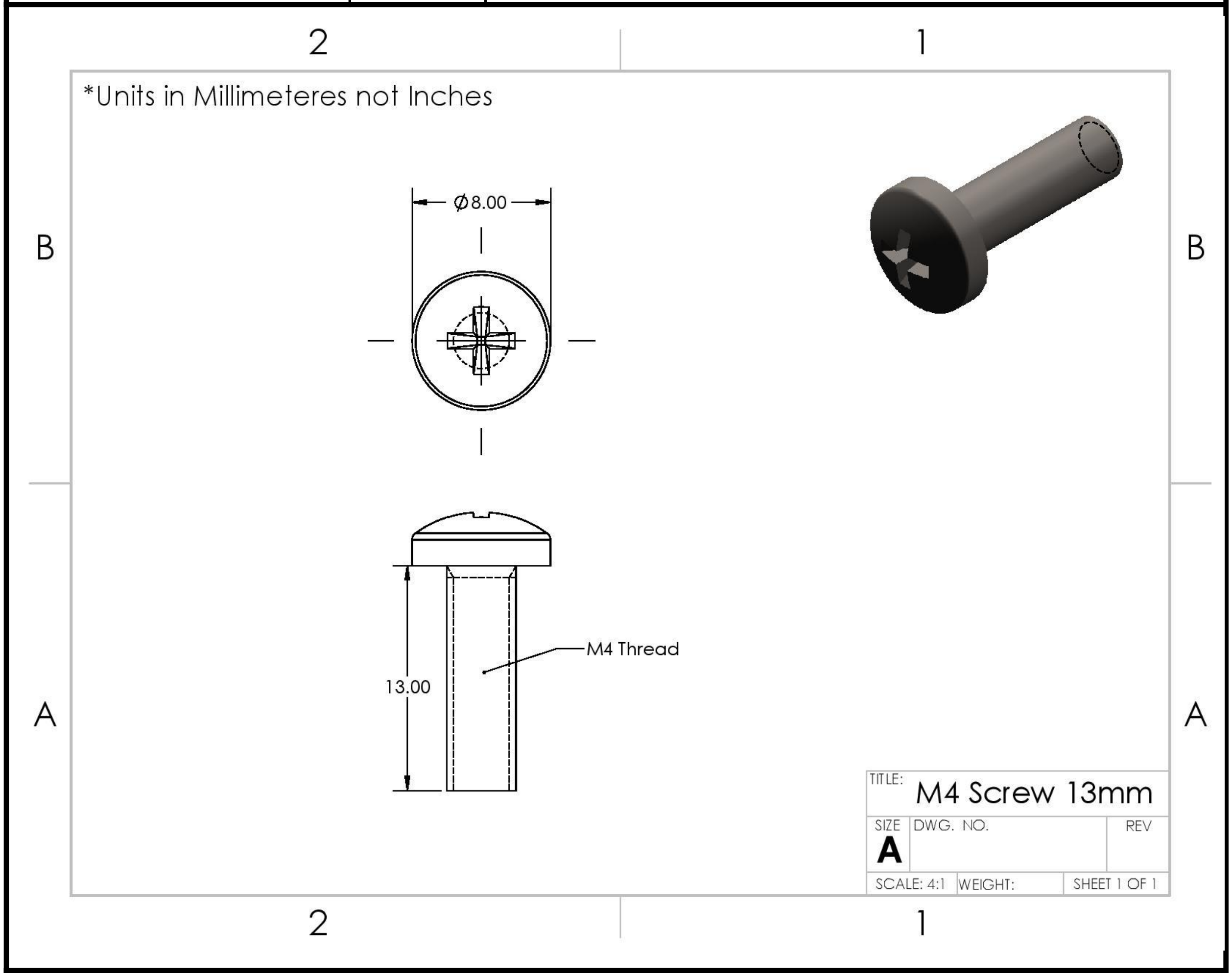
Part Number:	9	Wooden Dowel



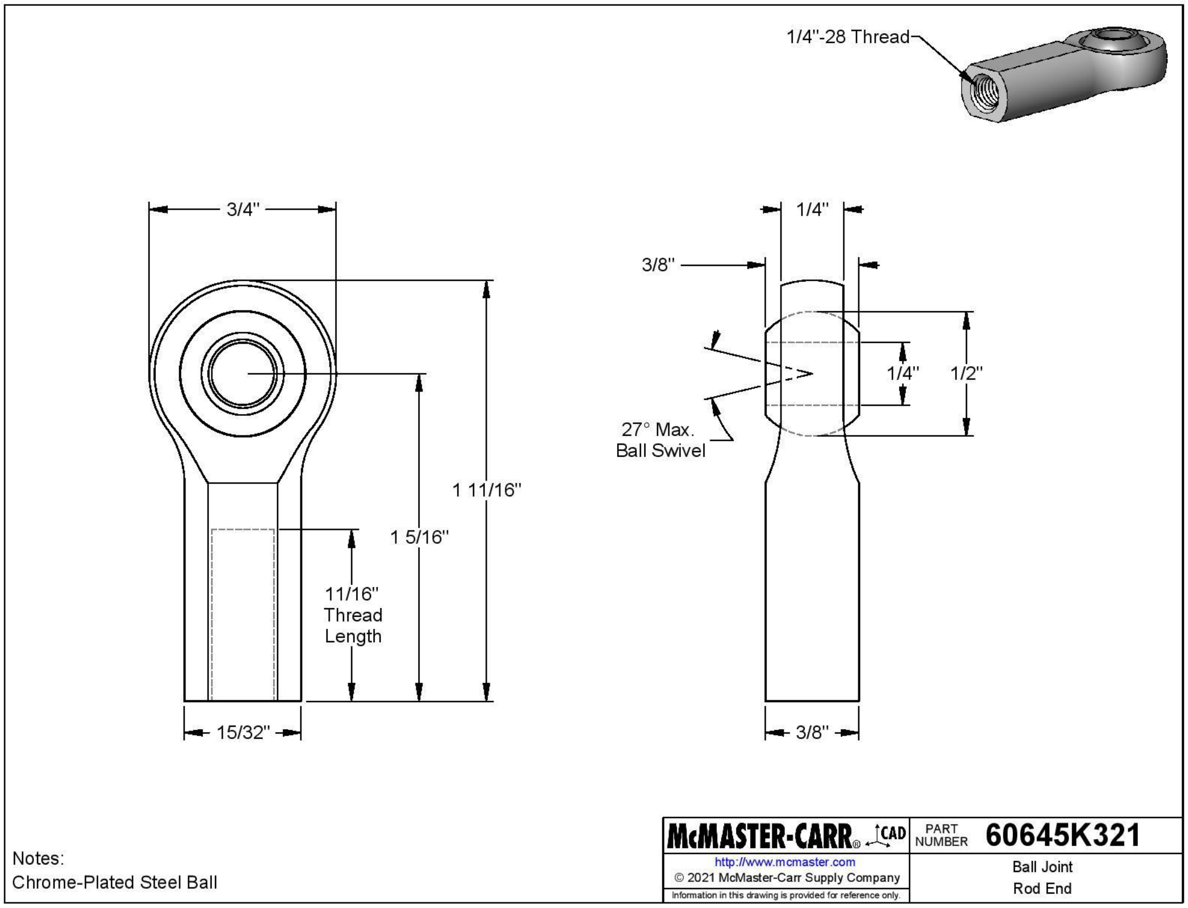
Part Number:	10	Motor and Gearbox



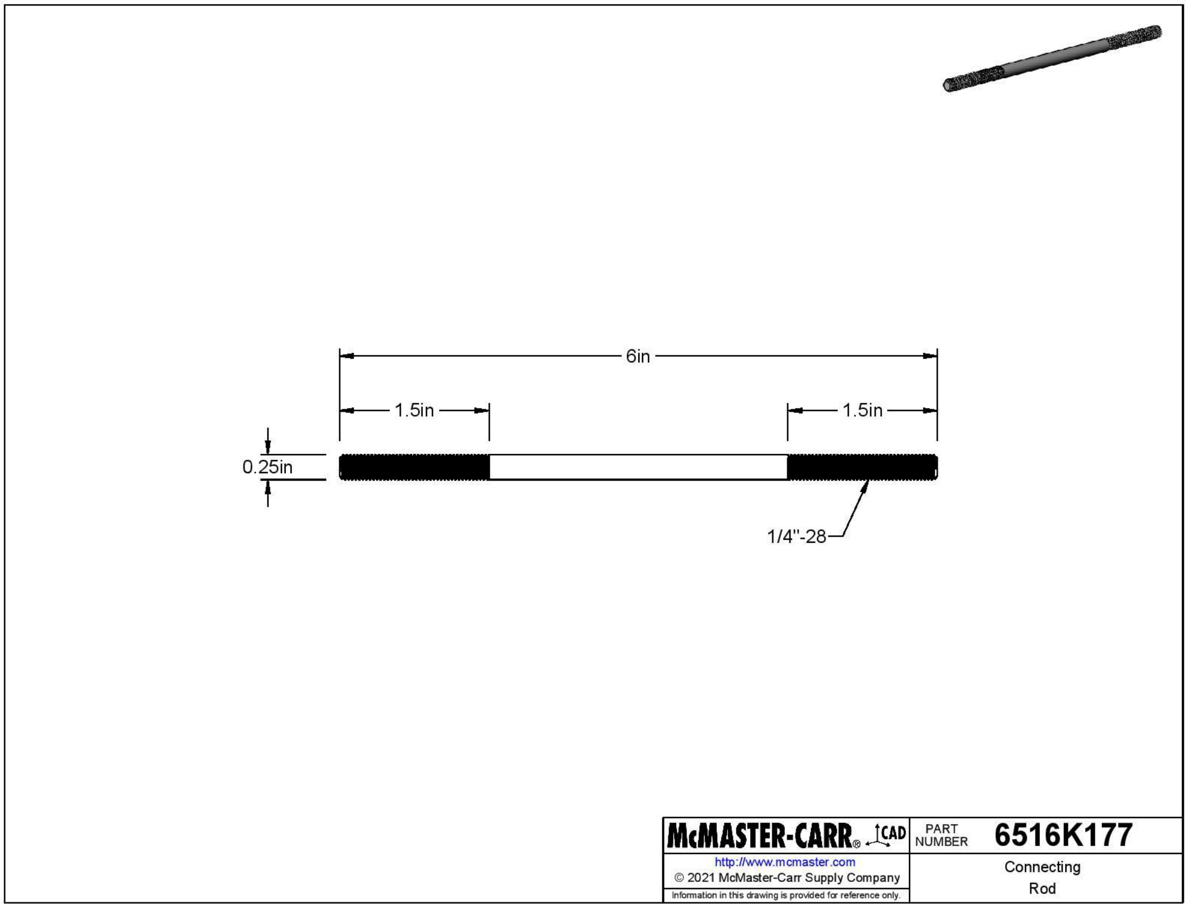
Part Number:	11	M4 Screw 13mm



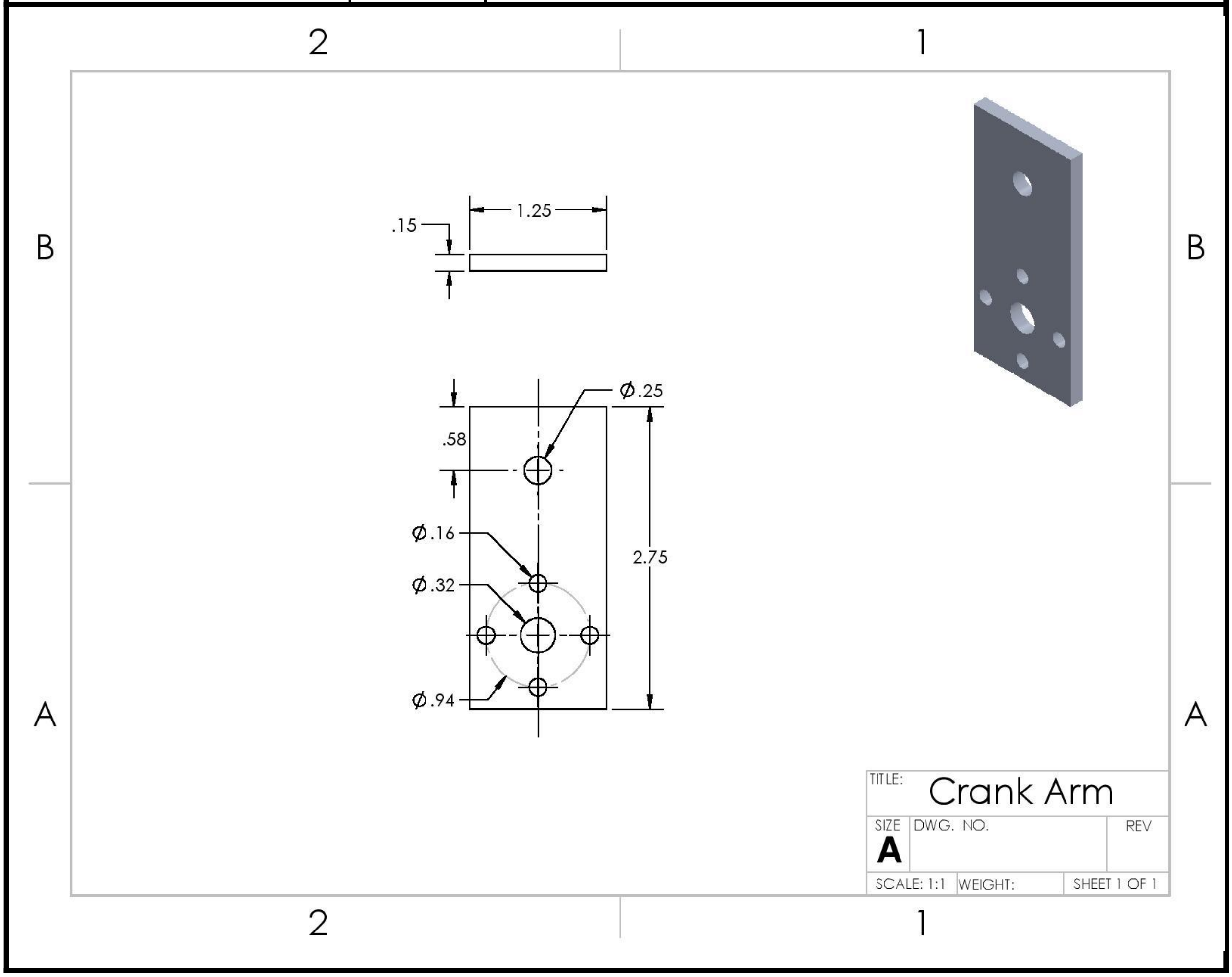
Part Number:	12	Ball Joint Rod End



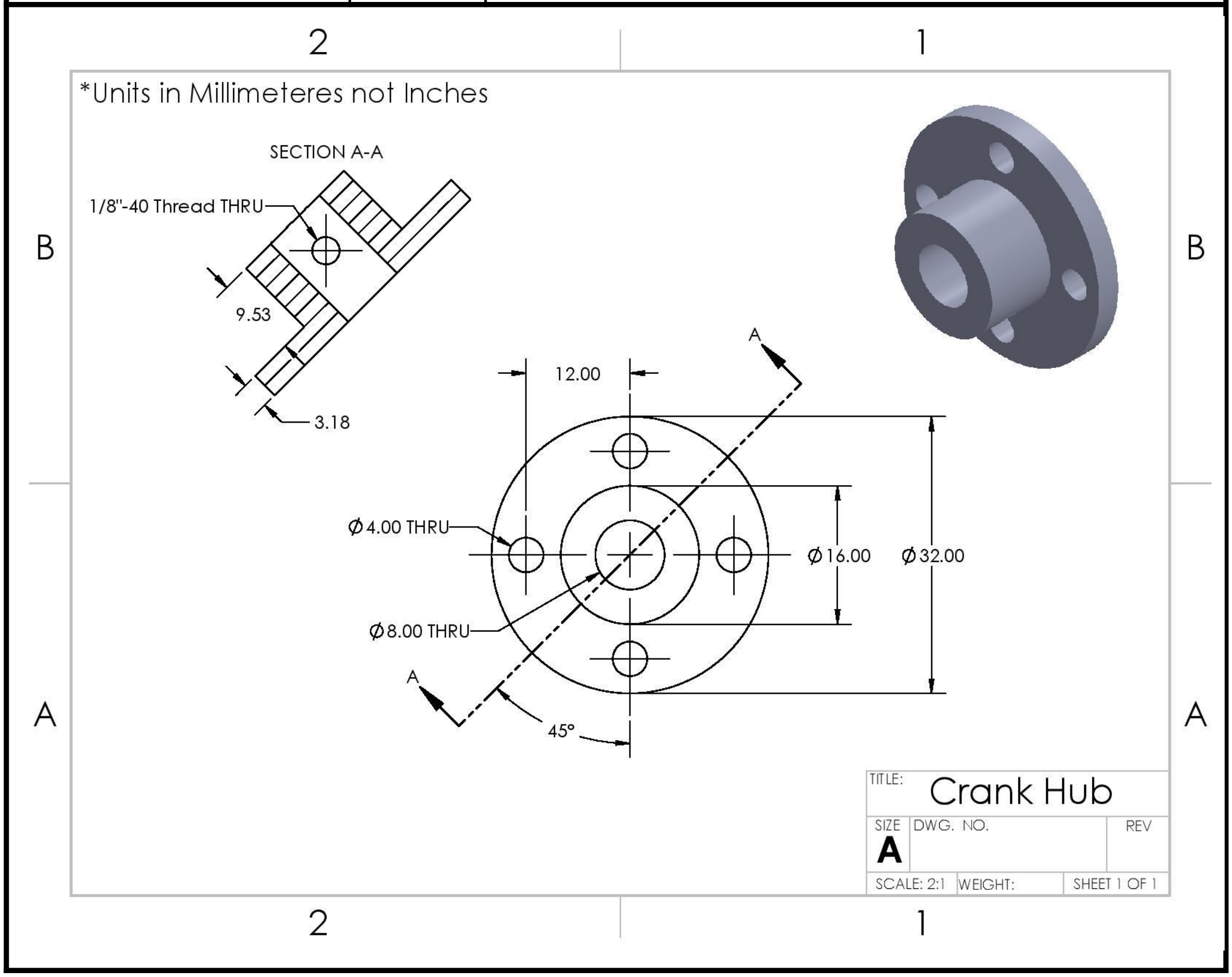
Part Number:	13	Connecting Rod



