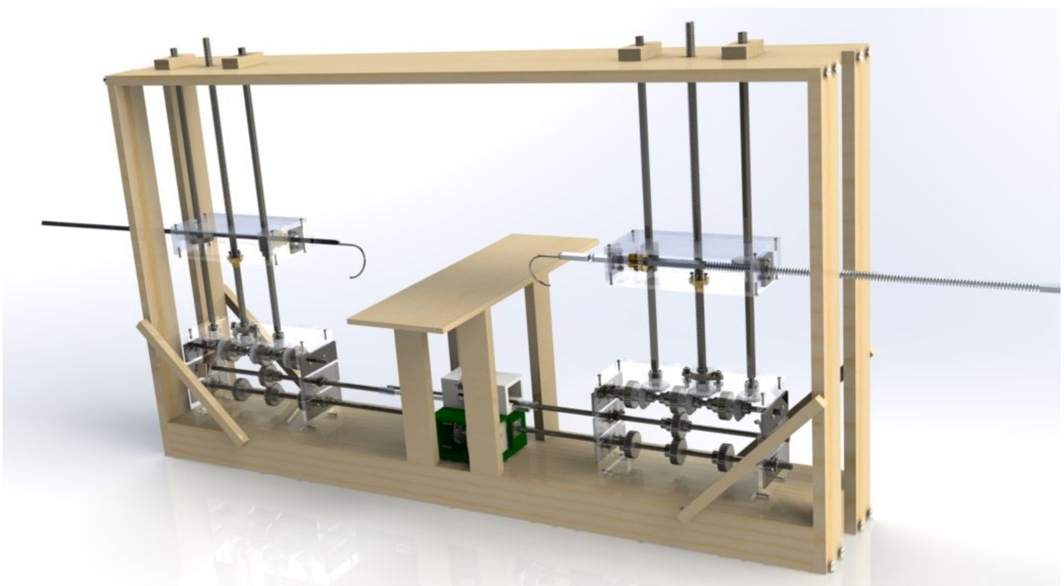
Automated Shoe Tying Machine

Technical Report #4: Final Design



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Team Name: Team Tightens

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Introduction

Mission Statement

Having neatly laced and tied shoes on our feet is a luxury the majority of us take for granted. Tying our shoes is a skilled learned at a young age that becomes a second nature ability. As we age though, our hand dexterity may decrease, our back begins to ache, and we lose flexibility. All these factors can lead to losing our ability to tie our shoes. Imagine being hindered from performing one of your earliest skills due to your age, a new disability, or during the challenges of pregnancy. It can be very disheartening to lose your long held ability to wear shoes that define part of your style and personality and be forced into settling for simple strapped shoes and slip ons that just aren't the same. In order to challenge this issue and bring back a sense of confidence, dignity, and independence to people who've been forced into wearing laceless shoes, our team's mission is to develop a fully automated shoe tying machine that works for them. There exist hobbyist machines that demonstrate knot tying capabilities but none that would be of use for the elderly, as all are not fully automated and require the user to secure the laces to preset locations. Our primary sponsor is Professor Moore from the University of California, Davis and we were given the directive to design based on our main competition evaluation criteria: time it takes to tie a shoe, the amount of energy the machine consumes, and the machine's overall success rate over multiple runs. Although the driving factor in the design parameters lies with winning the competition, we hope that our shoe tying machine can act as a precursor for a more practical future iteration of a shoe tying machine that can be widely used and benefit the elderly and disabled community, our primary stakeholders.

Problem Description

Often, the elderly and/or disabled have difficulties grabbing and tying their shoelaces on their own, so they have to resort to wearing velcro shoes, slip ons, or seek assistance from a care provider. Therefore, an automated shoe tying machine that is capable of tying a safe and lasting initial and final standard shoelace knot (shown in Figure 1 below), without requiring human assistance, has been designed and manufactured so that the user can gain more independence.

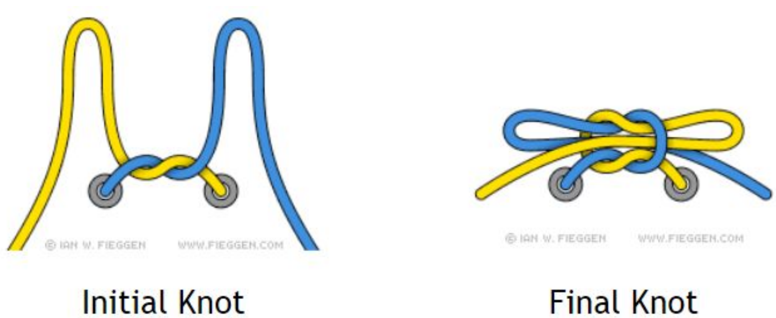

Figure 1. Examples of the initial knot and final standard shoelace knot [1].

In creating such a machine, the problem was broken down into several, more manageable sub-problems as follows:

Sub-Problems

1. Power - How will the shoe tying machine be powered?
2. Controls - How will the shoe tying machine be automated?
3. Actuators - What type of motors will be used?
4. Lace Grabbing Mechanism - How will the shoe tying machine grab the laces?
5. Moving Mechanism - How will the two motors move the lace grabbing mechanism?

These sub-problems address the major functions of the shoe tying machine that our design concept must address. Overall, a shoe tying machine will enable more independence for the elderly and disabled in tying their shoes. Farther downstream market applications may include use of the machine as a novelty device in a shoe store or assistive device in well equipped locker rooms.

Existing External Concepts/Solutions

Several external concepts were researched to aid the design of the shoe tying machine. Among these external concepts, no fully automated machine was found but certain components of these concepts inspired ideas. One external concept is a patented shoe tying device created by Leah D. Holmes et al. [2]. A schematic of this device can be seen in Figure 8 of the Appendix. This machine was designed to assist individuals with at least one able hand. Although our machine must be fully automated, we gained valuable insight from the design's use of one motor for symmetrical motion. Another device uses rods and fixture patterns to secure and tie a free string into the final knot; the string is tied as the fixtures are carefully removed layer by layer and the rods are lowered simultaneously [3]. Although this device did not tie the knot with a string attached to a shoe, insight was gained by the simplicity of using layers to tie a knot. Furthermore, the usage of simple rods with hooks for the lace grabbing mechanism was inspired by a shoe tying robot created by Andrew Stone, a mechanical engineering student at the University of Minnesota [4].

Needs, Specifications, and Standards

Since the project is meant for a competition rather than commercial viability, the needs derived from competition evaluation and parameters, which are listed below, are of highest priority and essentially drive the specifications of the shoe tying machine.

Competition Parameters

1. Must only use up to two motors.
2. Must be powered through a wall outlet.
3. Must be able to grab the shoelaces without human assistance.
4. Must tie a standard shoe knot on a stationary shoe.
5. Must stay under a $600 budget.

Competition Evaluation Criteria

1. Speed
2. Success Rate
3. Energy Consumption

Needs and Specifications

Target specifications were organized into six major categories: reliability, safety, energy efficiency, speed, versatility/compatibility, and cost. The competition parameters and evaluation criteria result in target specifications such as a 70% success rate, a run time of 7 minutes per cycle, energy consumption of less than or equal to 1.2 Watt-hours per shoe tying cycle while being powered from a wall outlet, tying a total of two knots, and costing less than $600. The target specifications are organized into Table 1 below.

Table 1. High Priority Needs & Specifications

Category	Needs	Specifications	Metrics	Target Specifications	Priority	Proof Test
Reliability	High success rate	STM successfully ties shoes consistently	Percentage	70%	•••••	Prototyping
Energy Efficiency	Powered by Wall Outlet	STM has a physical cord/plug	AC Voltage	120 V AC	•••••	DMM
	Max energy efficiency	STM consumes the least amount of energy possible upon completion of event	Watt Hours	1.2 Wh	•••••	Watts Up Power Meter
Speed	Motorized mechanism	STM uses up to two motors	Number of Motors	≤ 2	•••••	Design Inspection
	Quick completion time	Run Time	Minutes/ Cycle	≤ 7 minutes/cycle	•••••	Time Cycles (Stopwatch)
Versatility/ Compatibility	Ties both the initial knot and the standard shoelace knot	STM ties a total of 2 knots (initial and final)	# of knots	2	•••••	Visual Inspection
Cost	Stay within Budget	STM's design and manufacturing process stays within budget	Dollars	≤ $600	•••••	Track Budget

Standards

Table 2 below shows the engineering standards followed in the design and manufacturing of the shoe tying machine, where the standards apply, and the purpose of the standards.

Table 2. Engineering Standards used to Design Shoe Tying Machine.

Part or Deliverable	**Standard**	**Purpose of Standard**
NEMA 17 Stepper Motor	NEMA 17	Standard dimensions and performance out of rated NEMA motors [5]
Motors	IEEE Standard C95.6	Human exposure to electromagnetic fields should not exceed 3 kHz [6]
Mod 1 Spur Gears	ISO 54:1996	Reliable proportions and formulas to produce metric spur gears [7]
Mod 1 Miter Gears	ISO 678:1976	Reliable proportions and formulas to produce metric mitre gears [8]
Part Drawings	ASME Y14.5	Facilitate technical drawing clarity among engineers and manufacturers [9]
Controls	OSHA Instruction PUB 8-1.3 SEP 21, 1987	Positioning of kill or reset switch of robotic system outside of system's work envelope [10]
Gearboxes	DIR Subchapter 7, Group 6, Article 37	An enclosure guard shall be installed so that it completely guards the moving parts [11]

Design Description

The shoe tying machine (STM) design can be broken into five sub-systems to conquer the five sub-problems: power, actuators, moving mechanisms, lace grabbing mechanisms, and controls. The product architecture shown in Figure 2 shows how the five sub-systems interact with each other.

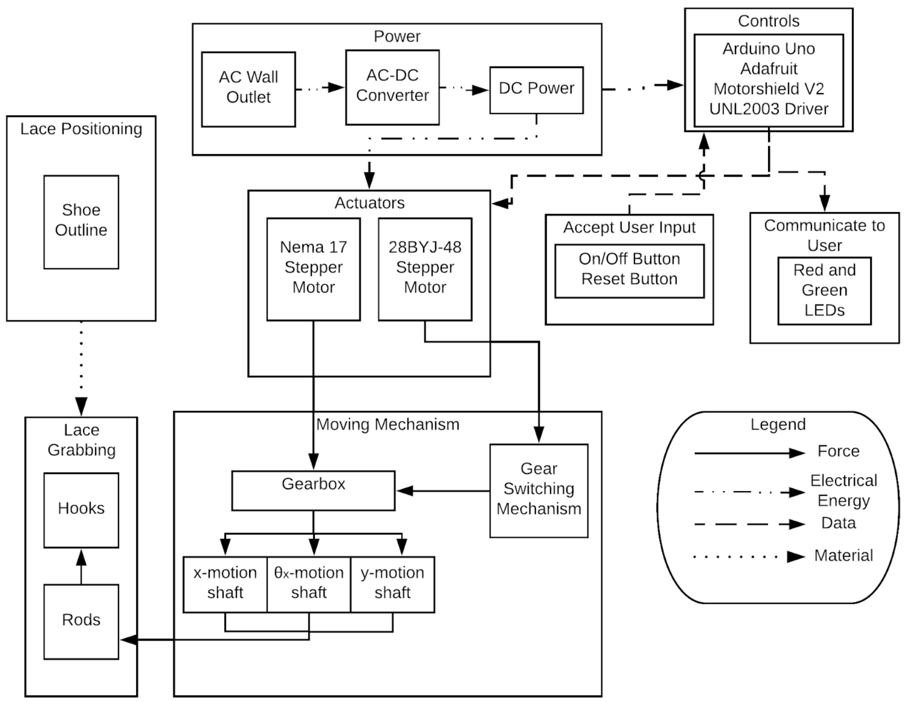

Figure 2. Product Architecture.

Power and Actuators

For the power sub-system, a simple circuit connects the NEMA17 and 28BYJ-48 stepper motors to an Arduino microcontroller and motor shields which are connected to a Dell Laptop Charger that can be plugged into a wall outlet. A complete circuit diagram is shown below.

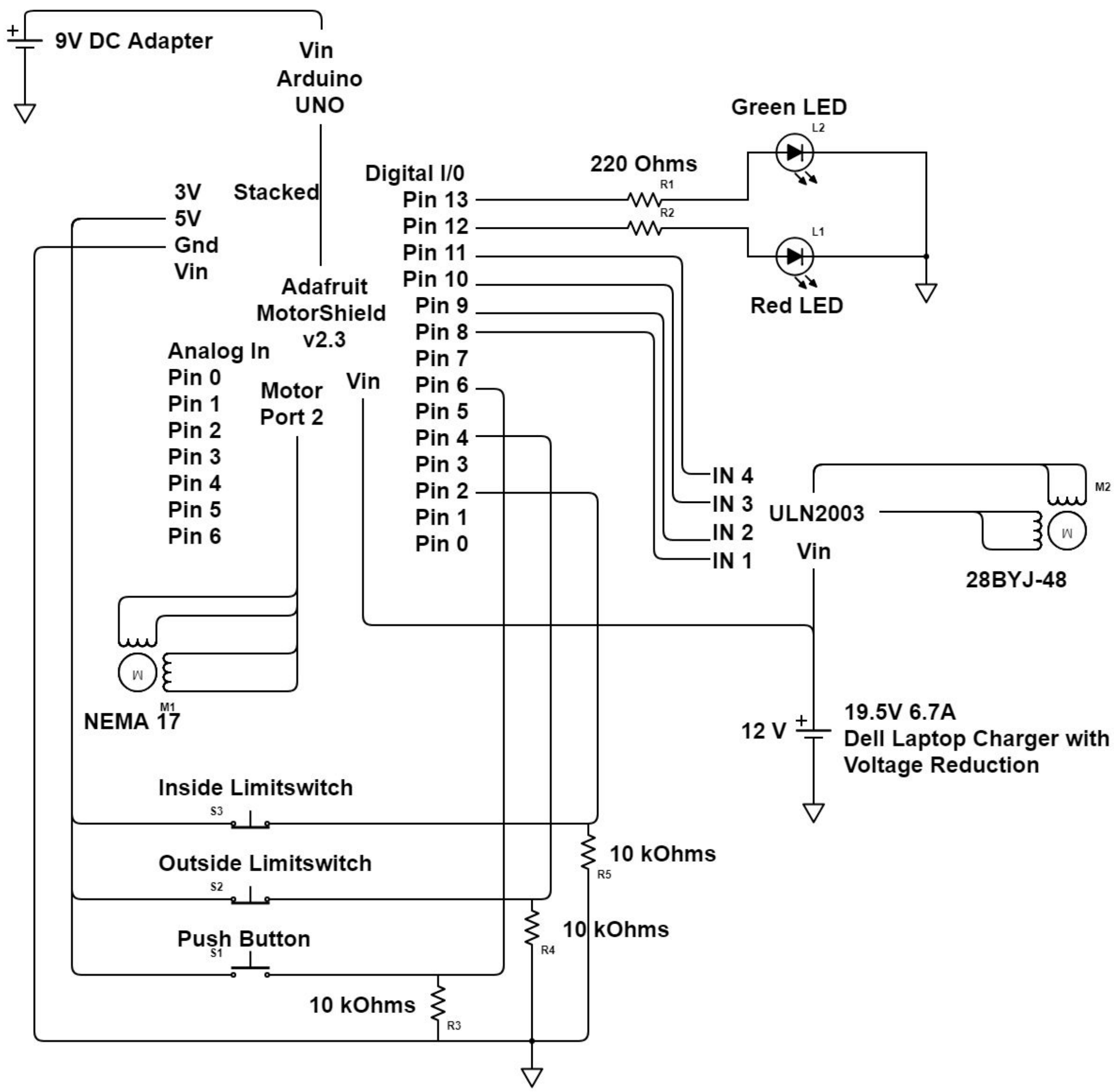

Figure 3. Circuit Diagram.

Moving Mechanisms

The two motors actuate four gearboxes, two on each side of the shoe platform as shown below.

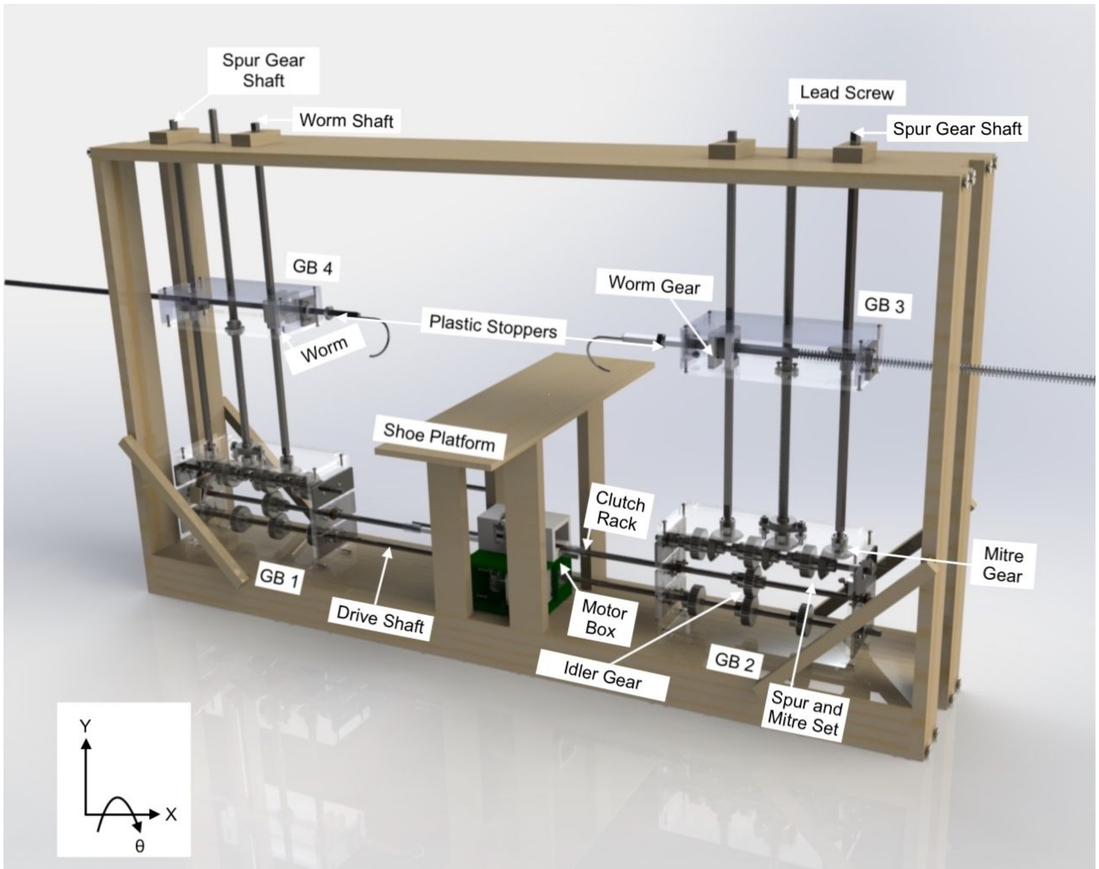

Figure 4. Rendered CAD model with Integral Parts Labeled.

In the bottom gearboxes (GB1&2), 30 tooth spur and mitre gears transmit power from the NEMA 17 motor and translate horizontal shaft rotation to vertical shaft rotation. The NEMA 17 motor drives a shaft connected to GB1&2 on the two sides of the shoe platform. On the drive shaft are a total of six 30 tooth spur gears, three inside each gearbox on each side. A 30 tooth idler gear in each gearbox transmits rotations from the bottom spur gears to the spur-mitre gear sets[1] on the top shafts. The 28BYJ-48 motor controls the horizontal movement of the idler gears using a rack and pinion system; the racks translate the idler gear shafts horizontally. The idler gear then engages with corresponding spur-mitre gear sets, and transfers power from the drive shaft to the spur-mitre gear sets which drive the movement of two rods with hooks in the top gearboxes (GB3&4). Often times the clutch gear teeth aligns perfectly with another set of teeth and jams the clutch mechanism. Rubber bands are used to hold the clutch motorbox in place while also giving it the ability to shift slightly until the clutch is able to fix itself. The top gearbox is controlled by two square shafts and a lead screw

[1] Mitre gear epoxied to a spur gear.

on each side. The lead screw controls translational y-axis movement. Square shafts are used so that the top gearboxes can move along the shafts and the gears on the shafts can be engaged and driven by each shaft at any point along the shaft. The square shaft closest to the shoe platform (Worm Shaft) drives a worm and a 20 tooth worm gear with a modulus of 1 which controls the rotation of the rod about the x-axis. The worm was purchased and it had a circular bore so an acrylic insert sits inside the worm using the set screw and has a square bore that would allow the square shaft to rotate the worm. Last, the square shaft farthest away from the shoe platform (Spur Gear Shaft) controls the translational x-axis movement of the rod by driving a 33 tooth, modulus 1 spur gear with a 0.25”x0.25” square bore. The hook rod is designed to have 12.89” of rack with a modulus of 1 and is driven by the spur gear. The spur gear was restricted by the worm and worm gear because the distance between the worm and worm gear needed to match the distance between the spur and hook rod so that the hook rod would be straight while both gear systems maintained a strong mesh. Collars were used to secure the positions of the gears and shafts.

After multiple test iterations of the shoe tying algorithm using a simple wooden prototype, it was determined that a 0.5” offset of the hooks was the ideal position. This offset determined most of the design aspects because everything under the hooks had to be offset in order for the hooks to be offset. Slots were designed in the side plates of GB1&2 to allow for adjustability of the gears in order to achieve the best gear meshing. Two different sets of slots were designed into the side plates: one was for the drive shaft and the other for the idler gear and spur-mitre gear sets. The drive shaft slots were identical for both GB1&2 because there was only one drive shaft. But the slots for the idler and spur-mitre gear sets are offset by 0.25” from the drive shaft slots in opposite directions on each gearbox so that the total offset is 0.5”.

Lace Grabbing Mechanism

The shoelaces were controlled with a pair of hooks. Two paper clips with a diameter of 0.1” were used to make hooks with 0.75” diameters designed to reach across the 0.5” offset and grab the opposing laces. The rod was designed to be a square shaft to allow translational movement through the worm gear but also be able to be rotated by the worm gear when needed. Since the worm gears had circular bores, acrylic inserts with a square bore were placed inside the worm bear bore. The set screw of the worm gear was used to hold the acrylic inserts in place. The square bore would catch the square rod and rotate the rod as the worm gear rotated. There are also plastic stoppers on the hook rod about 3.34” away from the hook. These stoppers prevent the shoelaces from moving along the hook rod as it moves inwards toward the shoe. They stop the shoelaces so that the hooks on the opposite rod are able to grab the lace during the shoe tying operation. The flexibility and elasticity of the stoppers were an integral part of the design. The stoppers needed to be stiff enough to hold the shoelaces back but flexible enough to bend when the hooks hit it.

