Corp 2: Army Robot

Critical Design Review
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Auburn University
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Abstract:

Corp 2 was formed in August 2012 to develop a tension control device for an AMRDEC thermoplastic applicator robot. In its current state, the device has no method for knowing or controlling tension in the thermoplastic. The goal is to develop a design that will allow an operator to input a desired tension between 1 lb and 50 lbs, which will be maintained throughout the thermoplastic application process regardless of orientations or vibrations.

As detailed in the Preliminary Design Review (PDR), various solutions to the problem statement were developed. The designs were weighed against each other and a design was chosen for further design. The optimal design included a servo motor with a motor driver, a microcontroller, and a three-spool tension sensor with a user interface development. A transfer function was derived from a model of the system. The transfer function was used to create a tension control system for the project. The controller was then simulated using MATLAB to prove the design was possible.

The bulk of the work since the PDR has involved the final selection of motors and sensors to be used in the final prototype. The details of the selection process are outlined in this report. In addition to selecting the motors and sensors, the group built a test apparatus for the purpose of proving the tension control design and also to experimentally derive a transfer function between voltage and tension, which will lead to a more accurate controller design.

In addition to the test apparatus, the final detailed design as it will be implemented into the robot was also developed. This design will use the same motor, microcontroller, motor driver, optical encoder, tension sensor, voltage regulators, and display as the test apparatus. Implementation of the design will take place once the design has been tested on the test apparatus and the group is confident that the final design is ready.

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Introduction:

The purpose of the project outlined in this report is to develop a tension control device for a robot owned by AMRDEC, located on the Redstone Arsenal in Huntsville, AL. The robot is capable of developing various parts by wrapping a thermoplastic material around different molds. Currently, the robot has no method of sensing or controlling tension in the thermoplastic applicator. Corp 2 was approached to develop a system that to provide this function.

Although there are several tension control systems commercially available, none of the researched systems adequately satisfied the design requirements. There were three main design constraints that ruled out the commercially available objects. The first was the size limitation. All of the commercial designs were too large and would be unable to fit on the end effector of the thermoplastic robot. The commercial designs also relied upon a known feed rate into the system whereas the thermoplastic robot has a variable feed rate. The last constraint that ruled out the commercially available systems was the requirement to be able to operate at different orientations relative to the ground. Most commercial systems used either a dancer tension control systems that needed to maintain the dancer orientation perpendicular to the ground or a radial sensor which can only operate in one orientation. These systems were ruled out since the control system would be mounted onboard a constantly moving and rotating robot head.

The steps of the design process that led to the optimal design were outlined previously in the Preliminary Design Review. There was concern at the PDR that a sufficient motor and sensor could not be found that would be implemented within the design constraints. These concerns were addressed by conducting further research to find a suitable motor that utilized a gearbox to deliver the additional torque necessary to control the system and by moving from a three-spool tension sensor to a custom tension sensor developed from a load cell. The justification for the aforementioned design choices are outlined further into the report.

Two detailed designs are required for the implementation of the tension control device that will take place after the holidays. The first is a test apparatus, shown in Figure 1: Test Apparatus, which will be used to develop a controller design. The apparatus includes two motors: one to simulate the control motor and another to simulate the thermoplastic applicator. The test apparatus contains the majority of the actual components that will be used in the final product. This will allow the team to mimic the performance of the robot without having to be in Huntsville. This is a critical to being able to design a controller that will accomplish the mission statement.

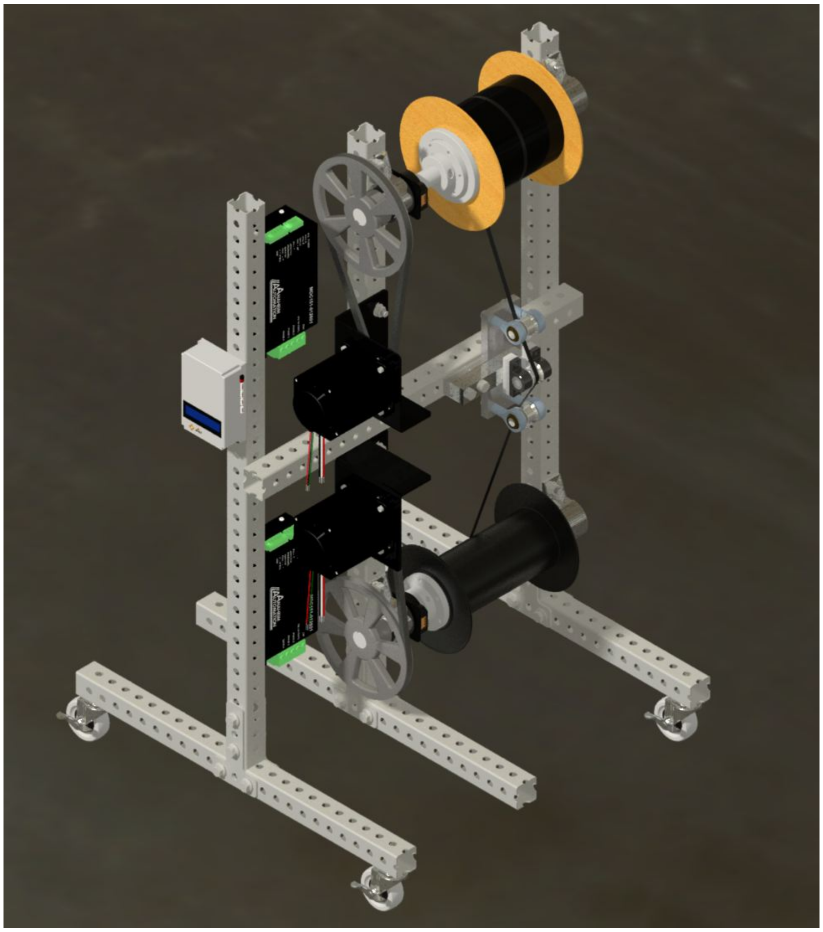


Figure 1: Test Apparatus

The second detailed design is for the final product that will be implemented on the actual thermoplastic robot. This design is shown in Figure 2: Final Design. The final prototype design will be described in the report as well. The final product will only use one motor as opposed to the two motors used in the test apparatus. The second motor in the test apparatus will be packaged along with the system as a spare part for future maintenance if necessary. In addition, this report will include a brief summary of the concept generation which was covered in the PDR, the modeling and development of equations of motion for the system, CAD drawings and analysis of both the test apparatus and final design, and a plan for the testing and implementation of the design.

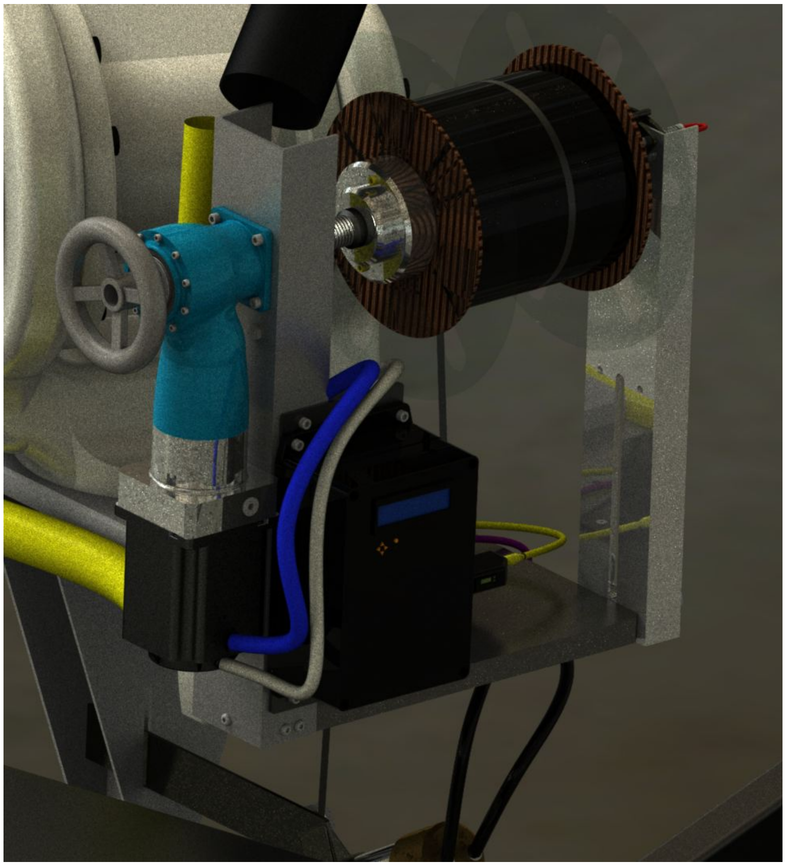


Figure 2: Final Design

Mission Objective:

The overall objective of this project is to design a system to implement with the existing robotic thermoplastic applicator which actuates the feed spool in order to maintain the desired tension of the thermoplastic tape, as determined by the operator, regardless of any vibrations or orientations of the end effector.

Architectural Design:

Although several solutions to the mission objective immediately jumped out, the team followed the engineering design process to decide upon a design. The first thing the group accomplished after defining the problem statement was the development of a functional decomposition, shown below in Figure 3. The functional decomposition is composed of the base level functions that the design had to accomplish in order to satisfy the objective.

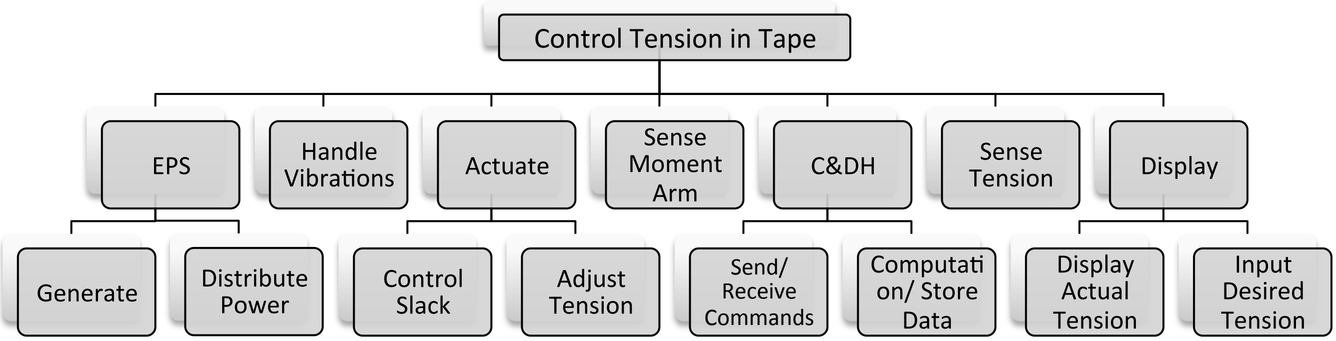


Figure 3: Functional Decomposition

The group then came up with different methods that would satisfy each of the base level functions. The goal was to develop as many feasible alternatives to each function as possible before deciding upon the best method. This would allow the group to combine the different solutions to each alternatives into distinct designs as well as preventing the group from getting locked into a design early which could lead to missing out on unique designs that otherwise would not have been conceived. The design alternatives to accomplish each function are shown in Table 1 below.

Table 1: Morphological Matrix

Functions	**Option 1**	**Option 2**	**Option 3**	**Option 4**
Generate Power	Battery	Wall Supply	Mechanical system	
Distribute Power	Wires	Multiple Power Supplies		
Control Slack	Electric Motor with Controller	Arm and Roller	Torsional Spring with Clutch	Pneumatic motor
Adjust Tension	Clutch	Motor	Hydrodynamic Bearing	
Computation/ Store Data	Microcontroller	Fully mechanical	Motor with Controller	OP Amp Circuit
Send/ Receive Commands	Wireless Data	Wire	Mechanical System	
Handle Vibrations	Isolate (Spring/ Damper System)	Mechanical Supports	Rigid Attachment	
Sense Moment Arm	Constant Radius	IR Sensor	Ultrasonic	
Tension Sensor	3-Spool Sensor	Radial Force Sensor	Dancer Roll	From Motor
Display Tension	Analog	Digital		
Input Tension	Analog	Digital		

Different combinations from each row of the morphological matrix were select in order to form seven distinct design alternatives. The different feasible design alternatives were then graded on a ten point scale based on how well they satisfied each of the design requirements in the Requirement section featured later in the report. Based on the weighted average from the decision matrix, it was determined that three of the designs were significantly superior. These three designs were analyzed further in depth to choose which would be most suitable for the project.

The first alternative, shown in Figure 4, was a simple design that lacked a tension sensor. Based on the system model that is described in the Concept of Operations section of this report, the measurements of radius, feed rate, and motor position could be used to calculate and control the tension in the thermoplastic. It was determined that the design would be ideal for constant feed rate only during further analysis of the design. There would be no elegant way to measure the feed rate in the applicator because temperatures at the applicator are too high to use an off-the-shelf optical encoder. Since the feed rate at the applicator is variable, there is no way of knowing what the feed rate is without an optical encoder; therefore, this design was eliminated from consideration.

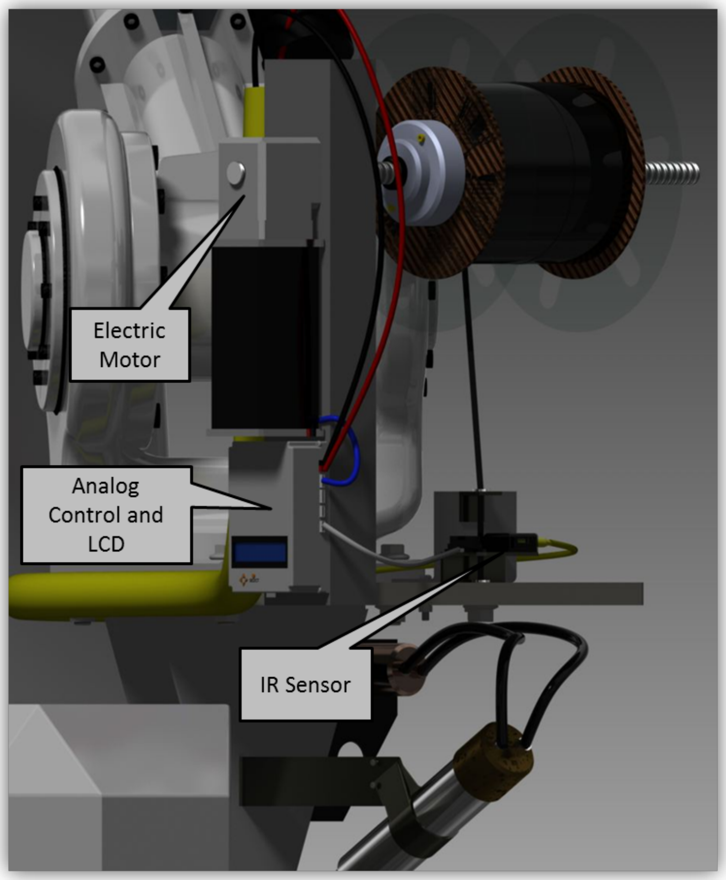


Figure 4: Design 1

The second alternative design, shown in Figure 5, also received higher scores in the decision matrix than the other designs. The design fed the thermoplastic from the spool to a controlled capstan before the tension was measured. This allowed for the elimination of an IR sensor which would simplify the controller design because it removed the need to account for the changing mass of the dwindling spool. The trade-off was adding a second motor to the system. The capstan was something that was used in other tension sensors but upon further testing which was discussed in detail in the PDR, the decision was made that a capstan was impractical with the material properties of the thermal plastic tape.

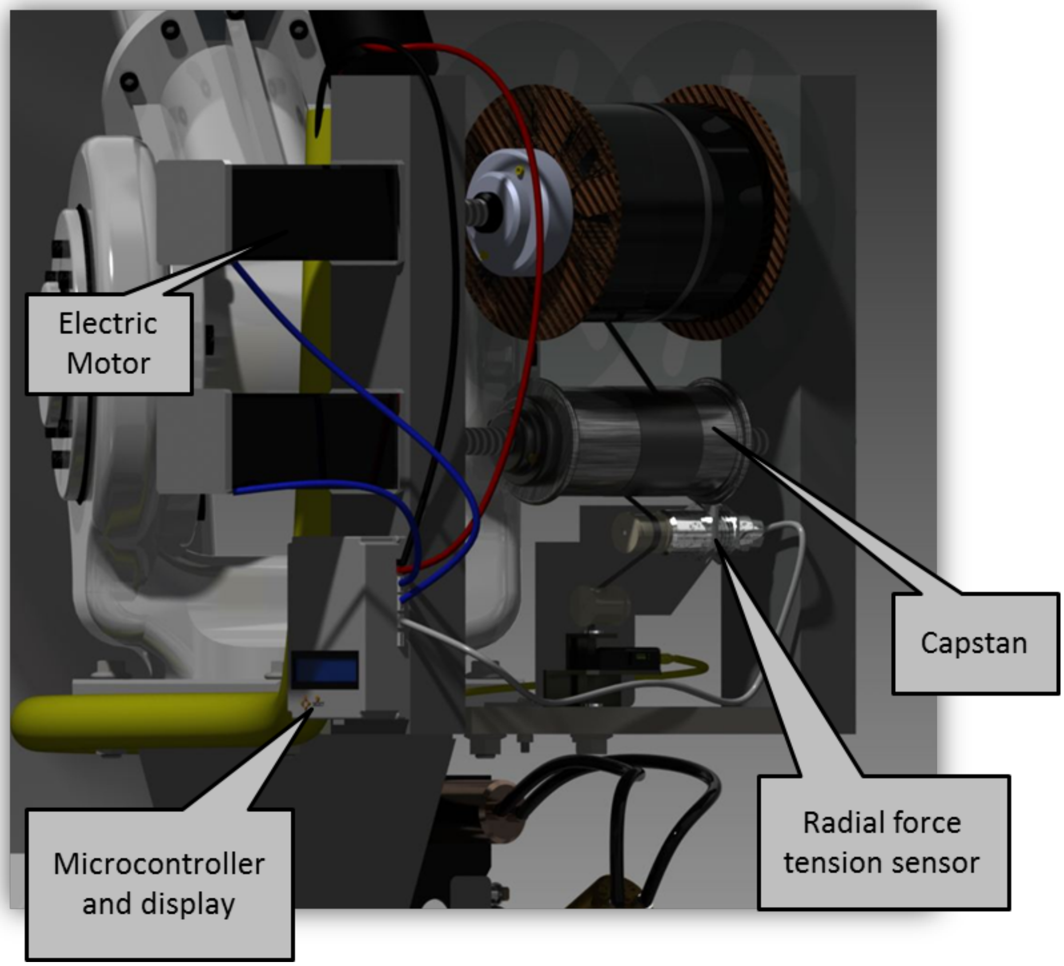


Figure 5: Design 2

In the testing, it was found that even after wrapping the thermoplastic tape around the capstan upwards of ten times, there was still slippage occurring between the rotating capstan and the thermoplastic tape. One of the requirements under the Mechanical Support header in the Requirements section is “Allow for quick and easy spool replacement”. Having to wrap the beginning of each spool more than ten times around the capstan would cause this design to fail that particular design requirement. In addition, the last section of thermo plastic tape would run freely from the capstan, thus essentially wasting at least ten times the circumference of the capstan spool’s worth of tape.

The group chose to proceed with the design shown in Figure 6. This design includes an electric motor with a gear box, a microcontroller for sending and receiving signals, a three-spool tension sensor, and an optical encoder to measure feed rate.

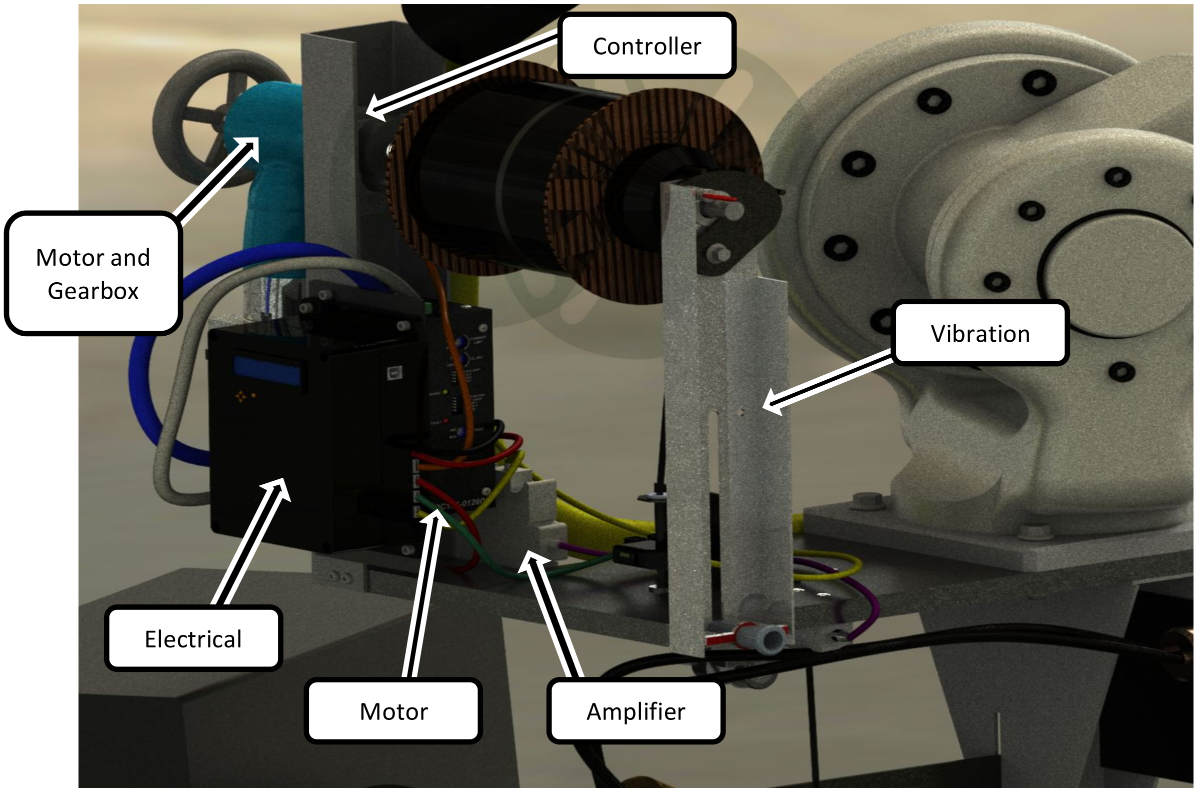


Figure 6: Final Design

The optical encoder will be eliminated when a direct transfer function between voltage and tension is determined using the test apparatus.

The above design was presented in the Preliminary Design Review and has since been modified slightly to improve the design. A breakdown of the components is shown in the product hierarchy in Figure 7 below. Beyond that, each specific component is broken down into its detailed components. A bill of materials has been included in the Project Management section of the report.

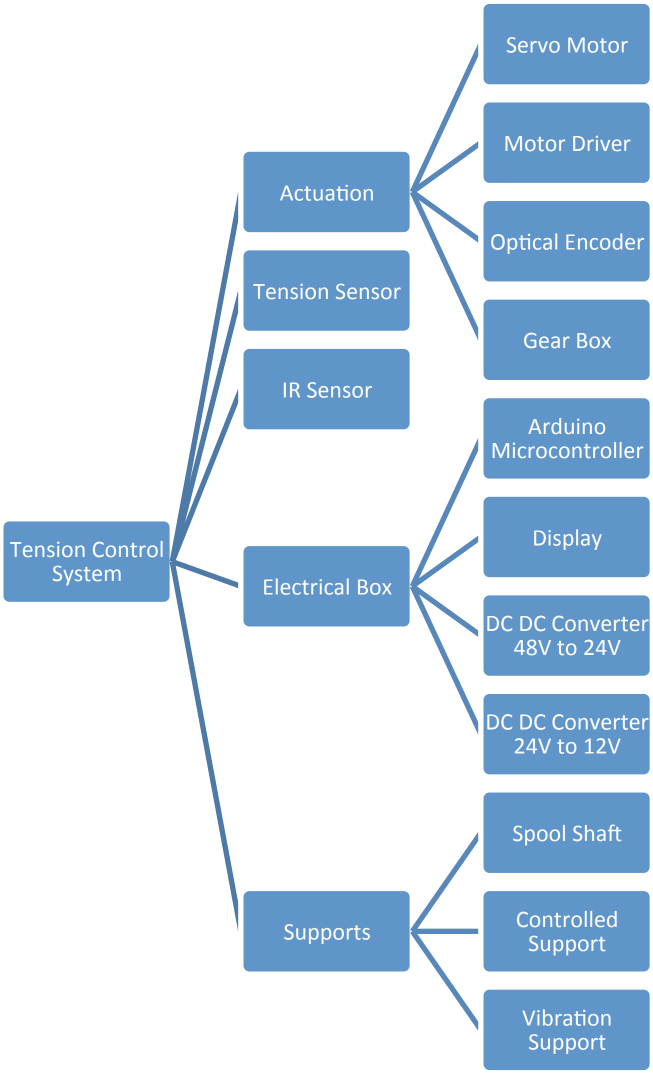


Figure 7: Product Hierarchy

Spool Actuation

It was determined that a servo motor that ran off of 24-48 VDC of power to supply 30 N-m of torque at a rate of 30 rpm was going to be adequate for the control design. The main difficulty was finding a motor that could deliver the required torque with such a limited power supply. It was decided that a 25:1 gear box would allow the motor to supply the correct amount of torque given the 24-48 VDC power limit.

The chosen motor was purchased from Anaheim Automation and is pictured in Figure 8. The brushless DC servo design of the motor will allow for the control angular velocity. A stepper motor would have been inadequate because the time response was too long to allow for proper motion control. There is very little required maintenance due to the brushless design. There is also no electric arc that can be created as there can be when using brushed motors so it is a safer design.

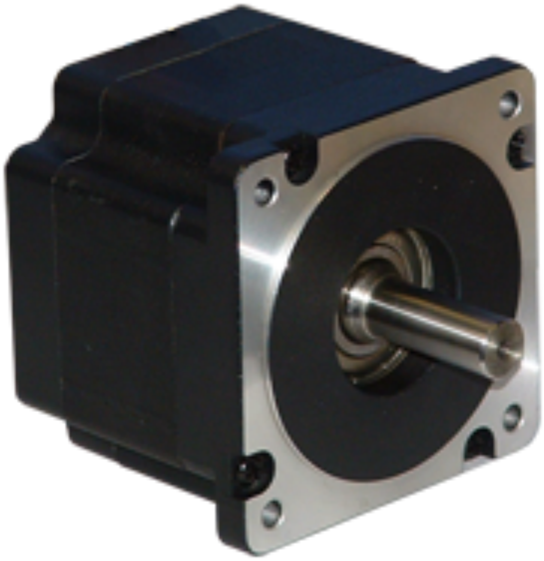


Figure 8: DC Motor

The motor will run off of 48 V DC but will not be able to supply the correct amount of torque without the 25:1 gearbox shown in Figure 9. The gearbox will feature a manual turning wheel so that the user will be able to turn the shaft manually. This 90° gearbox purchased from Wittenstein will connect to the motor and shaft to provide for the needed torque. The 90° gearbox was chosen so that it would fit the system's spatial constraints. The group was concerned about damaging the teeth of the gearbox when driving the motor in the opposite direction of the motion but after consulting a Sales Engineer at Wittenstein, he confirmed that this would not be an issue and that the gearbox would be suitable for this specific application.

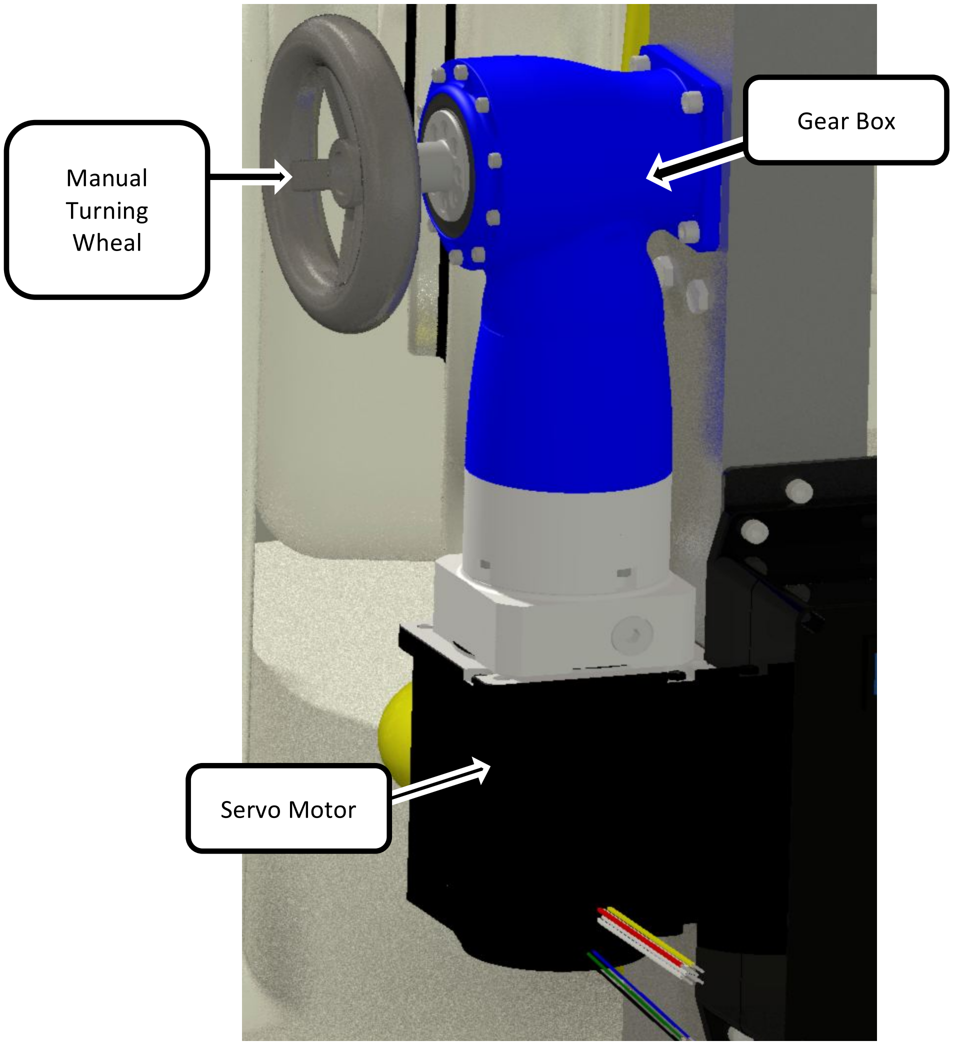


Figure 9: Gearbox

The motor will also be connected to a motor driver is which shown in Figure 10 and the optical encoder shown in Figure 11, which will be used for motion control. The motor driver was also purchased from Anaheim Automation to ensure compatibility with the motor which was also purchased there. The encoder was purchased from US Digital. As shown in the Concept of Operations section of this report, the motor driver will receive a signal from the microcontroller specifying the angular velocity the motor needs to run at and then drive the motor to that particular angular velocity. The motor driver dynamics should be negligible. The optical encoder will measure actual angular velocity of the motor and then send this signal back to the microcontroller to be used in the closed loop cascaded control.

Figure 10: Motor Driver

Figure 11: Optical Encoder

The group plans investigate designing its own motor driver for the final product that will be incorporated onto a printed circuit board that will handle voltage regulation, motor driver responsibilities, and encoder counts. This will take some processing responsibility from the microcontroller as well as reduce the footprint of the electrical design.

The encoder is used to measure the angular velocity of the shaft. It was chosen because at similar price ranges, it offers superior performance to Hall-effect sensors. It operates at 1024 counts per revolution, so it has a high degree of accuracy. It will be connected directly to the spool shaft, as shown in Figure 12.

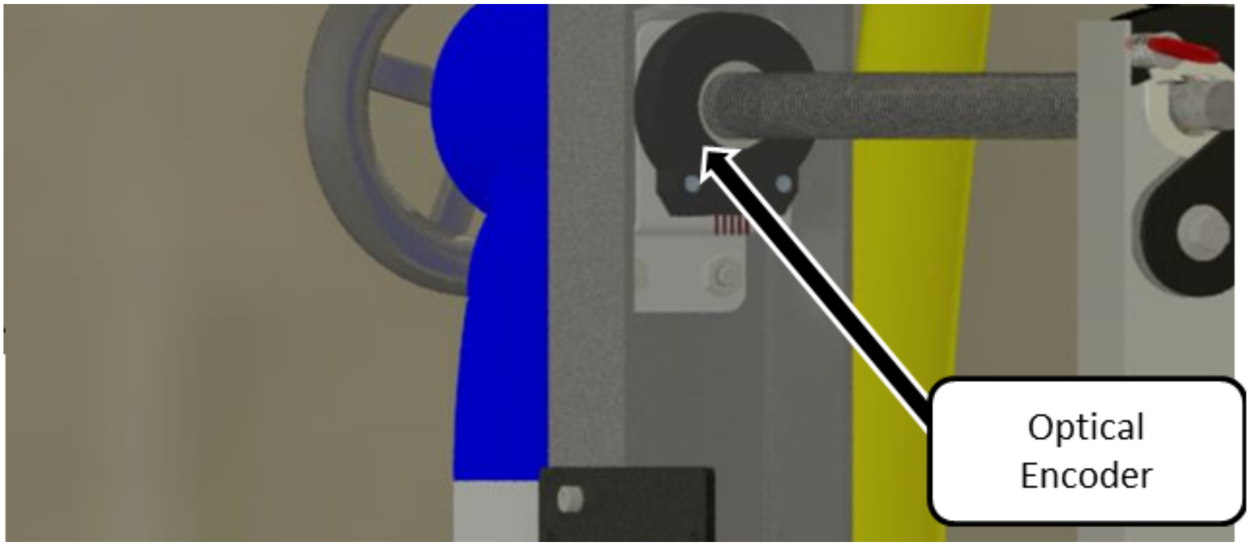


Figure 12: Optical Encoder Mounted on Spool Shaft

In order to ensure that the motor would operate correctly, it was simulated in MATLAB using the Anaheim Automation motor's technical specifications. The goal was to ensure that the motor would have a fast enough response time to control tension within the system. As shown in Figure 13, the motor is capable of tracking a desired tension. The system was given a step input for desired tension. This desired tension is reached in roughly 0.2 seconds. The MATLAB code used to generate the program can be seen in Appendix A.

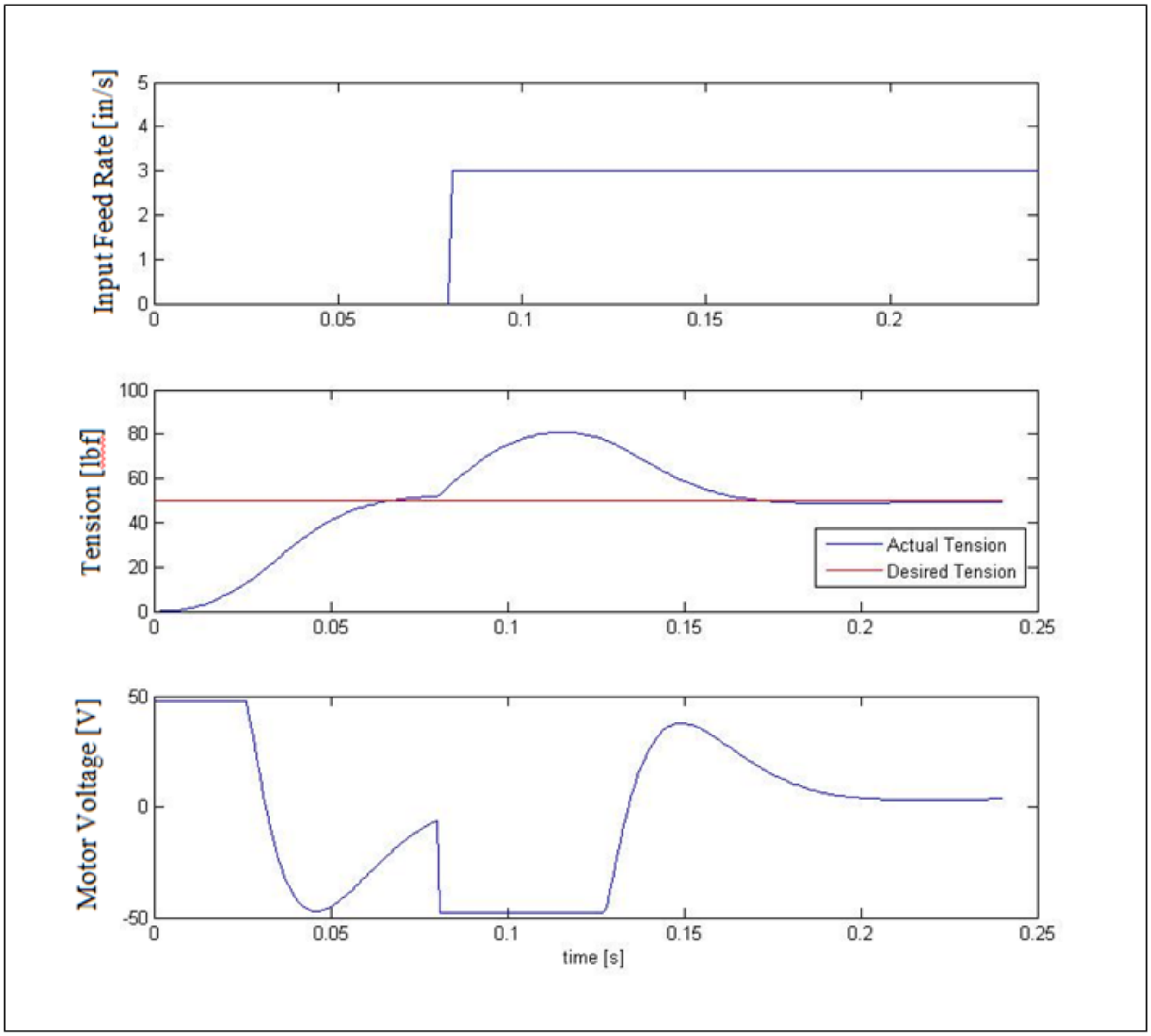


Figure 13: Motor Step Response

Tension Sensor

The greatest constraint in choosing a sensor for measuring tension in the thermoplastic tape was spatial limitations. A majority of the tension transducers on the market within the desired tension range do not fit these spatial constraints. These pre-assembled sensors are also significantly more expensive. It was decided that a tension transducer should be manufactured specific to the system to specifically address the spatial requirements and tension range. The designed tension transducer uses a load cell with a mounted bearing/roller assembly and can be seen in Figure 14: Tension Sensor Design. With the tension applied at a constant angle in a symmetrical fashion, the reaction force acting on the spool can be related directly to the tension in the tape. This force induces a voltage which is then amplified, filtered, and measured by the microcontroller.

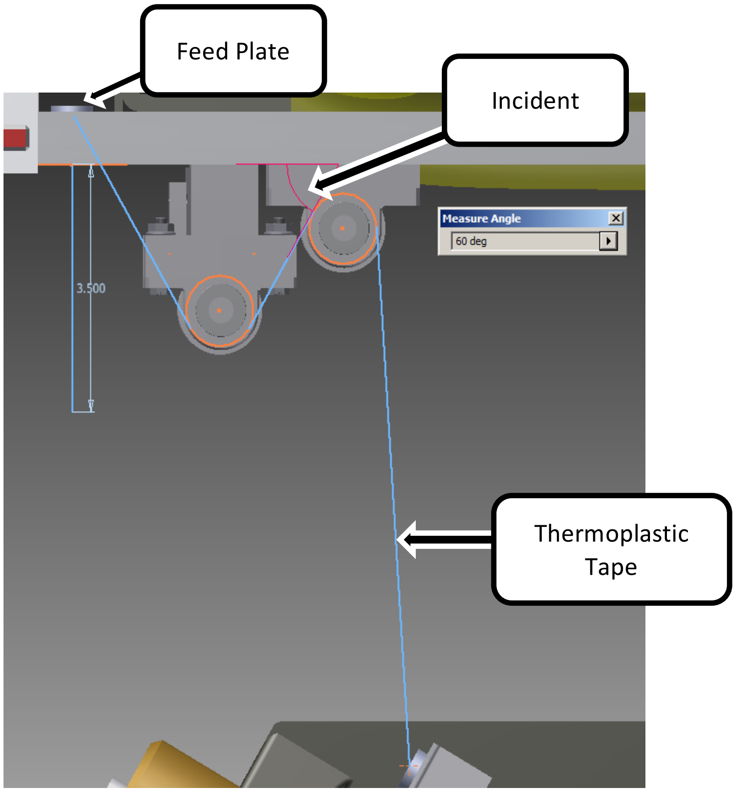


Figure 14: Tension Sensor Design

The cantilever style load cell was chosen because of its low profile, sensitivity, and ease of mounting. An outrigger bearing/roller configuration was designed because the incident angle on the roller must be held constant. This spool also helps keep the tape in contact with the transducer roller and eliminates any catenary effects of the tape which can be seen in Figure 14. The angle of the feed side tape is held at a symmetric angle by contact with the pre-existing feed plate. The angle of the tape to the feed plate is kept low to reduce wear on the plate itself.

There was some concern about a pressure point being generated in thermoplastic tape by the feed plate, so an experiment was set up to test if the point would break the tape. The test setup can be seen below in Figure 15. The thermoplastic tape was subject to 100 pounds of tension. The tape was tested with an 1/8" diameter pressure point and an incident angle of 40°. The pressure point of the actual system is greater in diameter (roughly ¼") and the angle is greater than the intended angle (30°) after implementing the tension transducer. Further tests will be performed once the text fixture is made to determine if a roller bearing would need to be used in place of the static feed plate to reduce friction wear.

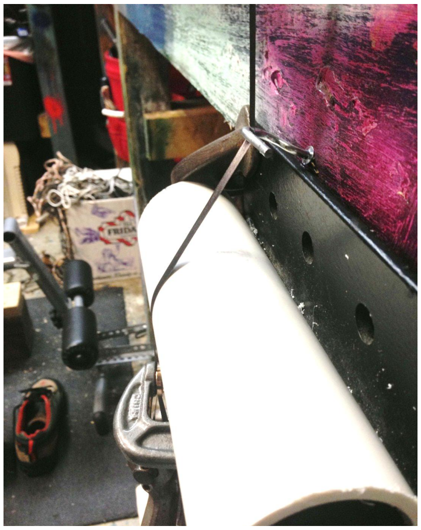


Figure 15: Pressure Point Test Setup

Microcontroller

The chosen microcontroller that was chosen was the Arduino Mega2560 which is shown in Figure 16. The microcontroller has a high count of analog and digital pins to accommodate for a variety of signals, its own internal voltage regulator for power, and it is simple to program. It was chosen based on having previous experience using this particular microcontroller as well as meeting all the technical specifications to handle a variety of inputs and outputs. More in depth detail how the different signals interact with the microcontroller are shown in both the Concept of Operations and Subsystems Engineering section of the report.

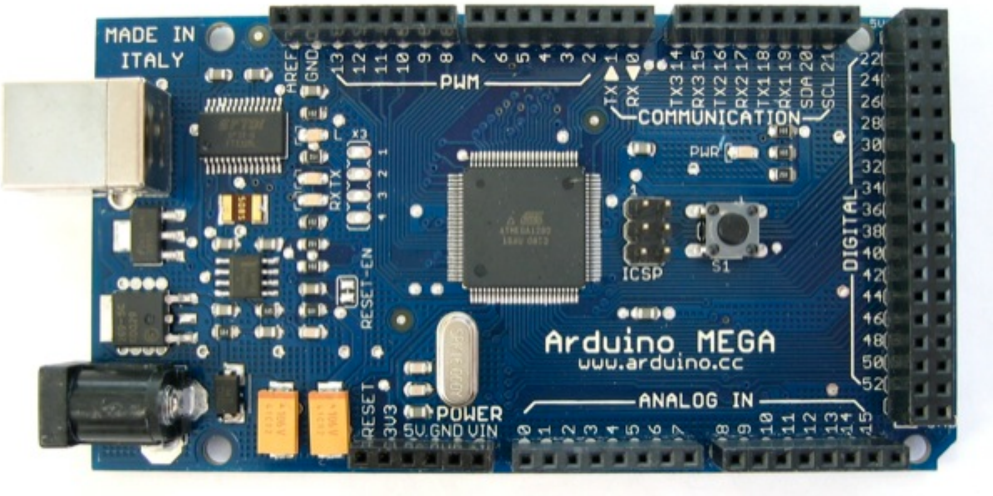


Figure 16: Arduino Mega2560 Microcontroller

Controller Support Design

The controlled support design, shown in Figure 17, will be custom manufactured and will be made out of aluminum. Its purpose is to house the electrical box, motor, and gearbox. Fabrication for this support arm will begin at the beginning of next semester.