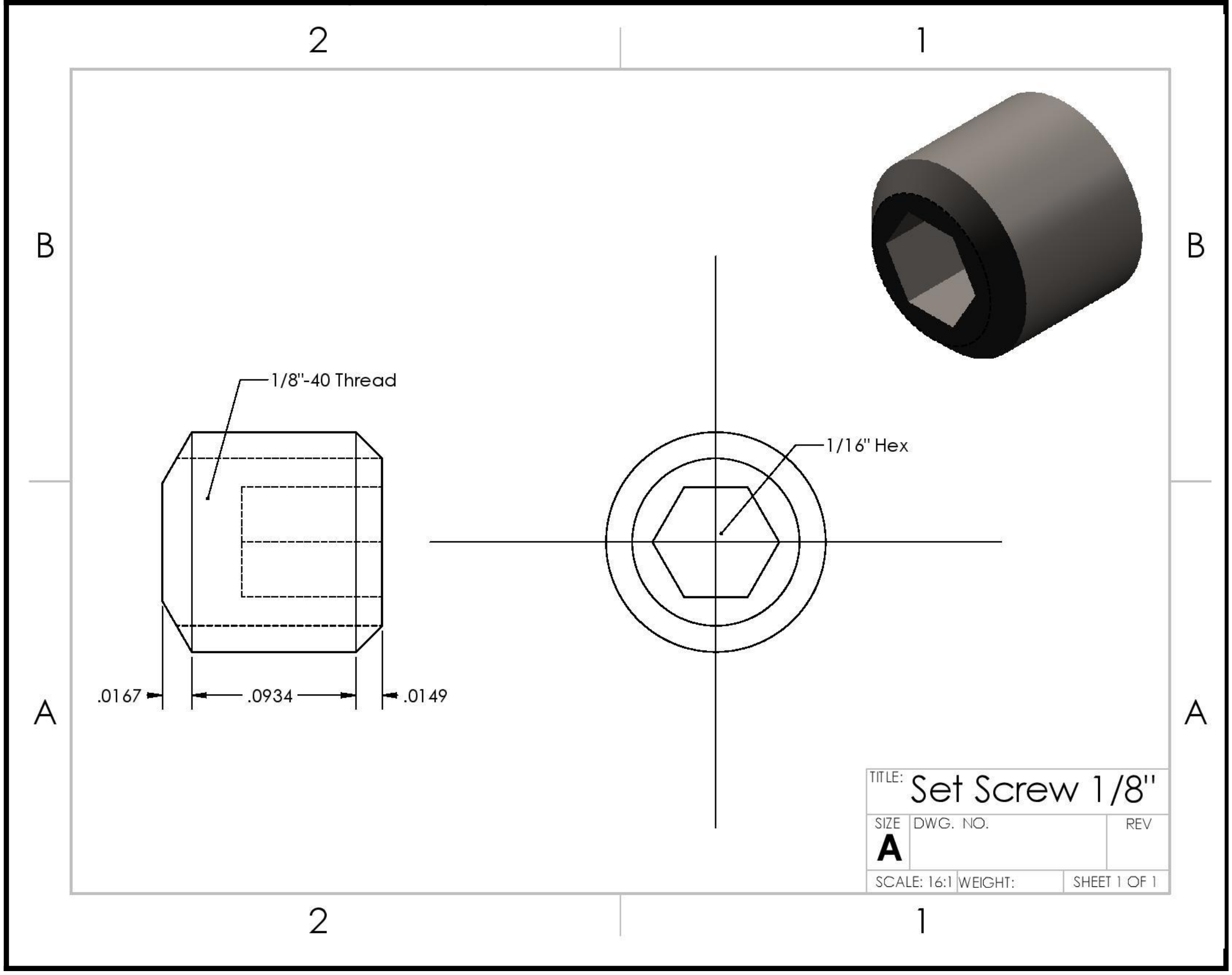
Part Number:	14	Crank Arm



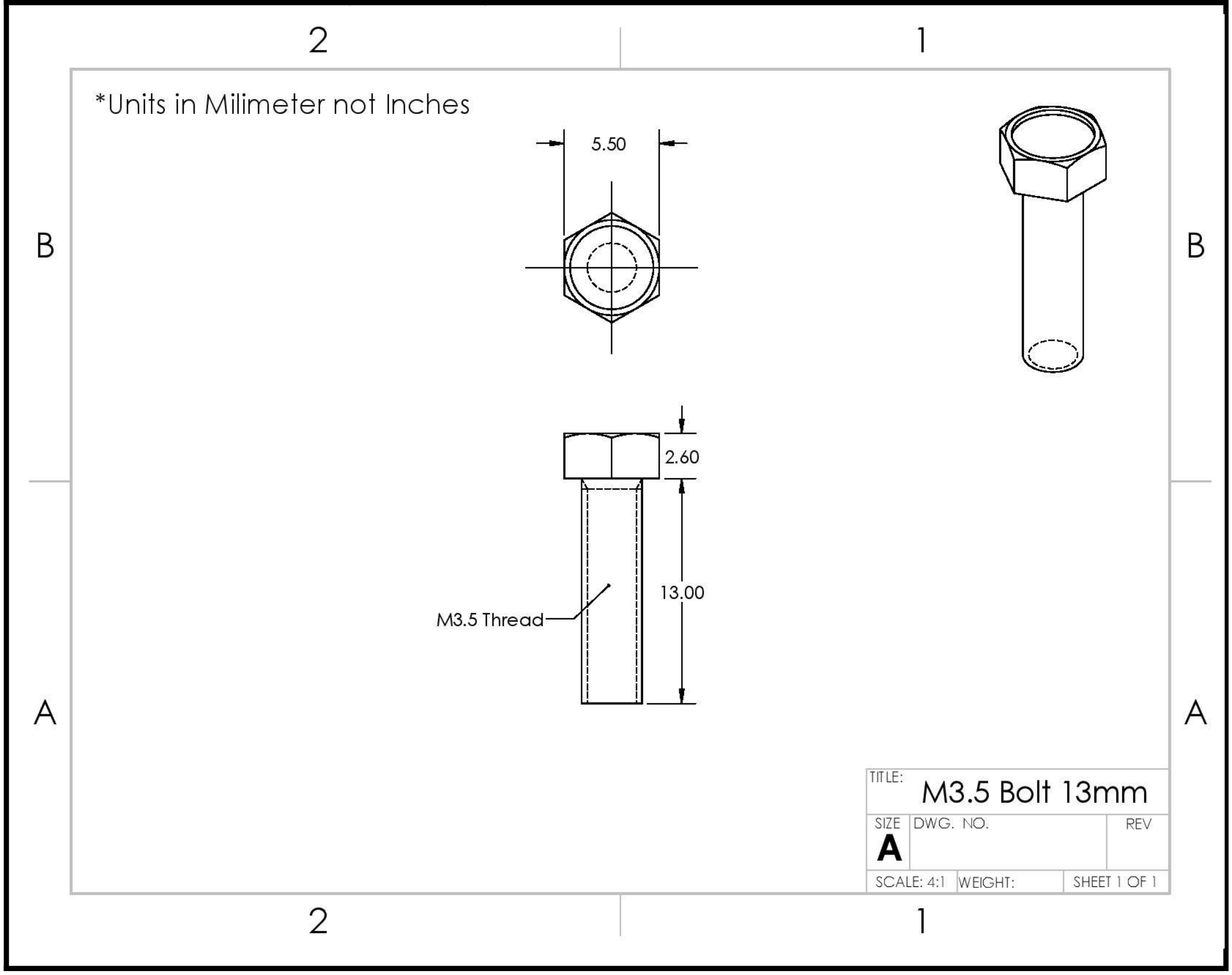
Part Number:	15	Crank Hub



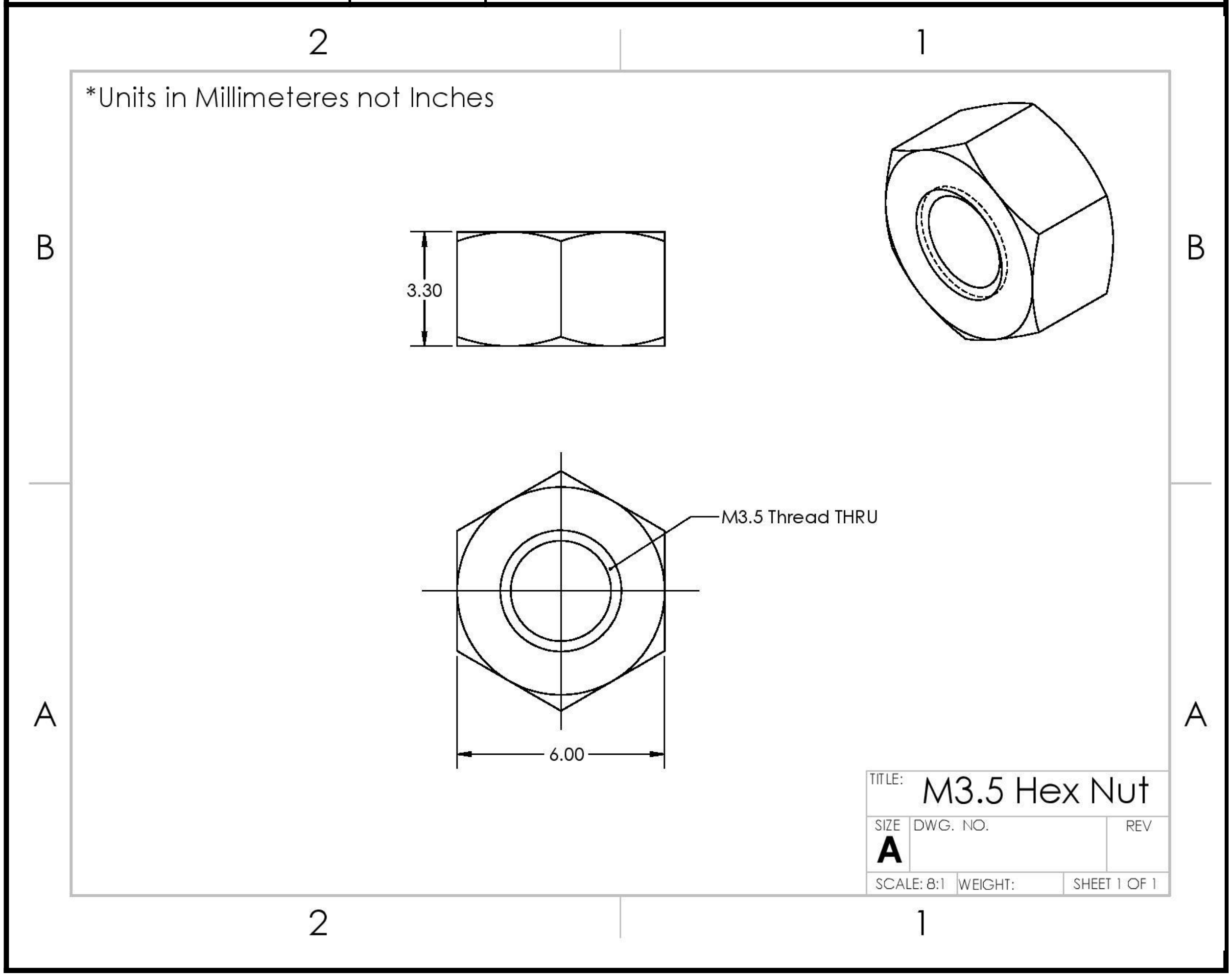
Part Number:	**16**	Set Screw ⅛”



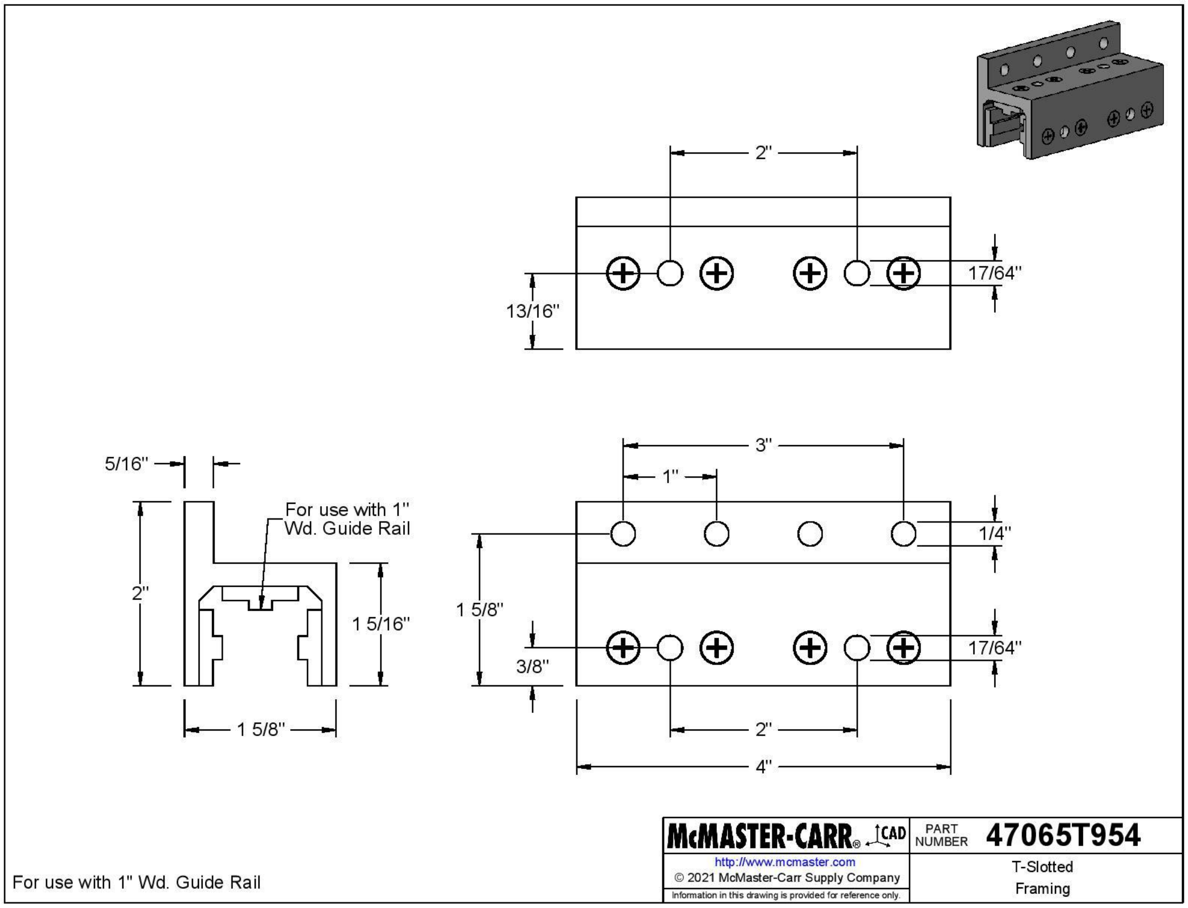
Part Number:	17	M3.5 Bolt 13mm



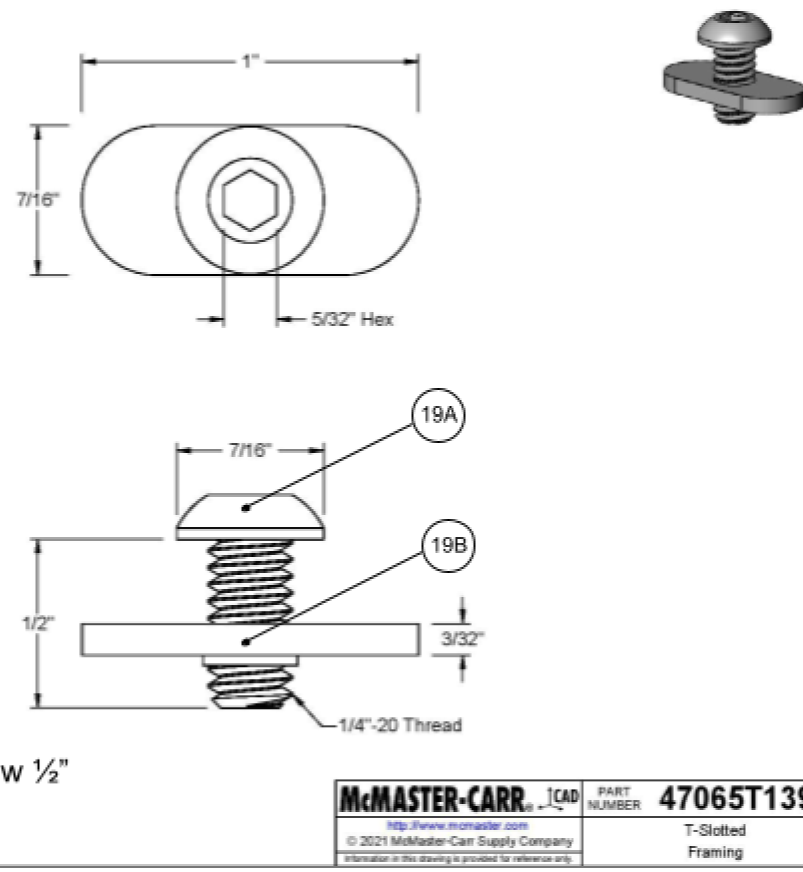
Part Number:	18	M3.5 Hex Nut



Part Number:	**19**	80-20 Rail Slider 1”

