Final Report

Ein: The Robotic Leg

RoboMeks

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Abstract

Team RoboMeks has designed, built, and tested a passive dynamic robotic leg named Ein. The leg was designed to be a modular subsystem, that may later be implemented into a multi-legged robot. The three biggest challenges facing robotics today are: mobility, manipulation, and the unpredictability of environments. Ein addresses all three issues by swinging, retracting, and hopping.

Preliminary analysis was performed using newtonian mechanics to prove the functionality of the conceptual design. Further calculation was conducted using Lagrangian motion analysis for manipulators and trajectory analysis to develop a control system. Two types of motion, swinging and retracting, are necessary to perform a successful step. A motor was added at the leg's hip to produce the swinging motion; a second motor was implemented with the slider-crank mechanism to enable the retraction function; and hopping is achieved by the simultaneous use of both.

The overall leg assembly weighs less than 2.3 kg and can support an additional applied load of 3 kg. Networked actuators powerfully swing the leg at speeds between 6.4 and 19.3 revolutions per minute and retract the leg radially at a minimum speed of 0.5 meters per second. Ein has proven capable of addressing the challenges of mobility, manipulation, and environmental unpredictability. The robotic leg will undergo further testing at the Robotics and Motion Laboratory in preparation for its implementation in a multi-legged robot that may travel across uneven surfaces.

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1.0 Introduction and Background

Although sophisticated robotic systems exist today, the field of robotics engineering still faces tough challenges including issues such as: mobility, manipulation, and the unpredictability of environments. With these challenges in mind, a team of senior design mechanical engineering students designed a robotic leg by the name of, "Ein" that has already proven to be a very useful tool in furthering robotic legged locomotion research. The team worked with The Robotics and Motion (RAM) Laboratory at The University of Texas at San Antonio. Research value of the project is equivalent to the leg's performance during testing and has proven to be an insight in heavily studied areas such as passive dynamics, gait behavior and planning, natural environment behavior predictability, and the planning of multi-legged robotic implementation.

The objective of this final report is to provide the reader with a clear and comprehensive understanding as outlined by the members of Team RoboMeks, for the development of Ein: The Robotic Leg in fulfillment of the course, ME 4813 (Senior II) at UTSA.

2.0 Purpose

The purpose of the project was to design, build, and analyze a series of tests on a fixed robotic leg prototype that would perform according to the specifications set by Dr. Pranav Bhounsule of The Robotics and Motion Laboratory at UTSA.

3.0 Objectives

3.1.0. Programmatic Objectives

The main objectives of the program are as follows: develop a unique design, plan and execute fabrication of the prototype, test the performance of the prototype based on the initial specifications, analyze results and deliver/present conclusions while adhering to a set schedule and finances.

3.2.0. Technical Objectives

The main technical objectives of this project were to develop a robotic leg that would swing between a speed of 6.4 rpm and 19.3 rpm, retract in the radial direction at a minimum speed of 0.5 m/s, and support an additional maximum mass of 3.0 kg.

4.0 Engineering Design Specifications

Specifications were set by the team to ensure the delivered prototype was satisfactory according to the requests of the client. The following engineering design specifications were separated into various categories and are considered by the team to be the foundational basis of the robotic leg design.

4.1.0. Initial Requested Specifications by client:

4.1.1. Degrees of Freedom

The robotic leg must encompass a minimum of 2 degrees of freedom.

4.1.2. Appearance, Movement, Balance, and Support of Mass

The appearance and movement of the robotic leg must be non-human like. The robotic leg must also be attached to a testing fixture that limits motion to the vertical plane (X-Y plane). The robotic leg must support an additional maximum mass of 3.0 kg.

4.1.3. Walking Mechanisms

When attached to the fixture, the leg must swing at a speed between 6.4 and 19.3 rpm. The leg must retract in the radial direction at a minimum speed of 0.5 m/s (Figure 2).

4.1.4. Step Size

The stepping size of the leg must be between 0.129 m to 0.388 m, when theta is equal to 30 degrees as shown in Figure 1.

4.1.5. Control System

The control system must operate with the use of a single-board micro-controller.

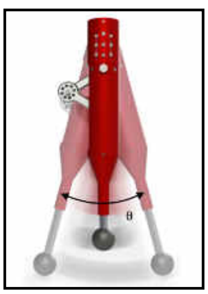


Figure 1: Reference Angle for Swing Angle, Speed, Acceleration, and Stepping Size

Figure 2: Retraction Position, Speed, and Acceleration

4.2.0. Physical Specifications

4.2.1. Mass and Dimensions of Robotic Leg

The mass of the robotic leg must fall between 1.0 kg and 12.0 kg. The maximum height and width of the robotic leg must fall between 0.25 m and 0.75 m.

4.2.2.Power Supply

The system must be powered with a DC power supply.

4.2.3.Mechanics

The mechanics components are defined as the metallic rigid structures (ex. shank,…etc.).

4.3.0. Design Specifications

4.3.1. Dimensions and Mass

The robotic leg must meet dimensional requirements as specified above as well as mass requirements.

4.3.2. Servo Motor Selection

A smart servo motor was selected based on the torque requirements of the preliminary static and dynamic design analysis. In particular, the Robotis brand was chosen based on the recommendation of the client.

4.3.3. Testing Compatibility

The leg must be able to attach/detach easily from a secured testing fixture by use of a testing mount.

4.4.0. Testing Environment Specifications

Testing of the robotic leg will take place in The Robotics and Motion Laboratory (BSE 2.216) under the following conditions:

- Room temperature will fall within a range of 65 to 75 degrees Fahrenheit
- UV rays will remain at a minimum and may be rejected for testing if desired by closing Aluminum blinds in testing laboratory.
- Fluorescent lab lighting also produces minimal UV rays, which are considered to have negligible damaging effects to the materials to be used for the robotic leg structure.
- The laboratory is considered to be a "dry" lab and the robotic leg will not undergo exposure to harmful gases of any sort.
- Water exposure is limited to a single sink within the lab, however the testing table chosen to attach the robotic leg and its holding fixture will be separated by a minimum of 5 feet.
- Figure 30 display the selected testing table/environment and located within the lab.

5.0 Conceptual Designs

As a fulfillment of the course requirements for ME 4812 (Senior I), Team RoboMeks designed 3 unique conceptual designs named: Rex, Ein, and Gilliam. To ensure each of the designs were distinct, the team searched for similar patented projects and were certain not to match any other designs.

5.1.0. Concept Design 1: Rex

Figure 3: CAD of "Rex" Concept

The design for Rex (Figure 3) was inspired by the walking Atrias 2.0 Monopod, designed and built in the Dynamic Robotics Laboratory at Oregon State University[1]. Both Atrias and Rex were conceptually designed for the specialty of jumping.Rex had a novel movement due to the use of its sliding mechanism. Due to symmetry about the Y axis, it was also predicted to be the most statically stable of the three designs. The design however, would have required the most amount of energy usage to achieve the overall movement. This was due to the need to both motors to be used continuously. One of its most important strengths was that it was calculated to be the most statically stable of the three. It would have required the highest amount of energy usage and would have been the most expensive to manufacture. The control system was thought to be the most complex due to its coordination of members. Also negatives, the leg was the heaviest and the width was the widest.

5.2.0. Concept Design 2: Ein

A simplified telescopic leg can be actuated by the implementation of a slider crank mechanism that turns rotary motion to linear motion and requires no pneumatic actuators. Based on the advice of the team's machinist, the design could have been easily manufactured with minimal lead time. The slider crank mechanism turned a complicated set of members and joints into just two members with three joints to create significant ground clearance for achieving a hopping motion. Leg control planning was predicted to be difficult due to the calculated opposing forces experienced by the leg during motion and need to achieve a desired gait. Regarding aesthetics, Ein (Figure 4) was voted by the team and client to have the highest scores. The placement of motors was also thought to be difficult as they needed to be positioned away from direct forces that would have been experienced by achieving gaits.

Figure 4: CAD of "Ein" Concept

5.3.0. Concept Design 3: Gilliam

The Gilliam (Figure 5) concept design drew inspiration from *ScarLETH*, a robotic leg built at the Legged Robotics Autonomous Systems Lab at The Swiss Federal Institute of Technology in Zurich, Switzerland [2]. Joint designs were modeled for the enhancement of natural dynamics by the implementation of springs. With limited joint connections, there are two main movements of the design-that of the thigh and that of the shank, thought to have simplified programming. With the addition of springs, the design should have demonstrated the highest elasticity and mechanical energy storage. It was thought to perform the best during the "hopping" tests, however, the level of danger regarding "back emf" was unknown. The special order of certain components would have proven the design to be very costly as opposed to its contenders when calculated. The look of design itself was voted lowest in the aesthetics category. Due to the analysis of a two toned pendulum, it was the most complex to further analyze and lost points during voting.

Figure 5: CAD of "Gilliam" Concept

5.4.0 Selection Criteria

Three conceptual designs: Ein, Gilliam, and Rex, were analyzed with the objective of selecting the optimal robotic leg design. A Pugh chart, being one of the most common selection techniques, was created to grade the designs by priority. High priority was based on the specifications of the client. Medium priority was selected from the motion and force requirements, and low priority from the team's selections. The criteria analyzed was: swinging and retraction speeds, leg's length, width and mass, material's cost, and manufacturing complexity. It can be seen that Ein beat out the other two conceptual designs based on the results seen in Table 1, for this reason it was selected for full development by the team.

Table 1: Pugh Chart based on Selection Criteria

Categories		Required Ranges	Importance	Rex	Gilliam	Ein
Motion Criteria	RPM while Swinging	6.440-19.300 RPM	20%	10.786	12.066	9.355
	Speed while Retracting	0.500 m/s	20%	0.928	0.882	1.070
Physical Criteria	Length of Leg	0.250-0.750 m	15%	0.469	0.409	0.565
	Width of Leg	0.250-0.750 m	12%	0.282	0.257	0.250
	Mass of Leg	1-12 kg	13%	1.350	0.658	1.030
Materials Criteria	Material Cost	Lowest	10%	139.437	116.886	130.327
	Manufacturing Complexity	1-25	10%	~16 (3)	~15 (1)	~12 (2)
TOTAL			100%	28%	19%	80%

6.0 Final Design- Key Features

Due to Ein being the selected conceptual design to be further developed by the team, it had to undergo further calculations and analysis by the members. To insure project success,Ein, was subjected to motion analysis and stress/strain analysis.

6.1.0. Motion Analysis

6.1.1. Basic Statics

Basic motion analysis was conducted to analyze the loads and distributions throughout the leg. The assumptions taken are that the net moment and forces on every component equaled zero. The static analysis was performed with the objective of proving that the design could withstand the forces and moment acted upon it during operation.

6.1.2. Dynamics

6.1.2.1. Mechanics Based on Newtonian Mechanics:

The equations have three dependent variables: position, velocity, and acceleration, and one independent variable, time. By using free body analysis (Figure 1, Appendix A) to find the resultant forces, newtonian mechanics gave an accurate description of the motion of the leg components.

6.1.2.2. Euler-Lagrange:

The Euler-Lagrange analysis of points describes the: position, velocity, and acceleration of a point. The basis of the Euler-Lagrange method involves the summation of the energy of a point. The function to be found is designated as ‘q’ and is input into the Lagrangian equation. The Lagrangian is then partially derived and later differentiated with respect to ‘q’ or the derivative of ‘q’. The variable ‘q’ describes the position of the particle, and differentiation displays the velocity and acceleration of the particle. For initial periodic motion and future control system analysis, Lagrange mechanics is considered to be the best method. The Euler-Lagrangian technique was chosen for its applicability to systems which may or may not conserve energy and/or momentum.

6.1.2.3. Path Generation:

The method of “Path Generation” was used to generate a planned polynomial function with initial conditions to find the position of a single link. A system of equations was created (in the form of Ax = B), where “A” is a matrix containing all of the coefficients for the polynomial, “x” the terms of the polynomial (e.g. a0, a1, a2…), and B a vector containing the conditions specified for the system. The result was an equation for the position and its derivatives (velocity and acceleration) that follows the initial conditions set upon it.

6.2.0. Calculation Summary

6.2.1. Statics Analysis

Figure 1 (Appendix A) below displays a free body diagram of Ein. Figure 2 (Appendix A) describes the nomenclature of the free body diagram.

6.2.2. Assumptions

Based on the physical specifications and functional requirements, a range of applied loads as well as leg mass values were chosen (Table 2). Together, they formed a total of 9 possible analysis combinations. The first number refers to the mass of the leg, and the second number to the mass to the applied load.

The resultant forces from the free body diagram can be seen in Table 3. The ideal angle was defined as 30 degrees because it gave the lowest resultant force based on the forces in the x and y directions. The torque calculated was determined to be the moment force required for the leg to start swinging.

Table 2: Possible combinations for the Free Body Diagram (FBD)

M_{LEG} , M_{LOAD}	Mass of Load (kg)		
Mass of Leg (kg)	1 , 1	1 , 2	1 , 3
	6 , 1	6 , 2	6 , 3
	12 , 1	12 , 2	12 , 3

Table 3: Resultant Forces from the Free Body Diagram (FBD)

Static Analysis Results	
θ_{IDEAL}	30
F_t (N)	1.416
F_{Mt} (N)	0.818
F_s (N)	15.575
F_{Ms} (N)	8.993

6.2.3. Dynamics Analysis

<u>6.2.3.1. Mechanics Based on Newtonian Mechanics</u>

For this phase of analysis, resultant forces for the standing leg were calculated in (Figure 1, Appendix A) based on the main assumptions that the mass of leg is equal to 1kg and experienced an applied load of 3 kgs. Calculation revealed that the servo motor required to move the leg at the hip needed an output of 1.417 Nm.The torque found from the dynamic analysis was determined as the force required to stop the leg from moving higher than it should be allowed. From the torque results (Figure 5, Appendix A), a proper motor was selected. Dynamic analysis of Ein was performed in two steps; kinematic and kinetic to determine motion and resultant forces/torques, respectively. Kinetic analysis was used to predict the acceleration needed to achieve a leg swing from -15° to 15° in 520 ms with initial and final velocities of 0 m/s. The general equations of motion were used to model the position as a second order polynomial (with respect to time). After the necessary acceleration was determined, kinetic analysis was performed and modeled the leg as a lever with torque applied at one end. The inertia, *I,* and the rotational acceleration, α, in the equation $\tau = I\alpha$ were used to determine the necessary torque to maintain a desired acceleration.

6.2.3.2. Euler-Lagrange

Denavit-Hartenberg parameters were first assigned (Table 4 & Figure 2, Appendix A) to express the systems geometry and the trajectory. They were used with Sympy (a module in the Python programming language) to symbolically produce the position and orientation of each link as a function of the DH-parameters. Next the Jacobians of velocity were determined using Equations 1 and 3.

$$J_i = \begin{bmatrix} J_{v,i} \\ J_{\omega,i} \end{bmatrix} = revolute jacobian \begin{bmatrix} R_0^0\hat{k} \times (O_i^0 - O_0^0) & R_1^0\hat{k} \times (O_i^0 - O_1^0) & \dots & R_{i-1}^0\hat{k} \times (O_i^0 - O_{i-1}^0) \\ R_0^0\hat{k} & R_1^0\hat{k} & \dots & R_i^0\hat{k} \end{bmatrix}$$

$$\text{prismatic jacobian} \begin{bmatrix} R_1^0\hat{k} & R_2^0\hat{k} & \dots & R_{i-1}^0\hat{k} \\ 0^{3\times1} & 0^{3\times1} & \dots & 0^{3\times1} \end{bmatrix}$$

Equation 1: Jacobian Equation

$$L = K - P \textit{ (Lagrangian)}$$

$$K = \frac{M_i V_i^2}{2} = \frac{1}{2}\dot{q}^T \left[\sum_{i=1}^{n} M_i J_{v,i}^T J_{v,i} + J_{\omega,i}^T R_i I_{b,i} R_i^T J_{\omega,i} \right] \dot{q} \textit{ (Kinetic Energy, K)}$$

$$P = M_i gh = \sum_{i=1}^{n} \vec{g}^T M_i \vec{r}_{c,i} \textit{ (Potential Energy, P)}$$

Equation 2: Lagrangian Inertia Equations

$$\frac{\partial}{\partial t}\left(\frac{\partial L}{\partial \dot{q}_i}\right) - \frac{\partial L}{\partial q_i} = 0$$

Equation 3: Jacobian Equation

Table 4: Assigned DH Parameters

$Link_i$	a_i	α_i	d_i	θ_i
1	0	π/2	d	θ_1
2	0	0	d	0

Then derivation of the Lagrangian, using Equation 2, was derived to produce the equations of motion and then used to develop the state space representation of the system. Finally, by modeling the effective leg motion as two links, an animation of Ein's uncontrolled motion was produced by integrating the state space equations with Python's "odeint", or ODE integrator module.

6.2.3.3. Path Generation

For determination of acceleration, velocity and position necessary to meet the requirements, a technique known as trajectory generation was used. Using this method it was necessary to determine points of interest (POI) or specific positions the foot should be at specific times. Next, based on what characteristics needed to be specified (position, velocity, and acceleration) the change in position between POI were modeled as a polynomial functions of time time with an order greater than the highest order characteristic. Using this technique, curves expressing the acceleration, velocity and position as a function of time were determined. Figure 6 displays the dynamic results for a 2 link assumption. Figure 7 displays the optical path based on leg retraction for Ein.

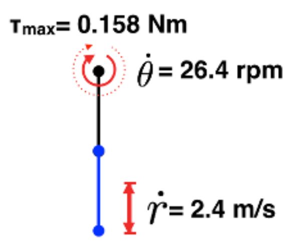


Figure 6: Dynamic Results for a 2 Link Assumption

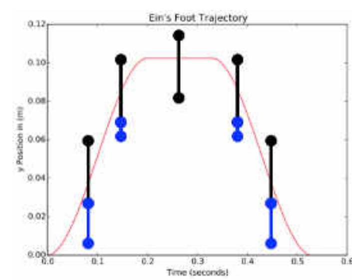


Figure 7: Optimal Path based on Leg Retraction

6.2.4. Stress/Strain CAD Modeling

SolidWorks Simulation was used to perform stress and strain analysis of the three main components: the Crank Driver, the Follower Link, and the Shank. The stress analysis was calculated using the von Mises distortion-energy theory for ductile materials. The assumption was used based on its high level of ductility. Strain analysis was calculated using the equivalent prediction that, *yielding occurs when the distortion strain energy per unit volume reaches or exceeds the distortion strain energy per unit volume for yield in simple tension or compression of the same material* [5].

6.2.4.1. 3D Stress/Strain Simulation of the Crank Driver

The SolidWorks analysis of the crank driver was done with a torque of 1.723 Nm on the larger end, and a directional force of 17.23 N perpendicular to the link on the smaller end. The fixed parts of the link were designated to be the two center circles on both ends. The maximum stress (shear) experienced by the link was 3.93601 e 6 N/m^2, which is much less than the yield strength of the material (Aluminum 7075, 5.05 e 8 N/m^2). The results are included in the Appendix Figure 48, they showed that the crank driver will not fail during normal operation of the leg.

6.2.4.2 3D Stress/Strain Simulation of the Follower Link

The SolidWorks analysis of the follower link (which is physically the same to the crank driver) was done with two opposing forces on the link both equal to 17.23 N. The forces acted parallel to the length of the link. The fixed parts of the link were designated to be the two center circles on both ends. The maximum stress (compressive) obtained from the simulation was 601810 N/m^2, which is, like the crank driver, much less than the yield strength of the material (Aluminum 7075, 5.05 e 8 N/m^2). The visual attached in the Appendix, Figure 49, shows that the follower link will not fail during normal operation of the leg.

6.2.4.3 3D Stress/Strain Simulation of the Follower Link

The SolidWorks analysis of the shank was done with two opposing forces (12.183 N) acting along the length of the shank. The maximum stress (compressive) acting on the link was 42636.7 N/m^2, which is much less than the strength of the material (Aluminum 7075, 5.05 e 8 N/m^2). The Appendix Figure 50, show that the leg shank will not fail during normal operation of the leg.

6.3.0. Product Failure Modes

6.3.1 Zero Mechanical Advantage:

The sliding crank mechanism that drives the leg must be limited to prevent an instance of zero mechanical advantage. The solution was to create the bottom go the leg cover to be a mechanical stop, preventing the shank from hyperextending. This mode is a final resort, with the leg's control system being the main action preventing zero mechanical advantage. The mechanical stop during retraction is the leg's foot. The ball will stop the shank from over-retracting and damaging the two links.

6.3.2 Material Failure

Because the leg is made from primarily aluminum parts, there is a high possibility of galling for the surfaces in moving contact with each other. The team had all of the pieces anodized, limiting the possibility of galling. For the surfaces in contact with pins, bronze bushings were made to serve as the contact surface between the aluminum components and the steel pins.

6.4.0. Design Refinements

6.4.1 Crank Driver and Follower Link

The original design for Ein placed the crank driver and follower link side by side in their complete assembly. After receiving advice, the team decided to have the two links slip into each other with the crank driver being the male end and the follower link the female end. This led to a more machinable part and a more stable movement.

6.4.2 Motor Selection

To ensure the leg had ample power, the team chose the Dynamixel MX-64AR and MX-106R smart servo motors. The smaller MX-64AR was placed inside the leg and the larger, more powerful MX-106R was attached to the outside of the leg. These two motors (Figures 5 & 6, Appendix A) exceed the requirements calculated by the dynamic analysis of 1.72 Nm as they have a stall torque of 7.3 and 10 Nm respectively. The overhead for the motor power was due to the desire for the team to not have to deal with any lack of power during Senior Design 2. An electric motor's actual working power is less than the stall torque, further backing the team's decision to purchase extremely strong motors.

6.4.3 Weight Conservation

Because the leg was much heavier than anticipated, the team made great strides to cut weight from the leg. Almost every part that could be reduced in weight was. These weight changes were made without any changes in the overall design and function of the components.

6.4.4 Sprocket and Chain

The leg's motors needed an strong, simple way to transfer power. By using a miniature chain and sprocket the team was able to transfer the motor's torque to the first pin, which activates the slider crank mechanism that retracts and extends the leg. The chain was chosen over other options, such as belts and pulleys, because of its vastly higher strength of 180 lbs average (Figure 8, Appendix A). Analysis on the maximum torque possibly experience by the sprocket (Figure 7, Appendix A) shows that using the MX-64 motor stall torque, the maximum tension is 1147 Nm or about 257 lbf. This is much more than the strength of the chain, but the motor cannot actually produce 7 Nm of torque in actual applications. this means that the chain can withstand the motor's power.

6.5.0. Design Conclusions

Ein the robotic leg is a design validated by static, dynamic, and stress analysis. The static analysis, which included a free body diagram, gave an understanding of the forces endured by the leg. The forces from the static analysis ensured that the leg would perform as required by the project specifications. From Solidworks simulations, the stresses experienced by the leg components during regular operation were found to be safely within the material's limits. The Euler-Lagrange motion analysis gave an accurate prediction for the movement of the leg. Using the equations of motion (from the Euler-Lagrange method) and the D-H parameters for an end effector the team was able to plan and predict the movement of the leg to ensure it met the specifications. The safety mechanisms put in place to prevent the system from failing were successful, with the mechanical stops being able to stop the shank from exceeding its bounds. The design refinements that took the team decided on helped the realization of the project immensely. The change in the crank driver and follower link helped the leg's movement by preventing any failures in those parts and conserving weight by machining out extra material lessened the load on the motors. The analysis, its results, product failsafes, and design refinements transformed the original idea into a fully working prototype.

7.0 Prototype Fabrication

7.1.0. Fabrication Methods

Figure 8: Machined Main Components

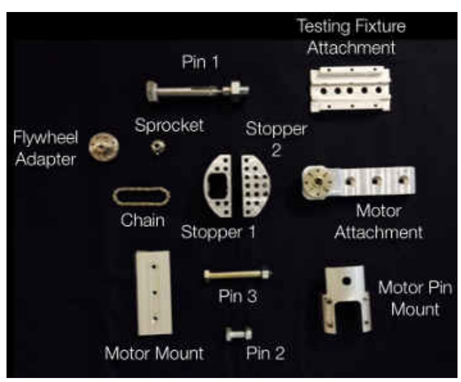


Figure 9: Machined Sub Components

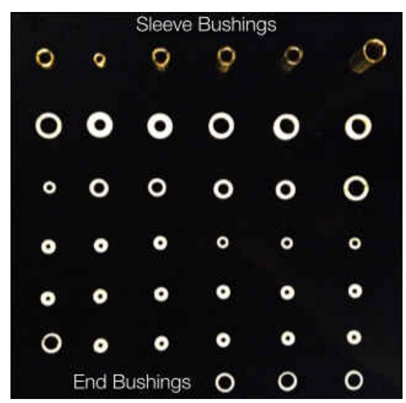


Figure 10: Machined End and Sleeve Bushings

The machine shop at UTSA was used by the team to machine all of the following components as displayed in Figures 8,9,and 19 with the assistance of Paul Krueger and Dave Kuenstler. Various machines were used in the machine shop such as the lathe, vertical mill, bandsaw, and belt sander. Regarding anodization of the Aluminum 6061 and Aluminum 7075 parts, all of the processes were done at Wright's Metal Finishing by professionals. The parts that were anodized include all of the main components, some of which were dyed red (as seen in Figure 8).

7.2.0. Drawings

Drawings using Solidworks were created for creating the design of each individual component. Then, sub assemblies were created in order to complete a full assembly drawing. Ein: The Robotic Leg has 47 unique pieces (all of which were designed by Team RoboMeks), and 85 pieces in the overall assembly.

A complete drawing package along with assembly instructions was submitted in compliance with course requirements for ME 4813. The objective of the drawing package and assembly instructions was for the recreation of Ein: The Robotic Leg. With the various enclosed drawings, schematics, diagrams, and instructions; a machinist would be able to machine the parts that were manufactured and a fellow engineering student assemble the leg. Both cases would find the instructions for questions that may arise throughout either process. Sample drawings from the drawings package may be found in Appendix B.

7.3.0. Bill of Materials

The purpose of the Bill of Materials is to provide the reader with a list of materials needed to recreate Ein: The Robotic Leg. It can be found in Appendix B.

8.0 Testing of the Prototype

The purpose of the test plan was to ensure that Ein met the physical and functional specifications requested by the sponsor, Dr. Pranav Bhounsule.

8.1.0. Test Plan Summary

Ein was also tested to prove its capability for future implementation in a four legged system that would travel at half a meter per second. Preliminary testing was performed as the first phase of testing. The first phase included physical measuring and functionality testing of all mechanical, electromechanical and electrical components and assemblies.

For Ein to function as desired by Dr. Bhounsule, it needed to meet the following three criteria: swinging, retraction and hopping. To complete a step Ein needed to be capable of performing 2 distinct motions, swinging and retracting. Therefore the second phase of testing consisted of trials of swinging and retracting motions. Third phase was exclusively for hopping test. For dynamic compatibility the leg needed to be capable of performing a hop.

Preliminary testing was performed prior to Ein's assembly. Each of the mechanical component's dimensions were measured, all of the electrical component's significant characteristics were recorded to ensure that they fell within the team's tolerances and the electromechanical components (motors) were tested as well to verify that they agreed with the manufacturer specifications. Prior to the second phase, it was determined that Ein's foot needed to swing about the hip at about 19 revolutions per minute and retract radially at about half a meter per second, as specified by the sponsor. Following Ein's assembly, swinging and retracting motion functions were tested. After, hopping test was performed. There were multiple attempts, each leading to the conclusion that the hopping test needed to be done at various angles, to prove leg functionality, and with springs to prevent motor damage after the leg impacts the floor

8.2.0. Test Apparatus and Setup

8.2.1. Test Apparatus

Initially the testing fixture was designed to be stand alone with six 3' T-slot extrusions as the frame, a control box and a power supply. The fixture had some significant faults. First a problem of mobility was encounter, even though the fixture was light (< 15 lbs), it was bulky and difficult to fit. Also, there was a problem of uncontrolled vibrations. The fixture would slip into resonant oscillations throughout testing, which made data recovery and analysis difficult. Due to the fixture's shortcoming, the testing fixture had to be modified. After multiple iterations, the frame eventually evolved into one 3' T-Slot extrusion for mounting Ein, and for support three 90° Edmund Optics angle brackets were mounted together to an Oak top table with roller wheels allowing mobility of the fixture. The current fixture, shown in the Figure 11, is sturdier, mobile and vibration free.

Figure 11: Ein attached to Testing Fixture

8.2.2. Experimental Setup

Two setups were required to perform Ein's testing. The setup was modified to better suit the characteristic needs of the test and to obtain optimal results. For swinging, retracting and stepping test (measure of step size), the leg was mounted with the foot away from the ground. The leg was allowed to go through its cycles undisturbed which result in optimal data acquisition. During the testing cycles, data was read from the serial port, stored in a CSV file, then extracted and graphed to analyzed using python. For standing and hopping testing, the criteria for success was determined as a yes or no, therefore no data was needed to be recorded or analyzed. For these tests, the fixture was modified to include springs between Ein and the fixture. Springs were added to prevent damage to the motor. After being sprung, tension across the springs was limited using a pulley crank. For data acquisition high speed cameras (frame rate > 120fps) were mounted at the base and in front of the fixture. The cameras were used to observe the clearance between the foot and floor as well as the motion of the Ein's mechanism during hopping. Both hopping and standing test were conducted with the leg tilted at 30°, 45°, 60°, 75° and 90° angles. These angles were achieved using the Pythagorean theorem measuring the length of the leg and the length of its shadow.

8.3.0. Test Results

8.3.1. Retraction Tests

As previously stated, retraction tests were conducted with Ein foot not touching the ground. The shank was retracting and extending perpendicular to the ground. A path guiding the foot through the cycle, beginning at the datum of 40 centimeters and moving to 34 centimeters displayed in Figure 12, was developed using a third order polynomial to map intermediate coordinates. This path was sent to the micro controller, where it was able to extract around 18 samples per cycle with about 1 sample per cycle being faulty and declared an outlier. After error analysis, results from the retraction test reflected that Ein followed the projected path with about 3% difference from the desired as display in Figure 13. With such a small percent error, the retraction test was deemed a success. Throughout this path the leg's shank was measured to retract at speeds exceeding 1 meter per second, achieving an average cycle retraction speed higher than 0.5 m/s. Therefore the retraction speed met the functional specification requested by the sponsor.

8.3.2. Swinging Tests

The swinging test was also conducted with Ein mounted about a foot off the ground, as previously specified, and the leg swinging around ± 15° from the perpendicular. A third order polynomial was also used to develop a path between end points of the leg, so that it will rotate

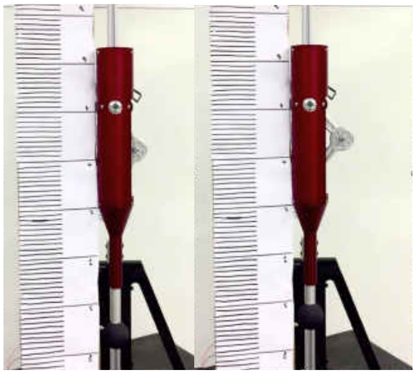


Figure 12: Ein Fully Extended & Retracted

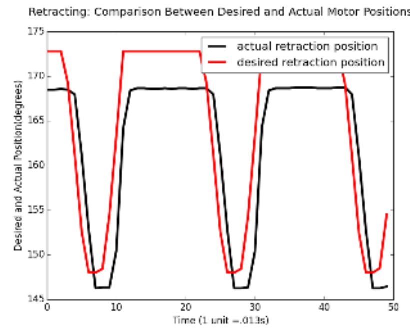


Figure 13: Actual vs Ideal Retraction Path

about the hip 15° in both directions as displayed in Figure 14. The micro controller was reprogrammed with the path coefficients for the swinging motion. Data collected was about 18 samples per cycle with about 1 sample per two cycles as outliers as in the retraction testing. Error analysis displayed a 1.67% difference from the desired path as shown in Figure 15. The average swinging speed was of 9.43 revolutions per minute, well above the minimum 6.4. Retraction and swinging motions were then combined and the results recorded matched the individual tests. Ein completed all tests proving itself capable of future implementation in a legged system to walk at 0.5 m/s.

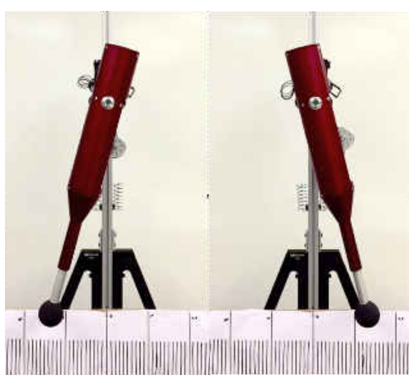


Figure 14: Ein Swinging

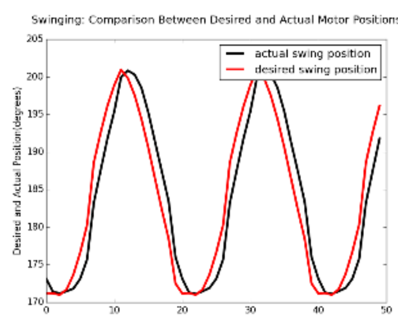


Figure 15: Actual vs Ideal Swinging Path

8.3.3. Hopping Tests

The hopping test was conducted with Ein mounted with springs as shown in Figure 16, allowing Ein to bound and land safely by reducing the severity of sudden impacts on the motors. Also, while actuating the springs, Ein was able to store the gravitation potential energy in the form of elastic potential energy and reclaim it during extension. The criteria for success of this test was that the foot clear the ground at some point throughout the actuating cycle of the test. In addition, though it was not necessary, data analysis of how well the foot followed the hopping path was conducted. This error analysis show that the foot followed the retraction path with a little more than 14% difference as display in Figure 17. The error in this test originated from multiple sources. The most significant source of error was the intentional overshooting of the desired extension point which was done to incite the use of the maximum torque by the motor's micro controllers. Other significant sources of error include play in the chain and loosening of the inner motor mount.

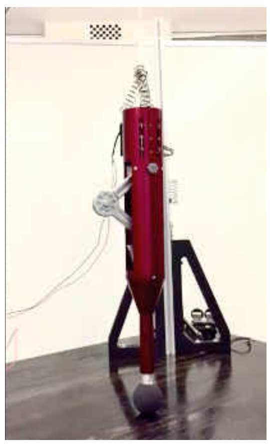


Figure 16: Ein Hopping

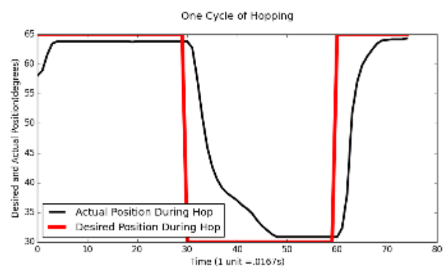


Figure 17: Actual vs Ideal Hopping Path

9.0 Project Management

The team developed a project management for the year to ensure all the requirements were made. The program includes all the deliverables as well as the costs included in the project. The team calculated and estimated the total costs to develop the senior design project. The team estimated the equivalent value in the industry for the project taking into account all the expenses that they may encounter.

9.1.0 Personnel

The team was provided with starting knowledge for the completion of the project. Some areas of the project were required to be explored by the team for the completion of the project. The team had taken one class in Robotics, Mechatronics and High Performance Computing as a base for their senior design project. However, the project required deeper knowledge in the areas of motor programming, use of strain gages, force sensor resistors, kinematics calculations using Euler-

Langrange and Denavit-Hartenberg parameters, among others. The team seek for help to Dr. Pranav Bhounsule and perform research on the areas required by the project. Dr. Pranav provided invaluable insight information on the use of Robotis motors and leg locomotion. The rest of the areas were split as shown below to ensure that all the material was cover.

Robert Brothers - Engineering Code and Controls System Developer

Raquel de la Garza - Manufacturing and Cost Analyst

Sebastian Sanchez - CAD and SolidWorks Design Specialist

Christian Trevino - Team Leader, Technical Writer, and Formatting

9.2.0 Overall Schedule (ME 8812 & 4813)

The Project's Schedule was divided into two semesters, Senior Design I and II. For SD1 the main deliverables encompassed the development of the three concept designs and further analysis of the selected concept. SD2 required the fabrication and testing of the selected design.

A detailed Schedule is included on the Appendix - A.

Projected and Actual Costs are displayed in Figure 18. RoboMeks delivered the robotic leg prototype under budget and on schedule.

Figure 18: Earned Value Graph

9.2.1. Percent Complete of Each Task

RoboMeks completed all the requirements for Senior Design I and II as displayed in Table 5.

Table 5: Project Tasks for Senior Design

Task	% Completed
Identification of Problem	100%
Conceptual Designs	100%
SD-1 Midterm Presentation	100%
Selection Process	100%
Static and Dynamic Analysis	100%
SD-1 Final Documentation	100%
Final Design/Drawing Package	100%
Adquisition of Materials	100%
Development of Testing Plan	100%
SD-2 Midterm Presentation	100%
Product Fabrication	100%
Engineering Change Orders	100%
Product Testing	100%
SD-2 Final Documentation	100%
Overall Percent Complete	100%

9.2.2. Personnel Assignments

Team collaboration was enforced when completing major assignments. The assignments were split into sections according to the strengths displayed by each team members. Eric Sanchez was in charge of leading the efforts in completing the Solid Works drawings and engineering change orders. Robert Brothers was in charge of leading the coding, electrical setup, and testing of the robotic leg. Raquel de la Garza was in charge of leading the preliminary testing and business project management efforts. Christian Trevino was in charge of leading the technical writing, presentations, and making sure the team met the deadlines for the deliverables.

9.3.0. Financial Performance (ME 4812 & 4813)

The Project Cost Analysis below (Table 6 to Table 8) represents RoboMeks prototype costs and projected costs for Senior Design I, and Senior Design II. The analysis includes the cost of the prototype as well as time spent for the completion of the class. (**for a detailed cost analysis, please refer to Appendix-B)**.

