Senior Design Final Report

Cocoa Bean Winnowing Project

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Introduction

The client for the Cocoa Bean Winnower project is US Roaster Corp. US Roaster Corp is located in downtown Oklahoma City, OK and they specialize in the manufacturing, design and repair of coffee bean roasters. Their roasters range in capacity from 3 oz to 300 kg. While the roasters are designed to roast coffee, they are easily adapted to roast cocoa beans. Recently, several small scale gourmet chocolate producers have started using US Roaster Corp roasters in the production of their product. The chocolate making process begins with roasting the cocoa beans. Once the beans are roasted they must be de-hulled, or winnowed. Winnowing separates the cocoa nib (the edible and sought after portion) from the outer hull, or chaff. The cocoa nibs are then processed into chocolate or other cocoa products. The winnowing process is important because if there is a high percentage of the hull present with the cocoa nibs then the quality of the chocolate will be poor.

Currently in the industry there is not a small scale winnower that is both efficient and affordable for small bean-to-bar chocolate producers. US Roaster Corp is interested in expanding their range of products to meet the needs of the gourmet chocolate industry.

Triad Enterprises has developed a cocoa bean winnower that will deliver improved results in winnowing efficiency while staying within the budget range of most small scale chocolate operations. The estimated cost of the winnower will be roughly $8,129 depending on the supply of materials and cost of labor. The efficiency of the winnower is 95%-98% depending on the calibration with the capacity to run 100 lb of cocoa beans per hour if manually fed.

Background

Problem Statement

Triad Enterprises will research, design, and produce a cocoa bean winnowing system that will be marketable to small scale chocolate producers.

Scope of Work

The winnower needs to incorporate competitive features at price range that will make it marketable to small scale chocolate producers. US Roaster Corp needs to be able to fabricate the majority of the components of the winnowing system at their facilities with their current equipment. Aspects that were out of the scope of this project will be other components of chocolate production such as roasting, grinding, and tempering.

Deliverables

Triad Enterprises deliver the following:

- A functioning cocoa bean winnowing system
- Marketable to small scale chocolate producers
- Primarily manufactured to food-grade standards
- Provide easy access for cleaning of critical components
- Designed to be operated with no direct supervision
- Designed to be self-contained
- Produce minimal noise

Engineering Specifications

- Winnow at a rate of 100 lbs/hr
- Winnow at an efficiency >95%
- Not allow greater than 2% shells in the final nib output
- Retail price near $3000
- Not exceed 100 dB of sound
- Minimize moving parts
- Be aesthetically pleasing
- Be easy to clean

Conceptual Testing

A series of experimental tests were developed to verify the feasibility of some of the conceptual designs from the fall report (see appendix for design concepts). The testing primarily focused on the roller design because it was decided that a roller crushing method was the most feasible due to the similarity of the manufacturing process that US Roaster Corp already has in place for their lines of coffee roller grinders.

Roller Testing

Utilizing the roller mill that we had access to, samples of cocoa beans were crushed into ranges of particle sizes. The machine was constructed of two main rollers that were powered by an AC electric motor. After the roller mill was cleaned, the distance between the rollers was adjusted to determine how well the roller mill design would crack the cocoa beans and what the optimal distance is between the two rollers. Another parameter that was tested utilizing the roller mill was the rotation speed of the rollers. To adjust the rotation speed, a variable frequency drive (VFD) was installed on the motor. Additionally, some samples were sent through the roller mill twice at different roller distances to test whether using two roller sets in series would crush more effectively, leaving less dust. The ranges of particle sizes that were produced from cracking the beans with the different parameters was measured. For testing the single roller, distances of 7 mm, 8 mm, 9 mm, 10 mm, 12 mm, and 14 mm were used. The effect of the roller speed on the cocoa bean cracking was tested with the 7 mm and 9 mm distances.

The particle sizes of the rollers were determined using a Ro-Tap machine that is housed in the Food & Agricultural Products Center (FAPC) at Oklahoma State University. The Ro-Tap is a machine that consist of a series of vertical mesh screens that have varying mesh sizes. The sample is then placed in the top most compartment and the machine then uses rotation and concussive forces to sift the sample through the different mesh sizes. The sample is then separated out based on the size of the particles with the largest particles staying at the top and the smallest settling on the bottom. The samples in each range were then weighed and the percentage of the total sample that fell into that range was determined.

From the results shown in Figures 1 & 2 there is little difference in particle size when running the rollers at a high speed and a low speed. The speed of the rollers should be adjustable to meet the desired feed rate of the customer but a lower roller speed would be preferable. A lower roller speed is preferable due to an observation made during the testing of the rollers. At higher roller speeds, more dust and particles are ejected into the air than at lower speeds. This could cause a breathing and food safety hazard and should be avoided.