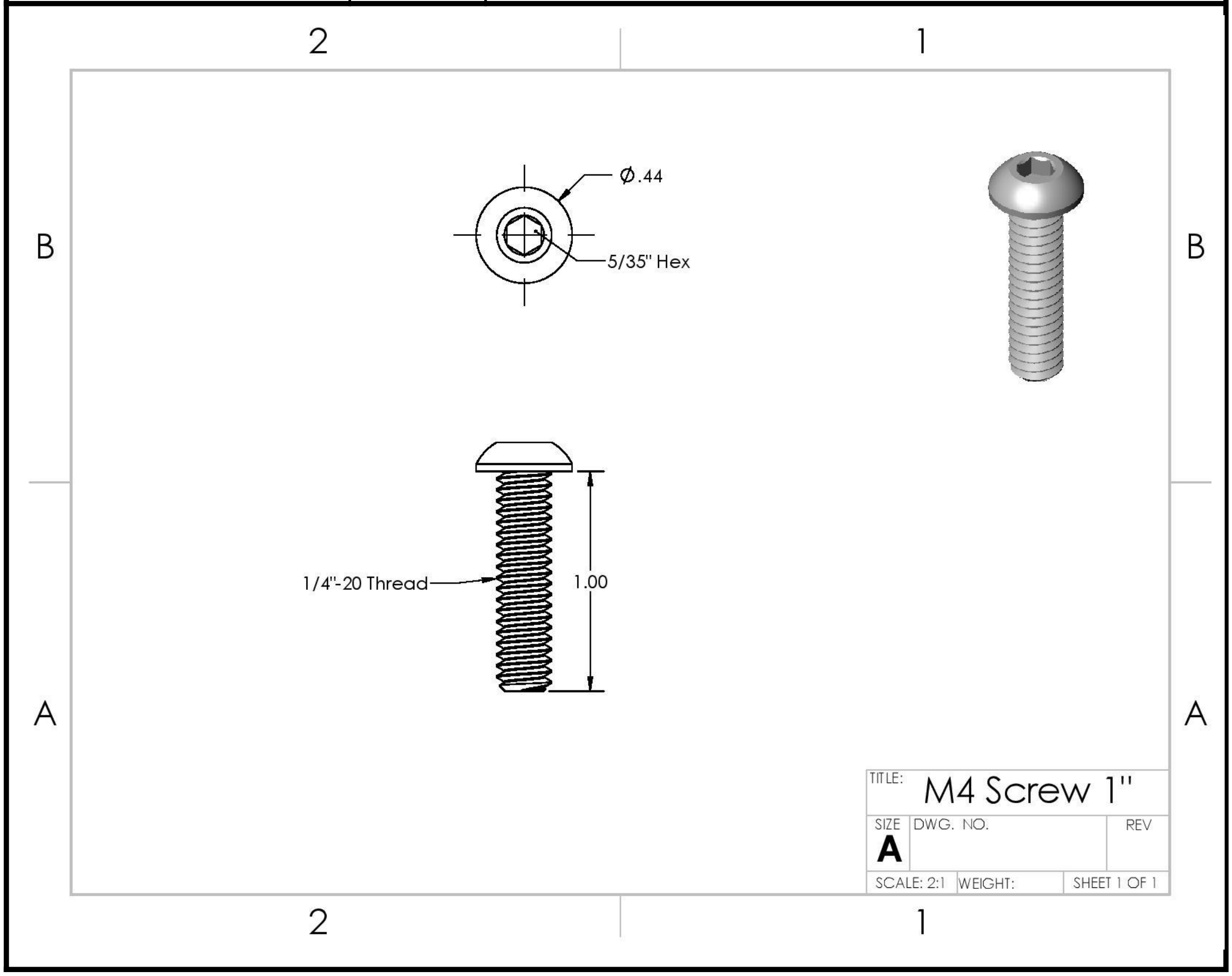


Part Number:	**20**	80-20 Hardware

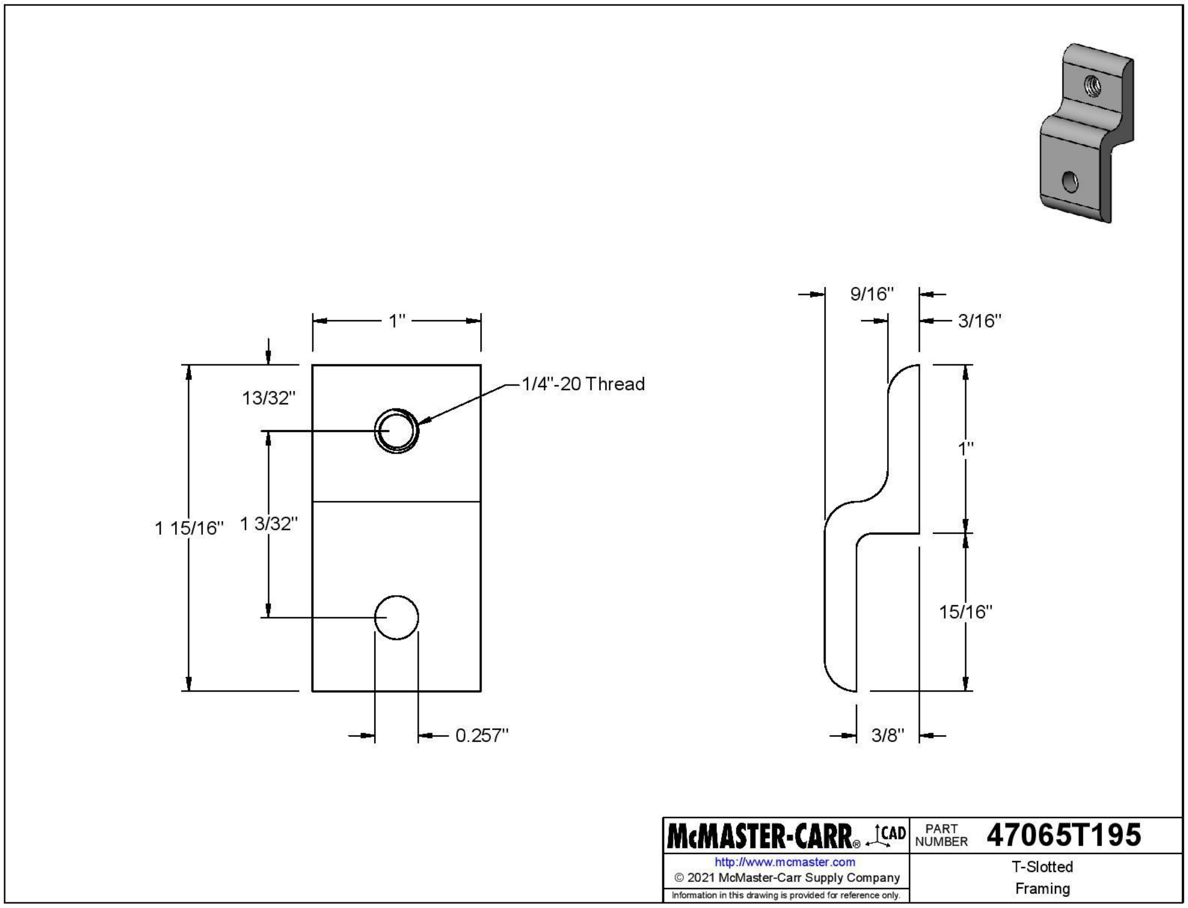


Part 20A: ¼"-20 Screw ½"
Part 20B: ¼"-20 Nut

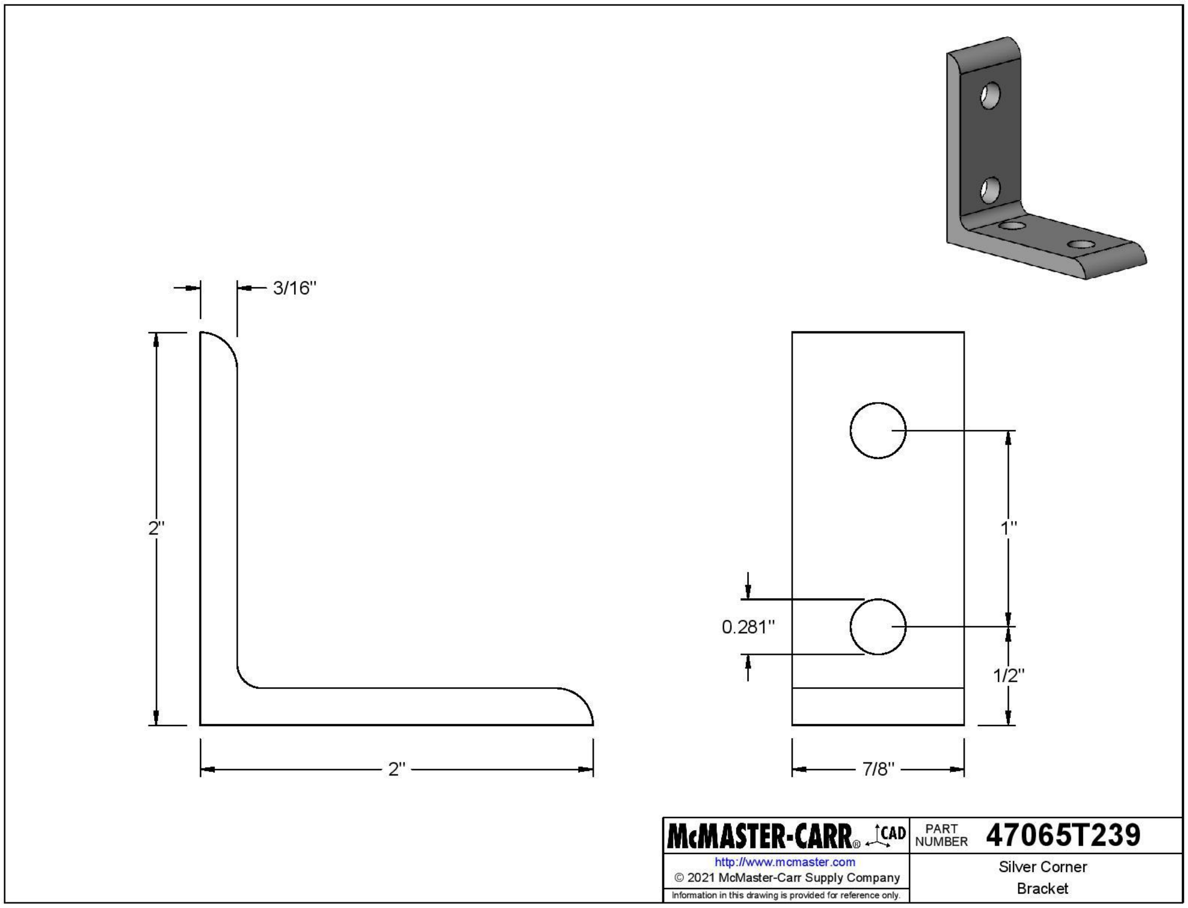
Part Number:	21	¼”-20 Screw 1”



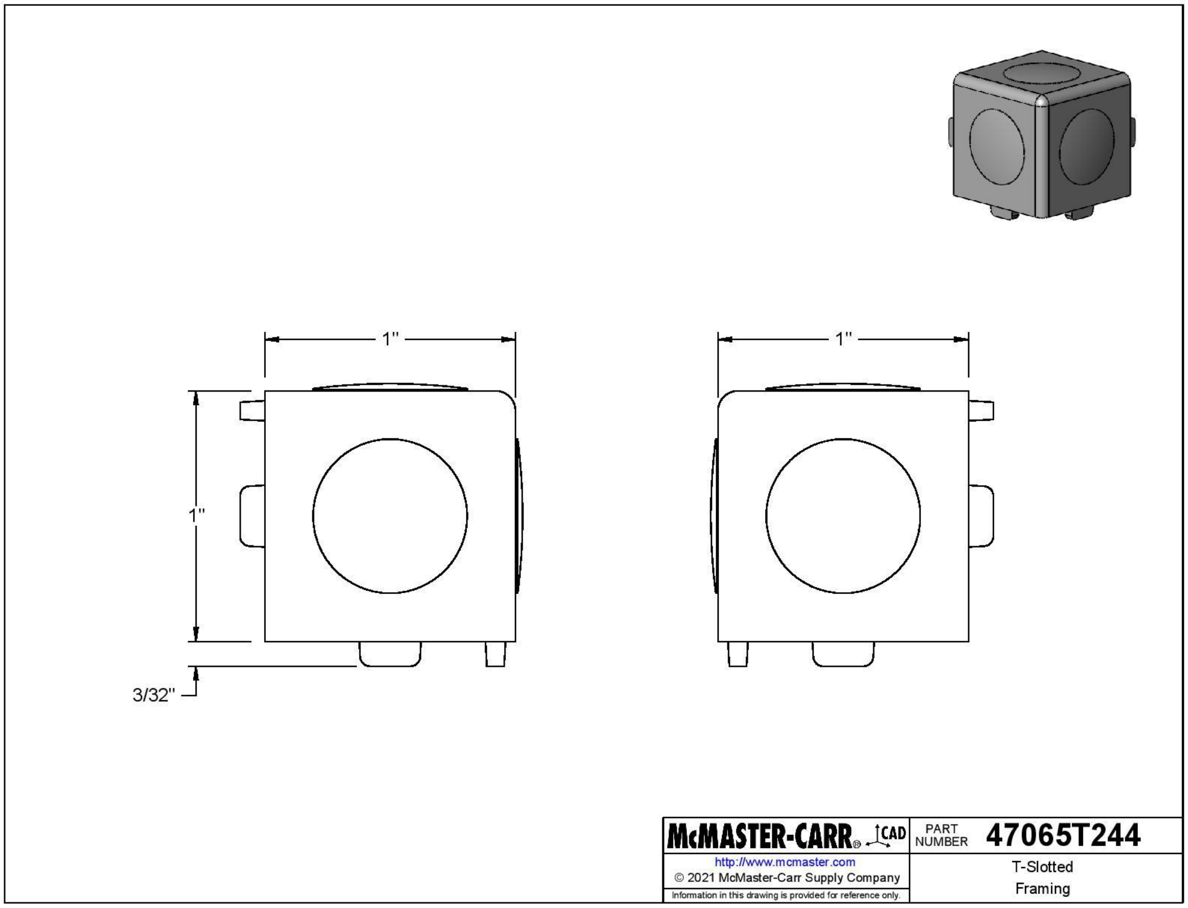
Part Number:	22	Offset Bracket



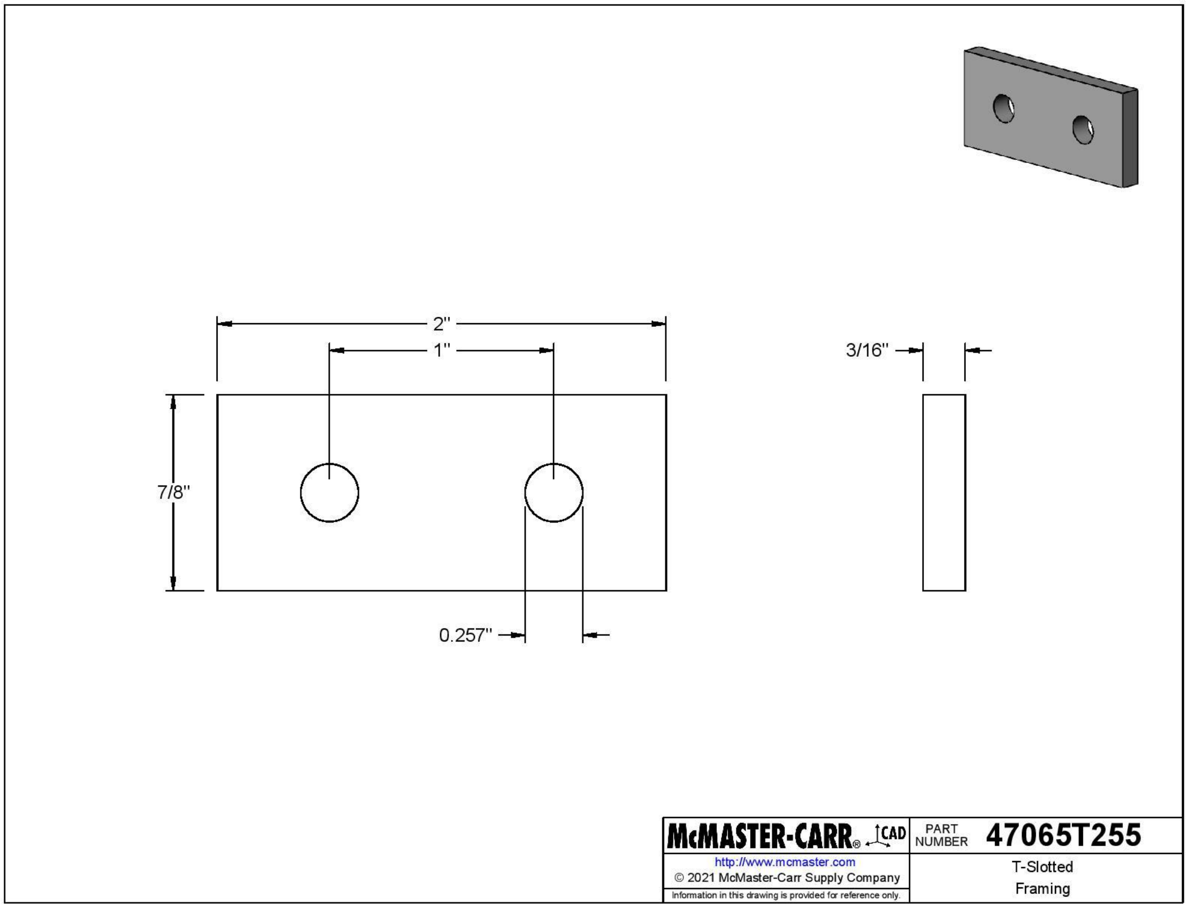
Part Number:	23	Corner Bracket



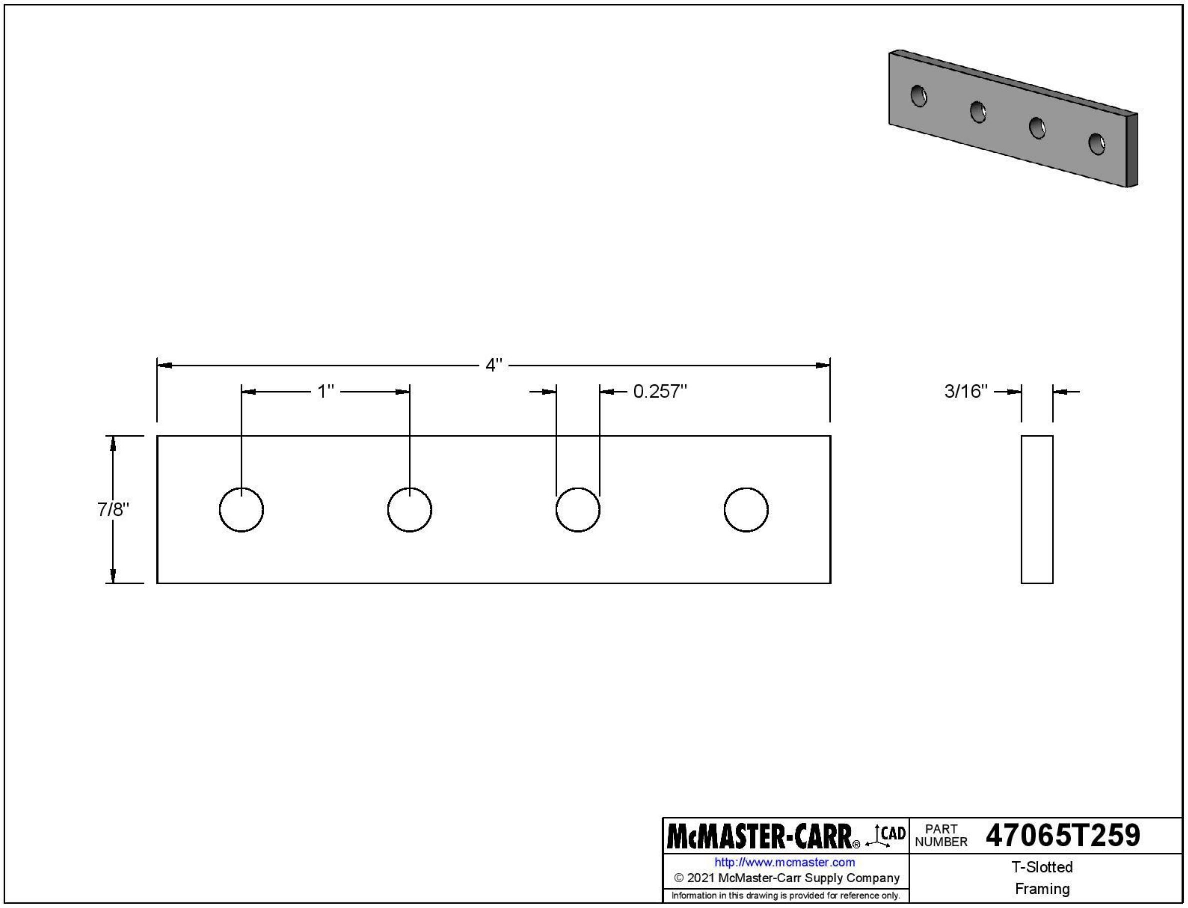
Part Number:	**24**	3-Way Connector



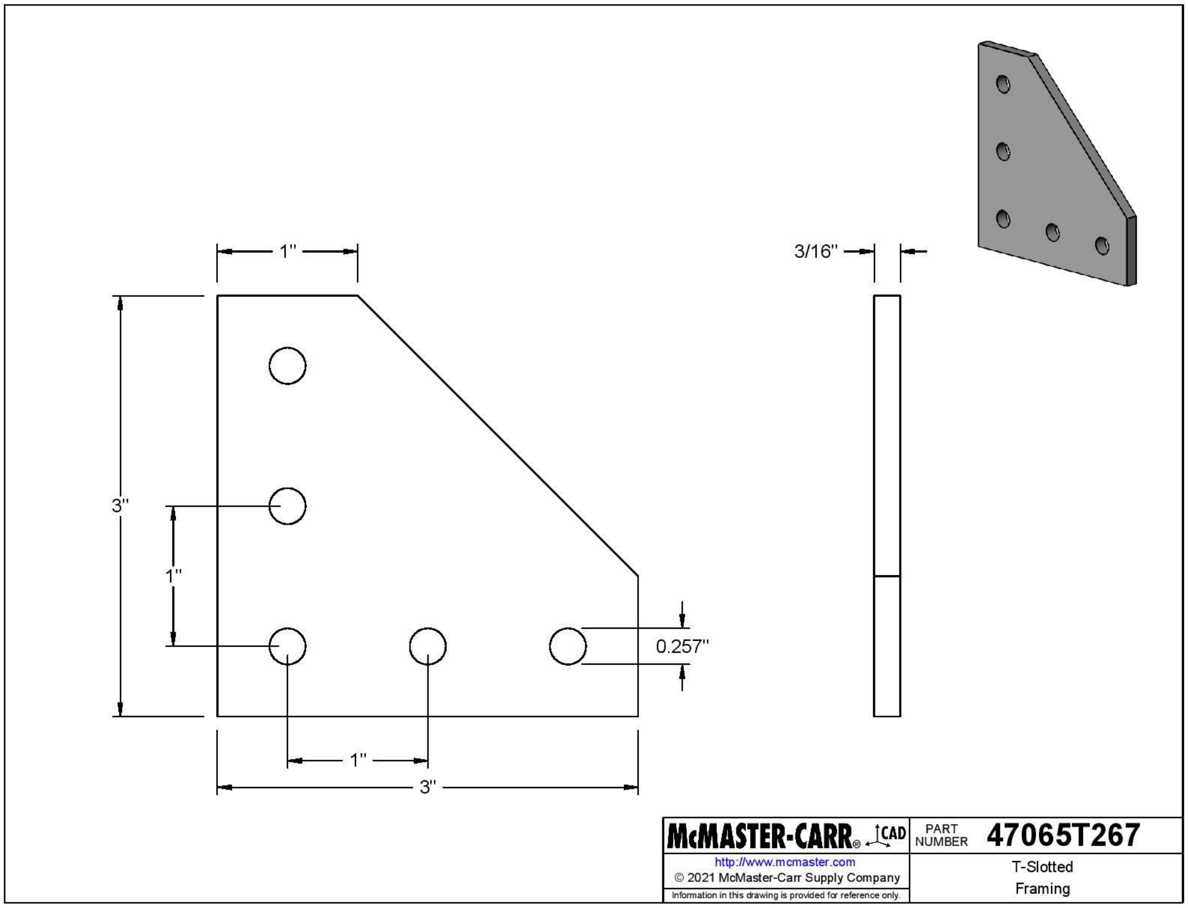
Part Number:	25	Strait Bracket 1”x 2”



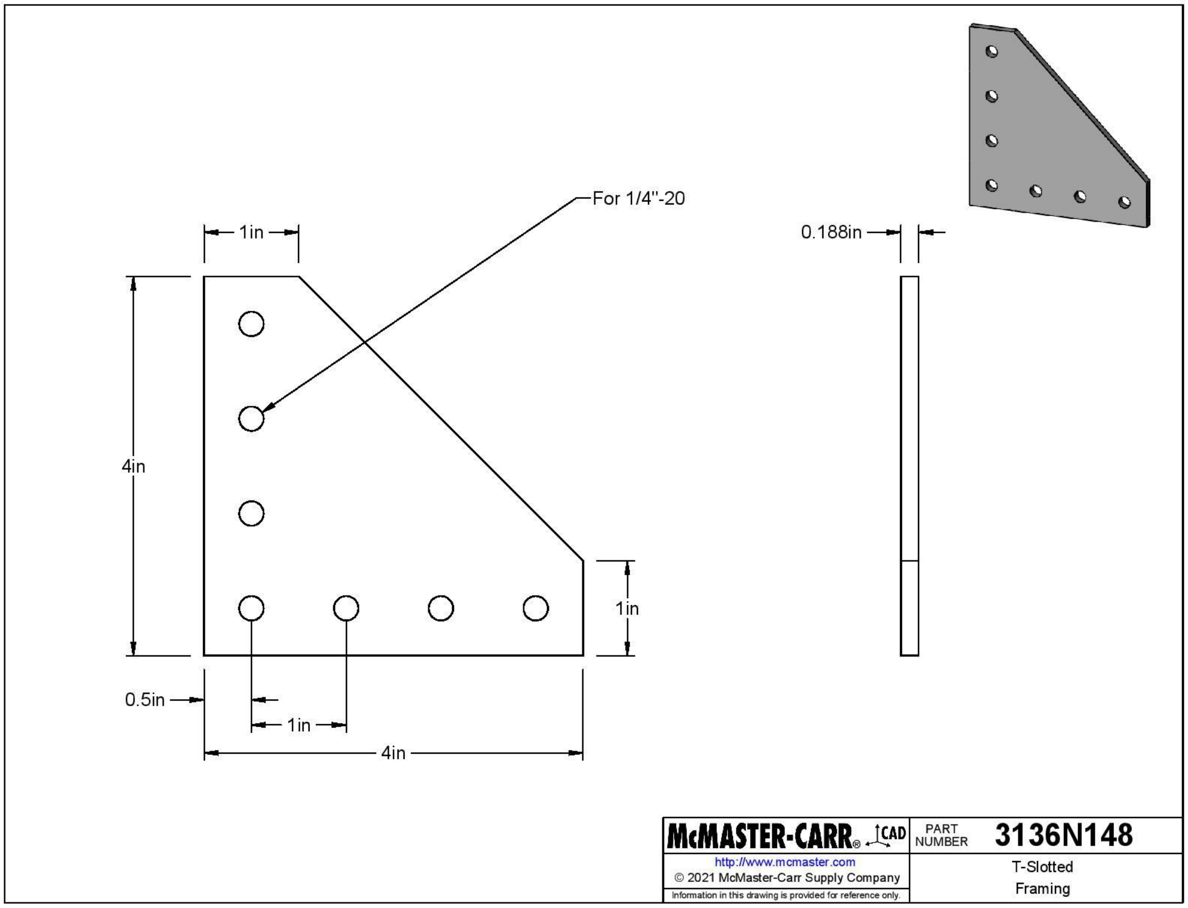
Part Number:	26	Strait Bracket 1"x 4"



