



Golf Putter Testing Mechanism

Senior Project
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I. Introduction

Kronos Golf designs, manufactures, and sells high-end putters and putter-related products in the US and Japan, and is based in the San Diego area. Kronos Golf uses high quality manufacturing and design to, in their words, “create the most precise and balanced putters possible without gimmicks, lies, or shortcuts.” Kronos putter heads are milled from single billets of metal and are finely finished to give ideal feel and appearance.

Phillip Lapuz, Co-Founder and President of Kronos, approached Cal Poly with a senior project idea to design and build a better putter. A better putter will improve any golfer’s chance of making any putt, regardless of their skill level or experience.

The Poly Putters senior project team worked with members of the Cal Poly faculty throughout the course of this project. Doctor Andrew Davol and Professor Eileen Rossman, as the senior project advisors, assisted with the structure and progression of the project, helped the team to stay focused and provided guidance in order to keep the project on schedule.

The initial goal for this project produce a putter designed and built to make more putts relative to existing products. In order to reach that stage, a number of prior steps had to be taken. The first stage of the project was researching putting success. That is, determining what factors with existing putters go into making a putt, including but not limited to balance, face angle, head weight, size, shaft angle, tempo, swing arc, and other technique aspects.

In order to accurately determine whether a putter is actually better, a consistent testing process had to be established. This leads into the other part of this project, which was to design and build a mechanism that can achieve a consistent putting stroke with a number of variable parameters, as will be discussed in greater detail later in this report. Kronos Golf currently does have a machine to perform this function, but for several reasons it does not meet Mr. Lapuz’s expectations, primarily because it does not account for several characteristics of a human golf swing. The design and build of this new machine was to be carried out concurrent with the putting research so that the machine would have be ready for testing relatively early in the project, allowing the team to gain insight from test results before building putters.

The Poly Putters found the putting machine phase was the most technically challenging which lasted longer than expected. As discussed later in this report, the extended time spent on the putting mechanism only left time to model putter designs rather than producing real concepts.

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II. Background

A. Putter Research

1. Balance

Putter balance essentially refers to the direction that the face of the putter points if it is allowed to spin about the shaft of the putter freely. A face-balanced putter will have a face that will point directly upwards. A full toe-balanced putter will have the face of the putter pointing horizontal (the toe of the putter will point directly to the ground). There are a range of putters designed to be balanced anywhere between full toe-balance and face-balanced, as shown in Figure 2.1. The balance of the putter is controlled by the location of the center of gravity (CG) relative to the primary line of the shaft.



Figure 2.1. Putter balance; the putter on the left is heavily toe-balanced, and the putters become decreasingly toe-balanced proceeding right to a putter that is nearly face-balanced.

Putter balance is supposed to reflect the swing of the golfer. Essentially, the greater the toe-hang of a putter, the more the putter will naturally open when on the backstroke and close on the forward stroke. Centripetal acceleration works to force the CG of the putter head away from the golfer during the swing. Golfers with a straight-back-straight-through swing (where the putter face remains perpendicular to direction of the shot through the swing, as shown in Figure 2.2) should prefer a face-balanced putter because it has the least propensity to change face angle as it is swung. Golfers who have an arced swing should prefer a toe-balanced putter because it more naturally opens and closes to match the arc. Theoretically, the greater the arc, the more toe-heavy the putter should be (Understanding Putters: Toe Hang).

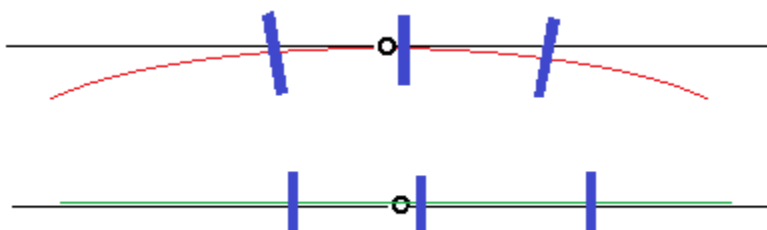


Figure 2.2. Arced (top) and straight-back-straight-through swings.

2. Face Loft

Putter loft refers to the angle made by the face of the putter relative to vertical. A putter with a 5° loft has a face that is 5° away from the direction of the shaft. Loft means the ball should go up upon impact, so the angle is away from the ball, not towards it. The reasoning for loft is that the ball will settle into (and partially create) a small divot in the green when it stops. In order to send the ball on a straight path, the theory is to jump the ball off the ground for just a moment so it is not deflected off of any part of the green when it starts to move, which would cause the shot to be off (Waddell).

Manufacturers vary on what the ideal loft angle is. Scotty Cameron putters always use a 4° loft, but they can range from as low as 2.5° to as much as 5.25° for other manufactures (Waddell). The reason for this variation is that the general agreement is that the loft should be about 4° relative to the vertical, but that not every golfer hits the ball with the same shaft angle (press angle). That is, if the grip of the club is leading the head at impact, the shaft is leaning forward, effectively decreasing the loft angle (Waddell).

3. Moment of Inertia

Moment of inertia, or MOI, refers to the weight distribution within the putter head. Every putter has a “sweet spot” where it is best to hit the ball. This spot is directly in front of the center of gravity, CG, so the putter will not twist when it hits the ball. However, hitting away from the sweet spot will cause the slightest rotation of the putter face, which could cause the ball to take a slightly different angle. It will also reduce the power of the contact. The accepted way to address this issue with putters, assuming that golfers will never hit the sweet spot every single time, is to increase the MOI, or to increase the resistance of the putter head to rotation about its CG.

Historically nearly all putters were “blade” putters, with roughly the shape of a hockey stick and more-or-less even weight distribution from toe to heel of the face. In 1966, PING introduced its Anser putter (PING). The Anser putter had weight concentrated near the toe and heel of the club with something of a void directly behind the sweet spot as shown in Figure 2.3. This means that a putter with the same weight and CG as a previous design now has a higher MOI.



Figure 2.3. PING Anser putter.

Generally speaking, a higher MOI is meant to give greater control over the putter and is a little more forgiving because it doesn't rotate as much when it strikes the ball (Hannon).

4. Sweet Spot

Every putter has a sweet spot, the theoretically ideal strike point for any putt. In theory, the sweet spot is the point at which hitting the ball will not cause the face of the putter to twist one way or another, so it is the point on the face directly between the ball and the center of gravity of the putter head. Hitting away from the sweet spot reduces a golfer's directional accuracy and distance control (Oldham). The loss of distance control is caused by both the inconsistency in a golfer's grip strength and the fact that some portion of the momentum that would otherwise be transferred from the putter to the ball is now being lost in twisting the putter head. The directional accuracy is hampered by the twist. No collision is truly elastic, so even if the putter face twists almost imperceptibly, it will guide the ball slightly off the intended path. This might be enough for the ball to miss the hole when a hit on the sweet spot would have made the putt.

5. Weight

There are two kinds of putter "weight". Swing weight essentially refers to what portion of the weight of the entire club is held in the head and also the ratio of shaft length to head weight, and head weight is just that, the weight of the head alone (Understanding Putters: Head Weights). For a certain club model, swing weight is kept consistent by reducing the head weight with increased shaft length. For instance, in 2010, Scotty Cameron put a 340g head on a 34-inch putter, and the weight decreases by 10g for every additional inch in length, and vice versa. This means that the moment required to accelerate the head a certain amount is kept relatively constant for different club lengths.

Head weights typically vary between 330g and 360g but can range as much as 315g to 400g for certain models (Understanding Putters: Head Weights). Several sources agree that a greater weight is better for a faster green (one where the ball rolls easily) because it slows down the speed of the club head for impact relative to a lighter head (Understanding Putters: Head Weights, Heavy Putter Mid-Weight Putters). However, some golfers say it is more difficult to judge the required power on a certain putt with a heavier head and others mentioned that heavier putters reduce the feel and feedback required to improve the next putt (Heavy Putter Mid-Weight Putters).

6. Size

In order for a putter to meet USGA regulations, it must be within certain size limitations. The club face may be a maximum of 2.5 inches tall and 7 inches wide. The overall club head width cannot be more than twice the width of the face and also cannot exceed 7 inches. The club depth cannot be greater than two-thirds of the face width (Rose).

7. Shaft

USGA rules mandate that putters must be at least 18 inches in length. No maximum length is specified. When a putter is at address (with the bottom edge of the face pressed against flat ground), the putter shaft cannot lean more than 20° towards the target or more than 10° away from the target. Also when at address, the shaft cannot exceed an angle of 80° from the ground as shown in Figure 2.4 (Rose).

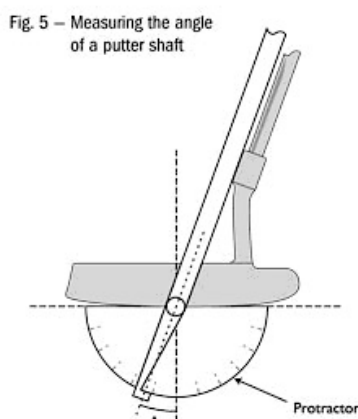


Figure 2.4. Putter shaft angle on plane of putter face. (Source: USGA Rules on USGA.org)

B. Competitors

For the most part Kronos Golf is not competing against the major golf brands. Kronos CEO and co-founder Phillip Lapuz told the Poly Putters team that Kronos wants to appeal to amateur golfers who want a unique, high-quality putter who are both serious enough about golf and wealthy enough to pay for this exclusivity.

In that sense, then, Kronos competes with other high-end putter brands like Bettinardi and some Scotty Cameron models. Scotty Cameron is owned by Titleist, one of the handful of major golf club makers. Bettinardi, founded in 1998, is a much smaller company and, much like Kronos, focuses on exclusive precision milled putters.

C. Swing Research

Golf is a sport driven by consistency and technique. This is even more true when it comes to putting. The tour professionals all have a technique that they have practiced to make as repeatable and consistent as possible. A lot of factors go into the putting stroke but it can be simplified in order to maximize repeatability and consistency on the green.

1. Stance and Posture

The outside edges of the player's feet should be about shoulder width apart. Putting is all about being comfortable to maximize consistency so adjusting the width of the player's stance to make him more comfortable is acceptable. A line drawn across the heels should point parallel to the target line, the line between the ball and where you are aiming. The knees and hips should follow the heels to point along the target line as well. The knees should be bent enough so the player cannot see his own shoelaces. The player should also bend at the hips, making sure to keep his back and spine straight. Using this set up, the player creates a strong base that is in line with the target without putting strain on his back.

The player's eyes should come to rest directly over the ball. The elbows should be slightly bent with the hands resting directly under the shoulders. The hands and shoulders form a triangle (Ruiter). An example of a correct stance and posture is shown in Figure 2.5. Notice how Rory McIlroy's knees are bent, his back is straight, and his eyes rest directly above the ball.

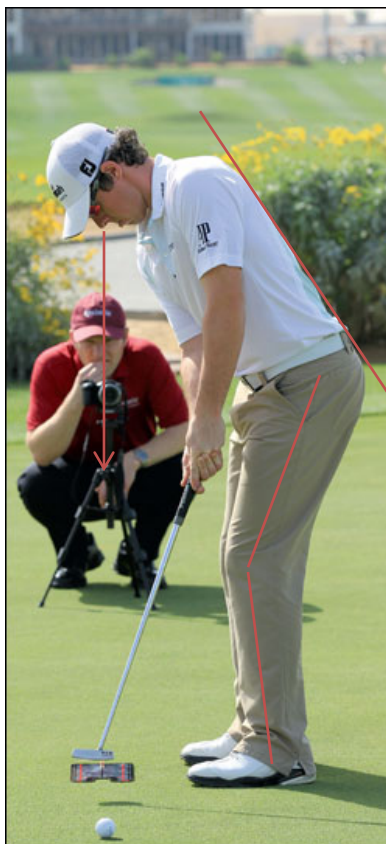


Figure 2.5. PGA professional Rory McIlroy shows correct stance and posture with his knees bent, a straight back and eyes over the ball. (Huron)

2. The Putting Stroke

Throughout the putting stroke, the triangle between the hands and shoulders should be maintained. The player should mimic a pendulum type motion on a plane between the ball and the spine between the shoulders. In Figures 2.6 and 2.7, the swing plane is shown. The player should rotate about the point on the spine, keeping the shoulders and hands in the triangle. The player's wrists should not break or rotate. The backstroke should be about the same length as the follow through shown in Figure 2.8, and the club head should accelerate through contact. By using this stroke, unnecessary motions are eliminated and the stroke is simplified and repeatable.



Figure 2.6. The swing plane is the plane between the ball and the point on the spine between the shoulders. (Thomas)

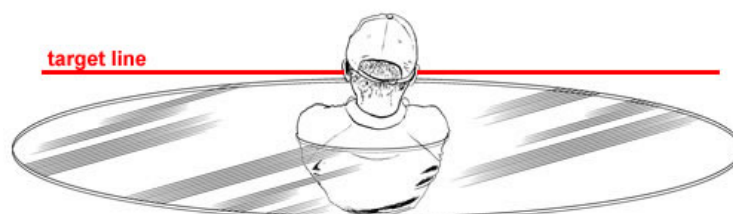


Figure 2.7. The swing plane, shown from above, is not vertical with the ground but is still in line with the target line. (Thomas)

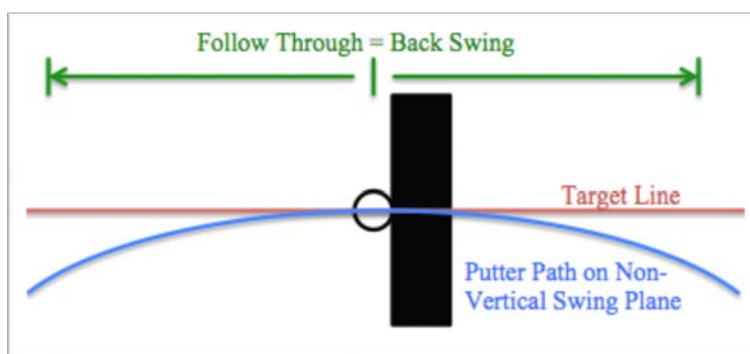


Figure 2.8. The top view shows the follow through and backswing lengths and the putter's path.

D. Putting Mechanism Research

Simply putting a putter head at the end of a pendulum would create the best putting stroke, but it would also ignore all the human factors that contribute to bad putts. To closely mimic a human putting stroke, a putter test mechanism would need to account for some of these factors.



Figure 2.9. (A) Putting Arc's Iron Archie and (B) Dave Pelz's Perfy putting robots

The existing putting stroke mechanisms are primarily used to teach the proper putting stroke. As seen in Figure 2.9A and 2.9B, each of these robots has human body shape so golfers can try to replicate the motion of the robots to improve their stroke. Both robots perform a great stroke because they have the proper swing path and alignment, but they are missing essential features needed for testing.



Figure 2.10. Kronos Golf putter testing robot.

Figure 2.10 shows a putting robot that was designed strictly for testing. Although this robot does have the capabilities of providing a repeatable stroke and adjusting the contact zone, its swing path is not similar to a human stroke because it rotates at the height of the hands and can only produce a straight back straight through stroke.

To create an accurate imitation of a human putting stroke certain elements from each of these previous models should be used. From the first two robots, the mechanism should rotate at shoulder height and have an adjustable swing plane. And from the Kronos robot, the repeatable stroke and contact zone adjustment are necessary for testing. Unfortunately, all three of these robots completely ignore any hand and wrist movement in the stroke.

Taking into account the wrist movement will not only allow for forward press, it will also allow us to test how the putter performs at different contact zones. Figure 2.11 show that wobble and misdirection can occur when the sweet spot is missed. With the current robot designs, the putting grip is rigidly attached to the swing arm and doesn't allow for any deflection of the putter head.

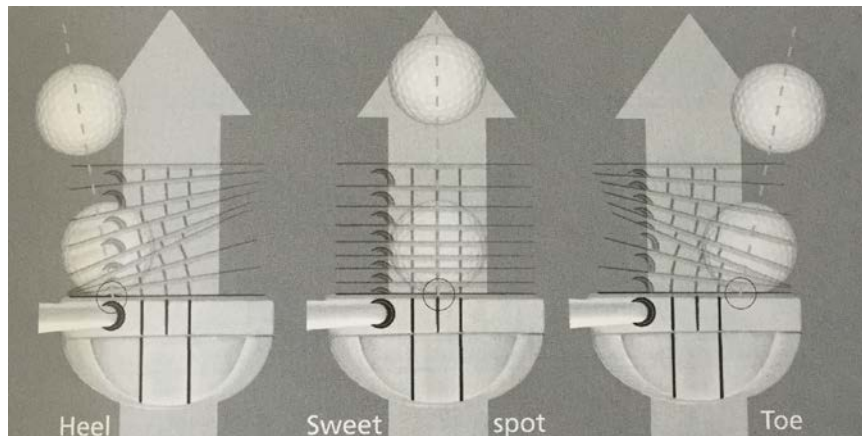


Figure 2.11. Putter head deflection and affect at different contact zones.

III. Objectives

A. Overall Goals

This senior project consists of four major parts, each of which was specified by the sponsor, Kronos Golf. The parts are as follows: putter and putting research, individual putter design-build-test, team putter design-build-test, and the production of a putting machine which will be used to perform the testing.

The Poly Putters team will focus first on the putting machine because it will necessarily have to be complete before controlled putter testing can be performed. This is also the most engineering-heavy portion of the project, meaning that the requirements for the putting machine can be translated into measurable engineering specifications to be achieved.

Concurrent with the design and build of the testing machine, the team will continue to research what makes for effective putting, both in terms of the putter and the technique used to putt. Once the putting machine is completed, the team will immediately use it to conduct testing with existing putters in order to find any strengths of current designs.

Once research and testing have been carried out to the satisfaction of the sponsor (within a reasonable timeframe), each member of the Poly Putters team will use the knowledge gained throughout the preceding process to design a putter that they believe will make for successful putting. Each putter will be made with the help of Cal Poly machine shop technicians and then tested with the putting machine and through human testing to identify whether the individual design was successful.

The final stage of the project will have the team members combine all research and testing findings into a single design. This last putter will incorporate as well as possible all of the best aspects of each individual and existing putter as determined through both machine and human testing. The putter will be built and tested with the same criteria as the individual putters. Lastly, this putter will be presented to Phillip Lapuz along with detailed reasoning behind its design and the results of its testing.

The Kronos Golf senior project will be finished once each of these stages has been completed to the standards of the sponsor. It is unknown at this point whether the Poly Putters team will build a better putter, but at the very least the team will build a useful testing machine and will be able to present a detailed analysis of the art of successful putting to be used by future designers.

B. Engineering Requirements and QFD Description

The Quality Function Deployment diagram, supplied in Appendix A, has been completed for the putter-testing machine. A Quality Function Deployment diagram, QFD, is a tool used to define customer needs or requirements and helps turn those requirements into specifications and plans to produce a product that meets the customer's needs. Several customer requirements, supplied by Phillip Lapuz from Kronos Golf as well as the Poly Putter team, were taken into account and considered in order to test a putter that's being used in a real golf swing rather than an ideal golf swing.

The requirements for the real golf swing were that the machine must replicate golfing posture, account for hand and wrist movement, and perform several swing paths. Golf testing machines that are in use today test putters using an ideal stroke, using rigid attachments and pivot points on the shaft of the club. The requirements outlined above will allow our machine to replicate a real stroke and test putters more

accurately in a more real world scenario. After further researching golf putting strokes, the swing path requirement was given lesser importance.

The requirements for testing the putters were to fit several club sizes (grip and length), perform a repeatable stroke, and to be able to adjust the contact position of the ball on the face. These requirements will allow us to accurately test several putters for impacts in the putter's sweet spot as well as off the toe or heel.

The final requirements for the testing machine are for it to be easy to use, portable, safe, and relatively inexpensive. All the requirements were waited and ranked, then correlated into engineering specifications and given target values. The engineering specifications as well as the target values can be seen in the QFD supplied in Appendix A.

The QFD also takes existing products that are similar or related and judges how well they meet the requirements and specifications previously listed. The figures at the right and bottom of the QFD show that the competitor products meet some of the requirements and specifications well but fall short for most of the defined requirements and specifications. Ideally, after completely the construction of our testing machine, we will have a product that meets or succeeds all of the requirements and specifications.

The QFD also shows how the requirements are correlated to the specifications. A filled in dot represents a strong relationship, a hollow dot represents a moderate relationship, an upside-down triangle represents a weak relationship, and a blank space means there is no relationship. Using this visual, we can see exactly how satisfying a specification contributes to completing a requirement. In the "roof" section of the QFD, specifications are related to each other. The plus is a positive correlation, the minus is a negative correlation, and a blank is no correlation. The purpose of this portion of the QFD is to help us understand which specifications will be more difficult to satisfy and how the specifications affect each other.

C. Formal Engineering Specifications

A summary of the QFD performed for the testing machine can be seen in Table 3.1. The formal engineering specification table is used to estimate the difficulty of meeting each of our specifications. The risk level ranges from low to high, L for low risk, M for medium risk, and H for high risk. The compliance test methods are as follows: (A) Analysis, (T) Test, (I) Inspection, and (S) Similar to Existing Designs.

Table 3.1. Putting Robot Formal Engineering Specifications

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Height Adjustment	from 4-5 (feet)	$\pm 3''$	L	A, I
2	Grip Replication	Wrist: 0.35 lbf-in/deg Hand: 3.78 lbf-in/deg	$\pm 33\%$	H	A, T
3	Swing Adjustment Procedure	10 (steps)	MAX	M	I
4	Putting Reset Procedure	4 (steps)	MAX	L	I
5	Disassembled Size	48"-24"-24"	MAX	M	I, T
6	Weight	100 (lbs.)	MAX	M	A, T
7	Accuracy	$\pm 4.25''$ per 10'	90% Reliability	M/H	T
8	Putter Heights	32" to 40"	$\pm 1''$	L	A, I
9	Putter grip diameter	1" to 2"	$\pm .5''$	L	A, I
10	Swing Plane Adjustment	From 71° to 90°	MIN	M	A, T, I
11	Safety Hazards	Clearly Marked	YES/NO	L	I
12	Contact Zone Adjustment	$\pm 1.5''$ from Neutral	MIN	L	A, T, I
13	Cost	\$1,000	MAX	M	A, S

We believe that meeting most of our specifications will be fairly straightforward. The only specifications labeled with a high or moderate to high risk are grip replication and accuracy. Mechanically modeling the human grip is very complex, so we will develop a few different grip replication attachments. Once the robot is complete, the grip replication attachments will be tested and compared to human interaction and a rigid connection. We also feel like the accuracy specification relies on every part of the robot to operate correctly, and for that reason it is marked moderate to high risk.

IV. Design Development

A. Selection Process

1. Concept Generation Stage 1

From our QFD, we had a list of design requirements and specifications. We took these design requirements and specifications and translated them into functions that the testing machine had to complete. The functions were to:

- Adjust to replicate swing pivot point height
- Adjust the contact point of the ball and putter
- Adjust to several swing planes
- Swing a golf putter
- Swing with variable power
- Replicate putting stroke accelerations
- Adjust for a putter's shaft length
- Adjust for a golfer's press angle
- Adjust for a putter's lie angle
- Replicate a golfer's wrist movement during contact

We held several design idea generation sessions where we thought of ways to accomplish each of the functions listed. At this point of the process, the goal was to generate as many ideas and concepts as possible and all members contributed with out of the box ideas.

2. Controlled Convergence Stage 1

After developing several ideas for each function the team was tasked with narrowing down the ideas into a single design. The first step in narrowing down the concepts was to use Pugh matrixes. A Pugh matrix judges a concept using the customer requirements as the criteria. The criteria used for our Pugh matrixes were:

- Replicates golf posture
- Accounts for hand movement
- Easy to use
- Portable
- Performs repeatable stroke
- Fits several club sizes (grip and length)
- Performs several swing paths
- Safe to use
- Adjustable contact position (toe/heel)
- Not expensive
- Manufacturability

In a Pugh matrix, a concept is judged against a chosen datum and is given a 1 if it is better, a -1 if it is worse, a 0 if it is the same, and a N/A if it doesn't affect the criteria. After being judged, the score is given to each concept by summing together its ratings. A Pugh Matrix was completed for each function, except

the wrist replication function (Appendix C). From the completed Pugh matrixes, we had ranked the concepts for each function and decided to move forward with the top three ideas in each function area.

3. Concept Generation Stage 2

The team took the data generated by the Pugh matrixes and moved forward to create complete design concepts. The best ideas from each function area were considered and brought together into three complete design concepts. Details of the three designs, A, B, and C, can be seen in Table 4.1 with how they satisfy each function area and in the sketches provided in Appendix D.

Table 4.1. Complete design concept summary.

Functions	Designs		
	A	B	C
Height Adjustment	Tripod Adjustment	Arm w/ Holes and Pin	Drill Press
Contact Zone	Lead Screw	Slide w/ Tightening Bolt	Slot and Screw
Swing Plane	Friction Fastener	Interlock Fastener	Plate and Pins
Swing	Bearing	Door Hinge	Leaf Spring
Swing Release	Door Latch	Spring Loaded	Magnets
Swing Weight	Weight on Slide	Lever Arm with Mass	Rotational Spring
Grip Position	Pin and Holes	Telescoping w/ Set Screws	Slot & Slide w/ Set Screws
Press Angle	Friction Fastener	Interlock Fastener	Plate and Pins
Lie Angle	Friction Fastener	Interlock Fastener	Plate and Pins
Grip Strength		TBD	

As shown, the concept for replicating the grip strength (wrist replication during contact) has not yet been specified. Because the grip replication is critical to our design and setting apart our testing machine from other testing machines, we have decided to have a more in depth idea generation session for this function. We also decided it best to build mock-ups and prototypes of the best ideas for this function and test to see how well each concept replicates the wrist movement. This will allow for adjustments and calibrations to be made independent of the rest of the machine. Because this function is independent of the remainder of the machine, we can still continue on.

4. Controlled Convergence Stage 2

The complete design concepts were then narrowed down to the best design idea using a decision matrix. The decision matrix, in Appendix E, judged each complete concept for each of the design criteria used previously in the Pugh Matrixes. Instead of being given a 1, -1, 0, or N/A, each concept was given a score out of 100 for each of the design criteria. In addition, each of the criteria was given a weight from 0 to 1. This weighting factor was generated from the QFD and adjusted to add in manufacturability. The higher the weighting score, the more critical the criterion is to our design. From the decision matrix, we have identified design A as the design that best satisfies all of our functions, requirements, and specifications. A layout concept of design A can be seen in Appendix D-1.

5. Satisfying the Specifications

Throughout the selection process, we always had the design specifications in mind. We used the specifications to create the functions that the putter-testing machine had to perform. We held individual

idea generation sessions for each of the function areas. We judged the concepts generated in these sessions with how well they completed each functions. We combined the concepts that best satisfied the specifications into three complete design concepts. We judged these complete concepts for how well they met the specifications and ended with a single design concept. By using a selection process that was constantly checking back to the design specifications, we created a design concept that completes all the functions, meets all the design specifications, and satisfies all the customer requirements. Our final design can be broken down into parts that satisfy each function.

The first function is to adjust to replicate swing pivot point height. This function was based from the specification that our machine needed to have a pivot point that ranged from four to five feet off the ground. This specification was based on the customer requirement to replicate golfing posture. To do this we have formulated a stable tripod base that has a vertical adjustment piece that will allow our testing machine to replicate golfers of several heights and postures.

The second function is to adjust the contact point of the ball and putter. This function was from the specification that stated without moving the ball or adjusting the posture, move the contact point plus/minus 1.5" from center of putter. This specification came from the customer requirement to have an adjustable contact point so we could test the influence of hitting a ball off the toe or heel of the putter. Our design will use a lead screw to move the system on top of the base to adjust where the putter makes contact with the ball.

The third function is to adjust to several swing planes. This function came from the specification to adjust the swing plane between 70 and 90 degrees. This will complete the requirement to perform several different swing paths. Our design will use a locking friction fastener between the base and the pivot point to adjust to several angles of swing plane.

The fourth function is to swing a golf putter. The swing function came from a combination of specifications and is used to satisfy the requirement that our machine must perform a repeatable stroke. Our design will use a bearing at the swing pivot point in order to swing the club.

The fifth function is to swing with variable power and was based off a combination of specification that stemmed from the customer requirement stating that our machine must perform several different swings. In order to accomplish a variable power for each swing, we will have a door latch type mechanism that adjusts the amplitude of the initial swing starting point, the length of the back swing.

The sixth function of our design is to replicate putting stroke acceleration. Again, this came from a combination of specifications that all pointed back to the requirement that we must replicate a golfing posture and several putting strokes. To accomplish the acceleration of a golfing stroke, we will use a counterweight on a slide. This will help to adjust for a varying tempo as well as a different back swing and follow through.

The seventh function of our design is to adjust for a putter's shaft length. This function stems from the specification stating that we must fit putters ranging from 32 to 40 inches long. The specification originates from the requirement that we must fit several different putters on our machine. To accomplish this function, we will use a channel with holes and pins to vary the length between the pivot point and the ground.

The eighth function of our design is to adjust for a golfer's press angle. This function takes in to account several specifications and comes from the requirement that we must replicate a golfer's posture. To adjust

the press angle, we will have a locking friction fastener above the grip attachment to mimic the location and angle of a golfer's wrists.

The ninth function of our design is to adjust for a putter's lie angle. This function stems from a few specifications and originates from the requirement that we must fit several different putters on our machine. To adjust for a putter's lie angle, we will have a locking friction fastener above the grip attachment to help the putter's sole lay flat of the ground.

The tenth and final function of our machine is to replicate a golfer's wrist movement during contact. This function was generated from the specification to replicate grip strength and stiffness. The function also will satisfy the requirement that our machine must account for a golfer's hand movement during the swing. The concept for this portion of the design has not yet been finalized but several concepts will be prototyped and test to see how well they perform the function. Because this portion of the design is critical to our machine and difficult to quantify, we will identify the best concept using trial and error.

When the design is finalized and built, we will place it into our QFD to accurately judge how well it meets all the requirements and specifications. Ideally, our machine will rank at the top of each category and will meet or exceed each specification.

V. Final Design Description

This is the final design and it has been approved by the sponsor, Phillip Lapuz. The robot will accomplish all of the functions listed in Table 5.1, and we believe this design will be capable of meeting all of our specifications and requirements. This design consists of a few fairly simple custom parts along with a large number of stock parts, which should keep fabrication time to a minimum.

Table 5.1. Functions for the Putting Robot

Functions
Height Adjustment
Contact Zone Adjustment
Swing Plane Adjustment
Perform a Putting Stroke
Latch Release Mechanism
Swing Weight
Grip Position Adjustment
Press Angle Adjustment
Lie Angle Adjustment
Grip Replication

The CAD layout models shown in Figure 5.1 are those of our preliminary and final designs. Though the components have been selected and finessed, we stayed true to our original preliminary layout.



Figure 5.1. Preliminary (left) and Final (right) Design CAD Models.

A. Stage 1: Tripod

We will be using a Norm's Grip Low Hefty Baby 2 Riser tripod as the base for our robot. The vertical adjustability of the tripod allows us to account for golfers of different heights by moving the pivot point up and down. This movement of the pivot point essentially replicates the height differences of several golfers. This tripod is typically used for heavy cameras and lighting found on movie and TV sets and is being provided by a third party free of charge. The tripod is heavier and more difficult to adjust than

typical camera tripods, but is rated to hold our required load and is less expensive than many of those models (some of which can cost more than \$700).

At the top of the tripod is a mounting point called a baby pin (Figure 5.2A) which attaches to an included baby receiver plate (Figure 5.2B).

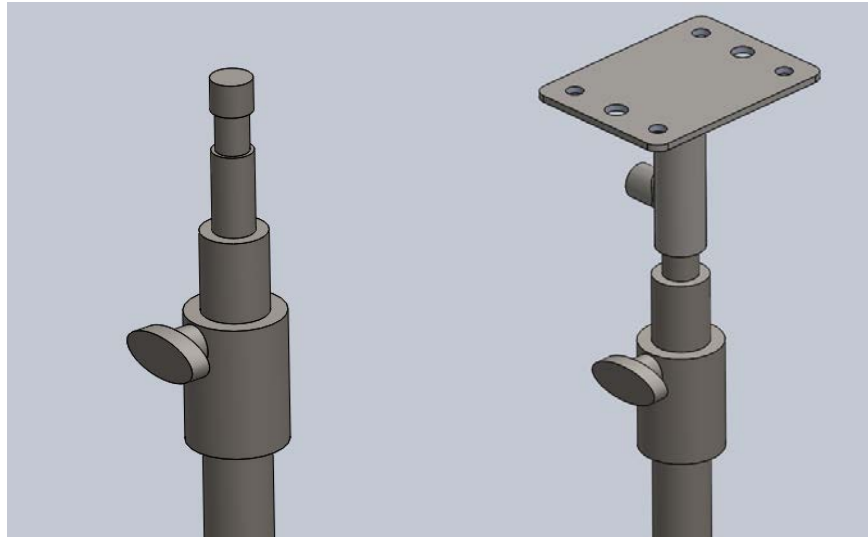


Figure 5.2. Baby pin at top of tripod (left) and baby receiver plate (right).

B. Stage 2: Vise

The base plate attaches to a custom-made front vise as seen in Figure 5.3. As the knob on the end of the threaded rod through the vise is turned, the middle block moves forward and back. This allows for the entire robot to have its position adjusted relative to the location of the ball so that we can study the effects of hitting at the toe, heel, or anywhere in between on the face of the club for a certain shot. This will be important when analyzing putter designs and how large of a sweet spot each putter design has. The vise attaches to a base tube for mounting the rest of the assembly. All stock material sizes have been verified and ordered. The stock parts have also been ordered.

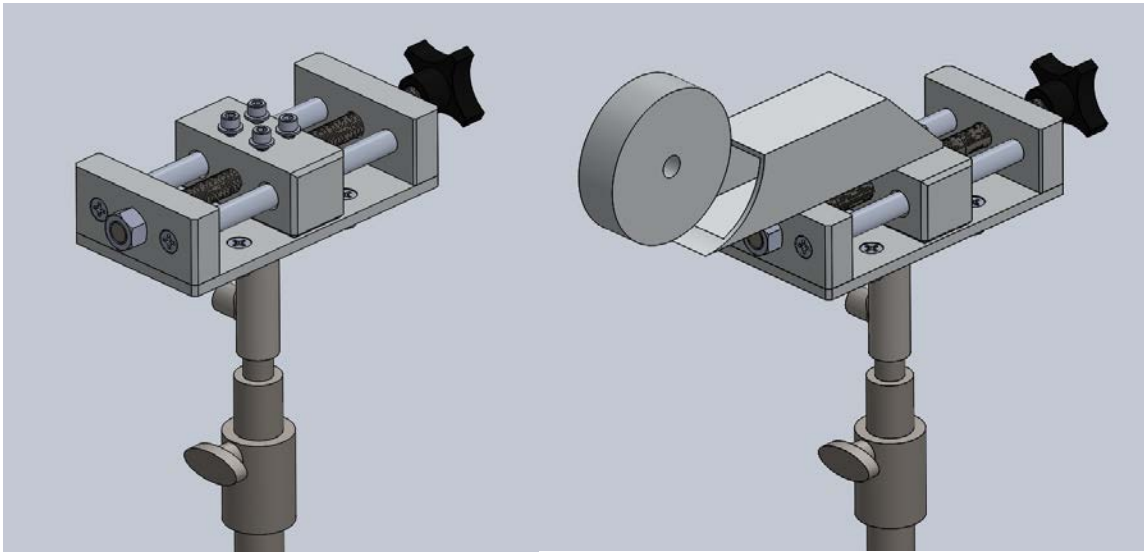


Figure 5.3 Front view for contact zone adjustment without (left) and with (right) base tube attached.

C. Stage 3: Swing Plane Adjustment

The swing plane is adjusted by changing the angle of the main upright tube as shown in Figure 5.4. The joint at the bottom of the main tube connects to a similar joint on the base tube using a large bolt tightened with a wingnut. We will have a thin piece of high-density polyethylene between the two joints to reduce wear on the system and increase friction so that, when tightened, the swing plane angle is maintained.



Figure 5.4. Swing plane adjusts to include 90-degree (left) and 71-degree (right) strokes, and anything in between.

At the top of the main tube is a stock $\frac{3}{4}$ -inch bearing with an included housing. The bearing can be loosened and tightened with an included fastener, eliminating the need to press fit, common to most bearings. Figure 5.5 shows that the bearing housing is mounted to a machined base piece which is

inserted into the top of the main tube and fixed with a fastener (not shown). Again, all stock material and parts exist in standard sizes and has been ordered.

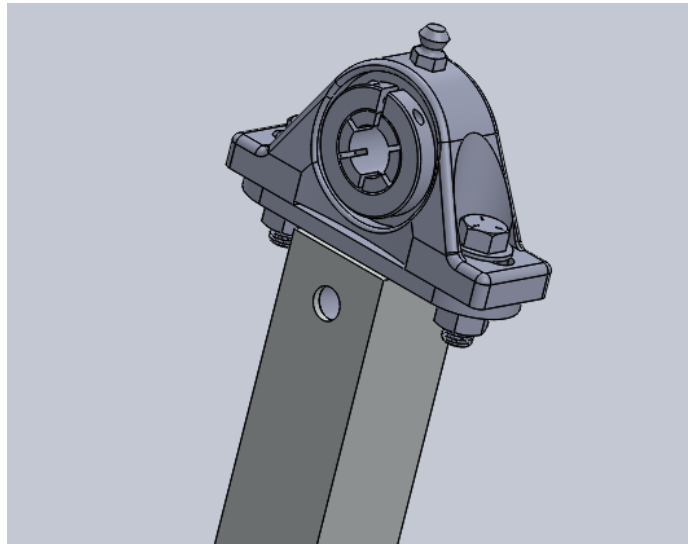


Figure 5.5. Bearing housing and attachment to the main tube.

D. Stage 4: Swing Arms

The bearing holds a shaft as shown in Figure 5.6. The shaft is machined from a piece of aluminum square stock, and the end of it is welded to the top of the large swinging tube. Between the main tube and the swinging down tube is a shaft collar with an attached rod which will be used as part of the latch and release mechanism (Figure 5.7).

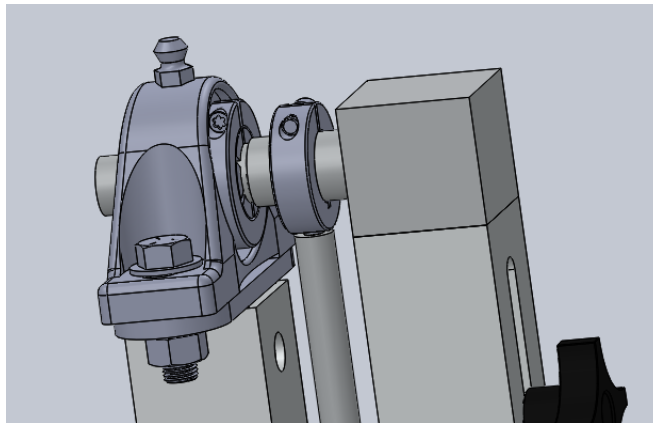


Figure 5.6. Bearing with attached shaft. The shaft is machined out of the block seen at the right end of the shaft. This square piece inserts into and is welded to the down tube.

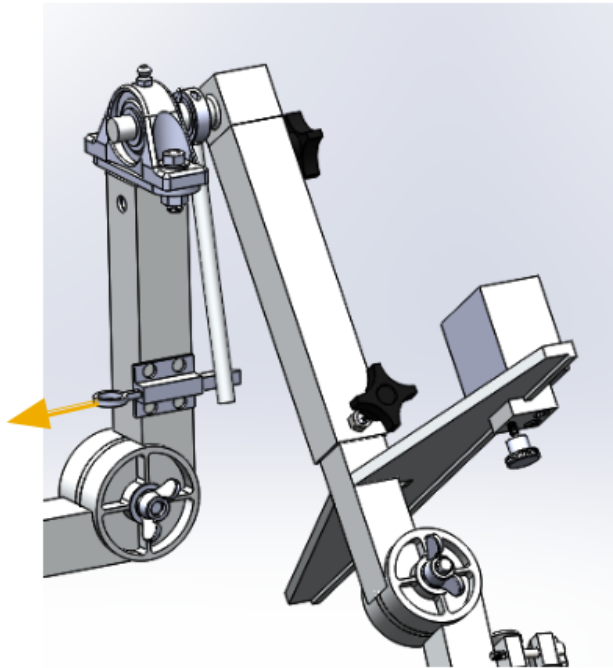


Figure 5.7. Backswing latch and release mechanism.

The large swinging tube, or down tube, has a slot machined into it as well as a nut welded over a hole towards the bottom. A smaller aluminum tube is inserted into the large tube as shown in Figure 5.8. This setup allows the small down tube to move up and down inside the larger tube and then be fastened in place by tightening the knobs. The slot allows for the tubing to extend as much as 8 inches, as per the specifications, and also restricts the smaller tube from falling out when loosened.

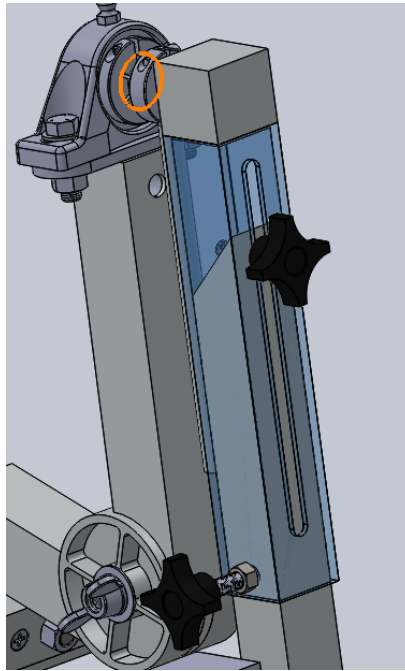


Figure 5.8. Down tube length adjustment. Both of the black knobs shown are used to tighten threaded rods into aluminum nuts welded to the tubing. (Note that the larger part of the down tube is aluminum and is just shown as partially transparent here to demonstrate the mechanism.)

To provide variable acceleration for the swing, we are using a steel swing weight block mounted on an aluminum slide that is welded to the smaller downtube as shown in Figure 5.9. The block is bolted to a smaller aluminum piece which can be tightened against the slide to hold it to a given position. Traditionally, a golfer is supposed to accelerate the putter through contact with the ball, so the weight would be placed behind the tube, as it is shown in the figure. This design also allows us to see the effects of having peak velocity at the bottom of the swing (weight in the middle) and having the putter decelerate through the swing (weight in front of the tube) both of which are never taught or recommended to golfers. Paired with the variable latch and release mechanism, the swing weight will be able to replicate both short putts and longer putts for testing purposes. Standard stock parts and material have been ordered.

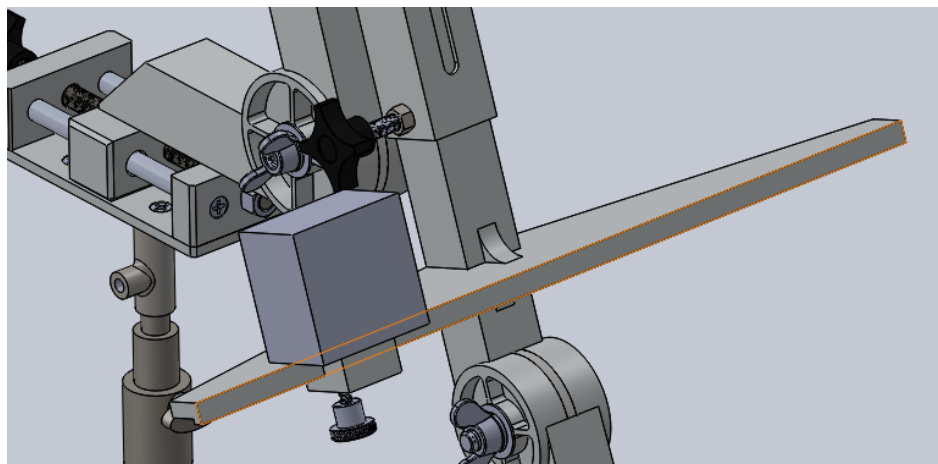


Figure 5.9. Swing weight slide and steel swing weight.

E. Stage 5: Putting Angle Adjustments

To adjust for putters with different lie angles (the angle the shaft makes when the putter sole is flat against the ground) as well as to keep the putter at the correct angle when the swing plane is adjusted, a second joint similar to that used for the swing plane is welded at the bottom of the small down tube as shown in Figure 5.10.

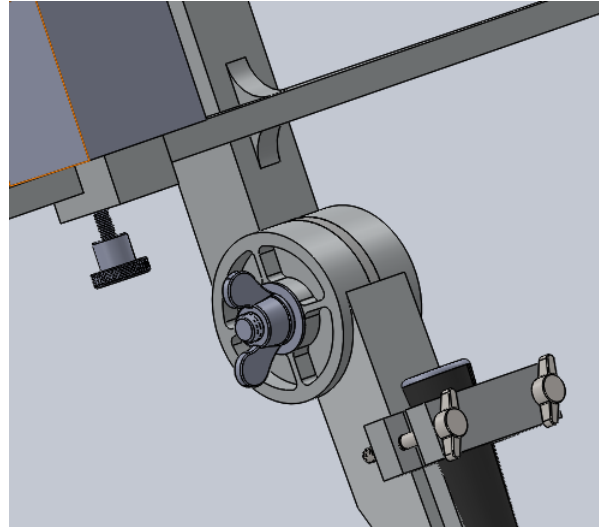


Figure 5.10. Lie angle adjustment.

The press angle (lean of the club when viewed from the golfer's front) is adjusted by a knob which tightens the grip assembly to the final piece of tubing as shown in Figure 5.11. A golfer's press angle essentially de-lofts the putter and is mostly used so that the golfer can create a comfortable swing. With this adjustment on our device, we will be able to analyze whether or not a forward press angle really influences the roll of the ball. The necessary material and standard parts have been ordered.

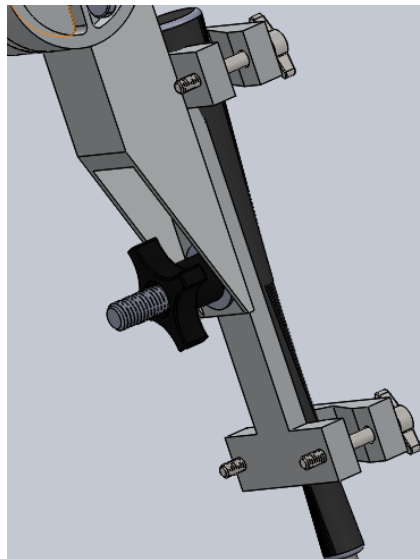


Figure 5.11. Press angle adjustment. The threaded section seen here is the end of a square head bolt recessed into the grip piece, so when tightened, the bolt maintains the press angle.

F. Stage 6: Grip Attachment to Putter

Finally, the putter is held in place with a rigid grip assembly as shown in Figure 5.12. The knobs tighten into threaded holes on the grip base. Ultimately, we will develop a “flexible” grip attachment that will replicate the movement and stiffness of a golfer’s wrists and soft tissue in the hand. We have designed several different grips with built-in compliance to account for the inherent non-rigidity of a true human grip and will test these flexible grips against the wrist and hand stiffness data gathered for several test subjects to determine which most accurately represents the human movements. The materials and parts for the rigid grip attachment has been ordered.

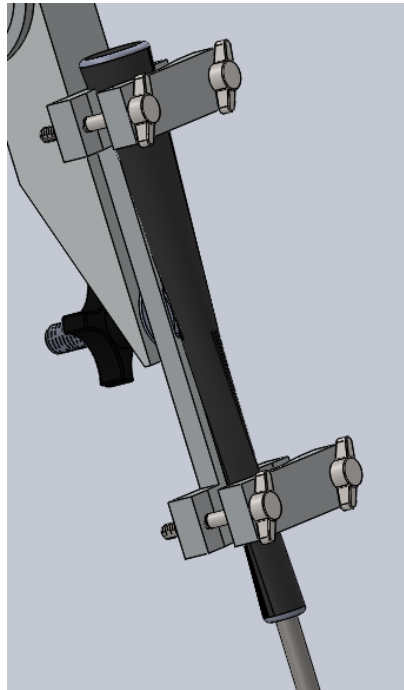


Figure 5.12. Rigid grip assembly.

VI. Management Plans

A. Manufacturing Considerations

Manufacturing the putters should be a fairly simple process. Two of the team members are taking part in the Cal Poly CNC machining course (IME 335) which gives them easy access and experience with CNC machines for those processes requiring CNC. The actual milling should be very easy. The putter heads are expected to be a single piece milled from a metal block. The team will explore finishing methods as necessary with the guidance of Kronos Golf. Putter shafts and grips will be provided by the sponsor and fitting a shaft to a putter head is apparently a very easy process involving epoxy and heat.

The more difficult, or at least more involved part of manufacturing, will be the testing machine. The design process is completed and the fabrication of a few custom parts will be necessary. Stock parts will be used wherever possible and have already been ordered, but the team will also need to use the machine shop for fabrication of custom parts. CNC machining, basic cutting and drilling, and welding will be required to complete the custom parts necessary for the robot. As soon as the stock material is received (it has already been ordered), the team will begin the manufacturing of the custom parts. When a sub-assembly has all of its custom parts completed, it will be assembled so that the robot can take shape.

B. Cost Analysis

The cost of the testing machine is primarily spent on the stock pieces ordered from McMaster-Carr. In addition to the stock parts, stock material was ordered for the fabrication of the custom parts. The stock material was ordered from Online Metals. A layout of all the stock parts and material ordered can be seen in Appendix F, Bill of Materials. Because only one of these robots is to be made for the sponsor, we have not included any expenses due to manufacturing. As stated above, the manufacturing will be completed by members of the Kronos Golf Senior Project team. The team is well under the budgeted \$1000 for the testing machine even with \$200 budgeted for the flexible grip attachments. The team will use the remaining funds for the stock material need for the putters themselves.

As the team progresses through the testing machine phase of the project to the putter design phase of the project, we will begin to perform a more in depth cost analysis. Ideally, the sponsor would like to take a final putter design and bring it to mass production. When a final putter design is developed, the team will produce a cost analysis for mass production with this final design. Material, machine and manufacturing costs, labor, and other overhead factors will be considered when producing a cost per putter for the final design.

C. Testing Machine Design Verification

The testing machine will be validated based on the engineering specifications. Each of these specifications is easily measured or confirmed. The testing machine can be judged using the same QFD diagram used to judge the competitor machines. The most important aspect of the testing machine will be its repeatability. In order to gather accurate data for the putters, the testing machine must be able to perform the same stroke at a given setup. Using scales and markers accurately placed on the machine, a user will be able to create a custom and repeatable setup for a given putter and putt length. These scales and markers, along with accurate recording will allow the machine to have a consistent setup.

In order to test the repeatability of each setup we will perform a test on level flat ground. Using a single setup for a club supplied by Kronos and a putt distance of 10 feet, we will putt 10 balls and mark the

ending position of each ball. In order to pass the repeatability test, 9 out of 10 of the putts must fall within a 4.5 inch diameter circle. This specification comes from the requirement to make 90% of putts from a 10 foot distance. The 4.5 inch diameter circle was determined from the size of a golf hole. If deemed necessary, the test verification can be repeated with several supplied putters from Kronos at the 10 foot distance. All the tests will be performed with the rigid grip attachment and the vice set so that the sweet spot, clearly marked on Kronos putters, contacts the ball. This is required so that the specific putter being used does not influence the roll of the ball and the only effects from the attributes of the machine are being noted.

D. Test Plans

Testing of all putters (already existing and those built for this project) will consist of both machine and human testing. Machine testing will be used to determine accuracy with a consistent stroke and form. As stated in the engineering specifications, the machine should place at least 9 out of every 10 balls putted within a 4.25-inch diameter circle (the size of a golf hole) for every 10 feet from the strike point. The team will adjust swing angle and tempo – putter speed at impact, controlled by swing acceleration from rest and distance from the strike point – with each putter according to a consistent testing plan that will be specified once the putting machine is complete. Putter size and shape will be accommodated by the adjustments in the machine and the same testing methods should still be achievable. Successful putter design and technique will be determined simply with accuracy. The smaller the radius in which putts for a certain putter and set up end up in, the better. From a technical perspective, there is nothing more important in golf than getting the ball into the hole, so accuracy is the only controlled factor worth testing.

Because golfing is performed by humans, not machines, putters will also be tested by people. Each member of the Poly Putters team will use every existing putter that is tested as well as each of the individual putters. This will not be a technical test because accuracy will have been determined with the machine. Rather, human testing will investigate the less tangible aspects of putting, and golfing in general. Individuals will record their thoughts on how a putter “feels” to use and what they like and dislike regarding the sensations of the putter. This might include, but is certainly not limited to, factors like the weight of the putter, the sound made when putting, the sensation of control and an ability to feel when the ball is hit, the aesthetics of the putter, et cetera. Though it has not yet been finalized, the Poly Putters will attempt to also get input from the Cal Poly golf team. This will help to add more samples to the testing as well as getting the putters into the hands of good golfers to learn their perspective. On the surface, human testing may seem unnecessary; people should simply buy the putter that works the best and learn to use it. However, the sponsor made it clear that putters are bought as much for, or perhaps more, the intangible parts of putting. Phillip Lapuz gave the example of a putter that he knew of which had tested well but people didn’t buy because of the unpleasant sound it made when striking the ball.

Machine and human testing results will have to be weighed by the Poly Putters team when designing the final putter. This may be a subjective process or the team might construct some kind of rubric to allow for more consistent input. Though this rubric hasn’t yet been designed, it might give a certain weight to the accuracy score and then ask human testers to rate various aspects of each putter on a numerical scale which can then be combined into an intangibles score.

E. Failure Mode and Effects Analysis (FMEA)

The failure mode and effects analysis can be seen visually in Table 11.1. The risk preference number (RPN) is calculated by multiplying 3 separate parameters together: (A) severity of the failure, (B)

probability of occurrence, and (C) probability of detection. All these parameters range from 1 to 10, with 10 being the most severe for (A), the highest probability for (B), and the lowest probability for (C).

Table 11.1. Failure Mode and Effects Analysis

Failure Mode	(A) Severity	(B) Probability of Occurance	(C) Probability of Detection	Risk Preference Number (RPN) AxBxC
Tipping Over	3	5	1	15
Latch Breaking	2	1	1	2
Joints Fail	2	2	1	4
Weight Becomes Loose	2	1	1	2

As you can see from our FMEA table, we are not expecting any significant failures with our design. This is mainly because there are no extreme operating circumstances for our robot. All the possible failures will be easily detected before they can become dangerous or problematic.

VII. Product Realization

A. Manufacturing

The putting machine was designed to simplify the manufacturing process as much as possible. Most of the components requiring machining were machined using a manual mill or lathe. There were a handful of parts that required CNC machining, as well as a number of parts that weren't machined at all (their manufacturing consisted of cutting, drilling, sanding, grinding, etc.) The only manufacturing not performed by the Poly Putters team were the waterjet cutting of the swing weight slide and the welding of the aluminum structure.

All of the square aluminum tubing used for the structure of the putting machine was cut with either a vertical or horizontal band saw. All of the holes in the tubing were drilled using a manual drill press. The quarter-circle cutouts at the ends of some of the tubing pieces (parts 111, 201, 401, and 501) were done with a large adjustable-radius cutter and a mill used as a drill press. The small down tube (401) was designed to slide inside of the large down tube (301). Nominally, the inside of the larger tube and the outside of the smaller tube were the same size, so the tube had to be made slightly smaller to slide freely. This was accomplished by liberal use of belt and rotary sanders. Taking a few thousandths off of each dimension of the tubing could have been done much faster and with better quality using a face mill. This is certainly a consideration to take into account for future manufacturing of this design. All threaded holes were hand-tapped. Unfortunately, we don't have any photos from before the machine was welded, but Figure 7.1 shows how the tubing was used in the final product.



Figure 7.1. Overview of tubing layout in final machine structure. Note that the smaller down tube is concealed inside the larger down tube (with the black knobs) in this photo.

Some of the parts manufactured with manual mill and/or lathe work include the vise guide rails (106), the bearing housing mount (203), the large down tube (301, cutting out the pin slot, see in Figure 7.2), the shaft (303, base cut out with mill, shaft done on a manual mill), the swing weight slide (402, faced down while leaving the tab on one side for the swing weight), the slide block (403), the swing weight (404), and the grip pieces (502 and 503, as shown in Figure 7.2).

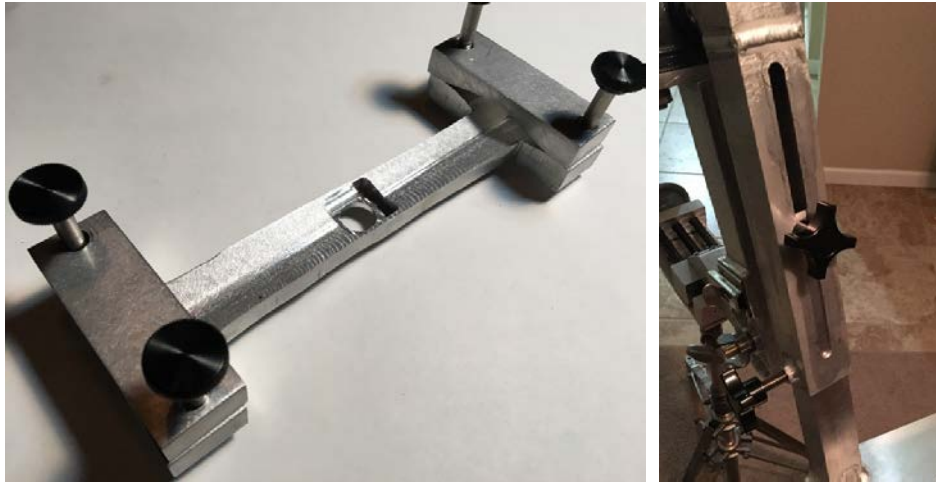


Figure 7.2. Examples of manual milling work: the grip pieces (left) and the slot in the larger down tube (right).

Parts made with CNC include the vise base (101), ends (104), and the moving base (105). Additionally, the slots in the joints (112, 202, 405, 603) and the rectangular pockets for bolts on two of the joints and the grip base (202, 502, 603) were also done with CNC machines, as can be seen in Figure 7.3.



Figure 7.3. This joint piece is one example of the use of CNC machining (for the quarter-circle pockets as well as the rectangular pocket to hold the bolt).

The profile of the swing weight slide was achieved using a waterjet cutter. This process as well as all of the aluminum welding (Figure 7.4) were performed by American Laser Fab in Escondido, CA.

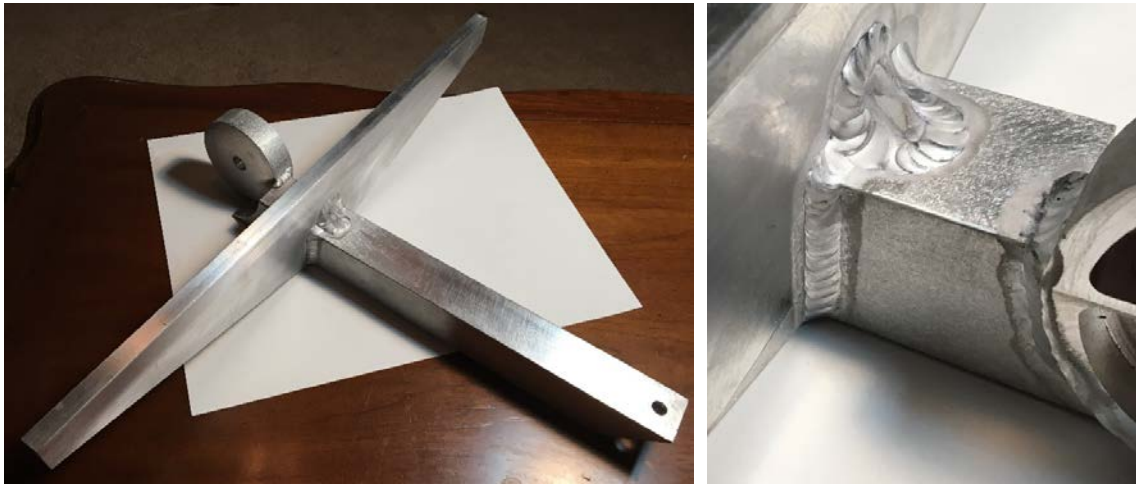


Figure 7.4. Swing weight slide (left, cut out with waterjet) and aluminum welding.

The remainder of the machine consists of stock components. The tripod (Figure 7.5) is a cinema lighting tripod donated by Cogswell Video Services of Valencia, CA. Nuts, bolts, washers, knobs (Figure 7.6), thumbscrews, and bearings (with housings) were purchased from McMaster Carr. Most of the metal was purchased from Online Metals, with the exception of the steel block for the swing weight and the aluminum round stock used for the joints, which were both also purchased from McMaster Carr.



Figure 7.5. Tripod at minimum height.



Figure 7.6. Knob from McMaster Carr.

B. Prototype

For the most part, the prototype follows the initial design plan. There are only two significant differences. The prototype does not have a functioning vise, which was to be used to adjust the contact point (that is, whether to hit the ball with the toe, sweet spot, or heel of the putter face) without changing the launch point of the ball, to see the effect this would have on the trajectory. The incomplete vise assembly can be seen in Figure 7.7. We also had to use a small piece of HDPE to prop up the vise tube, also seen in Figure 7.7. This significantly reduced quiver and shaking while the machine swung.

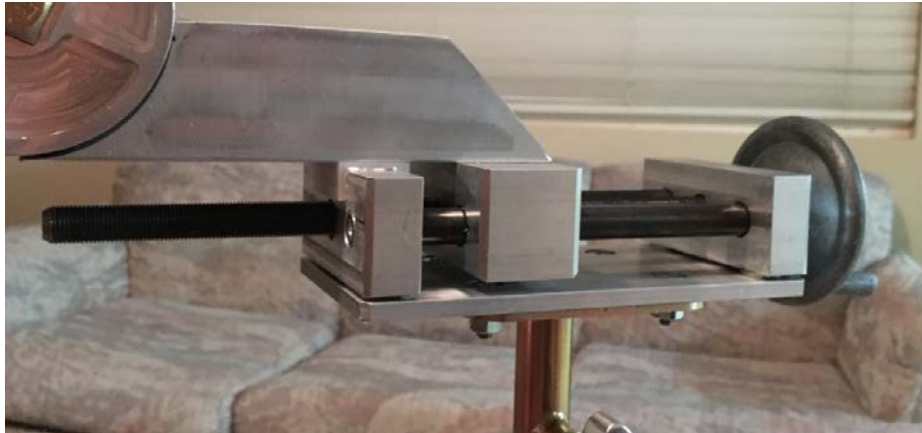


Figure 7.7. Vise assembly. The original plan called for the threaded rod through the middle being used to move the vise, and therefore the entire machine other than the tripod, forward and back relative to the ball. Note the piece of HDPE between the tube and the left-hand vise end.

The other significant difference is the addition of a second bearing for the pivot. The theory (perhaps not a sound one) behind using just one bearing was that the load was so small compared to the bearing's rated load that the moment applied by the weight of the swinging arm wouldn't have a major effect on the bearing's ability to spin. As it turns out, the load was significant and the swinging was severely inhibited by this. Adding a second bearing changed the applied moment to a force couple, and the arm swung much better. The ending bearing assembly is shown in Figure 7.8. We suspected we might need a second bearing from the start, but they are quite expensive so we elected to try just one to start with.



Figure 7.8. Final bearing assembly with two bearings.

C. Future Manufacturing Recommendations

To build this specific machine, there probably wouldn't be any major changes to the manufacturing process. The vise could have been done differently. The easiest way to adjust forward and back is certainly not with a lead screw-type design, which takes an absurd amount of turning to achieve the amount of movement we need. A simpler alternative would be some sort of clamp mechanism to hold the vise in place and simply pushing the assembly forward and back by hand. Also the vise ends and middle piece should share the same top height when assembled so the machine assembly isn't cantilevered out from the center piece (instead being supported by the vise end). The only other significant change would be to alter the drawings to account for the use of two bearings. Another thought, as mentioned previously, would be to reduce the size of the small down tube with a face mill instead of an excessive amount of sanding.

Additionally, if we had more time, we would have put angle markers (small machined tick marks, for instance) on each of the joints, the vise, the swing weight slide, and on the latch lever. Such markings would allow us to accurately judge things like the press, lie, and swing plane angles, as well as the ball position and swing start point and strength. Of course it would also mean we could set up the same configuration repeatedly, something that is essentially impossible to do right now with no markings.

Some of the components were not what they needed to be. The swing weight could have been much smaller and the swing weight slide could have been thinner and not nearly as long (it currently goes 10 inches in either direction).

Finally, and this will be covered later on in this report, the grip was never finished as we originally intended. It should mimic the grip strength and compliance of human hands where ours is more of a rigid design. We are able to make it somewhat flexible by simply not tightening it down hard, but this is hardly repeatable.

VIII. Design Verification

Below is Table 3.1, which outlines our verification procedure for each specification. A is analysis, I is inspection, T is test, and S is similar product. The table was produced when the design process began and our design verification hinged on meeting each specification.

Table 3.1. Putting Robot Formal Engineering Specifications

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Height Adjustment	from 4-5 (feet)	$\pm 3''$	L	A, I
2	Grip Replication	Wrist: 0.35 lbf-in/deg Hand: 3.78 lbf-in/deg	$\pm 33\%$	H	A, T
3	Swing Adjustment Procedure	10 (steps)	MAX	M	I
4	Putting Reset Procedure	4 (steps)	MAX	L	I
5	Disassembled Size	48"-24"-24"	MAX	M	I, T
6	Weight	100 (lbs.)	MAX	M	A, T
7	Accuracy	$\pm 4.25''$ per 10'	90% Reliability	M/H	T
8	Putter Heights	32" to 40"	$\pm 1''$	L	A, I
9	Putter grip diameter	1" to 2"	$\pm .5''$	L	A, I
10	Swing Plane Adjustment	From 71° to 90°	MIN	M	A, T, I
11	Safety Hazards	Clearly Marked	YES/NO	L	I
12	Contact Zone Adjustment	$\pm 1.5''$ from Neutral	MIN	L	A, T, I
13	Cost	\$1,000	MAX	M	A, S

A. Analysis

Most analysis was completed using SolidWorks and was used to compute angles, distances, and weights of our design. Before proceeding to fabrication, we made sure that each analysis specification was met. We also wanted to verify the SolidWorks analysis so we included a test, inspection, and/or similar product compliance for each analysis compliance. Excel was used to keep track of expenses for the cost analysis and the robot was under budget without factoring in the cost of fabrication, which was completed by team members.

B. Inspection

We began our design verification with a thorough inspection of our fabricated robot. We performed a 9-point inspection to determine if our product complied with the formal engineering specifications laid out from the beginning of the design process.

1. Height Adjustment

The target height adjustment for our robot was between 4 and 5 feet tall. We measured the height of the final bearing assembly to determine if our robot met the specification. The height of our robot adjusted between 4 feet and just above 5 feet, satisfying the engineering specification. Although the robot can adjust to be above 5 feet tall, at this height, it is a bit unstable and may tip over if bumped into or not operated on a flat surface in normal conditions. We determined that the best way to prevent the system from falling over when adjusted to its max height is to place a sand bag or weight over the back leg of the tripod. This adds stability to the base, prevents tipping, and is a simple solution.

2. Swing Adjustment Procedure

The next specification inspected was the swing adjustment procedure. We specified that for any change in swing, there must be a total of less than 10 adjustment steps. In order to verify, we assumed a swing change from someone short with a straight-back-straight-through swing path and a long putter to a tall person with an arced swing path and a short putter. Although a tall person doesn't typically use a short putter and vice versa, we figured that this scenario would maximize the number of adjustment steps. If the robot could perform under this scenario, it could pass all other swing changes. Table 8.1 below outlines how the robot performed. There was a total of 6 adjustments made in order to change swings, far below the number of adjustments specified.

Swing 1	Swing 2	Adjustment
Short Player	Tall Player	Tripod Raised
90° Swing Plane	72° Swing Plane	Swing Angle Tilted Back
Long Putter	Short Putter	Putter Switch in Grip Assembly
		Lie Angle Adjusted in Grip Assembly
		Down Tube Assembly Lengthened
Total Adjustments:		6

3. Putting Reset Procedure

Similar to the swing adjustment procedure specification, we also inspected for putting reset. To reset a putt and receive meaningful test data, you must 1) place the ball at the previously marked location, 2) pull the swing arm back to rest on the latch, 3) stop the putter from vibrating, and 4) pull the latch to putt. Our putting robot meets the putting reset procedure specification for the max number of steps to reset a putt with 4 total steps.

4. Disassembled Size

To inspect the disassembled size requirement, we folded the robot up into its shipping configuration and kept it in two parts: the tripod and the top piece. We placed both parts into a two-foot by one-foot by one-foot box and the box could be closed easily.

5. Putter Heights

We wanted our robot to be able to test all legal PGA putters and some illegal PGA putters so we specified that it must accommodate putters from 32 inches to 40 inches. By adjusting the tripod, down tube assembly, and lie angle in the grip assembly we were able to hold and swing putters in this range. Below, Figure 8.1 shows an image of the robot setup with a 36-inch putter for testing validation purposes.



Figure 8.1 Robot setup with 36" Kronos Touch putter.

6. Putter Grip Diameter

Following the trend from the Putter Height section, we wanted to accommodate putters with 1-inch to 2-inch grips in order to be able to test a wide range of putters. The current grip assembly being used easily meets this specification.

7. Swing Plane Adjustment

In order to test of wide variety of putting strokes, the robot must adjust between 90 and 71 degrees. Using an iPhone's accelerometer, we were able to set up the test robot at angles inside this range. The robot could also accommodate many angles less than 71 degrees to the horizontal and even angles greater than

90 degrees although, there is little value gained from testing angles further than 90 degrees because no one putts with that type of stroke.

8. Safety Hazards

Currently, this is the only inspection point that our robot does not pass. In order to pass this point, stickers and warnings must be placed on the robot at its pinch points.

9. Contact Zone Adjustment

The final point of the inspection was the contact zone adjustment and is necessary for the testing of putters once the robot is verified. Our robot can adjust the contact zone of the putter with the ball by at least 1.5" in either the toe or heel direction from the center of mass of the putter.

C. Testing

In addition to the 9-point inspection, we performed testing in order to verify the design on six of the specifications. The design passed each of the six test points and is verified for the purposes previously outlined.

1. Grip Replication

The robot passed the grip replication test, mainly due to the wide tolerance of the specification. The top of the robot was held rigid and there was a force applied at the head of the putter. The degree of deflection was measured. From using a fishing scale, the force was measured. Because the putter's length was known, we could calculate the hand and wrist stiffness values.

2. Disassembled Size

The purpose of our 2-foot by 1-foot by 1-foot disassembled size specification was to make sure that the robot could be transported in the trunk of a car. We tested this by placing the robot in the trunk of both Roger's and John's car. The disassembled robot fit in both trunks.

3. Weight

The weight test was verified in a similar way to the disassembled size test. The disassembled robot was measured using a bathroom scale and passed on each test occasion.

4. Accuracy

This was the most important test of our robot verification. We wanted the robot to be able to make nine out of ten putts from a ten-foot distance. The size of a hole is 4.25" so we said that the ball must pass through a 4.25" gate when putt from 10 feet away. We placed the ball at the same point on Cal Poly's putting green for each putt and had the sweet spot of the putter come in contact with the ball each time. We set the robot up for an average height golfer with a 72-degree swing plane angle. The putter used to conduct the accuracy test verification was Kronos Golf's Refined Touch putter supplied by Phillip Lapuz. The robot successfully putted through the 4.25" putting gate set up 15 feet away from the ball placement for ten out of ten putts. The robot is even more accurate than predicted. This accuracy will prove valuable

when judging putters based on their robot test results. Figure 8.2 shows a picture of our test setup on the Cal Poly putting green.



Figure 8.2 Accuracy test on the Cal Poly putting green with putting gate shown.

5. Swing Plane Adjustment

The swing plane adjustment test consisted of swinging the robot at several swing planes and observing the roll of the golf ball. Our robot was able to perform a repeatable stroke for each angle tested between 90 and 70 degrees.

6. Contact Zone Adjustment

The contact zone adjustment test was similar to the swing plane adjustment test. We adjusted the robot to make contact with the ball at several points on the putter face spread across the heel to the toe. The robot was again able to perform a repeatable stroke for each contact point tested. The repeatability of the robot verified by the swing plane adjustment test and the contact zone adjustment test allows the tests of future putters to have meaningful and quantifiable results.

IX. Conclusions and Recommendations

Initially, the intent of this project was to design a putter that would make any golfer, regardless of their skill level, better at putting. Whether it was the first time she had ever picked up a club, or if it was his tenth year on the PGA tour, this putter would be designed to make that person more successful. That part of this project never fully materialized.

From the beginning, we felt that it would be unrealistic to create a full mechanical engineering senior project around designing a single putter. Putter design itself is not a particularly scientific endeavor as it is. All of the major putter companies conduct little-to-no testing of their designs and most of the changes from one model to the next are cosmetic. Kronos Golf CEO Phillip Lapuz wanted to use engineering to support the design of a better putter, which could be marketed as superior as a result of clever design instead of its color or shape. However, without any consistent way of testing existing designs and potential prototypes, the project quickly shifted to first constructing a device that would allow the Poly Putters team to conduct testing. This project offered more engineering requirements, and would more closely follow the established senior project timeline.

We hoped to have the machine completed by the end of Spring Quarter 2016, which would leave the fall for putter design, building, and testing. It was not done by then. However, we were able to finish the machine over the summer, but didn't get to use it until about halfway through Fall Quarter of 2016, at which point it was too late to conduct complete testing. Additionally, we ran into significant trouble in our initial attempts to machine putters.

As such, in summary, the project shifted from putter design to the design and construction of a putting machine to be used in putter testing, which was validated as accurate and successful during the final quarter of the project. With more time we would move into putter design and analysis.

The putting machine was largely successful. We were able to build it without much trouble. The setbacks were fairly small (needing a second bearing was really the only issue with our design that needed to be corrected, and it was an easy fix). Our machine was somewhat overdesigned, as mentioned in Section VII. Every part of the machine was probably stronger than it really needed to be except the tripod, which ideally would have been more stable. The swing weight was heavier than it needed to be and the swing weight slide was both too long and too stout. Regardless, these issues are better than the opposite case of the machine not being strong enough. We also approximately met our budget of \$1000 for the machine (our first machine was under \$1000, but we ended up going a little over with the addition of the second bearing, each of which cost more than \$100).

The machine is easy to deploy once you've done it a few times. It is simple to operate, simple to adjust, light enough to be carried for a short distance, and small enough to be transported in the trunk of a car or in a golf cart. These attributes point to a solid design and the machine met most of our goals. The only functions we desired out of the machine that were not met were the vise adjustment and having a grip that more closely replicates hands. The vise probably needs a substantial redesign to make it easier to use, as discussed in Section VII. The grip currently consists of two solid attachments at the top and bottom of the putter grip.

Even with these problems, we created a putting machine that can produce a repeatable stroke with a variety of adjustable parameters, each time making for an accurate and consistent shot. These characteristics are crucial for performing tests on putters in order to determine if one putter can really be better than another one. There are no products on the market today that provide these capabilities and

characteristics. There are other machines that can be used to demonstrate a good stroke, but none of them are designed for testing purposes, and they are all vastly more expensive than our machine. This represents a success for our project.

Towards the end of the project, we were moving into putter design. We held a putter design contest at the Fall senior project expo, the results of which can be found in Appendix H. We were on track to make putters and test them with the machine, however we ran into trouble during machining (broke a tool in the CNC mill). This, combined with other classes, prevented us from machining our putters. Still, we created a machine for Kronos to use that will test putter designs in the future. Perhaps the next senior project group working with Kronos can use this machine to focus solely on putter design and manufacturing or on a grip replication to integrate with our machine.

Our project started out as one of putter design. It ended up resulting in the creation of a machine that will further a more scientific method of putter design. Now Kronos Golf has the tool it requires to pursue the original goal.

As a team, we would like to thank Phillip Lapuz of Kronos Golf for all his industry knowledge, helpful guidance, and genuine encouragement for the project and interest in our lives outside of school. We would also like to thank Professor Rossman for all the efforts she put into helping our project reach its realization, especially in understanding the changing scope of the project. We hope to keep in contact and receive updates of new putters designed using our testing robot.

X. Appendices

- A. QFD House of Quality
- B. Gantt Chart
- C. Pugh Matrices
- D. Concept Sketches
- E. Decision Matrix
- F. Bill of Materials
- G. Drawing Tree
- H. Drawing Packet
- I. Operation Manual
- J. Design Contest Results

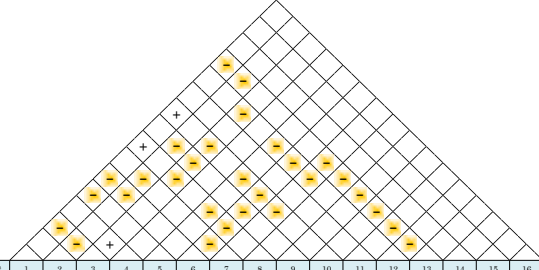
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Appendix A

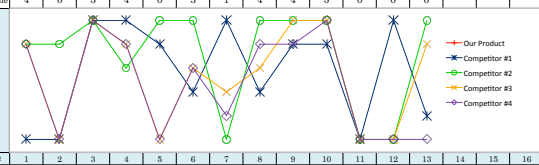
QFD: House of Quality
 Project: Kronos Golf
 Revision:
 Revision:

Correlations	
Positive	+
Negative	-
No Correlation	
Relationships	
Strong	●
Moderate	○
Weak	▽
Direction of Improvement	
Maximize	▲
Target	◇
Minimize	▼



Row#	WHO: Customers							HOW: Engineering Specifications																NOW: Current Product Assessment - Customer Requirements														
	Weight Chart	Relative Weight	Phillip Layout	Dimensional	Poly Platters	Panel User (Golf courses, etc.)	Maximum Relationship	Direction of Improvement	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	Kronos Robot	Z-Factor Rail	Pendulum Perfect Machine	Iron Archie	0	1	2	3	4	5	Row#			
1		11%	8	4	9	3	9	Replicates golf posture	●																													
2		10%	9	2	8	5	9	Accounts for hand movement		●	○																											
3		13%	6	10	4	9	9	Easy to use			●	●																										
4		6%	1	9	3	1	9	Portable	▽				●	●																								
5		10%	10	8	10	7	9	Performs repeatable stroke		○																												
6		11%	5	7	5	8	9	Fits several club sizes (grip and length)	▽	○																												
7		9%	4	3	7	5	9	Performs several different swing paths	▽		○																											
8		10%	3	6	2	10	9	Safe to use			▽	▽																										
9		11%	7	5	6	6	9	Adjustable contact position (toe/heel)	○		○																											
10		4%	2	1	1	4	9	Not expensive	▽	▽	○																											

HOW MUCH: Target		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Max Relationship		9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Technical Importance Rating		160.91	171.36	251.82	128.18	71.818	148.64	189.55	186.82	174.09	224.55	89.545	284.55	169.55			
Relative Weight		7%	8%	11%	6%	3%	7%	8%	8%	8%	10%	4%	13%	8%			
Weight Chart		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Kronos Robot		0	0	5	5	4	2	5	2	4	4	0	5	1			
Z-Factor Rail		4	4	5	3	5	5	0	5	5	5	0	0	5			
Pendulum Perfect Machine		4	0	5	4	0	3	2	3	5	5	0	0	4			
Iron Archie		4	0	5	4	0	3	1	4	4	5	0	0	0			



Appendix C - 1

Height Adjustment

Customer Requirements/Solution	Arm w/ Gear Adjust Knob	Jack	Scissor Lift	Arm w/ Holes and Pin	Fork Lift	Tripod Adjustment	Drill Press
Replicates golf posture	N/A	N/A	N/A		N/A	N/A	N/A
Accounts for hand movement	N/A	N/A	N/A	D	N/A	N/A	N/A
Easy to use	-1	0	0		-1	0	0
Portable	0	-1	-1	A	-1	1	-1
Performs repeatable stroke	N/A	N/A	N/A		N/A	N/A	N/A
Fits several club sizes (grip and length)	N/A	N/A	N/A	T	N/A	N/A	N/A
Performs several different swing paths	N/A	N/A	N/A		N/A	N/A	N/A
Safe to use	-1	-1	-1	U	-1	0	0
Adjustable contact position (toe/heel)	N/A	N/A	N/A		N/A	N/A	N/A
Not expensive	-1	-1	-1	M	-1	0	0
Manufactureablility	-1	-1	-1		-1	1	1
Net Score	-4	-4	-4	0	-5	2	0
Rank	T4	T4	T4	T2	7	1	T2
Continue?	No	No	No	Yes	No	Yes	Yes

Appendix C - 2

Contact Zone Adjustment

Customer Requirements/Solution	Slide w/ Tightening Bolt	Slot and Screw	Knob and Teeth	Lead Screw	Telescope
Replicates golf posture	N/A		N/A	N/A	N/A
Accounts for hand movement	N/A	D	N/A	N/A	N/A
Easy to use	0		1	1	-1
Portable	0	A	0	0	1
Performs repeatable stroke	N/A		N/A	N/A	N/A
Fits several club sizes (grip and length)	N/A	T	N/A	N/A	N/A
Performs several different swing paths	N/A		N/A	N/A	N/A
Safe to use	1	U	-1	0	-1
Adjustable contact position (toe/heel)	0		0	0	0
Not expensive	0	M	-1	-1	-1
Manufacturability	0		-1	0	-1
Net Score	1	0	-2	0	-3
Rank	1	T2	4	T2	5
Continue?	Yes	Yes	No	Yes	No

Appendix C - 3

Grip Forward Press

Customer Requirements/Solution	Interlock Fastener	Plate and Pins	Gear and Notch	Friction Fastener
Replicates golf posture	-1	-1	-1	
Accounts for hand movement	N/A	N/A	N/A	D
Easy to use	0	1	1	
Portable	0	-1	-1	A
Performs repeatable stroke	N/A	N/A	N/A	
Fits several club sizes (grip and length)	N/A	N/A	N/A	T
Performs several different swing paths	N/A	N/A	N/A	
Safe to use	0	0	-1	U
Adjustable contact position (toe/heel)	N/A	N/A	N/A	
Not expensive	-1	-1	-1	M
Manufacturability	0	0	-1	
Net Score	-2	-2	-4	0
Rank	T2	T2	4	1
Continue?	Yes	Yes	No	Yes

Appendix C - 4

Grip Position

Customer Requirements/Solution	Pin and Holes	Telescoping w/ Tightening Bolts	Slot and Slide w/ Set Screws	Slot and Slide w/ Pin and Holes
Replicates golf posture		N/A	N/A	N/A
Accounts for hand movement	D	N/A	N/A	N/A
Easy to use		-1	-1	-1
Portable	A	0	-1	-1
Performs repeatable stroke		N/A	N/A	N/A
Fits several club sizes (grip and length)	T	0	1	1
Performs several different swing paths		N/A	N/A	N/A
Safe to use	U	0	0	0
Adjustable contact position (toe/heel)		N/A	N/A	N/A
Not expensive	M	0	-1	-1
Manufacturability		0	-1	-1
Net Score	0	-1	-3	-3
Rank	1	2	T3	T3
Continue?	Yes	Yes	Yes	No

Appendix C - 5

Latch and Release

Customer Requirements/Solution	Spring Loaded	Pneumatics	Magnets	Ratchet	Door Latch
Replicates golf posture	N/A	N/A	N/A	N/A	
Accounts for hand movement	N/A	N/A	N/A	N/A	D
Easy to use	0	1	1	0	
Portable	0	-1	-1	0	A
Performs repeatable stroke	0	0	0	0	
Fits several club sizes (grip and length)	N/A	N/A	N/A	N/A	T
Performs several different swing paths	0	-1	0	0	
Safe to use	0	-1	0	-1	U
Adjustable contact position (toe/heel)	N/A	N/A	N/A	N/A	
Not expensive	0	-1	-1	0	M
Manufacturability	0	-1	-1	-1	
Net Score	0	-4	-2	-2	0
Rank	T1	5	T3	T3	T1
Continue?	Yes	No	Yes	No	Yes

Appendix C - 6

Grip Lie Angle

Customer Requirements/Solution	Interlock Fastener	Plate and Pins	Gear and Notch	Friction Fastener
Replicates golf posture	-1	-1	-1	
Accounts for hand movement	N/A	N/A	N/A	D
Easy to use	0	1	1	
Portable	0	-1	-1	A
Performs repeatable stroke	N/A	N/A	N/A	
Fits several club sizes (grip and length)	N/A	N/A	N/A	T
Performs several different swing paths	N/A	N/A	N/A	
Safe to use	0	0	-1	U
Adjustable contact position (toe/heel)	N/A	N/A	N/A	
Not expensive	-1	-1	-1	M
Manufacturability	0	0	-1	
Net Score	-2	-2	-4	0
Rank	T2	T2	4	1
Continue?	Yes	Yes	No	Yes

Appendix C - 7

Swing Plane Adjustment

Customer Requirements/Solution	Interlock Fastener	Plate and Pins	Friction Fastener	Rope Mount	Cable Adjustment	Push Bolt
Replicates golf posture	0	0		-1	0	0
Accounts for hand movement	N/A	N/A	D	N/A	N/A	N/A
Easy to use	1	1		-1	-1	1
Portable	0	-1	A	-1	-1	0
Performs repeatable stroke	0	0		0	0	-1
Fits several club sizes (grip and length)	N/A	N/A	T	N/A	N/A	N/A
Performs several different swing paths	-1	-1		-1	0	0
Safe to use	0	0	U	-1	-1	0
Adjustable contact position (toe/heel)	N/A	N/A		N/A	N/A	N/A
Not expensive	-1	0	M	-1	-1	0
Manufacturability	0	0		-1	-1	-1
Net Score	-1	-1	0	-7	-5	-1
Rank	2	T3	1	6	5	T3
Continue?	Yes	Yes	Yes	No	No	No

Appendix C - 8

Swing Weight

Customer Requirements/Solution	Lever Arm with Mass	Weight on Slide	Rotational Spring
Replicates golf posture		N/A	N/A
Accounts for hand movement	D	N/A	N/A
Easy to use		1	0
Portable	A	-1	1
Performs repeatable stroke		0	-1
Fits several club sizes (grip and length)	T	N/A	N/A
Performs several different swing paths		0	0
Safe to use	U	0	-1
Adjustable contact position (toe/heel)		N/A	N/A
Not expensive	M	0	0
Manufacturability		1	0
Net Score	0	1	-1
Rank	2	1	3
Continue?	Yes	Yes	Yes

Appendix C - 9

Swing

Customer Requirements/Solution	Bearing	Leaf Spring	Slide on Ring	Linkage	Ball and Socket	Door Hinge
Replicates golf posture		N/A	N/A	N/A	N/A	N/A
Accounts for hand movement	D	N/A	N/A	N/A	N/A	N/A
Easy to use		0	0	0	-1	0
Portable	A	0	-1	-1	0	0
Performs repeatable stroke		-1	0	0	-1	-1
Fits several club sizes (grip and length)	T	N/A	N/A	N/A	N/A	N/A
Performs several different swing paths		N/A	N/A	N/A	N/A	N/A
Safe to use	U	-1	0	-1	0	-1
Adjustable contact position (toe/heel)		N/A	N/A	N/A	N/A	N/A
Not expensive	M	0	-1	-1	-1	1
Manufacturability		0	-1	-1	0	0
Net Score	0	-2	-3	-4	-3	-1
Rank	1	3	T4	6	T4	2
Continue?	Yes	Yes	No	No	No	Yes

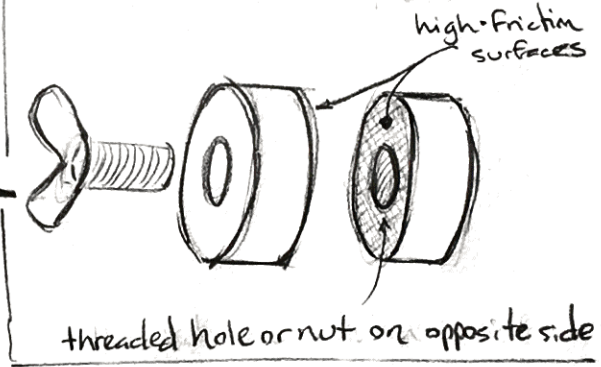
DESIGN A

Shaft and bearing pivot

Spring-loaded pin-and-hole system for adjustable height adjustment and to accept different putter lengths

Uses lead screw to adjust contact position

Friction fasteners to adjust swing plane, lie angle, and forward press

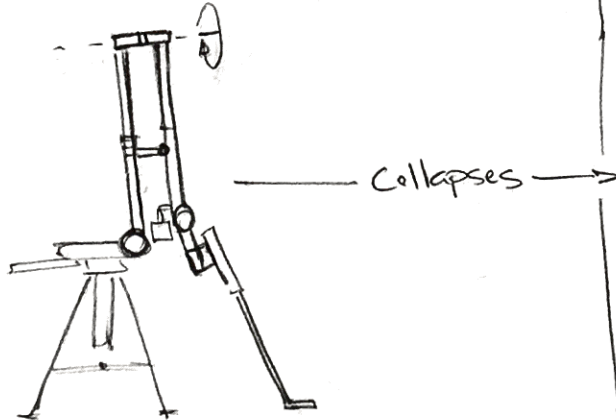


Simple door latch and release system

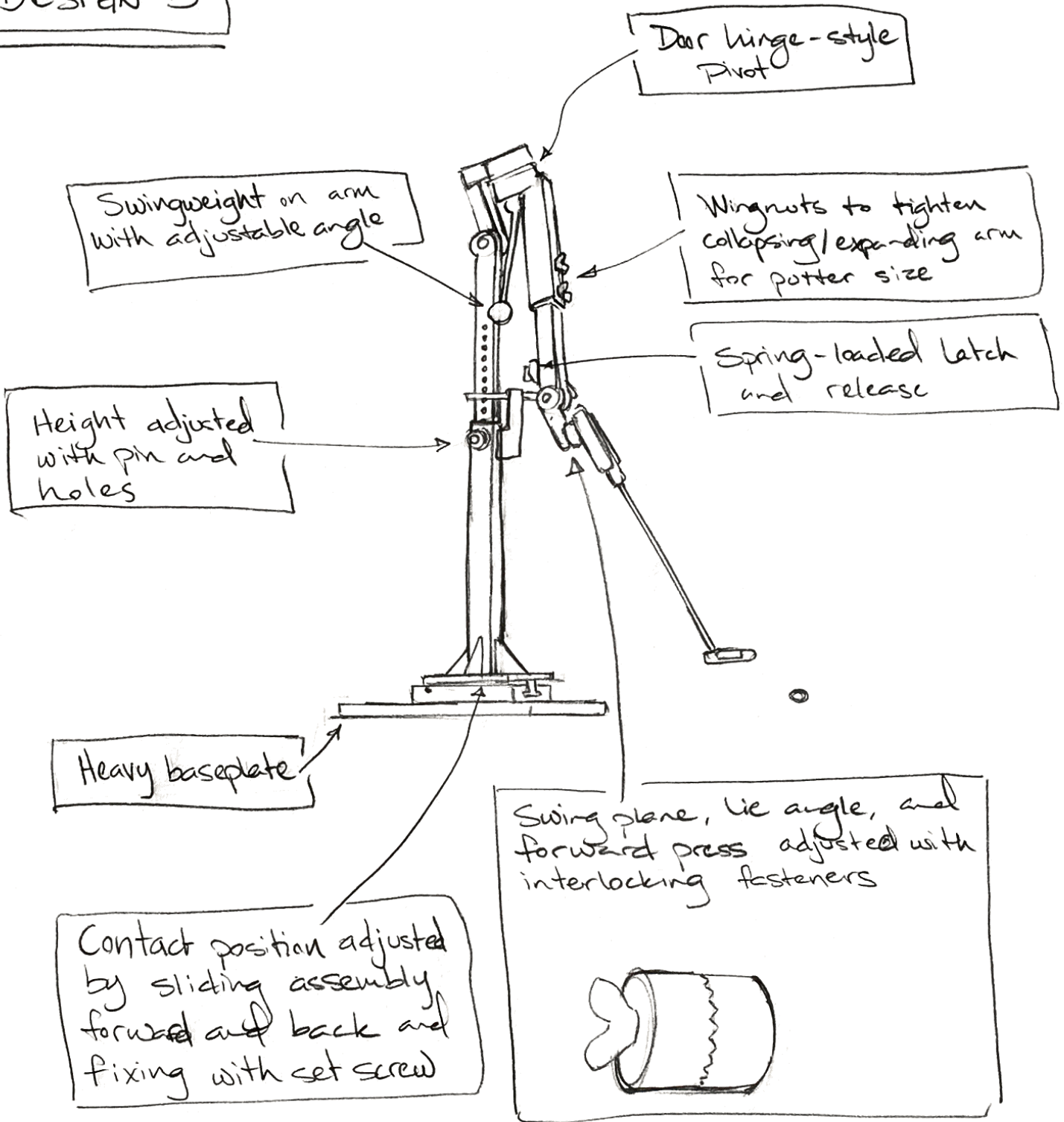
Swingweight on slide makes for easy adjustment

Adjustable tripod allows pivot point to range between 4 and 5 feet high

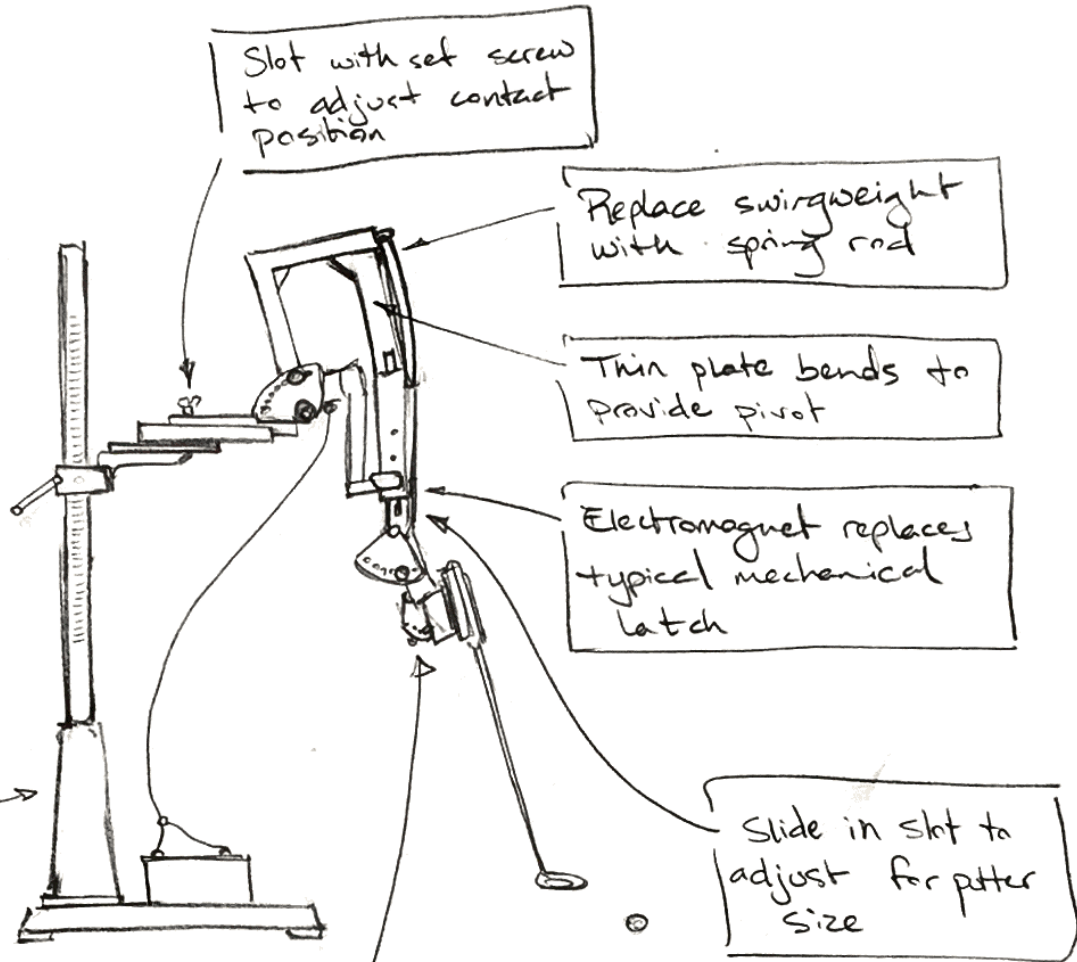
Fairly compact and easy to re-deploy



DESIGN B



DESIGN C



Swing plane, lie angle, and forward press adjusted with pins and plates

Appendix E

Design Criteria	Weight	Scoring Design		
		A	B	C
Replicates golf posture	0.10	90	75	80
		8.76	7.30	7.79
Accounts for hand movement	0.09	100	100	100
		8.85	8.85	8.85
Easy to use	0.12	75	70	80
		8.63	8.05	9.20
Portable	0.05	90	80	75
		4.78	4.25	3.98
Performs repeatable stroke	0.14	85	80	75
		12.04	11.33	10.62
Fits several club sizes (grip and length)	0.10	85	83	81
		8.27	8.08	7.88
Performs several different swing paths	0.08	90	75	60
		7.17	5.97	4.78
Safe to use	0.09	80	75	70
		7.08	6.64	6.19
Adjustable contact position (toe/heel)	0.10	90	80	70
		8.76	7.79	6.81
Not expensive	0.04	85	77	80
		3.01	2.73	2.83
Manufacturability	0.11	85	65	75
		9.03	6.90	7.96
Sum	1.00	86.37	77.88	76.91

Appendix F

Bill of Materials								
Sub Assembly	Part Name	Part Number	Dimensions	Stock	Quantity Needed	Quantity Bought	Cost	Vendor
Tripod								
	Tripod	given			1	1		0 Cogswell Video Services
	Feet	given			3	3		0 Cogswell Video Services
	Baby Receiver Plate	given			1	1		0 Cogswell Video Services
	1/4-20 x 3/4" 100° Steel Phillips Machine Screw	90471A413			12	25	7.49	McMaster Carr
	1/4-20 Low-Strength Steel Nut	90473A029			4	100	2.68	McMaster Carr
	1/4 Grade-8 Steel Washer	98023A029			4	100	6.36	McMaster Carr
Vice - 100								
	Bottom Plate		3.5 x 7 x 0.25 Al	0.25 x 3.5 x 12	1	1	5.56	Online Metals
	Ends		3.5 x 1.5 x 0.75 Al	1.5 x 3.5 x 10	2	1	24.68	Online Metals
	Moving Base		3.5 x 1.5 x 1.5 Al	done (ends)	1 -	-		Online Metals
	Rails	5911K33	0.5 DIA x 6.5	0.5 DIA x 18	2	1	24.6	McMaster Carr
	Lead Screw	94210A186	1/2-20 x 1ft medium steel threaded rod		1	1	5.66	McMaster Carr
	1/4-20 x 1/2" Set Screw	92505A537			1	50	8.4	McMaster Carr
	1/2-20 Threaded Knob	5993K440			1	1	4.08	McMaster Carr
	1/4-20 x 5/8" steel socket head cap screw	90128A243			4	25	4.7	McMaster Carr
	1/4 zinc plated steel washer	91090A105			4	50	3.25	McMaster Carr
	Base Tube		1.75 x 0.125 sq Al tubing 7"	1.75 x 0.125 sq Al tubing 4"	1	1	19.71	Online Metals
	Joint Large	1610T28	3.5 DIA x 0.75 Al Round	3.5 DIA x 1	1	1	10.44	McMaster Carr
Main Tube - 200								
	Main Tube Large		1.75 x 0.125 sq Al tubing 9.5"	done (Base Tube)	1 -	-		Online Metals
	Joint Large Hole	1610T28	3.5 DIA x 0.75 Al Round	3.5 DIA x 1	1	1	10.44	McMaster Carr
	Housing Mount		4.875 x 1.5 x 1.75 Al	1.75 x 1.75 x 12	1	1	19.48	Online Metals
	3/4 Shaft Bearing with Housing	2773T210			1	1	93.22	McMaster Carr
	7/16-20 1.5" Bolt	92865A316			2	25	11.45	McMaster Carr
	7/16-20 Nut	95505A614			2	100	9.78	McMaster Carr
	7/16 General Purpose Washer	98180A140			4	25	4.65	McMaster Carr
Down Tube Shaft - 300								
	Down Tube Large		1.75 x 0.125 sq Al tubing 10.25"	done (Base Tube)	1 -	-		Online Metals
	Shaft		1.75 sq Al solid 5.125"	done (Housing Mount)	1 -	-		Online Metals
	3/8-24 Knob	5993K370			1	1	2.27	McMaster Carr
	3/8-24 2" Thread Rod	90322A129			1	1	3.27	McMaster Carr
	3/8-24 Nut	90670A165			1	10	12.81	McMaster Carr
Down Tube Small - 400								
	Down Tube Small		1.5 x 0.125 sq Al tubing 14.75"	1.5 x 0.125 sq Al tubing 48	1	1	17.88	Online Metals
	Swing Weight Slide		3.5 x 20 x 0.5 Al	0.5 x 4 x 24	1	1	24.42	Online Metals
	Slide Block Top		1.5 x 1.5 x 0.875 Al	done (ends)	1 -	-		Online Metals
	Swing Weight	1388K8023660	3 x 3 x 2 Steel	2 x 3 x 3	1	1	36.6	McMaster Carr
	Joint Small	1610T19	3.0 DIA x 0.625 Al Round	3.0 DIA x 1	1	1	8.24	McMaster Carr
	3/8-24 Knob	5993K370			1	1	2.27	McMaster Carr
	3/8-24 Threaded Rod 2"	90322A129			1	1	3.27	McMaster Carr
	3/8-24 Nut	90670A165			1 -	-		McMaster Carr
	1/4-20 stainless steel knurled head thumb screw	91746A418			1	1	7.11	McMaster Carr
	1/4-20 1.5" 82° flat head phillips machine screw	90273A546			2	50	7.34	McMaster Carr
Grip - 500								
	Grip Tube		1.5 x 0.125 sq Al tubing 7"	done (Down Tube Small)	1 -	-		Online Metals
	Grip Base		3 x 8 x 0.5 Al	0.5 x 3 x 24	1	1	18.32	Online Metals
	Grip Top		3 x 1 x 0.5 Al	done (Grip Base)	2 -	-		Online Metals
	Joint Small Hole	1610T19	3.0 DIA x 0.625 Al Round	3.0 DIA x 1	1	1	8.24	McMaster Carr
Other - 600								
	HDPE Large	8624K641	3.5 DIA x 0.25 HDPE Round	4 DIA x 3	1	1	21.1	McMaster Carr
	HDPE Small	-	3.0 DIA x 0.25 HDPE Round	done (HDPE Large)	1 -	-		McMaster Carr
	1/2 General Purpose Washer	90107A033			2	25	9.71	McMaster Carr
	1/2-13 Wingnut	90876A326			2	2	10.2	McMaster Carr
	1/2-13 x 2.5" Square Bolt	92327A308			3	3	12.69	McMaster Carr
	1" shaft collar	6157K180			1	1	4.51	McMaster Carr
	Latch Rod		0.5 DIA x 8 Al Round	0.5 DIA x 10	1	1	2.65	Online Metals
	1/4-20 plastic thumb screws x 2	91185A430			4	5	8.13	McMaster Carr

Appendix G
Tree

Drawing

Part Number	Description	Rev	Complete	Checked	Date
22CRJ000	Complete Assembly		CDC	CDC	5/2/16
22CRJ100	Vise Assembly		CDC	CDC	5/2/16
22CRJ101	Base		JPV	JPV	4/28/16
22CRJ103	Vise Screw		JPV	JPV	4/28/16
22CRJ104	End		JPV	JPV	4/28/16
22CRJ105	Moving Base		JPV	JPV	4/30/16
22CRJ106	Guide Rail		JPV	JPV	4/30/16
22CRJ107	Vice Tube Weldment		JPV	JPV	4/30/16
22CRJ111	Base Tube		JPV	JPV	4/30/16
22CRJ112	Large Joint		JPV	JPV	4/30/16
22CRJ200	Main Tube Assembly		CDC	CDC	5/2/16
22CRJ201	Main Tube		RNH	RNH	5/1/16
22CRJ202	Large Joint with Hole		RNH	RNH	4/18/16
22CRJ203	Bearing Housing Mount		RNH	RNH	4/18/16
22CRJ204	Latch				
22CRJ250	Main Tube Weldment		RNH	RNH	5/2/16
22CRJ300	Down Tube Large and Shaft Assembly		CDC	CDC	5/2/16
22CRJ301	Down Tube Large		RNH	RNH	4/28/16
22CRJ303	Shaft		RNH	RNH	5/1/16
22CRJ350	Down Tube Large Weldment		RNH	RNH	5/2/16
22CRJ400	Down Tube Small Assembly		CDC	CDC	4/28/16
22CRJ401	Down Tube Small		RNH	RNH	5/1/16
22CRJ402	Swingweight Slide		RNH	RNH	5/1/16
22CRJ403	Slide Block		RNH	RNH	5/1/16
22CRJ404	Swingweight		RNH	RNH	5/1/16
22CRJ405	Joint Small		RNH	RNH	5/1/16
22CRJ450	Down Tube Small Weldment		RNH	RNH	5/2/16
22CRJ500	Grip Assembly		CDC	CDC	5/2/16
22CRJ501	Grip Tube		JPV	JPV	4/30/16
22CRJ502	Grip Base		JPV	JPV	4/30/16
22CRJ503	Grip Top		JPV	JPV	4/30/16
22CRJ504	Grip Tube Weldment		JPV	JPV	4/30/16
22CRJ600	Misc		-	-	-
22CRJ603	Small Joint Hole		JPV	JPV	4/30/16

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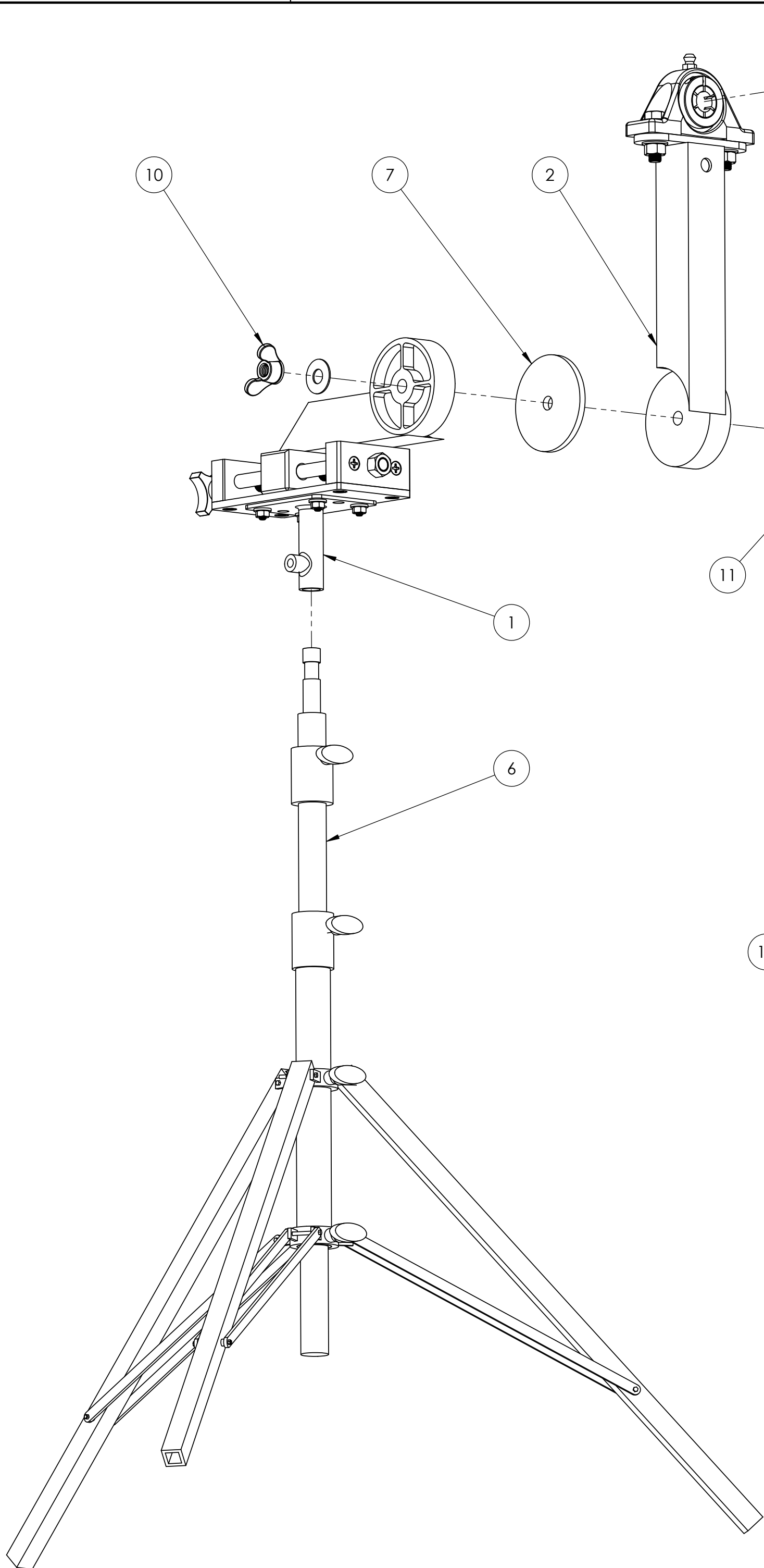
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13	22CRJ667	LATCH ROD	1
12	6157K170	McMASTER 7/8" SHAFT COLLAR - 6157K170	1
11	92327A308	McMASTER 1/2-13 SQUARE END CAP SCREW	2
10	90876A326	McMASTER 1/2-13 WINGNUT - 90876A326	2
9	90107A033	McMASTER 1/2" WASHER - 90107A033	2
8	22CRJ602	HDPE SMALL	1
7	22CRJ601	HDPE LARGE	1
6	-	NORM'S GRIP TRIPOD	1
5	22CRJ500	RIGID GRIP ASSEMBLY	1
4	22CRJ400	DOWN TUBE SMALL ASSEMBLY	1
3	22CRJ300	DOWN TUBE SHAFT ASSEMBLY	1
2	22CRJ200	MAIN TUBE ASSEMBLY	1
1	22CRJ100	VISE ASSEMBLY	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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UNLESS OTHERWISE SPECIFIED:
 DIMENSIONS ARE IN INCHES
 TOLERANCES:
 FRACTIONAL: ± 1/16
 ANGULAR: MACH ± 3
 BEND ± 1
 DECIMAL: .XX ± .01
 .XXX ± .005



Mechanical Engineering
 CAL POLY

NAME	DATE
CDC	5/2/16
CDC	5/2/16
ROBOT	

TITLE: **COMPLETE ASSEMBLY**
 DWG. NO. **22CRJ000**
 SCALE: 1:3.6 WEIGHT: 33 LBS SHEET 1 OF 1

N/A	22CRJ000	MATERIAL	N/A
NEXT ASSY	USED ON	FINISH	N/A
APPLICATION		DO NOT SCALE DRAWING	

DRAWN	CDC	5/2/16
CHECKED	CDC	5/2/16
STAGE	ROBOT	
VENDOR	POLY PUTTERS	

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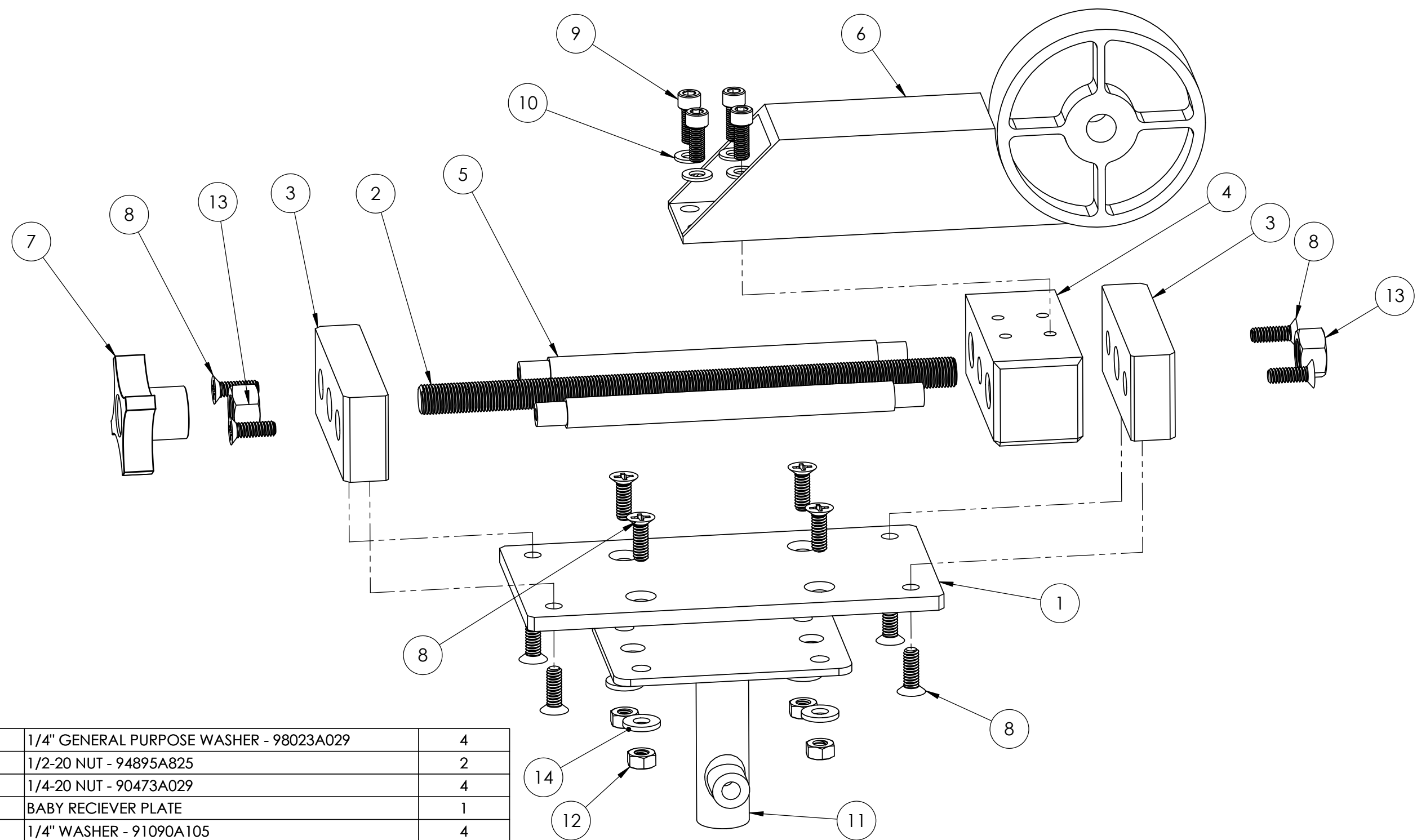
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14	22CRJ168	1/4" GENERAL PURPOSE WASHER - 98023A029	4
13	22CRJ167	1/2-20 NUT - 94895A825	2
12	22CRJ166	1/4-20 NUT - 90473A029	4
11	22CRJ120	BABY RECIEVER PLATE	1
10	22CRJ115	1/4" WASHER - 91090A105	4
9	22CRJ114	1/4-20 CAP SCREW - 90128A430	4
8	22CRJ109	100° FLAT HEAD SCREW - 90471A413	12
7	22CRJ108	1/2-20 THREADED KNOB - 5993K440	1
6	22CRJ107	VISE TUBE & AND JOINT LARGE WELDMENT	1
5	22CRJ106	VISE GUIDE RAIL	2
4	22CRJ105	MOVING VISE BASE	1
3	22CRJ104	END	2
2	22CRJ103	1/2-20 THREADED LEAD SCREW - 94210A186	1
1	22CRJ101	VISE BASE	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± 1/16 ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX ± .01 .XXX ± .005		
22CRJ000	22CRJ000	MATERIAL	N/A	DRAWN: CDC 5/2/16 CHECKED: CDC 5/2/16 STAGE: ROBOT
NEXT ASSY	USED ON	FINISH	N/A	SIZE: B DWG. NO.: 22CRJ100 REV: -
APPLICATION		DO NOT SCALE DRAWING		VENDOR: POLY PUTTERS SCALE: 1:1.7 WEIGHT: 4.2 LBS SHEET 1 OF 1

4

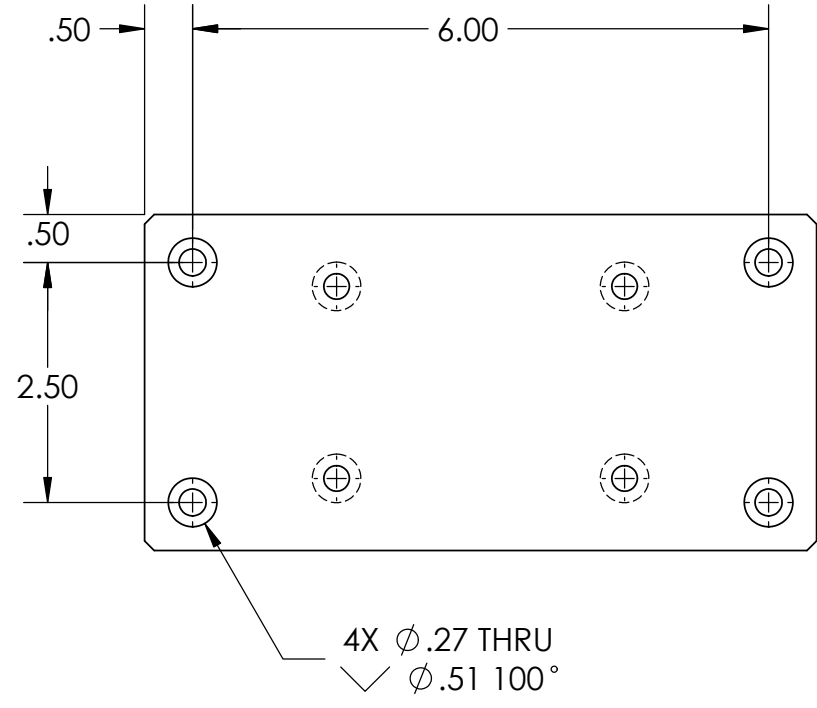
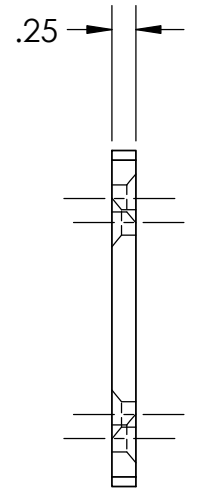
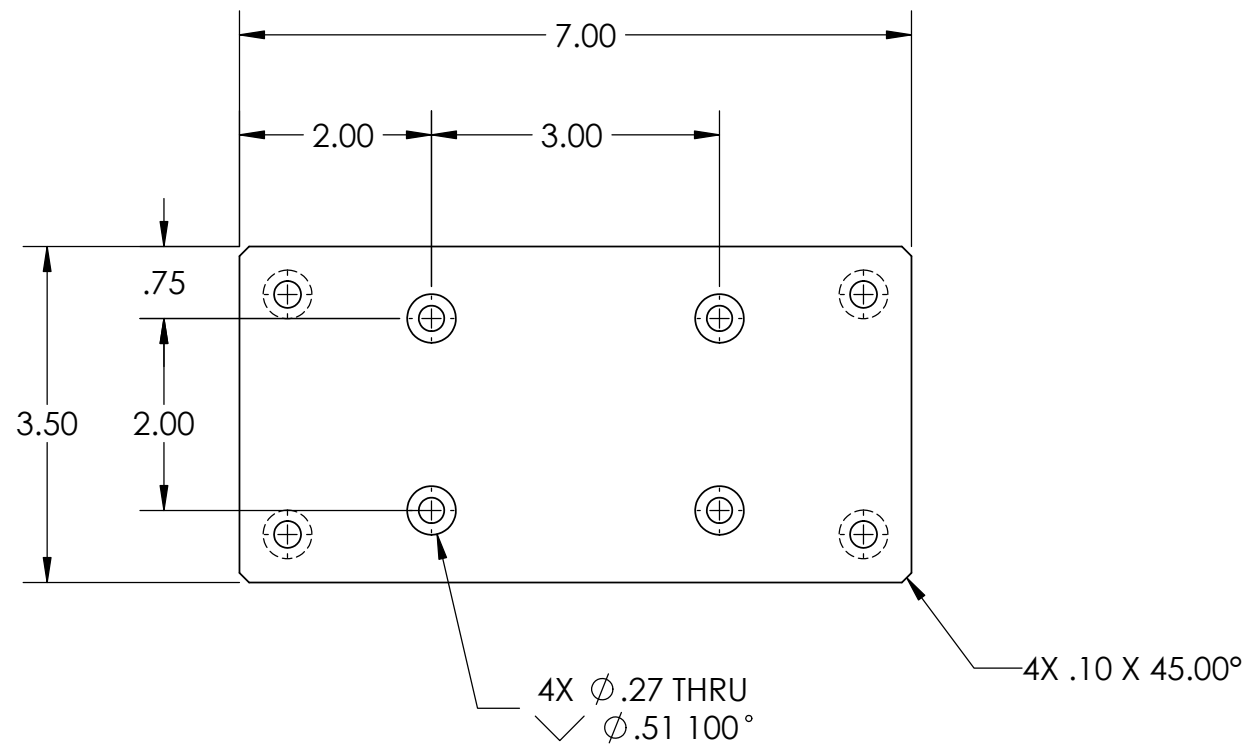
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1		.25 X 3.5 X 7.0 PLATE	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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22CRJ100	22CRJ000	MATERIAL	6061	DRAWN	JPV	4/28/16	TITLE: BASE
NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV	4/28/16	SIZE B
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT		DWG. NO. 22CRJ101
				VENDOR	POLY PUTTERS		REV -
				SCALE: 1:2		WEIGHT:	SHEET 1 OF 1

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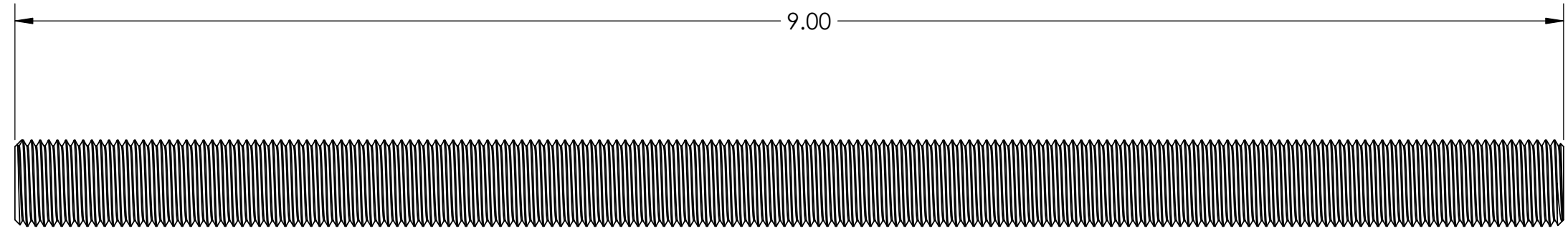
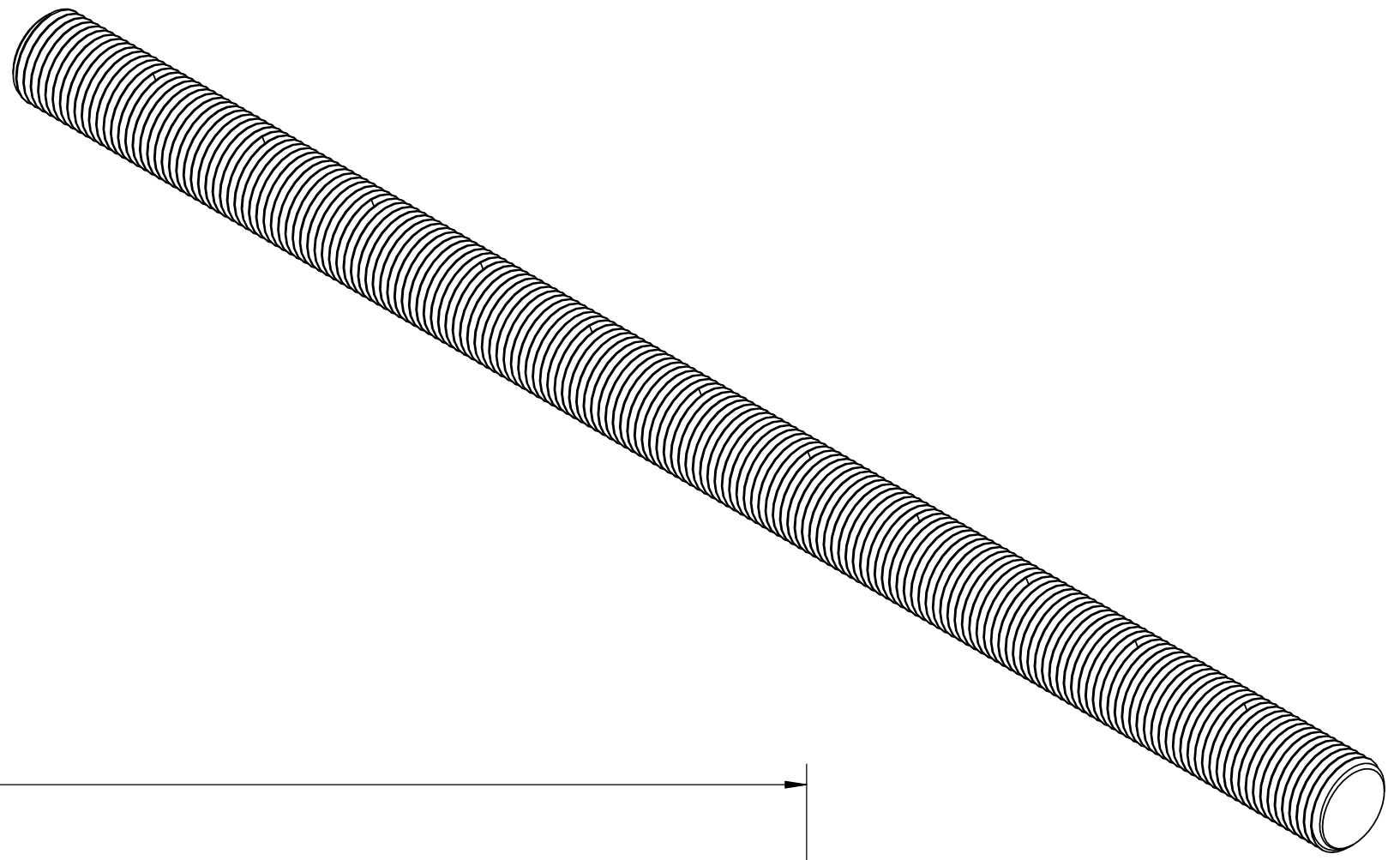
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1	94210A186	McMASTER - THREADED ROD	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± 1/16 ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX ± .01 .XXX ± .005			TITLE: <h2>WISE SCREW</h2>		
	22CRJ100	22CRJ000	MATERIAL	DRAWN	JPV	4/22/16
	NEXT ASSY	USED ON	FINISH	CHECKED	JPV	4/22/16
APPLICATION		DO NOT SCALE DRAWING	STAGE	ROBOT		
			VENDOR	POLY PUTTERS		

SIZE	DWG. NO.	REV
B	22CRJ103	-

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SCALE: 3:2 WEIGHT: SHEET 1 OF 1

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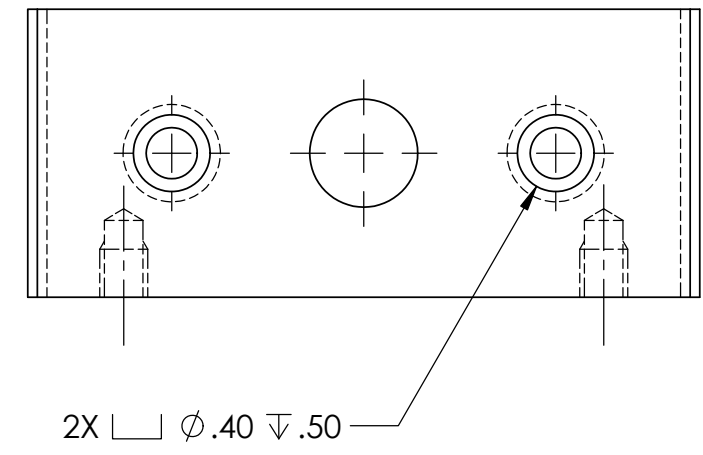
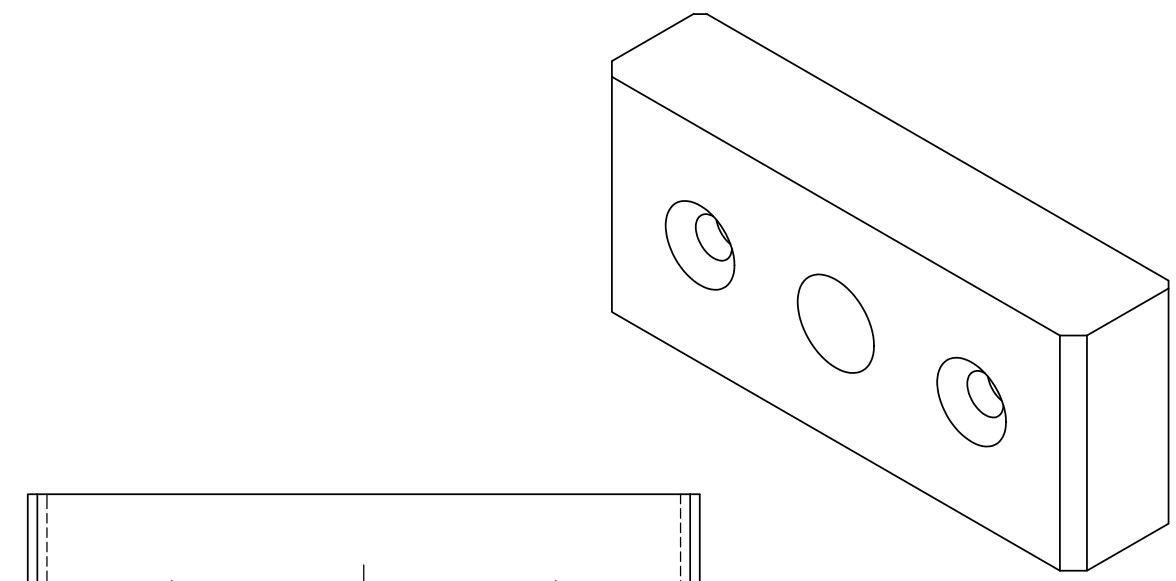
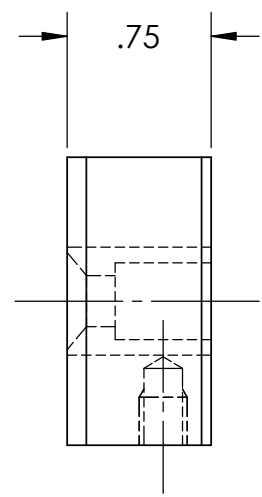
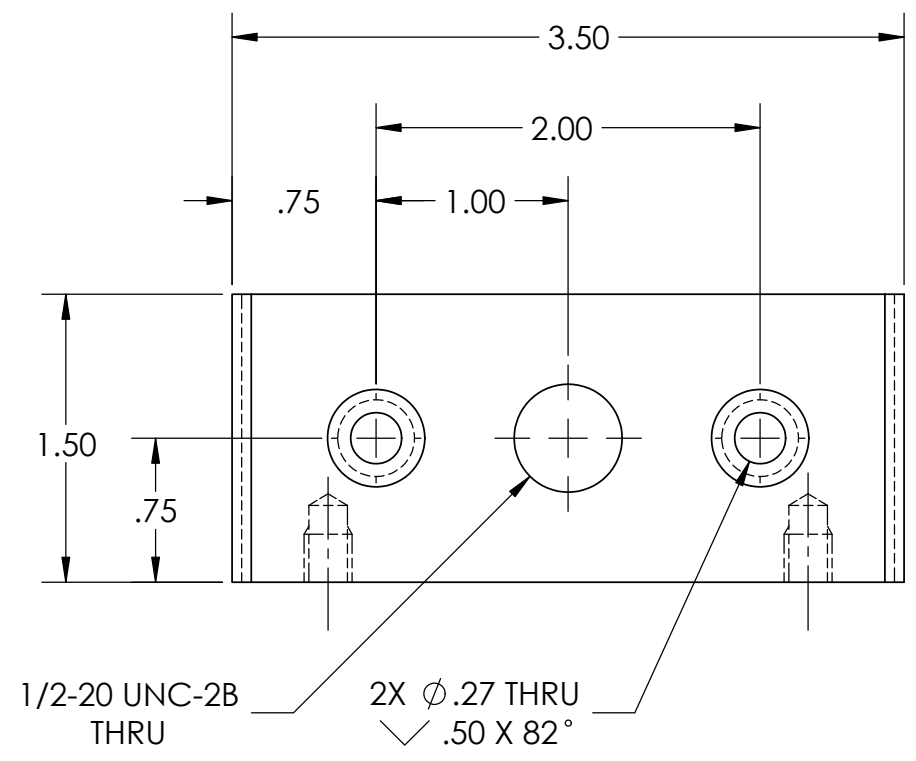
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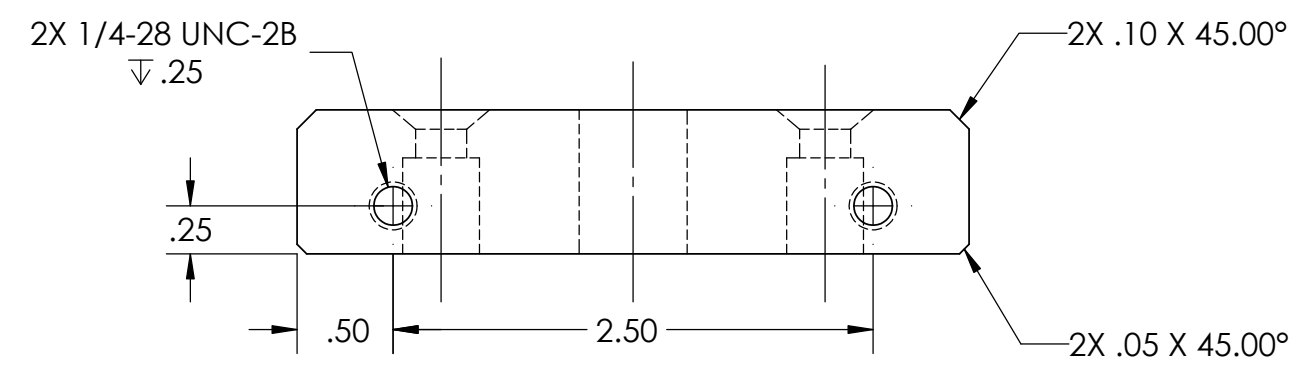
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1		.75 X 1.5 X 3.5 BLOCK	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: \pm 1/16 ANGULAR: MACH \pm 3 BEND \pm 1 DECIMAL: .XX \pm .01 .XXX \pm .005			END		
	MATERIAL	6061		DRAWN	JPV	4/22/16
	FINISH	125		CHECKED	JPV	4/22/16
NEXT ASSY	USED ON	STAGE	ROBOT		SIZE B DWG. NO. 22CRJ104 REV -	
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS	
				SCALE: 1:1	WEIGHT: SHEET 1 OF 1	

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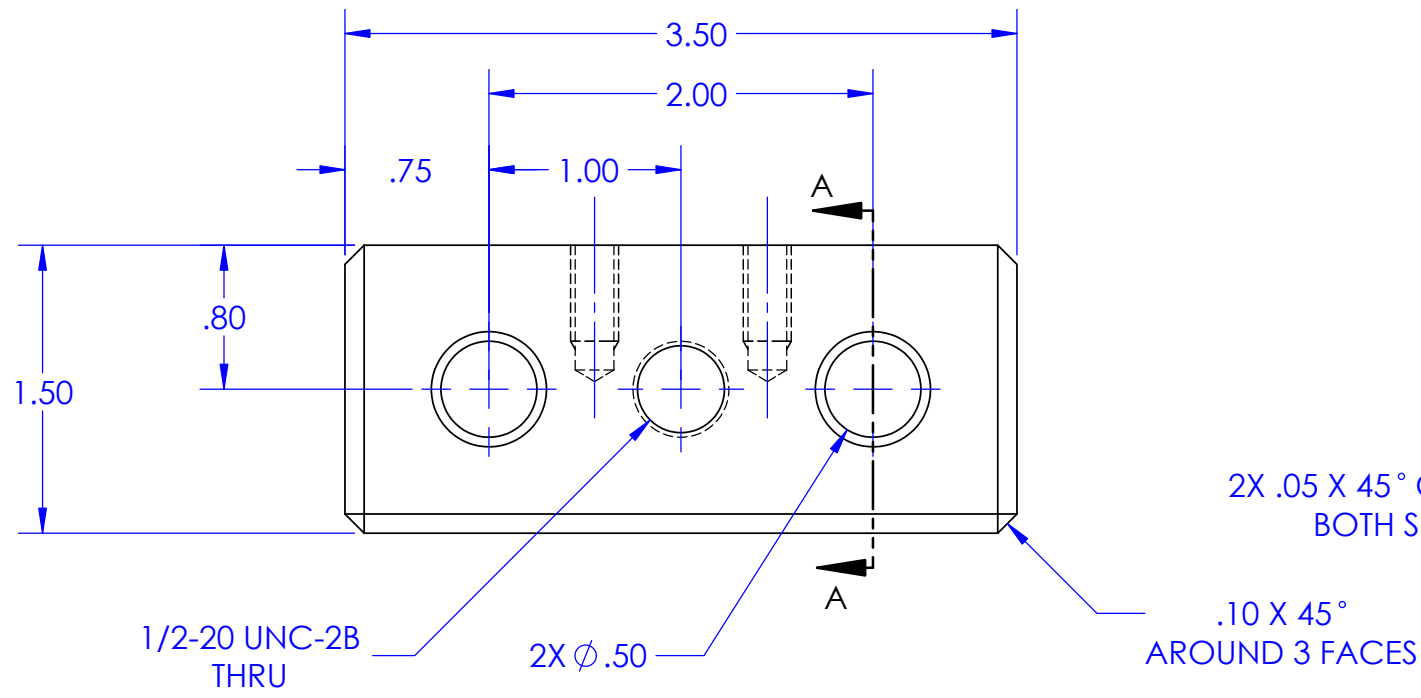
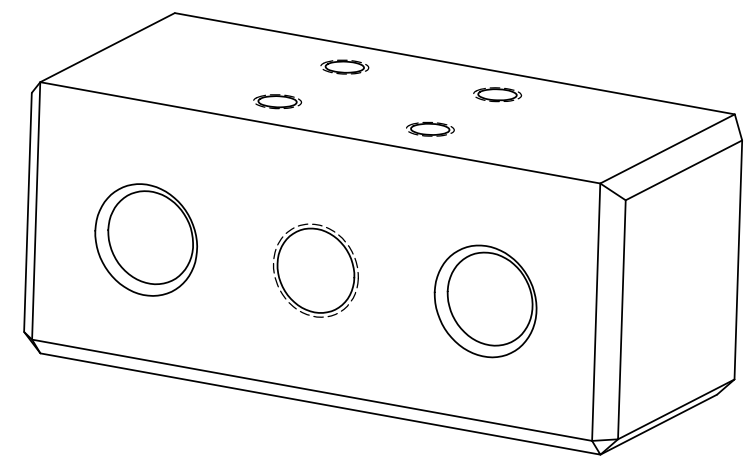
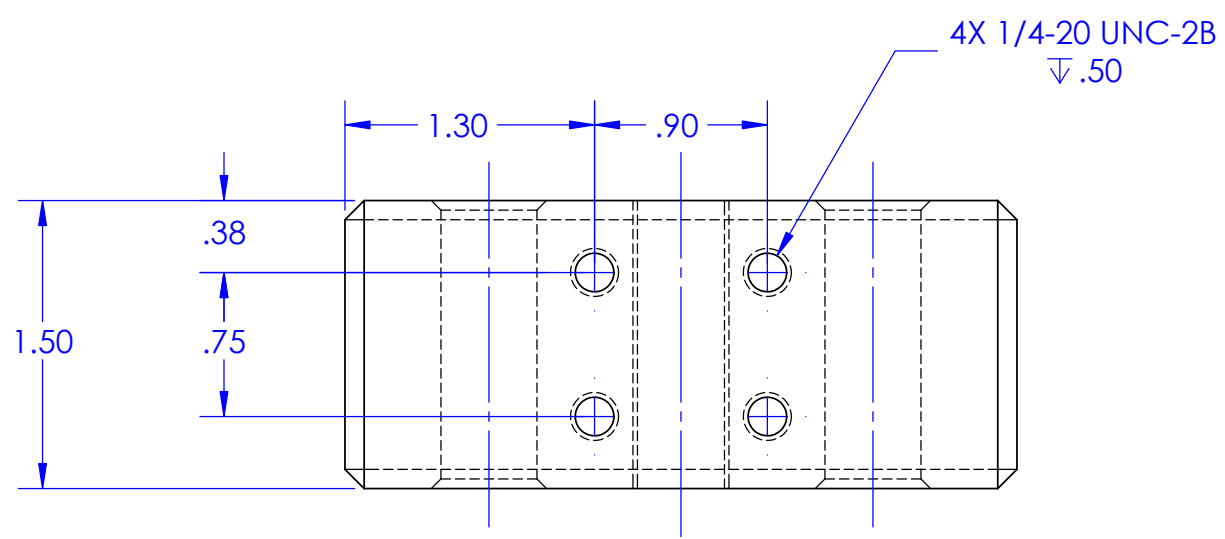
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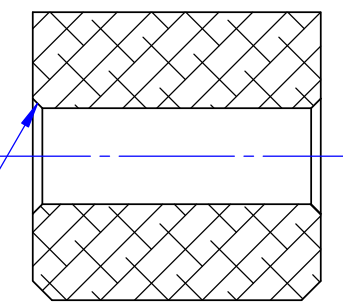
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2X .05 X 45° CHAMFER BOTH SIDES



SECTION A-A

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1		1.5 X 1.5 X 3.5 BLOCK	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

PROPRIETARY AND CONFIDENTIAL		UNLESS OTHERWISE SPECIFIED:				
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22CRJ100	22CRJ000	MATERIAL	6061	DRAWN	JPV	4/30/16
NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV	4/30/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT	
				VENDOR	POLY PUTTERS	

SIZE	DWG. NO.	REV
B	22CRJ105	-

SCALE: 1:1 WEIGHT: SHEET 1 OF 1

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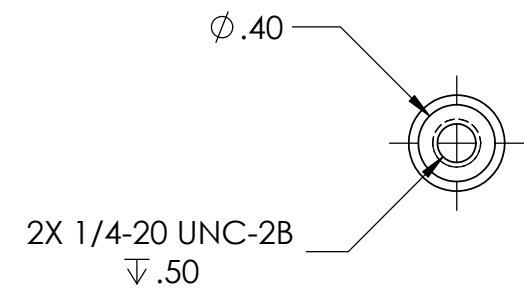
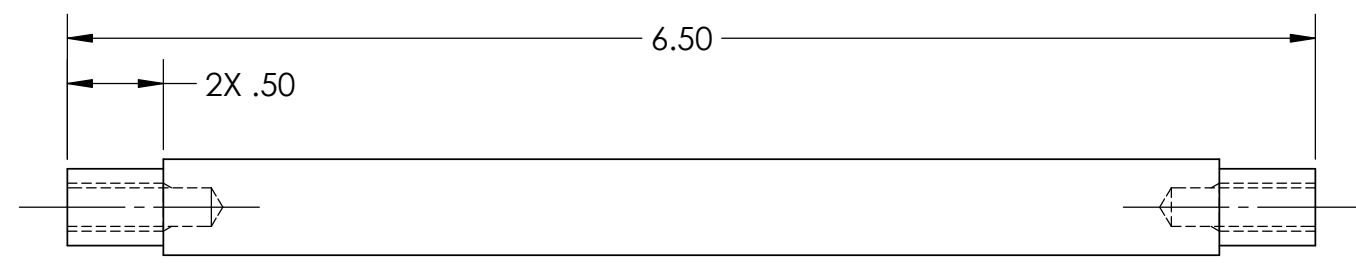
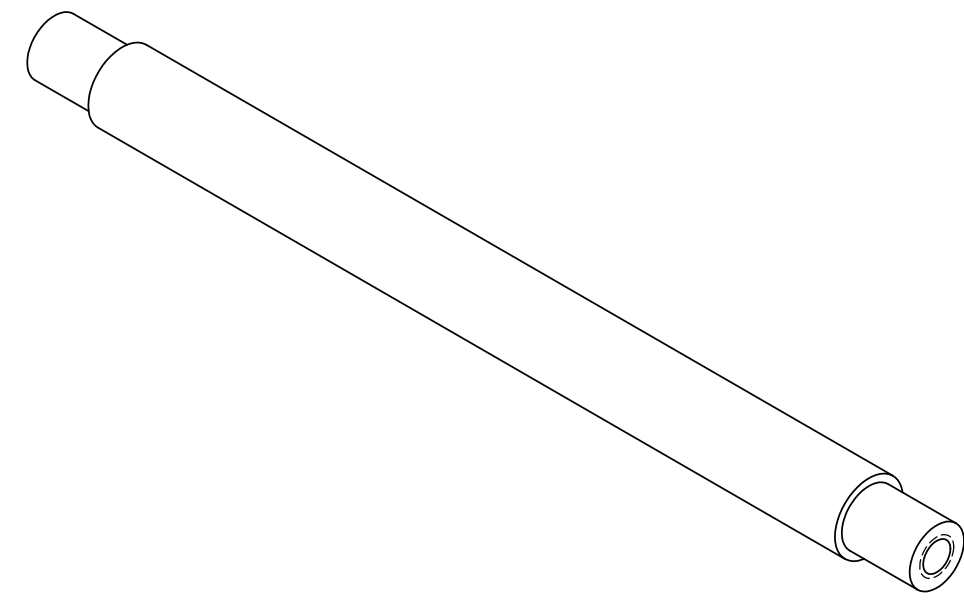
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1	5911K33	McMASTER - ALUMINUM RAIL	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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	MATERIAL 6061			TITLE: GUIDE RAIL	
22CRJ100	22CRJ000	FINISH 125	DRAWN JPV 4/30/16	SIZE B	DWG. NO. 22CRJ106
NEXT ASSY	USED ON	APPLICATION DO NOT SCALE DRAWING	CHECKED JPV 4/30/16	REV -	SCALE: 1:1 WEIGHT:
			STAGE ROBOT	SHEET 1 OF 1	
			VENDOR POLY PUTTERS		

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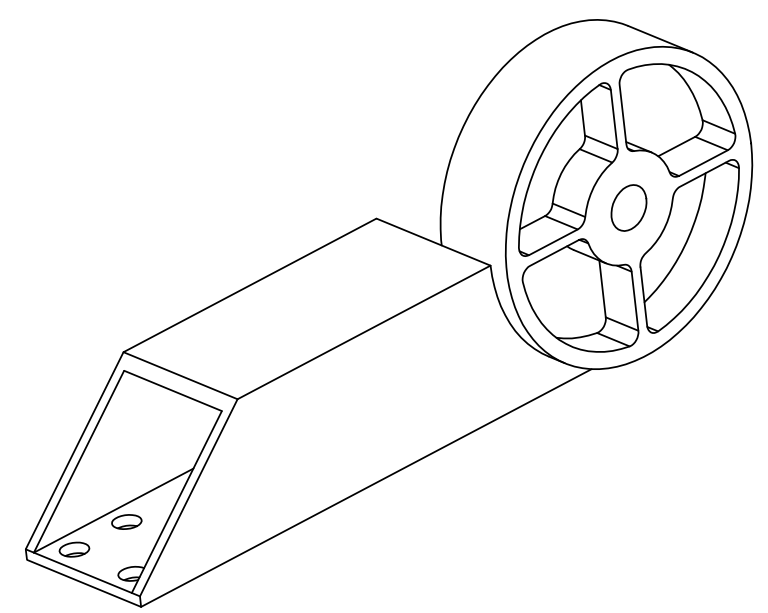
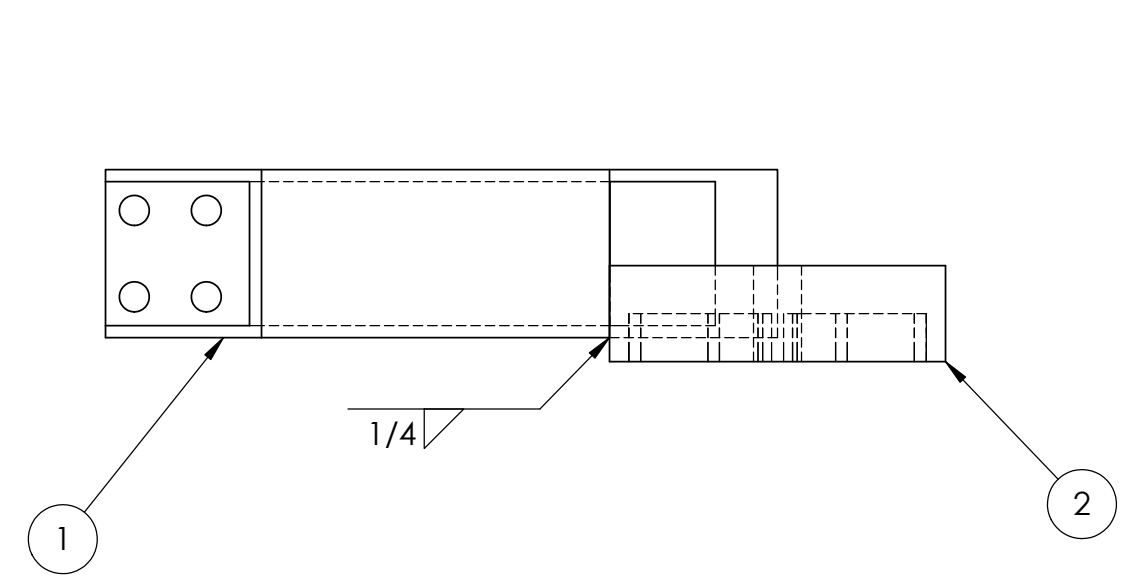
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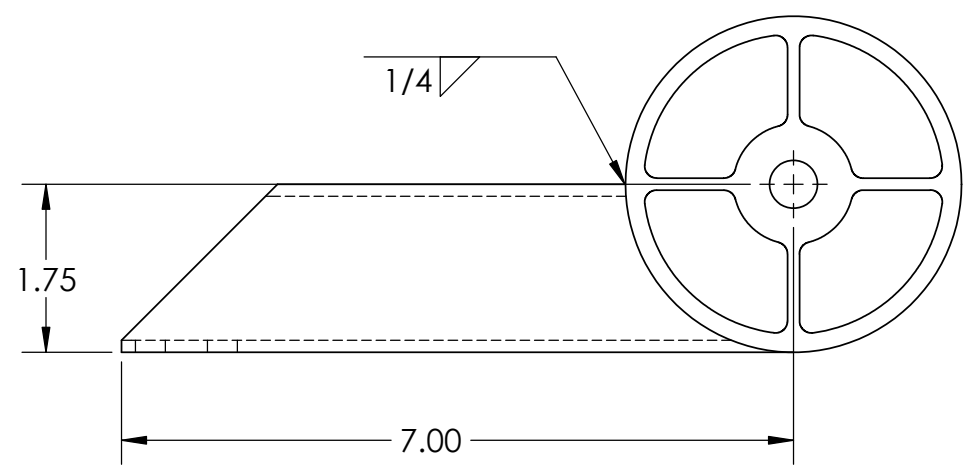
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A



2	22CRJ112	LARGE JOINT	1
1	22CRJ111	BASE TUBE	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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22CRJ100	22CRJ000	MATERIAL	6061	DRAWN	JPV	DATE	4/30/16
NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV	DATE	4/30/16
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS		
				TITLE:		VICE TUBE WELDMENT	
				SIZE	DWG. NO.	REV	
				B	22CRJ107	-	
				SCALE: 1:2	WEIGHT:	SHEET 1 OF 1	

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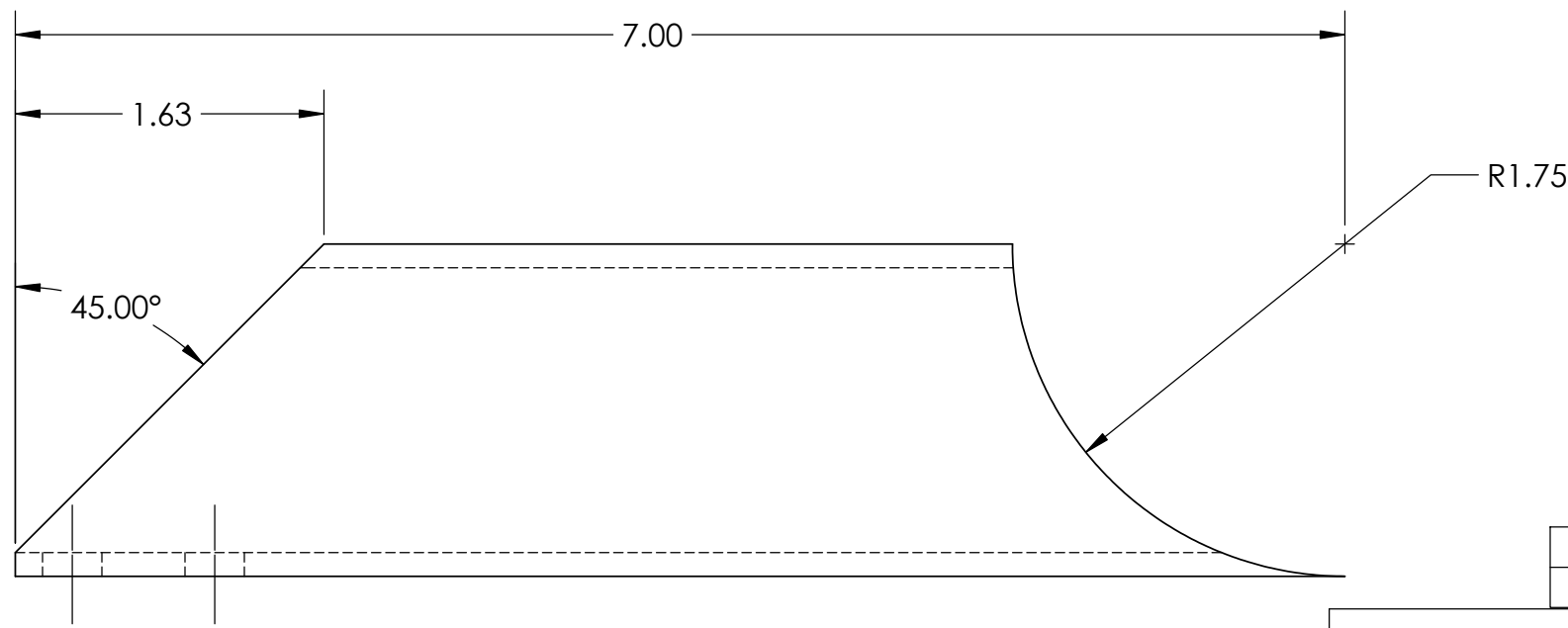
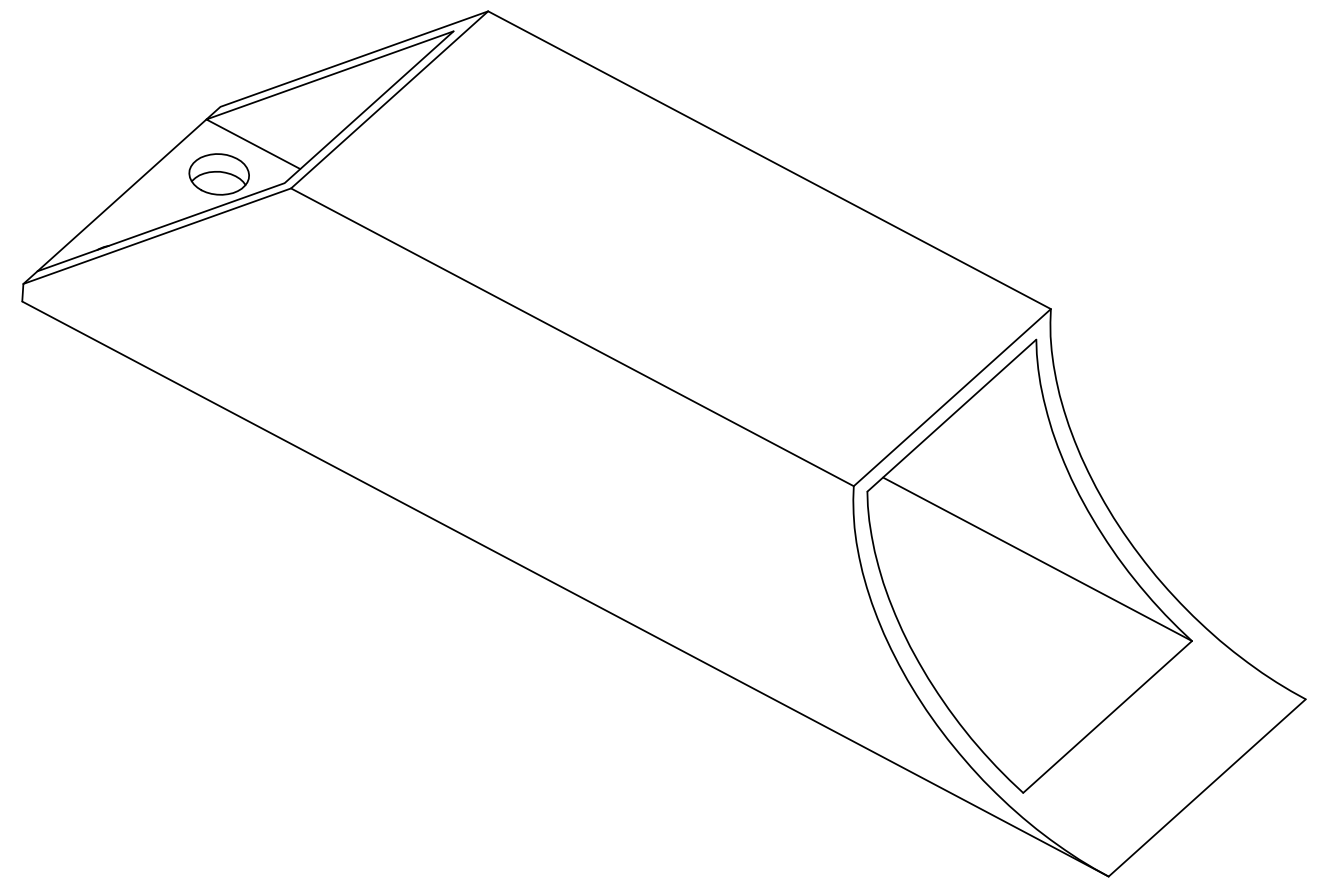
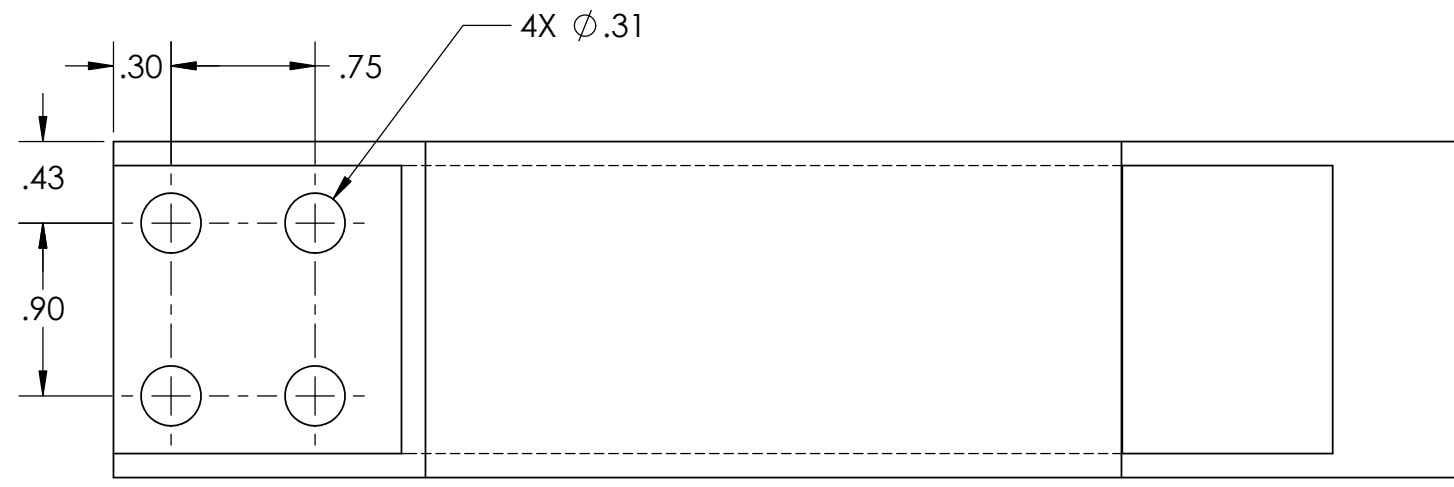
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B

B



1		1.75 X .125 SQUARE TUBING	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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22CRJ100	22CRJ000	MATERIAL	6061	DRAWN	JPV	DATE	4/30/16
NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV	DATE	4/30/16
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS		
				TITLE:		BASE TUBE	
				SIZE	DWG. NO.	REV	
				B	22CRJ111	-	
				SCALE: 1:1	WEIGHT:	SHEET 1 OF 1	

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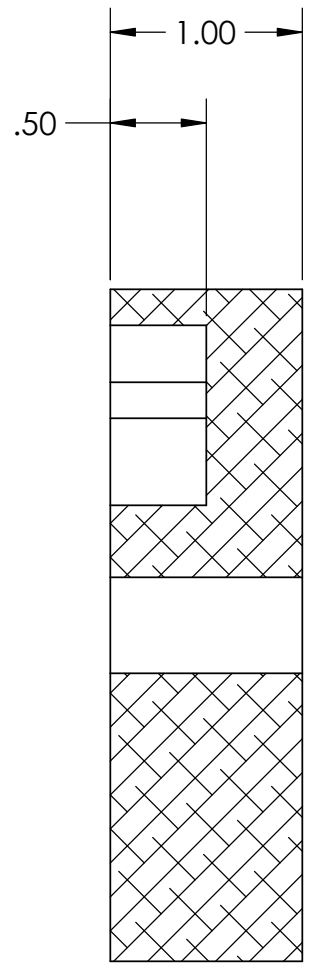
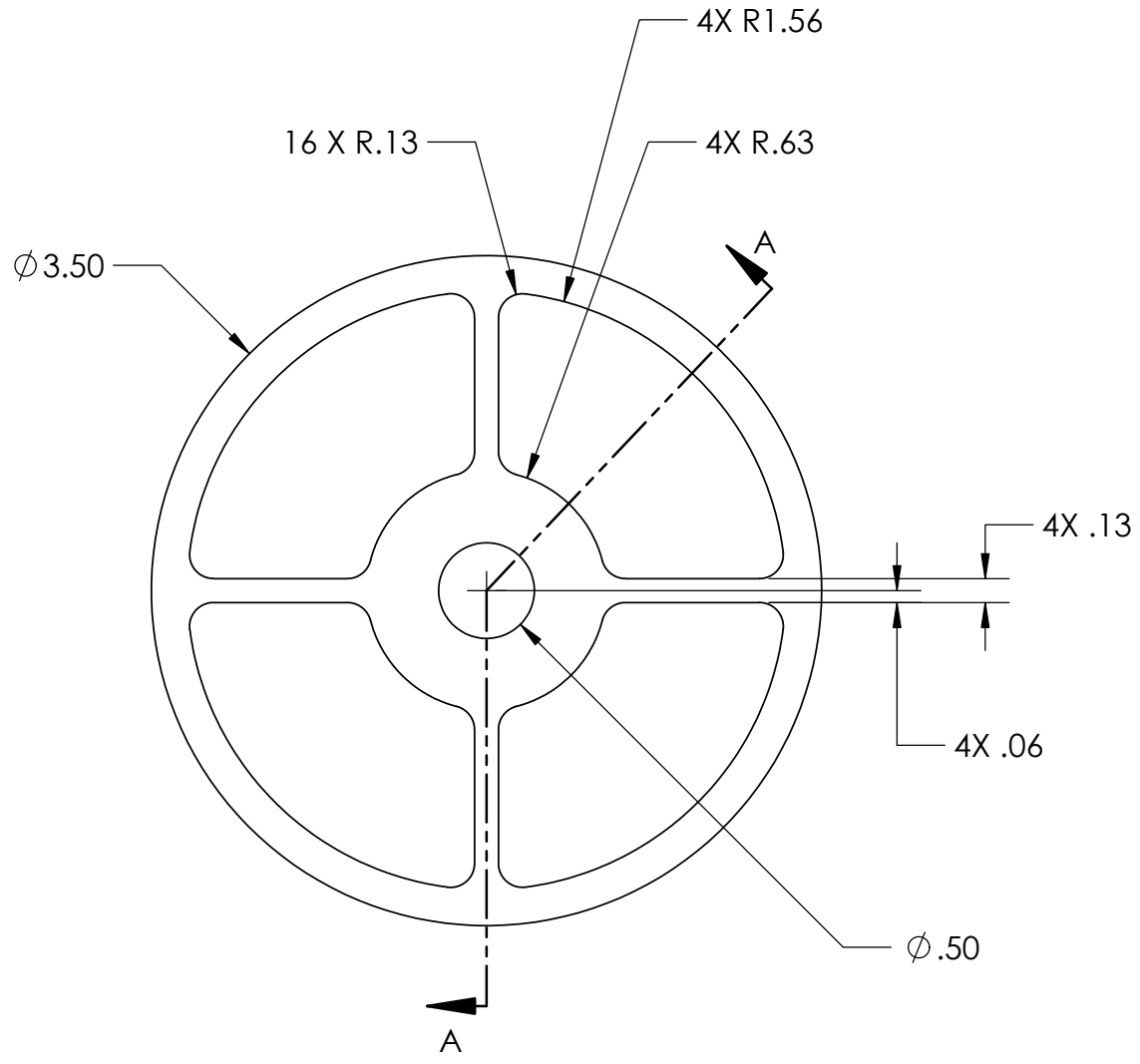
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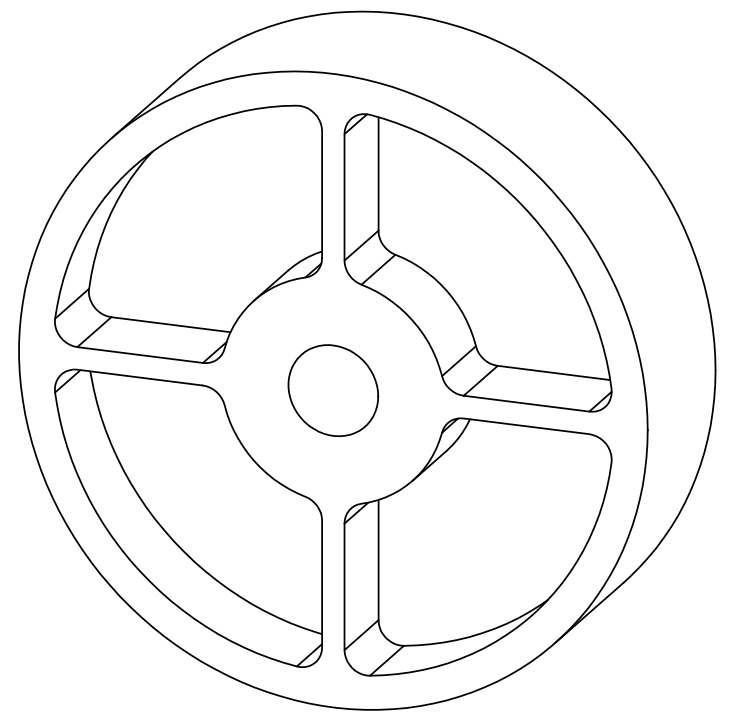
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SECTION A-A



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1		Ø3.5 X 1 BAR	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

<p>PROPRIETARY AND CONFIDENTIAL</p> <p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.</p>	UNLESS OTHERWISE SPECIFIED:					
	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± 1/16 ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX ± .01 .XXX ± .005			TITLE: <h1>LARGE JOINT</h1>		
	22CRJ100	22CRJ000	MATERIAL 6061	DRAWN JPV	DATE 4/30/16	SIZE B
	NEXT ASSY	USED ON	FINISH 125	CHECKED JPV	DATE 4/30/16	DWG. NO. 22CRJ112
APPLICATION		DO NOT SCALE DRAWING	VENDOR POLY PUTTERS	SCALE: 1:1	WEIGHT:	
			SHEET 1 OF 1		REV -	

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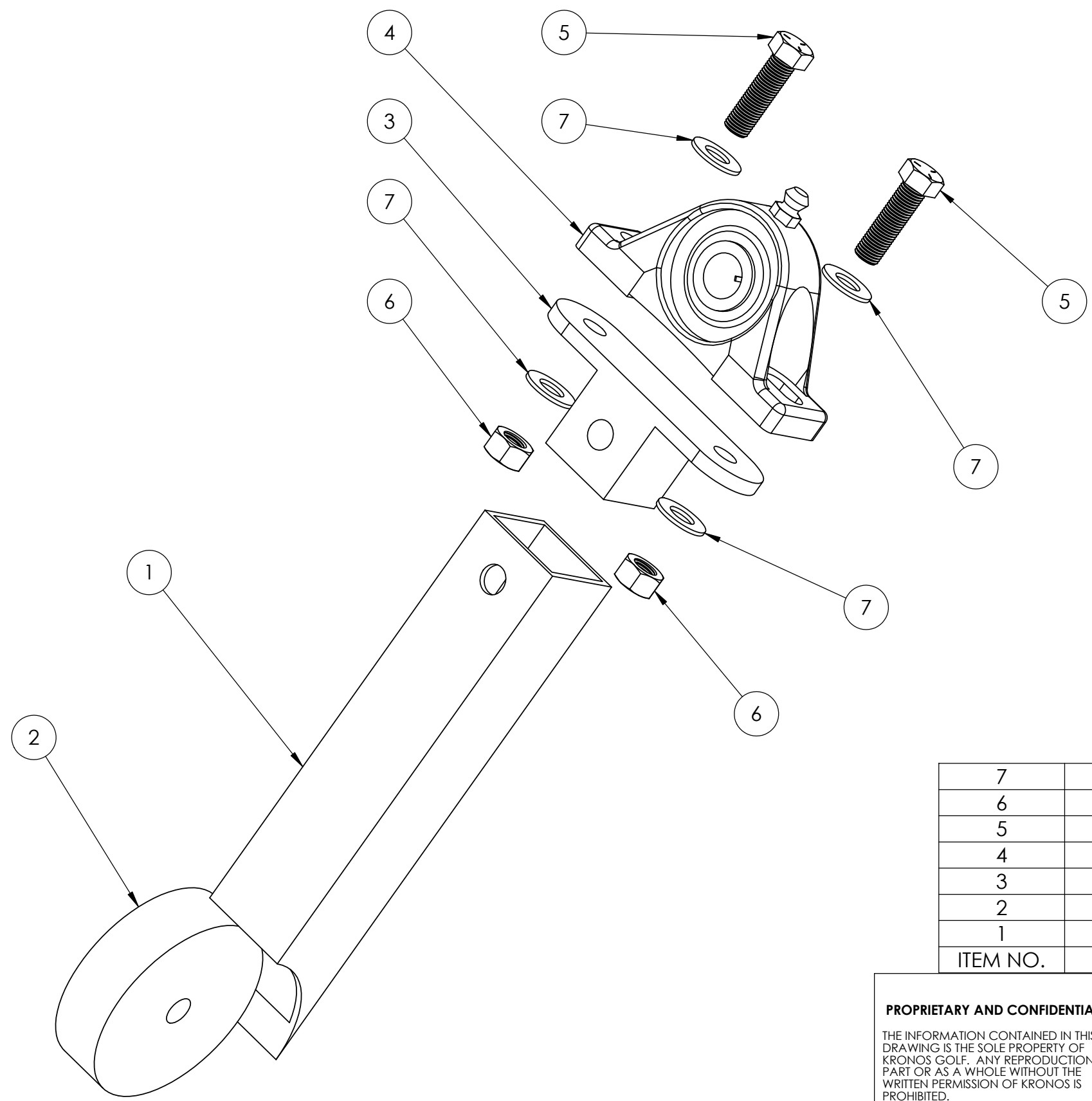
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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
7	22CRJ207	7/16" GENERAL PURPOSE WASHER	4
6	22CRJ206	7/16-20 NUT - 95505A614	2
5	22CRJ205	7/16-20 BOLT - 92865A316	2
4	22CRJ204	3/4" SHAFT BEARING W/ HOUSING - 2773T210	1
3	22CRJ203	HOUSING MOUNT	1
2	22CRJ202	JOINT LARGE HOLE	1
1	22CRJ201	MAIN TUBE LARGE	1

<p>PROPRIETARY AND CONFIDENTIAL</p> <p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.</p>		UNLESS OTHERWISE SPECIFIED:		 <p>Mechanical Engineering CAL POLY</p>	
		<p>DIMENSIONS ARE IN INCHES</p> <p>TOLERANCES:</p> <p>FRACTIONAL: ± 1/16</p> <p>ANGULAR: MACH ± 3</p> <p>BEND ± 1</p> <p>DECIMAL: .XX ± .01</p> <p>.XXX ± .005</p>			
22CRJ000	22CRJ000	MATERIAL	N/A	DRAWN	CDC 5/2/16
NEXT ASSY	USED ON	FINISH	N/A	CHECKED	CDC 5/2/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT
				VENDOR	POLY PUTTERS
				SIZE	B
				DWG. NO.	22CRJ200
				REV	-
				SCALE: 1:2	WEIGHT: 1.8 LBS
				SHEET 1 OF 1	

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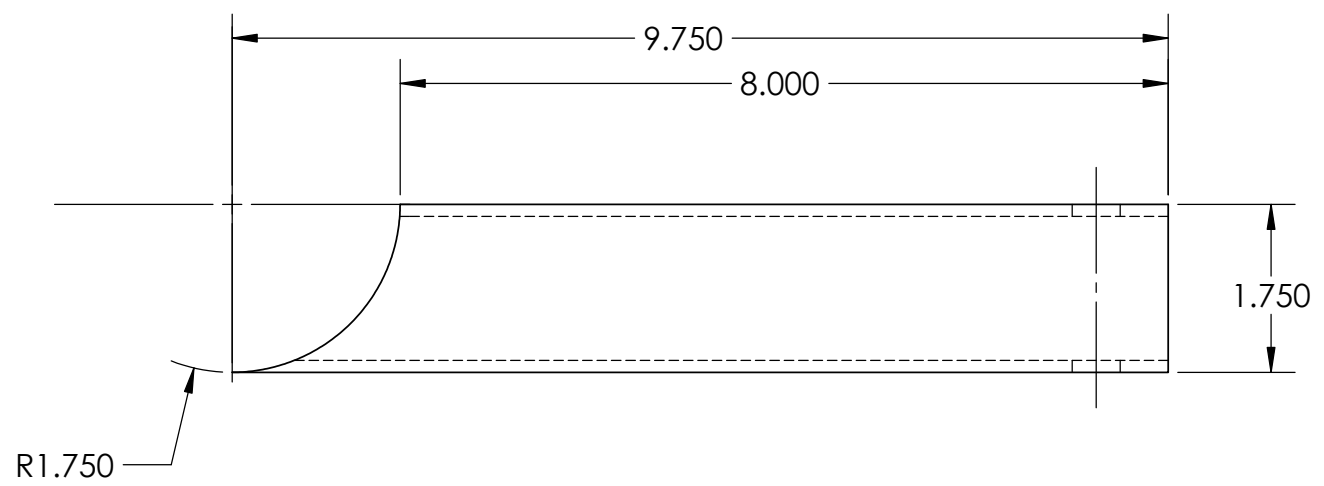
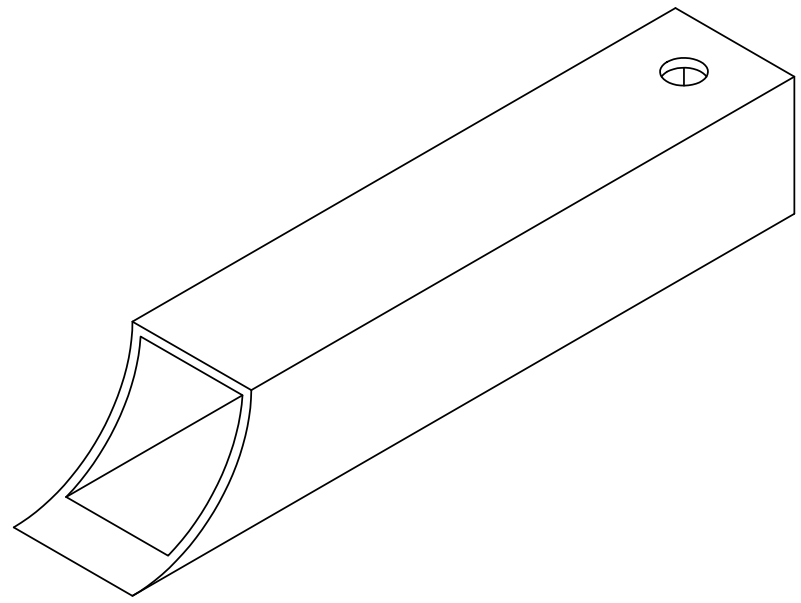
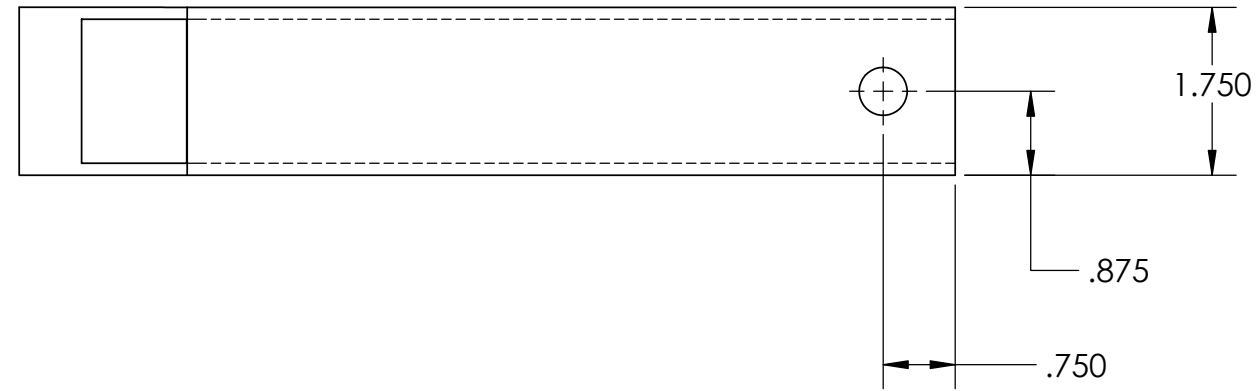
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1	1	22CRJ201	1.75" x 0.125" 6061 ALUMINUM SQUARE TUBING		
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION		
PROPRIETARY AND CONFIDENTIAL		UNLESS OTHERWISE SPECIFIED:		 Mechanical Engineering CAL POLY	
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			
22CRJ200	22CRJ000	MATERIAL	DRAWN	NAME	DATE
NEXT ASSY	USED ON	6061	CHECKED	RNH	5/1/16
APPLICATION		FINISH	STAGE	ROBOT	
		125	VENDOR	POLY PUTTERS	
		DO NOT SCALE DRAWING	TITLE:		
			MAIN TUBE		
			SIZE	DWG. NO.	REV
			B	22CRJ201	-
			SCALE: 1:2	WEIGHT: 0.67 LBS	SHEET 1 OF 1

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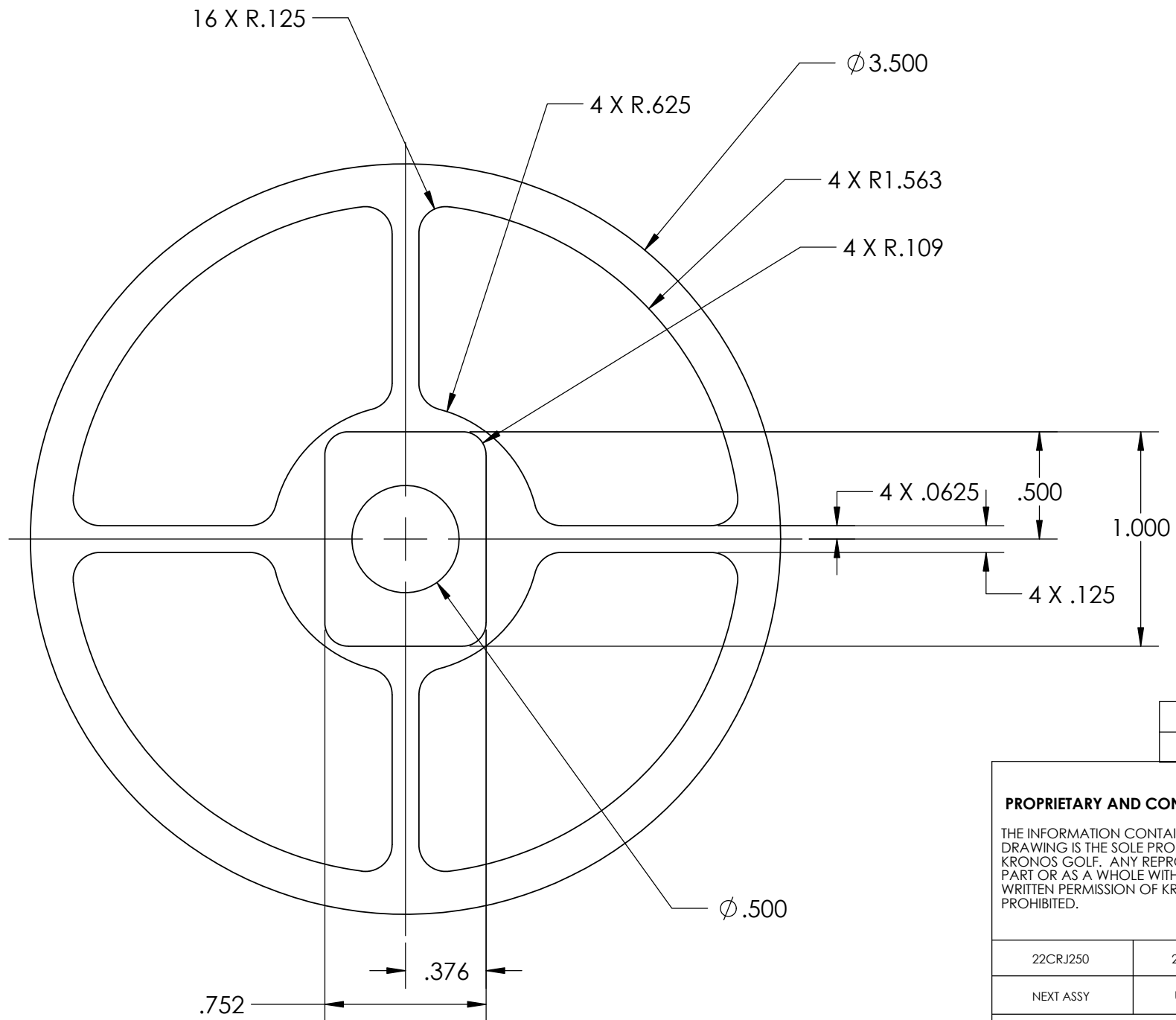
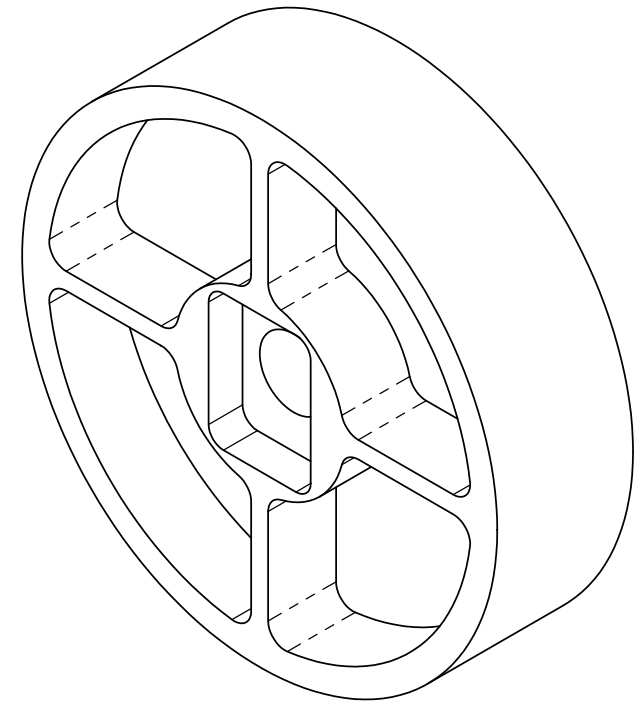
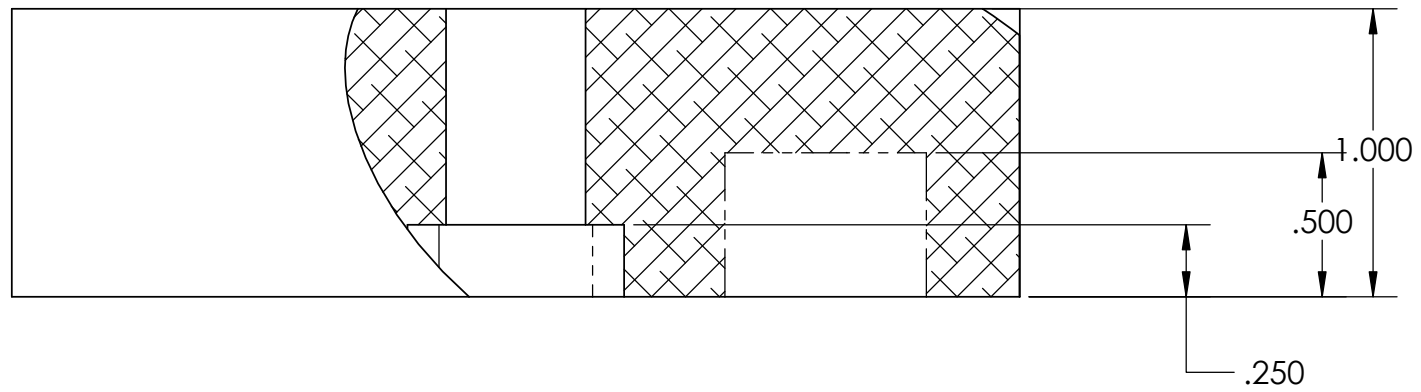
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1	22CRJ202	3.5" 6061 ALUMINUM BAR STOCK	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

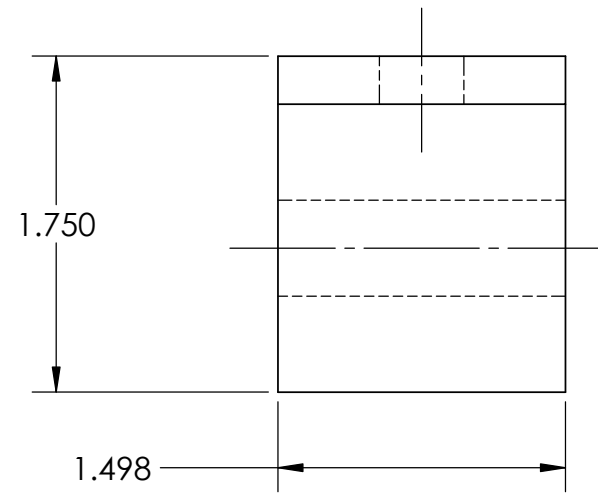
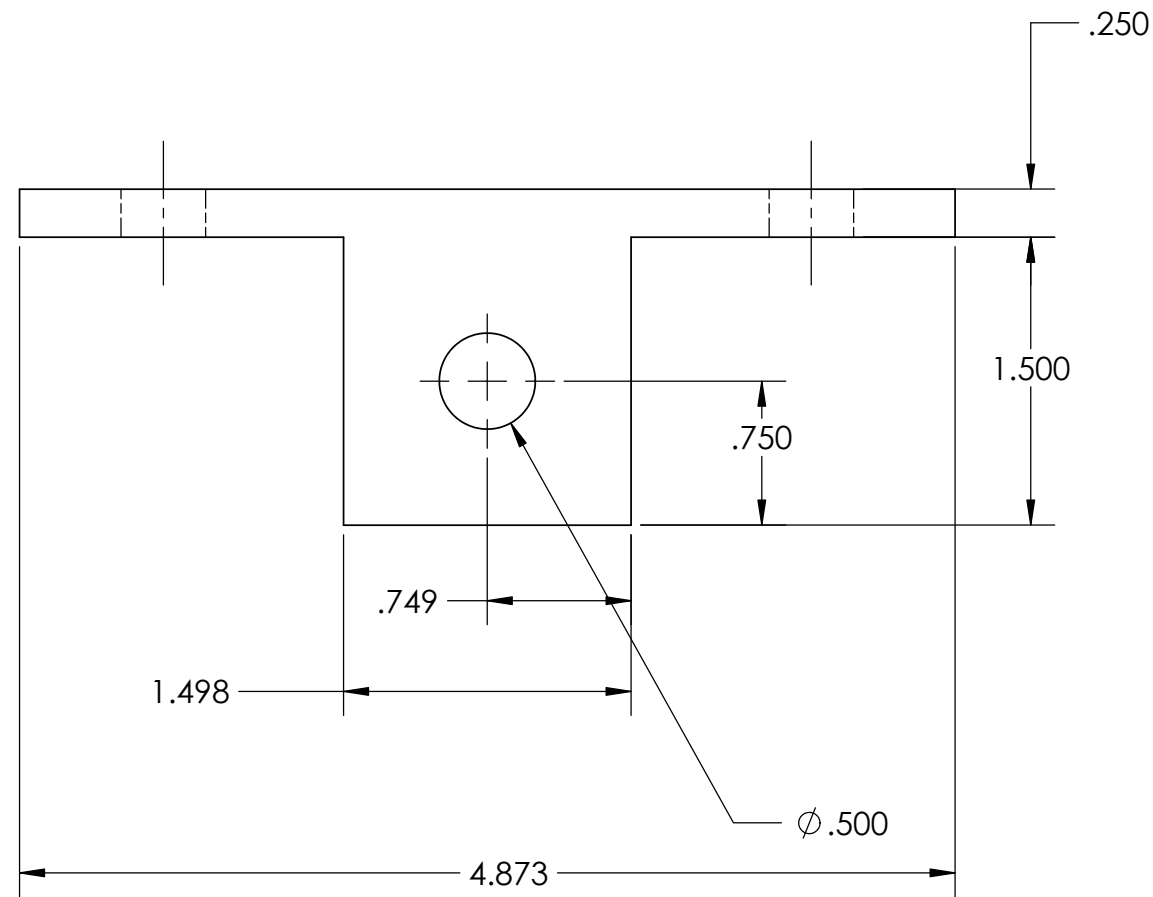
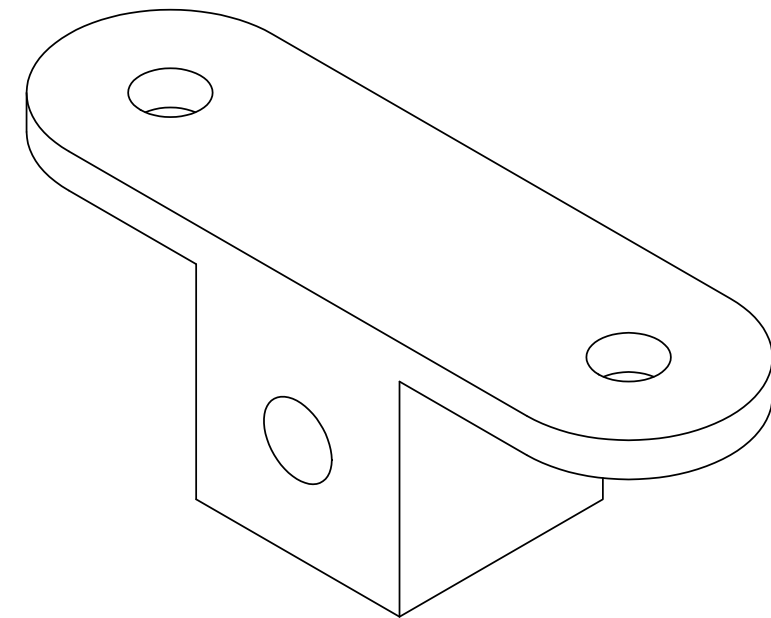
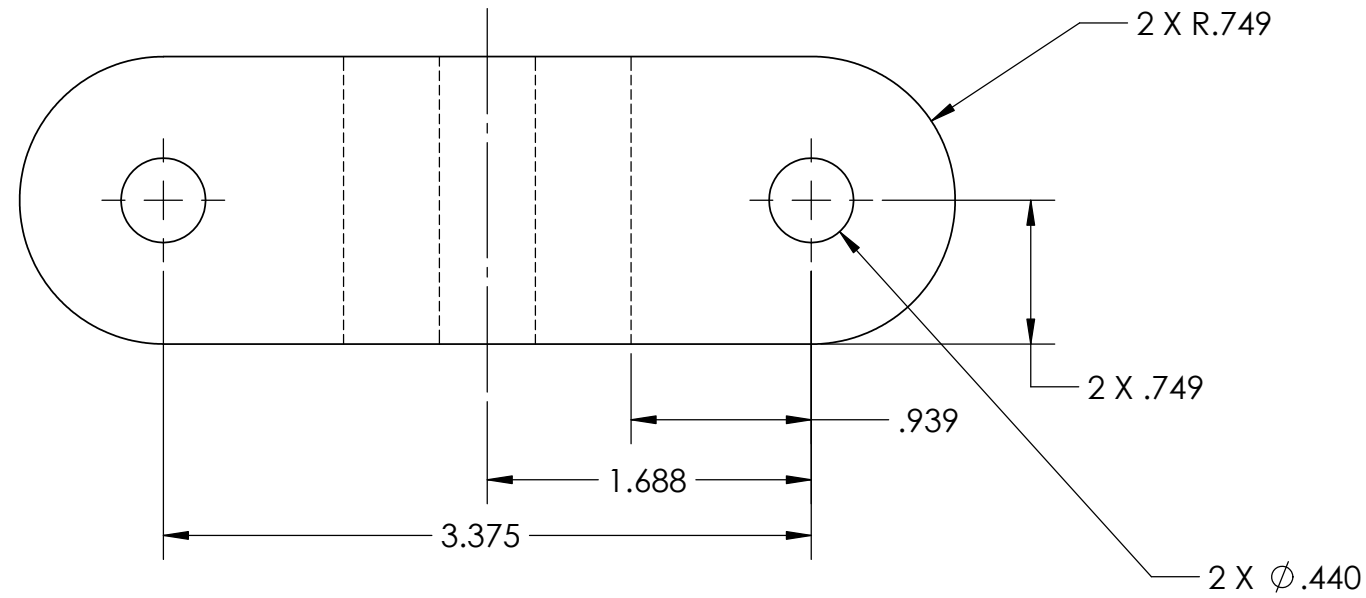
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22CRJ250	22CRJ000	MATERIAL	6061	DRAWN	RNH	DATE	4/18/16	
NEXT ASSY	USED ON	FINISH	125	CHECKED	RNH	DATE	4/18/16	
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT			
				VENDOR	POLY PUTTERS			
				TITLE:	LARGE JOINT HOLE			
		SIZE	B	DWG. NO.	22CRJ202		REV	-
				SCALE:	3:2		WEIGHT:	.39 LBS
				SHEET 1 OF 1				



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		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			TITLE: HOUSING MOUNT				
22CRJ200	22CRJ000	MATERIAL	6061	DRAWN	RNH	4/18/16	SIZE	DWG. NO.	REV
NEXT ASSY	USED ON	FINISH	125	CHECKED	RNH	4/18/16	B	22CRJ203	-
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS		SCALE: 1:1	WEIGHT: 0.46 LBS	SHEET 1 OF 1

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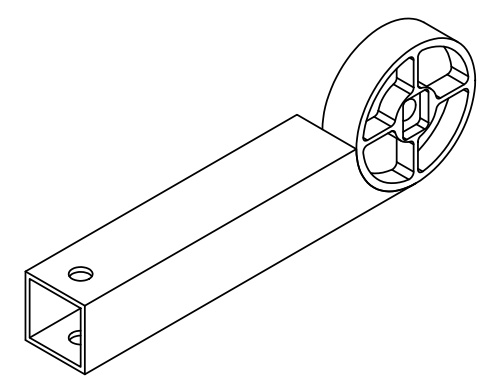
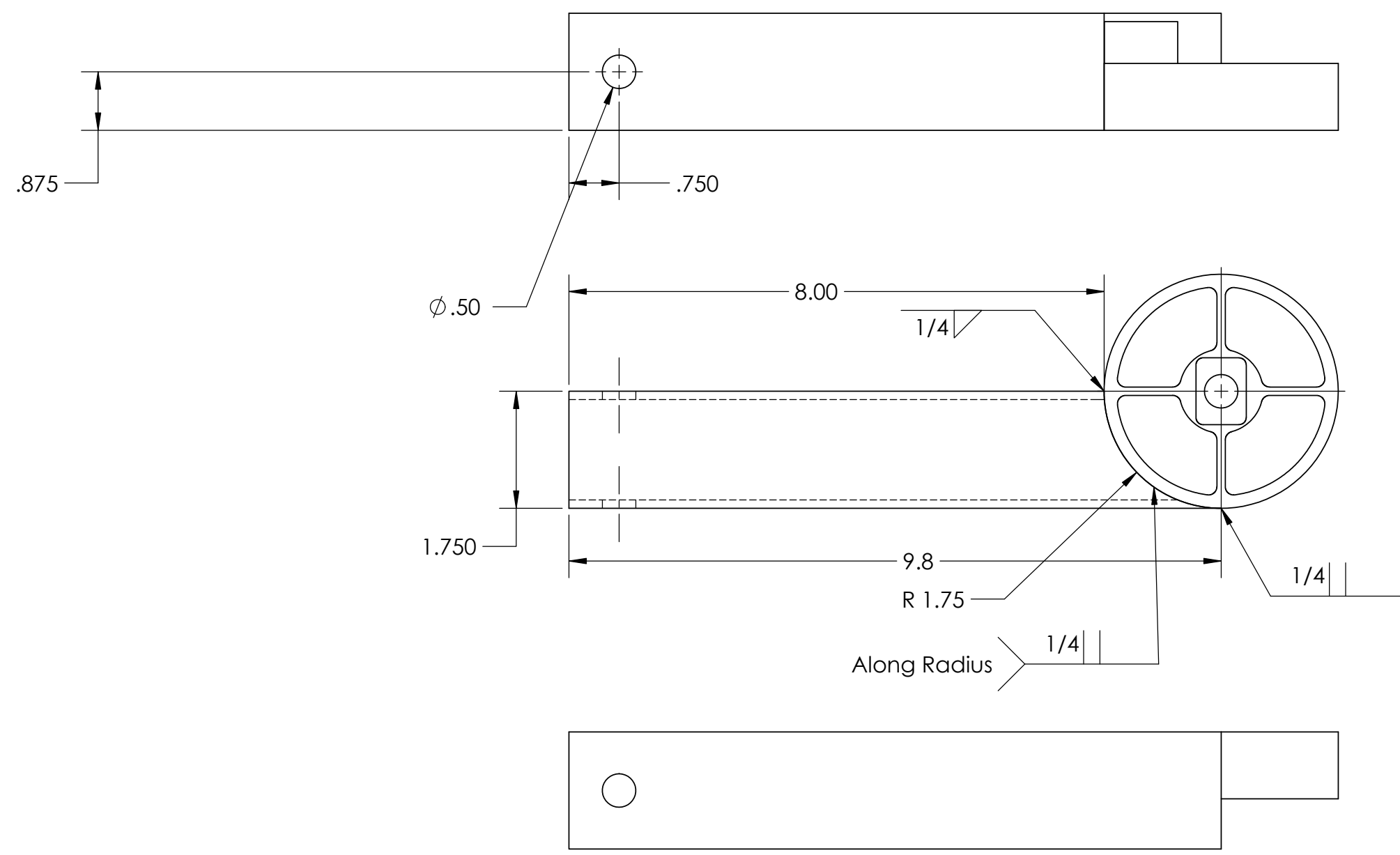
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		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± 1/16 ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX ± .01 .XXX ± .005			TITLE: MAIN TUBE	
22CRJ200	22CRJ000	MATERIAL	6061	DRAWN	RNH	4/18/16
NEXT ASSY	USED ON	FINISH	125	CHECKED	RNH	4/18/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT	
				VENDOR	POLY PUTTERS	
				SIZE	DWG. NO.	
				B	22CRJ250	
				SCALE: 1:2	WEIGHT: 1.55 LBS	
						SHEET 1 OF 1

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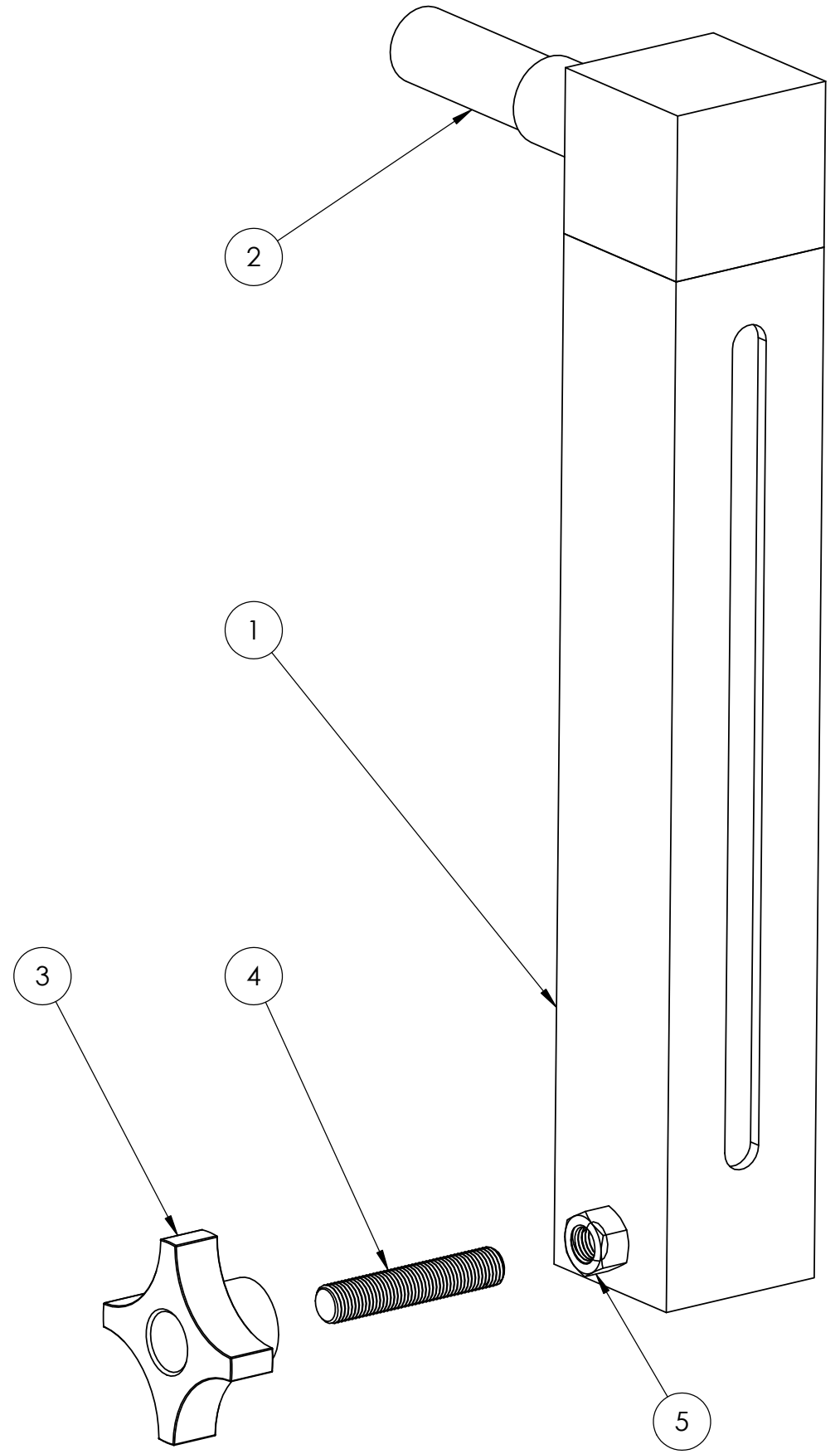
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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
5	22CRJ307	3/8-24 NUT - 90670A165	1
4	22CRJ306	3/8-24 THREADED ROD	1
3	22CRJ304	3/8-24 KNOB - 5993K370	1
2	22CRJ303	SHAFT	1
1	22CRJ301	DOWN TUBE LARGE	1

<p>PROPRIETARY AND CONFIDENTIAL</p> <p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.</p>		UNLESS OTHERWISE SPECIFIED:							
		<p>DIMENSIONS ARE IN INCHES</p> <p>TOLERANCES:</p> <p>FRACTIONAL: ± 1/16</p> <p>ANGULAR: MACH ± 3</p> <p>BEND ± 1</p> <p>DECIMAL: .XX ± .01</p> <p>.XXX ± .005</p>			<p>TITLE:</p> <p>DOWN TUBE LARGE & SHAFT ASSMEBLY</p>				
22CRJ000	22CRJ000	MATERIAL	N/A	DRAWN	CDC	5/2/16	SIZE	DWG. NO.	REV
NEXT ASSY	USED ON	FINISH	N/A	CHECKED	CDC	5/2/16	B	22CRJ300	-
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS		SCALE: 2:3	WEIGHT: .36 LBS	SHEET 1 OF 1

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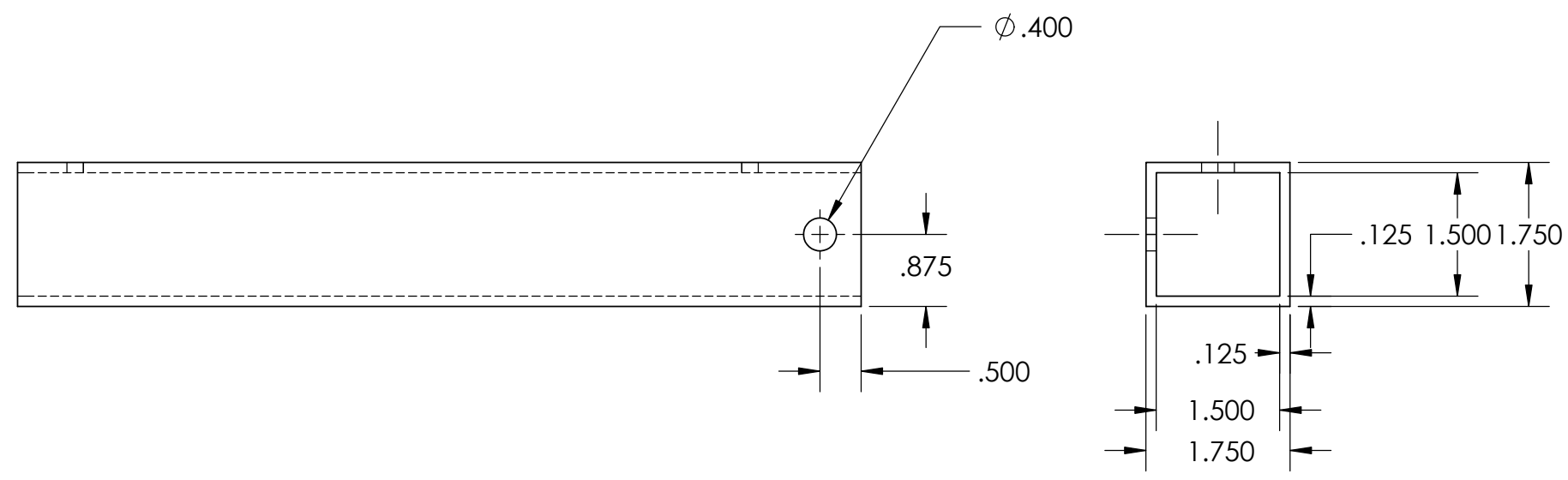
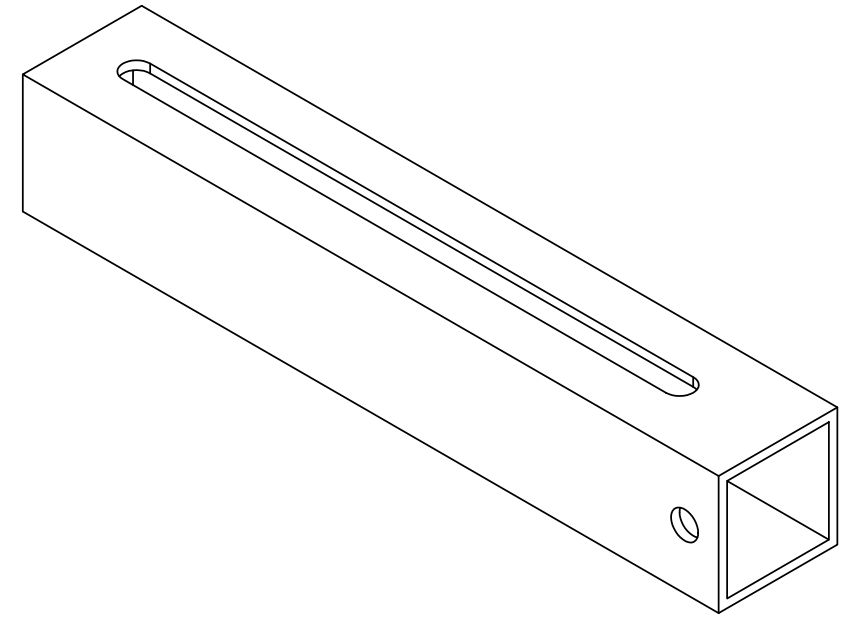
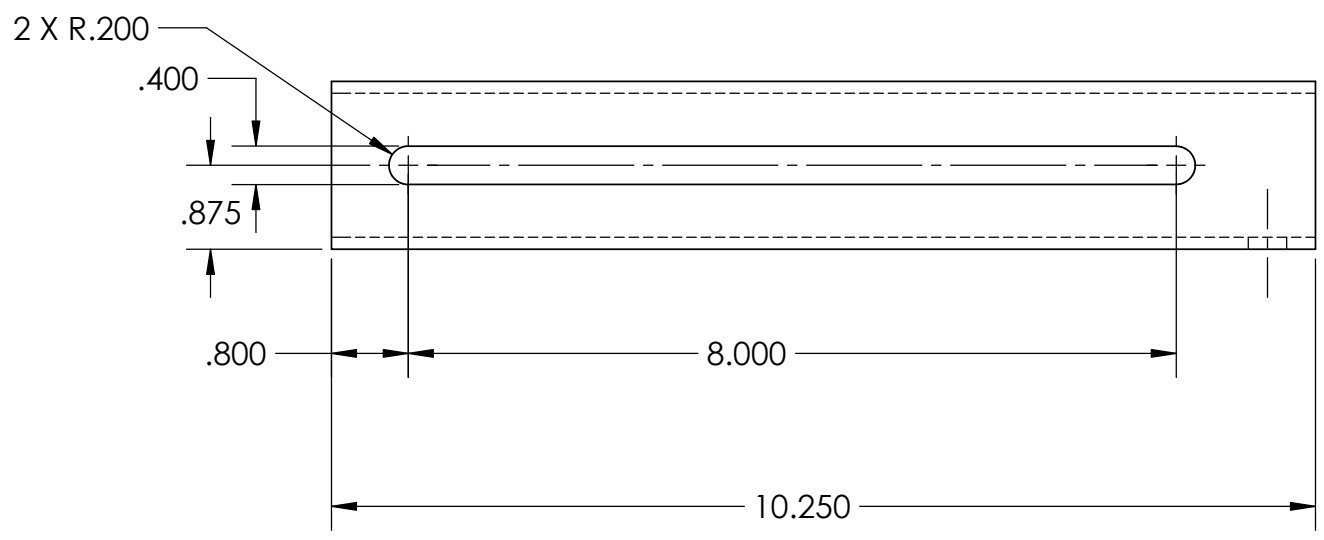
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1	1	22CRJ301	1.75" x 0.125" SQUARE 6061 AL TUBING
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION

<p>PROPRIETARY AND CONFIDENTIAL</p> <p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.</p>	UNLESS OTHERWISE SPECIFIED:					
	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			TITLE: <h2>Down Tube Large</h2>		
	22CRJ300	22CRJ000	MATERIAL 6061	DRAWN	RNH	4/28/16
	NEXT ASSY	USED ON	FINISH 125	CHECKED	RNH	4/28/16
APPLICATION		DO NOT SCALE DRAWING	STAGE	ROBOT		
			VENDOR	POLY PUTTERS		
			SIZE	DWG. NO.	REV	
			B	22CRJ301	-	
			SCALE: 1:2	WEIGHT: .77 LBS	SHEET 1 OF 1	

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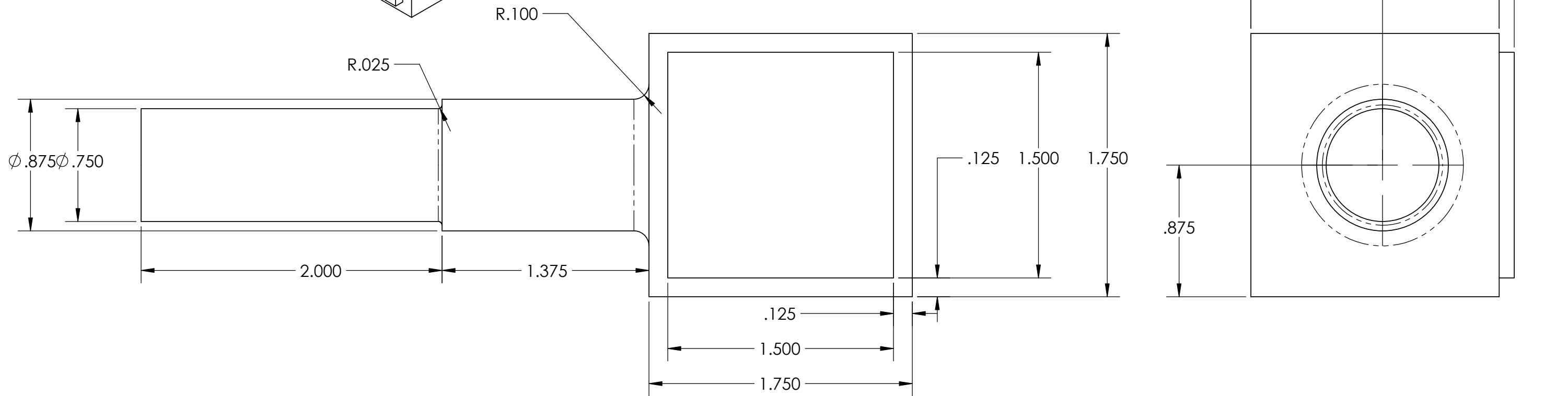
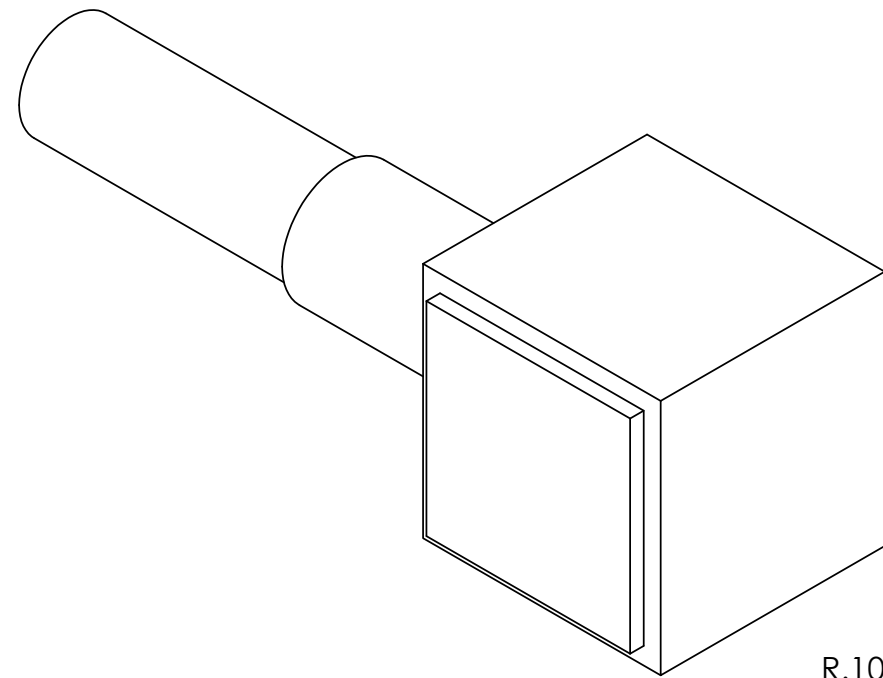
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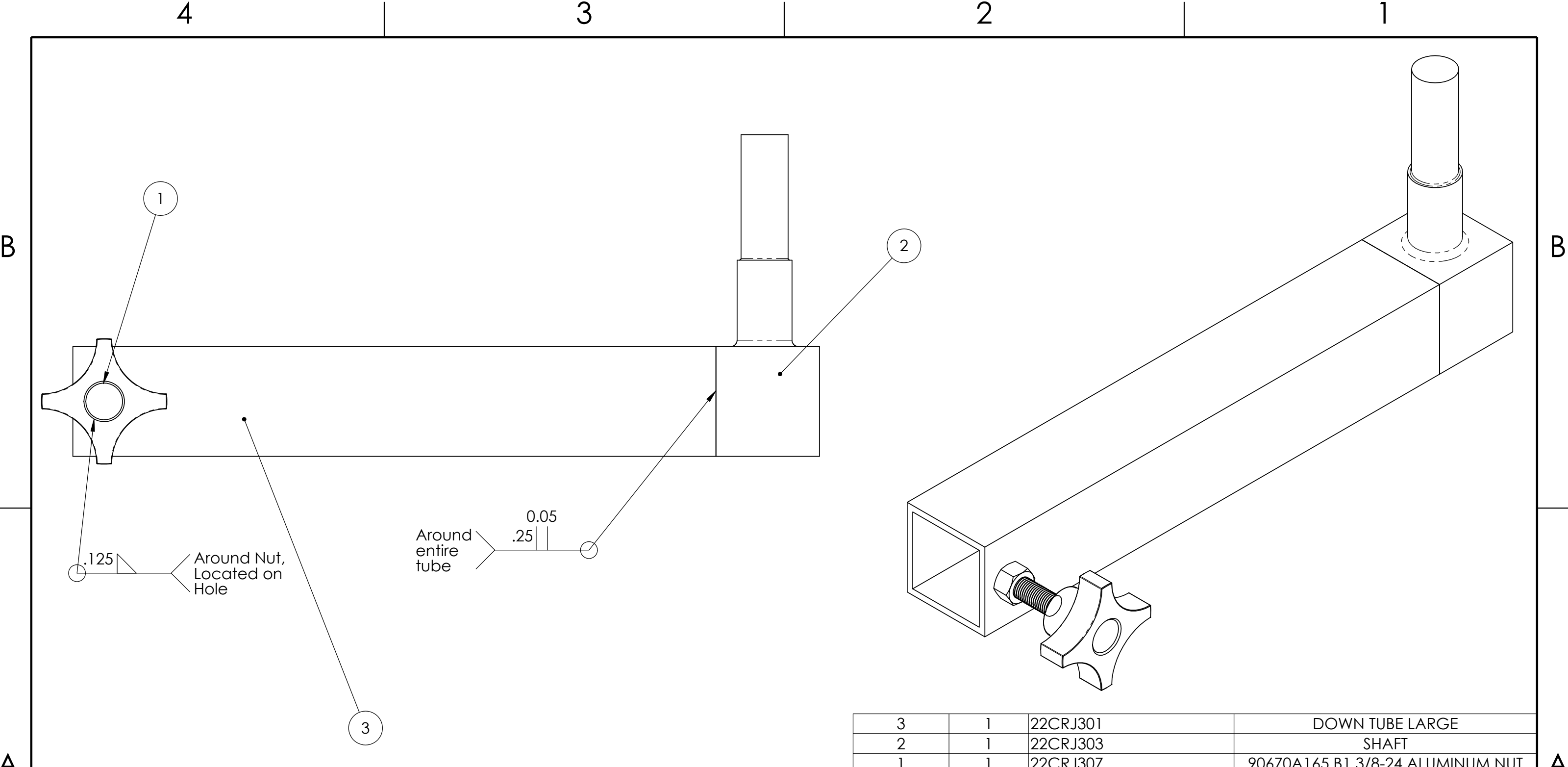
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1	22CRJ303			1
ITEM NO.	PART NUMBER	DESCRIPTION		QTY.
PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.		UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$		 Mechanical Engineering CAL POLY
22CRJ300	22CRJ000	MATERIAL	6061	
NEXT ASSY	USED ON	FINISH	125	TITLE: SHAFT
APPLICATION		DO NOT SCALE DRAWING		SIZE B DWG. NO. 22CRJ303 REV -
		VENDOR	POLY PUTTERS	SCALE: 3:2 WEIGHT: 0.68 LBS SHEET 1 OF 1



3	1	22CRJ301	DOWN TUBE LARGE
2	1	22CRJ303	SHAFT
1	1	22CRJ307	90670A165 B1 3/8-24 ALUMINUM NUT
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.		UNLESS OTHERWISE SPECIFIED:		 Mechanical Engineering POLY	TITLE: DOWN TUBE WELDMENT	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			NAME JPV DATE 4/18/16	SIZE B DWG. NO. 22CRJ102 REV -
22CRJ100	22CRJ000	MATERIAL	6061	DRAWN	JPV	4/18/16
NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV	4/18/16
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS	

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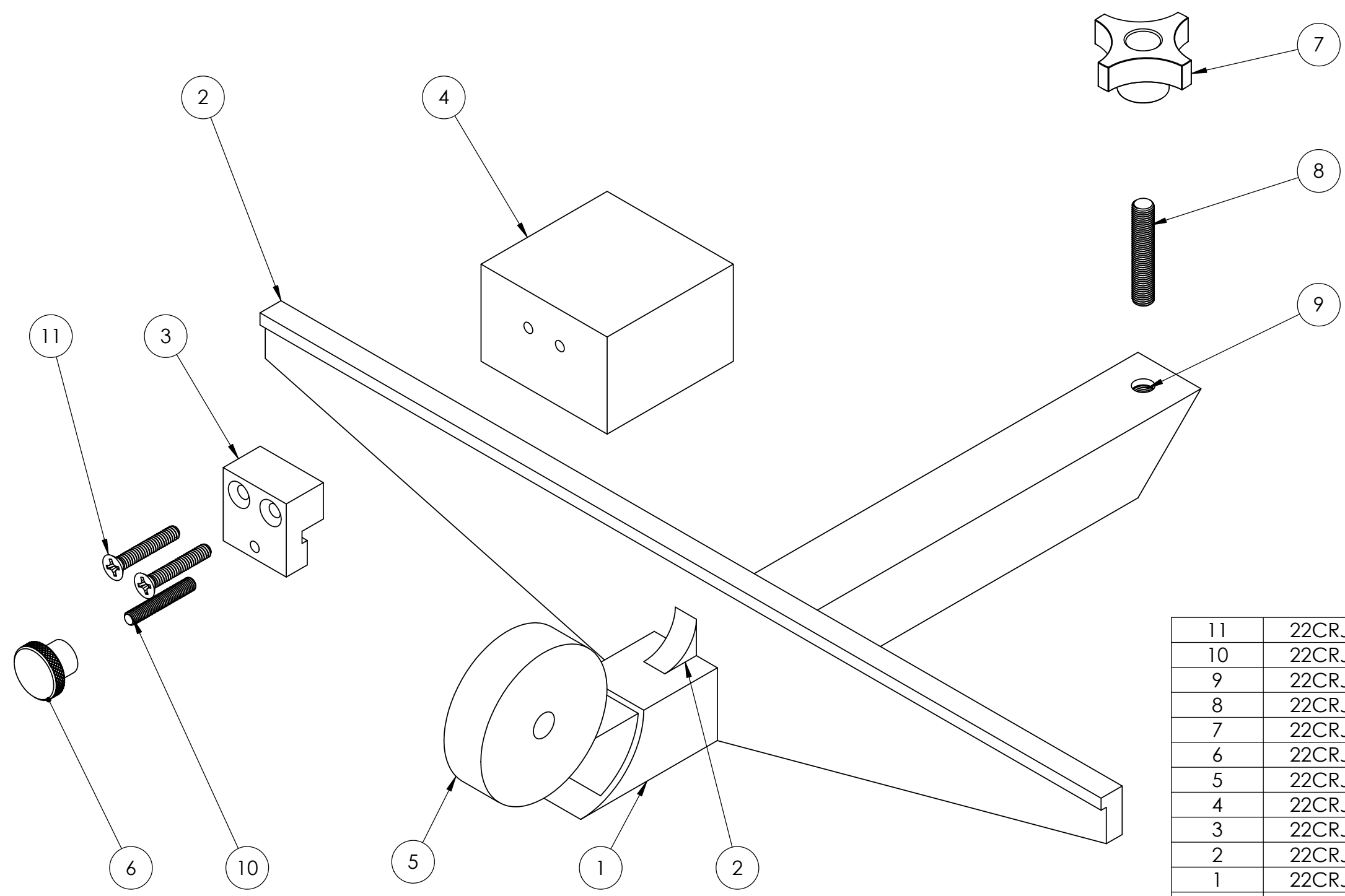
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11	22CRJ411	1/4-20 SCREW - 97124A649B3	2
10	22CRJ410	1/4-20 THREADED ROD - 93225A402	1
9	22CRJ409	3/8-24 NUT - 90670A165	1
8	22CRJ408	3/8-24 THREADED ROD - 90322A129	1
7	22CRJ407	3/8-24 KNOB - 5993K370	1
6	22CRJ406	1/4-20 BRASS KNOB - 5125K330	1
5	22CRJ405	JOINT SMALL	1
4	22CRJ404	SWINGWEIGHT	1
3	22CRJ403	SLIDE BLOCK TOP	1
2	22CRJ402	SWINGWEIGHT SLIDE	1
1	22CRJ401	DOWN TUBE SMALL	1
ITEM NO., PART NUMBER		DESCRIPTION	QTY.