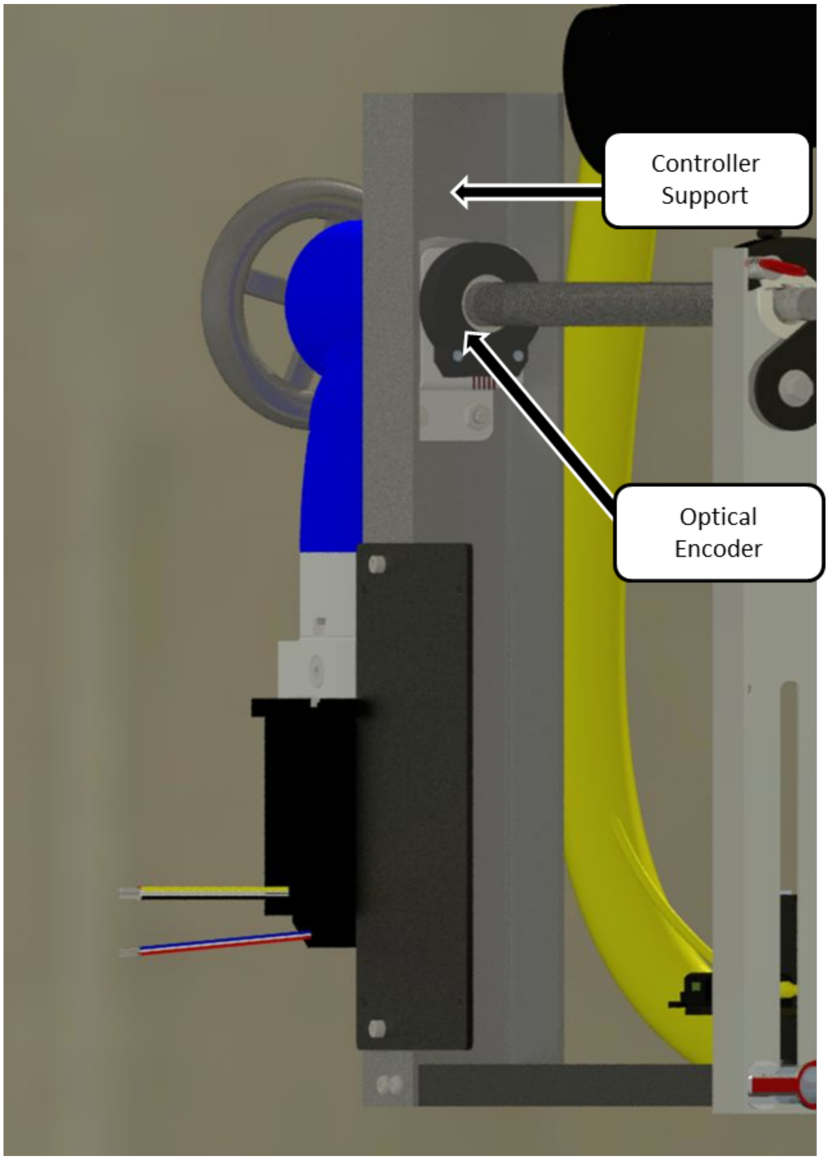


Figure 17: Controller Support

Mechanical Vibration Support Design

The mechanical vibration support, shown in Figure 18, will also be custom manufactured, and is made mostly out of aluminum. The gate hooks must be outsources since they will need to be laser cut. The additional support was included to ensure that the control system will be able to better handle orientations and vibrations introduced during the thermoplastic application process.

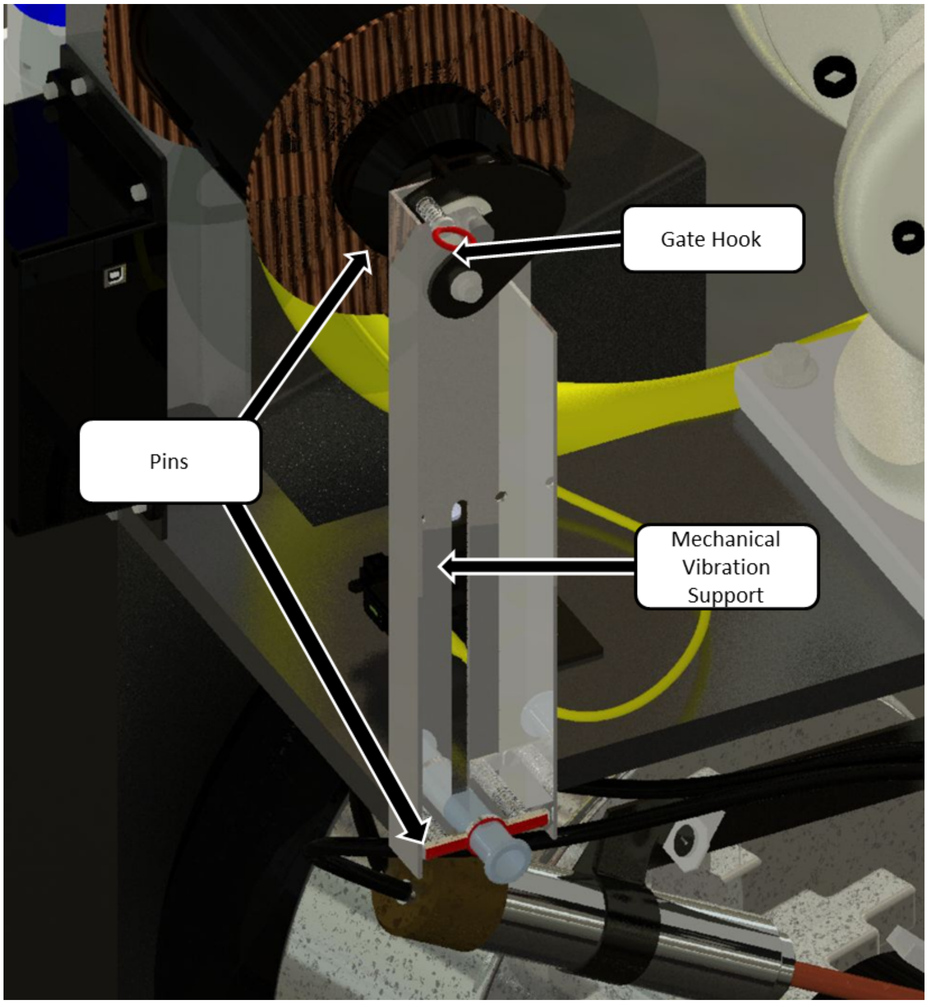


Figure 18: Mechanical Support Arm

The biggest design challenge that came during the design of the support arm was ensuring that it would still allow for easy spool replacement. Currently, the design only has one support so the spool is easy to replace. The mechanical support design operates using spring loaded pins located on the upper and lower part of the support. They can be removed to move the support up and down to allow for spool loading and unloading. After the spool is added, then the arm can be moved back up and locked into place for the application process.

Shaft Design

The shaft design, in Figure 19, will be redesigned from its current state. The design will be manufactured by the group and will contain the same thread as the current shaft design so spool loading will remain the same. The radius of the shaft will be turned down on both ends so it can be interfaced with the gearbox on one end and the mechanical vibration support on the other.

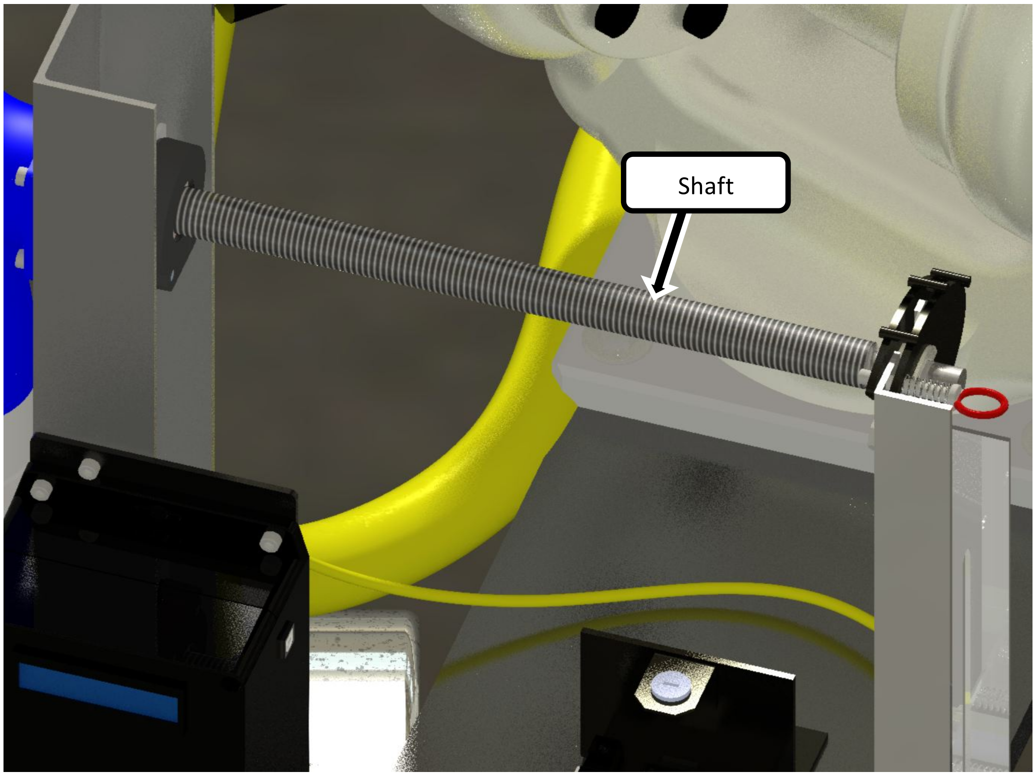


Figure 19: Shaft Design

Electrical Box Design

The electrical box, shown in Figure 20, has been designed, but is also subject to change. The intended box could be purchased from Polycase, and it would house the microcontroller, DC to DC converters, and display. In its current state, the box is larger than the group would prefer. The biggest reason for this is because the DC to DC converters are through hole mounted to a circuit board rather than surface mount. The electrical box should be sufficient for the test apparatus, but might be too big for the robot. If the change is made, the PCB will be tested extensively on the test apparatus to ensure that it is fully operational. The PCB will allow for a much smaller electrical box design, and the elimination of a motor driver mounted outside of the electrical box.

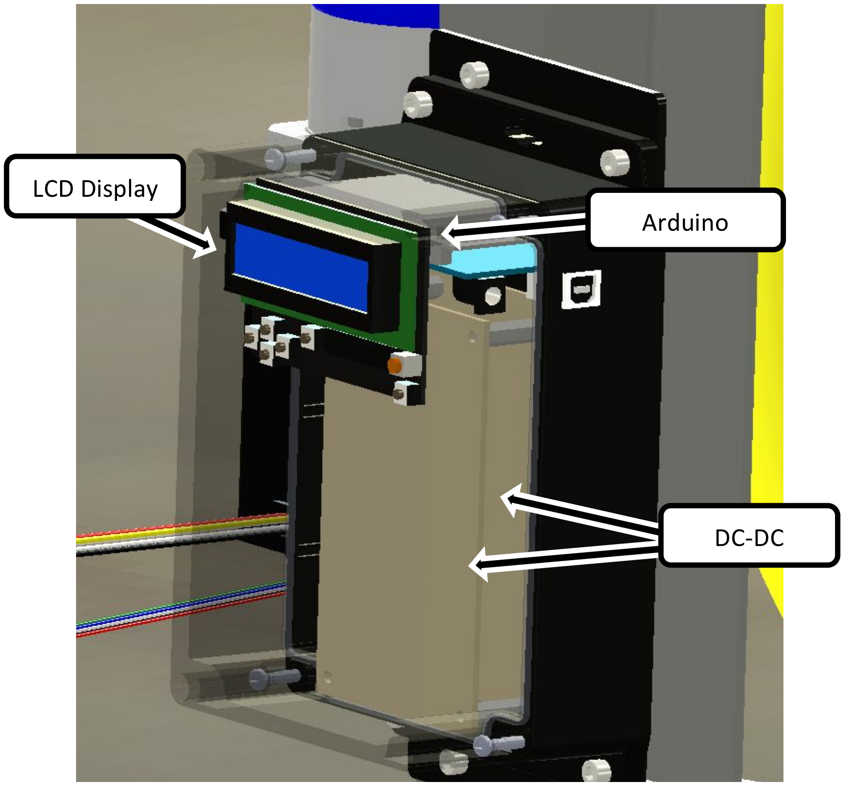


Figure 20: Electrical Box

Holes will be cut in the power box for all wires going to and from the subsystem. Two voltage regulators will be used for power distribution. The first one will step power down from

48 VDC to 24 VDC, and the second will step power from 24 VDC to 12 VDC. This power distribution will allow all of the items within the system to get the power required. This distribution of power can be seen in the electrical circuit in Appendix B.

IR Sensor

The IR Sensor, shown in Figure 21, is a Sharp 2D120X. It is included in the final design for now but may be removed once the design is implemented. For now it will be used to account for the continuously changing radius of the spool. This will affect the moment of inertia of the spool and the moment arm of the tension in the thermoplastic. If testing proves the radius change is negligible, then the sensor may be omitted in the final design.

Figure 21: Sharp IR Sensor

Modeling and Controller Design

The model of the system is outlined in full detail in Appendix C. The governing equation for the tension control design is,

$$T = k * (x_1 - x_2)$$

where T is tension, k is the stiffness of the thermoplastic material, x_1 is the position of the thermoplastic at the applicator, and x_2 is the position of the thermoplastic coming off of the spool. The controller design is based off of this model.

A block diagram for the system, shown below in Figure 22, was developed based on this system model. For now, the control design operates using a cascaded control. The design may change and become more simple after testing, as shown in the Validate and Verify section. A desired tension is input and compared to a measured tension. The controller then takes this error, and converts it into a angular velocity error, which is added to a measured angular velocity, to achieve a desired angular velocity. The controller then drives the motor to the particular angular velocity, which directly relates to a particular tension output. In the system H_1 represents the tension sensor dynamics, and H_2 represents the optical encoder dynamics.

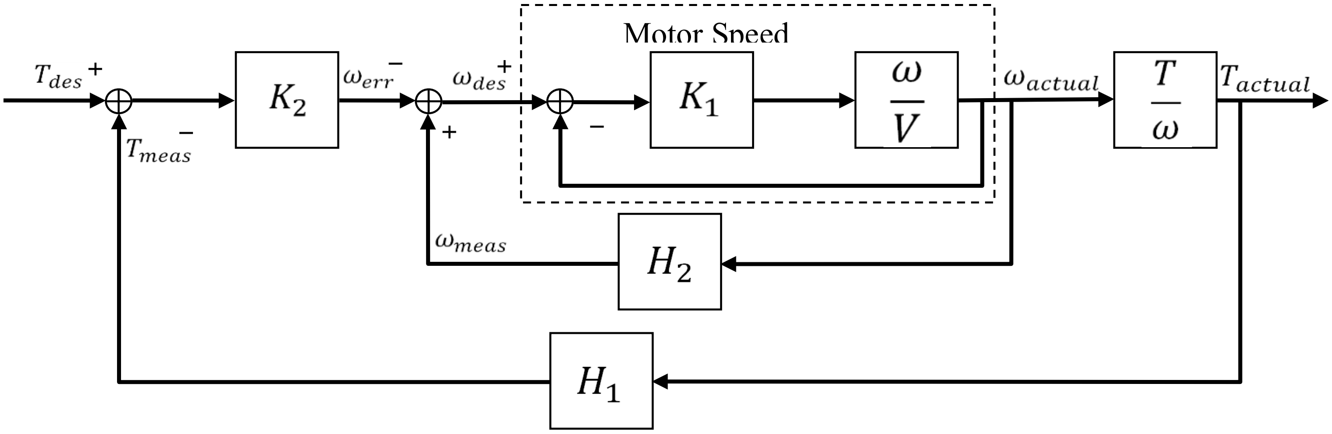


Figure 22: Block Diagram

The controller was simulated using MATLAB software. The motor driver dynamics were assumed to be perfect. Plots for the results, shown in Figure 23, show that the motor tracks tension very well. When position is graphed, there is a difference between the spool position and input position. This explains how tension is generated in the system. The difference in position when multiplied by the stiffness constant will be equal to the tension in the thermoplastic. The next two graphs show that angular velocity and tension are controlled.

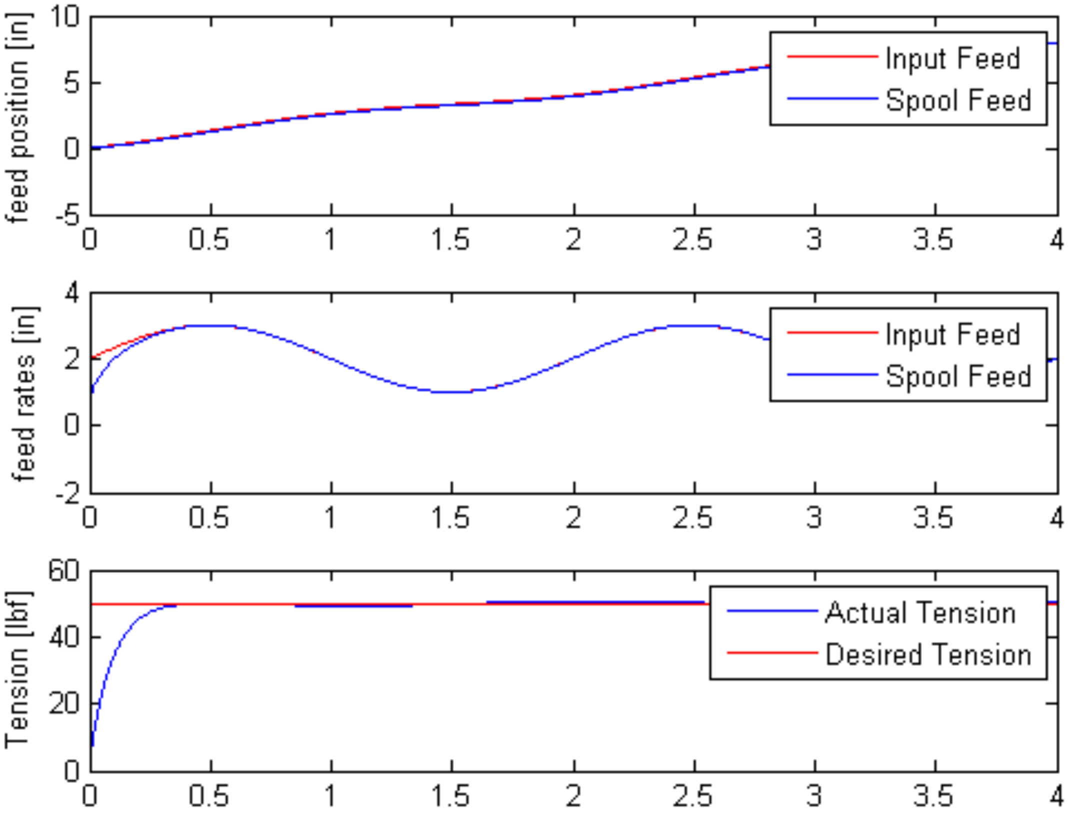


Figure 23: Controller Simulation

Requirements:

- **System Level:**
  - Maintain desired tension between 1 and 50 lbs.
  - Maintain safety throughout operation of the control system
  - Easy to maintain system
  - Cost less than $5,000 (This was a team generated goal)
  - Be reliable (This will be worked out in the test apparatus)
- **Tension Sensor**
  - Sense tension between 1 and 50+ lbs.
  - Allow for back and forth movement of spool feed
- **Actuator :**
  - Supply 30 N-m of torque to maintain tension of 50 lbs.
  - Run off of 24-48 V of power
  - Have fast dynamics so controller does not lag behind
- **Control Design**
  - Be able to maintain slack introduced during application process
  - Have a cutoff switch for when applicator is not feeding thermoplastic
- **Mechanical Supports**
  - Support actuator, electrical box, and shaft with spool in dealing with vibrations
  - Allow for quick and easy spool replacement
- **Electrical Box**
  - House microcontroller, voltage regulators, and LCD display
  - Display the measured tension while allowing for the setting of desired tension

Concept of Operations:

The tension control design operates largely on signals between all of the sensors and controllers. 48 VDC power is drawn and divided into 12 VDC and 24 VDC. The IR sensor, optical encoder, and microcontroller will operate off of 12 VDC, while the load cell operates off of 24 VDC. The motor draws from the original 48 VDC. The Arduino Mega2560 microcontroller receives signals from the IR sensor, optical encoder, and amplified signals from the load cell. Based on these signals, and the input tension, it supplies a signal to the motor controller, directing it to a desired angular velocity for the motor. The motor controller then drives the motor at that desired angular velocity to achieve the desired tension. The process iterates constantly as tension is measured, along with radius and angular velocity, and these signals are sent back to the microcontroller. The concept of operation is shown below in Figure 24.

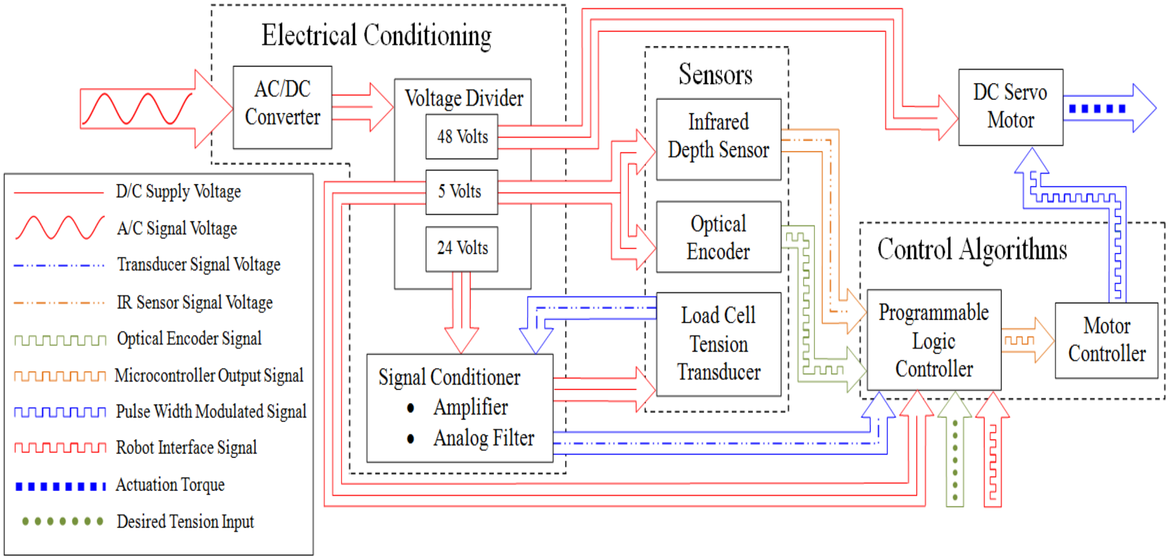


Figure 24: Concepts of Operation

Encoded safety precautions will be developed to ensure the safety of the operator and the machine. This would include a maximum tension limit at which the system would disengage the actuating motor. Also linked to the kill switch would be a physical E-stop button.

Validate and Verify:

It is important to verify that the selected motor was going to be able to operate in the system correctly so the motor was simulated using MATLAB software in order to prove that its dynamics would be suitable in the control design. A motor that reacted too slowly would not be able to properly control the tension in the feed line.

In order to prove the concept of the proposed tension control system, a test apparatus has been designed using 3D CAD software can be seen below in Figure 25.

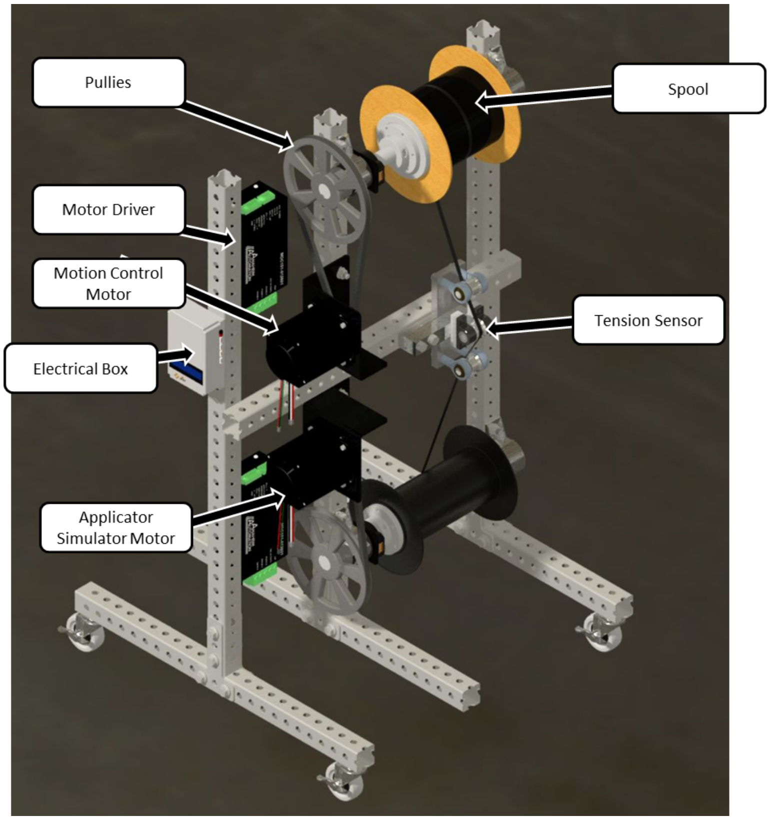


Figure 25: Test Apparatus

The design consists of two motors: one to simulate the controlled motor, and one to simulate the thermoplastic applicator. It also uses the microcontroller, tension sensor, optical encoder, motor driver, and electrical box that will all be implemented into the final design. Pulleys are being used in the place of the gearbox because of the delivery time of the gearbox. The gearbox will be added to the test apparatus when it arrives. Motor mounts and supports for the load cell still need to be manufactured prior to completing the test apparatus. Motor mounts will be manufactured at Sunair, in Red Bay, AL, while the supports for the load cell will be manufactured by the group. Detailed prints for the design are included in a print binder.

In order to test the tension control system and tune the control gains for the desired results, a transfer function needs to be derived from a controlled input to tension. Because a motor driver will be used with a built in closed loop velocity control, a desired angular velocity must be fed to the motor. This desired velocity is found by adding or subtracting a desired change in velocity (ω_{err}) from the current velocity measurement. A control function (K_2) will be used to determine this velocity error which is scaled based on the error in tension as well as the integral and derivative of the tension error. The output of the motor will be an angular velocity that forces the measured tension to the desired value. Because of the number of variables affecting the system, uncertainties in the system dynamics as well as in the sensor response, it makes it difficult to design the controller (K_2) based on desired results. The MATLAB system identification (SYSID) program allows for a system model to be determined experimentally, regardless of knowledge of the system. To use the program, a range of recorded inputs are compared to a time synced output measurement. The program takes these values and constrains the system to a likely system model. The larger boxed in area represents the part of the block diagram that would be replaced with an effective system model transfer function.

SYSID will be fed a range of input angular velocity errors and their associated output tension. To vary the value of inputs across a given range, a sinusoidal waveform will be used. Given this SYSID model, a closed loop transfer function can be acquired from T_{des} to T_{meas} which would allow for controller design based on results such as rise time, percent overshoot, settle time, etc. Figure 26 shows how the block diagram is grouped into a single box that represents the transfer function obtained from MATLAB

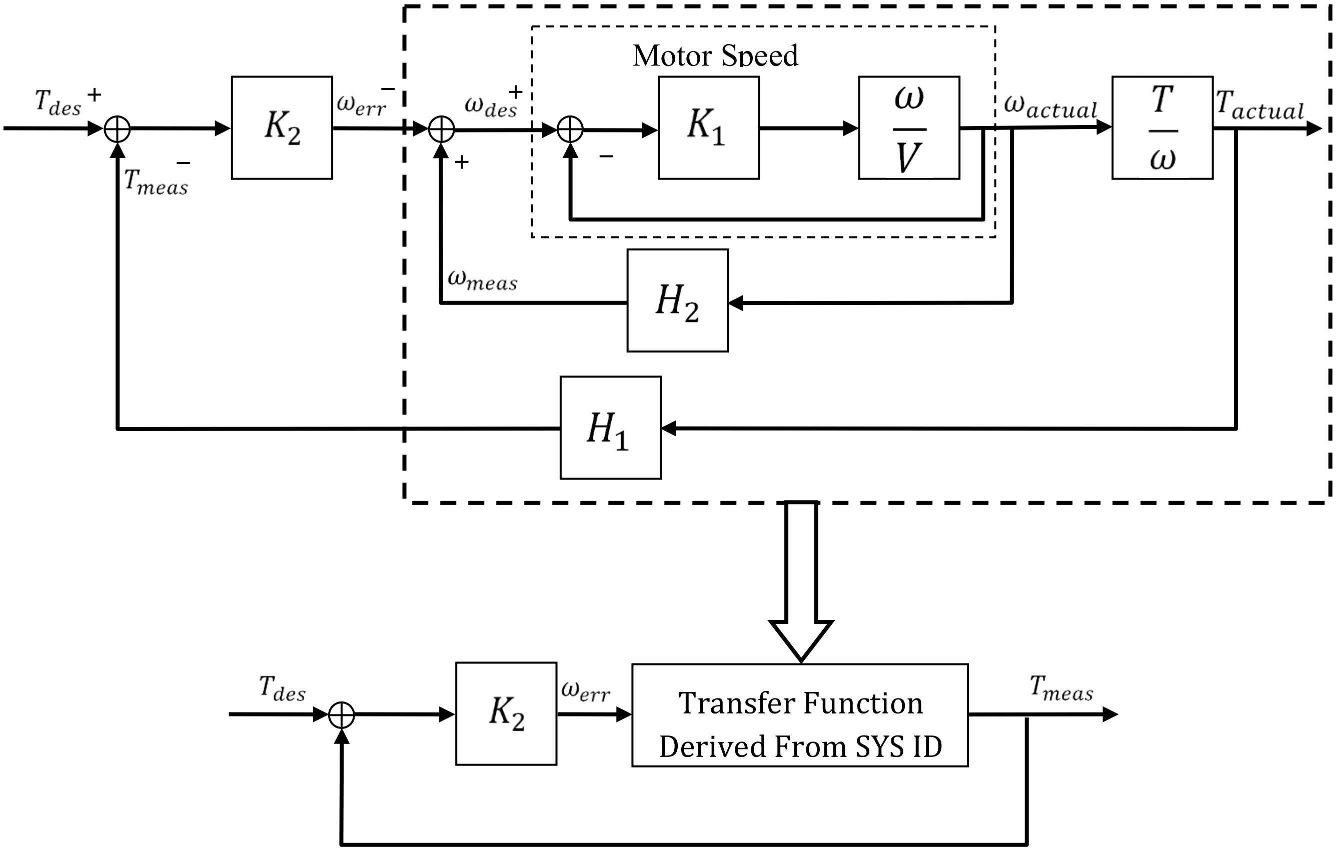
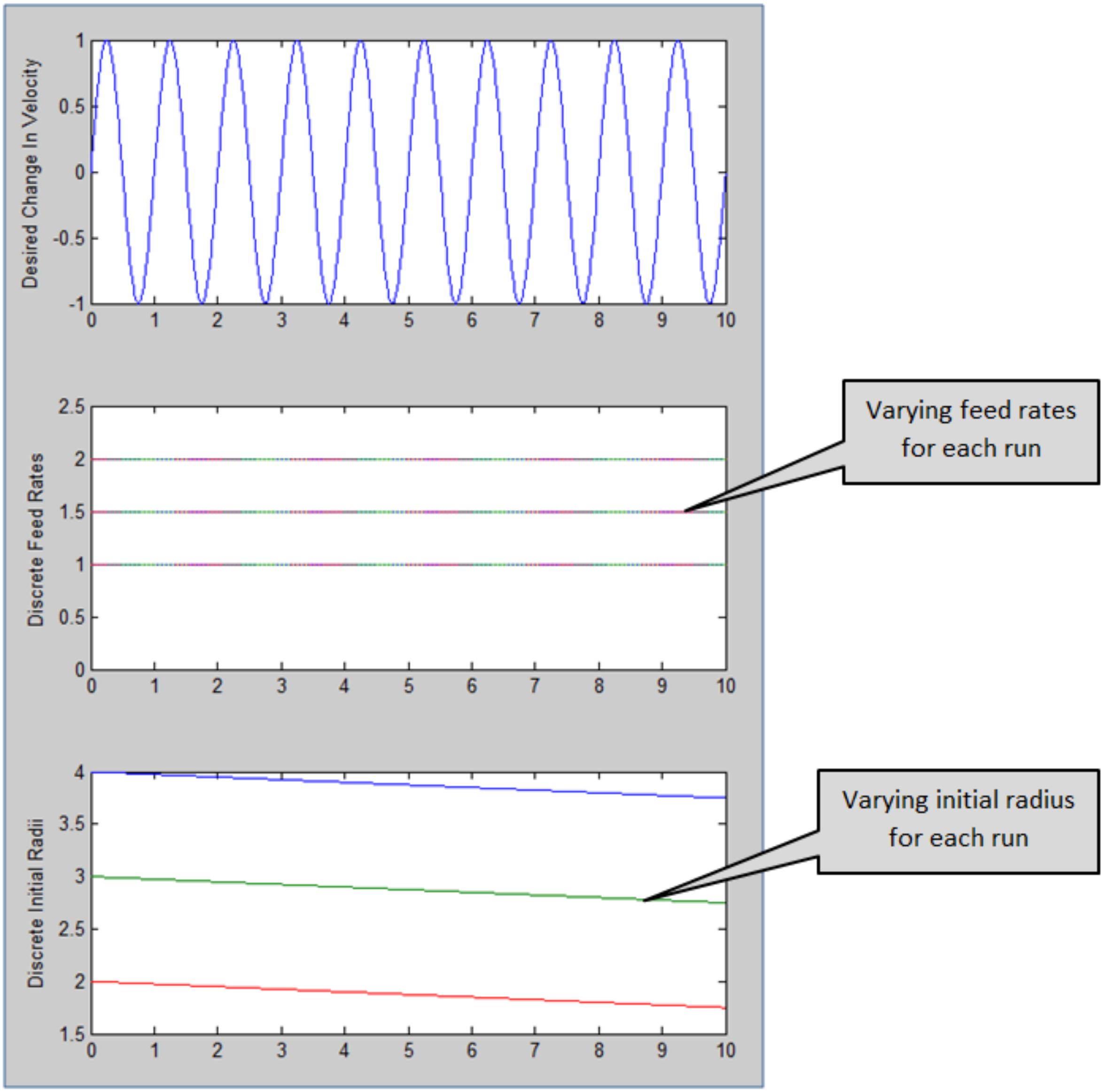


Figure 26: SYS ID Representation

When testing the system, a variety of situations will need to be considered. SYSID program will be used multiple times with increasing feed rate values for each run. By observing the results and seeing how the control gains vary for the same desired results, it can be determined whether these gains need to be compensated for given situation within the controller logic. For example, the controller gains programmed into the Arduino may be a function of angular velocity of the spool. The same can be done with varying radius of the unwinding spool. If the results show that the radius of the spool has negligible effects on the control gains, it may be possible to eliminate the need for an infrared depth sensor to compensate for various radii. This would depend on the desired accuracy of the system. Figure 27 below shows the SYS ID parameters into the controller.



Varying feed rates for each run

Varying initial radius for each run

Figure 27: SYS ID Parameters

Interfaces and ICD:

Overall, the tension control design is one big subsystem to the thermoplastic application robot. The controls for the tension control cannot interface directly with the robot. 48 VDC of power will be drawn from the robot, and that will be the systems only electrical interface. The tension control subsystem does, however, interface mechanically with the robot extensively. All of the supports for the current spool will be redesigned to incorporate the electrical components and motor of the tension control design. The load sell will also interface with the thermoplastic under the plate in order to measure tension.

The user will interface with the tension control system through the LCD display. Using the display, the user can input a desired tension in lbs. As the robot operates, actual tension can also be read through the LCD display.

Mission Environment:

The major environmental concern that considered during the design of the control system was the different orientations of the end effector of the robot. This affected the selection of many different components within the system. Many tension sensors are sensitive to gravity such as dancer rolls and were thus eliminated from consideration. A second mechanical support for the spool was also added to ensure the control design could deal with sudden movements, orientations, and vibrations.

The temperature of the applicator also had to be taken into consideration. Originally, the design had an optical encoder near the applicator to measure the feed rate. However, because temperatures are around 800°C where thermoplastic is applied, an optical encoder cannot be placed there to determine a feed rate. Using the previously described test apparatus plan to find a direct transfer function should eliminate this problem.

It was also brought to our attention that carbon fiber pieces in the air had potential to short circuit a motor. This was taken into consideration during the search for an adequate motor, and the brushless design chosen should not encounter this problem.

Technical Resource Budget Tracking:

Two main resource budgets had to be tracked: voltage and mass. The voltage requirements are met. Originally it was planned to not use anything higher than 24 VDC. The problem that occurred was a motor that operated off of 24 VDC could not supply a high enough torque to drive the correct amount of tension. After talking to Lance Hall, it was determined that the motor could be supplied with 48 VDC, and a suitable motor was found.

Mass was also a tracked requirement and the breakdown of each component is shown below in Table 2: System Mass Breakdown. It was said that the mass should be no more than around 20 pounds.

Table 2: System Mass Breakdown

Item	Weight (lbs.)
Motor	5.73
Gearbox	6
Motor Driver	1
Optical Encoder	0.25
Tension Sensor	2
Tension Sensor Supports	0.5
IR Sensor	0.25
Electrical Box	1
Display	0.25
Arduino	0.25
DC to DC Converter	0.419
DC to DC Converter	0.419
Vibration Support	2
Total	20.068

Risk Management:

The main risk identified at the Preliminary Design Review was the potential to not meet weight or special requirements. As demonstrated by 3D modeling, special requirements were met. The weight limit of 20 lbs. was also reached, as the actual design will add roughly 20.1 lbs. to the current system. The budget for the project was set by the team as $5,000, and with a final cost of $3352.86 this limit was not exceeded. There will probably be some unforeseen expenses, but the majority of the expenses are shown in this number. However, since there was no finite budget that needed to be kept, the costs will be taken into consideration but not used as an element of risk.

Other risks being dealt with in the project involve the actual control design. At the moment, the control design has been simulated using MATLAB, but has not been physically tested. This is a major reason for the construction of the test apparatus. The apparatus will not only be used to back out a transfer function for the block diagram, but also to test the final control design. Any unforeseen problems that might arise should be recognized and troubleshot during this initial testing phase. Once the group is confident the system will work, the design can be implemented to the robot in Huntsville.

Configuration Management and Documentation:

Our team has developed a system of Configuration Management and Documentation which includes the use of a shared Dropbox account amongst the team members in addition to a physical composition notebook which contains a daily log of our activity. The Dropbox folder has many advantages over using a university computer network or equivalent file management architecture. One such advantage is the readily available and stable cross-platform smartphone applications that can be downloaded to each member’s phone (five iPhones and two Android devices). The files uploaded to Dropbox are updated in real time and pushed to each person’s individual account. The team has found this advantageous because we can simply take pictures of the designs or brainstorming activity that we collectively think of and upload them to the shared folder straight from our phones. Another advantage is that the notes, design sketches, data tables, CAD models and MATLAB test code are available to access from any web enabled device.

The composition engineering notebook that is kept up-to-date by the team’s assigned scribe (Kellie Coker) is a log of the team’s collective achievements. It consists of dated entries cataloging the members in attendance as well as design drawings, a summary of group activity, notes, unanswered questions, and any other relevant design or project related material. The notebook provides the team with a means for recording progress and a central reference point for what has already been attempted or what remains to be accomplished. This differs from the Dropbox account because the Dropbox account only maintains the latest version of whichever document is uploaded to it. The project notebook contains different, dated versions of the design process which is useful because the design process is inherently cyclical.

Subsystems Design Engineering:

There are too many prints to present in the body of the report so all the prints are contained in a separate binder.

Project Management:

The project management structure, shown in Figure 28, shows how tasks were assigned based on given specialties of each of the group members. Although each member had an area they were assigned to, collaboration was always necessary to ensure that the final design system would work as a whole. Regular group meetings allowed for individual work to be accomplished while providing accessibility between group members. Biweekly meetings with the group Technical Advisor, Dr. Beale, also helped the group stay on task and get some of the more complicated questions answered.

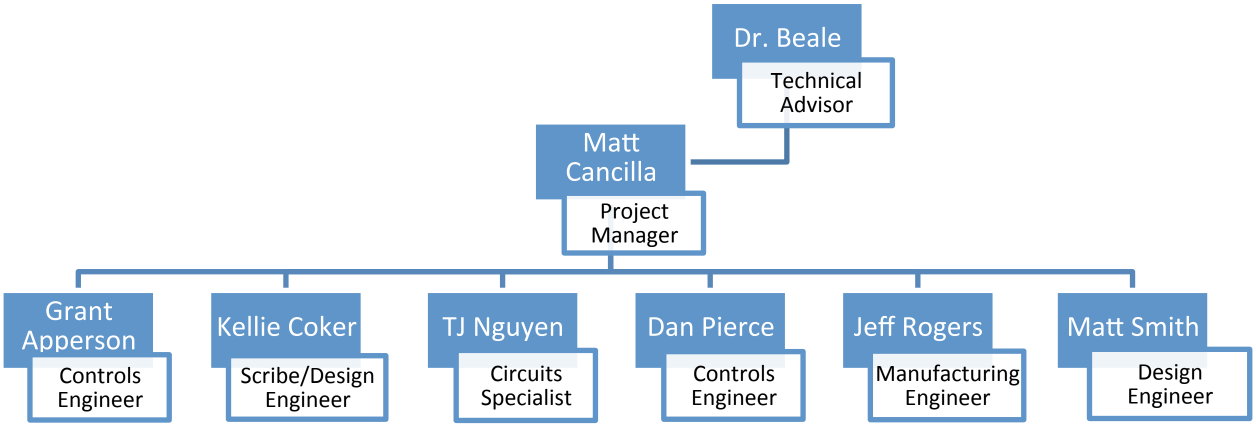


Figure 28: Project Management Structure

The bill of materials, shown in Table 3, has been broken up into items purchased specifically for the test apparatus, items used specifically for the final design, and items used for both. Most of the items used for the final design will come directly from the test apparatus. The extra motor in the test apparatus will serve as a backup motor for the final system.

Table 3: Bill of Materials

BOM					
Decription	**Source**	**Part Number**	**Qty**	**Unit Price**	**Total Price**
Male Rod End Bearings, 1/2-20, RH	Grainger	5RKD6	4	14.48	57.92
Perforated Steel Tubing, 1-1/2"W. 1-1/2"H, .083" Wall Thickness, 6' L	McMaster-Carr	6535K25	5	26.64	133.20
Stamped-Steel Mounted Ball Bearing--ABEC-1, 2-Bolt Base Mount, for 1" Shaft Diameter	McMaster-Carr	5913K64	4	12.69	50.76
Fully Keyed 1045 Steel Drive Shaft, 1" OD, 1/4" Keyway Width, 18" Length	McMaster-Carr	1497K961	2	35.48	70.96
Square U-Bolt, Zinc-Plated Steel, for 4" W, 6-5/8" L Inside, 1090# Work Load Limit	McMaster-Carr	3060T49	2	3.86	7.72
Multipurpose Aluminum (Alloy 6061) Rectangle Tube, 1/8" Wall Thickness, 2" X 3", 3' Length	McMaster-Carr	6546K412	1	38.92	38.92
Grade 8 Alloy Steel Hex Head Cap Screw, Zinc Yellow-Plated, 3/8"-16 Thread, 3-1/2" Length, packs of 10	McMaster-Carr	91257A638	3	8.42	25.23
Grade 5 Zinc-Plated Steel Hex Head Cap Screw, 3/8"-16 Thread, 2-1/4" Length, packs of 25	McMaster-Carr	91247A633	1	8.06	8.06
Plain Grade 8 Steel Hex Nut, 3/8"-16 Thread Size, 9/16" Width, 21/64" Height, packs of 100	McMaster-Carr	90499A031	1	6.51	6.51
Clamping U-Bolt, Steel, 3/8"-16 Thread, for 3-1/4" Outside Diameter	McMaster-Carr	3042T19	2	2.53	5.06
Zinc-Plated Steel Type A USS Flat Washer, 3/8" Screw Size, 1" OD, .06"-.11" Thick, packs of 100	McMaster-Carr	90108A417	11	6.65	6.65
1.5" OD, 0.5" ID Pulley	McMaster-Carr	6245K6	2	3.79	7.58
7" OD, 1" ID Pulley	McMaster-Carr	6245K74	2	13.90	27.80
4L Belt 0.5" x 5/16" x 32 3/4"	McMaster-Carr	6191K81	2	5.54	11.08
1" Bore Steel Flanged Shaft Collar	McMaster-Carr	9684T4	2	37.38	74.76
Adapter Ring 4 1/4" OD	McMaster-Carr	9684T24	1	33.45	33.45
3/8" shaft diameter self lubricating Al-mounted Bearing PTFE - filled bronze	McMaster-Carr	2820T5	2	12.47	24.94
10-24 cap screw	McMaster-Carr	91274A112	1	8.74	8.74
10-24 flanged nut	McMaster-Carr	93298A108	1	6.74	6.74
5.5"x3'x.625" Gen purpose low carbon steel	McMaster-Carr	8910K434	1	46.86	46.86
Al 2024 bar	McMaster-Carr	89215K345	1	84.53	84.53
Al 6061 rod	McMaster-Carr	8974K181	1	12.78	12.78
Rod End Bearing	Omega	REC-012M	1	45.00	45.00
Reciprocating Saw	O'Reilly	APT2003	1	59.99	59.99
Saw Blades	O'Reilly	7624	5	3.99	19.95
48VDC 12.5A 600W Regulated Power Supply	Parts Express	PS-SP11142	1	129.00	129.00
Cables	Robot Shop			8.00	8.00
				TEST TOTAL	1012.186
Decription	**Source**	**Part Number**	**Qty**	**Unit Price**	**Total Price**
BLY34 - Brushless Motor	Anaheim Automation	BLY343S-48V-3200	2	368.00	736.00
Brushless Speed Controllers - Under 1 HP	Anaheim Automation	MDC151-012601	2	307.00	614.00
DC/DC converter 48-24	Mouser	709-PSD45C-24	1	22.20	22.20
DC/DC converter 24-12	Mouser	580-UEI30-120-Q12P-C	1	46.42	46.42
ARDUINO MEGA2560 REV 3	Mouser	782-A000067	1	38.95	38.95
Cantilever Load Cell	Omega	LC511-100	1	350.00	350.00
Twist Lock Connector	Omega	PT06F10-65	1	26.50	26.50
DIN Rail Version Transducer Signal Conditioner	Tension Measurement, MC	SGA21-25	1	295.00	295.00
Encoders	US Digital	E3-1024-1000-NE-H-D-B	2	105.80	211.60
				TEST & FINAL TOTAL	2340.67
Decription	**Source**	**Part Number**	**Qty**	**Unit Price**	**Total Price**
25:1 90° Gear Box	Wittenstein	HG060S-MF2-25	1	Get Quote	Get Quote
				FINAL TOTAL	0
				OVERALL TOTAL	3352.856

Future plans consist of the continued building and testing of the test apparatus and the tentative schedule can be shown below in Table 4. Fabrication of motor mounts and load cell supports will be required to complete the build of the test apparatus. Once these parts are fabricated and all of the purchased materials are received the construction of the test apparatus should not take more than a few days. After the construction is complete the testing can begin immediately as described in the Validate and Verify section of the report. The goal behind testing will be to back out that transfer function and to correct any unforeseen issues before final implementation. While the testing phase is being completed fabrication can begin for both of the supports and the spool shaft. Once sufficient testing on the apparatus is done the trip will be made to Huntsville for a final implementation and presentation of the design. An outline for the plans for next semester is shown below. Note that five weeks have been allotted for any unforeseen problems that arise.