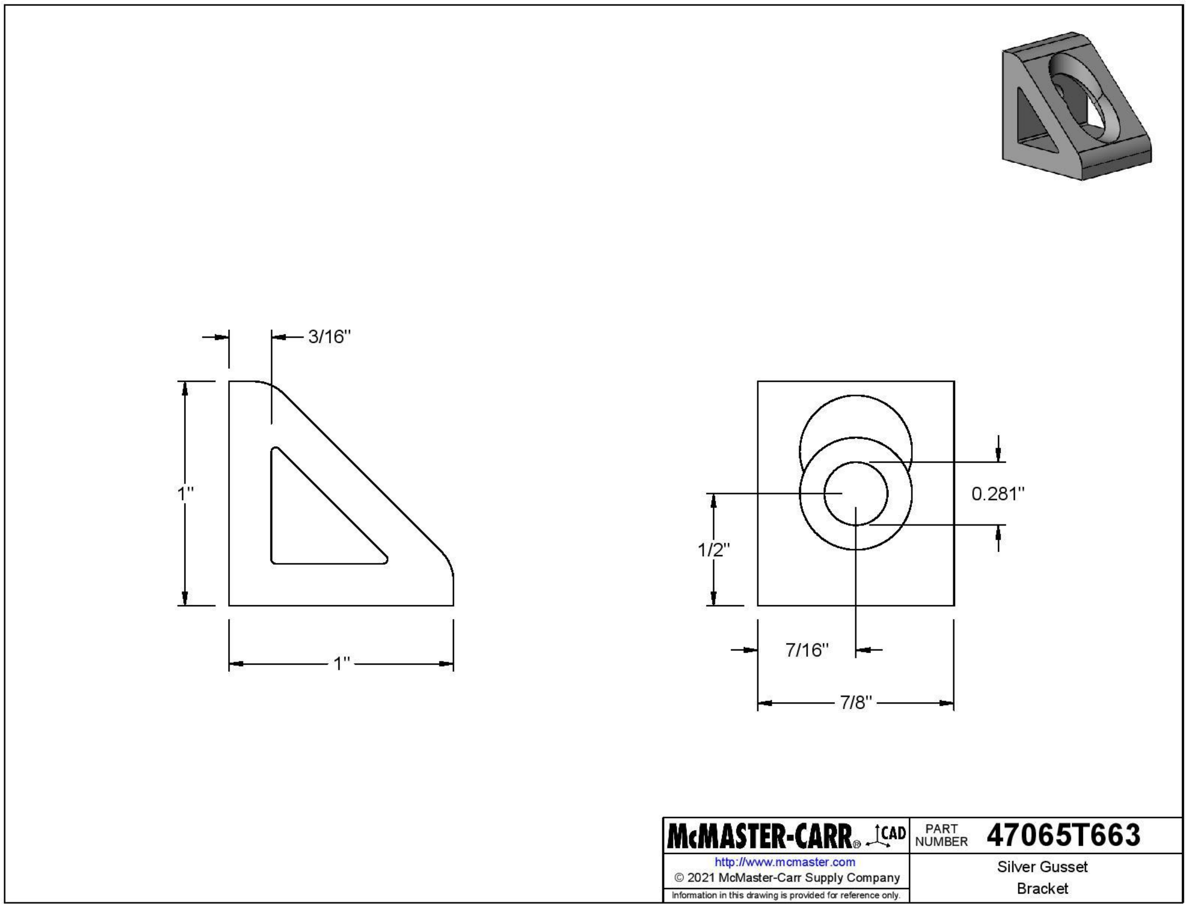
Part Number:	**27**	Angled Bracket



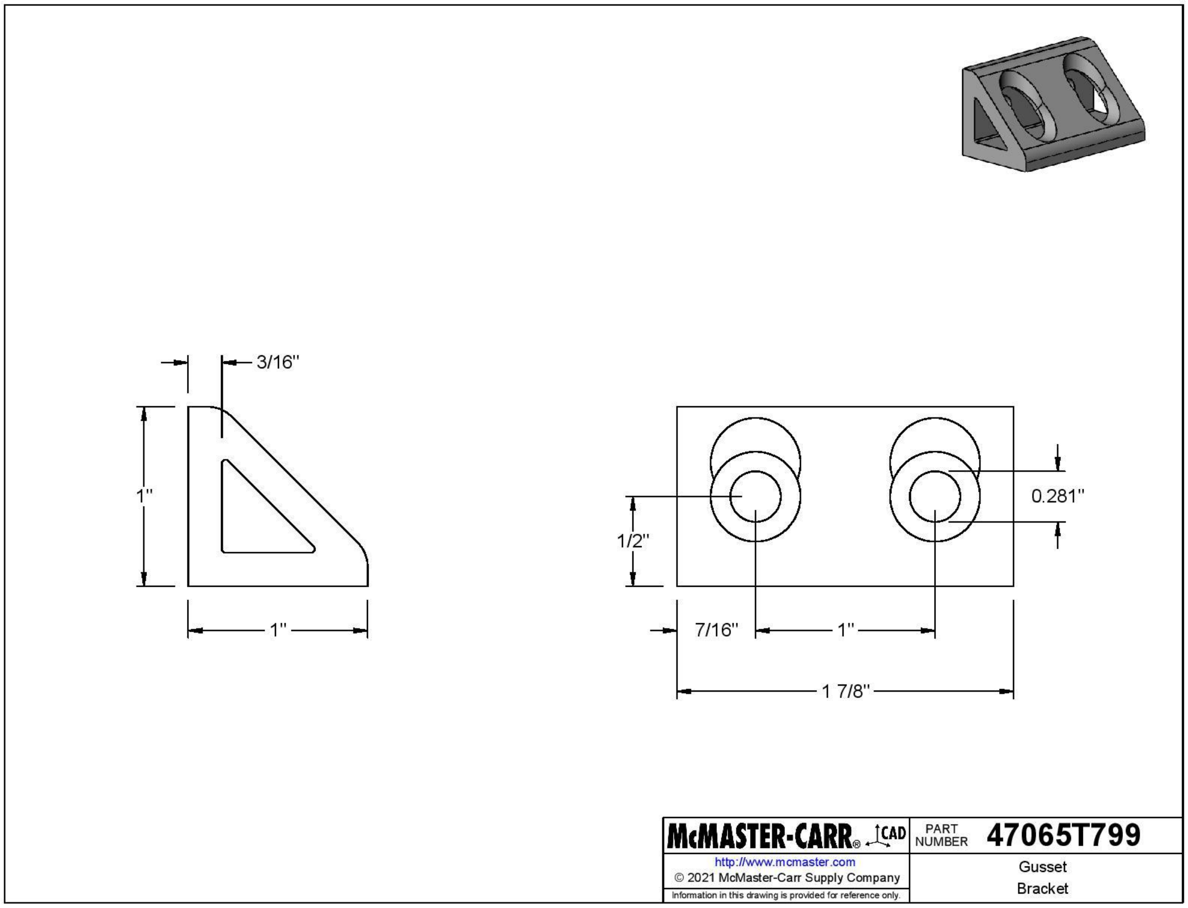
Part Number:	**28**	Angled Bracket Extended



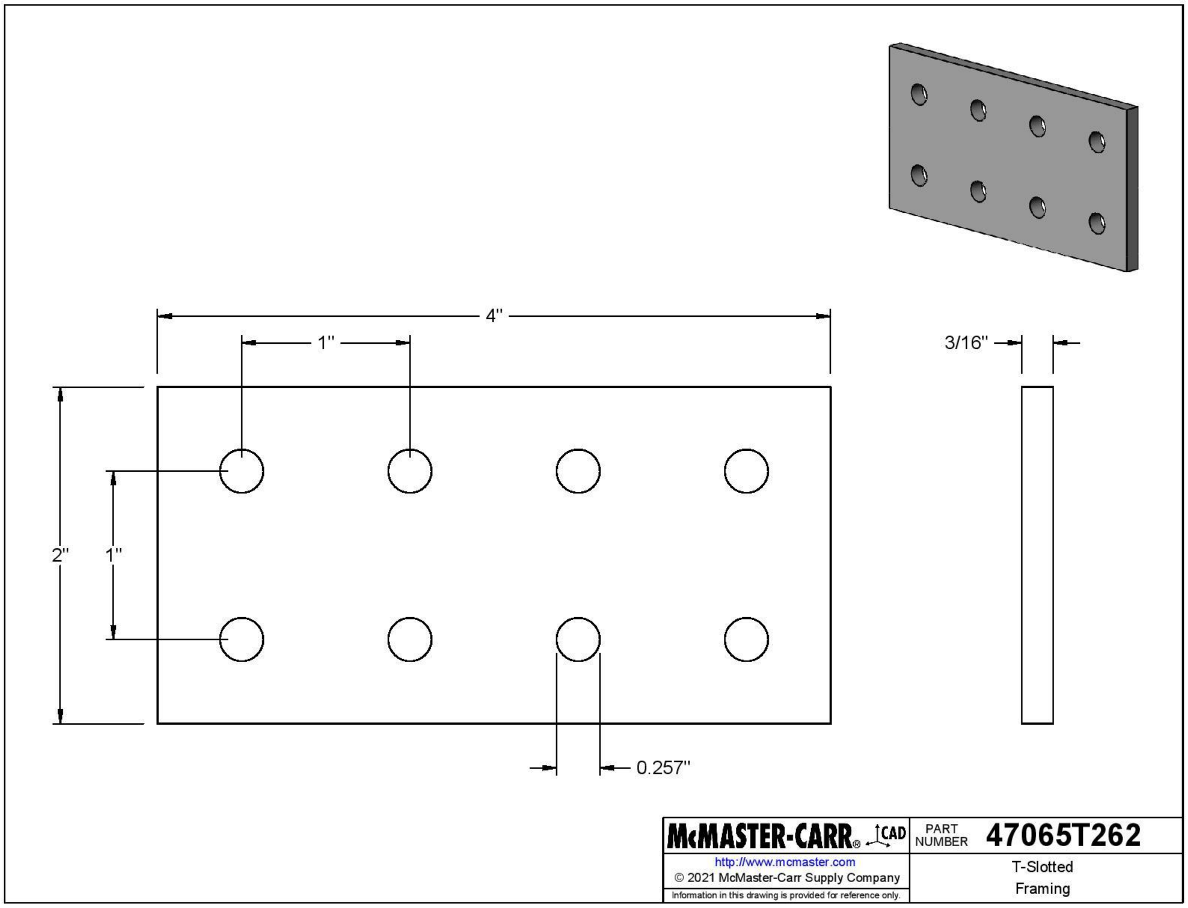
Part Number:	29	Gusset Bracket (Single)



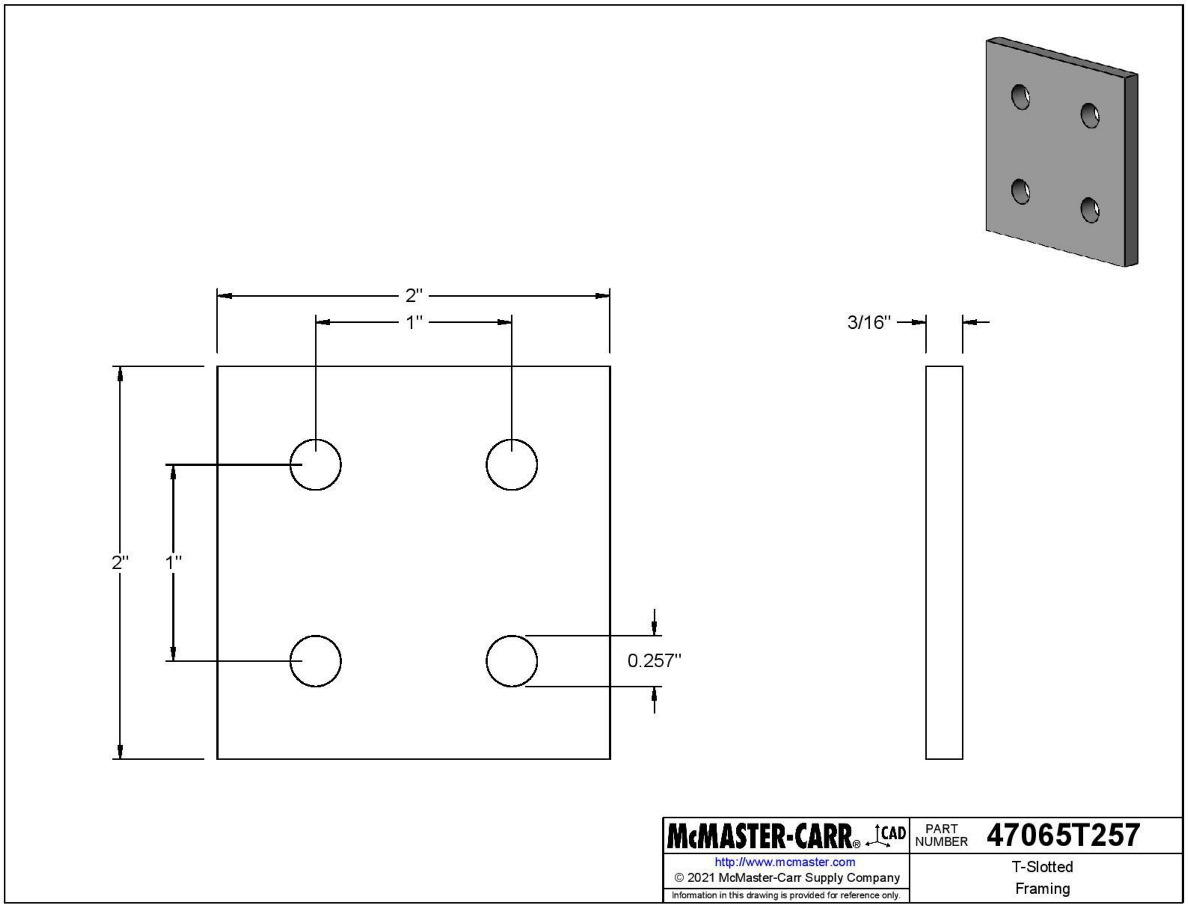
Part Number:	30	Gusset Bracket (Double)



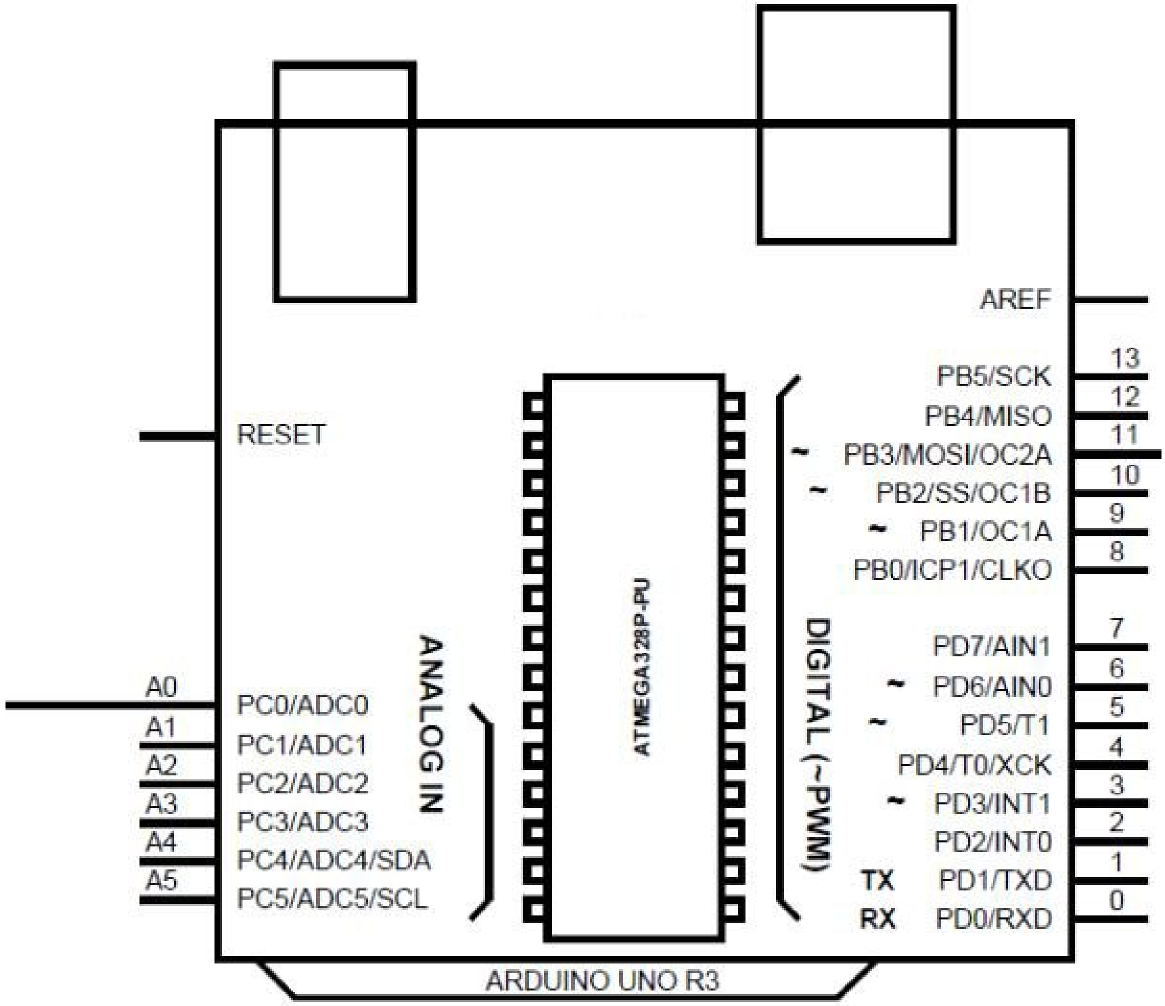
Part Number:	31	Strait Bracket 2”x4”