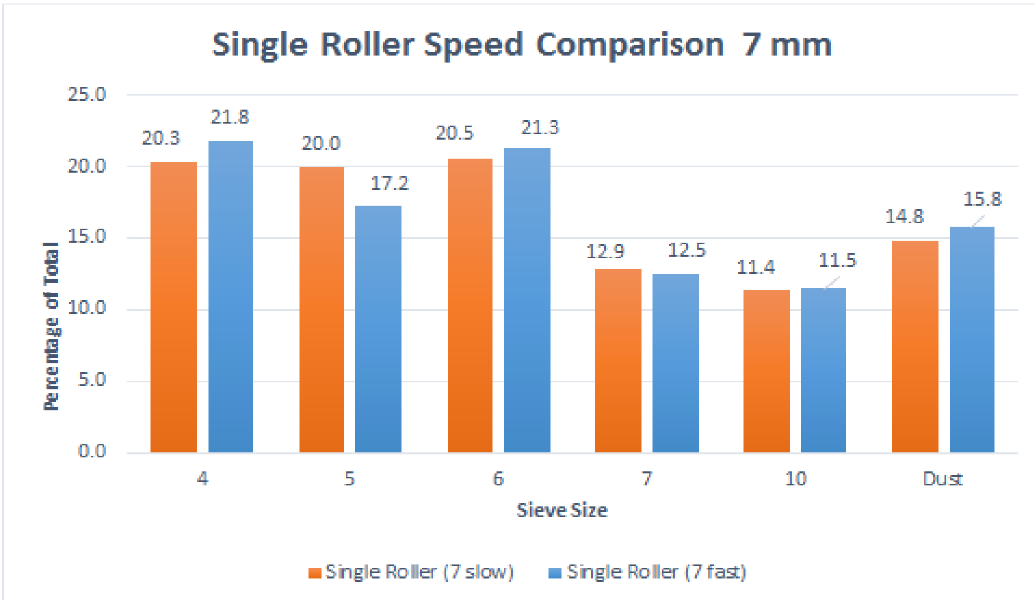

Figure 12: Single Roller Speed Comparison at 7mm

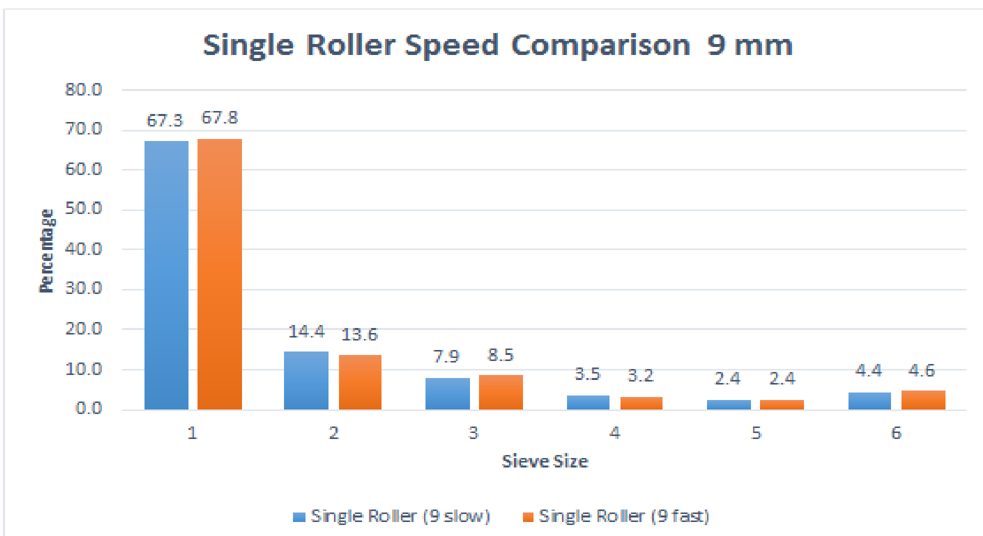

Figure 2: Single Roller Speed Comparison at 9 mm

With the single rollers, several distances were tested to help determine at which distance an optimal crack of cocoa beans would occur. An optimal crack means that all cocoa beans are fully cracked, the hulls are completely released from the nib, and little dust is produced from this process.

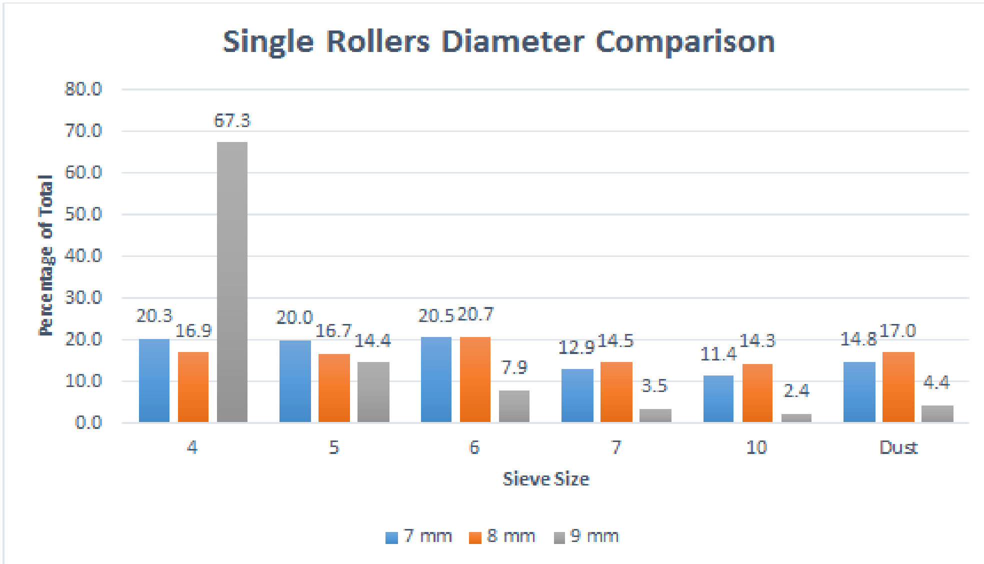

Figure 3: Single Roller Comparison at Various Gaps

From the results it is clear that while a roller gap of 9 mm does produce the least amount of dust, it does not crack all of the cocoa beans. This means that a smaller gap would be required to ensure that all the beans would be cracked and winnowed properly.

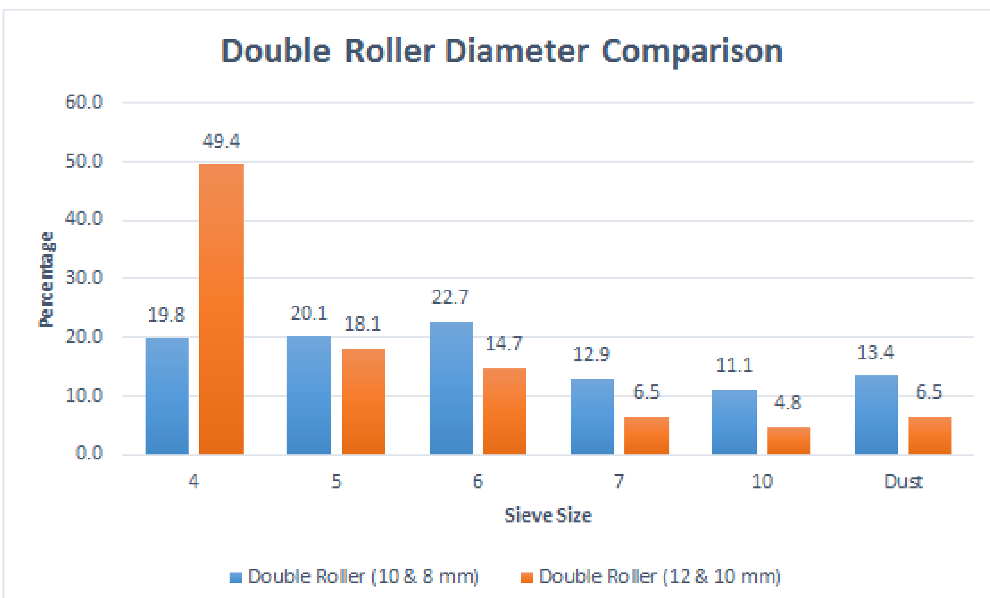

Figure 4: Double Roller Comparison at Various Gaps

Rollers in series, or “double rollers”, were also tested to see if multiple passes through the rollers would crack the cocoa beans better compared to a single roller system. The idea is that the first rollers, set at a bigger gap, would be able to do a gentle initial crack of the larger beans. The second set of rollers would then crack the smaller size beans that passed through the first set of rollers. To do this, a sample was run through the rollers at a specified gap, collected, and then run through the rollers at a smaller gap. The two main ranges tested were at 10 then 8 mm and 12 then 10 mm. In Figure 4, you can see that the double roller system with the larger gaps, 12 then 10 mm, left almost half of the beans in the 4-gauge sieve in the Ro-Tap. This indicates that the gap was too large, leaving whole beans which is unacceptable for a winnower. The 10 & 8 mm ranges showed more promising results with the bulk percentage of the cocoa beans falling between the 4 and 7-gauge range.

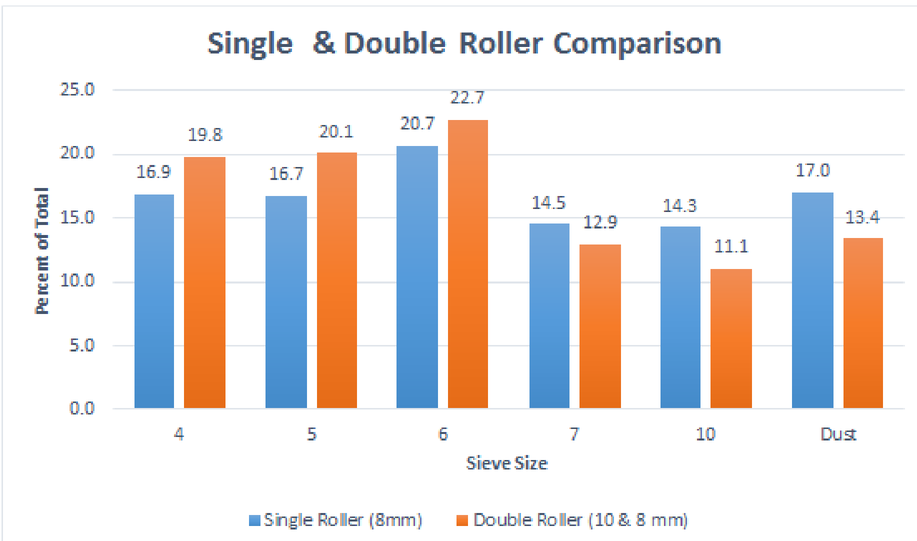

Figure 5: Single & Double Roller Comparison

The single & double roller systems were then compared to see which system performed better. The results from Figure 5 shows that overall the two systems performed similarly, with similar percentages of beans falling within the same gauge ranges. An important note is that the double roller system did produce less overall dust and more of the sample fell into the larger sieve sizes than the single roller system did. Overall the double roller system would be preferable because it was able to crack all of the cocoa beans, produce less dust than the single roller and keep the particle sizes larger. However, the double roller system would require about twice the amount of material, greatly increasing the cost of the roller system.

Because of this, it was decided a single roller system would be utilized for our prototype rather than a double roller system.

Winnower Design

The final prototype design consists of three main components, indicated in Figure 6. These components are the cracking component, sorting component, and separation component. These three components were identified as the main areas of consideration for the winnower to successfully and efficiently winnow the cocoa beans.

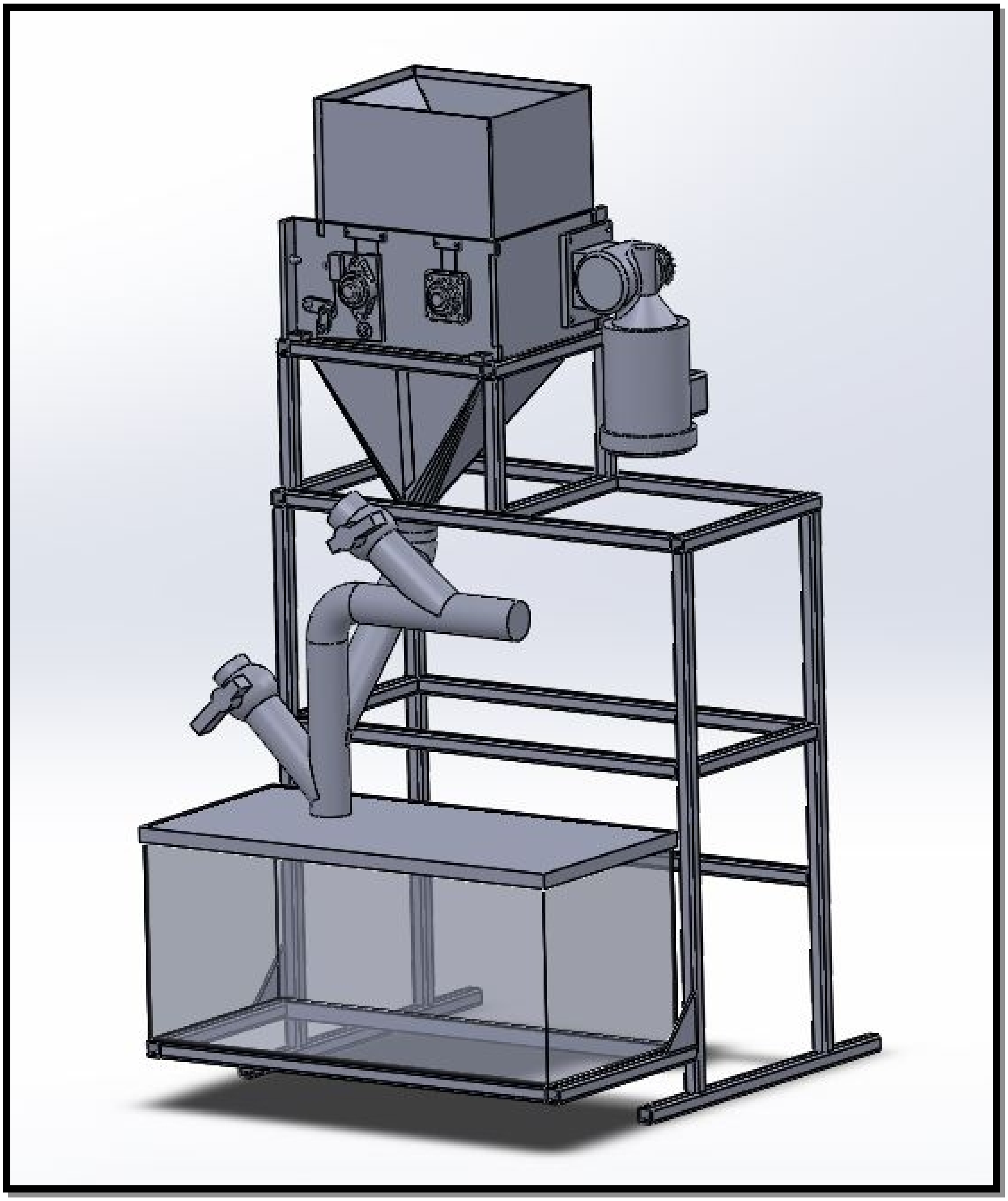

Figure 6: SolidWorks Model of Prototype

Each of the components were designed separately and then integrated together. In doing this, each component was given the specific focus that it required. Each of the following sections give a detailed analysis of each of the components and why the selected method was chosen for this part of the design.

Cracking Method

The first stage of the winnower is the cracking component. The roasted cocoa beans must first be cracked to initially separate the chaff from the nib. From the design concepts that were considered, rollers were selected to be the most viable option for the cracking component. The rollers are two grooved cylinders with an infinitely adjustable gap between them, rolling counter to each other to pull the beans into the gap. The rollers provide the force to crack the beans as they are pulled through the gap and drop to the next component. From testing, it was determined that rollers were capable of cracking the cocoa beans consistently into measurable ranges. These ranges would then be used to improve the efficiency of the sorting component of the winnower. Rollers also provide easier adjustment for the sizes of the roasted cocoa beans, giving the operator more range of product that they can handle. Another advantage of using rollers was that US Roaster Corp already has significant experience with coffee rollers, which are of similar design to cocoa bean rollers, and would be capable of producing this component in-house.

Sorting Method

The sorting component was designed to take the cracked cocoa beans and sort them into a measured range. This allows the separation component to be calibrated to the specific ranges, providing a better sort. A trommel was selected for the sorting component for multiple reasons. The overall design and operation of a trommel is simple and is within US Roaster Corp fabrication capabilities. A trommel is a cylindrical frame with specific screen sizes, starting with small screens and moving to larger screens, that rotates at a slight decline about its horizontal axis. As the trommel rotates, the cracked beans are sifted through the screens into the specifically calibrated separating component of the winnower. We recommend three screen sizes on the trommel to allow three ranges of pneumatic separation, though the number of screens used can be varied. If any beans are not able to fall through the trommel, this would indicate that they are still whole beans. These beans would be collected at the end of the trommel and recycled through the winnower to ensure they are cracked.

Separation Method

The separation component is where the chaff and the nibs are separated from each other. This is done pneumatically with the cracked and sorted cocoa beans being gravity fed into the separating apparatus. The chaff is pulled up and away from the nibs by vacuum pressure as the nibs continue to fall into a storage receptacle. This is possible because the chaff and the cocoa nibs have significantly different terminal velocities due to their different masses, densities and surface areas. The chaff, having a lower terminal velocity than the nib, requires lower air velocities to be displaced allowing it to be sucked upward. The chaff is then collected in the waste stream receptacle.

Operating Procedure

To properly and safely turn the winnower on and off, the following procedure should be followed:

Before the winnower is turned on, the operator should check to make sure that all components are properly connected and cleaned and that any debris or waste in the area is removed. There should be no left over nibs in the nib containment bin nor any waste in the waste bin. The operator should then connect the separating component, sorting component and cracking component to their respective power sources. The operator should then turn on each component in the following order: the separation component, the sorting component, then the cracking component. The operator should then load the hopper with the desired amount of roasted cocoa beans, ensuring not to exceed the hopper capacity. The operator should stay within the same room of the winnower while it is in operation and periodically check to ensure that it is functioning properly.

Once the desired amount of cocoa beans are winnowed, the operator should shut down the winnower according to the following steps. All of the components should be turned off in this order: the cracking component, the sorting component, then the separation component. Then the components should be removed from their power sources. Once all of the winnowing components are removed from their power sources, the nibs in the nib containment bin should be removed to be safely stored or further processed. The waste accumulated during the winnowing should be properly disposed of, as the owner sees fit. All necessary maintenance and cleaning of the winnower should then be done after each operation.

Safety

When operating the winnower, extreme caution should be taken by following the safety recommendations outlined below to ensure the safety of all personnel using the winnower and anyone in the operating area of the winnower. Each component of the winnower has varying degrees of hazard associated with it, but overall there are four areas that need to be addressed: Personal Protection Equipment (PPE) and housekeeping, cracker component safety precautions, sorter component safety precautions, and separator safety precautions.

PPE required when operating the winnower includes: slip resistant steel-toe boots, protective shatter resistant glasses, hair and beard nets when applicable, keeping long hair completely covered and tied back, button-less shirts, and pants that cover ankles that are not frayed. The operating area of the winnower should be clear of all clutter or waste to avoid trip hazards. Emergency fire suppression equipment, such as a fire extinguisher, should be easily accessible in the unlikely event of a fire.

The cracking component and the separator component require very similar safety precautions, and these precautions should be executed in conjunction with each other. While either component is running, operators should never place appendages in or near the hopper, roller housing, or trommel housing. Doing so could cause severe bodily harm or death. Should cleaning or maintenance be necessary, the operator should turn off the cracker component and the separator component and remove all components from their power sources. Only after the cracker and sorting components are removed from their power sources should the operator access the hopper, roller housing, or trommel housing. All other components of the winnower should also be turned off and disconnected from their power sources as well.
While the separation component is in operation, the operator should use extreme caution due to the separation component being closely integrated with the trommel housing. When calibrating the sorting component, the operator should be aware of their surroundings. Before conducting maintenance or cleaning of the separation

component, both the cracking and sorting component should be properly turned off and disconnected from their power sources.

Prototype & Proposed Budget

After consulting with the client, Dan Jolliff, about his expected costs for this project, he voiced his wishes to keep our testing and prototype construction near his expected retail price. His aim is to market these winnowers to small-scale chocolatiers with a price in the range of $3000-$4500. The total budget for the design of the prototype will be $3000. The actual cost of the final product will include the material cost, fabrication cost, and labor cost. Two costs are recorded, the actual cost of the prototype and the proposed budget for the actual product.

Prototype Material Cost

The raw materials for the project were separated into two major categories: the roller cracker and the winnowing system. Each of the following figures shows the quantity of each part or material that was purchased as well as the unit price for each component. Overall, the materials chosen for the design of the prototype were considerably cheaper than the materials considered for the proposed product. The reason for this was to stay within the given budget to build the prototype.

Table 1: Spreadsheet for Prototype Cracking Component Materials

Roller Cracker Materials			
Description	Quantity	Price/Unit	Price
Food Grade Four Bolt Flange Mount Ball Bearing	2	$ 75.64	$ 151.28
Food Grade Two-Bolt Flange mount ball bearing with 1” ID	2	$ 75.64	$ 151.28
Washdown Set Scew Shaft Collar of 7/16' Dia	2	$ 3.79	$ 7.58
Grade 5 Steel Flanged Hex Head Screws- 1 pack (12 individual)	1	$ 8.31	$ 8.31
18-8 Stainless Steel Shoulder Screw ½” Dia x 1-1/4” long shoulder, 3/8”-16 Thread	2	$ 6.71	$ 13.42
Grade 5 Flanged Hex Head Screws- 1 pack (12 individual)	1	$ 8.31	$ 8.31
Grade 5 Flanged Hex Head Screws- 1 pack (8 individual)	1	$ 6.14	$ 6.14
316 Stainless Steel Washer for ½” Screw Size, 0.531” ID, 1.25” OD	1	$ 8.82	$ 8.82
Compression Spring, Zinc-Plated, Tempered, Closed Ends, 6” Long, 7/8” OD, 0.635” ID	1	$ 12.99	$ 12.99
Pres-Fit Drill Bushing with Head 0.4375” ID, 5/8” OD, ½” Long	2	$ 8.47	$ 16.94
18-8 Stainless Steel Shoulder Screw 1/2 “ Dia x 5/8” long shoulder, 3/8”-16 Thread	2	$ 5.52	$ 11.04
Geamrotr,84 rpm,TRFC,208-230/460V (motor of the cracker)	1	$ 831.99	$ 831.99
316 Stainless Steel Washer 0.513” ID, 1.25” OD	1	$ 8.82	$ 8.82
Steel Cylinder * Donated	1	$ 348.00	$ 348.00

Table 2: Spreadsheet for Prototype Winnowing Component Materials

Winnowing System Materials			
Description	Quantity	Price/Unit	Price
3" to 2" reducer	1	$ 3.63	$ 3.63
2" coupling	2	$ 1.05	$ 2.10
2" ball valve	2	$ 11.44	$ 22.88
3" elbow	2	$ 6.87	$ 13.74
2", 2", 2" Wye	1	$ 4.11	$ 4.11
3" , 3" ,2" Wye 2"	2	$ 4.11	$ 8.22
2" PVC pipe -5'	1	$ 5.56	$ 5.56
3" PVC pipe-5'	1	$ 7.99	$ 7.99
2" Vacuum hose (included with vacuum & Oneida Dust Deputy)	1		$ -
Gorilla Glue PVC	1	$ 14.23	$ 14.23
100 Qt (25 gallon) Heaafty Clear Storage Container	1	$ 18.98	$ 18.98
10 Gallon Storage Container (Included with Oneida Dust Deputy)	1		$ -
DUST DEPUTY 10 GAL DELUXE PLASTIC CYCLONE-10 GAL STEEL	1	$ 198.75	$ 198.75
SV 14-GAL 6.5 PEAK HP Vacuum Pump	1	$ 199.00	$ 199.00
		Total	$ 499.19

The total calculated cost of the materials for the prototype is $1,951.07 which accounts for 65% of the total project budget of $3,000. However, the steel cylinder used for the rollers was donated from McElroy Manufacturing, making the actual cost of the prototype materials $1,603.07.

The bulk of the material cost was associated with the rollers and their housing. This was due to the complexity of the design as well as a few components being more expensive, such as the bearings and the motor. This is a financial drawback of the roller component because the motor needed to run the rollers at the speed and torque required are expensive. The winnowing system, in comparison, only cost $366.15. The materials being used for the system are relatively cheap due to the low cost of the material and the simplicity of the design. The main component of the separating system is made out of PVC pipe and adhesive glue which is easily sourced and inexpensive. The most expensive components of the winnowing component were the shop-vac and the cyclone vacuum filter. Both of these components are standard in related industries, so they too are inexpensive in comparison to the rest of the design.

Prototype Controls Cost

There are several control components for the prototype but most of them are already built into the systems. The winnowing discriminator valves and the vacuum pump controls are already built into their designated components, therefore no extra controls were needed. The motor that powers the rollers requires a VFD controller to convert from a single phase power outlet to the three phase power that the motor requires. The VFD selected cost $289.94.

Table 3: Spreadsheet for Prototype Control Spreadsheet

Controls			
Description	Quantity	Price/Unit	Price
ABB ACS 310 VFD Controler	1	$ 289.94	$289.94

Prototype Labor Cost

Labor cost was not included in the budget because all fabrication necessary for the winnower was performed at no cost to Triad Enterprises by the BAE Fabrication Lab and US Roaster Corp.

Final Prototype Cost

The final cost of the prototype was $2,026.50. This was below the design budget of $3,000.

Final Product Material Cost

The estimated cost of materials for the final design is $3,039.93. This is separated into three main components, the cracking component, sorting component, and the separation component. In total the materials needed for the winnower consist of 37% of the total estimated budget of $8,129.72. Each of the figures below give a list of the materials needed as well as the cost of each component.

Table 4: Spreadsheet for Final Design Cracking Component Materials

Roller Cracker Materials			
Description	Quantity	Price/Unit	Price
Food Grade Four Bolt Flange Mount Ball Bearing	2	$ 75.64	$ 151.28
Food Grade Two-Bolt Flange mount ball bearing with 1" ID	2	$ 75.64	$ 151.28
Washdown Set Scew Shaft Collar of 7/16' Dia	2	$ 3.79	$ 7.58
Grade 5 Steel Flanged Hex Head Screws- 1 pack (12 individual)	1	$ 8.31	$ 8.31
18-8 Stainless Steel Shoulder Screw ½" Dia x 1-1/4" long shoulder, 3/8"-16 Thread	2	$ 6.71	$ 13.42
Grade 5 Flanged Hex Head Screws- 1 pack (12 individual)	1	$ 8.31	$ 8.31
Grade 5 Flanged Hex Head Screws- 1 pack (8 individual)	1	$ 6.14	$ 6.14
316 Stainless Steel Washer for ½" Screw Size, 0.531" ID, 1.25" OD	1	$ 8.82	$ 8.82
Compression Spring, Zinc-Plated, Tempered, Closed Ends, 6" Long, 7/8" OD, 0.635" ID	1	$ 12.99	$ 12.99
Pres-Fit Drill Bushing with Head 0.4375" ID, 5/8" OD, ½" Long	2	$ 8.47	$ 16.94
18-8 Stainless Steel Shoulder Screw 1/2 " Dia x 5/8" long shoulder, 3/8"-16 Thread	2	$ 5.52	$ 11.04
Geamrotr, 84 rpm, TRFC, 208-230/460V (motor of the cracker)	1	$ 831.99	$ 831.99
316 Stainless Steel Washer 0.513" ID, 1.25" OD	1	$ 8.82	$ 8.82
Steel Cylinder * Donated	1	$ 348.00	$ 348.00
		Total	$1,584.92

Table 5: Spreadsheet for Final Design Trommel Materials

Trommel Materials			
Description	Quantity	Price/Unit	Price
.187" Screen (McMaster Carr) 4'x1' model #9211T772	1	$ 79.72	$ 79.72
.111" Screen (McMaster Carr) 4'x1' model #9211T281	1	$ 110.61	$ 110.61
.073" Screen (McMaster Carr) 4'x4' model #85385T51	1	$ 73.80	$ 73.80
Base-mount AC Motor 208-230V AC NEMA 48, 1/4 hp (5990k121)	1	$ 220.97	$ 220.97
Trommel Frame Material	1	$ 320.00	$ 320.00
Trommel Support Wheels	4	$ 10.00	$ 40.00
		Total	$ 845.10

Table 6: Spreadsheet for Final Design Separation Component Materials

Winnowing System Materials					
		Prototype		Final Design	
Description	Price/Unit	Quantity	Price	Quantity	Price
3" to 2" reducer	$ 3.63	1	$ 3.63	3	$ 10.89
2" ball valve	$ 11.44	2	$ 22.88	6	$ 68.64
3" elbow	$ 6.87	1	$ 6.87	1	$ 6.87
2", 2", 2" Wye	$ 4.11	1	$ 4.11	3	$ 12.33
3" , 3" ,2" Wye 2"	$ 4.11	2	$ 8.22	6	$ 24.66
2" PVC pipe -5'	$ 5.56	1	$ 5.56	2	$ 11.12
3" PVC pipe-5'	$ 7.99	1	$ 7.99	2	$ 15.98
2" Vacuum hose (included with vacuum & Oneida Dust Deputy)		1	$ -	3	$ -
Gorilla Glue PVC	$ 14.23	1	$ 14.23	3	$ 42.69
100 Qt (25 gallon) Heaafty Clear Storage Container	$ 18.98	1	$ 18.98	1	$ 18.98
10 Gallon Storage Container (Included with Oneida Dust Deputy)		1	$ -	1	$ -
DUST DEPUTY 10 GAL DELUXE PLASTIC CYCLONE-10 GAL STEEL	$ 198.75	1	$ 198.75	1	$ 198.75
SV 14-GAL 6.5 PEAK HP Vacuum Pump	$ 199.00	1	$ 199.00	1	$ 199.00
		Total	$ 490.22	Total	$ 609.91

Similar to the prototype, the bulk of the material cost for the final product is associated with the cracking component. Again, the most expensive part of the cracking component is the motor which was necessary to power the rollers on the cracker. For the sorting component, the most expensive material used is the food grade separation screens needed to sort the cracked cocoa beans into measured ranges. While still the cheapest aspect, the separation component of the winnower did become more complex with the addition two more separating components to handle the three product streams from the sorting component.

Final Controls Cost

The two controllers selected for the final design are listed in Table 7. The VFD selected is the same used in the prototype while the manual motor switch controls the sorting trommel. The motor specified to power the sorter requires less HP and is single phase, meaning that a VFD was not required.

Table 7: Spreadsheet for Final Design Control Systems

Controls			
Description	Quantity	Price/Unit	Price
ABB ACS 310 VRD Controler	1	$ 289.94	$289.94
Manual Motor Switch, DPST, 1 Phase, