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AkaBot 2.0: pet 3D printing filament from waste plastic

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ENTITLED

AKABOT 2.0: PET 3D PRINTING FILAMENT FROM WASTE PLASTIC

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AKABOT 2.0: PET 3D PRINTING FILAMENT FROM WASTE PLASTIC

By

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SENIOR DESIGN PROJECT REPORT

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Abstract

Extrusion is how 3D printing filament is created. Melted plastic is pushed through an extrusion die and is shaped into a long thin strand of plastic. Extrusion machines are usually sized for industrial use, capable of creating hundreds of feet of filament a day. This filament is expensive to purchase, and many end-users would prefer to extrude their own filament, from a virgin plastic input or plastic waste input. There are no home-scale filament extruders on the market for Polyethylene Terephthalate (PET) plastic waste. AkaBot was designed to allow end users to produce their own filament from a PET plastic input. AkaBot was designed and manufactured to created filament that has the required ductility for spooling and use in a 3D printer. It functioned well with PET pellets as the plastic input, but it was not as successful when trying to use recycled water bottles. The final filament product is dependent on the tension put on the filament as it exits the machine. At present, a skilled human operator is required to consistently produce acceptable filament. An automated spooling system for the filament would greatly improve the consistency of the output and decrease the cost of using AkaBot.

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Chapter 1: Introduction

1.1 Background

Lack of access to education and training puts workers in developing countries at a disadvantage when they build a business. Their enterprises struggle to compete with cheaper foreign goods and services. We have partnered with Anudip, a non-profit organization in India that provides job training to disadvantaged people, especially women, in rural areas. Anudip provides resources and training to level the playing field. Anudip has set up offices and training centers, seen in Figure 1, in India to teach vocational skills and train workers looking to jumpstart their careers. They focus on supporting small enterprises in rural villages. Anudip has already mentored over 200 different groups, and they continue to expand their operations. They operate over 150 training centers across Eastern India.

Figure 1: Anudip training facility. Photo courtesy of Anudip [1]

3D printing technology gives entrepreneaurs access to advanced manufacturing techniques at a fraction of the previous cost. The technology is scaled down, from factory to garage. Companies who previously lacked resources to make their ideas come to life now have the opportunity to try new avenues. Importing expensive filaments is the sole barrier to entry.

Used plastic water bottles are a constant problem in developing countries. The plastic waste litters the streets, or ends up in landfills, as seen in Figure 2.

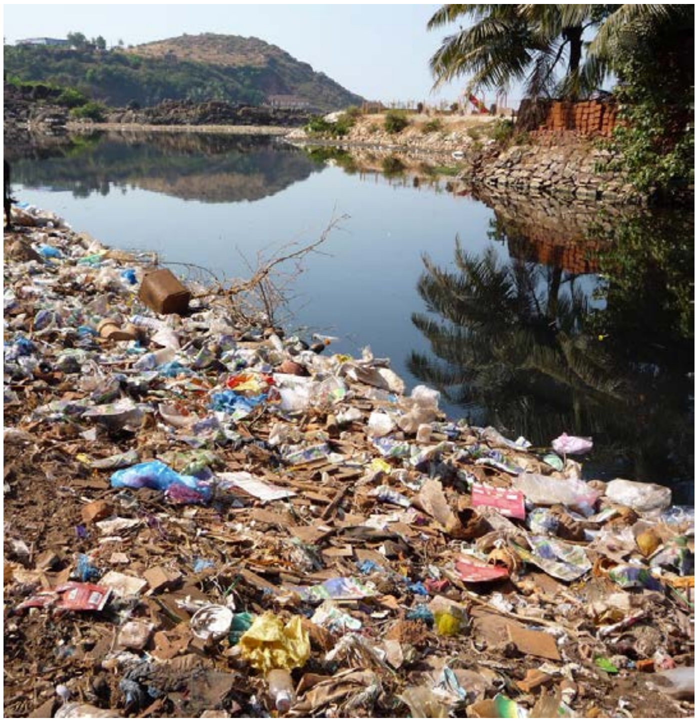


Figure 2: Plastic waste buildup in India. Photo courtesy of Anudip [1]

Utilizing this waste to make 3D printing filament solves two problems at once. It gives entrepreneurs a cheap resource, and removes a damaging element from the environment. A common pitfall that developing countries face is the expensive nature of “green industries.” 3D printing gives them a cheap option without the cost barriers associated with other green technologies.

AkaBot is different from other filament production machines on the market. Commercially available machines at this scale require virgin pellets of acrylonitrile butadiene styrene (ABS) or polylactic acid (PLA) plastic. They do not work with recycled or virgin polyethylene terephthalate (PET). Recycled plastic is cheaper and more accessible than factory produced pellets. AkaBot allows workers to create their own filaments at a much lower cost than what is currently available on the market. Anudip has supported this project from the inception, and AkaBot’s design will be vetted in their training facilities. Plastic waste is a common problem in developing countries, and AkaBot could be used by social enterprise partners across the developing world.

Small business development is the key to improving the lives of people in developing countries. 3D printing is a versatile process that simplifies existing manufacturing methods. Its simplicity allows for developing countries to grow their own manufacturing base, instead of relying on foreign countries. They can create local sustainable businesses to increase prosperity. 3D printing is the key that unlocks opportunities for workers and entrepreneurs in developing countries. AkaBot moves one step closer to that goal by giving them new options at a low cost.

1.2 Review of Field

1.2.1 Plastic Extrusion Process

The 3D printing process came from the need to quickly manufacture prototypes. While today the growing field is becoming more and more complex to include stereolithography and metals, 3D printing originally began with the use of extruding plastics to print small simple designs. Even in this fast growing field, small scale hobbyist 3D printers are still using extruded plastic filament in a fused deposition modeling (FDM) process. This process takes the filament input, a thick thread of plastic typically 1.75 mm or 3 mm in diameter, and melts it to produce a liquid plastic that is then pushed out of the tip of the printer nozzle. 3D designs are created on a computer and converted into the desired file format for the printer program and then sent to the printer. The printer program takes the model and converts the 3D model into small slices that can be printed at a consistent thickness. As the printer nozzle moves across the base of the printer, it deposits a thin layer of plastic that cools quickly and hardens. The printer then returns the nozzle back over the hardened plastic to add another layer to the print. As the plastic layers harden on top of one another, they fuse together. This slowly builds up to create the desired 3D part. [2]

The filament used in these FDM machines is critical for the functionality of the printer. Manufacturing of 3D printing filament is done through extrusion. This extrusion process is done by inputting plastic to a hopper, which then feeds it to a chamber. This chamber is heated, melting plastic in a barrel and slowly pushing it out using a rotating screw. This screw slowly builds up pressure forcing the melted plastic out the end through a small hole, or die, at the opposite end of the machine. [3]

There are many nuances and key components when designing a filament extruder, one of which is the die. The design of a die is extremely important to an extruding system. The shape of the die determines the characteristics of the final filament. It is hard to predict the exact behavior of the material, and this is where a series of equations can make a rough prediction. In order to get a better understanding of the design, computer modeling must be used to analyze the fluid dynamics of the flow through the die. [4]

Another critical design parameter of an extrusion device is the clearance between the auger and the barrel. The tolerance between these parts for most designs is less than 0.001in (0.0025 cm). These clearances are important, but are difficult to calculate. This clearance needs to be maintained over the entire length of the auger, which requires precise alignment. If a system is not accurately aligned and the proper tolerances are not maintained, then the wear on the motor and the auger will be great, reducing the lifespan of the product. 3D printing filament needs to meet a specific tolerance in order to be utilized by a printer. [5]

This can be controlled easily in a large-scale factory system, but specific measures need to be taken to improve precision in small scale, household production. Improving precision and achieving a consistent output is critical to having a good finished product. This study focuses on the variety of tools available for PET extrusion, and the relative precision of each product. Based on the final precision desired, different types of tools are needed. High precision jobs need more precise and expensive equipment such as 6- axis CNC machines. [5]

1.2.2 Differential Scanning Calorimetry

Differential scanning calorimetry (DSC) tests are a very useful tool when analyzing material properties. The test uses small samples with a weight of 10-15 mg and heats and cools them to determine different material properties. The heating profile can be changed based on the desired test, as can the cooling rate. The test inputs a constant heating profile and records the amount of heat flow at the progressing temperatures. This results in a graph such as the one shown in Figure 3.

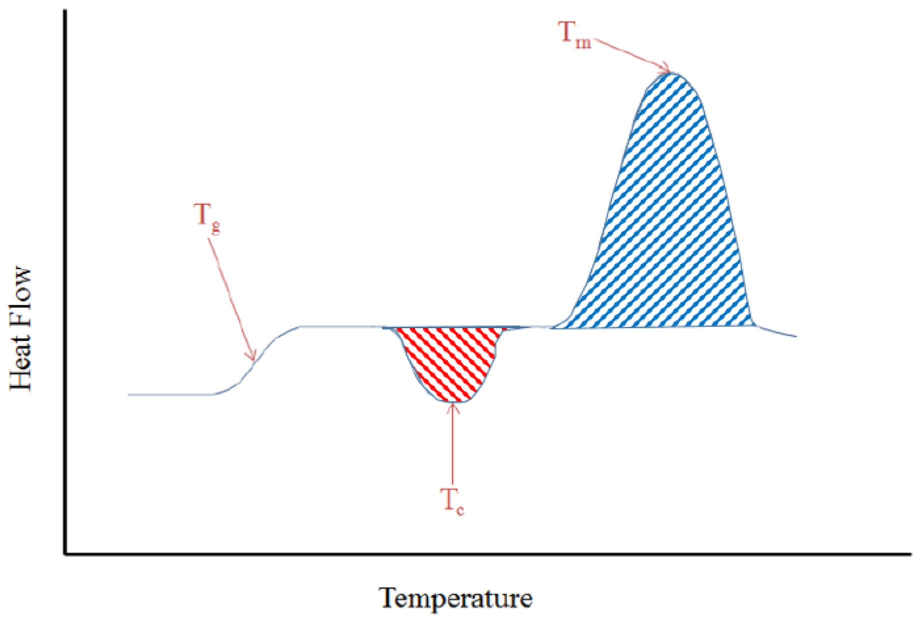


Figure 3: Example of a DSC test result graph

In this graph, T_g is the glass transition temperature, T_c is the cold crystallization temperature, and T_m is the melting temperature. The glass transition temperature indicates when the material transitions from elastic to brittle. The cold crystallization temperature indicates when the crystals in the material are aligning. The melting temperature is the temperature at which the material is completely melted. Using the area under these curves as denoted by the red and blue in the graph, the percent crystallinity can be determined. Both H_m and H_c are divided by the heat of melting of a 100% crystalline material to determine crystallinity. This is an important factor because it determines the ductility of the material being tested. Materials such as PET are considered semicrystalline materials, meaning they have both amorphous and crystalline regions. Figure 4 below shows a semicrystalline structure.

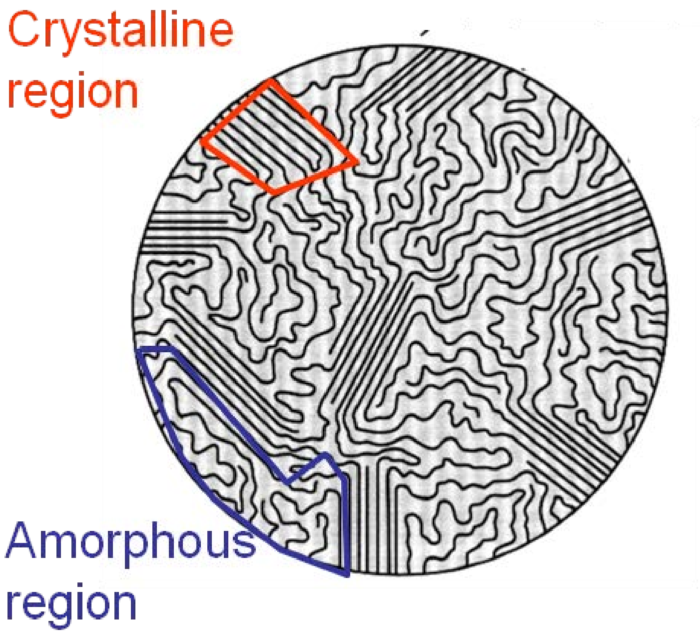


Figure 4: Semicrystalline polymer structure. Photo courtesy of *Journal of Chemical & Pharmaceutical Research* [5]

This percent crystallinity indicates the percentage of crystalline regions in the material. The fewer crystalline regions in the material, the more amorphous the material, and the more ductile the material. [6]

1.3 Project Objectives

The goal of this project was to design, build, and test an extruder that converts raw material into 3D printing filament. The focus was specifically on creating 3D printing filament made from PET, both from virgin pellets and from plastic waste. The produced filament needs to have material properties that either meet or exceed commercially available filament.

Chapter 2: Systems-Level

2.1 Customer Needs

The AkaBot team worked with Anudip to determine the requirements for the machine. Anudip had primary and secondary goals.

Primary Goals:

- The filament quality was on par with commercially available filament.
- The input material for the machine is virgin PET pellets.
- Machine can be operated by unskilled workers.
- Machine was robust enough to operate in rural India.

Secondary Goals:

- Plastic waste as the input material.
- Automated with little human interaction.

2.2 Benchmarked Results

AkaBot 2.0 was built upon the research conducted by the AkaBot 1.0 team. Students developed AkaBot 1.0 as a senior design project at Santa Clara University during the 2013-2014 school year. Their machine, seen in Figure 5, developed the initial concept and design. They were able to produce filament, but had problems with consistency, ductility, and filament diameter.

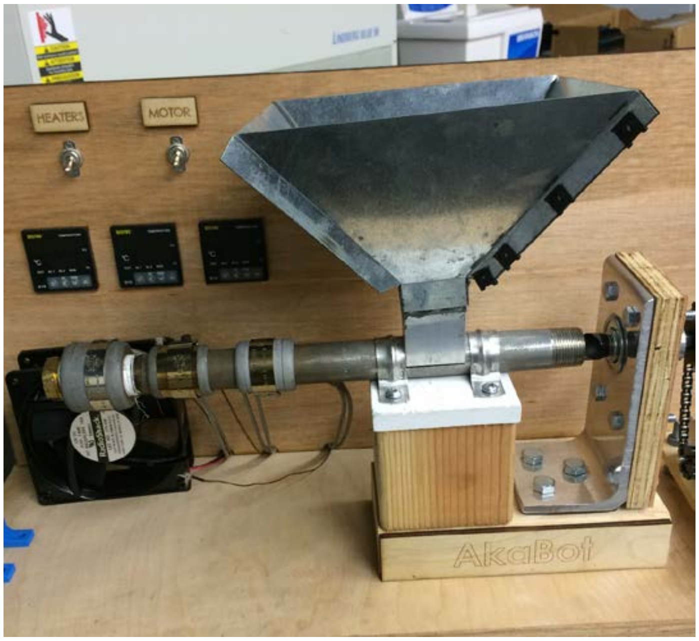


Figure 5: AkaBot 1.0 machine before modifications

Testing with the AkaBot 1.0 machine led us to change many of the components during our initial testing, including:

- Orientation of the machine – from horizontal orientation to vertical orientation
- New chamber mounts – to keep the chamber from rotating due to motor torque
- New die design – manufactured die for 1.75 mm filament vs. 3 mm filament, and with a smaller cone angle
- New cooling system – liquid cooling system vs. air cooling system

These tests gave us insight as to what changes we needed to make to our AkaBot 2.0 design. By making new parts and using them with the old machine, we could specify our design requirements. After conducting tests in the fall quarter on the existing machine, we included four major changes in our design.

1. Extrude a 1.75 mm filament
2. Change the orientation to a vertical design

3. Employ a liquid cooling system
4. Simplify the machine cleaning process

2.3 System Level Requirements

After working with AkaBot 1.0 as well as taking input from our customer, we set the system requirements for AkaBot 2.0. A summary of these requirements can be seen in Table 1, while the full list can be seen in the Project Design Specifications contained in Appendix C.

Table 1: System requirements for AkaBot 2.0

Baseline	Requirement
Filament Size	1.75 mm ± 0.1mm
Extrusion Speed	0.2-0.7 cm/s
Extrusion Temperature	250 °C
Time to Disassemble and Clean	<10 min
Cooling Rate	>34°C/min
Price	$500-$750

2.4 System-level Sketch

The first step is to clean and prepare the material. The PET is cleaned, shredded and dried, then the device is turned on, and the heating bands heat up the chamber to the proper level. The motor is turned on, and any blockages are cleared. The shredded PET is added to the system, and the filament is slowly pulled out by hand (automatic spooling was not included at that time). A block diagram of the system can be seen in Figure 6.

Figure 6: System-level sketch of extrusion process

2.5 Functional Analysis

1. Produce filament
    a. Clean and shred plastic: removes impurities.
    b. Melt plastic shards.
        i. Create a viscous liquid form of the plastic.
    c. Extrusion
        i. Push mixture along chamber towards extrusion point.
        ii. Create pressure in mixture to produce consistent extruded material.
    d. Cooling
        i. Lower temperature of filament as fast as possible: Fast solidification reduces crystallinity, which increases ductility.
        ii. Make filament safe to handle.
    e. Spooling
        i. Maintain constant tension on finished filament to reach desired tensile properties.
        ii. Collect filament for ease of use in 3D printer.

Inputs: Shredded plastic water bottles, raw PET pellets, heat, and auger rotation.

Output: 3D printer compatible PET filament, and waste heat.

Constraints: Cost, extrusion rate, heating rate, and cooling rate.

2.6 Design Process

We built on the work completed by the senior design team from last year. They were able to create a working prototype of a plastic extruder that showed promising results. We refined the design, made improvements, and created a new device that can be implemented in rural India.

Our primary goal for this project was to design a machine that produces a consistent filament output with the same properties as commercial 3D printing filament. The previous team was able to produce a filament, but it was not ductile enough to be used by a commercial 3D printer. We tested a variety of commercially available filaments to set specifications and tolerances for our final product.

Originally we believed that the mixing chamber and auger must be designed specifically for our purpose, in order to create an output of a consistent filament. The idea was that this specific design would allow for mixing of the plastic shreds, and for specific pressures and melting temperatures to be achieved, in order to create uniform material properties. The previous team used commercially available drill bits, but we planned to design a purpose-built auger from scratch that would exactly match our needs. After we designed this auger and ran simulations on it, we concluded that the cost to machine the hardware would outweigh the benefits. After testing AkaBot 1.0 with an off-the-shelf auger and making a few modifications, we concluded that we could in fact use an off-the-shelf auger and still improve the material properties by simply changing the orientation of the machine and decreasing the clearance between the chamber and the auger. The final step in creating a uniform filament was to design the die that the plastic is pushed through and then is cooled from a liquid to a solid. This die determined the final shape of the filament.

The next stage of our design was the cooling and spooling apparatus. The filament needed to be “pulled” out of the machine at a certain rate to maintain tension. Keeping the correct level of tension is critical to achieving the desired mechanical properties for the filament. We researched how the filament is affected by various spooling rates in order to determine the right one for our needs.

2.7 Key System Level Issues

There are two issues we had to solve for our iteration of the machine. First, we needed to increase the pressure at the extrusion die. Having a high pressure ensures consistency in the filament output, improving the yield of usable filament. There were two ways to accomplish this. First, we planned to have an extrusion auger machined to the exact specifications required to extrude PET. This is a complex and expensive process that would have taken up the majority of our budget. The complexity of the design requirements meant we would not be 100% confident in the auger until we had tested the final design extensively. If there were flaws, we would have had to find more money to construct a new auger, or find other ways to increase pressure. The drawbacks associated with a custom auger forced us to look for different ways to increase the pressure. We tested rotating AkaBot 1.0 into a vertical orientation, which generated enough pressure at the extrusion die to generate a consistent filament output. With a vertical orientation, we reached the required pressure levels without an expensive auger.

Cooling was the second issue we needed to solve. Based on our material research, we needed to reach a cooling rate of at least 34°C per minute in order to maximize ductility of the filament. We tested an air-cooling system using AkaBot 1.0, which did not provide the necessary cooling rate. A liquid cooling system was required, but we could not use water. PET readily absorbs water when it is in a semi-liquid state, and water absorption sharply decreases ductility. We decided to extrude into a bath of oil, which gave us the cooling rate needed to achieve the required ductility.

2.8 Hardware Limitations/ Lead Time

There were a couple of constraints that set our hardware limitations. We wanted to be able to do all of the machining of the components on campus, so this dictated some of the material choices. We also wanted to make the assembly process as easy as possible, so we did our best to select components that were off-the-shelf. This ensures the device can be easily repaired, and sourcing replacement parts will not be a long, drawn out, or expensive process. All parts and raw materials were sourced from Pinecone Lumber, Home Depot, McMaster Carr, and other online sources. The complete list of parts and where they were purchased from can be found in Appendix F.

2.9 Team and Project Management

There were three members on the AkaBot 2.0 team; Jay Dubashi, Brian Grau, and Alex McKernan. There were three major sections of the project, in terms of developing specialized knowledge: Finite Element Analysis (FEA) and business analysis; machine design and Computer Aided Design (CAD); and material properties including Differential Scanning Calorimetry (DSC). The leads for each part of the project were defined as follows:

- Jay Dubashi - Finite Element Analysis (FEA) and business analysis
- Brian Grau - machine design and Computer Aided Design (CAD)
- Alex McKernan - material properties including Differential Scanning Calorimetry (DSC)

Having a small team reduces the challenges of trying to arrange meeting times. While each of us had specialized tasks, we all contributed to all aspects of the project.

This project was divided into three distinct phases. The first phase was the material properties research, testing different prototype designs on AkaBot 1.0, and design of the auger, which was later scrapped. The second phase of the project was the design of AkaBot 2.0, construction, and testing of the machine. The final phase of the project was testing our results, preparing our senior design presentation and thesis, and preparing our machine for implementation in India. A summary of the project timeline can be seen in Table 2 and a full Gantt chart can be found in Appendix E.

Table 2: Timeline

Deliverable	Oct. '14	Nov. '14	Dec. '14	Jan. '15	Feb. '15	Mar. '15	Apr. '15	May '15	June '15
Material Properties Research	X	X	X	X					
Design		X	X	X					
Construction				X	X	X	X		
Filament Property Testing							X	X	
Senior Design Conference								X	
Implementation								X	X

2.10 Budget

The funding from our project came from a Roelandts Grant from the Center for Science, Technology, and Society at Santa Clara University. We received our full budget, seen in Table 3, of $5,120. We were able to substantially reduce the cost of the machine and using CAD to design and test the system, eliminate prototype costs. At the end of the project we still had $3,400 remaining. This money is being used to continue testing with AkaBot 2.0 during the summer of 2015.

Table 3: Initial budget

Item	**Cost**
Electronics	$900
Auger	$1,600
Spooling	$700
Hardware	$1,420
Raw Materials (PET)	$500
	$5,120

Chapter 3: Materials

3.1 Material Testing

The first step in this process is to analyze the input material, plastic water bottle shreds. PET is an incredibly sensitive material to work with, so the cooling profile of the material as it exits the machine is extremely important. Last year the team encountered problems with the filaments ductility. If the filament is not ductile enough it will not be able to be processed through a 3D printer. This problem last year was due to a slow cooling rate. The slower a material cools, the more time crystals have to form. The percent crystallinity can be found by Equation 1 below [7]. Higher crystallinity corresponds to a less ductile material.

$$\%\ Crystallinity = \frac{\Delta H_m - \Delta H_c}{\Delta H^{\circ}{}_m} \cdot 100 \qquad \text{(eq. 1)}$$

H_m is the heat of melting, H_c is the heat of cold crystallization and both are divided by the heat of melting of a 100% crystalline PET. In order to determine the proper cooling rate, the input material was run through a Differential Scanning Calorimetry (DSC) test. This test provided the team with a graph similar to the one seen in Figure 7 below.

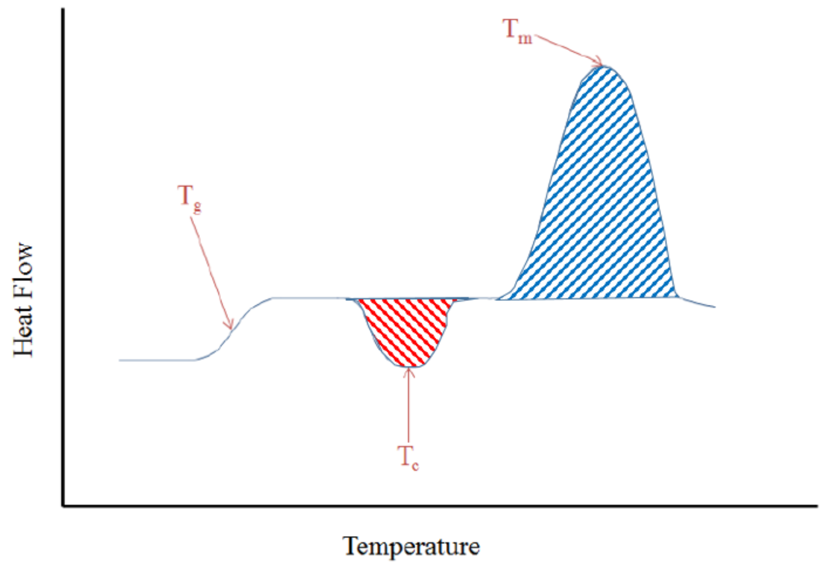


Figure 7: Example of a DSC test result graph

T_g is the glass transition temperature, T_c is the cold crystallization temperature, and T_m is the melting temperature. Using the area under these curves as denoted by the red and blue regions in the graph, the percent crystallinity can be determined.

The DSC was run in two phases, one to simulate the material going through AkaBot, and one to determine the resultant crystallinity. First the material was heated to 280°C from room temperature at a rate of 10°C/min to mimic the material in the auger. Next it was cooled with the initial cooling profile 34°C/min to mimic the cooling phase of the material. The second phase was to heat the material again at 10°C/min in order to obtain a graph similar to that seen in Figure 7. This determined the material's final crystallinity at the specific cooling rate.

This DSC profile was initially run to test the feasibility of using plastic water bottles. We ran small water bottle samples through this double DSC test in order to characterize the material we were working with. The results can be found below in Figure 8.

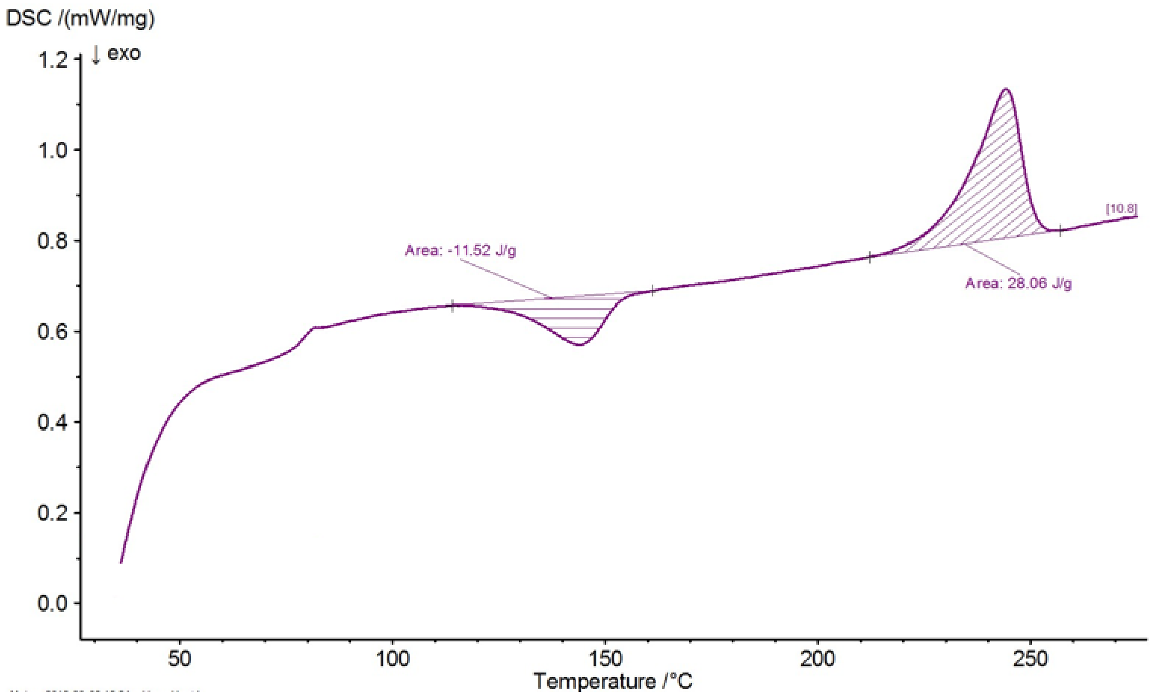


Figure 8: DSC results of Crystal Geyser water bottles

Using Equation 1 the percent crystallinity was found to be 11.8%. With this data, we determined that recycling plastic water bottles was, in fact, a feasible option for extrusion.

3.2 Preparation

Preparation of the PET is a crucial step in the process. The water bottles must be completely stripped of all labels and adhesives and thoroughly cleaned to ensure all contaminates are removed from the polymer. This is done using soap and water and is a labor-intensive process. The water bottles that are completely free of all labeling and adhesives are then cut into strips and fed through a standard paper shredder. Once cleaned and shredded, the PET must be completely dried. The material can then be processed. Figure 9 shows what the prepared material will look like.