Table 6: Estimated Costs

Estimated Costs for Senior Design Project					
	Senior Design I			Senior Design II	
Staff	Hourly Cost	Estimated Hours	Calculated Cost	Estimated Hours	Calculated Cost
Senior Project Manager	$375.00	64	$24,000.00	48	$18,000.00
Senior Engineer	$300.00	32	$9,600.00	32	$9,600.00
Engineer	$200.00	619.07	$123,814.00	419.00	$83,800.00
Technician	$150.00	0.00	$0.00	405.30	$60,795.00
Secretary	$90.00	888.94	$80,004.60	594.90	$53,541.00
Laborer	$75.00	0.00	$0.00	202.25	$15,168.75
Machining	$100.00	0	$0.00	254.4	$25,440.00
TOTAL		1604.01	$237,418.60	1955.85	$266,344.75
Project's TOTAL					$503,763.35

Table7: Outsourced Costs

Item Purchased	$
Aluminum 7075 7 x 7 x 1 -Links	$0.00
Aluminum 6061 3 1/2 x 14-Shank	$43.30
Aluminum 6061 3 1/2 X 0.375 x 18-Top Cover	$27.00
Aluminum 6061 3 1/2 x 12-Cover Bottom	$43.30
Aluminum 6061 3 x 6 -Motor Holder	$16.30
Bronze SAE 841 -Bronze Sleeve Bushings 1 X 13	$34.51
Aluminum 6061 3.5 X 1/4 X 3 - Motor and Pin Holder	$8.50
Aluminum 6061 1 X 2 -Foot Attachment	$3.19
Aluminum 6061 3 X 2 - Holder 1 and 2	$8.50
Delrin Plastic 1 1/4 Dia x 1ft	$6.95
Delrin Plastic Sheet 2 X 0.02 X 60	$10.18
Opto Isolator	$11.46
Force Sensitive Resistor	$13.00
OLLO Figure Kit	$27.39
Strain Gauges (2)	$18.00
Ektelon Classic Racquetballs (3)	$4.86
Current Sensor/Transducer	$9.95
USB2Dynamixel	$57.92
GE Silicone III K&B Clear	$6.75
Smooth Rod Caulk Gun	$2.67
Dynamixel MX64	$319.90
Dynamixel MX106	$499.90
Dynamixel 4 Pin Connectors (2)	$19.40
LM741 Op Amp (2)	$0.70
Robotis OpenCM 9.04 Microcontroller	$19.20
Robotis OpenCm 485 Expansion Board	$44.56

Table 8: Total Costs

Costs	
Budgeted Cost of Work Performed	$429,598.8
Budgeted Cost of Work Schedule	$429,598.8
Actual Cost of Work Performed	$428,407.1
Schedule Performance Index	0.997
Cost Performance Index	1.003
Cost Schedule Index	1.000
Assigned Deliverables Costs	$378,683.00
Total Raw Material Costs	$215.02
Outsourced Products	$1,314.66
TOTAL PROJECT COST	$505,293.03

10.0 Project Conclusions

Having designed, developed, and tested Ein: The Robotic Leg, Team RoboMeks has drawn several strong conclusions. With the development of Ein's control system that followed paths with little error, Ein addressed the problem of "manipulation." Secondly upon the completion of the swinging and retracting tests, it was proven that Ein is capable of producing the motions necessary for walking. With Ein able to produce the two motions most important to legged locomotion Ein has successfully addressed the problem of "mobility." Finally results from the hopping test showed that Ein is dynamically capable of performing a hop. Hopping would allow a system using Ein to overcome obstacles when walking addressing the problem “unpredictability of environments.” To conclude Ein, a modular leg, is capable of participating in the legged locomotion of a walking system that has the ability to address each of the big three problems of robotics: mobility, manipulation and unpredictability.

Team RoboMeks, through the course of Senior Designs I&II, has learned that teamwork is the key to success. Each individual’s dedication and belief in the project, helped to transform Ein: The Robotic Leg, from a sketch in the beginning of senior year, to a complete, working prototype. The team knew the value of aesthetics, analysis, and project management in design. Because of the team’s focus on these three aspects of design, the project completed in Senior Design performed excellently, looked pleasing, and was on time and budget. In addition to a second place medal from the 2015 Tech Symposium, each member of RoboMeks will take from senior design: improved time management skills, project management skills, and a renewed appreciation for hard work.

11.0 References

[1] “Legged Robots." *Dynamic Robotics Laboratory*. N.p., n.d. Web. 20 Oct. 2014.

[2] “ScarlETH.” Robots:scarleth – Legged Robotics. N.p., n.d. Web. 20 Oct. 2014.

[3] "DYNAMIXEL MX-106R." *ROBOTIS*. N.p., n.d. Web. 29 Apr. 2015.

[4]”DYNAMIXEL MX-64AR." *ROBOTIS*. N.p., n.d. Web. 29 Apr. 2015.

[5] Distortion Energy Theory, Shingley’s Mechanical Engineering Design, Budynas, Richard

Appendix A: Design Key Features

List of Figures

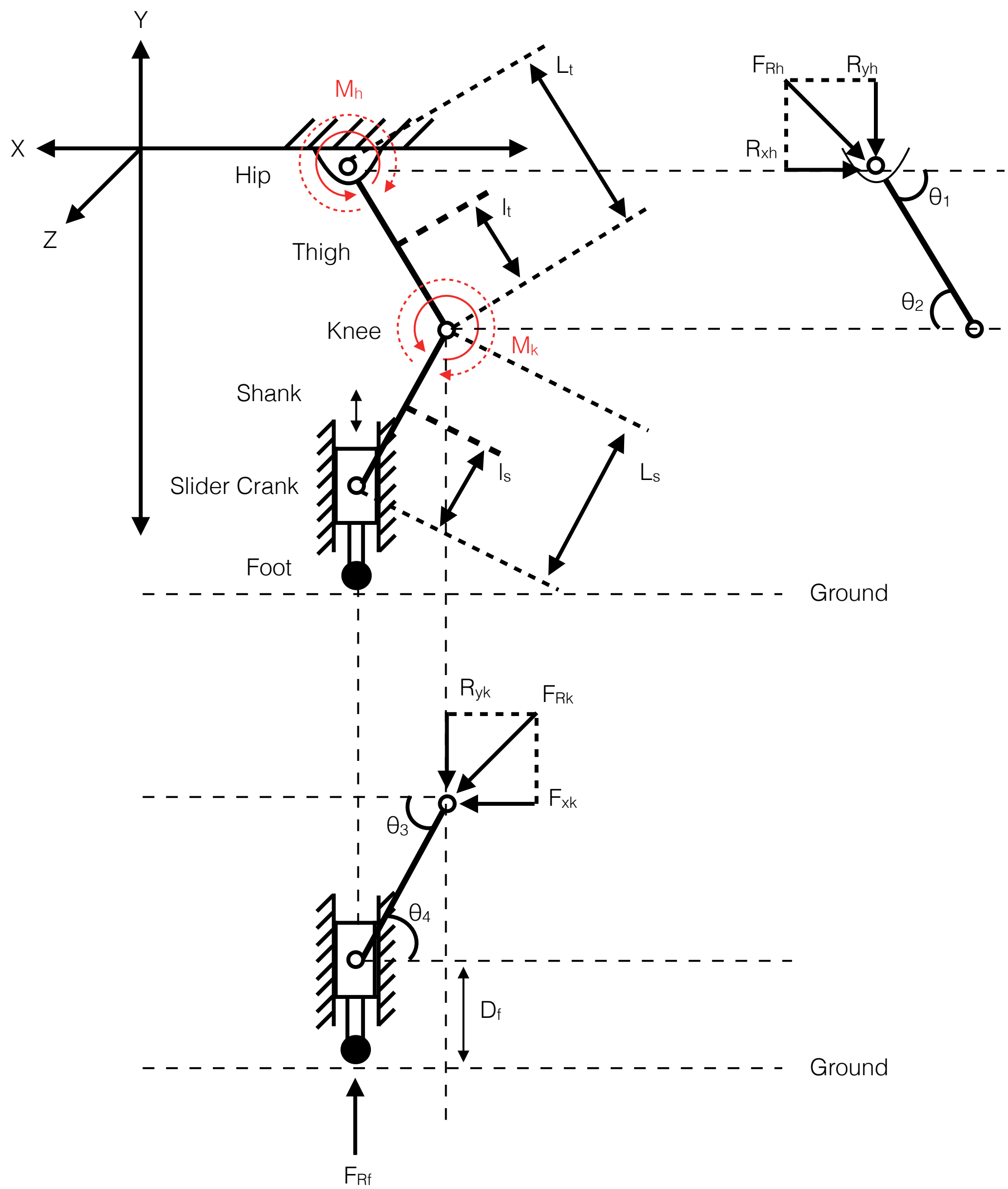


Figure 1: Free Body Diagram (FBD)

- L_t: length of thigh
- l_t: distance from hip to Center of Mass (CM)
- L_s: length of shank
- l_s: distance from knee to Center of Mass
- M_h: moment about the hip
- M_k: moment about the knee
- R_{xh}: reaction force in the x-direction (hip)
- R_{yh}: reaction force in the y-direction (hip)
- F_{Rh}: resultant force (hip)
- R_{xk}: reaction force in the x-direction (knee)
- R_{yk}: reaction force in the y-direction (knee)
- F_{Rk}: resultant force (knee)
- F_{Rf}: resultant force (foot)
- θ_1: angle between fixture and hip joint (45)
- θ_2: angle between thigh and knee joint (45)
- θ_3: angle between shank and knee joint (45)
- θ_4: angle between shank and foot (45)
- D_f: distance of foot retraction clearance
- W_{hj}: weight of hip joint
- W_1: weight of thigh including knee joint
- W_2: weight of shank including foot
- W_l: weight of leg structure
- W_{hf}: weight of hip fixture
- $W_l = W_1 + W_2 + W_h$
- $W_h = W_{hj} + W_{hf}$

Figure 2: Free Body Diagram Nomenclature

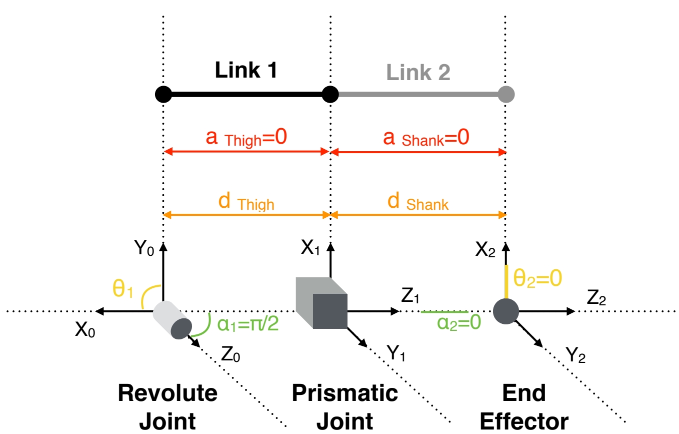


Figure 3: Schematic displaying the Denavit Hartenberg Assigned Parameters for Ein

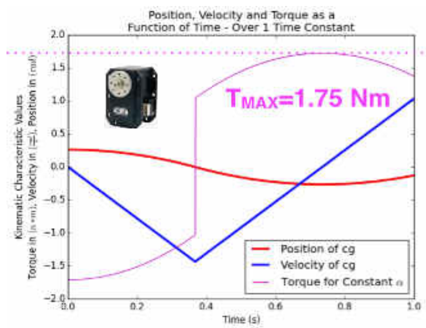


Figure 4: Position, Velocity, and Torque as a Function of Time Over 1 Time Constant

RX-64/ MX-64T/ MX-64R

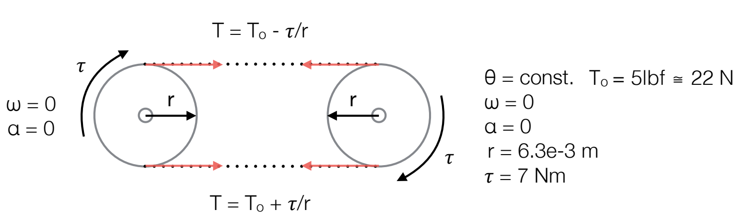
	MX-64T/ MX-64R		
Weight	126 g (4.44 oz)		
Dimension(mm) / (inch)	40.2×61.1×41(mm) 1.58×2.41×1.61(inch)		
Gear Ratio (material)	200 : 1 (metal)		
Network Interface	TTL / RS-485		
Position Sensor (Resolution)	Contactless Absolute Encoder (360°/ 4096)		
Motor	Maxon Motor		
Operation Voltage (V)	11.1	12.0	14.8
Stall Torque (N.m)	5.5	6.0	7.3
Stall Current (A)	3.9	4.1	5.2
No Load Speed (RPM)	58	63	78

Figure 5: Dynamixel MX-64AR Specifications

MX-106T/ MX-106R/ EX-106+

	MX-106T/ MX-106R		
Weight	153 g (5.39 oz)		
Dimension(mm) / (inch)	40.2×65.1×46(mm) 1.58×2.56×1.81(inch)		
Gear Ratio (material)	225 : 1 (metal)		
Network Interface	TTL / RS-485		
Position Sensor (Resolution)	Contactless Absolute Encoder (360°/ 4096)		
Motor	Maxon Motor		
Operation Voltage (V)	11.1	12.0	14.8
Stall Torque (N.m)	8.0	8.4	10.0
Stall Current (A)	4.8	5.2	6.3
No Load Speed (RPM)	41	45	55

Figure 6: Dynamixel MX-106R Specifications



$T = F \times r$

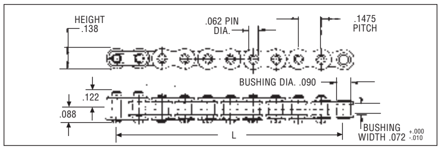
$T = T_o - \tau/r$

T = 1147 N ≅ 257 lbf

Figure 7: Sprocket Analysis Diagram

.1475 MINIATURE PITCH CHAINS

.1475 Pitch-Prestretched



Material: Stainless Steel Type 18-8 **Weight per Foot:** .035 lbs.
Tensile Strength: 180 lbs. Average

Part Number	L	Part Number	L	Part Number	L	Part Number	L
EL-4	5.900	**EL-13**	19.175	**EL-22**	32.450	**EL-31**	45.725
EL-5	7.375	**EL-14**	20.650	**EL-23**	33.925	**EL-32**	47.200
EL-6	8.850	**EL-15**	22.125	**EL-24**	35.400	**EL-33**	48.675
EL-7	10.325	**EL-16**	23.600	**EL-25**	36.875	**EL-34**	50.150
EL-8	11.800	**EL-17**	25.075	**EL-26**	38.350	**EL-35**	51.625
EL-9	13.275	**EL-18**	26.550	**EL-27**	39.825	**EL-36**	53.100
EL-10	14.750	**EL-19**	28.025	**EL-28**	41.300	**EL-37**	54.575
EL-11	16.225	**EL-20**	29.500	**EL-29**	42.775	**EL-38**	56.050
EL-12	17.700	**EL-21**	30.975	**EL-30**	44.250	**EL-39**	57.525

Extra Connectors Available

Catalog Number EL-C

Prestretched For:
- Reduced run in time
- Negligible preload expansion

All Chains Supplied With Connectors

Random lengths available: Specify part number by indicating total number of links ÷ 10 after series number. Specify even numbers of links including connector.

Example: EL-54.4 contains 544 links; **EL-12.8** contains 128 links.

Closed loop chain available on request (specify length)

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Figure 8: Miniature Chain Specifications

Appendix B: Drawings

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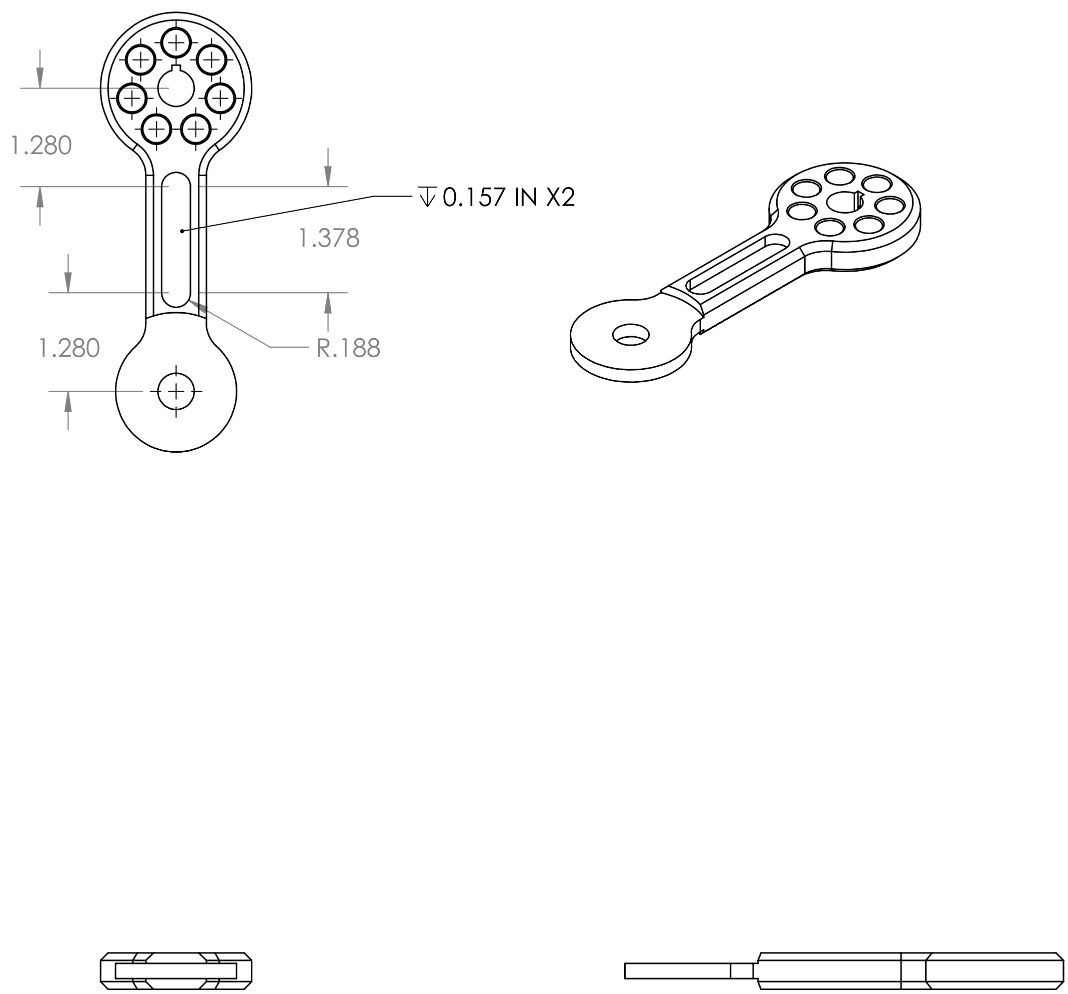
Appendix B: Drawings



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				ENG APPR.		
				MFG APPR.		
			MATERIAL	Q.A.		
			FINISH	COMMENTS:		
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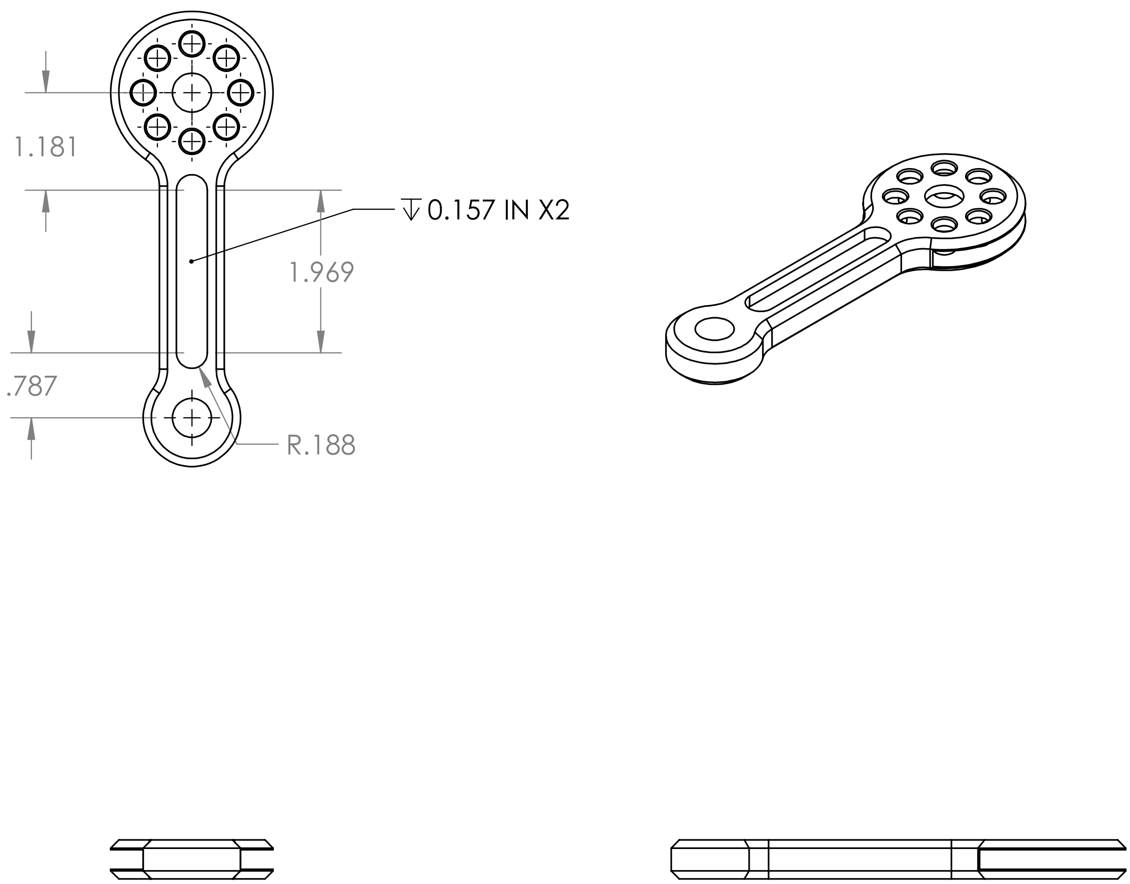
ROBOMEKS

DRIVER

SIZE A | DWG. NO. 3-01 | REV. B

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1



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THREE PLACE DECIMAL ±

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	NAME	DATE
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CHECKED		
ENG APPR.		
MFG APPR.		
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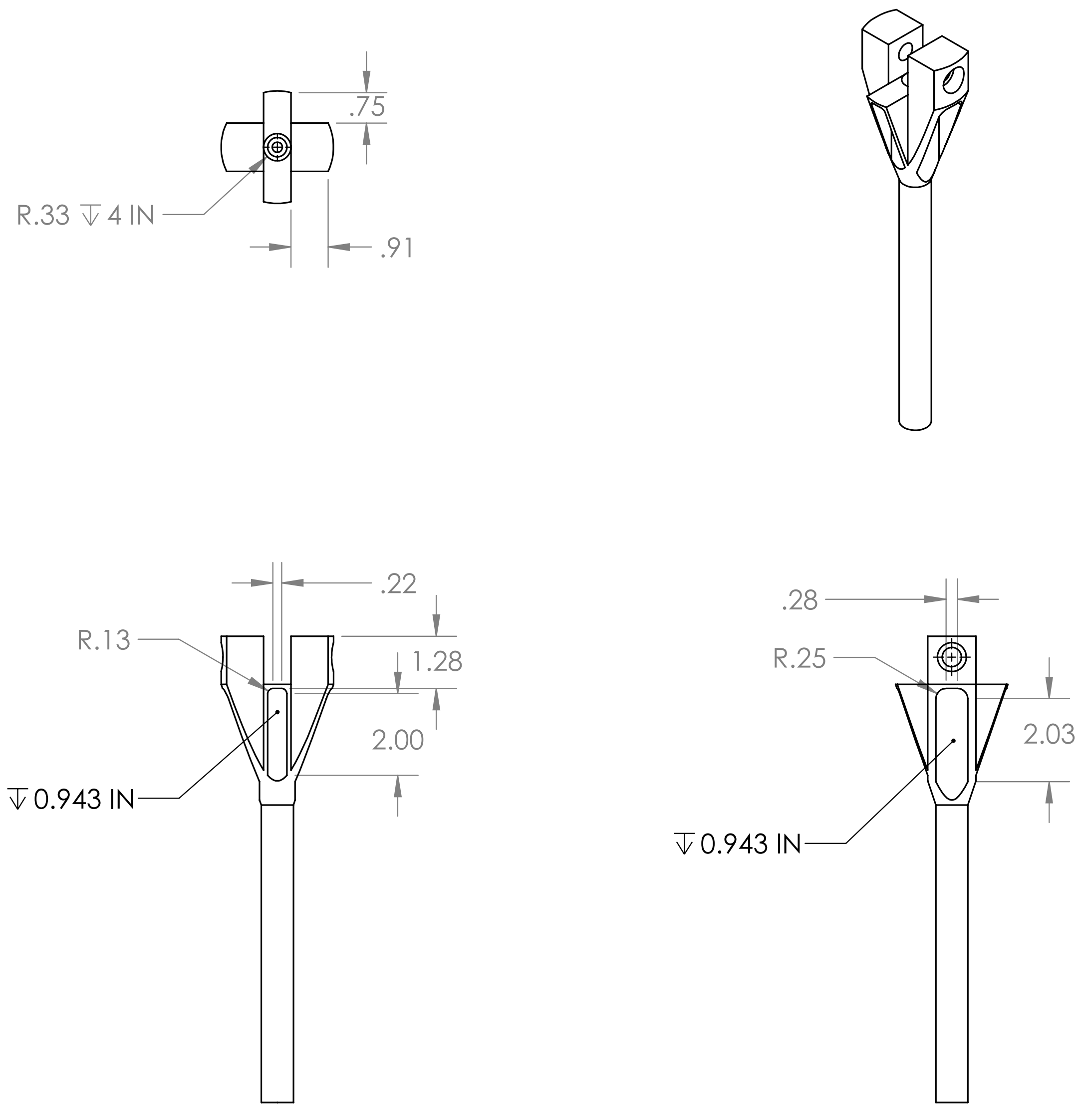
COMMENTS:

ROBOMEKS

FOLLOWER

SIZE	DWG. NO.	REV.
A	3-02	B

SCALE:1:2 WEIGHT: SHEET 1 OF 1



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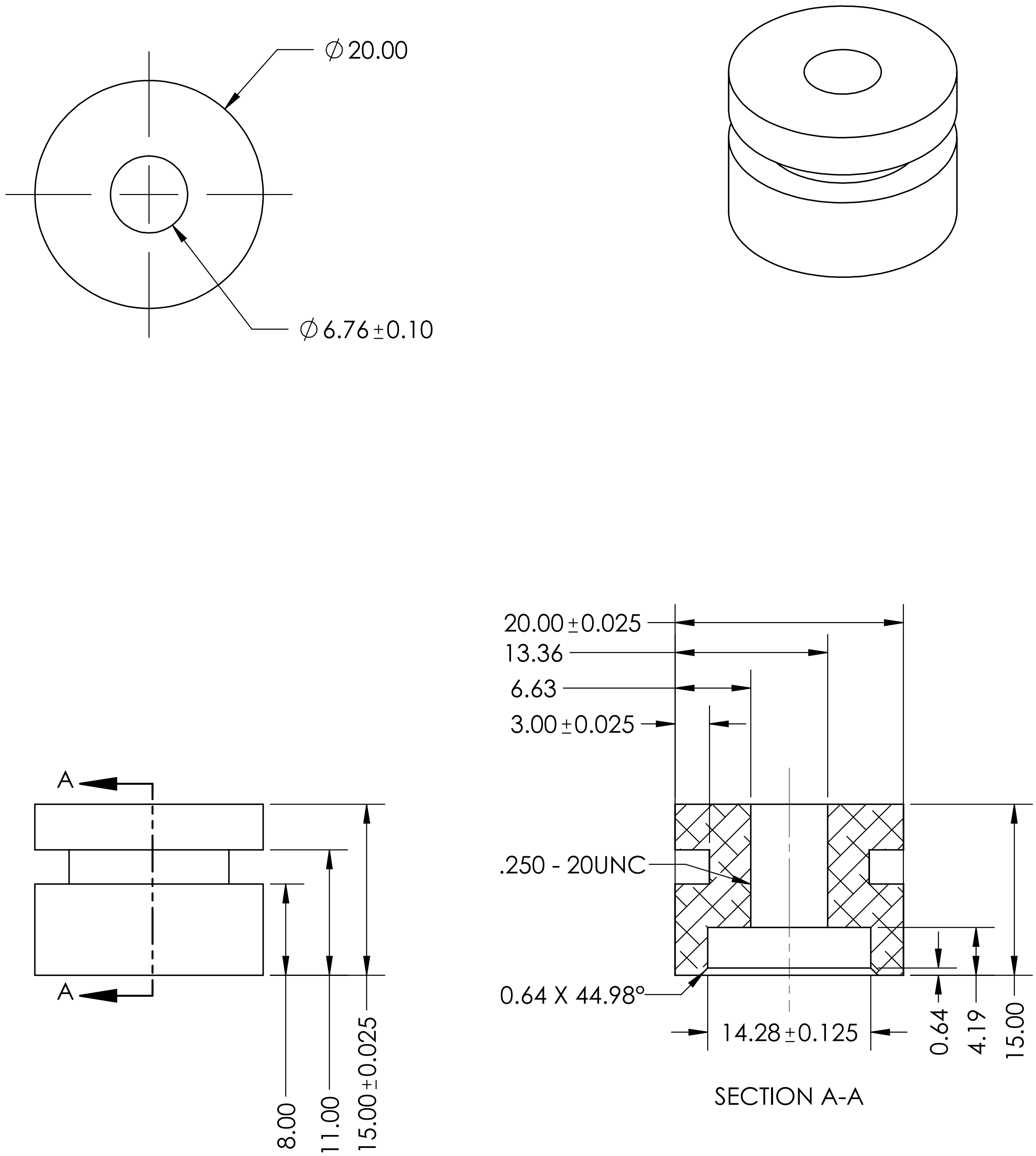

GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM ALUMINUM 6061-T6 ROD (3-1/2" DIA X 1' 2")

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MATERIAL ALUMINUM 6061-T6

FINISH MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ERIC S.	1/28/15
CHECKED	CHRIS T.	1/29/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

FOOT

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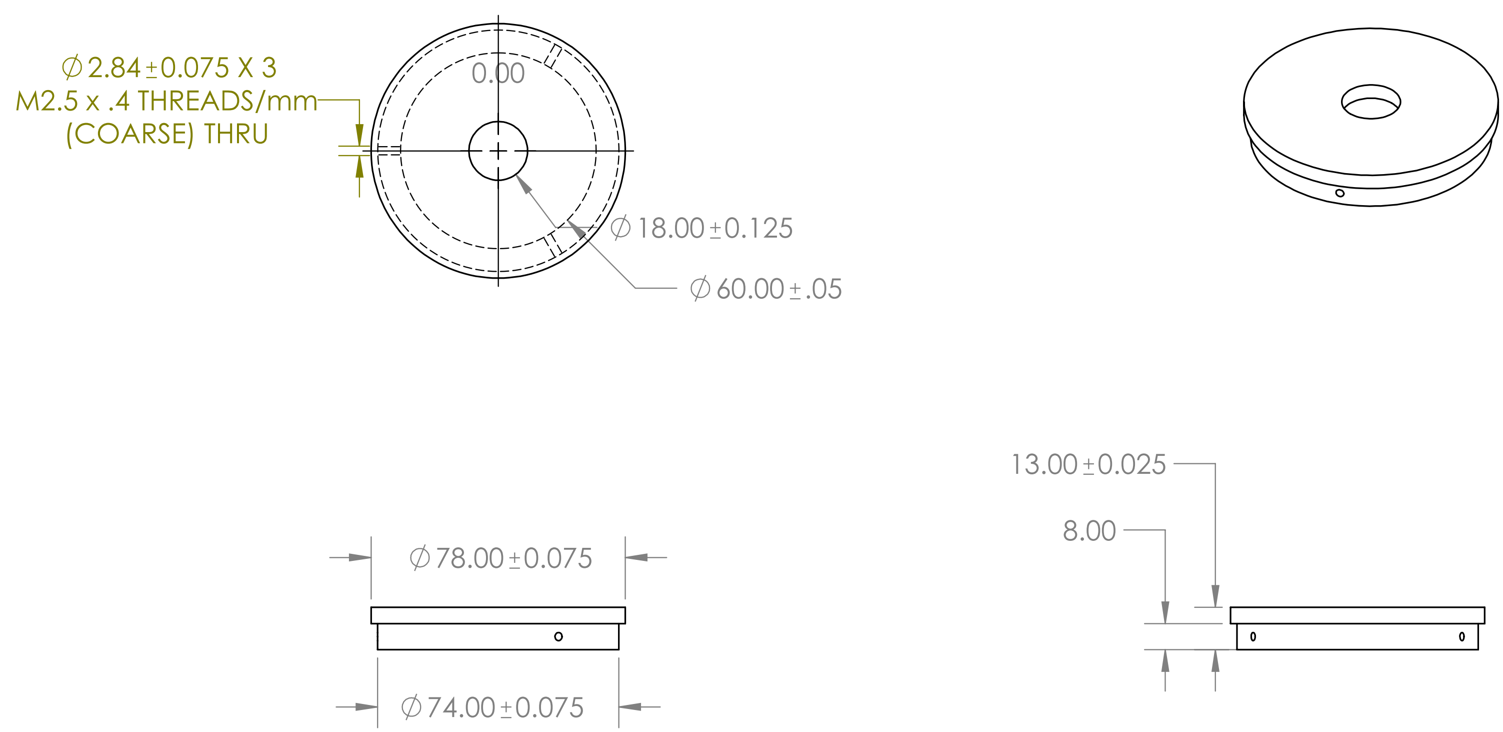

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FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

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CHECKED	CHRIS T.	1/29/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

TITLE:

LEG COVER - CAP

SIZE A | DWG. NO. 3-05 | REV B

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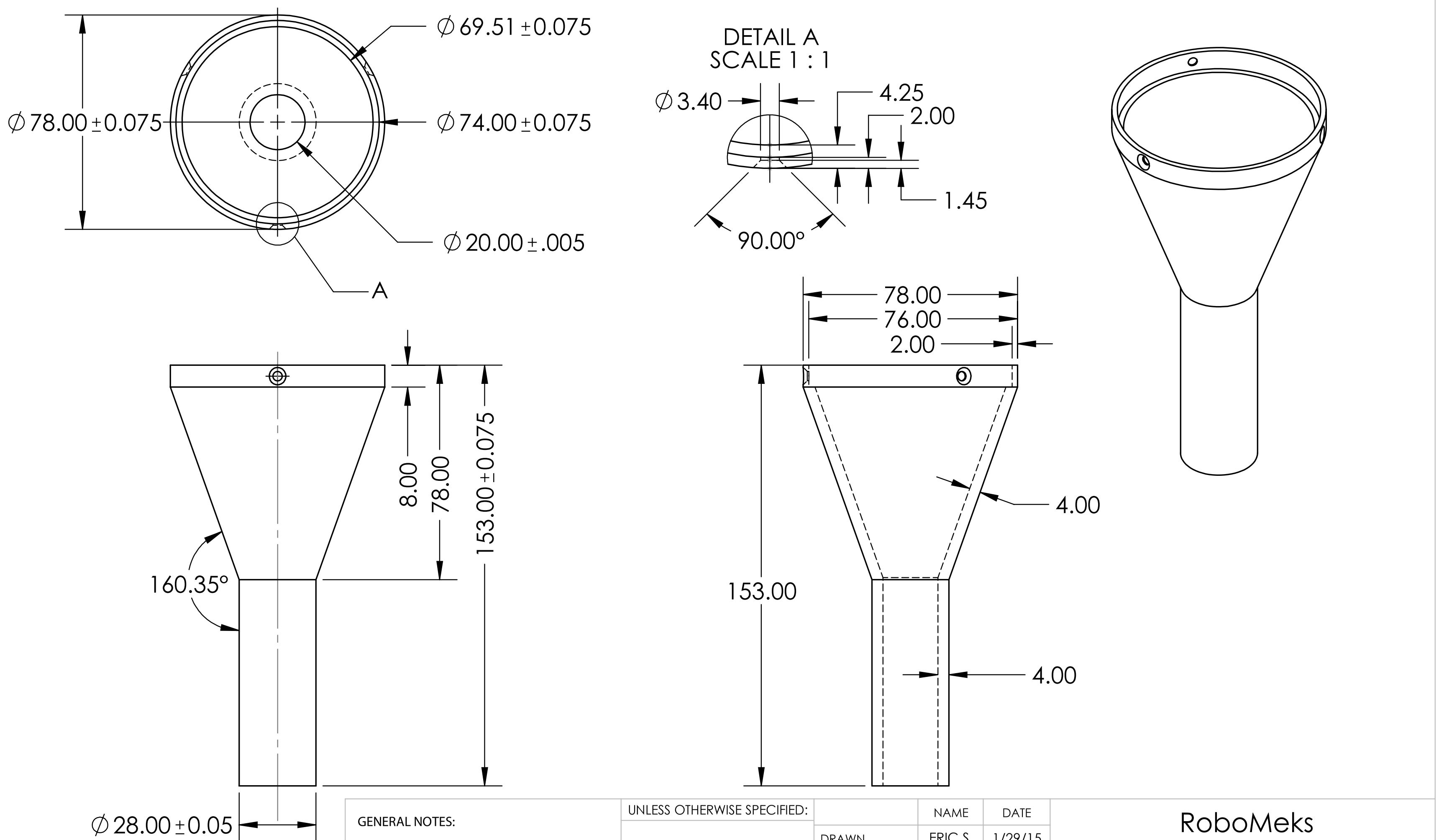

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4. THIS PART IS TO BE MACHINED FROM ALUMINUM 6061-T6 ROD (3"-1/2 DIA X 1')

UNLESS OTHERWISE SPECIFIED:

MATERIAL
ALUMINUM 6061-T6

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ERIC S.	1/29/15
CHECKED	RAQUEL	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

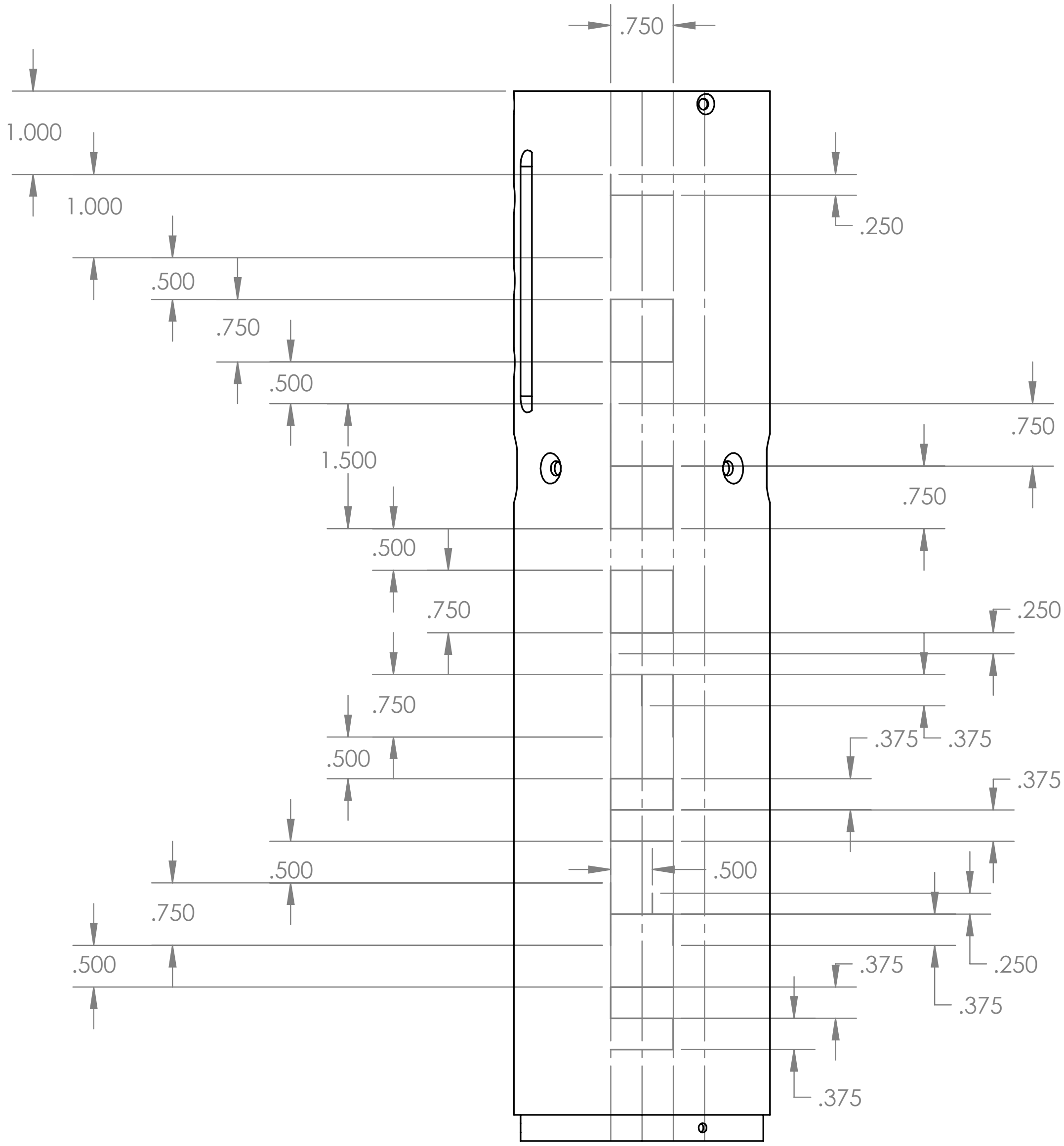
TITLE:

LEG COVER - BOTTOM

SIZE	DWG. NO.	REV
A	3-06	
SCALE: 1:2	WEIGHT: 194.13 g	SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

5 4 3 2 1



PROPRIETARY AND CONFIDENTIAL
THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY | USED ON

APPLICATION

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

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

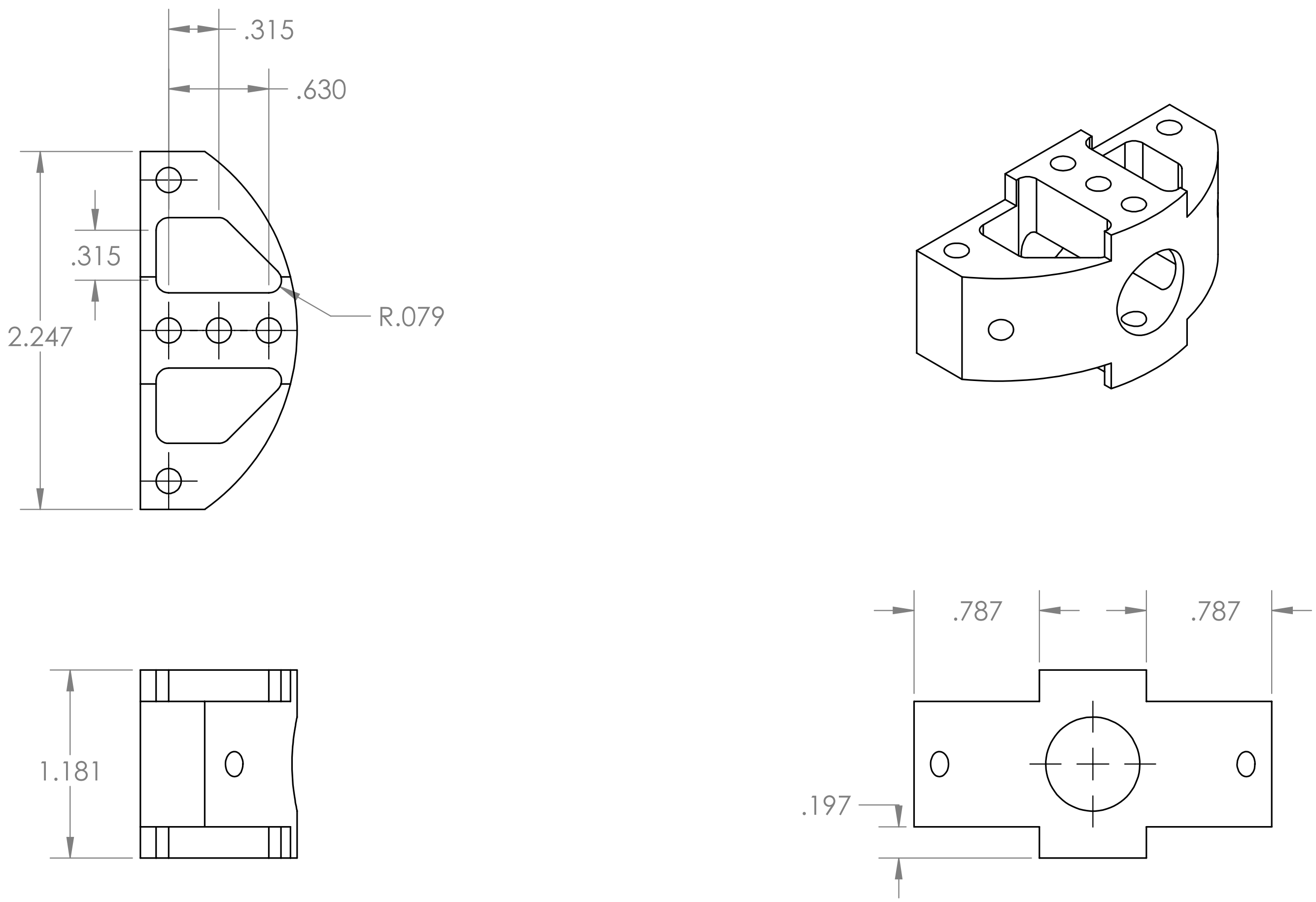
COMMENTS:

ROBOMEKS

LEG COVER - TOP

SIZE A | DWG. NO. 3-07 | REV. C

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



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

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

COMMENTS:

ROBOMEKS

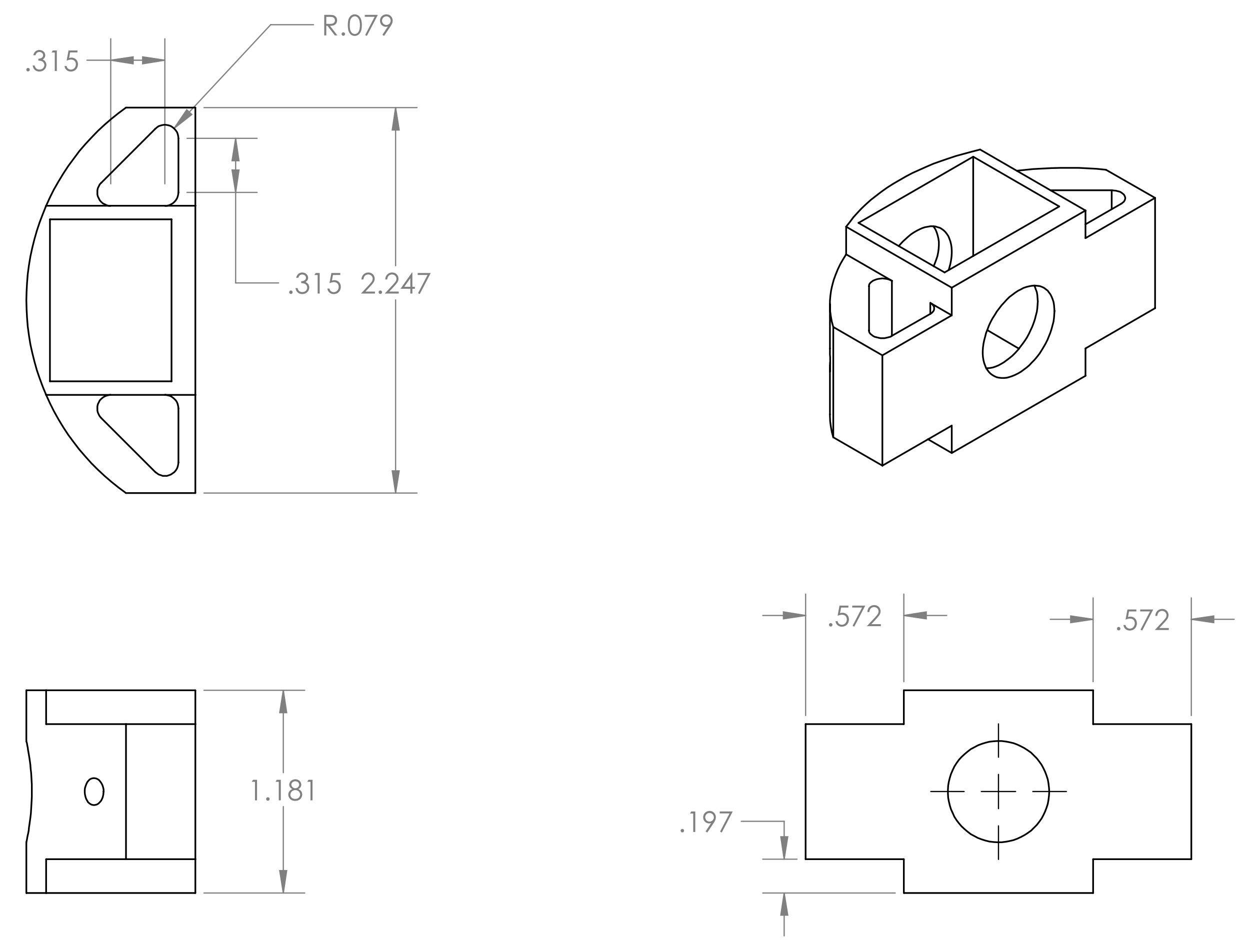
TITLE:

STOPPER 1

SIZE A | DWG. NO. 3-09 | REV B

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

5 4 3 2 1



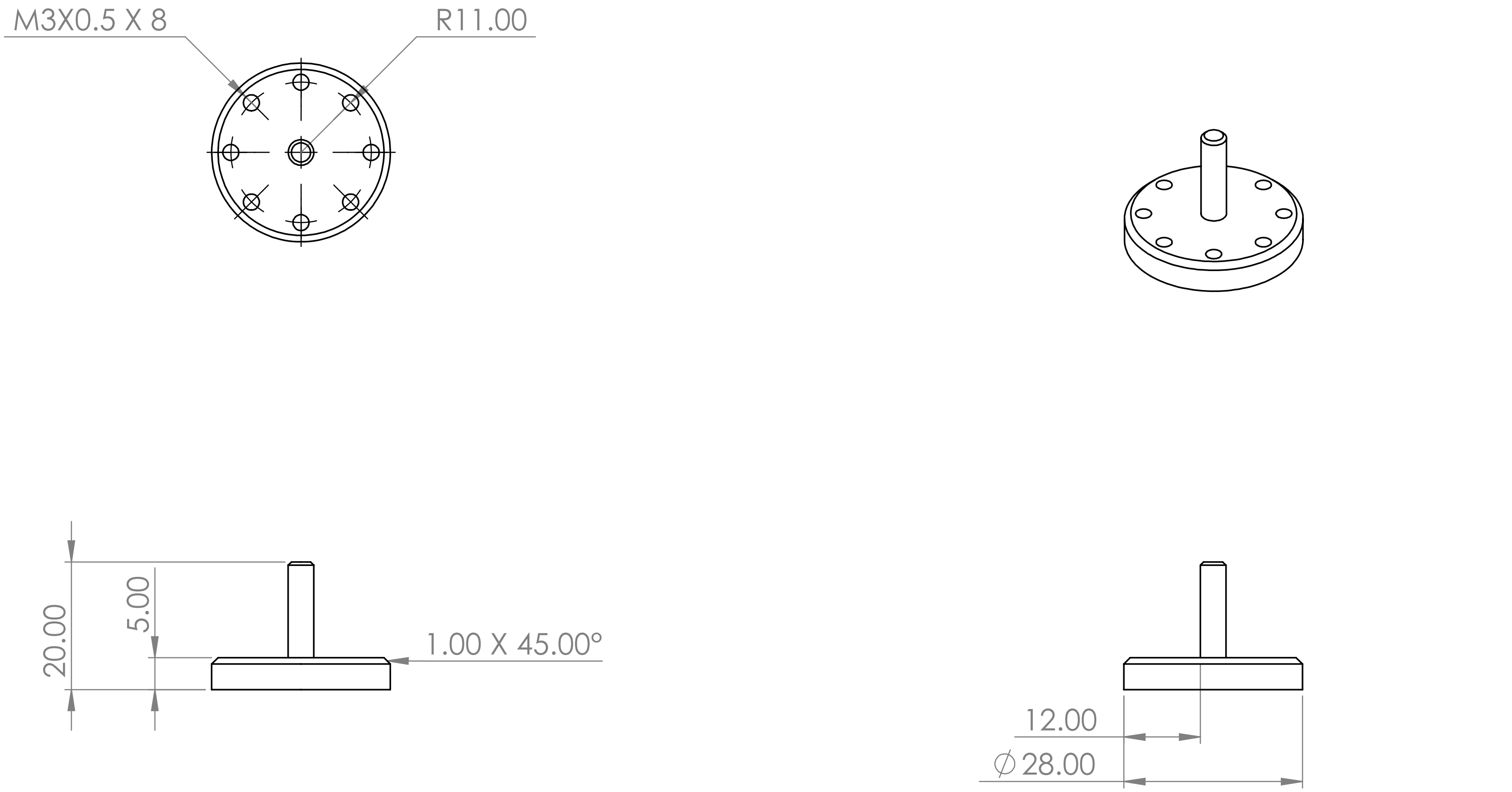
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	ROBOMEKS
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE:
	CHECKED			STOPPER 2
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A · DWG. NO. 3-10 · REV B
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.175

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
4130 ANNEALED STEEL

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ERIC	2/10/15
CHECKED	CHRIS	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

TITLE:

FLYWHEEL ADAPTOR PIN

SIZE A | DWG. NO. 3-10 | REV

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

PROPRIETARY AND CONFIDENTIAL

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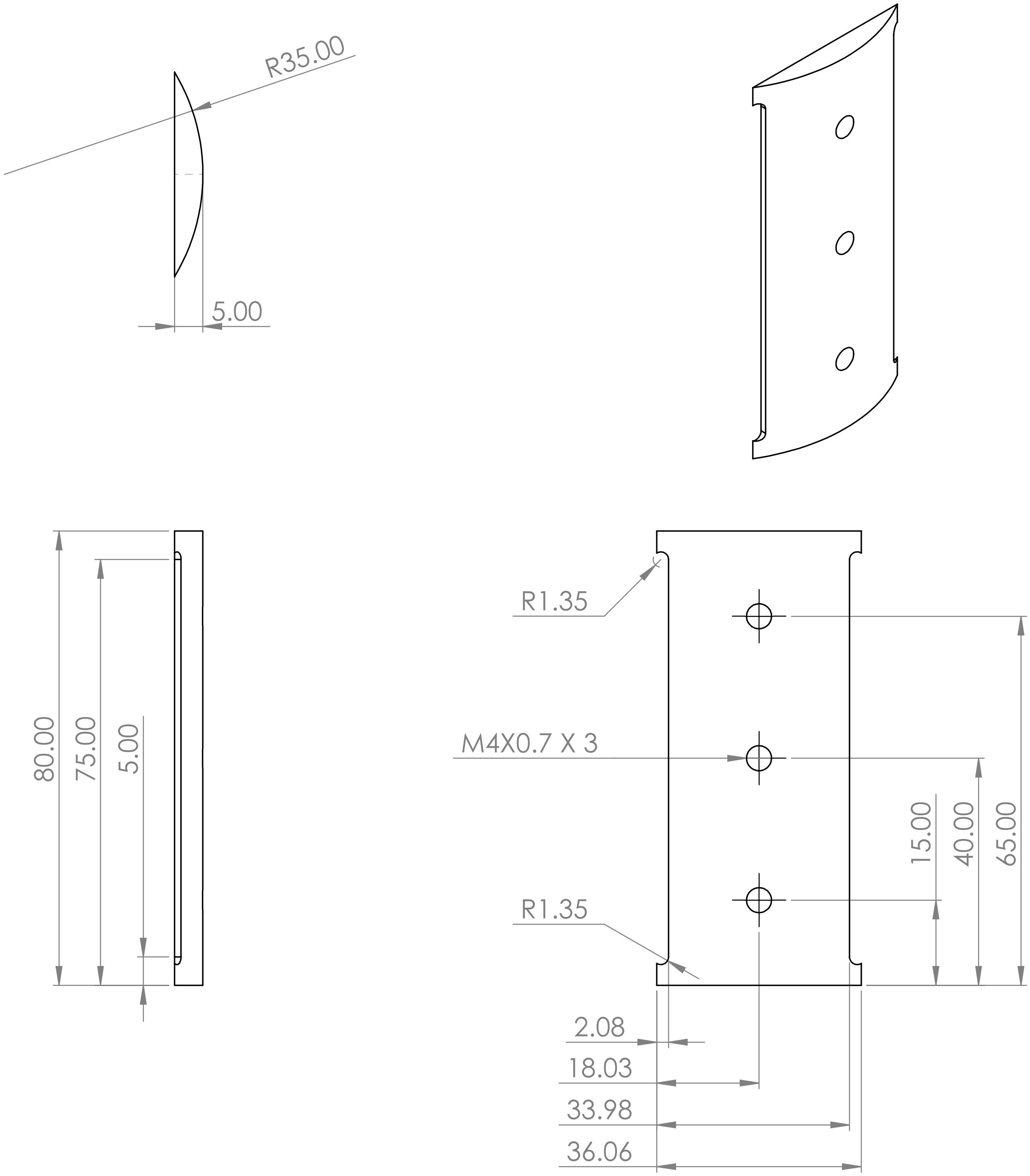
5 4 3 2 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OFROBOMEKS IS PROHIBITED.

GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM ALUMINUM 6061-T6 ROD (3"-1/2 DIA X 1')

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±.175

MATERIAL
ALUMINUM 6061-T6

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

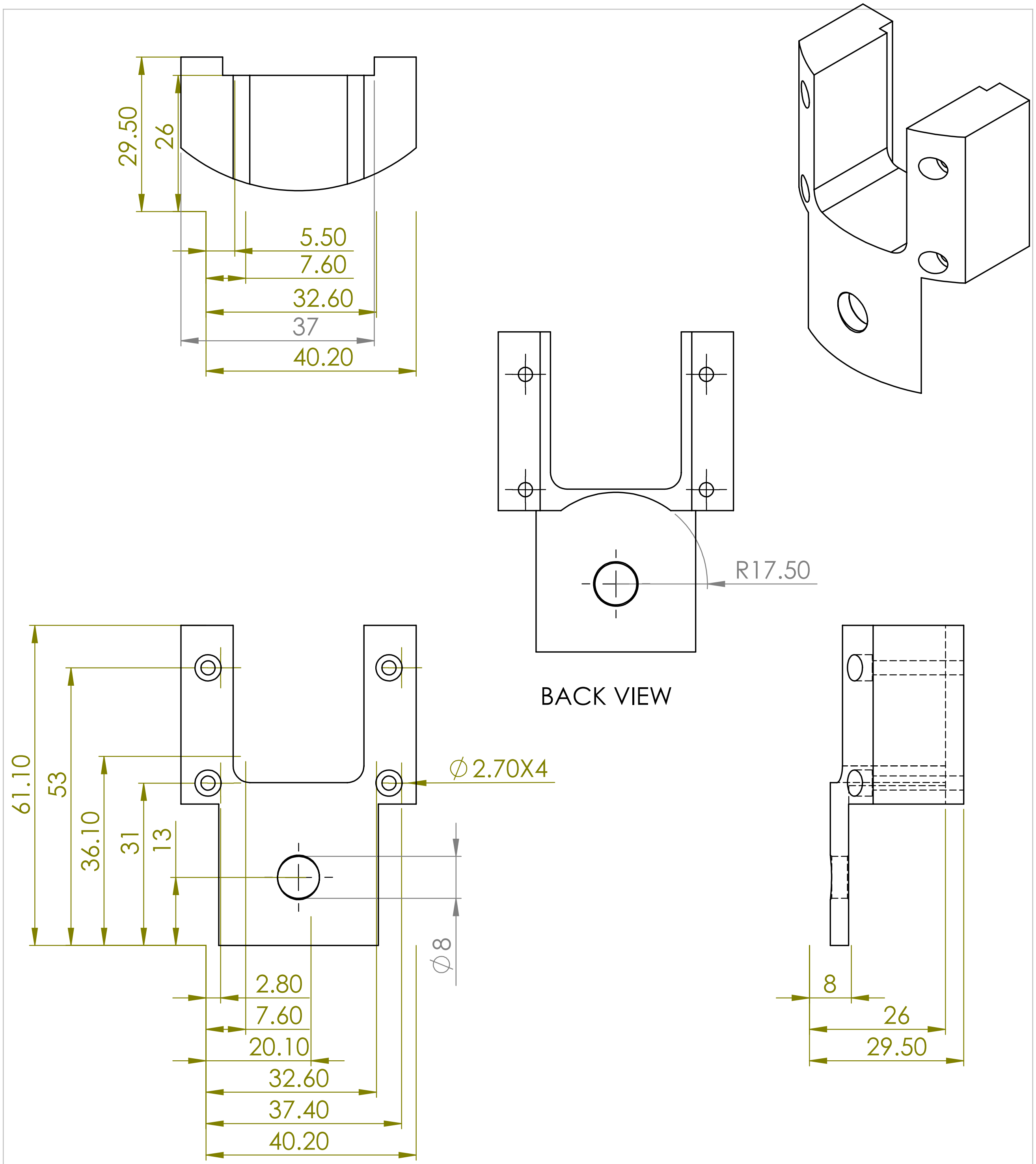
	NAME	DATE
DRAWN	ERIC	2/10/15
CHECKED	CHRIS	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

MOTOR MOUNT

SIZE	DWG. NO.	REV.
A	3-11	
SCALE:1:1	WEIGHT:	SHEET 1 OF 1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OFROBOMEKS IS PROHIBITED.

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

MATERIAL
ALUMINUM 6061-T6

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

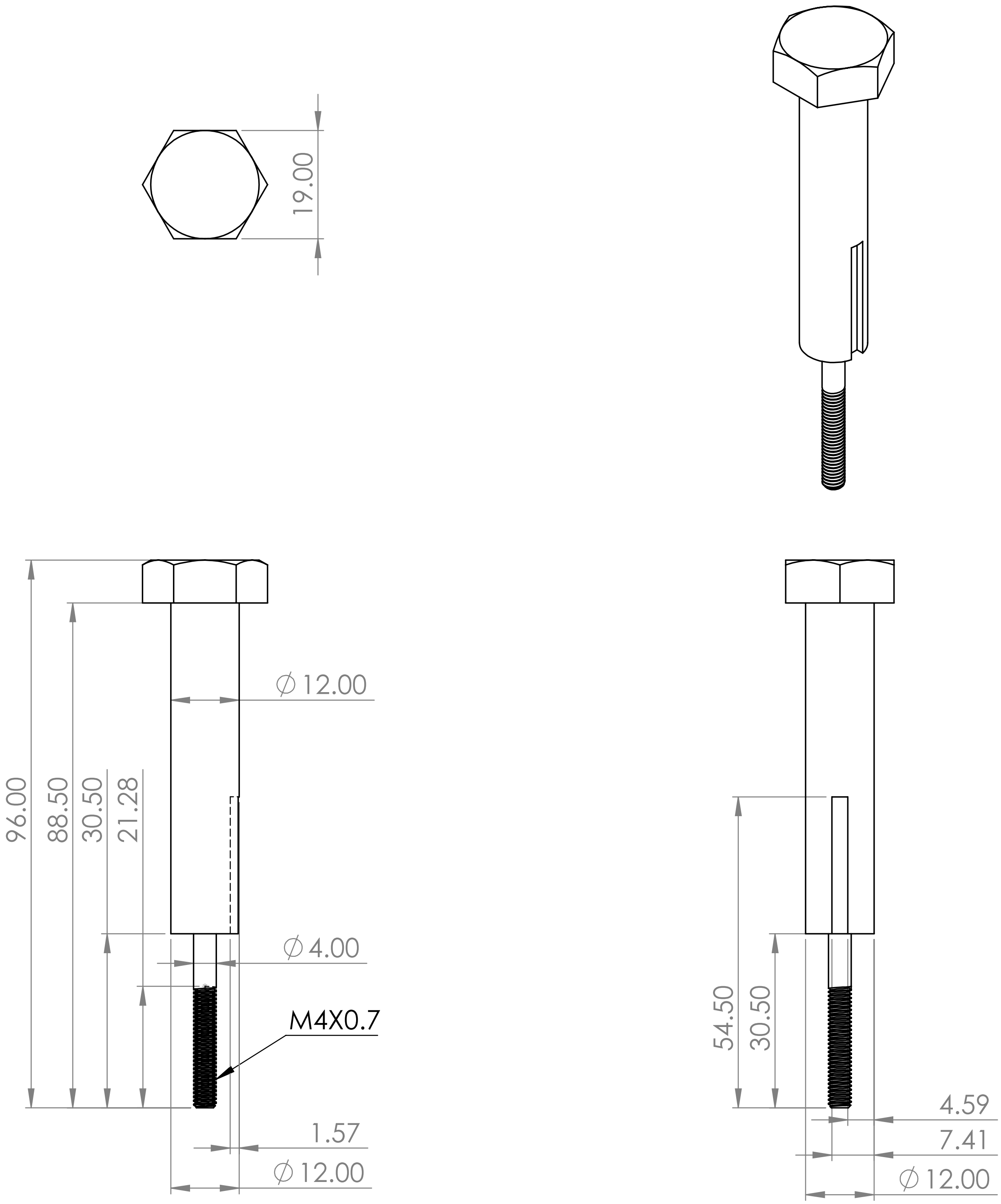
	NAME	DATE
DRAWN		
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

MOTOR PIN MOUNT

SIZE A | DWG. NO. 3-12 | REV. B

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



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OFROBOMEKS IS PROHIBITED.

GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.172

MATERIAL
4130 ANNEALED STEEL

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ERIC	2/10/15
CHECKED	CHRIS	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

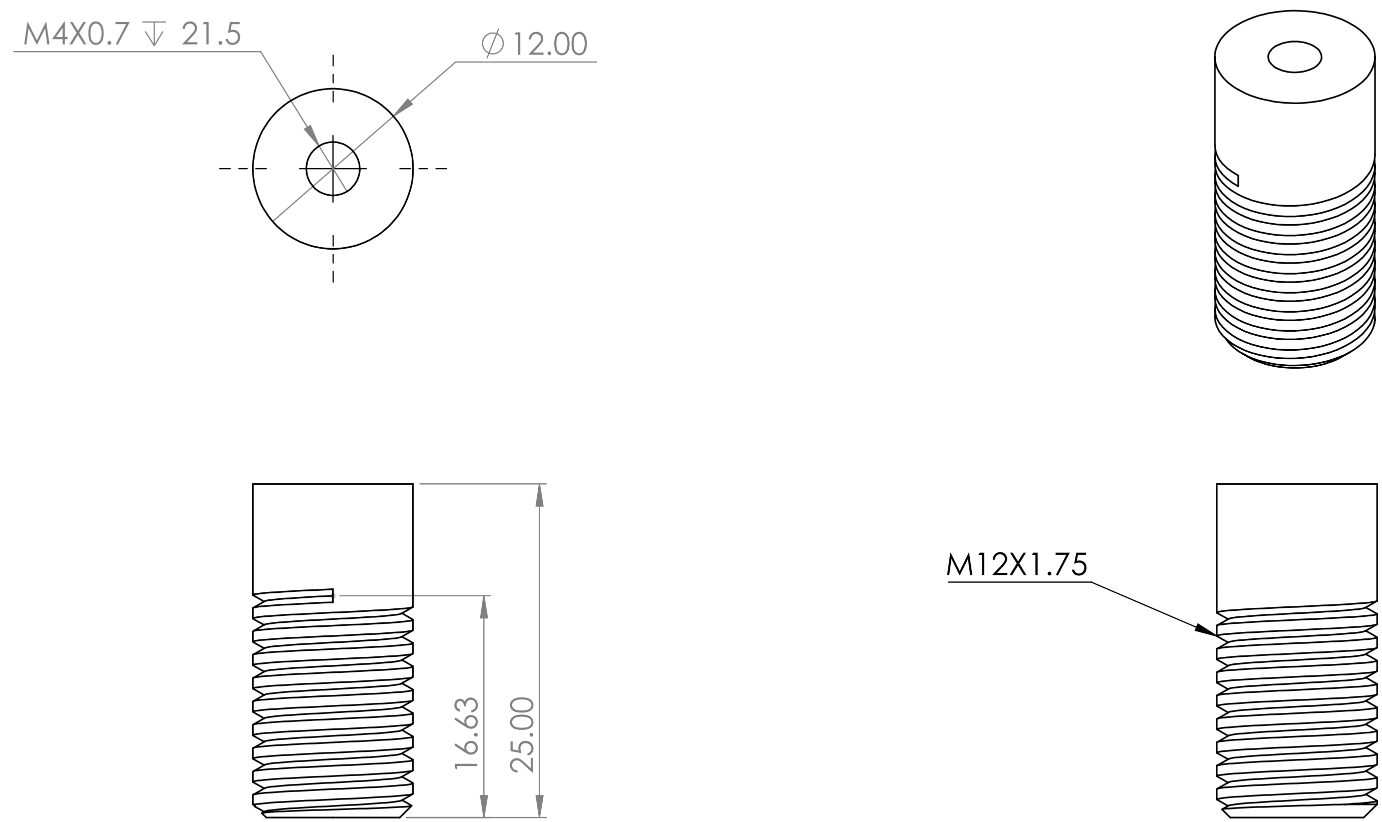
robo meks

RoboMeks

PIN 1

SIZE	DWG. NO.	REV.
A	3-13	

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



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ± 0.172 mm

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
4130 ANNEALED STEEL

FINISH
MACHINE FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ERIC	2/10/15
CHECKED	CHRIS	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

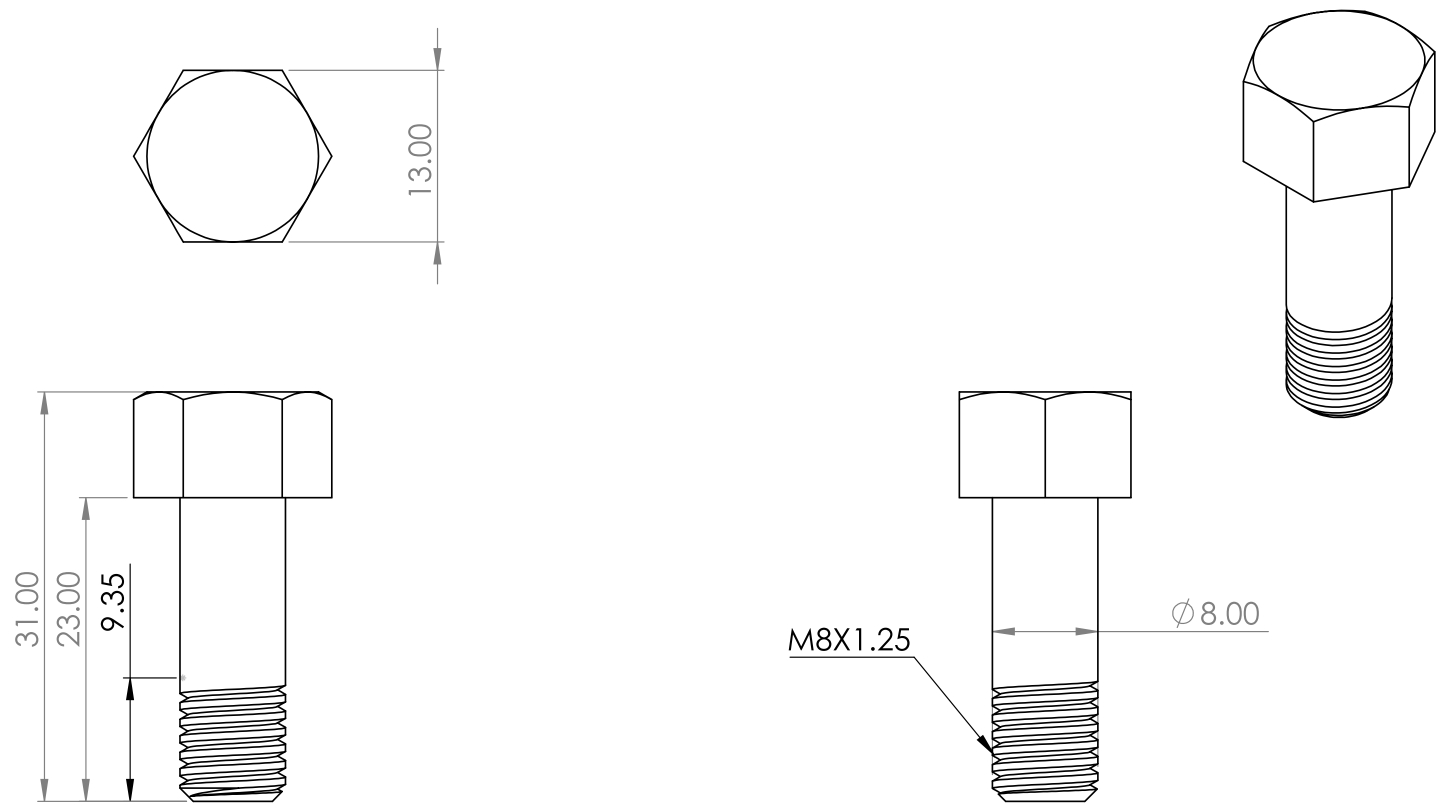
TITLE:

PIN 1 END CAP

SIZE **A** DWG. NO. 3-14 REV

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



	NAME	DATE
DRAWN	ERIC	2/10/15
CHECKED	CHRIS	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
4130 ANNEALED STEEL

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

RoboMeks

TITLE:

PIN 2

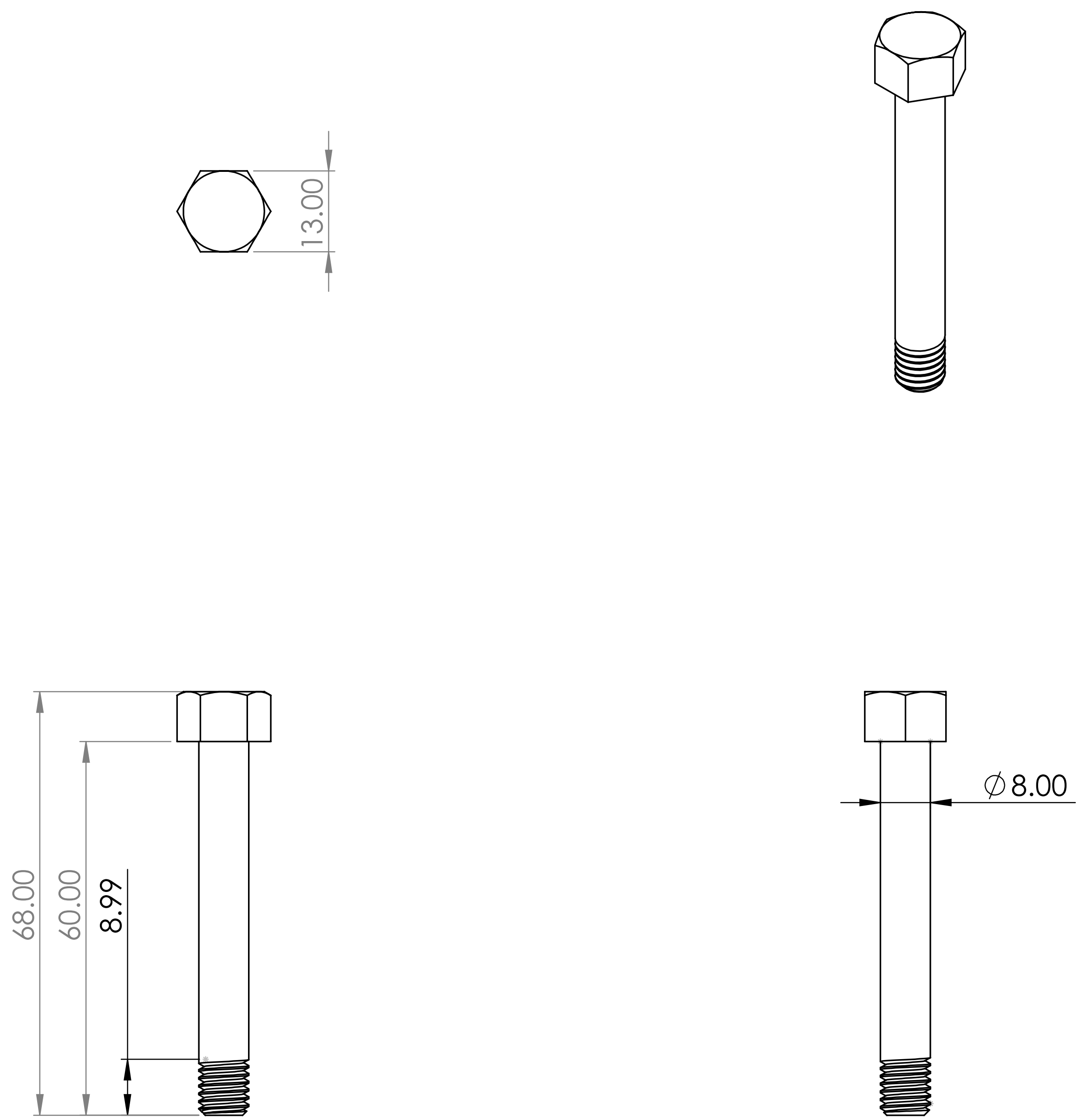
SIZE A | DWG. NO. 3-15 | REV

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

5 4 3 2 1



GENERAL NOTES:	DIMENSIONS ARE IN MILLIMETERS TOLERANCES: MACHINING ±0.127		NAME	DATE	RoboMeks
1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP. 2. ALL BURRS SHOULD BE REMOVED. 3. MACHINED FINISH ALLOVER ALL MOVING PARTS.		DRAWN	ERIC	2/10/15	PIN 3
		CHECKED	ROBERT	2/10/15	
		ENG APPR.			
		MFG APPR.			
	MATERIAL 4130 ANNEALED STEEL	Q.A.			
	FINISH MACHINED FINISH				SIZE A · DWG. NO. 3-15 · REV.
	DO NOT SCALE DRAWING				SCALE:1:1 · WEIGHT: · SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

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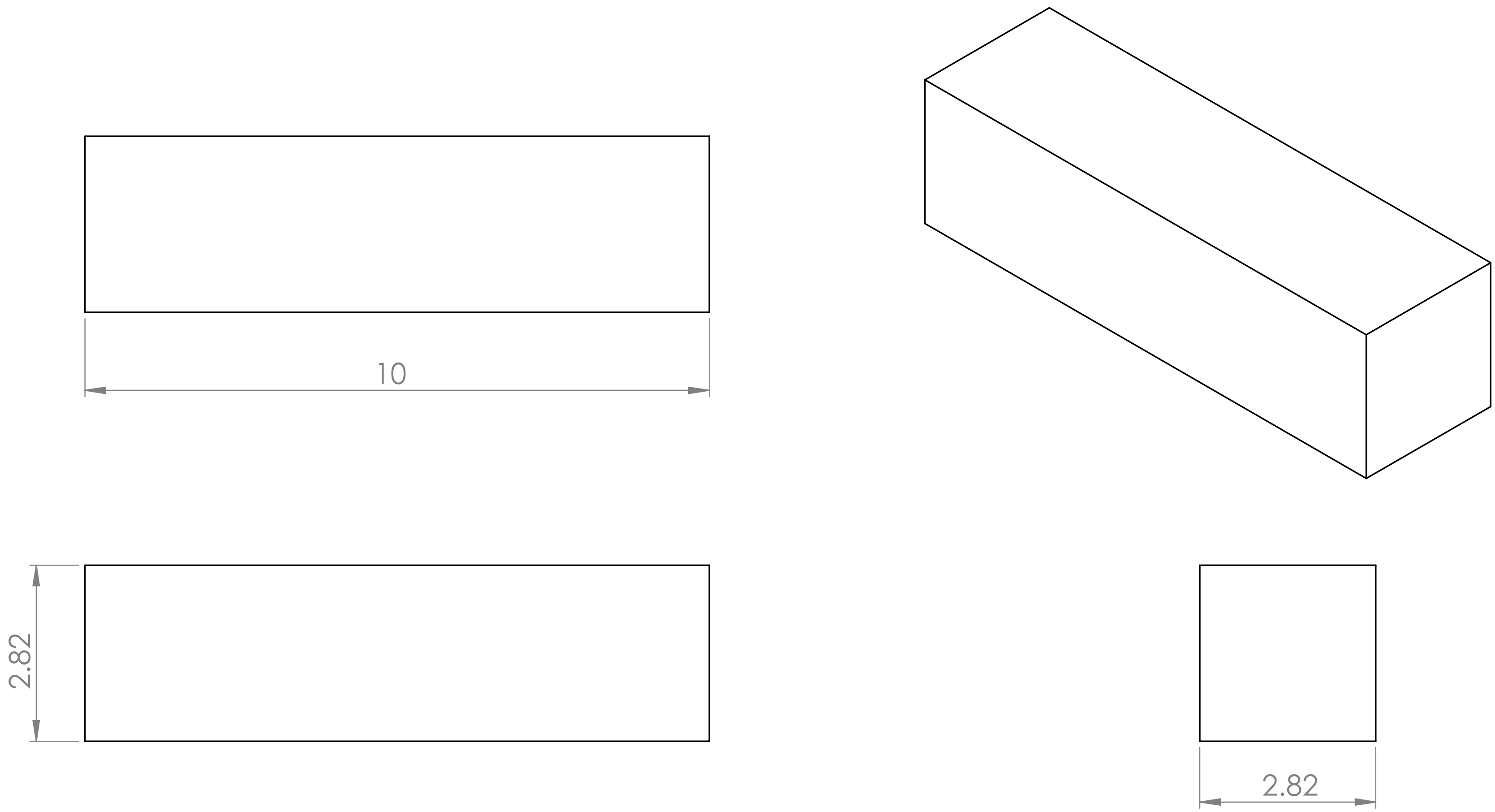

GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ± 0.025 mm

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
4130 ANNEALED STEEL

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ERIC	2/10/15
CHECKED	ROBERT	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

TITLE:

SQUARE KEY

SIZE	DWG. NO.	REV
A	2-17	

SCALE: 10:1 WEIGHT: SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL
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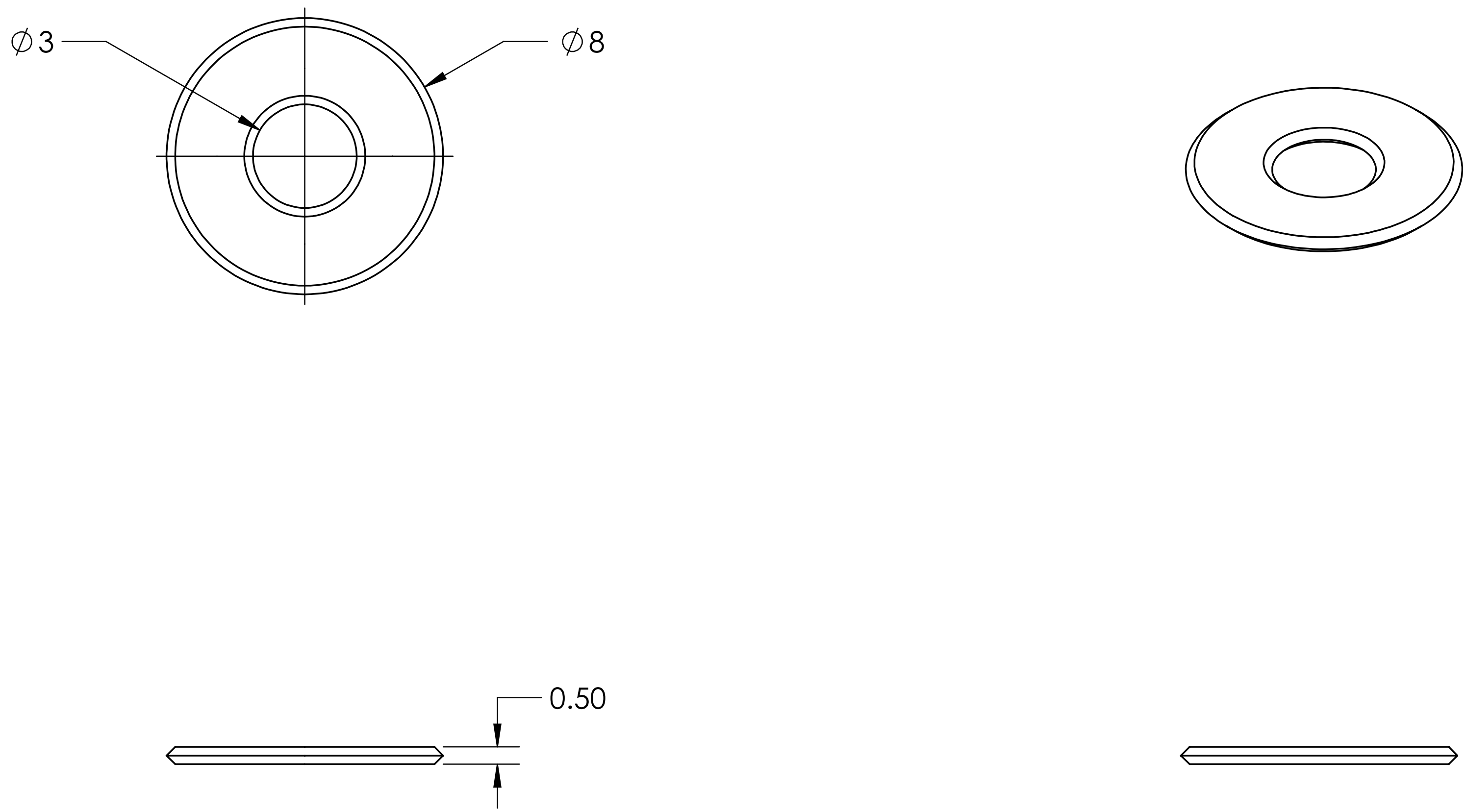
5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ± 0.025 mm

MATERIAL: DELRIN

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

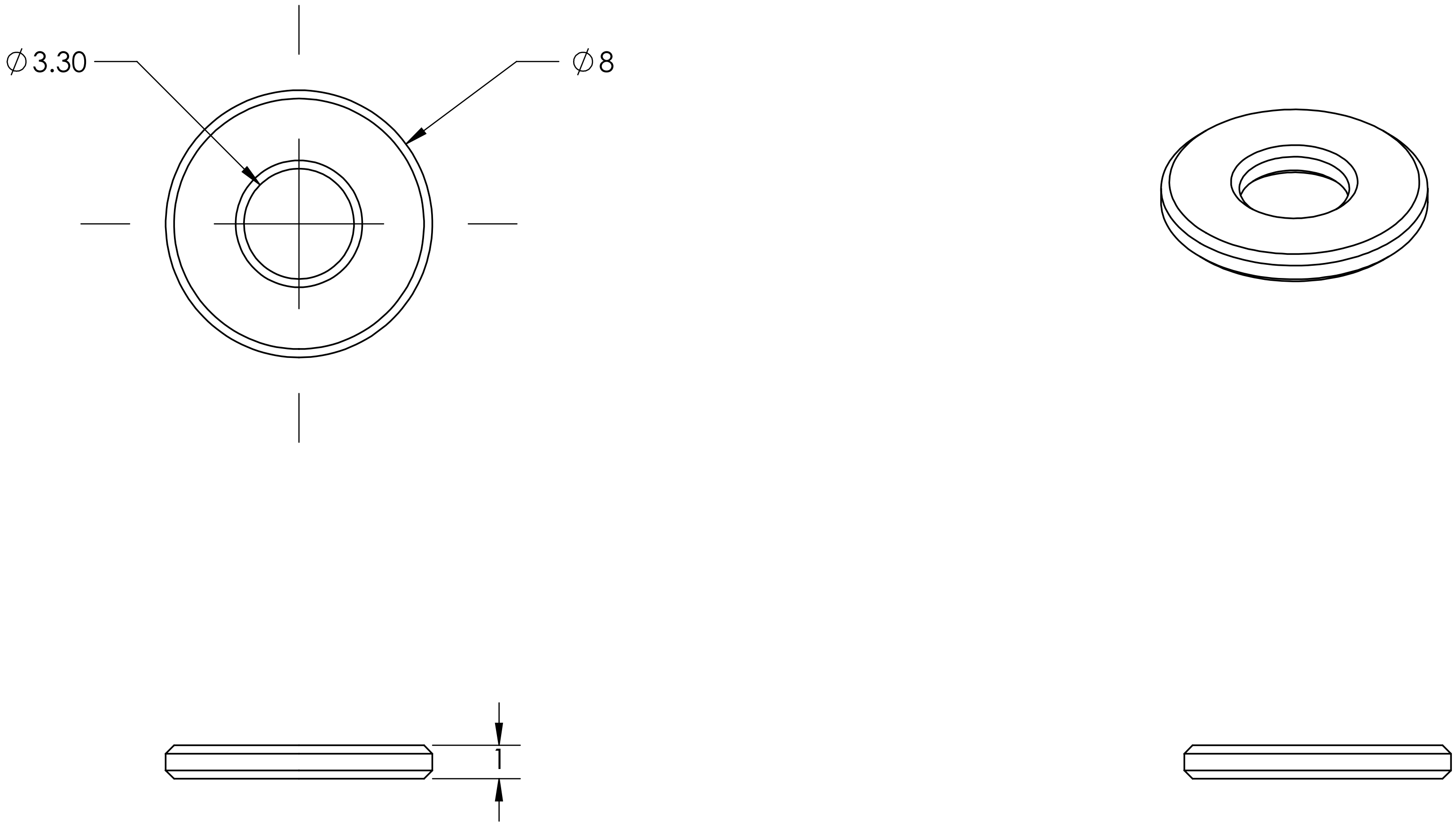
TITLE:

OD: 8 mm X t: 0.5 mm
DELRIN END BUSHING

SIZE	DWG. NO.	REV
A	3-21	

SCALE: 5:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: DELRIN

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	CHRISTIAN	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

TITLE:
OD: 8 mm x t:1 mm
DELRIN END BUSHING

SIZE: A | DWG. NO. 3-22 | REV

SCALE: 5:1 | WEIGHT: | SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

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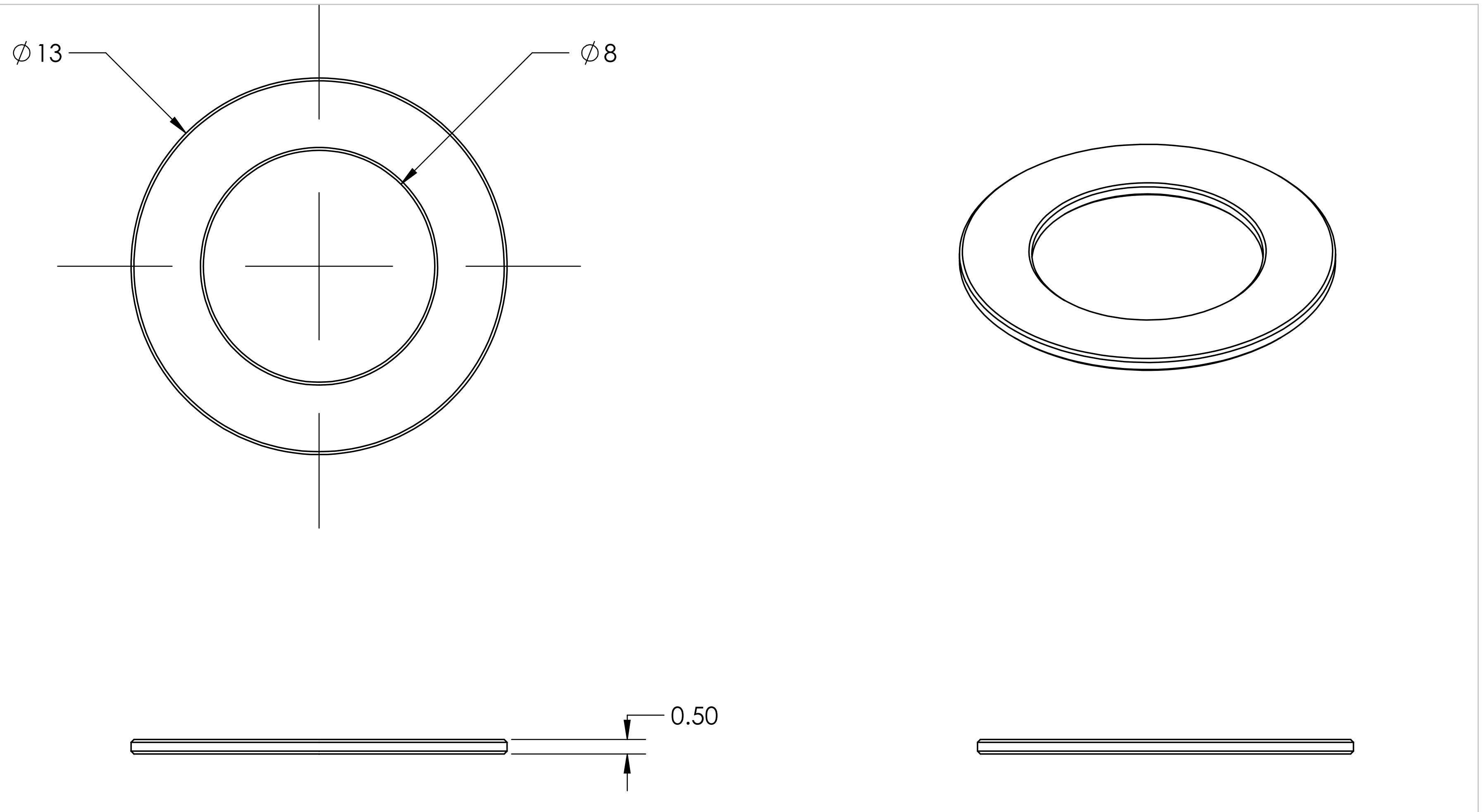
5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL DELRIN

FINISH MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

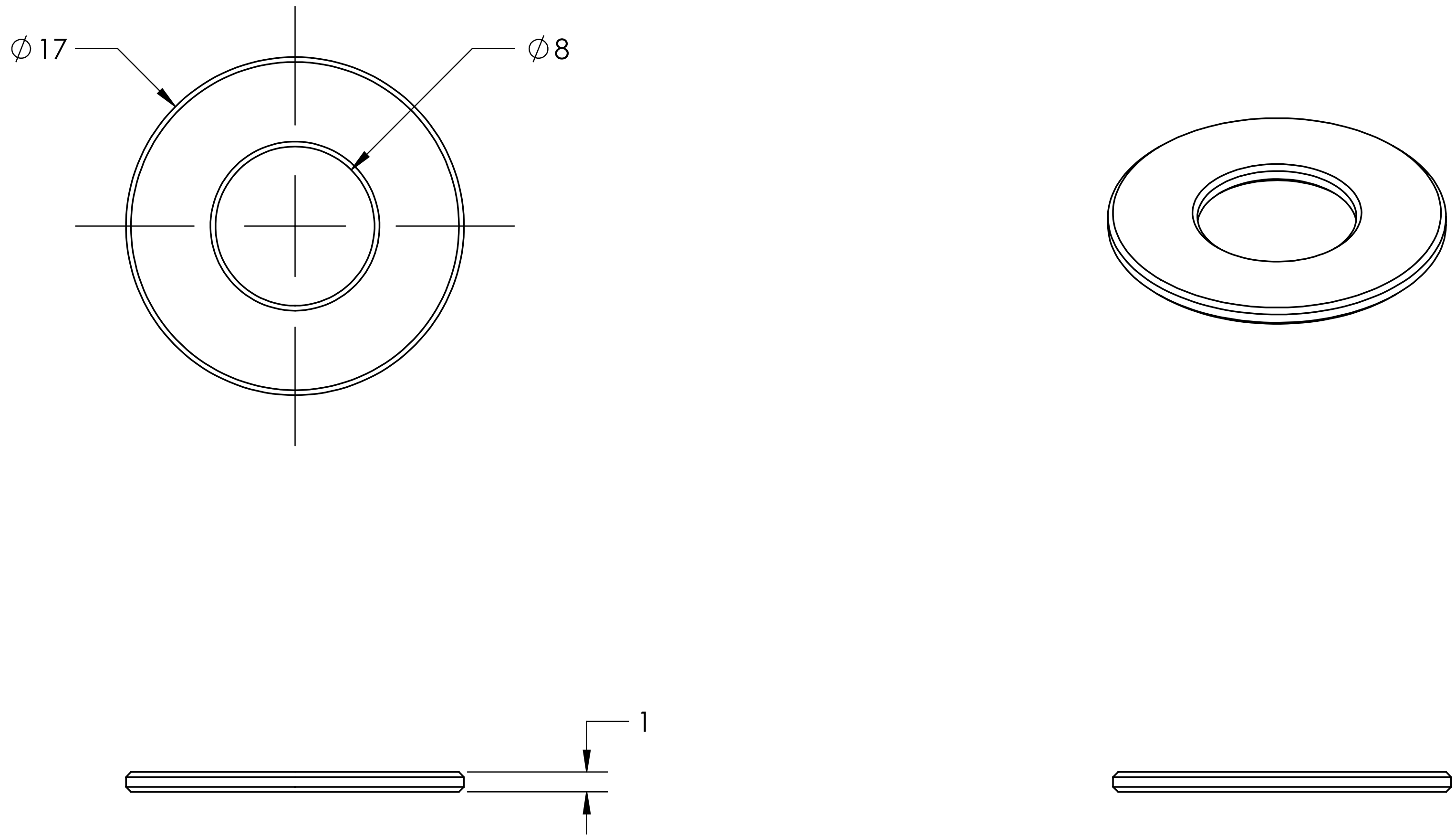
TITLE:

OD: 13 mm X t: 0.5 mm
DELRIN END BUSHING

SIZE	DWG. NO.	REV
A	3-23	

SCALE: 5:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING±0.025 mm

MATERIAL DELRIN

FINISH MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	CHRISTIAN	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

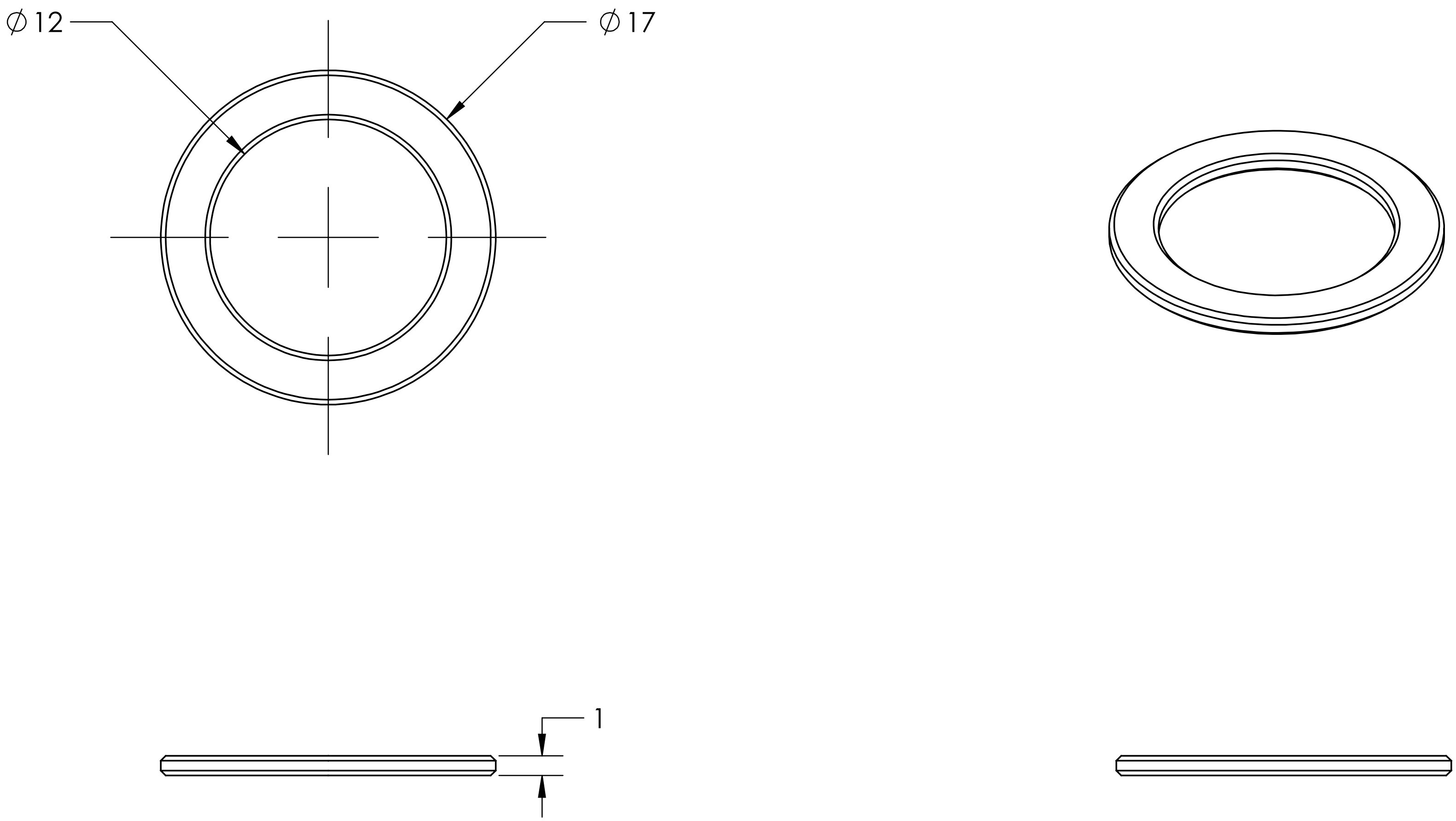
TITLE:

OD: 17 mm X t: 1 mm
DELRIN END BUSHING

SIZE A | DWG. NO. 3-24 | REV

SCALE: 3:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL
DELRIN

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

TITLE:

OD: 17 mm X t: 1 mm
DELRIN END BUSHING

SIZE	DWG. NO.	REV
A	3-25	

SCALE: 3:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1

PROPRIETARY AND CONFIDENTIAL

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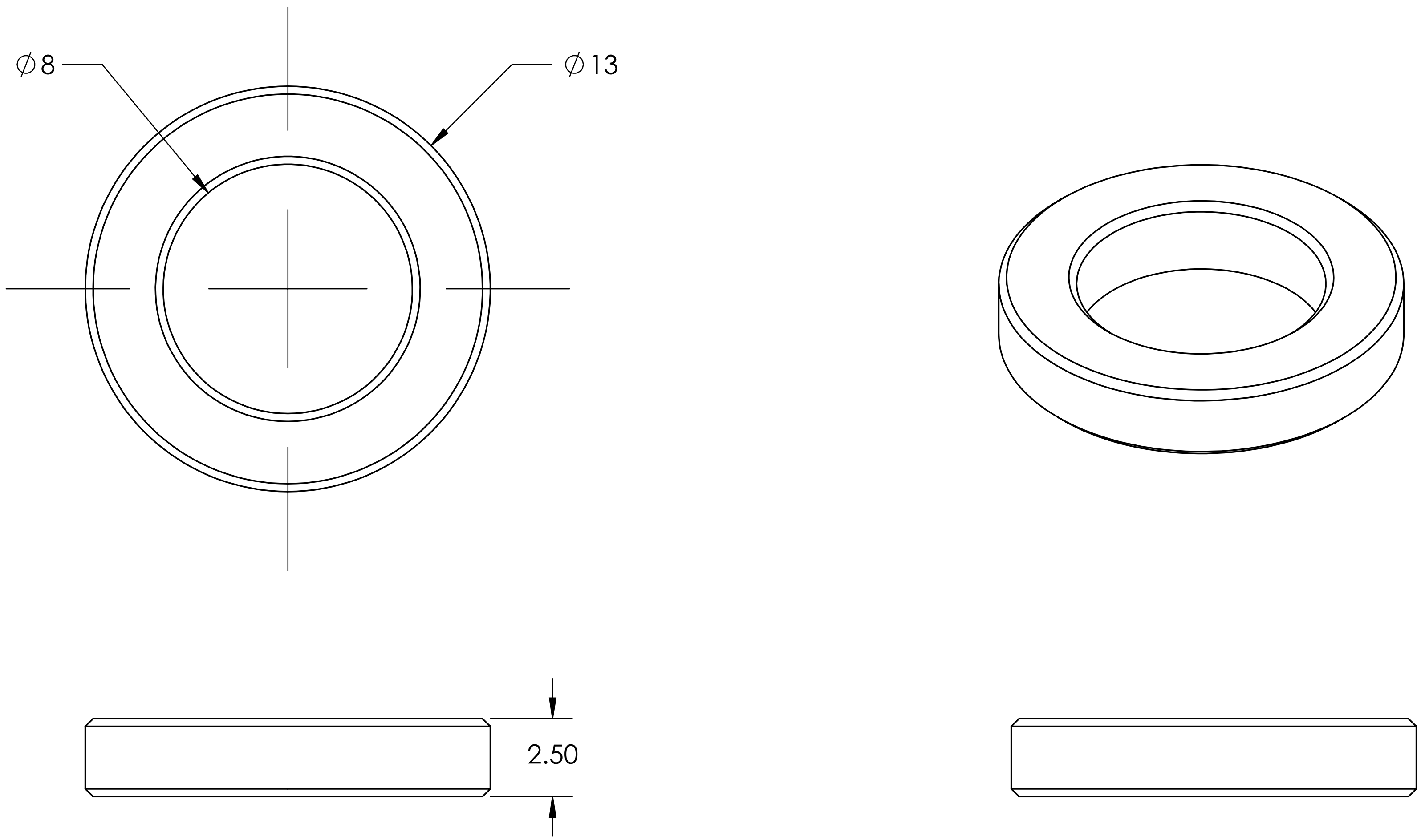

GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL
DELRIN

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	CHRISTIAN	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robomeks

RoboMeks

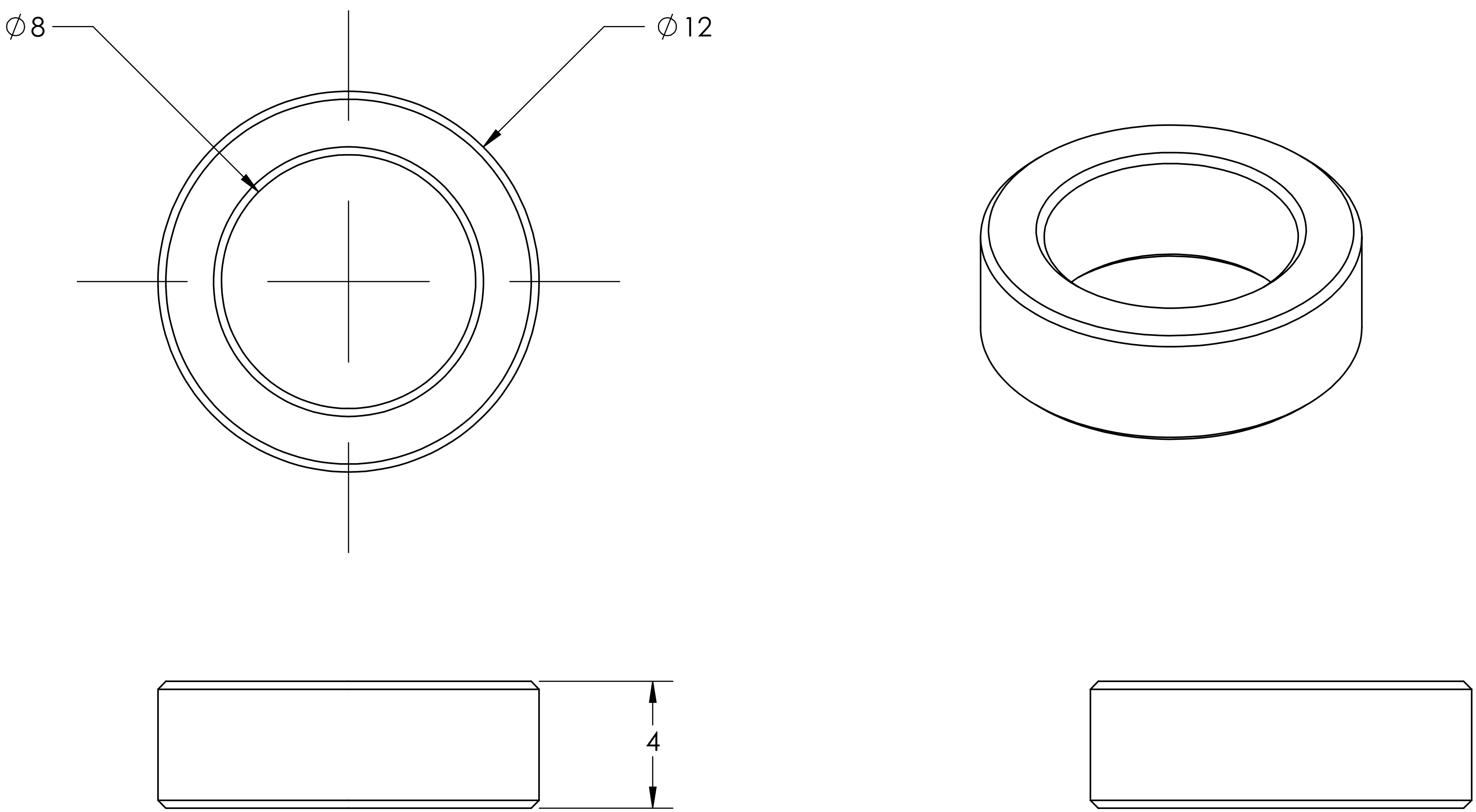
TITLE:

OD: 13 mm X t: 2.5 mm
DELRIN END BUSHING

SIZE	DWG. NO.	REV
A	3-26	

SCALE: 5:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: DELRIN

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

TITLE:

OD: 12 mm X t: 4 mm
DELRIN END BUSHING

SIZE	DWG. NO.	REV
A	3-27	

SCALE: 5:1 | WEIGHT: | SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

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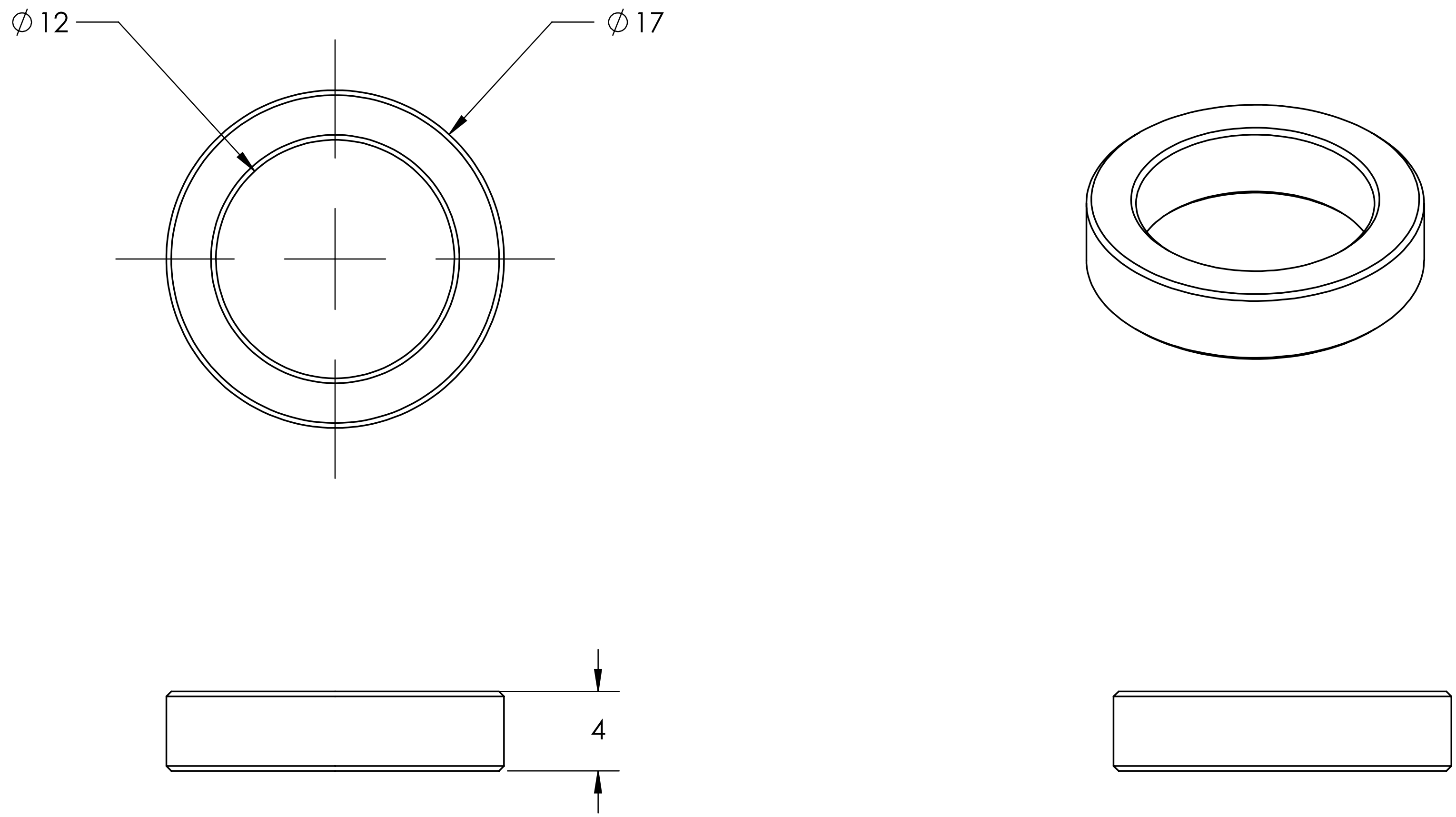
5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: DELRIN

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	CHRISTIAN	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

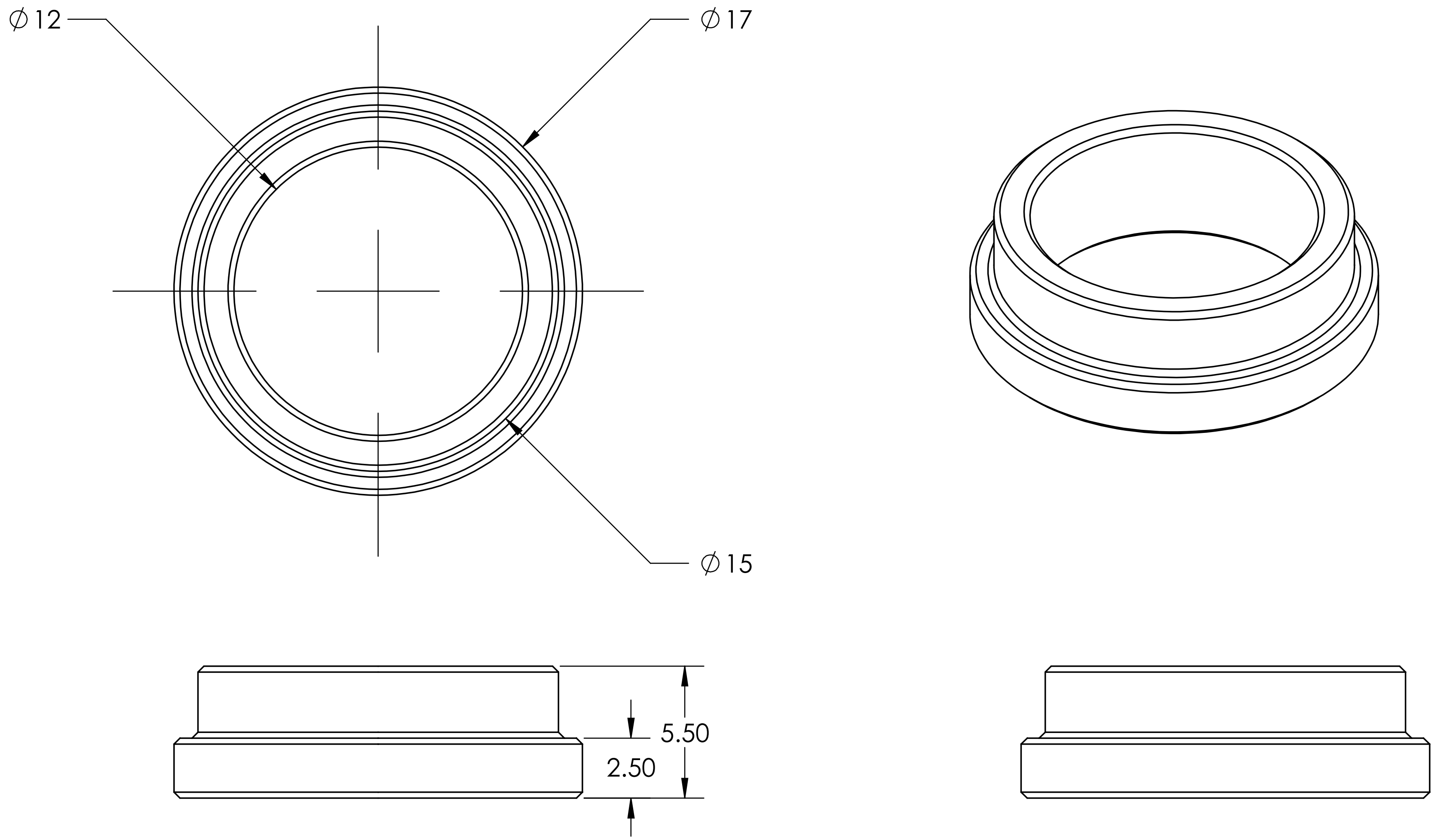
TITLE:

OD: 17 mm X t: 4 mm
DELRIN END BUSHING

SIZE	DWG. NO.	REV
A	3-28	

SCALE: 3:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL
DELRIN

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robomeks

RoboMeks

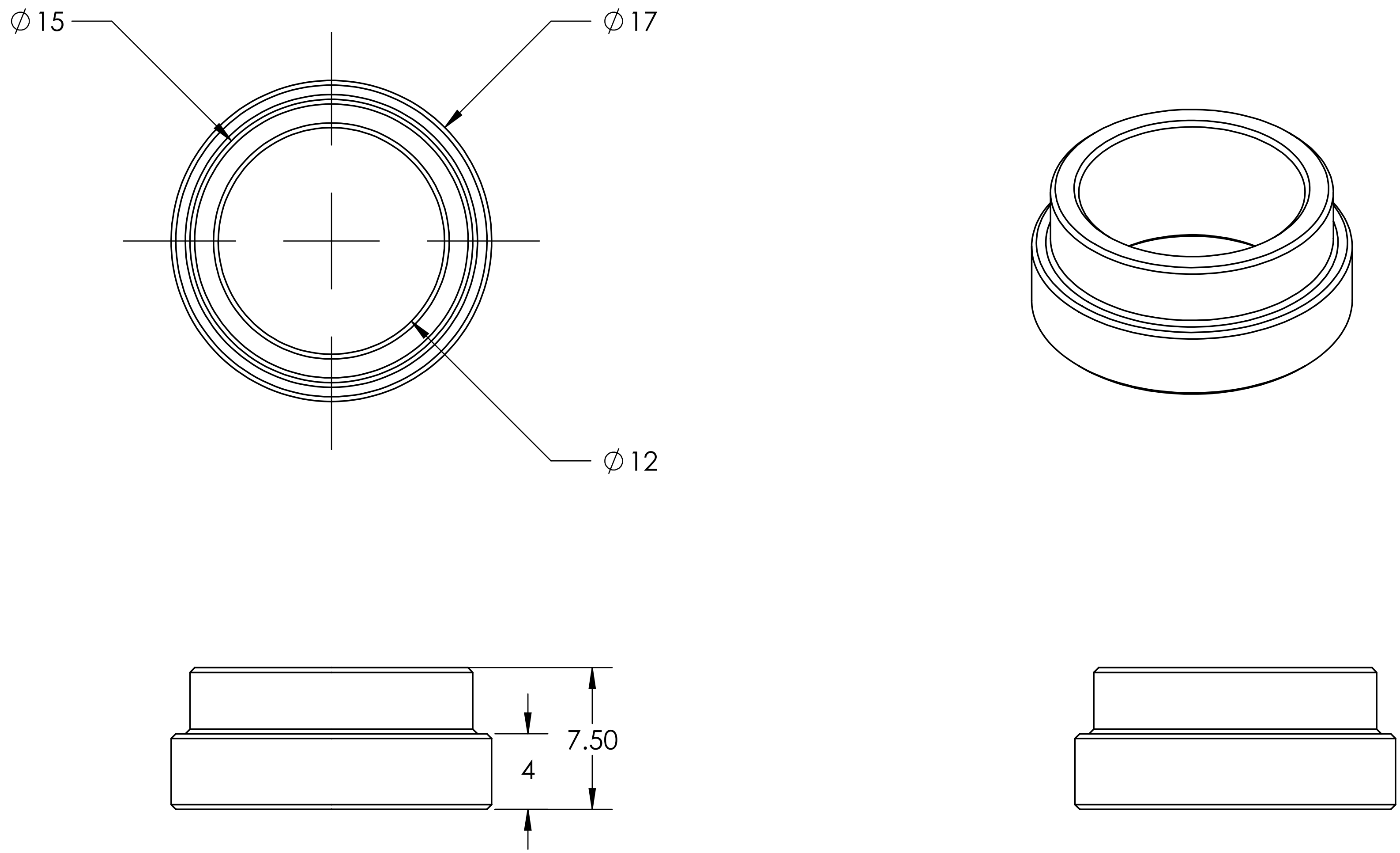
TITLE:

OD: 17 mm X t: 5.50 mm
DELRIN END BUSHING

SIZE	DWG. NO.	REV
A	3-29	

SCALE: 2:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM DELRIN CYLINDER STOCK (1-1/4 X 12 IN)

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: DELRIN

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	CHRISTIAN	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robomeks

RoboMeks

TITLE:

OD: 17 mm X t: 7.5 mm
DELRIN END BUSHING

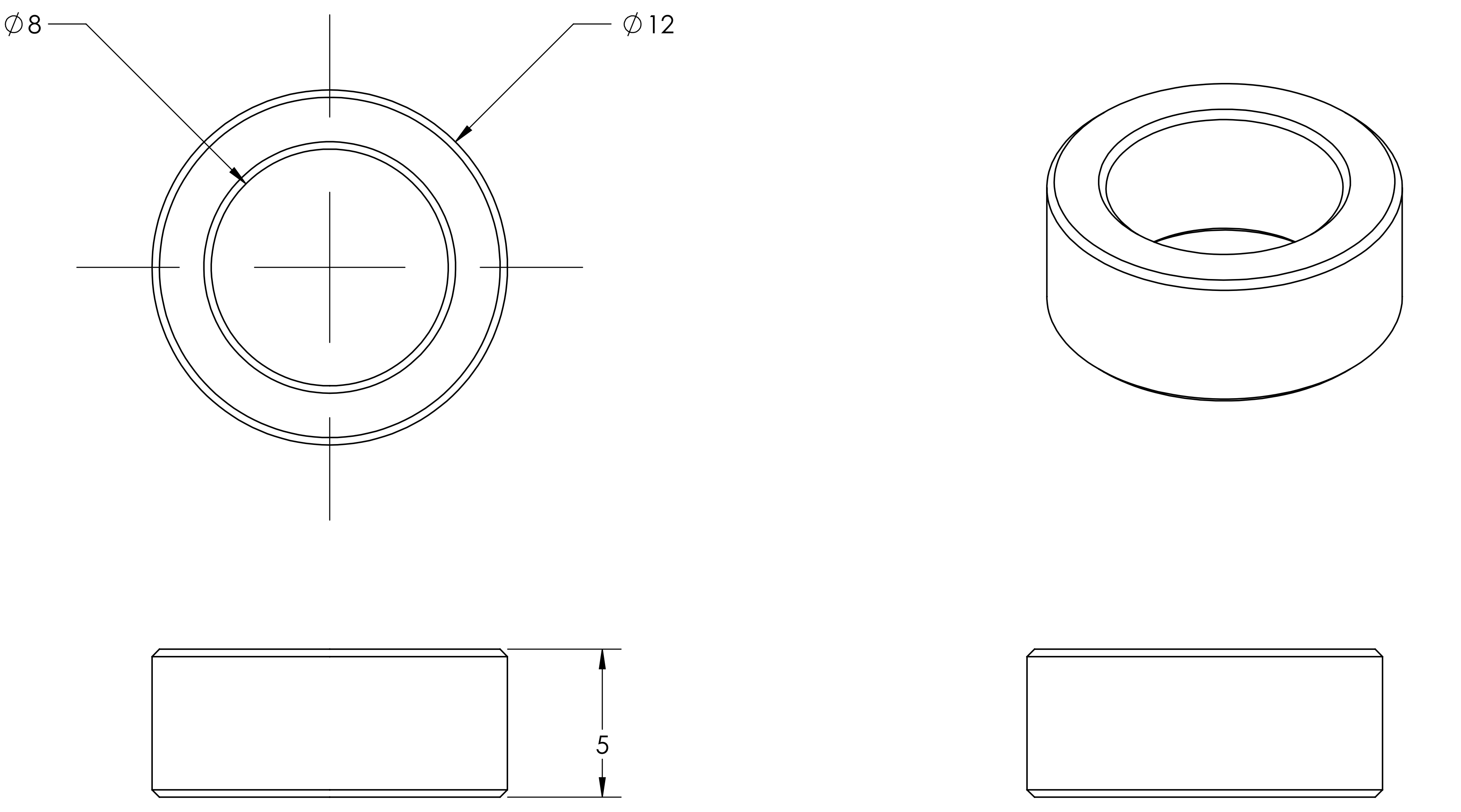
SIZE: A | DWG. NO. 3-30 | REV

SCALE: 3:1 | WEIGHT: | SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM BRONZE CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: BRONZE

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

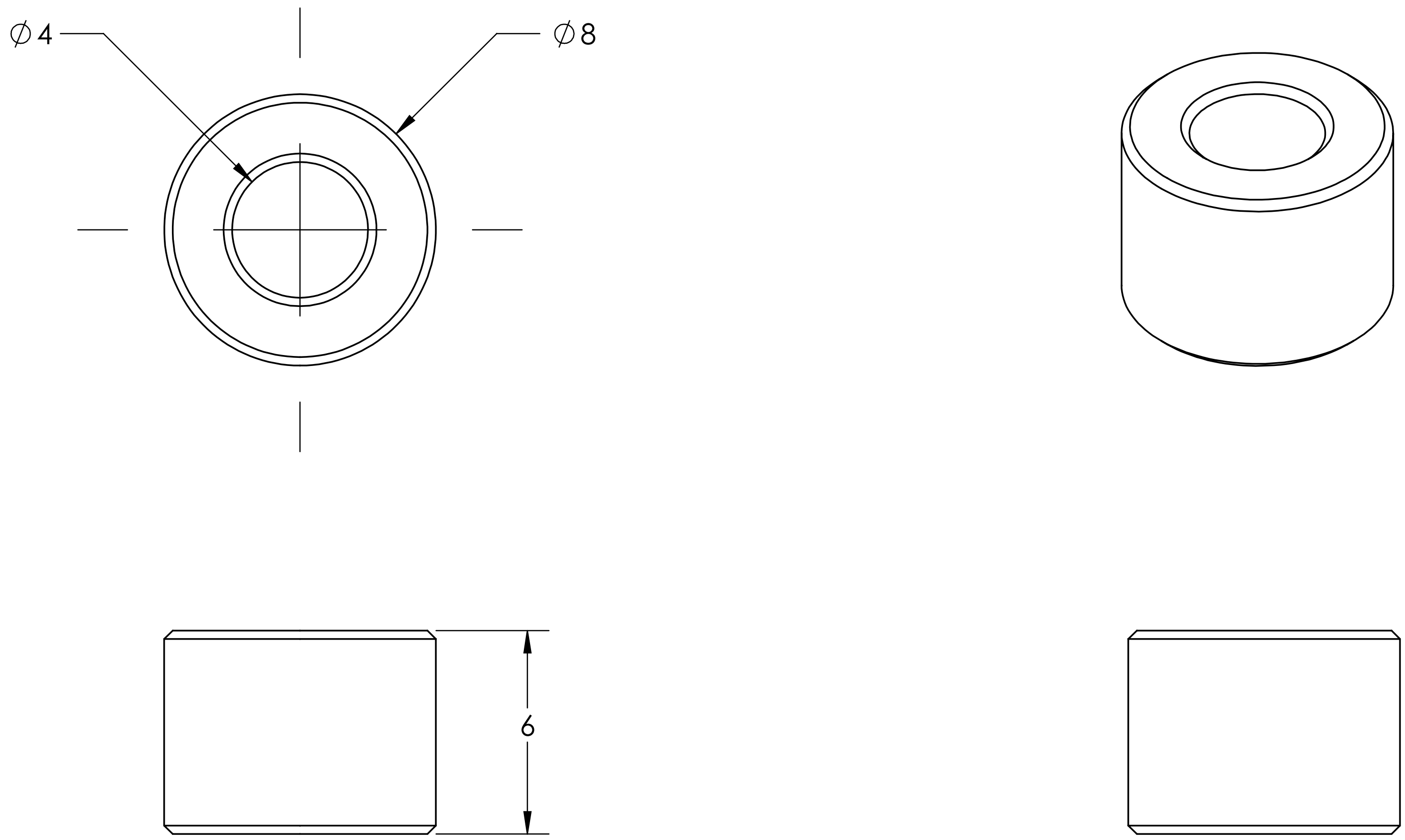
TITLE:

OD: 12 mm X t: 5 mm
Bronze Sleeve Bushing

SIZE	DWG. NO.	REV
A	3-31	

SCALE: 5:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM BRONZE CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF ROBOMEKS IS PROHIBITED.

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL BRONZE

FINISH MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	CHRISTIAN	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

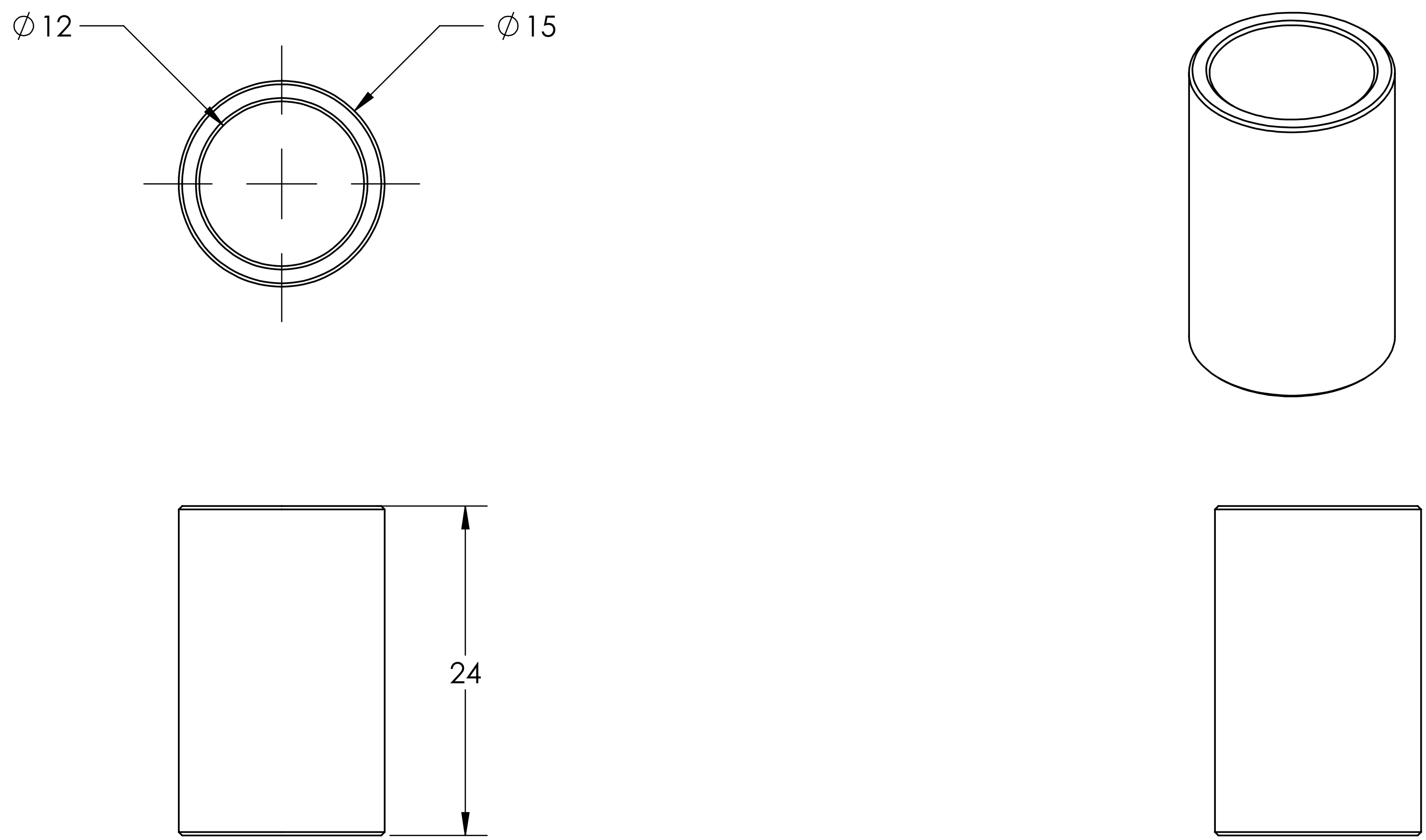
TITLE:

OD: 8 mm X t: 6 mm
BRONZE SLEEVE BUSHING

SIZE	DWG. NO.	REV
A	3-32	

SCALE: 5:1 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM BRONZE CYLINDER STOCK (1-1/4 X 12 IN)

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: BRONZE

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

TITLE:

OD: 15 mm X t: 24 mm BRONZE SLEEVE BUSHING

SIZE	DWG. NO.	REV
A	3-33	

SCALE: 2:1 WEIGHT: SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL

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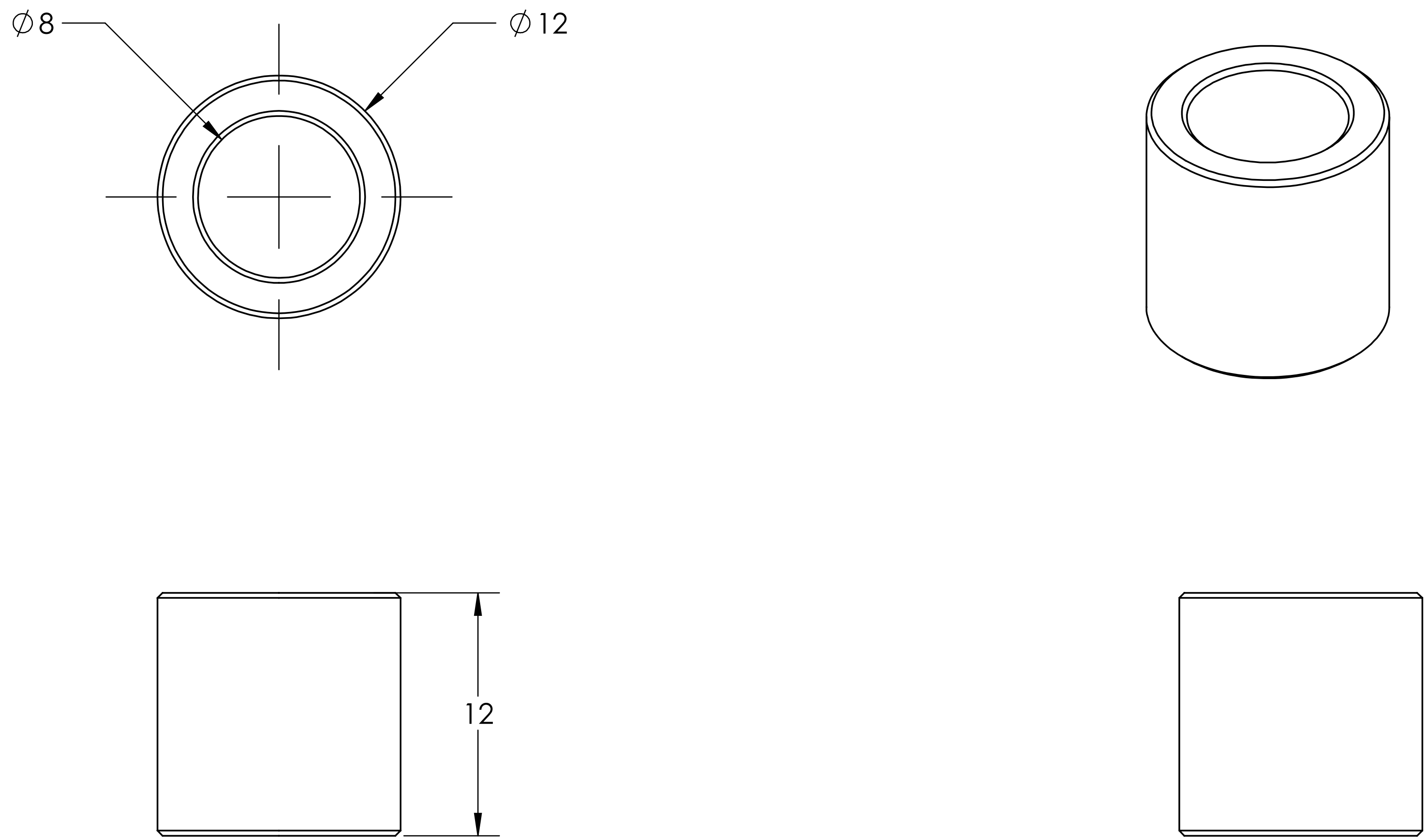
5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM BRONZE CYLINDER STOCK (1-1/4 X 12 IN)

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: MACHINED FINISH

FINISH: BRONZE

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	ERIC	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

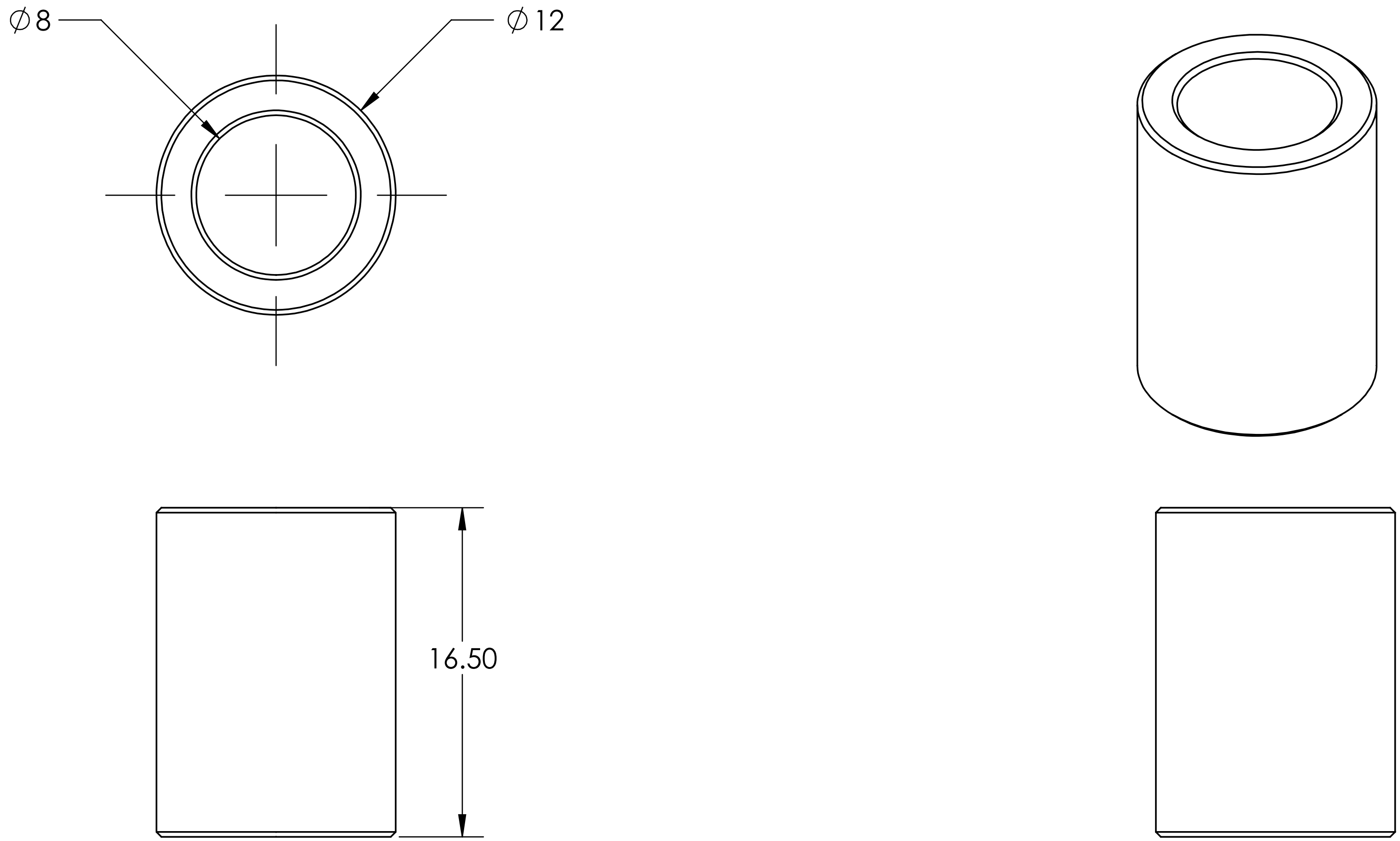
TITLE:

OD: 12 mm X t: 12 mm
BRONZE SLEEVE BUSHING

SIZE	DWG. NO.	REV
A	3-34	

SCALE: 3:1 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



GENERAL NOTES:

1. THIS PART SHALL BE PURCHASED FROM THE UTSA MACHINE SHOP.
2. ALL BURRS SHOULD BE REMOVED.
3. MACHINED FINISH ALLOVER ALL MOVING PARTS.
4. THIS PART IS TO BE MACHINED FROM BRONZE CYLINDER STOCK (1-1/4 X 12 IN)

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES:
MACHINING ±0.025 mm

MATERIAL: BRONZE

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/10/15
CHECKED	CHRISTIAN	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

TITLE:

OD: 12 mm X t: 16.50 mm
BRONZE SLEEVE BUSHING

SIZE: A | DWG. NO. 3-35 | REV

SCALE: 3:1 | WEIGHT: | SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL
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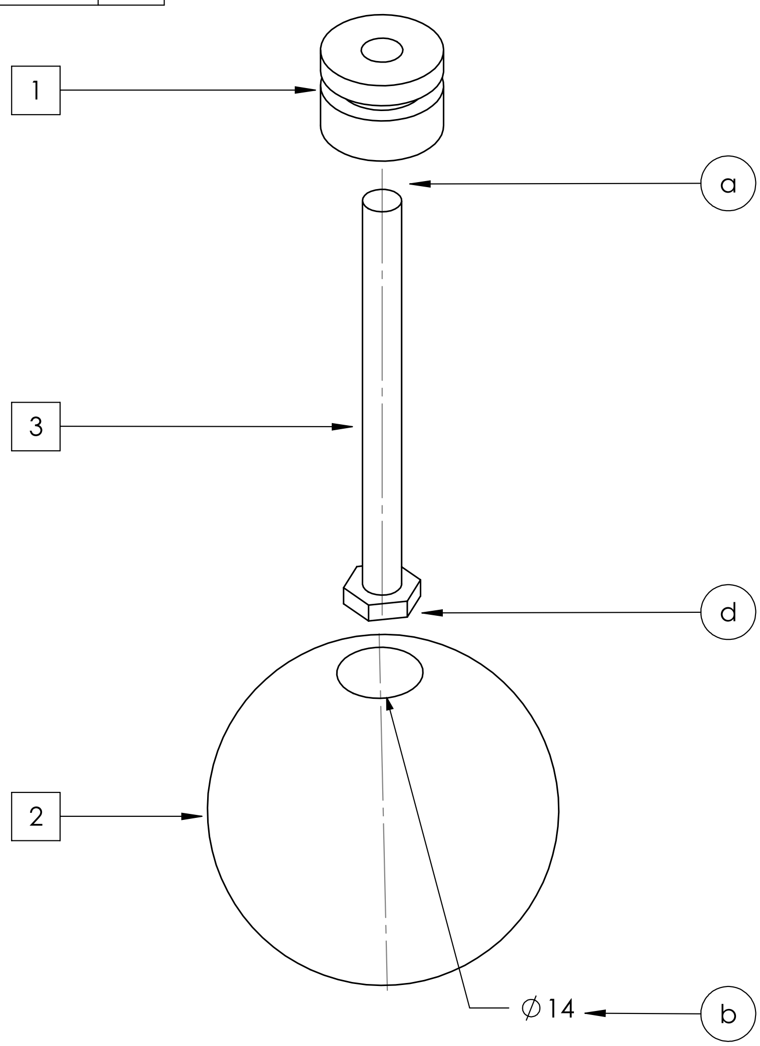
5 4 3 2 1

SubAssemblies

ITEM NO.	PART NUMBER	QTY.
1	Foot	1
2	Rubber Foot	1
3	1/4 in.-20 x 2 in. Phillips Hex-Head Machine Screw	1



GENERAL NOTES:

CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS

SQUARE REFERS TO ITEM NUMBERS

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OFROBOMEKS IS PROHIBITED.

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: MACHINING

MATERIAL: ALUMINUM 6061-T6, STEEL & RUBBER

FINISH: MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/8/15
CHECKED	CHRISTIAN	2/9/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

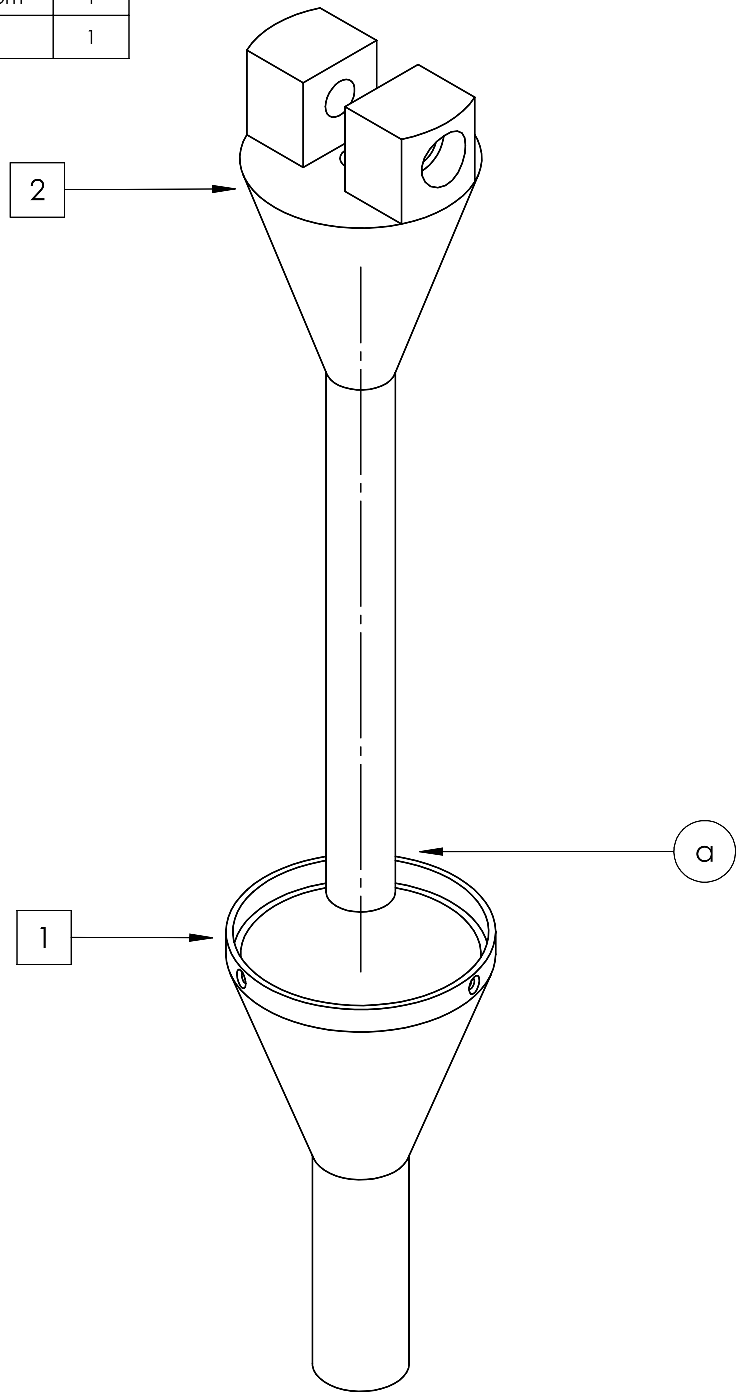
RoboMeks

SUBASSEMBLY 1-FOOT-RUBBER FOOT

SIZE: A | DWG. NO.: 2-01 | REV.:

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	Leg Cover - Bottom	1
2	Shank	1



PROPRIETARY AND CONFIDENTIAL THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OFROBOMEKS IS PROHIBITED.	GENERAL NOTES: CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS SQUARE REFERS TO ITEM NUMBERS	DIMENSIONS ARE IN MILLIMETERS TOLERANCES: MACHINING		NAME	DATE
			DRAWN	RAQUEL	2/8/15
			CHECKED	CHRISTIAN	2/9/15
			ENG APPR.		
			MFG APPR.		
		MATERIAL ALUMINUM 6061-T6	Q.A.		
		FINISH MACHINED FINISH			
		DO NOT SCALE DRAWING			

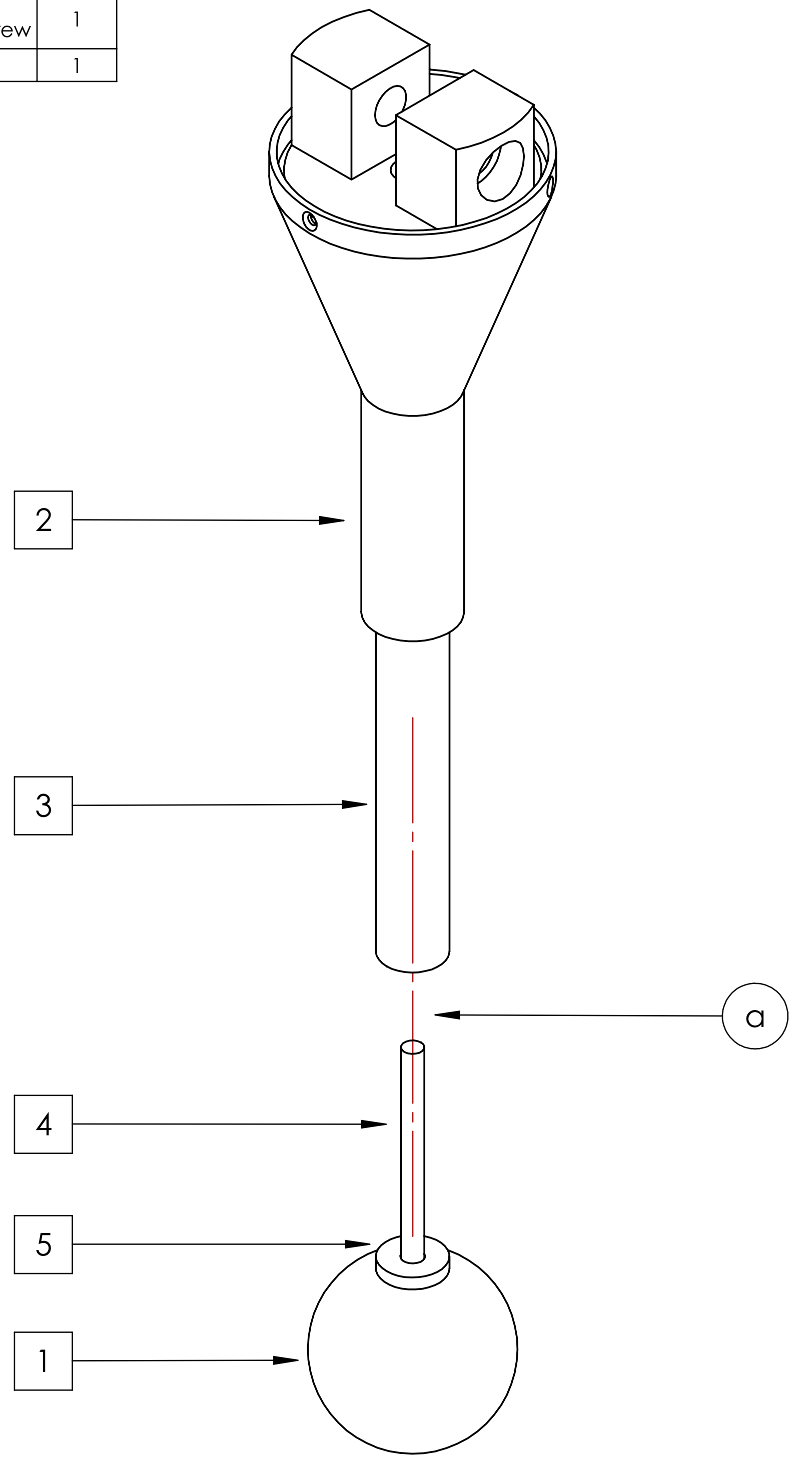
RoboMeks

SUBASSEMBLY 2 - LEG COVER BOTTOM

SIZE	DWG. NO.	REV.
A	2-02	

SCALE:1:2 WEIGHT: SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	Rubber Foot	1
2	Leg Cover - Bottom	1
3	Shank	1
4	1/4 in.-20 x 2 in. Phillips Hex-Head Machine Screw	1
5	Foot	1



GENERAL NOTES:

CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS

SQUARE REFERS TO ITEM NUMBERS

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OFROBOMEKS IS PROHIBITED.

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: MACHINING

MATERIAL
ALUMINUM 6061-T6, STEEL &RUBBER

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/8/15
CHECKED	CHRISTIAN	2/9/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

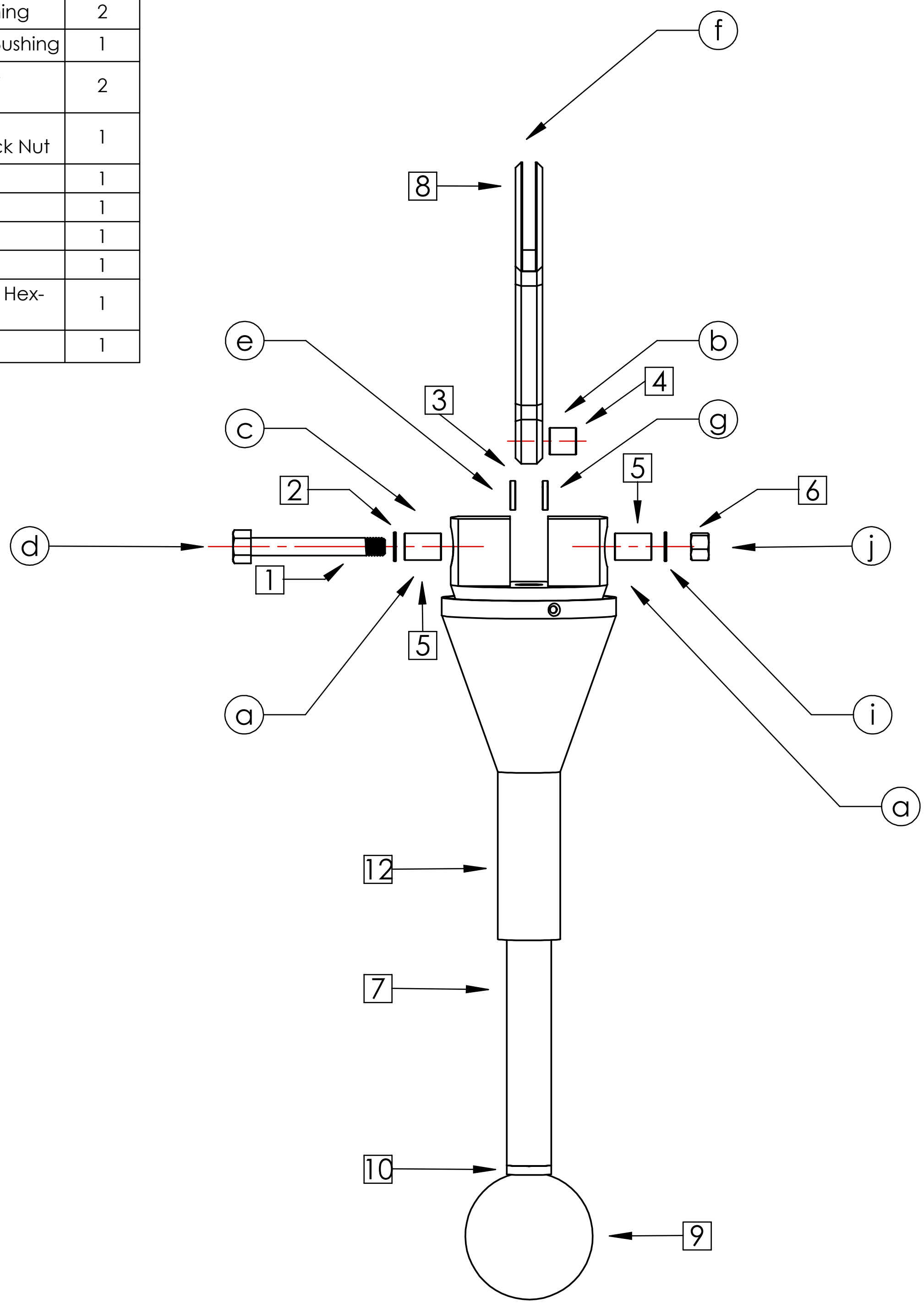
RoboMeks

SUBASSEMBLY 3 - FOOT-SHANK

SIZE A | DWG. NO. 2-03 | B-35 | REV.

SCALE:1:2 | WEIGHT: | SHEET 1 OF 1

ITEM NO.	PART NUMBER	QTY.
1	Pin 3	1
2	1mm Delrin End Bushing	2
3	2.5mm Delrin End Bushing	2
4	12mm Bronze Sleeve Bushing	1
5	16.5mm Bronze Sleeve Bushing	2
6	8-mm-1.25 Zinc-Plated Metric Nylon Insert Lock Nut	1
7	Shank	1
8	Follower Link	1
9	Rubber Foot	1
10	Foot	1
11	1/4 in.-20 x 2 in. Phillips Hex-Head Machine Screw	1
12	Leg Cover - Bottom	1



PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF ROBOMEKS. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OFROBOMEKS IS PROHIBITED.

GENERAL NOTES:

CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS

SQUARE REFERS TO ITEM NUMBERS

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: MACHINING

MATERIAL
ALUMINUM 6061-T6, BRONZE, DELRIN
ALUMINUM 7075-T6, STEEL & RUBBER

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/8/15
CHECKED	CHRISTIAN	2/9/15
ENG APPR.		
MFG APPR.		
Q.A.		

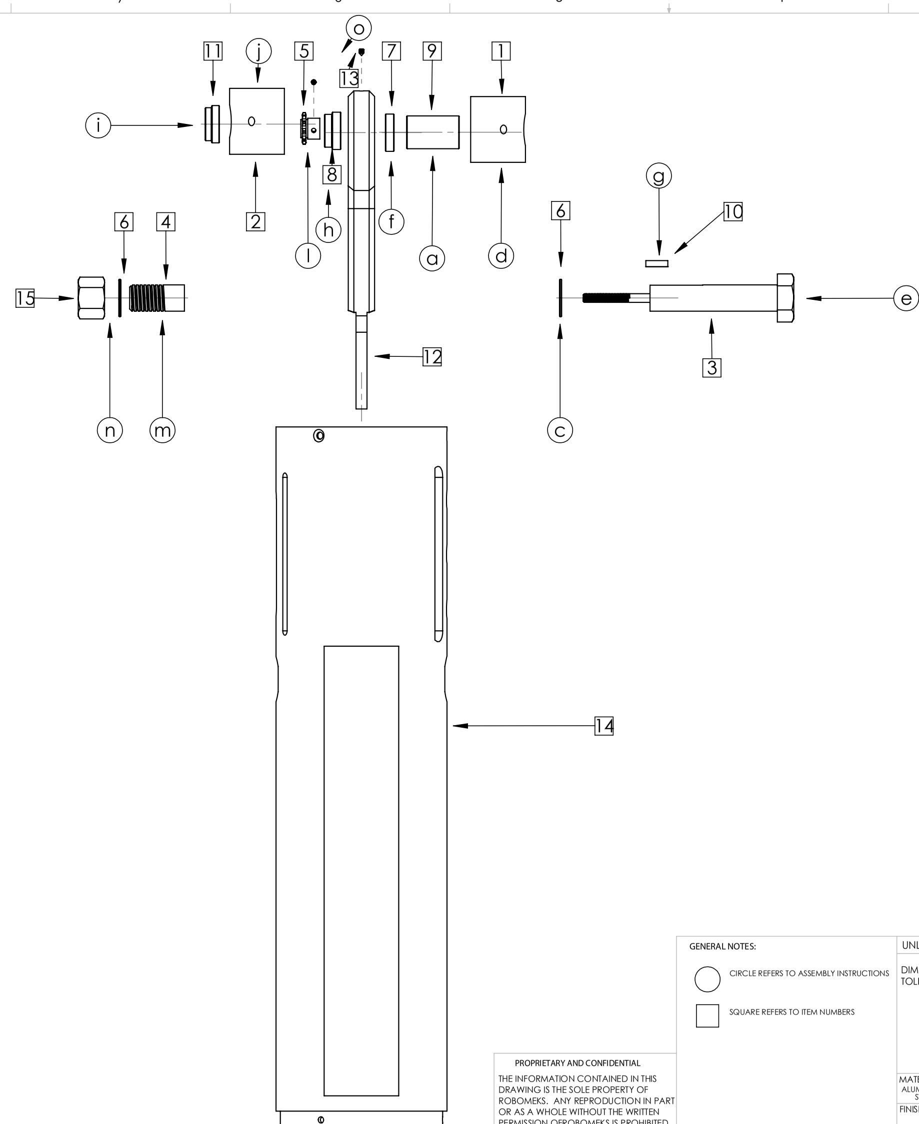
robo meks

RoboMeks

SUBASSEMBLY 4 - PIN 3

SIZE A | DWG. NO. 2-04 B-36 | REV.

SCALE:1:3 | WEIGHT: | SHEET 1 OF 1



ITEM NO.	PART NUMBER	QTY.
1	Stopper 1	1
2	Stopper 2	1
3	Pin 1	1
4	Pin 1 End Cap	1
5	Sprocket	1
6	17x1 mm Delrin End Bushing	2
7	17x4 mm Delrin End Bushing	1
8	17x7.5 mm Delrin End Bushing	1
9	15x24 mm Bronze Sleeve Bushing	1
10	Square Key	1
11	17x5.50 mm Delrin End Bushing	1
12	Crank Driver	1
13	B18.3.6M - M2 x 0.4 x 3 Hex Socket Cone Pt. SS --S	2
14	Leg Cover - Top	1
15	12-mm-1.75 Zinc-Plated Metric Nylon Insert Lock Nut	1

PROPRIETARY AND CONFIDENTIAL

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GENERAL NOTES:

CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS

SQUARE REFERS TO ITEM NUMBERS

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: MACHINING

MATERIAL
ALUMINUM 6061-T6, ALUMINUM 7075-T6, STEEL, BRONZE, DELRIN & RUBBER

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/8/15
CHECKED	CHRISTIAN	2/9/15
ENG APPR.		
MFG APPR.		
Q.A.		

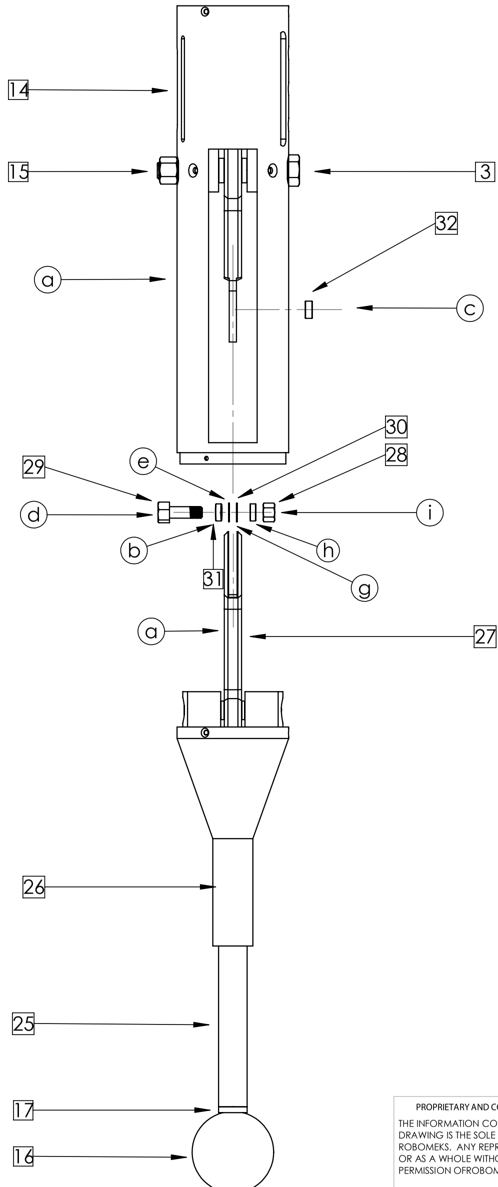
RoboMeks

TITLE:

SUBASSEMBLY 5 - PIN 1

SIZE	DWG. NO.	REV
B	2-05	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1



ITEM NO.	PART NUMBER	QTY.
1	Stopper 1	1
2	Stopper 2	1
3	Pin 1	1
4	Pin 1 End Cap	1
5	Sprocket	1
6	17x1 mm Delrin End Bushing	2
7	17x4 mm Delrin End Bushing	1
8	17x7.5 mm Delrin End Bushing	1
9	13x1.5mm Delrin Bushing	2
10	Square Key	1
11	17x5.5 mm Delrin End Bushing	1
12	Crank Driver	1
13	B18.3.6M - M2 x 0.4 x 3 Hex Socket Cone Pt. SS --S	2
14	Leg Cover - Top	1
15	12-mm-1.75 Zinc-Plated Metric Nylon Insert Lock Nut	1
16	Rubber Foot	1
17	Foot	1
18	1/4 in.-20 x 2 in. Phillips Hex-Head Machine Screw	1
19	17x1 mm Delrin End Bushing	2
20	13x2.5 mm Delrin End Bushing	2
21	12x12 mm Bronze Sleeve Bushing	1
22	12x16.5 mm Bronze Sleeve Bushing	1
23	12x16.5 mm Bronze Sleeve Bushing	1
24	Pin 3	1
25	Shank	1
26	Leg Cover - Bottom	1
27	Follower Link	1
28	8-mm-1.25 Zinc-Plated Metric Nylon Insert Lock Nut	2
29	Pin 2	1
30	15x24 mm Sleeve Bushing	1
31	17x4 mm Delrin End Bushing	2
32	12x5mm Bronze Sleeve Bushing	1

PROPRIETARY AND CONFIDENTIAL
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GENERAL NOTES:

○ CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS

□ SQUARE REFERS TO ITEM NUMBERS

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: MACHINING

MATERIAL
ALUMINUM 6061-T6, ALUMINUM 7075-T6, BRONZE, STEEL, DELRIN & RUBBER

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

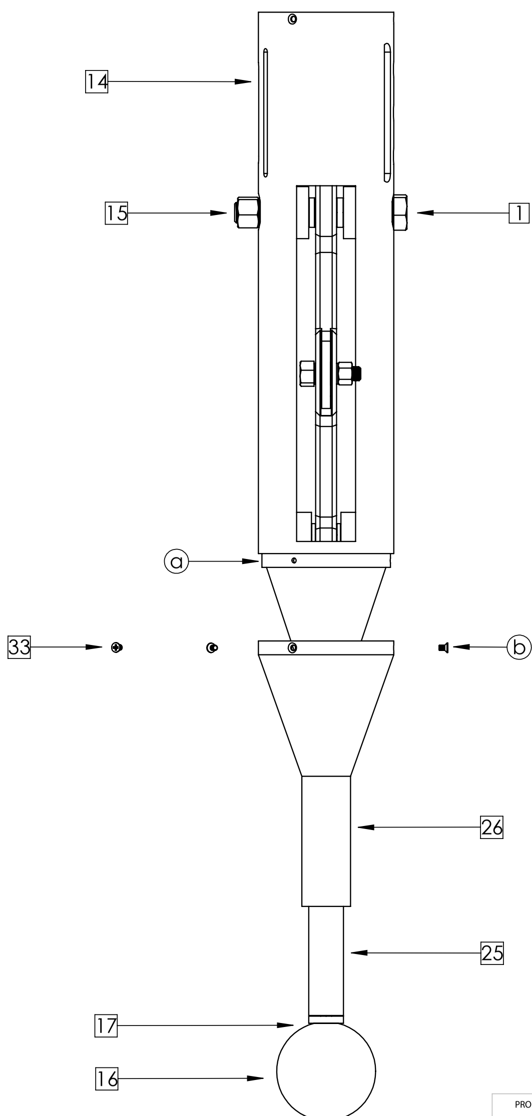
	NAME	DATE
DRAWN	RAQUEL	2/9/15
CHECKED	CHRISTIAN	2/9/15
ENG APPR.		
MFG APPR.		
Q.A.		

RoboMeks

TITLE:
SUBASSEMBLY 6 - PIN 2

SIZE: B | DWG. NO.: 2-06 | REV

SCALE: 1:3.25 | WEIGHT: | SHEET 1 OF 1



ITEM NO.	PART NUMBER	QTY.
1	Stopper 1	1
2	Stopper 2	1
3	Pin 1	1
4	Pin 1 End Cap	1
5	Sprocket	1
6	17x1mm Delrin End Bushing	2
7	17x4 mm Delrin End Bushing	1
8	17x7.5 mm Delrin End Bushing	1
9	15x24 mm Sleeve Bushing	1
10	Square Key	1
11	17x5.5 mm Delrin End Bushing	1
12	Crank Driver	1
13	B18.3.6M - M2 x 0.4 x 3 Hex Socket Cone Pt. SS --S	2
14	Leg Cover - Top	1
15	12-mm-1.75 Zinc-Plated Metric Nylon Insert Lock Nut	1
16	Rubber Foot	1
17	Foot	1
18	1/4 in.-20 x 2 in. Phillips Hex-Head Machine Screw	1
19	17x1 mm Delrin End Bushing	2
20	13x2.5 mm Delrin End Bushing	2
21	12x12 mm Bronze Sleeve Bushing	1
22	12x16.5 mm Bronze Sleeve Bushing	1
23	12x16.5mm Bronze Sleeve Bushing	1
24	Pin 3	1
25	Shank	1
26	Leg Cover - Bottom	1
27	Follower	1
28	8-mm-1.25 Zinc-Plated Metric Nylon Insert Lock Nut	2
29	Pin 2	1
30	13x0.5 mm Delrin Bushing	2
31	17x4 mm Delrin End Bushing	2
32	12x5 mm Bronze Sleeve Bushing	1
33	B18.6.7M - M3 x 0.5 x 5 Type I Cross Recessed FHMS --5S	3

PROPRIETARY AND CONFIDENTIAL

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GENERAL NOTES:

CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS

SQUARE REFERS TO ITEM NUMBERS

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: MACHINING

MATERIAL
ALUMINUM 6061-T6, ALUMINUM 7075-T6, BRONZE, DELRIN, STEEL & RUBBER

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	RAQUEL	2/9/15
CHECKED	CHRISTIAN	2/9/15
ENG APPR.		
MFG APPR.		
Q.A.		

robomeks

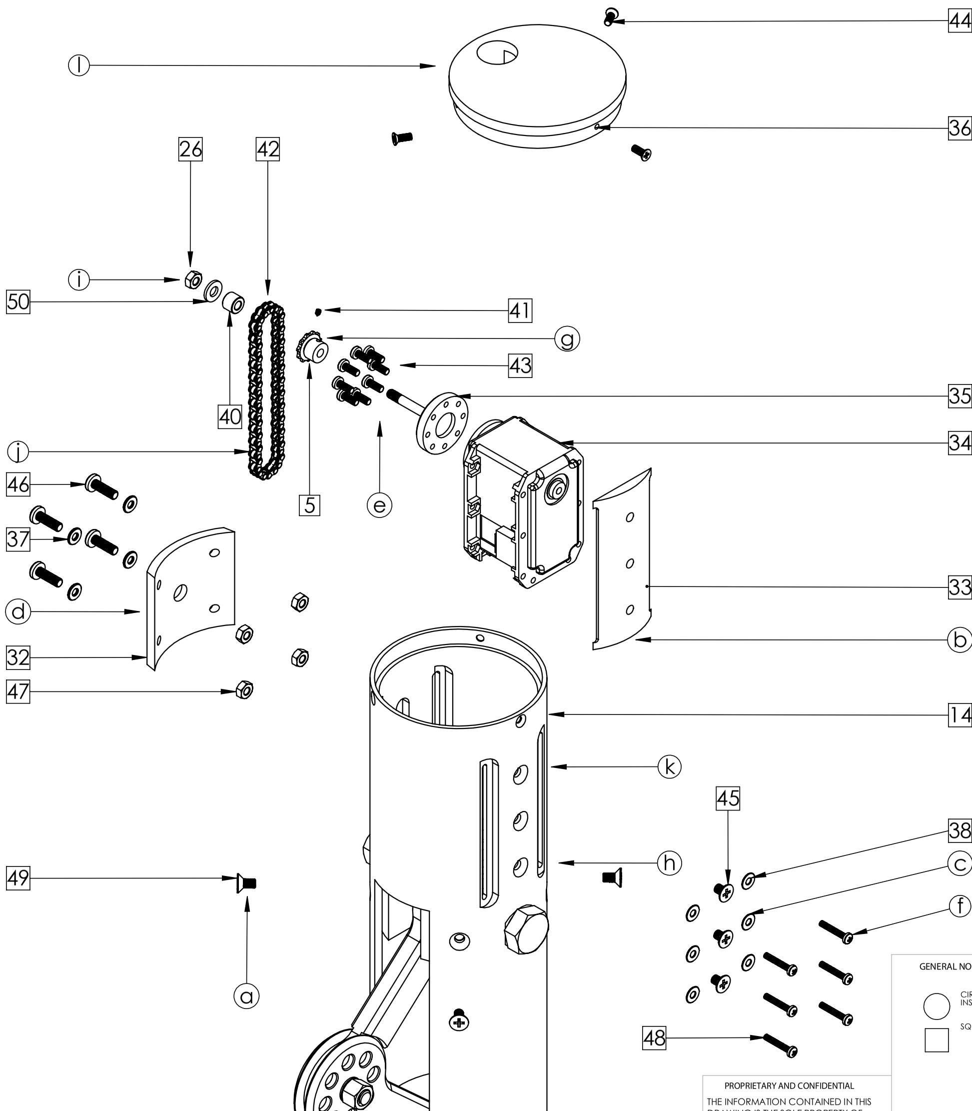
RoboMeks

TITLE:

SUBASSEMBLY 7 - LEG COVER

SIZE B | DWG. NO. 2-07 | REV

SCALE: 1:2.75 | WEIGHT: | SHEET 1 OF 1



ITEM NO.	PART NUMBER	QTY.
5	Sprocket	2
6	17x1 mm Delrin End Bushing	2
7	17x4 mm Delrin End Bushing	1
8	17x7.5 mm Delrin End Bushing	1
9	15x24 mm Bronze Sleeve Bushing	1
11	17x5.5 mm Delrin End Bushing	1
12	Crank Driver	1
13	B18.3.6M - M2 x 0.4 x 3 Hex Socket Cone Pt. SS --N	2
14	Leg Cover - Top	1
15	12-mm-1.75 Zinc-Plated Metric Nylon Insert Lock Nut	1
16	Leg Cover - Bottom	1
17	Shank	1
18	Follower Link	1
19	1/4 in.-20 x 2 in. Phillips Hex-Head Machine Screw	1
20	Foot	1
21	Rubber Foot	1
22	Pin 3	1
23	12x12 mm Bronze Sleeve Bushing	1
24	12x16.5 mm Bronze Sleeve Bushing	2
25	13x2.5 mm Delrin End Bushing	2
26	8-mm-1.25 Zinc-Plated Metric Nylon Insert Lock Nut	2
27	17x1 mm Delrin End Bushing	2
28	13x0.5 mm Delrin End Bushing	2
29	12x5 mm Bronze Sleeve Bushing	1
30	Pin 2	1
31	17x4 mm Delrin End Bushing	2
32	Motor Pin Mount	1
33	Motor Mount	1
34	Dynamixel MX-64T	1
35	Flywheel Adapter Pin	1
36	Leg Cover Cap	1
37	8x1 mm Delrin End Bushing	4
38	8x0.5 mm Delrin End Bushing	6
39	B18.6.7M - M3 x 0.5 x 5 Type I Cross Recessed FHMS --5S	3
40	8x6 mm Bronze Sleeve Bushing	1
41	B18.3.6M - M2 x 0.4 x 3 Hex Socket Cone Pt. SS --S	1
42	Miniature Chain	1
43	B18.6.7M - M3 x 0.5 x 8 Type I Cross Recessed PHMS --8S	8
44	B18.6.7M - M3 x 0.5 x 8 Type I Cross Recessed FHMS --8S	3
45	B18.6.7M - M4 x 0.7 x 6 Type I Cross Recessed FHMS --6S	3
46	B18.6.7M - M4 x 0.7 x 13 Type I Cross Recessed PHMS --13S	4
47	B18.2.4.1M - Hex nut, Style 1, M4 x 0.7 --D-N	5
48	B18.6.7M - M2.5 x 0.45 x 16 Type I Cross Recessed PHMS --16S	6
49	B18.6.7M - M4 x 0.7 x 8 Type I Cross Recessed FHMS --8S	4
50	17x4mm Delrin End Bushing	1

GENERAL NOTES:

CIRCLE REFERS TO ASSEMBLY INSTRUCTIONS

SQUARE REFERS TO ITEM NUMBERS

PROPRIETARY AND CONFIDENTIAL

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UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN MILLIMETERS
TOLERANCES: MACHINING

MATERIAL
ALUMINUM 6061-T6, ALUMINUM 7075-T6, BRONZE, STEEL, DELRIN & RUBBER

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ERIC S.	2/9/15
CHECKED	RAQUEL D.	2/9/15
ENG APPR.		
MFG APPR.		
Q.A.		

robo meks

RoboMeks

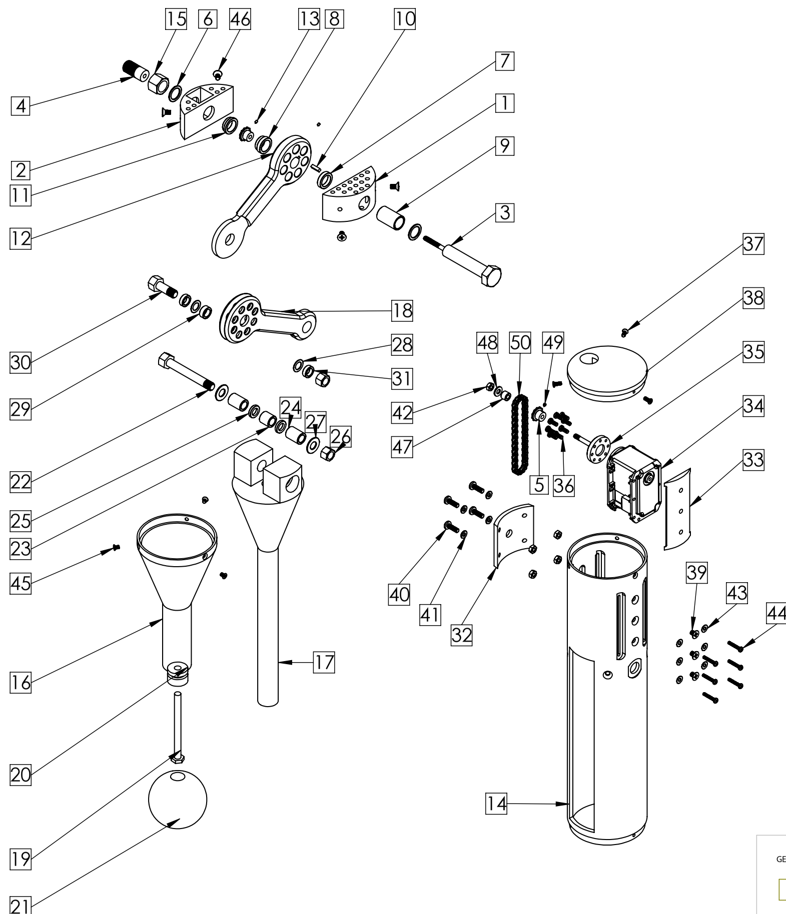
TITLE:

SUBASSEMBLY 8 - MOTOR PIN

SIZE	DWG. NO.	REV
B	2-08	

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

Main Assembly



ITEM NO.	PART NUMBER	QTY.
1	Slider Crank Holder	1
2	Stopper 2	1
3	Pin 1	1
4	Pin 1 End Cap	1
5	Sprocket	2
6	17x1mm Delrin Bushing	2
7	17x4 mm Delrin Bushing	1
8	17x7.5 mm Delrin Bushing	1
9	15x24 mm Sleeve Bushing	1
10	Square Key	1
11	17x5.5 mm Delrin Bushing	1
12	Crank Driver	1
13	B18.3.6M - M2 x 0.4 x 3 Hex Socket Cone Pt. SS --N	2
14	Leg Cover - Top	1
15	12-mm-1.75 Zinc-Plated Metric Nylon Insert Lock Nut	1
16	Leg Cover - Bottom	1
17	Shank	1
18	Follower Link	1
19	1/4 in.-20 x 2 in. Phillips Hex-Head Machine Screw	1
20	Foot	1
21	Rubber Foot	1
22	Pin 3	1
23	12x12 mm Bronze Sleeve Bushing	1
24	12x16.5 mm Bronze Sleeve Bushing	2
25	13x2.5 mm Delrin Bushing	2
26	8-mm-1.25 Zinc-Plated Metric Nylon insert Lock Nut	2
27	17x1mm Delrin End Bushing	2
28	13x0.5 mm Delrin End Bushing	2
29	12x5 mm Bronze Sleeve Bushing	1
30	Pin 2	1
31	17x4 mm Delrin End Bushing	2
32	Motor Pin Mount	1
33	Motor Mount	1
34	Dynamixel MX-64T	1
35	Flywheel Adapter Pin	1
36	B18.6.7M - M3 x 0.5 x 8 Type I Cross Recessed PHMS --8S	8
37	B18.6.7M - M3 x 0.5 x 8 Type I Cross Recessed FHMS --8S	3
38	Leg Cover Cap	1
39	B18.6.7M - M4 x 0.7 x 6 Type I Cross Recessed FHMS --6S	3
40	B18.6.7M - M4 x 0.7 x 13 Type I Cross Recessed PHMS --13S	4
41	8x1 mm Delrin End Bushing	4
42	B18.2.4.1M - Hex nut, Style 1, M4 x 0.7 --D-N	5
43	8x0.5 mm Delrin End Bushing	6
44	B18.6.7M - M2.5 x 0.45 x 16 Type I Cross Recessed PHMS --16S	6
45	B18.6.7M - M3 x 0.5 x 5 Type I Cross Recessed FHMS --5S	3
46	B18.6.7M - M4 x 0.7 x 8 Type I Cross Recessed FHMS --8S	4
47	8x6 mm Bronze Sleeve Bushing	1
48	17x4 mm Delrin End Bushing	1
49	B18.3.6M - M2 x 0.4 x 3 Hex Socket Cone Pt. SS --S	1
50	Miniature Chain	1

GENERAL NOTES:

SQUARE REFERS TO ITEM NUMBERS

UNLESS OTHERWISE SPECIFIED:

	NAME	DATE
DRAWN	ERIC S.	2/10/15
CHECKED	CHRIS T.	2/10/15
ENG APPR.		
MFG APPR.		
Q.A.		

MATERIAL
ALUMINUM 6061-T6 , ALUMINUM 7075-T6, DELRIN, RUBBER, 4130 ANNEALED STEEL

FINISH
MACHINED FINISH

DO NOT SCALE DRAWING

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TITLE:
EIN- FULL EXPLODED VIEW

SIZE B | DWG. NO. 1-01 | REV

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

Assembly Instructions:

Subassembly 1:

Foot-Rubber Foot

Materials Required:

Tools Required:

HDX 60:25 Caulk Gun	(1)
Stanley 5 in. Hobby Knife	(1)
Nut Driver 1/4 in.	(1)

Drawings:
Subassembly 1
Drawing 2-01

Instructions:
a.- Using the Nut Driver, screw the Hex-head machine screw into the Aluminum 6061 Foot as displayed in Drawing 201.
b.- Next, prepare the racquetball by using the Stanley 5-in Hobby Knife to cut a 14-mm diameter hole in the ball as specified in Drawing 201.
c.- Use the Caulk Gun to squeeze the Silicone into the hole of the racquetball, filling it about ¾ of the way.
d.- Place the Aluminum foot component inside of the Silicone filled hole with the threaded end of the bolt pointing upwards. The perimeter of the cut hole should line up with the notch on the outside of the foot component (refer to Drawing 201).
e.-Finally, allow the Silicone to fully dry before continuing with the Foot-Shank Assembly.
Reference for this assembly process is shown in Drawing 2-01.

SubAssembly 2:

Leg Cover Bottom

Materials Required:

Aluminum 6061 Shank	(1)
Aluminum 6061 Leg Cover Bottom	(1)

Drawings:
Subassembly 2 Drawing
Drawing 2-02

Instructions:
Instructions:
a.- Slide the Shank within the lower part of the leg cover as shown in Drawing 2-02.
Reference for this assembly process is shown in Drawing 2-02.

SubAssembly 3:
Foot-Shank

Materials Required:

Subassembly 1	(1)
Subassembly 2	(1)

Drawings:
Subassembly 1,2
Drawing 2-03

Instructions:
a.- Assembly the Foot-Rubber Foot Assembly to the Shank Subassembly using your hands to gently screw the bolt into the also threaded Shank, making sure to tighten just enough to hold the two assemblies together firmly.
Reference for this assembly process is shown in Drawing 2-03.

SubAssembly 4:
Pin 3

Materials Required:

Subassembly 3	(1)
Steel 4130 Annealed Pin 3	(1)
Aluminum 7075 Follower Link	(1)
12 x 12 Bronze Sleeve Bushing	(1)
12x 16.5 Bronze Sleeve Bushing	(2)
8 x 1 Delrin End Bushing	(2)
13 x 2.5 Delrin End Bushing	(2)
8 mm-1.25 Zinc-Plated Metric Bylon Insert Lock Nut	(1)

Tools Required: Nut Driver 8mm (2)
Drawings:
Drawing 2-04

Subassembly 4

Instructions:

a.- Insert the two 12 x 16.5 Bronze Sleeve Bushings into opposing holes located on the top of the shank.
b.- Insert the 12 x 12 Bronze Sleeve Bushing into the lower hole of the Follower Link.
c.- Place one of the 8 x 1 Delrin End Bushings around Pin 2.
d.- Take the End Bushing and Pin 2, and insert them through the first hole of the top of the Shank.
e.- Place one of the 13 x 2.5 Delrin End Bushings around Pin 2, as it extrudes from the first hole of the Shank.
f.- Set the lower end of the Following Link within the appropriate slot on the top of the Shank. Continue to push the End Bushing and Pin 2 into the lower hold of the Follower Link. Make sure to keep the Bronze Sleeve Bushing in place during this process.
g.- Insert the second 13 x 2.5 End Bushing between the lower hole of the Follower Link and the second hole of the top of the Shank. Continue to push Pin 2 through the assembly.
h.- Next, push Pin 2 through the remainder of the second hole of the Shank while keeping the Bronze Sleeve bushing in place.
i.- Place the second 8 x 1 Delrin end bushing around the exposed threads at the end of Pin 2.
j.- Using both Nut Drivers, use your right hand to screw the lock nut clockwise at the second end of the pin, while holding the hex head steady using the other Nut Driver in place of your left hand. Turn until firmly secured. Reverse the order of holding if left-handed.
Reference for this assembly process is shown in Drawing 2-04.

SubAssembly 5:

Pin 1

Materials Required:

Steel 4130 Annealed Pin 1	(1)
Steel 4130 Annealed Pin End Cap	(1)
Steel 4130 Annealed Square Key	(1)
Aluminum 6061 Stopper 1	(1)
Aluminum 6061 Stopper 2	(1)
Aluminum 7075 Crank Driver	(1)
Aluminum 6061 Leg Cover Top	(1)
Aluminum Chain Sprocket	(1)
15 x 24 Bronze Sleeve Bushing	(1)
17 x 1 Delrin End Bushings	(1)
17 x 4 Delrin End Bushing	(1)
17 x 5.5 Delrin End Bushing	(1)
17 x 7.5 Delrin End Bushing	(1)
12-mm-1.75 Zinc-Plated Metric Nylon Insert Lock Nut	(1)
B18.3.6M-M2X0.4X3 Hex Socket Cone Pt. SS-S	(1)

Tools Required:

Nut Driver 12 mm	(2)
Hex L-Key 0.9 mm	(1)

Drawings:
Subassembly 5 and Drawing 2-05

Instructions:
a.- Place the 15 x 24 Bronze Sleeve Bushing within the same diameter hole of Stopper 1.
b.- Orient the Leg Cover-Top so that the largest slot is facing you.
c.- Place the 17 x 1 Delrin End Bushing around the hex bolt with two shaft diameters (12 mm and 4 mm).
d.- Place Stopper 1 inside of the Leg Cover-Top on the furthermost right hand side, making sure to line the Stopper's 15 mm hole with the 12 mm hole found on the Leg Cover's right side.
e.- Insert the same hex bolt into the Leg Cover and through Stopper 1.
f.- Place the 17 x 4 Delrin End Bushing around the exposed threads of the hex bolt.
g.- Insert the Square Key into the machined slot of Pin1. Insert Pin 1 into the upper hole of the Crank Driver, fitting the Square Key into the machined slot.
h.- Place the 17 x 7.5 Delrin End Bushing into the 15 mm largest hole exposed to the flat side of Stopper 2.
i.- Place the 17 x 5.5 Delrin End Bushing also into the largest hole exposed to the flat side of Stopper 2.
j.- Lower Stopper 2 into the left side of the Leg Cover-Top. Align the hole on Stopper 2 with Pin .
k.- Push Pin 1 through the hole of Stopper 2.
l.- Push Pin 1 into the hole of the Aluminum Sprocket , sliding the Sprocket to the very end of the shaft.
m.- Place the Pin 1 End Cap with Pin 1, using your hand to screw until secure.
n.- Place the 1 mm Delrin End Bushing around the Pin 1 End Cap and then place a M12 Hex Nylon Insert Lock Nut using the two 12 mm Nut Drivers to secure the shaft into place.
o.- Using the Hex L-Key, secure the M2x.4 Tap Screws inside the allotted holes of the flange of the Sprocket and the Crank Driver.
For reference of this assembly, see Drawing 2-05.

SubAssembly 6:
Pin 2

Materials Required:

Subassembly 4 Drawing	(1)
Subassembly 5 Drawing	(1)
Steel 4130 Annealed Pin 2	(1)
12 x 5 Bronze Sleeve Bushing	(1)
12 x 4 Delrin End Bushing	(2)
13 x 0.5 Delrin End Bushing	(2)
8 mm 1.25 Zinc-Plated Metric Nylon Insert Lock Nut	(1)

Tools Required: Nut Driver 8 mm (2)

Drawings: Drawing 2-06, Subassembly 6

Instructions:
a.- Place the Crank Driver through the largest Leg Cover slot, placing the end of it outside the cover, then repeating for the Following Link.
b.- Place one of the 12 x 4 Delrin End Bushings around Pin 2, pushing to the Hex Head Machine Screw.
c.- Insert the 5 mm Bronze Sleeve Bushing into the Crank Driver 12 mm hole of the Crank Driver.
d.- Continue to Start insert Pin 2 into the first hole of the Follower Link.
e.- Place one of the two 13 x 0.5 Delrin End Bushings around Pin 2.
f.- Now insert Pin 2 into the hole, making sure the sleeve bushing stays inside.
g.- Insert the second 13 x 0.5 Delrin End Bushing around Pin 2 and push through the hole of the Follower Link.
h.- Place the second 12 x 4 Delrin End Bushing around Pin 2.
i.- Using both 8 mm Nut Drivers (same as previously stated), screw the Lock Nut around Pin 2 until both are fully secured.
For reference of this assembly, see Drawing 2-06.

SubAssembly 7:

Leg Cover

Materials Required:

Subassembly 6	(1)
B18.6.7M-M3 x 0.5 x 5 Type 1 Cross Recessed FHMS - 5 (Metric Flat Head Phillips Machine Screw)	(1)

Tools Required:
Small Phillips Screwdriver (3mm)

Drawings:
Subassembly 6
Drawing 2-07

Instructions:

a.-Align the top and the bottom of the leg cover until the holes located in the middle of the cover match each other.
b.-Using the small Phillips Screwdriver, screw each of the three Machine Screws on the leg cover until secure.
For reference of this assembly, see Drawing 2-07.

SubAssembly 8:

Motor Pin

Materials Required:

Subassembly 5	(1)
Sprocket	(1)
Leg Cover-Top	(1)
Dynamixel MX-64-R	(1)
Motor Pin Mount	(1)
Motor Mount	(1)
Flywheel Adapter Pin	(1)
M3 X 0.5 X 8 Phillips Head Machine Screw	(1)
M3 X 0.5 X 8 Phillips Flat Head Machine Screw	(1)
Leg Cover Cap	(1)
M4 X 0.7 X6 Phillips Flat Head Machine Screw	(1)
8 x 0.5 Delrin End Bushing	(1)
M2.5 X 0.45 X 16 Phillips Head Machine Screw	(1)
M4 X 0.7 X 8 Phillips Flat Head Machine Screw	(1)
8 x 6 Bronze Bushing	(1)
8 x 1 Delrin End Bushing	(1)
M2 X 0.4 X 3 Hex Socket Cone Set Screw	(1)
Chain	(1)

Tools Required:

Nut Driver 4mm	(1)
Needle Nose Pliers	(1)
Small Phillips Screwdriver	(1)
0.9 mm Hex L-Key	(1)
String	(1)

Drawings:
Subassembly 7 Drawing
Subassembly 8 Drawing

Instructions:

a. Using a Phillips Screwdriver, screw in the four M4 X 0.7 X 8 Phillips Flat Head Machine Screws into Stopper 1 and 2 from Subassembly 5. Screw until securely tightened.

b. Orient the Leg Cover - Top to where the slot is facing you. Lower the Motor Mount into the right hand side of the cover.

c. Align the three holes in the motor mount and the cover. Screw the two pieces together using three M4 X 0.7 X 6 Phillips Flat Head Machine Screws. Screw until securely fastened.

d. Place the Motor Pin Mount on the outside left of the leg cover. Push a 8 x 0.5 Delrin End bushing and a M4 X 0.7 X 13 Phillips Head Machine Screw through the four small (4 mm) holes on the mount and through the slots on the leg cover. Fasten the screws using a M4 X 0.7 Hex Nylon Lock Nut for each.

e. Align the Flywheel Adapter Pin to the horn (flywheel) on the Dynamical MX-64-R. Using eight M3 X 0.5 X 8 Phillips Head Machine Screws, screw the adapter pin to the horn.
f. Prepare the six M2.5 X 0.45 X 16 Phillips Head Machine Screws by putting a 8 x 0.5 Delrin End Bushing.
g. Slide the Sprocket onto the pin connected to the motor. Lower the pieces into the cover. Push the remaining length of the motor pin through the large hole (8 mm) in the motor pin mount. Slip the 8 x 6 Bronze Sleeve Bushing into the concentric space between the motor pin and the motor pin mount.
h. Align the six prepared M2.5 X 0.45 X 16 Phillips Head Machine Screws to the back of the motor housing through the slots in the cover. Fasten the screws into place.
i. Place a 8 x 0.5 Delrin End Bushing onto the protruding motor pin. Fasten the pin into place by using a M4 X 0.7 Hex Nylon Lock Nut.
j. Count 54 links of the chain and separate. Tie a string to one end, and lower the strung end of the chain into the leg cover past the two stoppers. Push the string past the space between the stopper and the attached sprocket and pull the string upwards using the needle nosed pliers. Align the teeth on the sprocket attached to Pin 1 to the chain's spaces. Then, align the teeth of the chain with the sprocket on the motor pin. Secure the two ends of the chain by using the connectors supplied by the manufacturer.
k. If the chain is not long enough to connect both ends, lower both the motor mount and the motor pin mount by loosening the machine screws. This should allow for slack in the chain. After the two ends are attached, create tension in the chain by elevating the motor pin mount and motor mount. Fasten securely to ensure tension for the chain.
l. Close the leg cover by capping the end using the Leg Cover Cap and secure into place by screwing in three M3 X 0.5 X 8 Phillips Flat Head Machine Screws to their respective holes. the large hole on the leg cover cap should be opposite side the motor.

Bill of Materials

Part No.	Part Name	Quantity	Make or Bu	Notes
HD5040 24C	GE Silicone II K&B Clear	1	Buy	9.8 oz.
HD109	Smooth Rod Caulk Gun	1	Buy	-
7W736020	telon Classic Racquetballs, Set o	1	Buy	-
DEL1250NATROD	Acetal Natural Rod	1	Buy	OD: 1' 1/4", Length: 1'
ART613500375	Aluminum 6061-T6 Round Tube	1	Buy	OD: 3' 1/2", Thickness: 0.3 Length: 1' 6"
AR061312	Aluminum 6061-T6 Rod	1	Buy	OD: 3' 1/2", Length: 1'
AR0613	Aluminum 6061-T6 Rod	1	Buy	OD: 3", Length: 6"
AR061312	Aluminum 6061-T6 Rod	1	Buy	OD: 3' 1/2", Length: 1' 2"
9478T163	Aluminum 7075 Sheet	2	Buy	Length: 14", Width: 7",
8932K45	Bronze SAE 841	1	Buy	OD: 1", Length: 6 1/2"
6673T25	Steel 4130 Annealed Rod	1	Buy	OD: 3/4", Length: 1'
902-0097-000	Dynamixel MX64	1	Buy	-

902-0066-000	Dynamixel MX106	1	Buy	-
903-0084-000	Dynamixel 4 Pin Connectors	2	Buy	Length: 240 mm
2760007	LM741 Op Amp	2	Buy	-
271-1133	470 kiloohm Resistors	2	Buy	-
882	330 microfarad Capacitor	2	Buy	-
902-0084-040	otis OpenCM 9.04 Microcontrol	1	Buy	32 bit ARM Cortex-M3 pro
902-0084-050	otis OpenCM 485 Expansion Bo	1	Buy	Connects to microcontroll
COM-00107	Voltage Regulator	1	Buy	-
CF1/4W103JR	10 kiloohm Resistor	1	Buy	-
1010,10 Series	T Slots Aluminum Extrusion Set	1	Buy	Used for testing fixture
FSR 400 Short	Force Sensing Resistor	1	Buy	-
EC35	JS Digital Optical Rotary Encode	1	Buy	-
785	Male/Female Jumper Wires	1	Buy	-
266	Female/Female Jumper Wires	1	Buy	-
826	Male/Female Jumper Wires	1	Buy	-
902-0032-000	USB2Dynamixel	1	Buy	-

Appendix C- Testing Plan

List of Figures:

List of Tables:

Main Test Facility

The Robotics and Motion Laboratory will serve as the main test facility for the designed tests for Ein: The Robotic Leg. It is located at the UTSA Main Campus, BSE building Room 2.216.

The RAM Laboratory operates within a temperature range of 65 degrees Fahrenheit and 75 degrees Fahrenheit.

UV rays remain at a minimum within the facility, and may be rejected if deemed necessary by closing Aluminum blinds on all of the windows leading to an outside environment. Fluorescent lab lighting produces minimal UV rays which are considered to have a negligible damaging effects to the materials that come within contact.

The laboratory itself is considered to be a “dry” lab and the robotic leg will not undergo any undesirable exposure to acids, fluids, or harmful gasses during the testing process within the RAM lab.

Water is limited to a single sink within the lab, however the testing table in which the testing fixture is mounted to, is located a minimum distance of 14 feet.

Figure 1: Testing Table with disassembled Testing Fixture at The Robotics and Motion Laboratory

Supplemental Test Facilities

The Materials Instruction Laboratory (EB 1.04.18) and the Measurements and Instrumentation Instruction Laboratory (EB 3.04.68) will be used as supplemental testing facilities due to a couple of equipment items needed for Ein’s test plan. Both of the labs are located at the Main Campus at UTSA.

Metallography instrumentation will be used to analyze and verify the composition of the purchased Aluminum metal raw stock (Aluminum 7075, Aluminum 6061). The equipment will be used in the Materials Instruction Laboratory.

A triple beam balance will be used to measure the mechanics main and sub components to ensure they are within weight range as displayed in the SolidWorks drawings included in the Drawing Package. The balance will be used in the Measurements and Instrumentation Instruction Laboratory.

Major Test Durations

The Test Plan presented before was developed in 15 working days. Detailed testing is shown in the Gantt Chart provided in the following pages. Testing includes preliminary testing for each component involved on the project, testing for the physical and functional requirements, and data handling. The time frame established for the execution of testing was 30 days. The preliminary testing has already been started with some measurements of the mechanic components. The major testing elements and their testing durations are:

1. Preliminary Testing (23 days)
2. Product Testing (6 days)
3. Analysis of Results (1 day)

Schedule of Deliverables

The testing plan was established to meet the major requirements established for the completion of ME 4813 - Senior Design 2 such as:

1. Draft of Senior Design Project Poster (04/07/2015)
2. Final Senior Design Project Poster (04/14/2015)
3. Draft of Final Presentation Powerpoint Slides (04/14/2015)
4. Draft of Final Report (04/16/2015)
5. Final Presentation Powerpoint Slides (04/21/2015)
6. Final Presentation (04/23/2015)
7. Final Report (04/29/2015)

Table 1: Testing Schedule

	Task Name	Start Date	End Date	
1	1. PRELIMINARY COMPONENT TESTING	02/24/15	03/25/15	100%
2	1.1. Mechanical Components	02/24/15	03/24/15	100%
3	1.1.1. Physical Measuring of Components' Dimensions	02/24/15	03/24/15	100%
4	1.1.1.1. Slider Crank	03/23/15	03/23/15	100%
5	1.1.1.1.1. Physical Measuring	03/23/15	03/23/15	100%
6	1.1.1.1.1.1. Sample Acquisition	03/23/15	03/23/15	100%
7	1.1.1.1.1.1.1. Data Display	03/23/15	03/23/15	100%
8	1.1.1.2. Follower Link	03/23/15	03/23/15	100%
9	1.1.1.2.1. Physical Measuring	03/23/15	03/23/15	100%
10	1.1.1.2.1.1. Sample Acquisition	03/23/15	03/23/15	100%
11	1.1.1.2.1.1.1. Data Display	03/23/15	03/23/15	100%
12	1.1.1.3. Leg Shank	03/23/15	03/23/15	100%
13	1.1.1.3.1. Physical Measuring	03/23/15	03/23/15	100%
14	1.1.1.3.1.1. Sample Acquisition	03/23/15	03/23/15	100%
15	1.1.1.3.1.1.1. Data Display	03/23/15	03/23/15	100%
16	1.1.1.4. Leg Cover	03/23/15	03/23/15	100%
17	1.1.1.4.1. Physical Measuring	03/23/15	03/23/15	100%
18	1.1.1.4.1.1. Sample Acquisition	03/23/15	03/23/15	100%
19	1.1.1.4.1.1.1. Data Display	03/23/15	03/23/15	100%
20	1.1.1.5. Leg Foot	03/23/15	03/23/15	100%
21	1.1.1.5.1. Physical Measuring	03/23/15	03/23/15	100%
22	1.1.1.5.1.1. Sample Acquisition	03/23/15	03/23/15	100%
23	1.1.1.5.1.1.1. Data Display	03/23/15	03/23/15	100%
24	1.1.1.6. Stopper 1	03/23/15	03/23/15	100%
25	1.1.1.6.1. Physical Measuring	03/23/15	03/23/15	100%
26	1.1.1.6.1.1. Sample Acquisition	03/23/15	03/23/15	100%
27	1.1.1.6.1.1.1. Data Display	03/23/15	03/23/15	100%
28	1.1.1.7. Stopper 2	03/23/15	03/23/15	100%
29	1.1.1.7.1. Physical Measuring	03/23/15	03/23/15	100%
30	1.1.1.7.1.1. Sample Acquisition	03/23/15	03/23/15	100%
31	1.1.1.7.1.1.1. Data Display	03/23/15	03/23/15	100%
32	1.1.1.8. Flywheel Adaptor Pin	03/24/15	03/24/15	100%
33	1.1.1.8.1. Physical Measuring	03/24/15	03/24/15	100%
34	1.1.1.8.1.1. Sample Acquisition	03/24/15	03/24/15	100%
35	1.1.1.8.1.1.1. Data Display	03/24/15	03/24/15	100%
36	1.1.1.9. Motor Mount	03/24/15	03/24/15	100%
37	1.1.1.9.1. Physical Measuring	03/24/15	03/24/15	100%
38	1.1.1.9.1.1. Sample Acquisition	03/24/15	03/24/15	100%
39	1.1.1.9.1.1.1. Data Display	03/24/15	03/24/15	100%
40	1.1.1.10. Motor Pin Mount	03/24/15	03/24/15	100%
41	1.1.1.10.1. Physical Measuring	03/24/15	03/24/15	100%
42	1.1.1.10.1.1. Sample Acquisition	03/24/15	03/24/15	100%
43	1.1.1.10.1.1.1. Data Display	03/24/15	03/24/15	100%
44	1.1.1.11. Pin 1	03/24/15	03/24/15	100%
45	1.1.1.11.1. Physical Measuring	03/24/15	03/24/15	100%
46	1.1.1.11.1.1. Sample Acquisition	03/24/15	03/24/15	100%
47	1.1.1.11.1.1.1. Data Display	03/24/15	03/24/15	100%
48	1.1.1.12. Pin 2	03/24/15	03/24/15	100%
49	1.1.1.12.1. Physical Measuring	03/24/15	03/24/15	100%
50	1.1.1.12.1.1. Sample Acquisition	03/24/15	03/24/15	100%
51	1.1.1.12.1.1.1. Data Display	03/24/15	03/24/15	100%
52	1.1.1.13. Pin 3	03/24/15	03/24/15	100%
53	1.1.1.13.1. Physical Measuring	03/24/15	03/24/15	100%
54	1.1.1.13.1.1. Sample Acquisition	03/24/15	03/24/15	100%
55	1.1.1.13.1.1.1. Data Display	03/24/15	03/24/15	100%
56	1.1.1.14. Square Key	03/24/15	03/24/15	100%
57	1.1.1.14.1. Physical Measuring	03/24/15	03/24/15	100%
58	1.1.1.14.1.1. Sample Acquisition	03/24/15	03/24/15	100%
59	1.1.1.14.1.1.1. Data Display	03/24/15	03/24/15	100%
60	1.1.1.15. Rubber Foot	03/24/15	03/24/15	100%
61	1.1.1.15.1. Physical Measuring	03/24/15	03/24/15	100%
62	1.1.1.15.1.1. Sample Acquisition	03/24/15	03/24/15	100%
63	1.1.1.15.1.1.1. Data Display	03/24/15	03/24/15	100%
64	1.1.1.16. Delrin End Bushings	02/24/15	02/24/15	100%
65	1.1.1.15.1. Physical Measuring	02/24/15	02/24/15	100%
66	1.1.1.15.1.1. Sample Acquisition	02/24/15	02/24/15	100%
67	1.1.1.15.1.1.1. Data Display	02/24/15	02/24/15	100%
68	1.1.1.16. Bronze Sleeve Bushings	02/24/15	02/24/15	100%
69	1.1.1.15.1. Physical Measuring	02/24/15	02/24/15	100%
70	1.1.1.15.1.1. Sample Acquisition	02/24/15	02/24/15	100%
71	1.1.1.15.1.1.1. Data Display	02/24/15	02/24/15	100%
72	1.2. Electrical Components	03/25/15	03/25/15	100%
73	1.2.1. Measuring of Electrical Components' Capacity	03/25/15	03/25/15	100%
74	1.2.1.1. Capacitor	03/25/15	03/25/15	100%
75	1.2.1.1.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
76	1.2.1.1.1.1. Sample Acquisition	03/25/15	03/25/15	100%
77	1.2.1.1.1.1.1. Data Display	03/25/15	03/25/15	100%
78	1.2.1.2. Resistors	03/25/15	03/25/15	100%
79	1.2.1.2.1. Measuring of Component Capacity	03/25/15	03/25/15	100%

	Task Name	Start Date	End Date	Progress
80	1.2.1.2.1.1. Sample Acquisition	03/25/15	03/25/15	100%
81	1.2.1.2.1.1.1. Data Display	03/25/15	03/25/15	100%
82	1.2.1.3. Op Amp	03/25/15	03/25/15	100%
83	1.2.1.3.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
84	1.2.1.3.1.1. Sample Acquisition	03/25/15	03/25/15	100%
85	1.2.1.3.1.1.1. Data Display	03/25/15	03/25/15	100%
86	1.2.1.4. Strain Gage	03/25/15	03/25/15	100%
87	1.2.1.4.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
88	1.2.1.4.1.1. Sample Acquisition	03/25/15	03/25/15	100%
89	1.2.1.4.1.1.1. Data Display	03/25/15	03/25/15	100%
90	1.2.1.5. Wire Leads	03/25/15	03/25/15	100%
91	1.2.1.5.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
92	1.2.1.5.1.1. Sample Acquisition	03/25/15	03/25/15	100%
93	1.2.1.5.1.1.1. Data Display	03/25/15	03/25/15	100%
94	1.2.1.6. Force Sensing Resistor	03/25/15	03/25/15	100%
95	1.2.1.6.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
96	1.2.1.6.1.1. Sample Acquisition	03/25/15	03/25/15	100%
97	1.2.1.6.1.1.1. Data Display	03/25/15	03/25/15	100%
98	1.2.1.6.2. Calibrate Force Sensing Sensor	03/25/15	03/25/15	100%
99	1.2.1.6.2.1. Trials	03/25/15	03/25/15	100%
100	1.2.1.6.2.1.1. Sample Acquisition	03/25/15	03/25/15	100%
101	1.2.1.6.2.1.1.1. Data Conversion	03/25/15	03/25/15	100%
102	1.2.1.6.2.1.1.1.1. Data Display	03/25/15	03/25/15	100%
103	1.2.1.7. Robotis OpenCM 9.04C	03/25/15	03/25/15	100%
104	1.2.1.7.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
105	1.2.1.7.1.1. Sample Acquisition	03/25/15	03/25/15	100%
106	1.2.1.7.1.1.1. Data Display	03/25/15	03/25/15	100%
107	1.2.1.8. Robotis OpenCM 485 EXP	03/25/15	03/25/15	100%
108	1.2.1.8.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
109	1.2.1.8.1.1. Sample Acquisition	03/25/15	03/25/15	100%
110	1.2.1.8.1.1.1. Data Display	03/25/15	03/25/15	100%
111	1.2.1.9. Dynamixel MX 64 AR	03/25/15	03/25/15	100%
112	1.2.1.9.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
113	1.2.1.9.1.1. Sample Acquisition	03/25/15	03/25/15	100%
114	1.2.1.9.1.1.1. Data Display	03/25/15	03/25/15	100%
115	1.2.1.10. Dynamixel MX 106 R	03/25/15	03/25/15	100%
116	1.2.1.10.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
117	1.2.1.10.1.1. Sample Acquisition	03/25/15	03/25/15	100%
118	1.2.1.10.1.1.1. Data Display	03/25/15	03/25/15	100%
119	1.2.1.11. 4 Pin Connectors	03/25/15	03/25/15	100%
120	1.2.1.11.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
121	1.2.1.11.1.1. Sample Acquisition	03/25/15	03/25/15	100%
122	1.2.1.11.1.1.1. Data Display	03/25/15	03/25/15	100%
123	1.2.1.12. Breadboard	03/25/15	03/25/15	100%
124	1.2.1.12.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
125	1.2.1.12.1.1. Sample Acquisition	03/25/15	03/25/15	100%
126	1.2.1.12.1.1.1. Data Display	03/25/15	03/25/15	100%
127	1.2.1.13. Testing Fixture Case	03/25/15	03/25/15	100%
128	1.2.1.13.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
129	1.2.1.13.1.1. Sample Acquisition	03/25/15	03/25/15	100%
130	1.2.1.13.1.1.1. Data Display	03/25/15	03/25/15	100%
131	1.2.1.14. NImyRio	03/25/15	03/25/15	100%
132	1.2.1.14.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
133	1.2.1.14.1.1. Sample Acquisition	03/25/15	03/25/15	100%
134	1.2.1.14.1.1.1. Data Display	03/25/15	03/25/15	100%
135	1.2.1.15. Voltage Regulator	03/25/15	03/25/15	100%
136	1.2.1.15.1. Measuring of Component Capacity	03/25/15	03/25/15	100%
137	1.2.1.15.1.1. Sample Acquisition	03/25/15	03/25/15	100%
138	1.2.1.15.1.1.1. Data Display	03/25/15	03/25/15	100%
139	1.3. Testing of Raw Materials	03/25/15	03/25/15	100%
140	1.3.1. Testing of Aluminum 7075-T6	03/25/15	03/25/15	100%
141	1.3.1.1. Material Composition Testing	03/25/15	03/25/15	100%
142	1.3.1.1.1. Sample Acquisition	03/25/15	03/25/15	100%
143	1.3.1.1.1.1. Data Display	03/25/15	03/25/15	100%
144	1.3.2. Testing of Aluminum 6065-T6	03/25/15	03/25/15	100%
145	1.3.2.1. Material Composition Testing	03/25/15	03/25/15	100%
146	1.3.2.1.1. Sample Acquisition	03/25/15	03/25/15	100%
147	1.3.2.1.1.1. Data Display	03/25/15	03/25/15	100%
148	2. PRODUCT TESTING	03/27/15	04/05/15	100%
149	2.1. Leg Movement	03/27/15	03/29/15	100%
150	2.1.1. Retraction of Leg	03/27/15	03/28/15	100%
151	2.1.1.1. Test Motors' Internal Encoders	03/27/15	03/28/15	100%
152	2.1.1.1.1. Trials	03/27/15	03/28/15	100%
153	2.1.1.1.1.1. Trial 1	03/27/15	03/27/15	100%
154	2.1.1.1.1.2. Trial 2	03/27/15	03/27/15	100%
155	2.1.1.1.1.3. Trial 3	03/28/15	03/28/15	100%
156	2.1.1.1.2. Sample Acquisition	03/28/15	03/28/15	100%
157	2.1.1.1.2.1. Data Conversion	03/28/15	03/28/15	100%
158	2.1.1.1.2.1.1. Data Display	03/28/15	03/28/15	100%

	Task Name	Start Date	End Date	
159	2.1.1.2. Extra Encoder	03/27/15	03/28/15	100%
160	2.1.1.2.1. Trials	03/27/15	03/28/15	100%
161	2.1.1.2.1.1. Trial 1	03/27/15	03/27/15	100%
162	2.1.1.2.1.2. Trial 2	03/27/15	03/27/15	100%
163	2.1.1.2.1.3. Trial 3	03/28/15	03/28/15	100%
164	2.1.1.2.2. Sample Acquisition	03/28/15	03/28/15	100%
165	2.1.1.2.2.1. Data Conversion	03/28/15	03/28/15	100%
166	2.1.1.2.2.1.1. Data Display	03/28/15	03/28/15	100%
167	2.1.2. Leg Swinging	03/28/15	03/29/15	100%
168	2.1.2.1. Swing Leg on Fixture	03/28/15	03/29/15	100%
169	2.1.2.1.1. Test Motors' Internal Encoders	03/28/15	03/28/15	100%
170	2.1.2.1.1.1. Trials	03/28/15	03/28/15	100%
171	2.1.2.1.1.1.1. Trial 1	03/28/15	03/28/15	100%
172	2.1.2.1.1.1.2. Trial 2	03/28/15	03/28/15	100%
173	2.1.2.1.1.1.3. Trial 3	03/28/15	03/28/15	100%
174	2.1.2.1.1.2. Sample Acquisition	03/28/15	03/28/15	100%
175	2.1.2.1.1.2.1. Data Conversion	03/28/15	03/28/15	100%
176	2.1.2.1.1.2.1.1. Data Display	03/28/15	03/28/15	100%
177	2.1.2.1.2. Extra Encoder	03/29/15	03/29/15	100%
178	2.1.2.1.2.1. Trials	03/29/15	03/29/15	100%
179	2.1.2.1.2.1.1. Trial 1	03/29/15	03/29/15	100%
180	2.1.2.1.2.1.2. Trial 2	03/29/15	03/29/15	100%
181	2.1.2.1.2.1.3. Trial 3	03/29/15	03/29/15	100%
182	2.1.2.1.2.2. Sample Acquisition	03/29/15	03/29/15	100%
183	2.1.2.1.2.2.1. Data Conversion	03/29/15	03/29/15	100%
184	2.1.2.1.2.2.1.1. Data Display	03/29/15	03/29/15	100%
185	2.2. Control System	03/29/15	03/29/15	100%
186	2.2.1. Test Mechanic Control System (Stoppers)	03/29/15	03/29/15	100%
187	2.2.1.1. Trials	03/29/15	03/29/15	100%
188	2.2.1.1.1. Trial 1	03/29/15	03/29/15	100%
189	2.2.1.1.2. Trial 2	03/29/15	03/29/15	100%
190	2.2.1.1.3. Trial 3	03/29/15	03/29/15	100%
191	2.2.1.2. Sample Acquisition	03/29/15	03/29/15	100%
192	2.2.1.2.1. Data Conversion	03/29/15	03/29/15	100%
193	2.2.1.2.1.1. Data Display	03/29/15	03/29/15	100%
194	2.3. Complete Leg Testing	03/30/15	04/05/15	100%
195	2.3.1. Swing and Retract Leg Simultaneously	03/30/15	03/30/15	100%
196	2.3.1.1. Trials	03/30/15	03/30/15	100%
197	2.3.1.1.1. Trial 1	03/30/15	03/30/15	100%
198	2.3.1.1.2. Trial 2	03/30/15	03/30/15	100%
199	2.3.1.1.3. Trial 3	03/30/15	03/30/15	100%
200	2.3.1.1.4. Trial 4	03/30/15	03/30/15	100%
201	2.3.1.1.5. Trial 5	03/30/15	03/30/15	100%
202	2.3.1.1.6. Trial 6	03/30/15	03/30/15	100%
203	2.3.1.1.7. Trial 7	03/30/15	03/30/15	100%
204	2.3.1.1.8. Trial 8	03/30/15	03/30/15	100%
205	2.3.1.1.9. Trial 9	03/30/15	03/30/15	100%
206	2.3.1.1.10. Trial 10	03/30/15	03/30/15	100%
207	2.3.1.2. Sample Acquisition	03/30/15	03/30/15	100%
208	2.3.1.2.1. Data Conversion	03/30/15	03/30/15	100%
209	2.3.1.2.1.1. Data Display	03/30/15	03/30/15	100%
210	2.3.2. Leg Hopping	03/31/15	04/05/15	100%
211	2.3.2.1. Hopping with 0 kg Load	03/31/15	03/31/15	100%
212	2.3.2.1.1. Trials	03/31/15	03/31/15	100%
213	2.3.2.1.1.1. Trial 1	03/31/15	03/31/15	100%
214	2.3.2.1.1.2. Trial 2	03/31/15	03/31/15	100%
215	2.3.2.1.1.3. Trial 3	03/31/15	03/31/15	100%
216	2.3.2.1.1.4. Trial 4	03/31/15	03/31/15	100%
217	2.3.2.1.1.5. Trial 5	03/31/15	03/31/15	100%
218	2.3.2.1.1.6. Trial 6	03/31/15	03/31/15	100%
219	2.3.2.1.1.7. Trial 7	03/31/15	03/31/15	100%
220	2.3.2.1.1.8. Trial 8	03/31/15	03/31/15	100%
221	2.3.2.1.1.9. Trial 9	03/31/15	03/31/15	100%
222	2.3.2.1.1.10. Trial 10	03/31/15	03/31/15	100%
223	2.3.2.1.2. Sample Acquisition	03/31/15	03/31/15	100%
224	2.3.2.1.2.1. Data Conversion	03/31/15	03/31/15	100%
225	2.3.2.1.2.1.1. Data Display	03/31/15	03/31/15	100%
226	2.3.2.2. Hopping with 1 kg Load	04/01/15	04/02/15	100%
227	2.3.2.2.1. Trials	04/01/15	04/01/15	100%
228	2.3.2.2.1.1. Trial 1	04/01/15	04/01/15	100%
229	2.3.2.2.1.2. Trial 2	04/01/15	04/01/15	100%
230	2.3.2.2.1.3. Trial 3	04/01/15	04/01/15	100%
231	2.3.2.2.1.4. Trial 4	04/01/15	04/01/15	100%
232	2.3.2.2.1.5. Trial 5	04/01/15	04/01/15	100%
233	2.3.2.2.1.6. Trial 6	04/01/15	04/01/15	100%
234	2.3.2.2.1.7. Trial 7	04/01/15	04/01/15	100%
235	2.3.2.2.1.8. Trial 8	04/01/15	04/01/15	100%
236	2.3.2.2.1.9. Trial 9	04/01/15	04/01/15	100%
237	2.3.2.2.1.10. Trial 10	04/01/15	04/01/15	100%

	Task Name	Start Date	End Date	Feb				Mar					Apr			
				Feb 1	Feb 8	Feb 15	Feb 22	Mar 1	Mar 8	Mar 15	Mar 22	Mar 29	Apr 5	Apr 12	Apr 19	Apr 26
238	2.3.2.2.2. Sample Acquisition	04/02/15	04/02/15									100%				
239	2.3.2.2.2.1. Data Conversion	04/02/15	04/02/15									100%				
240	2.3.2.2.2.1.1. Data Display	04/02/15	04/02/15									100%				
241	2.3.2.3. Hopping with 2 kg Load	04/02/15	04/03/15									100%				
242	2.3.2.3.1. Trials	04/02/15	04/03/15									100%				
243	2.3.2.3.1.1. Trial 1	04/02/15	04/02/15									100%				
244	2.3.2.3.1.2. Trial 2	04/02/15	04/02/15									100%				
245	2.3.2.3.1.3. Trial 3	04/02/15	04/02/15									100%				
246	2.3.2.3.1.4. Trial 4	04/02/15	04/02/15									100%				
247	2.3.2.3.1.5. Trial 5	04/02/15	04/02/15									100%				
248	2.3.2.3.1.6. Trial 6	04/02/15	04/02/15									100%				
249	2.3.2.3.1.7. Trial 7	04/03/15	04/03/15									100%				
250	2.3.2.3.1.8. Trial 8	04/03/15	04/03/15									100%				
251	2.3.2.3.1.9. Trial 9	04/03/15	04/03/15									100%				
252	2.3.2.3.1.10. Trial 10	04/03/15	04/03/15									100%				
253	2.3.2.3.2. Sample Acquisition	04/03/15	04/03/15									100%				
254	2.3.2.3.2.1. Data Conversion	04/03/15	04/03/15									100%				
255	2.3.2.3.2.1.1. Data Display	04/03/15	04/03/15									100%				
256	2.3.2.4. Hopping with 3 kg Load	04/04/15	04/05/15										100%			
257	2.3.2.4.1. Trials	04/04/15	04/05/15										100%			
258	2.3.2.4.1.1. Trial 1	04/04/15	04/04/15										100%			
259	2.3.2.4.1.2. Trial 2	04/04/15	04/04/15										100%			
260	2.3.2.4.1.3. Trial 3	04/04/15	04/04/15										100%			
261	2.3.2.4.1.4. Trial 4	04/04/15	04/04/15										100%			
262	2.3.2.4.1.5. Trial 5	04/04/15	04/04/15										100%			
263	2.3.2.4.1.6. Trial 6	04/04/15	04/04/15										100%			
264	2.3.2.4.1.7. Trial 7	04/04/15	04/04/15										100%			
265	2.3.2.4.1.8. Trial 8	04/05/15	04/05/15										100%			
266	2.3.2.4.1.9. Trial 9	04/05/15	04/05/15										100%			
267	2.3.2.4.1.10. Trial 10	04/05/15	04/05/15										100%			
268	2.3.2.4.2. Sample Acquisition	04/05/15	04/05/15										100%			
269	2.3.2.4.2.1. Data Conversion	04/05/15	04/05/15										100%			
270	2.3.2.4.2.1.1. Data Display	04/05/15	04/05/15										100%			
271	3. ANALYSIS OF RESULTS	04/06/15	04/06/15										100%			
272	3.1. Data Handling	04/06/15	04/06/15										100%			
273	3.1.1. Calculation of Arithmetic Mean	04/06/15	04/06/15										100%			
274	3.1.1.1. Comparison Between Results and Range Provided	04/06/15	04/06/15										100%			

Appendix D: WBS and Main Deliverables

List of Figures

Appendix D: WBS and Main Deliverables

	Task Name	Start Date	End Date	Duration	Progress
1	1. CONCEPTUAL DESIGN	09/24/14	11/07/14	33	100%
2	1.1. Design Specifications	09/24/14	10/10/14	13	100%
3	1.1.1. Functional	10/01/14	10/10/14	8	100%
4	1.1.2. Physical	09/24/14	09/30/14	5	100%
5	1.2. Mechanisms	09/24/14	10/03/14	8	100%
6	1.2.1. Foot Clearance	09/24/14	10/03/14	8	100%
7	1.2.2. Leg Swinging	09/29/14	10/03/14	5	100%
8	1.3. Aesthetics	09/24/14	10/03/14	8	100%
9	1.3.1. Materials	09/24/14	09/30/14	5	100%
10	1.3.2. Shape	09/30/14	10/03/14	4	100%
11	1.4. Testing Fixture	10/30/14	11/07/14	7	100%
12	1.4.1. Functional Design Encompassing Tests	10/30/14	11/07/14	7	100%
13	2. ANALYSIS	10/03/14	12/01/14	42	100%
14	2.1. Simple Preliminary Analysis	10/03/14	10/16/14	10	100%
15	2.1.1. Free Body Diagram	10/03/14	10/09/14	5	100%
16	2.1.2. Static Analysis	10/08/14	10/13/14	4	100%
17	2.1.3. Dynamic Analysis	10/15/14	10/16/14	2	100%
18	2.2. Link Position Analysis	10/30/14	11/06/14	6	100%
19	2.2.1. Denavit-Hartenberg Analysis	10/30/14	11/05/14	5	100%
20	2.2.2. Jacobian Derivation Analysis	10/30/14	11/05/14	5	100%
21	2.2.3. Euler-Lagrange Analysis	10/30/14	11/06/14	6	100%
22	2.3. Motor Selection Analysis	10/16/14	10/27/14	8	100%
23	2.3.1. Calculate Required Torque Analysis	10/16/14	10/20/14	3	100%
24	2.3.2. Select Motor from Recommended MX Series Motors Analysis	10/17/14	10/27/14	7	100%
25	2.4. Material Selection Analysis	10/28/14	11/20/14	18	100%
26	2.4.1. Recommended Metals Analysis	10/28/14	10/29/14	2	100%
27	2.4.1.1. Aluminum Selection	10/28/14	10/28/14	1	100%
28	2.4.1.2. Grade Number, Temper Grade Number and Machining Finish	10/28/14	10/28/14	1	100%
29	2.4.1.3. Aluminum Cost	10/28/14	10/29/14	2	100%
30	2.4.2. Rubber Selection Analysis	10/28/14	10/30/14	3	100%
31	2.4.3. Aesthetic Components Analysis	10/28/14	11/20/14	18	100%
32	2.5. Single Board Micro-controller Selection Analysis	11/13/14	11/28/14	12	100%
33	2.6. Cost Analysis	10/31/14	12/01/14	22	100%
34	2.6.1. Testing Fixture Analysis	10/31/14	12/01/14	22	100%
35	2.6.1.1.Static Analysis	10/31/14	11/03/14	2	100%
36	2.6.1.2. Bending Analysis (Axial and Torsional)	11/24/14	12/01/14	6	100%
37	2.6.1.3. Dynamic Analysis	11/19/14	11/28/14	8	100%
38	3. PRELIMINARY DRAWING DEVELOPMENT	10/17/14	11/28/14	31	100%
39	3.1. 3-D Preliminary Leg Design	10/17/14	10/28/14	8	100%
40	3.1.1. Exploded View	10/17/14	10/21/14	3	100%
41	3.1.2. Motion Analysis	10/22/14	10/28/14	5	100%
42	3.1.3. Static Loads Analysis	10/22/14	10/22/14	1	100%
43	3.2. Material Selection from Analysis	10/27/14	10/27/14	1	100%
44	3.3. Testing Fixture Design	11/20/14	11/28/14	7	100%
45	3.4. Assembly (Leg and Testing Fixture)	11/01/14	11/24/14	17	100%
46	3.4.1. Exploded View of Assembly	11/01/14	11/11/14	8	100%
47	3.4.2. Motion Analysis of Assembly	11/11/14	11/17/14	5	100%
48	3.4.3. Static Load Analysis of Assembly	11/18/14	11/24/14	5	100%
49	4. CIRCUITRY	11/11/14	12/10/14	22	100%
50	4.1. Sensor Selection	11/21/14	11/28/14	6	100%
51	4.2. Circuit Schematic	11/11/14	11/28/14	14	100%
52	4.2.1. Motor Circuits	11/13/14	11/27/14	11	100%
53	4.2.2. Sensor Circuits	11/11/14	11/28/14	14	100%
54	4.3. Integrate Circuitry into 3-D Drawing	11/20/14	12/10/14	15	100%
55	5. FINAL DRAWING PACKAGE	11/20/14	02/06/15	57	100%
56	5.1. Final Leg Drawing	11/20/14	01/15/15	41	100%
57	5.1.1. Final Leg Drawing and Dimensions	11/20/14	12/05/14	12	100%
58	5.1.2. Final Circuit Schematics	11/23/14	12/08/14	12	100%
59	5.1.3. Final Circuit Assembly Directions	12/01/14	12/10/14	8	100%
60	5.1.4. Final Machining Directions	11/30/14	12/05/14	6	100%

	Task Name	Start Date	End Date	Duration	Q3–Q2 (Jul–Jun)
61	5.1.5. Final Leg Assembly Directions	12/01/14	01/15/15	34	100%
62	5.2. Final Test Fixture Drawing	12/10/14	02/06/15	43	100%
63	5.2.1. Final Test Fixture Drawing and Dimensions	12/10/14	01/26/15	34	100%
64	5.2.2. Final Test Fixture Circuit Schematics	12/20/14	01/29/15	30	100%
65	5.2.3. Final Test Test Fixture Circuit Assembly Directions	01/07/15	01/23/15	13	100%
66	5.2.4. Final Test Fixture Machining Directions	01/13/15	01/30/15	14	100%
67	5.2.5. Final Test Fixture Assembly Directions	01/20/15	02/06/15	14	100%
68	6. COST ANALYSIS	10/20/14	02/27/15	95	100%
69	6.1. Man-Hour Costs	10/26/14	01/30/15	71	100%
70	6.1.1. Team Costs	10/26/14	01/30/15	71	100%
71	6.1.1.1. Engineering Costs	10/28/14	01/01/15	48	100%
72	6.1.1.2. Secretary Costs	10/27/14	01/30/15	70	100%
73	6.1.1.3. Technician Costs	10/26/14	01/30/15	71	100%
74	6.2. Machining Costs	10/26/14	02/27/15	91	100%
75	6.2.1. Raw Parts Costs	10/26/14	02/10/15	78	100%
76	6.2.1.1. Metals	10/26/14	02/09/15	77	100%
77	6.2.1.1.1. Slider Crank Mechanism	10/26/14	01/30/15	71	100%
78	6.2.1.1.2. Leg Shank	10/26/14	01/30/15	71	100%
79	6.2.1.1.3. Leg Cover	10/26/14	02/03/15	73	100%
80	6.2.1.1.4. Pins	10/27/14	02/09/15	76	100%
81	6.2.1.2. Rubber (EPDM)	10/26/14	02/10/15	78	100%
82	6.2.2. Machining Hours (Machine Shop)	10/28/14	02/27/15	89	100%
83	6.2.2.1. Slider Crank Mechanism	10/28/14	02/27/15	89	100%
84	6.2.2.2. Leg Shank	10/28/14	02/27/15	89	100%
85	6.2.2.3. Leg Cover	10/28/14	02/27/15	89	100%
86	6.2.3. Rubber Foot	10/27/14	02/20/15	85	100%
87	6.2.3.1. Testing Foot	10/28/14	02/17/15	81	100%
88	6.2.3.2. Final Foot	10/27/14	02/20/15	85	100%
89	6.3. Electronic Costs	10/20/14	02/27/15	95	100%
90	6.3.1. Costs of Sensors	10/20/14	02/25/15	93	100%
91	6.3.1.1. Encoder	10/20/14	02/25/15	93	100%
92	6.3.1.2. Force Sensing Resistor	10/26/14	02/20/15	86	100%
93	6.3.1.3. Timer	10/24/14	02/19/15	85	100%
94	6.3.2. Circuit Elements	10/24/14	02/27/15	91	100%
95	6.3.2.1. Resistors	10/26/14	02/25/15	89	100%
96	6.3.2.2. Transistors	10/24/14	02/27/15	91	100%
97	6.3.2.3. Operational Amplifiers (Op-Amps)	10/26/14	02/27/15	91	100%
98	6.3.2.4. Capacitors	10/24/14	02/17/15	83	100%
99	6.3.2.5. Wire Leads	10/27/14	02/27/15	90	100%
100	6.3.2.6. Inductor	10/24/14	02/20/15	86	100%
101	6.3.3. Motors	10/24/14	02/20/15	86	100%
102	6.3.3.1. Servos	10/24/14	02/20/15	86	100%
103	7. CONTROL SYSTEMS ANALYSIS	01/14/15	02/27/15	33	100%
104	7.1. Motor Manipulation	01/14/15	02/27/15	33	100%
105	7.1.1. Input and Output Torque	01/14/15	01/30/15	13	100%
106	7.1.2. Input and Output Velocity	02/01/15	02/20/15	16	100%
107	7.1.3. Input and Output Position	02/09/15	02/25/15	13	100%
108	7.1.4. Input and Output Current	02/08/15	02/27/15	16	100%
109	7.1.5. Input and Output Voltage	02/06/15	02/27/15	16	100%
110	7.2. Sensor Data	02/02/15	02/27/15	20	100%
111	7.2.1. Define Samples	02/02/15	02/27/15	20	100%
112	7.3. Mechanical Control Systems	01/15/15	02/27/15	32	100%
113	7.3.1. Calculation and Measurement of Physical Characteristics	02/04/15	02/27/15	18	100%
114	7.3.2. Turning of Physical Characteristics	01/15/15	02/27/15	32	100%
115	7.3.2.1. Proportional, Integral and Derivative Control (PID)	01/15/15	02/27/15	32	100%
116	7.4. Control System to Simulate Walking	02/04/15	02/27/15	18	100%
117	7.5. User Interface	02/04/15	02/27/15	18	100%
118	7.5.1. Create User Interface	02/04/15	02/27/15	18	100%
119	7.5.2. Debug User Interface	02/04/15	02/27/15	18	100%

	Task Name	Start Date	End Date	Duration	
120	8. PRODUCT FABRICATIONS	01/12/15	03/02/15	36	100%
121	8.1. Slider Crank Mechanisms Driver (4)	02/06/15	02/27/15	16	100%
122	8.1.1. Order Raw Materials	02/06/15	02/20/15	11	100%
123	8.1.2. Send to Machining	02/22/15	02/27/15	6	100%
124	8.2. Leg Shank (2)	02/01/15	02/09/15	7	100%
125	8.2.1. Order Raw Materials	02/01/15	02/05/15	5	100%
126	8.2.2. Send to Machining	02/06/15	02/09/15	2	100%
127	8.3. Leg (2)	02/10/15	02/17/15	6	100%
128	8.3.1. Order Raw Materials	02/10/15	02/12/15	3	100%
129	8.3.2. Send to Machining	02/13/15	02/17/15	3	100%
130	8.4. Rubber Foot (2)	02/10/15	03/02/15	15	100%
131	8.4.1. Order Raw Materials	02/10/15	02/25/15	12	100%
132	8.4.2. Set/Fix Rubber Foot to Shank	02/22/15	03/02/15	7	100%
133	8.5. Pins (4)	02/11/15	02/27/15	13	100%
134	8.5.1. Order Raw Materials	02/11/15	02/19/15	7	100%
135	8.5.2. Send to Machining	02/25/15	02/27/15	3	100%
136	8.6. 3D Printed Prototype	01/12/15	01/16/15	5	100%
137	9. OUTSOURCED PRODUCTS	01/07/15	02/27/15	38	100%
138	9.1. Motors	01/07/15	01/30/15	18	100%
139	9.1.1. Dynamixel MX-Series	01/07/15	01/30/15	18	100%
140	9.2. Single Board Micro Controller Unit	01/31/15	02/06/15	6	100%
141	9.3. Circuitry	01/30/15	02/25/15	19	100%
142	9.3.1. Wire Leads	01/30/15	02/18/15	14	100%
143	9.3.2. Transistors	02/22/15	02/25/15	4	100%
144	9.3.3. Resistors	02/19/15	02/24/15	4	100%
145	9.3.4. Capacitors	02/15/15	02/18/15	4	100%
146	9.3.5. Inductors	02/17/15	02/20/15	4	100%
147	9.4. Sensors	02/10/15	02/27/15	14	100%
148	9.4.1. Encoder	02/22/15	02/24/15	3	100%
149	9.4.2. Strain Gage	02/22/15	02/26/15	5	100%
150	9.4.3. Force Sensing Resistor	02/22/15	02/27/15	6	100%
151	9.4.4. Timer	02/10/15	02/18/15	7	100%
152	10. PRODUCT ASSEMBLY	02/12/15	03/10/15	19	100%
153	10.1. Leg Assembly	02/12/15	03/10/15	19	100%
154	10.1.1. Assemble Slider Crank Mechanism	02/12/15	03/04/15	15	100%
155	10.1.2. Assemble Foot and Leg Shank	02/25/15	03/05/15	7	100%
156	10.1.3. Assemble Leg Cover	02/25/15	03/06/15	8	100%
157	10.1.4. Assemble Circuitry to Leg	02/19/15	03/10/15	14	100%
158	10.1.4.1. Strain Gauge	03/01/15	03/10/15	8	100%
159	10.1.4.2. Encoder	03/03/15	03/10/15	6	100%
160	10.1.4.3. Strain Gage	03/04/15	03/04/15	1	100%
161	10.1.4.4. Force Sensing Resistor	03/04/15	03/09/15	4	100%
162	10.1.4.5. Timer	02/19/15	03/10/15	14	100%
163	10.1.5. Attach Motors to Leg	03/01/15	03/09/15	7	100%
164	10.2. Testing Fixture Assembly	02/23/15	03/06/15	10	100%
165	10.2.1. Assemble Testing Fixture	02/23/15	03/06/15	10	100%
166	10.2.2. Attach Sensors to Fixture	02/25/15	03/05/15	7	100%
167	10.2.3. Attach Circuitry to Fixture	02/27/15	03/04/15	4	100%
168	10.3. Complete Assembly	03/01/15	03/05/15	5	100%
169	10.3.1. Combine Leg and Fixture Assemblies	03/01/15	03/05/15	5	100%
170	11. PRELIMINARY COMPONENT TESTING	03/11/15	03/13/15	3	100%
171	11.1. Mechanical Components	03/11/15	03/13/15	3	100%
172	11.1.1. Physical Measuring of Components' Dimensions	03/11/15	03/13/15	3	100%
173	11.1.1.1. Slider Crank	03/11/15	03/13/15	3	100%
174	11.1.1.1.1. Physical Measuring	03/11/15	03/13/15	3	100%
175	11.1.1.1.1.1. Sample Acquisition	03/11/15	03/13/15	3	100%
176	11.1.1.1.1.1.1. Data Display	03/11/15	03/13/15	3	100%
177	11.1.1.2. Follower Link	03/11/15	03/13/15	3	100%
178	11.1.1.2.1. Physical Measuring	03/11/15	03/13/15	3	100%
179	11.1.1.2.1.1. Sample Acquisition	03/11/15	03/13/15	3	100%
180	11.1.1.2.1.1.1. Data Display	03/11/15	03/13/15	3	100%

	Task Name	Start Date	End Date	Duration	Q3			Q4			Q1			Q2		
					Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
181	11.1.1.3. Leg Shank	03/11/15	03/13/15	3									100%			
182	11.1.1.3.1. Physical Measuring	03/11/15	03/13/15	3									100%			
183	11.1.1.3.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
184	11.1.1.3.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
185	11.1.1.4. Leg Cover	03/11/15	03/13/15	3									100%			
186	11.1.1.4.1. Physical Measuring	03/11/15	03/13/15	3									100%			
187	11.1.1.4.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
188	11.1.1.4.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
189	11.1.1.5. Leg Foot	03/11/15	03/13/15	3									100%			
190	11.1.1.5.1. Physical Measuring	03/11/15	03/13/15	3									100%			
191	11.1.1.5.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
192	11.1.1.5.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
193	11.1.1.6. Stopper 1	03/11/15	03/13/15	3									100%			
194	11.1.1.6.1. Physical Measuring	03/11/15	03/13/15	3									100%			
195	11.1.1.6.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
196	11.1.1.6.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
197	11.1.1.7. Stopper 2	03/11/15	03/13/15	3									100%			
198	11.1.1.7.1. Physical Measuring	03/11/15	03/13/15	3									100%			
199	11.1.1.7.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
200	11.1.1.7.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
201	11.1.1.8. Flywheel Adaptor Pin	03/11/15	03/13/15	3									100%			
202	11.1.1.8.1. Physical Measuring	03/11/15	03/13/15	3									100%			
203	11.1.1.8.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
204	11.1.1.8.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
205	11.1.1.9. Motor Mount	03/11/15	03/13/15	3									100%			
206	11.1.1.9.1. Physical Measuring	03/11/15	03/13/15	3									100%			
207	11.1.1.9.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
208	11.1.1.9.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
209	11.1.1.10. Motor Pin Mount	03/11/15	03/13/15	3									100%			
210	11.1.1.10.1. Physical Measuring	03/11/15	03/13/15	3									100%			
211	11.1.1.10.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
212	11.1.1.10.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
213	11.1.1.11. Pin 1	03/11/15	03/13/15	3									100%			
214	11.1.1.11.1. Physical Measuring	03/11/15	03/13/15	3									100%			
215	11.1.1.11.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
216	11.1.1.11.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
217	11.1.1.12. Pin 2	03/11/15	03/13/15	3									100%			
218	11.1.1.12.1. Physical Measuring	03/11/15	03/13/15	3									100%			
219	11.1.1.12.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
220	11.1.1.12.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
221	11.1.1.13. Pin 3	03/11/15	03/13/15	3									100%			
222	11.1.1.13.1. Physical Measuring	03/11/15	03/13/15	3									100%			
223	11.1.1.13.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
224	11.1.1.13.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
225	11.1.1.14. Square Key	03/11/15	03/13/15	3									100%			
226	11.1.1.14.1. Physical Measuring	03/11/15	03/13/15	3									100%			
227	11.1.1.14.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
228	11.1.1.14.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
229	11.1.1.15. Rubber Foot	03/11/15	03/13/15	3									100%			
230	11.1.1.15.1. Physical Measuring	03/11/15	03/13/15	3									100%			
231	11.1.1.15.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
232	11.1.1.15.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
233	11.1.1.16. Delrin End Bushings	03/11/15	03/13/15	3									100%			
234	11.1.1.15.1. Physical Measuring	03/11/15	03/13/15	3									100%			
235	11.1.1.15.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
236	11.1.1.15.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
237	11.1.1.16. Bronze Sleeve Bushings	03/11/15	03/13/15	3									100%			
238	11.1.1.15.1. Physical Measuring	03/11/15	03/13/15	3									100%			
239	11.1.1.15.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
240	11.1.1.15.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
241	11.2. Electrical Components	03/11/15	03/13/15	3									100%			

	Task Name	Start Date	End Date	Duration	Q3			Q4			Q1			Q2		
					Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
242	11.2.1. Measuring of Electrical Components' Capacity	03/11/15	03/13/15	3									100%			
243	11.2.1.1. Capacitor	03/11/15	03/13/15	3									100%			
244	11.2.1.1.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
245	11.2.1.1.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
246	11.2.1.1.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
247	11.2.1.2. Resistors	03/11/15	03/13/15	3									100%			
248	11.2.1.2.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
249	11.2.1.2.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
250	11.2.1.2.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
251	11.2.1.3. Op Amp	03/11/15	03/13/15	3									100%			
252	11.2.1.3.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
253	11.2.1.3.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
254	11.2.1.3.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
255	11.2.1.4. Strain Gage	03/11/15	03/13/15	3									100%			
256	11.2.1.4.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
257	11.2.1.4.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
258	11.2.1.4.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
259	11.2.1.5. Wire Leads	03/11/15	03/13/15	3									100%			
260	11.2.1.5.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
261	11.2.1.5.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
262	11.2.1.5.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
263	11.2.1.6. Force Sensing Resistor	03/11/15	03/13/15	3									100%			
264	11.2.1.6.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
265	11.2.1.6.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
266	11.2.1.6.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
267	11.2.1.7. Robotis OpenCM 9.04C	03/11/15	03/13/15	3									100%			
268	11.2.1.7.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
269	11.2.1.7.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
270	11.2.1.7.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
271	11.2.1.8. Robotis OpenCM 485 EXP	03/11/15	03/13/15	3									100%			
272	11.2.1.8.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
273	11.2.1.8.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
274	11.2.1.8.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
275	11.2.1.9. Dynamixel MX 64 AR	03/11/15	03/13/15	3									100%			
276	11.2.1.9.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
277	11.2.1.9.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
278	11.2.1.9.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
279	11.2.1.10. Dynamixel MX 106 R	03/11/15	03/13/15	3									100%			
280	11.2.1.10.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
281	11.2.1.10.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
282	11.2.1.10.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
283	11.2.1.11. 4 Pin Connectors	03/11/15	03/13/15	3									100%			
284	11.2.1.11.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
285	11.2.1.11.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
286	11.2.1.11.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
287	11.2.1.12. Breadboard	03/11/15	03/13/15	3									100%			
288	11.2.1.12.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
289	11.2.1.12.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
290	11.2.1.12.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
291	11.2.1.13. Testing Fixture Case	03/11/15	03/13/15	3									100%			
292	11.2.1.13.1. Measuring of Component Capacity	03/11/15	03/13/15	3									100%			
293	11.2.1.13.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
294	11.2.1.13.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
295	11.3. Testing Fixture	03/11/15	03/13/15	3									100%			
296	11.3.1. Physical Measuring of Components' Dimensions	03/11/15	03/13/15	3									100%			
297	11.3.1.1. T-slots	03/11/15	03/13/15	3									100%			
298	11.3.1.1.1. Physical Measuring	03/11/15	03/13/15	3									100%			
299	11.3.1.1.1.1. Sample Acquisition	03/11/15	03/13/15	3									100%			
300	11.3.1.1.1.1.1. Data Display	03/11/15	03/13/15	3									100%			
301	12. PRODUCT TESTING	03/15/15	04/01/15	14										100%		
302	12.1. Leg Extension and Retraction	03/15/15	03/24/15	8										100%		

	Task Name	Start Date	End Date	Duration	Q3: Jul Aug Sep; Q4: Oct Nov Dec; Q1: Jan Feb Mar; Q2: Apr May Jun
303	12.1.1. Retract Leg (Slider Crank Mechanisms)	03/15/15	03/23/15	7	100%
304	12.1.1.1. Trials	03/15/15	03/23/15	7	100%
305	12.1.1.1.1. Sample Acquisition	03/15/15	03/23/15	7	100%
306	12.1.1.1.1.1. Data Conversion	03/15/15	03/23/15	7	100%
307	12.1.1.1.1.1.1. Data Display	03/15/15	03/23/15	7	100%
308	12.1.2. Test Motors' Internal Encoders	03/15/15	03/24/15	8	100%
309	12.1.2.1. Trials	03/15/15	03/24/15	8	100%
310	12.1.2.1.1. Sample Acquisition	03/15/15	03/24/15	8	100%
311	12.1.2.1.1.1. Data Conversion	03/15/15	03/24/15	8	100%
312	12.1.2.1.1.1.1. Data Display	03/15/15	03/24/15	8	100%
313	12.1.3. Measuring of Time Taken for Each Step with the High Speed Camera	03/15/15	03/24/15	8	100%
314	12.1.3.1. Trials	03/15/15	03/24/15	8	100%
315	12.1.3.1.1. Sample Acquisition	03/15/15	03/24/15	8	100%
316	12.1.3.1.1.1. Data Conversion	03/15/15	03/24/15	8	100%
317	12.1.3.1.1.1.1. Data Display	03/15/15	03/24/15	8	100%
318	12.2. Leg Swinging	03/15/15	03/27/15	11	100%
319	12.2.1. Swing Leg on Fixture	03/15/15	03/26/15	10	100%
320	12.2.1.1. Trials	03/15/15	03/26/15	10	100%
321	12.2.1.1.1. Sample Acquisition	03/15/15	03/26/15	10	100%
322	12.2.1.1.1.1. Data Conversion	03/15/15	03/26/15	10	100%
323	12.2.1.1.1.1.1. Data Display	03/15/15	03/26/15	10	100%
324	12.2.2. Test Rotational Sensor	03/15/15	03/27/15	11	100%
325	12.2.2.1. Trials	03/15/15	03/27/15	11	100%
326	12.2.2.1.1. Sample Acquisition	03/15/15	03/27/15	11	100%
327	12.2.2.1.1.1. Data Conversion	03/15/15	03/27/15	11	100%
328	12.2.2.1.1.1.1. Data Display	03/15/15	03/27/15	11	100%
329	12.2.3. Calibrate Rotational Sensor	03/15/15	03/27/15	11	100%
330	12.2.3.1. Trials	03/15/15	03/27/15	11	100%
331	12.2.3.1.1. Sample Acquisition	03/15/15	03/27/15	11	100%
332	12.2.3.1.1.1. Data Conversion	03/15/15	03/27/15	11	100%
333	12.2.3.1.1.1.1. Data Display	03/15/15	03/27/15	11	100%
334	12.3. Control System	03/15/15	03/31/15	13	100%
335	12.3.1. Test Motor Manipulation	03/15/15	03/30/15	12	100%
336	12.3.1.1. Trials	03/15/15	03/30/15	12	100%
337	12.3.1.1.1. Sample Acquisition	03/15/15	03/30/15	12	100%
338	12.3.1.1.1.1. Data Conversion	03/15/15	03/30/15	12	100%
339	12.3.1.1.1.1.1. Data Display	03/15/15	03/30/15	12	100%
340	12.3.2. Test User Interface	03/15/15	03/30/15	12	100%
341	12.3.2.1. Trials	03/15/15	03/30/15	12	100%
342	12.3.2.1.1. Sample Acquisition	03/15/15	03/30/15	12	100%
343	12.3.2.1.1.1. Data Conversion	03/15/15	03/30/15	12	100%
344	12.3.2.1.1.1.1. Data Display	03/15/15	03/30/15	12	100%
345	12.3.3. Test Mechanic Control System	03/15/15	03/31/15	13	100%
346	12.3.3.1. Trials	03/15/15	03/31/15	13	100%
347	12.3.3.1.1. Sample Acquisition	03/15/15	03/31/15	13	100%
348	12.3.3.1.1.1. Data Conversion	03/15/15	03/31/15	13	100%
349	12.3.3.1.1.1.1. Data Display	03/15/15	03/31/15	13	100%
350	12.4. Complete Leg	03/15/15	04/01/15	14	100%
351	12.4.1. Swing and Retract Leg Simultaneously	03/15/15	04/01/15	14	100%
352	12.4.1.1. Trials	03/15/15	04/01/15	14	100%
353	12.4.1.1.1. Sample Acquisition	03/15/15	04/01/15	14	100%
354	12.4.1.1.1.1. Data Conversion	03/15/15	04/01/15	14	100%
355	12.4.1.1.1.1.1. Data Display	03/15/15	04/01/15	14	100%
356	12.4.2. Hop with 3 Kg Load Applied	03/15/15	03/31/15	13	100%
357	12.4.2.1. Trials	03/15/15	03/31/15	13	100%
358	12.4.2.1.1. Sample Acquisition	03/15/15	03/31/15	13	100%
359	12.4.2.1.1.1. Data Conversion	03/15/15	03/31/15	13	100%
360	12.4.2.1.1.1.1. Data Display	03/15/15	03/31/15	13	100%
361	12.5 Sensors	03/15/15	03/31/15	13	100%
362	12.5.1. Test and Calibrate Sensors	03/15/15	03/31/15	13	100%
363	12.5.1.1. Encoder	03/15/15	03/31/15	13	100%

	Task Name	Start Date	End Date	Duration	Q3 Jul Aug Sep / Q4 Oct Nov Dec / Q1 Jan Feb Mar / Q2 Apr May Jun
364	12.5.1.1.1. Trials	03/15/15	03/31/15	13	100%
365	12.5.1.1.1.1. Sample Acquisition	03/15/15	03/31/15	13	100%
366	12.5.1.1.1.1.1. Data Conversion	03/15/15	03/31/15	13	100%
367	12.5.1.1.1.1.1.1. Data Display	03/15/15	03/31/15	13	100%
368	12.5.1.2. Strain Gage	03/15/15	03/31/15	13	100%
369	12.5.1.2.1. Trials	03/15/15	03/31/15	13	100%
370	12.5.1.2.1.1. Sample Acquisition	03/15/15	03/31/15	13	100%
371	12.5.1.2.1.1.1. Data Conversion	03/15/15	03/31/15	13	100%
372	12.5.1.2.1.1.1.1. Data Display	03/15/15	03/31/15	13	100%
373	12.5.1.3. Force Sensing Resistor	03/15/15	03/27/15	11	100%
374	12.5.1.3.1. Trials	03/15/15	03/27/15	11	100%
375	12.5.1.3.1.1. Sample Acquisition	03/15/15	03/27/15	11	100%
376	12.5.1.3.1.1.1. Data Conversion	03/15/15	03/27/15	11	100%
377	12.5.1.3.1.1.1.1. Data Display	03/15/15	03/27/15	11	100%
378	12.5.1.4. Timer	03/15/15	03/27/15	11	100%
379	12.5.1.4.1. Trials	03/15/15	03/27/15	11	100%
380	12.5.1.4.1.1. Sample Acquisition	03/15/15	03/27/15	11	100%
381	12.5.1.4.1.1.1. Data Conversion	03/15/15	03/27/15	11	100%
382	12.5.1.4.1.1.1.1. Data Display	03/15/15	03/27/15	11	100%
383	13. ANALYSIS OF RESULTS	04/01/15	04/09/15	7	100%
384	13.1. Sensor Data Handling	04/01/15	04/06/15	4	100%
385	13.1.1. Input and Output Active Filtering	04/01/15	04/01/15	1	100%
386	13.1.2. Input and Output Signal Interpretation	04/03/15	04/03/15	1	100%
387	13.1.3. Input and Output Data Storage	04/04/15	04/04/15	1	100%
388	13.1.4. Sensor Support	04/06/15	04/06/15	1	100%
389	13.2. Interpretive Functions	04/01/15	04/09/15	7	100%
390	13.2.1. Extracted Motor Signals	04/06/15	04/09/15	4	100%
391	13.2.2. Extracted Sensor Data	04/02/15	04/02/15	1	100%
392	13.2.3. Extracted Proportional, Integral and Derivative Control (PID)	04/01/15	04/01/15	1	100%
393	13.2.4. Extracted Remote Input Data	04/04/15	04/04/15	1	100%
394	14. PRODUCT MODIFICATIONS	04/08/15	04/16/15	7	100%
395	14.1. Physical Leg Component Modifications	04/09/15	04/16/15	6	100%
396	14.1.1. Modify Leg Cover (if Applicable)	04/09/15	04/13/15	3	100%
397	14.1.2. Modify Leg Shank (if Applicable)	04/10/15	04/16/15	5	100%
398	14.1.3. Modify Circuitry (if Applicable)	04/10/15	04/10/15	1	100%
399	14.1.4. Modify Sensors (if Applicable)	04/11/15	04/11/15	1	100%
400	14.2. Control System Modifications	04/10/15	04/11/15	1	100%
401	14.2.1. Implement further Proportional, Integral and Derivative Control (PID)	04/10/15	04/10/15	1	100%
402	14.2.2. Implement further Signal Filtering	04/10/15	04/10/15	1	100%
403	14.2.3. Change Motor Signals (if Applicable)	04/11/15	04/11/15	1	100%
404	14.3. Testing Fixture Modifications	04/08/15	04/12/15	3	100%
405	14.3.1. Modify Testing Fixture Dimensions (if Applicable)	04/12/15	04/12/15	1	100%
406	14.3.2. Modify Circuitry (if Applicable)	04/08/15	04/08/15	1	100%
407	14.3.3. Modify Sensors (if Applicable)	04/11/15	04/11/15	1	100%
408	15. DELIVERABLES	08/27/14	05/01/15	178	100%
409	15.1. Assignment 1	08/27/14	09/03/14	6	100%
410	15.1.1. Research of 25 Senior Design Projects	08/27/14	08/29/14	3	100%
411	15.1.2. Analysis of 2 Senior Designs Projects	08/29/14	08/29/14	1	100%
412	15.1.3. Design of 1 Unique Senior Design Project	09/01/14	09/03/14	3	100%
413	15.2. Assignment 2	08/27/14	09/08/14	9	100%
414	15.2.1. Design and Analyze English-Long Bow	08/27/14	09/08/14	9	100%
415	15.2.1.1. Static Analysis	08/27/14	08/27/14	1	100%
416	15.2.1.2. Material Analysis	08/30/14	08/30/14	1	100%
417	15.2.1.3. Dynamic Analysis	08/31/14	08/31/14	1	100%
418	15.2.1.4. Bending Analysis	09/01/14	09/03/14	3	100%
419	15.2.1.5. Cycles to Failure	09/03/14	09/08/14	4	100%
420	15.3. Assignment 3	09/03/14	09/10/14	6	100%
421	15.3.1. Deliverables Deadlines Recorded	09/03/14	09/10/14	6	100%
422	15.4. Assignment 4	09/08/14	09/15/14	6	100%

	Task Name	Start Date	End Date	Duration	Q3 Q4 Q1 Q2 (Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun)
423	15.4.1. Team Expectations and Individual Requirements	09/08/14	09/15/14	6	100%
424	15.5. Assignment 5	10/15/14	10/22/14	6	100%
425	15.5.1. Research of 10 Publications	10/15/14	10/17/14	3	100%
426	15.5.2. Research of 15 Patents Similar to Project	10/18/14	10/22/14	4	100%
427	15.6. Work Package 1	09/10/14	09/17/14	6	100%
428	15.6.1. Team Formation and Criteria for Selection	09/10/14	09/11/14	2	100%
429	15.6.2. Team Logo, Name, and Goals	09/12/14	09/12/14	1	100%
430	15.6.3. Formal Commitment to Team	09/14/14	09/15/14	2	100%
431	15.6.4. Time Commitment	09/16/14	09/17/14	2	100%
432	15.7. Work Package 2	09/17/14	09/22/14	4	100%
433	15.7.1. Identification of Design Problem, Purpose, and Objectives	09/17/14	09/19/14	3	100%
434	15.7.2. Functional Requirements and Preliminary Specifications	09/20/14	09/20/14	1	100%
435	15.7.3. Member and Member Qualifications	09/21/14	09/21/14	1	100%
436	15.7.4. Team Strength and Weaknesses	09/21/14	09/22/14	2	100%
437	15.8. Work Package 3	10/08/14	10/20/14	9	100%
438	15.8.1. Functional Requirements and Specifications	10/08/14	10/10/14	3	100%
439	15.8.2. Three Conceptual Designs	10/11/14	10/20/14	7	100%
440	15.8.2.1. Ein Conceptual Design	10/11/14	10/14/14	3	100%
441	15.8.2.1.1. Ein Strengths and Weaknesses	10/11/14	10/14/14	3	100%
442	15.8.2.2. Gilliam Conceptual Design	10/15/14	10/17/14	3	100%
443	15.8.2.1.1. Gilliam Strengths and Weaknesses	10/15/14	10/17/14	3	100%
444	15.8.2.3. Rex Conceptual Design	10/18/14	10/20/14	2	100%
445	15.8.2.3.1. Rex Strengths and Weaknesses	10/18/14	10/20/14	2	100%
446	15.9. Work Package 4	10/20/14	10/29/14	8	100%
447	15.9.1. Detailed Work Breakdown Structure (WBS)	10/20/14	10/24/14	5	100%
448	15.9.2. Detailed Cost Estimated	10/25/14	10/29/14	4	100%
449	15.10. Work Package 5	11/12/14	11/24/14	9	100%
450	15.10.1 Detailed Concept Drawings	11/12/14	11/14/14	3	100%
451	15.10.2. Description of Analytical Methods	11/15/14	11/17/14	2	100%
452	15.10.3. Analytical Results and Performance Predictions	11/18/14	11/19/14	2	100%
453	15.10.4. Discussion of Results	11/20/14	11/21/14	2	100%
454	15.10.5. Future Analysis Plans	11/22/14	11/22/14	1	100%
455	15.10.6. Revised Program Management Charts	11/23/14	11/24/14	2	100%
456	15.11. Monthly Status Report - September	09/01/14	09/30/14	22	100%
457	15.11.1. Project Purpose and Objectives	09/01/14	09/09/14	7	100%
458	15.11.2. Accomplishments Up to Date and Plans for Next Monthly Status Report	09/10/14	09/10/14	1	100%
459	15.11.3. Problems Encounter and Resolution	09/11/14	09/16/14	4	100%
460	15.11.4. Schedule	09/17/14	09/22/14	4	100%
461	15.11.5. Financial Plan	09/23/14	09/30/14	6	100%
462	15.12. Monthly Status Report - October	10/01/14	11/03/14	24	100%
463	15.12.1. Project Purpose and Objectives	10/01/14	10/10/14	8	100%
464	15.12.2. Accomplishments Since Last Monthly Status Report and Plans for Next Monthly Status Report	10/11/14	10/15/14	4	100%
465	15.12.3. Problems Encounter and Resolution	10/16/14	10/20/14	3	100%
466	15.12.4. Schedule	10/21/14	10/24/14	4	100%
467	15.12.5. Financial Plan	10/25/14	11/03/14	7	100%
468	15.13. Monthly Status Report - November	11/01/14	12/08/14	27	100%
469	15.13.1. Project Purpose and Objectives	11/01/14	11/07/14	6	100%
470	15.13.2. Accomplishments Since Last Monthly Status Report and Plans for Next Monthly Status Report	11/08/14	11/12/14	4	100%
471	15.13.3. Problems Encounter and Resolution	11/13/14	11/18/14	4	100%
472	15.13.4. Schedule	11/19/14	11/25/14	5	100%
473	15.13.5. Financial Plan	11/26/14	12/08/14	9	100%
474	15.14. December/January Progress Report	12/17/14	02/02/15	34	100%
475	15.15. February Progress Report	02/01/15	03/02/15	22	100%
476	15.16. March Progress Report	03/01/15	04/01/15	24	100%
477	15.17. April Progress Report	04/01/15	05/01/15	23	100%
478	15.18. Fabrication and Testing Status -1	02/01/15	02/17/15	13	100%

	Task Name	Start Date	End Date	Duration	
479	15.19. Fabrication and Testing Status -2	03/01/15	03/19/15	15	100%
480	15.20. Midterm Presentation SD-1	10/01/14	10/24/14	18	100%
481	15.20.1. Midterm Slides SD-1	10/01/14	10/15/14	11	100%
482	15.20.2. Midterm Backup Slides SD-1	10/16/14	10/24/14	7	100%
483	15.21. Final Presentation SD-1	11/17/14	12/01/14	11	100%
484	15.21.1. Final Slides SD-1	11/17/14	11/26/14	8	100%
485	15.21.2. Final Backup Slides SD-1	11/27/14	12/01/14	3	100%
486	15.22. Final Poster Board for Project SD-1	11/05/14	11/18/14	10	100%
487	15.23 Final Report for Project SD-1	11/17/14	12/08/14	16	100%
488	15.24. Drawing Package	01/19/15	02/03/15	12	100%
489	15.25. Testing Plan	02/01/15	02/19/15	15	100%
490	15.26. Critical Design Review	02/23/15	03/03/15	7	100%
491	15.27. Final Poster SD-2	03/30/15	04/15/15	13	100%
492	15.28. Final Presentation SD-2	04/05/15	04/24/15	16	100%
493	15.29. Final Project Review	04/12/15	04/24/15	11	100%
494	15.30. Final SD-2 Documentation	04/15/15	04/30/15	12	100%
495	15.31. Leg	04/01/15	04/30/15	22	100%
496	15.31.1. Swing Speed Meets Criteria	04/05/15	04/30/15	20	100%
497	15.31.2. Leg Can Hop with Load	04/01/15	04/30/15	22	100%
498	15.32. Testing Fixture	03/15/15	04/17/15	26	100%
499	15.32.1. Sensor Capture Accurate Data	03/15/15	04/08/15	19	100%
500	15.32.2. Fixture Facilitates Testing Requirements	04/01/15	04/17/15	13	100%

Main Deliverables WBS

	Task Name	Start Date	End Date	% Complete	Duration	
1	DELIVERABLES	08/27/14	05/01/15	100%	178	DELIVERABL
2	SD1- Assignments	08/27/14	10/22/14	100%	41	SD1- Assignments
3	Work Packages	09/10/14	09/17/14	100%	6	Work Packages
4	Work Package 2	09/17/14	09/22/14	100%	4	Work Package 2
5	Work Package 3	10/08/14	10/20/14	100%	9	Work Package 3
6	Work Package 4	10/20/14	10/29/14	100%	8	Work Package 4
7	Work Package 5	11/12/14	11/24/14	100%	9	Work Package 5
8	Monthly Status Report - September	09/01/14	09/30/14	100%	22	Monthly Status Report - September
9	Monthly Status Report - October	10/01/14	11/03/14	100%	24	Monthly Status Report - October
10	Monthly Status Report - November	10/31/14	12/08/14	100%	27	Monthly Status Report - November
11	December/January Progress Report	12/17/14	02/02/15	100%	34	December/January Progress Report
12	February Progress Report	02/01/15	03/02/15	100%	22	February Progress Report
13	March Progress Report	03/01/15	04/01/15	100%	24	March Progress Repo
14	April Progress Report	04/01/15	05/01/15	100%	23	April Progress
15	Fabrication and Testing Status -1	02/01/15	02/17/15	100%	13	Fabrication and Testing Status -1
16	Fabrication and Testing Status -2	03/01/15	03/19/15	100%	15	Fabrication and Testing S
17	Midterm Presentation SD-1	10/01/14	10/24/14	100%	18	Midterm Presentation SD-1
18	Final Presentation SD-1	11/17/14	12/01/14	100%	11	Final Presentation SD-1
19	Final Poster Board for Project SD-1	11/05/14	11/18/14	100%	10	Final Poster Board for Project SD-1
20	Final Report for Project SD-1	11/17/14	12/08/14	100%	16	Final Report for Project SD-1
21	Drawing Package	01/19/15	02/03/15	100%	12	Drawing Package
22	Testing Plan	02/01/15	02/19/15	100%	15	Testing Plan
23	Critical Design Review	02/23/15	03/03/15	100%	7	Critical Design Review
24	Final Poster SD-2	03/30/15	04/15/15	100%	13	Final Poster SD-2
25	Final Presentation SD-2	04/05/15	04/24/15	100%	16	Final Presentati
26	Final Project Review	04/12/15	04/24/15	100%	11	Final Project Re
27	Final SD-2 Documentation	04/15/15	04/30/15	100%	12	Final SD-2 Do
28	Leg	04/01/15	04/30/15	100%	22	Leg

Appendix E: Detail Cost Analysis

List of Tables

Appendix E: Detail Cost Analysis

Time Detailed Cost Estimate:

- **Labor for Senior Design 1**

The majority of the costs were from the team's work due to the fact that the robotic leg was not built until Senior Design II.The main tasks for Senior Design I were:

- **Work Packages**

  The work packages (WP) written for SD1 encompass the majority of the analysis to be completed for the course and success of the project outside the final report. WP-1 developed the team goals, name, logo and team members. WP-2 relates to the identification of the design project to be proposed, including the problem statement, functional requirements, preliminary specifications, supporting mentor, and team strengths and weaknesses. WP-3 encompassed the engineering project specifications and selection of the best concept out of the three developed. WP-4 provided the project costs and scheduling. And lastly, WP-5 include all the project's preliminary design and analysis.

- **Reporting Costs for Senior Design 1**

  The reporting costs for Senior Design include tasks as the final report, assignments, materials, printing, office supplies, software and the time required to perform all the deliverables.

- **Miscellaneous Material Costs for Senior Design 1**

  Miscellaneous costs include some of the time spend working on Senior Design deliverables that are not major tasks. Meeting minutes, meeting agendas, project's research, group meetings, class time, and group weekly meetings. The assigned deliverable costs are displayed in Table 1.

Table 1: Senior Design I Assigned Deliverables Costs

Task	Time Spend (hrs)	Money Spend ($)
Assignments	172	$34400.0
WPs	398	$79599.0
MSR	94	$14025.0
Presentations	312	$62334.0
Miscellaneous	206	$51595.6
TOTAL	975	$195033.0

- **Labor for Senior Design 2**

The majority of the costs during SD2 were from the final design, fabrication and testing of Ein: the Robotic Leg. The main tasks for Senior Design II were the Drawing Package and Testing Plan:

- **Drawing Package:**

  The Drawing Package encompassed all the drawings required for the fabrication of the prototype. All the components to be machined were required to be included in the drawing package. Main Assembly and Sub-Assemblies were required to be included as well as detailed instructions for the complete assembly.

- **Testing Plan:**

  The Testing Plan was required to include the testing fixture, testing fixture attachment, compliance matrix, and detailed testing instructions. The team had to plan a series of tests to prove all the functional and physical specifications set at the beginning of the project. Preliminary testing was established as well to prove that every component met the physical dimensions set on the drawing package and the material was the composition specified by the team.

- **Reporting Costs for Senior Design 2**

  Senior Design II costs include time spend on reports, status review presentations, drawing package, testing plan, critical design review, and progress reports delivered for SD-2.

  -Miscellaneous Costs for Senior Design II: Include the time spent in miscellaneous assignments such as meeting agendas, meeting minutes, team meetings and time spender while acquiring the outsourced materials/components.

Table 2: Senior Design II Assigned Deliverables Costs

Task	Time Spend (hrs)	Money Spend ($)
Status Reviews	226.5	33975
Drawing and Testing Packages	469.5	70425
MSR	80	7200
Presentations	240.25	48050
Miscellaneous	160	24000
TOTAL	1176	183650

Detail Cost Estimated Based on Hours Spend by the Team per Month:

Table 3: Hours Spent by the Team - September

MONTH/ WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
September TOTAL	110.00	0.00	365.80	0.00	55229.64	54922
01-07	75.5	0	40	0	X	18700
%	0.65	0.00	0.35	0.00	16190.48	X
08-14	0.00	0.00	71.13	0.00	X	6401.70
%	0.00	0.00	1.00	0.00	9000.00	X
15-21	0.00	0.00	75.30	0.00	X	6777.00
%	0.00	0.00	1.00	0.00	9000.00	X
22-28	0.00	0.00	89.00	0.00	X	8010.00
%	0.00	0.00	1.00	0.00	9000.00	X
29-05	34.50	0.00	90.37	0.00	X	15033.30
%	0.28	0.00	0.72	0.00	12039.16	X

Table 4: Hours Spent by the Team - October

MONTH/ WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
October TOTAL	248.00	0.00	184.49	0.00	62059.72	66204.10
06-12	70.50	0.00	37.07	0.00	X	17436.30
%	0.66	0.00	0.34	0.00	16209.26	X
13-19	52.00	0.00	20.17	0.00	X	12215.30
%	0.72	0.00	0.28	0.00	16925.73	X
20-26	62.00	0.00	62.25	0.00	X	18002.50
%	0.50	0.00	0.50	0.00	14488.93	X
27-02	63.50	0.00	65.00	0.00	X	18550.00
%	0.49	0.00	0.51	0.00	14435.80	X

Table 5: Hours Spent by the Team - November

MONTH/ WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
November TOTAL	261.07	0.00	257.65	0.00	**58286.16**	**75402.50**
03-09	66.00	0.00	55.00	0.00	X	18150.00
%	0.55	0.00	0.45	0.00	15000.00	X
10-16	68.00	0.00	50.75	0.00	X	18167.50
%	0.57	0.00	0.43	0.00	15298.95	X
17-23	71.50	0.00	73.40	0.00	X	20906.00
%	0.49	0.00	0.51	0.00	14427.88	X
24-30	55.57	0.00	78.50	0.00	X	18179.00
%	0.41	0.00	0.59	0.00	13559.33	X

Table 6: Hours Spent by the Team - December

MONTH/ WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
December TOTAL	0.00	0.00	81.00	0.00	**36000.00**	**7290.00**
01-07	0.00	0.00	65.00	0.00	X	5850.00
%	0.00	0.00	1.00	0.00	7200.00	X
08-14	0.00	0.00	4.00	0.00	X	360.00
%	0.00	0.00	1.00	0.00	7200.00	X
15-21	0.00	0.00	4.00	0.00	X	360.00
%	0.00	0.00	1.00	0.00	7200.00	X
22-28	0.00	0.00	4.00	0.00	X	360.00
%	0.00	0.00	1.00	0.00	7200.00	X
29-04	0.00	0.00	4.00	0.00	X	360.00
%	0.00	0.00	1.00	0.00	7200.00	X

Table 7: Hours Spent by the Team - January

MONTH/ WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
January TOTAL	63.50	98.75	139.70	72.25	47758.91	45504.25
05-11	0.00	40.00	50.00	0.00	X	10500.00
%	0.00	0.44	0.56	0.00	11666.67	X
12-18	29.75	25.25	26.25	28.25	X	14218.75
%	0.27	0.23	0.24	0.26	12985.16	X
19-25	0.00	17.00	33.00	14.00	X	6570.00
%	0.00	0.27	0.52	0.22	10265.63	X
26-01	33.75	16.50	30.45	30.00	X	14215.50
%	0.30	0.15	0.28	0.27	12841.46	X

Table 8: Hours Spent by the Team - February

MONTH/ WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
February TOTAL	145.00	121.50	129.00	125.00	53111.22	68210.00
02-08	38.75	36.75	44.50	38.75	X	20173.75
%	0.24	0.23	0.28	0.24	12707.87	X
09-15	34.25	34.25	34.25	34.25	X	17638.75
%	0.25	0.25	0.25	0.25	12875.00	X
16-22	48.25	39.00	38.25	40.00	X	21942.50
%	0.29	0.24	0.23	0.24	13258.31	X
23-01	23.75	11.50	12.00	12.00	X	8455.00
%	0.40	0.19	0.20	0.20	14270.04	X

Table 9: Hours Spent by the Team - March

MONTH/WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
March TOTAL	135.50	124.05	131.20	150.45	65949.38	68799.25
02-08	10.00	10.50	8.00	2.20	X	4460.00
%	0.33	0.34	0.26	0.07	14527.69	X
09-15	39.00	34.00	53.45	70.00	X	22960.50
%	0.20	0.17	0.27	0.36	11687.71	X
16-22	11.75	27.25	28.25	22.25	X	10648.75
%	0.13	0.30	0.32	0.25	11898.04	X
23-29	19.75	32.30	30.00	42.50	X	14682.50
%	0.16	0.26	0.24	0.34	11788.44	X
30-05	55.00	20.00	11.50	13.50	X	16047.50
%	0.55	0.20	0.12	0.14	16047.50	X

Table 10: Hours Spent by the Team - April

MONTH/ WEEK	Engineering	Technician	Secretary	Laborer	TOTAL PLANNED	TOTAL ACTUAL
	200	150	90	75		
April TOTAL	75.00	61.00	195.00	5.00	51203.77	42075.00
06-12	45.00	15.00	25.00	5.00	X	13875.00
%	0.50	0.17	0.28	0.06	18500.00	X
13-19	25.00	34.00	50.00	0.00	X	14600.00
%	0.23	0.31	0.46	0.00	13394.50	X
20-26	5.00	12.00	80.00	0.00	X	10000.00
%	0.05	0.12	0.82	0.00	10309.28	X
27-03	0.00	0.00	40.00	0.00	X	3600.00
%	0.00	0.00	1.00	0.00	9000.00	X

Budget Cost of Work Performed Vs. Actual Cost of Work Performed per Month: Budget

Table 11: Project Cost vs Actual Costs

	Budgeted Cost of Work Performed	Actual Cost of Work Performed
Up to Sep	55229.64	54922
Up to Oct	117289.36	121126.1
Up to Nov	175575.52	196528.6
Up to Dec	211575.52	203818.6
Up to Jan	259334.44	249322.85
Up to Feb	312445.66	317532.85
Up to Mar	378395.04	386332.1
Up to Apr	429598.81	428407.1

Total Cost for Senior Design Project:

Table 12: Total costs for RoboMeks Senior Design Project

Estimated Costs for Senior Design Project					
	Senior Design I			Senior Design II	
Staff	Hourly Cost	Estimated Hours	Calculated Cost	Estimated Hours	Calculated Cost
Senior Project Manager	$375.00	64	$24,000.00	48	$18,000.00
Senior Engineer	$300.00	32	$9,600.00	32	$9,600.00
Engineer	$200.00	619.07	$123,814.00	419.00	$83,800.00
Technician	$150.00	0.00	$0.00	405.30	$60,795.00
Secretary	$90.00	888.94	$80,004.60	594.90	$53,541.00
Laborer	$75.00	0.00	$0.00	202.25	$15,168.75
Machining	$100.00	0	$0.00	254.4	$25,440.00
TOTAL		1604.01	$237,418.60	1955.85	$266,344.75
Project's TOTAL					$503,763.35