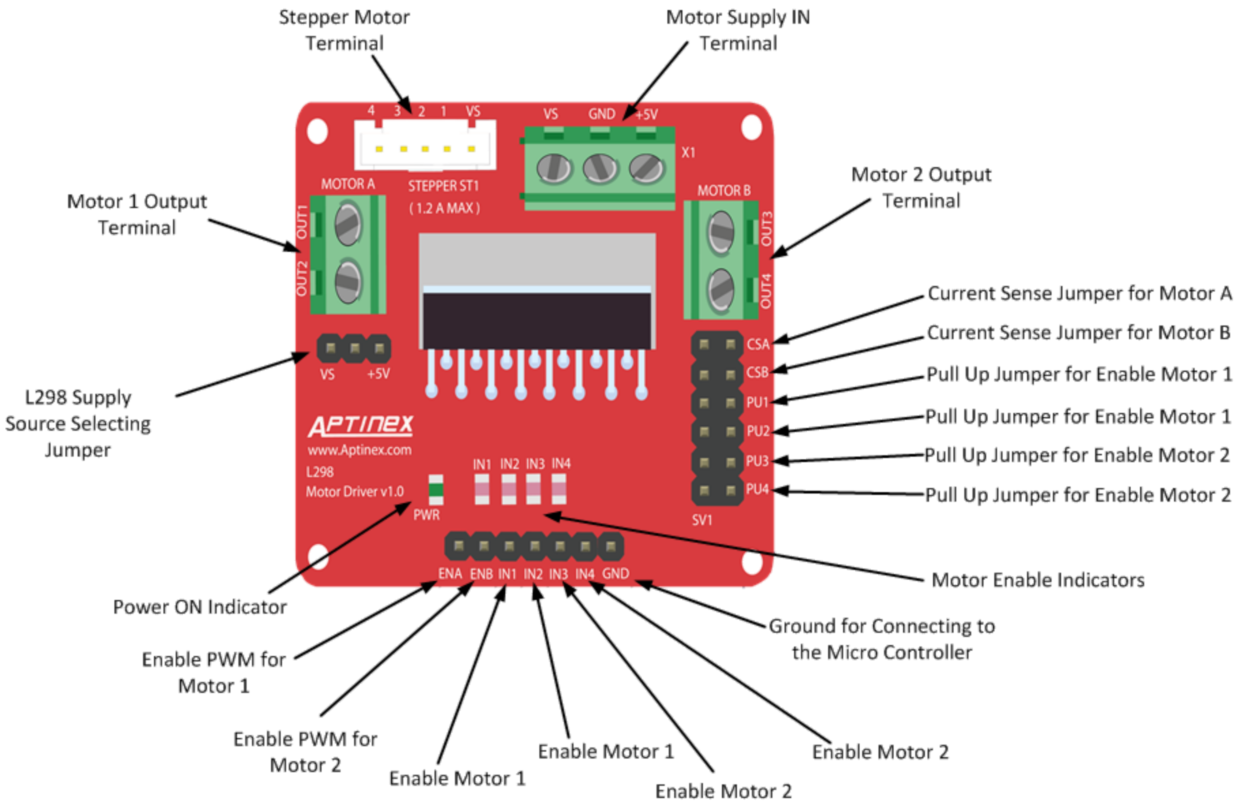
Part Number:	32	Square Bracket 2”x2”



