THE DESIGN OF AN ASSISTIVE SPHERICAL DRIVETRAIN

FOR

LOAD TRANSPORT APPLICATIONS

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Daniel J Mathewson

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Major Professor: Edwin M. Odom, Ph.D.

AUTHORIZATION TO SUBMIT THESIS

This thesis of Daniel J. Mathewson, submitted for the degree of Master of Science and titled "THE DESIGN OF AN ASSISTIVE SPHERICAL DRIVETRAIN FOR LOAD TRANSPORT APPLICATIONS" has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final copies to the College of Graduate Studies for approval.

Major Professor: ______________________ Date: ______________
Edwin M. Odom, Ph.D.

Committee Members: ______________________ Date: ______________
Herbert L. Hess, Ph.D.

______________________ Date: ______________
Eric Wolbrecht, Ph.D.

Department Administrator: ______________________ Date: ______________
John Crepaeu, Ph.D.

Discipline's College Dean: ______________________ Date: ______________
Larry Stauffer, Ph.D.

Final Approval and Acceptance by the College of Graduate Studies:

______________________ Date: ______________
Jie Chen, Ph.D.

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ABSTRACT

An assistive spherical drivetrain for load transport applications was designed, fabricated and tested. The drivetrain of this system (robot) uses a spherical interface, an inexpensive basketball, to provide the traction to the ground *i.e.* to serve as a tire. The ball was driven via three omni-wheels each driven by independent electric motors. These in turn were driven by custom designed and fabricated PWM controllers. This powers a spherical drivetrain along with two ball casters in a cart utilized by a percussionist in the University of Idaho marching band to carry a full complement of instruments. The cart is controlled by measuring the movements of the percussionist thus the cart was an assistive device. This cart was code named Band Beesten and has performed at a number of University of Idaho events.

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Chapter 1: Introduction

Most universities across the United States have marching bands. Although marching bands are not a part of a collegiate sports competition, the members still seek to be different and notable. This leads to the question that every band must face; “How do we make ourselves unique? What can we do to stand out among the masses?” The simple answer is to do something different.

At the University of Idaho several faculty members suggested that one way to be different would be to create a device allowing a more diverse percussion set to participate in the marching sequences of the band performances. This thesis describes the design, fabrication and testing of a cart that has one spherical drive and two ball casters that provided such a percussion platform. This project is code named Band Beesten. Although created for utilization in entertainment the design and fabrication aspects of this cart have far broader uses and applications than the entertainment world.

Chapter 2 presents the background of the beginning of this project along with a relevant literature search. Chapter 3 consists of the design and fabrication of all the hardware for the Band Beesten. Chapter 4 is a summary of the finial outcomes of this project. Chapter 5 will cover the future recommendations.

Chapter 2: Background and Literature Review

The need for a device that can transport a full percussion set in half time performance was expressed by Professor Dan Bukvich, a member of the University of Idaho's Lionel Hampton School of Music[1]. He has been teaching for 35 years at University of Idaho and has been associated with the Sound of Idaho. During his time at the University of Idaho, Bukvich has been awarded the 2012 U.S. Professor of the Year Award in Idaho and recognized by the American College of Band Directors' Association as top 50 most influential band composers of the 20th century[2]. It is Bukvich's belief that having a full drum arrangement on the field, actively participating in the performance would provide a greater variety of music to be played.

During the course of this investigation, half-time shows of many universities across the nation were observed and it was concluded that no one is presently using a device such as this in their shows. A review of the history books reviewed a cart design by Leonardo Da Vinci, it is unknown if it was ever built. This cart is shown in Figure 1 [3]

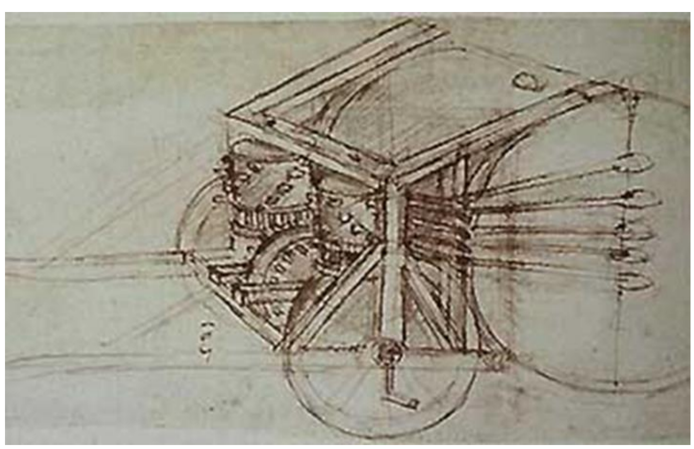

Figure 1: Sketch of Da Vinci's cart

There has been previous work done during the 2011-12 school year at the University of Idaho as part of a senior capstone design project. The final product was an aluminum framed cart with a rigidly mounted harness [Figure 2]. The cart could perform all marching band maneuvers; this includes traveling backwards, crab walking and turning about any given axis and weighed in at just about 60lbs. The breakdowns of the individual weights of the first prototype are included in Table 1.

Table 1 Component Weights of First Prototype

Drum	Quantity	Weight
10" Tom	1	7 lbs
12" Tom	1	8 lbs
14" Snare	1	13 lbs
14" Tom	1	12 lbs
18" Cymbal	1	4 lbs
Cart	1	16 lbs
Total		60 lbs

The CAD model of the first proto type is shown in Figure 2. As this figure shows, this cart has large caster wheels that allowed for a low rolling resistance. The cart also had adjustable mount locations for the instruments and percussionist. This allows for the fitting of different instruments and different size of people. Not shown in this figure are the cymbols.

Figure 2: Team Drumroll's cart

After fabrication of the prototype, members of the capstone design team and Sound of Idaho members discussed the various aspects of how useful the device would be in its current form. Two main areas of improvement for the cart were suggested. First, the caster wheels had a large trailing distance that results in a wobble during a change of direction. This phenomenon is commonly seen or felt on grocery shopping carts [Figure 3]. By reducing the trailing distance the wobble will be minimized but the wheel will be less stable at speed in straight operation.

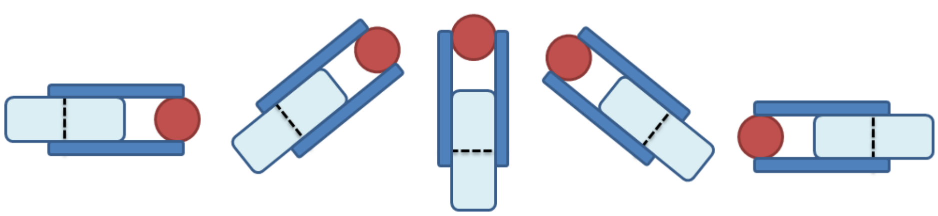

Figure 3: Caster changing direction of travel

The second area of concern is that the cart has no brakes and more inertia that a human can comfortably control. When attempting a turn, the inertia of the cart requires over compensation by the performer. When the cart and the user are turning or rotating the cart tends to continue, requiring the user again to over compensate. It is the action of stopping the cart that users found to be difficult to deal with. It is suspected that within the human strength envelope, humans are stronger in pushing forward vs. pulling backwards. Based on the system's present mass and inertia an average human will need assistance to adequately control the cart.

The area of human assistive robotics is very large and diverse in application and approach. A survey was conducted of current robots in this field. Common applications included load bearing exoskeletons to precision medical robots used during surgery. Examples of these are shown in Figure 4 [4], [5].

Figure 4: HAL exoskeleton and Da Vinci Si surgical robot

While each of these has their unique qualities none were an ideal conceptual solution for the Band Beesten's application, therefor a custom design was pursued.

Ballbots are a type of robot that utilizes a ball for the interface with the ground as opposed to traditional tire or wheel. One of the first of this kind was created by a group at Carnegie Mellon University (CMU) [6]. CMU's robot is shown in Figure 5. Note this robot can't rotate about its center axis.

Figure 5: CMU's Ballbot

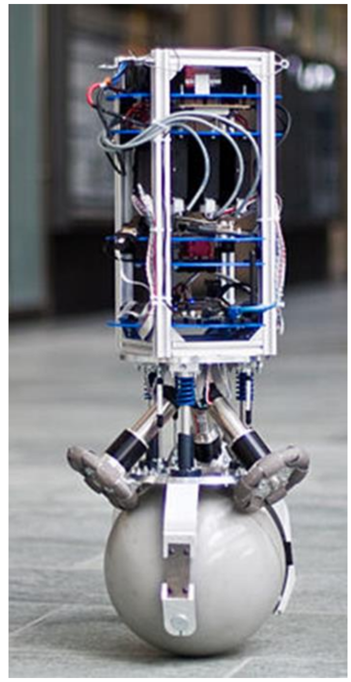

Figure 6: Rezero

A team from the University of Zürich created another ballbot named Rezero[7]. Rezero, shown in Figure 6, was inspired by CMU's robot [6], but has the added ability to rotate about it center axis, effectively letting it face any direction.

Chapter 3: Methods

Per the improvements needed as outlined in chapter 2, several design decisions were made. To eliminate wobble during change of direction, a passive ball caster design was pursed. To provide the assistance needed to move, a powered drive ball was selected. This project can be broken down into two main parts, electrical and mechanical.

The chosen methodology is that of Dr. Terry Soule[8]. His methodology is designed to be applied to cell phone operated robots but was adapted to the Band Beesten. Dr. Soule's design consists of three basic components as defined by him:

- The 'brains' - typically a smart phone
- The 'body' - the platform from an RC car, truck, or vehicle
- The 'spinal cord' – A microcontroller or motor controller, Phidgets

In this system the brain reads and senses the environment, the body moves within the environment and the spinal cord interprets the brains commands and makes them usable by the body. Dr. Soule's methodology utilizes a smart phone as the brain do to the integrated peripherals *i.e.* camera, GPS, Bluetooth. The Band Beesten does not require that level of complexity; therefore a suitable brain with a lower level controller such as an embedded microcontroller can be used. This methodology lends itself to most robots[9]. By having the spinal cord the brain is able to execute computationally intense top level commands while the spinal cord is takes over time sensitive low level control of the motors.

3.1 The "Body"

The 'body' of the Band Beesten for this thesis was the same structure as the prototype created in 2012. The structure was modified to incorporate a powered drive ball, two passive ball casters and the input systems. Figure 7 shows the proposed changes to the cart. The complete drawing package for the Band Beesten can be found in Appendix D.

Figure 7: Before and after of proposed "Body" showing new casters and drive ball

3.1.1 Power Drive Ball Understanding and Sizing

Ball drive systems come in two forms. Both utilize omni-wheels to apply a traction force to the ball. There is a dual motor drive system where the traction is applied at 90 degrees from each other. Also, there is a three motor drive system (tri-drive) where the motors are 120 degrees apart. An initial calculation showed that a dual drive system required higher loads from the motor as compared to a tri-drive system. Consequently, the dual drive was removed from further consideration. An omni-wheel as shown in Figure 8 applies a force to the ball perpendicular of its axis of rotation, but allows travel parallel to this axis. This travel is termed the slip direction.

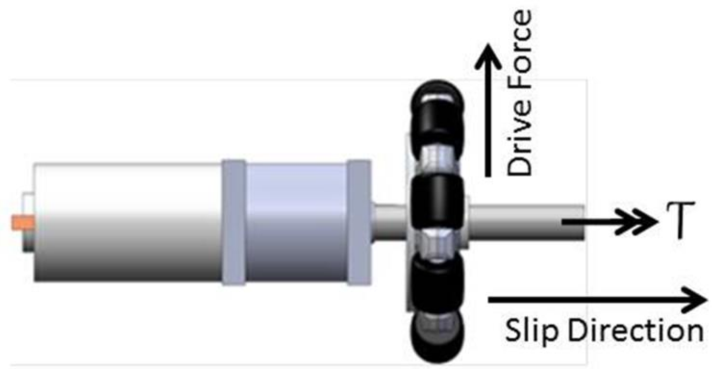

Figure 8: Side view of a DC motor and omni-wheel showing traction and slip directions

In this tri-motor drive design the omni-wheel drives are mounted 45 degrees from the horizontal and are 120 degrees apart. These three drive wheels apply drive forces to the ball. The contact points of these three wheels define a plane that passes through the ball, this plane is termed the drive plane. The three drive forces on the ball can be combined into a single force. This single force acts on the traction plane in the desired direction of travel. This is shown in Figure 9 which has a ball with three omni-wheels and also shows the drive plane that serves as a local reference for force analysis.

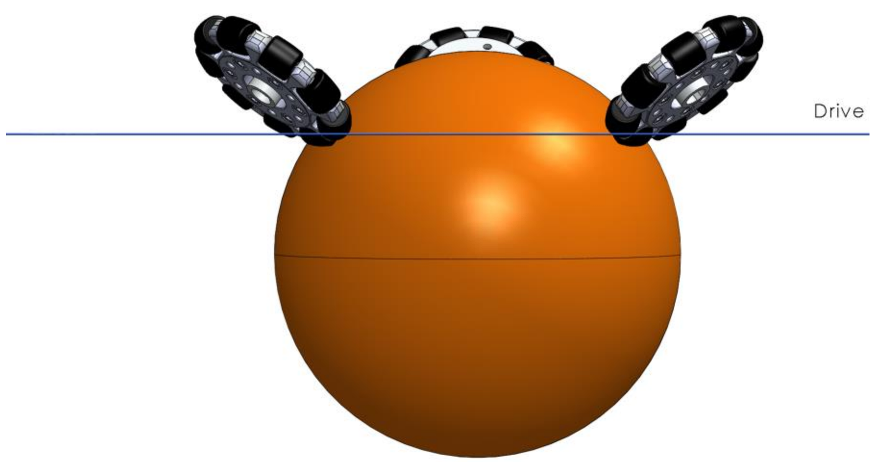

Figure 9: The blue line represents the drive plane dissecting the ball

The global coordinate system for the Band Beesten is shown in Figure 10. As this figure shows, the X-axis is the forward direction of Band Beesten; the desired direction of travel is measured in a counterclockwise fashion starting at the X-axis and ranges from 0 to 360 degrees. Note that the torque that is applied to the ball is perpendicular to the desired direction of travel.

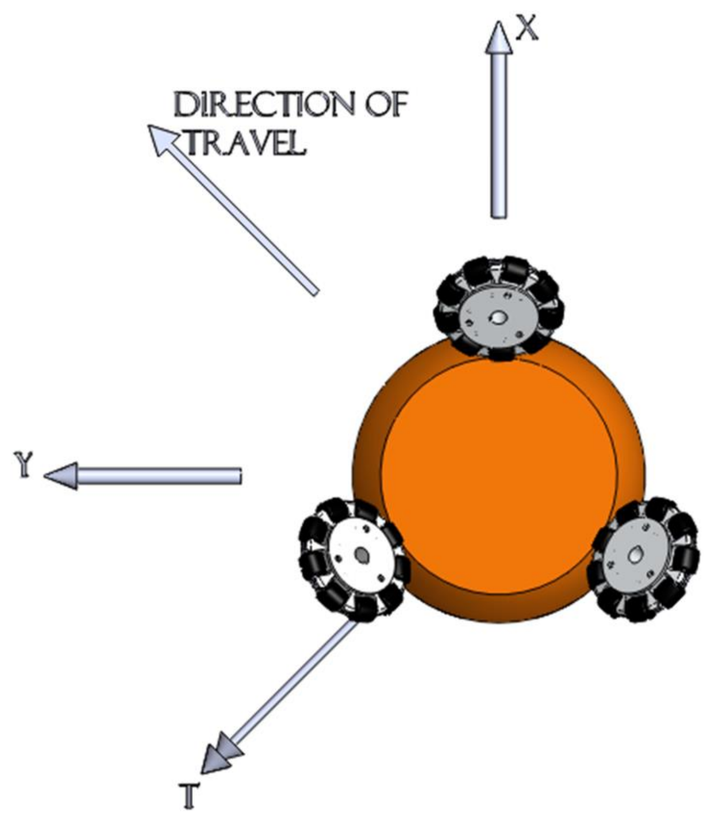

Figure 10: Global coordinate system

The local coordinate system is shown in Figure 11, note that the local z-axis and the global Z-axis are coincident. Consequently the variable θ in the global and local coordinate systems is the same. This figure shows the three independent forces f_1, f_2 andf_3 applied by each omni wheel acting on the drive plane. It also shows the resultant force F that is created when forces f_1, f_2 andf_3 summed together acting on the drive plane.

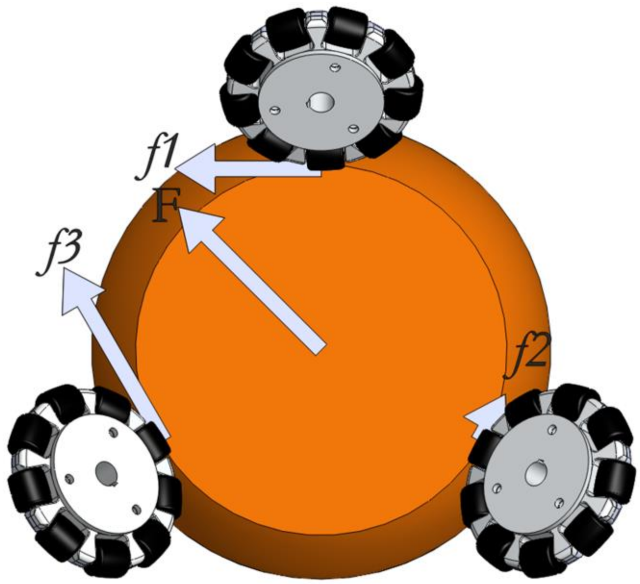

Figure 11: Local coordinate system

Now that the local and global coordinate systems have been presented, a relationship between these two systems needs to be established. This accomplished through a drive force reduction ratio λ as shown in Figure 12. This figure shows the resultant force F acting on the drive plane a distance D_{DP} for the center of the ball as well as the ground force F_{ground} acting a distance r_{ball} away from the center of the ball.

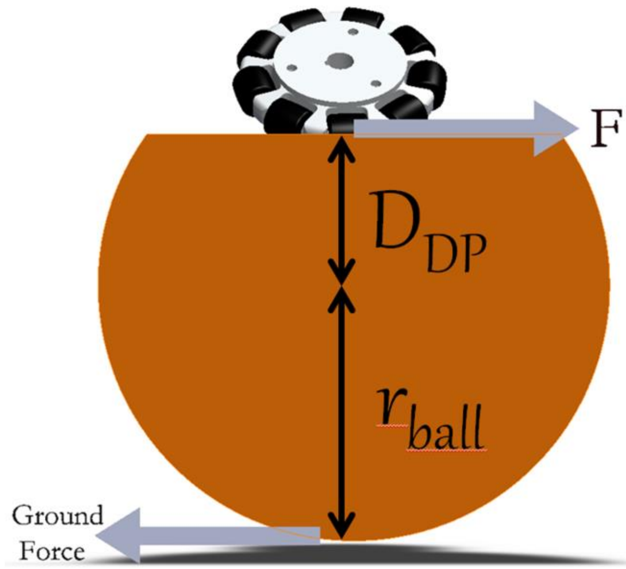

Figure 12: A power drive free body diagram.

Equation Eq. 1 quantifies the ratio into a scalar by summing moments about the center of the ball.

$$F_{ground} * r_{ball} = F * D_{DP} \quad \textbf{Eq. 1}$$

Eq. 2 introduces the scalar λ to represent the force reduction ratio.

$$\text{Setting } \lambda = \frac{D_{DP}}{r_{ball}} \quad \textbf{Eq. 2}$$

$$\therefore F_{ground} = F * \lambda \quad \textbf{Eq. 3}$$

For the Band Beesten to move the required direction, the drive ball must produce a force at the point of contact with the ground. Therefore, the moments about the z-axis produced by the omni-wheel drives must sum to zero. This is represented in Eq. 4 where r_{DP} is the distance between the points of contact at each omni-wheel and the z-axis.

$$f_1 * r_{DP} + f_2 * r_{DP} + f_3 * r_{DP} = 0 \quad \textbf{Eq. 4}$$

Note that r_{DP} can be canceled out and the result is the first relationship needed in the control algorithm.

$$f_1 + f_2 + f_3 = 0 \qquad \textbf{Eq. 5}$$

The next relationship begins with the desired drive force F in the local coordinate system which can be resolved into its components, F_X and F_y [Eq. 6].

$$F_x = \mathrm{F} * \cos\theta\,, \qquad F_y = \mathrm{F} * \sin\theta \qquad \textbf{Eq. 6}$$

The forces applied by each omni-wheel drive are resolved into their respective components relative to the local x and y axis and then summed and set to equal the respective components of the resultant force F [Eq. 7, Eq. 8].

$$F_x = f_1 * \cos 90 + f_2 \cos 330 + f_3 \cos 210 \qquad \textbf{Eq. 7}$$

$$F_y = f_1 * \sin 90 + f_2 \sin 330 + f_3 \sin 210 \qquad \textbf{Eq. 8}$$

For demonstration purposes, it is assumed the desired drive force F will have a magnitude of 100. Now, solving Eq. 4 through Eq. 8 simultaneously while varying θ for 0 to 180 in increments of 10 degrees for the forces f_1, f_2, and f_3 results of which are shown in Figure 13. The solutions here are shown in a graphical representation; however they are utilized in a table format by the Band Beesten's microcontroller.

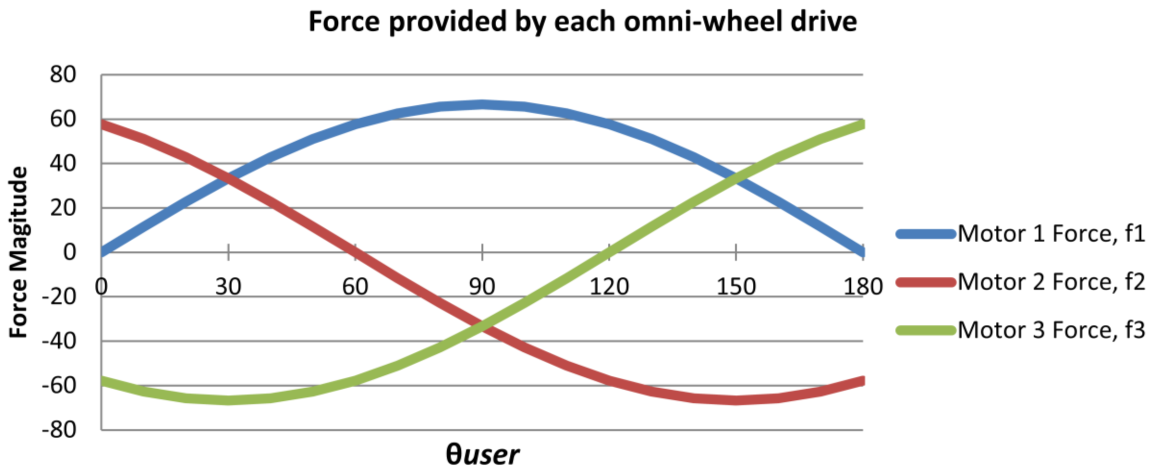

Figure 13: Demonstration of forces at each omni-wheel drive for a tri-drive with a resultant force *F* of 100

Second, this figure shows that a maximum of 2/3 (@ 30°, 90°, 120°) of the desired drive force *F* will ever be supplied by a singular omni-wheel drive. This has implications in the sizing of the physical components of the drive ball system.

3.1.2 Sizing of physical components

This project was completed with minimal funding. Therefore, the approach was to find the most inexpensive drive components as possible and manufacture that which could not be acquired within the budget. After potential components were identified, it was determined that there were many options for motors and balls with fewer options for omni-wheels. Therefore, sizing and locating venders for omni-wheels was the top priority, thus it drove the sizing of all other drive ball components.

Utilizing *a priori* knowledge of electric motors; an omni-wheel of a smaller diameter are more desirable due to the reduction in torque required, thus decreasing the required current. This trend is discussed in more detail in Section 3.1.3. Of the available omni wheel on the market, three standards sizes were available: 2”, 4” and 6”. The 4” version carried by Andy Mark[10] shown in Figure 14 was selected over the 2” version due to their aluminum housings and minimal discontinuities between rollers. However; do to the square cross section of the slip wheels (also shown in black cylinders in Figure 14) and the gap between them, the contact between the slip wheels and drive ball is uneven.

Figure 14: 4in omni wheel by AndyMark.com

Based on the selection of an omni-wheel, a complementary drive ball was then selected. The ball needed the following attributes to be the best fit.

- Deformable for rough driving surfaces
- Deformable for omni-wheel uneven contact
- Provide frictional drive contact with the ground
- Must be large enough to not sink into field turf

Using these specifications, the ball selection is summarized in Table 2. Based on this table a rubber basketball was selected.

Table 2: Drive ball comparison; 0-6 scale, higher is better

	Weight	Cost	Deformability	Friction	Ground Contact	Availability	Total Score
Bowling Ball	2	3	0	1	3	2	11
Steel Ball	1	2	0	1	3	1	8
Hollow steel Ball	3	0	0	1	3	1	8
Plastic Ball	5	4	0	1	3	4	17
Nylon Ball	5	1	0	1	3	2	12
Rubber Basketball	6	6	5	5	3	6	31
Soccer Ball	6	6	5	2	3	6	28

3.1.3 Motor Sizing and Selection

According to Dan Buckvich, the Sound of Idaho (University of Idaho's marching band) currently plays arrangements that vary in tempo from 120 to 180 beats per minute with an average stride length of 30 inches and during many of the performances the goal is to accelerate to speed in a single stride. This results in an average speed of 6.6 ft/s (2.0 m/s) [Eq. 9] and an average acceleration of 17.6ft/s^2 (5.4m/s^2) [Eq. 10] achievable with a force of 33lbf (146.8N) [Eq. 11]. Eq. 12 translates F_{ground} to F which must be produced by the motors.

$$\left(\frac{160\ beats}{min}\right)\left(\frac{1min}{60sec}\right)\left(\frac{30in}{1beat}\right)\left(\frac{1ft}{12in}\right) = 6.6\frac{ft}{sec} \qquad \textbf{Eq. 9}$$

$$a = \frac{dy}{dt} \quad \therefore \quad a = \frac{6.6ft/sec}{\left(60\frac{sec}{min}\right)\left(\frac{1\ min}{160\ beets}\right)} = 17.6\frac{ft}{s^2} \qquad \textbf{Eq. 10}$$

$$F_{ground} = M \times a \quad \therefore F_{ground} = \left(\frac{60lbf}{32.2\frac{ft}{s^2}}\right)17.6\frac{ft}{s^2} = 33\ lbf \qquad \textbf{Eq. 11}$$

$$\lambda = \frac{D_{DP}}{r_{ball}} = \frac{2.67in}{4.54in} = .588 \quad \therefore \quad \frac{33.lbf}{.588} = 56lbf$$ **Eq. 12**

The Ballbot will need to supply a force of 56lbf and only 66.6% the maximum force will need to be supplied by any singular motor. From these requirements in combination with the 4" omni-wheel the motors must be at least capable of supply a maximum torque (τ_{max}) of 6.16 lbf-ft, (8.35Nm) [Eq. 13] with a RPM_{max} of 414.7 [Eq. 14]

$$56lbf * .66 * 2in\left(\frac{1ft}{12in}\right) = 6.16\ lbf - ft$$ **Eq. 13**

$$\left(6.6\frac{ft}{sec}\right)\left(\frac{60sec}{1min}\right)\pi(4in)\left(\frac{1ft}{12in}\right) = 414.7\ RPM$$ **Eq. 14**

A number of electric motor sizes and vendors where considered. It was found that a Magnum 775 brushed DC motor met the design criteria. The specifications for these motors include a theoretical stall torque of 17.6Nm or 13lbf-ft and a maximum operating rpm of 720 at 14.4V. Figure 15 shows a Magnum 775 brushed DC motor [11]; note the preinstalled 20:1 gear reduction on the left side. The motors come with mounting holes and a keyed output shaft.