Design Justification

Motor Justification

Clutch Motor: 12V 28BYJ-48 Stepper

In choosing the clutch motor, a major limitation was created by the necessary 0.5" offset between the clutch rods. To satisfy the 0.5" offset, a thin motor shaft that could fit a 0.3"OD laser cut spur gear was needed. Additionally, a second NEMA17 was nearly chosen to act as the clutch motor for its speed and energy efficiency but was decided to be infeasible due to its larger shaft size which would lead to fragile spur gear. Therefore, to satisfy this offset, the 28BYJ-48 motor was chosen instead for its small size, relatively high torque, and most importantly its 5mm shaft. Although the 28BYJ-48 has speeds of up to only 20rpm, the small size of the 28BYJ-48 allowed the 0.5" offset to be possible. Therefore, the lower speed of the 28BYJ-48 was deemed a necessary sacrifice. During testing, this speed proved to be just enough for the machine to achieve the highest success rate.

Drive Motor: 350mA NEMA17 Stepper

For the drive motor, several motors were contemplated: a 350mA NEMA17 that has a 16 Ncm holding torque, a 2A NEMA17 with a 59 Ncm holding torque, and a 2.8A NEMA23 with a 1.9Nm holding torque. The output torque between these motors varied greatly and thus, a decision was made based upon which motor had the highest chance of being able to win the competition. A motor was needed that had high enough speeds to minimize run time, the necessary torque to not stall, and was not unnecessarily strong because that would lead to wasteful energy consumption.

To determine which speeds were desired, a 350mA NEMA17 was purchased as a preliminary test motor. Using this motor, it was shown that slower rpms were often more desirable. High rpms would often cause excessive vibrations throughout the machine due to being made out of acrylic which would led to laces falling off the rod with hooks. It was shown that the 350mA NEMA17 had adequate torque for quick x-translational and x-rotational movements but lacked speed in y-translational movement. Despite this, it was decided to stick with the 350mA NEMA17. The 2A NEMA17 and the 2.8A NEMA23 were deemed to be unnecessarily powerful as the marginal benefits of having a faster y-translational movement time would be overshadowed by the heightened energy usage.

Gear Justification

By selecting motors with sufficient torque, the correct gear ratios were chosen – specifically, the gears between the motor shaft and the drive shaft which has a 4:5 gear ratio (20T:25T). Otherwise, to simplify the overall design, all other gears have a 1:1 ratio with module of 1.

Circuit Justification

Motor Shield: Adafruit Motorshield V2.3 and ULN2003

In determining proper motor drivers for the NEMA17 and 28BYJ-48, the Adafruit Motorshield V2.3 and the ULN2003 motorshields were chosen, respectively. The Adafruit

Motorshield V2.3 was chosen for its easy and intuitive Arduino library as well as its ability to microstep stepper motors which was necessary for smooth clutch transitions. The Adafruit's 1.2A current support was also more than adequate for powering the 350mA NEMA17. The ULN2003 was chosen as it is a standard for controlling 12V 28BYJ.48 steppers. Furthermore, as the Adafruit shield is powered through a 12V source, both shields were able to be powered through the same power source which led to a more convenient circuit setup.

Meeting Specifications

The majority of target specifications were met by the shoe tying machine which include the competition parameters as well as desired competition evaluation parameters. All competition parameters were met as the STM

- Stayed under a $600 budget, costing a total of $580.90
- Is powered through a wall outlet using a 19.5V 6.7A Dell Laptop charger with a DC to DC step down converter
- Used only two motors: a 12V 28BYJ-48 and 350mA NEMA17

For contest evaluation parameters, several target values were predetermined that we believed would make the STM competitive with the Japanese team. These values and the actual outcomes are discussed below.

Speed

A target specification of under 7 minutes was chosen for speed. Using the aforementioned two motors, the total shoe tying operation was timed to be 4 minutes and 10 seconds, far exceeding expectations. Thus, the STM design met the speed criteria.

Energy Efficiency

For energy efficiency, a total energy consumption of under 1.2 Wh was calculated by first calculating the power consumption of both stepper motors and then finding the total power consumption. Last, the target time per cycle (7 minutes) was used to calculate the target total energy consumption, which ended up to be 0.96 Wh. Since stepper motors often consume more than their rated current at peak times, this energy consumption was multiplied by a factor of 1.25 for a total energy consumption of 1.2 Wh. This calculation is shown below.

$$P = V * I$$

$$P_{NEMA17} = 12V * \ 350mA = 4.2W$$

$$P_{28BYJ-48} = 12V * 350mA = 4.2W$$

$$P_{total} = 8.4W$$

$$E = P_{total} * t_{spec} = 8.2W * 7mins * \frac{1\ hour}{60\ mins} = 0.96\ Wh$$

$$n = 1.25$$

$$E_{spec} = n * E = 1.2\ Wh$$

Using the Watts Up meter, the total power consumed by the machine in one cycle was measured to be 0.6 Wh. This value makes sense as the time it took to complete the shoe tying algorithm decreased from 7 minutes to 4 minutes and 10 seconds. Therefore, the STM design met the energy efficiency criteria.

Success Rate

A target success rate of 70% was chosen as it was thought to be highly competitive. In actuality, after testing, the success rate of the first initial knot came out to be approximately 90% while the completion of the second knot dropped down to 30%. The STM design did not satisfy this specification due to the complexity of getting laces to act consistently between trials. Although the overall success rate of 70% was not achieved, the 30% success rate is still satisfactory as it was enough to win the competition.

Manufacturing

Manufacturing consisted of several main sub-assemblies listed below:

- Gearbox Frames
- Vertical Shafts
- Horizontal Shafts
- Gears/Racks/Inserts
- Motorboxes
- Rods with Hooks
- Mounting Plates/Acrylic Bearings
- Wood Frame

Gearbox Frames

Gearbox frames were made out of cast acrylic for its ease of manufacturing, relative sturdiness, as well as its opacity. Each gearbox frame consists of four plates: bottom, top, and sides for a total of 16 plates. Front and back plates were excluded to allow for rapid troubleshooting. Each plate was approximately 0.18 inches thick with a tolerance of ±0.01

inches. All of the plates were cut with the Trotec Speedy 400 Laser. Holes were then drilled into the sides of the plates using a #43 drill bit on a Bridgeport mill. These holes were then tapped for 4-40 screws. The side plates have 3 slots that allow for mounting plates to be fixed using 4-40 screws and nuts. The top plates for gearboxes 1 and 2 have holes to which ⅝" bearings are press fit and the lead screw bearing is mounted. The top and bottom plates for gearboxes 3 and 4 have 0.35" diameter holes so that the vertical 0.25" square shafts can fit through. The middle hole on the bottom plate of gearboxes 3 and 4 have a lead screw nut screwed into it using 4-40 screws. These plates were then held together using 4-40 screws to create the frames for each gearbox.

Vertical Shafts

Three vertical shafts were used on each side of the machine: two 0.25" cold rolled mild steel square shafts and a 8mm stainless steel lead screw. The lead screw was used as is and a turning tool on a lathe was used to turn down the 0.25" vertical shafts to 0.25" diameter circular shafts 1.5 inches from the top and bottom end so that the shafts can sit in the bores of the bearings, collars, and mitre gears.

Horizontal Shafts

Three 3 feet cold rolled mild steel 0.25" circular rods were used for the horizontal shafts. The first shaft was used as is for the drive shaft. The second shaft was cut into two 8.75" shafts for the two top rods. The third shaft was cut into two 15" shafts for the middle clutch rods. All rods had their ends deburred on a belt sander.

Gears/Racks/Inserts

Gears consisted of 12 acetal mitres, 14 acetal spurs, two bronze worm gears, two 1045 steel worms, and 5 cast acrylic spurs. Reamers were used on the lathe to drill out the bores of many of the gears. The mitre gears had their original 6mm bore expanded to 6.35mm so that they would fit onto the 0.25" horizontal and vertical shafts. The other two mitres were drilled out ot 8mm to fit onto the lead screws. All 14 of the acetal spur gears had their bores drilled out to 0.25". Six of the mitres were epoxied concentrically to six spurs. These spur-mitre gear sets as well as the rest of the spurs had their teeth faces shaved down using a dremel for tip relief during clutch shifting; this lowered the probability of the clutch gear teeth running directly into the other spur teeth and jamming the clutch. The two 1045 steel worms had their bores drilled out to 10mm. The cast acrylic spurs in gearbox 3 and 4, and in the two motorboxes were cut using the Trotec Speedy 400 Laser. Cast acrylic inserts were created to fit into the worm bores to create square bore shapes to fit onto the vertical shafts and rod with hook. These acrylic inserts were laser cut into 10mm OD and 0.25" square inner bore pieces. These were then acrylic cemented on top of each other to fit along the worm and worm gear lengths. Acrylic racks for the clutch motorbox were laser cut and couplers were used to connect the racks to the clutch shaft; acrylic cement was used to attach the coupler to the racks and friction from rubber was used to hold the coupler to the steel clutch shaft. All acrylic pieces were 0.25" thick.

Motorboxes

Motorboxes were 3D printed with polylactic acid (PLA) material. Each motorbox was printed in halves so that the surfaces were as smooth as possible with no overhangs. The halves were then epoxied together. The 28BYJ-48 stepper motor was secured onto the clutch motorbox using two 1.15" 6-32 screws and nuts. The NEMA17 motor was secured onto the drive motorbox using four M3 socket head screws. Because bearings were needed to hold the drive shaft and 3D printing does not print perfect circles, cast acrylic bearing inserts were laser cut and put into the drive motorbox on each of its sides to ensure a perfect circle for the bearings.

Rod with Hooks

The rod with hooks were made from 6061-T6 aluminum by cutting a 3' x 1" plate into to two 21.2" x 0.25" square shafts. A Bridgeport mill was then used to make the custom racks on each face of the square shaft using a CNC program and an 1/16" (0.0625") end mill to perform the following motions: move up in a vertical line perpendicular to the rod, offset to the right to complete the gap between the teeth (0.071"), and move down in a vertical line perpendicular to the rod. These motions were then repeated 105 times for each face of each square shaft.

Mounting Plates/Acrylic Bearings

Mounting plates were made for the rods with hooks in gearboxes 3 and 4, as well as the horizontal shafts in gearboxes 1 and 2. Cast acrylic bearings were laser cut with 0.55" OD and a 0.25" square bores and were held in the mounting plates for gearboxes 3 and 4 using washers and 4-40 screws and nuts so that the rods with hooks could freely rotate in the mounting plates. All were made with 0.125" cast acrylic. For gearboxes 1 and 2, the four bottom mounting plates have 0.625" bearings press fit into the middle hole. The four middle mounting plates have 0.375" oil impregnated bronze bushings press fit into the middle hole. The top four mounting plates have the 0.25" circular shaft press fit into the middle hole. All mounting plates are secured using 4-40 screws and nuts.

Wood Frame

The wood frame was manufactured using a 2' x 4' x 0.5" plywood to keep the machine level and make it easier to transport. Additionally, the side walls have a gap in order to allow the rods with hooks to travel up and down and in and out of the gearboxes. Furthermore, the roof of the frame has three 10mm holes on each side to allow each vertical rod to pass through, and blocks with 0.625" holes for press fitted bearings were added to the top each square rod to stabilize and reduce friction in their rotation.

Assembly

With all the major pre-assemblies completed, the overall shoe tying machine can be assembled. Assembly consists of the following chronological steps.

1. Gearbox frames are screwed together.
2. Idler shafts and top shafts are fitted through the slots of each side plate of gearboxes 1 and 2 with the respective mounting plates on the outsides of the frame. Three spur-mitre gear sets are put onto the top shafts while one acetal spur is placed into the idler shaft. Collars are used to secure the positioning of the gears.
3. The bottom drive shaft is driven through gearbox 1, the motorbox, and then gearbox 2. Three acetal spur gears are placed onto the shaft inside both gearbox 1 and 2. These gears are secured to the shaft using set screws. An acrylic spur gear is placed onto the shaft inside the motorbox and is secured using collars and glue. Mounting plates are also used on the outside sides of both gearbox 1 and 2.
4. Mounting plates are leveled and secured by 4-40s and nuts to the proper heights for proper gear meshing.
5. Two vertical shafts are secured onto the top plates of gearboxes 1 and 2 each. Both square shafts and the lead screw have a mitre gear fit onto it after being placed through a bearing mounted onto the top plate. The square shafts are held up by collars while the lead screw is set screwed into the lead screw bearing mount at levels where the mitres properly mesh with the spur-mitre gear sets on the top shaft.
6. Gearboxes 3 and 4 are then placed through the vertical shafts. The worm with inserts and the acrylic spur with spacers are placed through their respective square shafts inside gearboxes 3 and 4. At this point, gearboxes 3 and 4 should be held up entirely by gearboxes 1 and 2.
7. The gearboxes are then placed onto the wooden frame. The vertical square shafts are straightened and stabilized by a bearing that is mounted on the top of the wooden frame. The lead screws simply go through a hole the top of the wooden frame. Gearboxes 1 and 2 are held in place by wooden stoppers that are glued to the frame.
8. The NEMA17 motor is now screwed into the drive motorbox using M3-.05x10 screws. A cast acrylic 20 tooth spur gear with a d-bore is placed into the NEMA17's d-shaft and secured where it meshes with the other 25 tooth spur gear inside the drive motorbox. The clutch motorbox is placed right above the drive motorbox and is fastened with rubber bands onto an acrylic plate that is glued onto the drive motorbox and the wooden frame. The clutch rods are then secured onto the couplers of the clutch motorbox racks.The 28BYJ-48 stepper motor is secured into the clutch box using 6-32s and has an acrylic spur gear secured on the double d-shaft.
9. The NEMA17 and 28BYJ-48 wires are fed through and connected to the main circuit board. Limit switches are also installed on the inner side plate of gearbox 2 and the outer side plate of gearbox 1 in the area of the clutch shaft.
10. Rods with hooks are fed through gearboxes 3 and 4. The worm gears are held in place against the worms using C-shaped acrylic holders. The mounting plates are secured with 4-40 screws and nuts so that the rods with hooks are level, properly meshes with

the 33 tooth spur gear, and pushes the worm gear against the worm enough for proper meshing.

Mass Production

Mass production of the shoe tying machine is achievable because the parts can be simply manufactured and laser cut. Most of the parts were purchased and used as is, such as the shafts and gears, and if they were modified, they were all simple modifications. An assembly line can be used to laser cut and assemble each individual component along with the entire assembly.

Deliverables

The deliverables are as follows:

- *Final design report*: An engineering report discussing the mission statement and problem the STM is trying solve, detailing the needs and target specification that need to be satisfied, and describing the design, justification, and manufacturing process and how the machine satisfied the specifications.
- *Physical product*: A physical prototype of the STM that can tie a shoe successfully.
- *Technical documentation and drawings*: A complete set of drawings of all the manufactured parts along with the Bill of Materials required to build the STM.
- *Code Files*: The Arduino code used to control the STM.
- *Circuit schematic*: A circuit schematic detailing all the electrical components and connections.

Conclusion

Overall, this design can be considered a success for being able to tie a shoe while adhering to the contest parameters. Strengths of the design include its use of low power motors, its simplistic controls, and its decent chance to overcome clutch failure. A strength of the machine is its high success rate of performing the initial knot. Weaknesses include its inherent bulkiness, the clutch occasionally missing the mesh with the other gears, long run times, and relatively low success rate of performing the final knot. Some improvements to be made in the future are minimizing the jamming of the clutch mechanism, adding a damper to the base to reduce vibrations, refining the rod design to minimize the chances of the laces travelling out of the reach of the hooks as well as fine-tuning of the shoe tying algorithm and code to remove any unnecessary motions. Clutch failure plays a huge role in the success rate of the machine. Hence, getting rid of gears catching is imperative. Ways to improve the clutch system is to decrease the diameter of the mitre gears, use a spline or extruded gear for the drive shaft instead of three separate gears, and install limit switches on both sides of the gearboxes. Another issue with the design was that the lead screw nut was too smooth so the gearboxes would move downwards on the lead screw due to gravity. One way to improve the lead screw would be to use an anti-backlash lead screw nut. Vibrations were also an issue at higher speeds, therefore the addition on dampening at the base could decrease run time. If these improvements were implemented in a future version of the machine, the machine would have a much better success rate, and potentially faster cycle times as well.

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[6] *IEEE Standard for Safety Levels With Respect to Human Exposure to Electromagnetic Fields, 0-3 kHz*, IEEE Standard C95.6, 2015.

[7]I. 54:1996, "ISO 54:1996 - Cylindrical gears for general engineering and for heavy engineering -- Modules", *Iso.org*, 2018. [Online]. Available: https://www.iso.org/standard/22644.html. [Accessed: 10- Jun- 2018].

[8]"ISO 678:1976 - Straight bevel gears for general engineering and heavy engineering -- Modules and diametral pitches", *Iso.org*, 2018. [Online]. Available: https://www.iso.org/standard/4846.html. [Accessed: 10- Jun- 2018].

[9]"ASME - STANDARDS - Dimensioning and Tolerancing", *Asme.org*, 2018. [Online]. Available: https://www.asme.org/products/codes-standards/y145-2009-dimensioning-and-tolerancing. [Accessed: 10- Jun- 2018].

[10]"Guidelines For Robotics Safety | Occupational Safety and Health Administration", *Osha.gov*, 2018. [Online]. Available: https://www.osha.gov/enforcement/directives/std-01-12-002. [Accessed: 08- Jun- 2018].

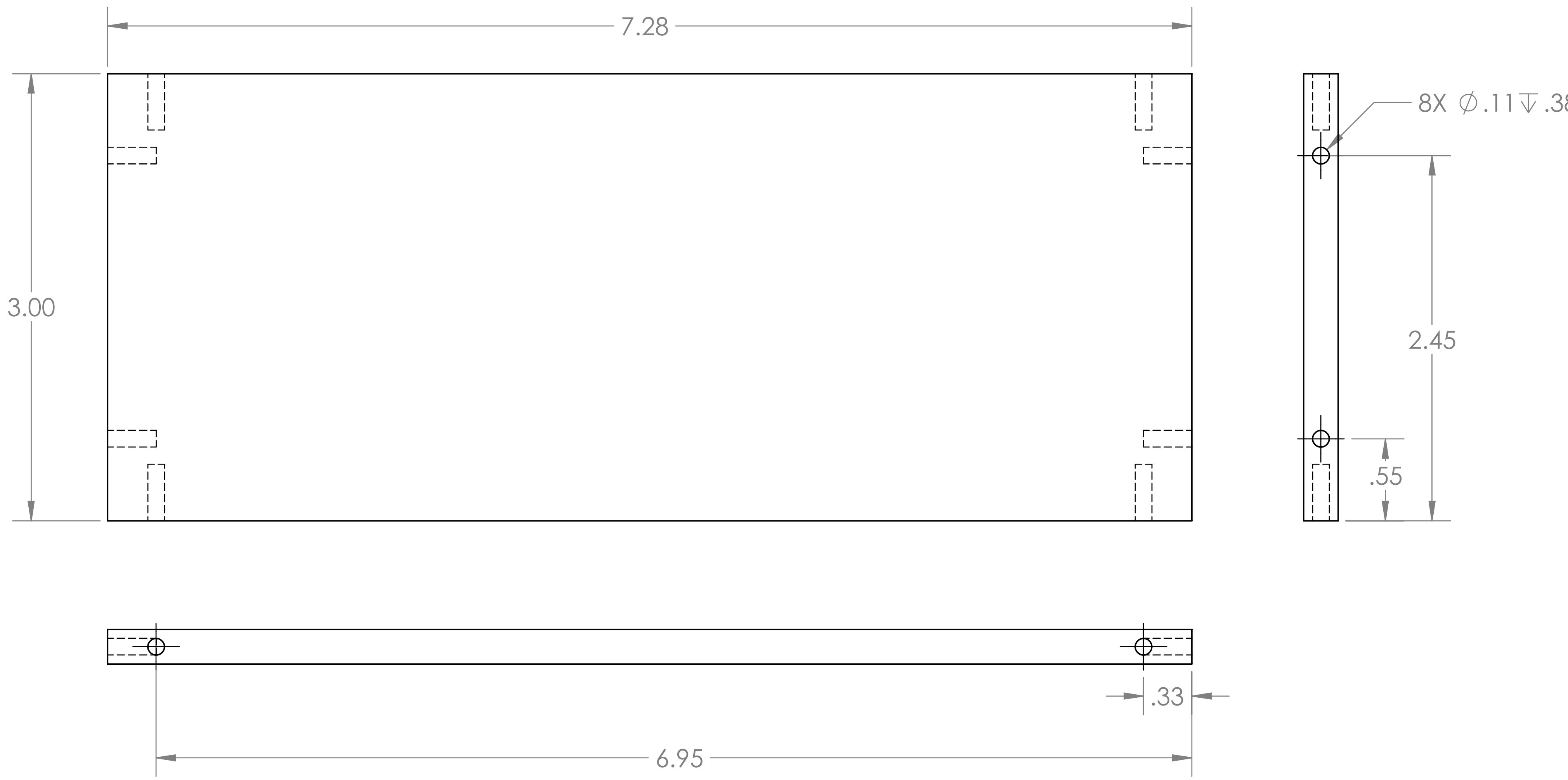
[11]"California Code of Regulations, Title 8, Section 3943. Guard Standards.", *Dir.ca.gov*, 2018. [Online]. Available: https://www.dir.ca.gov/title8/3943.html. [Accessed: 10- Jun- 2018].