Table 4: Future Work

Week	Task 1	Task 2	Task 3
7-Jan-13	Build Test Apparatus	Design PCB for Electrical Box	
14-Jan-13	Build Test Apparatus	Design PCB for Electrical Box	
21-Jan-13	Testing on Apparatus	Manufacture Components for Final Design	Order Parts for New Electrical Box
28-Jan-13	Testing on Apparatus	Manufacture Components for Final Design	
4-Feb-13	Testing on Apparatus	Manufacture Components for Final Design	Solder PCB Board
11-Feb-13	Test New PCB on apparatus		
18-Feb-13			
25-Feb-13	Initial Implimentation in Huntsville		
4-Mar-13	Any Required Redesign		
11-Mar-13	Any Required Redesign		
18-Mar-13	Final Implementation in Huntsville		
25-Mar-13			
1-Apr-13			
8-Apr-13			
15-Apr-13			
22-Apr-13			

Conclusion:

The group has confidence that the design described above will adequately perform all of the requirements and functions decided upon at the beginning of the project. The chosen tension sensor will be able to sense tension up to 100 lbs. which exceeds the 50 lbs. requirement. The motor fits both the voltage limitations and torque requirements. Command and data handling has been shown through circuit design that all signals will be accounted for to ensure that the system works correctly, as described in the concepts of operation.

Even though the group is satisfied with the design to date, continuous improvement is what will make the design truly impressive. Although confidence is expressed in the proposed detail design, the group is open to any updating or redesigning required to improve the system. A potential redesign of the electrical box is already being looked into for spatial concerns. As more and more testing is done modifications to the overall design may become necessary.

With a design this complicated, it is one thing to ensure that the design is operable on paper, but entirely another to make sure the design works in the real world. The testing design done at the beginning of next semester will prove everything done on paper is accurate. It will also allow any potential problems to be troubleshot before the final design is implemented.

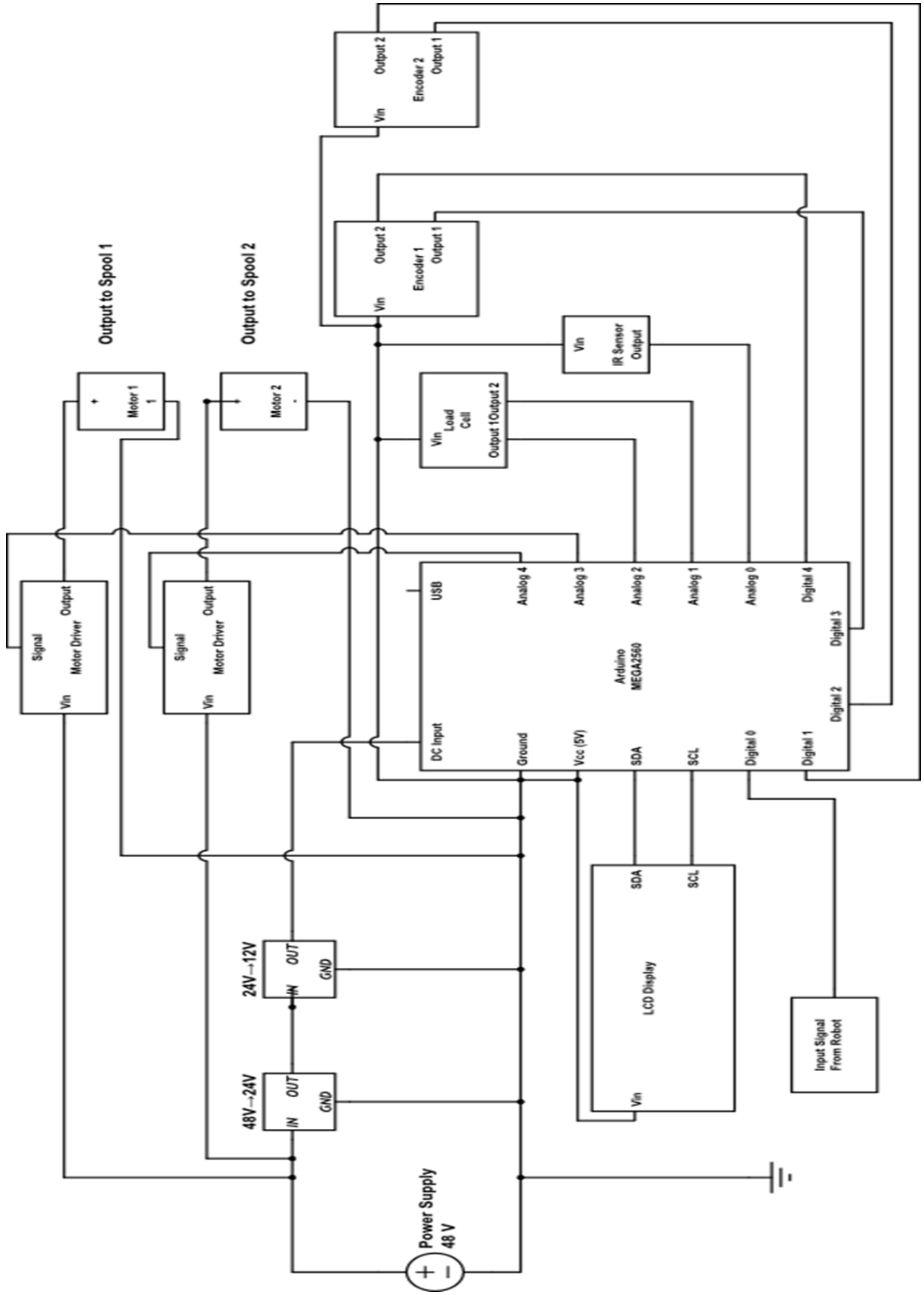
Appendix A: Motor Simulation

```
% Model with Speed Motor Controller
% Assuming perfect motor controller and neglecting system dynamics

clear
clear plots
clc
dt=.001;
tfinal=.24;
time=0:dt:tfinal;
k_stiff=500; % lbf/in

%Motor Constants
L=.00048; % Motor Inductance [H]
R=.2; % Motor Resistance [ohms]
nG=25; % Gearing Ratio [25:1]
KT=1.125*nG; % Motor Torque Constant w/ gearing ratio factor in (18 [oz-in/A]
= 1.125 [in-lb/A] )
KB=.129*nG; % Back EMF Constant w/ gearing ratio factor  (13.5[V/kRPM] = .129
[V-s/rad] )

V_max=48; % Max Voltage [V]

J_motor=0.5468; % Motor Rotor Intertia [lbm-in^2]
J_gearbox=50; % Estimated
J_spool=250;
J_tot=J_spool+J_gearbox+J_motor;

b=20; % Bearing Damping Coefficient [lbf-s/rad]
r=4; % Radius Of Spool [in]

k_p=4; % Proportional Gain
k_d=.1; % Derivative Gain
k_i=4; % Integral Gain

% k_p=4; % Proportional Gain
% k_d=.1; % Derivative Gain
% k_i=4; % Integral Gain

%x_feed_rate=4+sin(2*pi*time); % [in/s]
x_feed_rate(1:81)=0;
x_feed_rate(82:length(time))=3;

Tension_des(1:length(time))=50;% Desired Tension [lbf]
%Tension_des=15+7*sin((pi/2)*time);  % Harmonic Desired Tension

theta(1)=0; % Initial Position of Spool [rad]
x_feed(1)=0; % Initial Feed Position [in]
I(1)=0; % Initial Motor Current [A]
w(1)=0; % Initial Spool Velocity [rad/s]
dT_err(1)=0;
int_err(1)=0;
```

```
for i=1:(length(time)-1)
    x_spool(i)=theta(i)*r;

    Tension(i)=k_stiff*(x_feed(i)-x_spool(i));
    T_err(i)=Tension_des(i)-Tension(i);

    if i>1
        dT_err(i)=(T_err(i)-T_err(i-1))/dt;
    end

    V(i)=k_p*T_err(i)+k_d*dT_err(i)+k_i*int_err(i); % the amount angular
velocity needs to change
    if V(i)>V_max;
        V(i)=V_max;
    else if V(i)<-V_max
            V(i)=-V_max;
        end
    end
    %%%%%%%%%%%%%%%%%%%%%%% Motor Driver %%%%%%%%%%%%%%%%%%%%%%%%%%%
    % From TF
%     ddw(i)=(V(i)*KT-(b*L+J_tot*R)*dw(i)-(b*R+KT*KB)*w(i))/(J_tot*L);
%     dw(i+1)=dw(i)+ddw(i)*dt;
%     w(i+1)=w(i)+dw(i)*dt;
    % From equations
    dI(i)=(V(i)-KB*w(i)-R*I(i))/L;
    I(i+1)=I(i)+dI(i)*dt;
    dw(i)=(-KT*I(i)+Tension(i)*r-b*w(i))/J_tot;
    w(i+1)=w(i)+dw(i)*dt;
    %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
    int_err(i+1)=int_err(i)+T_err(i)*dt;

    theta(i+1)=theta(i)+(w(i+1)+w(i))*(dt/2);
    x_feed(i+1)=x_feed(i)+(x_feed_rate(i+1)+x_feed_rate(i))*(dt/2);
end

x_spool(i+1)=theta(i+1)*r;
Tension(i+1)=k_stiff*(x_feed(i+1)-x_spool(i+1));
V(i+1)=V(i);

SSerr=Tension_des(i)-Tension(i);

hold on
subplot(3,1,1)

plot(time,x_feed_rate)
axis([0 time(length(time)) 0 5])
%plot(time,x_feed_rate,'r',time,w.*r,'b')
ylabel('Input Feed Rate [in/s]')
%legend('Input Feed','Spool Feed')

subplot(3,1,2)
plot(time,Tension,'b',time,Tension_des,'r-')
ylabel('Tension [lbf]')
legend('Actual Tension','Desired Tension')
hold off
```

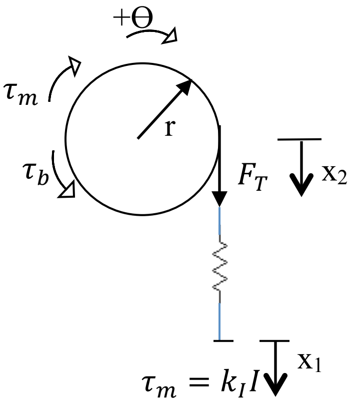
```
subplot(3,1,3)
plot(time,V)
ylabel('Motor Voltage [V]')
xlabel('time [s]')
hold off
```

Appendix B: Electrical Circuit



Appendix C: Modeling

	Description
J	Motor Moment of Intertia
θ	Motor Angular Position
k_T	Stiffness of Thermoplastic
x_1	Applicator Feed
x_2	Actuator Feed
r	Spool Radius
τ_m	Motor Torque
τ_b	Damping Torque
F_T	Tension Force
V_{In}	Input Voltage
V_L	Voltage over Inductor
R	Resistor
I	Current
L	Inductor
e_b	Back EMF Constant
k_I	Motor Torque Constant



$$\tau_m = k_I I$$

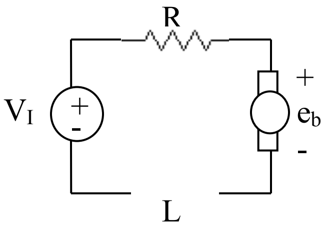
$$\tau_b = b\dot{\theta}$$

$$x_2 = r\theta$$

$$F_T = k_T(x_1 - x_2)$$

$$\Sigma M = J\ddot{\theta} = F_T r - \tau_m - \tau_b$$

$$J\ddot{\theta} = k_T x_1 r + k_T r^2\theta - k_I I$$



$$e_b = k_b\dot{\theta}$$

$$V_L = L\dot{I}$$

$$V_{In} = IR + e_b + V_L$$

$$L\dot{I} + IR = V_{In} - k_b\dot{\theta}$$

$$I(s)[Ls + R] = V_{In} - k_b s\theta(s)$$

$$\theta(s)[Js^2 + \left(b - \frac{k_I k_b}{LS + R}\right)s + k_T r^2 = k_T r x_1(s) - \frac{k_I}{LS + R} V_{In}(s)$$

With X_1=0,

$$\theta(s)[Js^2 + bs + k_T r^2] = \frac{-k_I(V_{In}(s) - k_b s\theta(s))}{LS + R}$$

$$\frac{\theta(s)}{V_{In}(s)} = \frac{-k_I}{JLs^3 + (JR + bL)s^2 + (bR + k_T r^2 L - k_I k_b)s + k_T r^2 R}$$

Appendix D: Controller Simulation

```
clc;clear all;close all;

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%               constants
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
time_step=.01; %sec
test_duration=4; %sec
material_thickness=.005; %in
time=0:time_step:test_duration;
material_stiffness=1000; %lbf/in
material_width=1/4; %in

%Motor Constants
L=.48; % Motor Inductance [H]
R=.2; % Motor Resistance [ohms]
nG=25; % Gearing Ratio
KT=1.125*nG; % motor torque constant w/ gearing ratio factored in (18 [oz-
in/A] = 1.125 [in-lb/A] )
KB=.129*nG; % back emf constant w/ gearing ratio factored in  (13.5[V/kRPM] =
.129 [V-s/rad] )

Vi_max=48; % max voltage intake [V]

J_motor=0.5468; %lbm*in^2 Motor Rotor Intertia OLD WAS 51.59 [lbm-in^2]????
J_gearbox=50; % fudge

%Motor Encoder Constants
enc_BW=10000; %Hz

%Spool Constants
spool_rad_init=4; %in
spool_length=6; %in
material_density=.0643 ;%lbm/in^3


%Rod Constants
rod_rad=.375; %in
rod_length=18; %in
rod_mass=5; %lbm
J_rod=rod_mass*(3*rod_rad^2+rod_length^2)/12; %lbm*in^2

%Ball Bearing Constant
b=10; %lbf-s/rad -> ball bearing damping

%desired Tension
Tension_des(1:length(time))=50;%lbf
%Tension_des=15+7*sin((pi/2)*time);  % harmonic reference tension

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%         Initial Conditions
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

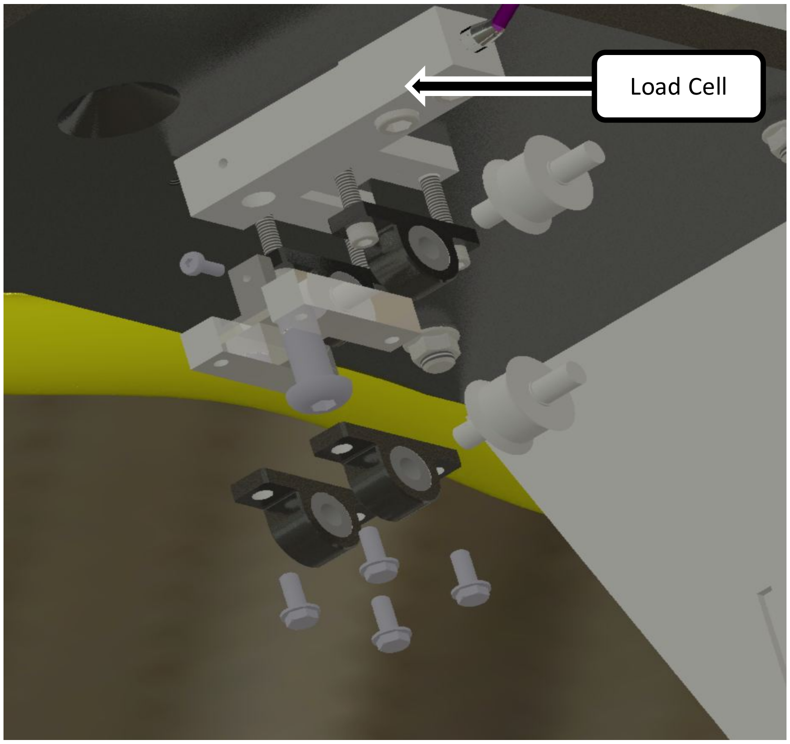
```
spool_rad=spool_rad_init;
spool_mass=material_density*spool_length*pi*spool_rad^2; %lbm
J_spool=spool_mass*(3*spool_rad^2+spool_length^2)/12; %lbm*in^2
J_total=J_spool+J_rod+J_motor+J_gearbox; %lbm*in^2

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%     Simulating Material Feed
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%X_feed_rate=2*square(time,75)+2; %in/s
X_feed_rate=0.5*ones(length(time));
%X_feed_rate=1-cos((pi/2)*time); % harmonic feed rate

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%           preallocating
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
X_feed=zeros(1,length(time));
theta=zeros(1,length(time));

%dtheta=zeros(1,length(time));
%dtheta(1)=X_feed_rate(1)/spool_rad; % if spool starts with same velocity as
feed
dtheta(1)=0;
ddtheta=zeros(1,length(time));
dddtheta=zeros(1,length(time));
theta_error=zeros(1,length(time));
dtheta_error=zeros(1,length(time));
theta_des=zeros(1,length(time));
Tension_error=zeros(1,length(time));
Tension_Meas=zeros(1,length(time));
dTension_Meas=zeros(1,length(time));
Vi=zeros(1,length (time));
int_theta_error=zeros(1,length(time));




%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%          Controller Design
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

%plant TF:  theta(s)/V(s)
% num=-KT;
%
den=[L*J_total,J_total*R+L*b,R*b+L*material_stiffness*spool_rad+KB*KT,R*mater
ial_stiffness*spool_rad^2];
% H_plant=tf(num,den);
%
% %Sensor Dynamics
% Num_sensor=1;
% Den_sensor=1;
% %Den_sensor=[1,enc_BW*2*pi];
% H_sensor=tf(Num_sensor,Den_sensor);
%
```

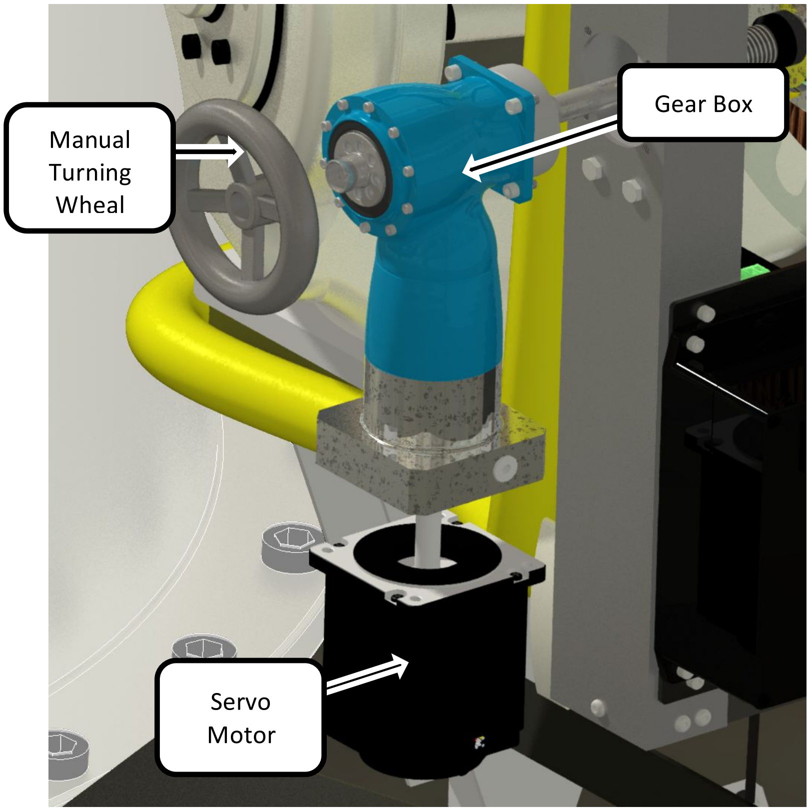
```
% %PD Controller TF:
controller_a=.001;
controller_b=.01;
% H_controller=tf([1,controller_a,controller_b],[1,0]);
% A=(1/material_stiffness*spool_rad);
% H=A;
%H_LT=-*H_plant*H_sensor*H_controller;


%rootlocus
%rlocus(H_LT)
K=-1;
% %Simulating step Response
% H_FP=K*H_controller*H_plant;
% H_FB=H_sensor;
% H_CL=feedback(H_FP,H_FB);
% figure
% %step(H_CL);
% eig_CL=eig(H_CL);
% figure
% hold on
% grid on
% title('Closed Loop eigenvalues')
% plot(real(eig_CL),imag(eig_CL),'*b')
% hold off

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%        Running Control Loop
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for k=1:length(time)-1
X_feed(k+1)=X_feed(k)+((X_feed_rate(k)+X_feed_rate(k+1))/2)*time_step;
spool_rad(k+1)=spool_rad_init-
(X_feed(k+1)*pi*2*spool_rad(k))/(2*pi*(spool_length/material_width))*material
_thickness; %in
%spool_rad(k+1)=4;
spool_mass=material_density*spool_length*pi*spool_rad(k+1)^2; %lbm
J_spool=spool_mass*(3*spool_rad(k+1)^2+spool_length^2)/12; %lbm*in^2
J_total=J_spool+J_rod+J_motor; %lbm*in^2

% if Tension_error <=0
%     theta_des(k+1)=X_feed(k+1)/spool_rad(k+1);
% elseif Tension_error >0
    theta_des(k+1)=(X_feed(k+1)-
(Tension_error(k)/material_stiffness))/spool_rad(k+1);
% end

%theta_des(k+1)=X_feed(k+1)/spool_rad(k+1)+sin(2*time(k));


dddtheta(k+1)=(-(J_total*R+b*L)*ddtheta(k)-
(R*b+L*material_stiffness*spool_rad(k+1)^2+KB*KT)*dtheta(k)-
(R*material_stiffness*spool_rad(k+1)^2)*theta(k)+X_feed_rate(k+1)*spool_rad(k
+1)*material_stiffness*L+X_feed(k+1)*spool_rad(k+1)*material_stiffness*R-
KT*Vi(k))/(J_total*L);
ddtheta(k+1)=ddtheta(k)+((dddtheta(k+1)+dddtheta(k))/2)*time_step;
```

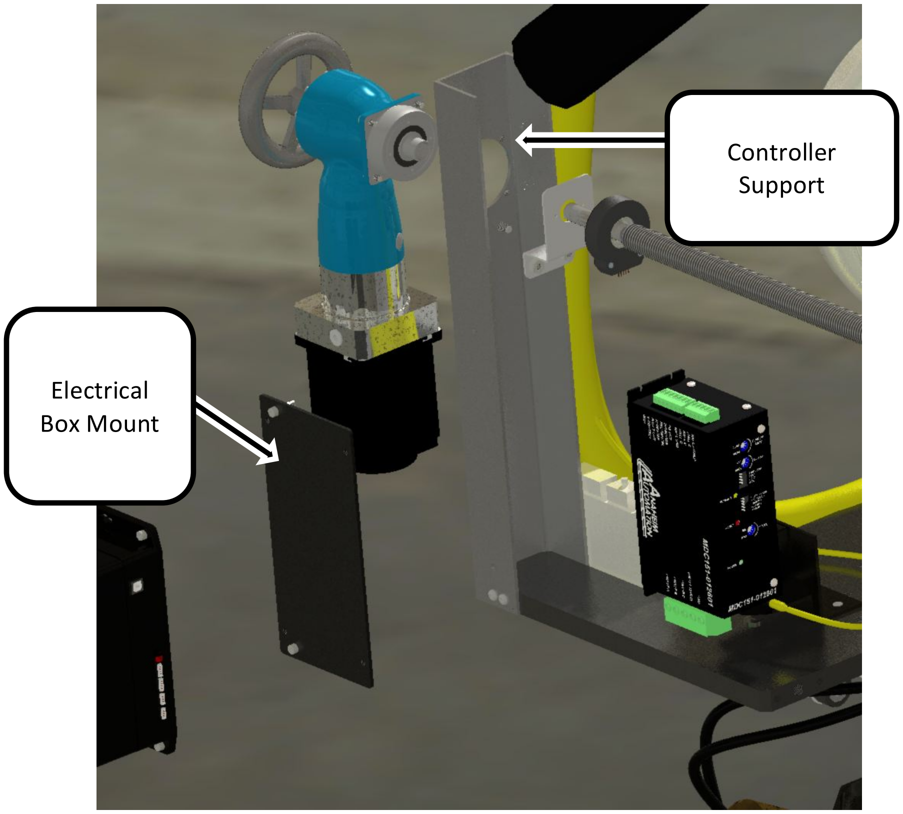
```
dtheta(k+1)=dtheta(k)+((ddtheta(k+1)+ddtheta(k))/2)*time_step;
theta(k+1)=theta(k)+((dtheta(k+1)+dtheta(k))/2)*time_step;


Tension_Meas(k+1)=material_stiffness*((X_feed(k+1)/spool_rad(k+1))-
theta(k+1));


theta_error(k+1)=theta_des(k+1)-theta(k+1);
dtheta_error(k+1)=(theta_error(k+1)-theta_error(k))/time_step;
int_theta_error(k+1)=int_theta_error(k)+((theta_error(k+1)+theta_error(k))/2)
*time_step;

Vi(k+1)=K*(dtheta_error(k+1)+controller_a*theta_error(k+1)+controller_b*int_t
heta_error(k+1));
if Vi(k+1) > Vi_max
    Vi(k+1)=Vi_max;
else if Vi(k+1)< (-Vi_max)
        Vi(k+1)=-Vi_max;
    end
end
Tension_error(k+1)=Tension_des(k+1)-Tension_Meas(k+1);

%     if Vi(k+1)>=0
%         Vi(k+1)=0;
%     elseif Vi(k+1)<-Vi_max
%         Vi(k+1)=-Vi_max;
%
%     end
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%          Plotting Results
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% figure
% subplot(2,1,1)
% plot(time,X_feed_rate)
% ylabel('Feed Rate(in/s)');
% xlabel('time(sec)');
% subplot(2,1,2)
% plot(time,X_feed)
% ylabel('Feed distance(in)');
% xlabel('time(sec)');
%
% figure
% plot(time,theta_des)

figure
% subplot(4,1,1)
% plot(time,dddtheta)
% ylabel('dddtheta(rad/s^3)');
% xlabel('time(sec)');
% subplot(4,1,2)
% plot(time,ddtheta)
% ylabel('ddtheta(rad/s^2)');
```

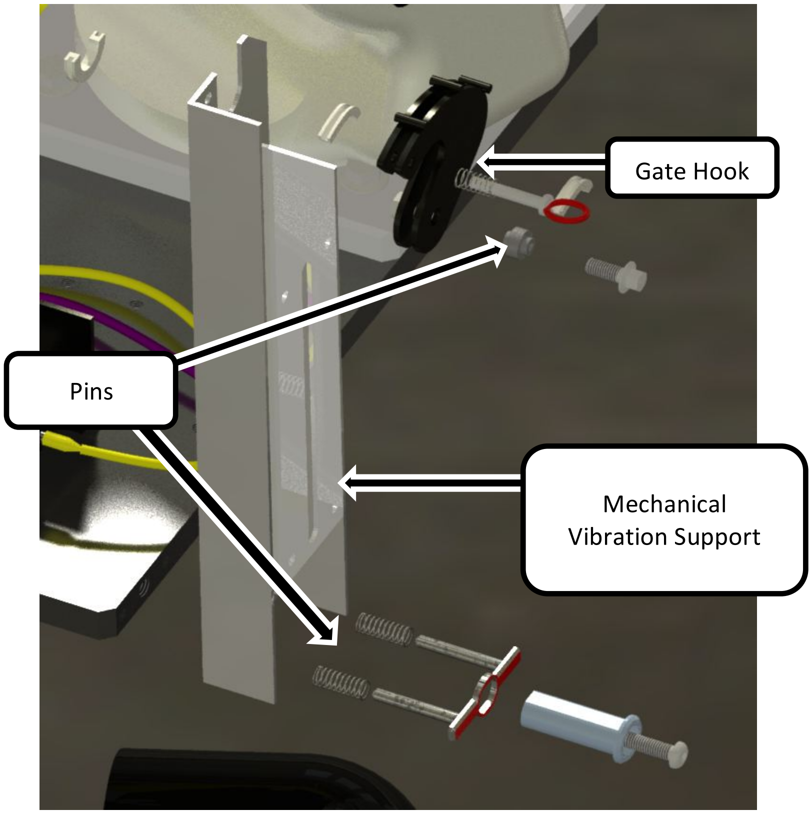
```
% xlabel('time(sec)');
% subplot(4,1,3)
% plot(time,dtheta)
% ylabel('dtheta(rad/s)');
% xlabel('time(sec)');
% subplot(4,1,4)
hold on
title('Position Tracking')
plot(time,theta)
plot(time,theta_des,'r')
ylabel('Theta(rad)');
xlabel('Time(sec)');
legend('Measured Theta','Desired Theta')
hold off

figure
hold on
plot(time,Tension_des,'r');
plot(time,(X_feed-(theta.*spool_rad))*material_stiffness+Tension_Meas);
xlabel('Time (sec)')
ylabel('Tension (lbf)')
legend('Measured Tension','Desired Tension')
hold off

%
figure
hold on
title('Motor input Voltage')
plot(time,Vi)
xlabel('time(sec)');
ylabel('Voltage (V)');
hold off

% figure
% subplot(2,1,1)
% hold on
% title('Measured Tension')
% plot(time,dTension_Meas)
% ylabel('dTension/dt (lbf/s)');
% xlabel('Time (sec)');
% subplot(2,1,2)
% plot(time,Tension_Meas);
% ylabel('Tension (lbf/s)');
% xlabel('Time (sec)');
% hold off
%
%