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.		UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± 1/16 ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX ± .01 .XXX ± .005		 Mechanical Engineering CAL POLY		TITLE: DOWN TUBE SMALL ASSEMBLY		
22CRJ000	22CRJ000	MATERIAL N/A	DRAWN CDC			DATE 4/28/16	SIZE B	DWG. NO. 22CRJ400
NEXT ASSY	USED ON	FINISH N/A	CHECKED CDC	4/28/16	SCALE: 1:2		WEIGHT: 8.1 LBS	SHEET 1 OF 1
APPLICATION		DO NOT SCALE DRAWING		VENDOR POLY PUTTERS				

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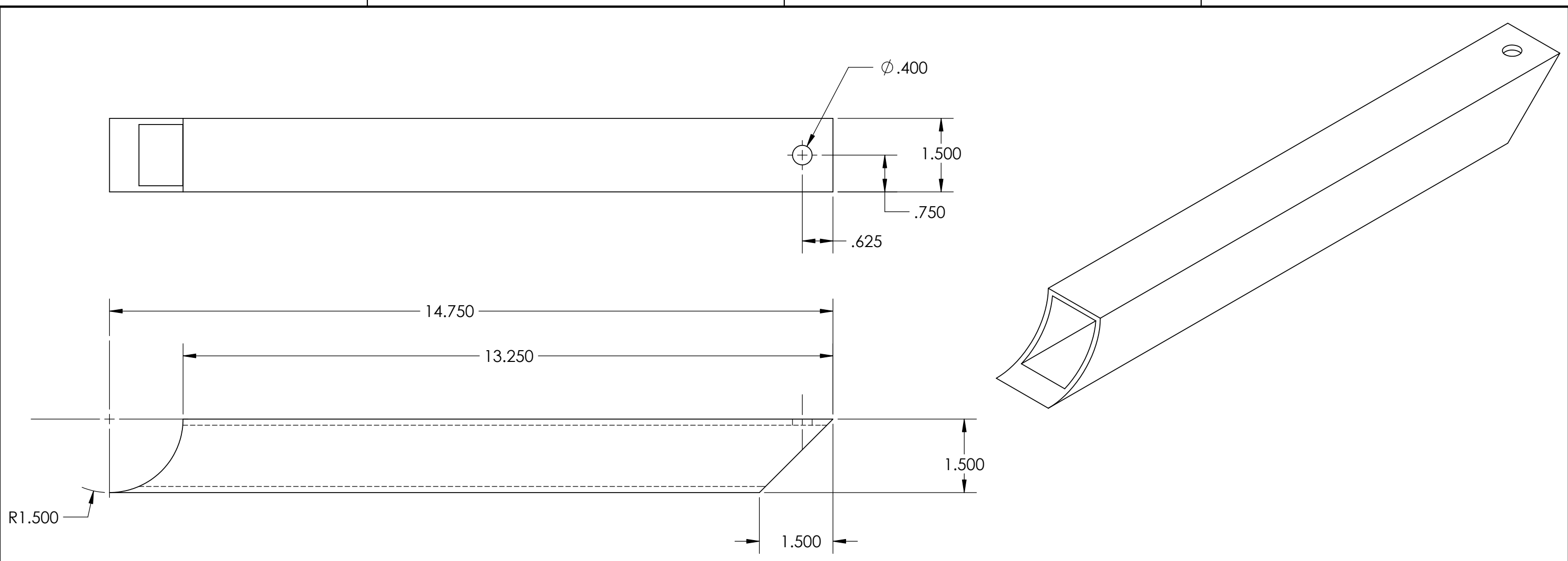
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1	1	22CRJ401	1.5" x 0.125" 6061 ALUMINUM SQUARE TUBING
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION

<p>PROPRIETARY AND CONFIDENTIAL</p> <p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.</p>	UNLESS OTHERWISE SPECIFIED:		 <p>Mechanical Engineering CAL POLY</p>	TITLE:			
	DIMENSIONS ARE IN INCHES			DOWN TUBE SMALL			
	TOLERANCES:			DRAWN	NAME	DATE	
	FRACTIONAL: $\pm 1/16$			RNH	RNH	5/1/16	
ANGULAR: MACH ± 3		CHECKED	RNH	5/1/16	SIZE	DWG. NO.	REV
BEND ± 1		STAGE	ROBOT		B	22CRJ401	-
DECIMAL: .XX $\pm .01$		APPLICATION	POLY PUTTERS		SCALE: 1:2	WEIGHT: 0.87 LBS	SHEET 1 OF 1
.XXX $\pm .005$		DO NOT SCALE DRAWING					

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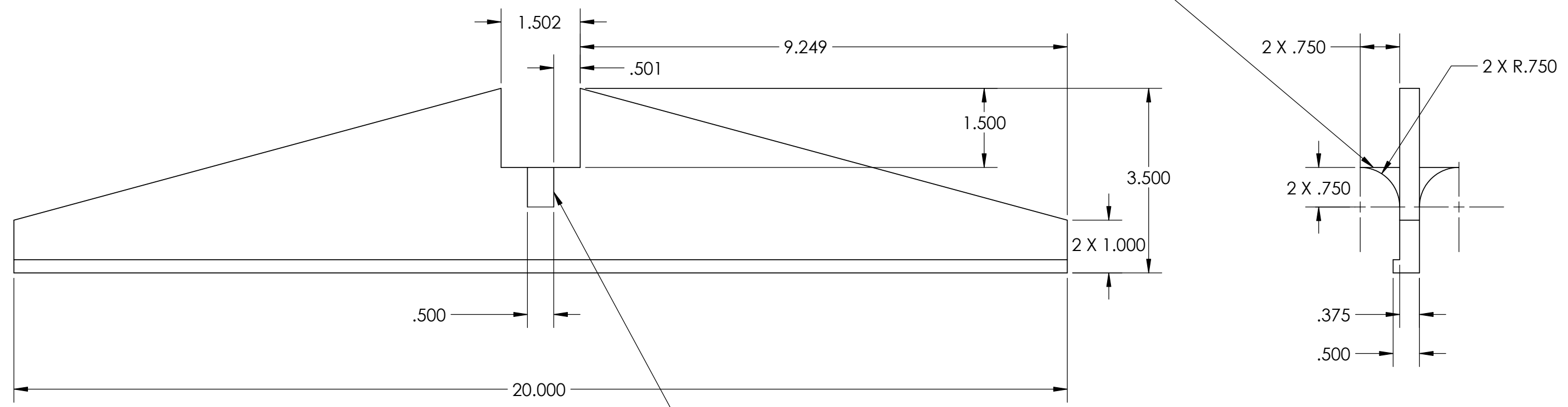
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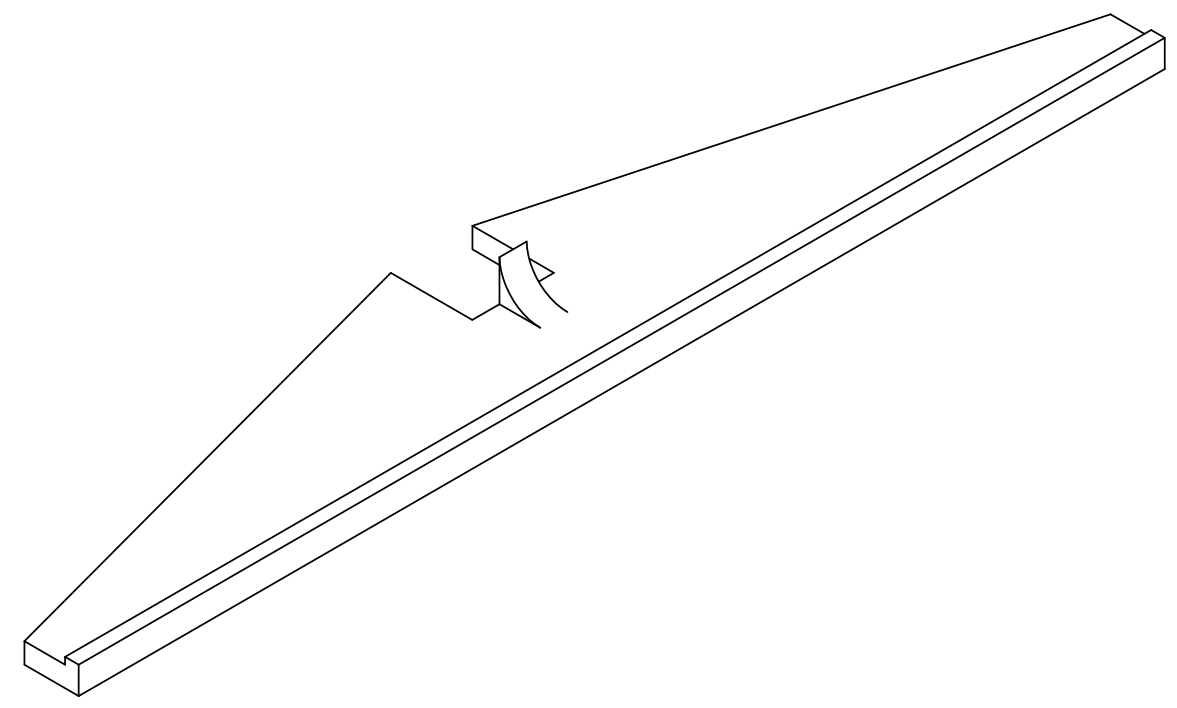
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These two tabs are made from the same .5" plate and then welded on as indicated.



0.125 Along both sides and on tapering edge but not on slot side (must sit flush against tubing)



1	1	22CRJ402	.5" x 4" x 24" 6061 ALUMINUM PLATE
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION

<p>PROPRIETARY AND CONFIDENTIAL</p> <p>THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.</p>	UNLESS OTHERWISE SPECIFIED:					
	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: ± 1/16 ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX ± .01 .XXX ± .005			TITLE: SWING WEIGHT SLIDE		
	22CRJ400	22CRJ000	MATERIAL	6061	DRAWN	RNH 5/1/16
	NEXT ASSY	USED ON	FINISH	125	CHECKED	RNH 5/1/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT	
		VENDOR	POLY PUTTERS	SIZE	DWG. NO.	REV
				B	22CRJ402	-
				SCALE: 1:2	WEIGHT: 1.71 LBS	SHEET 1 OF 1

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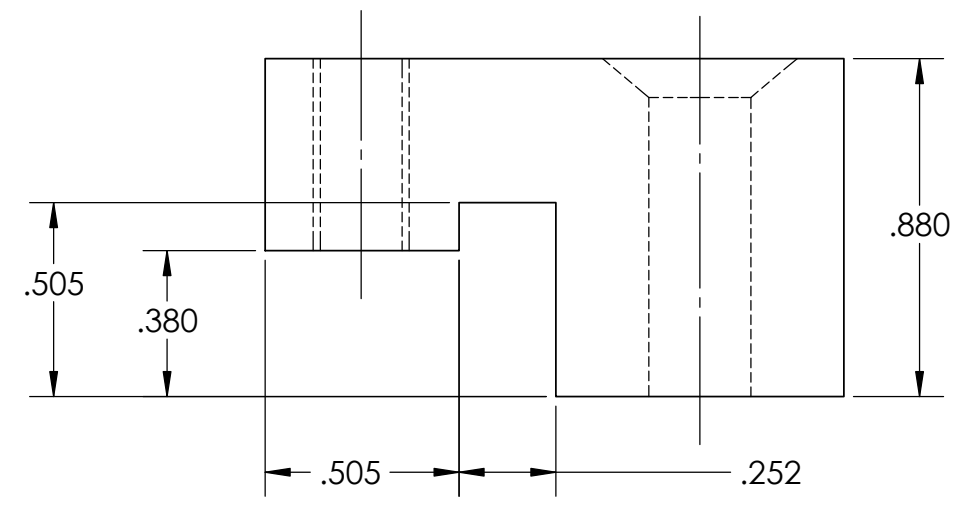
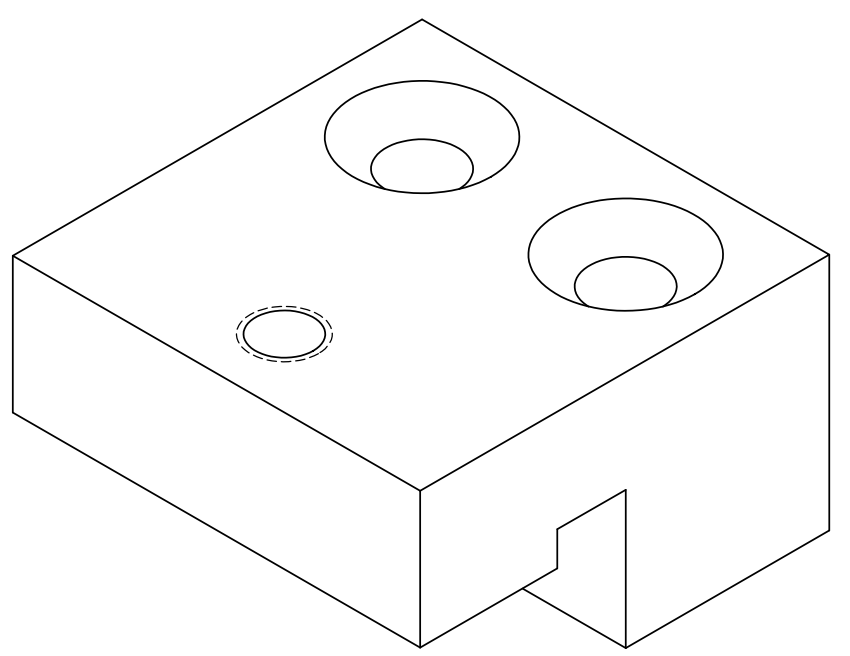
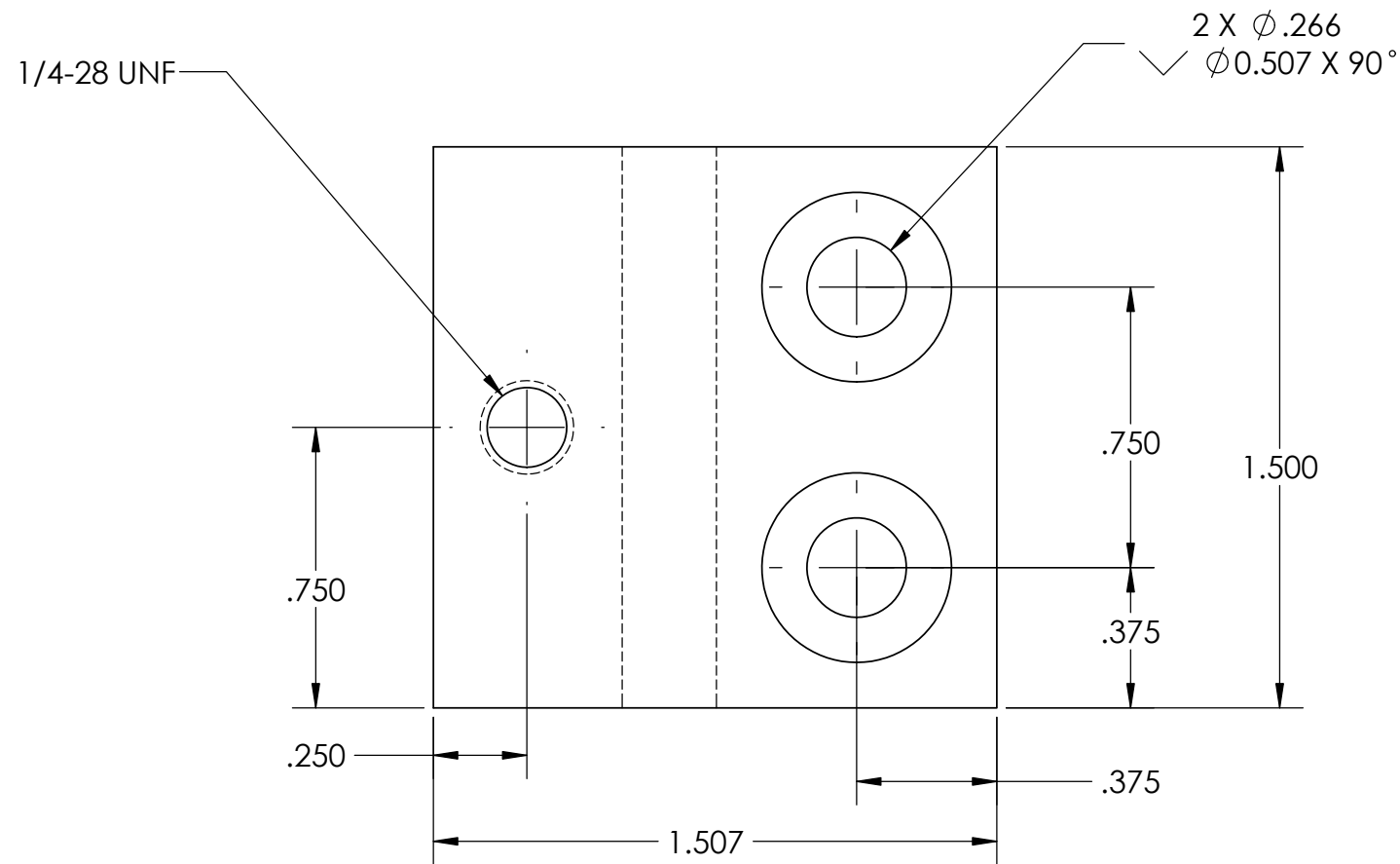
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1	1	22CRJ403	1.5" x 3.5" 6061 ALUMINUM BAR STOCK
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION

PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF KRONOS GOLF. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF KRONOS IS PROHIBITED.	UNLESS OTHERWISE SPECIFIED: DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$						
	MATERIAL 6061			TITLE: SLIDE BLOCK			
22CRJ400	22CRJ000	FINISH 125	DRAWN RNH 5/1/16	CHECKED RNH 5/1/16	SIZE B	DWG. NO. 22CRJ403	REV -
NEXT ASSY		USED ON	STAGE	ROBOT	SCALE: 2:1	WEIGHT: 0.13 LBS	SHEET 1 OF 1
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS		

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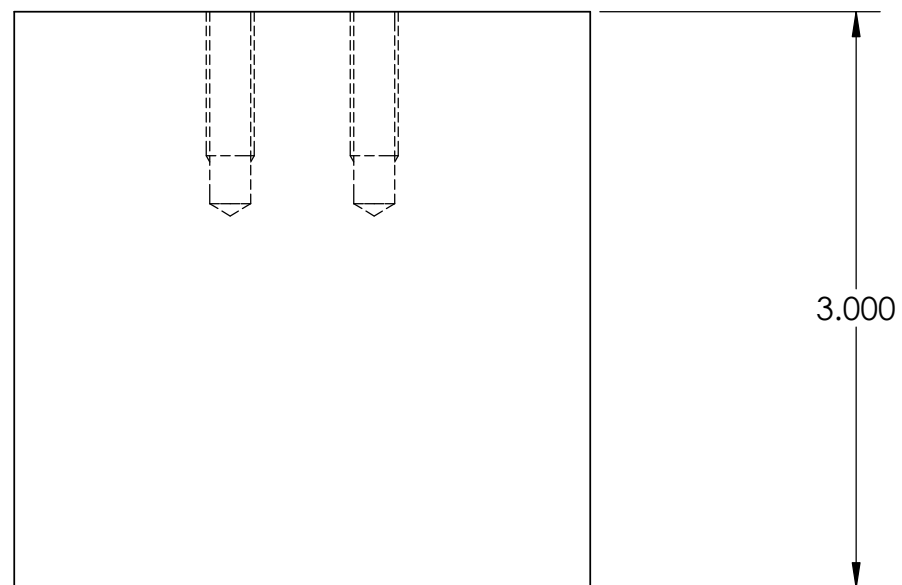
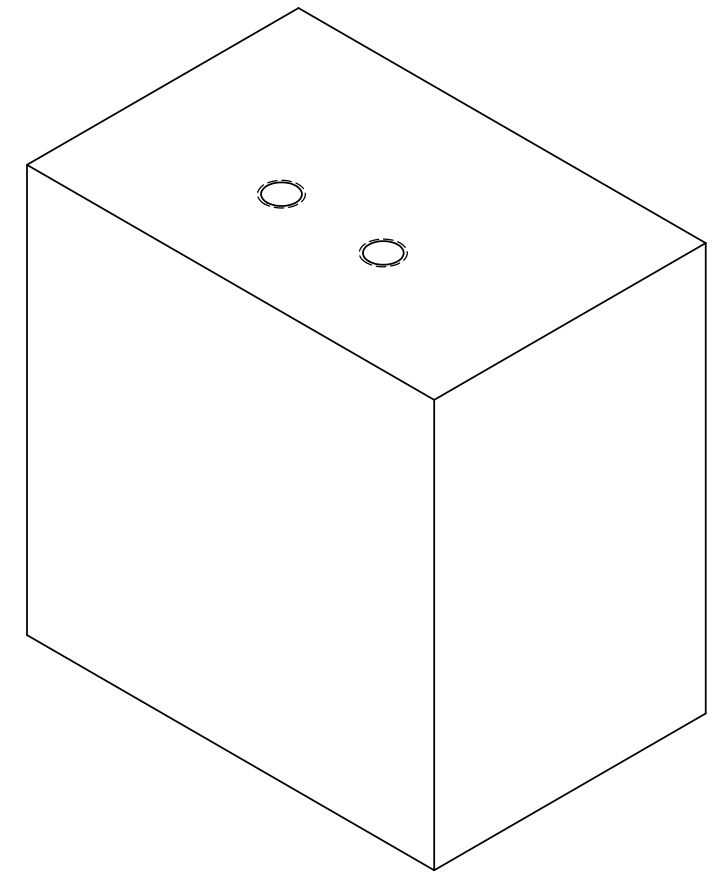
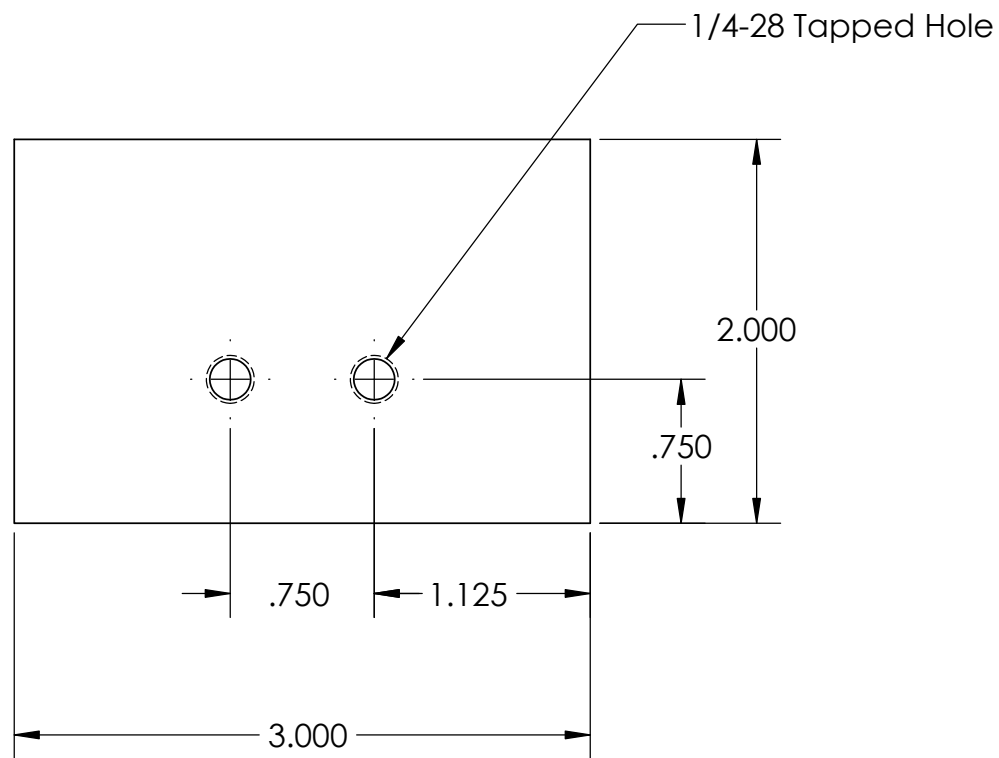
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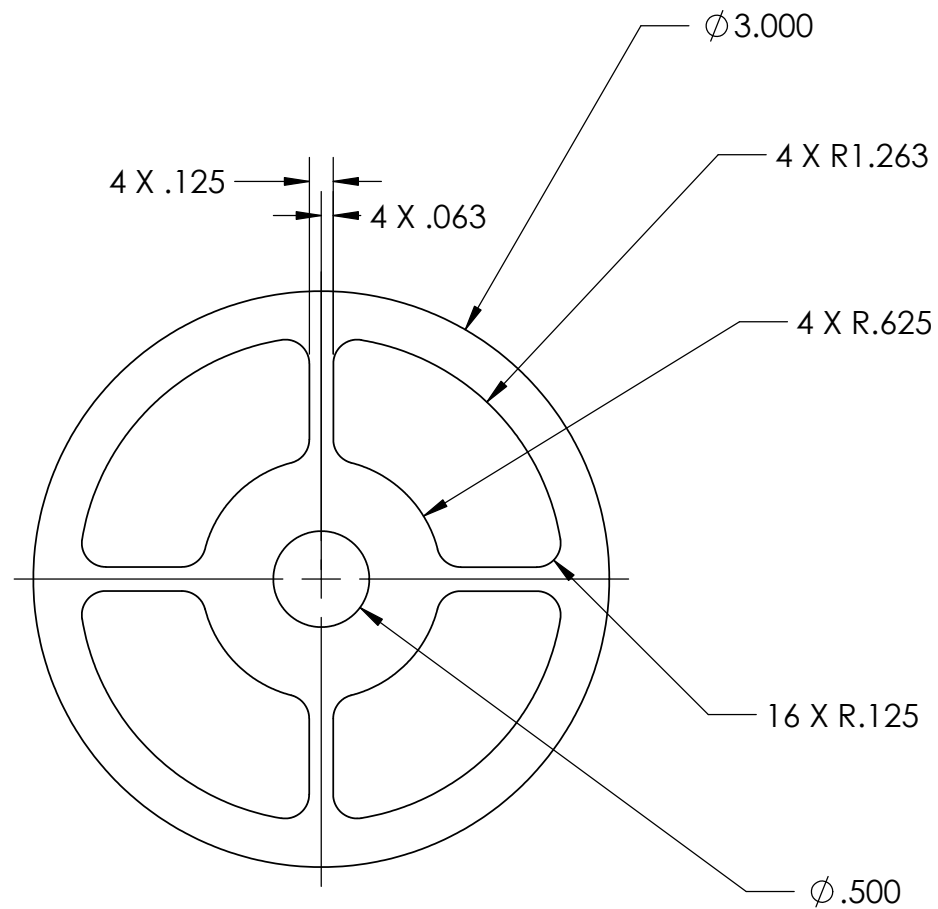
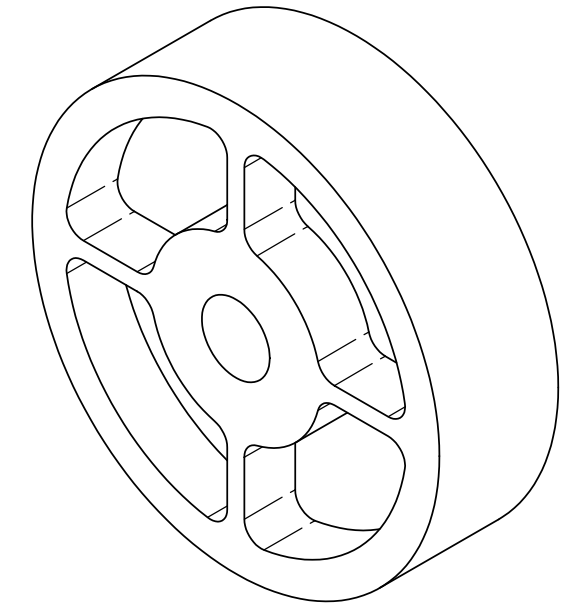
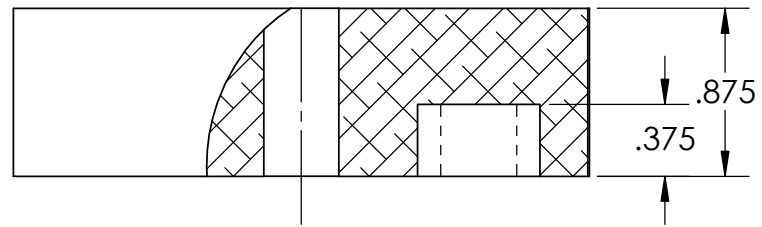
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1	1	22CRJ404	2" x 3" x 3" 1020 STEEL STOCK
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION

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	MATERIAL 1020			TITLE: SWINGWEIGHT			
22CRJ400	22CRJ000	FINISH 125	DRAWN RNH 5/1/16 CHECKED RNH 5/1/16 STAGE ROBOT	SIZE B	DWG. NO. 22CRJ404	REV -	
APPLICATION		DO NOT SCALE DRAWING	VENDOR	POLY PUTTERS	SCALE: 1:1	WEIGHT: 5.21 LBS	SHEET 1 OF 1



1	1	22CRJ405	3" 6061 ALUMINUM ROUND STOCK
ITEM NO.	QTY.	PART NUMBER	DESCRIPTION

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	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			TITLE: <h1>SMALL JOINT</h1>						
	22CRJ400	22CRJ000		MATERIAL	6061	<table border="1"> <tr> <th>NAME</th> <th>DATE</th> </tr> <tr> <td>RNH</td> <td>5/1/16</td> </tr> </table>	NAME	DATE	RNH	5/1/16
	NAME	DATE								
RNH	5/1/16									
NEXT ASSY	USED ON	FINISH	125	<table border="1"> <tr> <th>SIZE</th> <th>DWG. NO.</th> <th>REV</th> </tr> <tr> <td>B</td> <td>22CRJ405</td> <td>-</td> </tr> </table>	SIZE	DWG. NO.	REV	B	22CRJ405	-
SIZE	DWG. NO.	REV								
B	22CRJ405	-								
APPLICATION		DO NOT SCALE DRAWING		<table border="1"> <tr> <td>VENDOR</td> <td>POLY PUTTERS</td> <td>SCALE: 1:1</td> <td>WEIGHT: 0.29 LBS</td> <td>SHEET 1 OF 1</td> </tr> </table>	VENDOR	POLY PUTTERS	SCALE: 1:1	WEIGHT: 0.29 LBS	SHEET 1 OF 1	
VENDOR	POLY PUTTERS	SCALE: 1:1	WEIGHT: 0.29 LBS	SHEET 1 OF 1						

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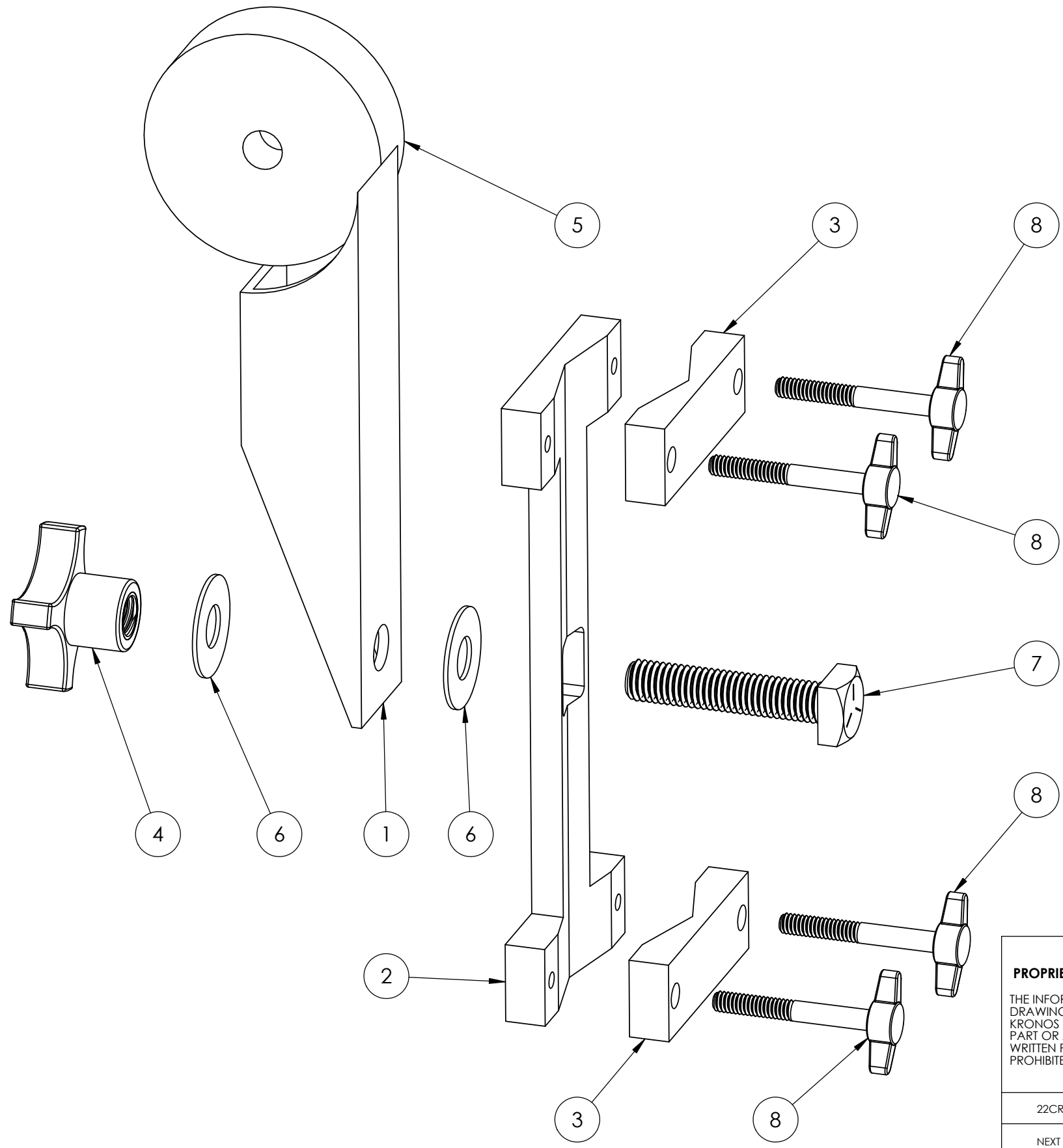
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8	22CRJ566	1/4-20 THUMB SCREW - 91185A933	4
7	22CRJ606	1/2-13 SQUARE BOLT - 92327A308	1
6	22CRJ604	1/2" WASHER - 90107A033	2
5	22CRJ603	JOINT SMALL HOLE	1
4	22CRJ566	1/2-13 THUMB SCREW - 5993K330	1
3	22CRJ503	GRIP TOP	2
2	22CRJ502	GRIP BASE	1
1	22CRJ501	GRIP TUBE	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

PROPRIETARY AND CONFIDENTIAL		UNLESS OTHERWISE SPECIFIED:		 Mechanical Engineering <small>CAL POLY</small>	
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22CRJ000	22CRJ000	MATERIAL	N/A	DRAWN	CDC 5/2/16
NEXT ASSY	USED ON	FINISH	N/A	CHECKED	CDC 5/2/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT
				VENDOR	POLY PUTTERS
TITLE:			RIGID GRIP ASSEMBLY		
SIZE	DWG. NO.	REV			
B	22CRJ500	-			
SCALE: 2:3		WEIGHT: 1.6 LBS		SHEET 1 OF 1	

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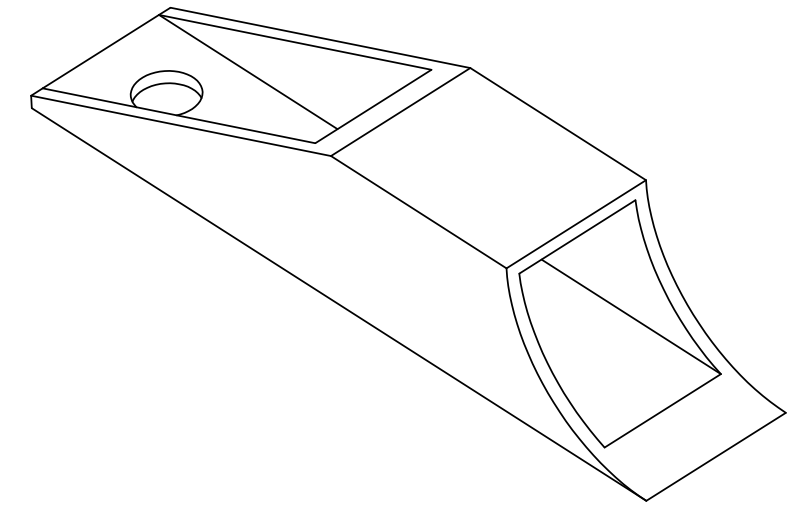
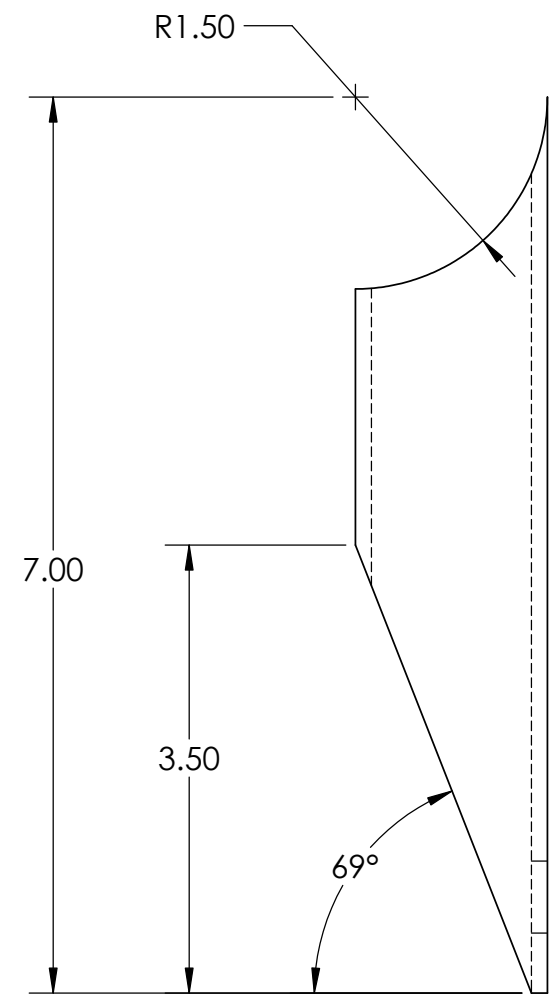
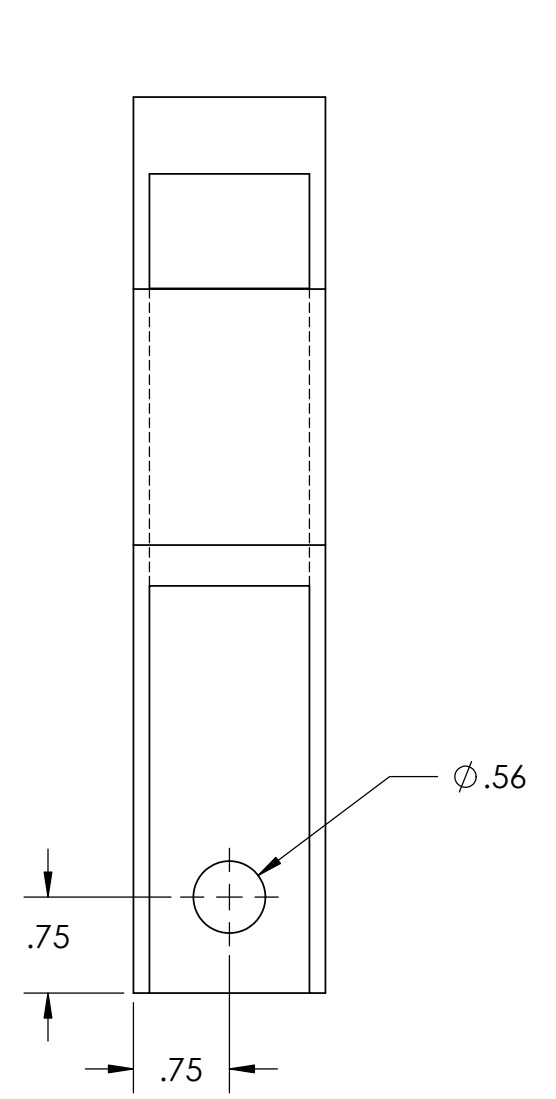
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1	1.5 SQUARE TUBING	1
ITEM NO.	PART NUMBER	QTY.

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	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			TITLE: <h1>GRIP TUBE</h1>		
	22CRJ500	22CRJ000	MATERIAL	6061	DRAWN	JPV 4/30/16
	NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV 4/30/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT	
				VENDOR	POLY PUTTERS	

SIZE	DWG. NO.	REV
B	22CRJ501	-

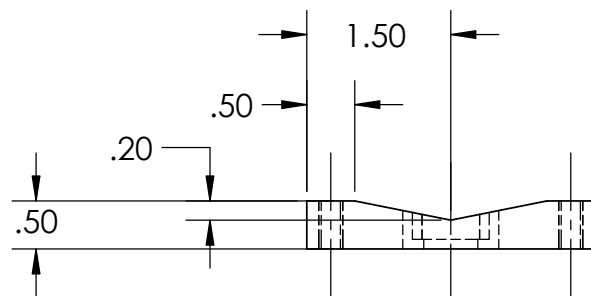
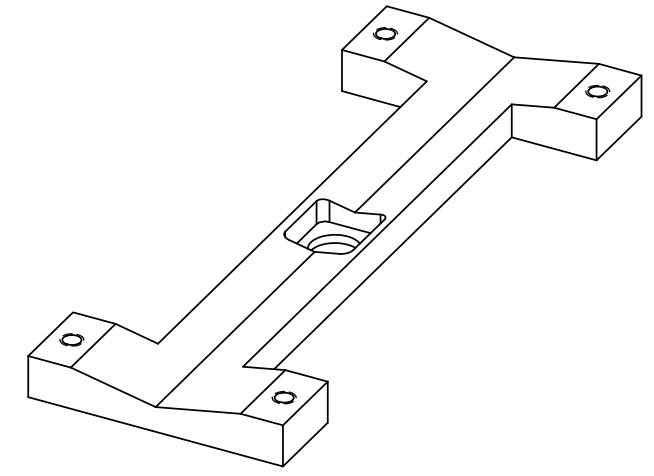
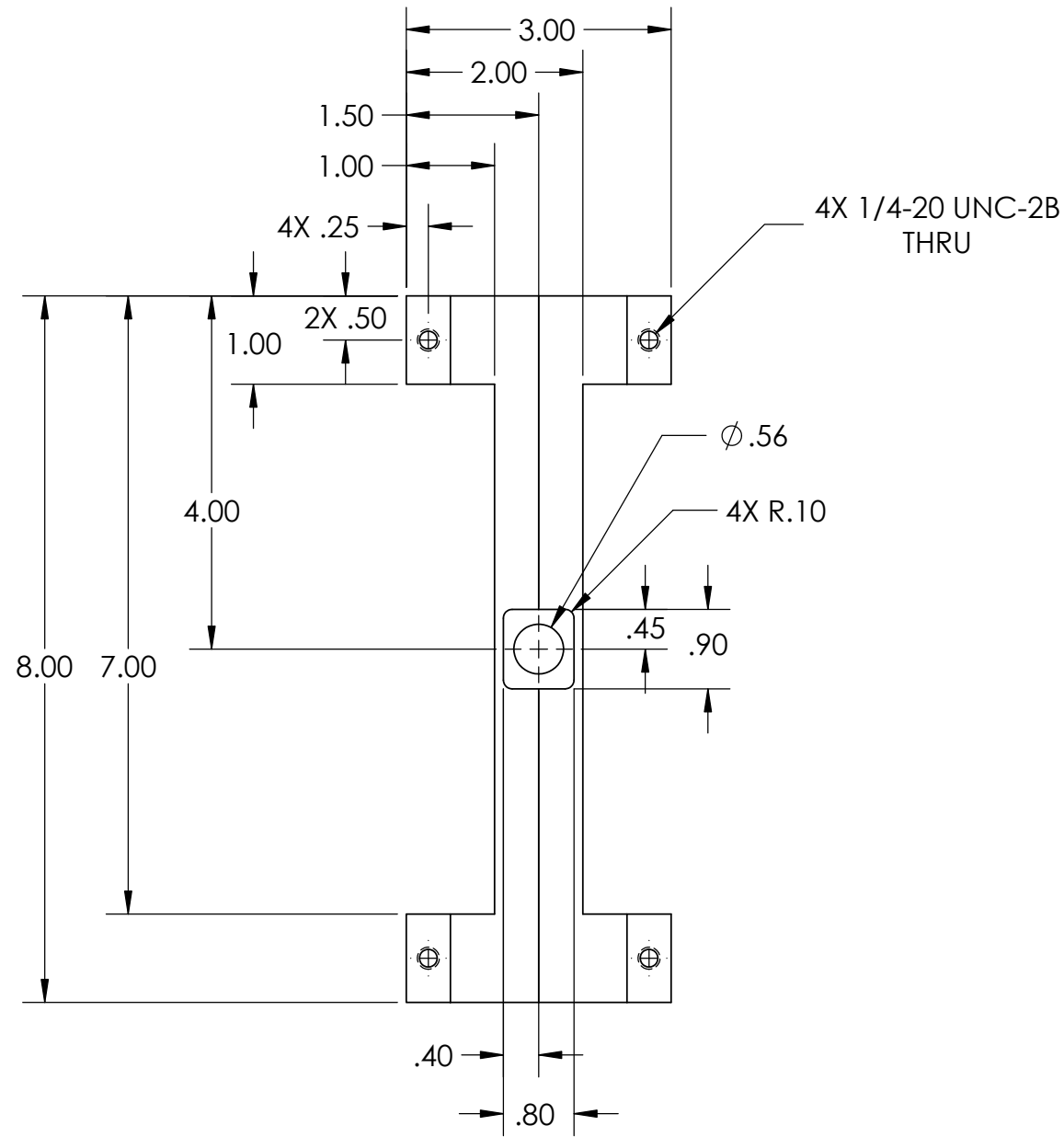
SCALE: 2:3 WEIGHT: SHEET 1 OF 1

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1		.5 X 3.0 X 8.0 PLATE	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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22CRJ500	22CRJ000	MATERIAL	6061	DRAWN	JPV	DATE	4/30/16
NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV	DATE	4/30/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT		
		VENDOR	POLY PUTTERS		SCALE: 1:2	WEIGHT:	SHEET 1 OF 1
				TITLE:		GRIP BASE	
				SIZE	DWG. NO.	REV	
				B	22CRJ502	-	

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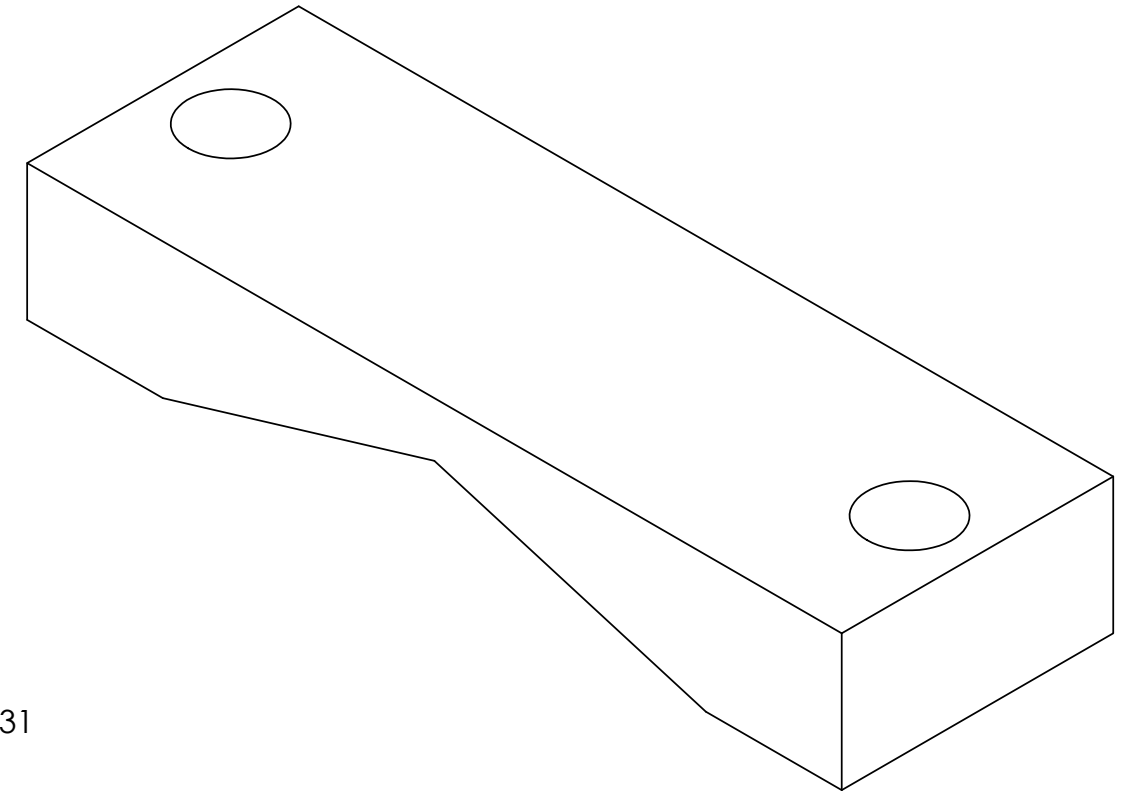
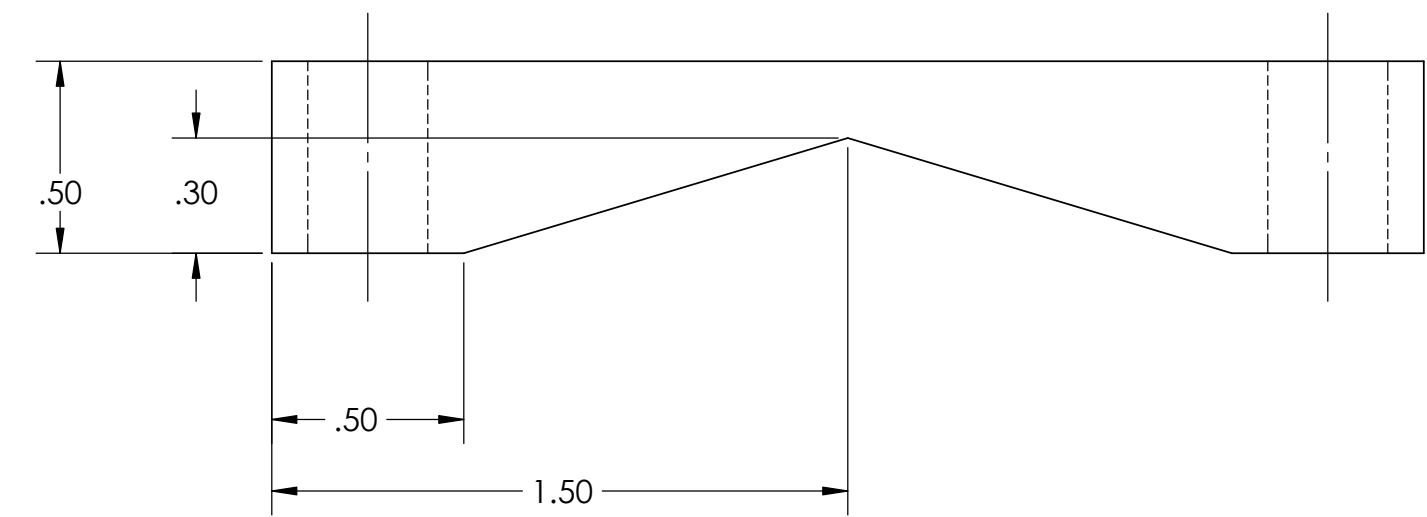
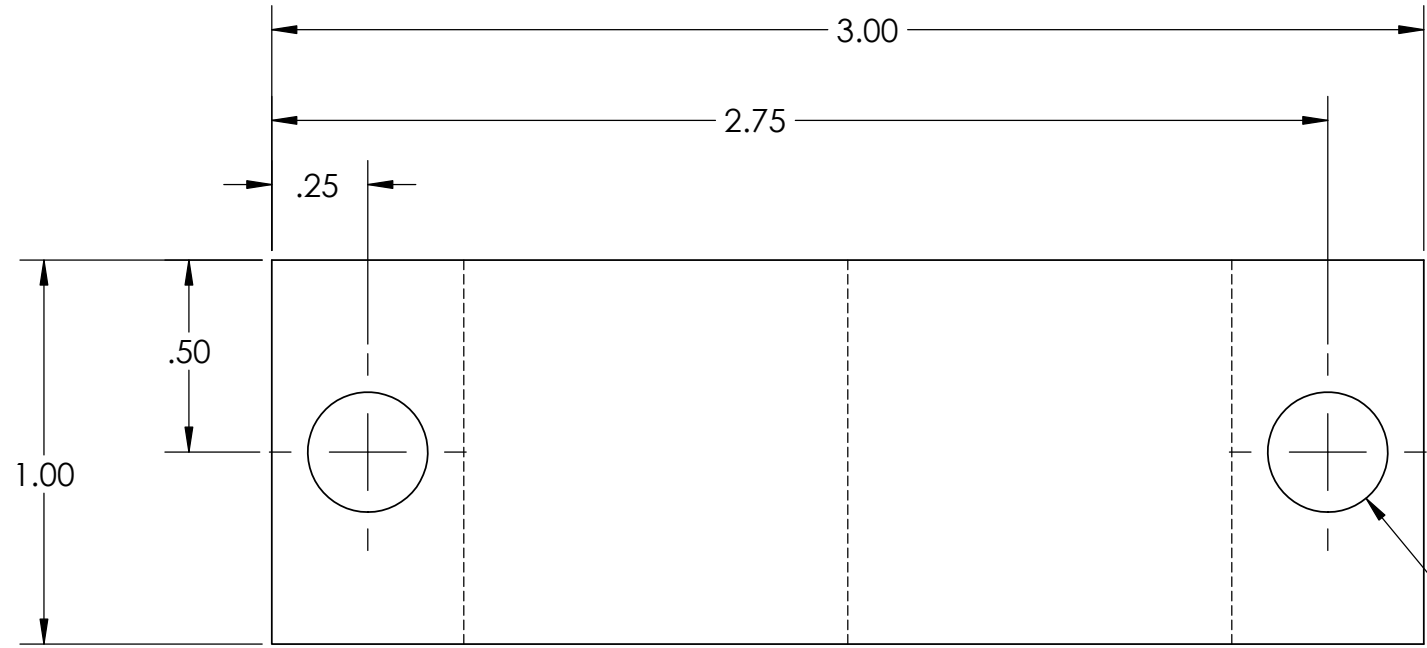
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2X ϕ .31

1	B1	.5 X 3.0 PLATE	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			TITLE: <h1>GRIP TOP</h1>	
22CRJ500	22CRJ000	MATERIAL	6061	DRAWN	JPV	4/30/16
NEXT ASSY	USED ON	FINISH	125	CHECKED	JPV	4/30/16
APPLICATION		DO NOT SCALE DRAWING		STAGE	ROBOT	
		VENDOR	POLY PUTTERS		SCALE: 2:1	WEIGHT:

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SIZE	DWG. NO.	REV
B	22CRJ503	-
SCALE: 2:1		WEIGHT:
		SHEET 1 OF 1

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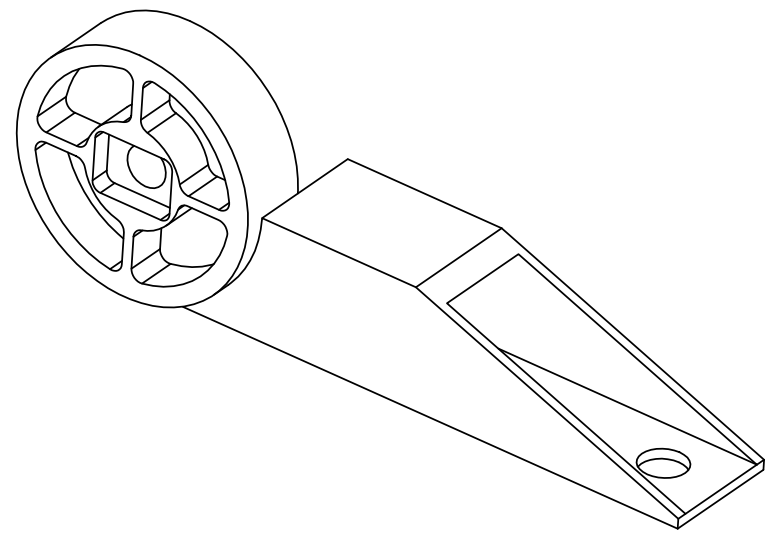
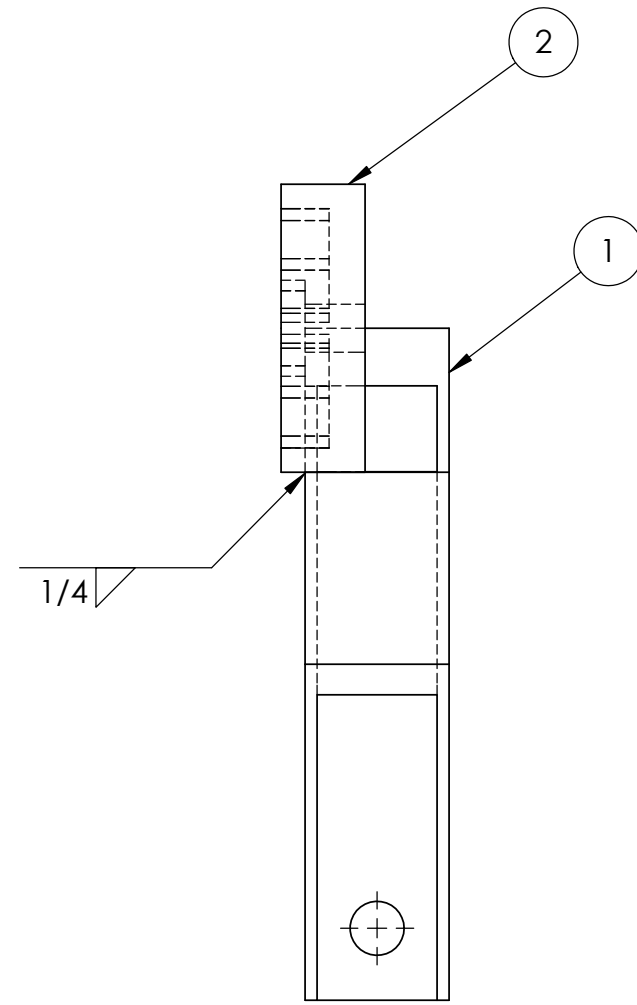
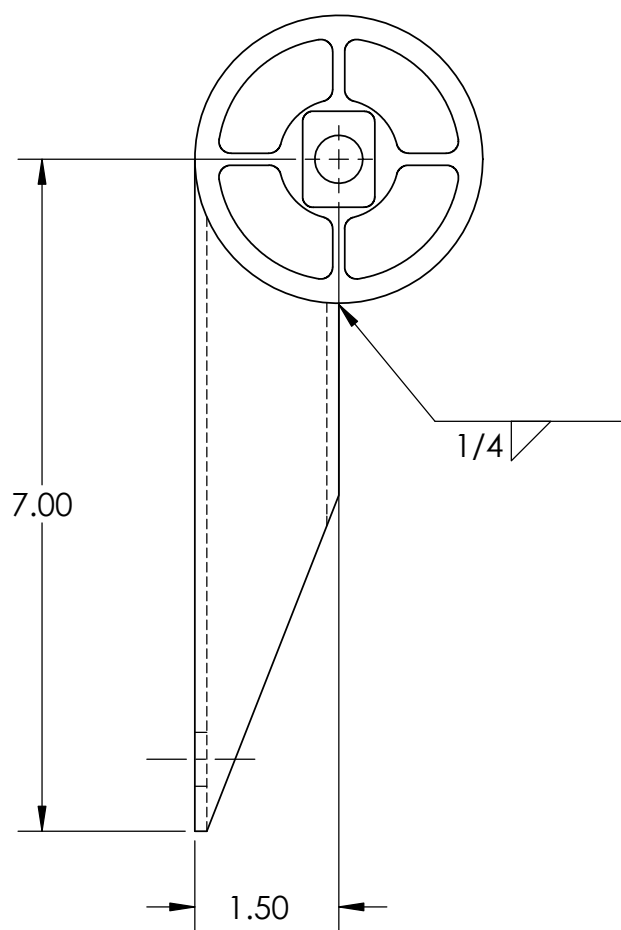
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ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	22CRJ501	GRIP TUBE	1
2	22CRJ603	SMALL JOINT HOLE	1

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	DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL: $\pm 1/16$ ANGULAR: MACH ± 3 BEND ± 1 DECIMAL: .XX $\pm .01$.XXX $\pm .005$			TITLE: GRIP TUBE WELDMENT		
	22CRJ500	22CRJ000	MATERIAL	DRAWN	NAME	DATE
	NEXT ASSY	USED ON	FINISH	CHECKED	JPV	4/30/16
APPLICATION		DO NOT SCALE DRAWING	STAGE	ROBOT	REV	
			VENDOR	POLY PUTTERS	SCALE: 1:2	
			WEIGHT:		SHEET 1 OF 1	

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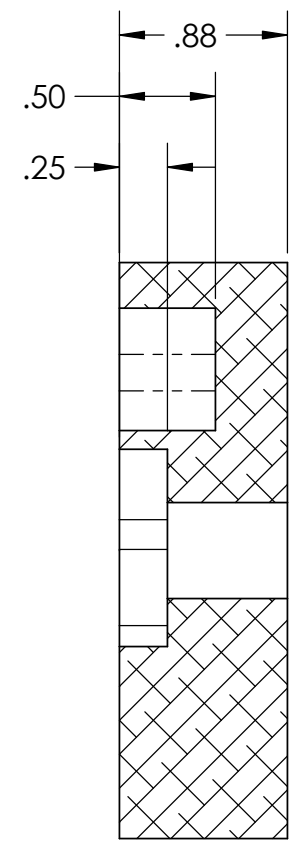
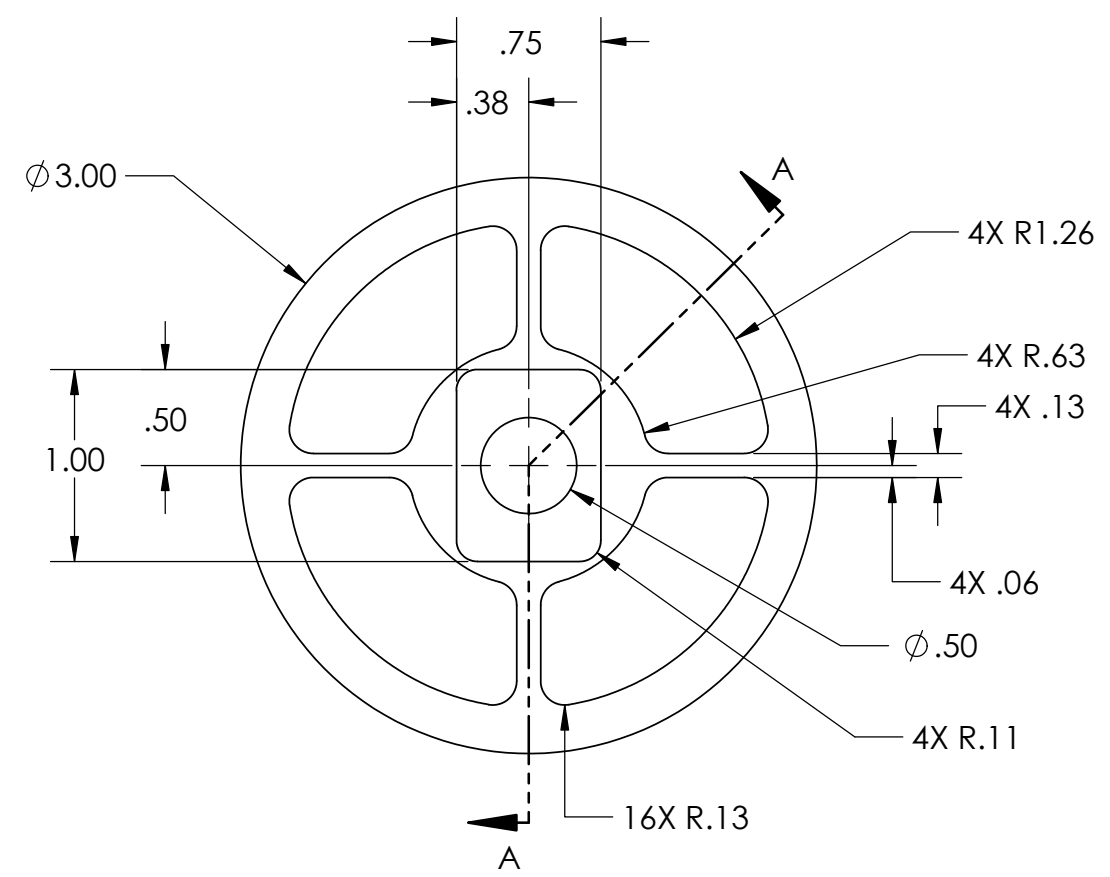
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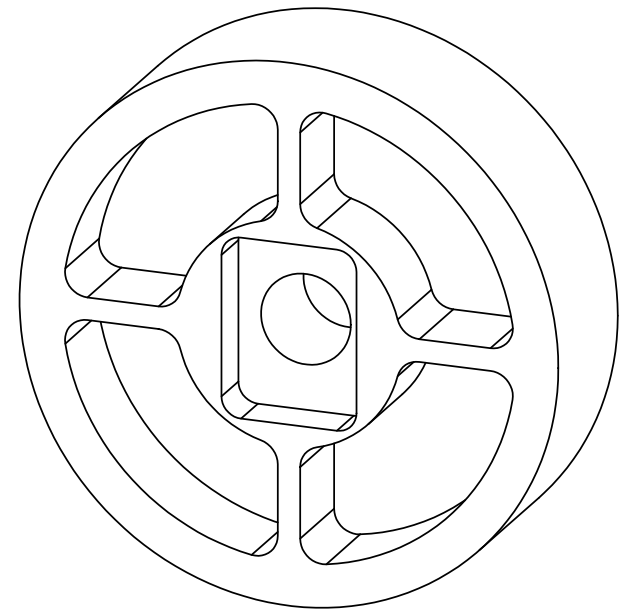
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SECTION A-A



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1	22CRJ603	$\phi 3.0 \times 1$ BAR	1
ITEM NO.	PART NUMBER	DESCRIPTION	QTY.

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	<p>DIMENSIONS ARE IN INCHES</p> <p>TOLERANCES:</p> <p>FRACTIONAL: $\pm 1/16$</p> <p>ANGULAR: MACH ± 3</p> <p>BEND ± 1</p> <p>DECIMAL: .XX $\pm .01$</p> <p>.XXX $\pm .005$</p>			<p>SMALL JOINT HOLE</p>					
	MATERIAL	6061		DRAWN	JPV	4/30/16	SIZE	DWG. NO.	REV
	FINISH	125		CHECKED	JPV	4/30/16	B	22CRJ603	-
NEXT ASSY	USED ON	STAGE	ROBOT		SCALE: 1:1	WEIGHT:	SHEET 1 OF 1		
APPLICATION		DO NOT SCALE DRAWING		VENDOR	POLY PUTTERS				

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Operation Manual

Machine Set-Up

1. Deploy tripod: fully extend legs and tighten tripod leg pin; the middle tube of the tripod should not be touching the ground; push the tripod side to side, it should feel stable.
2. Attach machine: lower vise sleeve onto the top of the tripod; position the machine so it will extend between two of the legs of the tripod (as opposed to being in-line with one of the legs), this is the most stable set-up; fix the machine to the tripod by firmly tightening the pin.
3. Loosen both of the circular joints by turning the wingnuts clockwise.
4. Tilt the main upright arm until it stands at about 90°, then tighten the wingnut on the larger joint (connecting the upright arm to the vise); push the arm back to the desired swing plane angle (this is required because tightening the joint with the wingnut only isn't strong enough to hold the angle through a swing).
5. Fix putter into grip: insert putter grip into the grip piece; tighten each of the thumbscrews until the putter is held in place but still has some compliance (should be able to turn relatively easily a few degrees either way, and then return to its original position); adjust the lie angle of the putter at the smaller circular joint and then firmly tighten the wingnut at this joint.
6. Adjust the press angle: if desired, the press angle can be changed by loosening the knob on the backside of the grip piece; tilt the grip forward or back and tighten the knob.
7. Optional: attach the swing weight: fit the swing weight onto the edge of the swing weight slide; fix it in place by tightening the thumbscrew.
8. Extend machine arm: loosen the two pins on the swinging arm of the machine; adjust the length of the arm until the putter sole rests less than a quarter inch off the ground.
9. Adjust swing arm start point: using the correct-size Allen wrench, loosen the latch arm (between the bearings and the swinging arm of the machine); adjust the angle to set the swing start angle; it may be necessary to do this multiple times after attempting the first shot to get the correct power.

Operation

1. Place ball at the sweet spot of the putter while it is at the bottom of its swing.
2. Pull machine arm back so that the latch arm is behind the latch; extend the latch; rest the arm on the latch.
3. Steady the putter end: briefly hold the grip or shaft of the putter to stop the putter end from shaking.
4. Pull the latch.

Safety Considerations

Make sure all appendages are clear of the machine before releasing the latch. Using one finger to pull the latch back. DO NOT release the latch while fingers or any other body part is between the swinging arm and upright.

When setting up the machine, make sure that it is stable during all stages of deployment. Do at least one test swing to ensure the machine will not fall over during use. If necessary, the feet of the tripod can be covered by sandbags or a similar weight to secure the machine (for its use on a slope, for instance).

Design Contest Results

Table J.1. Putter designs were awarded three points for each first place vote, two for each second place vote, and one for each third place vote.

Design	1st Place Votes	2nd Place Votes	3rd Place Votes	Total Points
D	3	5	0	19
B	4	1	1	15
E	2	4	1	15
I	2	0	4	10
A	2	0	2	8
F	0	0	2	2
H	0	1	0	2
C	0	0	1	1
G	0	0	0	0

Table J.2. Putter design contest vote breakdown. The average voter had a self-proclaimed skill level of 3.1 out of 5. The last two voters were not included in the voting results.

Voter	Skill Level (1-5)	1st Place	2nd Place	3rd Place	Comments
1	1	E	D	I	
2	4	I	B	A	
3	3	E	D	B	“Looks great!”
4	1.1	I	D	E	
5	2	D	E	I	
6	1	D	H	A	
7	3	B	D	I	
8	3	A	E	F	
9	5	B	E	C	“I like the classic blade style putter”
10	4	B	E		
11	5	A	M	F	

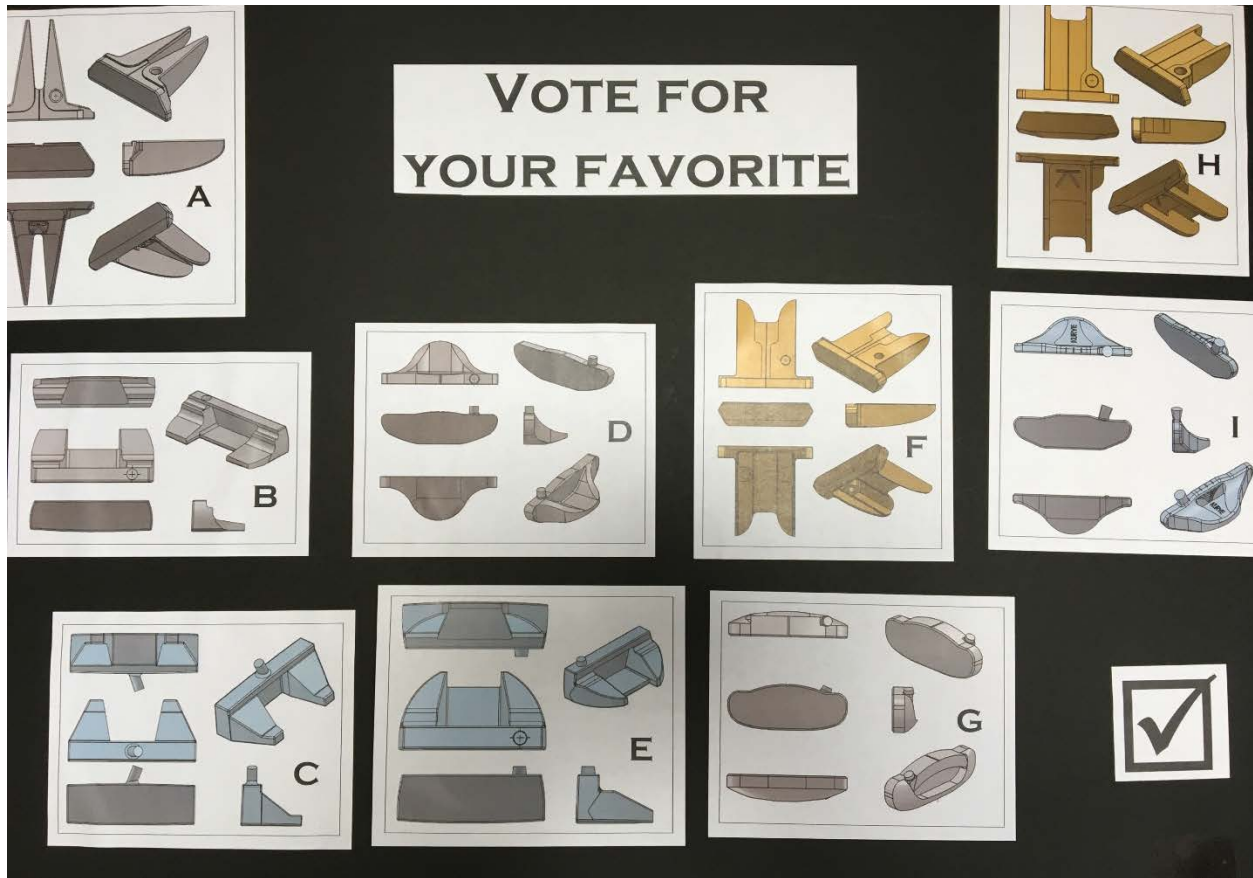


Figure J.1. Putter design contest voting board.

Table J.3. Putter designs.

Design	Name	Creator
A	Krooked	Roger H.
B	Tap	John V.
C	Kraig	John V.
D	Deko	Chris C.
E	Karla	John V.
F	Backwards	Roger H.
G	Pocket	Chris C.
H	Karry	Roger H.
I	Kurve	Chris C.

The top three putters were Deko by Chris C., then Tap and Karla by John V., letters D, B, and E on the voting board, respectively.