Appendices

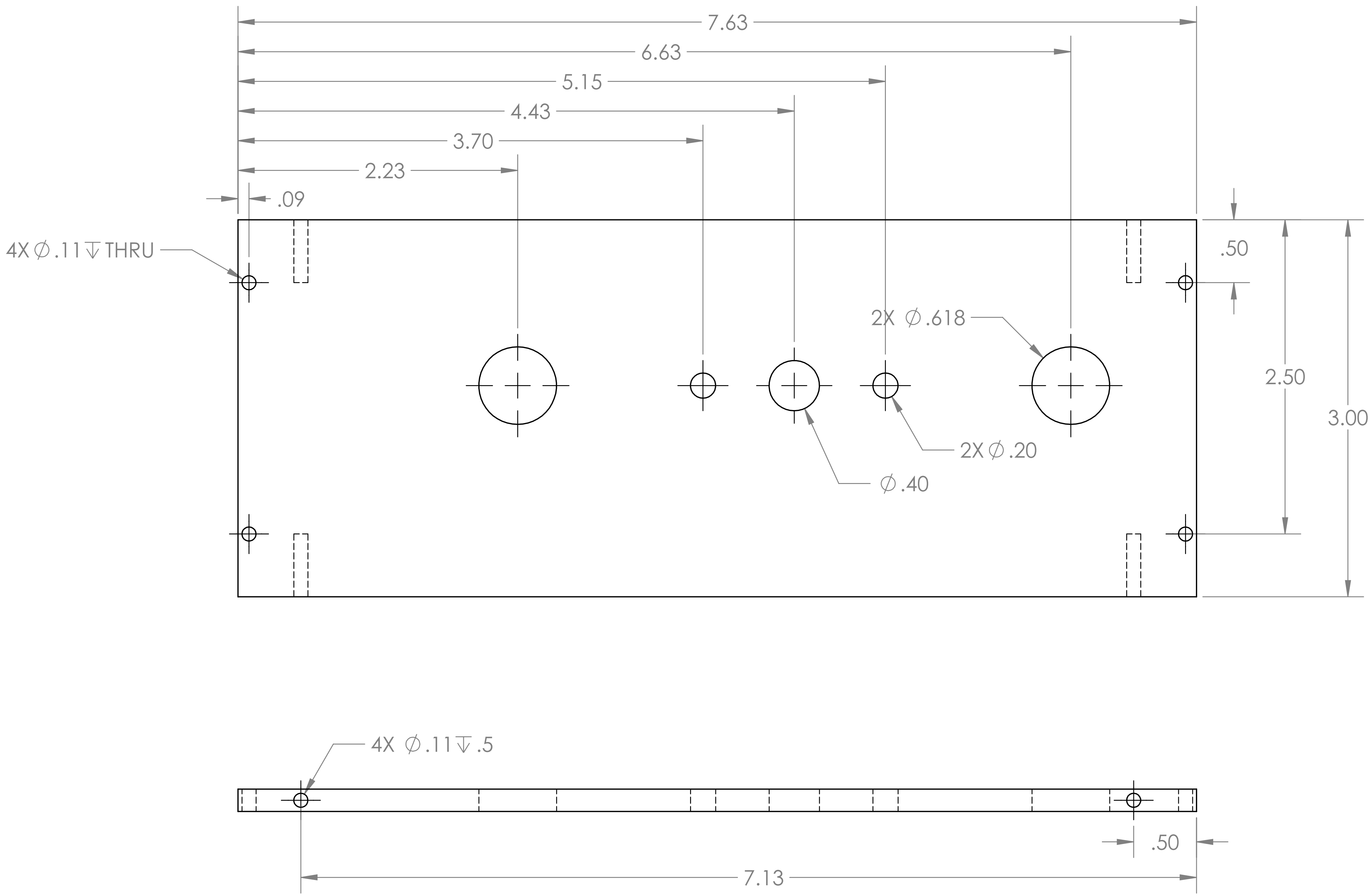
Table 1. Bill of Materials.

Team Tightens Bill of Materials							
Beginning Cash Balance							**$600.00**
Part Number	**Description**	**Manufacturer**	**Quantity**	**Unit of Measure**	**Cost Per Unit**	**Estimated Subtotal**	**Purchased**
N/A	Acrylic (8" x 8" x 3/8")	TapPlastics	10	Scrap Sheet	$1.00	$10.00	✓
N/A	Acrylic (12" x 12" x 1/8")	TapPlastics	1	Scrap Sheet	$6.50	$6.50	✓
N/A	Plywood 4' x 2' x1/2"	Home Depot	1	Sheet	$20.00	$20.00	✓
ssbscs440058-100	4-40 Screws 1/2"	Amazon	1	Pack of 100	$9.00	$9.00	✓
3SNLF004C	4-40 Nylon Hex Nuts	Amazon	1	Pack of 100	$8.00	$8.00	✓
N/A	8-36 Socket Screws	N/A	4	N/A	$0.00	$0.00	✓
N/A	8-36 Nylon Lock Nuts	N/A	4	N/A	$0.00	$0.00	✓
N/A	M3 x 0.5 x 8mm Socket Screws	Home Depot	4	N/A	$1.50	$6.00	✓
N/A	6-32 x 1.25" Socket Screws and Nuts	Home Depot	1	Pack of 6	$2.00	$2.00	✓
N/A	Wood Screws	N/A	8	N/A	$0.00	$0.00	✓
C-025	1/4" Collars	Home Depot	30	Each	$1.00	$30.00	✓
N/A	Paper Clip	N/A	2	N/A	$0.00	$0.00	✓
A 1P 2MYD08020C	30T Acetal/Brass Insert Spur Gear Module 1	QTC	14	Each	$9.00	$126.00	✓
GM-1MOD-30-H-A	Mitre Gear Set Θ/X/Y	AccuGroup	6	Set	$11.40	$68.40	✓
N/A	Worm (8mm bore) and Worm Gear (10 mm bore)	Ebay	2	Set	$25.00	$50.00	✓
50176H	JB Weld Kwikweld	Home Depot	1	Each	$8.00	$8.00	✓

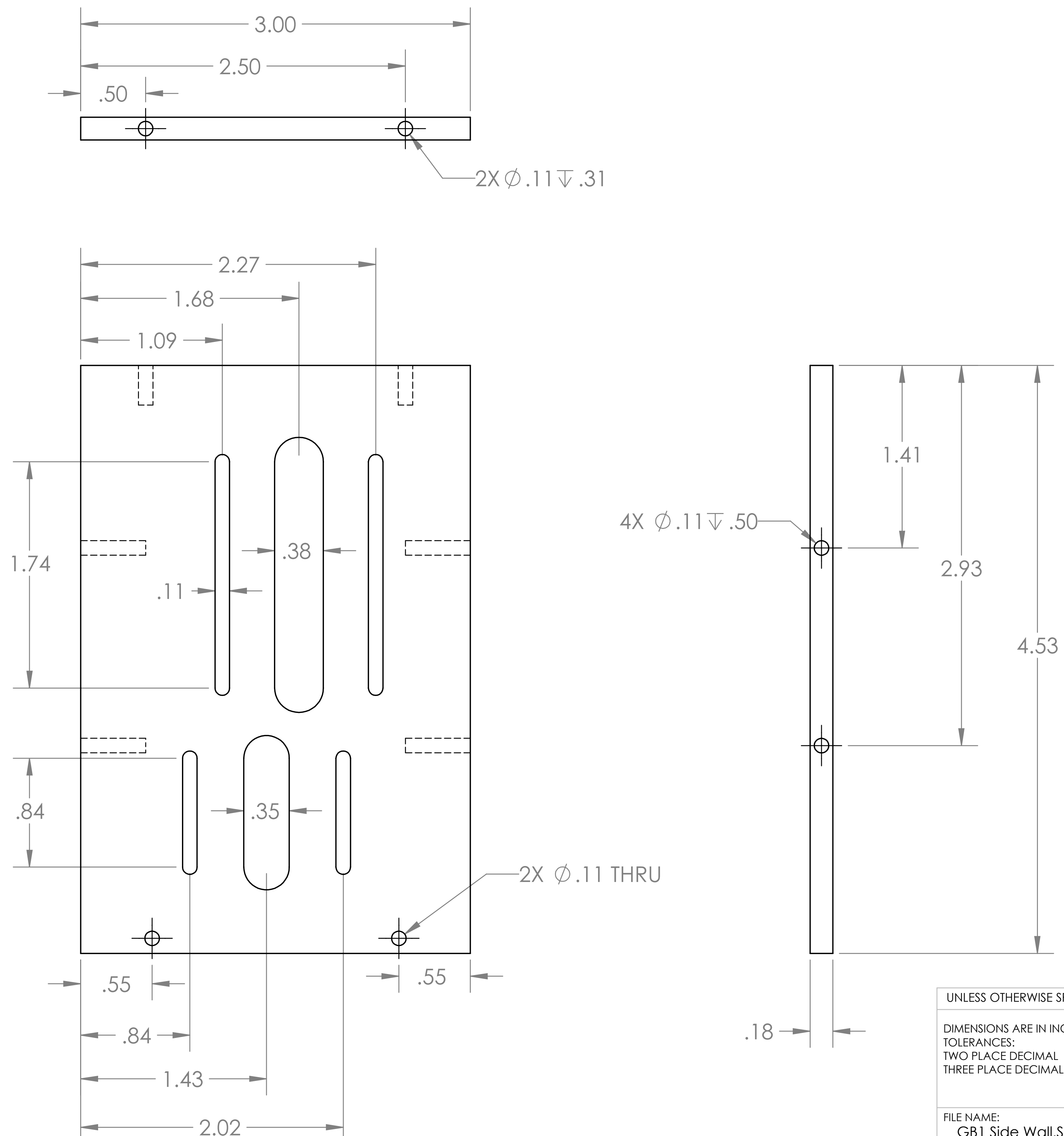
93410A912	500mm 8mm T8 Lead Screw Set Lead Screw+ Pillow Bearing Block + Copper	Amazon	2	Each	$17.00	$34.00	✓
801197	1/4" x 3' Cold Rolled Steel Square Bar	Home Depot	2	Each	$5.00	$10.00	✓
802427	1/4" x 3' Cold Rolled Steel Round Bar	Home Depot	2	Each	$3.50	$7.00	✓
801587	1/4" x 4' Cold Rolled Steel Round Bar	Home Depot	1	Each	$5.00	$5.00	✓
#99R4-2RS-X10	1/4" x 5/8" x 10/51" Bearings	Amazon	2	Pack of 10	$12.00	$24.00	✓
2907483	1/4" x 1" x 3' 6061 Aluminum Bar	Orchard	1	Each	$20.00	$20.00	✓
a17042700ux1270	NEMA 17	Amazon	1	Each	$18.00	$18.00	✓
1145-1072-ND	Transformer	Aggie Reuse Store	1	Each	$0.00	$0.00	✓
B00PUTH3B0	Motor Shield	Amazon	1	Each	$23.00	$23.00	✓
71008	Power Switch	Amazon	1	Each	$5.00	$5.00	✓
RGBZONE	Jumper Cables	Amazon	1	Pack	$7.00	$7.00	✓
N/A	Arduino Uno	Walmart	1	Each	$12.00	$12.00	✓
Q112-ND	Plug	Aggie Reuse Store	1	Each	$5.00	$5.00	✓
B06XRN7NFQ	Step Down Voltage Regulator	Amazon	1	Pack of 2	$7.00	$7.00	✓
43237-2	Limit Switch	Amazon	1	Pack of 2	$7.00	$7.00	✓
N/A	Atomic 3D Printer Filament	Atomic	1	Spool	$35.00	$35.00	✓
Estimate Total:						$580.90	
Ending Cash Balance						**$19.10**	



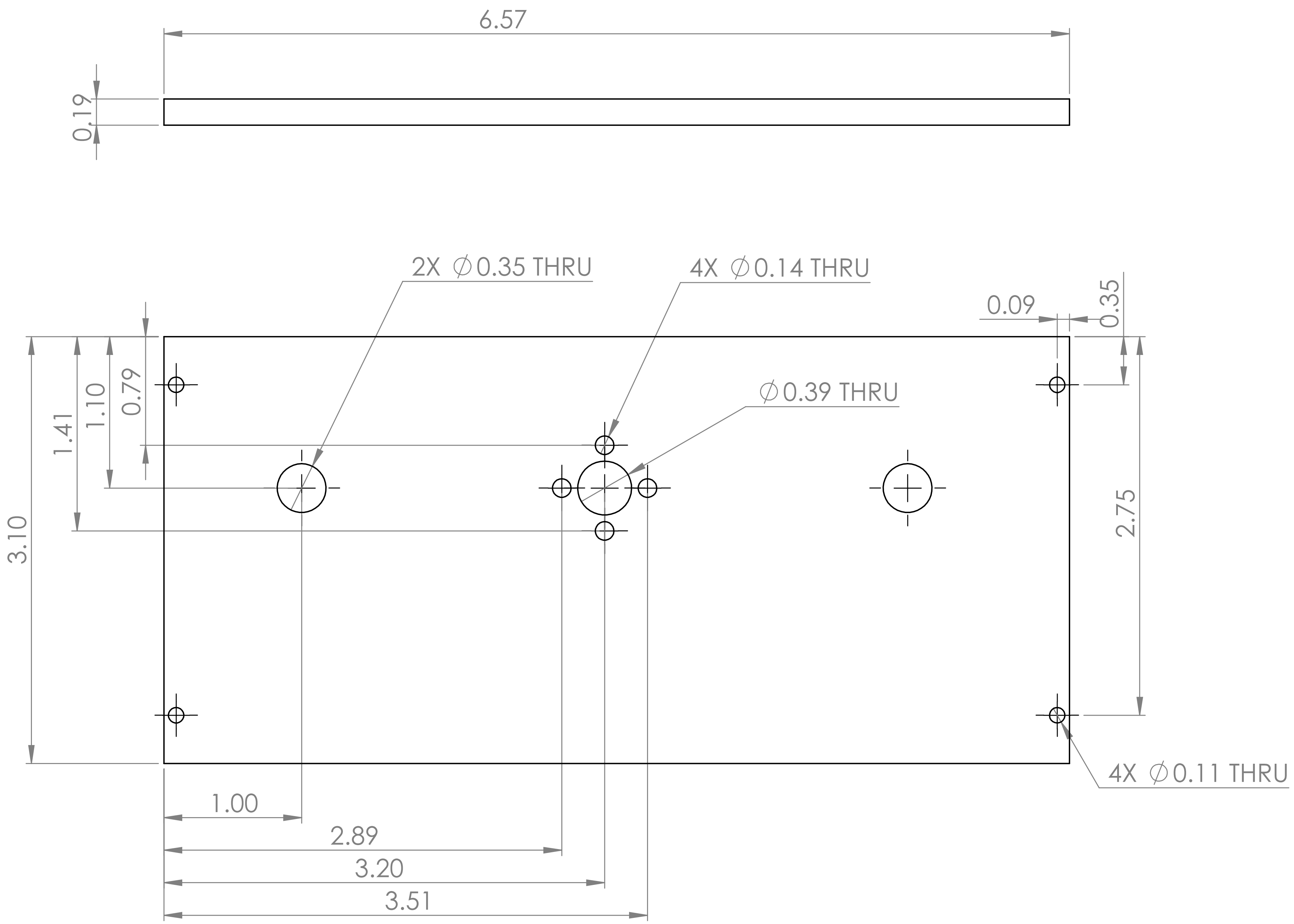
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: GB 1&2 BOTTOM PLATE	
FILE NAME: GB1 Bottom Plate.SLDPRT	TEAM NAME: TEAM TIGHTENS	
MATERIAL EXTRUDED ACRYLIC	SIZE **B**	PART NO: A01 — QUANTITY: 2
DATE DRAWN: 5/2/2018	SCALE: 1:2	SHEET 1 OF 25



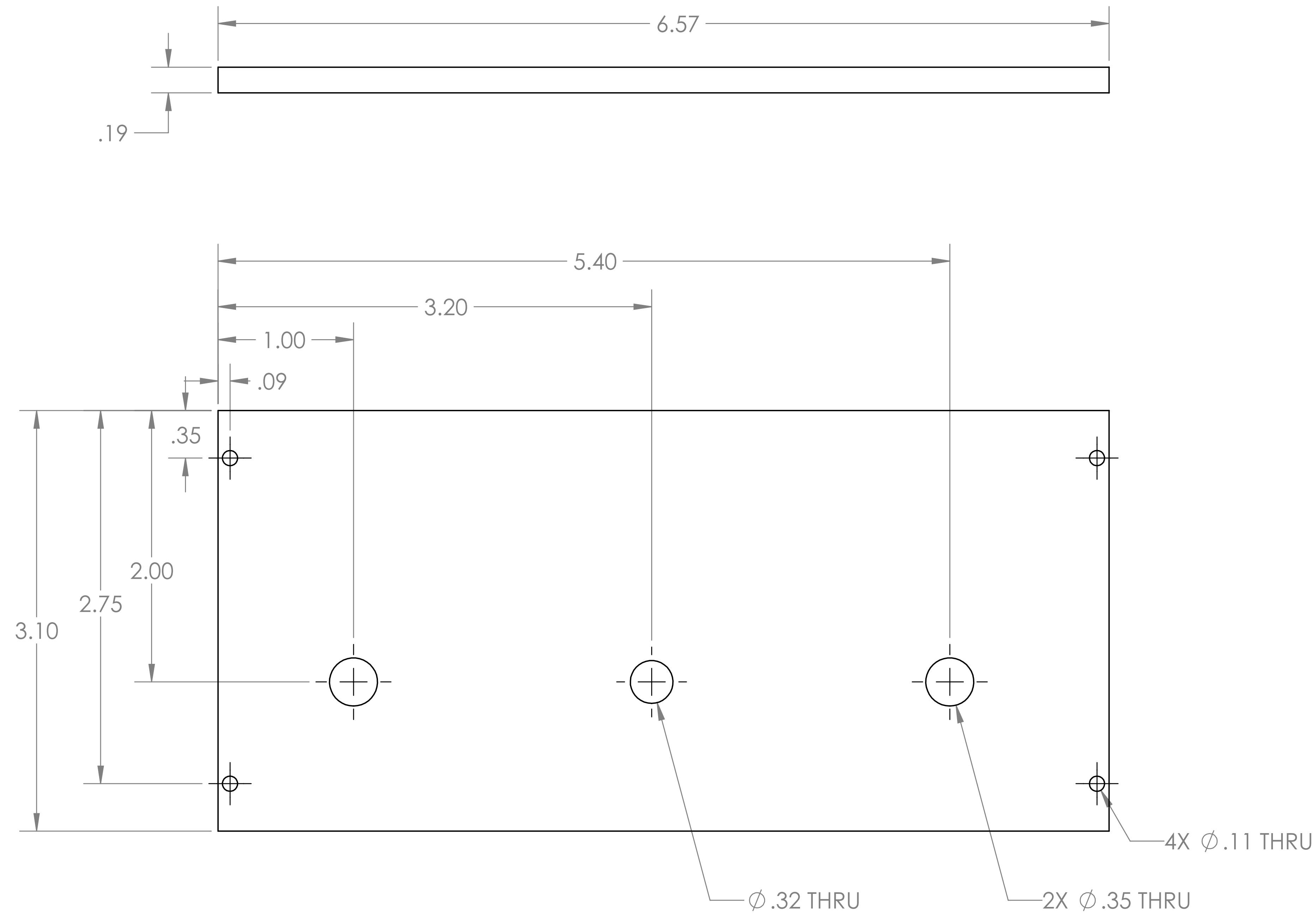
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: GB 1&2 TOP PLATE		
FILE NAME: GB1 Top Plate.SDWPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL: CAST ACRYLIC	SIZE: B	PART NO: A02	QUANTITY: 2
DATE DRAWN: 5/2/2018	SCALE 1: 1		SHEET 2 OF 25



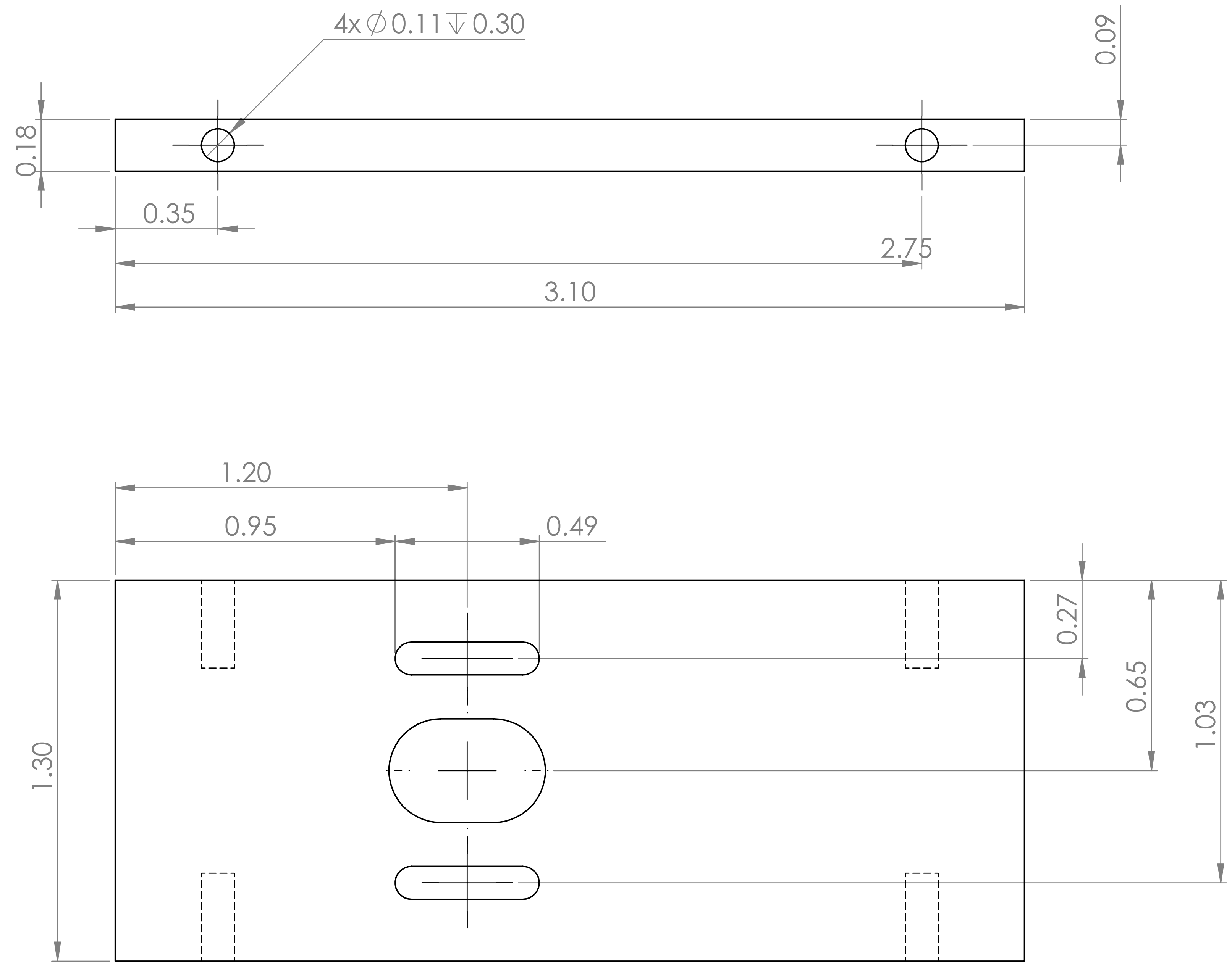
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: GB1 & 2 SIDE PLATES		
FILE NAME: GB1 Side Wall.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE **B**	PART NO: A03	QUANTITY: 4
DATE DRAWN: 6/5/2018	SCALE: 1:1	SHEET 3 OF 25	



UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: GB 3&4 BOTTOM PLATE		
FILE NAME: GB3 Bottom Plate.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE B	PART NO: A04	QUANTITY: 2
DATE DRAWN: 5/2/2018	SCALE: 1:2	SHEET 4 OF 25	

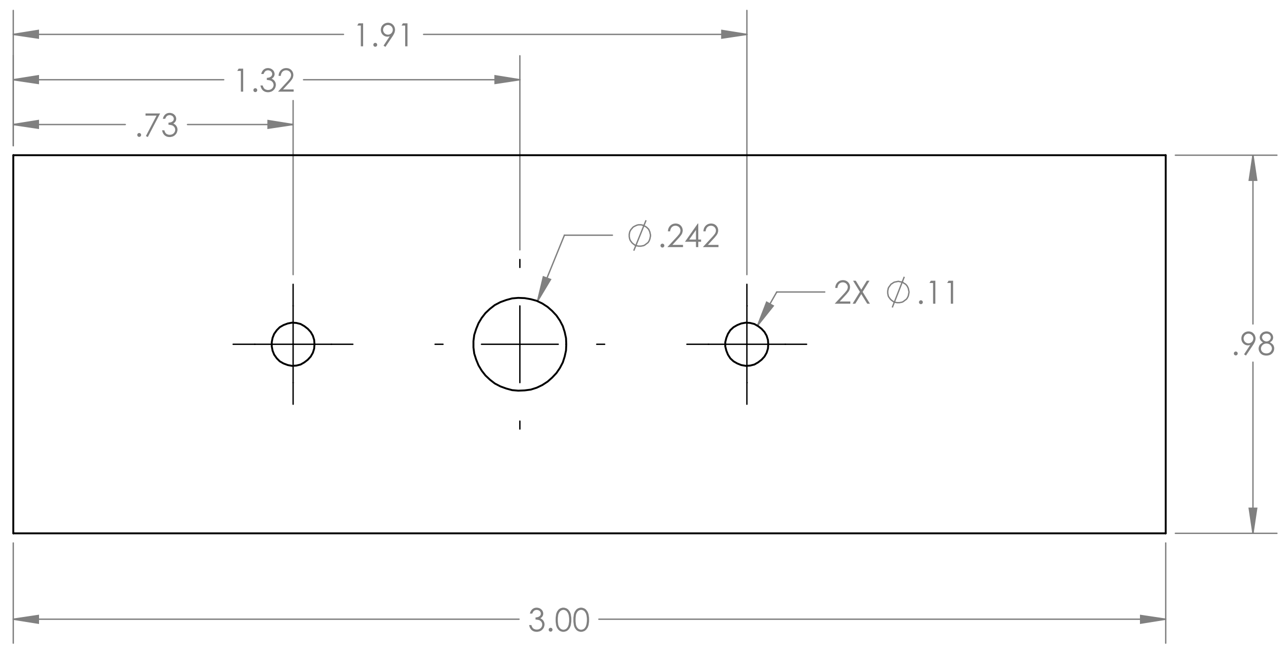


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: GB 3 & 4 TOP PLATE		
FILE NAME: GB3 Top Plate.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE **B**	PART NO: A05	QUANTITY: 2
DATE DRAWN: 6/6/2018	SCALE: 1:1	SHEET 5 OF 25	



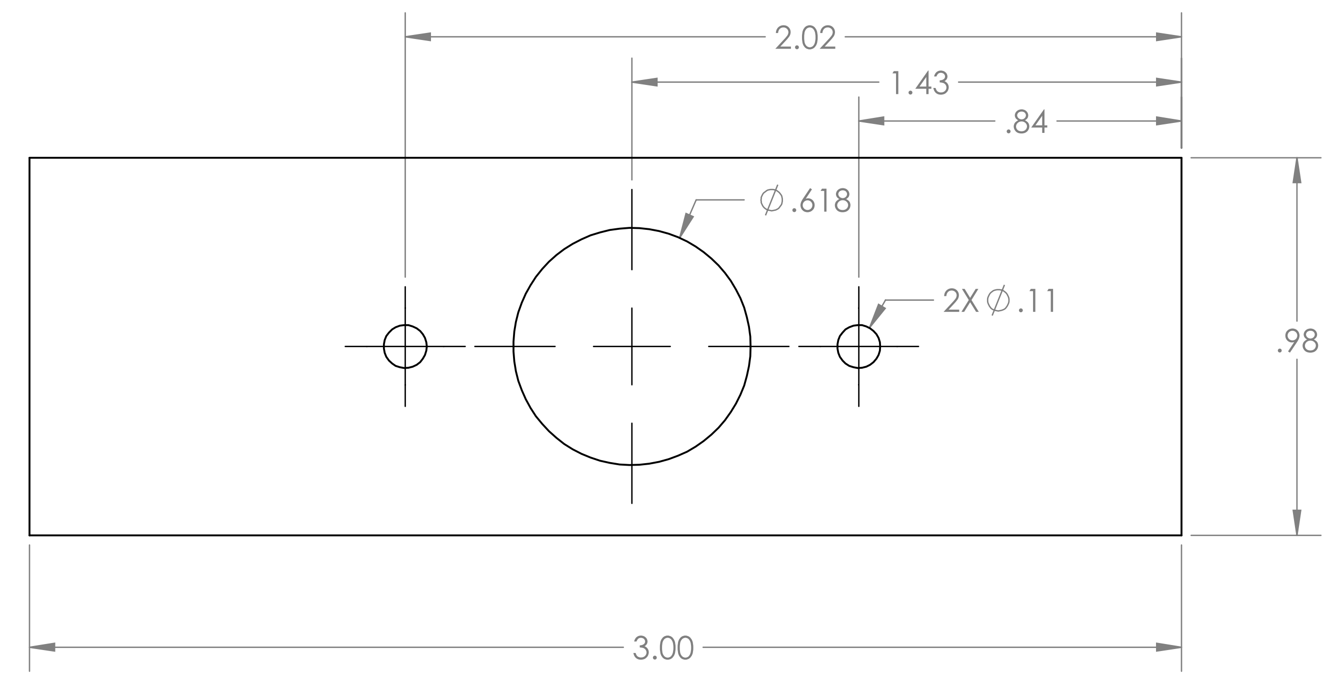
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: GB 3 & 4 SIDE PLATE		
FILE NAME: GB3 Side Plate.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE **B**	PART NO: A06	QUANTITY: 4
DATE DRAWN: 6/6/2018	SCALE: 2:1	SHEET 6 OF 25	

TOP

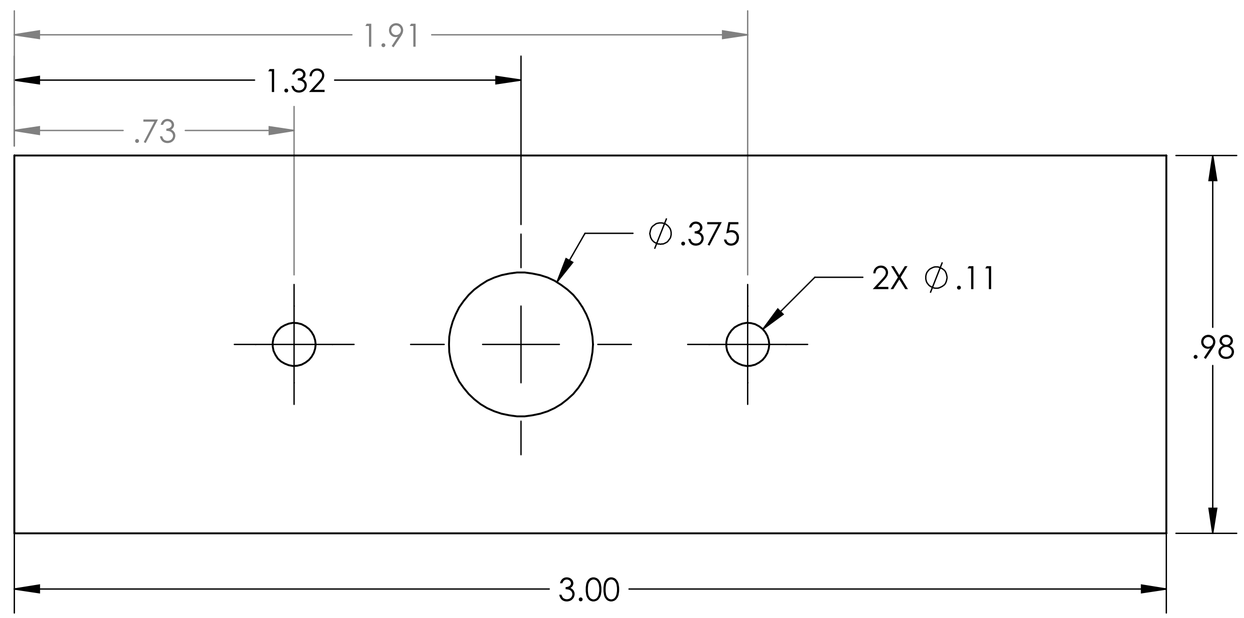


NOTE: NOMINAL THICKNESS FOR ALL MOUNTING PLATES: 1/8"

BOTTOM



MIDDLE

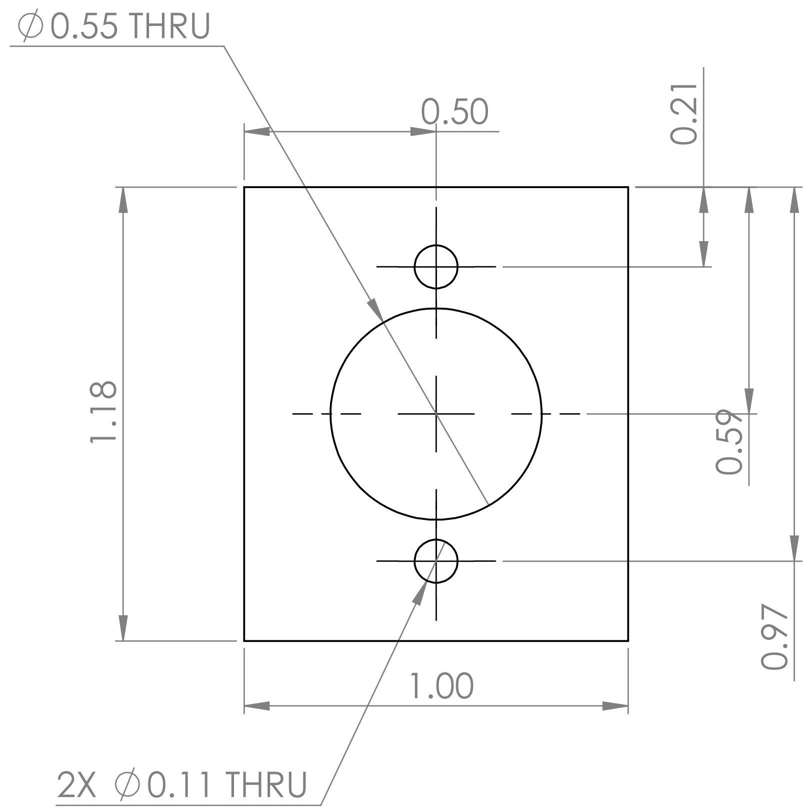


UNLESS OTHERWISE SPECIFIED:	TITLE: TOP MIDDLE AND BOTTOM MOUNTING PLATES		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005			
FILE NAMES: mounting wall (top).SLDPRT mounting wall (middle).SLDPRT mounting wall (bottom).SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE **B**	PART NO: A07-A08 A09	QUANTITY: 4
DATE DRAWN: 5/2/2018	SCALE: 2:1		SHEET 7 OF 25

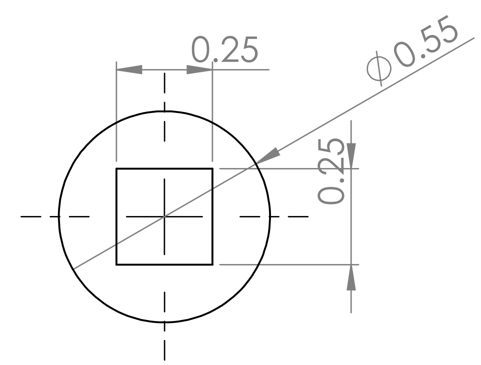
4 3 2 1

B

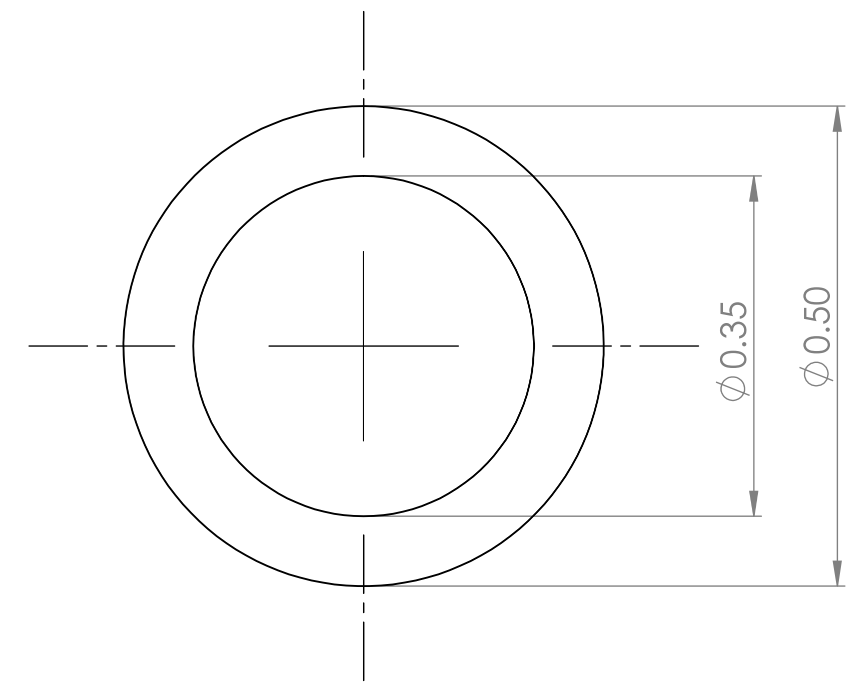
MOUNTING PLATE - 1/8' THICK - QT: 4



ACRYLIC BEARING - 1/8" THICK - QT: 4



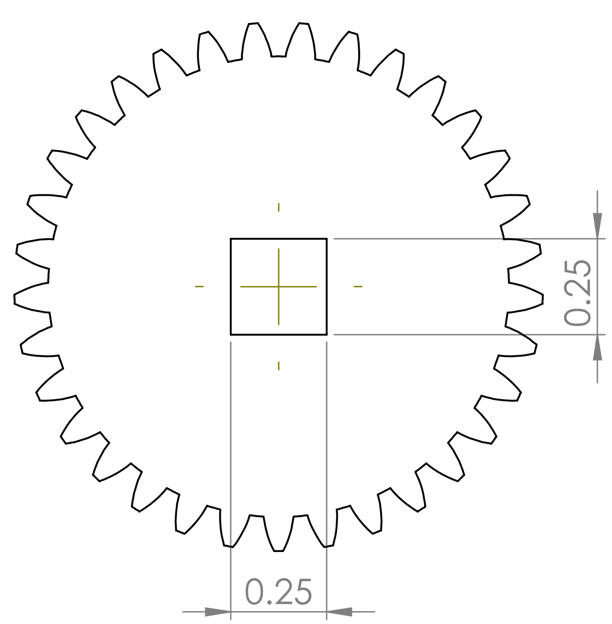
SHAFT 1 SPACER - 1/2" THICK - QT: 2



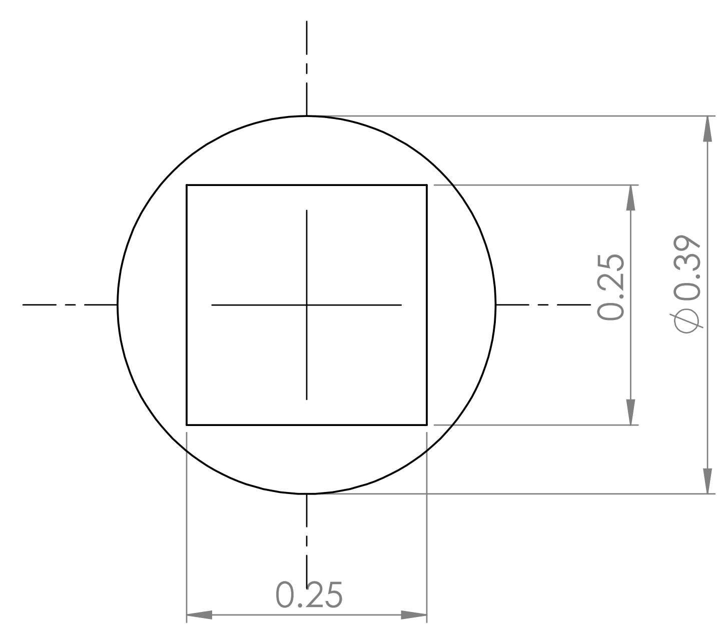
B

A

33T MOD 1 SPUR GEAR - 1/4" THICK - QT: 2



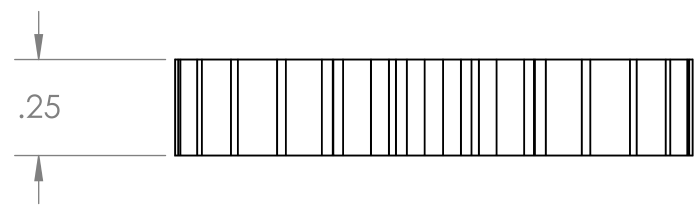
WORM AND WORM WHEEL INSERTS - 1/4" THICK - QT: 16



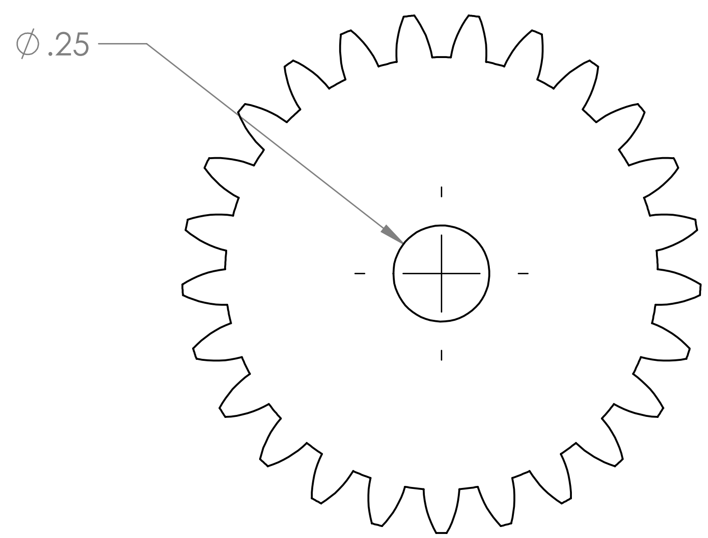
A

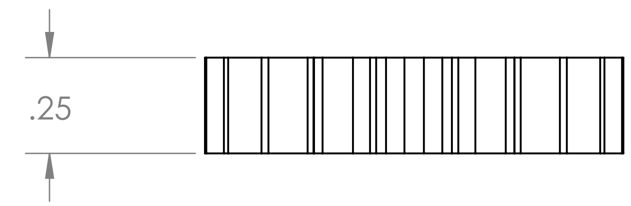
UNLESS OTHERWISE SPECIFIED:	TITLE: GB3 ASSORTED ACRYLIC PARTS		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005			
FILE NAME: Mounting Plate.SLDPRT Worm Gear Insert.SLDPRT Acrylic Bearing.SLDPRT Spacer Bottom.SLDPRT Spur Gear MOD1-33T.SLDPRT	TEAM NAME: TEAM TIGHTENS		
	SIZE **B**	PART NO: A10 - A11 - A12 A13 - A14	QUANTITY: SEE NOTES
MATERIAL CAST ACRYLIC			
DATE DRAWN: 6/6/2018	SCALE: 2:1		SHEET 8 OF 25

4 3 2 1

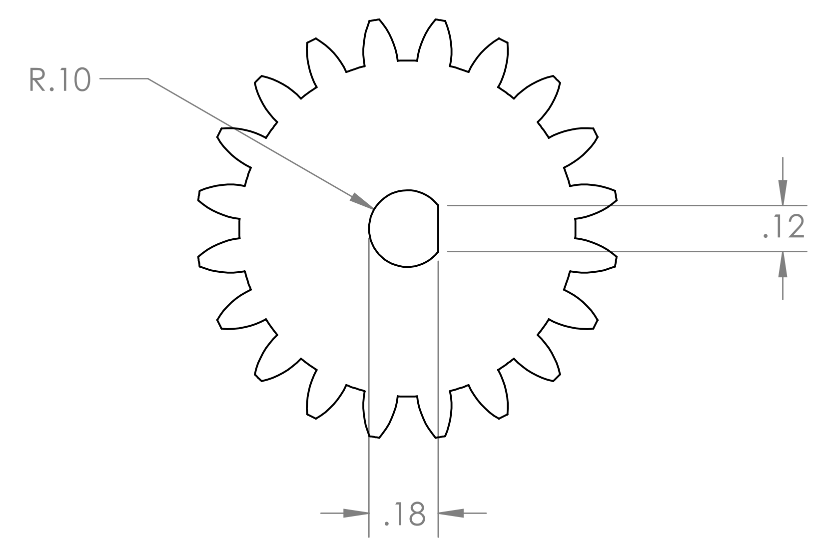


NEMA 17 GEAR
TEETH: 25
DIAMETRAL PITCH: 20
TEETH/IN.



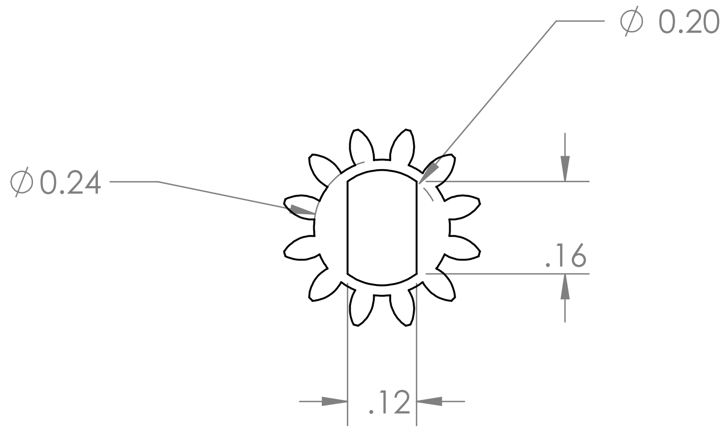


NEMA 17 PINION
TEETH: 20
DIAMETRAL PITCH: 20 TEETH/IN.

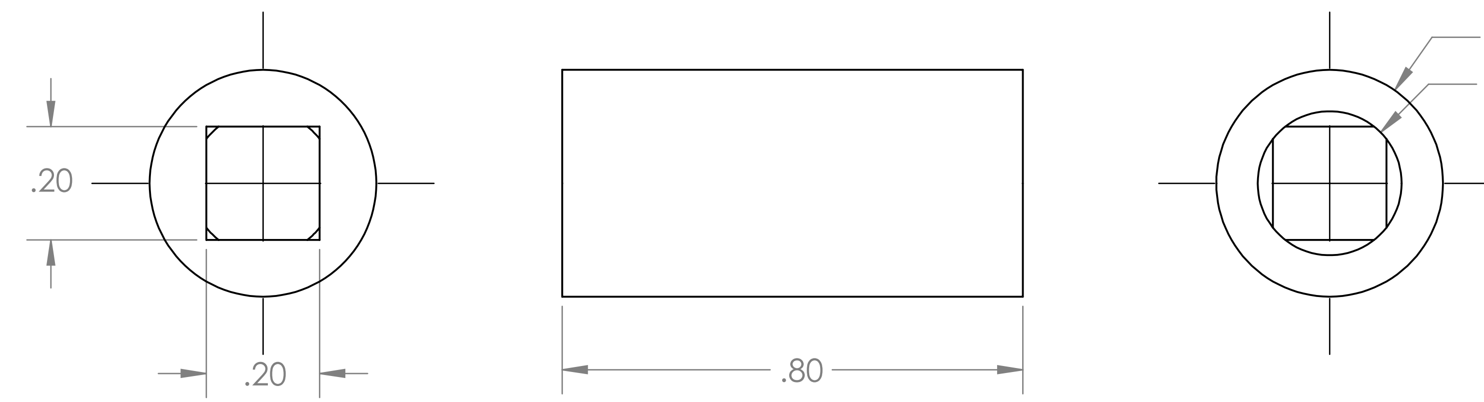


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: NEMA17 GEAR AND PINION		
FILE NAME: 25T Gear.SLDPRT 20T Gear.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE **B**	PART NO: A15-A16	QUANTITY: 1 each
DATE DRAWN: 6/2/2018	SCALE: 2:1		SHEET 9 OF 25

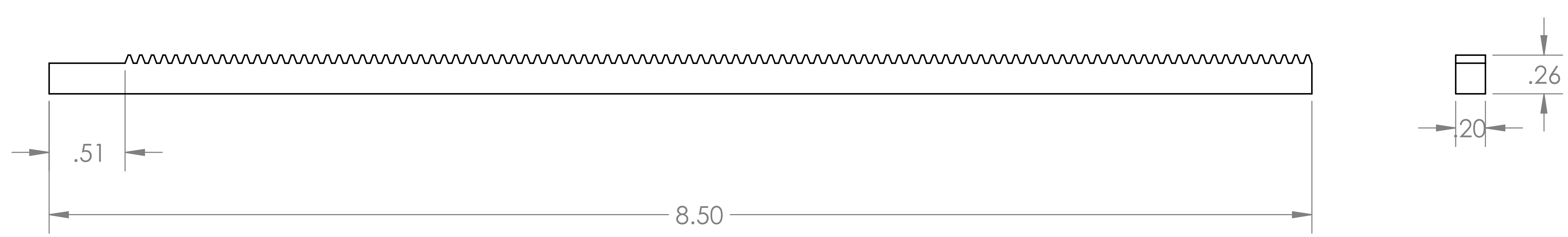
28BYJ-48 PINION - QT: 1
TEETH: 12
DIAMETRAL PITCH: 40 TEETH/IN.



CLUTCH COUPLER - QT: 2

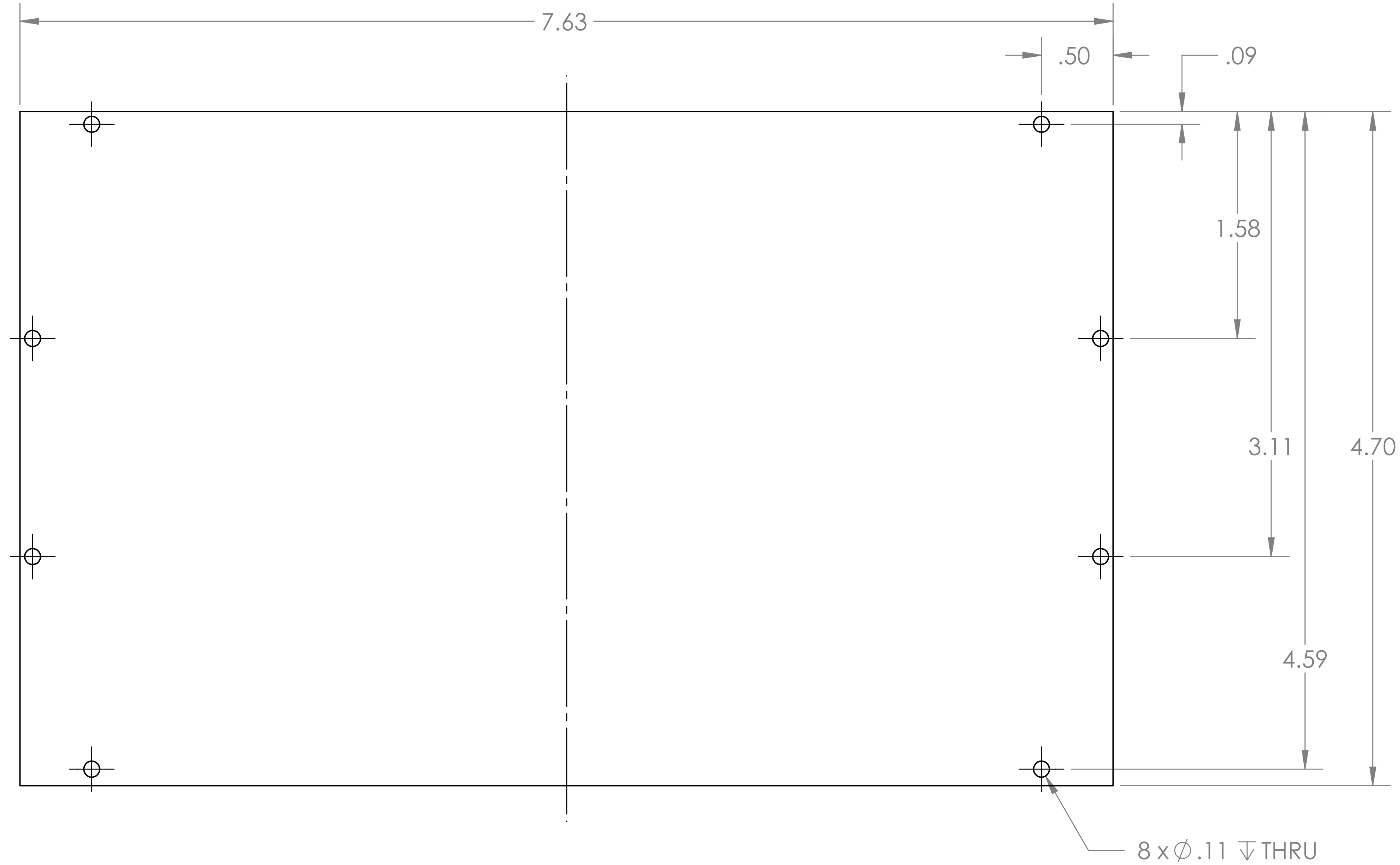


28BYJ-48 RACK - QT: 2
DIAMETRAL PITCH: 40 TEETH/IN



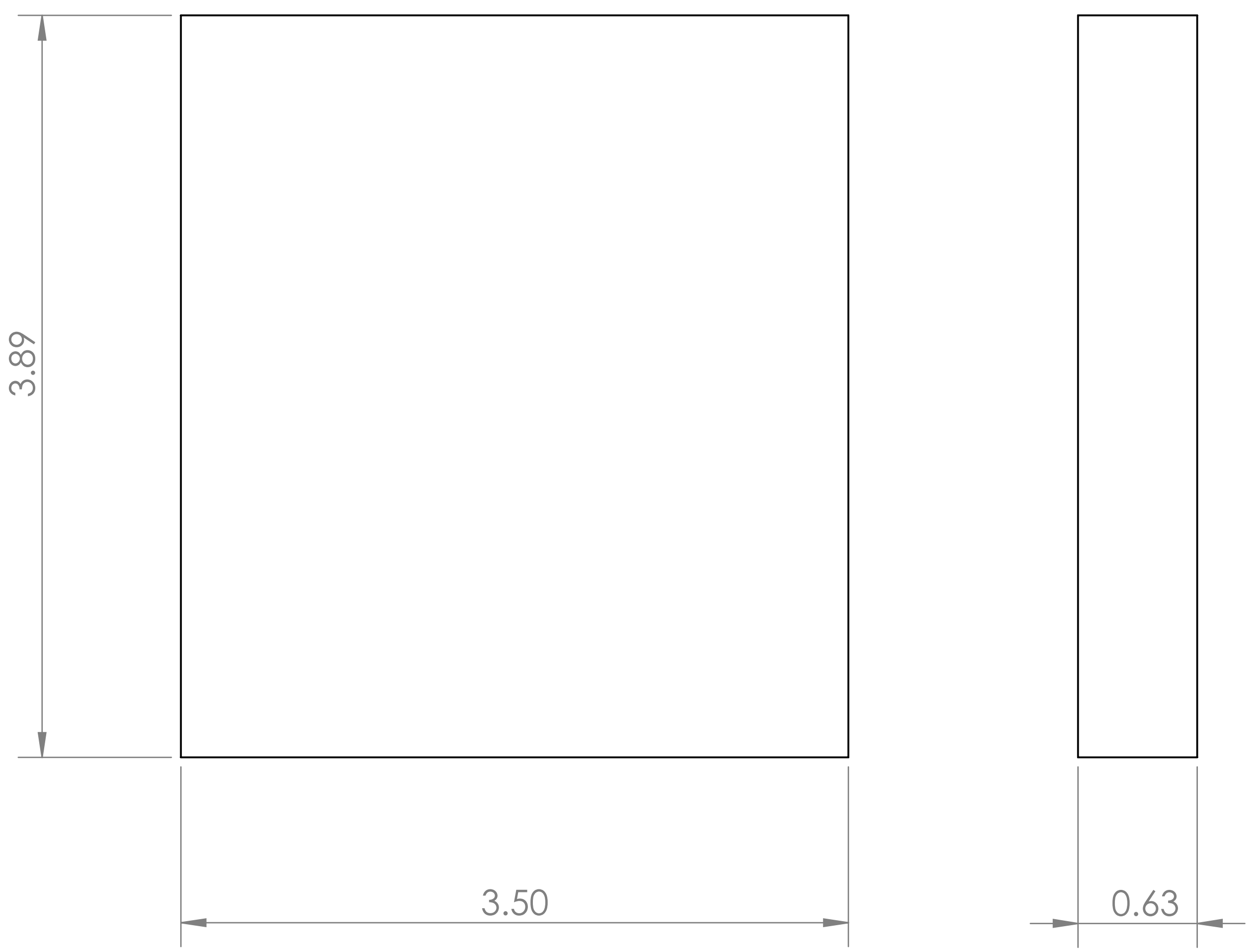
UNLESS OTHERWISE SPECIFIED:	TITLE: 28BYJ - 48 RACK AND PINION CLUTCH COUPLER		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005			
FILE NAME: 28BYJ-48 Pinion.SLDPRT Idler Rack.SLDPRT clutch coupler.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE B	PART NO: A17 - A18 A22	QUANTITY: SEE NOTE
DATE DRAWN: 5/2/2018	SCALE: 3:1		SHEET 10 OF 25

NOTE 1: 1/8" NOMINAL THICKNESS
NOTE 2: OPTIONAL PART

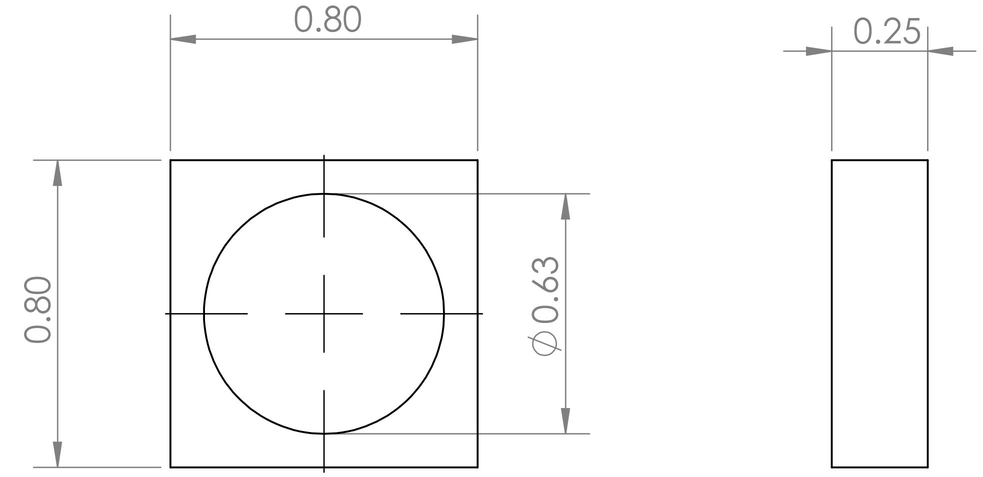


UNLESS OTHERWISE SPECIFIED:	TITLE: GB 1 & 2 FRONT AND BACK PLATES		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005			
FILE NAME: GB1 Front_Back Wall.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL: CAST ACRYLIC	SIZE: **B**	PART NO: A18	QUANTITY: 4
DATE DRAWN: 5/2/2018	SCALE: 1:4	SHEET 11 OF 25	

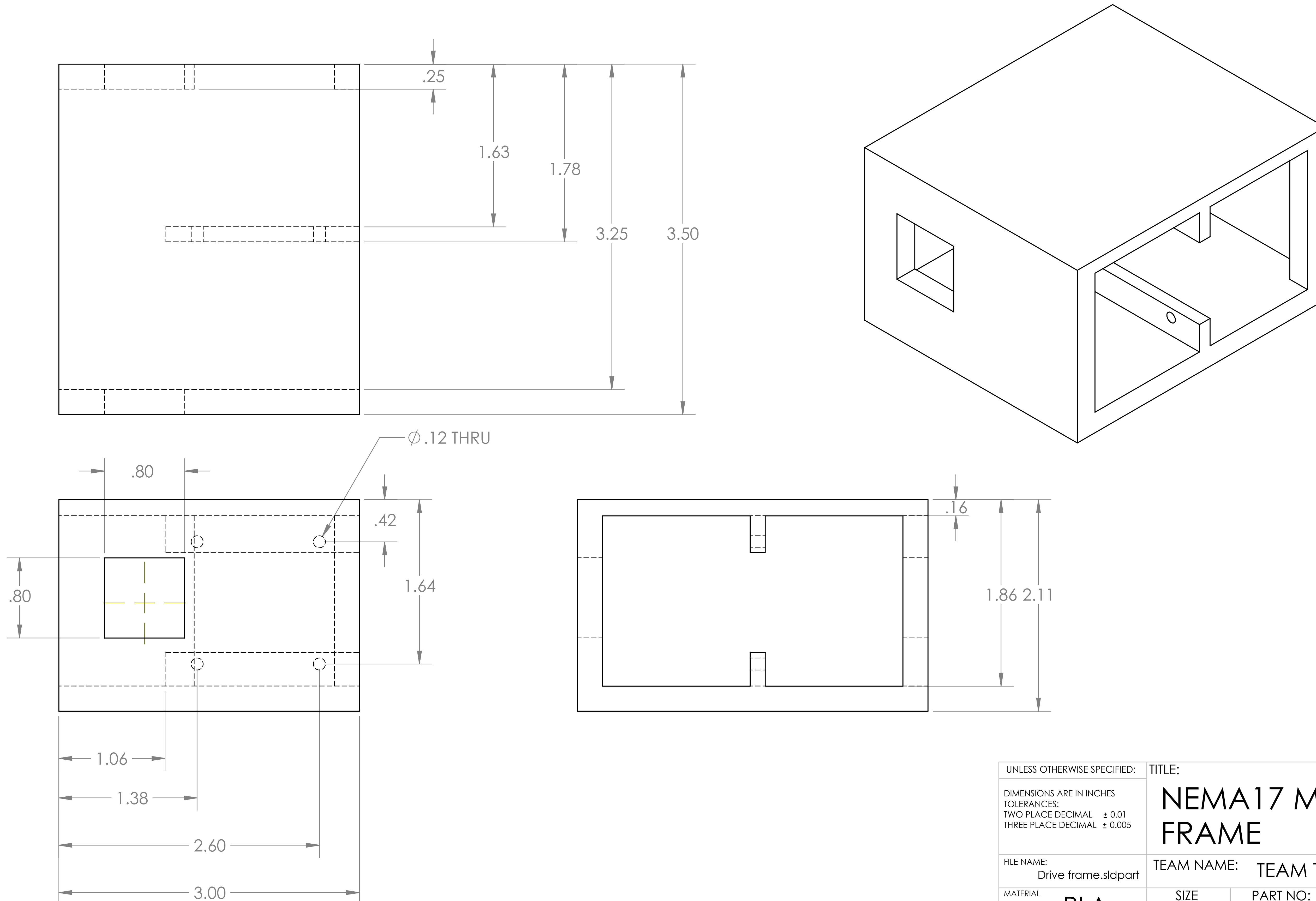
MOTOR BOX BACK SUPPORT - QT: 1



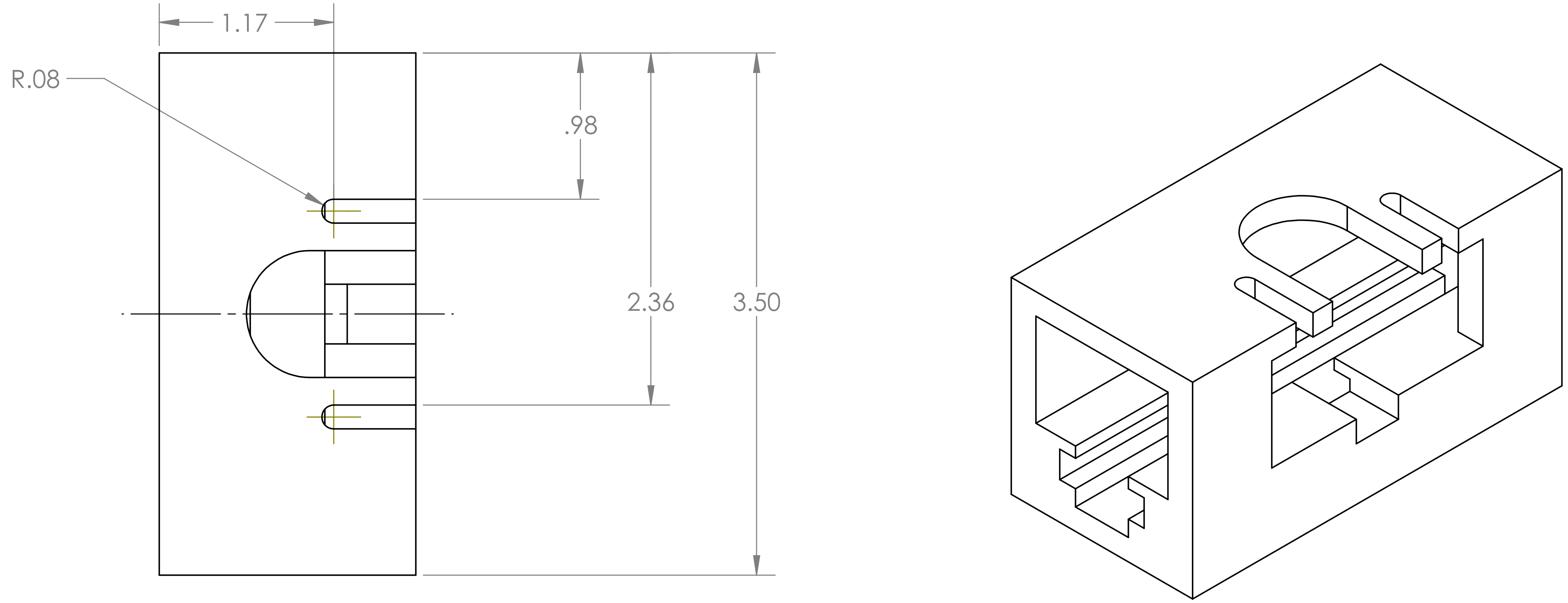
MOTOR BOX BEARING WINDOW - QT: 2

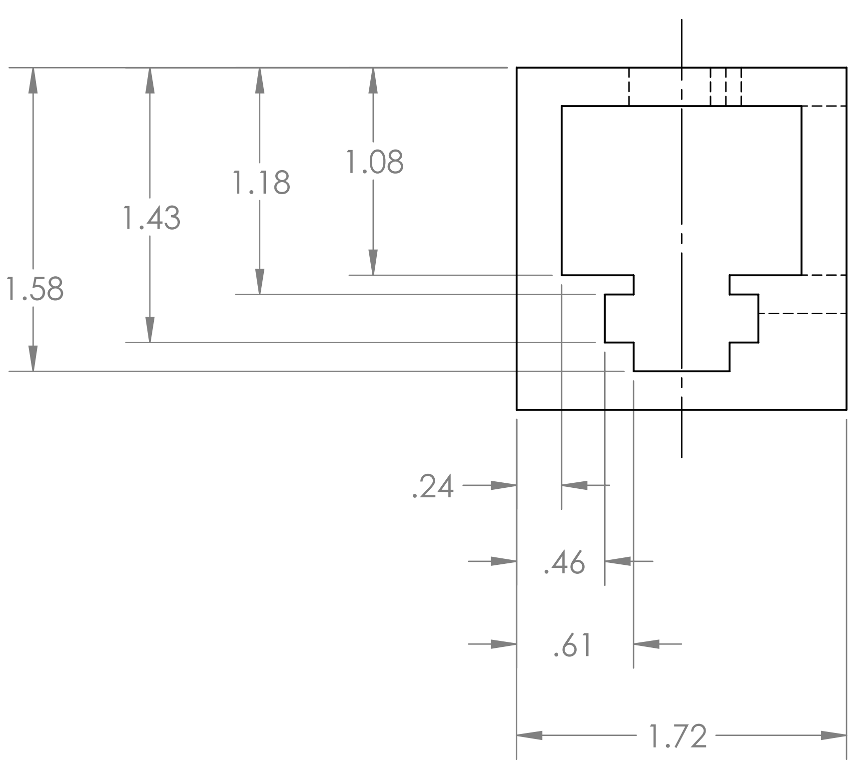


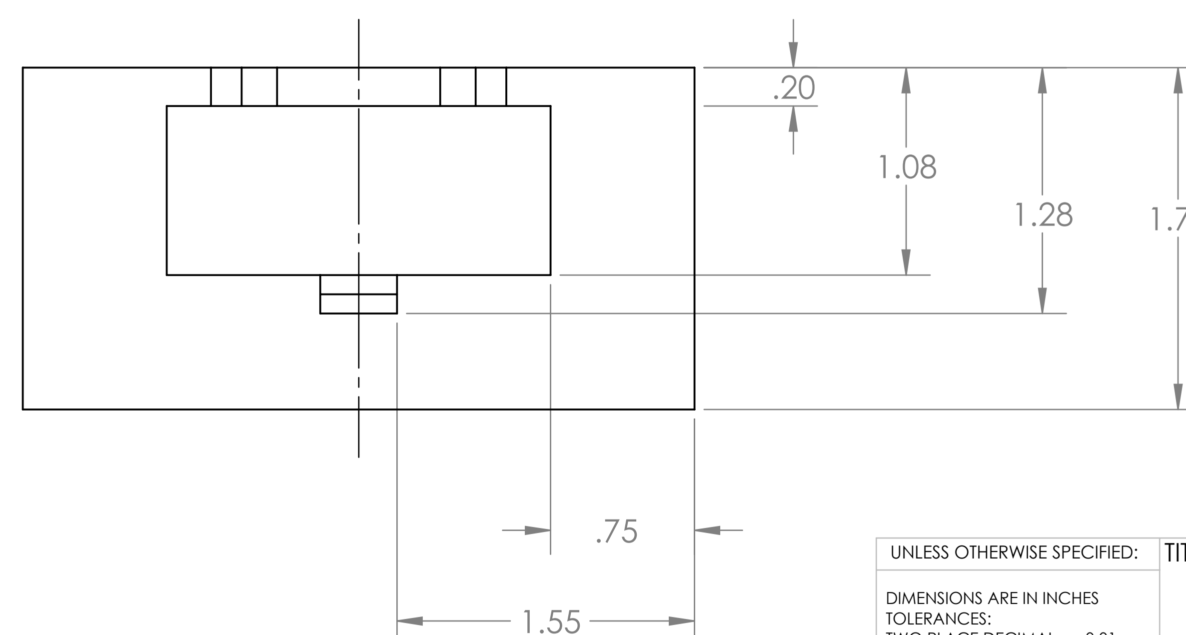
UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: MOTOR BOX BACK SUPPORT MOTOR BOX BEARING WINDOW		
FILE NAME: Motor Box Back Support.SLDPRT Motor Box Bearing Window.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL CAST ACRYLIC	SIZE B	PART NO: A-20 A-21	QUANTITY: See Notes
DATE DRAWN: 6/8/2018	SCALE: 1:1	SHEET 12 OF 25	



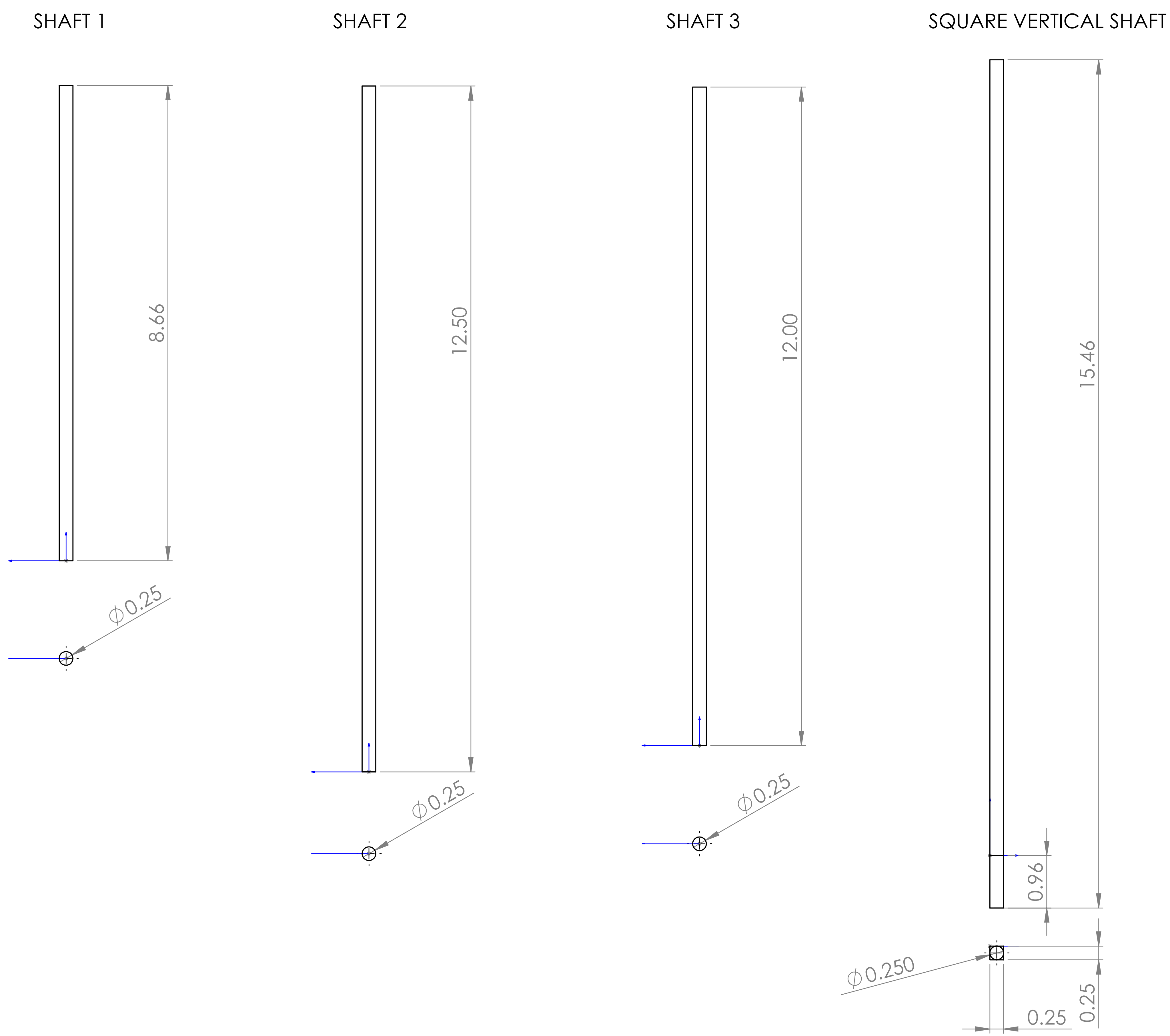
UNLESS OTHERWISE SPECIFIED:	TITLE: NEMA17 MOTOR FRAME		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ± 0.005			
FILE NAME: Drive frame.sldpart	TEAM NAME: TEAM TIGHTENS		
MATERIAL: PLA	SIZE: **B**	PART NO: P01	QUANTITY: 1
DATE DRAWN: 5/2/2018	SCALE: 1:1	SHEET 13 OF 25	







UNLESS OTHERWISE SPECIFIED:	TITLE: SMALL STEPPER FRAME		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005			
FILE NAME: 28BYJ-48 Motor Frame.SLDPRT idler frame.sldpart	TEAM NAME: TEAM TIGHTENS		
MATERIAL POLYLACTIC PLASTIC (PLA) PLA	SIZE **B**	PART NO: P02	QUANTITY: 1
DATE DRAWN: 5/2/2018	SCALE: 1:1		SHEET 14 OF 25



NOTE: ALL SHAFTS SANDED TO SMOOTH FINISH

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

FILE NAME: Bevel Shaft.sldprt
Clutch Shaft.sldprt
Drive Shaft.sldprt
Vertical Square Shaft.sldprt

MATERIAL
COLD ROLLED STEEL

DATE DRAWN:
5/2/2018

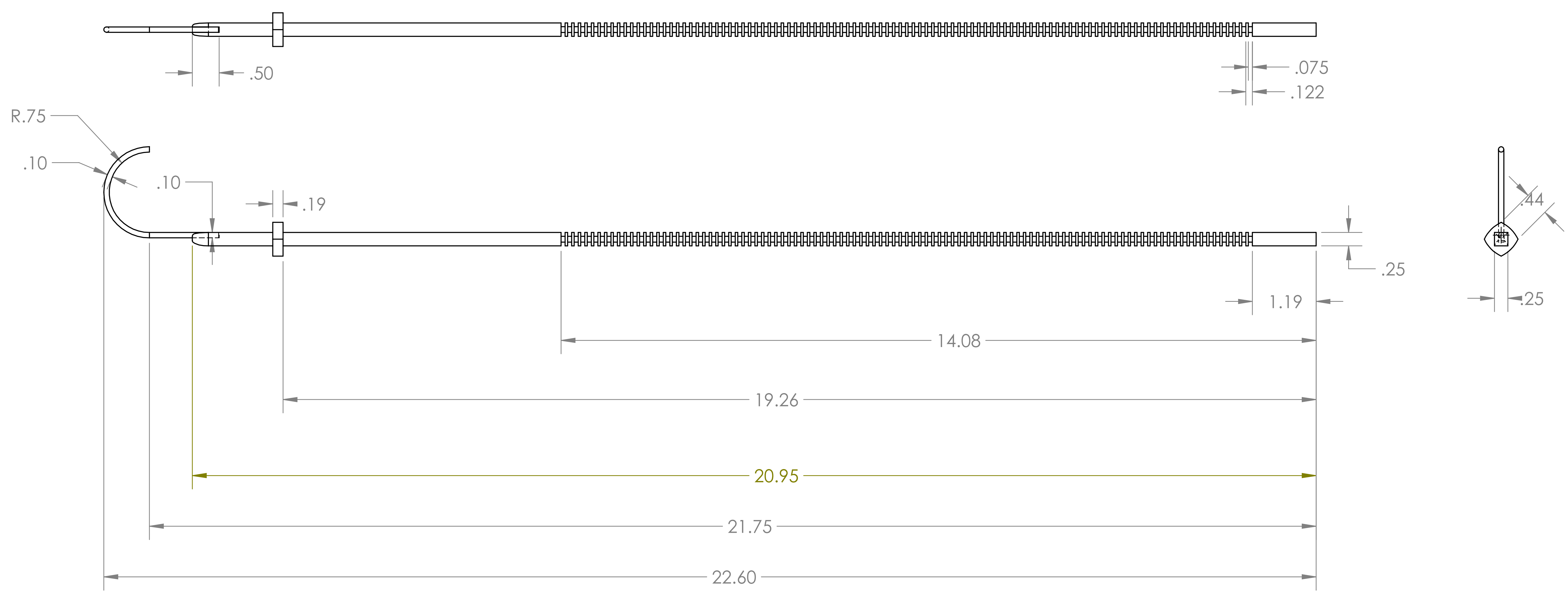
TITLE:
SQUARE VERTICAL SHAFT
SHAFT 1
SHAFT 2
SHAFT 3

TEAM NAME: TEAM TIGHTENS

SIZE	PART NO:	QUANTITY:
B	M01 - M02 M03 - M04	1

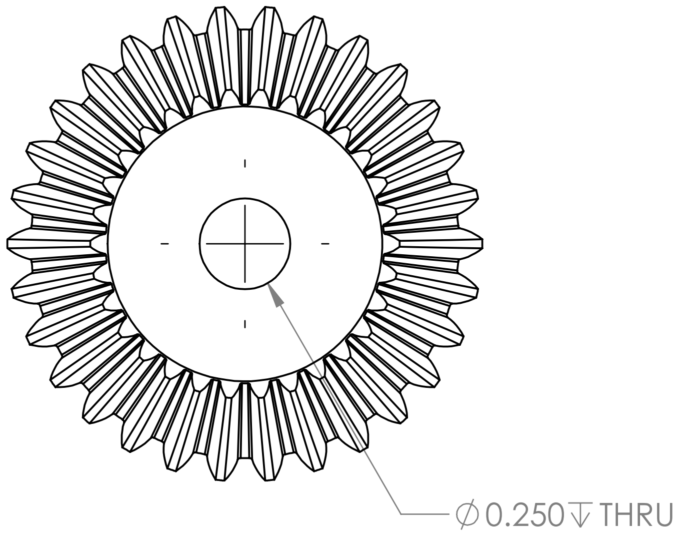
SCALE: 1:2 SHEET 15 OF 25

NOTE 1: Rack made to mesh with MOD 1 Gear
NOTE 2: Rack section contains 106 grooves
NOTE 3: Hook fashioned from a paper clip and attached using metal reinforced epoxy

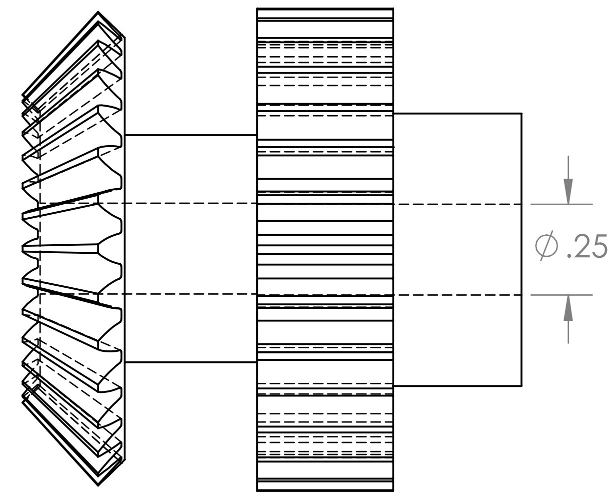


UNLESS OTHERWISE SPECIFIED:	TITLE:		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	Rod With Hook		
FILE NAME: rod w. hook mod1(v3).SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL 6061-T6 ALUMINUM	SIZE **B**	PART NO: M07	QUANTITY: 2
DATE DRAWN: 6/5/2018	SCALE: 1:2	SHEET 16 OF 25	

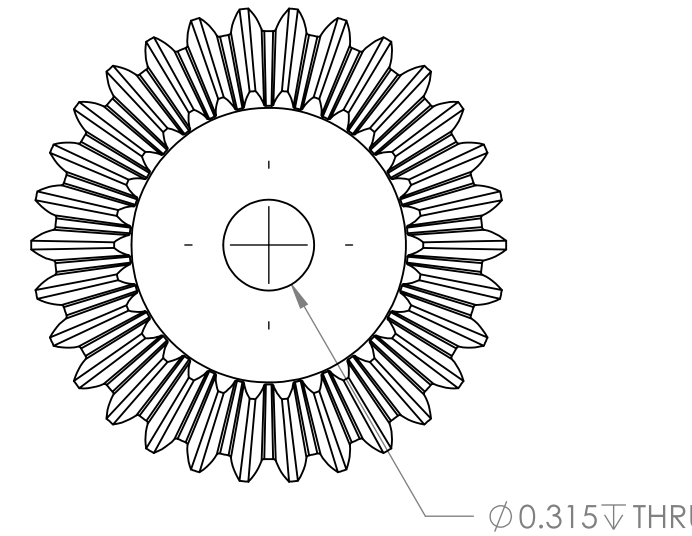
MITER GEAR - QT: 4



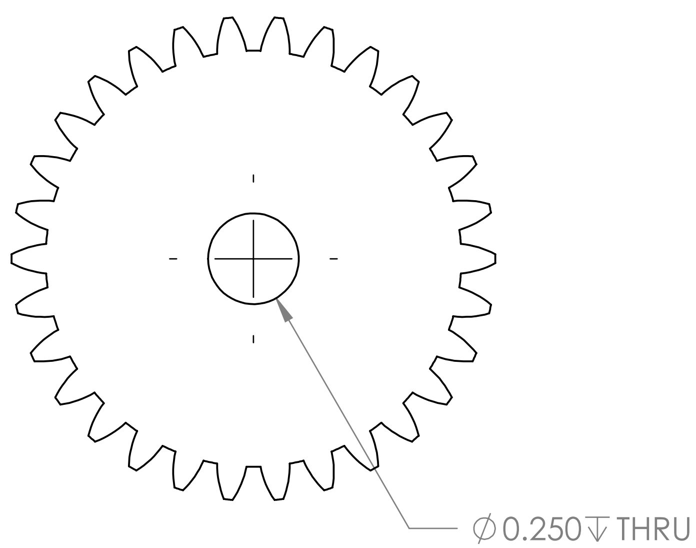
BEVEL-SPUR GEAR - QT: 6



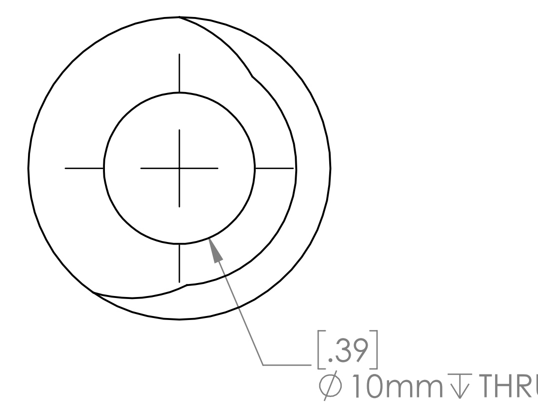
LEAD SCREW MITER GEAR - QT: 2



SPUR GEAR - QT: 8

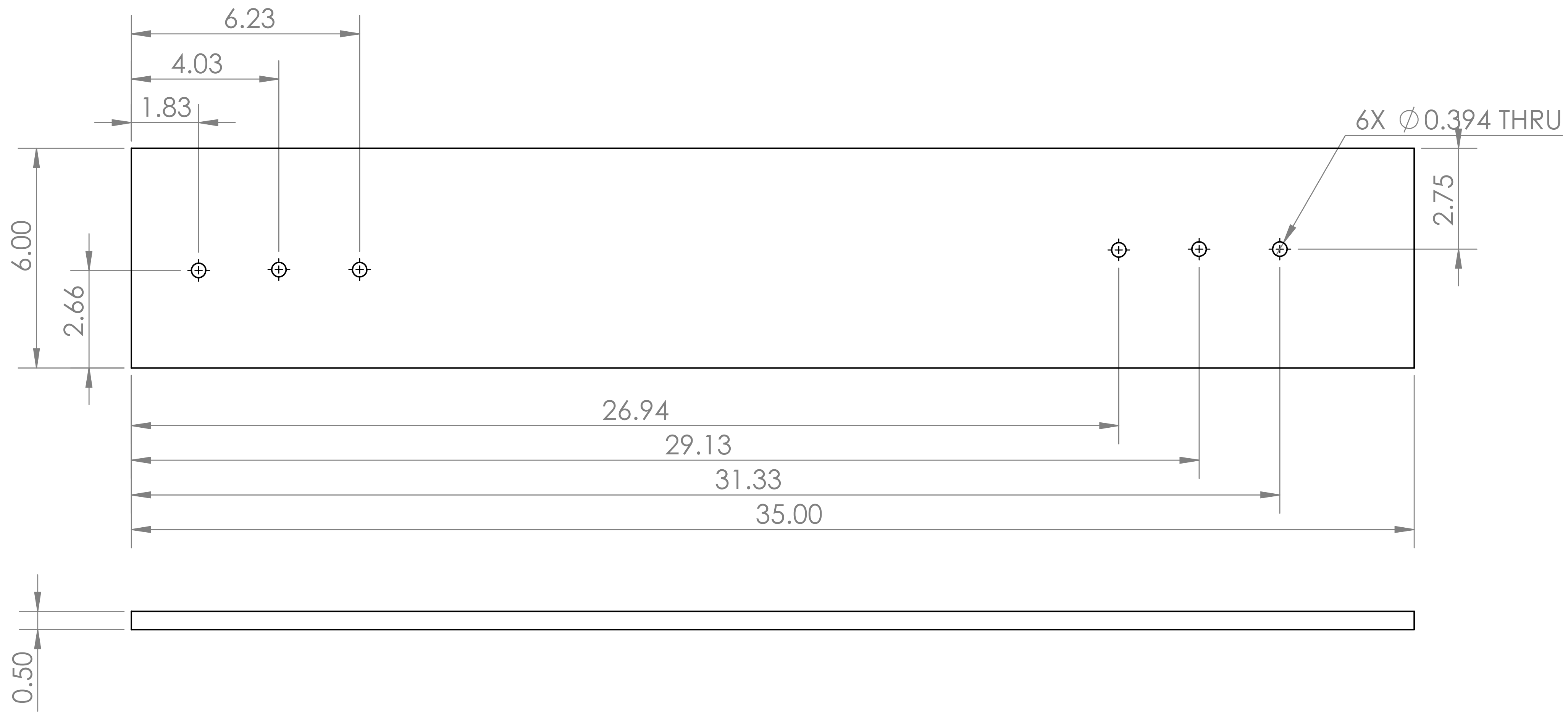


WORM - QT: 2



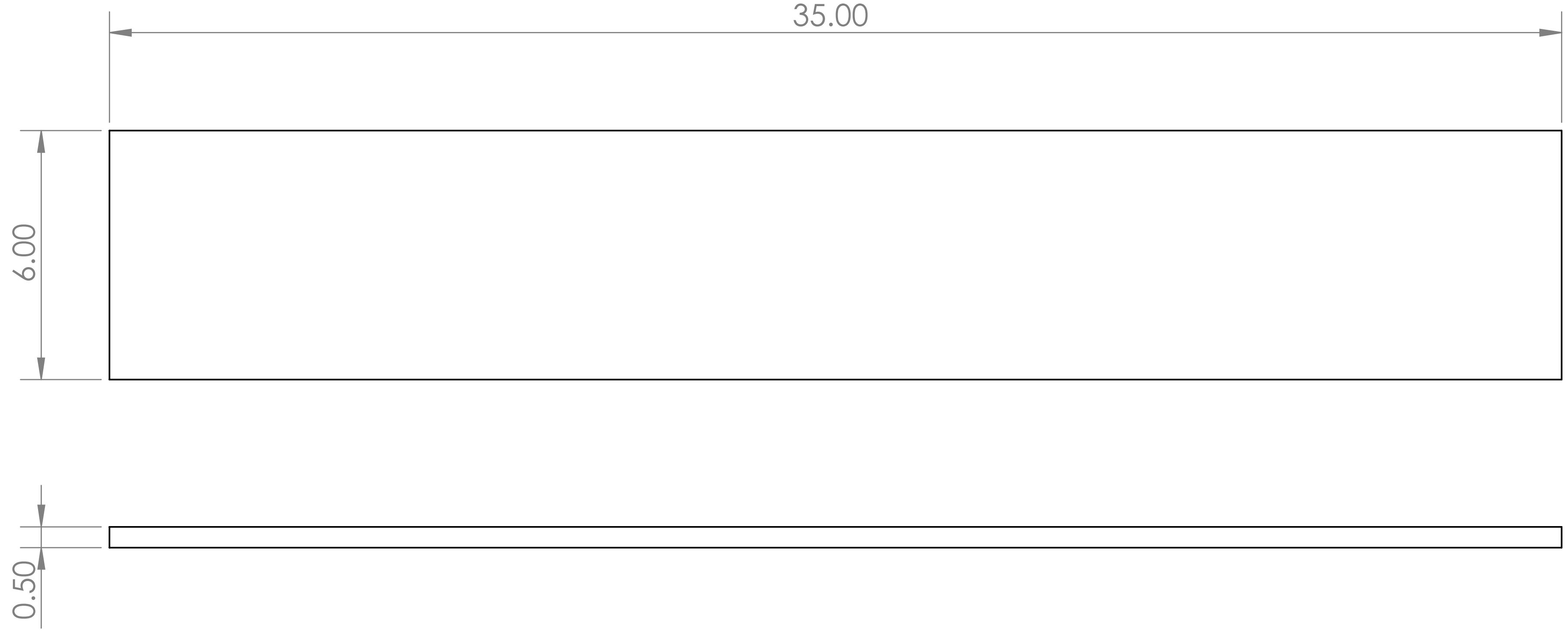
NOTE 1: 6 MITER GEARS WERE SANDED TO PROVIDE SUFFICIENT CLEARANCE FOR CLUTCH GEAR
NOTE 2: TIP RELIEF OPERATION DONE TO ALL SPURS
NOTE 3: BEVEL-SPURS ARE BEVEL GEARS EPOXIED TO SPUR GEARS

UNLESS OTHERWISE SPECIFIED:	TITLE:		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	MITER GEAR LEAD SCREW MITER GEAR SPUR GEAR - WORM		
FILE NAME: Bevel Gear.SLDPRT Spur Gear.SLDPRT Worm MOD1.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL ACETAL - BEVELS AND SPURS 1045 STEEL - WORM	SIZE **B**	PART NO: G01 - G02 G03 - G04	QUANTITY: SEE NOTES
DATE DRAWN: 5/2/2018	SCALE: 2:1		SHEET 18 OF 25

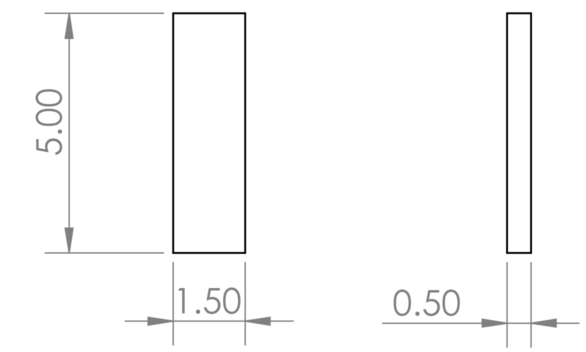


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: OUTER FRAME TOP
FILE NAME: Top.SLDPRT	TEAM NAME: TEAM TIGHTENS
MATERIAL PLYWOOD	SIZE B · PART NO: W04 · QUANTITY: 1
DATE DRAWN: 6/10/2018	SCALE: 1:4 · SHEET 19 OF 25

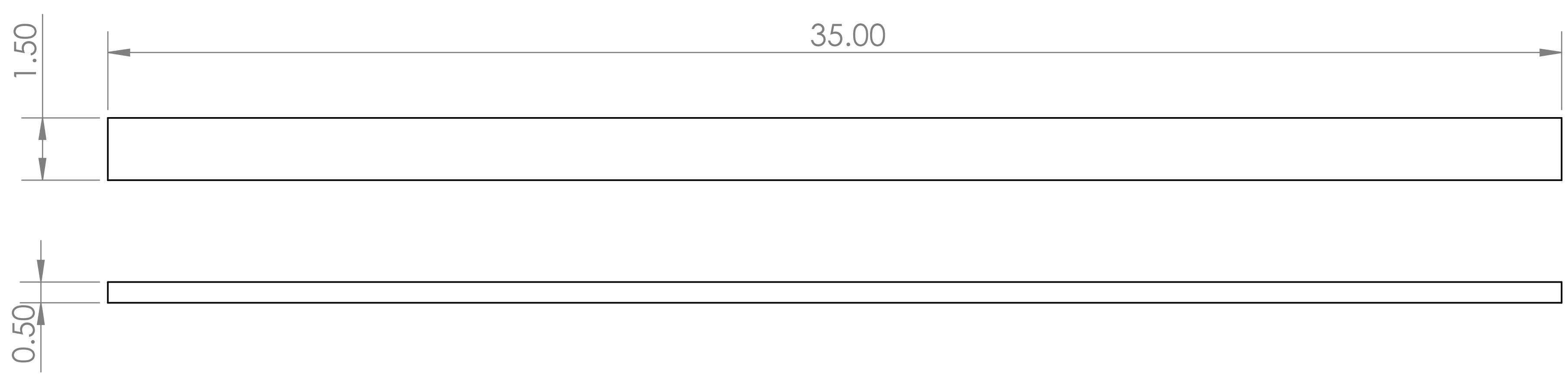
BOTTOM PLATE - QT: 1



BOTTOM PLATE SHORT SUPPORT - QT: 5

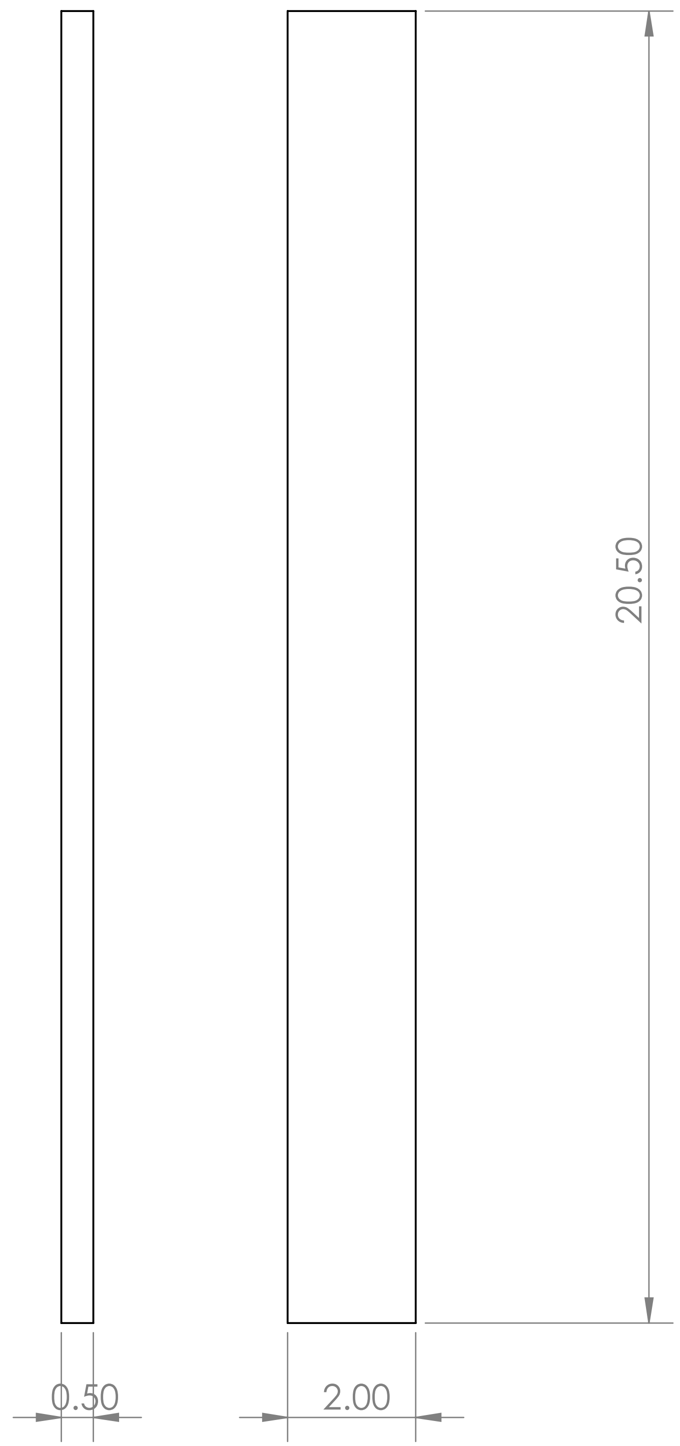


BOTTOM PLATE LONG SUPPORT - QT: 2

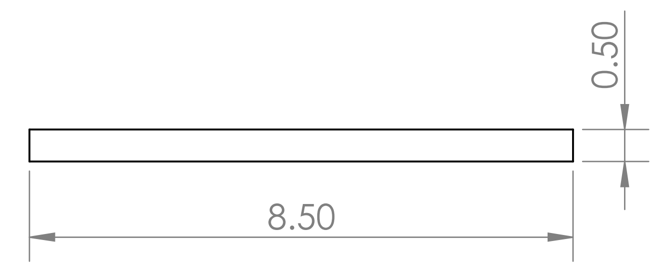


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: OUTER FRAME BOTTOM AND SUPPORTS		
FILE NAME: Bottom.SLDPRT Bottom Long Support.SLDPRT Bottom Short Support.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL PLYWOOD	SIZE B	PART NO: W05 - W07 W08	QUANTITY: See Notes
DATE DRAWN: 6/10/2018	SCALE: 1:4		SHEET 20 OF 25

SIDE PLATE - QT: 4

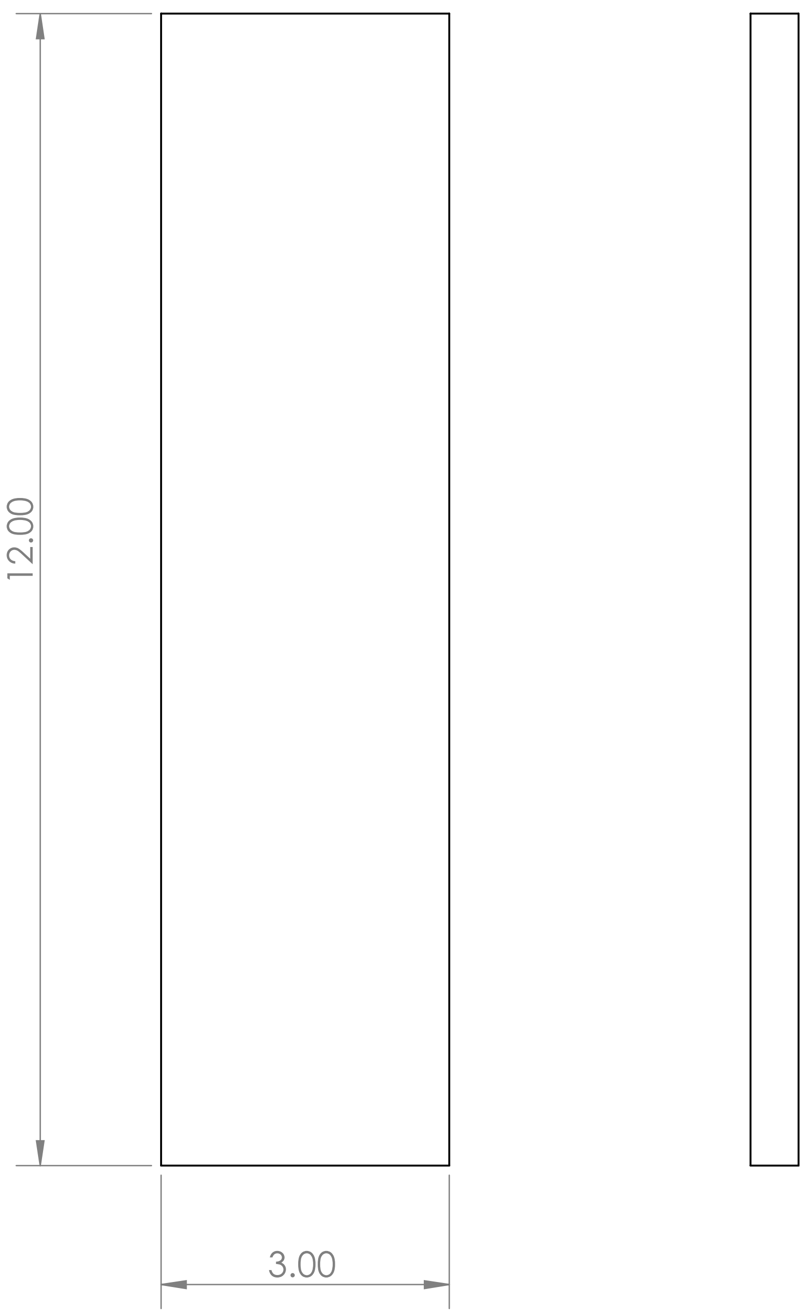


BRACE - QT: 4

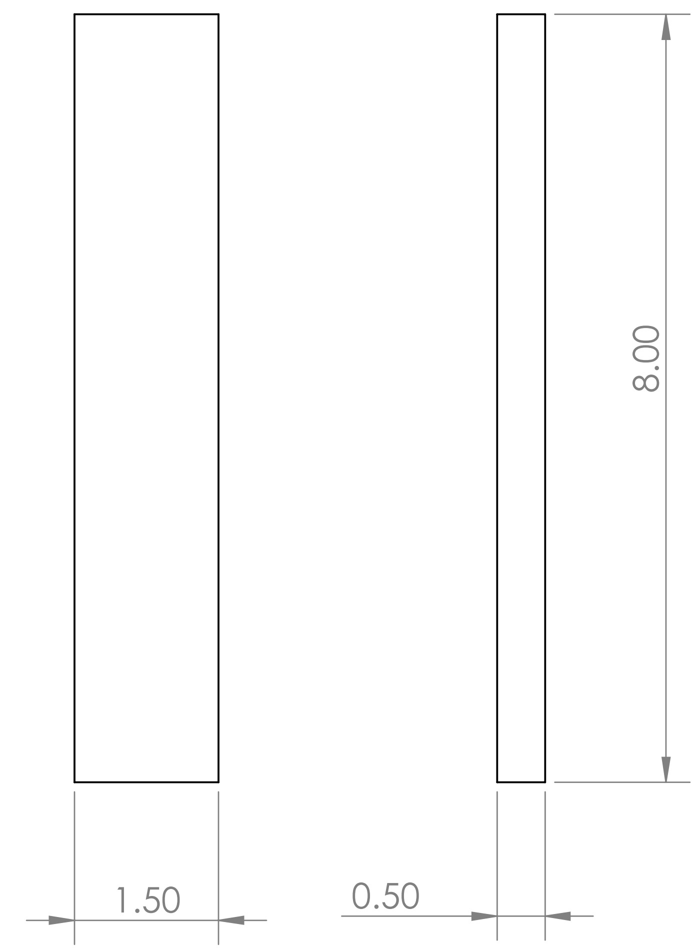


UNLESS OTHERWISE SPECIFIED:	TITLE: OUTER FRAME SIDE PLATE AND BRACE		
DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005			
FILE NAME: Side.SLDPRT Brace.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL PLYWOOD	SIZE **B**	PART NO: W06 - W09	QUANTITY: See Notes
DATE DRAWN: 6/8/2018	SCALE: 1:3		SHEET 21 OF 25

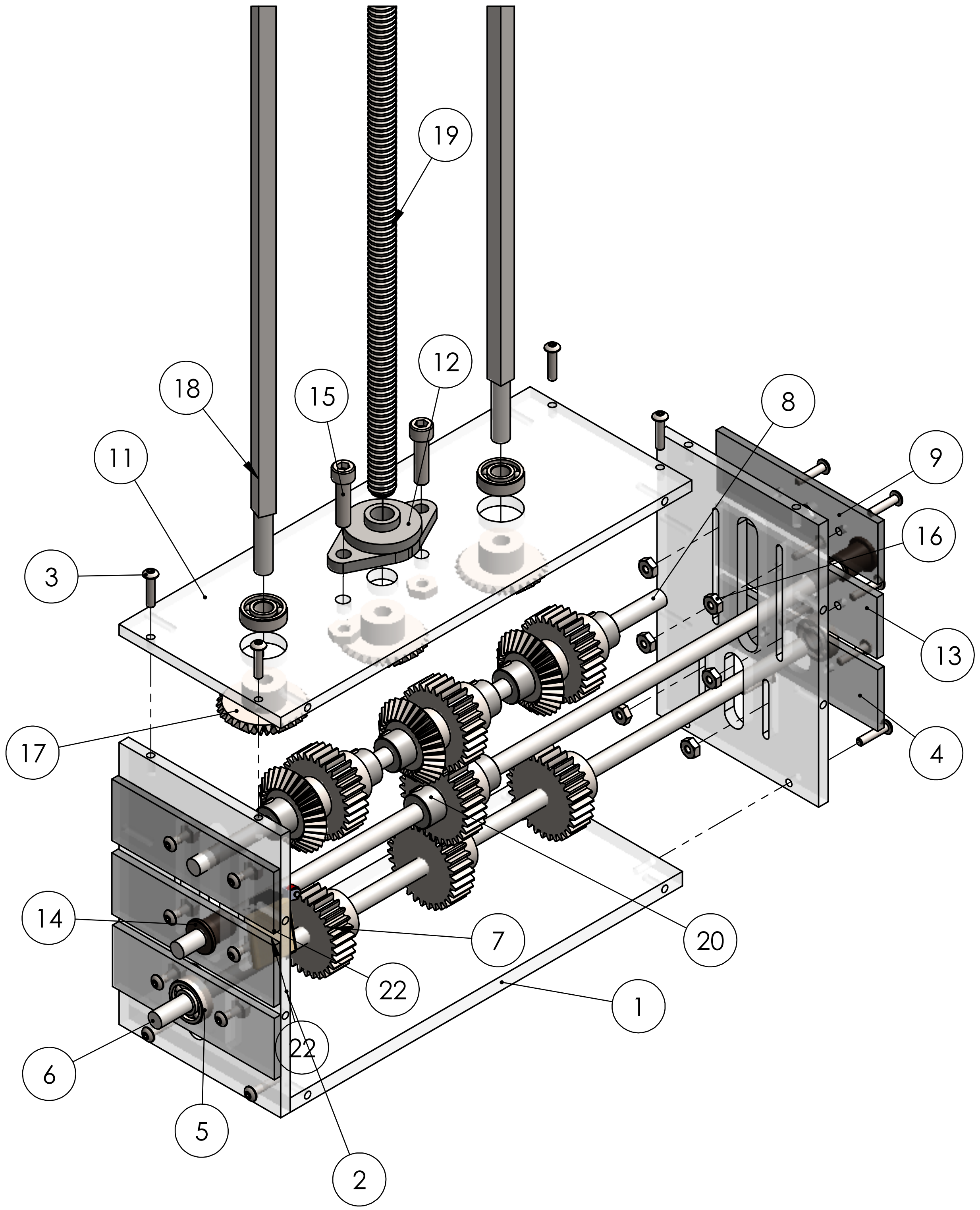
BASE - QT: 1



LEGS - QT: 4

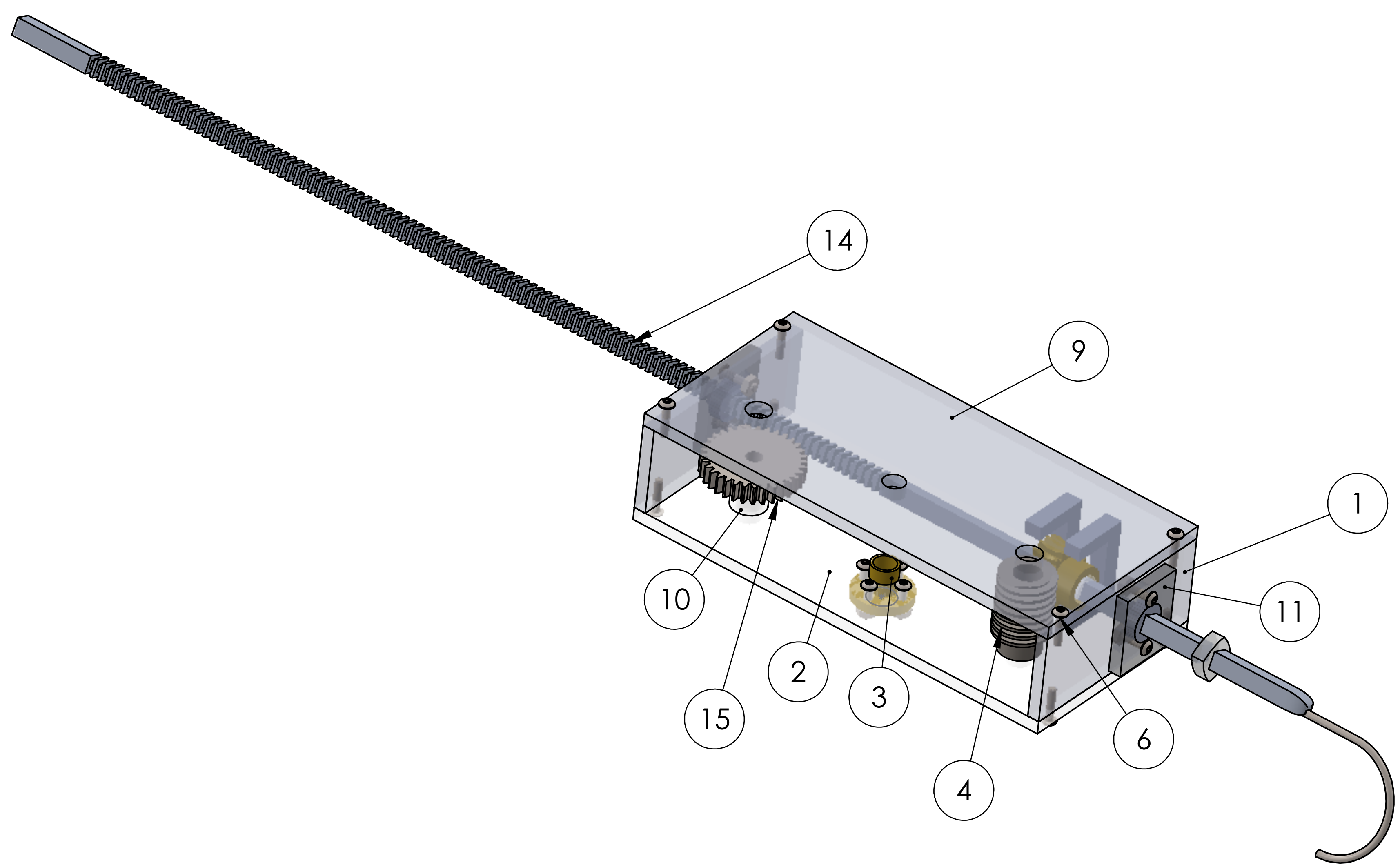


UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: SHOE PLATFORM BASE AND LEGS		
FILE NAME: Base.SLDPRT Legs.SLDPRT	TEAM NAME: TEAM TIGHTENS		
MATERIAL PLYWOOD	SIZE **B**	PART NO: W10 - W11	QUANTITY: See Notes
DATE DRAWN: 5/2/2018	SCALE: 1:2		SHEET 22 OF 25



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A01	Bottom Plate	1
2	A03	Side Plate	2
3	H01	.5in 4-40 Hex Machine Screws	20
4	A09	Mounting Plate (Bottom)	2
5	H08	.25in Ball Bearings	4
6	M03	.25in Drive Shaft	1
7	G03	Metric - Spur gear 1M 30T	7
8	M01	Top Horizontal Shaft	1
9	A07	Mounting Plate (Top)	2
10	M02	.25in Clutch Shaft	1
11	A02	Top Plate	1
12	H09	Lead Screw Bearing	1
13	A08	Mouting Plate (middle)	2
14	H10	Oil Impregnated Bronze Bushing	2
15	H04	.75in 8-36 Hex Machine Screws	2
16	H02	4-40 Nylon Lock Nuts	14
17	G02	Straight Miter Gears - 1M 30T	6
18	M04	Vertical Square Shaft	2
19	M05	Lead Screw	1
20	H11	Collar w/ setscrew	8
21	E18	Limit Switch	8
22	W01	Limit Switch Mount	1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: GEAR BOXES 1&2 ASSEMBLY		
FILE NAME: GB!1Assembly Final.SDWASM	TEAM NAME: TEAM TIGHTENS		
MATERIAL See Part Drawings	SIZE B	PART NO: -	QUANTITY: 2
DATE DRAWN: 5/2/2018	SCALE 1:2		SHEET 23 OF 25



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	A06	Side Plate	2
2	A04	GB3 Bottom Plate	1
3	M06	Leadscrew Nut Flange	1
4	G04	Worm MOD1	1
5	G05	Worm Gear MOD1	1
6	H01	SBHCSCREW 0.112-40x0.5-HX-N	16
7	H02	MSHXNUT 0.112-40-S-N	8
8	A23	Worm Gear Stopper	2
9	A05	GB3 Top Plate	1
10	A14	Spacer Bottom	1
11	A10	Mounting Plate	2
12	A11	Mounting Plate Insert	2
13	A12	Worm Gear Insert	3
14	M07	Rod w. Hook mod1(v3)	1
15	A13	Metric - Spur gear 1M 33T 20PA 6.35FW --- S33N75H50L6N	1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.005

TITLE:

GB 3 & 4 ASSEMBLY

FILE NAME: GB3 assembly_final.SLDASM

TEAM NAME: TEAM TIGHTENS

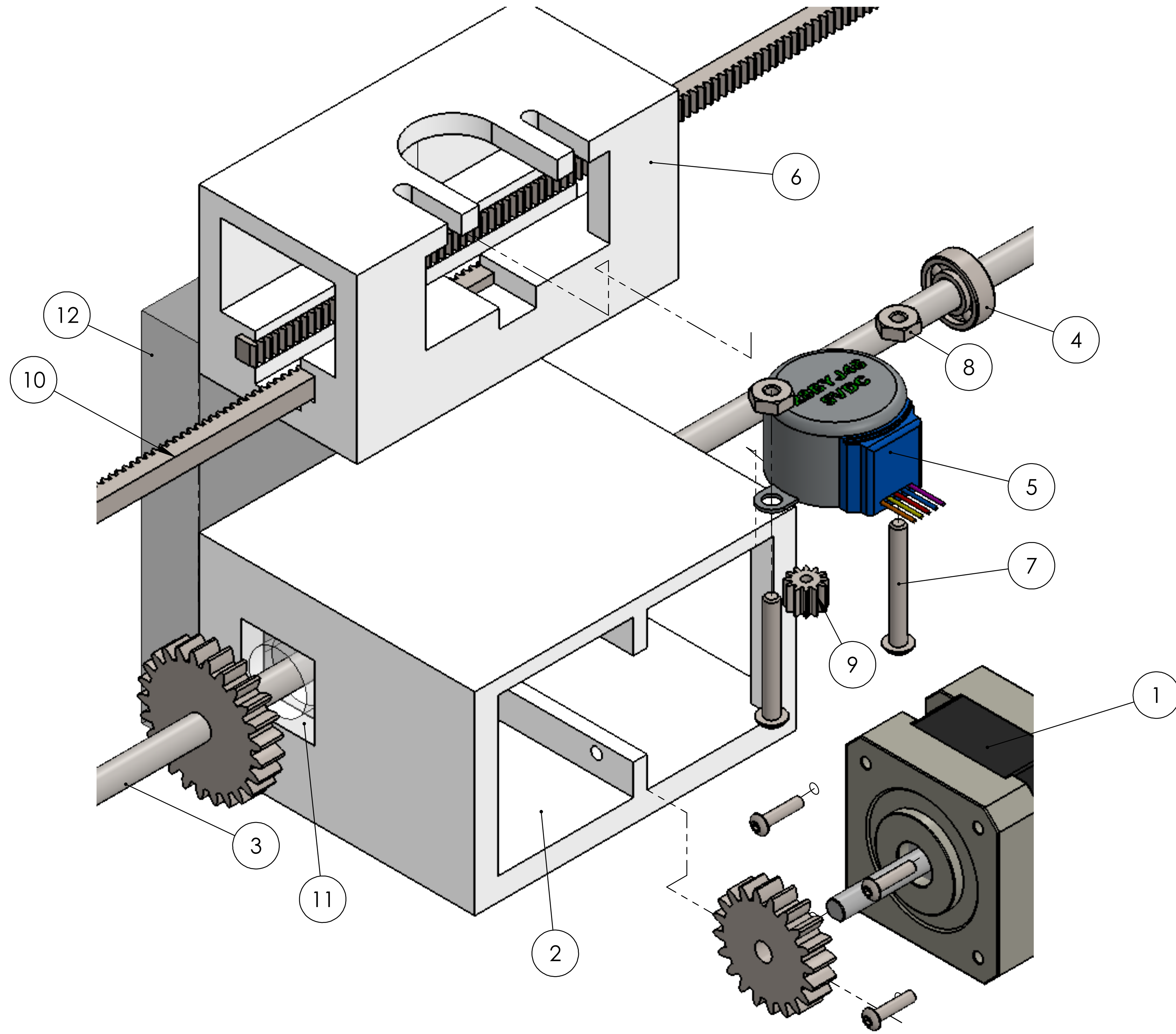
MATERIAL: See Part Drawings

SIZE: **B** | PART NO: AS3 | QUANTITY: 2

DATE DRAWN: 6/8/2018

SCALE: 1:2

SHEET 24 OF 25



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	E04	Adafruit NEMA17 Stepper Motor	1
2	P01	NEMA 17 Frame	1
3	M08	Drive Shaftf	1
4	H09	AFBMA 12.2 - 0.2500 - 0.6250 - 0.1960 - 10,DE,NC,10	2
5	E05	28BYJ-48 Stepper Motor	1
6	P02	28BYJ-48 Frame	1
7	H05	SBHCSCREW 0.099-48x0.4375-HX-N	6
8	H06	MSHXNUT 0.138-32-S-N	2
9	A-17	Inch - Spur gear 40DP 12T 20PA 0.25FW ---S12N3.0H2.0L0.0938N	3
10	A-18	Inch - Rack-spur - rectangular 40DP 20PA 0.2FW 0.175PH 8L---SAll	2
11	A-21	Motor Box Bearing Window	2
12	A-20	Motor Box Back Support	1

UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.005	TITLE: MOTOR BOX ASSEMBLY		
FILE NAME: Exploded Motor Box.SLADSM	TEAM NAME: TEAM TIGHTENS		
MATERIAL SEE BOM	SIZE B	PART NO: -	QUANTITY: 1
DATE DRAWN: 6/6/2018	SCALE: 1:1	SHEET 25 OF 25	

Arduino Code

```
// Include all necessary libraries for Adafruit
Motorshield v2.3 and ULN2003.
#include <Wire.h>
#include <Adafruit_MotorShield.h>
#include
"utility/Adafruit_MS_PWMServoDriver.h"
#include <Stepper.h>

// Create motorshield object.
Adafruit_MotorShield AFMS =
Adafruit_MotorShield();

// Create and define NEMA17 motor object.
Adafruit_StepperMotor *NEMA17 =
AFMS.getStepper(200, 2);

// Create and define 28BYJ-48 motor object.
const int stepsPerRevolution = 2048;
Stepper s28BYJ48 =
Stepper(stepsPerRevolution,8,10,9,11);

// Define Arduino button pins and boolean
states.
int i = 0;
int j = 0;
int p = 0;
int t1 = 0;
int t2 = 0;
int firstjump = 0;
int firstadjust = 0;
int firstlimitadjust = 0;
int firstINjumpback = 0;
int firstOUTjumpback = 0;
int secondjump = 0;
int secondlimitadjust = 0;
int secondINjumpback = 0;
int secondOUTjumpback = 0;
int JUMP = 0;
char Direction = FORWARD;
const int limitINPin = 4;
const int limitOUTPin = 6;
const int buttonPin = 2;
const int redledPin =  12;
const int greenledPin = 13;
boolean lastButton = LOW;
boolean currentButton = LOW;
boolean ledOn = false;

void setup() {
  Serial.begin(9600);

  // Connect to Adafruit Motorshield to Arduino.
  AFMS.begin();

  // Boost I2C rate to 400kHz for faster speed.
  Wire.begin();
  Wire.setClock(400000);

  // Set speeds (rpm) for both motors.
  NEMA17->setSpeed(1);
  s28BYJ48.setSpeed(14);

  // Define output and inputs.
  pinMode(redledPin, OUTPUT);
  pinMode(greenledPin, OUTPUT);
  pinMode(limitINPin, INPUT);
  pinMode(limitOUTPin, INPUT);
  pinMode(buttonPin, INPUT);
}

// Button debounce function for proper
pushbutton read.
boolean debounce(boolean last)
{
  boolean current = digitalRead(buttonPin);
  if (last != current)
  {
    delay(5);
    current = digitalRead(buttonPin);
  }
  return current;
}

// Clutch function. Input is either
13,31,12,23,21,32. First number is starting
shaft, second number is destinatinon shaft. 1
being closest to the shoe.
```

```
// Input 130 exists for a specific part of the shoe tying algorithm in which the drive shaft must microstep the opposite direction.
int clutch(int j)
{
  int clutchstep;

  // Number of steps to jump between gears ending right before gear mesh begins.
  JUMP = 825;

  Direction = FORWARD;

  // Step numbers for each clutch case
  if (j == 31){
    clutchstep = 4;
    firstjump = JUMP;
    firstadjust = 100;
    firstlimitadjust = 0;
    firstINjumpback = 0;
    firstOUTjumpback = 0;
    p = 25;
    t1 = 0;
    t2 = 5000;
    secondjump = JUMP;
    secondlimitadjust = 1;
    secondINjumpback = -50;
    secondOUTjumpback = 0;
  }
  else if (j == 13){
    clutchstep = -4;
    firstjump = -JUMP;
    firstadjust = -100;
    firstlimitadjust = 0;
    firstINjumpback = 0;
    firstOUTjumpback = 0;
    p = 25;
    t1 = 0;
    t2 = 5000;
    secondjump = -JUMP;
    secondlimitadjust = -1;
    secondINjumpback = 0;
    secondOUTjumpback = 80;
  }
  else if (j == 32){
    clutchstep = 4;
    firstjump = JUMP;
    firstadjust = 100;
    firstlimitadjust = 0;
    firstINjumpback = 0;
    firstOUTjumpback = 0;
    p = 0;
    t1 = 0;
    t2 = 0;
    secondjump = 0;
    secondlimitadjust = 0;
    secondINjumpback = 0;
    secondOUTjumpback = 0;
  }
  else if (j == 21){
    clutchstep = 4;
    firstjump = JUMP;
    firstadjust = 0;
    firstlimitadjust = 1;
    firstINjumpback = -50;
    firstOUTjumpback = 0;
    p = 0;
    t1 = 5000;
    t2 = 0;
    secondjump = 0;
    secondlimitadjust = 0;
    secondINjumpback = 0;
    secondOUTjumpback = 0;
  }
  else if (j == 12){
    clutchstep = -4;
    firstjump = -JUMP;
    firstadjust = -100;
    firstlimitadjust = 0;
    firstINjumpback = 0;
    firstOUTjumpback = 0;
    p = 0;
    t1 = 0;
    t2 = 0;
    secondjump = 0;
    secondlimitadjust = 0;
    secondINjumpback = 0;
    secondOUTjumpback = 0;
```

```
  }
  else if (j == 23){
   clutchstep = -4;
   firstjump = -JUMP;
   firstadjust = 0;
   firstlimitadjust = -1;
   firstINjumpback = 0;
   firstOUTjumpback = 80;
   p = 0;
   t1 = 5000;
   t2 = 0;
   secondjump = 0;
   secondlimitadjust = 0;
   secondINjumpback = 0;
   secondOUTjumpback = 0;
  }
  else if (j == 130){
   clutchstep = -4;
   firstjump = -JUMP;
   firstadjust = -100;
   firstlimitadjust = 0;
   firstINjumpback = 0;
   firstOUTjumpback = 0;
   p = 25;
   t1 = 0;
   t2 = 5000;
   secondjump = -JUMP;
   secondlimitadjust = -1;
   secondINjumpback = 0;
   secondOUTjumpback = 80;
   Direction = BACKWARD;
  }
   // First initial Jump
   NEMA17->setSpeed(5);
   s28BYJ48.step(firstjump);
   // Dual motor movement to prevent gear
catching
   while(i < (25))
   {
   NEMA17->step(2, FORWARD, MICROSTEP);
   s28BYJ48.step(clutchstep);
   i++;
   }
   i=0;
   // Adjust for proper realignment after passing
through gear
   s28BYJ48.step(firstadjust);
   // Infinite clutch movement until limit switch
activation
   while(i < (t1))
   {
   s28BYJ48.step(firstlimitadjust);
   i++;
   if (digitalRead(limitINPin) == 0){
    i = 5000;
   }
   if (digitalRead(limitOUTPin) == 0){
    i = 5000;
   }
   }
   i=0;
   // Jump back values after limitswitch is hit
   s28BYJ48.step(firstINjumpback);
   s28BYJ48.step(firstOUTjumpback);

   // Another iteration to move into second gear
position for clutch(13) and clutch(31). If not,
this part is disabled because p = 0.
   s28BYJ48.step(secondjump);
   while(i < (p))
   {
   // Dual motor movement during clutch action
to prevent gear catching
   NEMA17->step(2, Direction, MICROSTEP);
   s28BYJ48.step(clutchstep);
   i++;
   }
   i=0;
   // Infinite clutch movement until limit switch
activation
   while(i < (t2))
   {
   s28BYJ48.step(secondlimitadjust);
   i++;
   if (digitalRead(limitINPin) == 0){
    i = 5000;
   }
   if (digitalRead(limitOUTPin) == 0){
```

```
      i = 5000;
    }
    }
    i=0;
    // Jumpback values after limitswitch is hit
    s28BYJ48.step(secondINjumpback);
    s28BYJ48.step(secondOUTjumpback);
}

void loop() {
  currentButton = debounce(lastButton);

  // Logic statement analyzing button states.
  if (lastButton == LOW && currentButton ==
HIGH)
  {
    ledOn = !ledOn;
  }
  lastButton = currentButton;

  // During standby, only green LED is on. When
button is pressed, red LED turns on and green
LED turns off.
  digitalWrite(redledPin,ledOn);
  digitalWrite(greenledPin,!ledOn);

  // Logic statement that engages if button has
been pressed.

  // Y-AXIS 7 INCHES ---> 5650 STEPS FORWARD
IS UP!
    // X-AXIS          ---> use FORWARD IS IN
BACKWARD IS OUT
  // CLUTCH          ---> + is going in - is going out
  Serial.print(digitalRead(limitOUTPin));
  if (ledOn == 1)
  {
    // SHOE TYING ALGORITHM

    NEMA17->setSpeed(40);
    NEMA17->step(160,BACKWARD,DOUBLE);  //
X-axis move out: Grab laces
    clutch(32);
    NEMA17->setSpeed(150);
    NEMA17->step(6800,FORWARD,DOUBLE);  //
Y-axis Move up: Move up past shoe
    clutch(21);
    NEMA17->setSpeed(120);
    NEMA17->step(1400,FORWARD,DOUBLE);  //
90 degrees rotate: Have hooks facing up
    clutch(13);
    NEMA17->setSpeed(150);
    NEMA17->step(260,FORWARD,DOUBLE);   //
X-axis move in: Move in until laces are past
hooks
    clutch(31);
    NEMA17->setSpeed(150);
    NEMA17->step(3090,FORWARD,DOUBLE);  //
225 degrees rotate: Rotate so that hooks can
grab laces
    clutch(13);
    NEMA17->setSpeed(40);
    NEMA17->step(110,BACKWARD,DOUBLE);  //
X-axis move out: Pull out until laces are
engaged in the hooks
    clutch(31);
    NEMA17->setSpeed(120);
    NEMA17->step(670,BACKWARD,DOUBLE);   //
45 Degrees rotate: Rotate down so that hooks
are pointing down to avoid collision
    clutch(130);                    // Clutch: 1 to 3
SPECIAL CASE
    NEMA17->setSpeed(30);
    NEMA17->step(27,BACKWARD,DOUBLE);    //
X-axis move out: move out in 8 individual spurts
seperated by 500ms
    delay(500);
    NEMA17->step(27,BACKWARD,DOUBLE);
    delay(500);
    NEMA17->step(27,BACKWARD,DOUBLE);
    delay(500);
    NEMA17->step(27,BACKWARD,DOUBLE);
    delay(500);
    NEMA17->step(27,BACKWARD,DOUBLE);
    delay(500);
    NEMA17->step(27,BACKWARD,DOUBLE);
    delay(500);
    NEMA17->step(27,BACKWARD,DOUBLE);
```

```
   delay(500);
   NEMA17->step(27,BACKWARD,DOUBLE);
   clutch(32);
   NEMA17->setSpeed(200);
   NEMA17->step(1000,BACKWARD,DOUBLE);
// Y-axis move down: move down to be more
level with shoe
   clutch(21);
   NEMA17->setSpeed(120);
   NEMA17->step(1370,FORWARD,DOUBLE);   //
90 degrees rotate: Rotate so hooks are side to
side
   clutch(13);
   NEMA17->setSpeed(150);            // X-axis
mvoe out: move out in 3 large spurts so that
laces shoot through to the opposite side
   NEMA17->step(90,BACKWARD,DOUBLE);
   delay(500);
   NEMA17->step(90,BACKWARD,DOUBLE);
   delay(500);
   NEMA17->step(120,BACKWARD,DOUBLE);
   clutch(32);
   NEMA17->setSpeed(200);
   NEMA17->step(6000,BACKWARD,DOUBLE);
// Y-axis move down:  Go down to reset

   //*** FIRST LACE IS DONE / SECOND KNOT
START ***

   clutch(23);
   NEMA17->setSpeed(40);
   NEMA17->step(215,FORWARD,DOUBLE);   //
X-axis move in : reset
   clutch(32);
   NEMA17->setSpeed(150);
   NEMA17->step(6650,FORWARD,DOUBLE);  //
Y-axis Move up: Move up past shoe
   clutch(21);
   NEMA17->setSpeed(120);
   NEMA17->step(1175,FORWARD,DOUBLE);  //
90 degrees rotate: Have hooks facing up
   clutch(13);
   NEMA17->setSpeed(150);
   NEMA17->step(255,FORWARD,DOUBLE);   //
X-axis move in:  Move in until laces are past
hooks
   clutch(31);
   NEMA17->setSpeed(120);
   NEMA17->step(3000,FORWARD,DOUBLE);  //
225 degrees rotate:   Rotate so that hooks can
grab laces
   clutch(13);
   NEMA17->setSpeed(40);
   NEMA17->step(95,BACKWARD,DOUBLE);   //
X-axis move out just in case:   Move out until
hooks catch laces
   clutch(31);
   NEMA17->setSpeed(120);
   NEMA17->step(575,BACKWARD,DOUBLE);
//45 Degrees rotate: rotate so that hooks are
facing down to avoid collision
   clutch(130);                  // Clutch: 1 to 3
SPECIAL CASE
   NEMA17->setSpeed(30);
   NEMA17->step(26,BACKWARD,DOUBLE);    //
X-axis move out: move out in 3 spurts
   delay(500);
   NEMA17->step(26,BACKWARD,DOUBLE);
   delay(500);
   NEMA17->step(26,BACKWARD,DOUBLE);
   clutch(32);
   NEMA17->setSpeed(200);
   NEMA17->step(1275,BACKWARD,DOUBLE);
// Y-axis Move down to level with shoe
   clutch(23);
   NEMA17->setSpeed(40);
   NEMA17->step(290 ,BACKWARD,DOUBLE);
// X-axis move out:  Pull until Shoeknot is done

   // Reverts boolean variables back to standby
values.
   ledOn = 0;
   lastButton = LOW;
   i=0;
  }
}
```