% %Bode Plots
%
% Loop Transmission
% figure
% bode(H_LT)
```

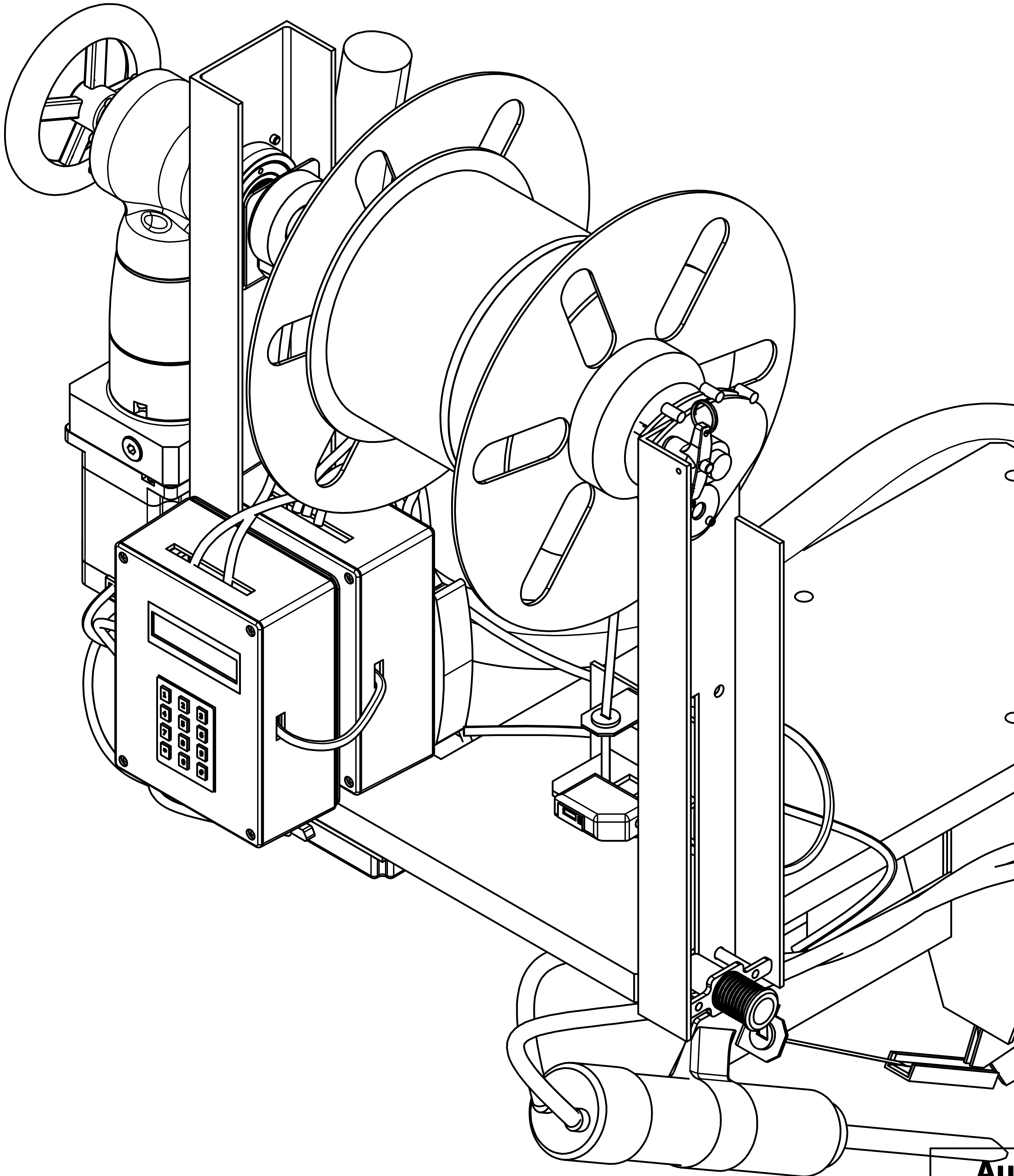
Appendix E: Exploded Views






Controller Support
Electrical Box Mount


Gate Hook
Pins
Mechanical Vibration Support



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THIRD ANGLE PROJECTION

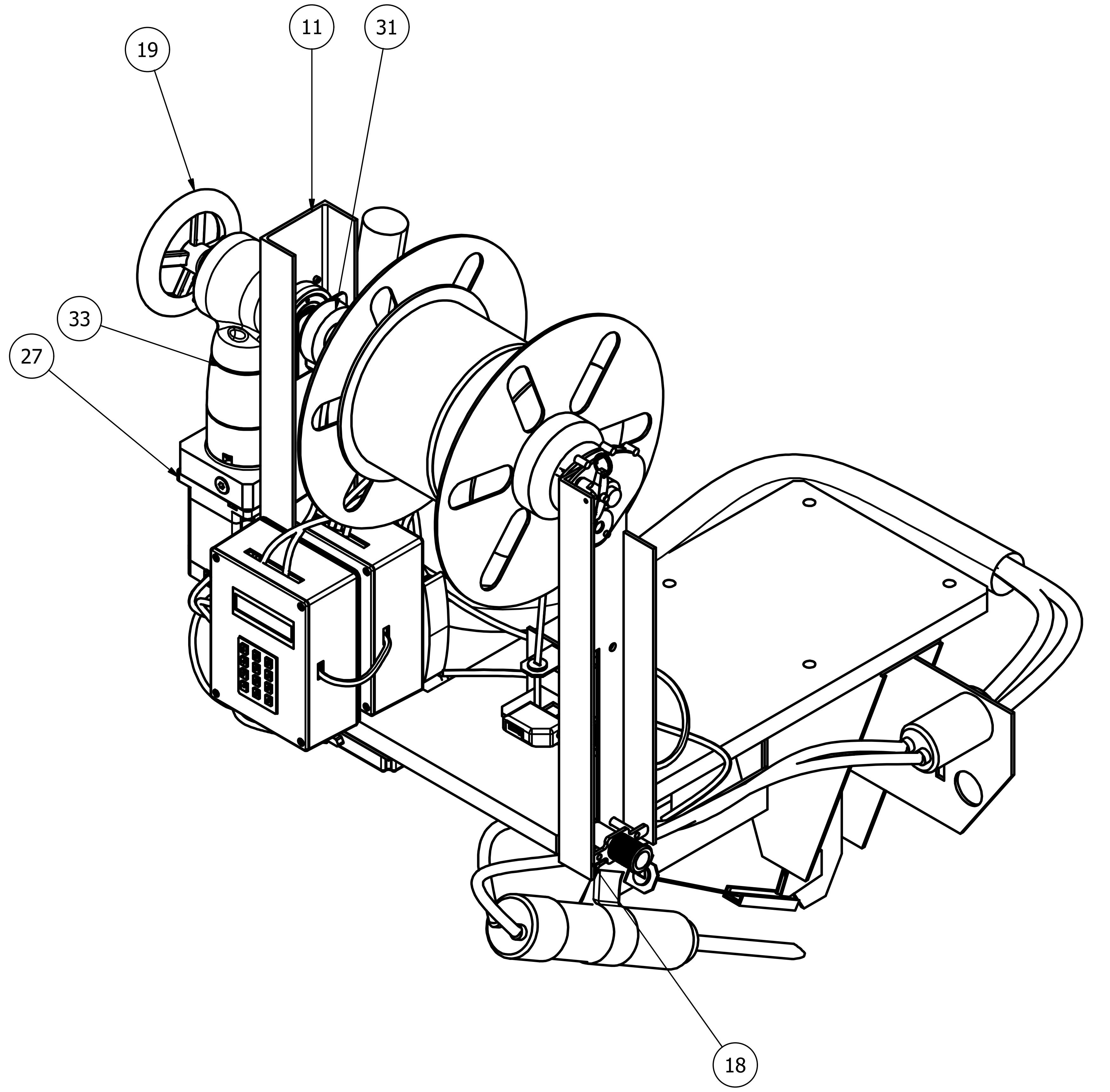
SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/20/2012
APPROVED:
DATE:
MATERIAL:
TITLE: End Effect. Final Design
SHEET: 1 / 2
PART NUMBER: Detailed Design
SCALE: NONE



PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	00-0013	
2	1	00-0014	
3	1	00-0015	
4	1	00-0016	
5	1	00-0017	
6	1	00-0019	
7	1	00-0020	
8	1	00-0021	
9	1	00-0030	Spool Shaft
10	1	00-0034	
11	1	00-0036	Controler Support Arm
12	1	02-0000.noseloom	
13	1	02-0001.heatgun	
14	1	02-0002.colorsensor	
16	1	03-0000	
18	1	06-0003	Vibration Reducing Support Arm
19	1	6033K82	
21	5	ANSI B18.3 - 10 - 24 x 1/8	Hexagon Socket Button Head Cap Screw
23	2	ANSI B18.3 - 8-32 UNC x 0.75	Hexagon Socket Flat Countersunk Head Cap Screw
24	4	ANSI B18.3 - No. 10 - 24 UNC - 1/2 HS HCS	Hexagon Socket Head Cap Screw
27	1	BLY343S	30V DC Brushless Motor
28	1	Base Plate	Base Plate (With Edits)
29	1	Color sensor mount	
30	2	Composite feed plate	
31	1	E3-X-787-X-H-D-X	
32	1	Feed Brkt.	
33	1	HG+060S-MF2-25-6C1	
34	1	LowerCompositeFeed	
36	1	SignalConditioner	
37	1	Spool Assy	
40	1	spool Stop-metal	
41	1	spool Stop-metal left side	
42	2	spool Stop-plastic	
45	1	05-0004	
46	1	06-0016	
47	1	05-0006	Main Electrical Box
48	1	00-0037	Lower Motor Support Brkt
49	2	ANSI B18.3 - 8 - 32 x 1/8	Hexagon Socket Button Head Cap Screw
50	2	ANSI B18.3 - 4 - 40 x 3/8	Hexagon Socket Button Head Cap Screw
51	1	00-0038	Elec. Box Mount
52	3	ANSI B18.6.3 - No. 8 - 32 - 3/16	Cross Recessed Binding Head Machine Screw - Type II
53	1	05-0009	
54	1	Final Final Design.Harness1	
55	1	08-0004	Load Cell Final Design

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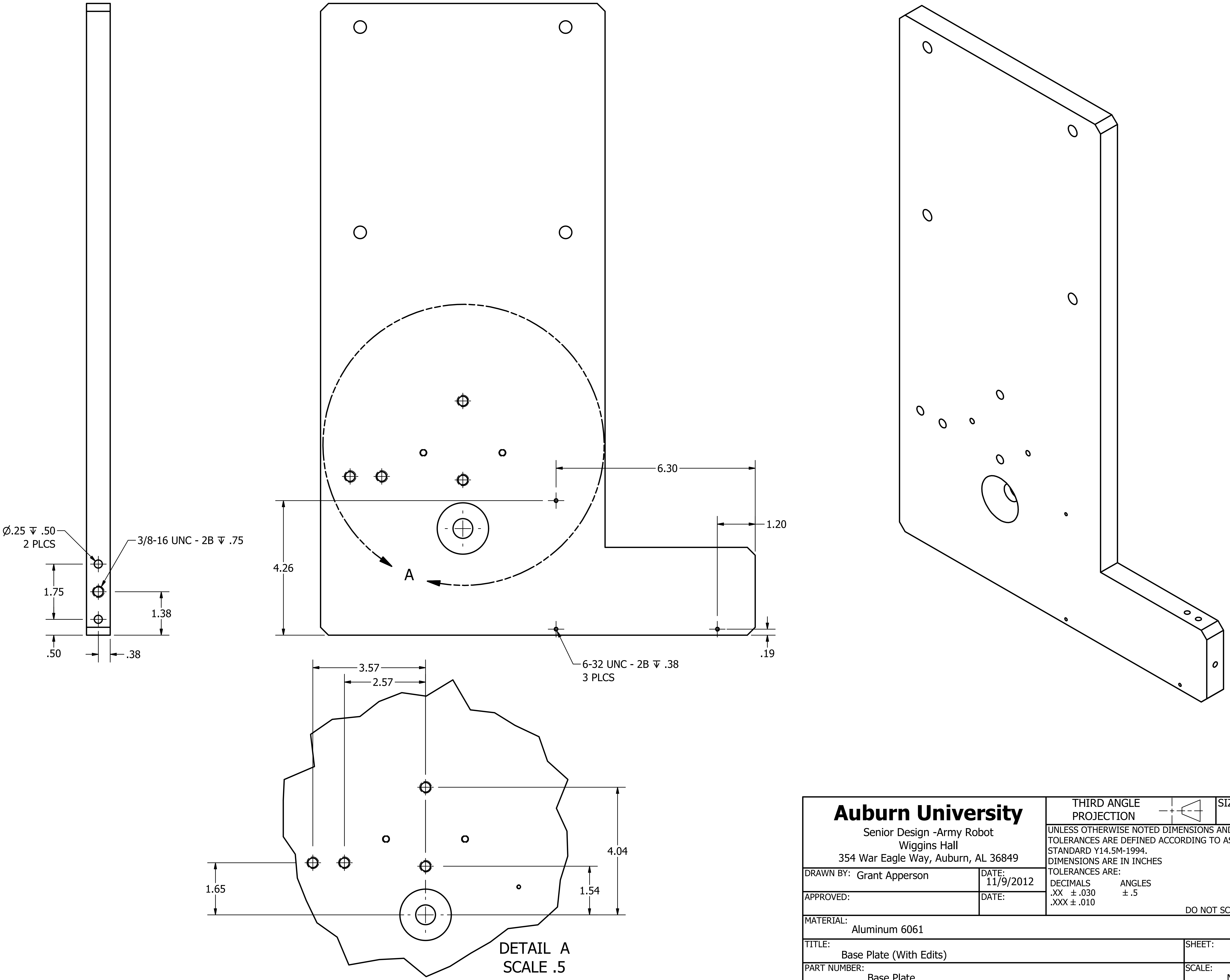
THIRD ANGLE PROJECTION
SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/20/2012
APPROVED:
DATE:
MATERIAL:
TITLE: End Effect. Final Design
SHEET: 2 / 2
PART NUMBER: Detailed Design
SCALE: NONE



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THIRD ANGLE PROJECTION

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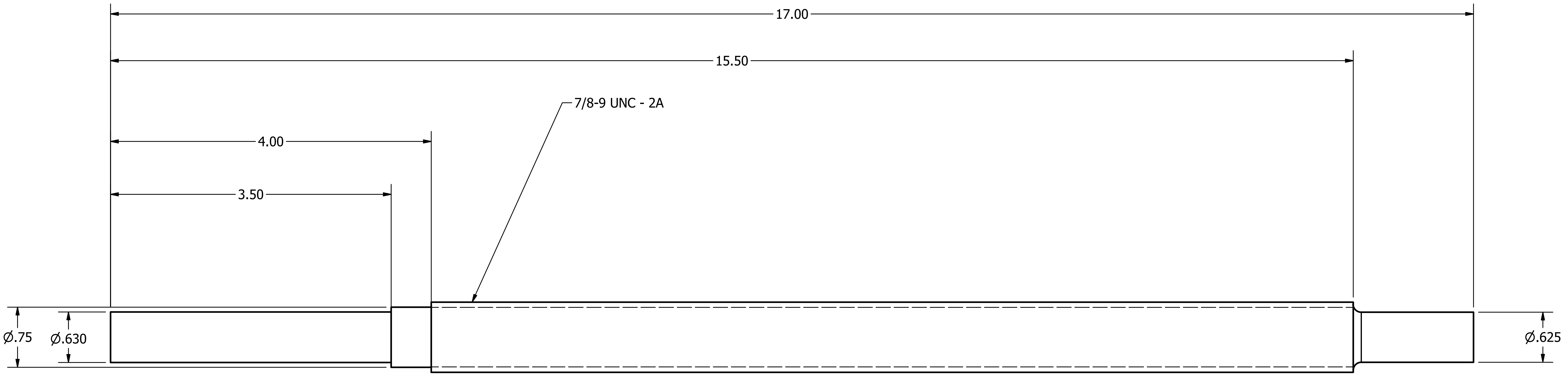
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 11/9/2012
APPROVED:
DATE:
MATERIAL: Aluminum 6061
TITLE: Base Plate (With Edits)
SHEET: 1 / 1
PART NUMBER: Base Plate
SCALE: NONE



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THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

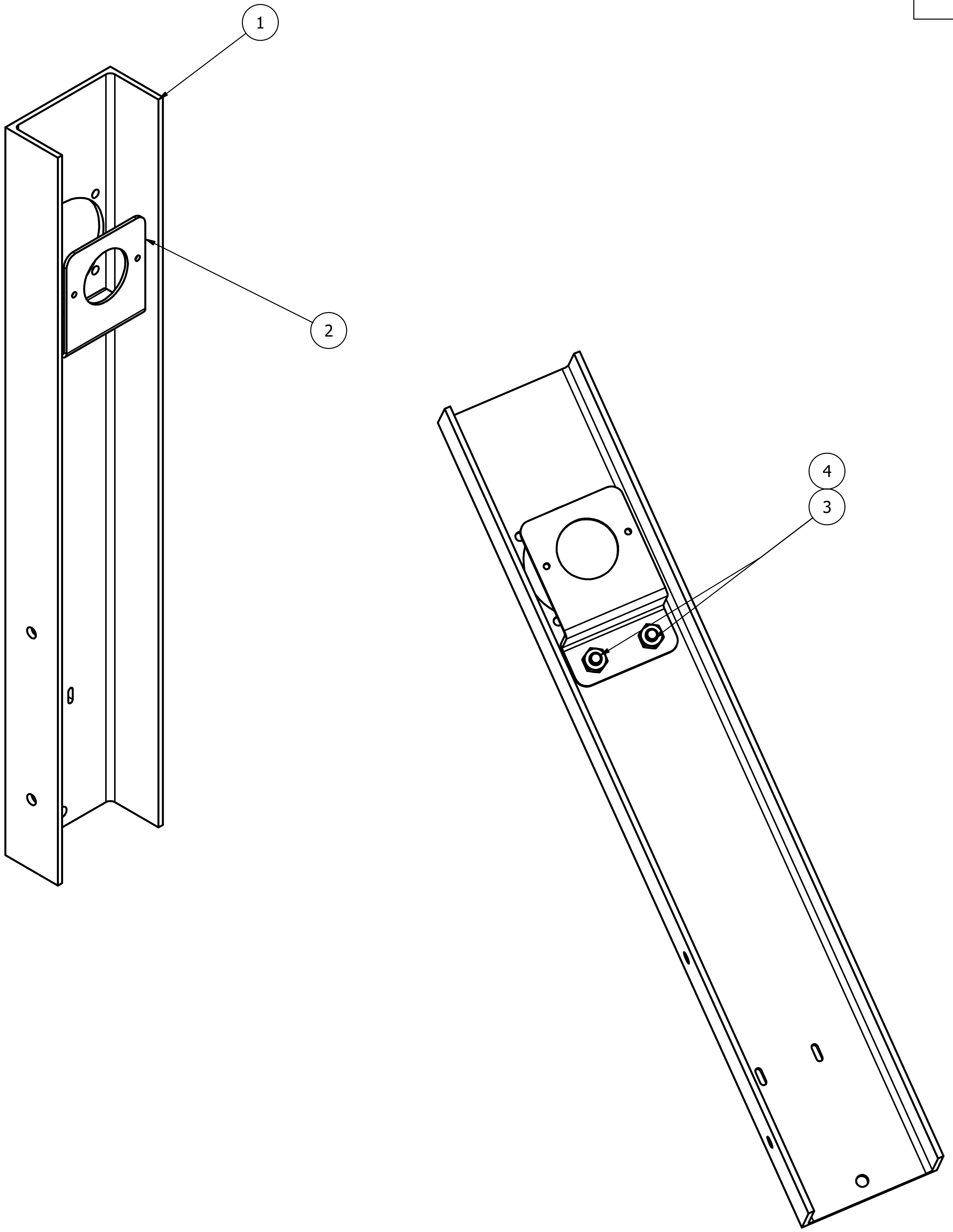
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 11/27/2012
APPROVED:
DATE:
MATERIAL: Stainless Steel
TITLE: Spool Shaft
SHEET: 1 / 1
PART NUMBER: 00-0030
SCALE: NONE

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Vertical Support	Controler Arm Support
2	1	00-0031	Optical Encoder Mnt.
3	2	ANSI B18.2.1 - 1/4-20 UNC - 0.5	Hex Cap Screw
4	2	ANSI B18.2.2 - 1/4 - 20	Hex Nuts (Inch Series) Hex Nut



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THIRD ANGLE PROJECTION

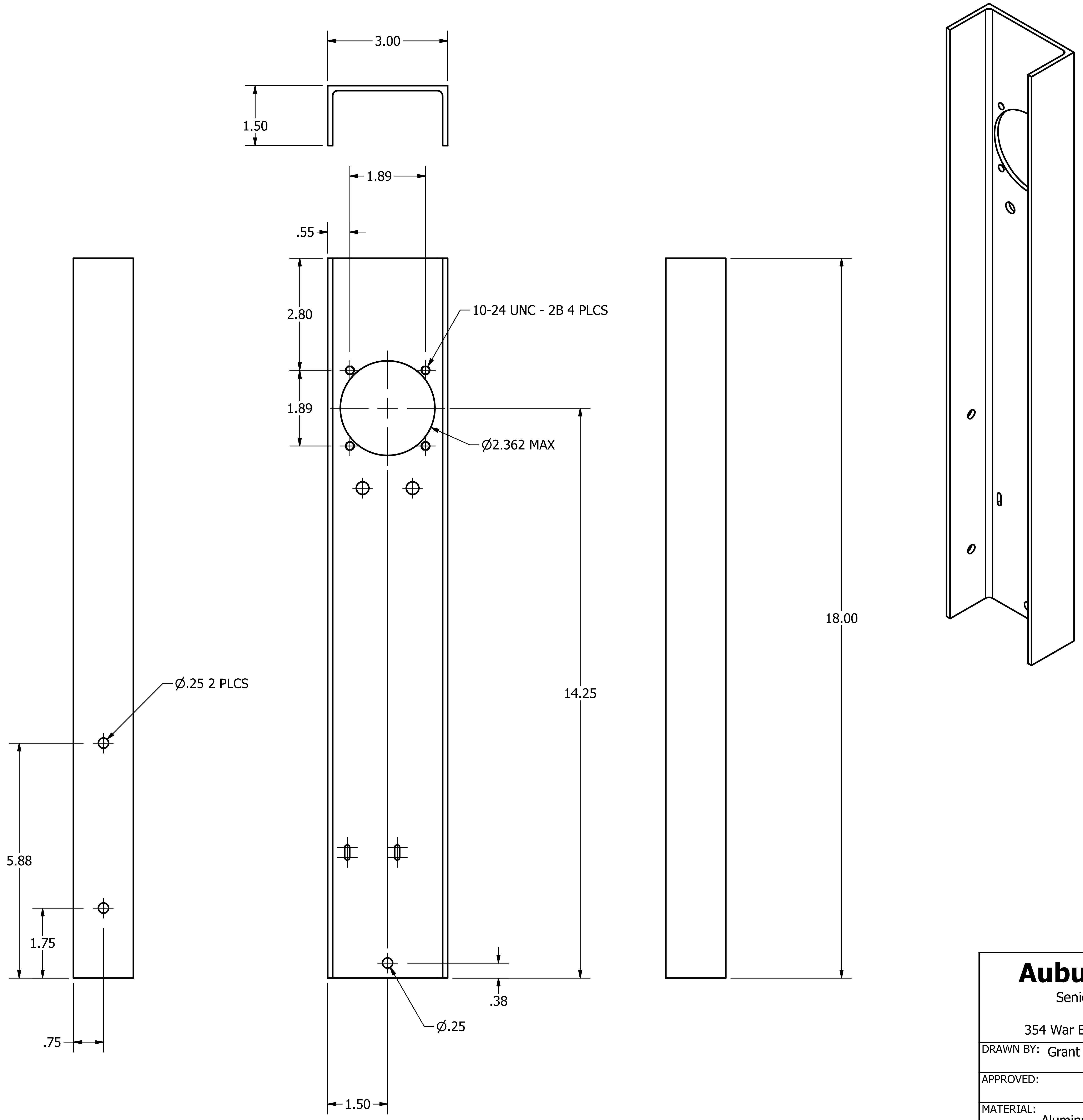
SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 11/29/2012
APPROVED:
DATE:
MATERIAL:
TITLE: Controler Support Arm
SHEET: 1 / 5
PART NUMBER: 00-0036
SCALE: NONE



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THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 11/21/2012
APPROVED:
DATE:

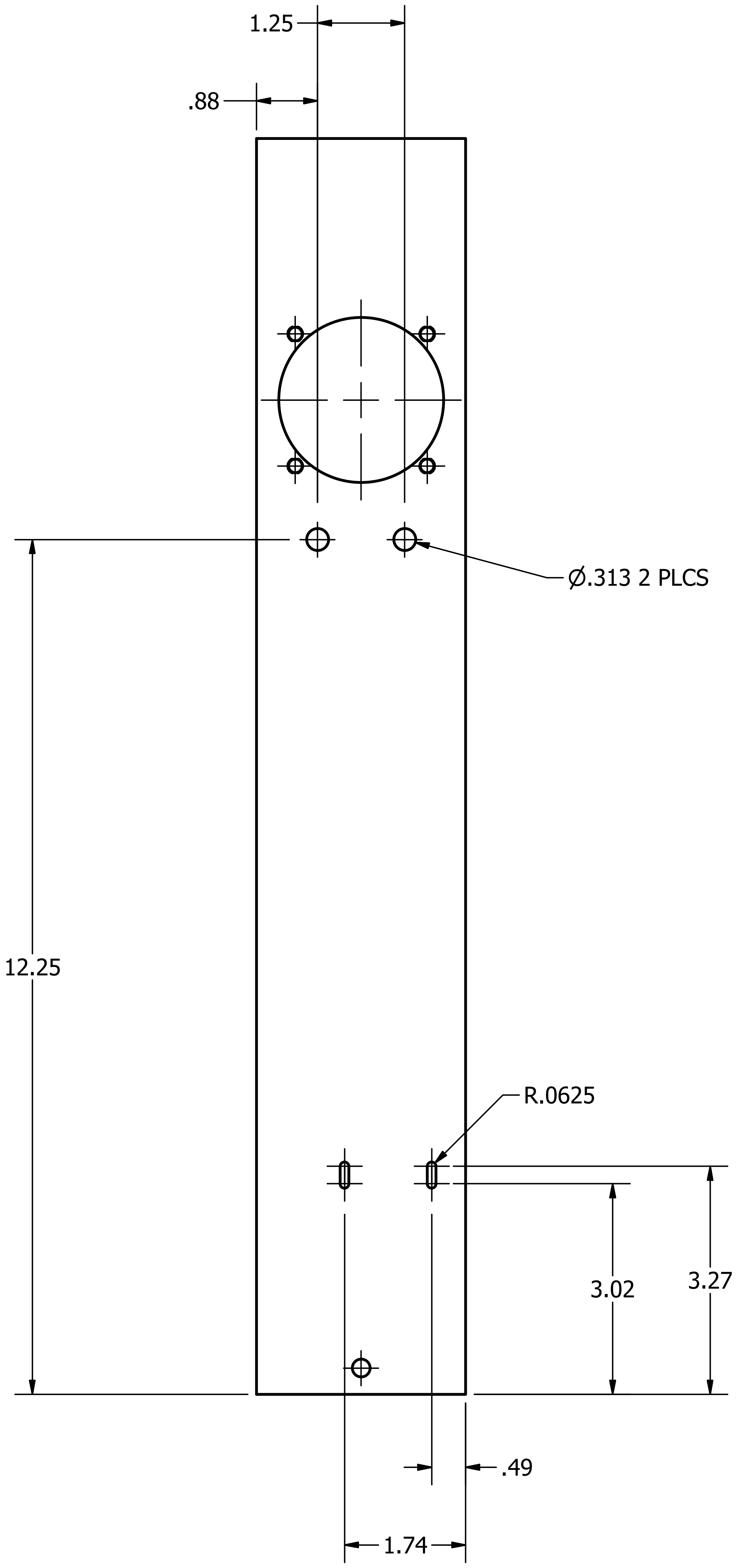
MATERIAL: Aluminum 6061

TITLE: Controler Arm Support

SHEET: 2 / 5

PART NUMBER:

SCALE: NONE



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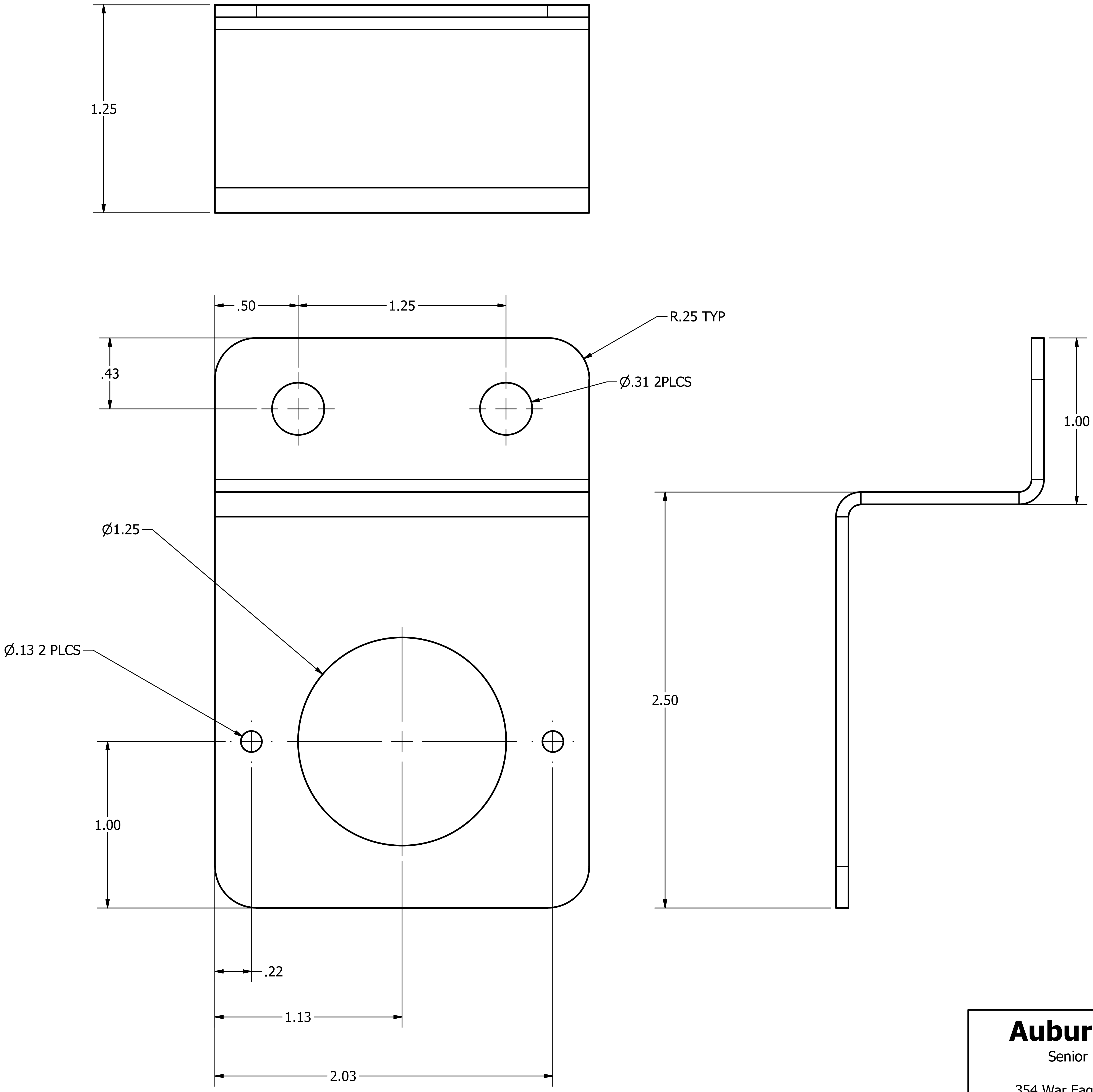
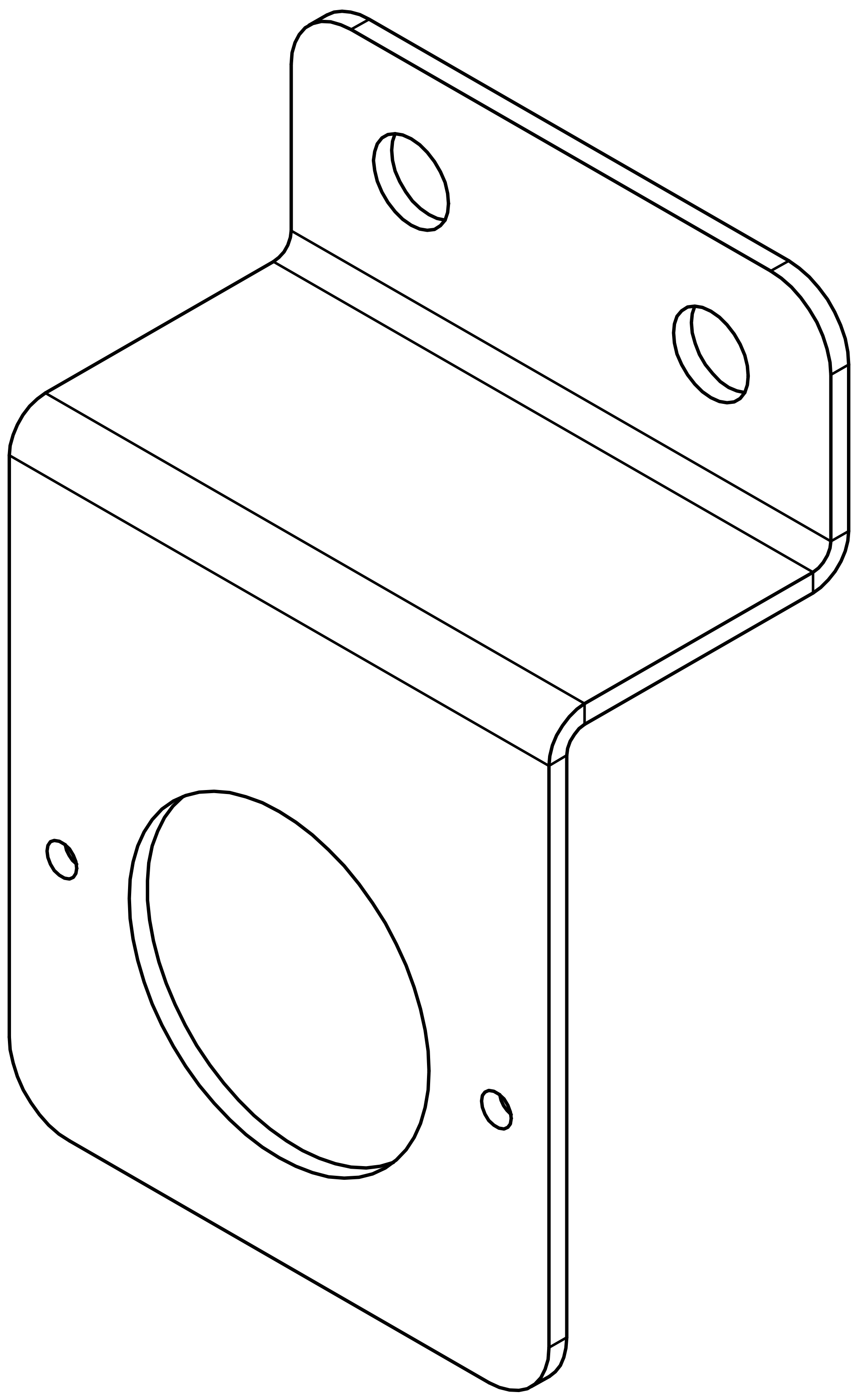
THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:
DECIMALS .XX ± .030 .XXX ± .010
ANGLES ± .5
DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 11/21/2012
APPROVED:
DATE:
MATERIAL: Aluminum 6061
TITLE: Controler Arm Support
SHEET: 3 / 5
PART NUMBER:
SCALE: NONE





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THIRD ANGLE PROJECTION

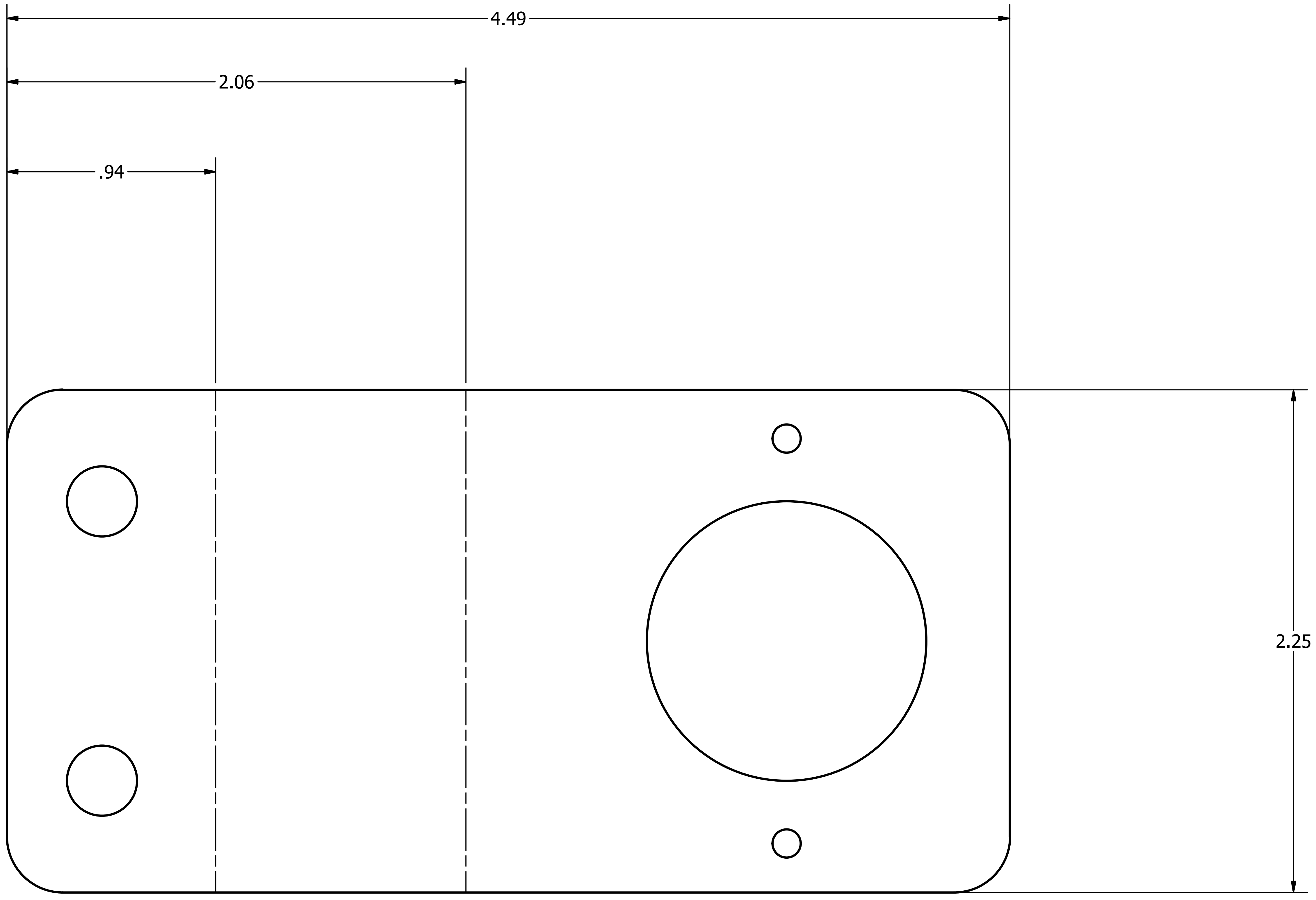
SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 11/27/2012
APPROVED:
DATE:
MATERIAL: 1010 HRS 14GA
TITLE: Optical Encoder Mnt.
SHEET: 4 / 5
PART NUMBER: 00-0031
SCALE: NONE



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DRAWN BY: Grant Apperson	DATE: 11/27/2012	THIRD ANGLE PROJECTION	SIZE: C
APPROVED:	DATE:		

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

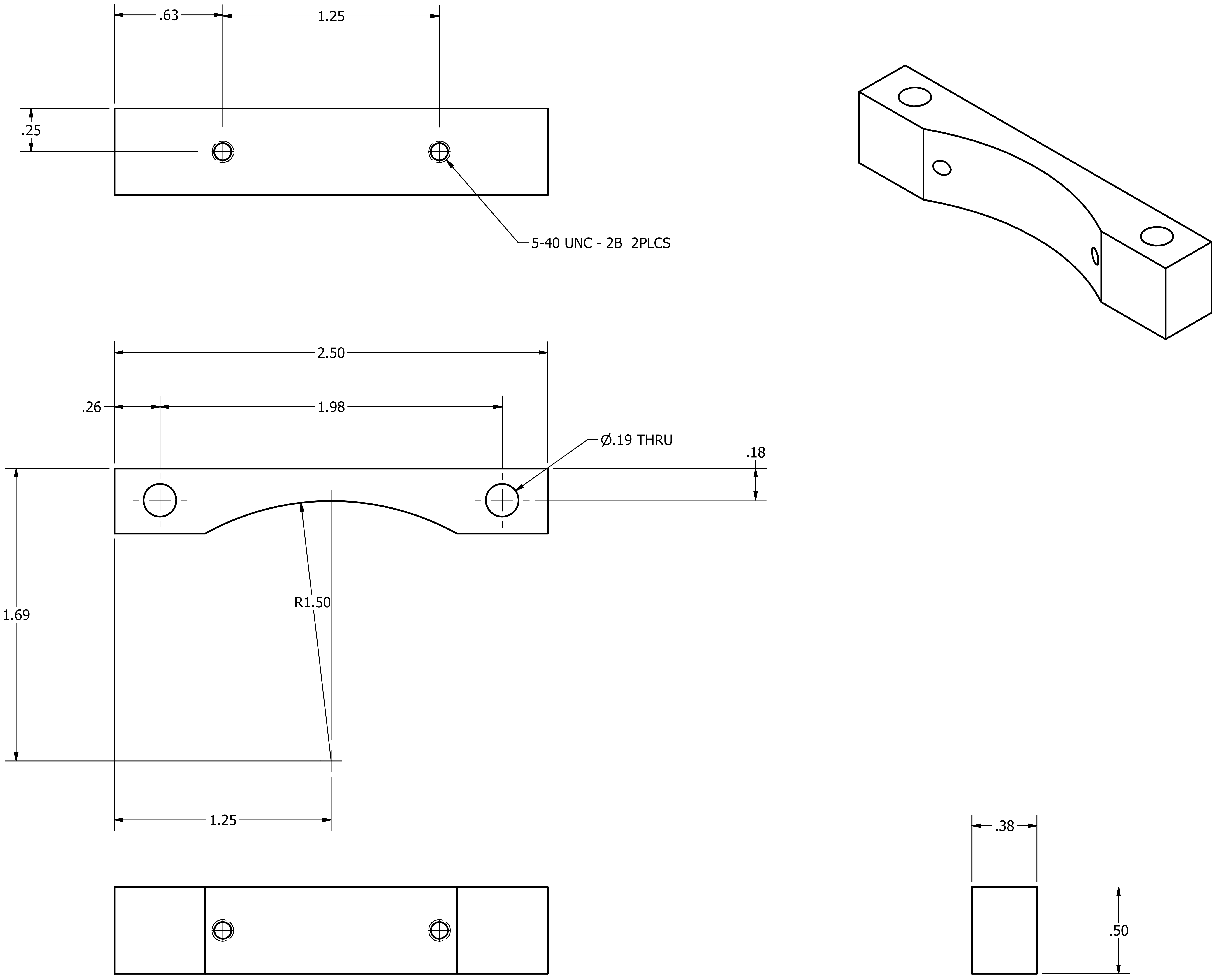
MATERIAL: 1010 HRS 14GA

TITLE: Optical Encoder Mnt.

SHEET: 5 / 5

PART NUMBER: 00-0031

SCALE: NONE



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THIRD ANGLE PROJECTION

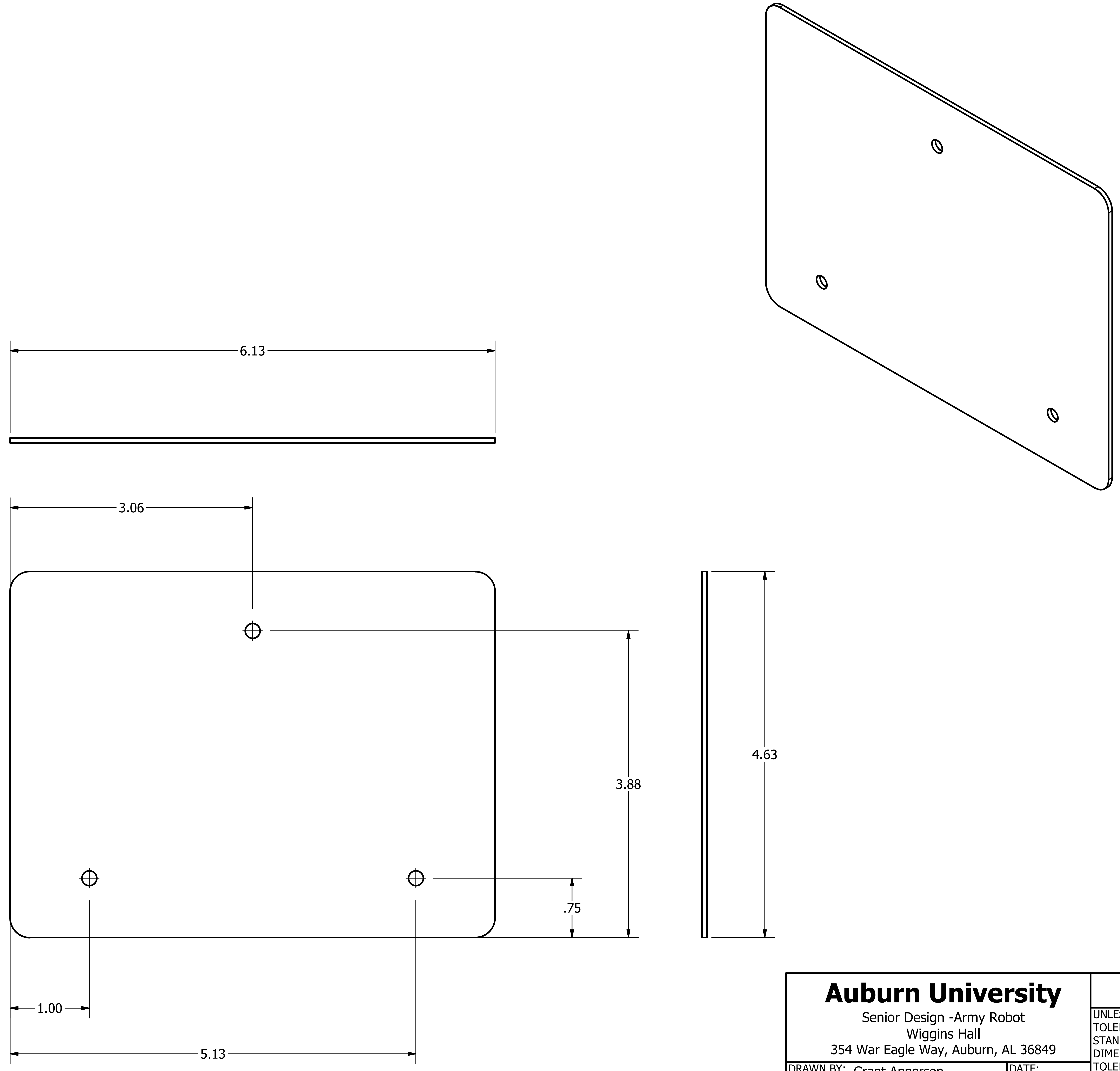
SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 4/15/2013
APPROVED:
DATE:
MATERIAL: Aluminum 6061
TITLE: Lower Motor Support Brkt
SHEET: 1 / 1
PART NUMBER: 00-0037
SCALE: NONE



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354 War Eagle Way, Auburn, AL 36849

DRAWN BY: Grant Apperson
DATE: 4/23/2013
APPROVED:
DATE:

THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

MATERIAL: Aluminum 6061

TITLE: Elec. Box Mount

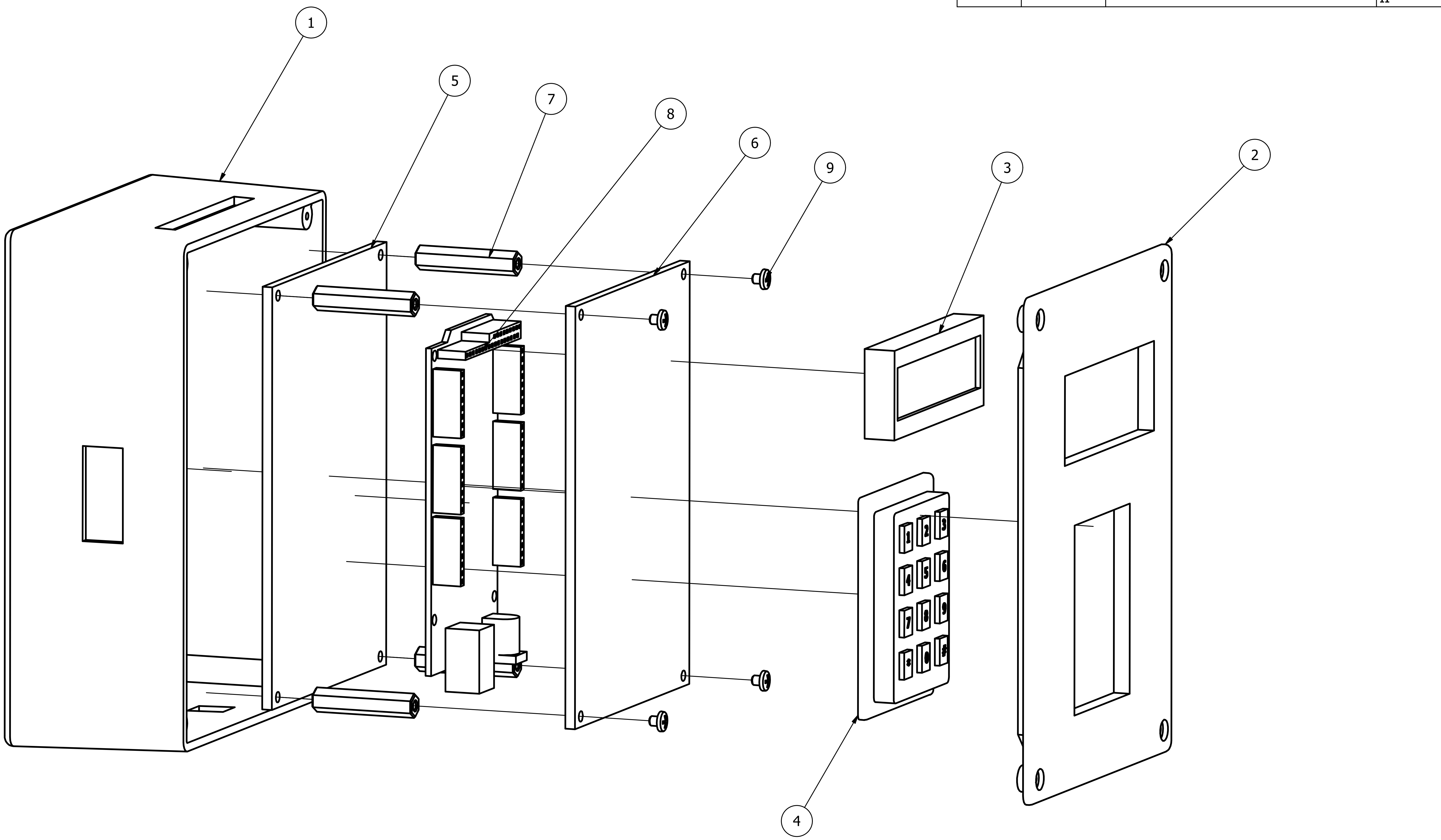
SHEET: 1 / 1

PART NUMBER: 00-0038

SCALE: NONE

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	05-0003	Box Base
2	1	05-0005	Box Lid
3	1	05-0002	LCD Disiplay
4	1	05-0008	Keypad
5	1	05-0011	Prototype Board
6	1	05-0010	PCB
7	4	Standoff, 6-32x.250_STD-6321.250H	Standoff
8	1	05-0004	Arduino MEGA 2560
9	4	ANSI B18.6.3 - No. 4 - 40 - 1/8	Cross Recessed Binding Head Machine Screw - Type II



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THIRD ANGLE PROJECTION

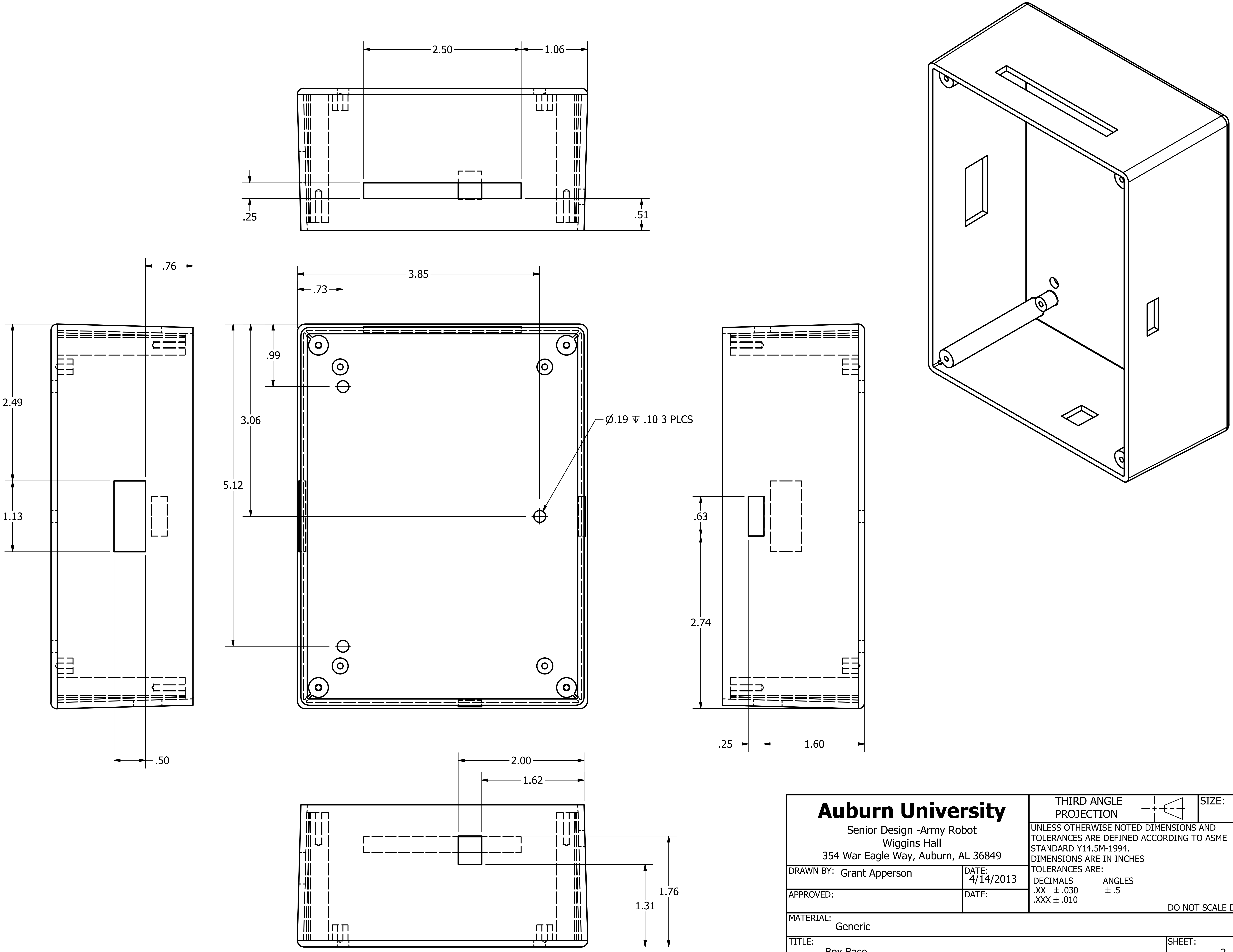
SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 4/14/2013
APPROVED:
DATE:
MATERIAL:
TITLE: Main Electrical Box
SHEET: 1 / 3
PART NUMBER: 05-0006
SCALE: NONE



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THIRD ANGLE PROJECTION

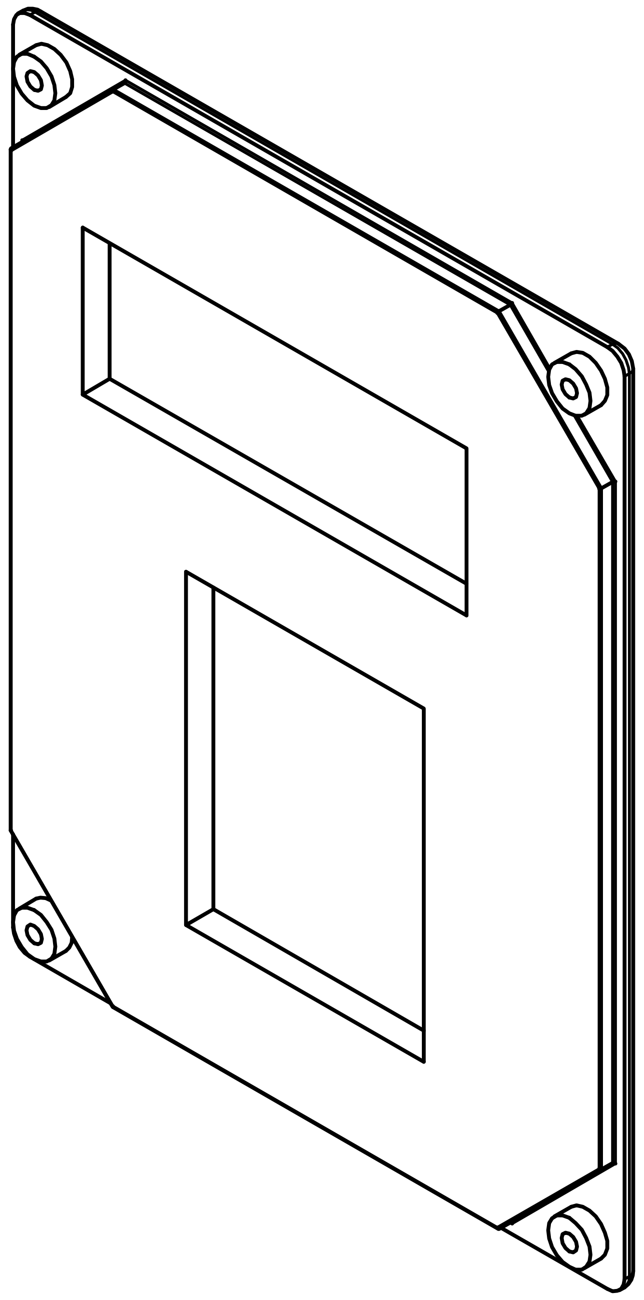
SIZE: C

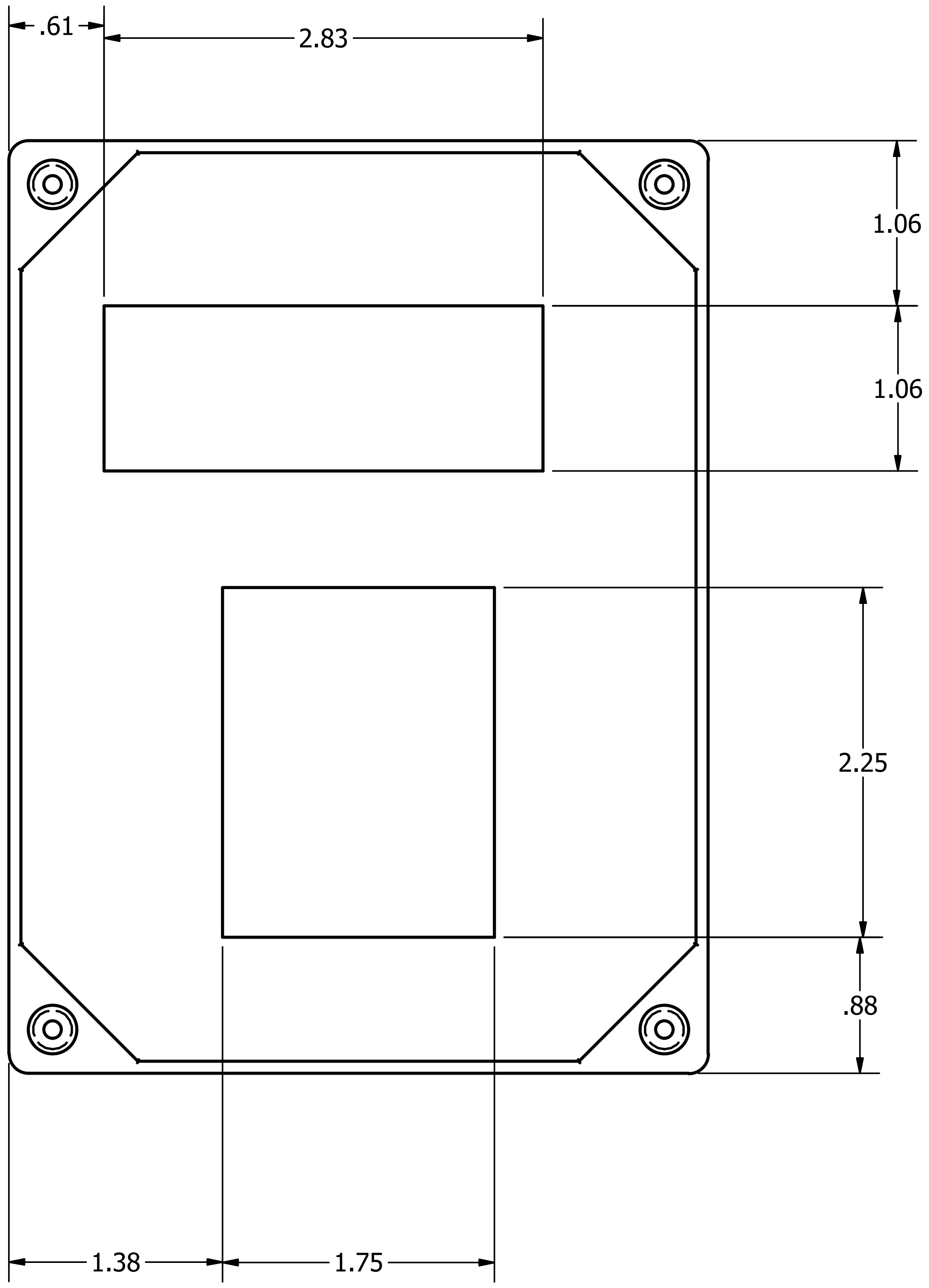
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 4/14/2013
APPROVED:
DATE:
MATERIAL: Generic
TITLE: Box Base
SHEET: 2 / 3
PART NUMBER: 05-0003
SCALE: NONE





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THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

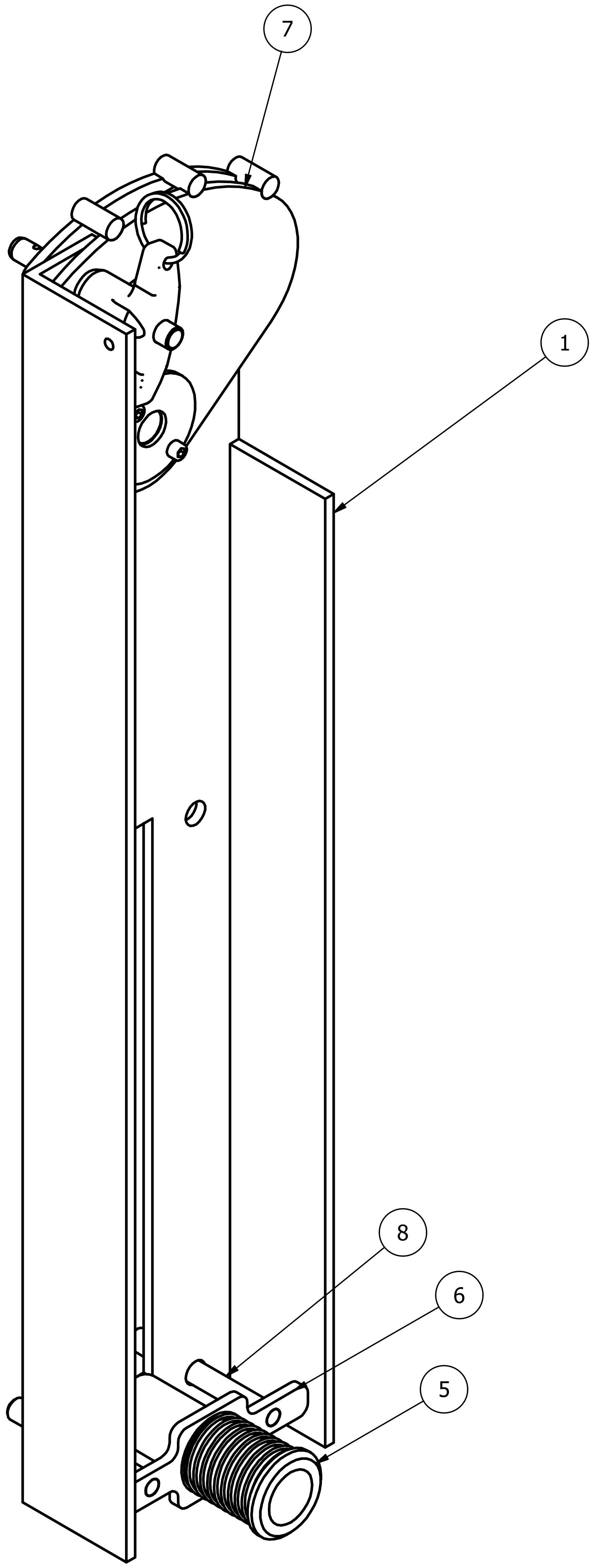
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 4/14/2013
APPROVED:
DATE:
MATERIAL: Generic
TITLE: Box Lid
SHEET: 3 / 3
PART NUMBER: 05-0005
SCALE: NONE

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	06-0000	Virtical Support Arm
4	1	06-0006	Lower Pin Spring
5	1	06-0008	Lower Pin Slide
6	1	06-0009	Lower Pull Pins
7	1	06-0013	
8	2	06-0015	
18	1	90293A135	



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THIRD ANGLE PROJECTION

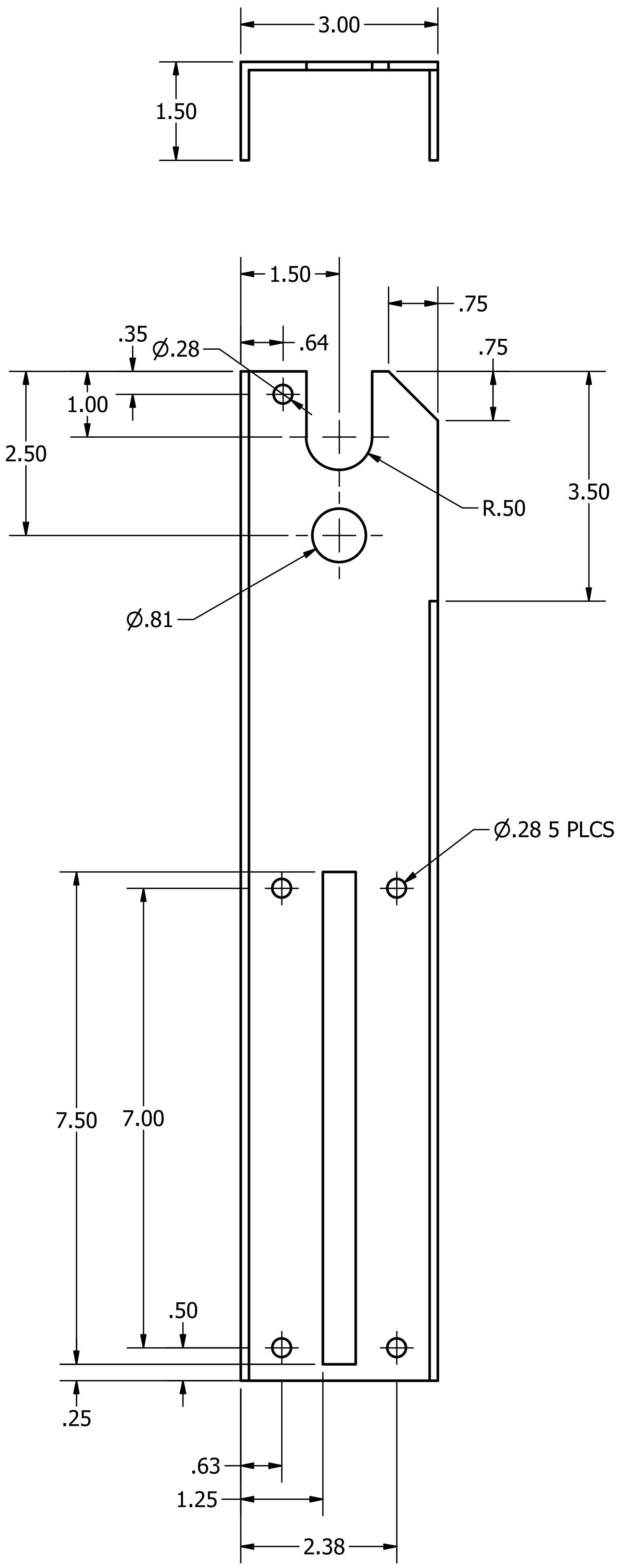
SIZE: C

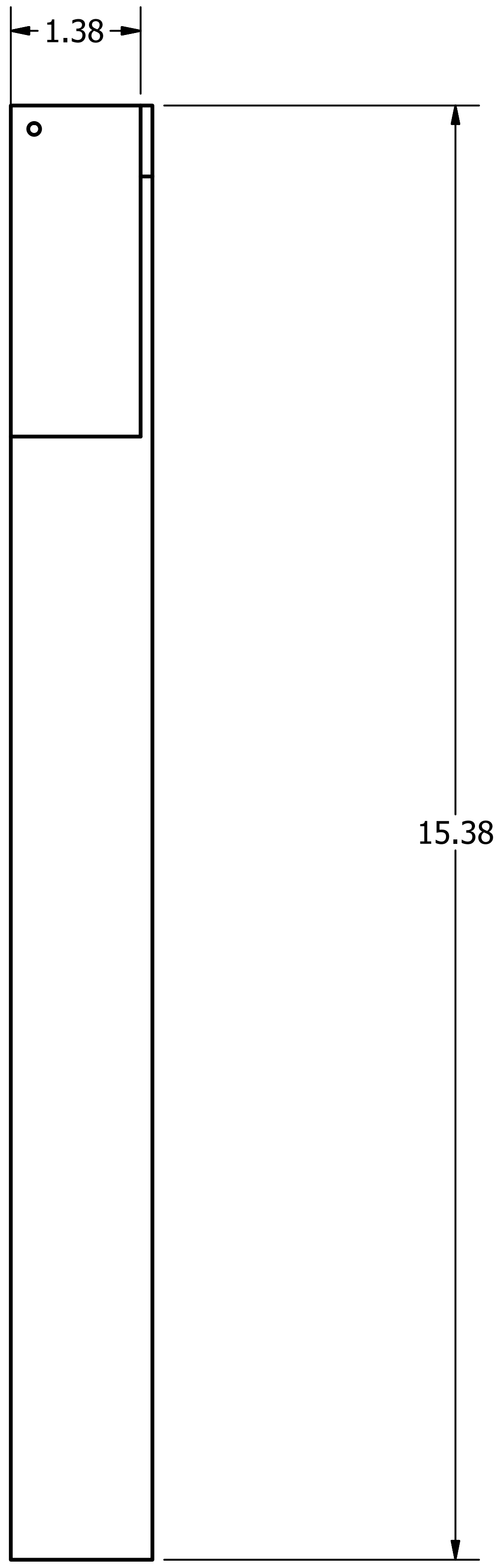
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

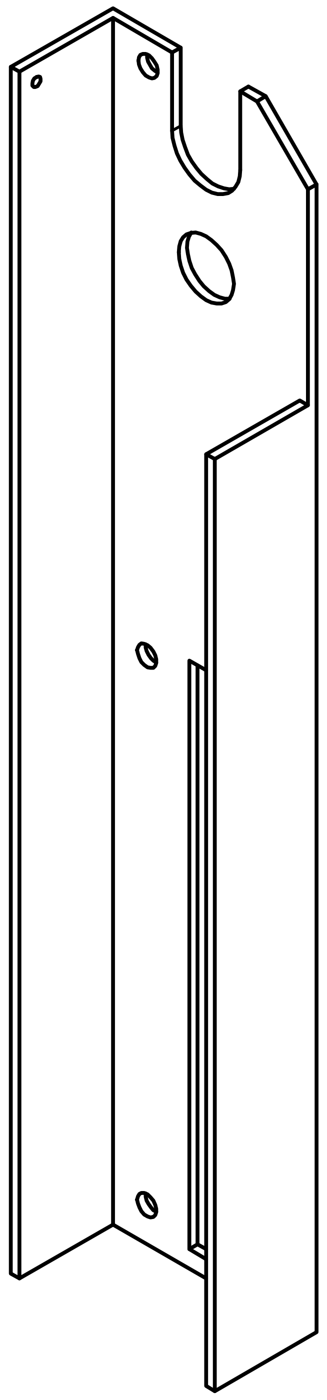
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/22/2012
APPROVED: Matt Cancilla
DATE:
MATERIAL:
TITLE: Vibration Reducing Support Arm
SHEET: 1 / 9
PART NUMBER: 06-0003
SCALE: NONE







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THIRD ANGLE PROJECTION

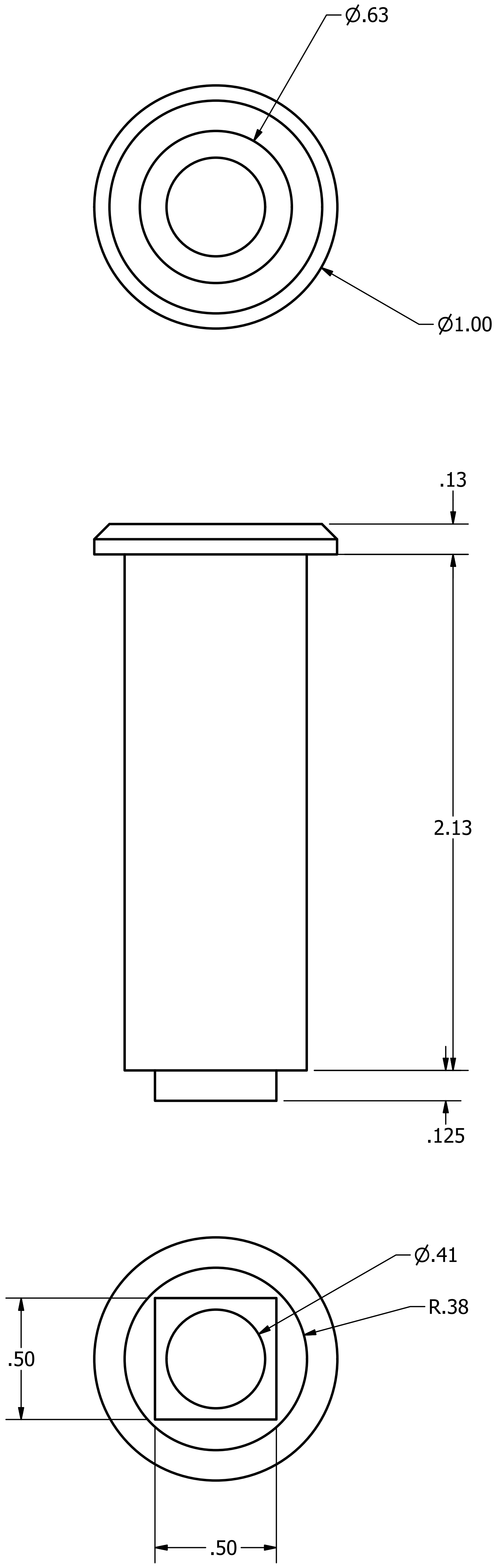
SIZE: C

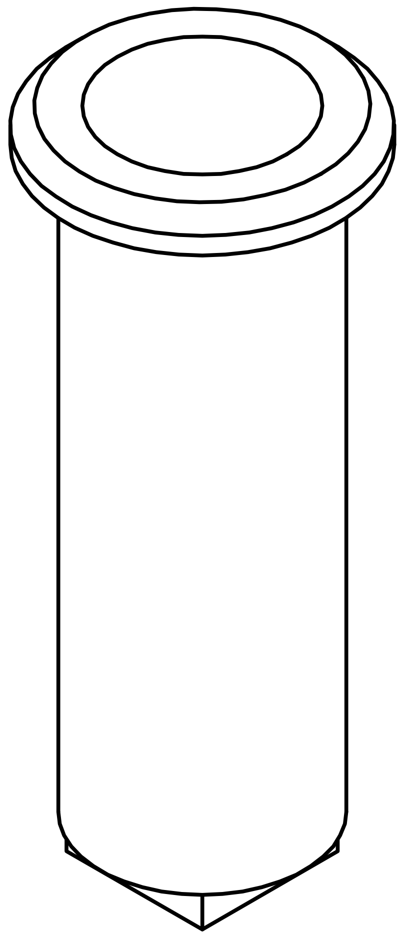
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/22/2012
APPROVED: Matt Cancilla
DATE:
MATERIAL: Aluminum 6061
TITLE: Virtical Support Arm
SHEET: 2 / 9
PART NUMBER: 06-0000
SCALE: NONE





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THIRD ANGLE PROJECTION

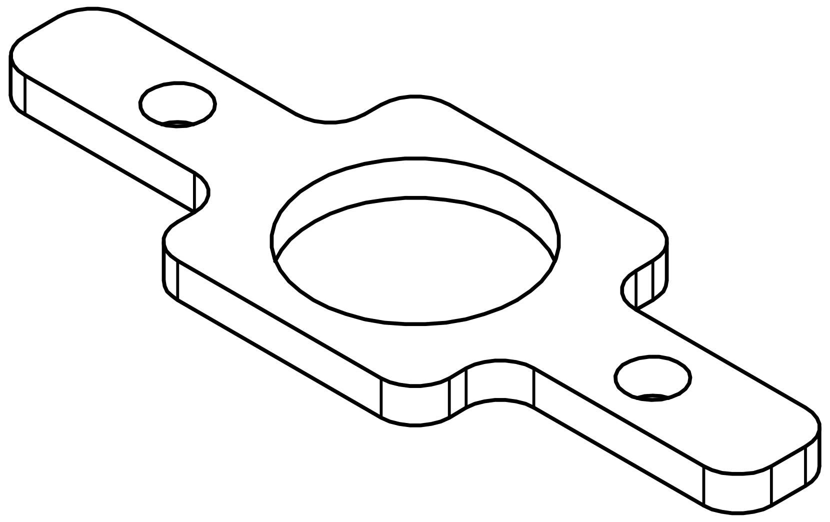
SIZE: C

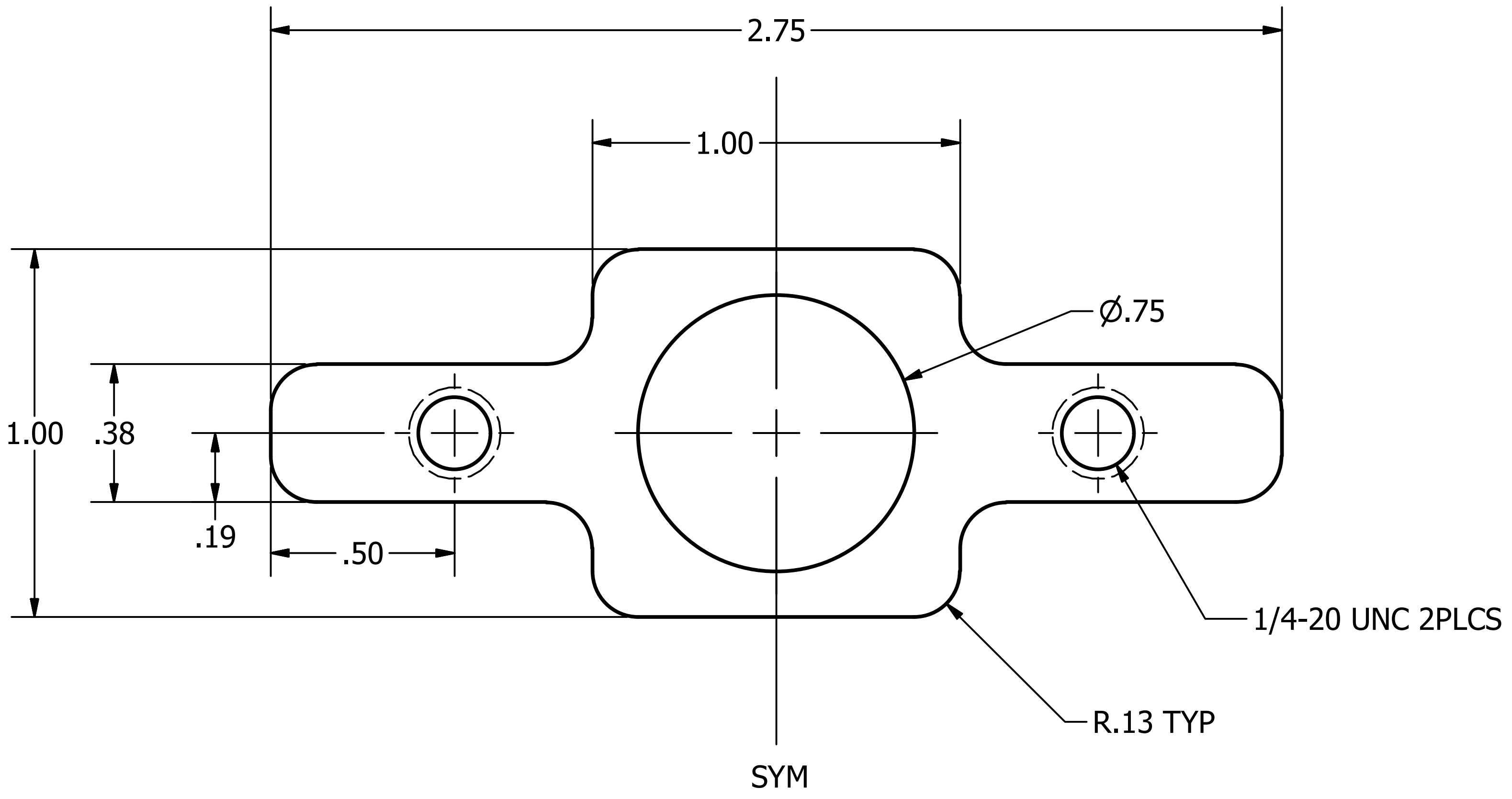
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

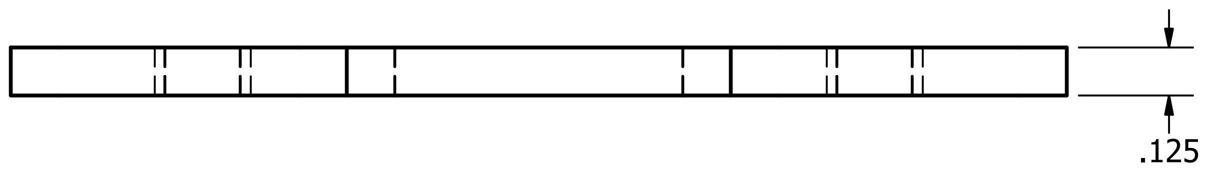
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/22/2012
APPROVED: Matt Cancilla
DATE:
MATERIAL: Aluminum 6061
TITLE: Lower Pin Slide
SHEET: 3 / 9
PART NUMBER: 06-0008
SCALE: NONE







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354 War Eagle Way, Auburn, AL 36849

DRAWN BY: Grant Apperson	DATE: 10/22/2012
APPROVED: Matt Cancilla	DATE:

THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

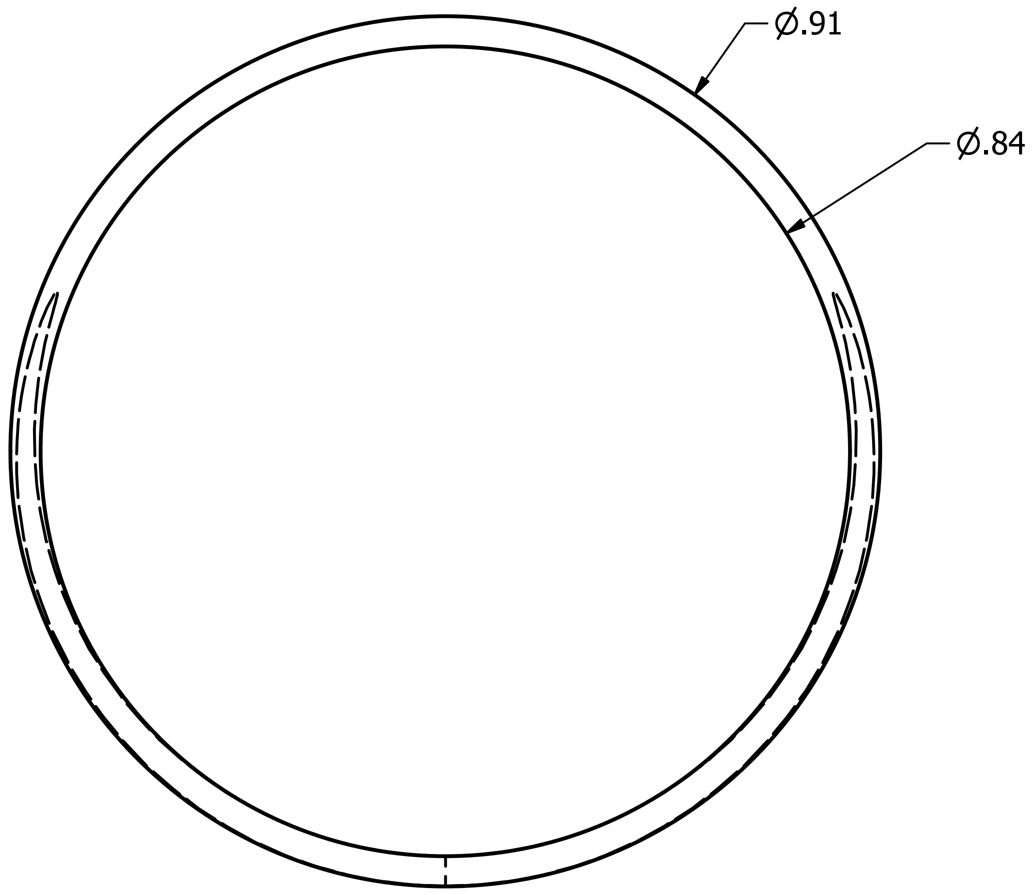
MATERIAL: Stainless Steel

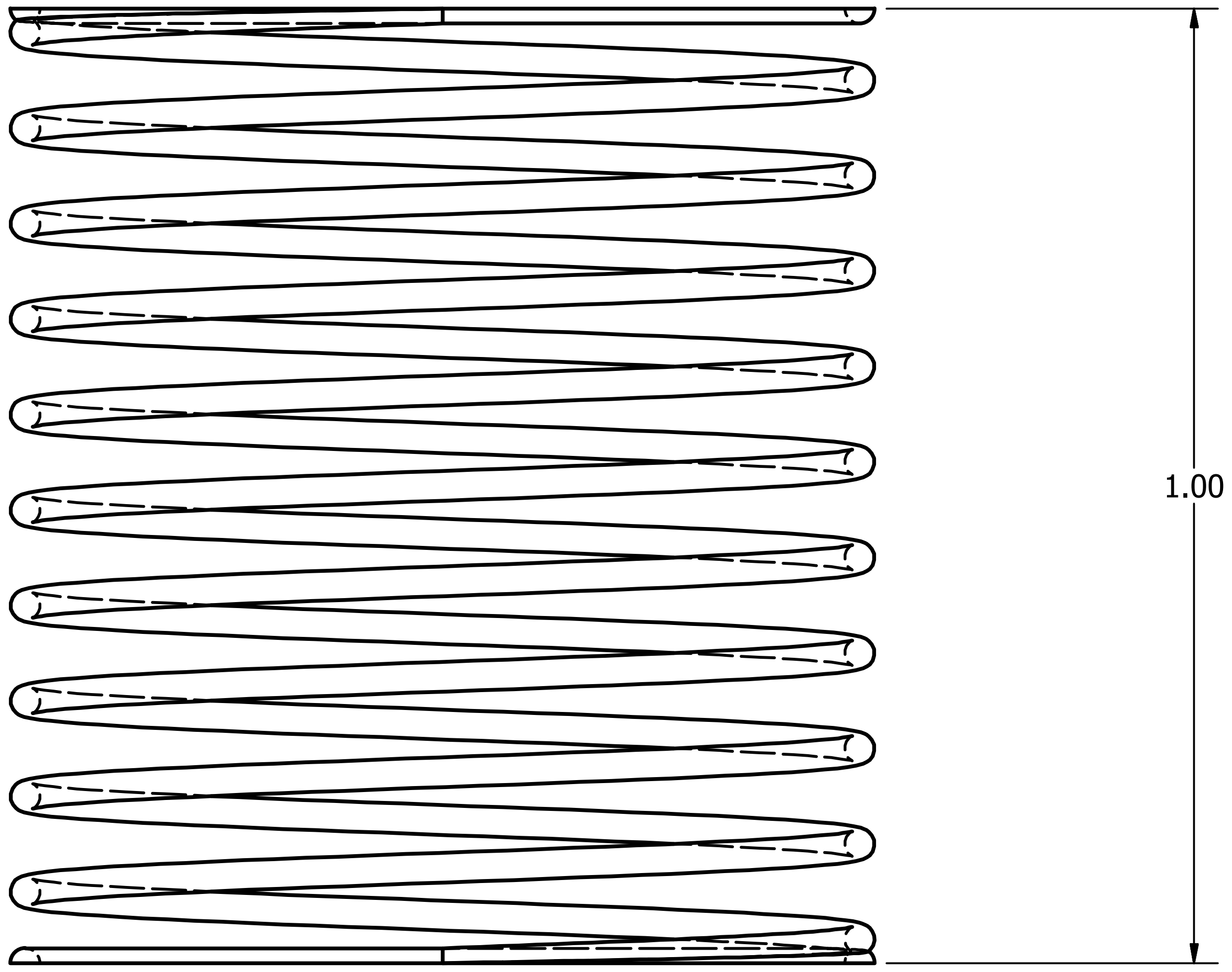