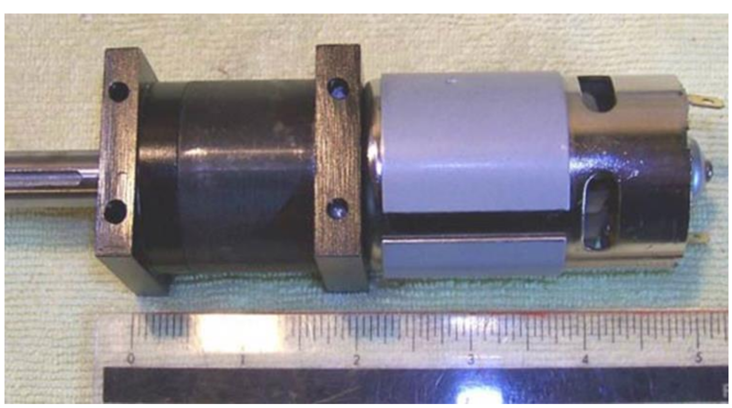

Figure 15: Magnum 775 brushed DC motor

3.1.4 Input system

The input system of the Band-Beesten must sense the user's movements and then create a signal that can be processed by the "brain" or microcontroller. The movements can come in two types, a distance and an angle between the user and the frame. Figure 16 shows both the angle θ_{user} and user distance d_{user}. Note, θ_{user} is measured from an axis parallel to the positive Y axis in a counter clock wise fashion.

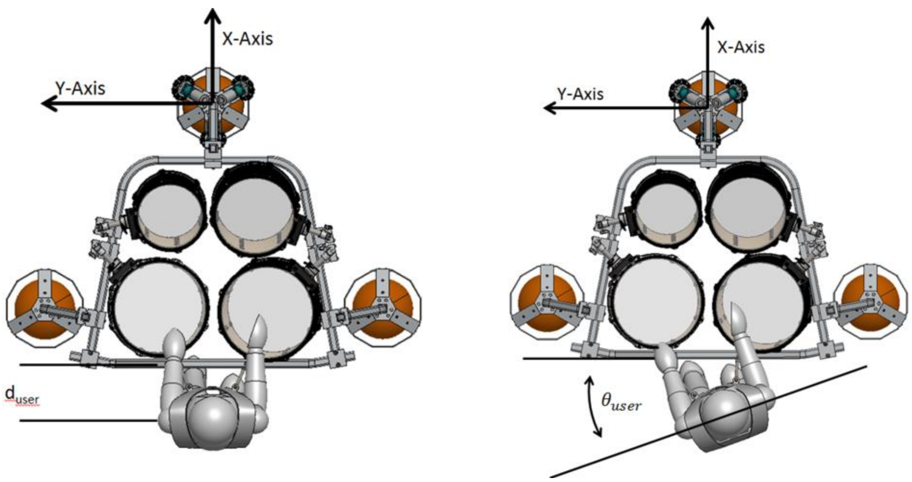

Figure 16: θ_{user} and d_{user} defined

To measure distance and angle (θ_{user}), a sensor is placed on each side of a standard harness. These sensors are shown in Figure 17. Note they utilize a vertically opposed spring design found on early model motorcycles integrated with a potentiometer on a linkage system. As shown in Figure 17, the sensor linkage clamps to the square tubing of the frame. At this clamping location, a bell crank translates the user's horizontal push/pull into a vertical motion. This motion is measured utilizing a rotational potentiometer attached via a linkage.

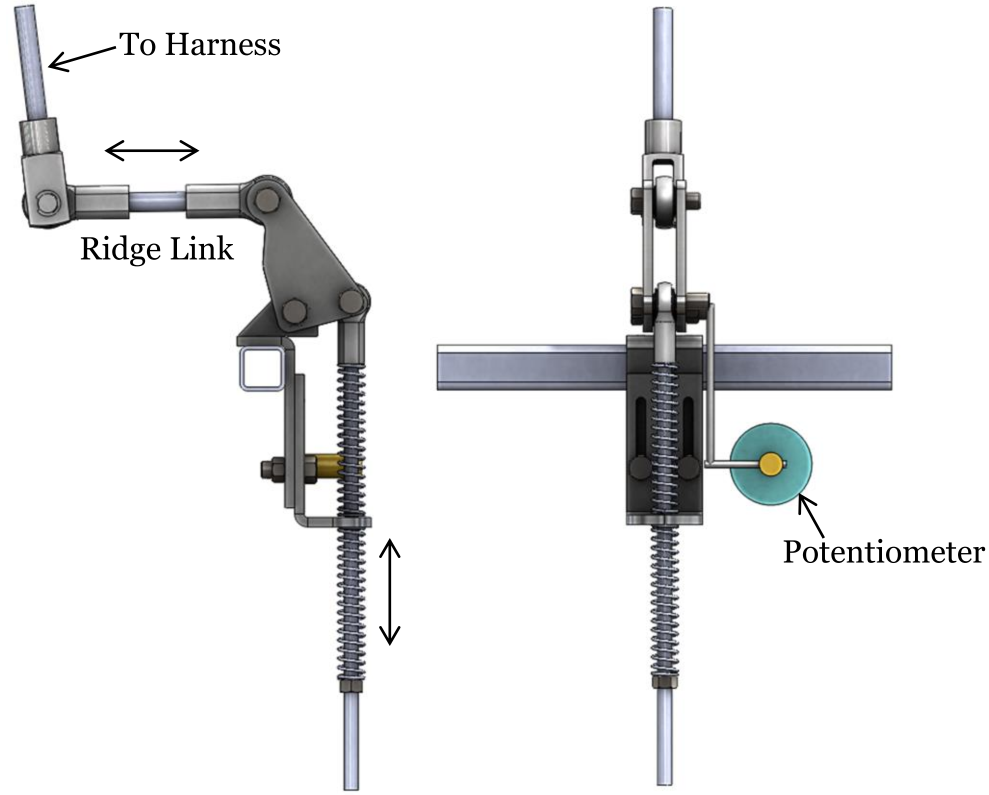

Figure 17: Side and Front of a single distance of input system

The ridged link allows for the user to move freely about and to back step which requires a change in the drummer's height. The springs can be adjusted to change the performance and the feel of the Band Beesten. Also, the springs apply a resistive force to the user's movements. This feature decreases the load needed by the drive ball. By having the pivot in the input system's linkage the system benefits from two main factors. First, the pivot gives the system a lower profile allowing for more room for the drums. Second, the bell crank ratio can be modified to produce different spring feedbacks rates. A change in voltage is produced via potentiometers that are attached to the bell cranks. Figure 18 shows the linkages and potentiometers.

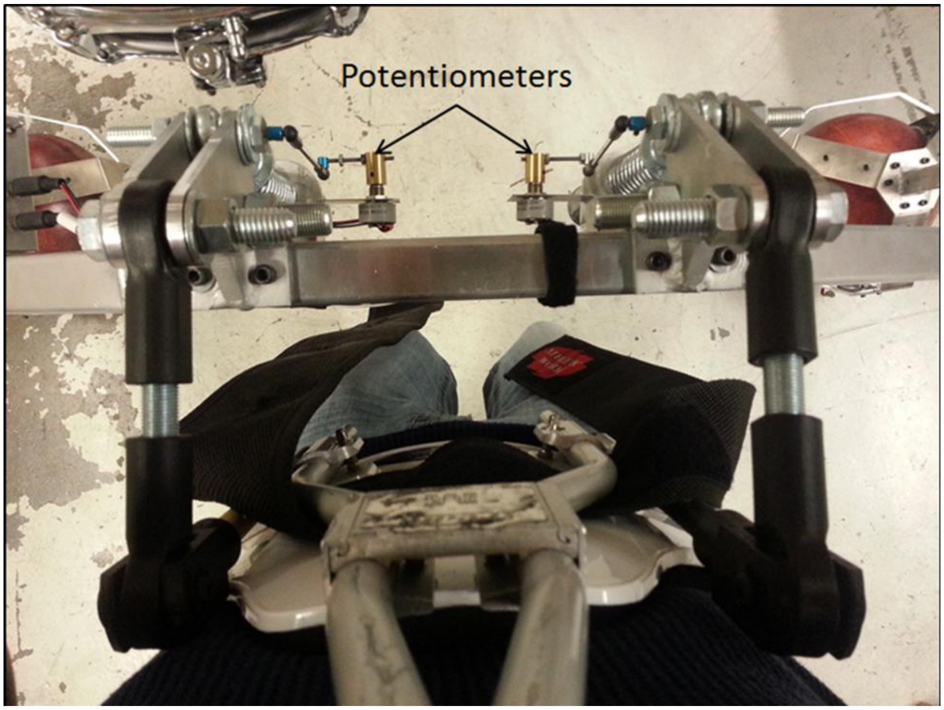

Figure 18: Top down view of the input system

The analog voltages produced by the potentiometers are fed into the brain where the control algorithm derives both the user distance and relative angle.

3.2 The "Brain"

The "brain" of the Band Beestand is an Adriano Pro Mini[12]. The Arduino was selected due to the community support and ease of programming from previous project experiences. Arduino is actually an Atmel brand chip with a preinstalled boot loader that allows for the use for of the "Arduino" language. Arduinos come in many physical configurations. Specifically, this project used Arduino Pro Mini because of its .7in x 1.3in breadboard friendly configuration. The Pro Mini offers 13 digital I/O pins with 8 additional analog pins. Figure 19 show the size comparison of a Pro Mini compared to a Uno. Note, the Pro Mini has exposed terminals and is designed for permanent installation in a project.

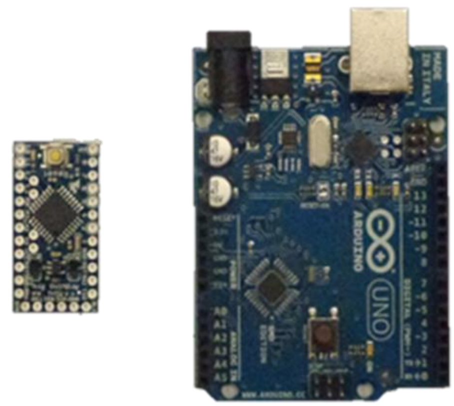

Figure 19: Size comparison between Pro Mini (left) and Uno (right)

The control algorithm that runs the Band Beesten is stored in the memory in the Arduino board. Figure 20 shows a simplified block diagram of the control algorithm. As this diagram indicates, after the power is turned on the calibration routine occurs.

The calibration block reads the input system's distance sensors for one second when the system is turned on. It then takes the minimum and maximum values read for each potentiometer and calculates their respective averages. Theses averages are used as offsets to zero out each sensor. This process is needed so that they system can compensate for adjustments made to the springs of the input system.

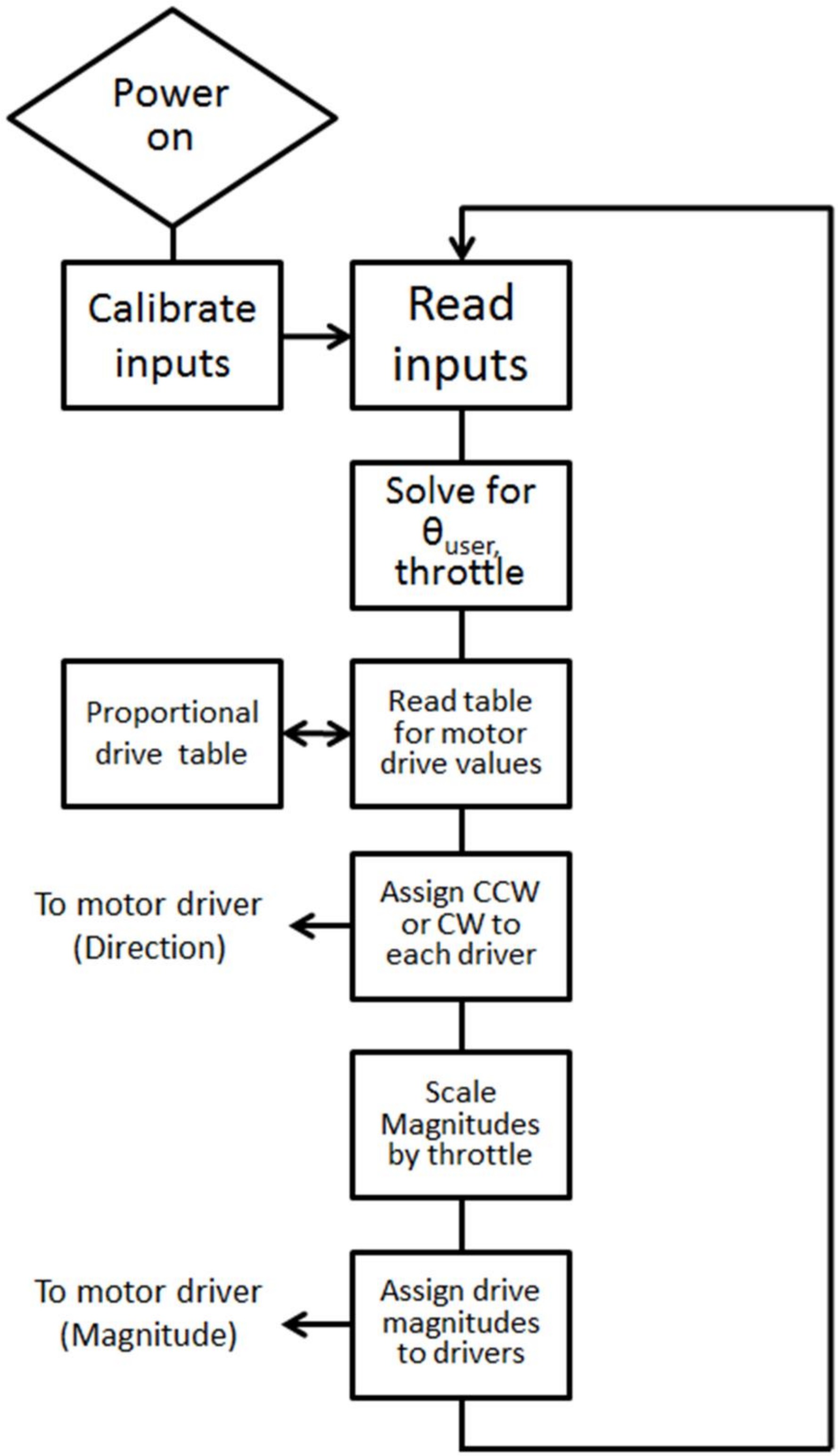

Figure 20: Control algorithm flow diagram

The "Solve for θ_{user}, throttle" block calculates the angular orientation (θ_{user}) and distance (d_{user}) of the user from the frame, this is accomplished by Eq. 15-Eq. 18. The goal of the algorithm is to bring the angular orientation back to equilibrium. The rate of correction is dictated by the distance (d_{user}).

$$X_{throttle} = d_{right} + d_{left} \qquad \textbf{Eq. 15}$$

$$Y_{throttle} = d_{right} - d_{left} \qquad \textbf{Eq. 16}$$

$$\theta_{user} = \tan\left(\frac{X_{throttle}}{Y_{throttle}}\right) \qquad \textbf{Eq. 17}$$

$$Throttle = \sqrt{X_{throttle}^2 + Y_{throttle}^2} \qquad \textbf{Eq. 18}$$

This control scheme is shown visually in Figure 21. A straight forward motion is shown in Figure 21a. in this case d_{right}, d_{left} are equal and the resultant is straight ahead drive response. Next Figure 21b shows the user inputting a desire to turn right. In this case d_{left} is equal in magnitude but opposite in sign to d_{right}. Finally Figure 21c show a less sharp right hand turn.

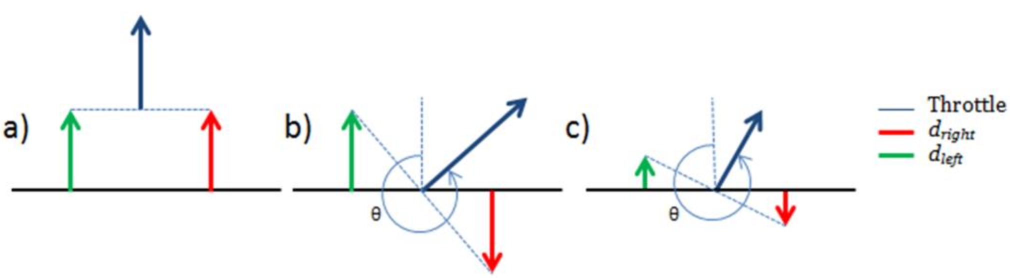

Figure 21: Visual presentation of various control outcomes

The numerical values of the "Read table for motor drive values" block in Figure 20 are in Appendix A. The action taken in this portion of the algorithm is to use an input θ_{user} to get three outputs, one for each motor of the drive ball. These values are proportional to the force required to achieve the desired motion.

The "Assign CCW or CW to each driver" block represents a series of if-then statements. These statements dictate the direction of rotation of the motors. The motor drivers' directions are updated at this point. The motor drivers' are located in the "Spinal cord" discussed next.

The "Scale Magnitudes by throttle" block is where the three dive magnitudes are scaled by a percentile, determined by the throttle position solved for previously.

The output of the 'brain' is in the form of an I2C serial command sent for further processing and implementation.

The complete notated code is attached in Appendix A.

3.3 The "Spinal Cord"

The 'spinal cord' communicates with the 'brain' and ensures the motors apply the appropriate amount of torque to the drive ball. A device such as this is more commonly known as a driver. The 'spinal cord' in this design provides no feedback to the 'brain', in future iterations it could. However, there is feedback provided by the human via the input system. Torque ($T_{applied}$) for a brushed DC motor is proportional to applied current ($A_{applied}$) as shown in Eq. 19 [13] where K_t is the torque constant. Similarly, a brushed DC motors rotational velocity is a proportional to the voltage applied. This trend is represented in Eq. 20 [13]where K_v is the speed constant. The "spinal cord" of the Band Beesten regulates torque by controlling the current through the motor.

$$K_t \times A_{applied} = T_{applied} \qquad \textbf{Eq. 19}$$

$$K_v \times V_{applied} = RPM \qquad \textbf{Eq. 20}$$

The Magnum 775 motors have a known K_t of .12Nm/A or 17.0oz-in/A[11]. Applying Eq. 19 with a T_{max} of 6.16lbf (8.35Nm) results in maximum $A_{applied}$ of 69.58A. Utilizing Eq. 20 with a no load speed of 414RPM_{max} and a K_v of 50RPM/V[11] it was found that a minimum voltage of 8.28V must be controlled by the driver and supplied by the batteries.

A survey was conducted of commercially available motor drivers that would comply with 69.58A and 8.28V maximum loads. Of the solutions found, all were cost prohibitive therefore a custom design was pursued. Figure 22 shows how the commanded current value from the 'brain' is transformed into a usable current to drive a motor. Note the 'spinal cord' is composed of three components, the digital to analog converter (DAC), the current regulating chip and H-Bridge.

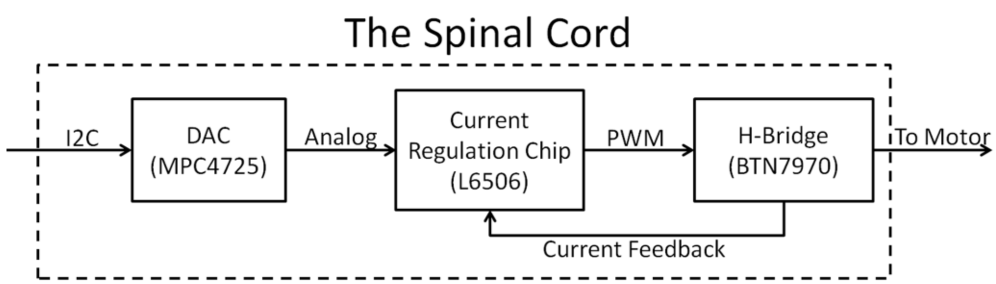

Figure 22: Spinal cord layout

The first transformation the signal from the 'brain' goes through is the conversion from I2C serial to a usable voltage. The MPC4725 DAC breakout board[14] by Adafruit.com was used for this. Through experimentation it was determined that maximum transmission distance of the I2C signal from the MPC4725 breakout board was one foot. Since our breakout board was about 6 feet from the microcontroller, the boards had to be modified to transmit the distance from the brain to drive ball assembly. This modification entailed changing the stock onboard pull-up resistors to 2Kohm. Next, since three addresses were needed, but the stock boards are only capable of two, one of the stock boards had to be modified further. This entailed modifying the MPC4725 chip to a different sub group (A2 and A1 in Figure 23[15]) of the same chip.

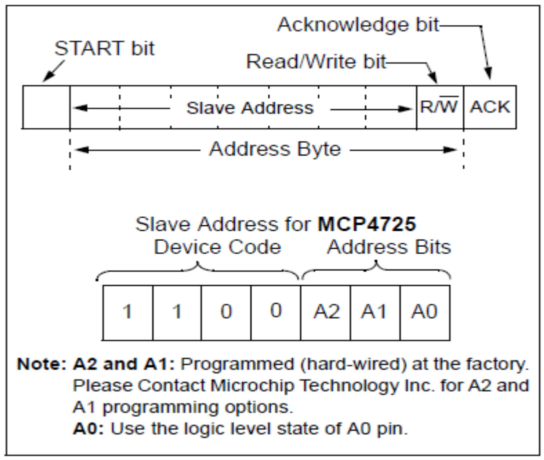

Figure 23: MCP4725 I2C addressing

The "Current Regulation Chip" block in Figure 22 is the L6506 by ST electronics [16]. This chip produces a Current Regulated Pulse Width Modulated (CRPWM) signal based on a reference voltage which in this design is the output from the DAC. For more information on PWM see Appendix B. The chip works by comparing a reference voltage to a current feedback voltage. When the current feedback voltage becomes greater than the reference voltage, an output (to the H-bridge) is turned OFF (set to logic low). Based on a fixed clock frequency, the chip is reset to an ON(set to logic high) position until the reference voltage is surpassed by the current feedback voltage. The reference voltage is representative of the current commanded by the brain and the sense voltage is the current feedback produced by the H-bridge (BTN7970) discussed in the following.

The H-bridge, Figure 22, receives the PWM signal (voltage, GND or 5v) and amplifies it to the final voltage (GND to 18v) used by the motors. To perform this action, the BTN7960 Half Bridge produced by Infineon[17] was selected. The specifications for these are maximums of 28volts and 44amperes while featuring current feedback. This feedback is in the form of a current (0-4ma) that is proportional to the output current of the H-bridge. When the feedback current is run through a resistor it produces a voltage that is feed back into the L6506 as the sense voltage and drives the PWM signal. For more information on H-bridges see Appendix C

The final driver schematic is shown in Figure 24. Note the header in the bottom center; this is the MPC4725 header whose output is directly connected to REF1 via a wire. The motor is connected between the heat sinks on the BTN7970s. The final board layout is shown in Figure 25. The final built board is shown in Figure 26 and Figure 27. Note the board is made of 4oz copper clad to minimize internal resistance.

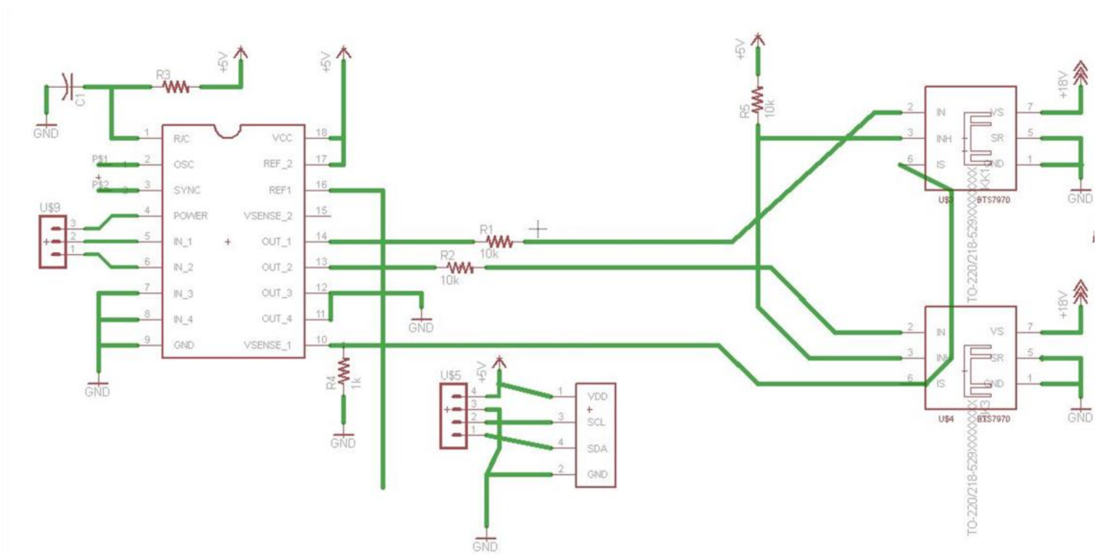

Figure 24: Final schematic

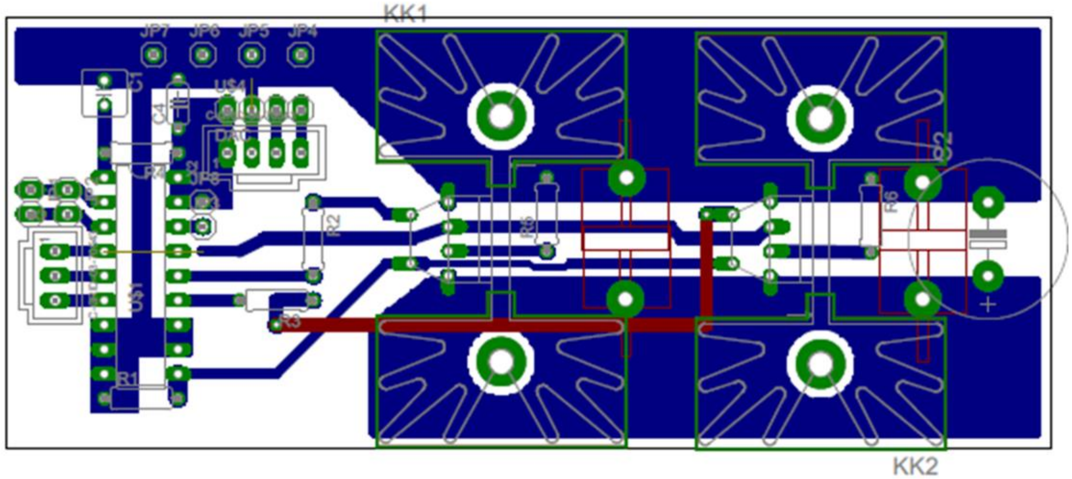

Figure 25: Finial board layout

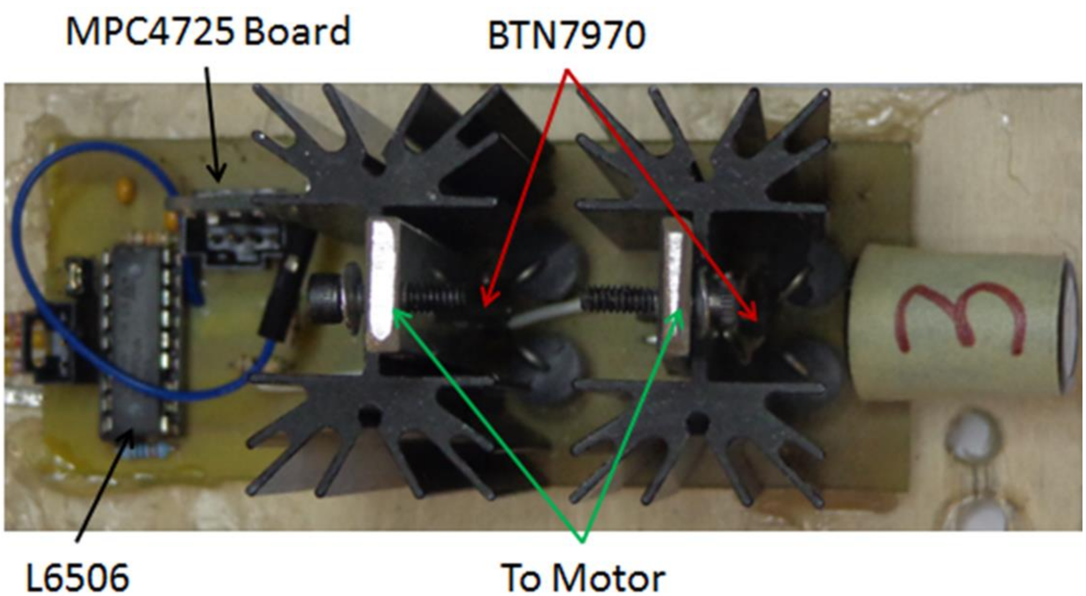

Figure 26: Top view of built board

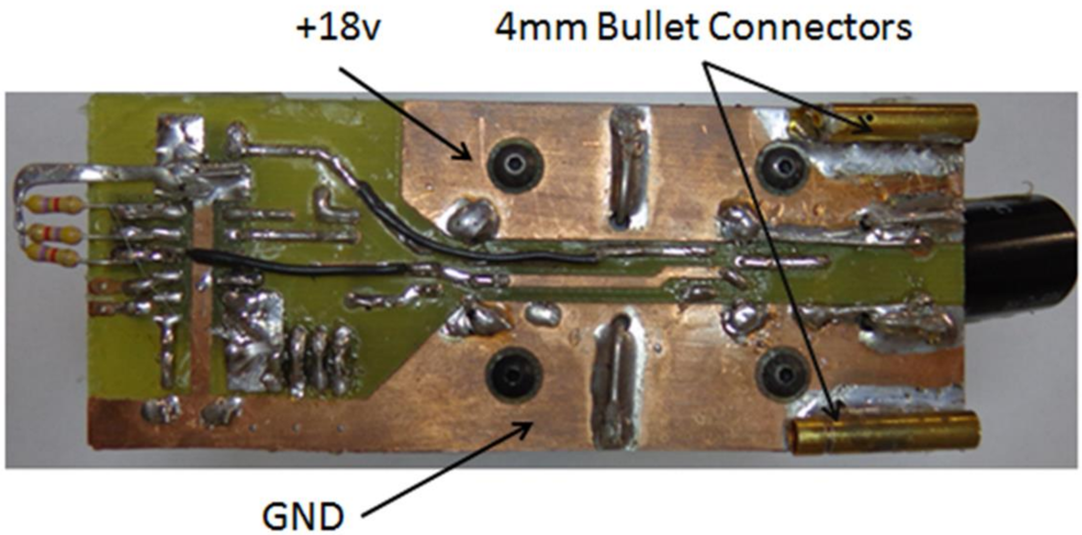

Figure 27: Bottom view of built board

Chapter 4: Results and Conclusion

Figure 28: Senior Matt playing the Band Beesten during the San Jose state halftime show.