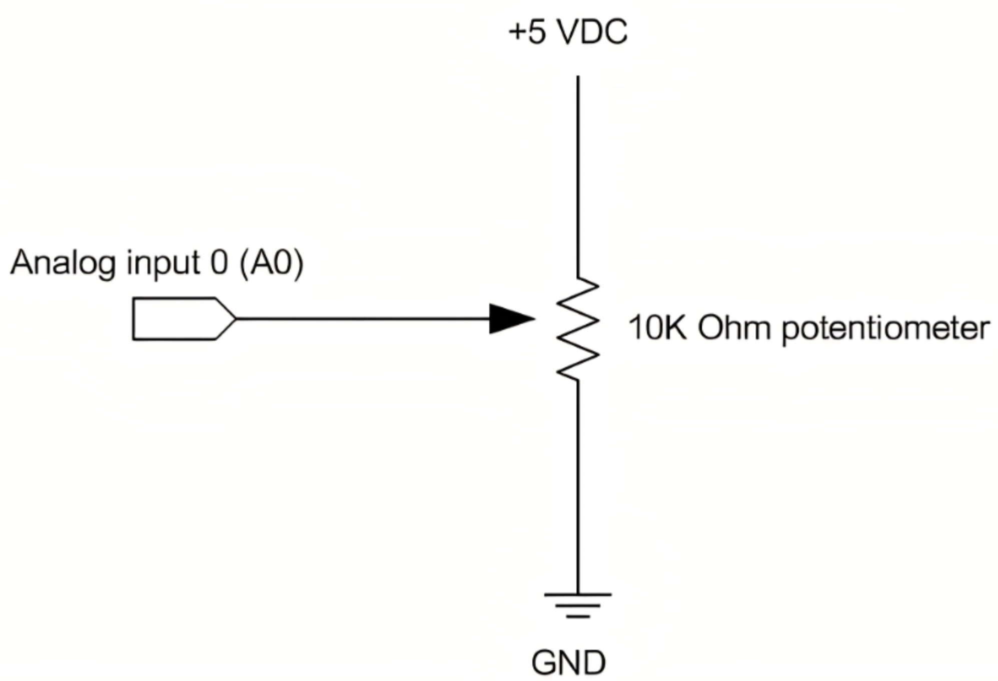
Part Number:	**33**	Arduino Uno



Part Number:	34	L298N H-Bridge Motor Controller

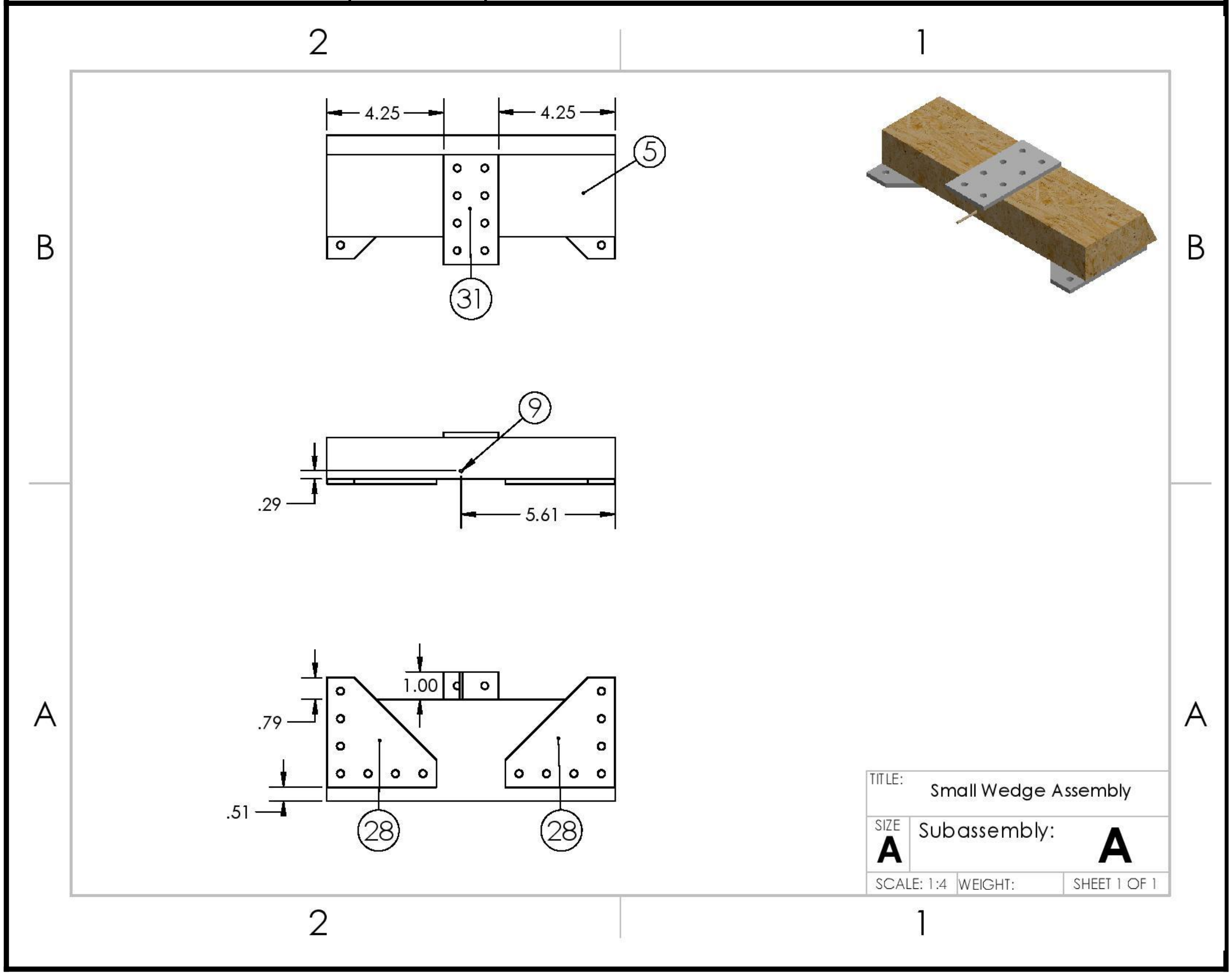


Part Number:	**35**	Potentiometer Diagram (10k ohm Variant)*

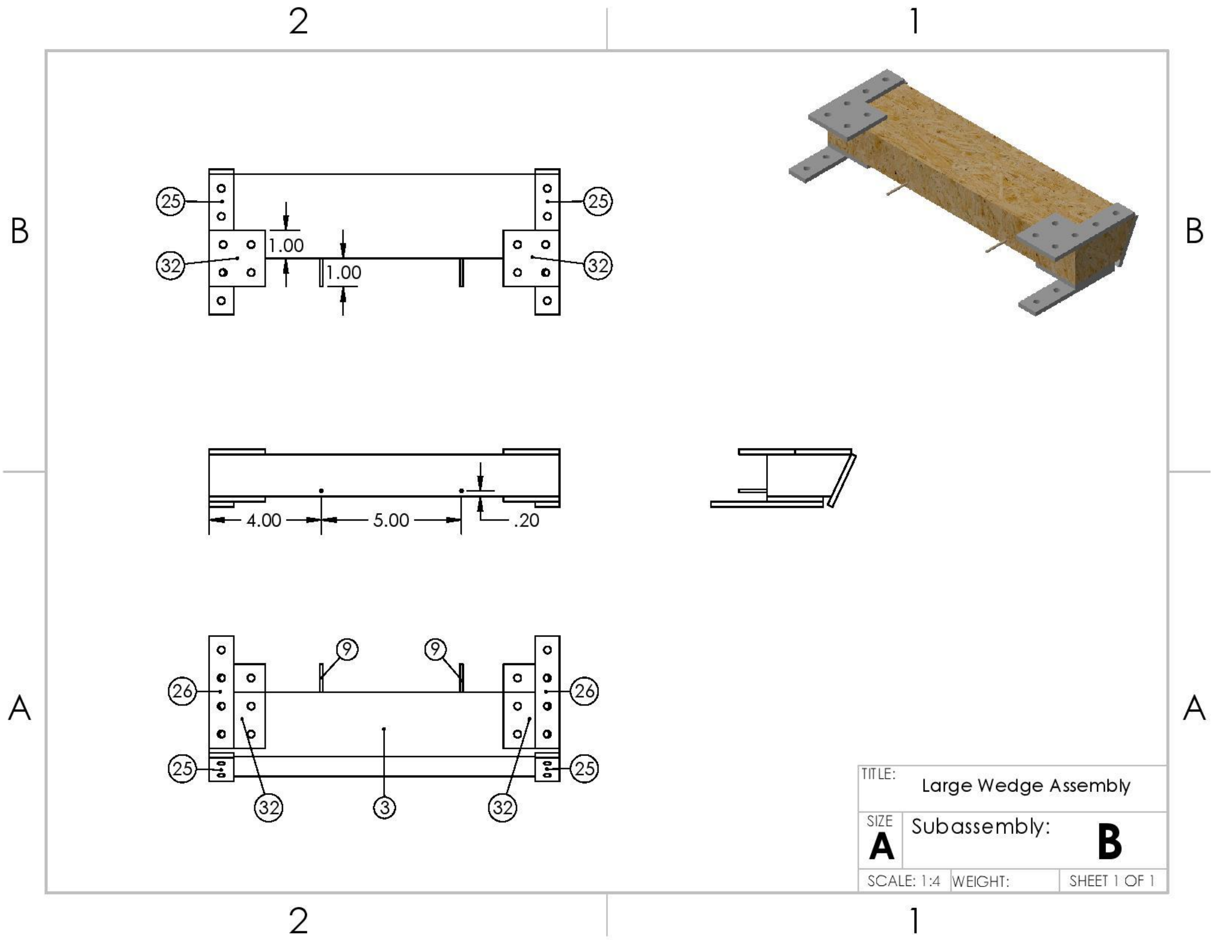


**Note: Standard potentiometers typically have the same circuit diagram, no matter what the resistance level is.*

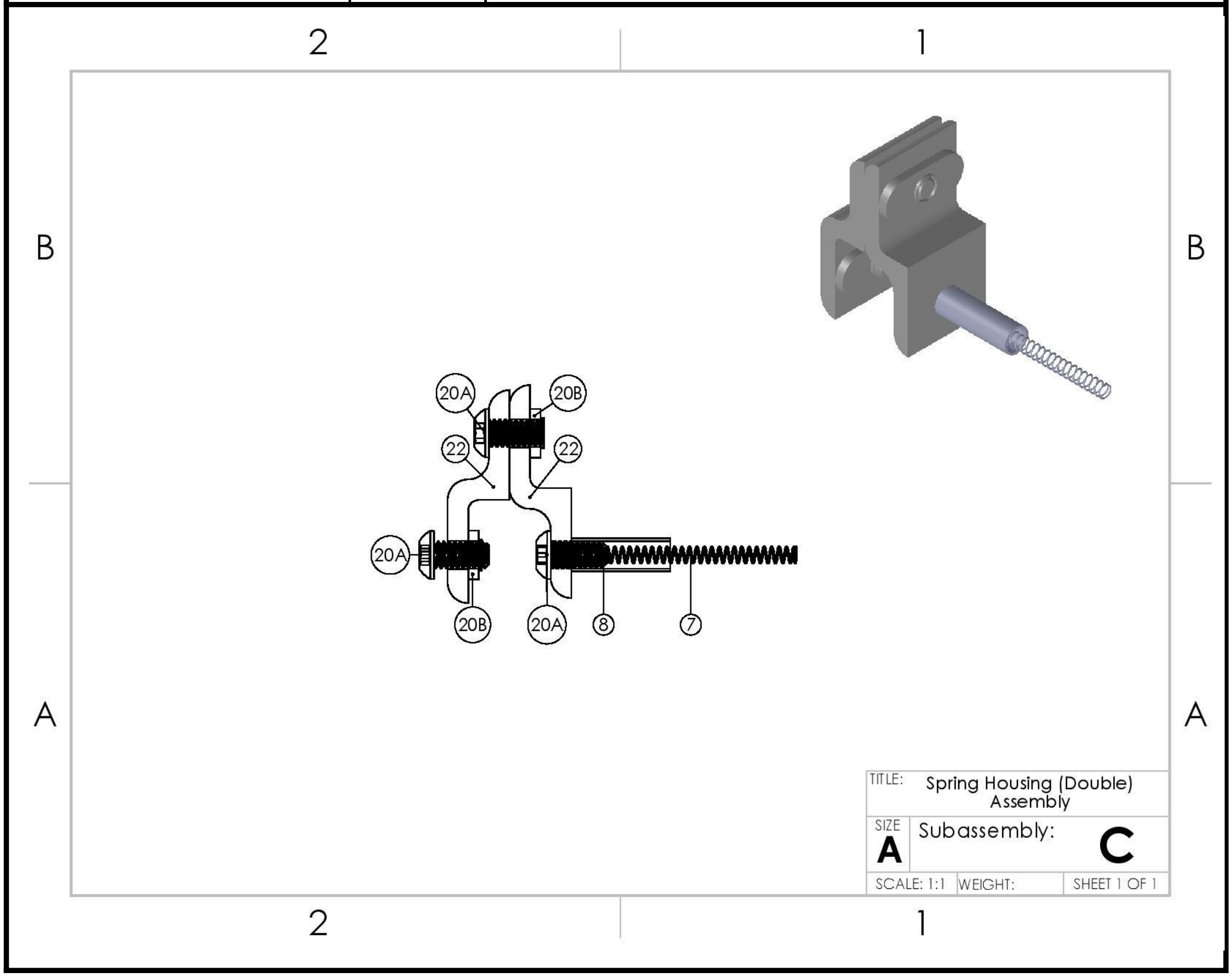
Subassembly:	A	Small Wedge Subassembly



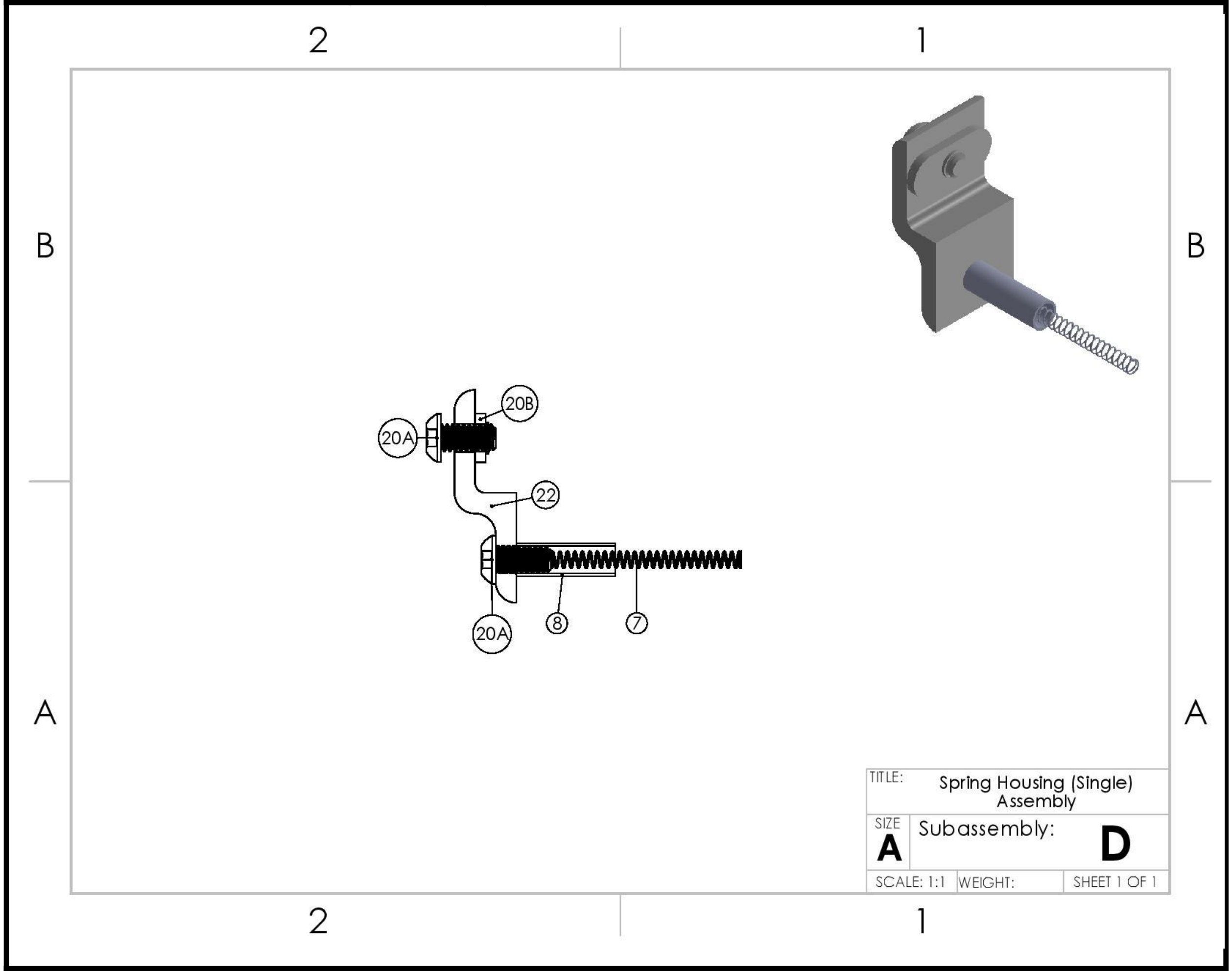
Subassembly:	B	Large Wedge Subassembly



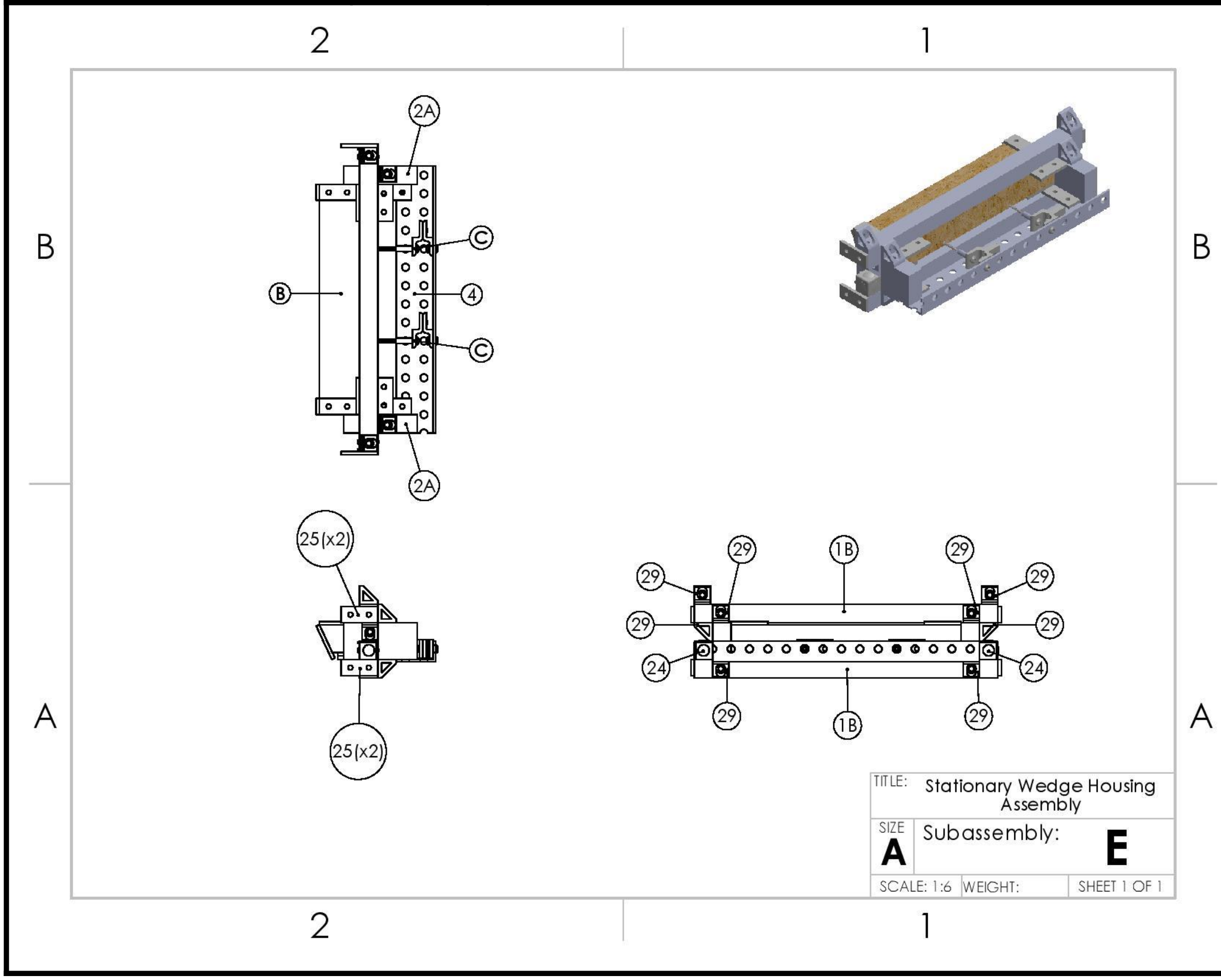
Subassembly:	C	Spring Housing (Double)



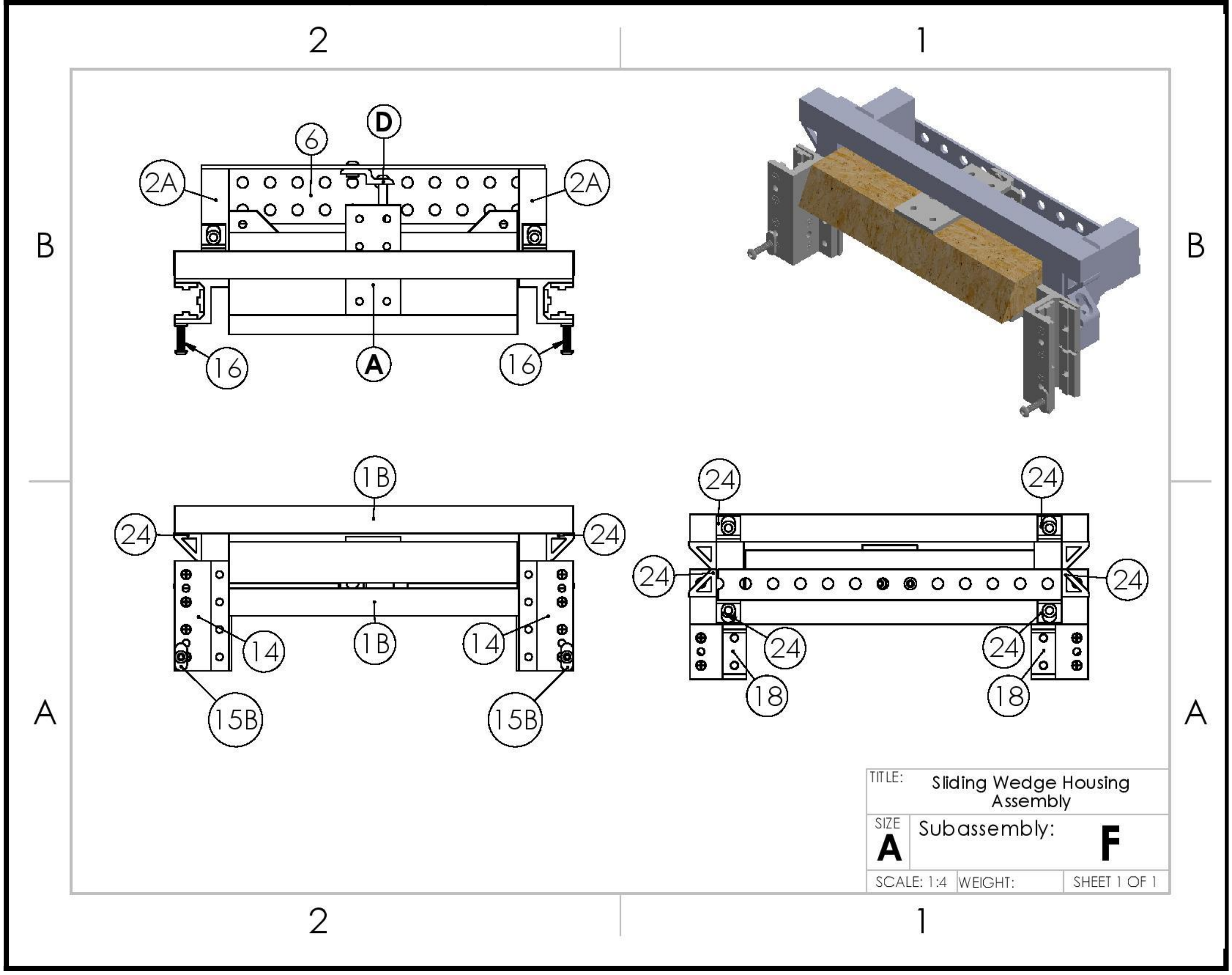
Subassembly:	D	Spring Housing (Single)



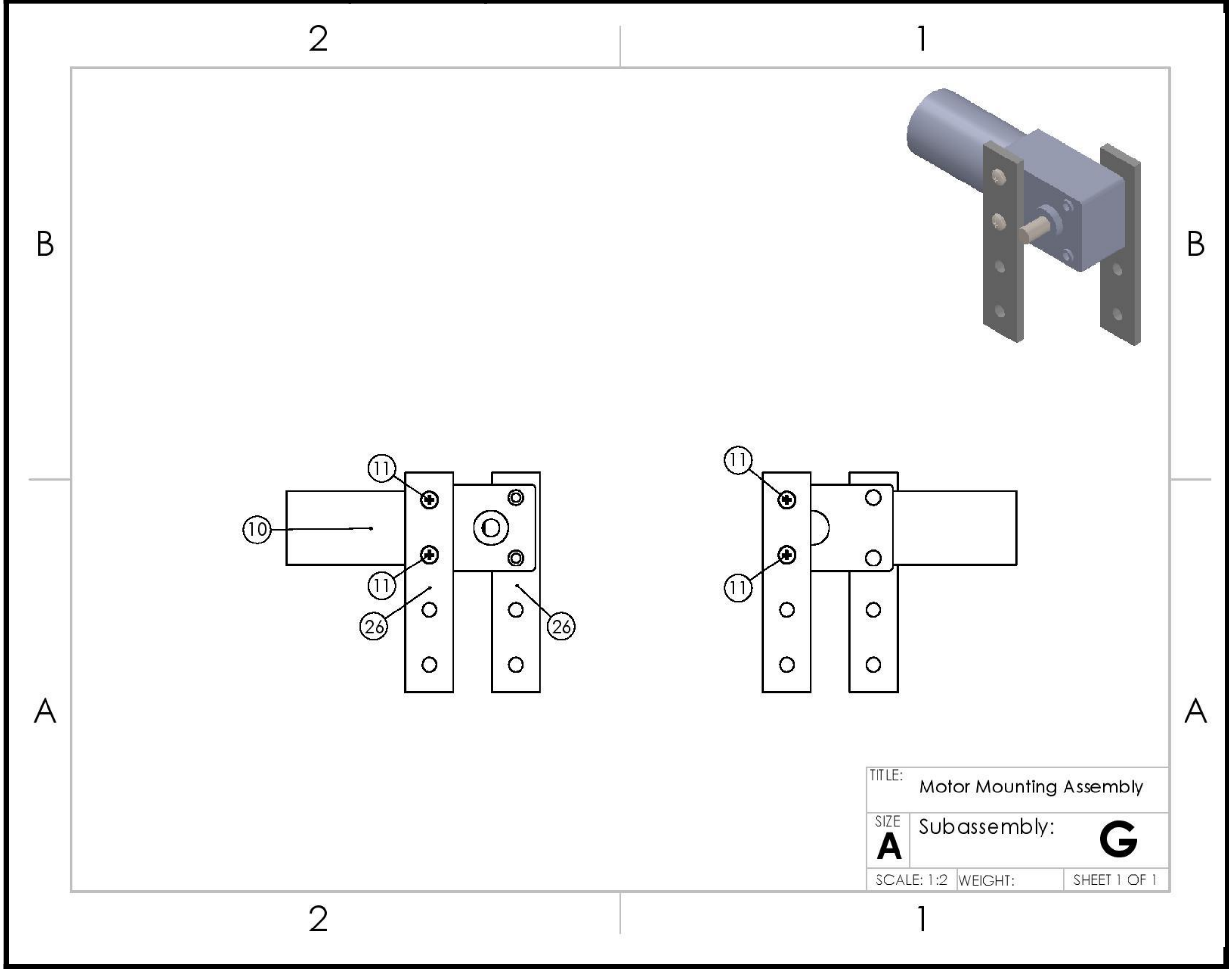
Subassembly:	E	Stationary Wedge Housing



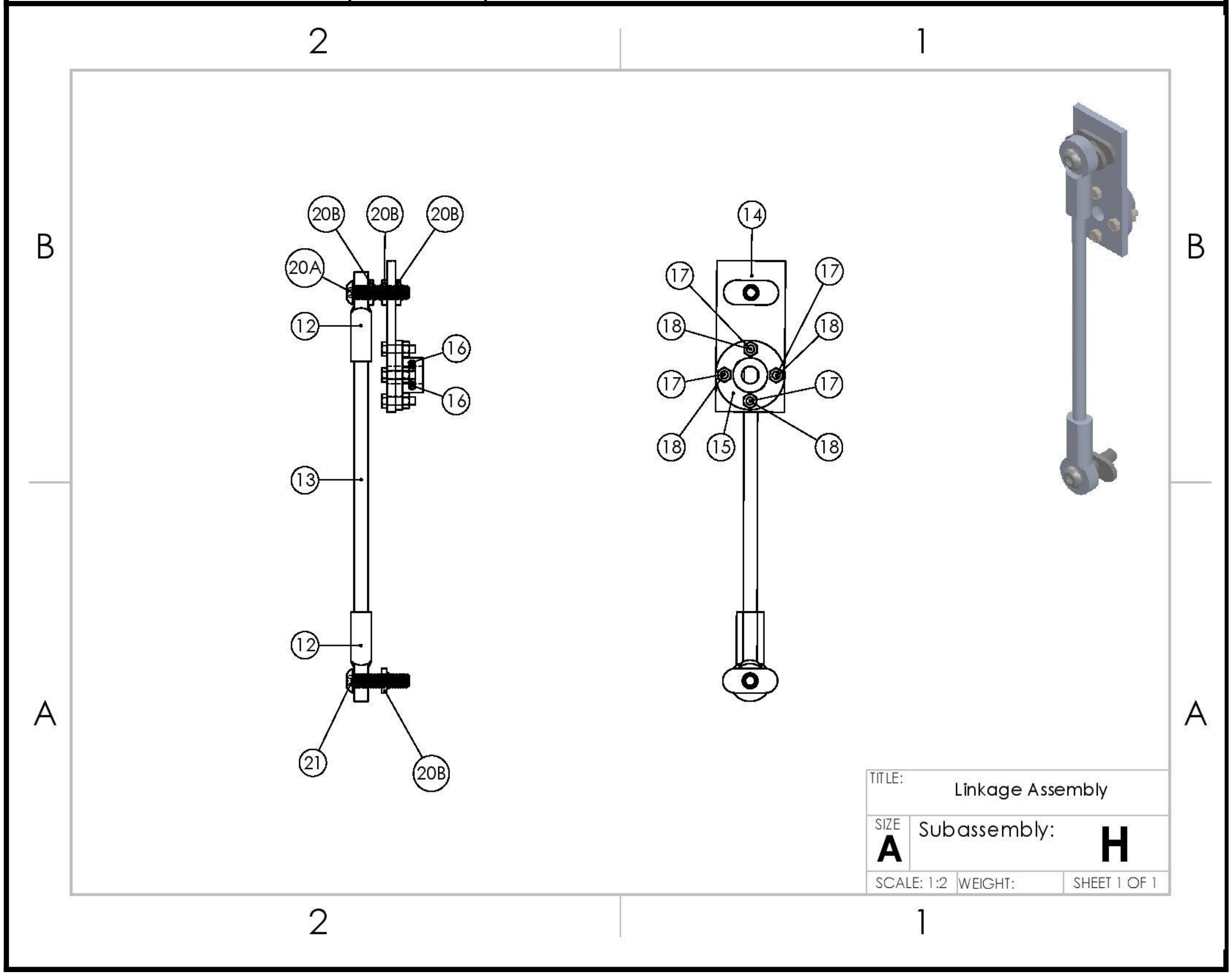
Subassembly:	F	Sliding Wedge Housing



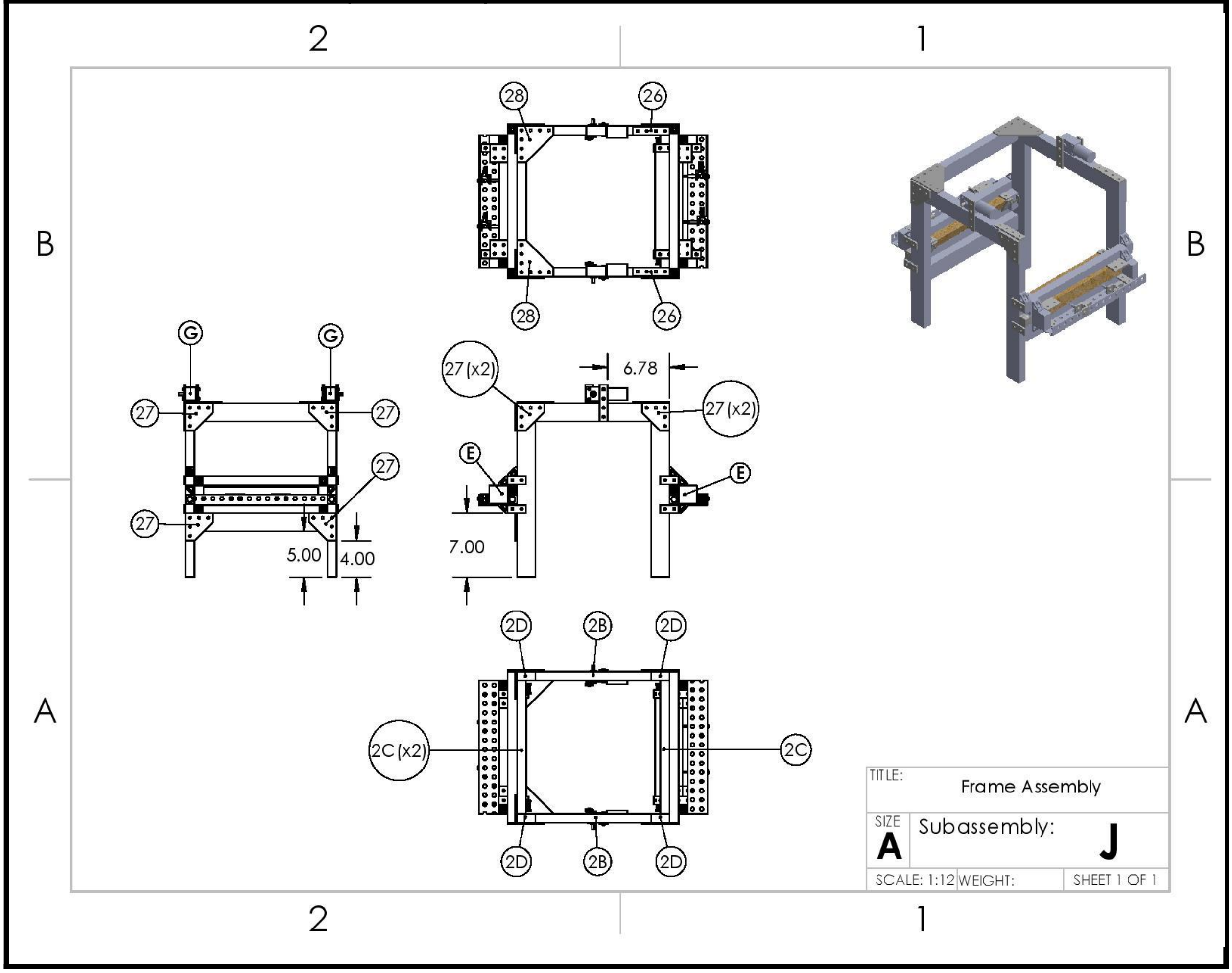
Subassembly:	G	Motor and Mounts



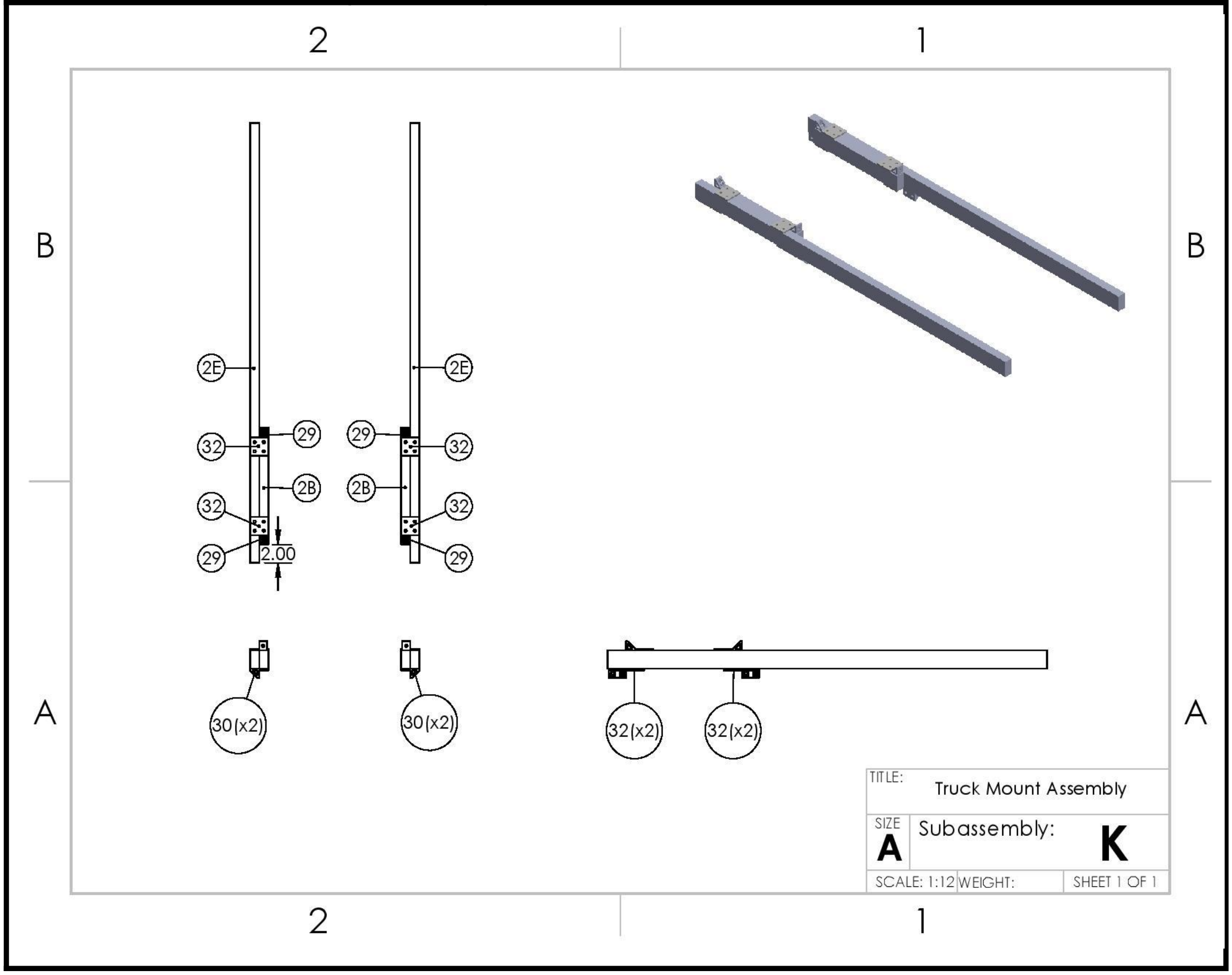
Subassembly:	H	Crank-Slider Linkage



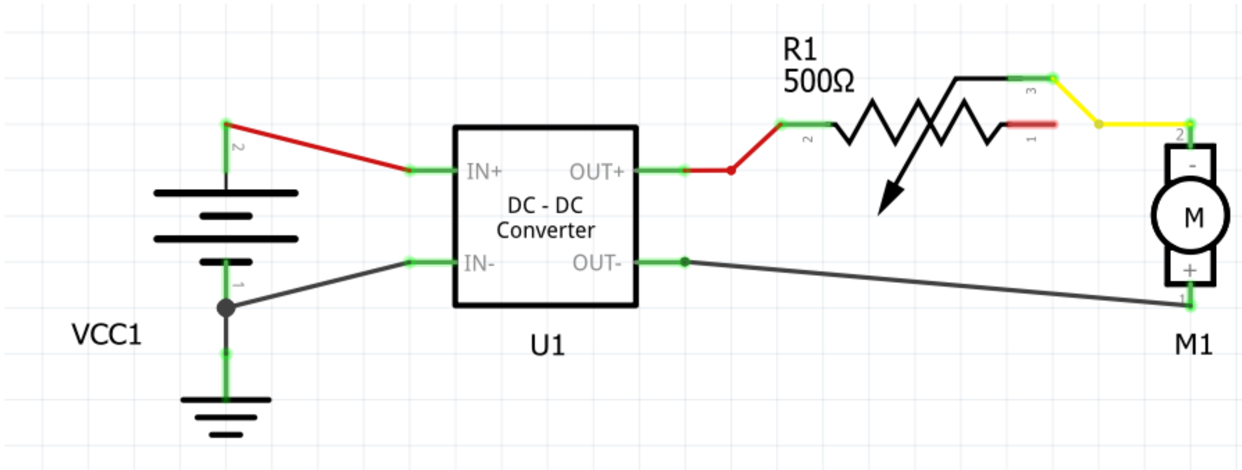
Subassembly:	J	Frame



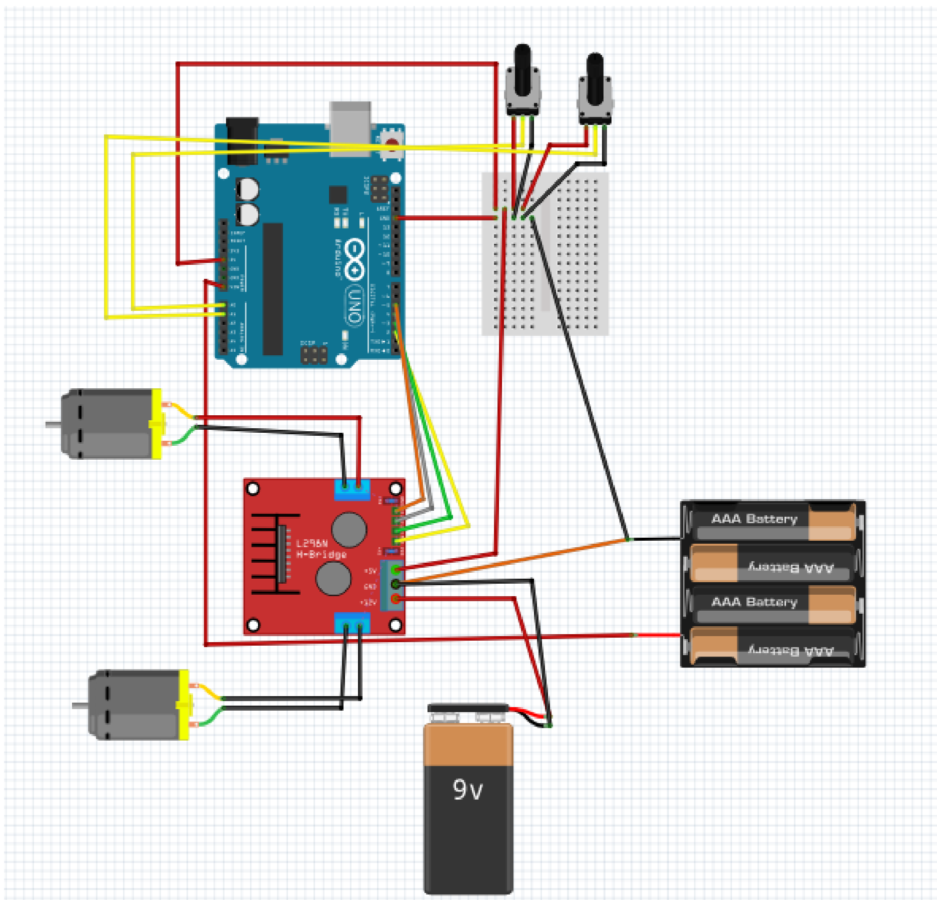
Subassembly:	K	Truck Mounts



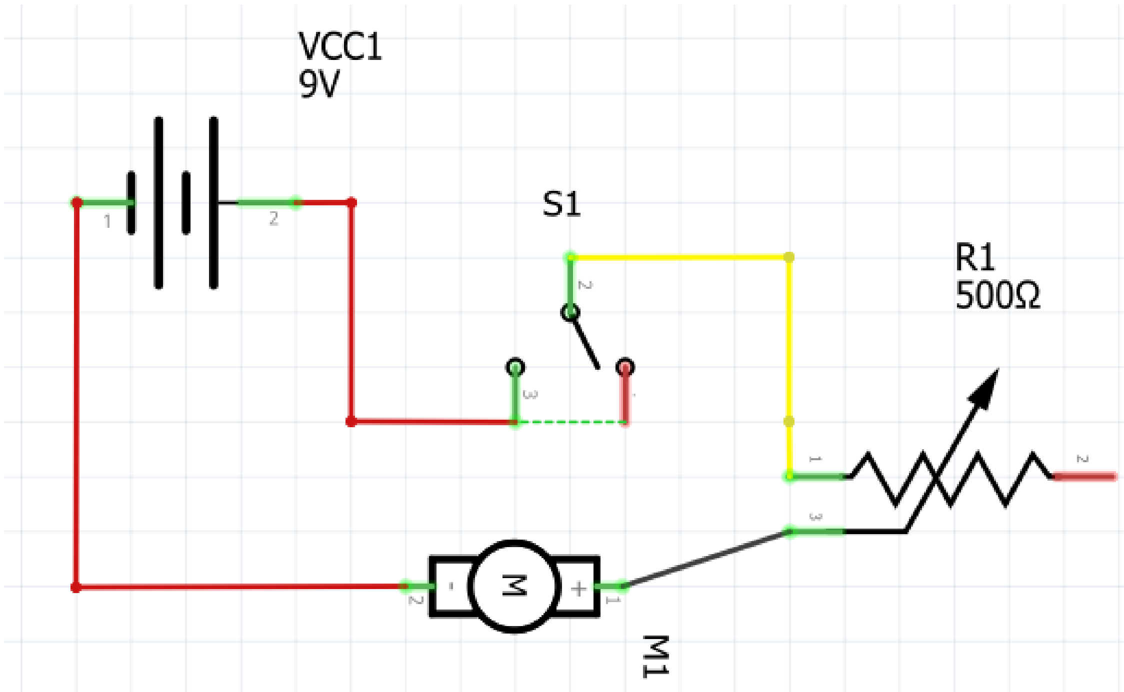
Appendix C - Electrical Schematics



1. Electrical Schematic of the first design utilizing a 4.8v battery, a DC-DC Step Up Converter, and a 500 ohm potentiometer used to power the 12VDC motors



2. Physical Schematic of the second design using a 4.8v battery, an Arduino Uno, an L298N H-Bridge, 500 ohm potentiometers, and 12V DC Motors.



3. Electrical Schematic of the third design using a 9v battery, 500 ohm potentiometers, and 12VDC motors