TITLE: Lower Pull Pins

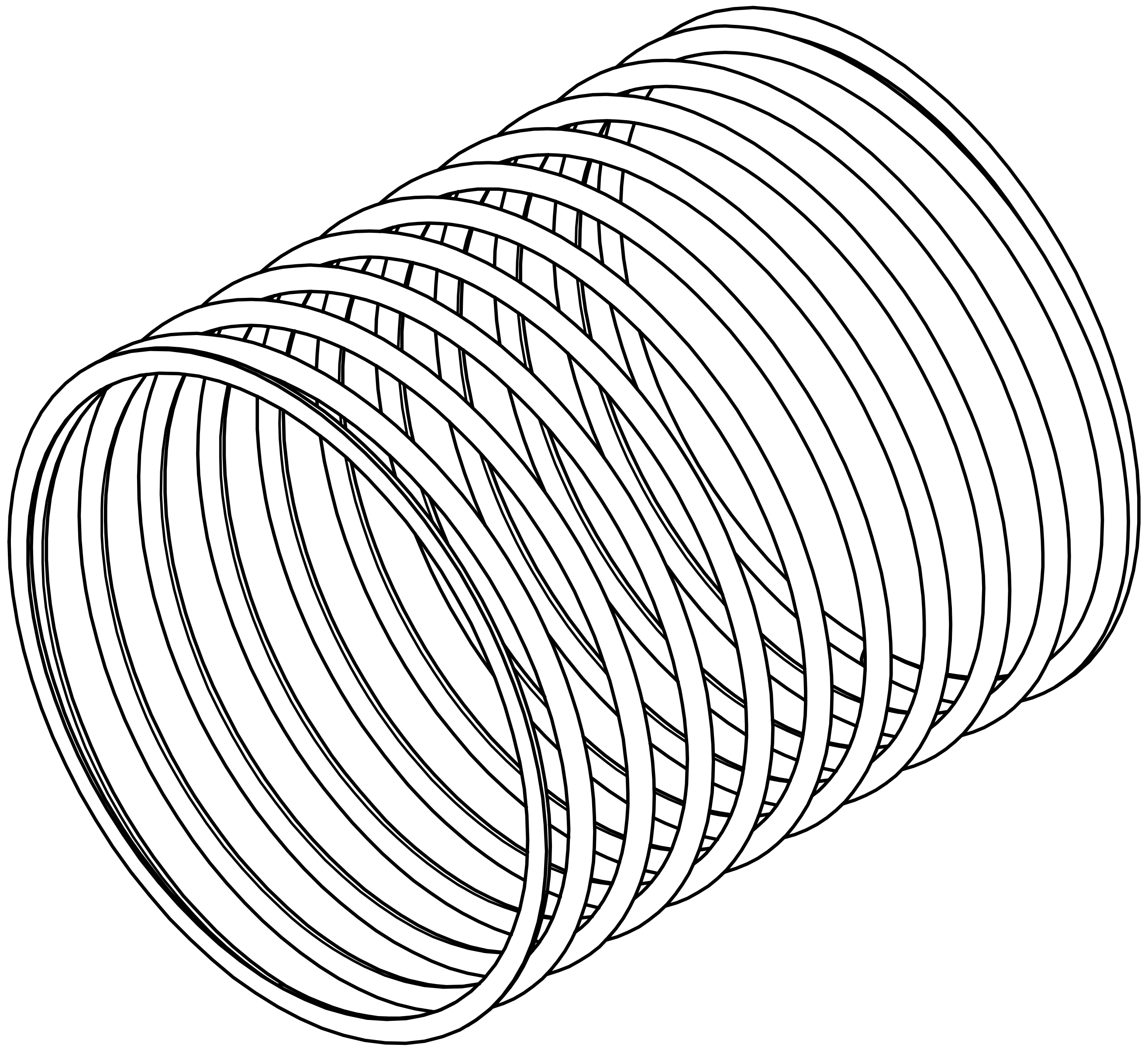
SHEET: 4 / 9

PART NUMBER: 06-0009

SCALE: NONE







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THIRD ANGLE PROJECTION

SIZE: C

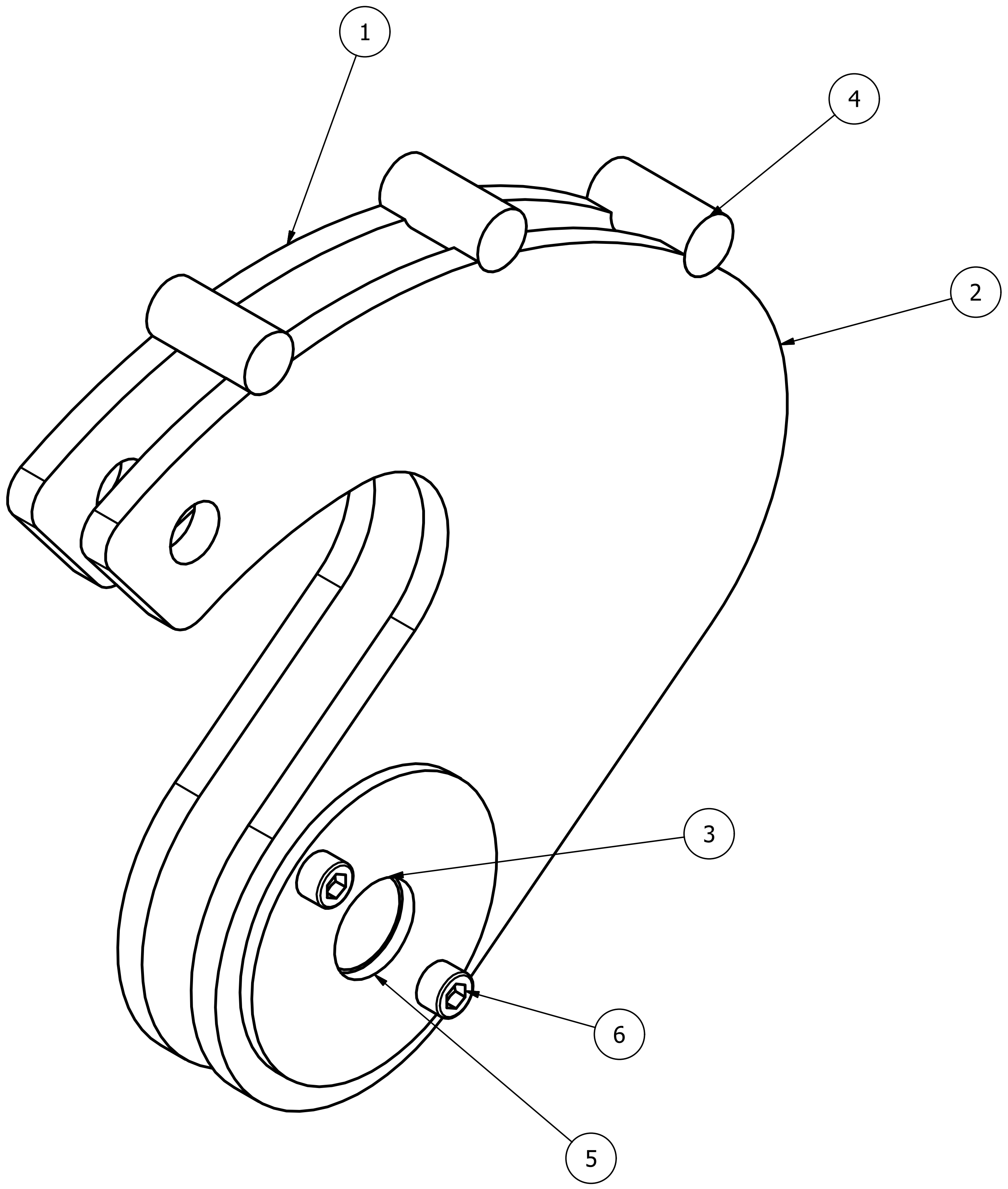
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/22/2012
APPROVED: Matt Cancilla
DATE:
MATERIAL: 9657K276
TITLE: Lower Pin Spring
SHEET: 5 / 9
PART NUMBER: 06-0006
SCALE: NONE

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	06-0002	Locking Gate Arm
2	1	06-0010	Locking Gate Arm
3	1	06-0011	Latch Bushing
4	3	06-0012	
5	1	06-0014	Gate Lock Washer
6	2	ANSI B18.3 - No. 4 - 40 UNC - 3/16 HS HCS	Hexagon Socket Head Cap Screw



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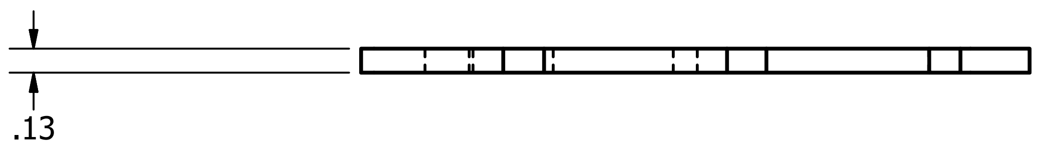
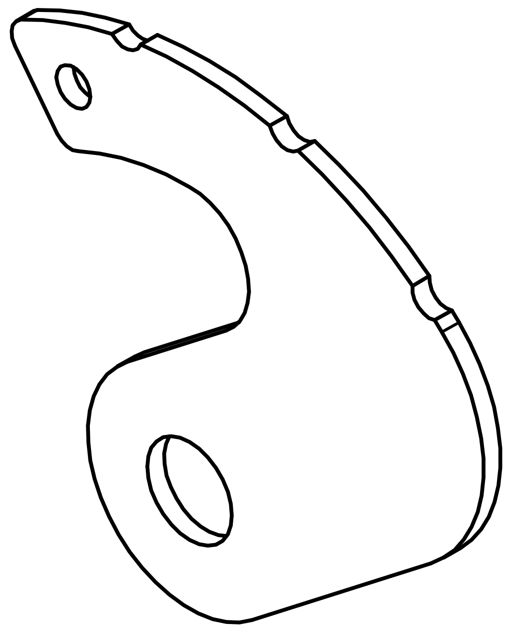
DRAWN BY: Grant Apperson	DATE: 2/18/2013	THIRD ANGLE PROJECTION	SIZE: C
APPROVED: Matt Cancilla	DATE:		
MATERIAL:			
TITLE:			SHEET: 6 / 9
PART NUMBER:			SCALE: NONE

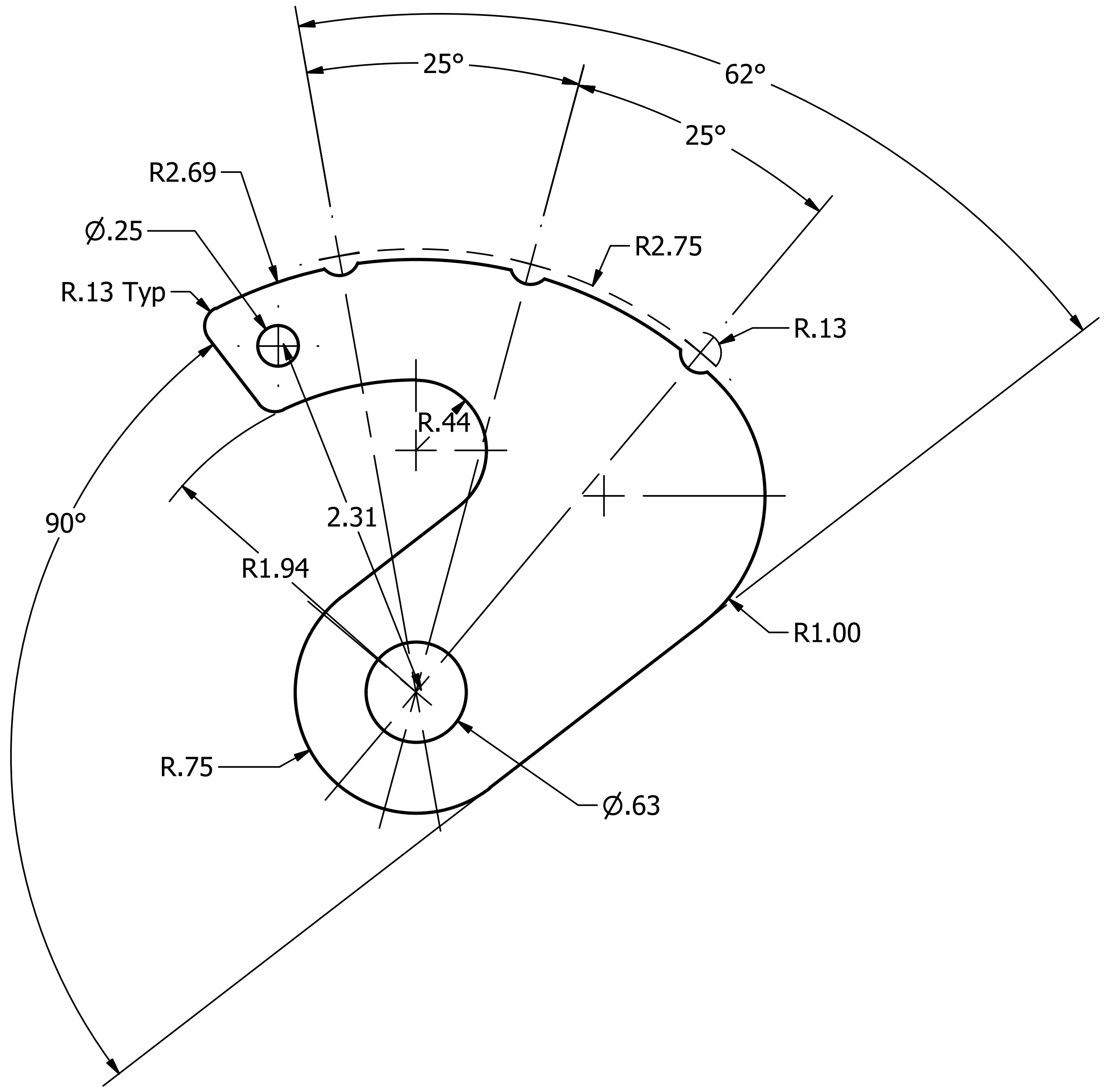
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

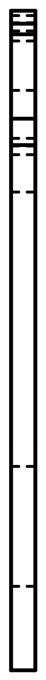
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING









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THIRD ANGLE PROJECTION

SIZE: C

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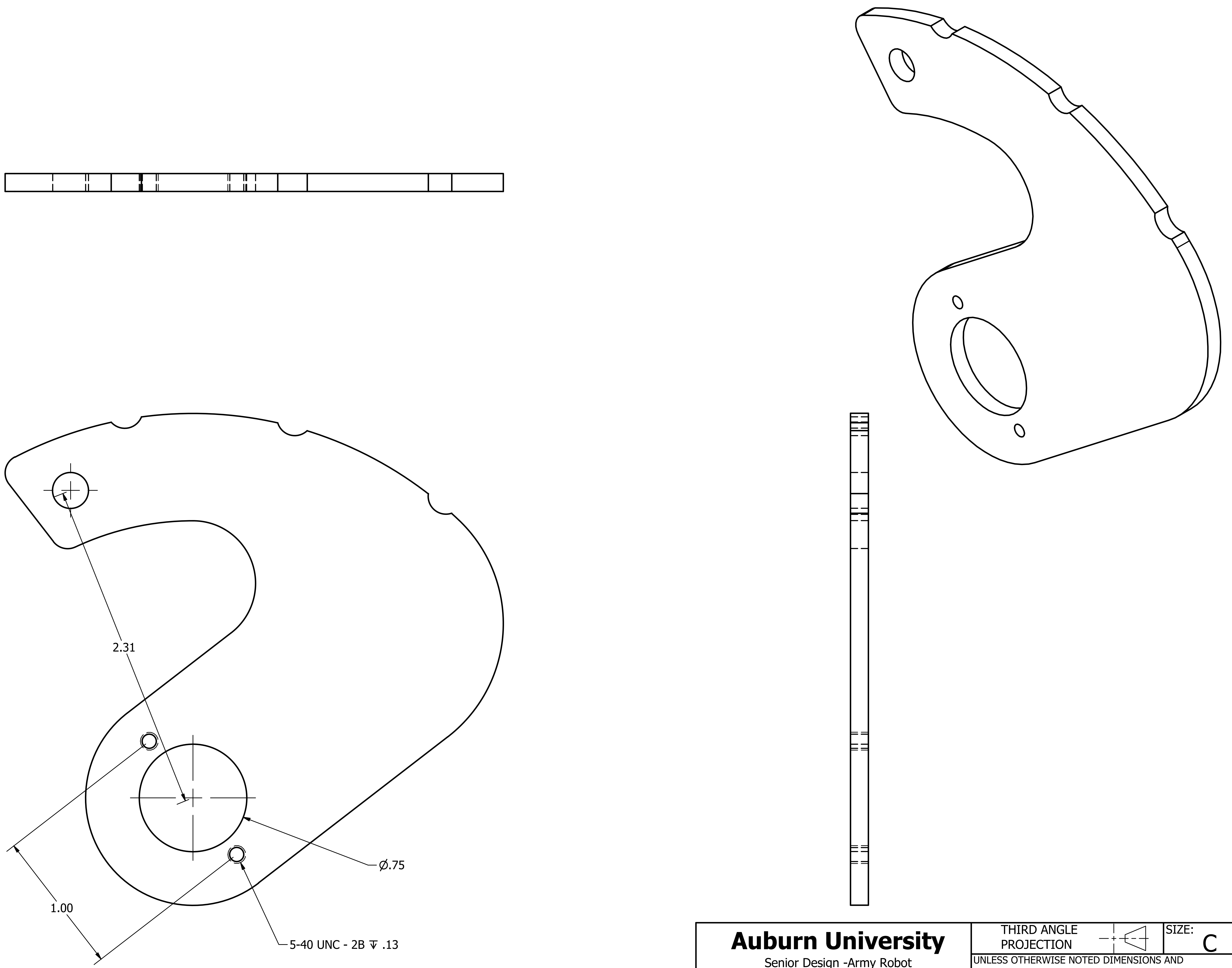
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/22/2012
APPROVED: Matt Cancilla
DATE:
MATERIAL: 1010 HRS 1/8 "
TITLE: Locking Gate Arm
SHEET: 7 / 9
PART NUMBER: 06-002
SCALE: NONE



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THIRD ANGLE PROJECTION

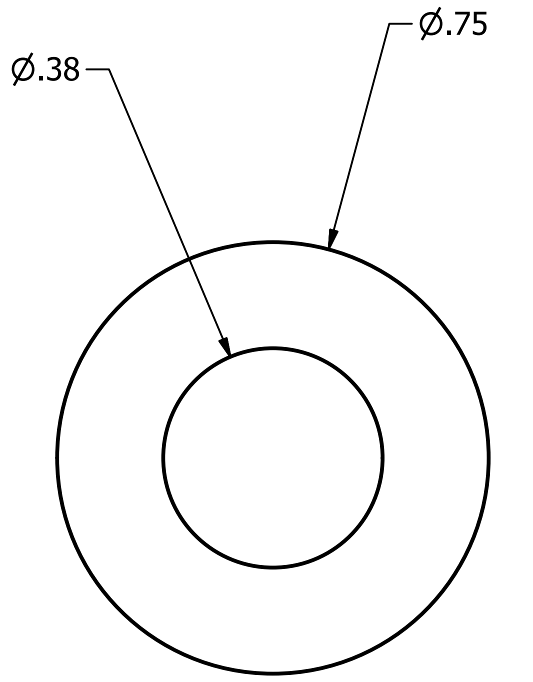
SIZE: C

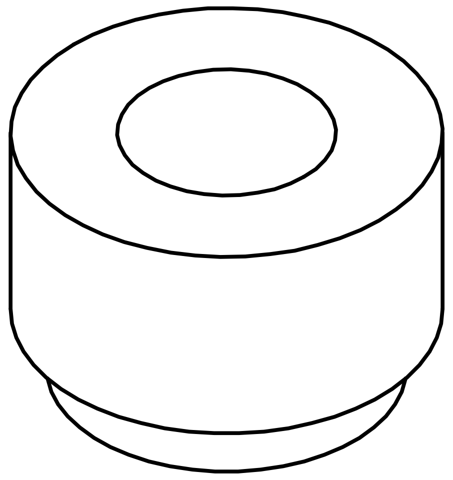
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

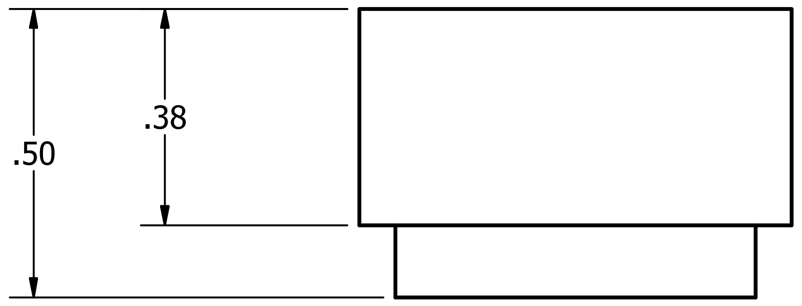
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

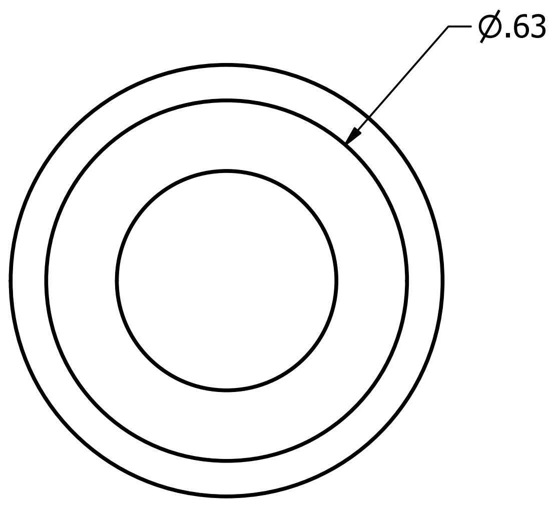
DO NOT SCALE DRAWING

DRAWN BY: Grant Apperson
DATE: 10/22/2012
APPROVED: Matt Cancilla
DATE:
MATERIAL: 1010 HRS 1/8 "
TITLE: Locking Gate Arm
SHEET: 8 / 9
PART NUMBER: 06-002
SCALE: NONE









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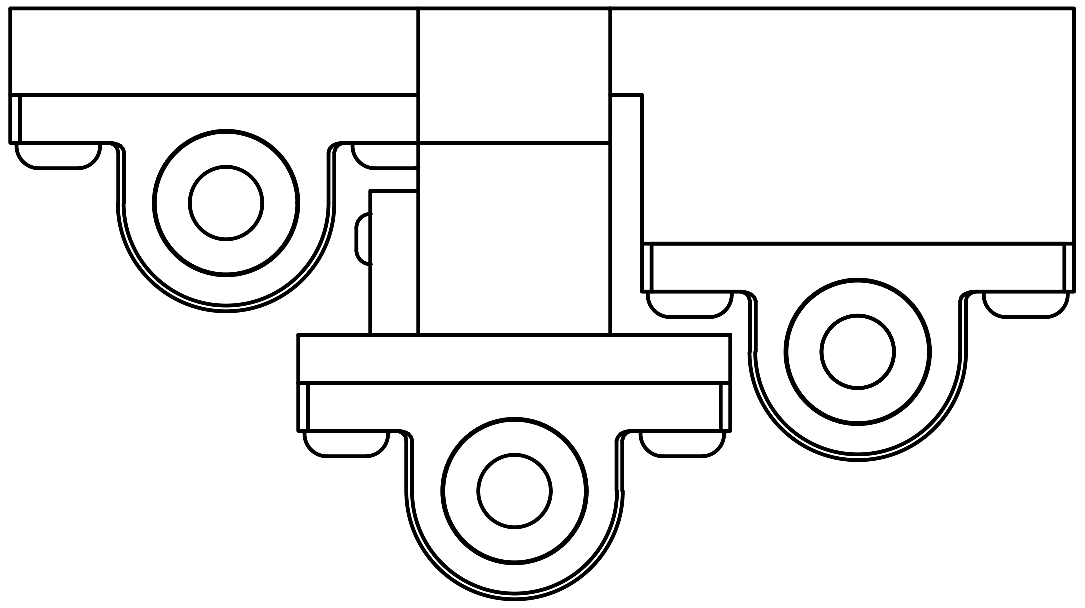
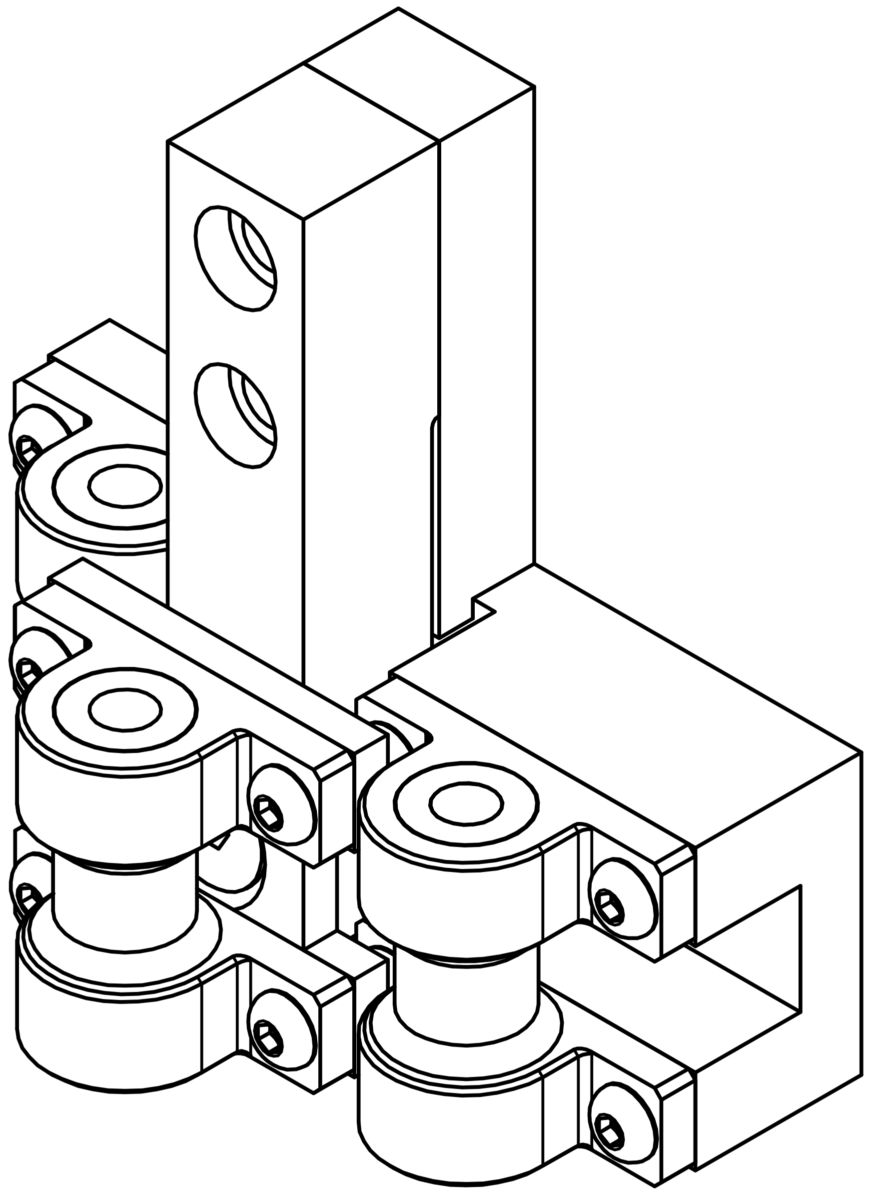
DRAWN BY: Grant Apperson	DATE: 2/18/2013	THIRD ANGLE PROJECTION	SIZE: C
APPROVED: Matt Cancilla	DATE:		
MATERIAL: Aluminum 6061			
TITLE: Latch Bushing		SHEET: 9 / 9	
PART NUMBER: 92320A726		SCALE: NONE	

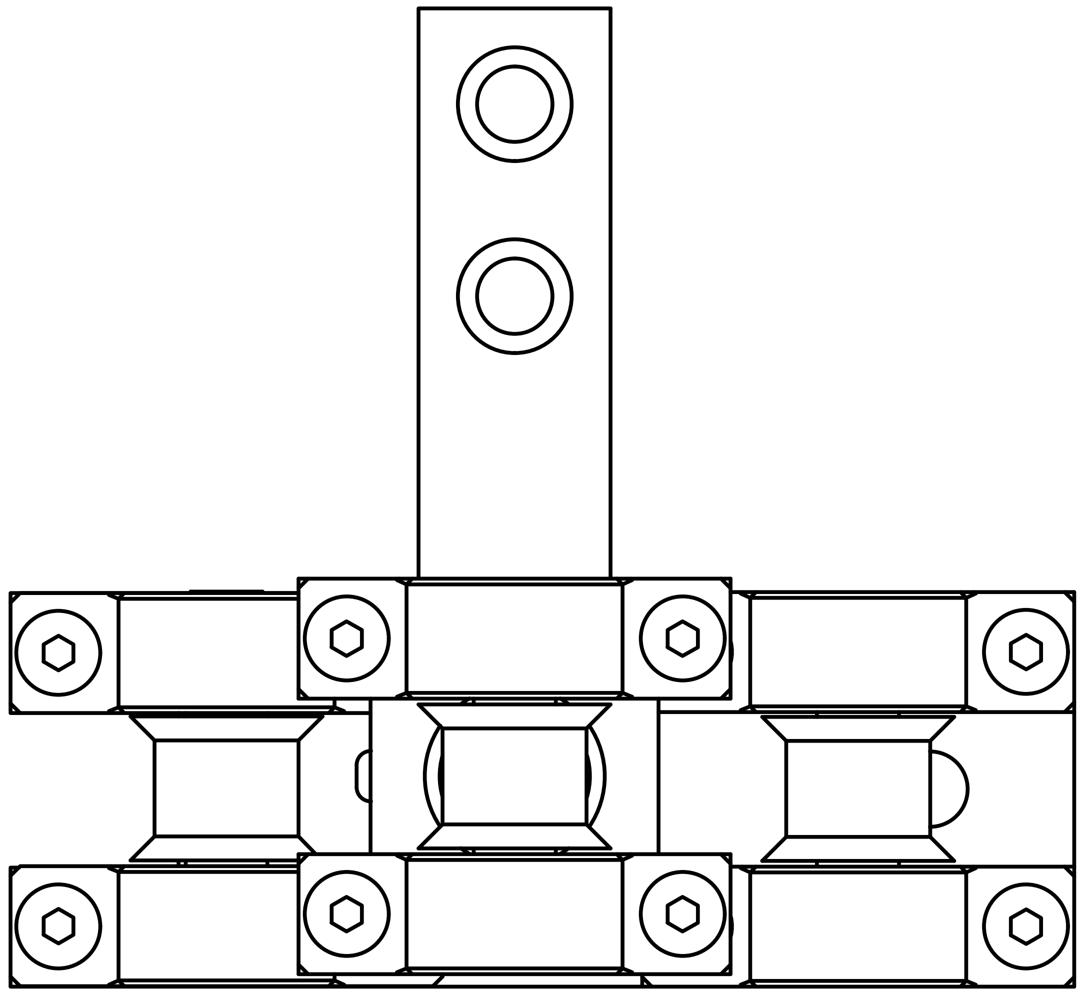
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

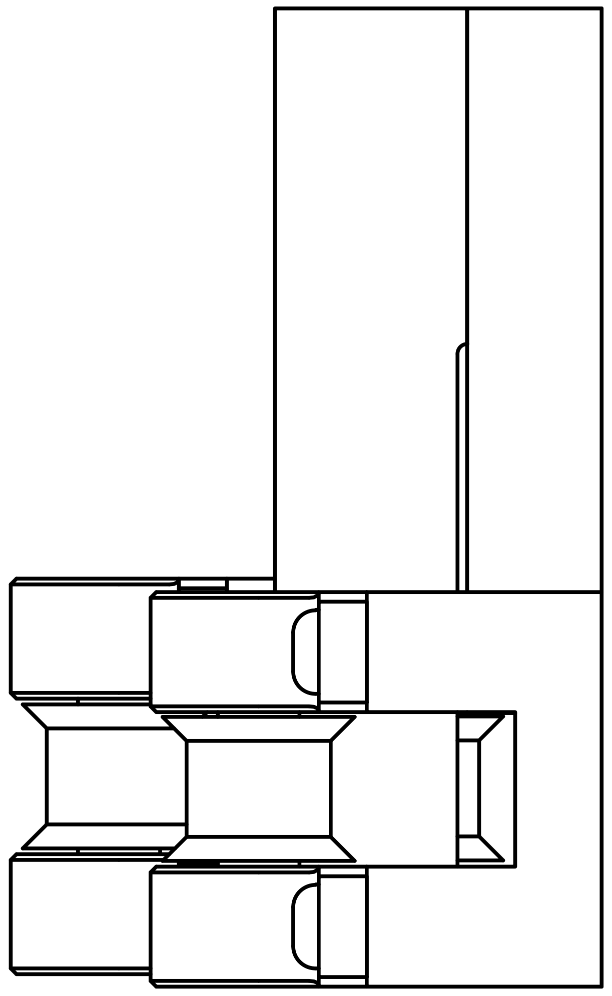
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING









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THIRD ANGLE PROJECTION

SIZE: C

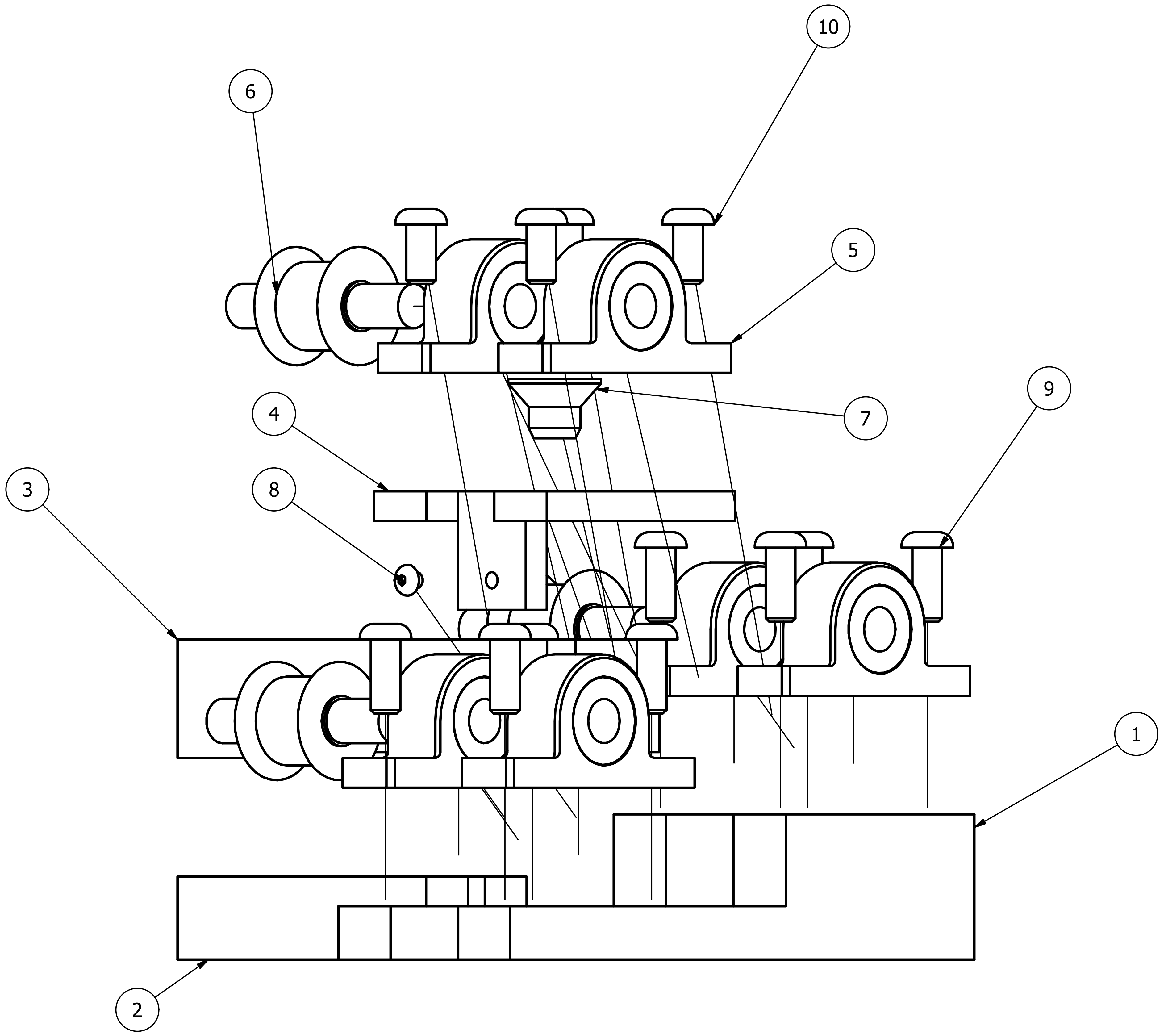
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Dan Pierce
DATE: 5/1/2013
APPROVED:
DATE:
MATERIAL:
TITLE: Load Cell Final Design
SHEET: 1 / 7
PART NUMBER: 08-0004
SCALE: NONE

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	08-0002	Outrigger Spool Mount
2	1	08-0003	Load Cell Mount
3	1	LoadCell	
4	1	08-0001	Transducer Bearing Mount Plate
5	6	Part2	
6	3	Roller2	
7	1	ANSI B18.3 - 7/16-14 UNC x 0.5	Hexagon Socket Flat Countersunk Head Cap Screw
8	1	ANSI B18.3 - 6 - 32 x 1/8	Hexagon Socket Button Head Cap Screw
9	8	ANSI B18.3 - 1/4 - 20 x 5/8	Hexagon Socket Button Head Cap Screw
10	4	ANSI B18.3 - 1/4 - 20 x 1/2	Hexagon Socket Button Head Cap Screw



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THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Dan Pierce
DATE: 5/1/2013
APPROVED:
DATE:
MATERIAL:
TITLE: Load Cell Final Design
SHEET: 2 / 7
PART NUMBER: 08-0004
SCALE: NONE

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THIRD ANGLE PROJECTION

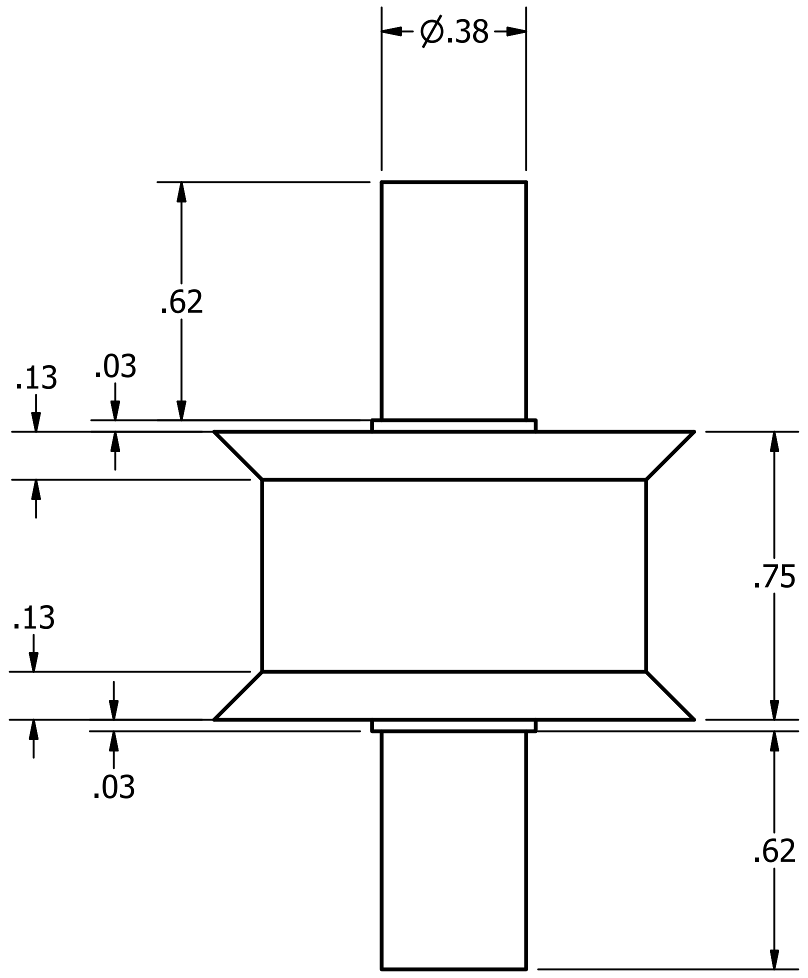
SIZE: C

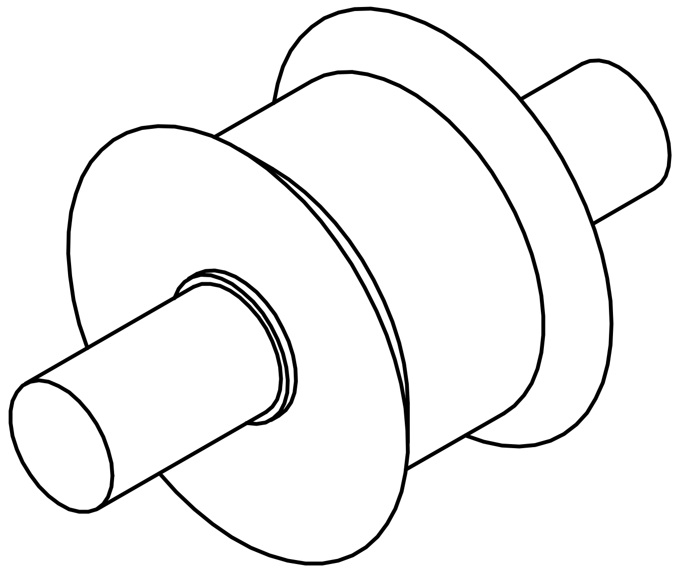
UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

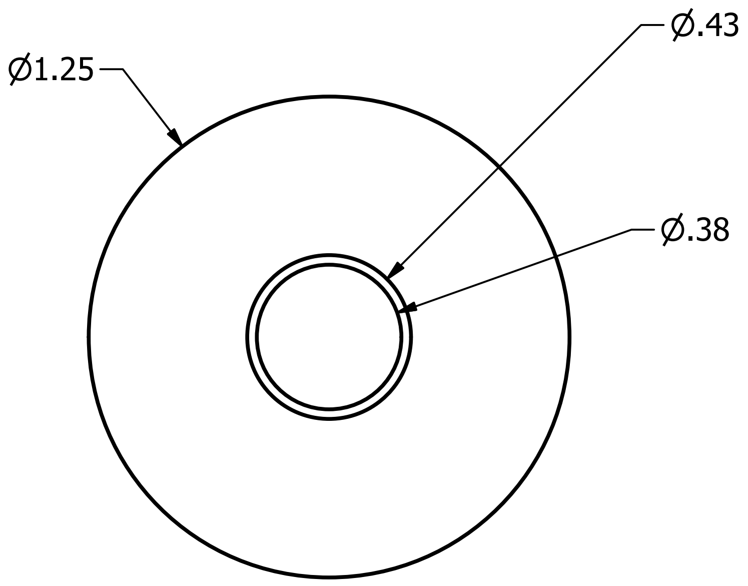
DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY:
DATE:
APPROVED:
DATE:
MATERIAL:
TITLE:
SHEET: 3 / 7
PART NUMBER:
SCALE: NONE







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DRAWN BY: Dan Pierce	DATE: 11/14/2012
APPROVED:	DATE:

THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

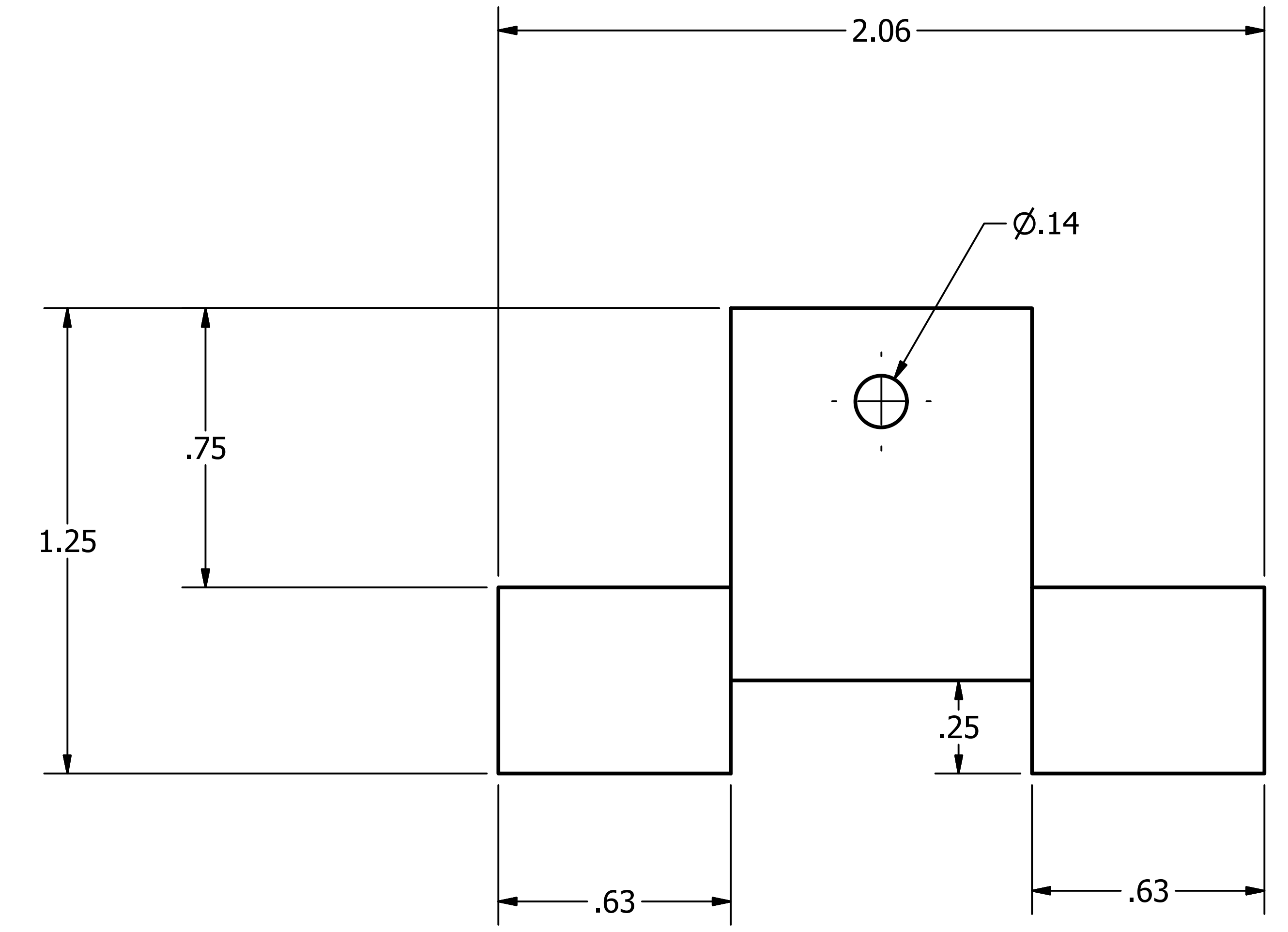
MATERIAL: Aluminum 6061

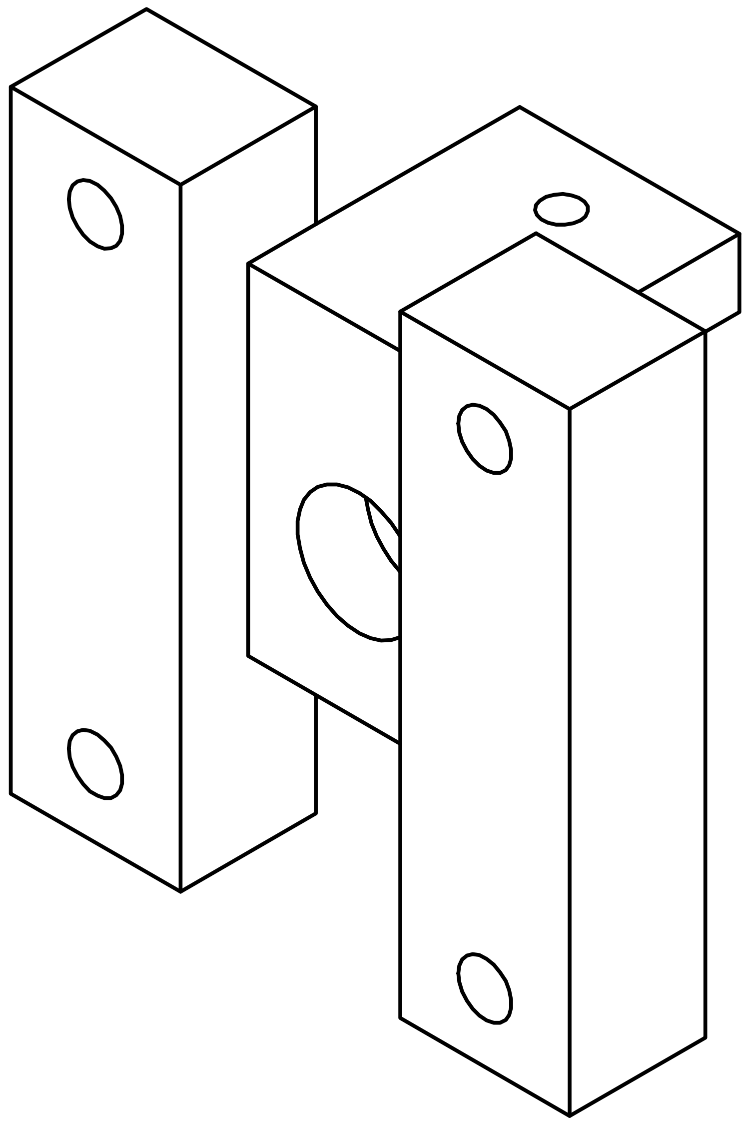
TITLE: Load Cell Roller

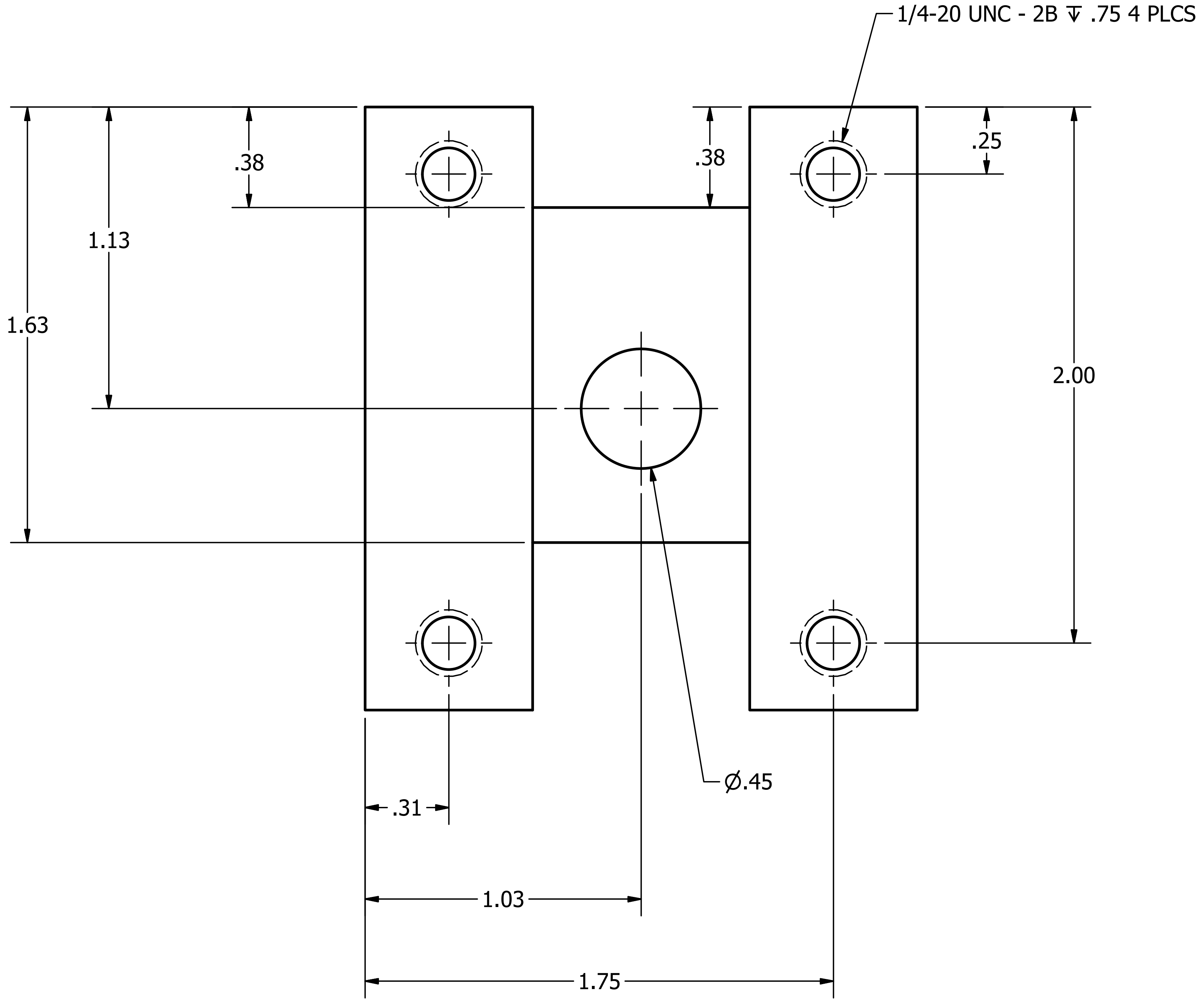
SHEET: 4 / 7

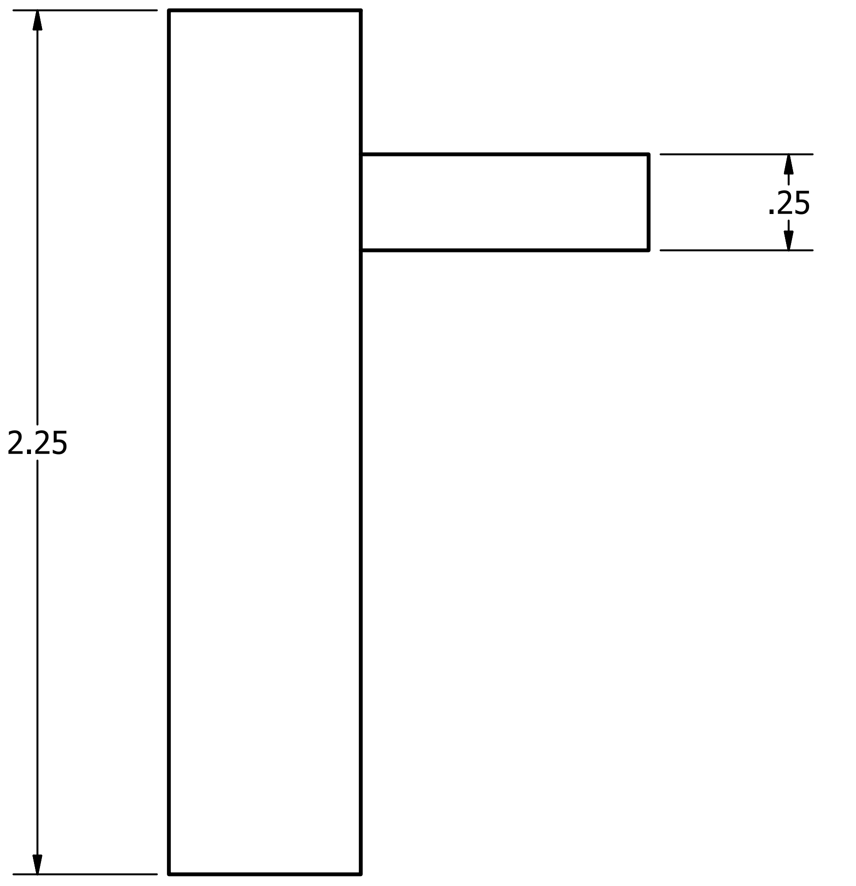
PART NUMBER: Load Cell Roller

SCALE: NONE









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THIRD ANGLE PROJECTION

SIZE: C

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DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

DRAWN BY: Dan Pierce
DATE: 11/16/2012
APPROVED:
DATE:

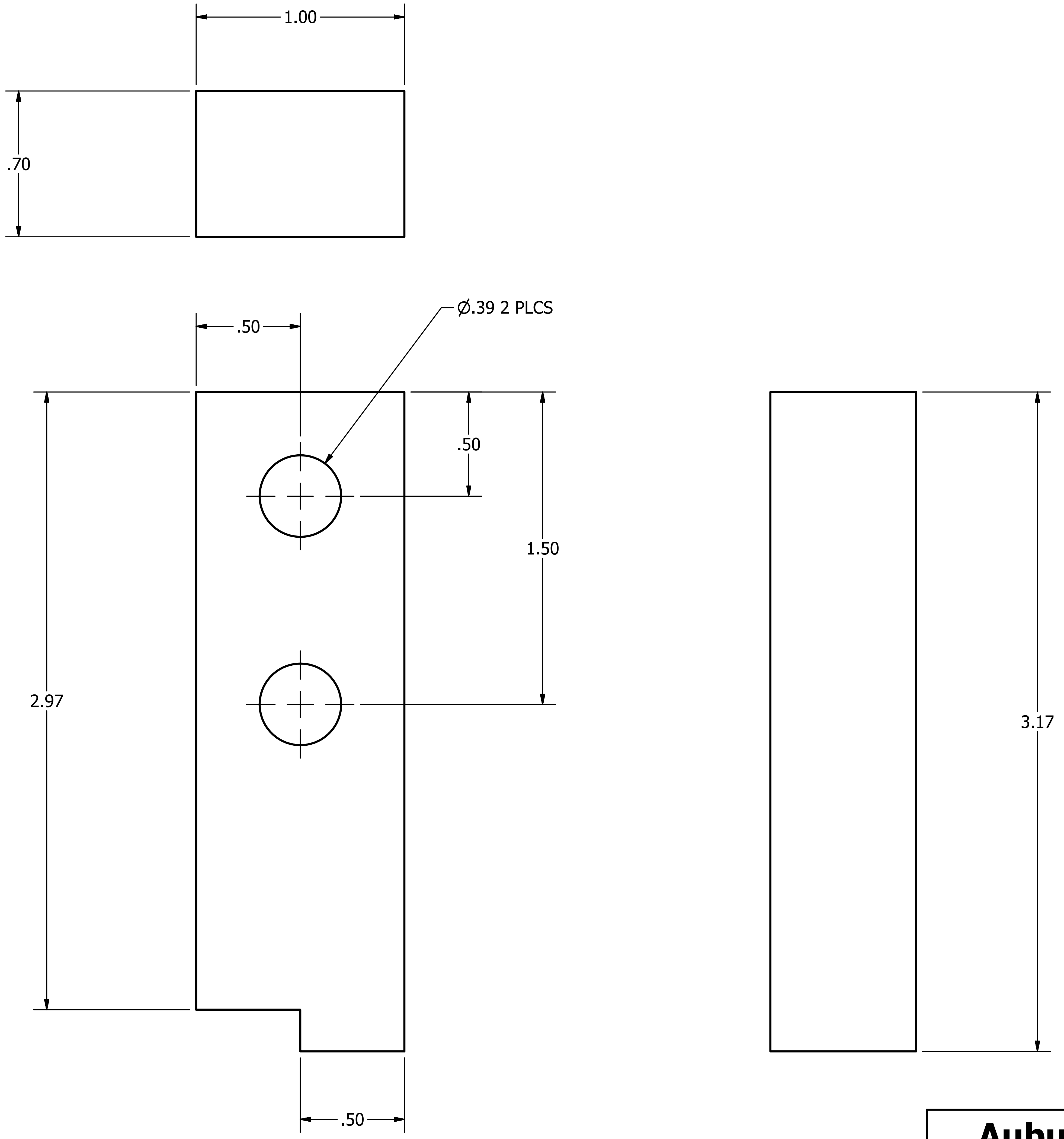
MATERIAL: Aluminum 6061

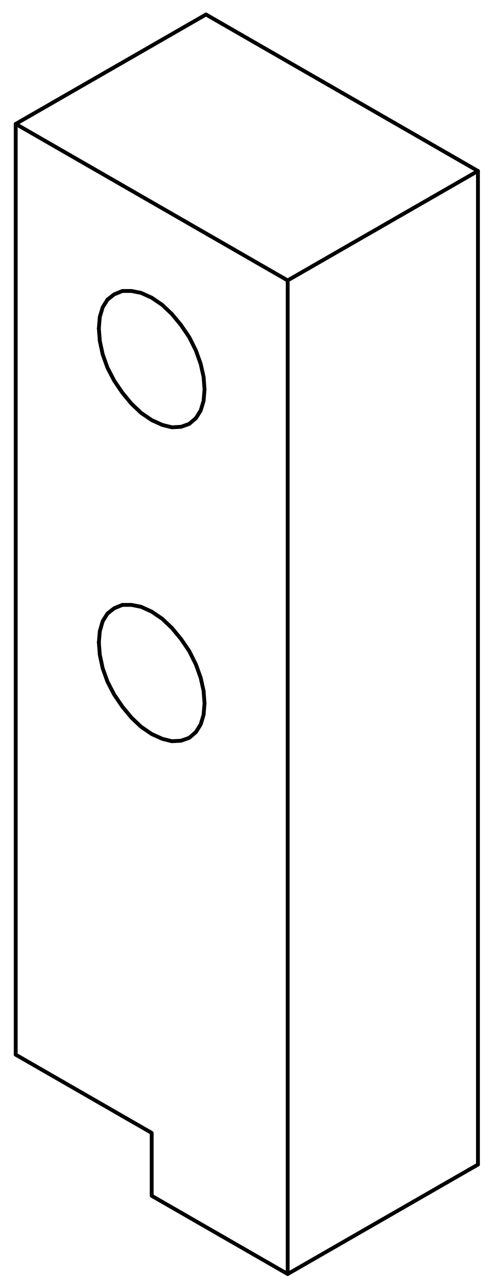
TITLE: Loadcell Bearing Mount

SHEET: 5 / 7

PART NUMBER: Loadcell Bearing Mount

SCALE: NONE





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Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

DRAWN BY: Dan Pierce
DATE: 5/1/2013
APPROVED:
DATE:

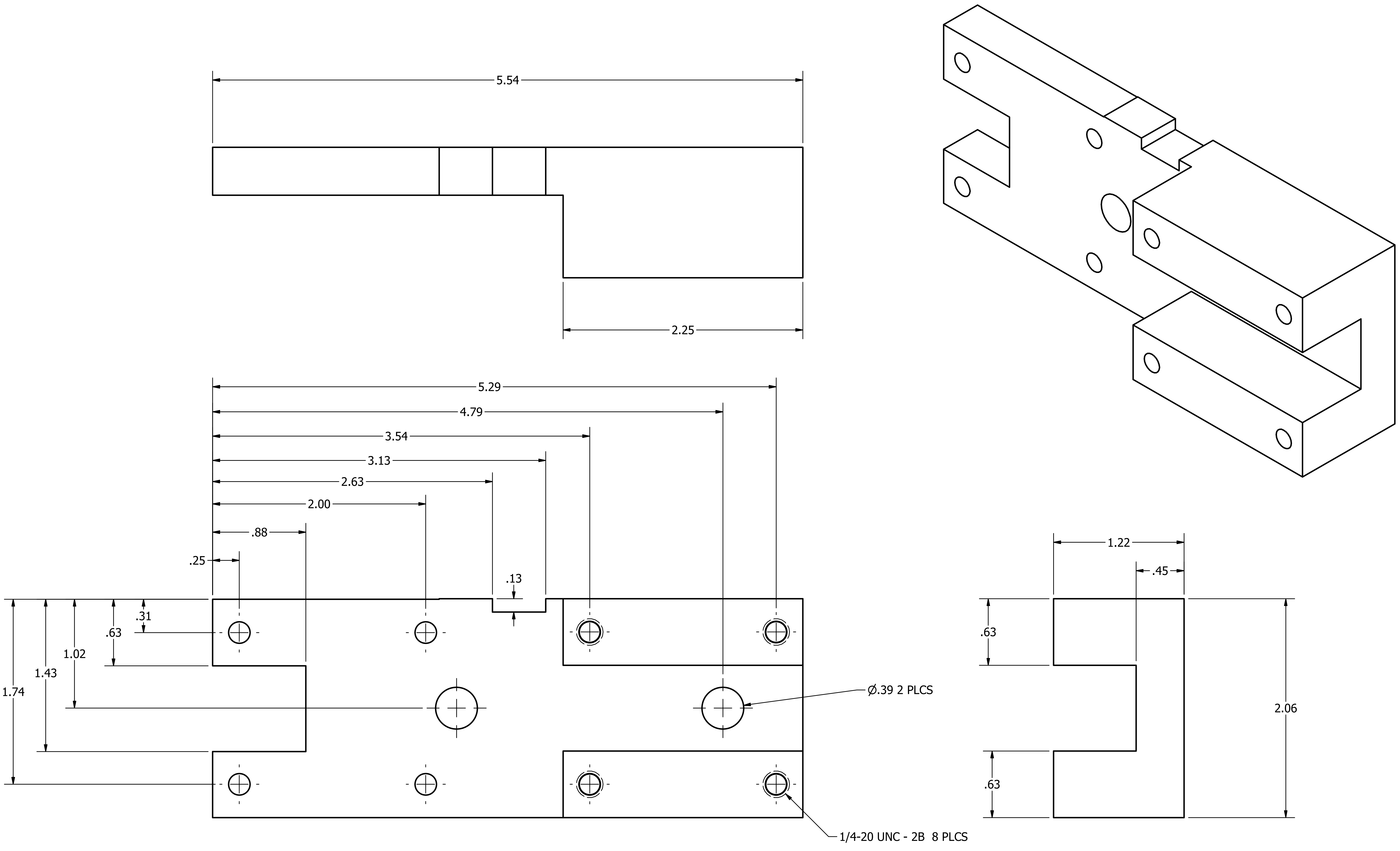
THIRD ANGLE PROJECTION
SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

MATERIAL: Aluminum 6061
TITLE: Load Cell Mount
SHEET: 6 / 7
PART NUMBER: 08-0003
SCALE: NONE



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Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

DRAWN BY: Dan Pierce
DATE: 5/1/2013
APPROVED:
DATE:

THIRD ANGLE PROJECTION

SIZE: C

UNLESS OTHERWISE NOTED DIMENSIONS AND TOLERANCES ARE DEFINED ACCORDING TO ASME STANDARD Y14.5M-1994.
DIMENSIONS ARE IN INCHES
TOLERANCES ARE:

DECIMALS	ANGLES
.XX ± .030	± .5
.XXX ± .010	

DO NOT SCALE DRAWING

MATERIAL: Aluminum 6061

TITLE: Outrigger Spool Mount

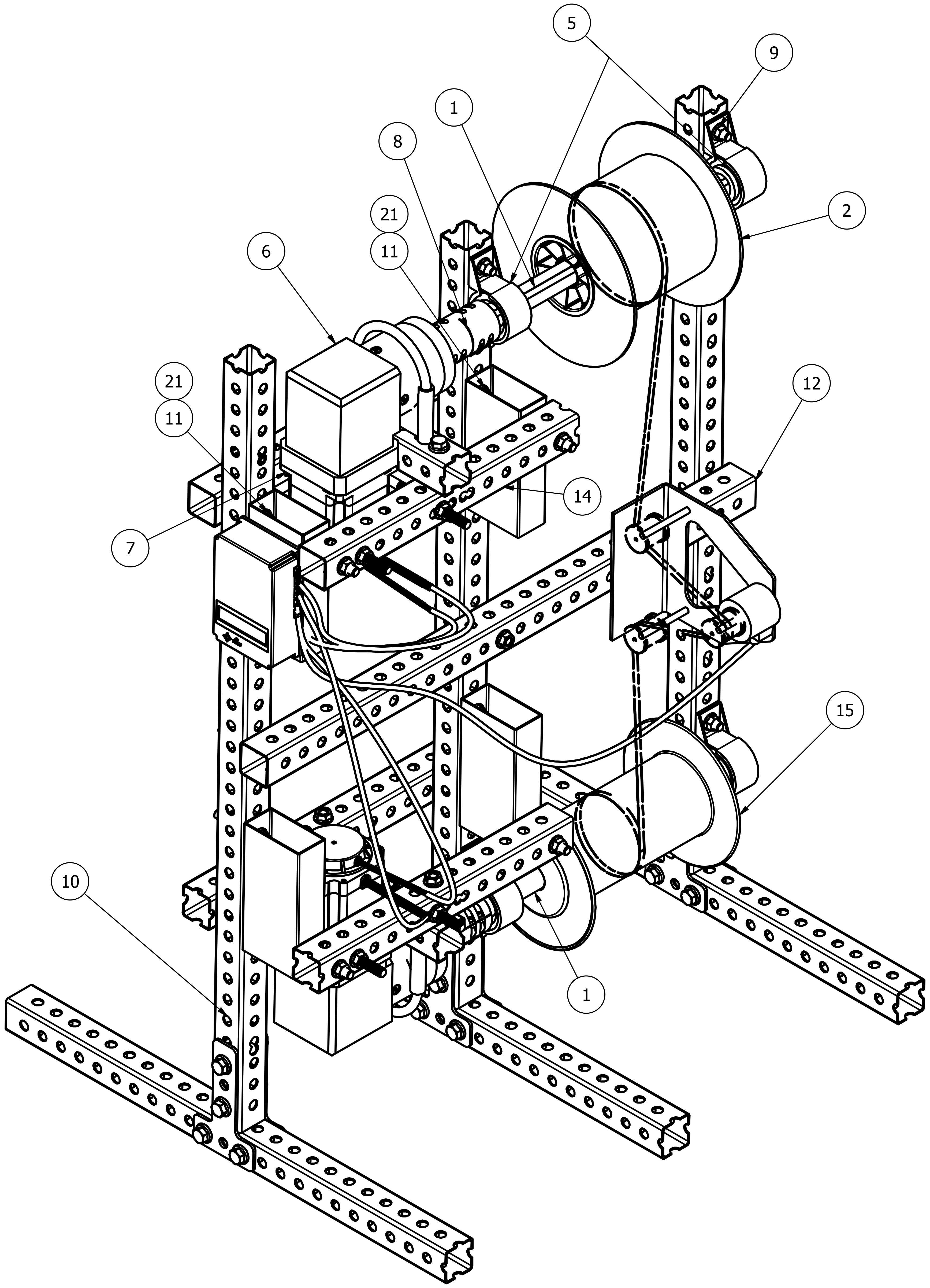
SHEET: 7 / 7

PART NUMBER: 08-0002

SCALE: NONE

PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	07-0003	Keyed Drive Shaft
2	1	07-0008.ipt	Thermoplastic Spool
3	14	IFI 111 - 3/8-16 UNC x 2.25	Hex Flange Screw - Regular Thread - Inch
5	4	5913K64	Stamped-Steel Mounted Ball Bearing
6	2	GBPNR-0802-CS	25:1 Right Angle Gearbox
7	2	BLY343S	30V DC Brushless Motor
8	2	60845K76	1" -3/4" Shaft Coupling
9	8	DIN EN 1661 - M8	Hex Nut
10	3	07-0000	Base Stand
11	5	IFI 111 - 3/8-16 UNC x 3	Hex Flange Screw - Regular Thread - Inch
12	1	07-0012	Crossbrace
13	1	05-0005	Controll Box
14	2	07-0014	Motor Mount Sub Assembly
15	1	07-0015	Empty Spool
16	1	07-0016	Tension Sensor Mount
17	1	03-0014	Radial Tension Sensor
20	1	07-0010.Harness	Wiring Harness
21	10	IFI - I0.375 - 16	Hex Flange Nut



DRAWN Grant Apperson	11/1/2012
CHECKED	
QA	
MFG	
APPROVED	

Auburn University
Senior Design -Army Robot
Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

TITLE Tension Test Aparatus

MATERIAL

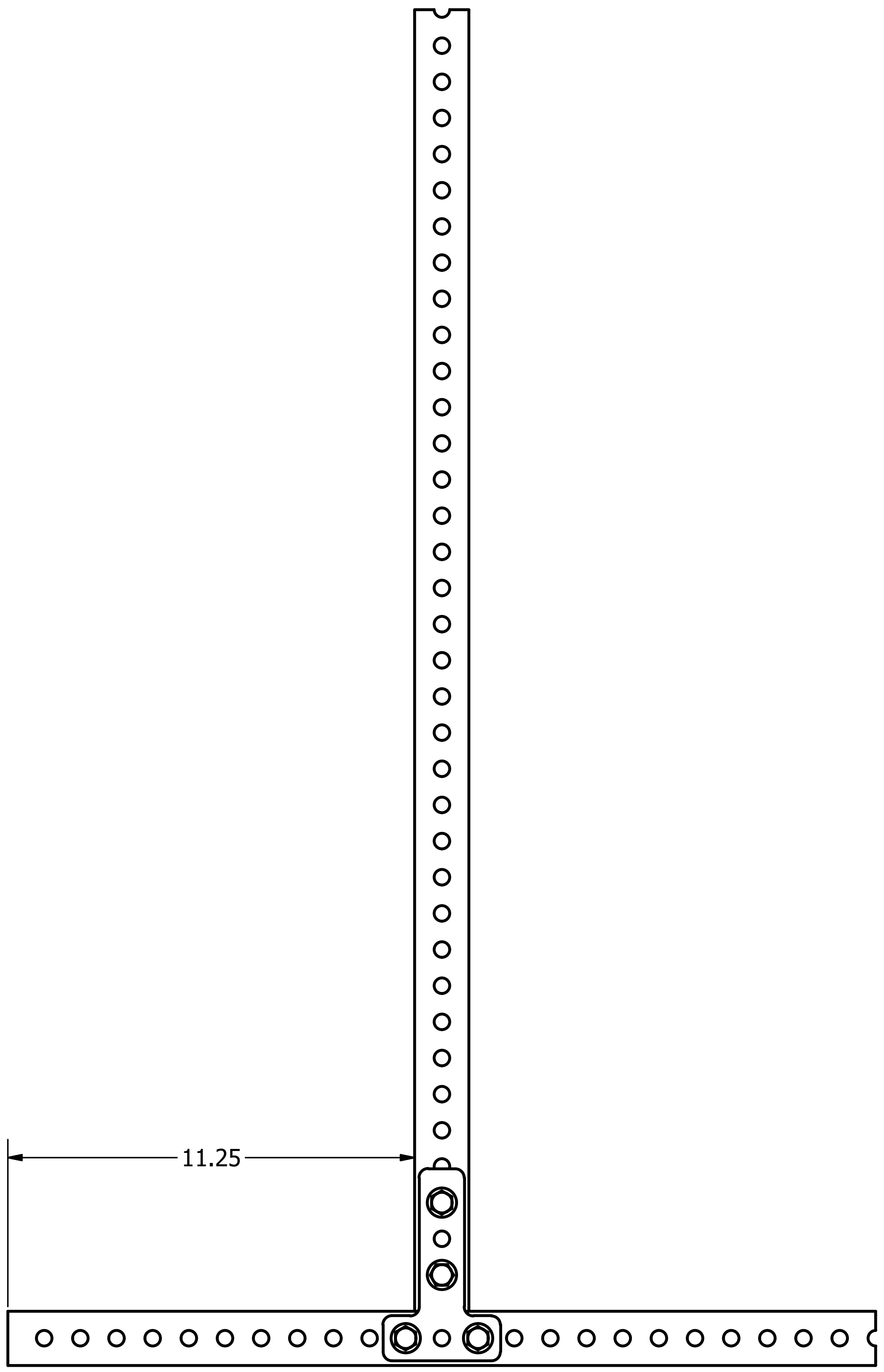
SIZE	DWG NO	REV
C	07-0010	

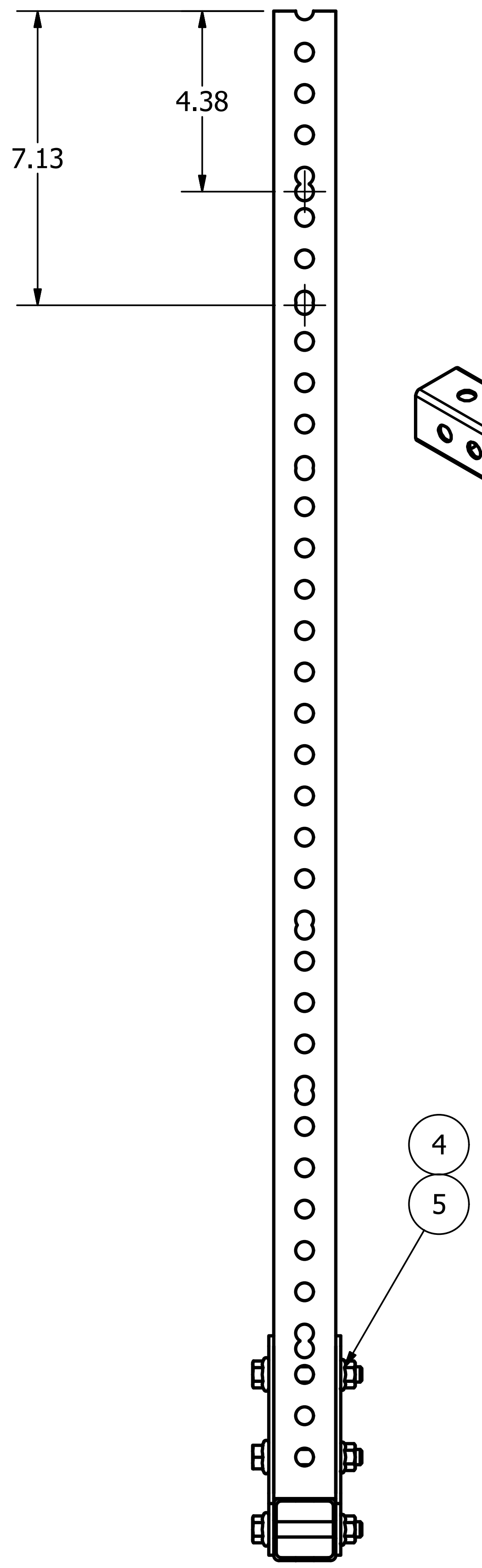
SCALE

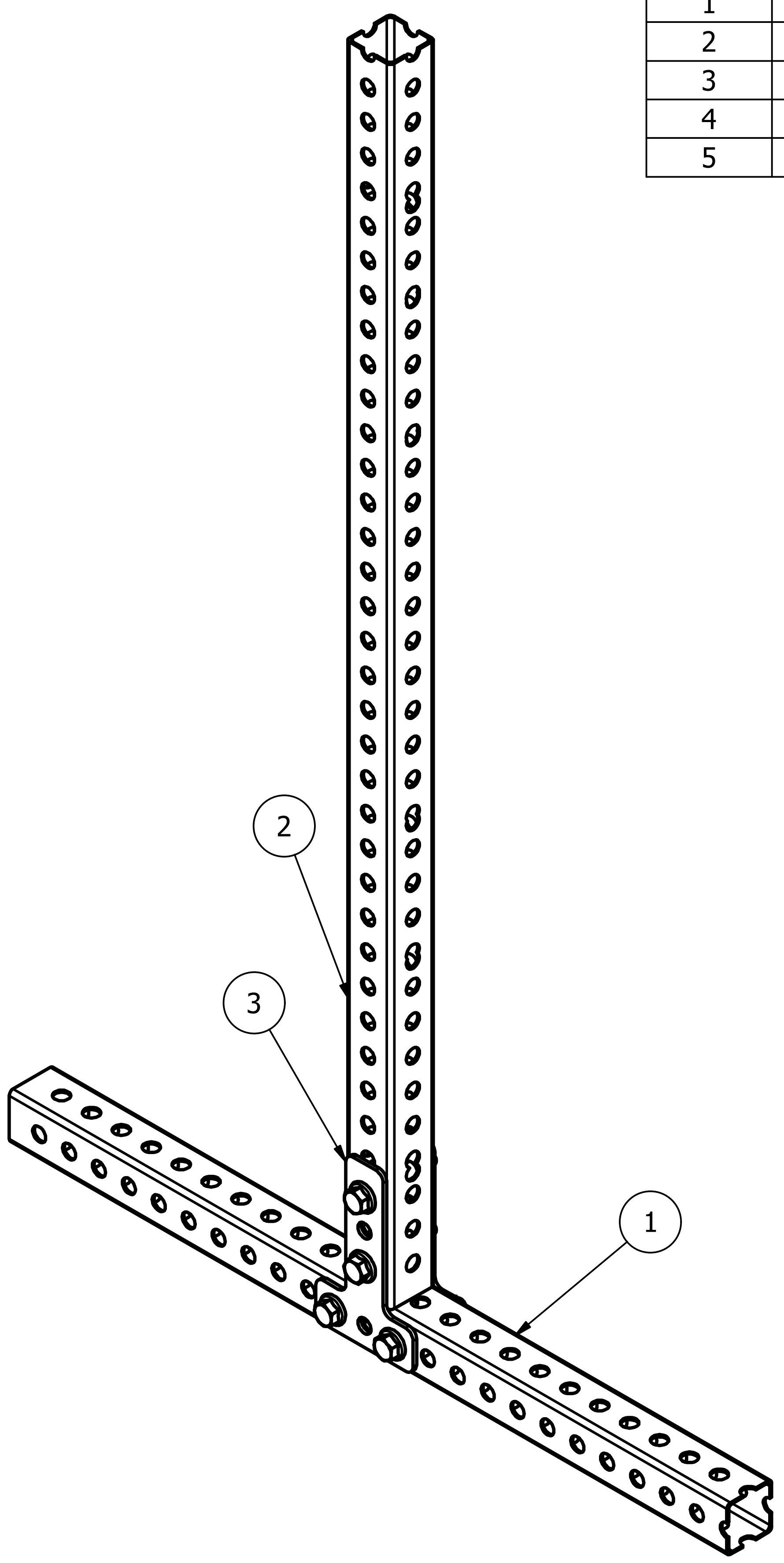
SHEET 1 OF 9

PARTS LIST

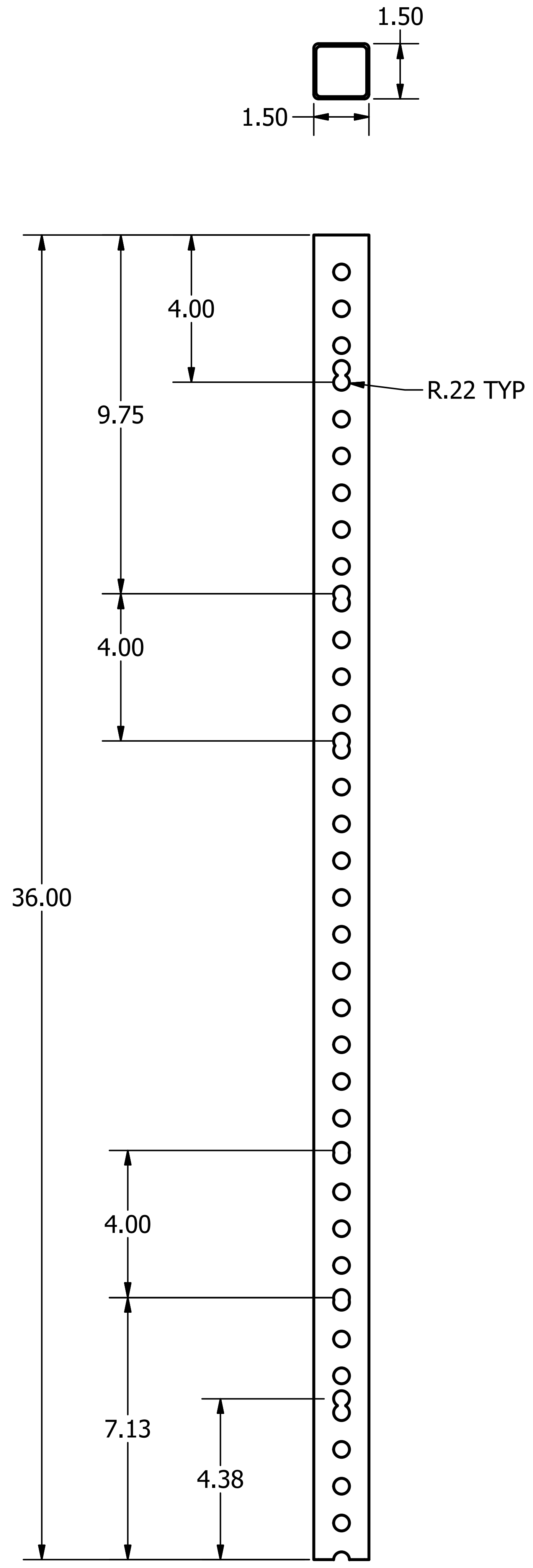
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	07-0002	Horizontal Leg
2	1	07-0000	Vertical Leg
3	2	4931T219	Tee Connecting Plate
4	4	IFI 111 - 3/8-16 UNC x 2.25	Hex Flange Screw - Regular Thread - Inch
5	4	IFI - I0.375 - 16	Hex Flange Nut

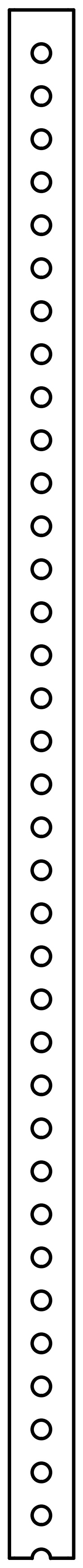


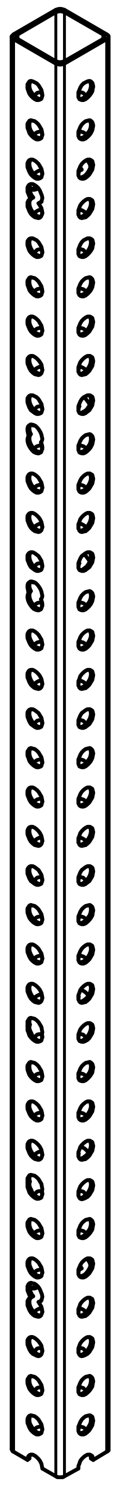




DRAWN Grant Apperson	11/1/2012	**Auburn University** Senior Design -Army Robot Wiggins Hall 354 War Eagle Way, Auburn, AL 36849
CHECKED		TITLE Base Stand
QA		MATERIAL
MFG		SIZE C · DWG NO 07-0000 · REV
APPROVED		SCALE · SHEET 2 OF 9







DRAWN Grant Apperson	11/1/2012
CHECKED	
QA	
MFG	
APPROVED	

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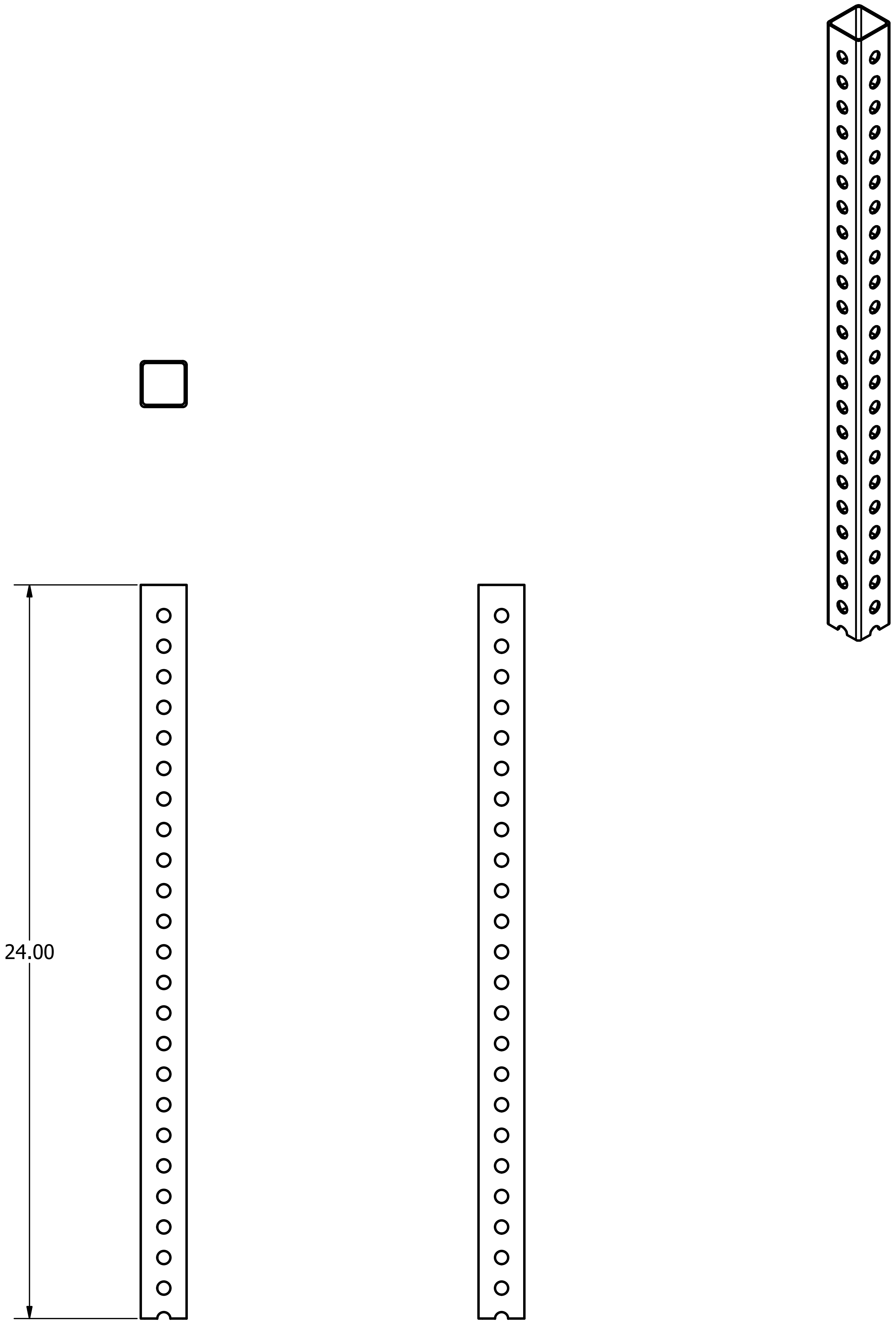
Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

TITLE Vertical Leg

MATERIAL 1497K961

SIZE C
DWG NO 07-0000
REV

SCALE
SHEET 3 OF 9



DRAWN Grant Apperson	11/1/2012
CHECKED	
QA	
MFG	
APPROVED	

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Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

TITLE Horizontal Leg

MATERIAL 1497K961

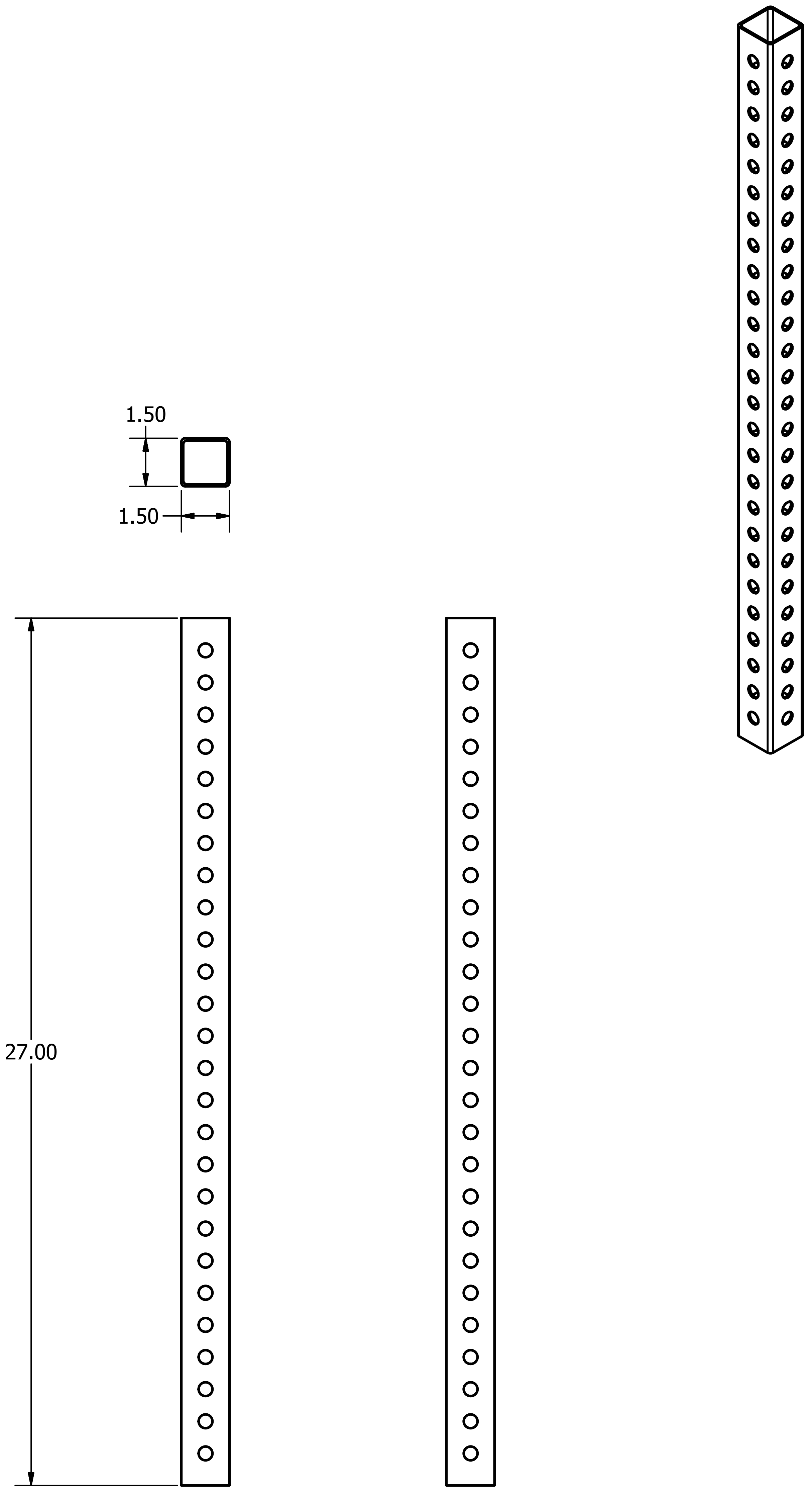
SIZE C

DWG NO 07-0002

REV

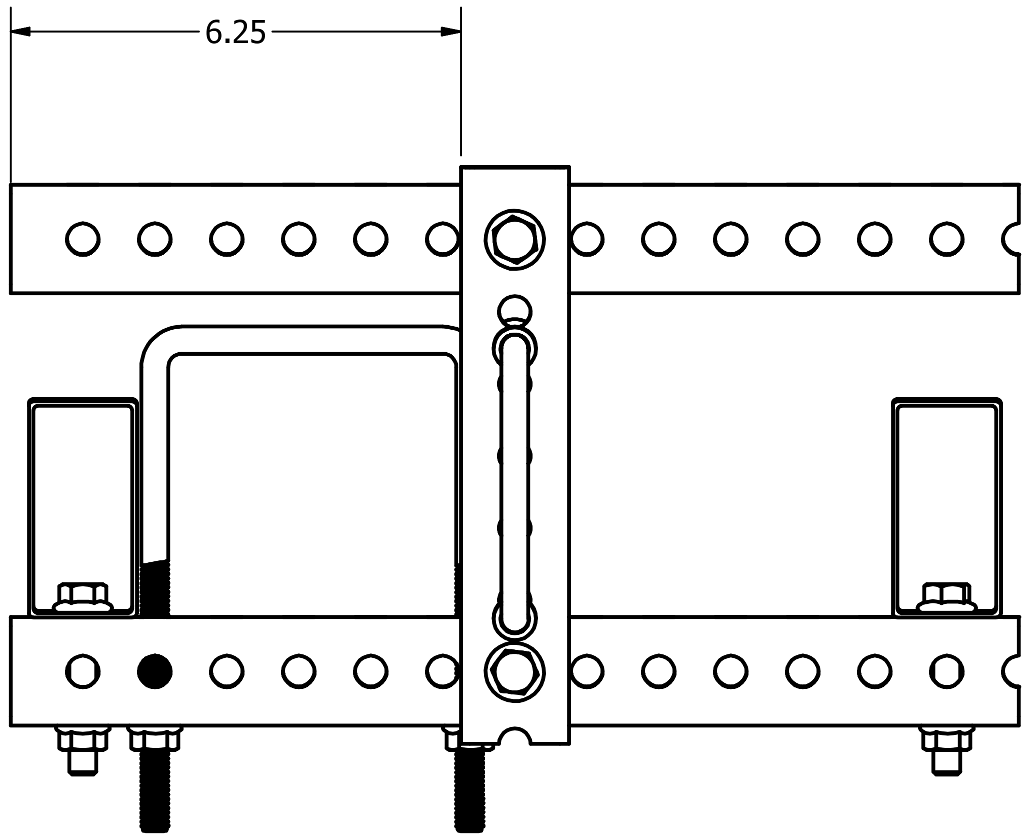
SCALE

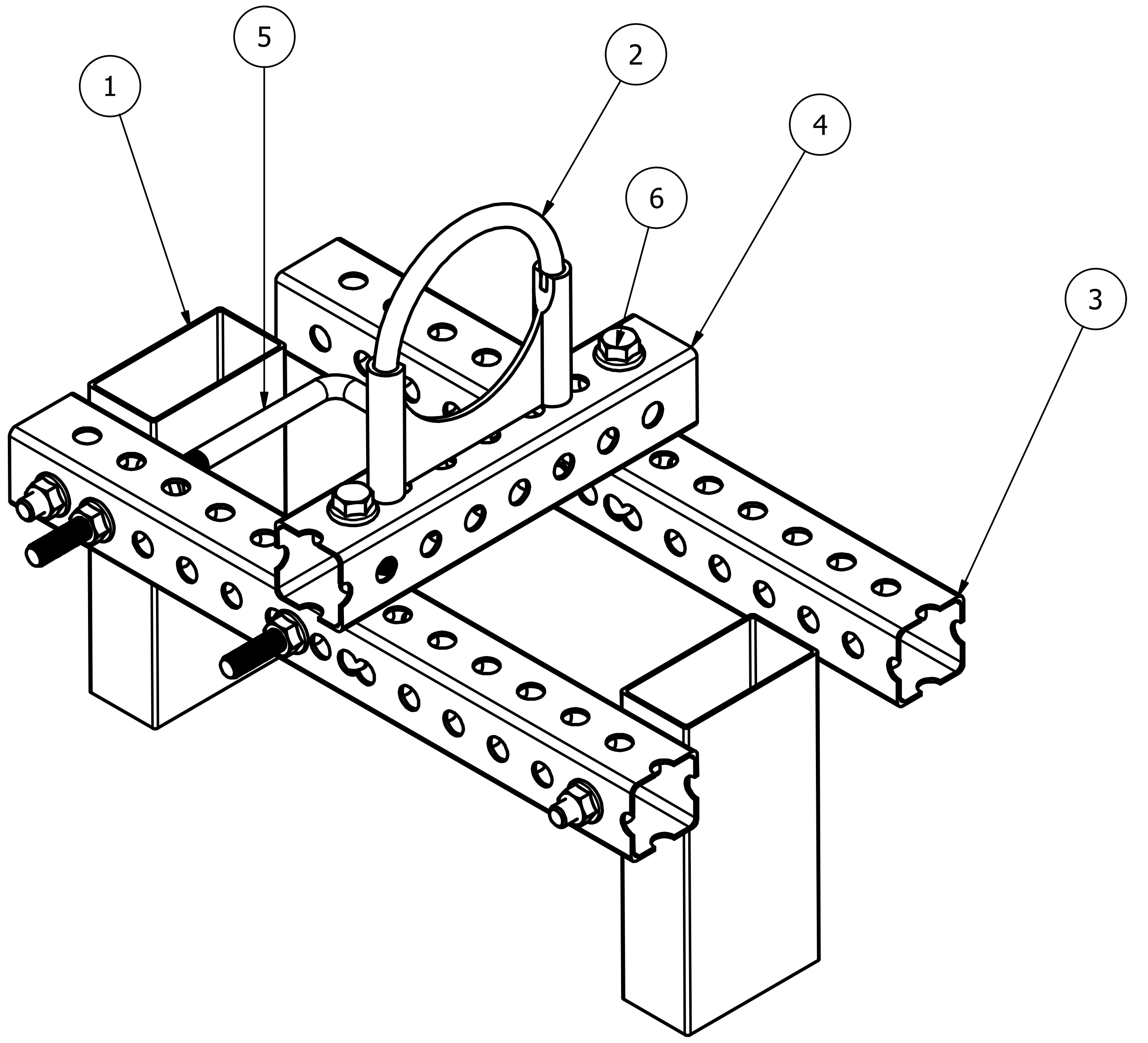
SHEET 4 OF 9

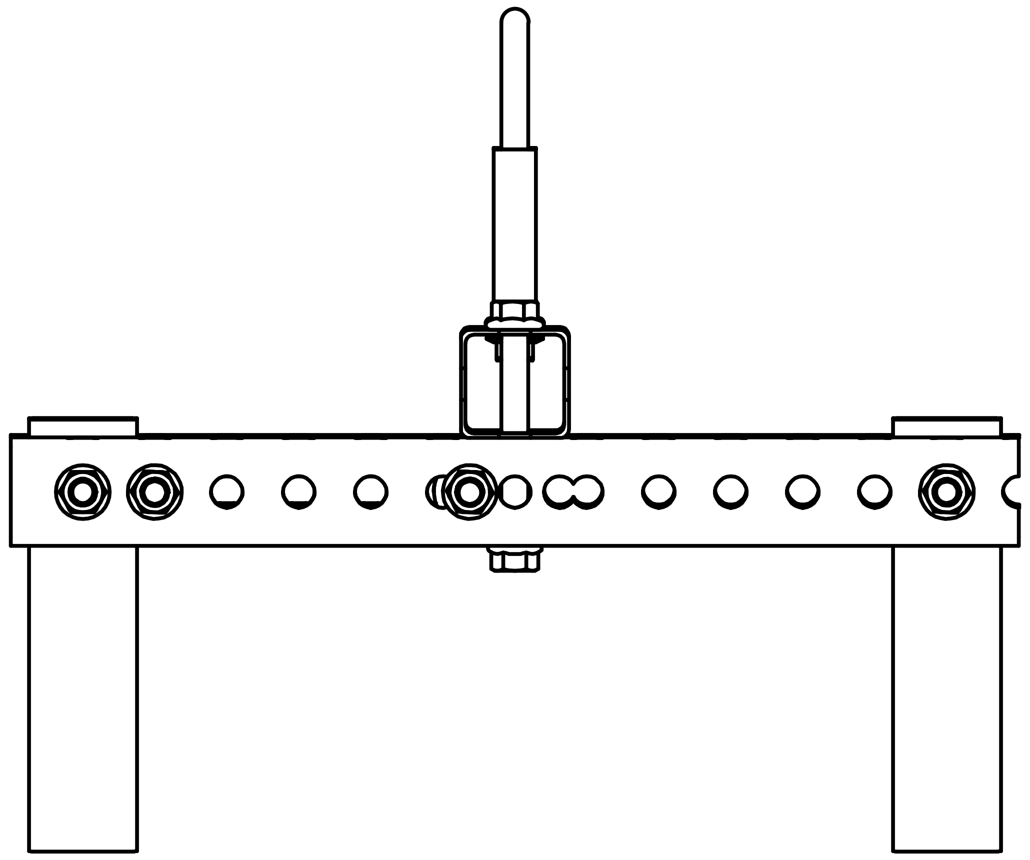


DRAWN Grant Apperson	11/1/2012	**Auburn University** Senior Design -Army Robot Wiggins Hall 354 War Eagle Way, Auburn, AL 36849		
CHECKED				
QA		TITLE Crossbrace		
MFG				
APPROVED		MATERIAL 1497K961		
		SIZE C	DWG NO 07-0012	REV
		SCALE		SHEET 5 OF 9

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	2	07-0011	Tubing Offset
2	1	3042T190	3-1/4 " Clamp
3	2	07-0009	Motor Mount Crossbrace
4	1	07-0013	Motor Mount
5	1	3060T49	Square Clamp
6	2	IFI 111 - 3/8-16 UNC x 3	Hex Flange Screw - Regular Thread - Inch
7	2	IFI 111 - 3/8-16 UNC x 2.25	Hex Flange Screw - Regular Thread - Inch
8	6	IFI - I0.375 - 16	Hex Flange Nut







DRAWN
Grant Apperson 11/1/2012
CHECKED
QA
MFG
APPROVED

Auburn University

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Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

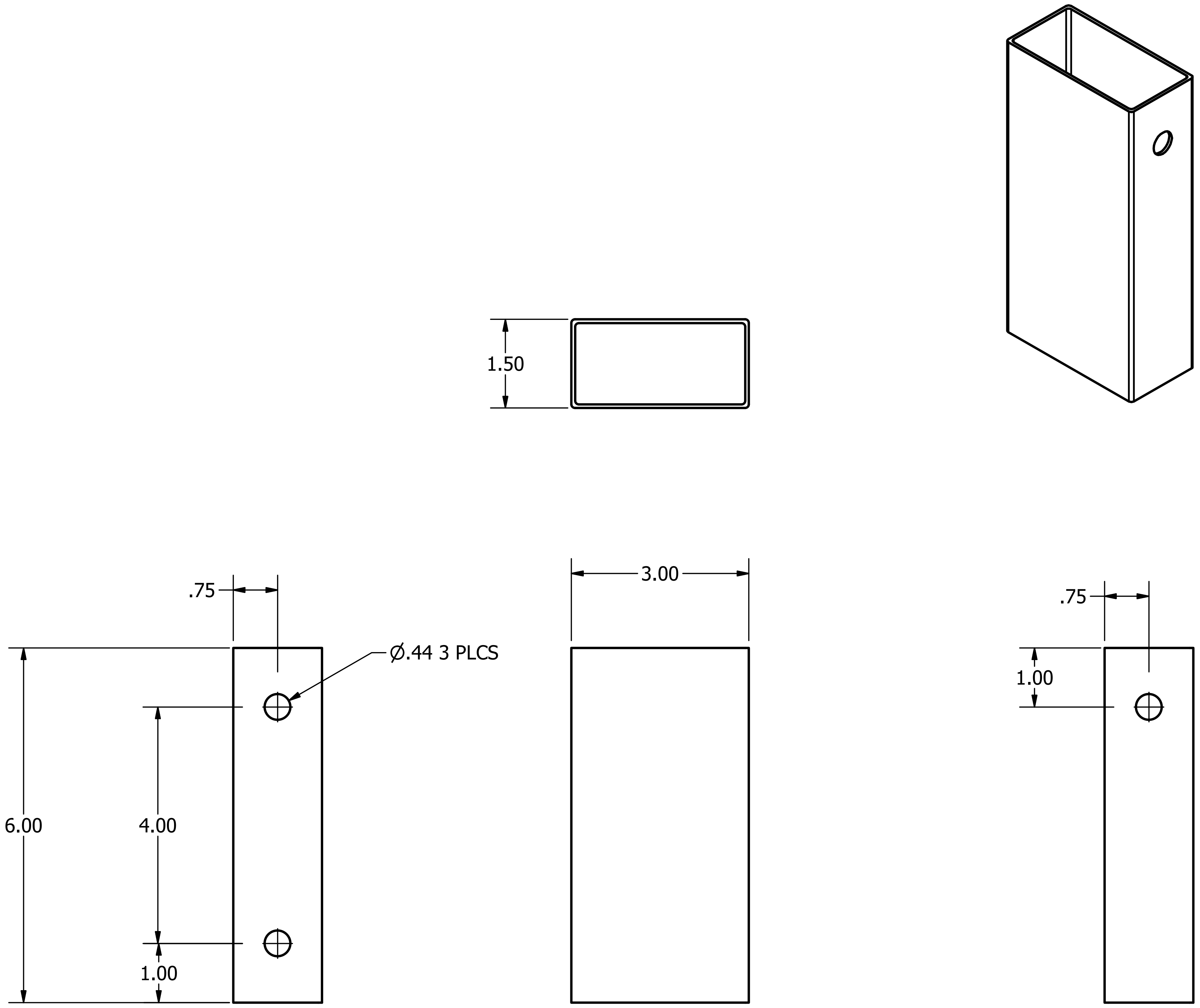
TITLE Motor Mount Sub Assembly

MATERIAL

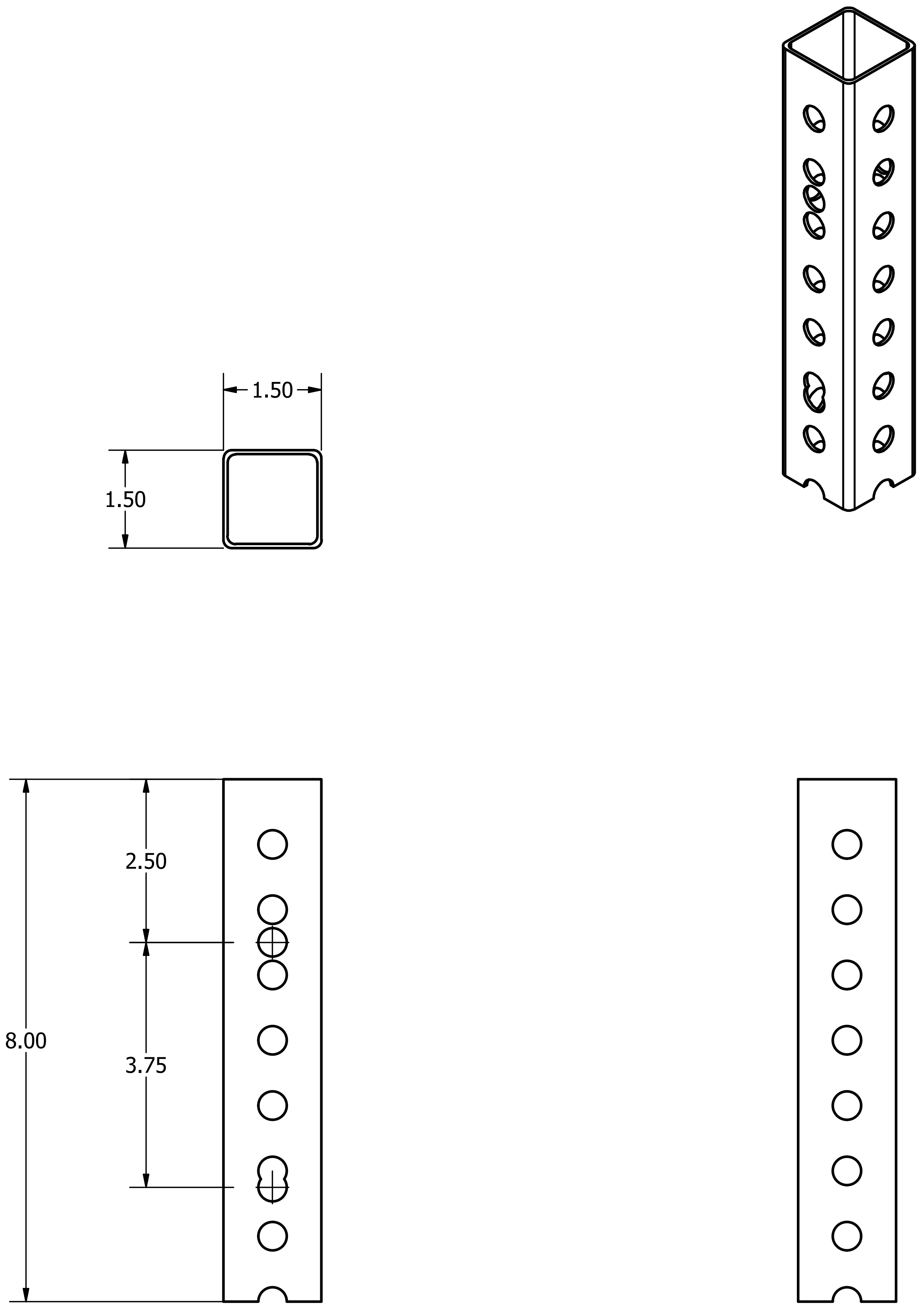
SIZE C
DWG NO 07-0014
REV

SCALE

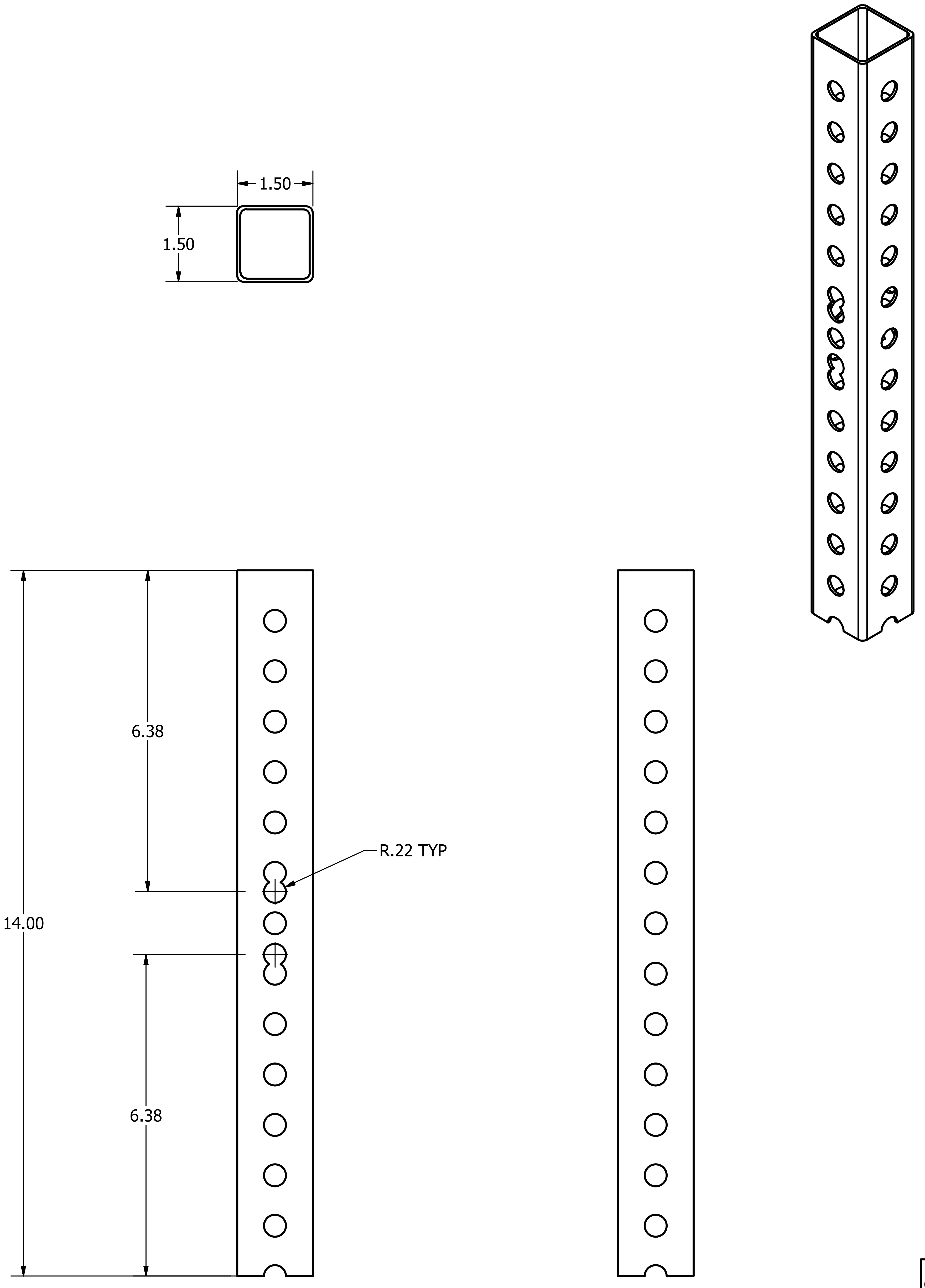
SHEET 6 OF 9



DRAWN Grant Apperson	11/1/2012	**Auburn University** Senior Design -Army Robot Wiggins Hall 354 War Eagle Way, Auburn, AL 36849
CHECKED		TITLE Tubing Offset
QA		
MFG		
APPROVED		MATERIAL 3" X 1-1/2" Steel Tubing
		SIZE C · DWG NO 07-0011 · REV
		SCALE · SHEET 7 OF 9



DRAWN Grant Apperson	11/1/2012	**Auburn University** Senior Design -Army Robot Wiggins Hall 354 War Eagle Way, Auburn, AL 36849
CHECKED		TITLE Motor Mount
QA		
MFG		
APPROVED		MATERIAL 1497K961
		SIZE C | DWG NO 07-0013 | REV
		SCALE | SHEET 8 OF 9



DRAWN Grant Apperson	11/1/2012
CHECKED	
QA	
MFG	
APPROVED	

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Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

TITLE Motor Mount Crossbrace

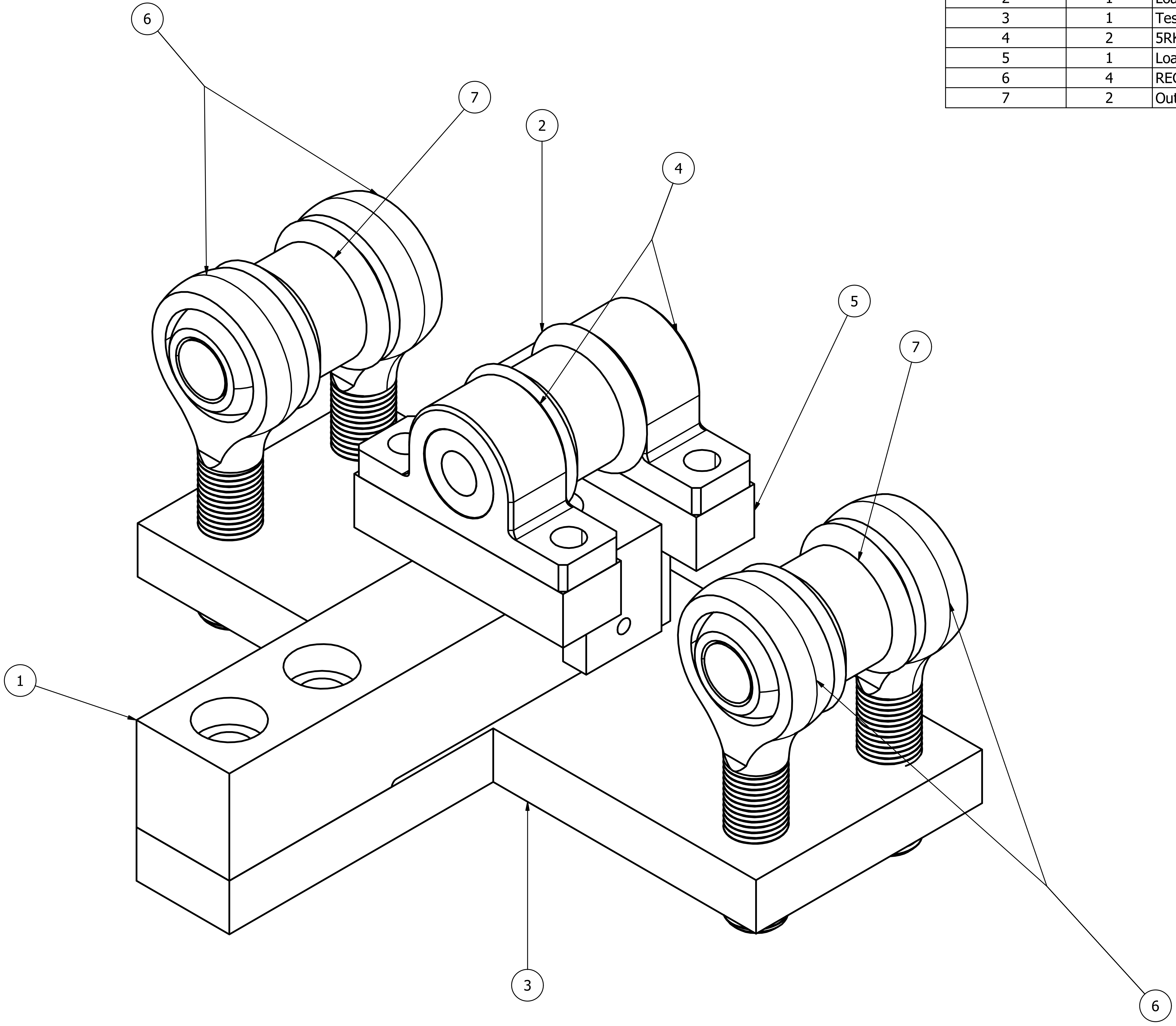
MATERIAL 1497K961

SIZE	DWG NO	REV
C	07-0009	

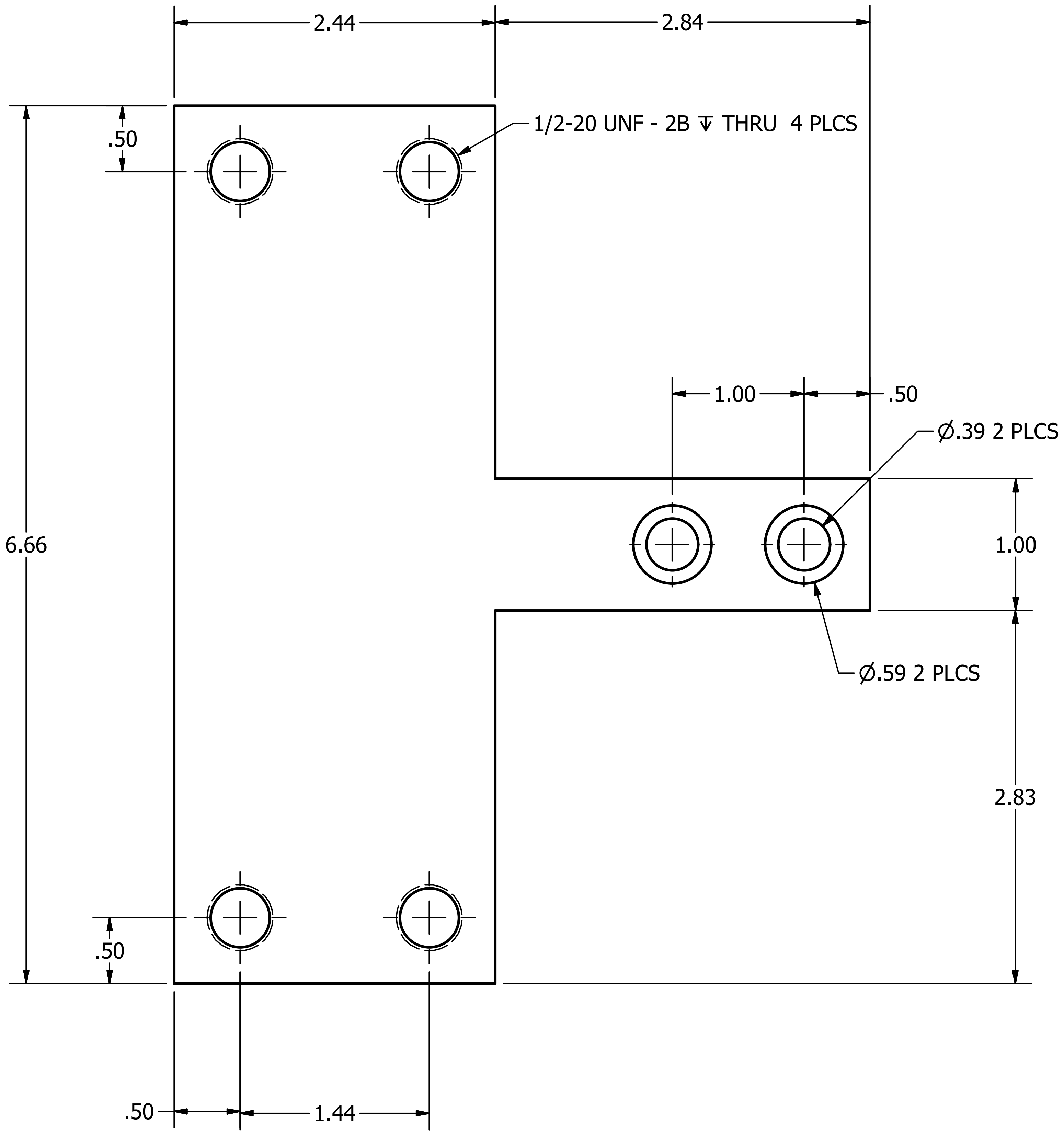
SCALE

SHEET 9 OF 9

PARTS LIST			
ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	LoadCell	
2	1	Load Cell Roller	Load Cell Roller
3	1	TestFixtureBracket	
4	2	5RKD6	Load Cell Bearing
5	1	Loadcell Bearing Mount	Loadcell Bearing Mount
6	4	REC-012M	Outrigger Spool Bearings
7	2	Outrigger Roller	Outrigger Roller



DRAWN Dan Pierce	11/27/2012	**Auburn University** Senior Design -Army Robot Wiggins Hall 354 War Eagle Way, Auburn, AL 36849
CHECKED		TITLE Test Fixture Loadcell Config.
QA		
MFG		MATERIAL
APPROVED		SIZE C · DWG NO Test Fixture Loadcell Config. · REV
		SCALE · SHEET 1 OF 6



DRAWN
Dan Pierce
11/27/2012
CHECKED
QA
MFG
APPROVED

Auburn University
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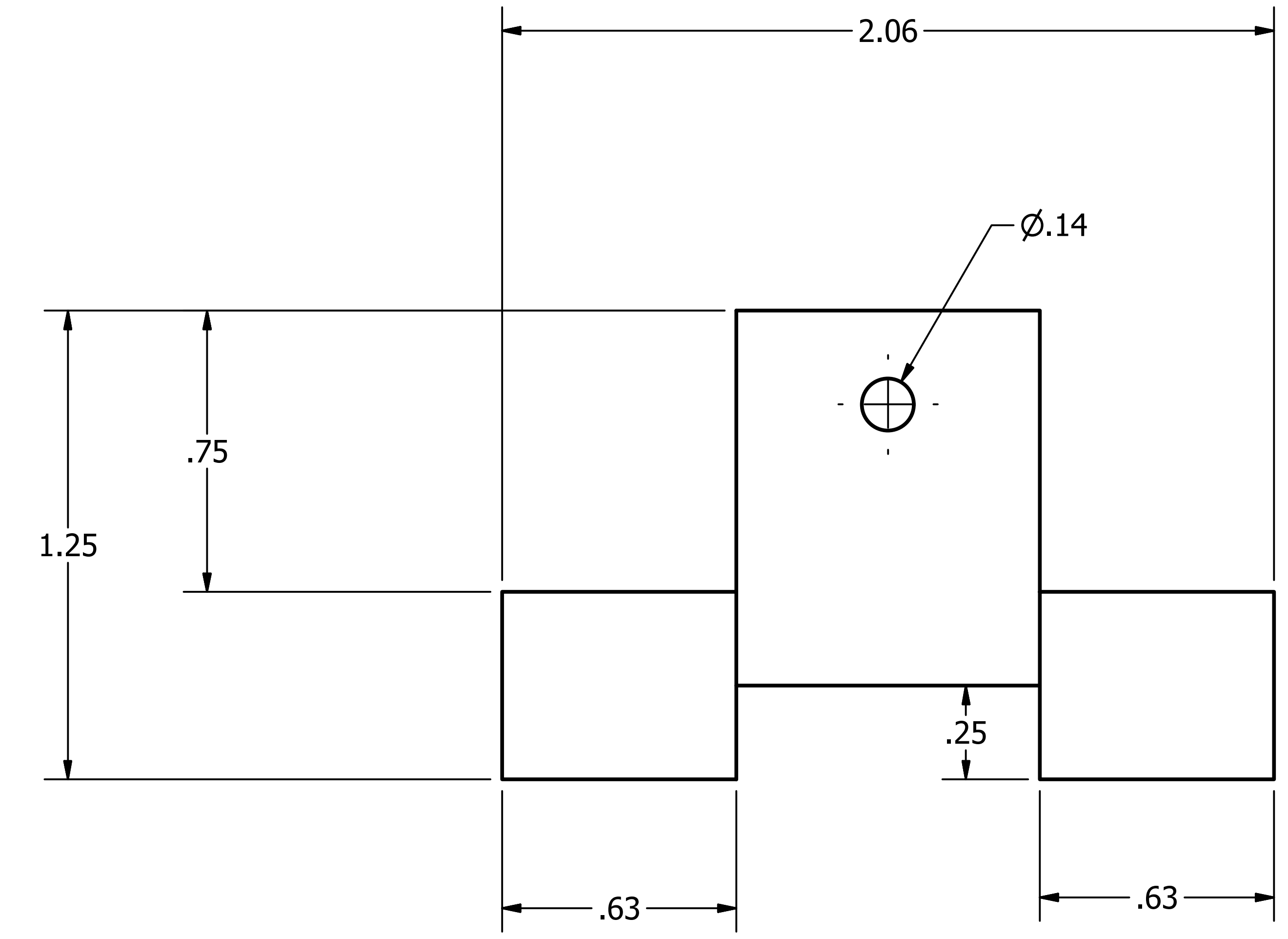
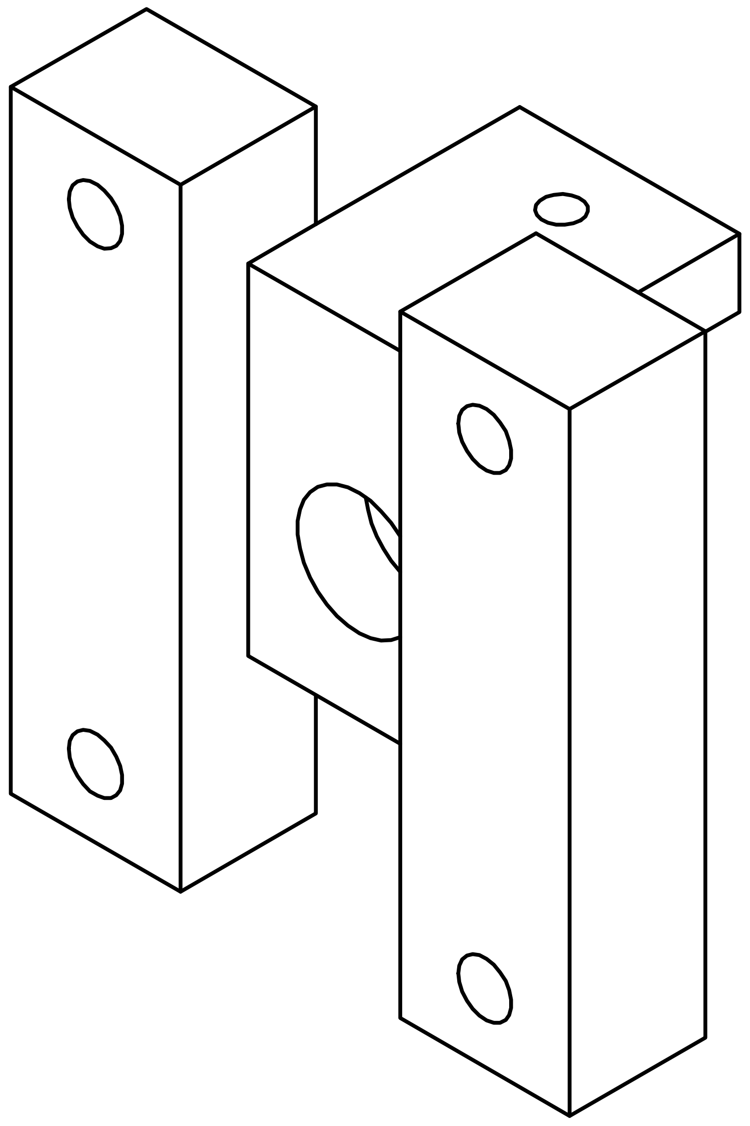
Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

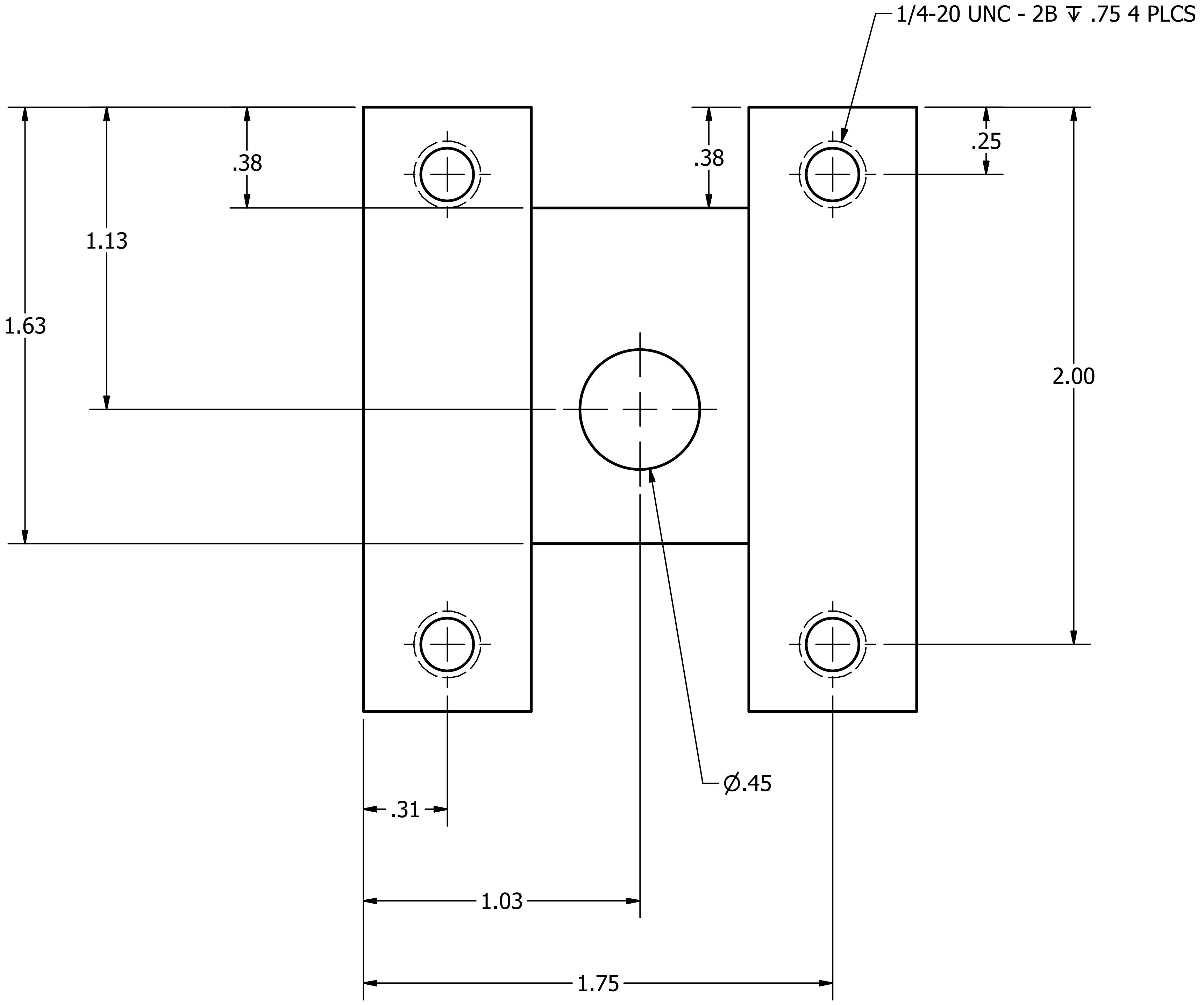
TITLE

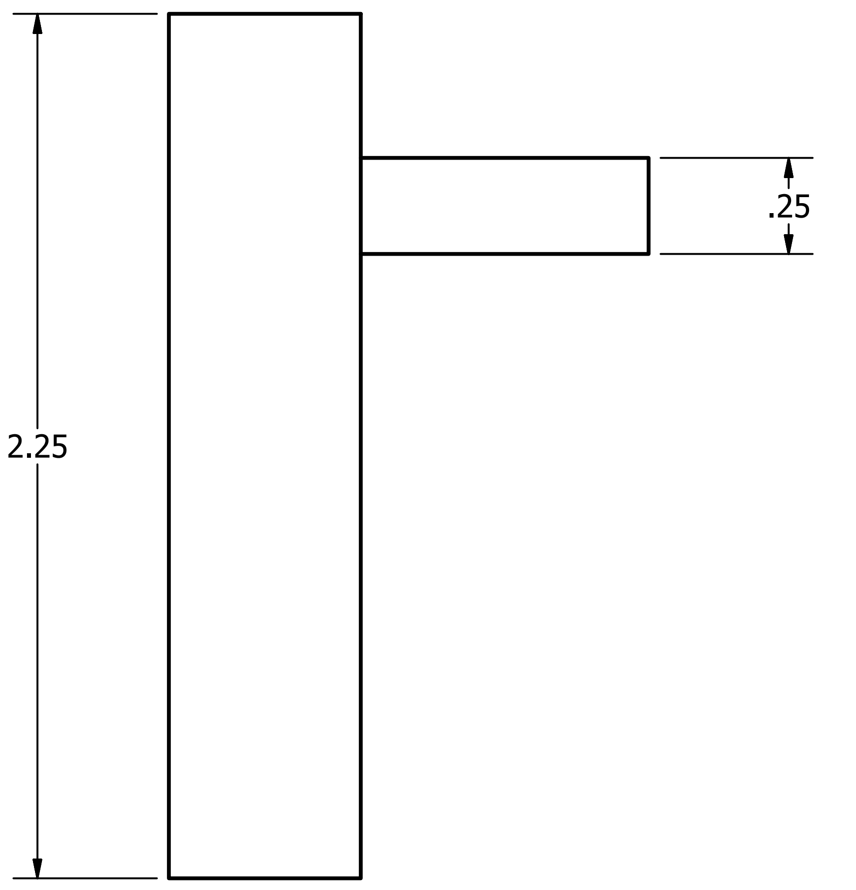
MATERIAL Steel, Carbon

SIZE C
DWG NO
REV
SCALE
SHEET 2 OF 6









DRAWN Dan Pierce	11/27/2012
CHECKED	
QA	
MFG	
APPROVED	

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Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

TITLE Loadcell Bearing Mount

MATERIAL Aluminum 6061

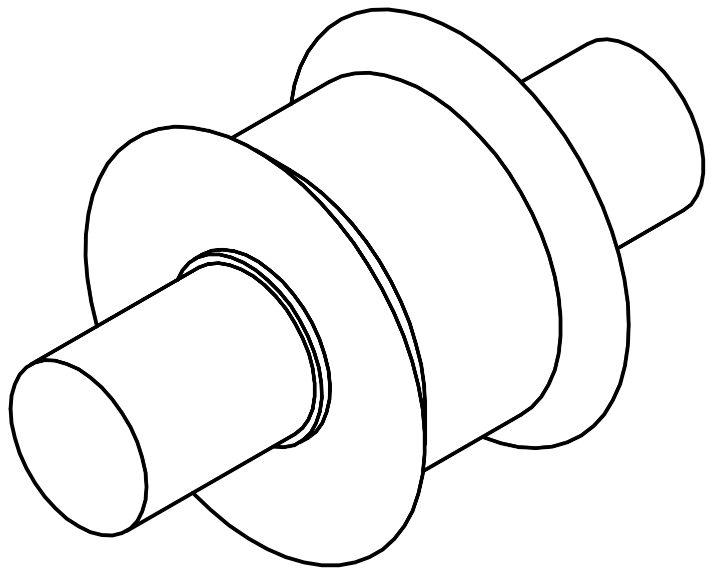
SIZE C

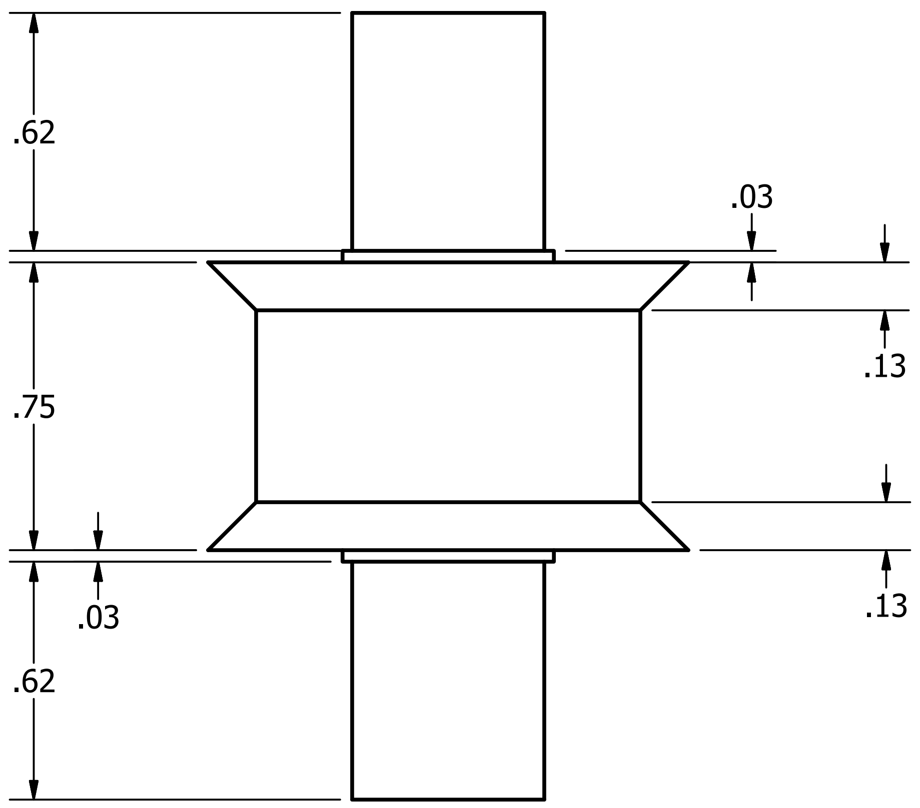
DWG NO Loadcell Bearing Mount

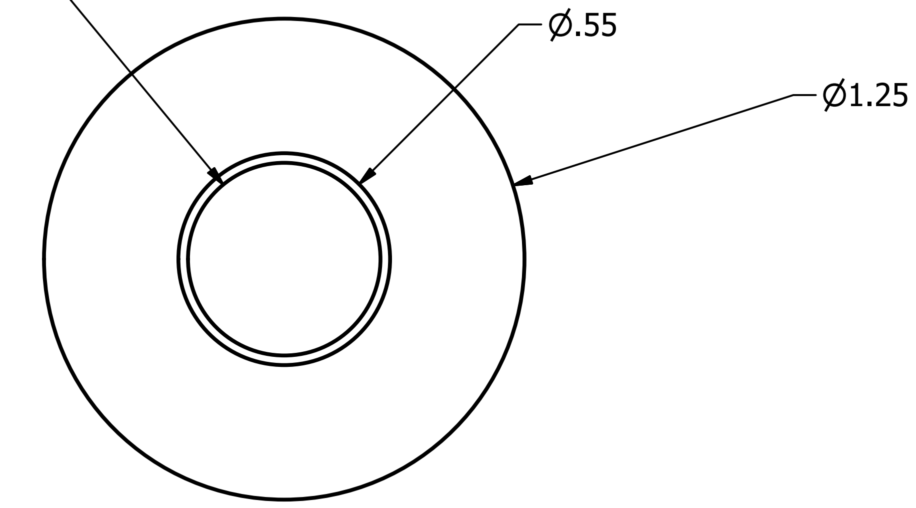
REV

SCALE

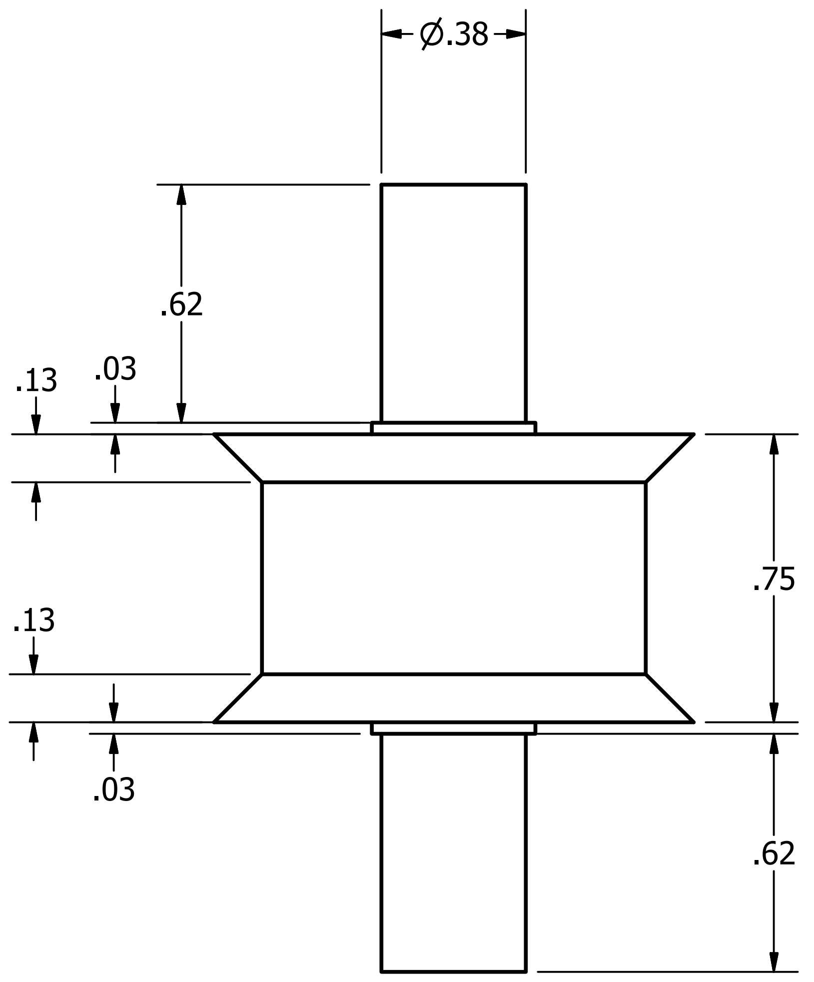
SHEET 3 OF 6

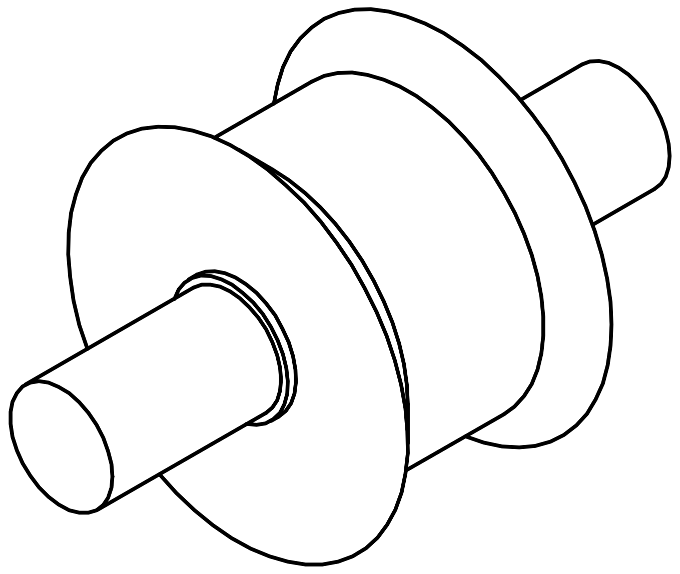


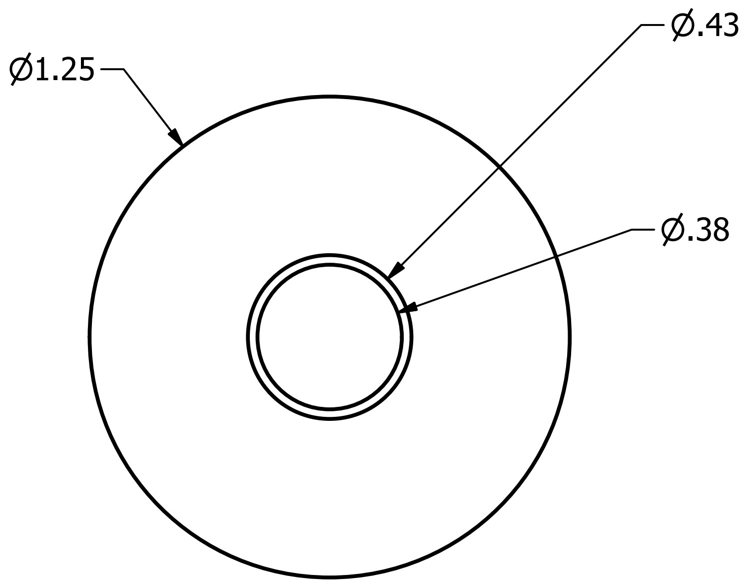




DRAWN Dan Pierce	11/27/2012	**Auburn University** Senior Design -Army Robot Wiggins Hall 354 War Eagle Way, Auburn, AL 36849
CHECKED		
QA		TITLE Outrigger Roller
MFG		
APPROVED		MATERIAL Aluminum 6061
		SIZE C | DWG NO Outrigger Roller | REV
		SCALE | SHEET 4 OF 6







DRAWN Dan Pierce	11/27/2012
CHECKED	
QA	
MFG	
APPROVED	

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Wiggins Hall
354 War Eagle Way, Auburn, AL 36849

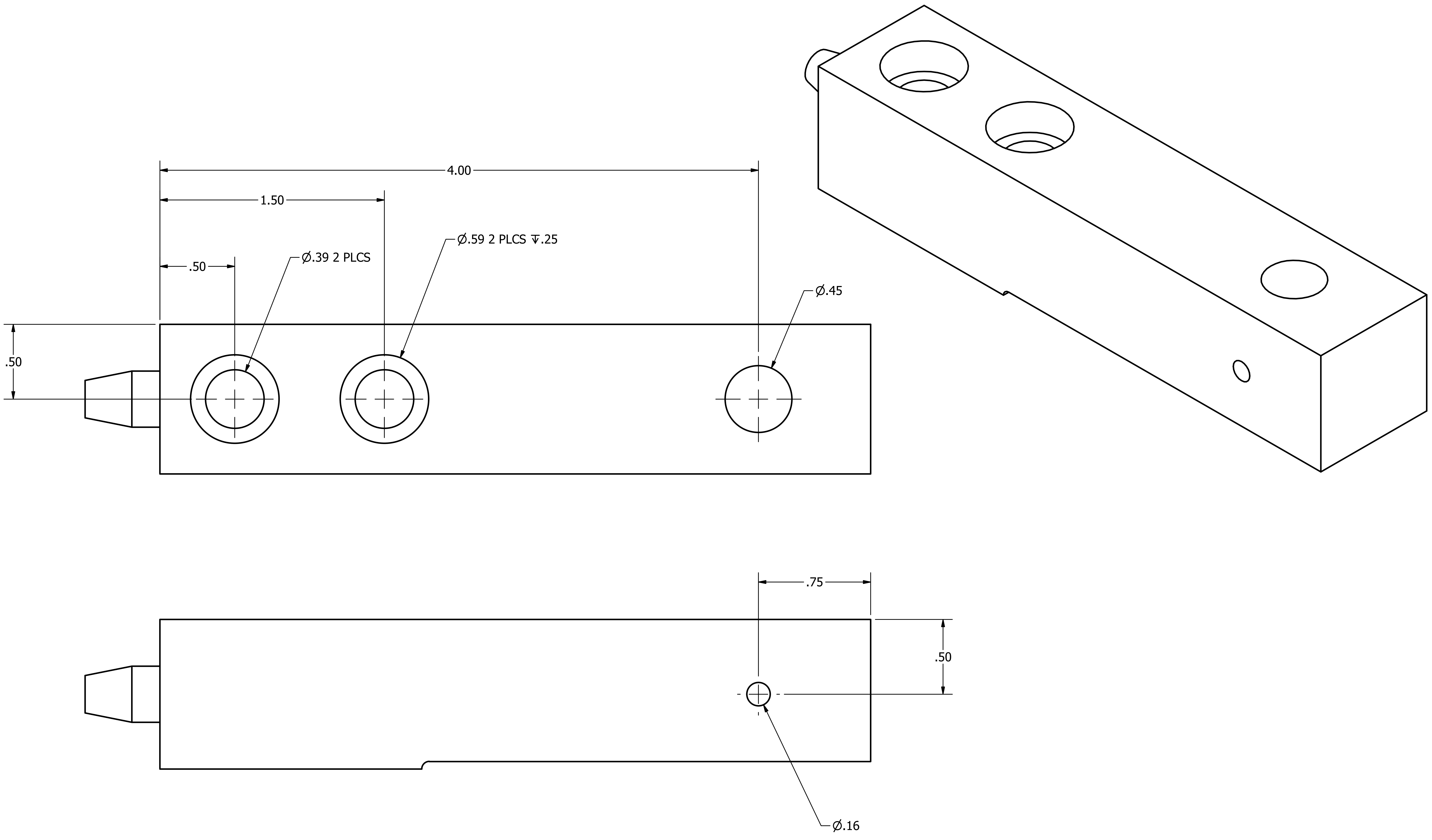
TITLE Load Cell Roller

MATERIAL Aluminum 6061

SIZE		DWG NO	REV
C		Load Cell Roller	

SCALE

SHEET 5 OF 6



DRAWN Dan Pierce	11/27/2012
CHECKED	
QA	
MFG	
APPROVED	

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Wiggins Hall
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TITLE Cantilever Load Cell

MATERIAL LC511-100

SIZE		DWG NO	REV
C		Cantilever Load Cell	

SCALE

SHEET 6 OF 6