The final result of this project was a working musical platform. The Band Beesten's success was witnessed by an almost sold out crowded during the halftime show for the 2012 home football game vs. San Jose State. The performance included the demonstration of the Band Beesten capability to move forward and turn about the drummer.

Figure 29: The Band Beesten

Aside from its début performance, the Band Beesten also appeared in the University of Idaho vs. Texas-San Antonio halftime show, the Senior Band Performance, and the 2013 Holiday Concert.

The Band Beesten is also the focus articles by University of Idaho[18], Halftime.com[19] and ASME.org[20]and was selected by ASEE First Bell.

Chapter 5: Future Recommendations

In future iterations of the Band Beesten, many areas can be improved. The areas that would benefit the most are the control logic and motor drivers.

The control logic would benefit greatly if either a proportional integral derivative (PID) or an adaptive algorithm was use to translate user input into direction and magnitude for the drive ball. Consideration should also be given to creating a solution for dampening the noise in the input system caused by the users walking stride.

The motor drivers were never able to be checked for actual current flowing to the motor vs feedback from the BTN7970 Half H-bridges. In the final code the current commanded is limited to a maximum value. Verifying the feedback ratio vs. actual current will ensure that the drivers will supply the appropriate current to the motors. Alternately, an off the shelf driver such as Waterproof TorqueMaster BR-XL by Holmes Hobbies[21] maybe a better solution, however the update rate of 50Hz may not be sufficient to create smooth moving drive ball.

The system would also benefit from the implantation of circuit protection beyond that built into the “spine”.

There is also the possibly of the turning the motors 90 degrees such that there drive forces would intersect the Z-axis. This would remove the ability to rotate about the Z-axis but there would no longer be a drive ratio λ. This alone would greatly increase the performance of the Band Beesten.

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Appendix A Arduino Sketch

```
/* Dan Mathewson
  This code pull values from a table for 3 different motors vectors.
  This code also demonstrates a sub function called CCWorCW(angle);
  In CCWorCW the direction of the motors will be set. Serial.print place holders are there just to prove that the code is working. The can be commented out to improve performance.
with last test this code was running at 3112 HZ.
THIS SHOULD FIX THE VECTOR CONTROL
*/

#include <Wire.h>
#include <Adafruit_MCP4725.h>
#include <math.h>

const int IN_1E = 2;        // L6506 IN Enable
const int IN_1A = 4;        // L6506 IN_1A
const int IN_1B = 3;        // L6506 IN_1B

const int IN_2E = 5;        // L6506 IN Enable
const int IN_2A = 7;        // L6506 IN_1A
const int IN_2B = 6;        // L6506 IN_1B

const int IN_3E = 10;       // L6506 IN Enable
const int IN_3A = 11;       // L6506 IN_1A
const int IN_3B = 12;       // L6506 IN_1B

int Left_Knot = 0;        // The value read in by the respective side of the input system
int Right_Knot = 0;
int RMin = 1023;            // minimum sensor value
int RMax = 0;               // maximum sensor value
int LMin = 1023;            // minimum sensor value
int LMax = 0;               // maximum sensor value
int maxpower = 1800;    // maximum power to the motors 1800 is 44 amps

const int LEFT = A2;
const int RIGHT = A0;

Adafruit_MCP4725 daca;     //defines a variable/object of type ADAfruit_MCP4725 with name daca
Adafruit_MCP4725 dacb;
Adafruit_MCP4725 dacc;

void setup() {
  Serial.begin(9600);
  Serial.println ("testing data types and math when pulling from table");

pinMode(IN_1E, OUTPUT);
pinMode(IN_1A, OUTPUT);
pinMode(IN_1B, OUTPUT);

pinMode(IN_2E, OUTPUT);
pinMode(IN_2A, OUTPUT);
pinMode(IN_2B, OUTPUT);

pinMode(IN_3E, OUTPUT);
```

```
pinMode(IN_3A, OUTPUT);
pinMode(IN_3B, OUTPUT);

 //Stuff for the DAC
  // For Adafruit MCP4725A1 the address is 0x62 (default) or 0x63 (ADDR pin tied to VCC)
  // For MCP4725A0 the address is 0x60 or 0x61
  // For MCP4725A2 the address is 0x64 or 0x65
  // Starts I2C communications with DACs
  daca.begin(0x62);
  dacb.begin(0x66);
  dacc.begin(0x63);


       digitalWrite(IN_1E, HIGH);
       digitalWrite(IN_1A, HIGH);
       digitalWrite(IN_1B, LOW);

       digitalWrite(IN_2E, HIGH);
       digitalWrite(IN_2A, HIGH);
       digitalWrite(IN_2B, LOW);

       digitalWrite(IN_3E, HIGH);
       digitalWrite(IN_3A, HIGH);
       digitalWrite(IN_3B, LOW);

while (millis() < 1000) {                    //This function is averaging the min and max values that are captured
in
                                             the first second of the robot being turned on.
    Left_Knot = analogRead(LEFT);
    Right_Knot = analogRead(RIGHT);

    // record the maximum sensor value Left side
    if (Left_Knot > LMax) {
      LMax = Left_Knot;
    }
     // record the minimum sensor value Left side
    if (Left_Knot < LMin) {
      LMin = Left_Knot;
    }
        // record the maximum sensor value
    if (Right_Knot > RMax) {
      RMax = Right_Knot;
    }

    // record the minimum sensor value
    if (Right_Knot < RMin) {
      RMin = Right_Knot;
    }
  }
Left_Knot = LMin/2 + LMax/2;      //Finding the neutral point by taking the average of the min and max
                                          recorded values
Right_Knot = RMin/2 + RMin/2;

 Serial.print("  L:  ");
 Serial.print(Left_Knot);
```

```
 Serial.print("  R:  ");
 Serial.print(Right_Knot);
 }

void loop()    // This is the main loop in the code;
{
//  This table is all the value for the motors based on drive angle, read left to right then top down, the table is  angle 0 to 360 degrees.

static int table[360] =
 {
3546,     3582,  3616,  3649,  3681,  3711,  3741,  3769,  3797,  3823,
3848,     3872,  3895,  3916,  3936,  3955,  3973,  3990,  4006,  4020,
4033,     4045,  4055,  4064,  4073,  4079,  4085,  4089,  4093,  4094,
4095,     4094,  4093,  4089,  4085,  4079,  4073,  4064,  4055,  4045,
4033,     4020,  4006,  3990,  3973,  3955,  3936,  3916,  3895,  3872,
3848,     3823,  3797,  3769,  3741,  3711,  3681,  3649,  3616,  3582,
3546,     3510,  3473,  3434,  3395,  3354,  3313,  3270,  3227,  3182,
3137,     3091,  3043,  2995,  2946,  2896,  2845,  2793,  2740,  2687,
2632,     2577,  2521,  2464,  2407,  2349,  2290,  2230,  2170,  2109,
2048,     1985,  1922,  1859,  1795,  1731,  1666,  1600,  1534,  1468,
1401,     1333,  1265,  1197,  1129,  1060,  991,   921,   851,   781,
711,641,  570,   499,   428,   357,   286,   214,   143,   71,
0,   71,  143,   214,   286,   357,   428,   499,   570,   641,
711,781,  851,   921,   991,   1060,  1129,  1197,  1265,  1333,
1401,     1468,  1534,  1600,  1666,  1731,  1795,  1859,  1922,  1985,
2048,     2109,  2170,  2230,  2290,  2349,  2407,  2464,  2521,  2577,
2632,     2687,  2740,  2793,  2845,  2896,  2946,  2995,  3043,  3091,
3137,     3182,  3227,  3270,  3313,  3354,  3395,  3434,  3473,  3510,
3546,     3582,  3616,  3649,  3681,  3711,  3741,  3769,  3797,  3823,
3848,     3872,  3895,  3916,  3936,  3955,  3973,  3990,  4006,  4020,
4033,     4045,  4055,  4064,  4073,  4079,  4085,  4089,  4093,  4094,
4095,     4094,  4093,  4089,  4085,  4079,  4073,  4064,  4055,  4045,
4033,     4020,  4006,  3990,  3973,  3955,  3936,  3916,  3895,  3872,
3848,     3823,  3797,  3769,  3741,  3711,  3681,  3649,  3616,  3582,
3546,     3510,  3473,  3434,  3395,  3354,  3313,  3270,  3227,  3182,
3137,     3091,  3043,  2995,  2946,  2896,  2845,  2793,  2740,  2687,
2632,     2577,  2521,  2464,  2407,  2349,  2290,  2230,  2170,  2109,
2048,     1985,  1922,  1859,  1795,  1731,  1666,  1600,  1534,  1468,
1401,     1333,  1265,  1197,  1129,  1060,  991,   921,   851,   781,
711,641,  570,   499,   428,   357,   286,   214,   143,   71,
0,   71,  143,   214,   286,   357,   428,   499,   570,   641,
711,781,  851,   921,   991,   1060,  1129,  1197,  1265,  1333,
1401,     1468,  1534,  1600,  1666,  1731,  1795,  1859,  1922,  1985,
2048,     2109,  2170,  2230,  2290,  2349,  2407,  2464,  2521,  2577,
2632,     2687,  2740,  2793,  2845,  2896,  2946,  2995,  3043,  3091,
3137,     3182,  3227,  3270,  3313,  3354,  3395,  3434,  3473,  3510,

};


  int del_right = analogRead(RIGHT) - Right_Knot;
  int del_left = analogRead(LEFT) - Left_Knot;

  float x = del_left + del_right;
  float y = del_right - del_left;
```

```
  int scale = sqrt(x*x+y*y);   //solving for magnitude

 scale = map(scale, 0, 1023, 0, 512); // is there a more effective way?
 scale = min(scale, 175);  // setting a max value for the scale
Serial.print("  scale:  ");
Serial.print(scale);
  float beta = atan2(y,x); // radians
  int angle = beta * 180/PI; // degrees

 if (angle < 0)
    { angle= 360+angle;} //corrected range
    int angle_2 = angle+120;
     if (angle_2>359) {angle_2=angle_2-360;}
 int angle_3 = angle+240;
     if (angle_3>359) {angle_3=angle_3-360;}


CCWorCW(angle);   // calls the sub function CCWorCW and feeds in the value for angle,

 int motor_1 = table[angle];             // Due to known geometry it is possible to use the value table for all
three
                                        // motors, the values are just pulled out of phase from the base angle. The
                                        // values are scaled 0 to 4096 due to the constraint of intiger values in the
                                        // table. So by increasing the range of values, the resolution is preserved.
 int motor_2 = table[angle_2];
 int motor_3 = table[angle_3];


 // This is motor magnitude
 float resolution = .0025;  //  =1/400, This is the scalar used to make the values usable again

 int Mag_1 = motor_1*resolution*scale;
 int Mag_2 = motor_2*resolution*scale;
 int Mag_3 = motor_3*resolution*scale;

  daca.setVoltage(Mag_1, false);
  dacb.setVoltage(Mag_2, false);
  dacc.setVoltage(Mag_3, false);

delay(10); // this may help with writing all 3 values to the dacs

 // this is for checking that motor mag is working right
// Serial.print(" Motor_1: ");
 //Serial.print(motor_1);
// Serial.print(" Res: ");
// Serial.print(resolution,4); // the 4 specifies the # of decimal places
// Serial.print (" Scale: ");
// Serial.print(scale);
// Serial.print("  Mag_1: ");
// Serial.print(Mag_1);
// Serial.print("  Mag_2: ");
// Serial.print(Mag_2);
// Serial.print("  Mag_3: ");
// Serial.println(Mag_3);
 //Serial.print (motor_2);
```

```
//Serial.print("  mag: ");
//Serial.println(Mag_2);
// Serial.println(Mag_3);
 //Serial.println("    end ");

 }

 void CCWorCW(int angle) {   // This is the direction matrix for the rotion of the motor. I have done it in this manerism due to the ablity of creating dead zones around each of the transition points, 0, 60,120, 180, 240, 300, 360
// cw is defined by looking down at the system.
Serial.print("  angle: ");
Serial.print(angle);

  if (angle==0)
  {    Serial.print(" a  ");

       digitalWrite(IN_1A, LOW);
       digitalWrite(IN_1B, HIGH);

       digitalWrite(IN_2A, HIGH);
       digitalWrite(IN_2B, LOW);

       digitalWrite(IN_3A, LOW);
       digitalWrite(IN_3B, LOW);
  }
 else if (angle>0   && angle<60)
 {   Serial.print(" b  ");

       digitalWrite(IN_1A, LOW);
       digitalWrite(IN_1B, HIGH);

       digitalWrite(IN_2A, HIGH);
       digitalWrite(IN_2B, LOW);

       digitalWrite(IN_3A, LOW);
       digitalWrite(IN_3B, HIGH);
 }
 else if (angle==60)
  {
        Serial.print(" c  ");
       digitalWrite(IN_1A, LOW);
       digitalWrite(IN_1B, LOW);

       digitalWrite(IN_2A, HIGH);
       digitalWrite(IN_2B, LOW);

       digitalWrite(IN_3A, LOW);
       digitalWrite(IN_3B, HIGH);
  }
 else if (angle>60 && angle<120)
{
        Serial.print(" d  ");

       digitalWrite(IN_1A, HIGH);
       digitalWrite(IN_1B, LOW);
```

```
      digitalWrite(IN_2A, HIGH);
      digitalWrite(IN_2B, LOW);

      digitalWrite(IN_3A, LOW);
      digitalWrite(IN_3B, HIGH);
}
 else if (angle==120)
 {
       Serial.print(" e  ");
      digitalWrite(IN_1A, HIGH);
      digitalWrite(IN_1B, LOW);

      digitalWrite(IN_2A, LOW);
      digitalWrite(IN_2B, LOW);

      digitalWrite(IN_3A, LOW);
      digitalWrite(IN_3B, HIGH);
 }
 else if (angle>120 && angle<180)
 {
       Serial.print(" f  ");

      digitalWrite(IN_1A, HIGH);
      digitalWrite(IN_1B, LOW);

      digitalWrite(IN_2A, LOW);
      digitalWrite(IN_2B, HIGH);

      digitalWrite(IN_3A, LOW);
      digitalWrite(IN_3B, HIGH);
 }
 else if (angle==180)
     {
      Serial.print(" g  ");
      digitalWrite(IN_1A, HIGH);
      digitalWrite(IN_1B, LOW);

      digitalWrite(IN_2A, LOW);
      digitalWrite(IN_2B, HIGH);

      digitalWrite(IN_3A, LOW);
      digitalWrite(IN_3B, LOW);
     }

else if (angle>180 && angle<240)
      {
       Serial.print(" h  ");
      digitalWrite(IN_1A, HIGH);
      digitalWrite(IN_1B, LOW);

      digitalWrite(IN_2A, LOW);
      digitalWrite(IN_2B, HIGH);

      digitalWrite(IN_3A, HIGH);
      digitalWrite(IN_3B, LOW);
```

```
        }
 else if (angle==240)
        {
        Serial.print(" i ");
        digitalWrite(IN_1A, LOW);
        digitalWrite(IN_1B, LOW);

        digitalWrite(IN_2A, LOW);
        digitalWrite(IN_2B, HIGH);

        digitalWrite(IN_3A, HIGH);
        digitalWrite(IN_3B, LOW);
        }
else if (angle>240 && angle<300)
 {
            Serial.print(" j  ");
        digitalWrite(IN_1A, LOW);
        digitalWrite(IN_1B, HIGH);

        digitalWrite(IN_2A, LOW);
        digitalWrite(IN_2B, HIGH);

        digitalWrite(IN_3A, HIGH);
        digitalWrite(IN_3B, LOW);
 }
 else if (angle==300)
  {
    Serial.print(" k  ");

        digitalWrite(IN_1A, LOW);
        digitalWrite(IN_1B, HIGH);

        digitalWrite(IN_2A, LOW);
        digitalWrite(IN_2B, LOW);

        digitalWrite(IN_3A, HIGH);
        digitalWrite(IN_3B, LOW);
  }
else if (angle>300 && angle<360)
   {
     Serial.print(" l  ");

        digitalWrite(IN_1A, LOW);
        digitalWrite(IN_1B, HIGH);

        digitalWrite(IN_2A, HIGH);
        digitalWrite(IN_2B, LOW);

        digitalWrite(IN_3A, HIGH);
        digitalWrite(IN_3B, LOW);
   }
}
```

Appendix B PWM

Pulse width modulation (PWM) is a method for synthesizing an “analog” voltage. The fundamental concept is that a supply voltage is toggled on and off at proportional time intervals resulting in an average analog voltage.

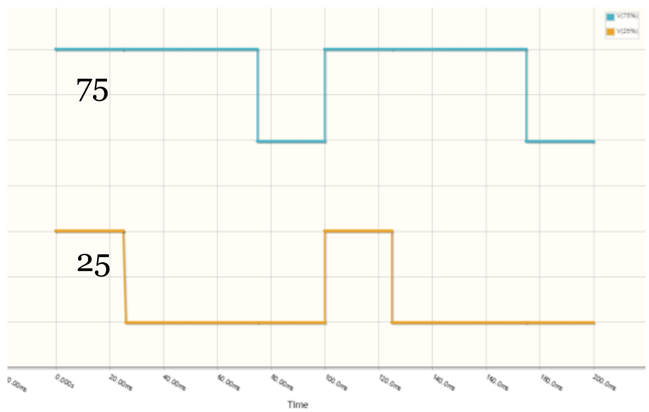

Figure 30: 25% and 75 PWM signal

$$\frac{T_{on}}{T_{on}+T_{off}} \times V_{applied} = V_{analog} \quad \textbf{Eq. 21}$$

By controlling the supplied voltage, it is possible to control the current to a motor. With a torque regulated control scheme, it’s necessary for the driver to regulate current to the motor. This can be achieved by monitoring the current to the motor and adjusting the PWM signal such that the commanded current is flowing through the motor. The current through a motor can be measured by placing a shunt resistor in line with the motor and measuring the voltage drop across the resistor. There are also driver chips that come with built in current sensing and feedback.

Appendix C H-Bridge

An H-bridge is the name of an arrangement of transistors or switches used to control the direction of current through a motor or other electrical devices [Figure 31].

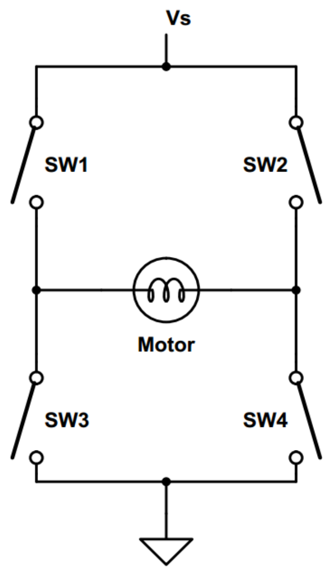

Figure 31: H-Bridge Composed of Switches

Due to a brushed DC motors rotational directional dependence on current flow, it is possible to control a motor's directional output utilizing an H-bridge. By activating sections of the bridge together, current can be applied in different directions. Activating M1 and M4 will result in current flowing to the right [Figure 32a]. Activating M2 and M3 will result in current flowing to the left [Figure 32b]. The prior two statements apply to a stationary motor. If the motor is already rotating then applied current will either accelerate or decelerate the motor. Care must be taken to ensure that both switches on one half of the bridge are not active at the same time. If both switches on a single side are active at the same time, the state is known as "Shoot-through". If shoot-through occurs, the system has short circuited and may damage the motor drivers with a current surge. H-Bridges can be constructed from individual MOSFETs, half bridges, or purchased as full H-Bridges. Half bridges and full bridges are generally more favorable due to the availability of built in protection against phenomena such-as shoot-through, overheating, under- or over-voltage.

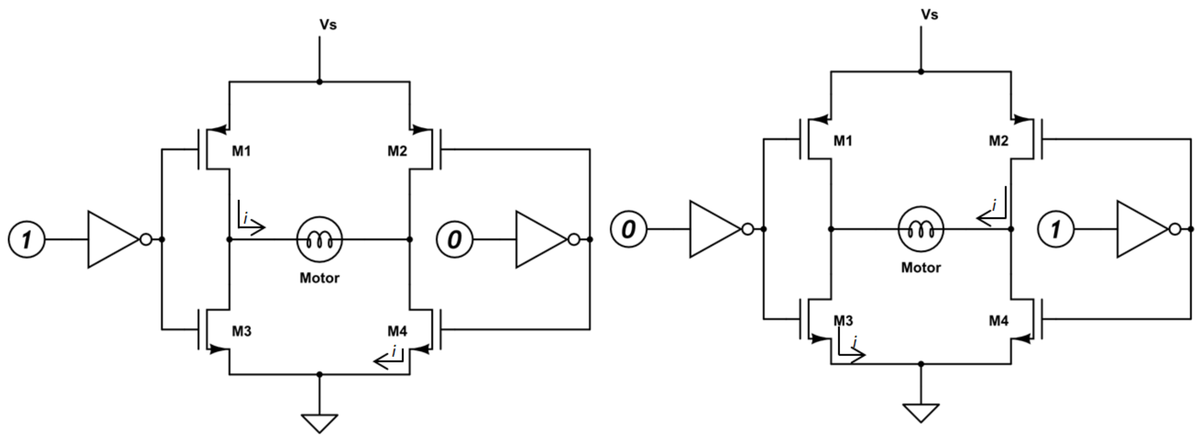

Figure 32 Direction of Current in an H-Bridge

The H-Bridge used in this thesis receives a PWM signal to one side of the bridge while the other is pulled to ground. Consider the case, were M1 and M3 receives the PWM signal and M2 and M4 are grounded, similar to Figure 32a. During the “ON” part current will flow through M1 to the motor and out M4. In the “OFF” or low state any current produced from the motors rotation will flow out M4 and back through M3 to the motor.

Appendix D Drawing Package

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:

LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0 30'

DESCRIPTION: Full Assembly with Drums

CHECKED BY: Dan Mathewson DATE: 11/28/12

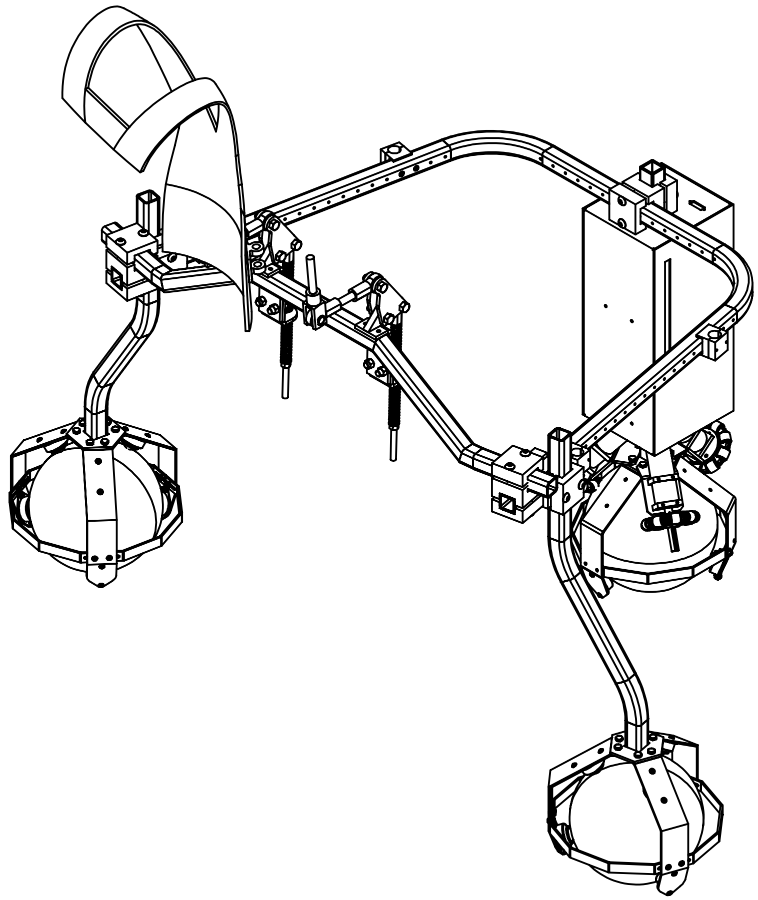
DRAWN BY: DATE: 5/17/2013

FILE NAME: Final Assembly.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 00-00 QTY: 1

SCALE: 1:10 SHEET: 1 OF 39



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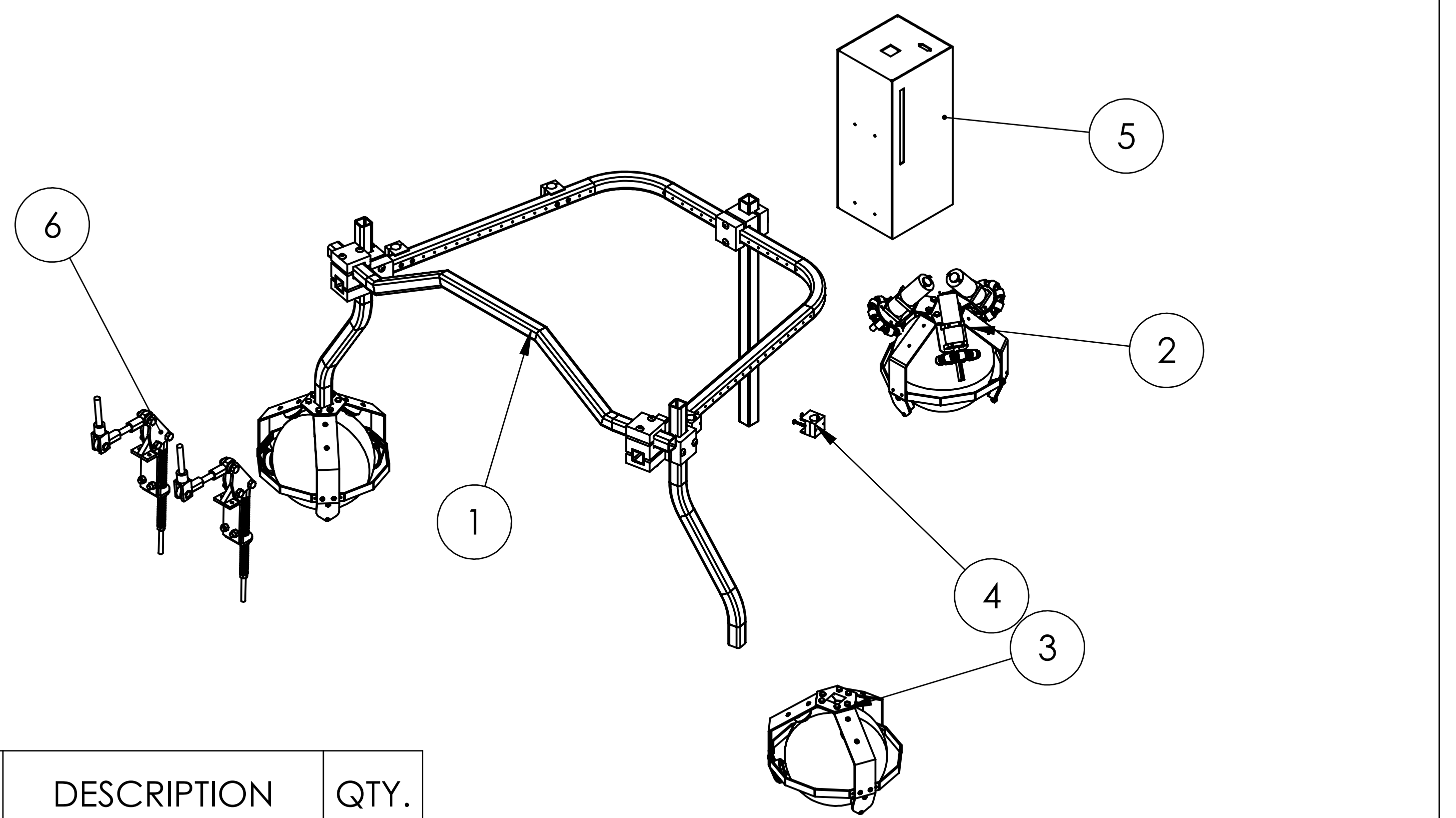
DEFAULT TOLERANCES: LINEAR: X.±.25 X.X±.1 X.XX±.01 X.XXX±.002 ANGULAR: X.± 2 X.X± 1 X.XX± 0 30'	DESCRIPTION: Full Assembly CHECKED BY: Dan Mathewson DATE: 11/28/12 DRAWN BY: DATE: 5/17/2013 FILE NAME: Final Assembly No Drums.SLDPRT	UNIVERSITY OF IDAHO ME DEPARTMENT PART #: 00-00 QTY: 1 SCALE: 1:10 SHEET: 2 OF 39



ITEM NO.	PartNo	DESCRIPTION	QTY.
1	01-00	Frame	1
2	02-00	Power Caster	1
3	03-00	Passive Caster	2
4	04-00	Drum connection bracket	4
5	05-00	electronics cover	1
6	06-00	Input System	2

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

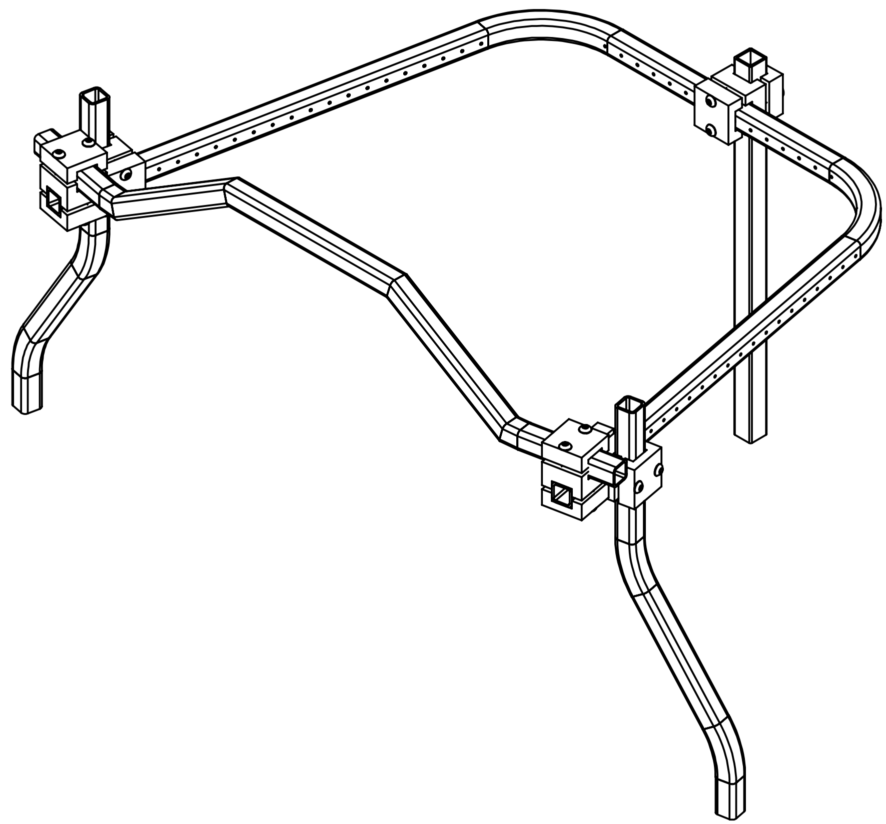
BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'

DESCRIPTION: Full Assembly
CHECKED BY: Dan Mathewson DATE: 11/28/12
DRAWN BY: DATE: 5/17/2013
FILE NAME: Final Assembly No Drums - exploded.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 00-00 QTY: 1
SCALE 1:12 SHEET: 3 OF 39



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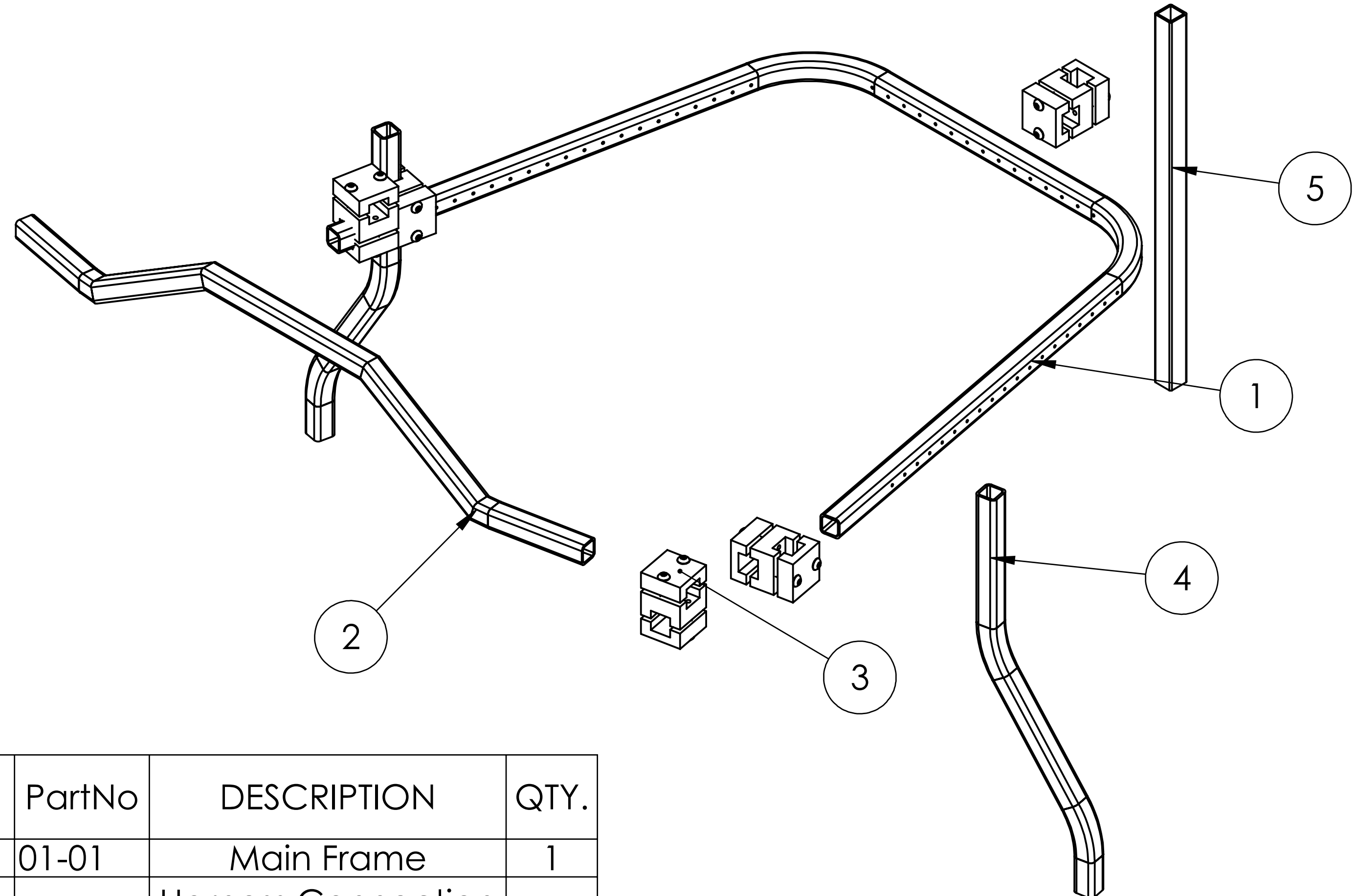
DEFAULT TOLERANCES: LINEAR: X. ±.25, X.X ±.1, X.XX ±.01, X.XXX ±.002 ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'	DESCRIPTION: Frame CHECKED BY: Dan Mathewson — DATE: 11/28/12 DRAWN BY: — DATE: 12/5/2012 FILE NAME: 01-00_Frame.SLDPRT	**UNIVERSITY OF IDAHO ME DEPARTMENT** PART #: 01-00 — QTY: 1 SCALE: 1:8 — SHEET: 4 OF 39



ITEM NO.	PartNo	DESCRIPTION	QTY.
1	01-01	Main Frame	1
2	01-02	Harness Connection Bar	1
3	01-03	Leg Connection Assembly	5
4	01-04	Leg	2
5	01-05	power caster leg	1

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

BAND BEESTEN
Rolling Drumset

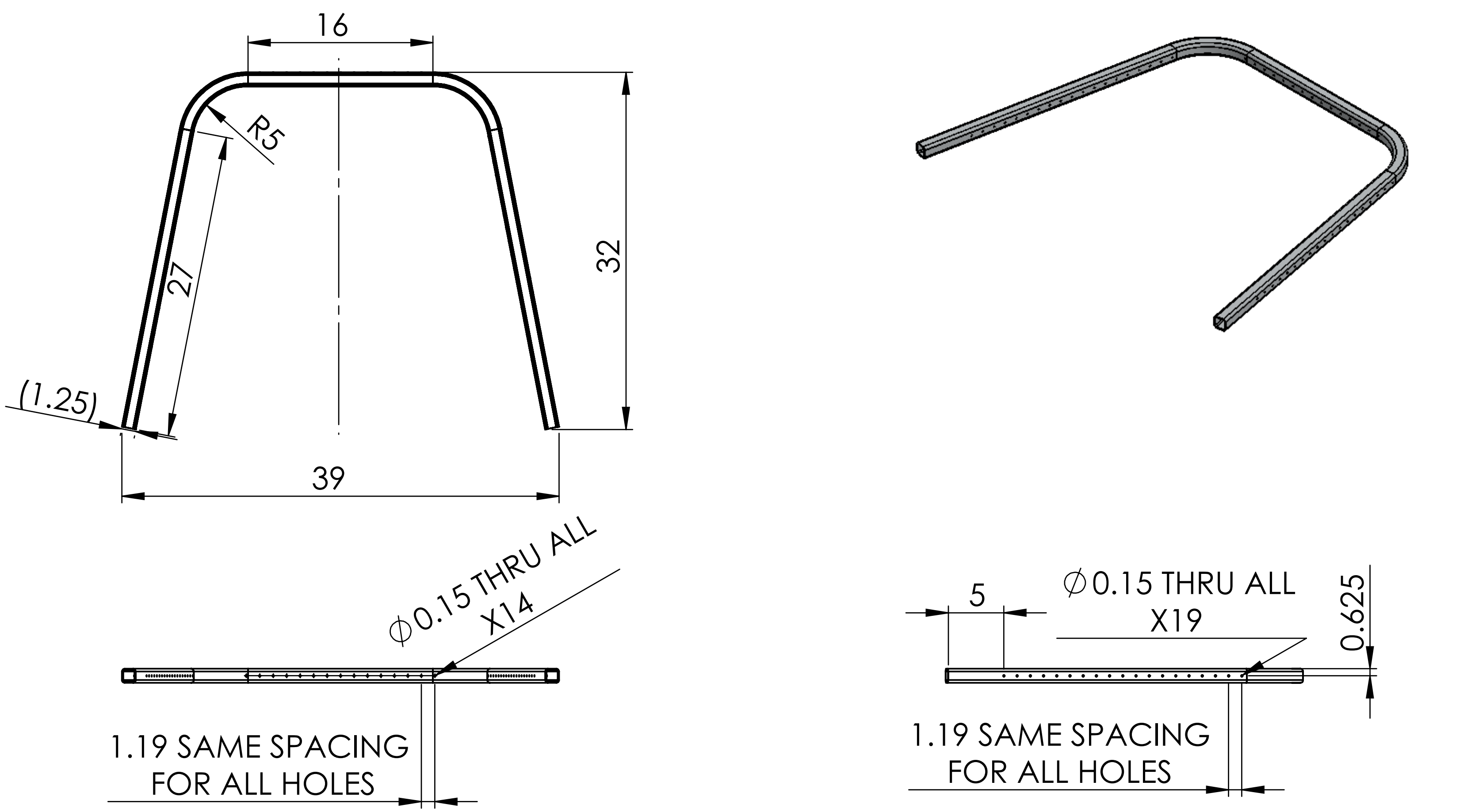
DEFAULT TOLERANCES:
LINEAR: X. ±.25, X.X ±.1, X.XX ±.01, X.XXX ±.002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Frame
CHECKED BY: Dan Mathewson — DATE: 11/28/12
DRAWN BY: — DATE: 12/5/2012
FILE NAME: 01-00 Frame exploded.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 01-00 — QTY: 1
SCALE: 1:10 — SHEET: 5 OF 39

NOTE: 1.25X1.25 SQUARE TUBE STOCK



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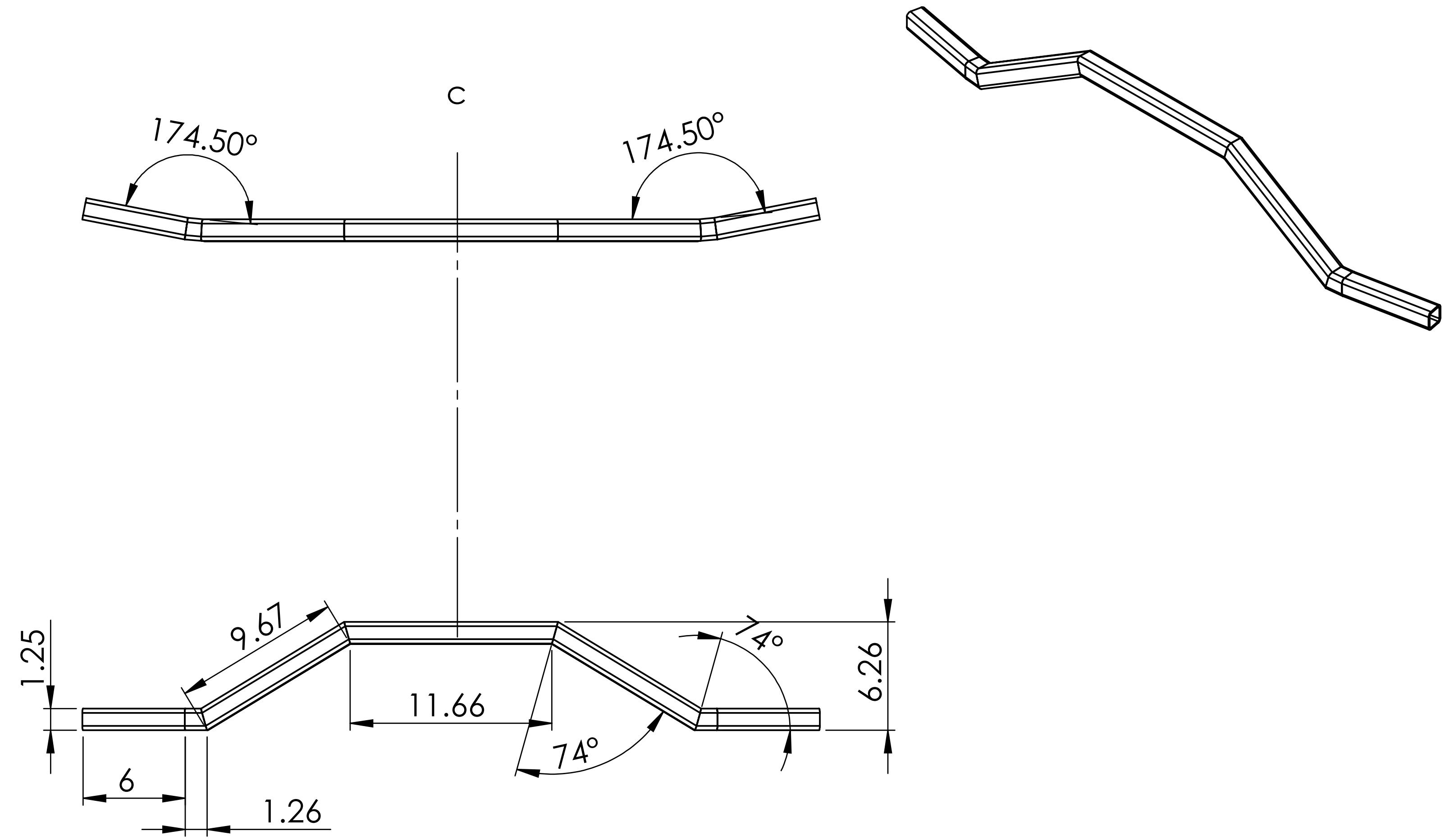
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

BAND BEESTEN
Rolling Drumset

MATERIAL: 6063-T6

DEFAULT TOLERANCES:	DESCRIPTION: Main Frame		**UNIVERSITY OF IDAHO ME DEPARTMENT**
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002 / ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'	CHECKED BY: Dan Mathewson	DATE: 11/28/12	
	DRAWN BY: Toni Topfer	DATE: 5/17/2013	PART #: 01-01 / QTY: 1
	FILE NAME: Main Frame.SLDPRT		SCALE: 1:8 / SHEET: 6 OF 39



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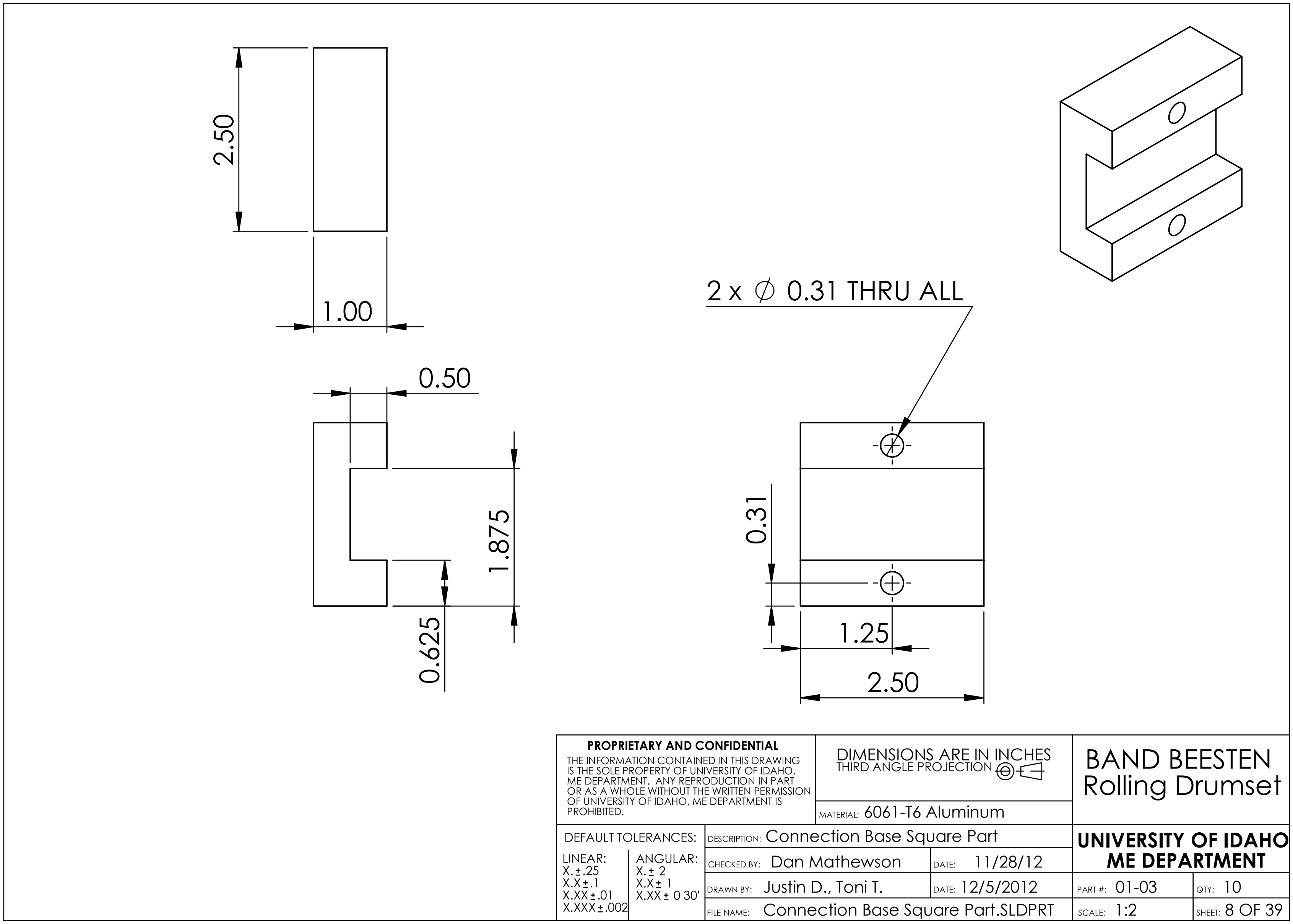
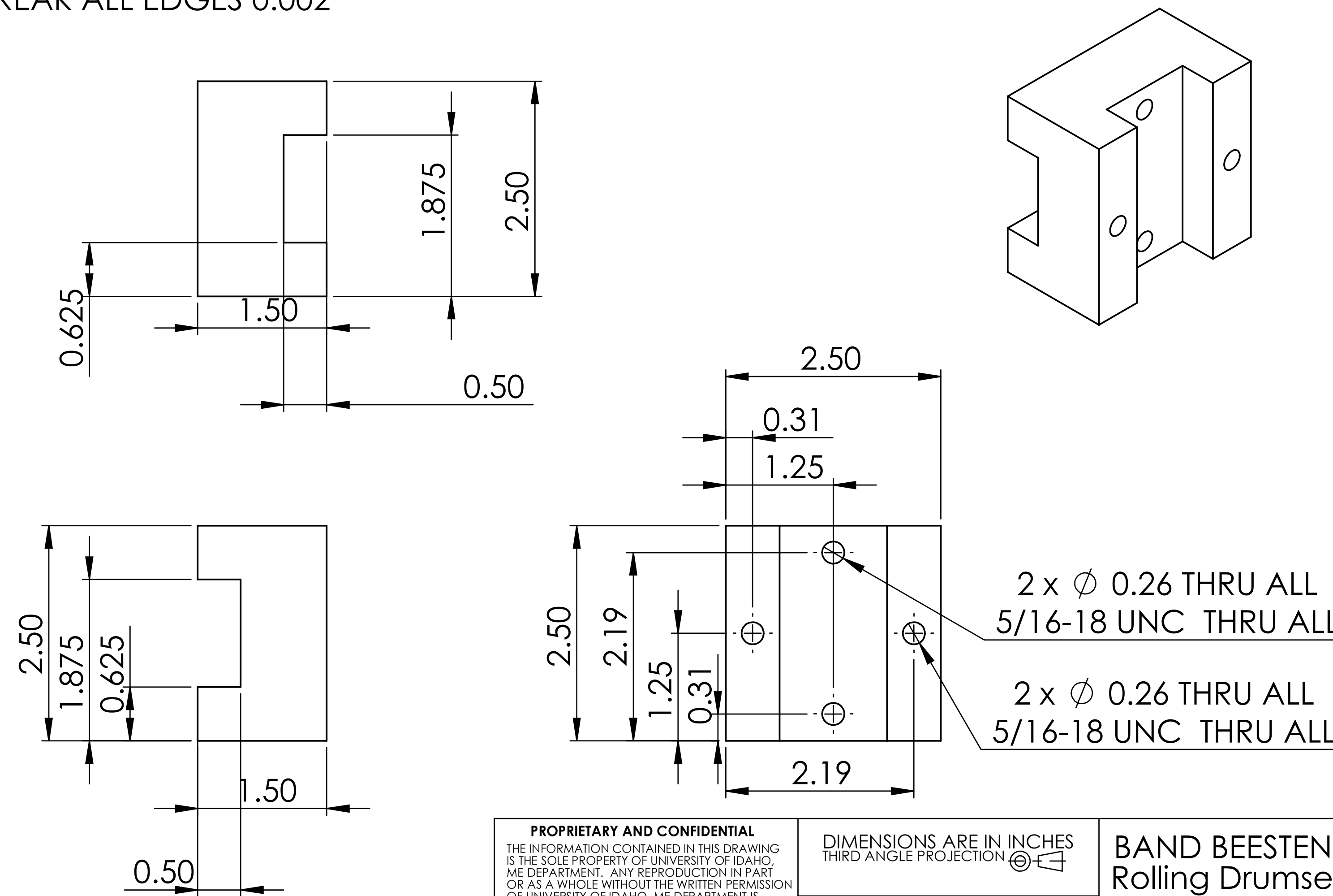
DEFAULT TOLERANCES:	DESCRIPTION: Harness Connection Bar		**UNIVERSITY OF IDAHO ME DEPARTMENT**	
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002 / ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'	CHECKED BY: Dan Mathewson	DATE: 11/28/12		
	DRAWN BY: Justin Dilworth	DATE: 12/2/2012	PART #: 01-02	QTY: 1
	FILE NAME: User Interface Raised.SLDPRT		SCALE: 1:6	SHEET: 7 OF 39