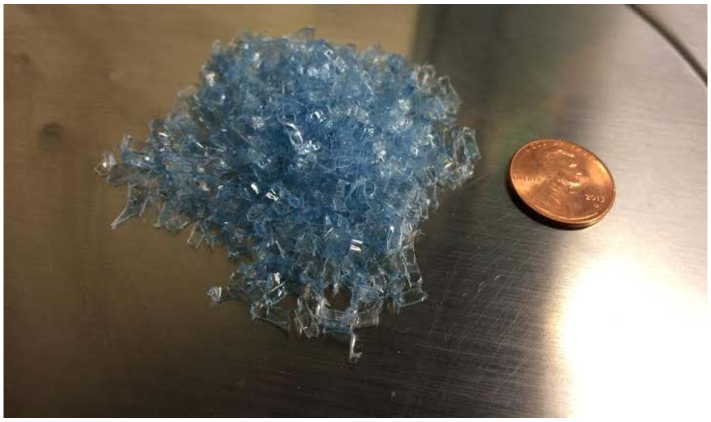


Figure 9: PET water bottles after cleaning and shredding

Ultimately, the goal of AkaBot is to take this pure recycled PET and convert it into a usable 3D printing filament. However, upon testing with AkaBot 1.0, it was clear that the shreds captured too much air in the extrusion system. This led to a decrease in pressure, and as a result the material was burned as it exited the machine. Upon discussing our result with Anudip, we reached the conclusion that virgin PET pellets could be used as a viable option for reducing the cost of the filament. While the PET pellets are not made of recycled material, they are a cheaper option than purchasing PET filament.

Chapter 4: Machine Design

4.1 Machine Overview

There are four main subsystems to our machine, as seen in Figure 10. In addition, several auxiliary subsystems complement these.

Figure 10: Main subsystems

AkaBot 2.0, the final machine, is 2 feet [60.96 cm] wide by 1 foot [30.48 cm] deep by 2 feet [60.96 cm] tall. Figure 11 shows the machine in its final form.

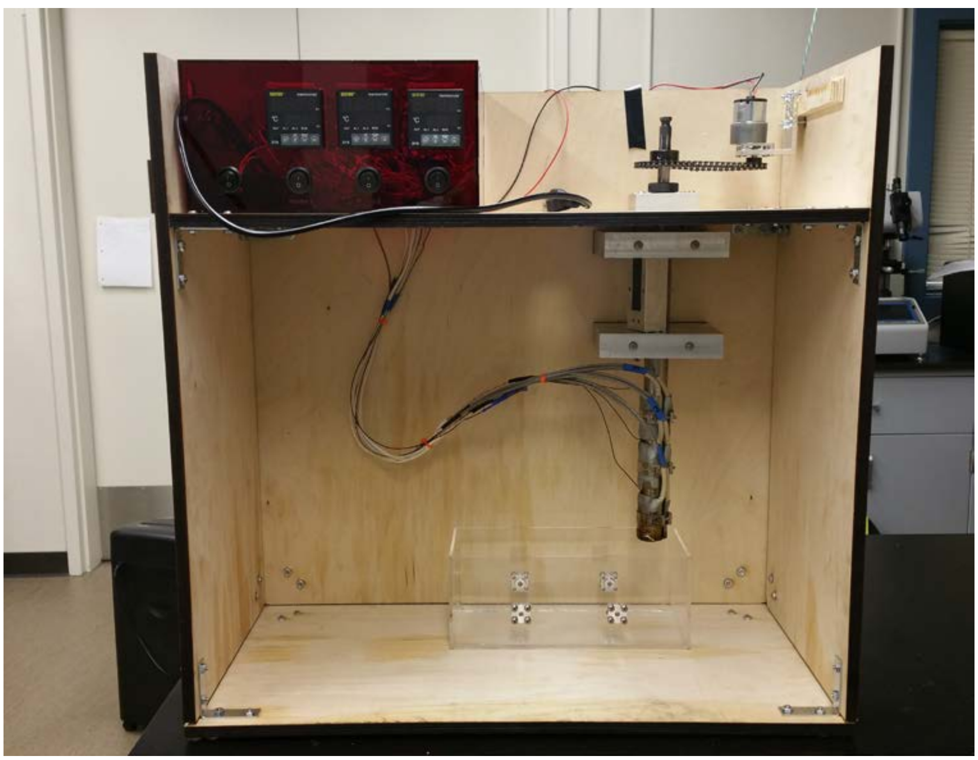


Figure 11: AkaBot 2.0 final machine

4.2 Hopper

Changing the machine to a vertical orientation necessitated a redesign of the hopper from AkaBot 1.0. We chose a gravity-fed hopper design because of its simplicity. The material is loaded at the top of the machine and then as the auger picks up material, the pressure due to gravity keeps the material flowing to the input part. Figure 12 is a computer rendering of the hopper.

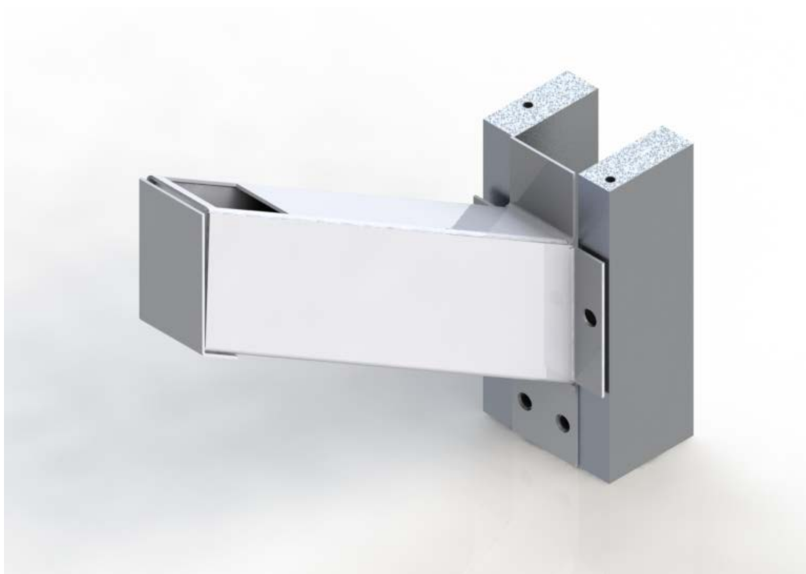


Figure 12: Sheet metal hopper

We tested this hopper design, and the angle was not steep enough to keep a constant feed of material into the machine. We hand fed the material into AkaBot 2.0 for all of our tests because we did not have enough time to implement a new hopper design.

4.3 Chamber and Heating

4.3.1 Chamber and Heating Overview

As the material travels through the melting section of the chamber, band heaters melt the solid plastic material to a liquid. We designed the chamber and selected the heating bands for their ability to be customizable and movable. Flexibility was critical because the theoretical calculations are extremely complex. We selected band heaters because they could be positioned on the outside of the chamber to allow for them to be moved along the length after construction is completed. These were also a proven design from AkaBot 1.0.

4.3.2 Chamber

The chamber is the component that transfers the heat from the heating bands to the material inside. It houses the auger and has to withstand temperatures of 260°C. The material selection, the manufacturing technique, as well as the design, were all done in parallel.

We evaluated three different materials for possible usability; 6061-T6 Aluminum, Carbon Steel, 316 Stainless Steel. The first material we evaluated was 6061-T6 aluminum due to its low cost, ease of manufacturing, and availability. When looking at the material properties of aluminum we concluded that it would deform over time, making it an undesirable choice. The melting temperature is 660°C. [8] We are operating at a temperature range between 250°C and 270°C, and this is greater than 1/3 the melting temperature, resulting in possible creep. The next material that we looked into was carbon steel. While the melting temperature of 1,425°C is much greater than our operating temperature, steel enters an embrittlement region right at 250°C, which is where we are operating. [8] This can lead to failure of the machine. Ultimately, we chose 316 stainless steel as the final material because it has a high melting temperature (1,510°C), and will have a long life. [8] This material does require more time to machine and more specialized tools.

The design of the chamber, seen in Figure 13, required a few different machining operations to be performed. Because of the limitations of the tools on campus in the machine shop, we bought a stock tube that has an outer diameter of 1.000 ± 0.005 in (2.54 ± 0.013 cm) and inside diameter of 0.76 ± 0.005 in (1.930 ± 0.013 cm). This meant that no work needed to be done on the inside of the tube for the auger of 0.75 in (1.91 cm) to have a clearance fit. We selected an outside diameter of 1.000 in (2.54 cm) because there was a commercially available heating band for this size.

Figure 13: SolidWorks rendering of the chamber

We used a mill to remove a section at the top for the hopper connection. Along the rest of the length of the tube there is a groove so the thermocouples can be recessed into the chamber for a more accurate reading, and to keep the heating bands from applying pressure to the tip of the thermocouple, which could reduce its life span. At the bottom there are four tapped holes 90° apart for 8-32 set screws to hold the die in place.

4.3.3 Band Heaters

There are three 250 Watt band heaters on the outside of the chamber. These band heaters are 2.000 in (5.08 cm) in length and operate on 120 VAC. They are made by Tempco and are in the same product line as those used on AkaBot 1.0. They have a maximum temperature of 482°C (900°F), making them an ideal choice. At peak operation they have a power draw of 2.08 Amps. These heating bands were chosen because there are 220 V equivalent models, so that the entire system can be converted over for use in India.

Figure 14: Heating band

4.4 Extrusion

4.4.1 Extrusion Overview

The material is forced through the length of the chamber by a screw auger. Initially, we believed this to be the most important part of the system and much of our initial design work was spent on this single component. As testing progressed, we determined the importance of this part was less than anticipated and we could use a cheaper solution.

4.4.2 Custom Auger Design

There are three main sections in a screw auger: feed zone, metering and melting zone, and the pumping zone. These are shown in Figure 15 below.

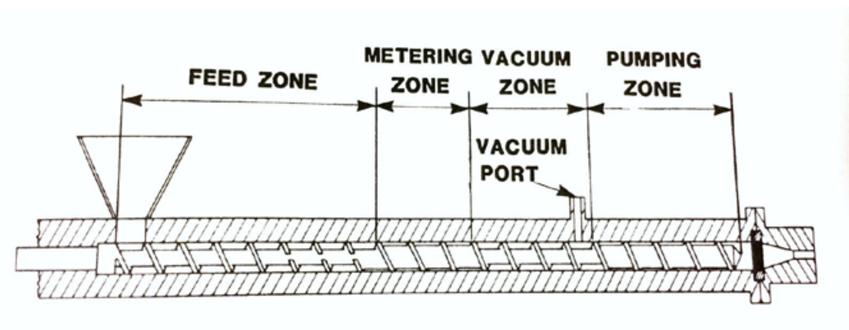


Figure 15: Sections to an auger design. Photo courtesy of *Polymer Mixing and Extrusion Technology* [9]

In order to do a complete analysis of the design for an auger, there are multiple different geometric parameters that must be taken into account including the pitch angle, the helix angle, the length to diameter ratio, the channel depth, and the clearance between the auger and the chamber. After research into all of these we determined that for our needs the optimal design configuration would be as seen in Table 3. [9]

Table 4: Parameters for custom designed auger

Parameter	Value
Pitch Angle	17.61°
Helix Angle	17.61°
Length to diameter ratio	16:1 – 36:1
Channel depth	Different for each section
Clearance between auger and chamber	0.001 in (0.0025 cm)

Using these parameters and other design recommendations we designed our auger using SolidWorks. This auger, seen in Figure 16, is 22.00 in (55.88 cm) in length and has a maximum diameter of 1.00 in (2.54 cm).

Figure 16: SolidWorks rendering of the custom auger design

While the pitch angle and the helix angle remain constant, the depth varies over the length of the auger. The depth of the feed zone, where the material enters the chamber, is a constant depth and relatively deep. The melting zone, between the feed zone and the metering zone, has a depth that is decreasing as the material travels from left to right. The metering zone has a constant depth, shallower than the feed zone. Finally, the pumping zone has a constant shallow depth, where pressure is built up before material exits through the die.

4.4.3 Commercial Augers

Based on our testing with AkaBot 1.0, we concluded that the auger could be simplified greatly and still work adequately. With other design decisions that we made, including rotating the machine to a vertical orientation and decreasing the filament size, we found that a commercial auger would be able to build up enough pressure at the die. Looking at different commercial augers, the design that matched our custom auger specifications closest was a ship bore auger (see Figure 17). We selected a diameter of 0.75 in (1.905 cm) after the chamber was designed.

Figure 17: Commercial ship bore auger

4.5 Die

4.5.1 Die Overview

The die of the machine determines the final filament size. We designed the die to be easily removed in order to clean it, and to switch it out for different filament types.

4.5.2 Die Design

The die is made from 360 Brass. We chose this material for a variety of reasons. The temperature on the die needs to be controlled very precisely to make sure the material does not begin to solidify in the die, but it also cannot be so hot that it takes a long time to cool when it comes out the end. Brass has a melting temperature of 930°C, meaning we did not have to worry about material deformation. [8] It also has a high thermal conductivity so that it can transfer its heat. Finally, the linear thermal expansion coefficient of brass is 18.7. [8] This needed to be greater than that of 316 stainless steel, of 16.0. [8] The design of the interchangeable die uses 4 set screws. When the machine is off and cold, there is a slight gap between the components, meaning it can be swapped out. When the machine is brought up to temperature, the materials expand, brass more than stainless steel, and this seals off the end of the tube so plastic will not leak, as well as creating a friction surface so the pressure is distributed between this friction interface as well as the set screws.

The design for the die was such that it can slide into the chamber and not protrude past a 1.00 in (2.54 cm) diameter. This means the heating bands can be moved along the entire length of the chamber, all the way to the end, because maintaining a set temperature at the die is crucial to the material properties. Figure 18 shows the final die after machining.

Figure 18: Brass die

Figure 19 shows a section view of the die. The inside cone angle of the die is 60°, which was the smallest angle that we could machine on campus. The output diameter was 0.089 in (0.226 cm) and took into account the swelling of both the die as well as the PET material. There are four circular pockets, all 90° apart around the outside, which match up to the 8-32 tapped holes on the chamber.

Figure 19: Section view of a SolidWorks rendering of the die

4.6 Cooling

4.6.1 Cooling System Overview

After the material exits the extrusion barrel through the die, it needs to be rapidly cooled. This is completed by the cooling system, seen in Figure 20. Immediately after the material exits the die it goes into a cooling bath of vegetable oil. We chose vegetable oil because it is nontoxic and readily available. There are hubs on the side of the chamber to allow for metal rods and pulleys to be put in place. These can guide the filament out and onto a spooling system in the future. The oil bath allows for a rapid decrease in temperature of 36°C/sec. The oil does heat up from room temperature of 20°C to 40°C, and then it needs to be replaced. We estimate that this change needs to happen once every hour.

Figure 20: Acrylic trough to hold cooling fluid

4.7 Controls

4.7.1 Controls Overview

There are two independent control systems, the heating system and the motor, that control the various aspects of the machine and ensure that it is functioning properly in order to create a uniform filament.

4.7.2 Heating System

The first of these systems are the control systems for the band heaters along the length of the chamber, which melt the filament before mixing and extrusion. An electrical schematic, shown in Figure 21, shows the control system for one of these heaters. The only user input is the desired temperature, which is keyed into the temperature controller.

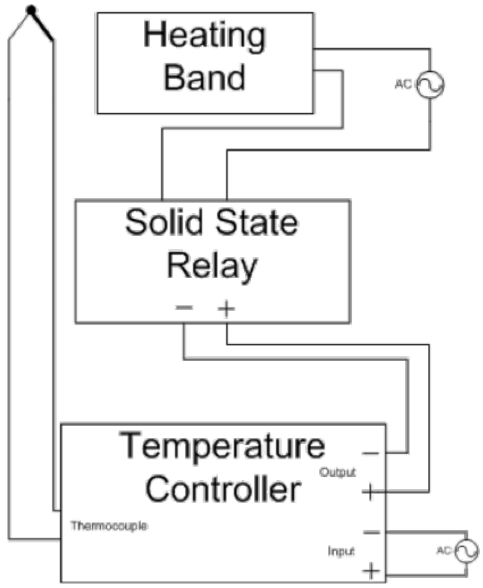


Figure 21: Electrical schematic for the control of a single heating element

The temperature controller we are using is made by Sestos and can be seen in Figure 22. This controller uses a PID control algorithm in order to maintain a precise steady temperature.

Figure 22: Sestos DIS-VR-220 PID temperature control unit

A thermocouple embedded into the heating element is the feedback part of the control loop. Table 5 summarizes the characteristics of this controller.

Table 5: Sestos DIS-VR-220 temperature control unit specifications

Parameter	Value
Sensor Input	K, S, Wre, T, E, J, B, N,CU50, PT100
Control Range	50-1300C (K sensor)
Control Accuracy	0.1°C
PID	On/Off Modes
Power	AC 110-240 °C
Output	12 V for SR

The temperature control unit provides a 12 V signal that is wired to a relay, which switches the high voltage AC current that is fed to the band heater. The solid state relay we are using is manufactured by Fotek and can handle the load. A picture of the relay can be seen in Figure 23, and Table 6 summarizes the specifications.

Figure 23: Fotek solid-state relay for switching high voltage and high current

Table 6: Summary of specifications for the Fotek SSR-40 DA

Parameter	Value
Rated Load Current	**40 A**
Input Operating Voltge	**3-32 VDC**
Min On/Off Voltage	**ON > 2.4V, OFF < 10 V**
Trigger Current	**7.5 mA @ 12 V**
Output Operating Voltage	**24-380 VAC**
Response Time	**ON <10 ms, OFF <10ms**
Operating Temperature	**-20C to +80 °C**

4.7.3 Motor

The motor for the system is a 10 RPM motor with a stall torque of 368 oz-in (26.5 kg-cm). The motor is controlled by a Single Pole Single Throw switch. This switch is wired in series with the power source from a 12 V supply and the motor. This was the simplest control system. It is a single speed system with the revolutions per minute selected by the speed of the motor and the gearing between the motor and the auger. The gear ratio was selected to be 2.5:1, resulting in an auger speed of 4 RPM. This speed transfer occurred using a chain drive.

Figure 24: Chain drive connecting motor and auger

Chapter 5: System Integration

5.1 Assembly and Systems Testing

Once AkaBot 2.0 was fully assembled, we tested each system to ensure that it was operating properly. First, we turned on the heating bands and the control system to see if our design would reach the required heating profile. We tested this by using a thermocouple to measure the temperature on the outside of each heating band. We also tuned the PID controllers by using the built-in automatic tuning function. This eliminated the variability in the temperature of the heating bands that we had seen in AkaBot 1.0. Once the controllers were tuned, the temperature of the heating bands only varied by 1°C.

Next, we tested the mechanical power system. The rotational speed of the auger slowed significantly as pellets were loaded into the chamber. If too many were loaded, the auger stopped, and it required manual assistance to start again. We decided to limit the pellet supply to 35ml at any given time, to assist the motor.

Our first major problem came from the hopper. We planned on a 30 degree angle from the funnel to the chamber, but the pellets did not self-feed, and had to be pushed into the chamber. We scrapped the initial hopper design for our first tests, and put filament into the system by hand.

5.2 Extrusion Process

From viewing videos of other DIY extruders (small-scale devices designed for home use), we knew that the extrusion and filament collection process was just as important as the design of the machine. The consistency and final shape of the filament was dependent on the tension applied as it left the die. Without applying tension, the filament would collect in a pile within the oil bath. The internal structure of the filament was as desired (clear), but it was wound too tightly to be used in a 3D printer. The filament had to be guided out and away from the extrusion die to form the long straight pieces needed for 3D printing. We assigned one team member to hold the filament and gently pull it out of the machine. This tension had a significant impact on the variance of the filament diameter.

While the tension created a straighter, more consistent filament, the filament occasionally drifted or spun in the oil bath, which created inconsistencies in the diameter and sharp kinks and corners in the filament. The more accustomed the user becomes to these issues, the better the filament output.

In order to attempt to produce a more uniform filament without extensive user training, we designed and manufactured a trough, seen in Figure 25. This trough allows the filament to sit in it and keep the filament from drifting from side to side.

Figure 25: Trough to guide material through cooling system

5.3 Extrusion Testing

3D printing filament does not need to meet precise technical requirements. The only requirement is that it can be used in a 3D printer. The ductility and diameter can have some variation and still be usable. If the produced filament can be spooled and fed like commercial filament, it is usable. Therefore, most of our testing was qualitative, and we backed it up with two quantitative tests. We tried to spool our filament in the same manner as the produced filament, and visually compared the internal properties. The ideal filament is clear, almost transparent. Cloudy regions signify high crystallinity and thus low ductility. We also sampled the diameter of the produced filament at fixed intervals to determine the average diameter and tolerance.

Once we obtained a consistent filament, we initially tested it for ductility by winding it into a 3 inch (7.62 cm) diameter circle. If the filament did not snap, we conducted further tests to determine its characteristics.

First we conducted a DSC test on a segment of 1.75 mm filament. This was filament extruded into a room temperature, 20°C, oil bath. The filament was found to be clear and uncloudy, and could be tightly wound without snapping. The test we conducted was a simple single DSC test. This meant that there was no preliminary heating and cooling profile. The samples were simply heated to 280°C at a rate of 10°C/min to obtain the data graph seen in Figure 26.

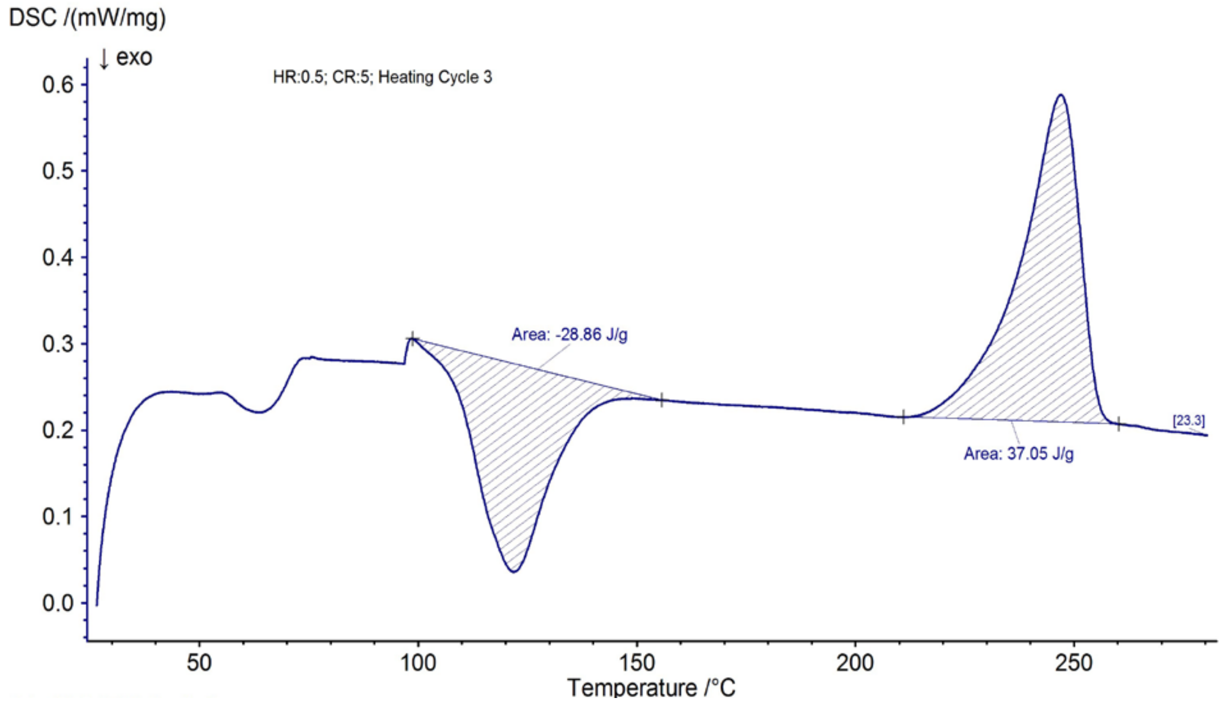


Figure 26: DSC test results of AkaBot 2.0 1.75mm filament extruded into 20C oil bath

Using Equation 1, and the areas obtained from the DSC, the percent crystallinity of the AkaBot 2.0 filament was found to be 5.85%. After comparing these results to those found in the thesis from AkaBot 1.0, we found that they were actually quite similar. AkaBot 1.0 was achieving similar crystallinity; however, the previous tests were conducted with filament of a much smaller diameter of around 1 mm. This diameter difference makes cooling AkaBot 1.0 filament much easier due to the thinner diameter. Had the same cooling system been applied to AkaBot 2.0, the results would have been drastically different. The cooling rate made all the difference in these results. AkaBot 1.0 simply had a fan blowing room temperature air over the filament as it came out of the machine. While it worked better than stagnant air, this cooling rate was slow when larger samples were extruded. The system worked to reduce crystals in the thin filament because it had less to cool; however, it was less successful at lowering the ductility of a larger sample because of the longer time it takes to cool the larger diameter samples. AkaBot 2.0 extruded into room temperature vegetable oil. Due to oils thermodynamic properties, it draws out heat much faster than air blowing over the filament. This means that even in a larger diameter filament, the cooling rate remains high.

Once we concluded that the oil bath extrusion was successful, we conducted tests to compare the effects of lowering the oil temperature. We placed vegetable oil in the freezer, cooled it to 0°C, and then mixed it with room temperature oil. The resulting temperature was 10°C. After numerous rounds of extruding, it was qualitatively concluded that the cooler oil did not have a drastic effect on the ductility of the filament. Each test from both the 10°C oil and 20°C oil (room temperature) was able to be wound tightly into a spool with a 2 in (5.08 cm) diameter. We thus concluded that both samples were ductile enough to be processed through a 3D printer. From here, we made the decision to maintain the oil at room temperature, in order to keep the extruding process more simple and reduce its energy input.

In order to verify quantitatively that the ductility of AkaBot 2.0 actually did surpass that of its predecessor, we conducted tensile tests and compared the results to both AkaBot 1.0 and purchased filament. While conducting the tensile tests, we found that Akabot 2.0's filament was actually far more ductile than both the purchased filament and last year's filament.

The most crucial comparison that was drawn, however, was between the Akabot 2.0 filament and the purchased filament. In order to obtain most consistent and true results, all of our samples were prepared in the same manner. Samples of equal lengths were cut and placed into the tensile tester. Clamps holding the sample at either end were 86 mm for every test. During each test the strain rate was 20 mm/min. We conducted tests in two sessions. Session 1 tested two strands of AkaBot filament and one strand of purchased filament. This round of testing produced results that were slightly inconsistent, as the two samples of AkaBot filament produced different results. Session 2 was conducted in order to gather more data and confirm the team's conclusions about an increased ductility. Unfortunately, session 2 yielded mostly inconclusive data, as all but one of the samples broke at the clamps. Once a sample fractures at the clamp, it becomes unreliable data, as the pressure of the clamp may have compromised the integrity of the sample. The one sample that fractured in the middle of the sample was compared to the tests run during session 2. Similarities in ductility were found between one of the tests in session 1 and one of the tests in session 2. These results were compared to the successful test of purchased filament in session 1. A graphical representation of a stress strain curve can be seen in Figure 27 to compare the two samples that were tested.

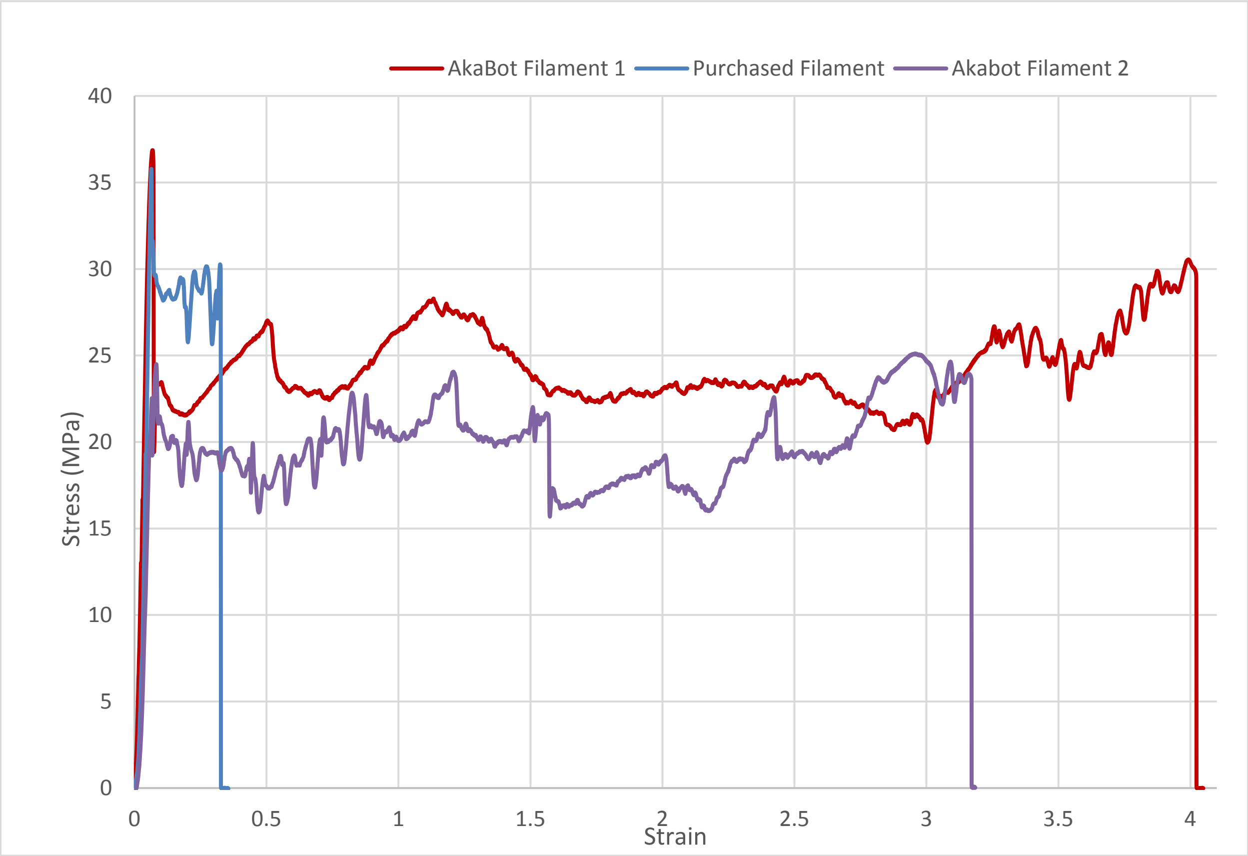


Figure 27: Stress-strain curve of 86mm long samples of purchased filament with a 1.80 diameter and AkaBot 2.0 filament 1 with a 1.77mm diameter and AkaBot 2.0 filament 2 with a diameter of 1.70mm

While some similarities can be seen, the data is still not conclusive. Table 7 further examines these differences and compares this year's results to the results from last year.

Table 7: Tensile test comparison

	Purchased Filament	Akabot 1.0 Filament 1	AkaBot 2.0 Filament 1	AkaBot 2.0 Filament 2
Diameter (mm)	1.80	1.04	1.77	1.70
Yield Strength (MPa)	34.48	29.5	35.98	24.04
Modulus of Elasticity (MPa)	909.76	366	731.60	758.25
Strain at Fracture (%)	35.6	4.35	405	317

As seen in the table above, both AkaBot 2.0 filaments had extremely large elongations, as seen by their % strain at fracture. The modulus of elasticity was also very similar. The yield strength varied more than anticipated between the samples. Future testing must be done in order to come to any final conclusions about the filaments exact properties.

For future testing, we recommend that short samples be prepared directly from extrusion. One issue we found in retrieving samples was that when the filament was spooled, kinks and inconsistencies in the diameter formed. If small sections are extruded with greater precision specifically for a tensile test, this could yield more consistent results. Also, while a total of 9 tensile tests were conducted, 3 for the purchased filament and 6 for AkaBot 2.0 filament, only 3 tests were deemed to have usable data. For this reason, many more tests must be conducted to gain more useful data. In addition, a fixture to hold the filament without deforming it as the clamps do would help the issue of fracturing at the clamps. Finally, the rate at which the machine was pulling the samples should be slowed, as this could also affect where the samples fracture. Future research will benefit greatly from these small changes to the design of the experiment.

Chapter 6: Cost Analysis

6.1 System Cost

The material cost of AkaBot 2.0 is $637.96, as shown in Table 8. The complete cost breakdown can be seen in Appendix F. This cost includes just the parts that it takes to make the machine.

Table 8: Material cost of Akabot 2.0

Subassembly	Cost
Frame	$32.48
Hardware	$21.32
Heating	$99.75
Mechanical Power	$85.18
Hopper	$2.35
Auger, Chamber, and Die	$66.69
Cooling	$35.82
Electronics	$234.79
Raw Material	$59.58
Total	**$637.96**

If the labor was outsourced to professionals it would be:

- Machining Time: 6 hours
- Laser Cutting: 1 hour
- Final Mechanical Assembly: 2 hours
- Electrical System: 2 hours

This is a total of 11 hours at $100/hour for a total labor cost of $1,100. This would bring the entire machine to a cost of $1,737.96.

6.2 Economic Analysis

AkaBot needs to provide a cost savings over a short time period in order to be a viable option for implementation in India. We constructed an economic analysis in order to see where AkaBot becomes a cost-effective option when compared to purchasing filament. This analysis is based on several assumptions. First, three workers are required to operate the machine, and they will be paid the semi-skilled minimum wage for workers in West Bengal State (65.94 USD per month). Second, we assumed that the input prices of PET pellets and purchased filament remains constant. We also assumed that this machine is operated by a large print shop, operating approximately five 3D printers, and using nearly 20 kg of filament per month.

Figure 28 shows the cost progression over a one-year period. Based on this analysis, AkaBot will start off with a higher cost than purchasing filament, but will produce cost savings between the fifth and sixth months. After one year, the device will save approximately $900. This shows how AkaBot can save money for a business, especially with a high print volume. This is also assuming just four hours of extrusion per day, with one machine. With more machines, there could be more savings and higher print volumes.

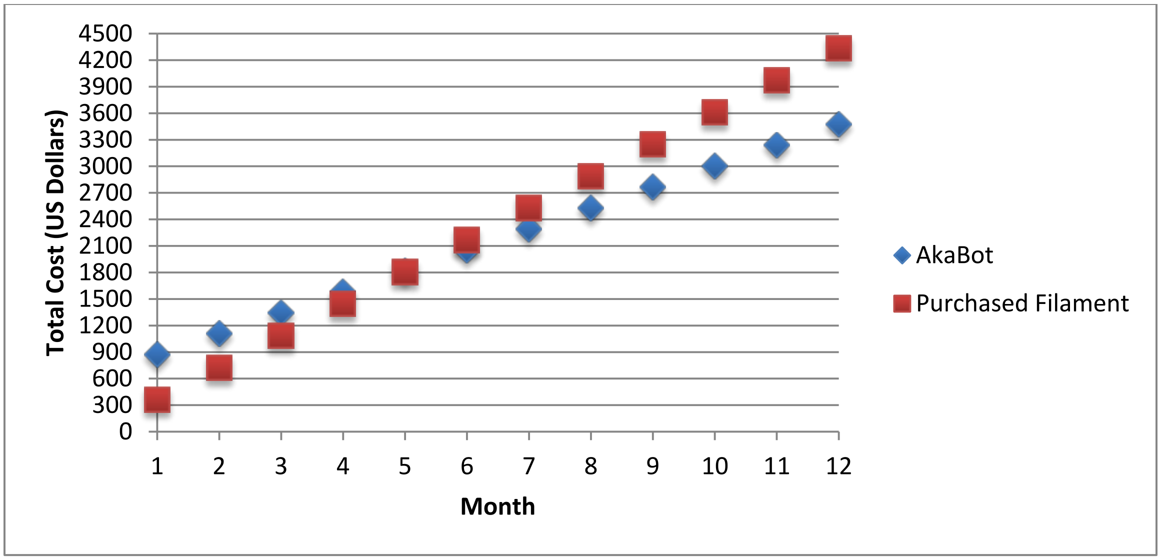


Figure 28: Economic comparison between purchased filament and filament produced by AkaBot 2.0

Chapter 7: Business Plan

7.1 Executive Summary

Hobbyists and small groups at MakerSpaces primarily use plastic 3D printing. The material limitations of PET plastic prevent its use in large-scale industrial processes. PET recycling does exist at the industrial level, but those devices have not been scaled down in a cost-effective manner. AkaBot will fill that market niche, allowing people to produce their own PET filament at a lower cost than repeated commercial purchases. 3D printing has the potential to replace existing manufacturing processes in developing countries. With low labor costs, companies can pay people to collect plastic water bottles and increase their profits by taken advantage of free raw material.

7.2 Introduction

AkaBot is an extruder that creates 3D printing filament from a raw plastic input, either PET pellets, or water bottles. It has the potential to produce filament at a low price point, and help with the recycling of plastic PET waste. Throughout this project, we have been working with the Anudip Foundation, a non-profit organization based in Eastern India. They run vocational training centers for impoverished and marginalized women. This plan is based on how they would run the business to achieve their goals.

The uses of 3D printing grow along with the technology. With its low startup costs and ease-of-use, 3D printing is a viable option in many developing countries. Anudip wants to teach the skills related to 3D printing and help young entrepreneurs grow their own businesses. AkaBot is designed to offset the main drawback of 3D printing, the cost of raw material. By producing filament at home, costs can be reduced significantly. There are several filament extruders on the market that allow people to make filament from their own substrate, like pellets or shredded plastic. However, these devices are limited to PLA and ABS plastic, not PET. They cannot be adjusted to make PET filament either.

Plastic waste is a huge problem in India. The water infrastructure cannot deliver clean drinking water to many locations. The poor make do with unsanitary water from wells or rivers, while those with means rely almost entirely on bottled water. These bottles end up in landfills or as litter; few are recycled. These bottles represent a wealth of raw material. AkaBot is a way to repurpose this trash into a useful product.

7.3 Goals and Objectives

As AkaBot will be used by a non-profit organization, it has different goals than a traditional business. Anudip wants to use this machine to produce large quantities of 3D printing filament for use in training programs. It will not be a commercial product; the filament will be used in training programs. They do not plan on commercializing AkaBot at this time, either by selling filament or extruders. We have identified three separate goals that will make this project a success for Anudip

1. Produce filament that is both materially and economically viable.
2. Provide a viable method for recycling plastic waste.
3. Encourage adoption of 3D printing technology in India.

As previously stated, importing filament is prohibitively expensive, especially for a non-profit that relies on donations for operating income. Implementing 3D printing training is dependent on reducing the cost of filament. By necessity, training uses and wastes a lot of filament. If AkaBot can result in significant cost savings over purchased filament within a reasonable time frame, it becomes a good choice for Anudip to use. Plastic waste is a significant problem in eastern India, and other developing countries. Without recycling infrastructure, the water bottles pile up on the side of the road. These water bottles are usually made from PET, and provide a nearly limitless source of material for filament. Existing PET recycling just turns old bottles into new bottles. AkaBot provides a way to break out of this cycle, and turn the PET into something else. 3D printing allows manufacturing firms to greatly reduce their startup costs in comparison to traditional manufacturing methods. Right now, it is still a niche technology without standardized training regimens, in either the US or India. By encouraging the use of this new technology, entrepreneurs in India can start their own businesses at a much lower cost than before.

7.4 Description of Product

AkaBot is a filament extruder. It takes in raw plastic material, melts it down, and pushes it through an extrusion die to form a 3D printing filament. It allows the user to produce filament on their own, and not rely on outside suppliers. It allows a business to control their own supply chain for material and inputs. For Anudip, it lets them reduce costs, and provide more employment and training opportunities for their clients. Businesses and non-profits are constantly trying to find ways to reduce their costs, and increase control over all aspects of the market. Vertical integration (owning the entire supply chain) is the "Holy Grail" for many businesses, but nearly unattainable for most industries. Any product that gives a business more control over its supply chain is going to be attractive to executives.

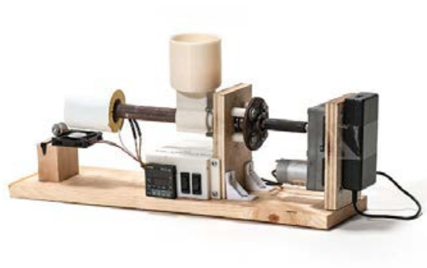
7.5 Potential Markets

Our target consumer is Anudip, and we have designed AkaBot based on their requirements. Filament extruders are generally used by hobbyists and MakerSpaces, groups who have small operating margins. Small-scale extruders do exist, but for other plastics like ABS and PLA. PET extruders do not exist on this scale. PET is uniquely suited for Anudip because of the plastic waste prevalent in its operating area. By extruding PET, they can take advantage of the resources surrounding their area. Once Anudip has established their operations, AkaBot will be opened to other potential markets and users. These users are the same hobbyists, MakerSpace users, and entrepreneurs that other extruders are targeted towards. AkaBot could be sold in two forms. First, it could be sold as a completely assembled machine that requires minimal tinkering to begin extrusion. Second, it could be sold as a kit that contains all the parts required for AkaBot, but with assembly and testing left to the user. This is the hobbyist option, because it allows the end-user to make adjustments as they see fit. The largest market for AkaBot would exist in the US and other countries that have seen mass adoption of 3D printing, where hobbyists and entrepreneurs are more likely to try out new technology. In India, AkaBot will have to prove its worth as a filament extruder by reliably creating large amounts of filament over a long period of time, and as a recycling machine by producing good filament from water bottles. Anudip’s training centers will be the proving grounds for AkaBot. There will be more local interest once 3D printing and local filament are shown to be viable options for Indian businesses.

7.6 Competition

As previously stated, AkaBot is a unique product. It is the only extruder for PET at the hobbyist level. Numerous other products exist for extrusion, but not for PET plastic. Some of these products can be seen in Table 9. Other extrusion devices are designed around the plastic they extrude, and cannot be adjusted to extrude different plastics. AkaBot has this ability, which makes it stand out from the competition. The heating profile and cooling system can be changed to extrude ABS or PLA. This makes AkaBot more useful as a ‘do-it-all’ extruder than other products.

Table 9: Comparison of existing extruders on the market

	Image	Price
Filastruder		$310 [10]
Filabot		$649-$1,949 [11]
Protocycler		$699 [12]

The above machines are all examples of ‘home-level’ extruders on the market. Filastruder and Protocycler are available as fully constructed machines, or as kits. However, none of these machines can extrude PET. They are all limited to ABS or PLA, and cannot be switched between the two. AkaBot has more flexibility in usage.

7.7 Sales & Marketing

Anudip is planning to implement the machine in India this summer, to test and determine the viability of using it to extrude filament for 3D printing. They will take ownership of the machine and be responsible for making decisions on expansion. Any marketing for AkaBot will focus on the savings potential and different uses for the machine. It is cheaper than purchasing filament, and it gives the user more flexibility in their choice of plastic than other extrusion devices. This machine could be packaged with a simple 3D printer as a starter kit. It is not a consumer product with mass appeal; it is an enterprise product that allows businesses to control more of their supply chain. Marketing efforts would focus on this sector, and how businesses can reduce their costs by taking advantage of readily available material, and by purchasing a machine that can extrude three kinds of plastic instead of just one.

7.8 Manufacturing

AkaBot is designed for construction by hand. The majority of the parts are available off the shelf. There are some parts that require basic machining; these parts will be sourced in mass orders from a machine shop. Anudip will pay workers to assemble the machines, and deliver them to the final training center. If they decide to commercialize the design, Anudip can offer AkaBot as a fully assembled device, or in a kit. Machine shops exist in India that can handle the machining of parts, eliminating shipping costs. Labor wages for machining are much cheaper in India, which will greatly reduce the cost.

7.9 Product Cost and Price

The AkaBot 2.0 prototype cost approximately $1,737.96 to make in its current design. However, there are several ways to reduce the cost of a final machine. Lower quality plywood could be used for the frame, and the size of the interior could be reduced significantly. Replacing the PID controllers with a microcontroller and a program would reduce the cost of the control system from $95 to $25. The cooling system could be replaced with a bowl filled with oil, instead of a custom acrylic box. The labor costs can also be reduced by using different manufacturing techniques and by reducing the number of machining operations that need to be performed.

7.10 Service & Warranties

Anudip will be running AkaBot as an internal program at first, and they will be responsible for supporting and maintaining the devices during the initial testing and production phases (if necessary). If they decide to commercialize the machine, a 30-day return policy on assembled machines, and a 1-year parts and service agreement would be implemented. This policy would only cover defective parts. The quality of filament is entirely dependent on the operator pulling it out of the machine, so the end user would have to train their people to produce filament.

7.11 Financial Plan

Anudip plans on using one machine this summer as a test case, to see if they can produce enough filament to make AkaBot economically feasible. This initial test will be funded entirely out of their own pocket. If they decide to proceed, they will seek funding from outside sources in order to produce and staff the 150 machines they need to operate for their training centers. As Anudip’s operation would be focused on training and not production, they would need constant outside funding to maintain the product, unless they decided to commercialize and sell the machine. Assuming they purchase

200 machines to operate in their training centers, they will need to hire 600 employees to operate them. This would be funded with a combination of internal revenue and outside donations. However, any future planning depends on the results of the feasibility study to be conducted this summer.

Chapter 8: Engineering Standards and Realistic Constraints

8.1 Economic

Anudip has limited financial resources. They want to set up as many training centers as they can, but the full 3D printing process has high start-up costs. AkaBot needs to be a financially viable tool for Anudip. Sacrifices were made in the design to keep costs down. AkaBot needs to produce filament, but there are areas where standards can be relaxed and costs cut. Financial restraints exist in all phases of design. Designing the perfect extrusion device requires tolerances down to 0.000254 cm (0.0001 in) This level of precision could not be realistically achieved.

8.2 Environmental

AkaBot was designed to reduce plastic PET waste in its surrounding environment. PET waste is extremely common in areas like India where most people drink water from plastic bottles instead of the potentially harmful tap water. The extruder is designed to use recycled PET. This means that once the PET is recycled, the extruder will be able to process any scrap material again to ensure no material is wasted. The goal is to create less waste, not more. The second environmental consideration is the manufacturing of the device itself. Large-scale manufacturing for AkaBot will need to be done in India in order to both create more jobs and reduce waste from sending the parts all over the globe. When choosing manufacturing centers it is important to ensure that the site also has high environmental standards.

8.3 Manufacturability

Our target market is developing countries. They will invest in AkaBot as a cost-saving measure, and they must be able to assemble and source components locally. Having to import expensive high-precision parts from overseas would not make economic sense. AkaBot is designed for manufacturing in a simple machine shop. We used a mill and a lathe in manufacturing these parts. Both machines are available for use in developing countries. A laser cutter was used to make the manufacturing processing time of the frame, cooling system, and electronics easier, but these can be made with a drill and saw. The tolerances for the parts could be reached in a standard machine shop. Assembly requires basic hand tools and mechanical knowledge.

The design of many of the components could be changed to allow for them to be made on a 3D printer. These include the hopper, the mounts, and the trough.

8.4 Health & Safety

1. Manufacture
    a. Commercially available parts: no safety concern
    b. Machined parts: there is an inherent risk when operating heavy machinery. All machine shop policies will be obeyed in order to maintain a safe working environment.
2. Assembly
    a. All parts can be assembled with simple hand tools. Electronics will be soldered together and all wire connections will be done with proper insulation. All machine shop and lab safety policies will be followed.
    b. The electrical system will operate at a voltage of 120 VAC. There will be shutoff switches.
    c. When assembling the unit, safety glasses, long pants, and closed toed shoes will be worn.
3. Test/Operation

    a. Heat risk: the chamber is heated to 260°C, which can cause severe burns. The tube will have warning signs.
    b. Rotating parts: the auger will be driven with an exposed chain. These rotating parts can grab fingers or hair. Proper training will be used as well as signs to warn of the danger.
    c. Fumes: the device will only be tested under a fume hood. The hood will be cleared of hazardous materials prior to testing.
    d. Oil from the cooling system and water from the cleaning system will be kept away from electrical components to reduce electrocution risks.
4. Display
    a. The device will not be on during a display.
    b. The device will be completely cool before being put on display.
5. Storage
    a. The device will be turned off and be cool before it is stored.
6. Disposal
    a. PET residue within the device will be removed by disassembling the device and chipping out the auger.
    b. The components are all made from standard materials that can be readily disposed of.
    c. Any chemicals or oils used for cleaning plastic will be disposed of as hazardous waste.

8.5 Social

The social impacts of the device are taken into account during implementation. The purpose of 3D printing is to aid the start of small businesses in rural India. However, the main barrier for entry is the cost of the filament. AkaBot solves this problem, thus helping small businesses grow. This growth will lead to more jobs, and eventually an improvement in the living conditions for those employed.

8.6 Santa Clara University Arts Requirement

Each team member contributed to the project in an artistic way, shown in Table 10.

Table 10: Team members arts contributions

Team Member	Description	Location
Jay Dubashi	FEA model of the chamber	Figure 29
Brian Grau	Final Assembly CAD	Drawing A008
Alex McKernan	Frame Assembly CAD	Drawing A004

Chapter 9: Conclusion

9.1 Summary

In summary, the goal of this project is to create a PET filament from recycled plastic water bottles that meets the same standards as commercially available spools for 3D printing. Beginning with plastic water bottle shreds made of PET, the AkaBot design will melt and extrude the filament through a cooling system, which will then be spooled and ready for use. This process is important because it will give individuals in rural communities access to a cheap filament, thus making 3D printing an accessible means of advanced manufacturing. The importance of this project stretches beyond recycling, to the need for grassroots entrepreneurship in many low-income areas. With access to low cost manufacturing techniques, local enterprise and vocational training can help improve the lives of many, leading to an increase in the number of small businesses and jobs in rural communities.

9.2 Future Work

There are four main areas where we would like to see work done in the future.

1. Redesign the hopper so that the machine can have a constant feed to reduce the number of people it takes to operate the machine.
2. Using guides, or another system, reduce the variation of filament diameter.
3. Build an automated spooling system, so the machine can be completely autonomous after initially started.
4. Improve pre-processing of water bottles.

Appendix A: Bibliography

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Appendix B: Calculations

We wanted to create a Finite Element Analysis (FEA) model of the chamber and auger, in order to see if our auger design would create adequate pressure at the extrusion die. We also wanted to see if the heating bands would generate the temperature in the chamber required for melting. Constructing this model proved to be more difficult than we first believed. In order to find the temperature at the tip of the extrusion die, we needed to show the heat flow through the chamber, in three dimensions. The third dimension makes constructing the model much more difficult. The second part of the analysis is the pressure model; we had to model the buildup of the plastic as a fluid. We had to construct two models, a finite volume analysis thermal model, and a computational fluid dynamics model of the plastic. The time and knowledge required to build this model was beyond our abilities. We decided to limit our finite modeling to the temperature distribution on the surface of the chamber. We could prove the other properties via testing of the machine.

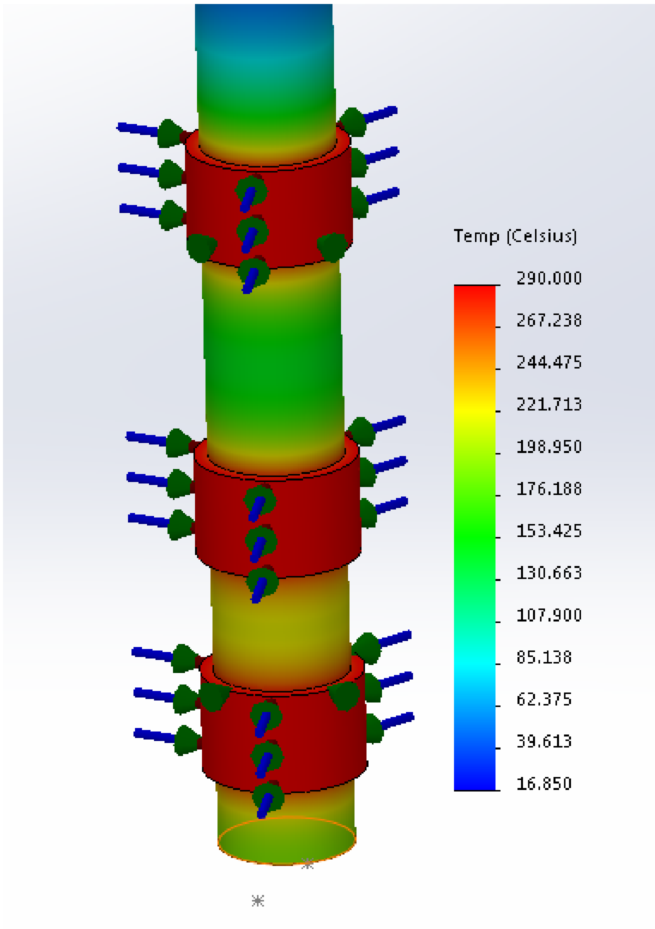


Figure 29: FEA model of heat propagation from heating bands

This analysis shows that the surface of the pipe will only reach as high as the setting of the heating bands. We used this analysis for our safety analysis, to show which parts of the chamber are too dangerous to touch.

Appendix C: Project Design Specifications (PDS)

Design Project _______AkaBot_________

Team: _AkaBot______ Date: ____March 21, 2015_ Revision: _3_

Datum description: ______AkaBot Project 2014_______________________________

ELEMENTS/ REQUIREMENTS	UNITS	PARAMETERS	
		DATUM	TARGET - RANGE
PERFORMANCE			
Size	m	0.6x0.3x0.6	0.7x0.7x0.7-1.2x1.2x1.2
Price	US Dollars	485	500 -750
Speed	cm/sec	0.5	0.2 -0.7
Tolerance	+/- mm	0.1	0.1
Extrusion Temperature	C	250	250
Filament Size	mm	3	1.75
Power	Volts	120	120
Lifetime	years	5-7	5-7
Sound	dB		
Time to Disassemble and Clean	minutes		<10
Cooling Temperature	C		<20
Material	Type	PET	PET
SAFETY			
Chemical Fumes			
Temperature of Outside	C		<50
Shutoff Time	sec		<5

Appendix D: Decision Matrix

This decision matrix uses two steps to compare designs. The first step is to assign the priorities for each of the categories of the system. Each design was then assigned a score in comparison to a baseline. This example analysis focuses on the cooling system of the extruder. The baseline was the air cooling system that used a fan, implemented by a group from Santa Clara University in 2014. The designs being considered were the ones produced by team members.

Project: AkaBot
System: Cooling System
Date: 11/18/2014

	Criterion	1	2	3	4	5	6	7	8	9	10	11	12	SUM	FACTOR
1	Weight		0	0	0	0	0	0	0	0	0	0		0	1
2	Speed	1		0	0	0.5	0	0	0	0	0	0		1.5	2
3	Consistency	1	1		1	1	1	1	1	1	1	1		10	10
4	Simplicity	1	1	0		0	0	1	1	0	0.5	0.5		5	4
5	Durability	1	0.5	0	1		1	1	1	1	1	1		8.5	10
6	Safety	1	1	0	1	0		1	1	0	1	0.5		6.5	8
7	Cost	1	1	0	0	0	0		1	1	0	0		4	4
8	Usage Time	1	1	0	0	0	0	0		0.5	0.5	0		3	2
9	Efficiency	1	1	0	1	0	1	0	0.5		0	0		4.5	4
10	Ease of Cleaning	1	1	0	0.5	0	0	1	0.5	1		0.5		5.5	6
11	Ease of Starting Extrusion	1	1	0	0.5	0	0.5	1	1	1	0.5			6.5	8

Figure 30: Prioritization matrix for the design specifications of the cooling system

Design Project = AkaBot **System=** Cooling System

	TARGET or	DESIGN IDEAS							
CRITERIA	FACTOR	1 = Baseline		Thermoelectrics		CounterFlow		Coil	
Time – Design	2	2		1		5		3	
Time – Build	1	1		2		3		3	
Time – Test	3	3		7		2		4	
Time Score	10		10		16.11		20.56		19.44
Cost – Prototype	100	$ 100.00		$ 100.00		$ 80.00		$ 80.00	
Cost – Production	30	$ 30.00		$ 50.00		$ 60.00		$ 40.00	
Cost Score	10		10		13.33		14.00		10.67
Weight	1	3	3	4	4	2	2	2	2
Speed	2	3	6	5	10	4	8	4	8
Consistency	10	3	30	5	50	5	50	5	50
Simplicity	4	3	12	1	4	2	8	2	8
Durability	10	3	30	3	30	3	30	4	40
Safety	8	3	24	3	24	3	24	3	24
Cost	4	3	12	2	8	2	8	2	8
Usage Time	2	3	6	3	6	4	8	4	8
Efficiency	4	3	12	4	16	4	16	4	16
Ease of Cleaning	6	3	18	3	18	2	12	2	12
Ease of Starting Extrusion	8	3	24	2	16	1	8	3	24
0	0	3	0		0		0		0
	TOTAL		177.0		176.6		159.4		189.9
	RANK								
	% MAX		93.2%		93.0%		84.0%		100.0%
	MAX	189.9							

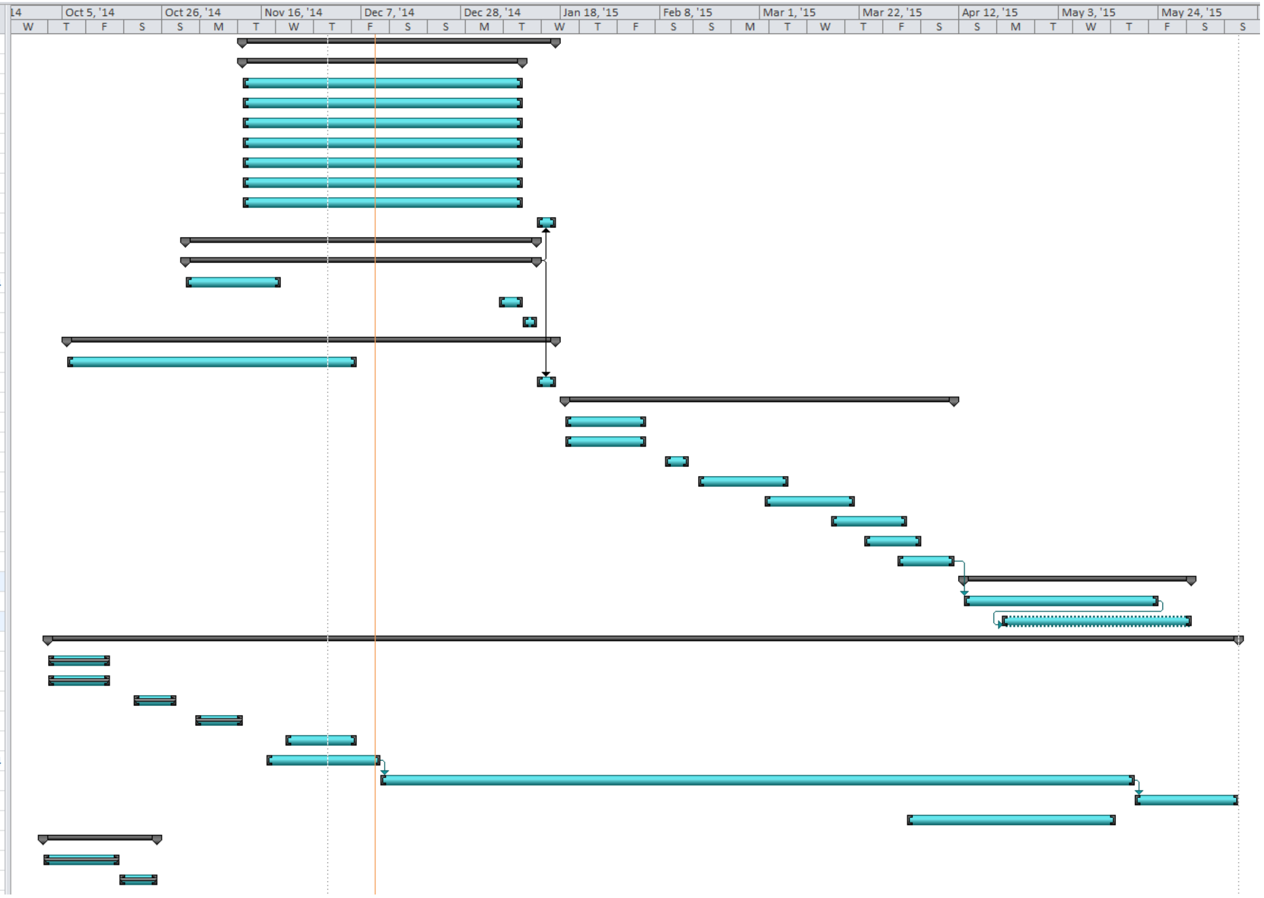
NOTE: User fills in Purple areas, gold areas are calculated or fixed
Light blue areas filled from prioritizing matrix

BASELINE = Air-cooling

Figure 31: Concept score in relation to baseline to determine best cooling system to use

Appendix E: Timeline

Task Name	Duration	Start	Finish
Design	**48 days**	**Wed 11/12/14**	**Fri 1/16/15**
Initial Design	**43 days**	**Wed 11/12/14**	**Fri 1/9/15**
Chamber Design	43 days	Wed 11/12/14	**Fri 1/9/15**
Auger Design	43 days	Wed 11/12/14	**Fri 1/9/15**
Thermal Calculations	43 days	Wed 11/12/14	**Fri 1/9/15**
Die Design	43 days	Wed 11/12/14	**Fri 1/9/15**
Cooling System	43 days	Wed 11/12/14	**Fri 1/9/15**
Spooling	43 days	Wed 11/12/14	**Fri 1/9/15**
Hopper	43 days	Wed 11/12/14	**Fri 1/9/15**
Final Design	4 days	Tue 1/13/15	Fri 1/16/15
Material Research	**52 days**	**Fri 10/31/14**	**Mon 1/12/15**
Initial DSC Testing	**52 days**	**Fri 10/31/14**	**Mon 1/12/15**
Preperation	14 days	Fri 10/31/14	Wed 11/19/14
Run Test	5 days	Mon 1/5/15	Fri 1/9/15
Analyzing	2 days	Sat 1/10/15	Mon 1/12/15
Finite Element Analysis	**75 days**	**Mon 10/6/14**	**Fri 1/16/15**
Initial Model	45 days	Mon 10/6/14	Fri 12/5/14
Final Model	4 days	Tue 1/13/15	Fri 1/16/15
Building	**60 days**	**Mon 1/19/15**	**Fri 4/10/15**
Auger Manufacturing	13 days	Mon 1/19/15	Wed 2/4/15
Chamber Manufacturing	13 days	Mon 1/19/15	Wed 2/4/15
Die Manufacturing	5 days	Mon 2/9/15	Fri 2/13/15
Spooling Manufacturing	15 days	Mon 2/16/15	Fri 3/6/15
Hopper Manufacturing	15 days	Mon 3/2/15	Fri 3/20/15
Cooling System	12 days	Mon 3/16/15	Tue 3/31/15
Controls	10 days	Mon 3/23/15	Fri 4/3/15
Final Assembly	10 days	Mon 3/30/15	Fri 4/10/15
Testing	**35 days**	**Mon 4/13/15**	**Sat 5/30/15**
Run Machine	31 days	Mon 4/13/15	Sat 5/23/15
DSC Testing	30 days	Tue 4/21/15	Sat 5/30/15
Reports	**179 days**	**Thu 10/2/14**	**Tue 6/9/15**
Problem Definition [O]	9 days	Thu 10/2/14	Tue 10/14/14
Problem Definition [W]	9 days	Thu 10/2/14	Tue 10/14/14
Customer Needs [W]	7 days	Mon 10/20/14	Tue 10/28/14
Design Ideas [W]	8 days	Sun 11/2/14	Tue 11/11/14
Conceptual Design Report [O]	11 days	Fri 11/21/14	Fri 12/5/14
Conceptual Design Report [W]	18 days	Mon 11/17/14	Wed 12/10/14
Thesis Draft [W]	113 days	Thu 12/11/14	Mon 5/18/15
Thesis Final [W]	16 days	Tue 5/19/15	Tue 6/9/15
Senior Design Presentation [O]	32 days	Wed 4/1/15	Thu 5/14/15
Funding	**18 days**	**Wed 10/1/14**	**Fri 10/24/14**
Roelandts Grant Proposal	12 days	Wed 10/1/14	Thu 10/16/14
School of Engineering Proposal	6 days	Fri 10/17/14	Fri 10/24/14



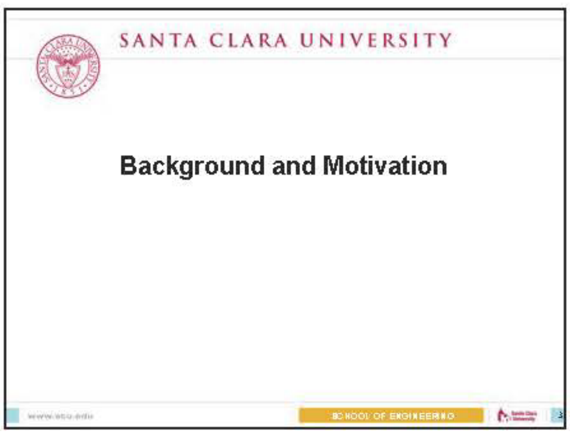
Appendix F: Budget

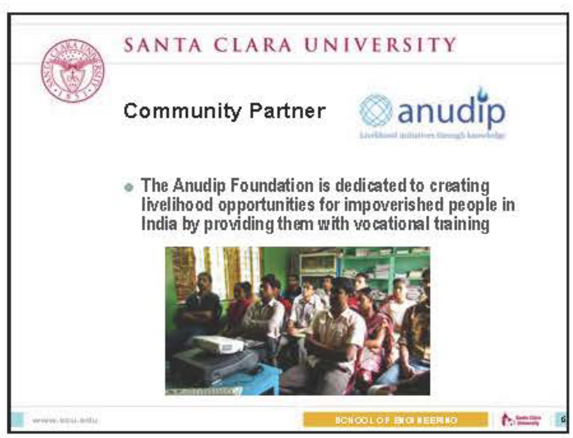
Part	Source	Part Number	Price Per Unit	Quantitiy Per Unit	Quantitiy Ordered	Price Per Unit	Number of Units	AkaBot Cost
Frame								$32.48
Russian Birch Plywood 12mm (5' x 5')	Southern Lumber	12RB	$42.79	25	1	$1.71	12	$20.54
Outside Corner-Reinforcing Bracket	McMaster	15705A34	$2.22	1	2	$2.22	2	$4.44
Inside Corner-Reinforcing Bracket 2" Length of Sides	McMaster	1088A31	$1.93	1	2	$1.93	2	$3.86
Bracket Zinc-Plated Steel, 2" Length of Sides	McMaster	1556A54	$0.91	1	4	$0.91	4	$3.64
Hardware								$21.32
Low-Strength Steel Hex Nut, Zinc Plated, 8-32 Thread Size, 11/32" Wide, 1/8" High	McMaster	90480A009	$1.49	100	1	$0.01	40	$0.60
Type 316 Stainless Steel Flat Washer, Number 8 Screw Size, 0.174" ID, 0.375" OD	McMaster	90107A010	$3.40	100	1	$0.03	100	$3.40
Type 316 Stainless Steel Button-Head Socket Cap Screw, 8-32 Thread, 3/4" Length	McMaster	98164A139	$7.98	25	1	$0.32	40	$12.77
18-8 Stainless Steel Button-Head Socket Cap Screw, 8-32 Thread, 1-1/2" Length	McMaster	92949A203	$11.36	100	1	$0.11	12	$1.36
Type 316 Stainless Steel Button-Head Socket Cap Screw, 6-32 Thread, 1-1/2" Length	McMaster	9816A445	$11.99	50	1	$0.24	4	$0.96
18-8 Stainless Steel Button-Head Socket Cap Screw, 8-32 Thread, 2" Length	McMaster	92949A207	$6.33	25	1	$0.25	4	$1.01
Steel Tee Nut for Wood, Zinc-Plated, 8-32 Interior Thread, 1/4" Long Barrel, 1/2" Flange Diameter	McMaster	90975A012	$8.54	100	1	$0.09	4	$0.34
Type 316 Stainless Steel Cup Point Set Screw, 8-32 Thread, 1/4" Long	McMaster	92313A190	$2.79	25	1	$0.11	4	$0.45
18-8 Stainless Steel Button-Head Socket Cap Screw, 4-40 Thread, 1-1/2" Length	McMaster	92949A120	$10.72	50	1	$0.21	2	$0.43
Low-Strength Steel Hex Nut, Zinc Plated, 6-32 Thread Size, 5/16" Wide, 7/64" High	McMaster	90480A007	$1.16	100	1	$0.01	4	$0.05
Type 316 Stainless Steel Flat Washer, Number 6 Screw Size, 0.156" ID, 0.312" OD	McMaster	90107A007	$3.39	100	1	$0.03	4	$0.14

Heating								$99.75
Band Heater, 900 Deg F, 1" Diameter, 2" Width	Grainger	2VXZ4	$33.25	1	4	$33.25	3	$99.75
Mechanical Power								$85.18
10 RPM Gear Motor	ServoCity	RZ12-300-10RPM	$24.99	1	1	$24.99	1	$24.99
90 Degree Hub Mount bracket A	ServoCity	585494	$5.99	1	1	$5.99	1	$5.99
Aluminum Motor Mount B	ServoCity	555128	$4.99	1	1	$4.99	1	$4.99
Metal Chain (.250) 1 ft length	ServoCity	C250	$8.99	1	1	$8.99	1	$8.99
16 Tooth Sprocket	ServoCity	615102	$3.99	1	2	$3.99	2	$7.98
6mm Bore Set Screw Hub	ServoCity	545576	$4.99	1	1	$4.99	1	$4.99
0.5" Bore Set Screw Hub	ServoCity	545560	$4.99	1	1	$4.99	1	$4.99
Type 316 Stainless Steel Button-Head Socket Cap Screw, 6-32 Thread, 3/8" Length	McMaster	98164A107	$10.00	100	1	$0.10	4	$0.40
Steel Ball Bearing-ABEC-1, Open Bearing No.R8 for 1/2" Shaft Diameter, 1-1/8" OD	McMaster	60355K505	$6.04	1	1	$6.04	1	$6.04
Hinged One-Piece Clamp-on Shaft Collar, for 1/2" Diameter, Black-Oxide Steel	McMaster	57145K72	$15.82	1	2	$15.82	1	$15.82
Hopper								$2.35
30 Gauge Sheet Metal	McMaster	89015K111	$4.01	48	1	$0.08	28.13	$2.35
Auger & Chamber & Die								$66.69
Weldtec Ship Auger 3/4"	Southern Lumber		$32.99	1	1	$32.99	1	$32.99
Seamless Stainless Tube 316 OD:1" ID:0.76" L:24"	Online Metals		$54.92	24	1	$2.29	13	$29.75
Ultra Machinable 360 Brass Rod Diameter:1-1/16" by 12" Length	McMaster	8953K33	$42.05	12	1	$3.50	1	$3.50
Type 316 Stainless Steel Cup Point Set Screw, 8-32 Thread, 1/4" Long	McMaster	92313A190	$2.79	25	1	$0.11	4	$0.45

Cooling								$35.82
18-8 Stainless Steel Sealing Pan Head Phillips Machine Screw, Silicone O-Ring, 6-32 Thread, 0.5" Length	McMaster	90825A717	$6.29	10	2	$0.63	12	$7.55
3/16 set screw hub	ServoCity	545544	$4.99	1	4	$4.99	4	$19.96
Optically Clear Cast Acrylic Sheet	McMaster	8560K261	$33.24	6	1	$5.54	1.5	$8.31
Electronics								$234.79
Solid State Relay - 40A (3-32V DC Input)	SparkFun	COM-13015	$9.95	1	3	$9.95	3	$29.85
Thermocouple Type-K Glass Braid Insulated	SparkFun	SEN-00251	$13.95	1	3	$13.95	3	$41.85
Sestos Dual Digital PID Temperature Controller 2 Omron Relay Output Black D1s-vr-220	Amazon		$28.99	1	3	$28.99	3	$86.97
Rocker Switch - SPST (round)	SparkFun	COM-11138	$0.50	1	4	$0.50	4	$2.00
6 Amp AC to 12V DC Power Adapter	Amazon		$11.98	1	1	$11.98	1	$11.98
22 - 16 AWG, #4 - 6 Stud Size Red Vinyl-Insulated Spade Terminals	Home Depot	410651	$6.97	75	3	$0.09	78	$7.25
Standard Wire, 300V AC, 20 Gauge, 50 ft, Black	McMaster	8054T14	$7.57	50	1	$0.15	8	$1.21
Standard Wire, 300V AC, 20 Gauge, 50 ft, Red	McMaster	8054T14	$7.57	50	1	$0.15	13	$1.97
Standard Wire, 300V AC, 20 Gauge, 50 ft, White	McMaster	8054T14	$7.57	50	1	$0.15	18	$2.73
300 VAC/VDC Terminal Block, 10 Circuits, 3/8" Center-to-Center, 20 Amps	McMaster	7527K51	$4.51	1	3	$4.51	3	$13.53
9' Power Tool Cord	Home Depot	756847000269	$13.97	1	1	$13.97	1	$13.97
Mounting Tape	Home Depot	21200471025	$9.97	75	1	$0.13	24	$3.19
Red Acrylic	Tap Plastic		$73.20	12	12	$6.10	3	$18.30
Raw Material								$59.58
Multipurpose 6061 Aluminum Rectangular Bar, 1-5/8" x 1-5/8" x 12"	McMaster	9008K48	$19.60	12	1	$1.63	1.5	$2.45
Oversized Multipurpose 6061 Aluminum	McMaster	89155K162	$91.41	24	1	$3.81	15	$57.13
							Total	**$635.61**

Appendix G: Senior Design Presentation Slides





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Problem Definition

- Anudip wants to implement 3D printing in vocational training centers
- Problem: 3D printing requires a large of volume of material; filament is expensive to import
- Solution: Locally produce filament using waste materials or cheaper materials

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Plastic Waste

- High usage of plastic water bottles for both clean water and as containers
- Lack of recycling infrastructure
- Used bottles pile up as trash

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Project Goals

- Produce acceptable PET filament
  - Pellets or water bottles
  - Ductility and consistency
- Keep machine affordable

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Previous Research

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Initial Testing With AkaBot 1.0

- Orientation of Machine
- New chamber mounts
- Die Design
- New cooling system

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Proposed Changes for AkaBot 2.0

- Extrude 1.75mm filament
- Vertical orientation
- Liquid cooling system

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Material Characterization

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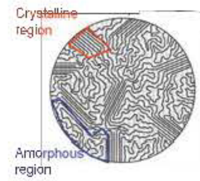
PET

- Polyethylene Terephthalate
- Semi-crystalline
- Ductility is sensitive to cooling profile and water absorption



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Test for Feasibility

- Differential Scanning Calorimetry (DSC)
  - Tests for:
    - Glass transition
    - Melting temperature
    - Percent crystallinity

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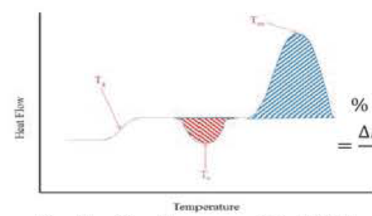
DSC Test



$$\%\ Crystallinity = \frac{\Delta H_m - \Delta H_c}{\Delta H^{\circ}_m} \cdot 100$$

Glass Transition Temperature (Tg), Cold Crystallization Temperature (Tc), Melting Temperature (Tm)

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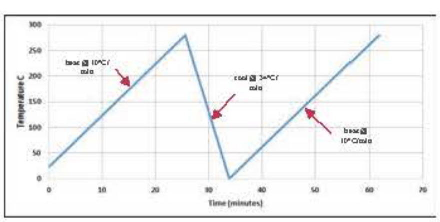
Plastic Testing



Heating Profile of Initial DSC Test

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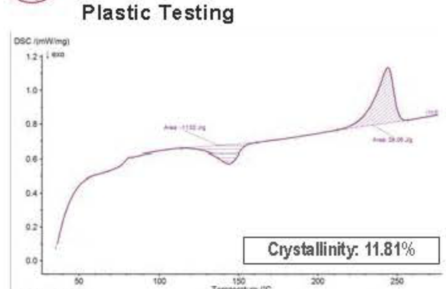
Plastic Testing



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Results: What We Learned

- Melting temperature must exceed 250°C
- A low crystallinity can be achieved with recycled water bottles
- Cooling profile must exceed 34°C/min

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Design Specifications

Baseline	Requirement
Filament Size	1.75 mm ±0.1mm
Extrusion Speed	0.2-0.7 cm/sec
Extrusion Temperature	250 °C
Time to Disassemble and Clean	<10 min
Cooling Rate	>34°C/min
Price	$500-$750

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AkaBot 2.0

Chamber & Heating > Auger > Extrusion Die > Cooling

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Chamber & Heating

- 316 stainless steel tube
- 250 Watt heating bands
- Groove for thermocouples

Chamber & Heating > Auger > Extrusion Die > Cooling

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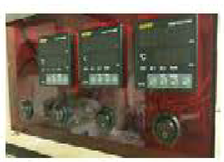
Temperature Control

- 3 PID controllers
- Individual switches
- Maintain ± 1°C



Chamber & Heating > Auger > Extrusion Die > Cooling

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Auger

- Functions as a screw pump
- Custom machined vs. purchased
- Vertical orientation generates sufficient pressure

Purchased

Custom

Chamber & Heating > Auger > Extrusion Die > Cooling


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Mechanical Power
10 RPM motor
2.5:1 gear ratio to increase torque
Chain drive
Chamber & Heating
Auger
Extrusion Die
Cooling
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Extrusion Die
360 brass
Conical shape
Swelling of material
Easy to remove
Chamber & Heating
Auger
Extrusion Die
Cooling
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26


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Cooling
Vegetable oil
Fast cooling rate
Replenished with fresh oil as it heats
Chamber & Heating
Auger
Extrusion Die
Cooling
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Bottle Preparation
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Material Issues
Paper shredder does not completely shred bottles
Too much space within chamber, not enough pressure at die
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Extrusion Process
Filament pulled through by hand
Cooled by oil
Oil residue cleaned off
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Extrusion Video

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Results and Conclusions

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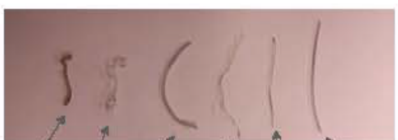
Filament Progression



Machine	1.0	1.0	2.0	2.0	2.0	Purchase
Date	2/22	3/4	4/26	5/7	5/10	N/A
Diameter	2.33	1.45	2.16	1.53	1.77	1.75

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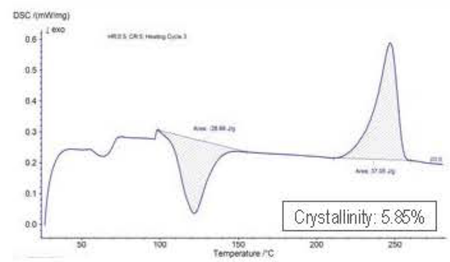
Results: DSC Tests



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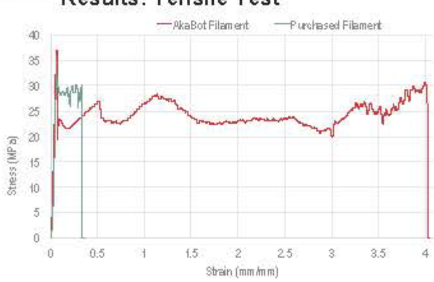
Results: Tensile Test



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Results: Tensile Tests

	Purchased Filament	AkaBot 1.0 Filament	AkaBot 2.0 Filament
Diameter (mm)	1.80	1.04	**1.77**
Yield Strength (MPa)	34.48	29.5	**35.98**
Modulus of Elasticity (MPa)	909.76	366	**731.60**
Elongation at Fracture (mm)	28.46	3.48	**323.91**

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Design Specifications

Baseline	Requirement	Actual
Filament Size	1.75 mm ±0.1mm	**1.77 mm ±0.3mm**
Extrusion Speed	0.2-0.7 cm/sec	**2 cm/sec**
Extrusion Temperature	250 °C	**260 °C**
Time to Disassemble and Clean	<10 min	**10 min**
Cooling Rate	>34 °C/min	**36 °C/sec**
Price	$500-$750	**$637.96**

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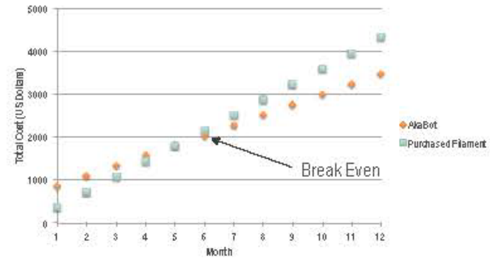
Economic Analysis



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Future Work

- **Spring Quarter:**
  - Filament size range
  - Redesign and implement hopper
  - Test data
  - 3D print with filament
- **Next Year:**
  - Design and build spooling system
  - Melting and pelletizing of water bottles

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Conclusion

- **Possible to produce 3D printing filament on small scale**
- **System can be deployed for testing in India**

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Acknowledgments

- **The Center for Science, Technology, and Society**
- **Dr. Panthea Sepehrband**
- **Donald MacCubbin, Joe Soares, Calvin Sellers**
- **Dr. Hohyun Lee**
- **SCU School of Engineering**
- **Bottle Collectors**

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Questions?

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Supplementary Slides

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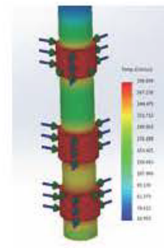
Finite Element Analysis



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Final Budget

Subassembly	Cost
Frame	$32.48
Hardware	$21.32
Heating	$99.75
Mechanical Power	$85.18
Hopper	$2.35
Auger, Chamber, and Die	$66.69
Cooling	$35.82
Electronics	$234.79
Raw Material	$59.58
Total	**$637.96**

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Economic Analysis Per Month

Inputs	Units	Price Per Unit	Quantity	Cost
PET Pellets	kg	$2.50	10	$25.00
Electricity	kWh	$0.12	115.2	$13.82
Labor	Monthly wage	$65.94	3	$197.82
				$236.64

Based on a production and usage level of 20kg per month

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Hopper

- Gravity fed for constant input

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Frame

- Laser cut wood for rapid assembly
- Room for future expansion

Appendix H: Tensile Test Graphs and Results

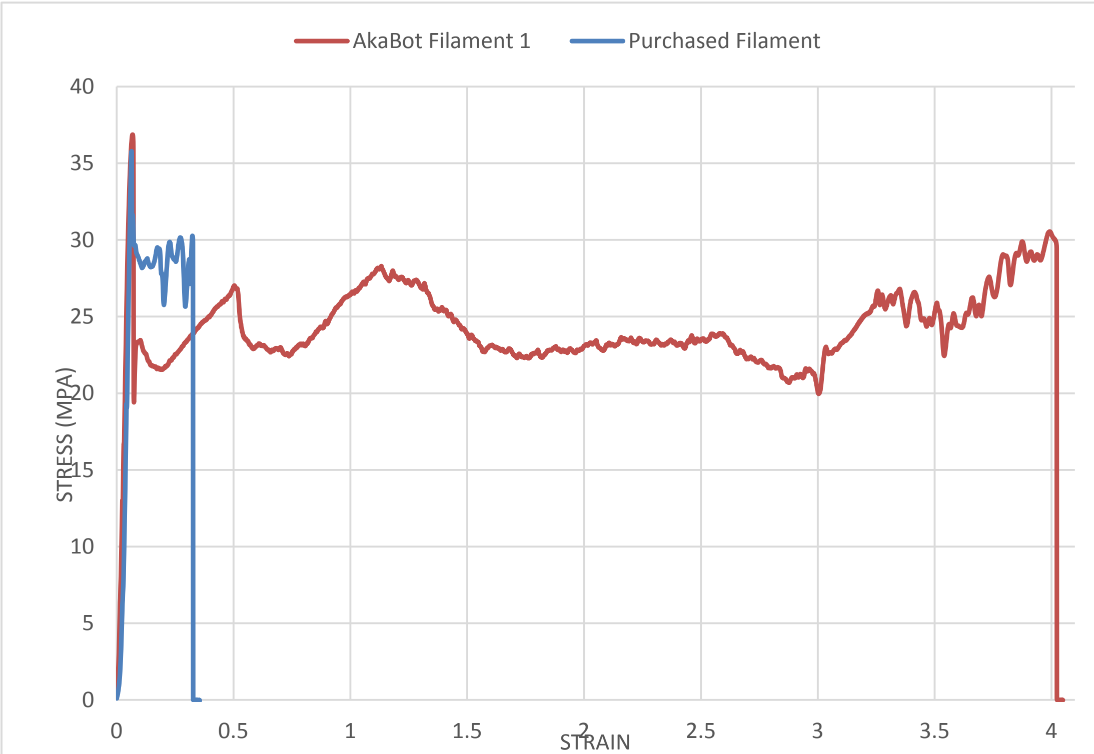


Figure 32: Session 1 tensile test of AkaBot 2.0 and purchased filament

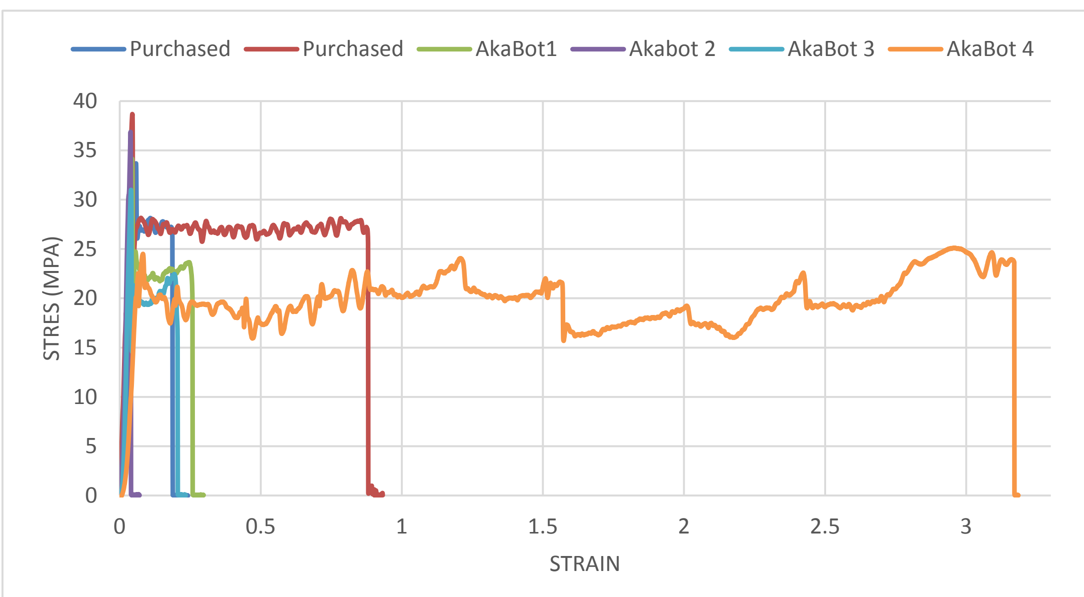
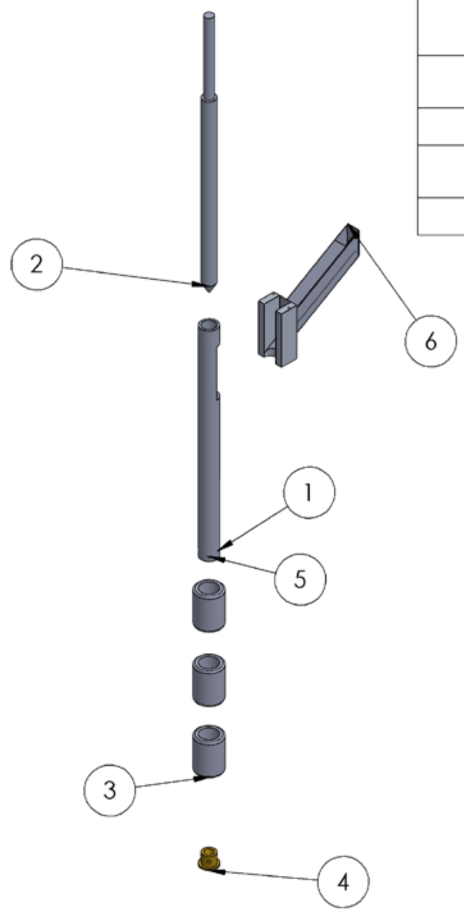


Figure 33: Session 2 tensile test AkaBot 2.0 and purchased filament

Appendix I: Detailed Drawings and Assembly Drawings

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Chamber		1
2	Auger	Deep-Hole Drill Bit for Wood 1" Bit Size, 17" Overall Length, 12" Drill Depth	1
3	Heating Band	Band Heater, 900 Deg F, 1-1/2 In. Dia. by 2 In. Length	3
4	Die_version 2		1
5	92313A190	Type 316 Stainless Steel Cup Point Set Screws, 8-32 Thread, 1/4" Long	4
6	Hopper Assembly		1



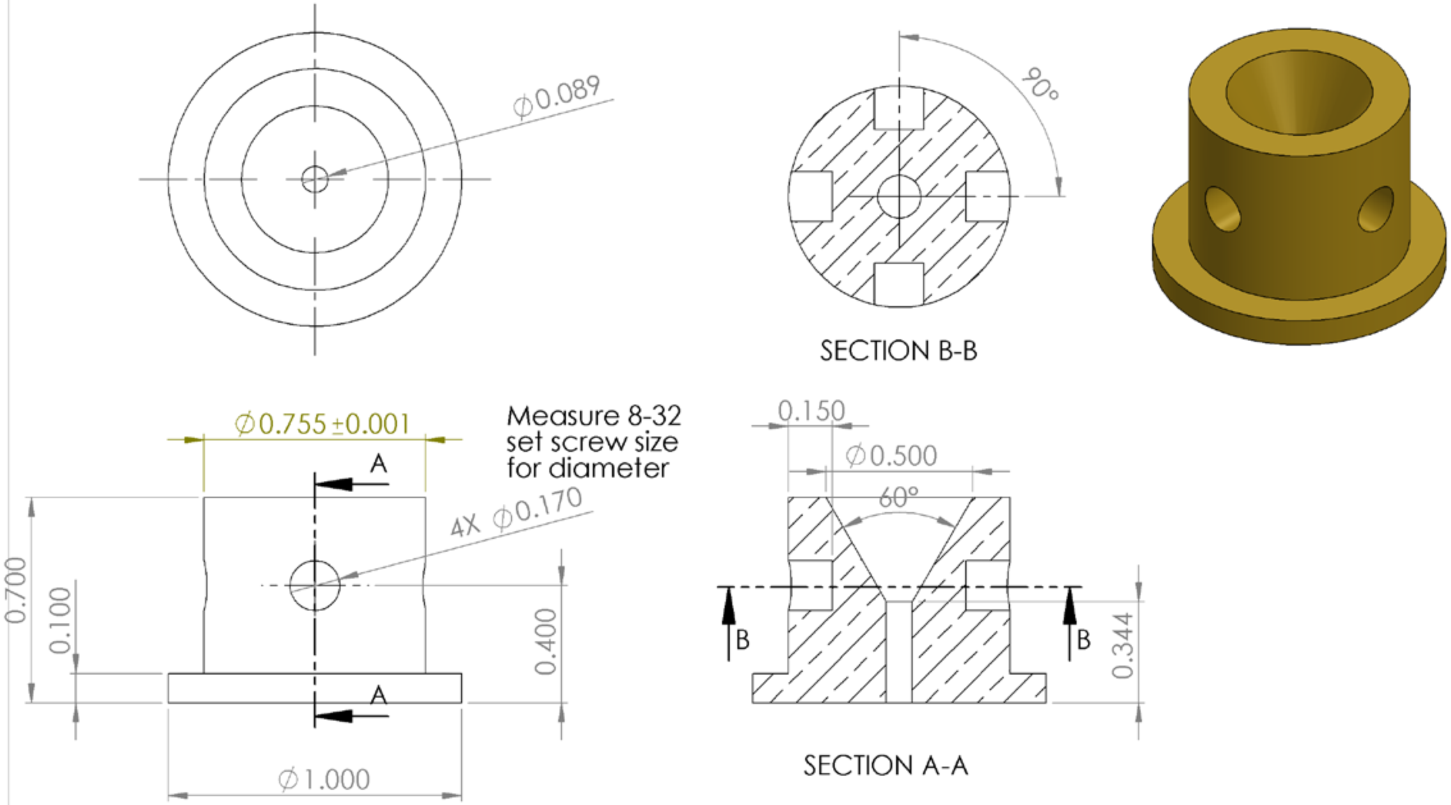
		NAME	DATE
UNLESS OTHERWISE SPECIFIED:			
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	BJG	3-15-15
	CHECKED	ANM	3-17-15
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

AkaBot 2015

TITLE: Auger & Chamber Assembly

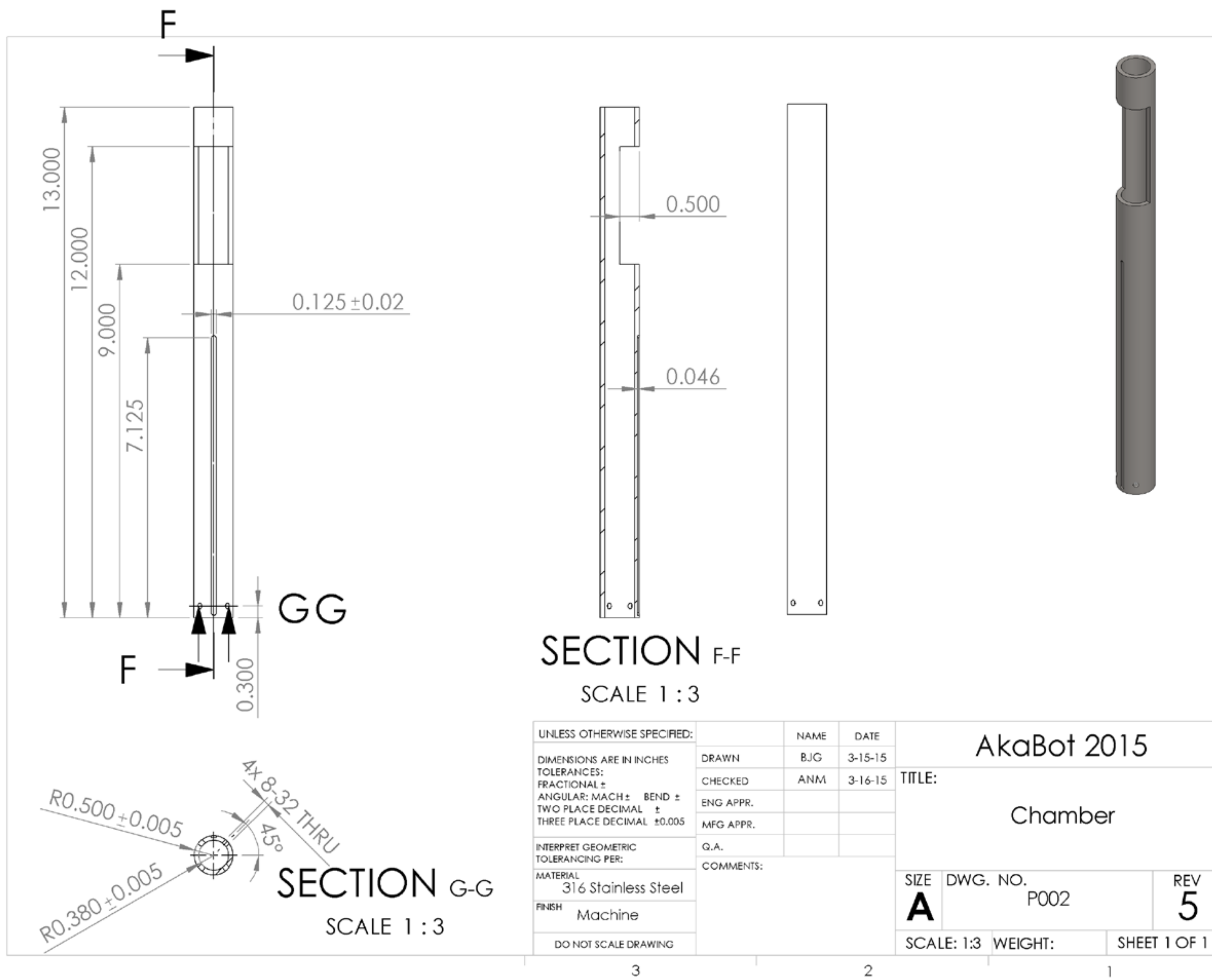
SIZE	DWG. NO.	REV
A	A001	2
SCALE: 1:6	WEIGHT:	SHEET 1 OF 1

3 2 1

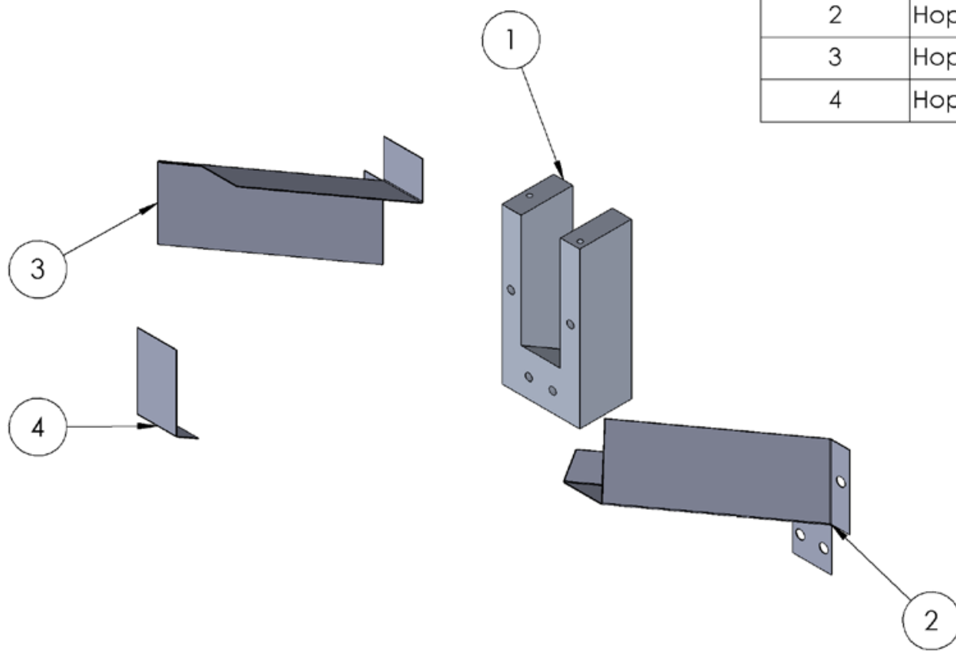


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±0.005	DRAWN	BJG	4-2-15	TITLE:
	CHECKED	ANM	4-3-15	Die
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Brass	COMMENTS:			SIZE A · DWG. NO. P003 · REV 2
FINISH Machine				
DO NOT SCALE DRAWING				SCALE: 2:1 · WEIGHT: · SHEET 1 OF 1

3 2 1

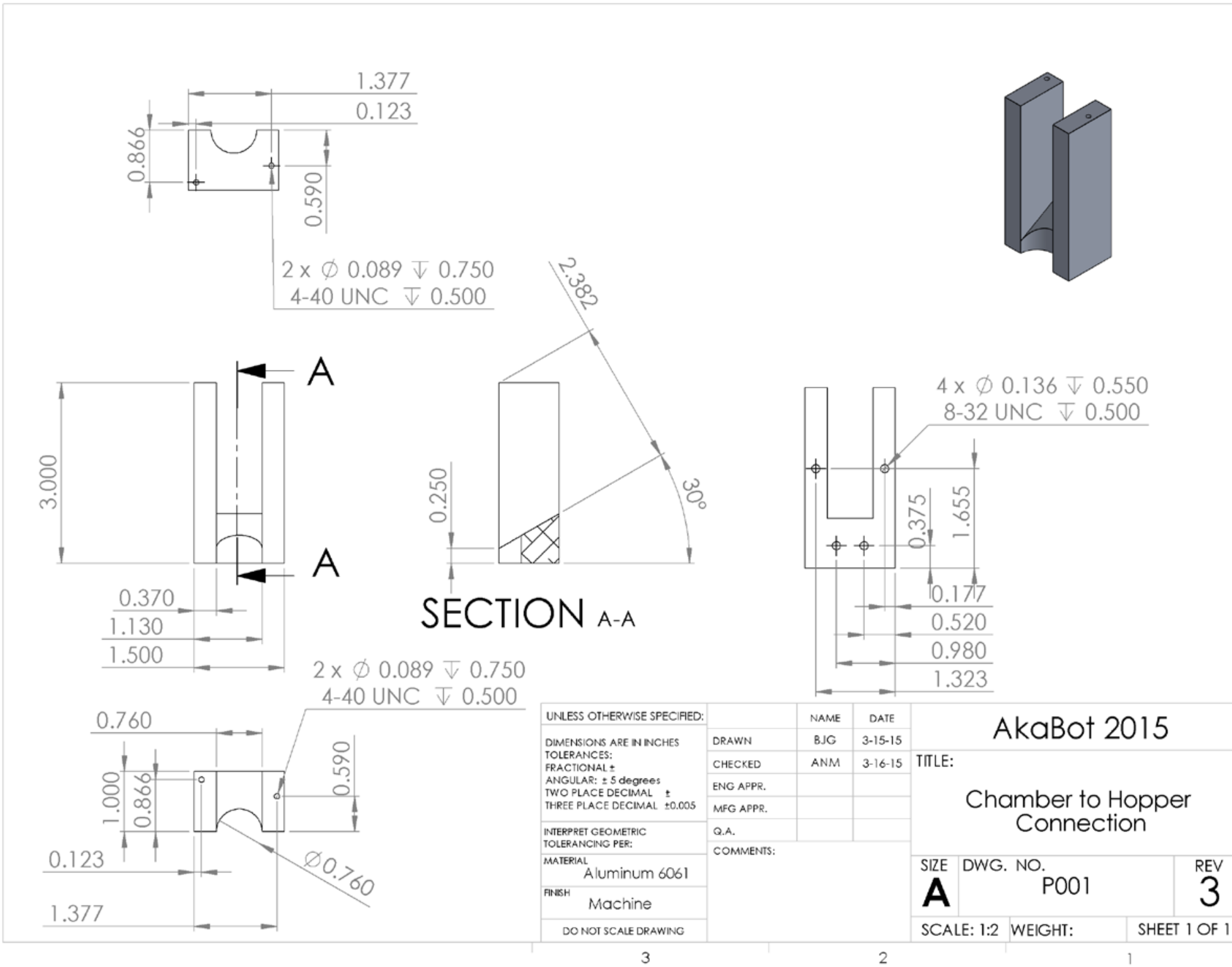

F
13.000
12.000
9.000
7.125
0.125 ±0.02
G G
F
0.300
0.500
0.046
SECTION F-F
SCALE 1 : 3
R0.500 ±0.005
R0.380 ±0.005
4x 8-32 THRU
45°
SECTION G-G
SCALE 1 : 3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
316 Stainless Steel
FINISH
Machine
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
BJG
3-15-15
CHECKED
ANM
3-16-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Chamber
SIZE
A
DWG. NO.
P002
REV
5
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
3
2
1

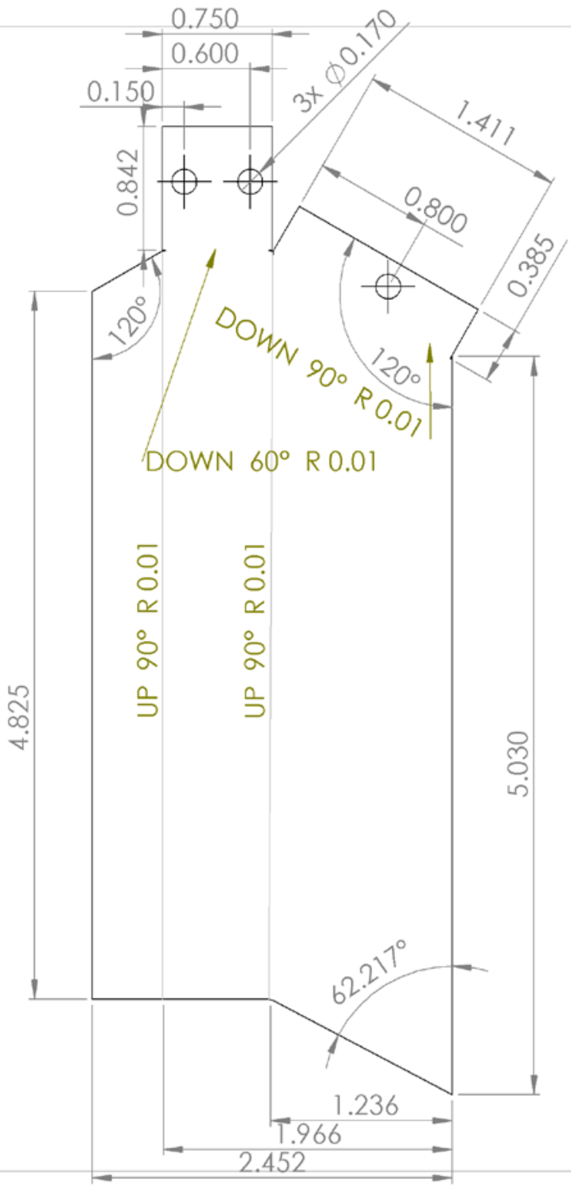
ITEM NO.	PART NUMBER	QTY.
1	Chamber to Auger Connection	1
2	Hopper_Bottom	1
3	Hopper_Top	1
4	Hopper_Back	1

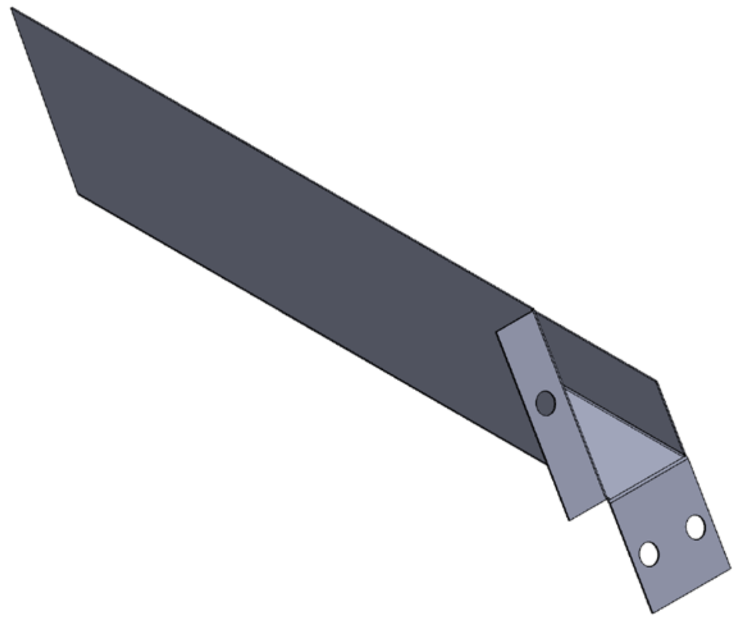


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	JKD	4-3-15	TITLE:
	CHECKED	BJG	4-4-15	Hopper Assembly
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A — DWG. NO. A005 — REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 — WEIGHT: — SHEET 1 OF 1

3 2 1

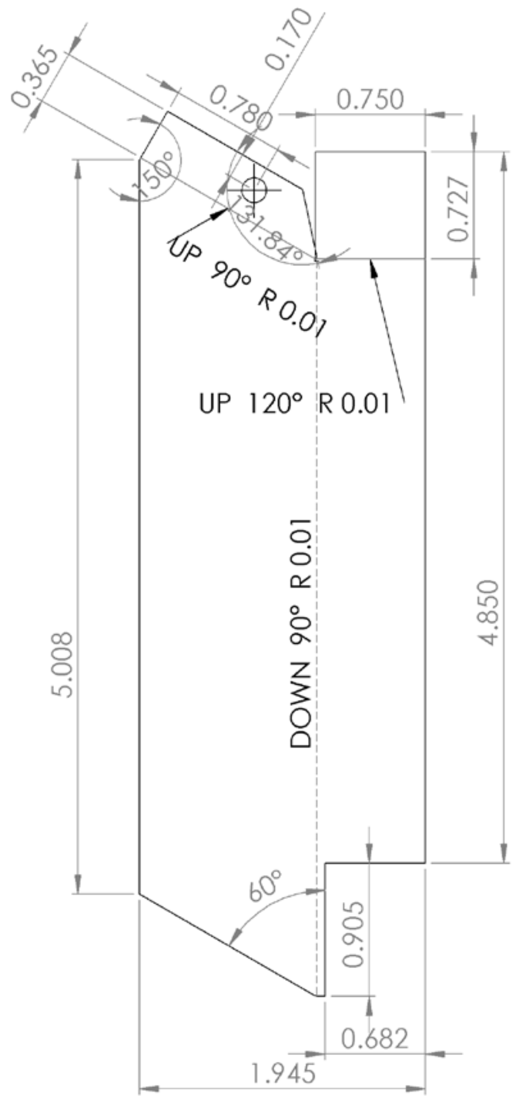

1.377
0.123
0.866
0.590
2 x ∅ 0.089 ↧ 0.750
4-40 UNC ↧ 0.500
2.382
A
A
3.000
0.250
30°
4 x ∅ 0.136 ↧ 0.550
8-32 UNC ↧ 0.500
0.375
1.655
0.370
1.130
1.500
SECTION A-A
0.177
0.520
0.980
1.323
2 x ∅ 0.089 ↧ 0.750
4-40 UNC ↧ 0.500
0.760
1.000
0.866
0.590
0.123
∅0.760
1.377
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: ± 5 degrees
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum 6061
FINISH
Machine
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
BJG
3-15-15
CHECKED
ANM
3-16-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Chamber to Hopper Connection
SIZE
A
DWG. NO.
P001
REV
3
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
3
2
1

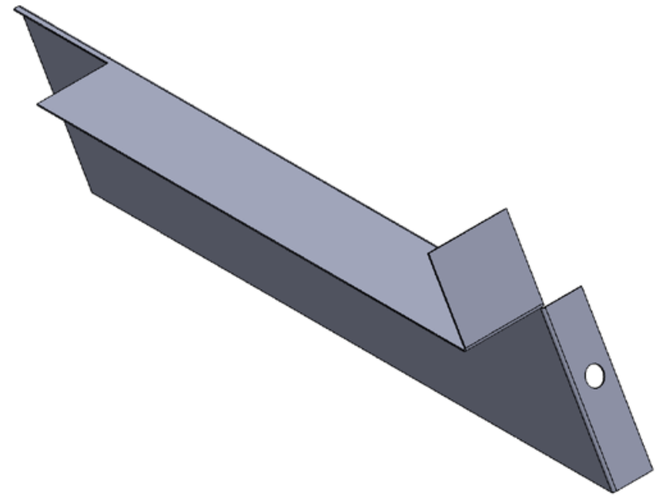




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±0.005	DRAWN	JKD	5-7-15	TITLE:
	CHECKED	BJG	5-8-15	Hopper Bottom
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Sheet Metal	COMMENTS: 30 gauge			SIZE A DWG. NO. P019 REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

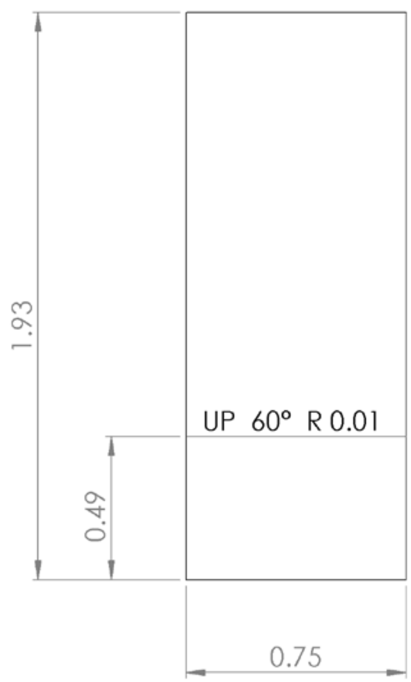
3 2 1

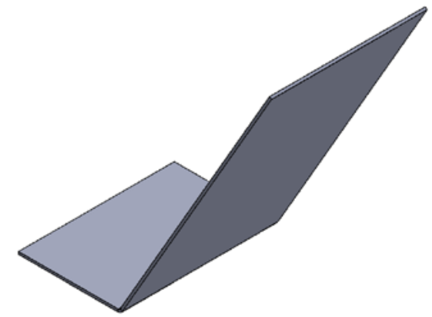




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±0.005	DRAWN	JKD	5-7-15	TITLE:
	CHECKED	BJG	5-8-15	Hopper Top
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Sheet Metal	COMMENTS: 30 Gauge			SIZE A DWG. NO. P020 REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:1 WEIGHT: SHEET 1 OF 1

3 2 1





UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL
Sheet Metal

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	JKD	5-7-15
CHECKED	BJG	5-8-15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:
30 Gauge

AkaBot 2015

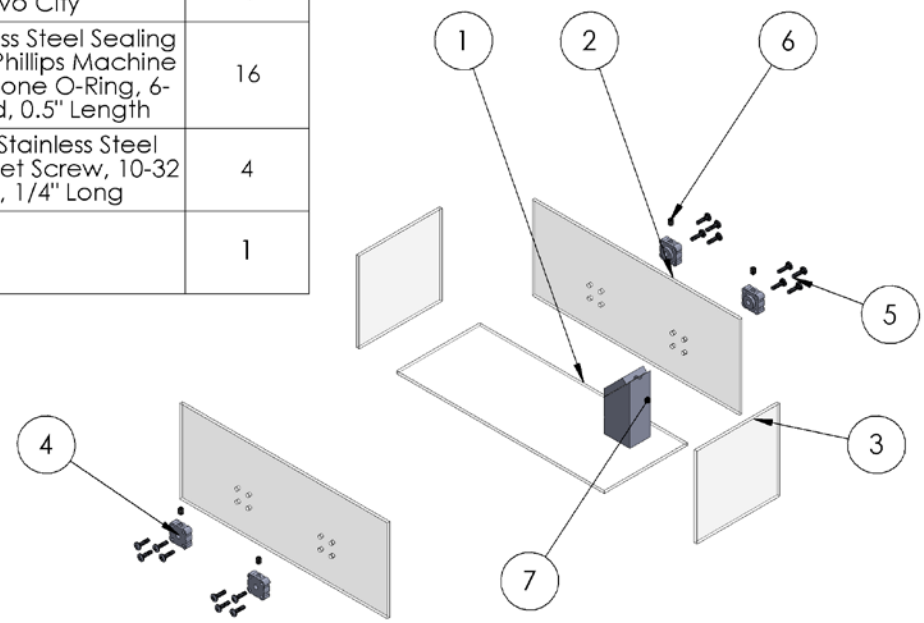
TITLE:
Hopper Back

SIZE A | DWG. NO. P018 | REV 2

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

3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bottom Plate		1
2	Side Plate		2
3	End Plates		2
4	545544_part	3/16 Set Screw Hub From Servo City	4
5	90825A717	18-8 Stainless Steel Sealing Pan Head Phillips Machine Screw, Silicone O-Ring, 6-32 Thread, 0.5" Length	16
6	92313A825	Type 316 Stainless Steel Cup Point Set Screw, 10-32 Thread, 1/4" Long	4
7	Trough		1



Note: Acrylic cement used to bond acrylic pieces

UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	BJG	3-15-15
	CHECKED	ANM	3-16-15
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

AkaBot 2015

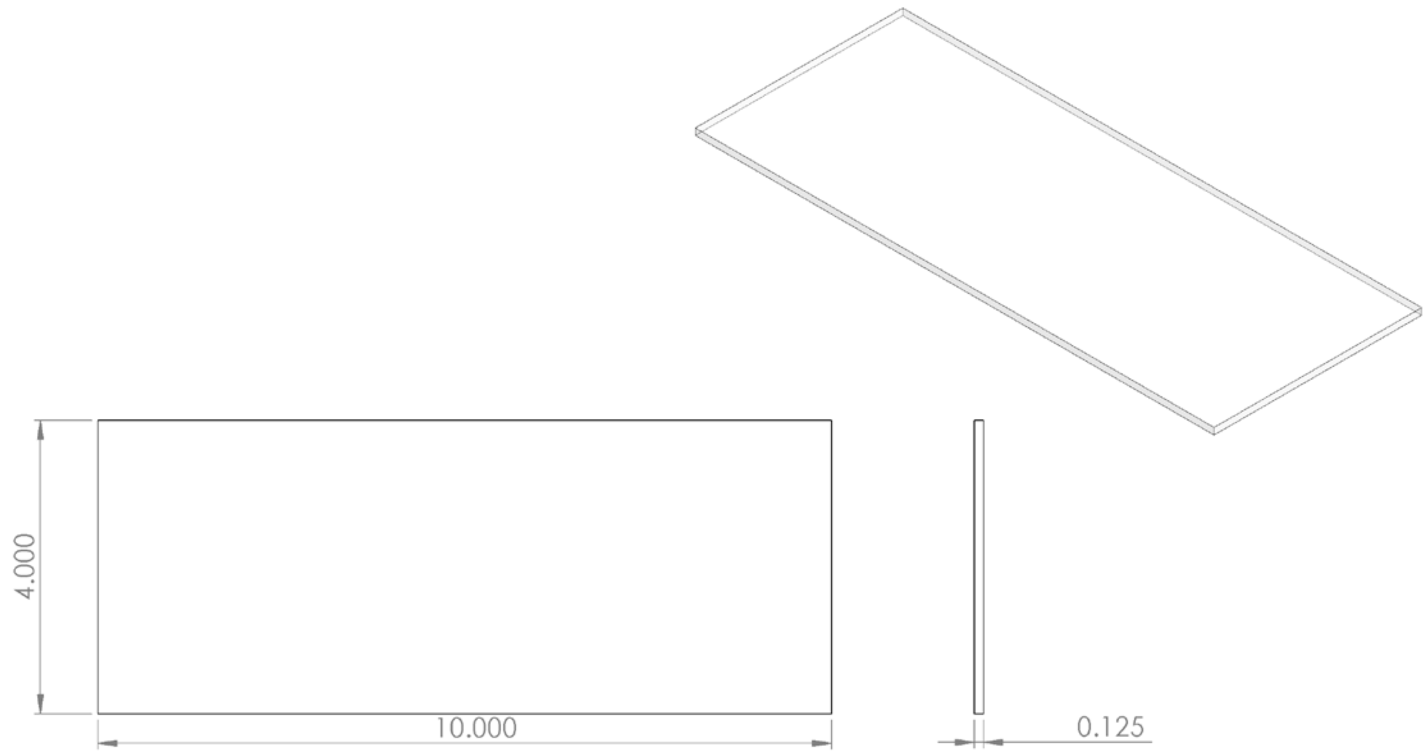
TITLE:

Cooling Box Assembly

SIZE	DWG. NO.	REV
A	A002	2

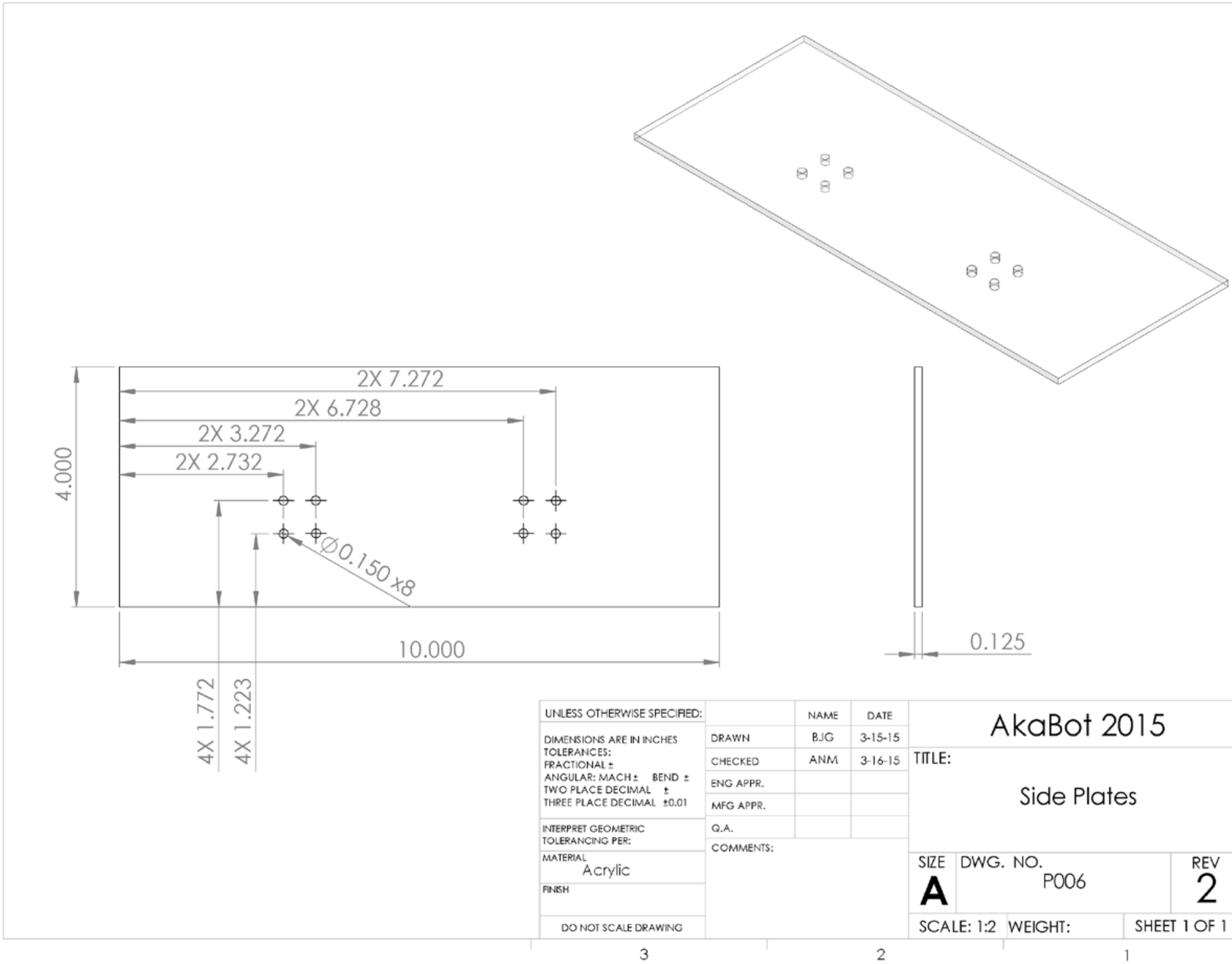
SCALE: 1:5 WEIGHT: SHEET 1 OF 1

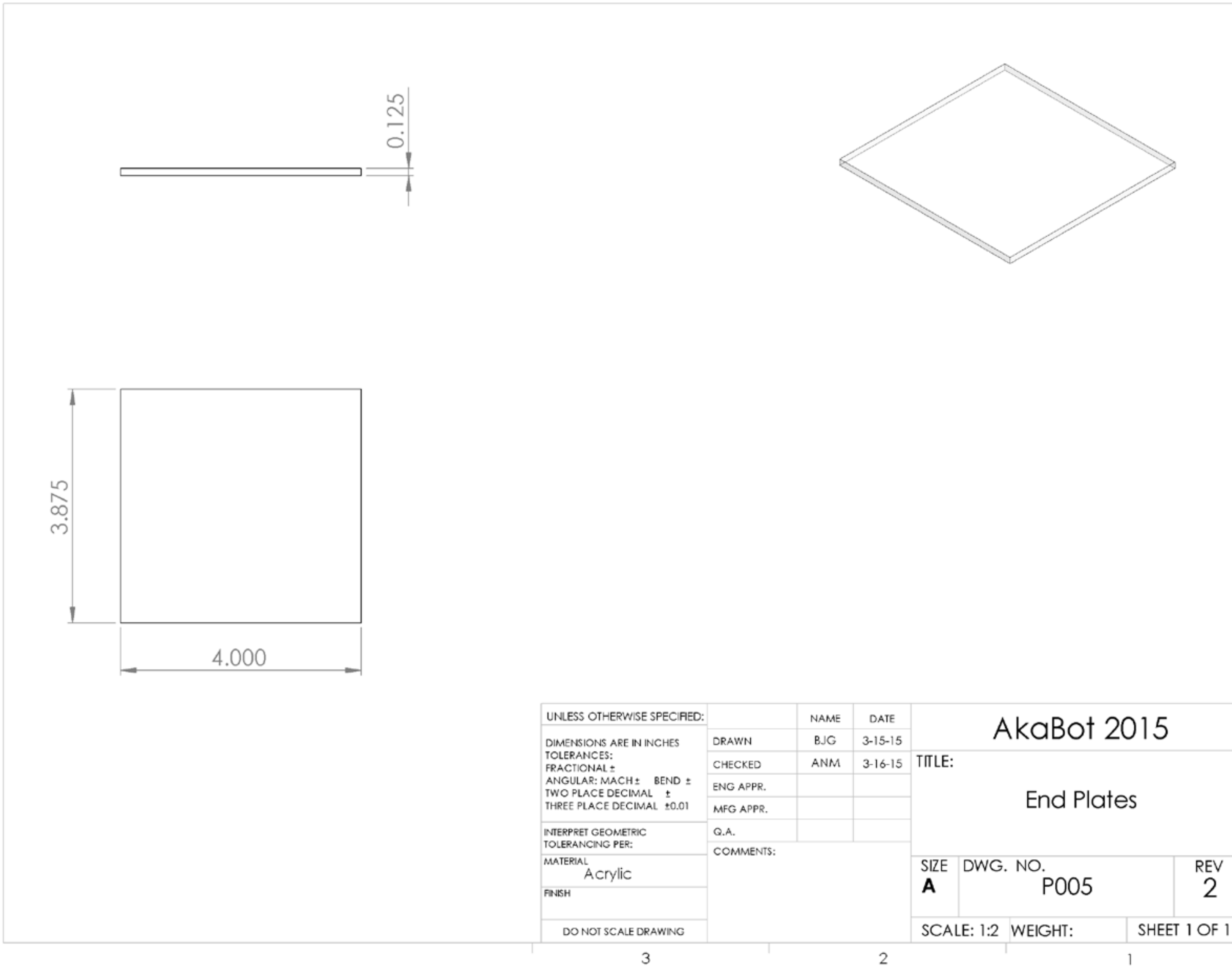
3 2 1

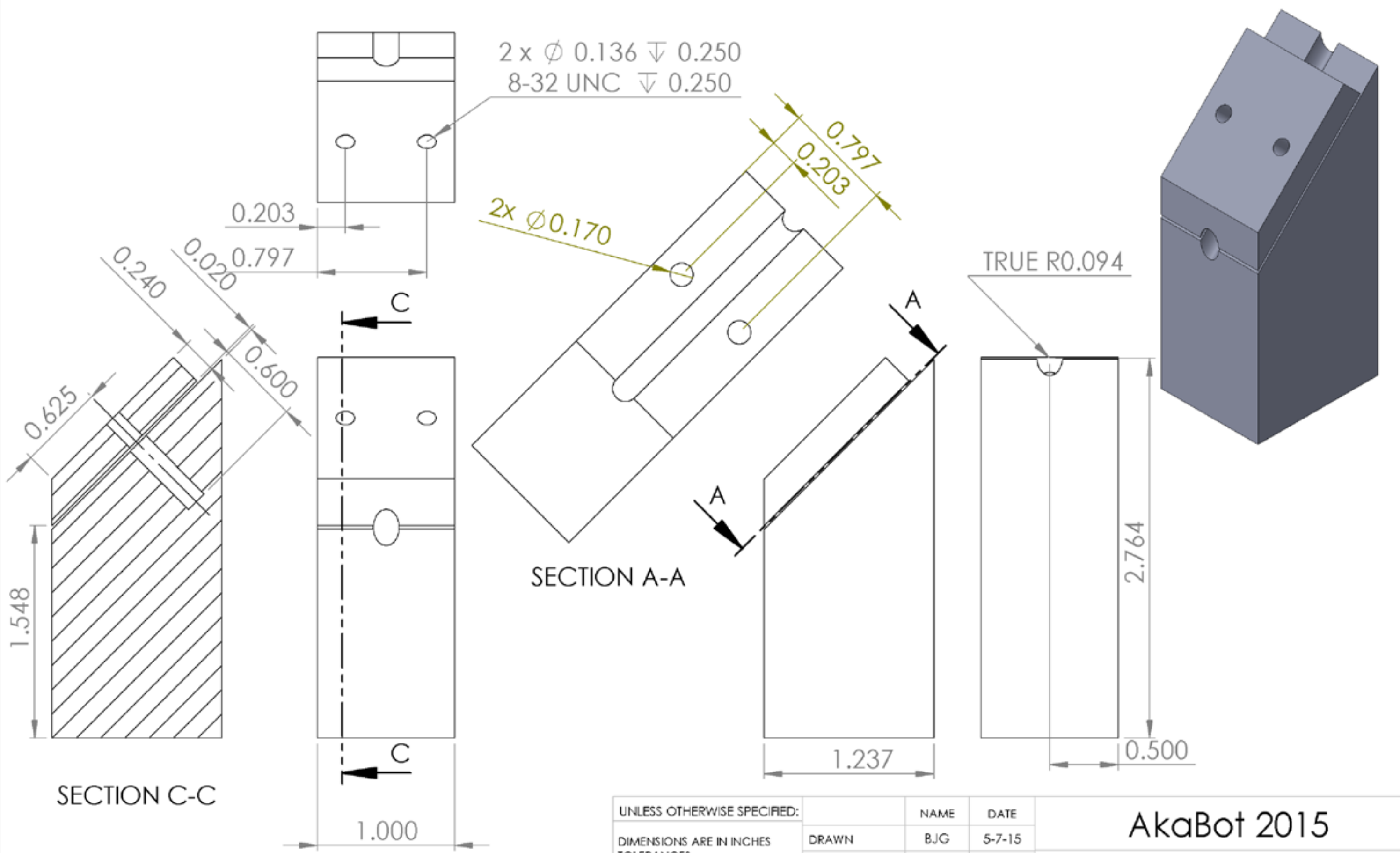


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±0.005	DRAWN	BJG	3-15-15	TITLE:
	CHECKED	ANM	3-16-15	Bottom Plate
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Acrylic	COMMENTS:			SIZE A DWG. NO. P004 REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 1 OF 1

3 2 1


2X 7.272
2X 6.728
2X 3.272
2X 2.732
4.000
∅0.150 x8
10.000
4X 1.772
4X 1.223
0.125
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.01
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Acrylic
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
BJG
3-15-15
CHECKED
ANM
3-16-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Side Plates
SIZE
A
DWG. NO.
P006
REV
2
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
3
2
1

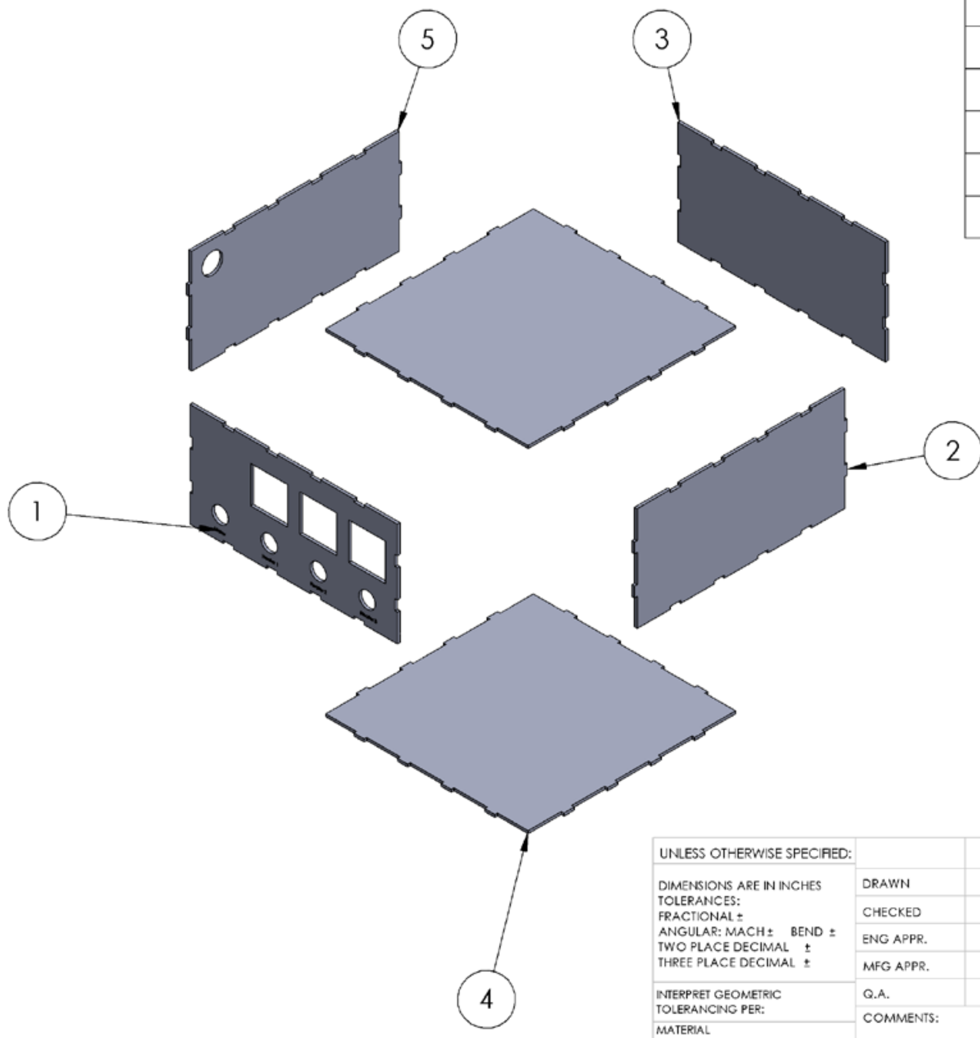

0.125
3.875
4.000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.01
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Acrylic
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN BJG 3-15-15
CHECKED ANM 3-16-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
End Plates
SIZE A
DWG. NO. P005
REV 2
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
3
2
1



Starting Material Block Size:
1" x 1.25" x 3.125"

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±0.002	DRAWN	BJG	5-7-15	TITLE:
	CHECKED	ANM	5-8-15	Trough
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Aluminum	COMMENTS:			SIZE A · DWG. NO. P007 · REV 1
FINISH Machine				
DO NOT SCALE DRAWING				SCALE: 1:1 · WEIGHT: · SHEET 1 OF 1

3 2 1

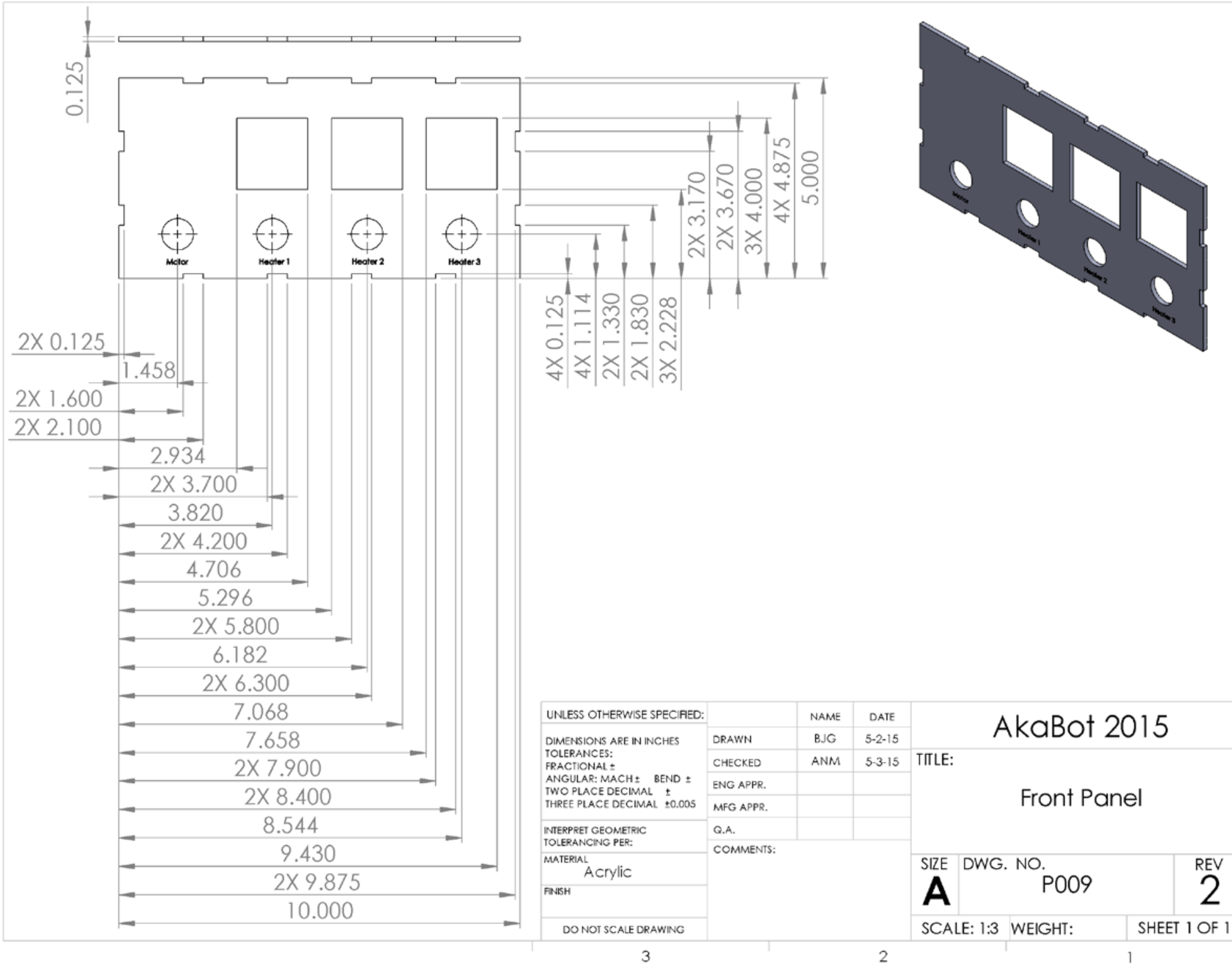


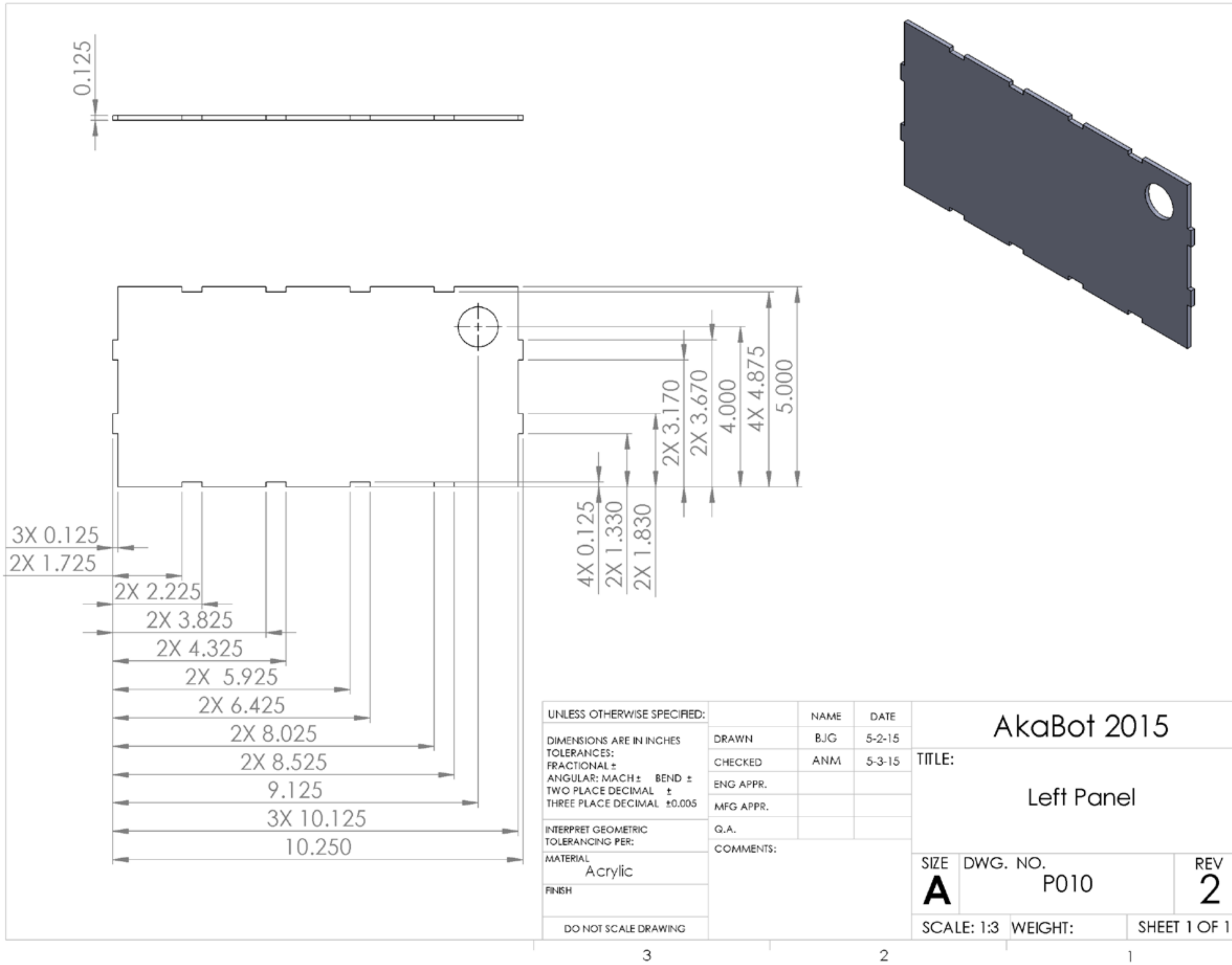
ITEM NO.	PART NUMBER	QTY.
1	Front Panel	1
2	Side Panels	1
3	Back Panel	1
4	Top Plate	2
5	Left Panel	1

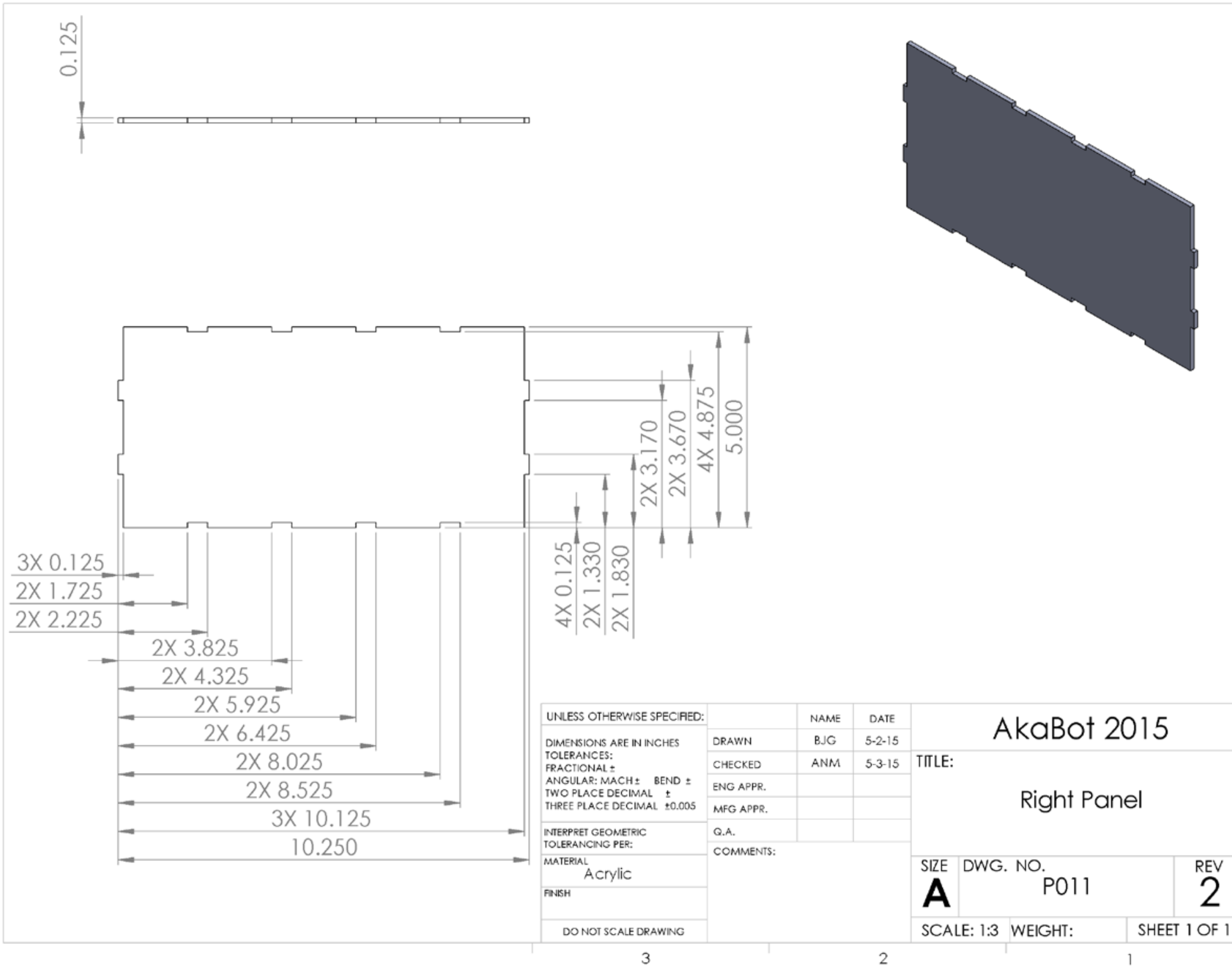
Note: Acrylic cement is used to hold the parts together

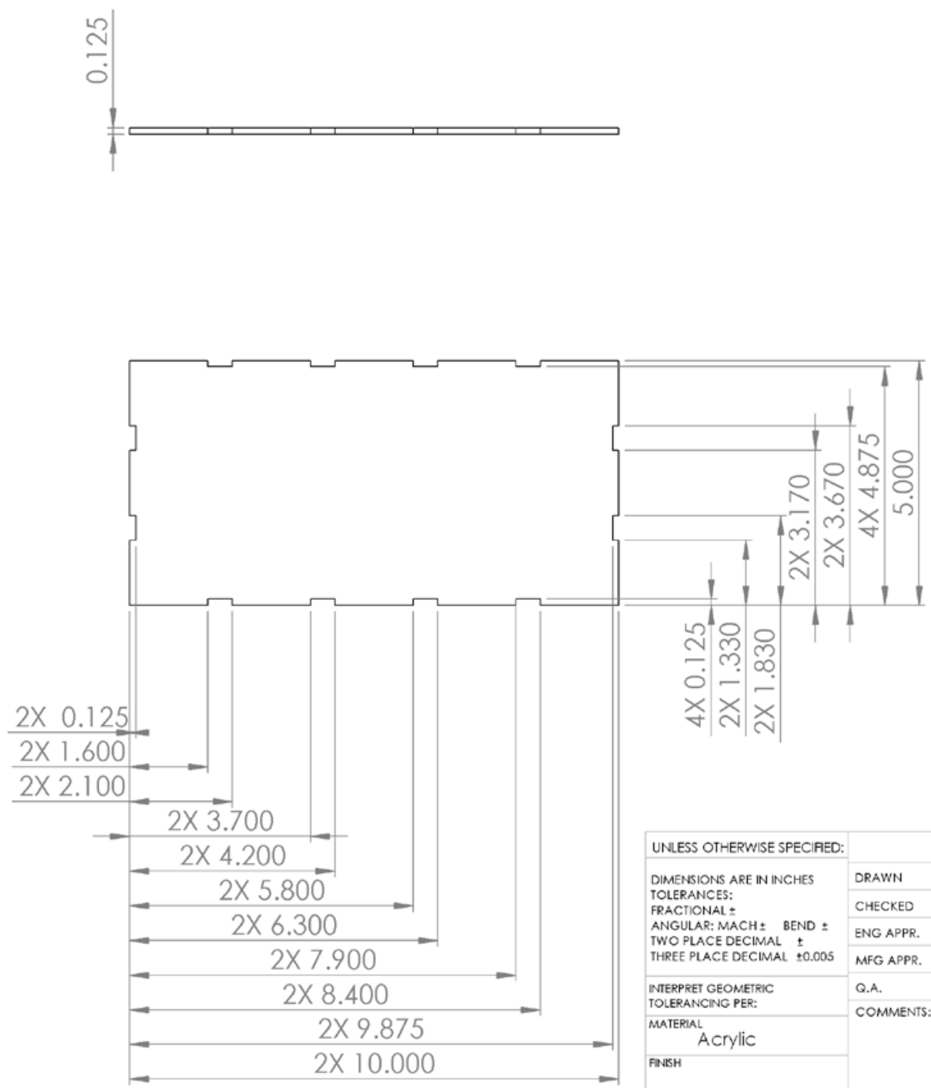
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	BJG	5-2-15	TITLE:
	CHECKED	ANM	5-3-15	Electronics Enclosure Assembly
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A DWG. NO. A003 REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:5 WEIGHT: SHEET 1 OF 1

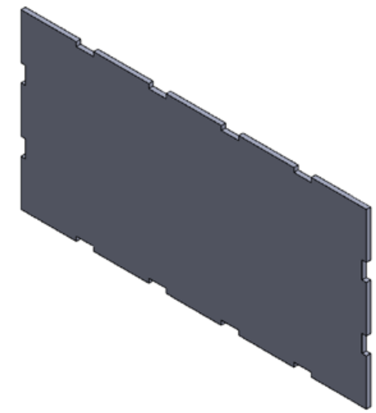
3 2 1


0.125
2X 0.125
1.458
2X 1.600
2X 2.100
2.934
2X 3.700
3.820
2X 4.200
4.706
5.296
2X 5.800
6.182
2X 6.300
7.068
7.658
2X 7.900
2X 8.400
8.544
9.430
2X 9.875
10.000
4X 0.125
4X 1.114
2X 1.330
2X 1.830
3X 2.228
2X 3.170
2X 3.670
3X 4.000
4X 4.875
5.000
Motor
Heater 1
Heater 2
Heater 3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Acrylic
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN BJG 5-2-15
CHECKED ANM 5-3-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Front Panel
SIZE A
DWG. NO. P009
REV 2
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
3
2
1


0.125
3X 0.125
2X 1.725
2X 2.225
2X 3.825
2X 4.325
2X 5.925
2X 6.425
2X 8.025
2X 8.525
9.125
3X 10.125
10.250
4X 0.125
2X 1.330
2X 1.830
2X 3.170
2X 3.670
4.000
4X 4.875
5.000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Acrylic
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN BJG 5-2-15
CHECKED ANM 5-3-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE: Left Panel
SIZE A
DWG. NO. P010
REV 2
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
3
2
1

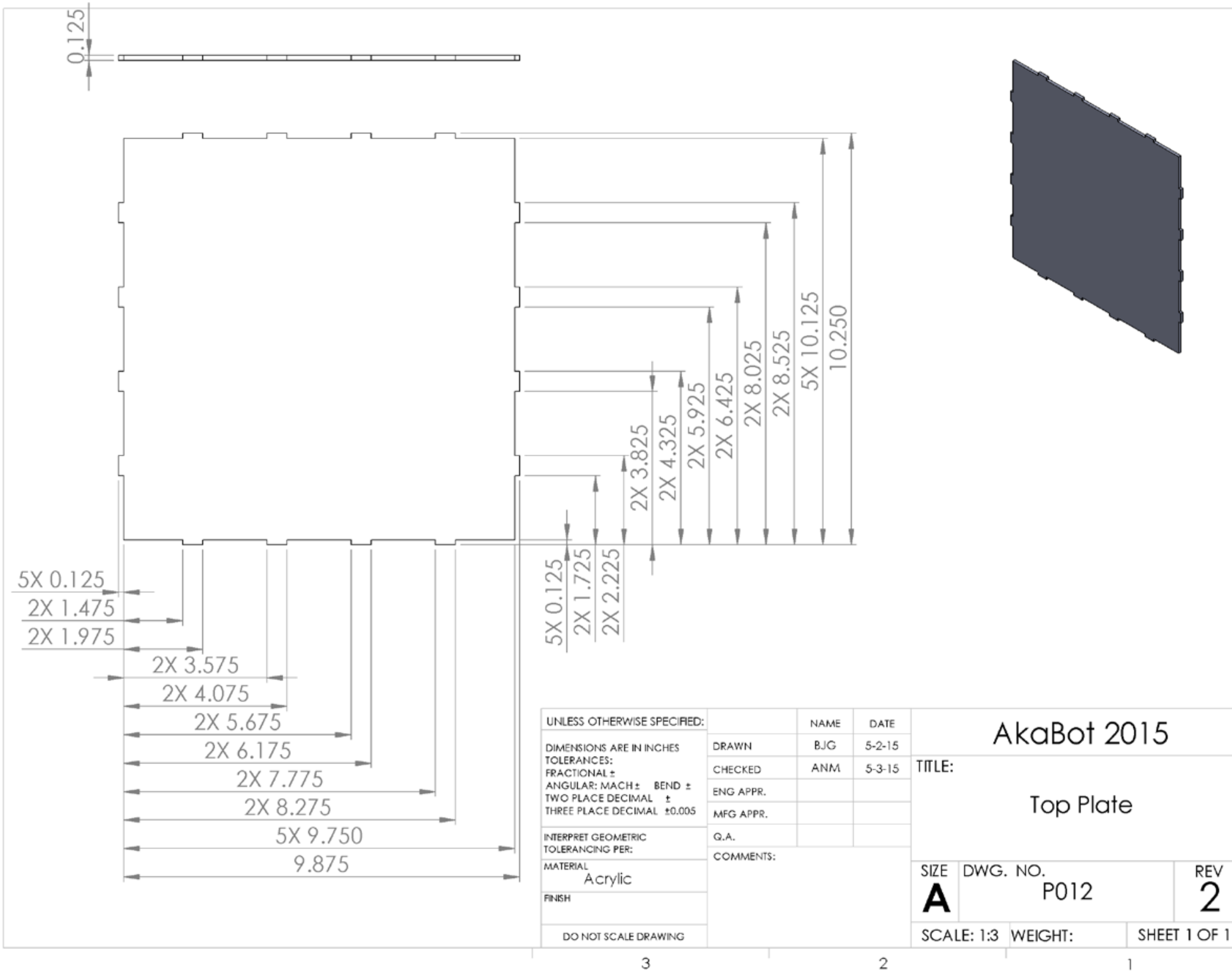

0.125
3X 0.125
2X 1.725
2X 2.225
2X 3.825
2X 4.325
2X 5.925
2X 6.425
2X 8.025
2X 8.525
3X 10.125
10.250
4X 0.125
2X 1.330
2X 1.830
2X 3.170
2X 3.670
4X 4.875
5.000
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Acrylic
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN BJG 5-2-15
CHECKED ANM 5-3-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE: Right Panel
SIZE A
DWG. NO. P011
REV 2
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
3
2
1

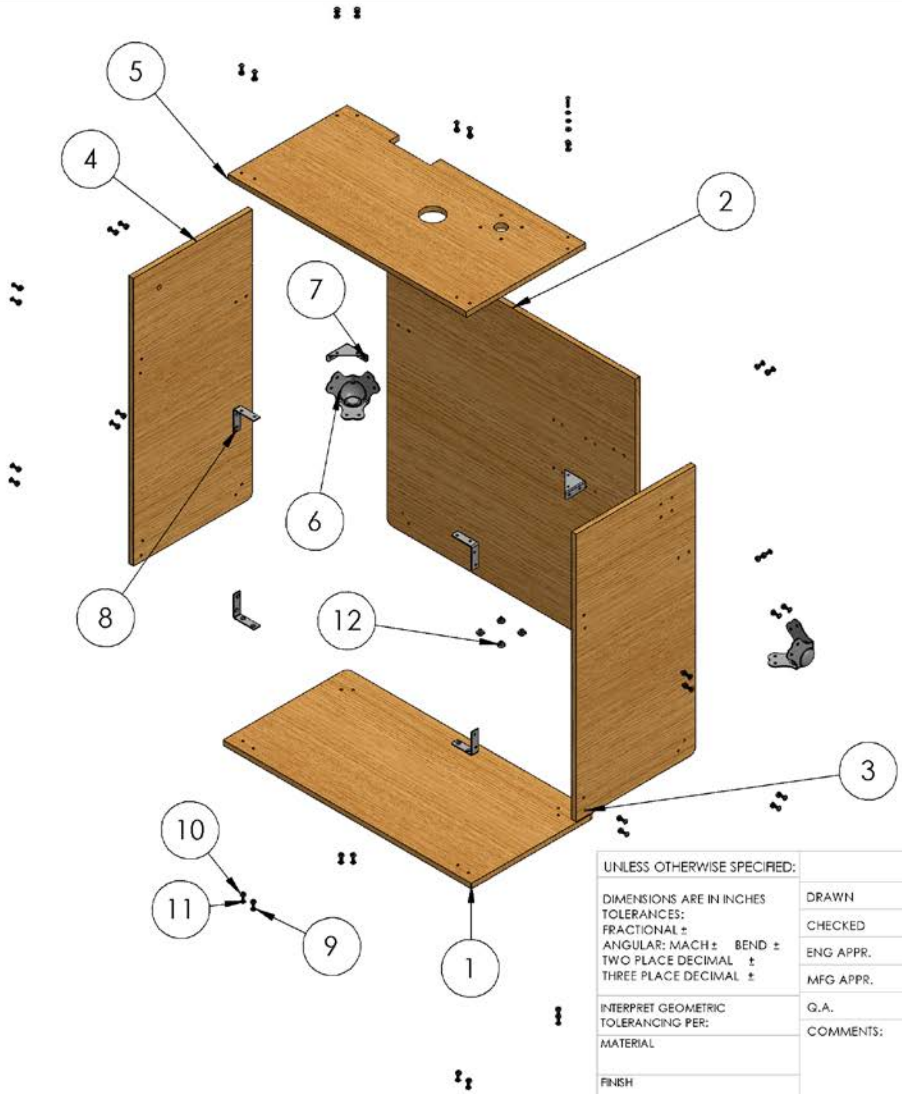




UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±0.005	DRAWN	BJG	5-2-15	TITLE:
	CHECKED	ANM	5-3-15	Back Panel
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Acrylic	COMMENTS:			SIZE A / DWG. NO. P008 / REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:3 / WEIGHT: / SHEET 1 OF 1

3 2 1


0.125
5X 0.125
2X 1.475
2X 1.975
2X 3.575
2X 4.075
2X 5.675
2X 6.175
2X 7.775
2X 8.275
5X 9.750
9.875
5X 0.125
2X 1.725
2X 2.225
2X 3.825
2X 4.325
2X 5.925
2X 6.425
2X 8.025
2X 8.525
5X 10.125
10.250
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Acrylic
FINISH
DO NOT SCALE DRAWING
NAME DATE
DRAWN BJG 5-2-15
CHECKED ANM 5-3-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Top Plate
SIZE A
DWG. NO. P012
REV 2
SCALE: 1:3
WEIGHT:
SHEET 1 OF 1
3
2
1



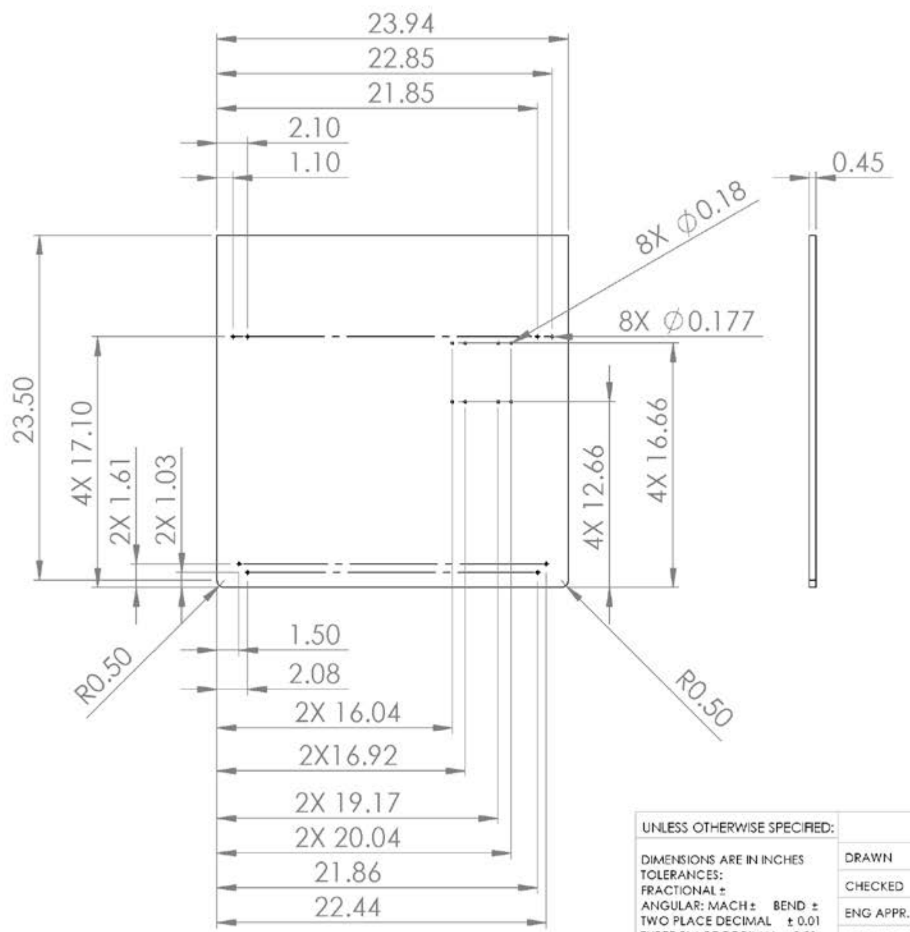
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	ANM	3-16-15	TITLE:
	CHECKED	BJG	3-17-15	Frame Assembly
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A · DWG. NO. A004 · REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 · WEIGHT: · SHEET 1 OF 2

3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Bottom Wood Plate		1
2	Back Wood Plate		1
3	Right Wood Plate		1
4	Left Wood Plate		1
5	Mounting Plate Top Wood		1
6	15705A34	Outside Corner-Reinforcing Bracket	2
7	1088A31	Inside Corner-Reinforcing Bracket 2" Length of Sides	2
8	1556A54	Brakcet Zinc-Plated Steel, 2" Length of Sides	4
9	90107A010	Type 316 Stainless Steel Flat Washer Type 316 Stainless Steel Flat Washer, Number 8 Screw Size, 0.174" ID, 0.375" OD	80
10	90480A009	Low-Strength Steel Hex Nut, Zinc Plated, 8-32 Thread Size, 11/32" Wide, 1/8" High	40
11	98164A139	Type 316 Stainless Steel Button-Head Socket Cap Screw, 8-32 Thread, 3/4" Length	40
12	90975A014	Steel Tee Nuts for Wood, Zinc-Plated, 8-32 Interior Thread, 1/4" Long Barrel, 1/2" Flange Diameter	4

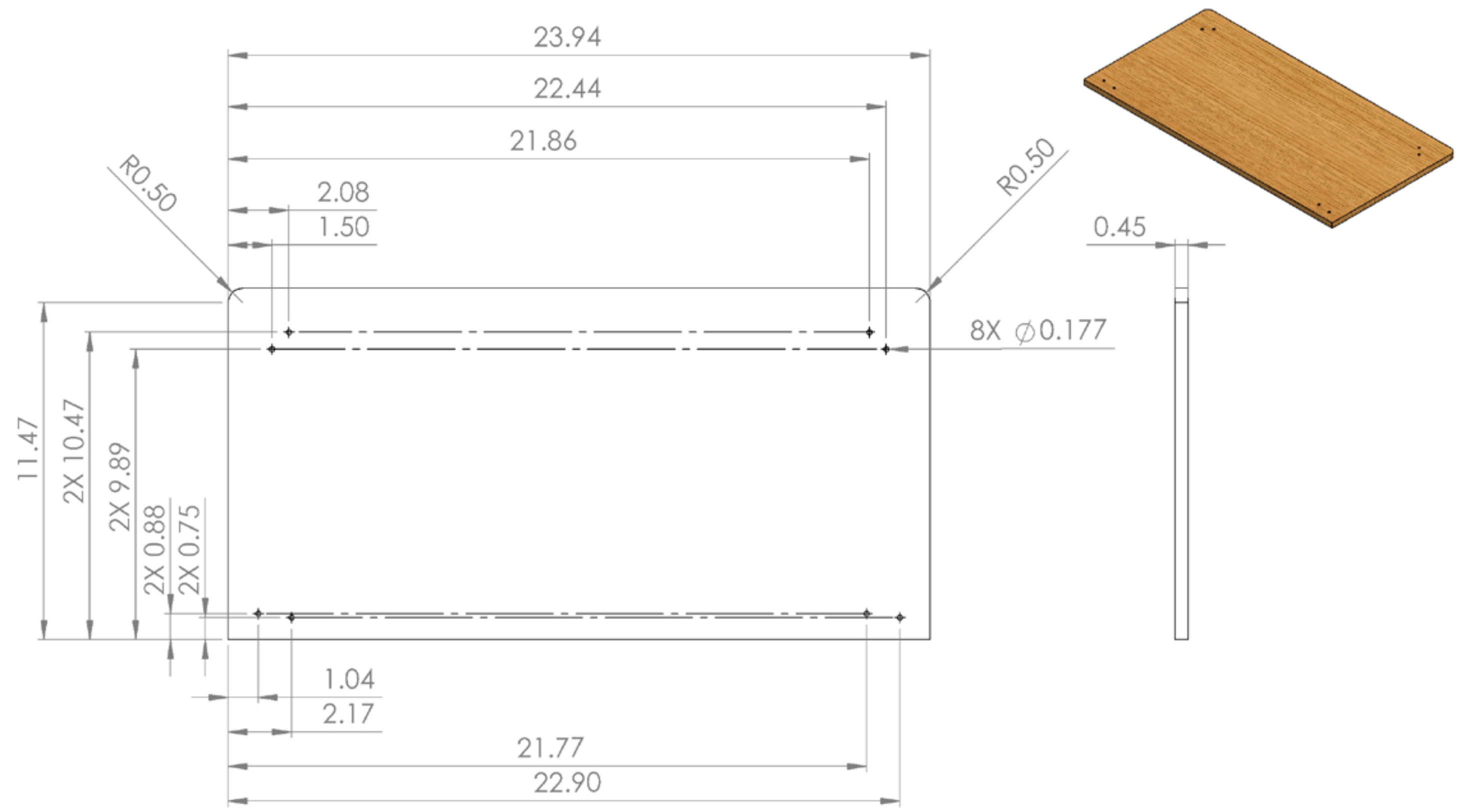
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	ANM	3-16-15	TITLE: Frame Assembly
	CHECKED	BJG	3-17-15	
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A · DWG. NO. A004 · REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 · WEIGHT: · SHEET 2 OF 2

3 2 1



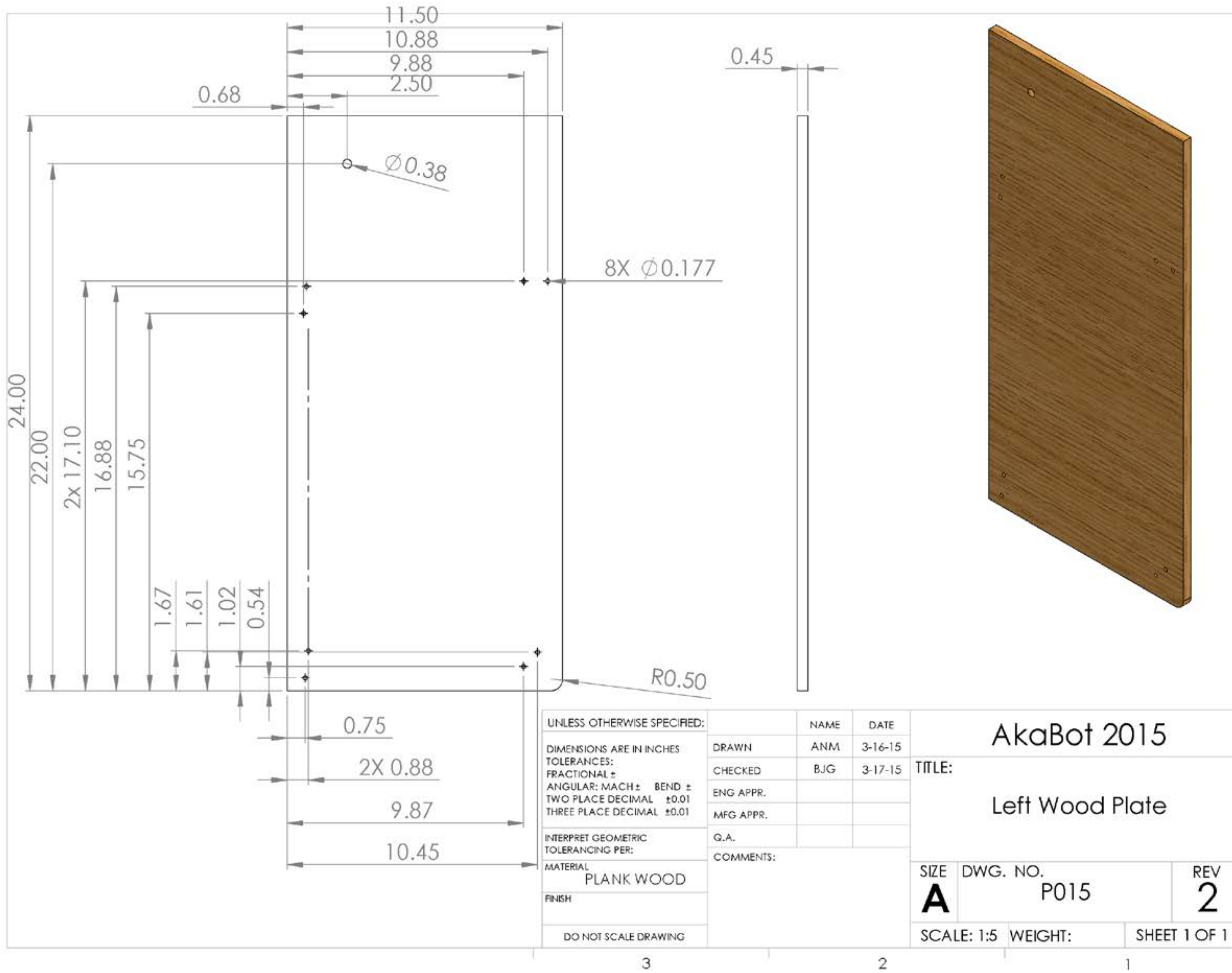
UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ±0.01	DRAWN	ANM	3-16-15	TITLE:
	CHECKED	BJG	3-17-15	Back Wood Plate
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
	COMMENTS:			
MATERIAL PLANK WOOD				SIZE A · DWG. NO. P013 · REV 4
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:10 · WEIGHT: · SHEET 1 OF 1

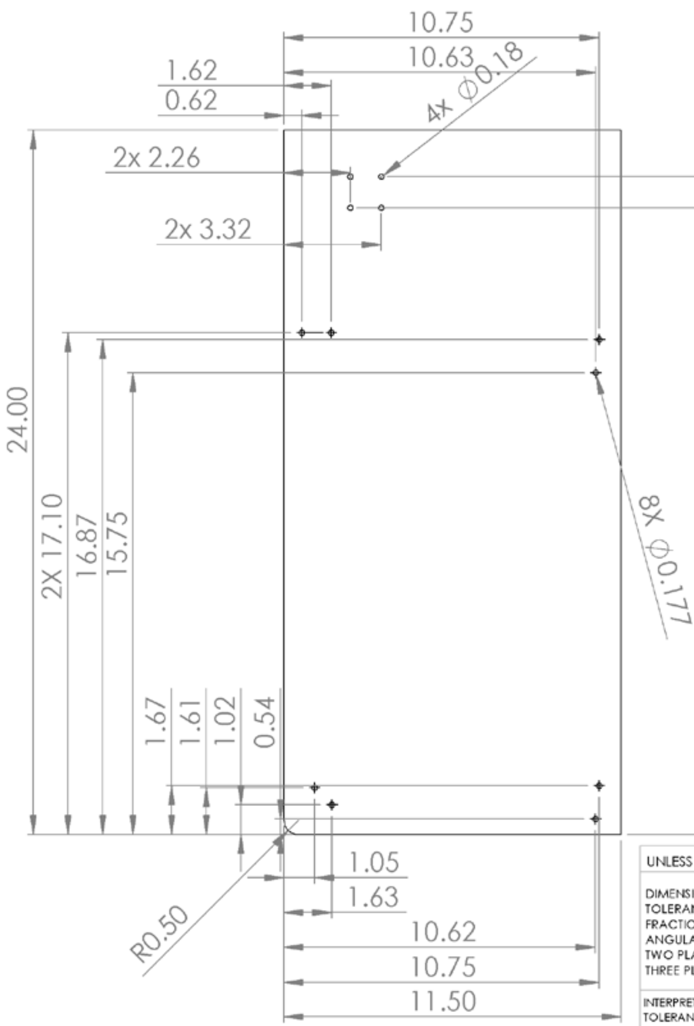
3 2 1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ±0.01 THREE PLACE DECIMAL ±0.01	DRAWN	ANM	3-16-15	TITLE:
	CHECKED	BJG	3-17-15	Bottom Wood Plate
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL PLANK WOOD	COMMENTS:			SIZE A · DWG. NO. P014 · REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE:1:5 · WEIGHT: · SHEET 1 OF 1

3 2 1

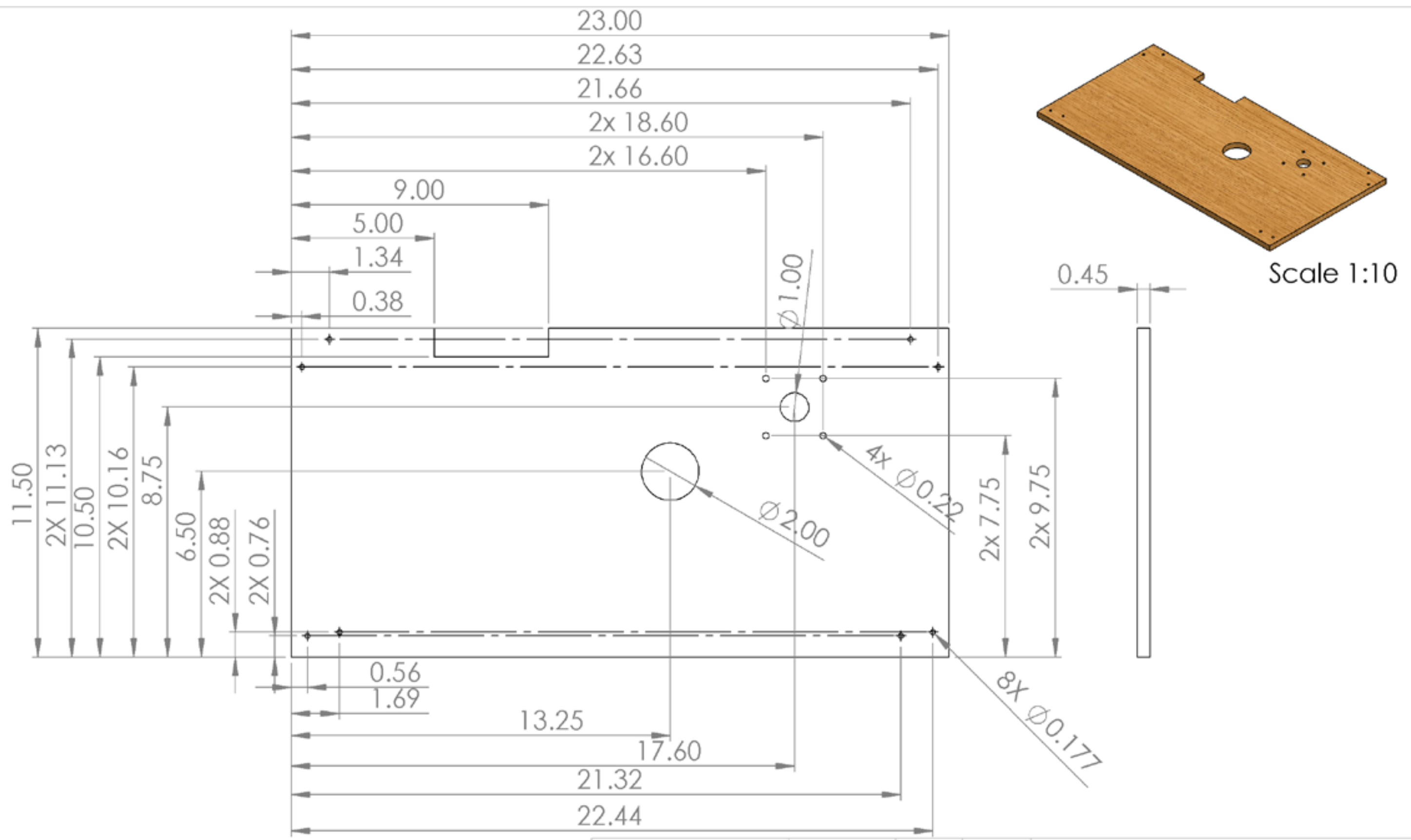

11.50
10.88
9.88
2.50
0.68
0.45
Ø0.38
8X Ø0.177
24.00
22.00
2x 17.10
16.88
15.75
1.67
1.61
1.02
0.54
R0.50
0.75
2X 0.88
9.87
10.45
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±0.01
THREE PLACE DECIMAL ±0.01
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
PLANK WOOD
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
ANM
3-16-15
CHECKED
BJG
3-17-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Left Wood Plate
SIZE
A
DWG. NO.
P015
REV
2
SCALE: 1:5
WEIGHT:
SHEET 1 OF 1
3
2
1




Scale 1:10

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± 0.01 THREE PLACE DECIMAL ±	DRAWN	ANM	3-16-15	TITLE:
	CHECKED	BJG	3-17-15	Right Wood Plate
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL PLANK WOOD	COMMENTS:			SIZE A · DWG. NO. P017 · REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:5 · WEIGHT: · SHEET 1 OF 1

3 2 1



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ± 0.01
THREE PLACE DECIMAL ±0.01

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL PLANK WOOD

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	ANM	3-16-15
CHECKED	BJG	3-17-15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

AkaBot 2015

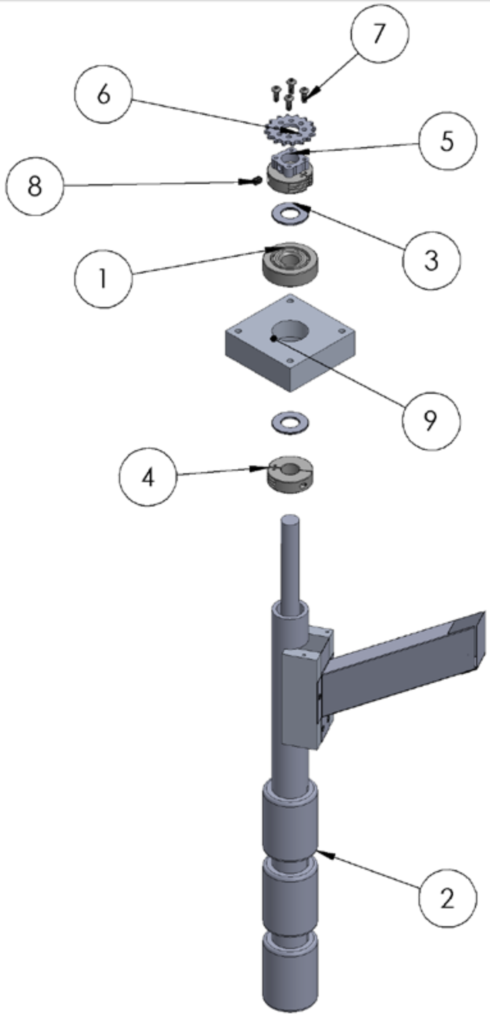
TITLE:

Top Mounting Plate

SIZE A | DWG. NO. P016 | REV 2

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

3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	6383K45	Steel Ball Bearing Plain Open for 1/2" Shaft Dia, 1-1/2" OD, 7/16" W	1
2	Auger & Chamber Assembly		1
3	Thrust Bearing	Graphite SAE 841 Solid Bronze Thrust Bearing for 1/2" Shaft Diameter, 1" OD, 1/16" Thick	2
4	57145K72	Hinged One-Piece Clamp-On Shaft Collars	2
5	545560_part	0.5" Bore Set Screw Hub from Servo City	1
6	615102_part	16 Tooth Sprocket from Servo City	1
7	98164A107	Type 316 Stainless Steel Button-Head Socket Cap Screw, 6-32 Thread, 3/8" Length	4
8	92313A825	Type 316 Stainless Steel Cup Point Set Screw, 10-32 Thread, 1/4" Long	1
9	Bearing Plate		1

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	BJG	3-16-15
CHECKED	ANM	3-17-15
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

AkaBot 2015

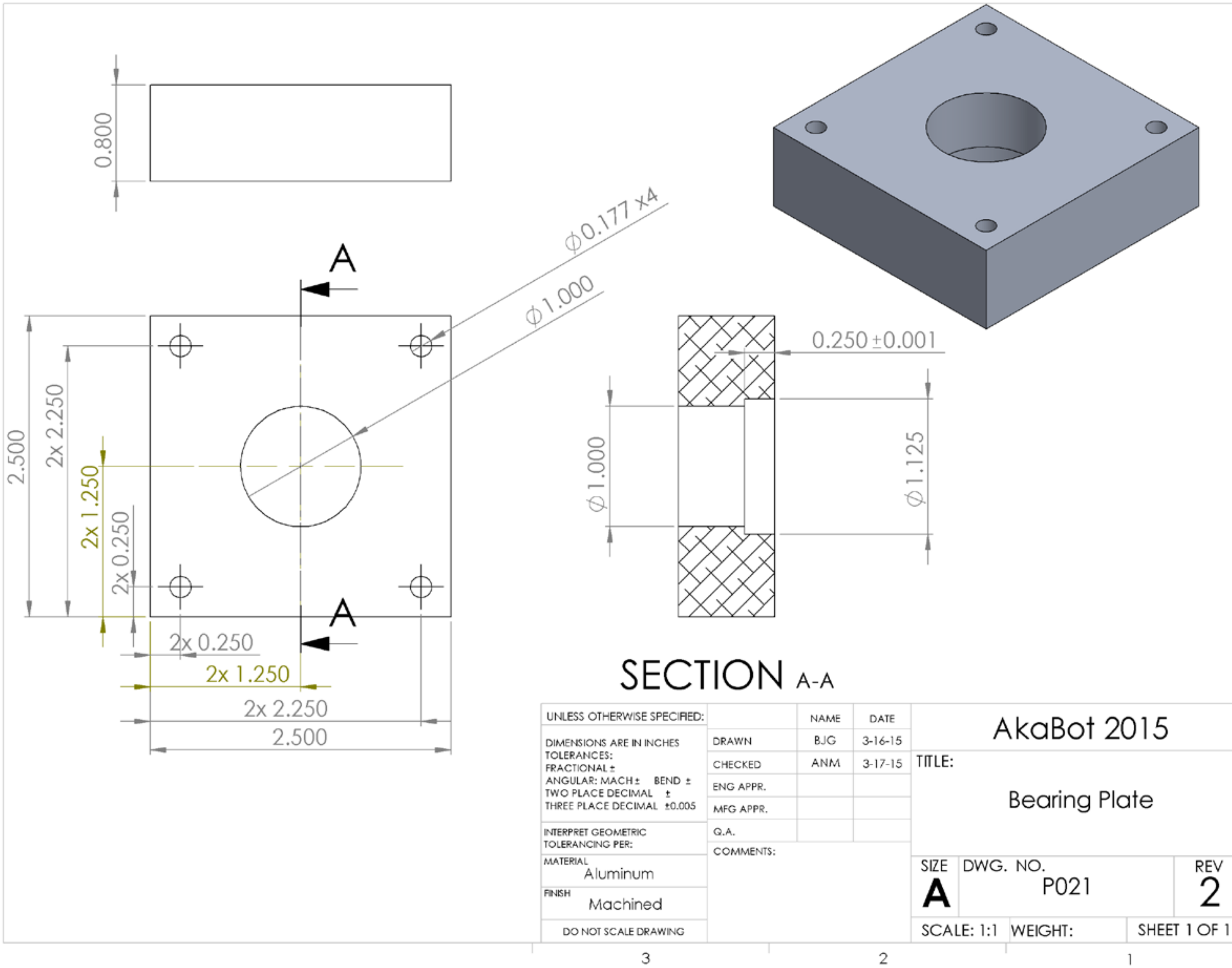
TITLE:

Mechanical Power Assembly

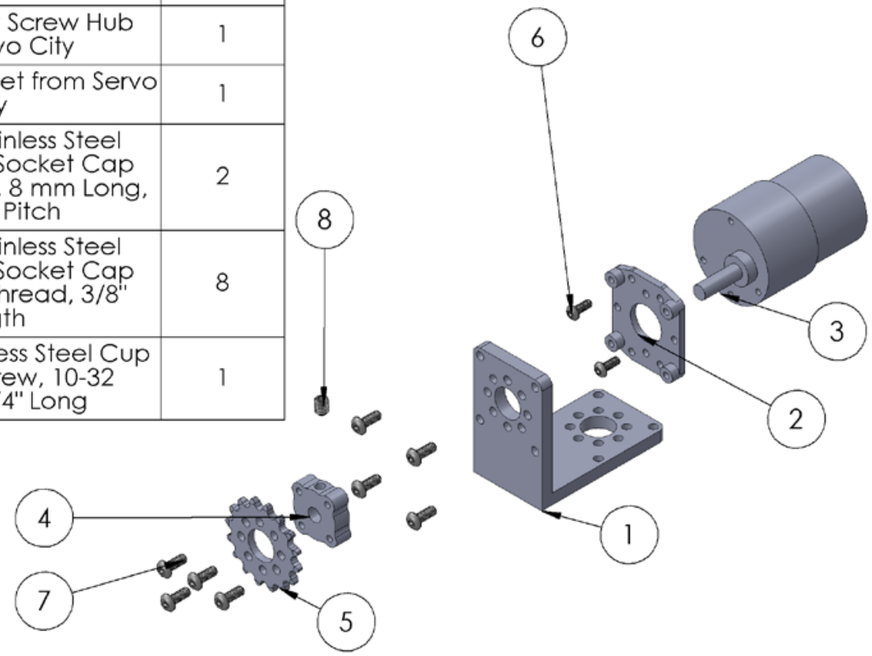
SIZE A | DWG. NO. A006 | REV 2

SCALE: 1:10 WEIGHT: SHEET 1 OF 1

3 2 1


0.800
A
A
⌀0.177 x4
⌀1.000
2.500
2x 2.250
2x 1.250
2x 0.250
2x 0.250
2x 1.250
2x 2.250
2.500
0.250 ±0.001
⌀1.000
⌀1.125
SECTION A-A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.005
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Aluminum
FINISH
Machined
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
BJG
3-16-15
CHECKED
ANM
3-17-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Bearing Plate
SIZE
A
DWG. NO.
P021
REV
2
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
3
2
1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	5854941	90 Degree Hub Mount bracket A from Servo City	1
2	5551281	Aluminum Motor Mount B from Servo City	1
3	4rpm motor	4 RPM 12 V DC Motor	1
4	545576_part	6mm Bore Set Screw Hub from Servo City	1
5	615102_part	16 Tooth Sprocket from Servo City	1
6	94500A222	Type 316 Stainless Steel Button-Head Socket Cap Screw, M3 Size, 8 mm Long, 0.5 mm Pitch	2
7	98164A107	Type 316 Stainless Steel Button-Head Socket Cap Screw, 6-32 Thread, 3/8" Length	8
8	92313A825	Type 316 Stainless Steel Cup Point Set Screw, 10-32 Thread, 1/4" Long	1



UNLESS OTHERWISE SPECIFIED:

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

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	BJG	3-15-15
CHECKED	ANM	3-16-15
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

AkaBot 2015

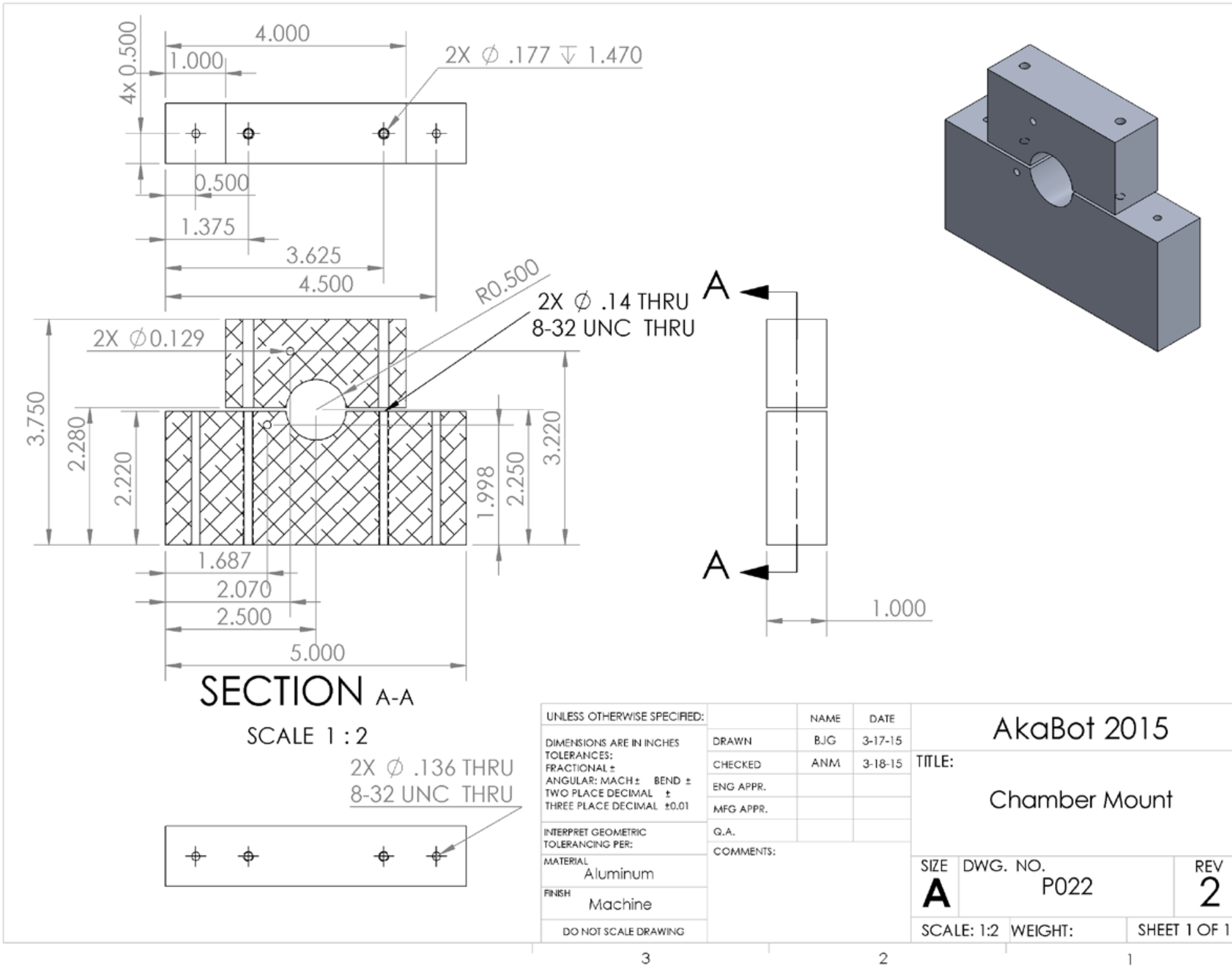
TITLE:

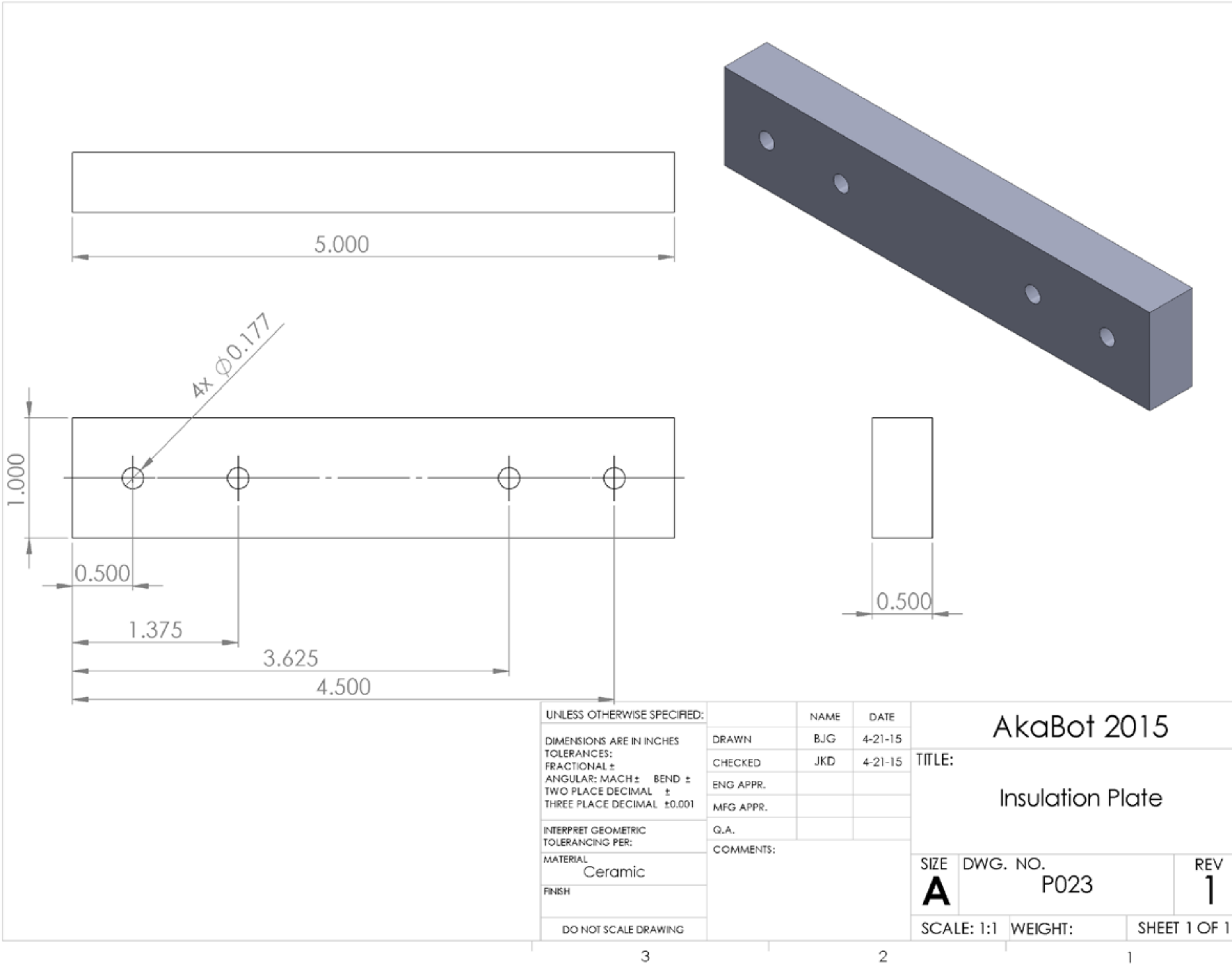
Motor Assembly

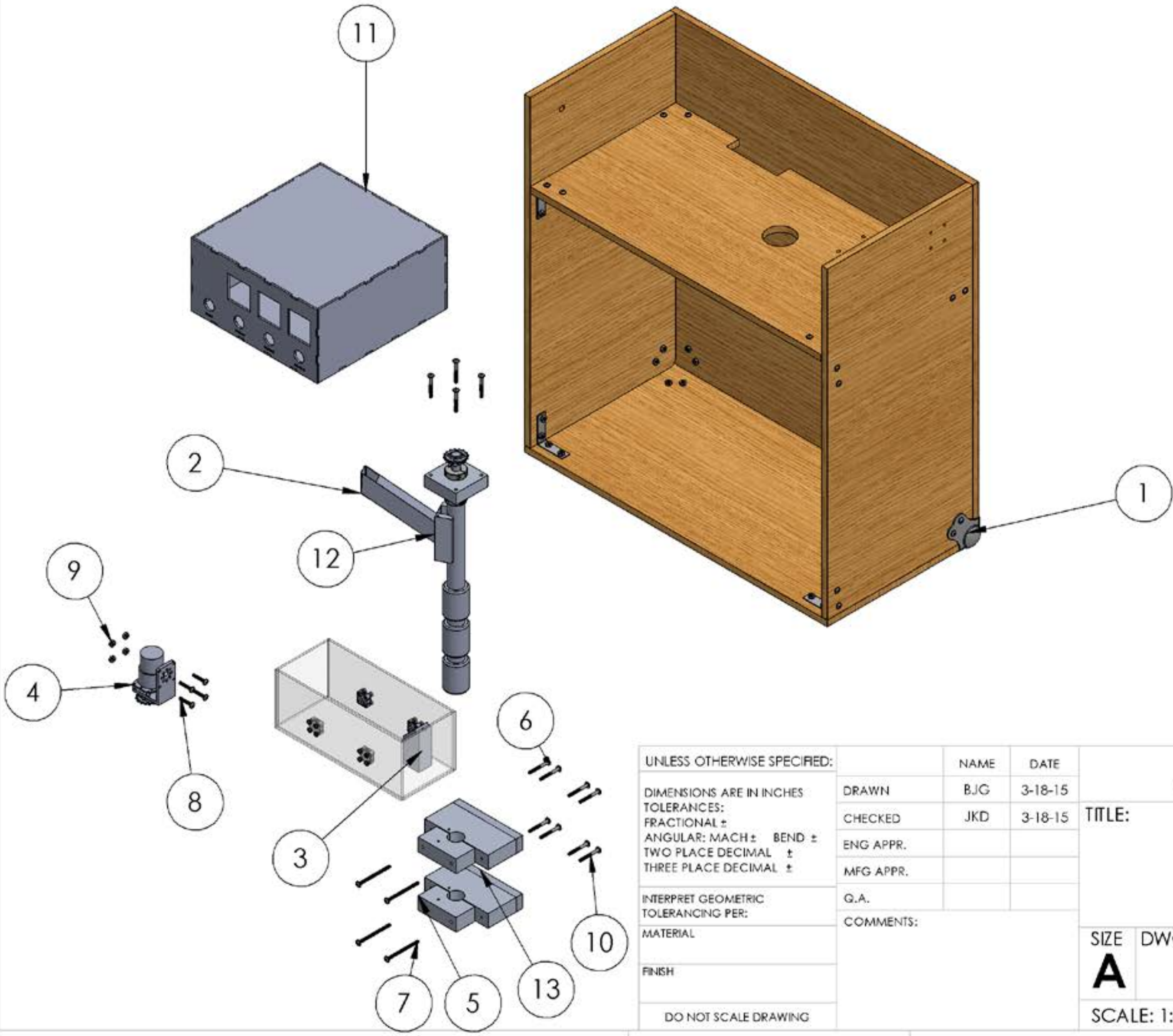
SIZE	DWG. NO.	REV
A	A007	2

SCALE: 1:2 WEIGHT: SHEET 1 OF 1

3 2 1


4.000
1.000
4x 0.500
2X ∅ .177 ↧ 1.470
0.500
1.375
3.625
4.500
R0.500
2X ∅ .14 THRU
8-32 UNC THRU
2X ∅0.129
3.750
2.280
2.220
1.998
2.250
3.220
1.687
2.070
2.500
5.000
A
A
1.000
SECTION A-A
SCALE 1 : 2
2X ∅ .136 THRU
8-32 UNC THRU
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.01
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL Aluminum
FINISH Machine
DO NOT SCALE DRAWING
NAME DATE
DRAWN BJG 3-17-15
CHECKED ANM 3-18-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Chamber Mount
SIZE A
DWG. NO. P022
REV 2
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1
3
2
1


5.000
4x ∅0.177
1.000
0.500
1.375
3.625
4.500
0.500
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±0.001
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
Ceramic
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
BJG
4-21-15
CHECKED
JKD
4-21-15
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
AkaBot 2015
TITLE:
Insulation Plate
SIZE
A
DWG. NO.
P023
REV
1
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1
3
2
1



UNLESS OTHERWISE SPECIFIED:		NAME	DATE
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	BJG	3-18-15
	CHECKED	JKD	3-18-15
	ENG APPR.		
	MFG APPR.		
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
MATERIAL	COMMENTS:		
FINISH			
DO NOT SCALE DRAWING			

AkaBot 2015

TITLE:

Final Assembly

SIZE	DWG. NO.	REV
A	A008	2

SCALE: 1:8 WEIGHT: SHEET 1 OF 2

3 2 1

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Frame Assembly		1
2	Mechanical Power Assembly		1
3	Cooling Box Assembly		1
4	Motor Assembly		1
5	Chamber Mount_v2		2
6	90107A010	Type 316 Stainless Steel Flat Washer Type 316 Stainless Steel Flat Washer, Number 8 Screw Size, 0.174" ID, 0.375" OD	26
7	92949A821	18-8 Stainless Steel Button-Head Socket Cap Screw, 8-32 Thread, 2-1/2" Long	4
8	98164A143	Type 316 Stainless Steel Button-Head Socket Cap Screw, 8-32 Thread, 1" Length	5
9	90480A009	Low-Strength Steel Hex Nut, Zinc Plated, 8-32 Thread Size, 11/32" Wide, 1/8" High	5
10	92949A203	18-8 Stainless Steel Button-Head Socket Cap Screw, 8-32 Thread, 1-1/2" Length	12
11	Electronics Enclosure Assembly		1
12	94500A222	Type 316 Stainless Steel Button-Head Socket Cap Screw, M3 Size, 8 mm Long, 0.5 mm Pitch	3
13	Insulation Plate		2

UNLESS OTHERWISE SPECIFIED:		NAME	DATE	AkaBot 2015
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ± ANGULAR: MACH ± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN	BJG	3-18-15	TITLE:
	CHECKED	JKD	3-18-15	Final Assembly
	ENG APPR.			
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL	COMMENTS:			SIZE A — DWG. NO. A008 — REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:8 — WEIGHT: — SHEET 2 OF 2

3 2 1