NOTE: BREAK ALL EDGES .002



NOTE: BREAK ALL EDGES 0.002



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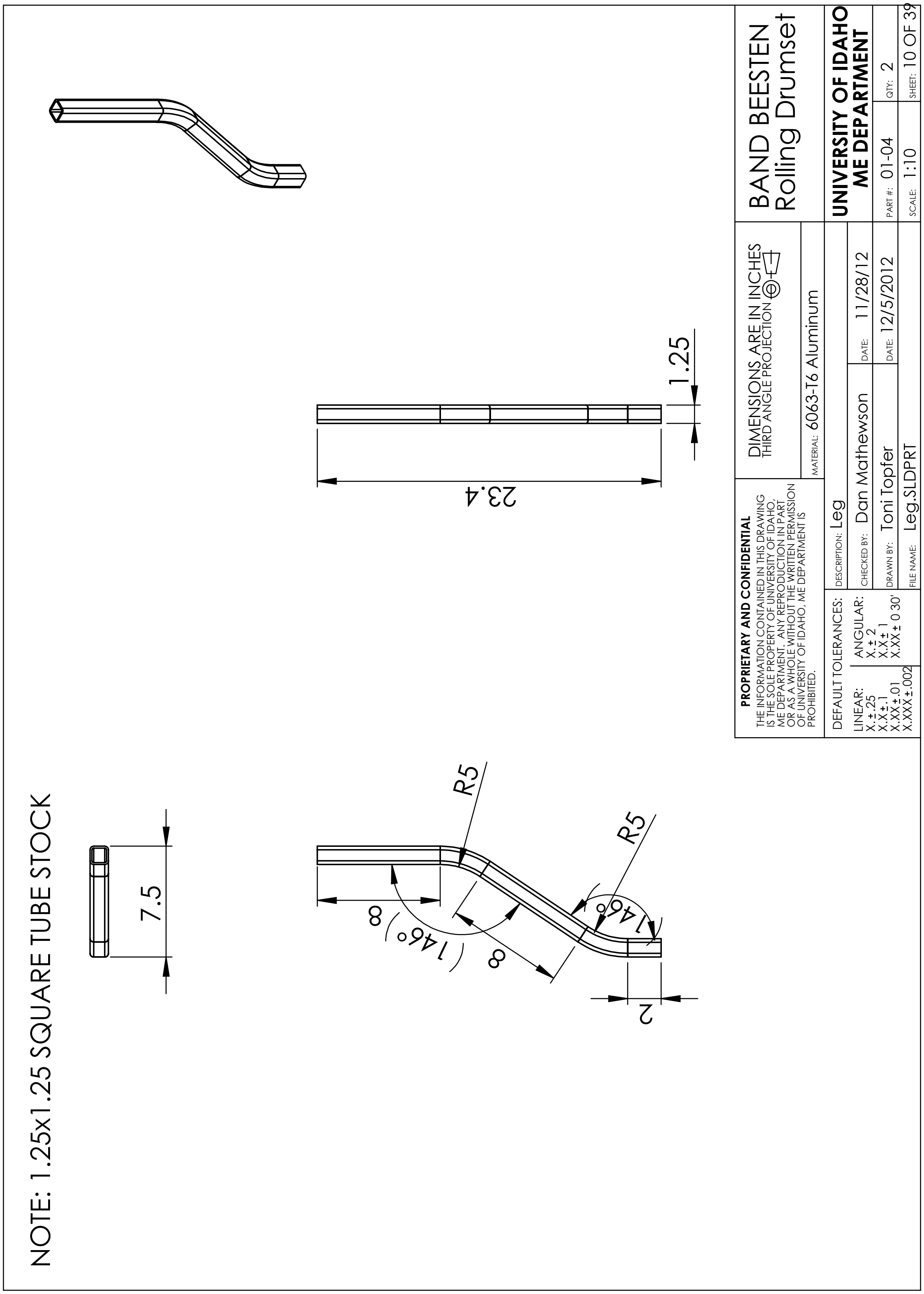
	MATERIAL: 6061-T6 Aluminum		
DEFAULT TOLERANCES:	DESCRIPTION: Leg Connection Base		**UNIVERSITY OF IDAHO ME DEPARTMENT**
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002 / ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'	CHECKED BY: Dan Mathewson	DATE: 11/28/12	
	DRAWN BY: Justin D., Toni T.	DATE: 12/5/2012	PART #: 01-03 C / QTY: 5
	FILE NAME: Leg Connection Base.SLDPRT		SCALE: 1:10 / SHEET: 9 OF 39



NOTE: 1.25x1.25 SQUARE TUBE STOCK
7.5
R5
R5
8
146°
8
146°
2
23.4
1.25
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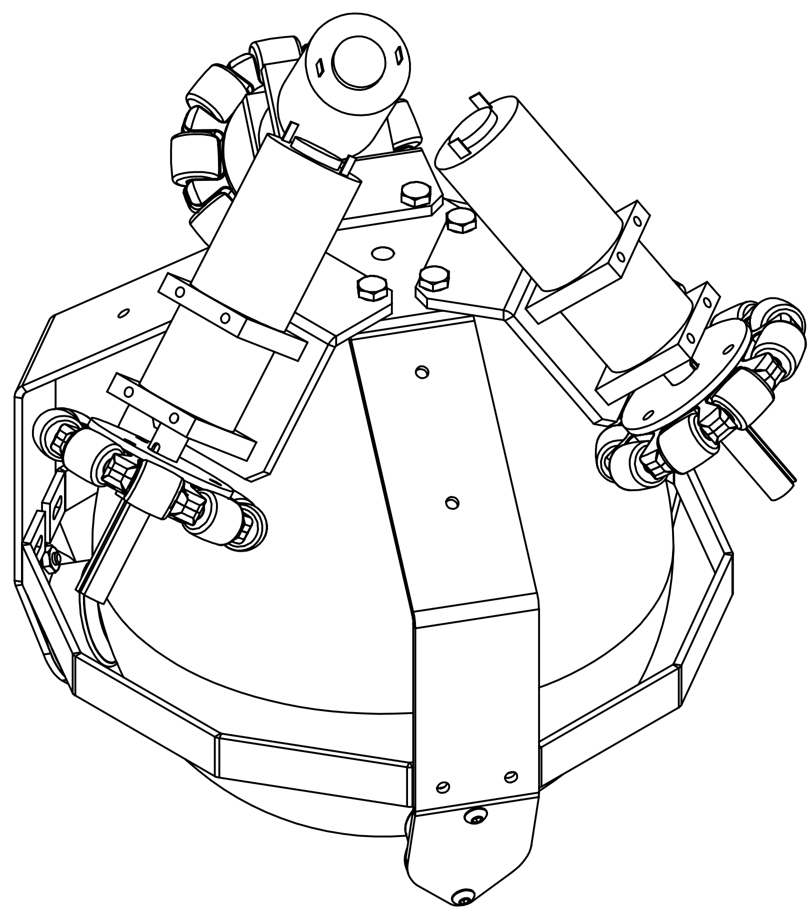
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6063-T6 Aluminum
BAND BEESTEN
Rolling Drumset
DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
DESCRIPTION: Leg
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Toni Topfer
DATE: 12/5/2012
FILE NAME: Leg.SLDPRT
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 01-04
QTY: 2
SCALE: 1:10
SHEET: 10 OF 39



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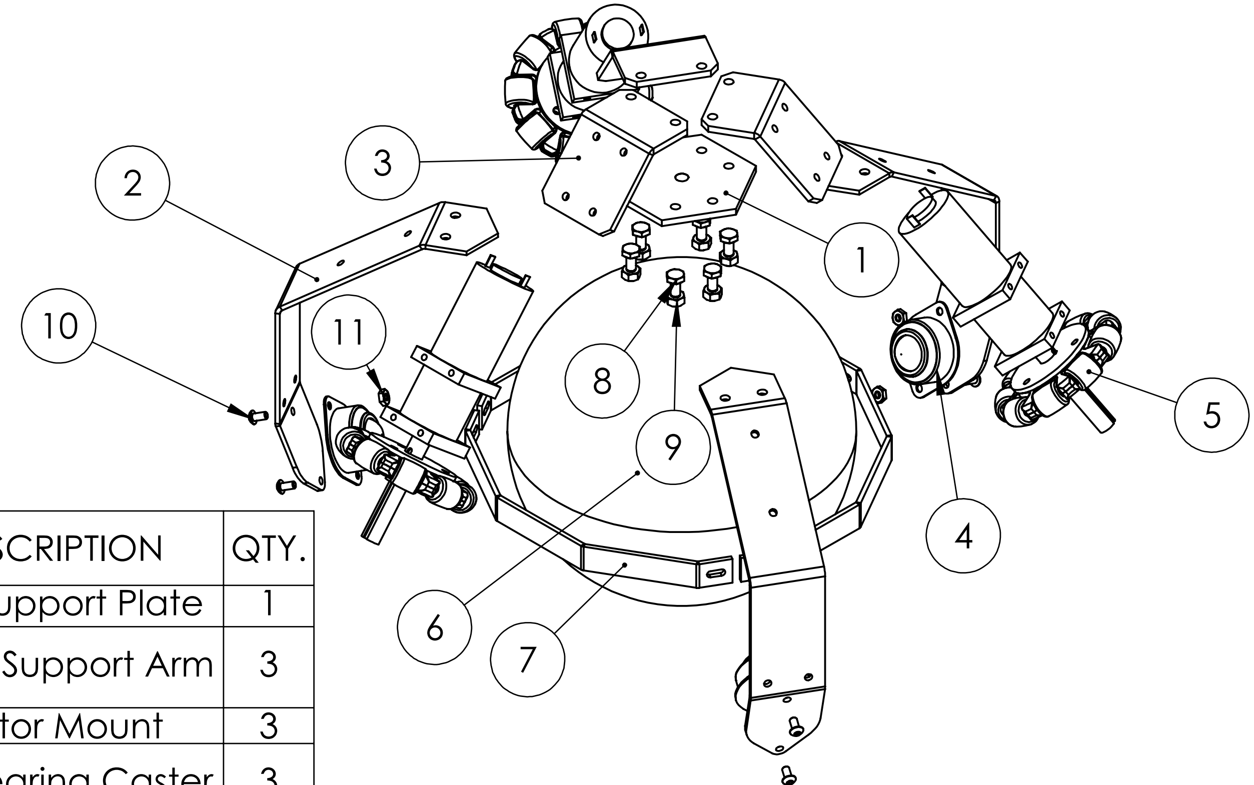
DEFAULT TOLERANCES:	DESCRIPTION: Power Caster	**UNIVERSITY OF IDAHO ME DEPARTMENT**
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002 / ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'	CHECKED BY: Dan Mathewson DATE: 11/28/12	
	DRAWN BY: Steven Watts DATE: 5/5/2013	PART #: 02-00 QTY: 1
	FILE NAME: 02-00 Power Caster 3.0.SLDPRT	SCALE: 1:3 SHEET: 11 OF 39

NOTE: BALL BEARING CASETER SUPPLIER WAS BIGHORN PURCHASED FROM AMAZON



ITEM NO.	PartNo	DESCRIPTION	QTY.
1	02-01	Top Support Plate	1
2	02-02	Down Support Arm	3
3	02-03	Motor Mount	3
4	Purchased	Ball Bearing Caster	3
5	Purchased	Omni Wheel Motor	3
6	Purchased	Basketball	1
7	02-04	support hoop	3
8	Purchased	0.25-20x1	6
9	Purchased	0.25-20 Nut	6
10	Purchased	10-28X0.375 Bolt	6
11	Purchased	10-28 Nut	6

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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

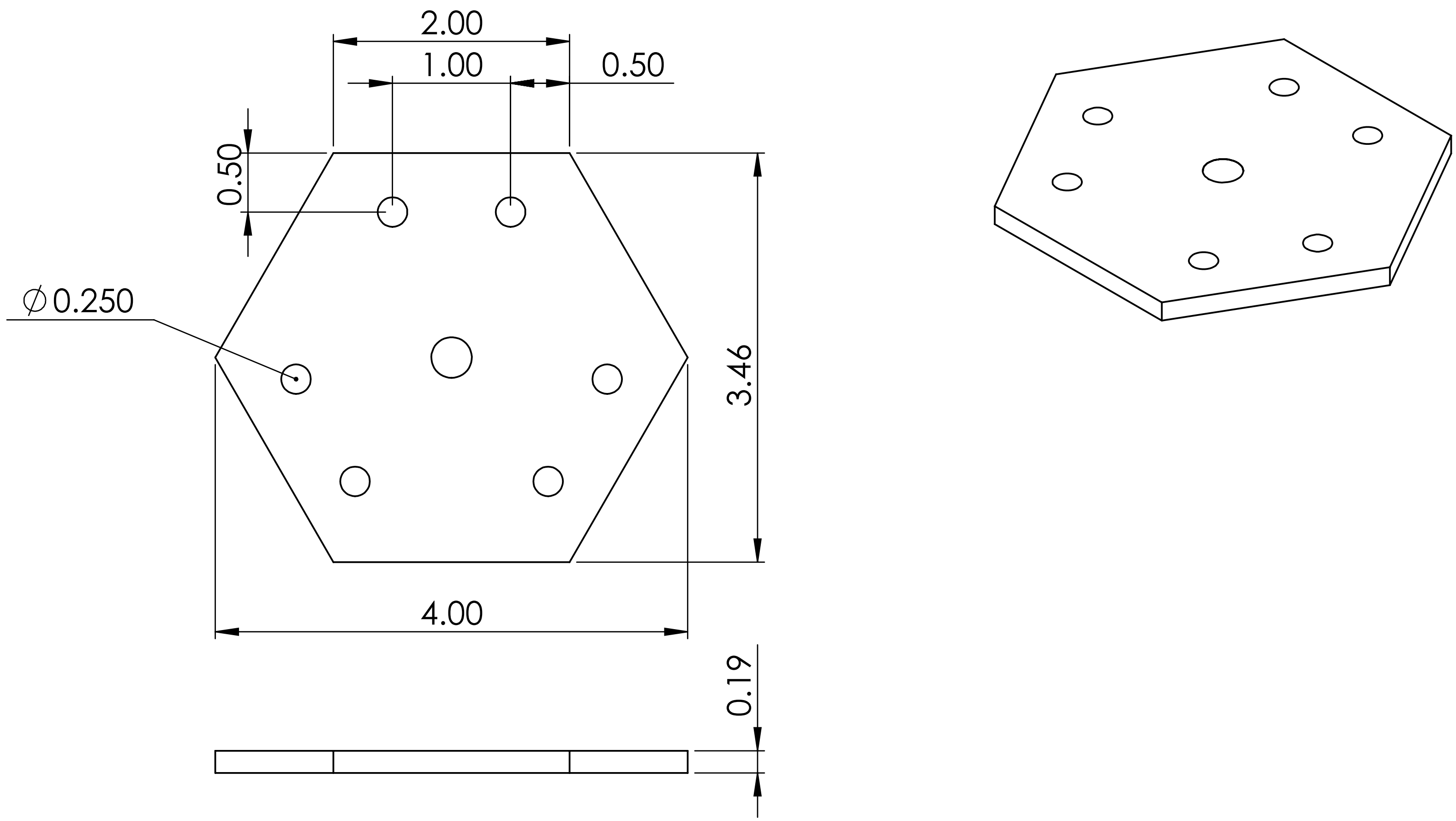
BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:
LINEAR: X. ±.25, X.X ±.1, X.XX ±.01, X.XXX ±.002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Power Caster
CHECKED BY: Dan Mathewson DATE: 11/28/12
DRAWN BY: Steven Watts DATE: 5/16/2013
FILE NAME: 02-00 Power Caster 3.0 - exploded.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 02-00 QTY: 1
SCALE: 1:4 SHEET: 12 OF 39



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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061 Alloy

BAND BEESTEN
Rolling Drumset

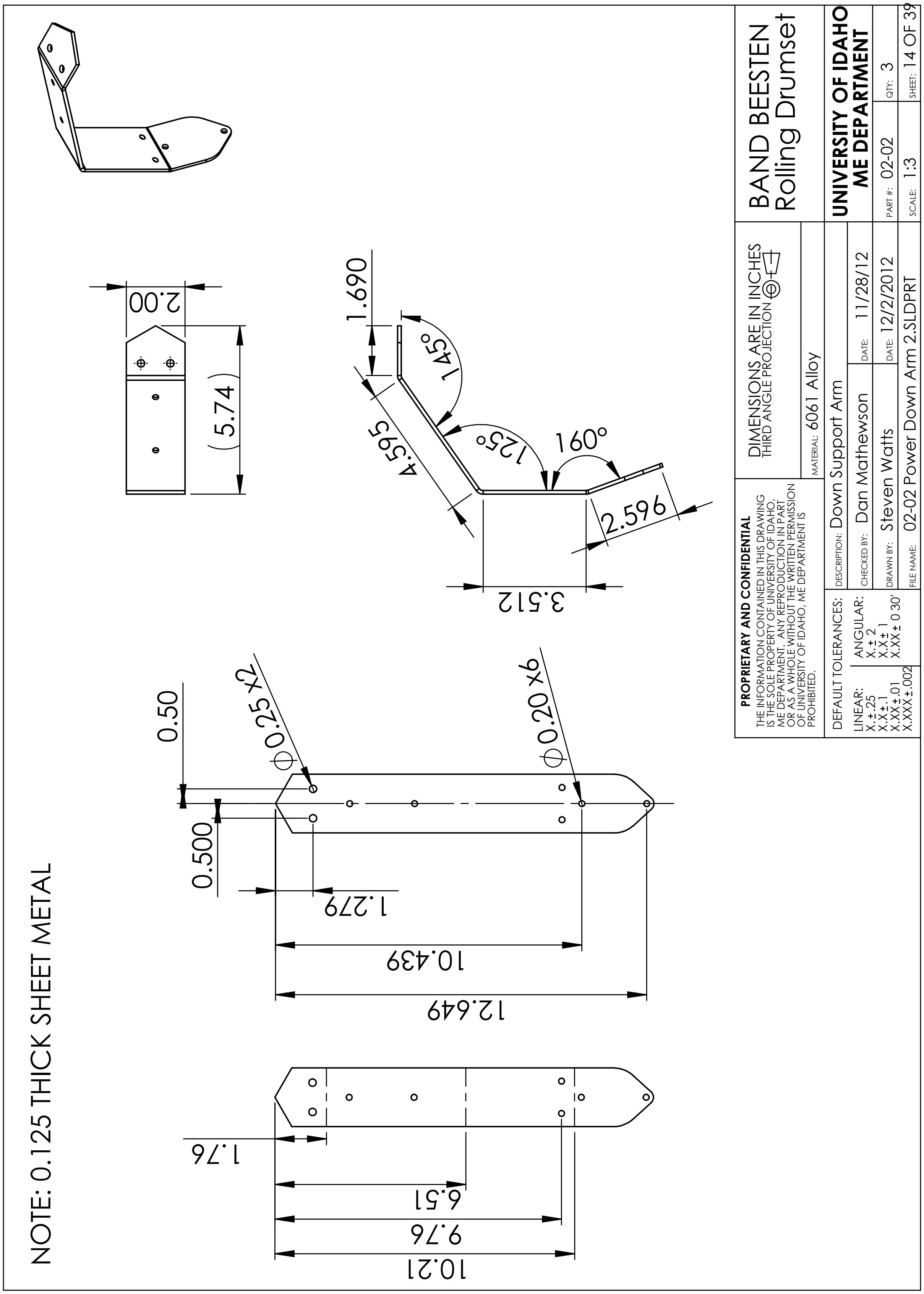
DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ±.25	X. ± 2
X.X ±.1	X.X ± 1
X.XX ±.01	X.XX ± 0 30'
X.XXX ±.002	

DESCRIPTION: Top Support Plate
CHECKED BY: Dan Mathewson DATE: 11/28/12
DRAWN BY: Steven Watts DATE: 11/15/2012
FILE NAME: 02-01 top support.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 02-01 QTY: 1
SCALE: 1:2 SHEET: 13 OF 39


NOTE: 0.125 THICK SHEET METAL
10.21
9.76
6.51
1.76
12.649
10.439
1.279
0.500
0.50
⌀0.25 X2
⌀0.20 X6
3.512
2.596
4.595
125°
160°
145°
1.690
(5.74)
2.00
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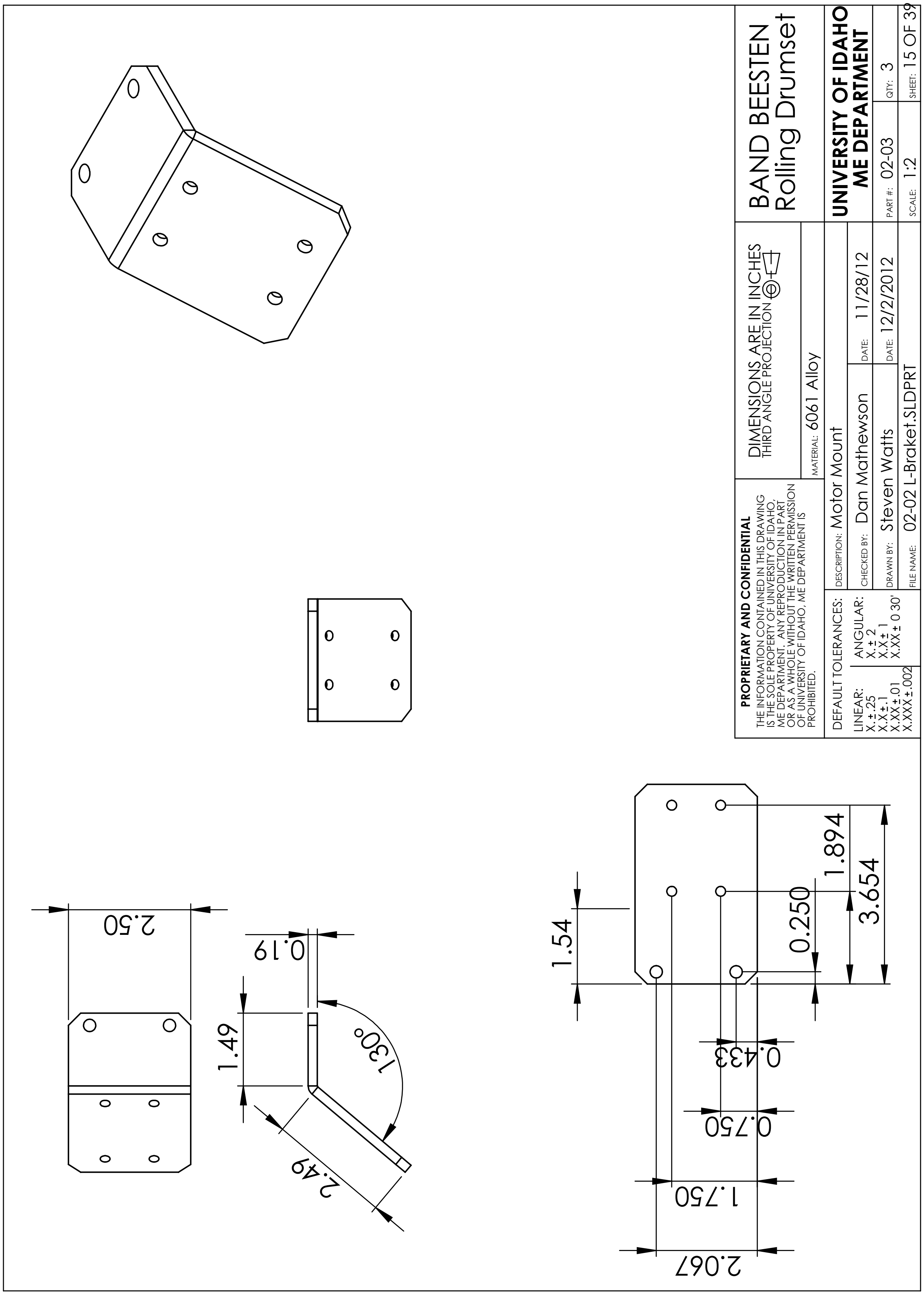
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6061 Alloy
BAND BEESTEN
Rolling Drumset
DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
DESCRIPTION: Down Support Arm
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Steven Watts
DATE: 12/2/2012
FILE NAME: 02-02 Power Down Arm 2.SLDPRT
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 02-02
QTY: 3
SCALE: 1:3
SHEET: 14 OF 39


2.50
0.19
1.49
130°
2.49
1.54
0.250
1.894
3.654
0.433
0.750
1.750
2.067
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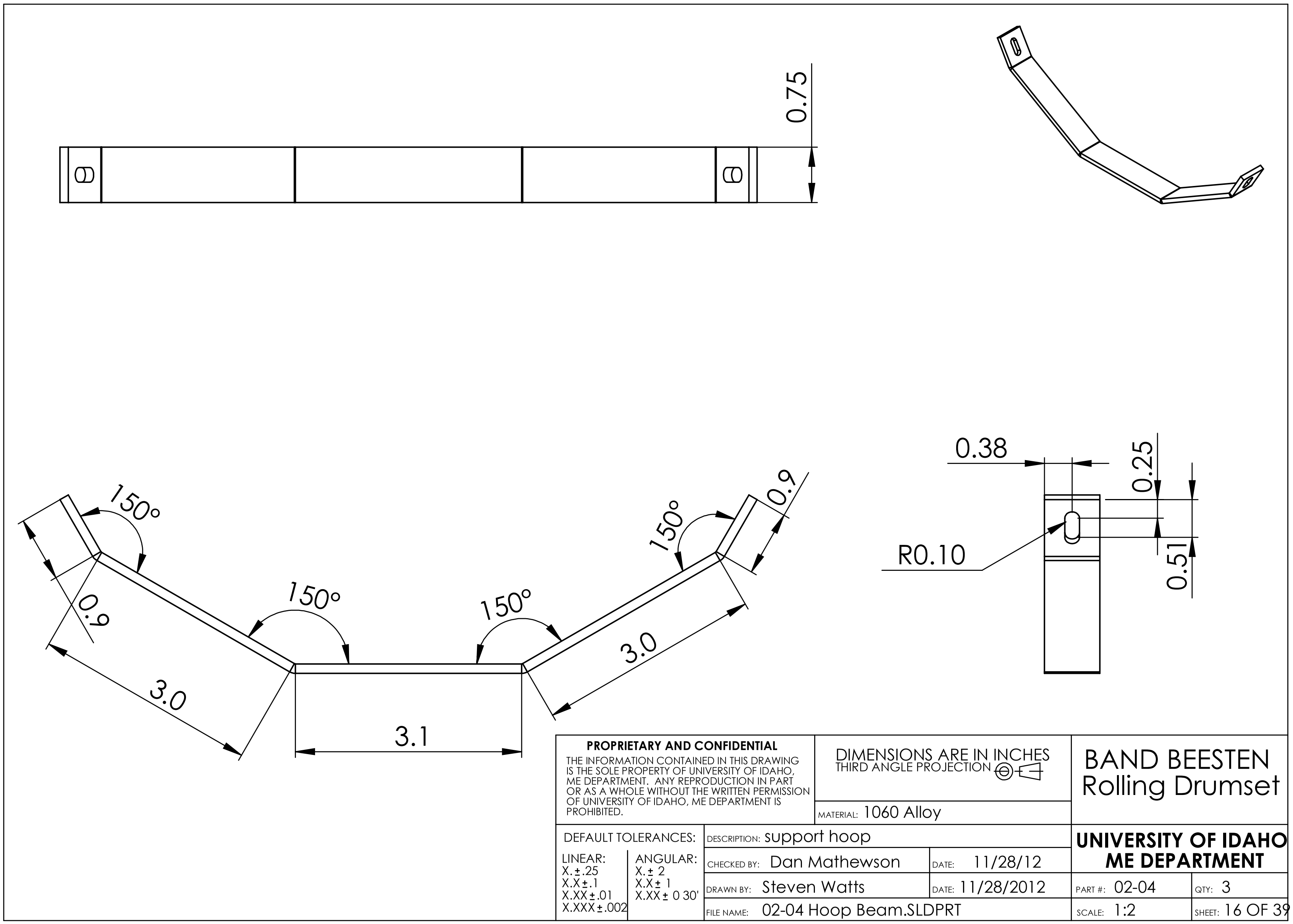
DEFAULT TOLERANCES:
LINEAR: X. ± .25 X.X ± .1 X.XX ± .01 X.XXX ± .002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6061 Alloy
DESCRIPTION: Motor Mount
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Steven Watts
DATE: 12/2/2012
FILE NAME: 02-02 L-Braket.SLDPRT
BAND BEESTEN
Rolling Drumset
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 02-03
QTY: 3
SCALE: 1:2
SHEET: 15 OF 39


0.75
150°
0.9
3.0
150°
3.1
150°
150°
3.0
0.9
0.38
0.25
R0.10
0.51
PROPRIETARY AND CONFIDENTIAL
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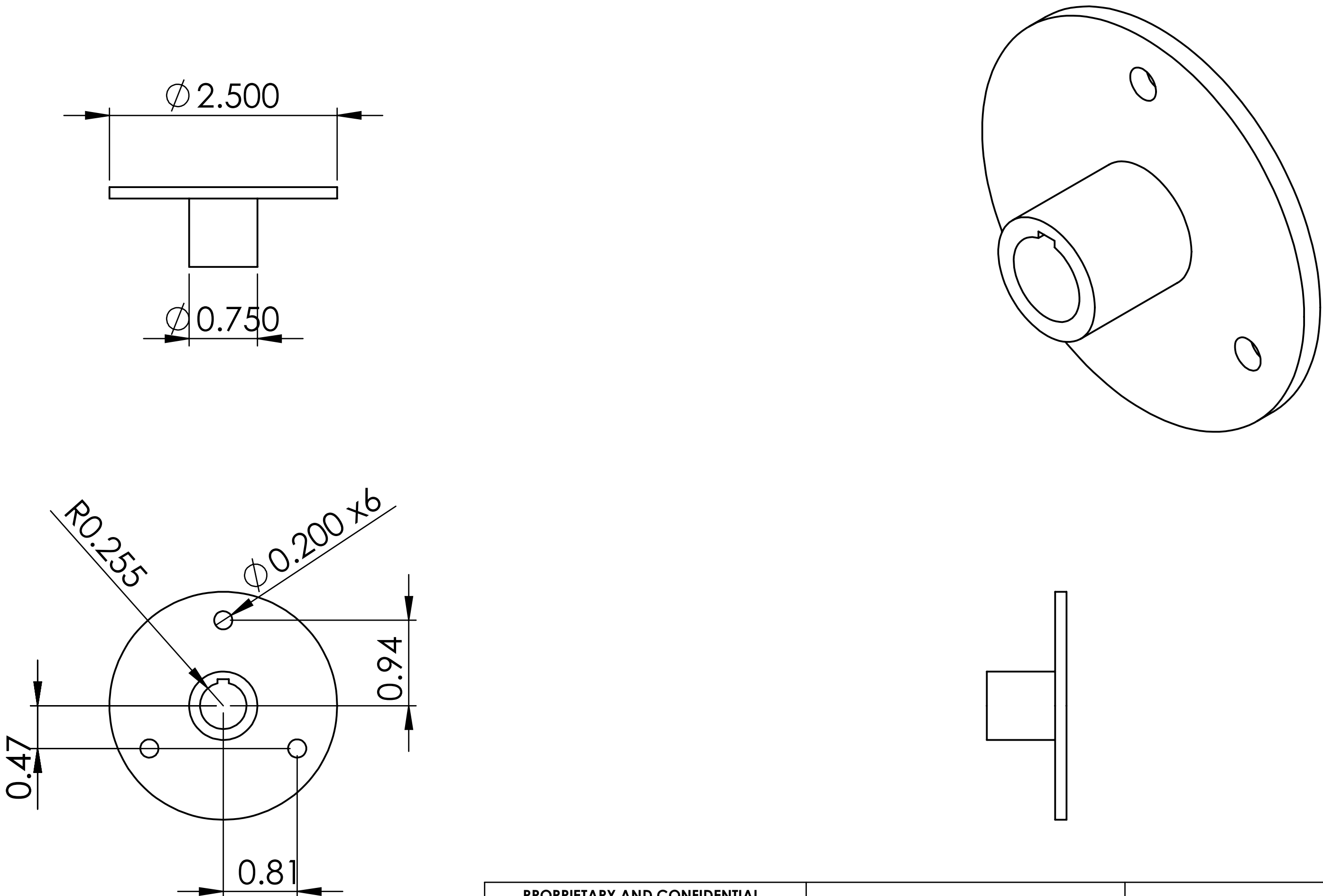
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 1060 Alloy
BAND BEESTEN
Rolling Drumset
DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
DESCRIPTION: support hoop
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Steven Watts
DATE: 11/28/2012
FILE NAME: 02-04 Hoop Beam.SLDPRT
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 02-04
QTY: 3
SCALE: 1:2
SHEET: 16 OF 39



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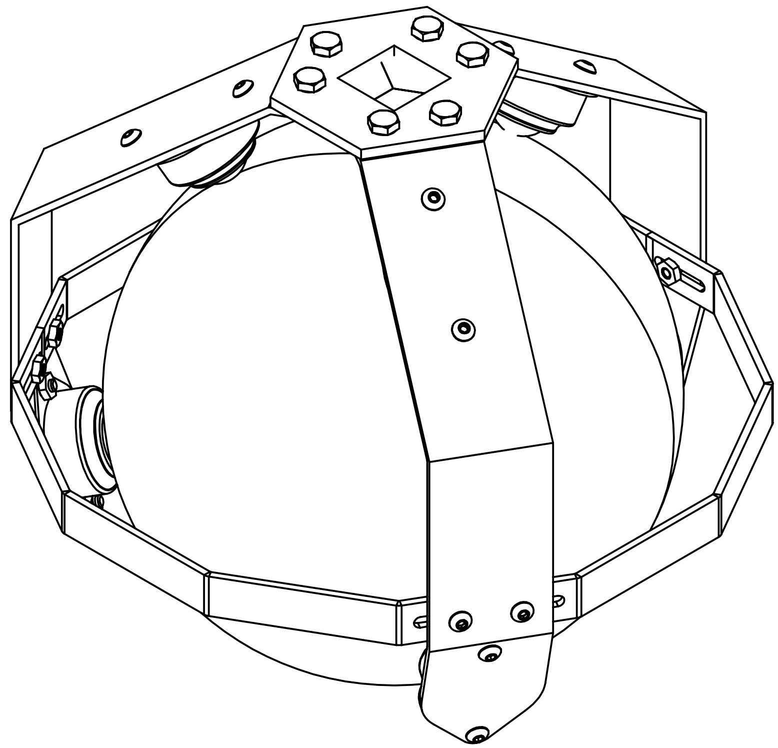
DEFAULT TOLERANCES: LINEAR: X. ±.25, X.X ±.1, X.XX ±.01, X.XXX ±.002 ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'	DESCRIPTION: Keyed Hub CHECKED BY: Dan Mathewson — DATE: 11/28/12 DRAWN BY: Steven Watts — DATE: 12/5/2012 FILE NAME: 02-05 Keyed hub.SLDPRT	**UNIVERSITY OF IDAHO ME DEPARTMENT** PART #: 02-05 — QTY: 3 SCALE: 1:1 — SHEET: 17 OF 39



PROPRIETARY AND CONFIDENTIAL

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Material <not specified>

BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ± .25	X. ± 2
X.X ± .1	X.X ± 1
X.XX ± .01	X.XX ± 0 30'
X.XXX ± .002	

DESCRIPTION: Passive Caster

CHECKED BY: Dan Mathewson DATE: 11/28/12

DRAWN BY: Travis Doerzaph DATE: 5/5/2013

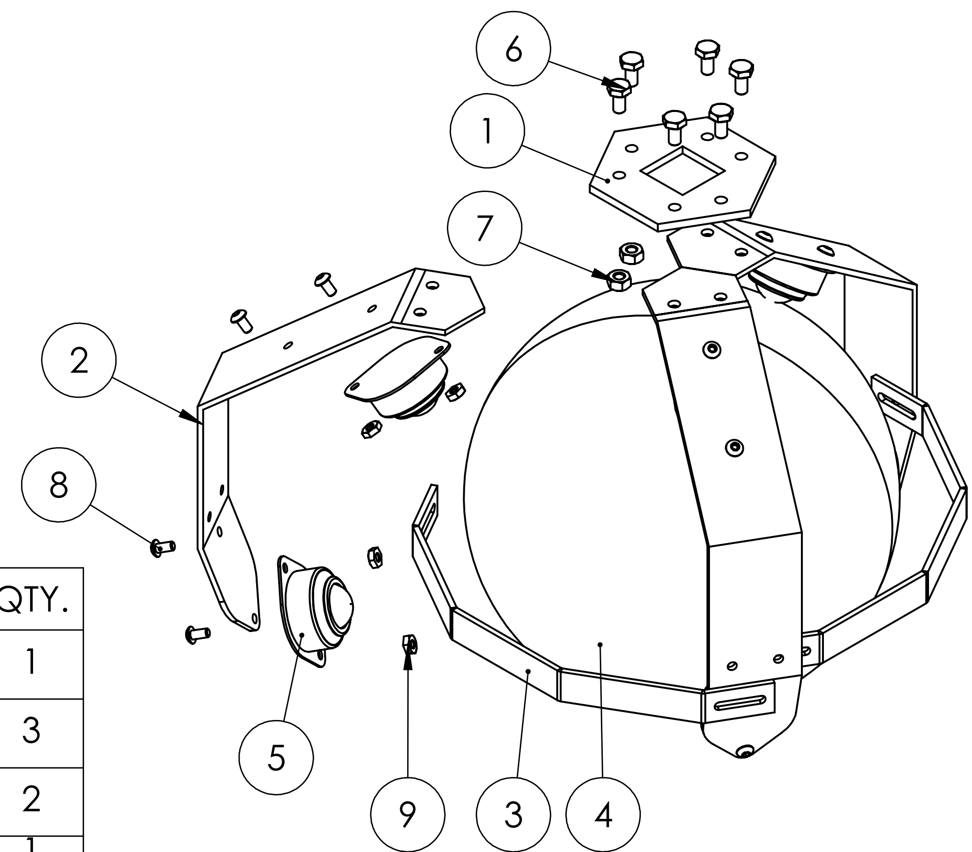
FILE NAME: passive caster.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 03-00 QTY: 2

SCALE: 1:2 SHEET: 18 OF 39

NOTE: BALL BEARING CASETER SUPPLIER WAS BIGHORN PURCHASED FROM AMAZON



ITEM NO.	PartNo	DESCRIPTION	QTY.
1	03-01	Top Support Plate	1
2	03-02	Down Support Arm	3
3	03-03	support hoop	2
4	Purchased	Basketball	1
5	Purchased	Ball Bearing Caster	6
6	Purchased	0.25-20X0.5 Bolt	6
7	Purchased	0.25-20 Nut	6
8	Purchased	10-28X0.375 Bolt	12
9	Purchased	10-28 Nut	12

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

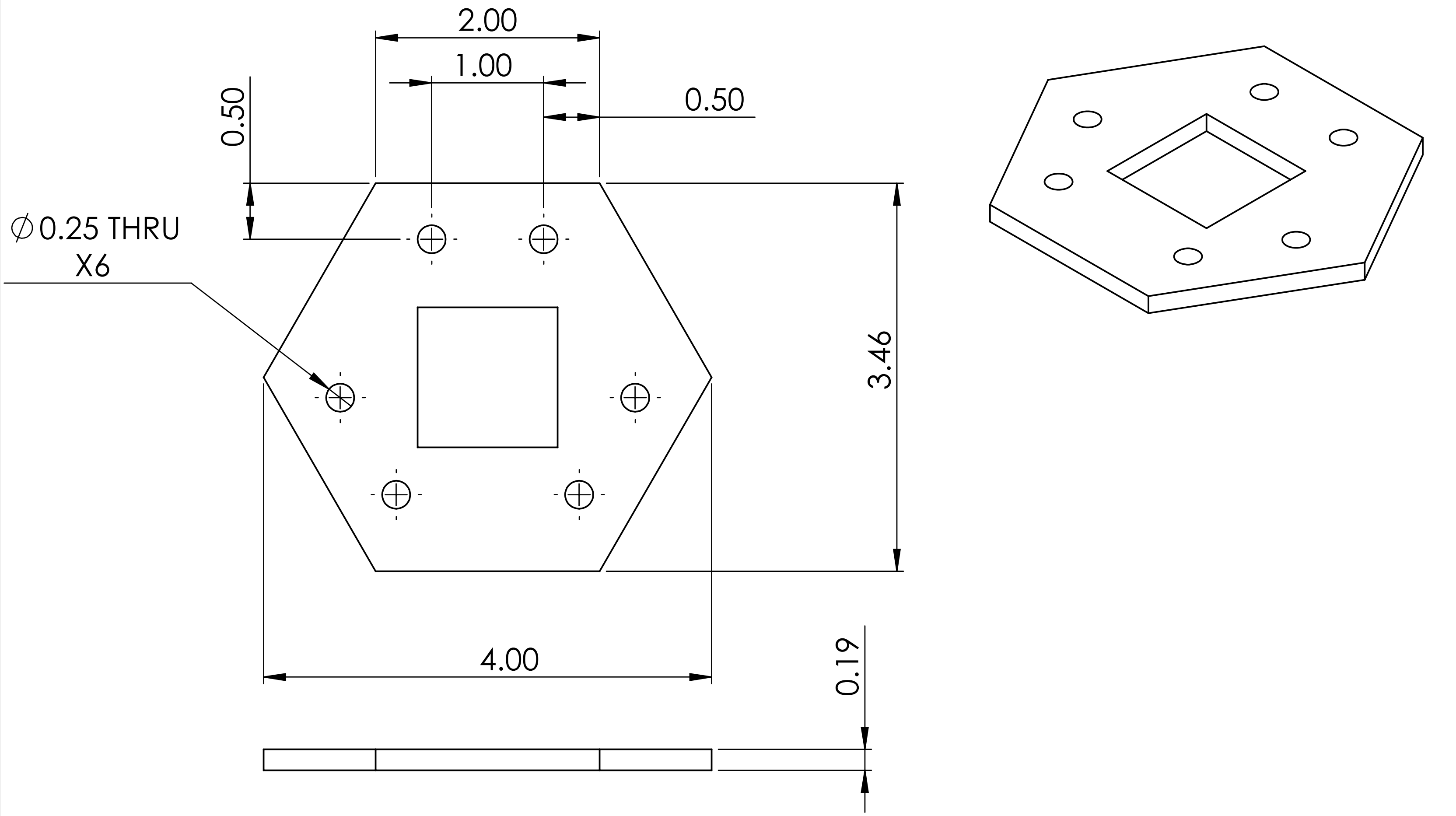
MATERIAL: Material <not specified>

BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:
LINEAR: X. ±.25, X.X ±.1, X.XX ±.01, X.XXX ±.002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: Passive Caster
CHECKED BY: Dan Mathewson DATE: 11/28/12
DRAWN BY: Travis Doerzaph DATE: 5/16/2013
FILE NAME: expolded View passive caster.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 03-00 QTY: 2
SCALE: 1:3 SHEET: 19 OF 39



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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061 Alloy

BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:

LINEAR:
X. ±.25
X.X ±.1
X.XX ±.01
X.XXX ±.002

ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0 30'

DESCRIPTION: Top Support Plate

CHECKED BY: Dan Mathewson DATE: 11/28/12

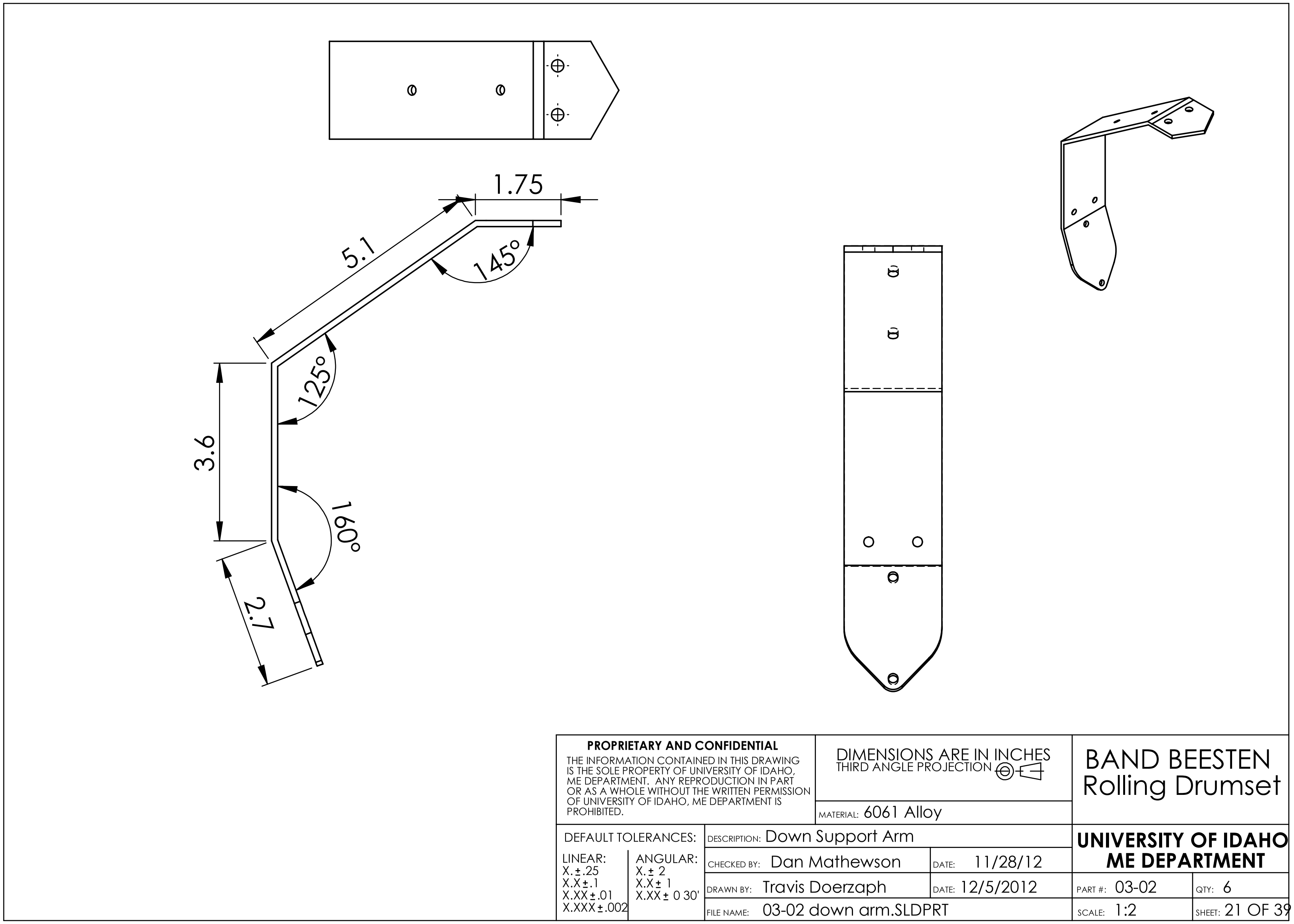
DRAWN BY: Travis Doerzaph DATE: 12/2/2012

FILE NAME: 03-01 top support.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 03-01 QTY: 2

SCALE: 1:1.5 SHEET: 20 OF 39


1.75
5.1
145°
125°
3.6
160°
2.7
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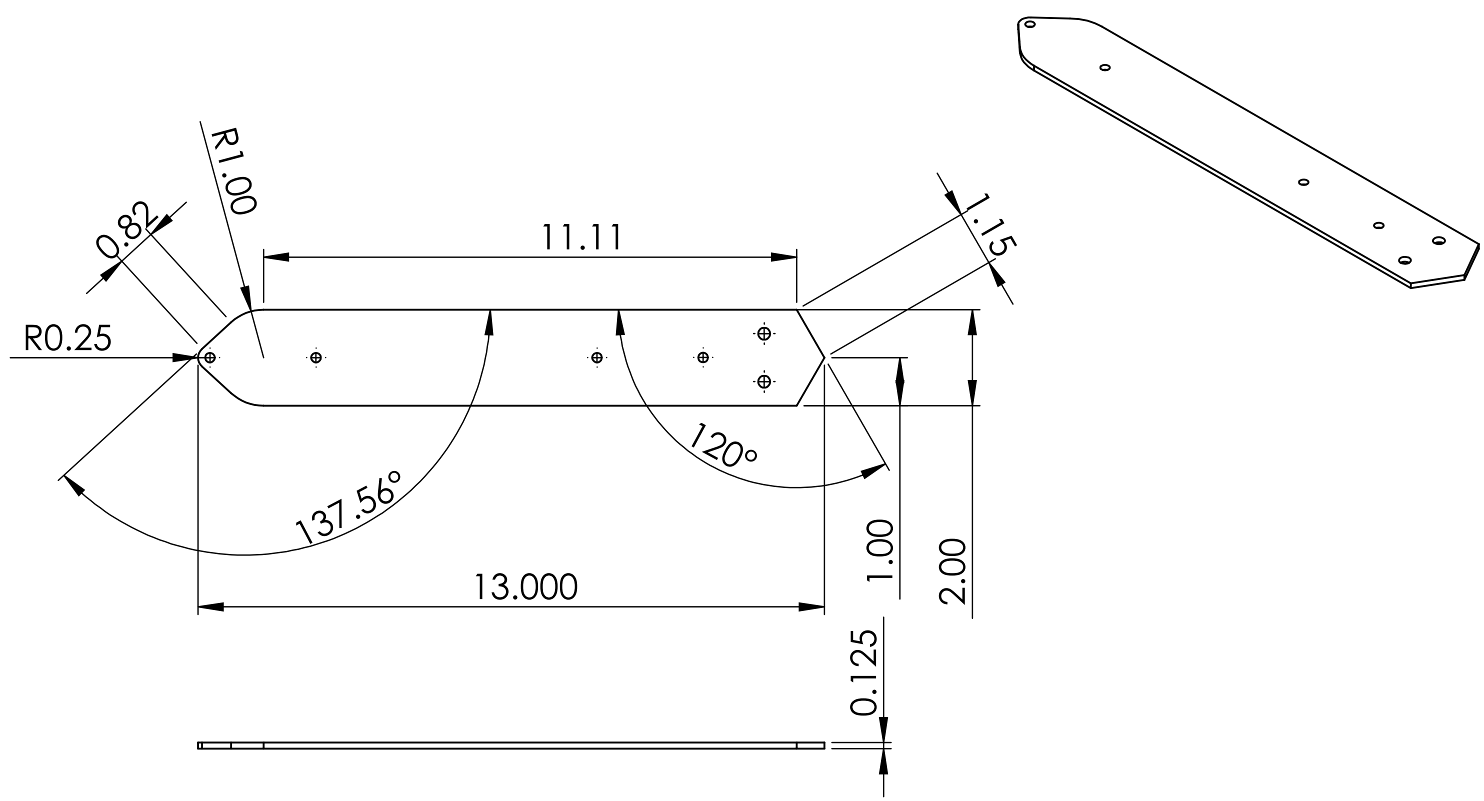
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6061 Alloy
BAND BEESTEN
Rolling Drumset
DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
DESCRIPTION: Down Support Arm
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Travis Doerzaph
DATE: 12/5/2012
FILE NAME: 03-02 down arm.SLDPRT
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 03-02
QTY: 6
SCALE: 1:2
SHEET: 21 OF 39



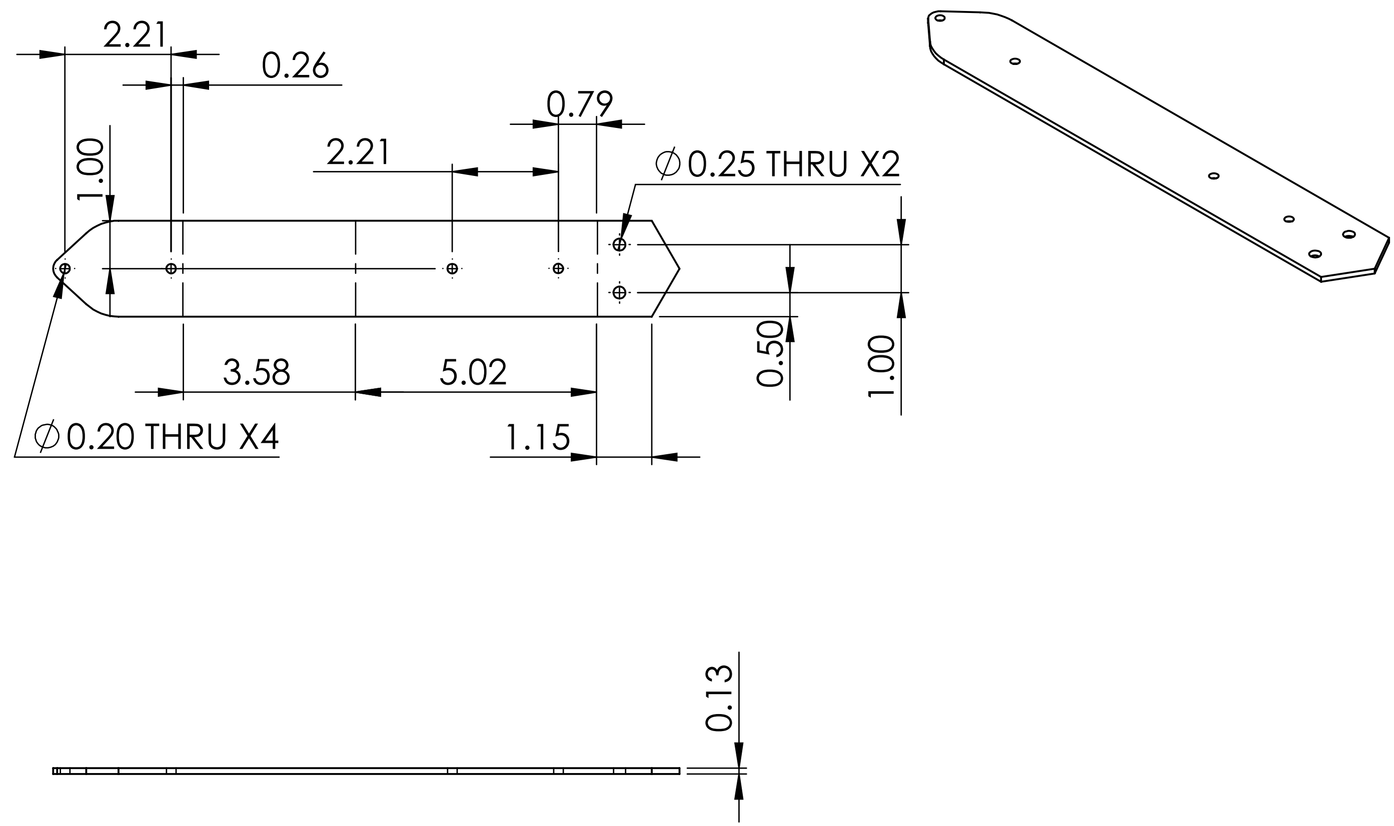
PROPRIETARY AND CONFIDENTIAL

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061 Alloy		BAND BEESTEN Rolling Drumset	
DESCRIPTION: Down Support Arm		UNIVERSITY OF IDAHO ME DEPARTMENT	
CHECKED BY: Dan Mathewson	DATE: 11/28/12		
DRAWN BY: Travis Doerzaph	DATE: 12/2/2012	PART #: 03-02	QTY: 6
FILE NAME: down arm sheet metal.SLDPRT		SCALE: 1:2	SHEET: 22 OF 39

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ± .25	X. ± 2
X.X ± .1	X.X ± 1
X.XX ± .01	X.XX ± 0 30'
X.XXX ± .002	



PROPRIETARY AND CONFIDENTIAL

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 6061 Alloy

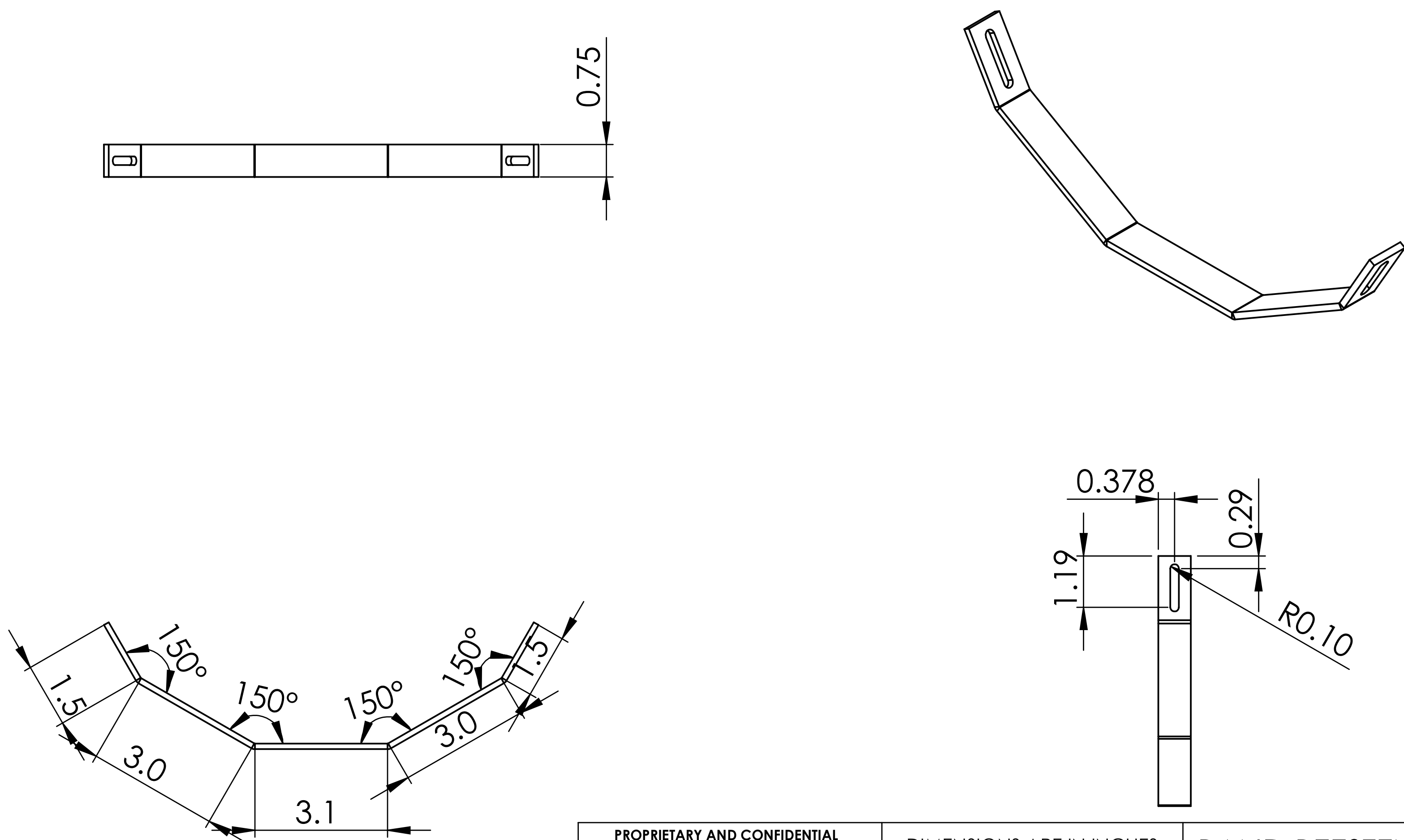
BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ±.25	X. ± 2
X.X ±.1	X.X ± 1
X.XX ±.01	X.XX ± 0 30'
X.XXX ±.002	

DESCRIPTION: Down Support Arm			
CHECKED BY: Dan Mathewson	DATE: 11/28/12		
DRAWN BY: Travis Doerzaph	DATE: 12/2/2012	PART #: 03-02	QTY: 6
FILE NAME: down arm sheet metal.SLDPRT		SCALE: 1:2	SHEET: 23 OF 39

UNIVERSITY OF IDAHO
ME DEPARTMENT



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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

BAND BEESTEN
Rolling Drumset

MATERIAL: 1060 Alloy

DEFAULT TOLERANCES:
LINEAR: X. ±.25, X.X ±.1, X.XX ±.01, X.XXX ±.002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

DESCRIPTION: support hoop

CHECKED BY: Dan Mathewson DATE: 11/28/12

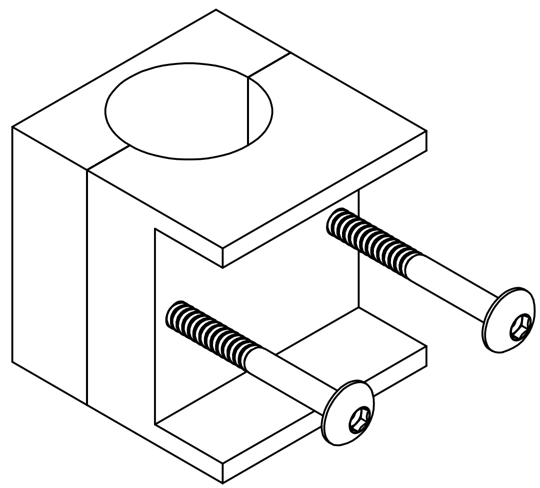
DRAWN BY: Travis Doerzaph DATE: 12/2/2012

FILE NAME: 02-03 Hoop.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 03-03 QTY: 3

SCALE: 1:2 SHEET: 24 OF 39



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DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Aluminum

BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ± .25	X. ± 2
X.X ± .1	X.X ± 1
X.XX ± .01	X.XX ± 0 30'
X.XXX ± .002	

DESCRIPTION: Drum connection bracket

CHECKED BY: Dan Mathewson DATE: 11/28/12

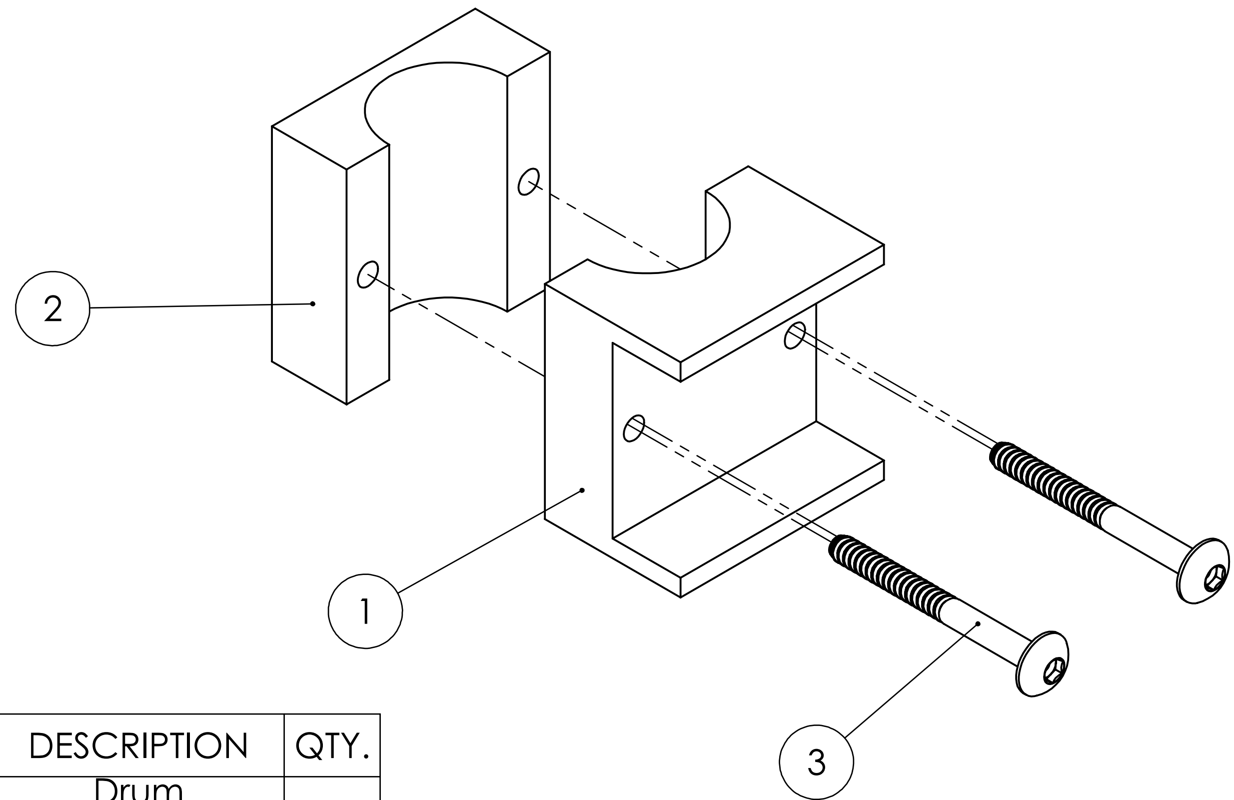
DRAWN BY: Chris Ohlinger DATE: 12/3/2012

FILE NAME: 04-00 Drum connection bracket assembly.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 04-00 QTY: 5

SCALE: SHEET: 25 OF 39



ITEM NO.	PartNo	DESCRIPTION	QTY.
1	04-01	Drum connection bracket (hoop side)	1
2	04-02	Drum connection bracket	1
3	Purchased	Socket Head Cap Screw #10-24 Partially Threaded	2

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: Aluminum

BAND BEESTEN
Rolling Drumset

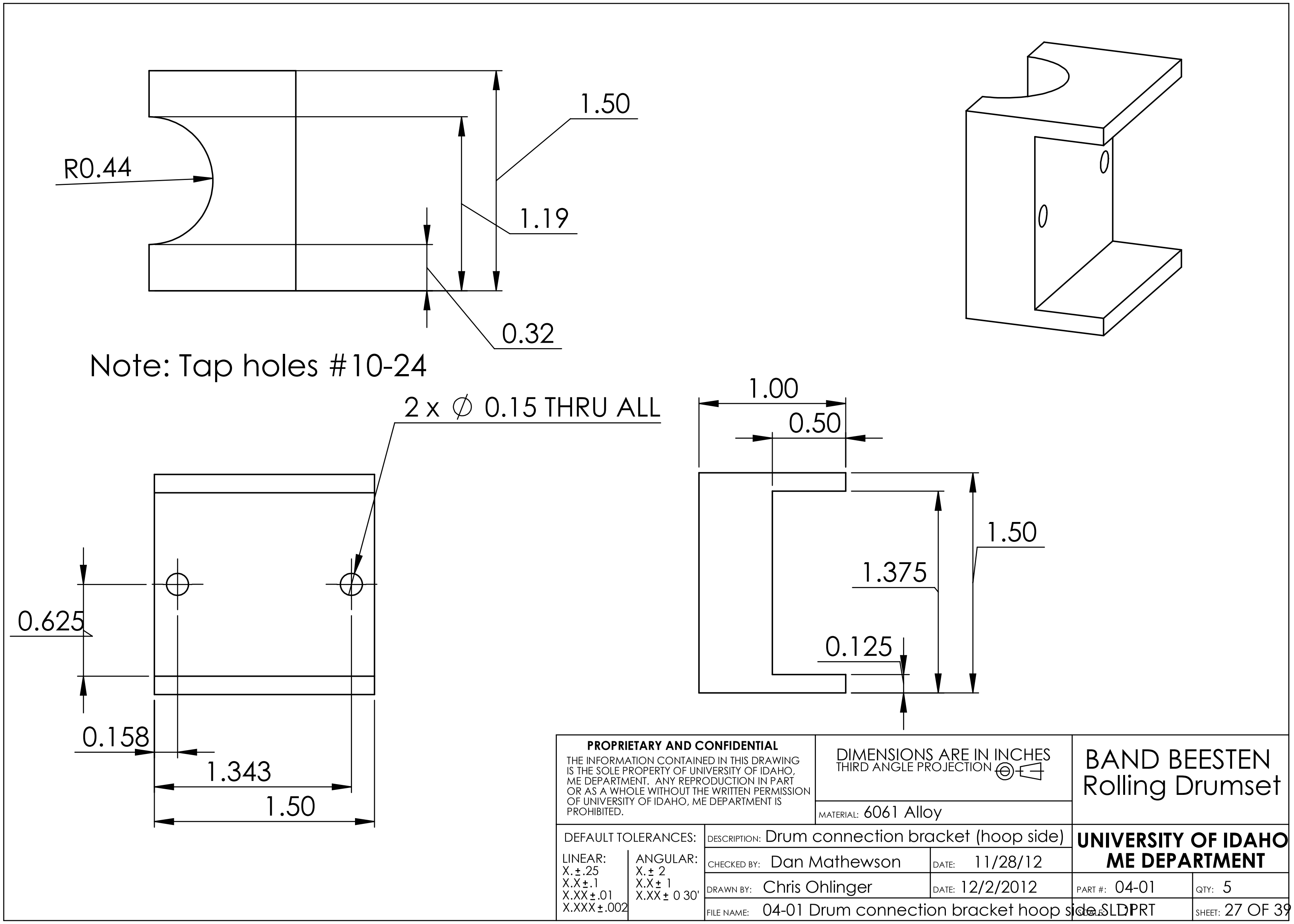
DEFAULT TOLERANCES:
LINEAR: X. ± .25, X.X ± .1, X.XX ± .01, X.XXX ± .002
ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'

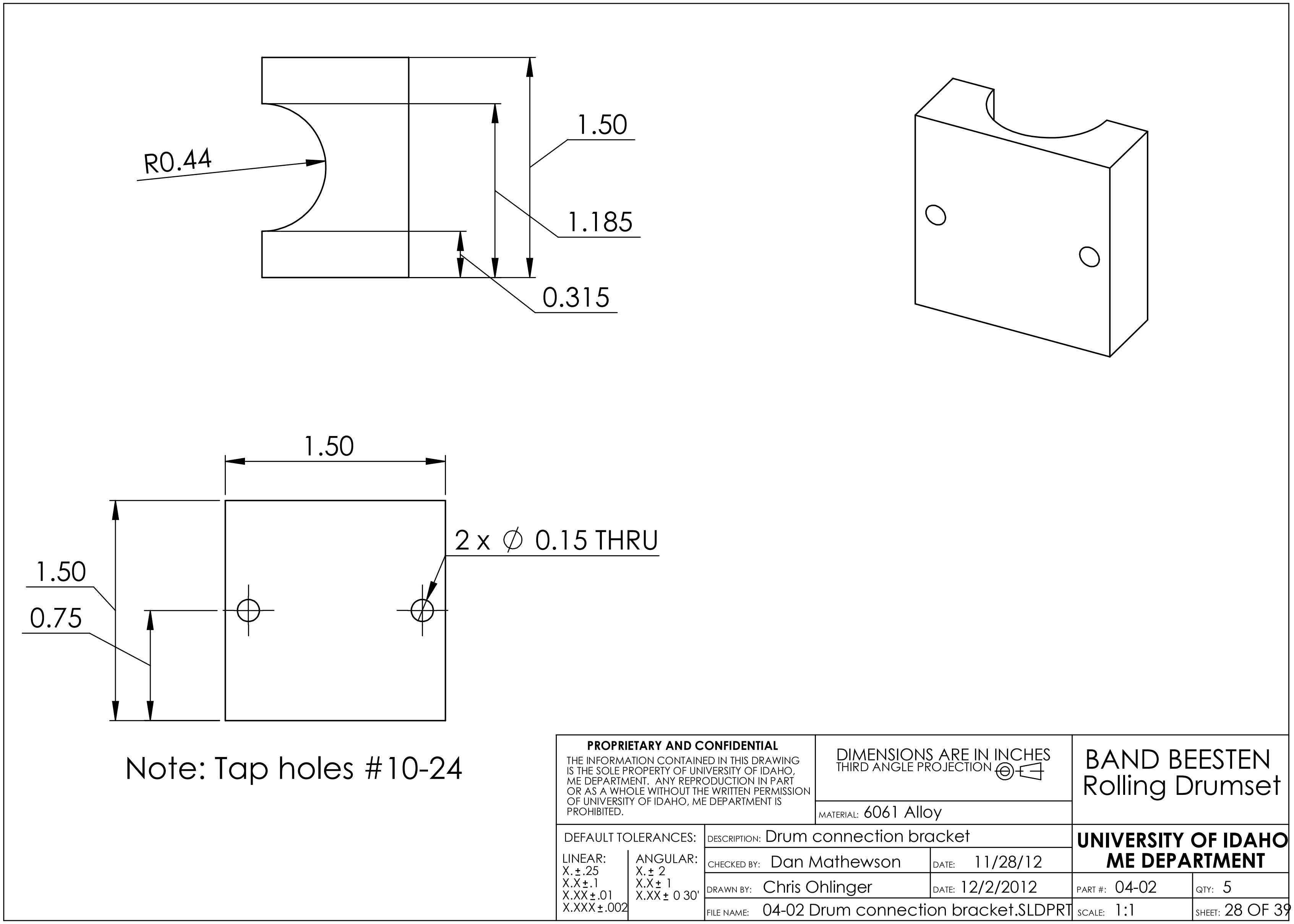
DESCRIPTION: Drum connection bracket
CHECKED BY: Dan Mathewson DATE: 11/28/12
DRAWN BY: Chris Ohlinger DATE: 12/2/2012
FILE NAME: 04-00 Drum connection bracket assembly - exploded.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 04-00 QTY: 5
SCALE: 1:1 SHEET: 26 OF 39

NOTE: BREAK ALL EDGES 0.002




R0.44
1.50
1.185
0.315
1.50
2 x ∅ 0.15 THRU
1.50
0.75
Note: Tap holes #10-24
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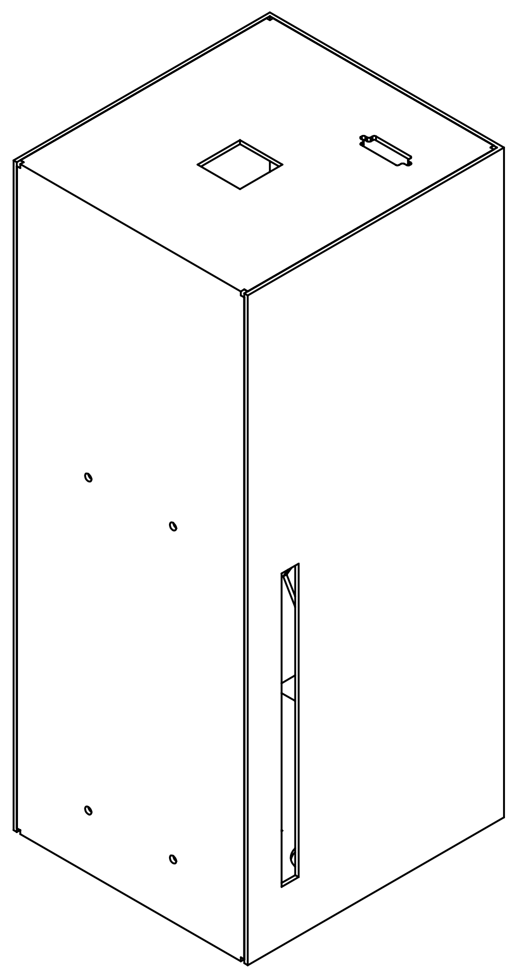
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6061 Alloy
BAND BEESTEN
Rolling Drumset
DEFAULT TOLERANCES:
LINEAR: X.±.25 X.X±.1 X.XX±.01 X.XXX±.002
ANGULAR: X.± 2 X.X± 1 X.XX± 0 30'
DESCRIPTION: Drum connection bracket
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Chris Ohlinger
DATE: 12/2/2012
FILE NAME: 04-02 Drum connection bracket.SLDPRT
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 04-02
QTY: 5
SCALE: 1:1
SHEET: 28 OF 39



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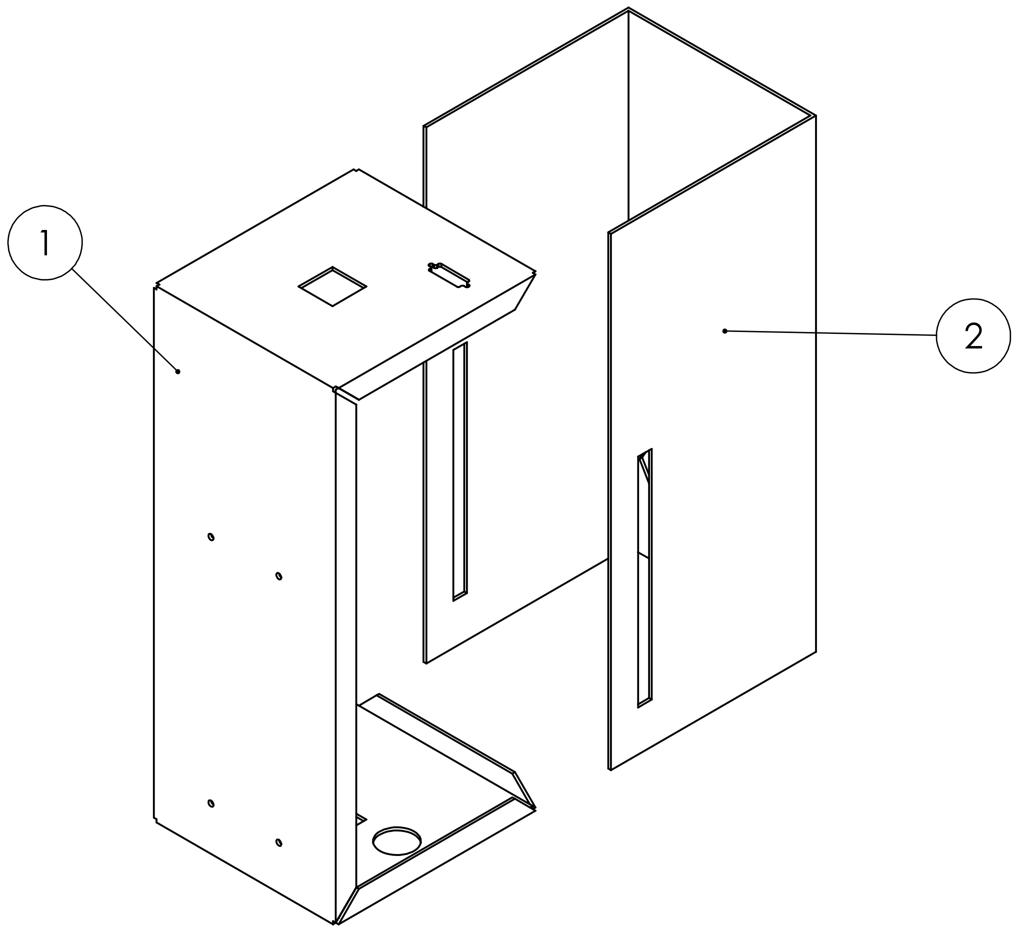
DEFAULT TOLERANCES: LINEAR: X. ±.25, X.X ±.1, X.XX ±.01, X.XXX ±.002 ANGULAR: X. ± 2, X.X ± 1, X.XX ± 0 30'	DESCRIPTION: Electronics cover CHECKED BY: Dan Mathewson — DATE: 11/28/12 DRAWN BY: Travis Dorzaph — DATE: 12/3/2012 FILE NAME: 05-00 electronics cover.SLDPRT	**UNIVERSITY OF IDAHO** **ME DEPARTMENT** PART #: 05-00 — QTY: 1 SCALE: 1:3 — SHEET: 29 OF 39



ITEM NO.	PartNo	DESCRIPTION	QTY.
1	05-01	Rear electronics cover	1
2	05-02	electronics cover	1

DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

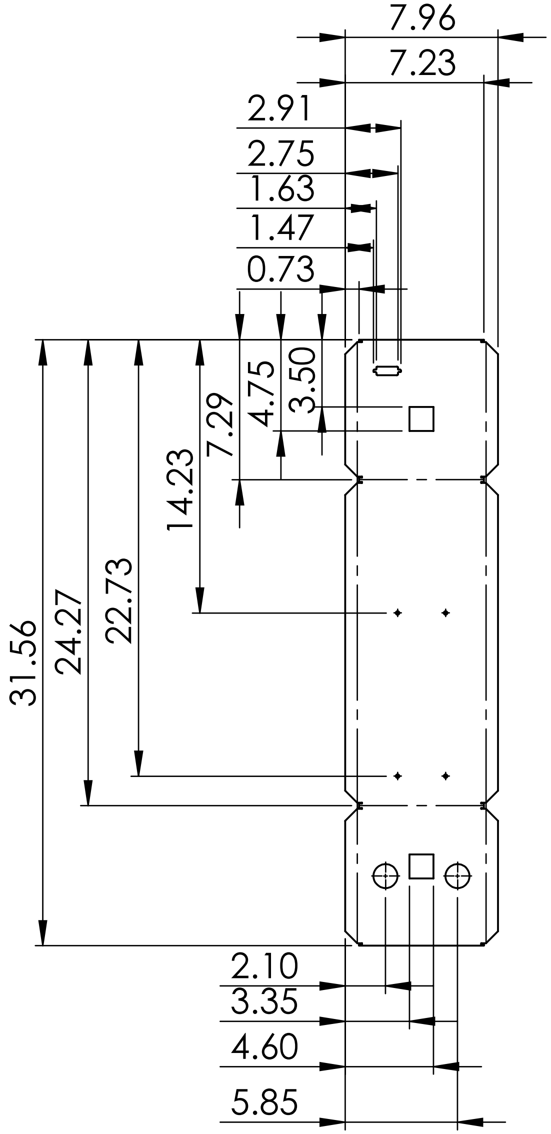
BAND BEESTEN
Rolling Drumset

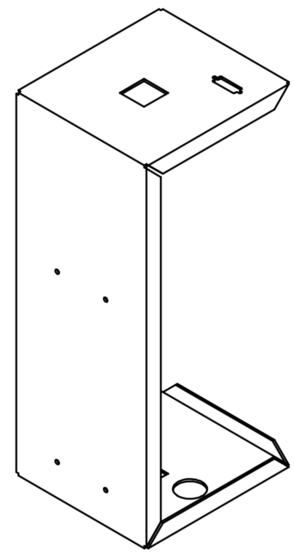
DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ± .25	X. ± 2
X.X ± .1	X.X ± 1
X.XX ± .01	X.XX ± 0 30'
X.XXX ± .002	

DESCRIPTION: Electronics Cover			
CHECKED BY: Dan Mathewson	DATE: 11/28/12		
DRAWN BY: Travis Doerzaph	DATE: 12/3/2012	PART #: 05-00	QTY: 1
FILE NAME: 05-00 electronics cover -exploded.SLDPRT		SCALE: 1:4	SHEET: 30 OF 39

UNIVERSITY OF IDAHO
ME DEPARTMENT





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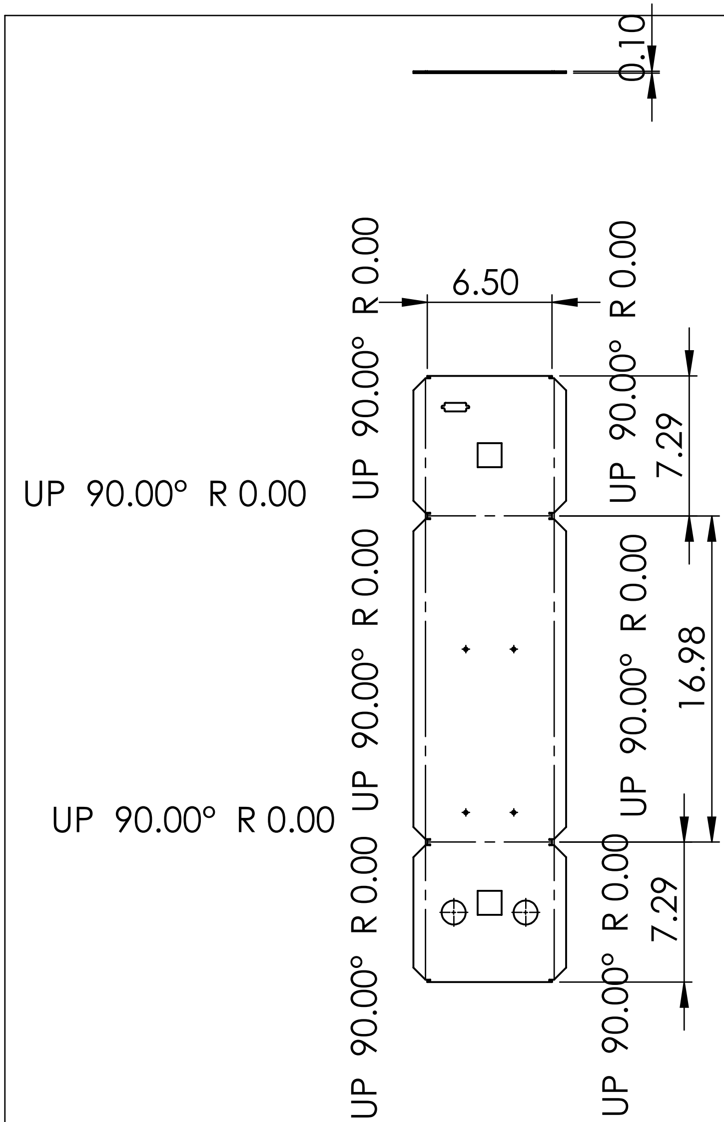
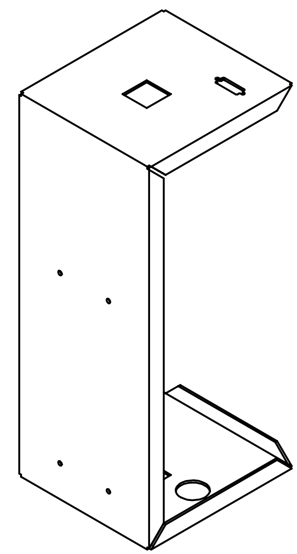
DEFAULT TOLERANCES:	DESCRIPTION: rear section of electronics box	**UNIVERSITY OF IDAHO ME DEPARTMENT**
LINEAR: X. ±.25 X.X±.1 X.XX±.01 X.XXX±.002 — ANGULAR: X. ± 2 X.X± 1 X.XX ± 0 30'	CHECKED BY: Dan Mathewson — DATE: 11/28/12	
	DRAWN BY: Travis Doerzaph — DATE: 12/3/2012	PART #: 05-01 — QTY: 1
	FILE NAME: rear case sheet metal.SLDPRT	SCALE: 1:6 — SHEET: 31 OF 39





DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL: 1060 Alloy

BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:

LINEAR:	ANGULAR:
X. ±.25	X. ± 2
X.X±.1	X.X± 1
X.XX±.01	X.XX ± 0 30'
X.XXX±.002	

DESCRIPTION: rear section of electronics box

CHECKED BY: Dan Mathewson — DATE: 11/28/12

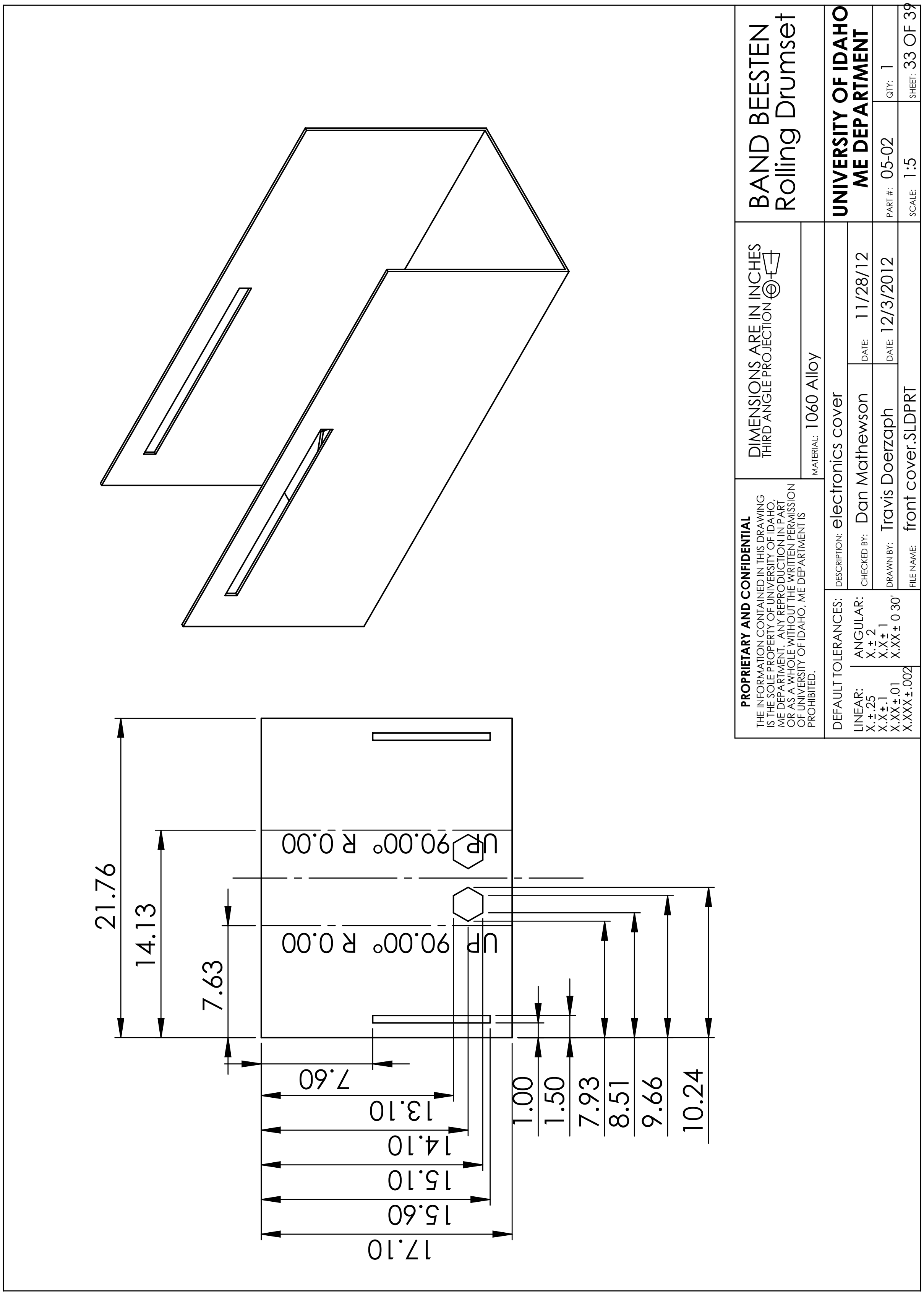
DRAWN BY: Travis Doerzaph — DATE: 12/3/2012

FILE NAME: rear case sheet metal.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 05-01 — QTY: 1

SCALE: 1:6 — SHEET: 32 OF 39


BAND BEESTEN
Rolling Drumset
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 05-02
QTY: 1
SCALE: 1:5
SHEET: 33 OF 39
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 1060 Alloy
DESCRIPTION: electronics cover
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Travis Doerzaph
DATE: 12/3/2012
FILE NAME: front cover.SLDPRT
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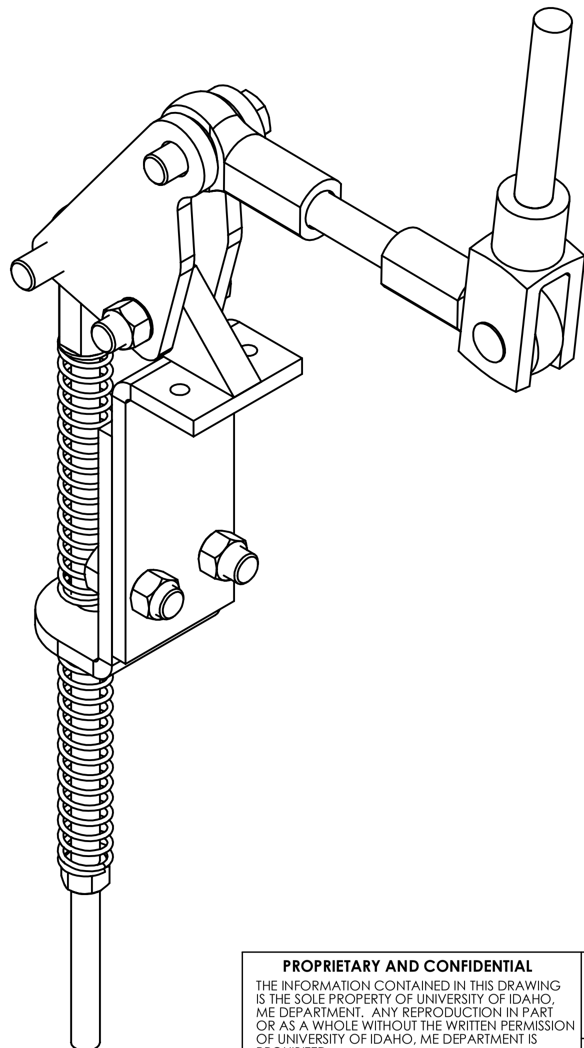
DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
21.76
14.13
7.63
UP 90.00° R 0.00
UP 90.00° R 0.00
7.60
13.10
14.10
15.10
15.60
17.10
1.00
1.50
7.93
8.51
9.66
10.24



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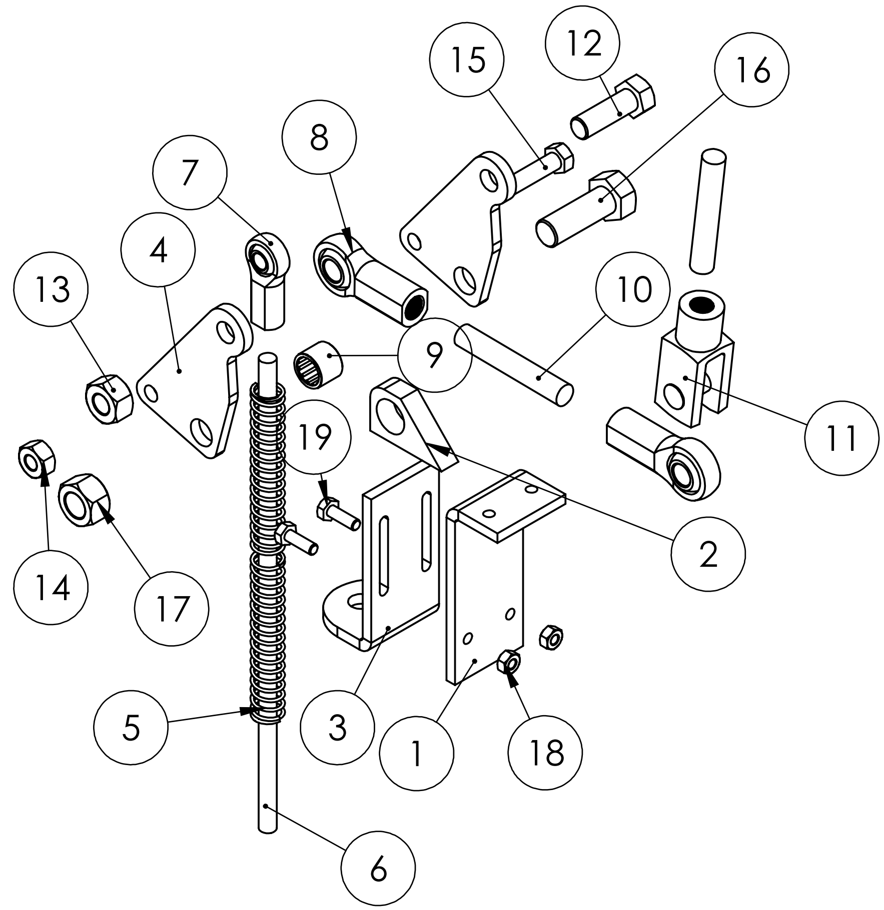
DEFAULT TOLERANCES:	DESCRIPTION: Input System		**UNIVERSITY OF IDAHO ME DEPARTMENT**
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002 / ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'	CHECKED BY: Dan Mathewson	DATE: 11/28/12	
	DRAWN BY: Travis Doerzaph	DATE: 5/17/2013	PART #: 06-00 / QTY: 2
	FILE NAME: 06-00 input system2.SLDPRT		SCALE: 1:2 / SHEET: 34 OF 39

ITEM NO.	PartNo	DESCRIPTION	QTY.
1	06-01	Top Base Support	1
2	06-02	Top Support Triangle	1
3	06-03	Lower L Bracket	1
4	06-04	Top Rotating Arm	2
5	Purchased	0.625 Diameter Spring	2
6	Purchased	0.375-24 All Thread	1
7	Purchased	0.375-24 Ball Rod End	1
8	Purchased	0.5-20 Ball Rod End	2
9	Purchased	0.625 Roller Bearing	1
10	Purchased	0.5-20 ALL THREAD	2
11	Purchased	0.5-20 HEIM CONECTION	1
12		.375 Bolt	1
13		.5Nut	1
14		.375 Nut	1
15		.5 Bolt	1
16		.375 Bolt	1
17		.5 Nut	1
18		#10 Nut	2
19		#10 Bolt	2



DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION

MATERIAL:

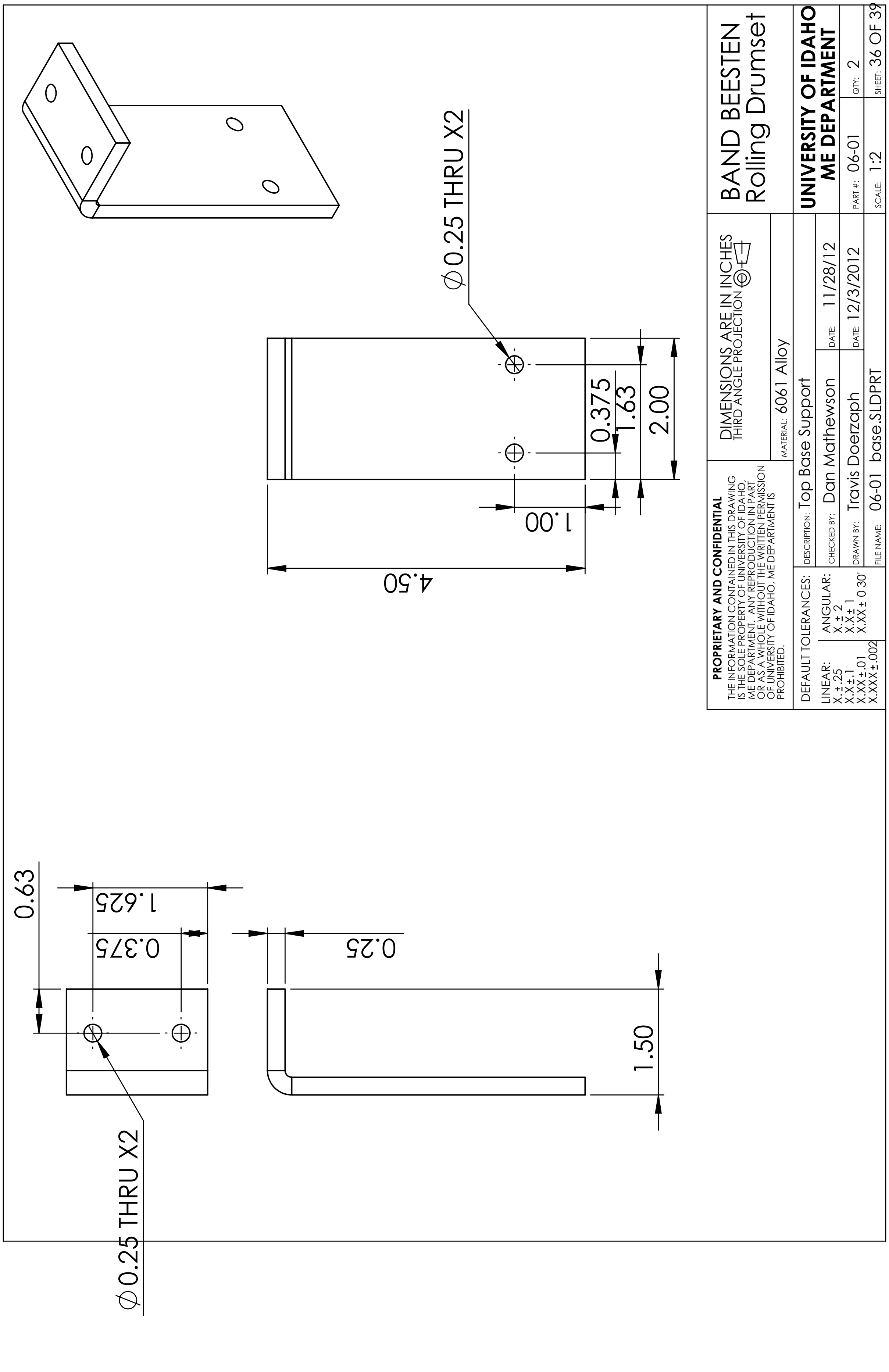
BAND BEESTEN
Rolling Drumset

DEFAULT TOLERANCES:
LINEAR: X.±.25 X.X±.1 X.XX±.01 X.XXX±.002
ANGULAR: X.± 2 X.X± 1 X.XX± 0 30'

DESCRIPTION: Input System
CHECKED BY: Dan Mathewson DATE: 11/28/12
DRAWN BY: Travis Doerzaph DATE: 5/17/2013
FILE NAME: 06-00 input system2 - exploded.SLDPRT

UNIVERSITY OF IDAHO
ME DEPARTMENT

PART #: 06-00 QTY: 2
SCALE: 1:3 SHEET: 35 OF 39


Ø0.25 THRU X2
0.375
1.63
2.00
1.00
4.50
0.63
1.625
0.375
0.25
1.50
Ø0.25 THRU X2
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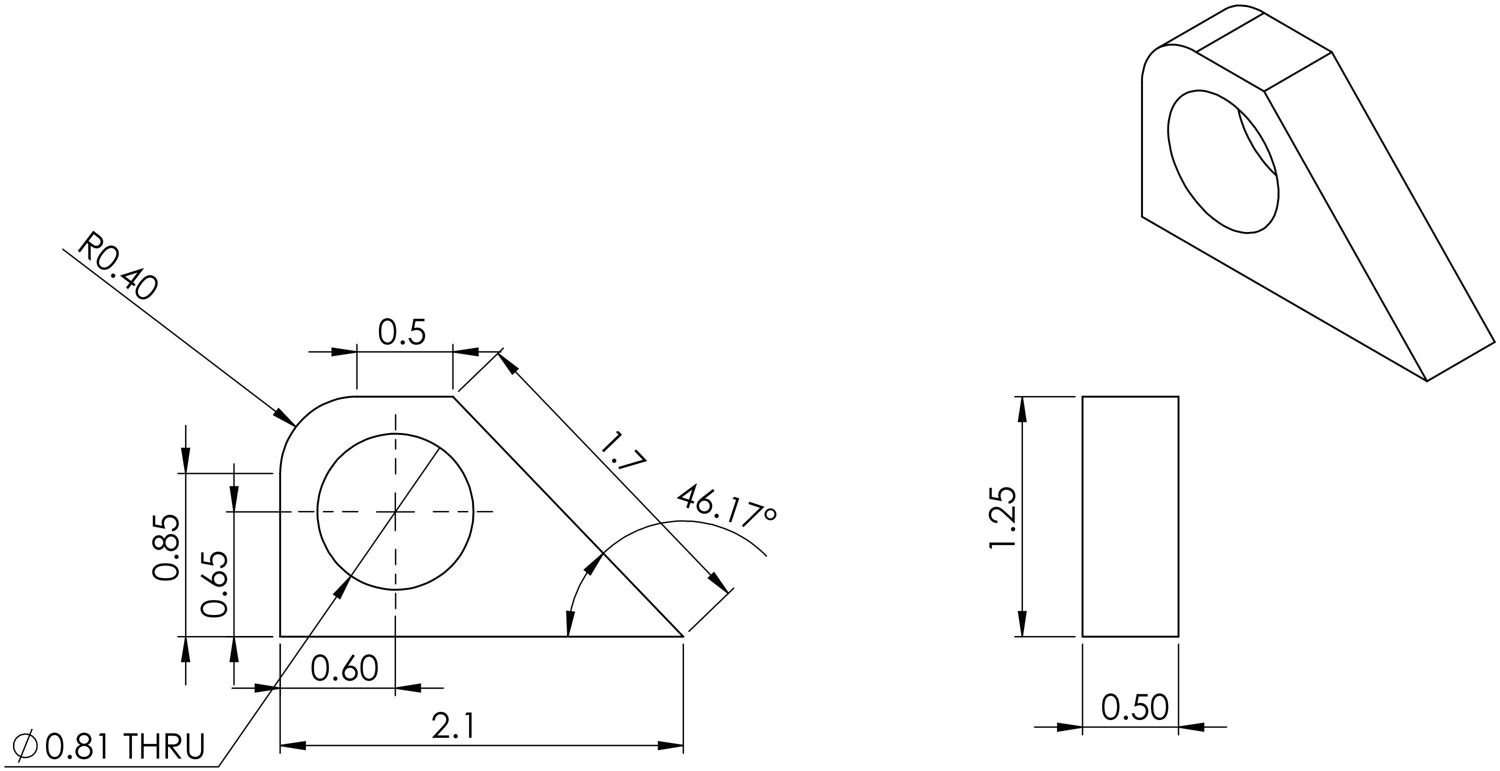
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6061 Alloy
BAND BEESTEN
Rolling Drumset
DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
DESCRIPTION: Top Base Support
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Travis Doerzaph
DATE: 12/3/2012
FILE NAME: 06-01 base.SLDPRT
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 06-01
QTY: 2
SCALE: 1:2
SHEET: 36 OF 39



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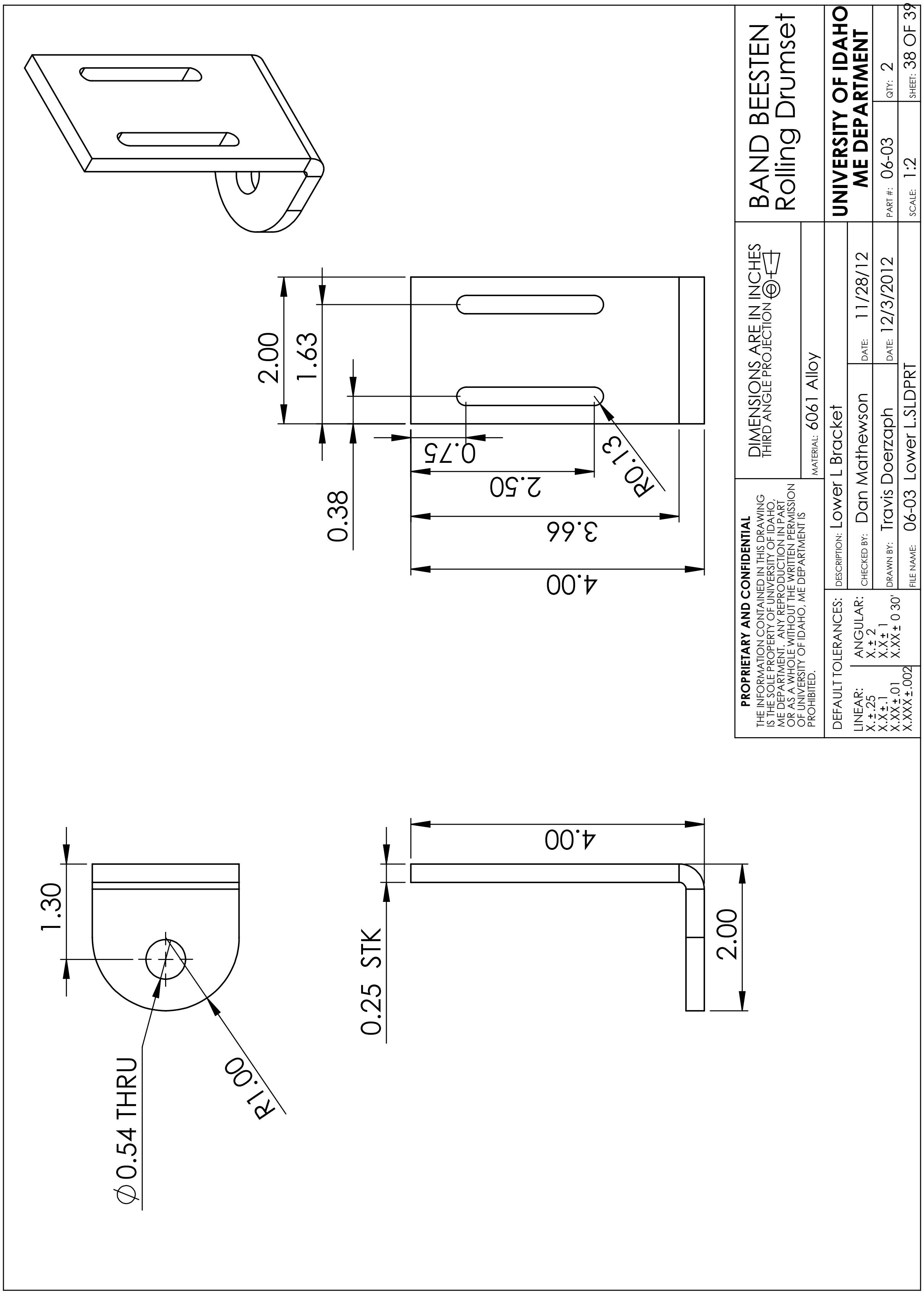
DEFAULT TOLERANCES: LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002 ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'	DESCRIPTION: Top Support Triangle CHECKED BY: Dan Mathewson — DATE: 11/28/12 DRAWN BY: Travis Doerzaph — DATE: 12/3/2012 FILE NAME: 06-02 Top support input.SLDPRT	**UNIVERSITY OF IDAHO ME DEPARTMENT** PART #: 06-02 — QTY: 2 SCALE: 1:1 — SHEET: 37 OF 39


BAND BEESTEN
Rolling Drumset
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 06-03
QTY: 2
SCALE: 1:2
SHEET: 38 OF 39
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6061 Alloy
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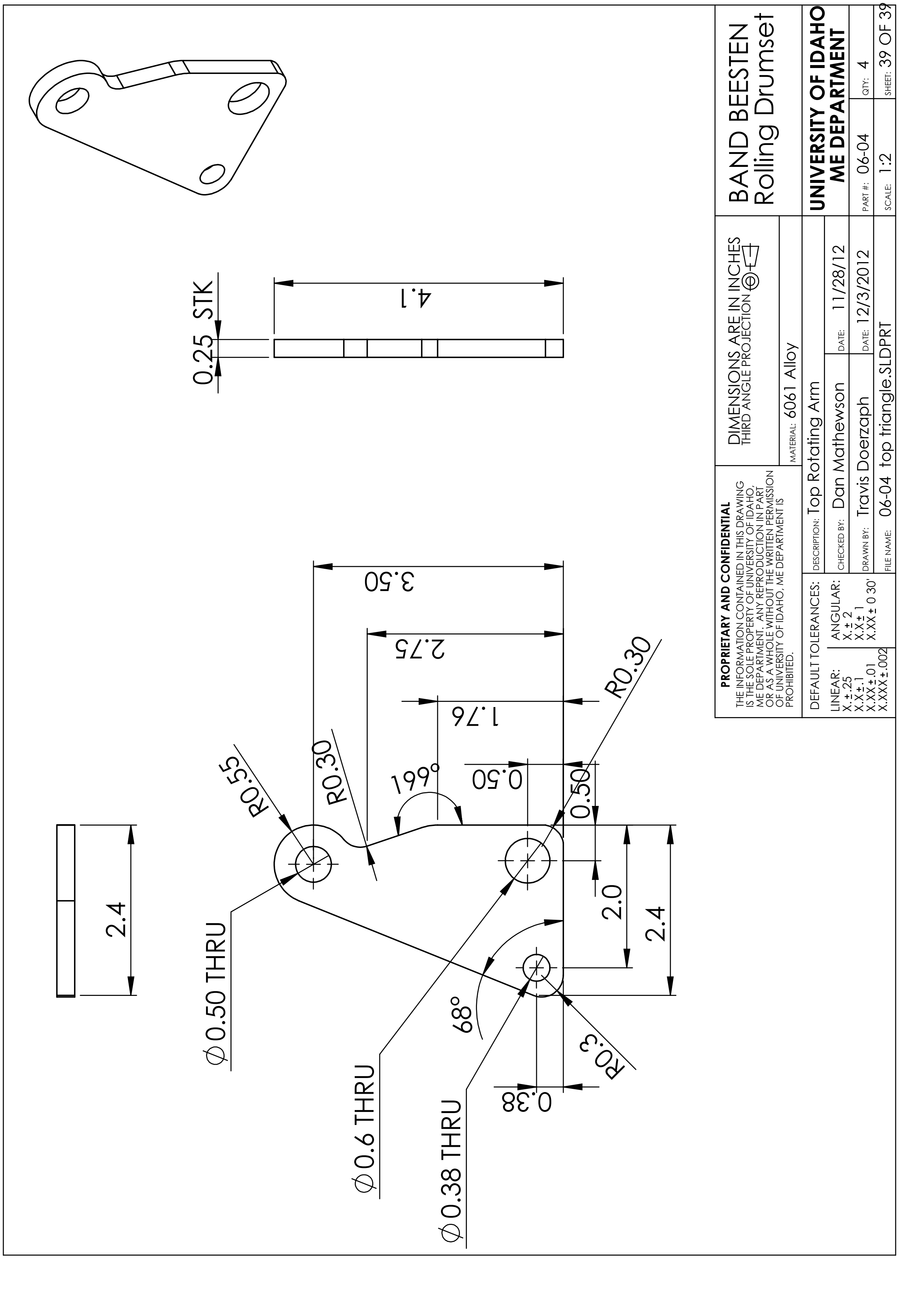
DEFAULT TOLERANCES:
LINEAR:
X. ± .25
X.X ± .1
X.XX ± .01
X.XXX ± .002
ANGULAR:
X. ± 2
X.X ± 1
X.XX ± 0 30'
DESCRIPTION: Lower L Bracket
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Travis Doerzaph
DATE: 12/3/2012
FILE NAME: 06-03 Lower L.SLDPRT
2.00
1.63
0.38
0.75
2.50
R0.13
3.66
4.00
1.30
⌀0.54 THRU
R1.00
0.25 STK
4.00
2.00



BAND BEESTEN
Rolling Drumset
UNIVERSITY OF IDAHO
ME DEPARTMENT
PART #: 06-04
QTY: 4
SCALE: 1:2
SHEET: 39 OF 39
DIMENSIONS ARE IN INCHES
THIRD ANGLE PROJECTION
MATERIAL: 6061 Alloy
DESCRIPTION: Top Rotating Arm
CHECKED BY: Dan Mathewson
DATE: 11/28/12
DRAWN BY: Travis Doerzaph
DATE: 12/3/2012
FILE NAME: 06-04 top triangle.SLDPRT
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DEFAULT TOLERANCES:
LINEAR: X. ±.25 X.X ±.1 X.XX ±.01 X.XXX ±.002
ANGULAR: X. ± 2 X.X ± 1 X.XX ± 0 30'
0.25 STK
4.1
3.50
2.75
1.76
R0.30
R0.55
R0.30
199°
0.50
0.50
2.0
2.4
2.4
68°
R0.3
0.38
⌀0.50 THRU
⌀0.6 THRU
⌀0.38 THRU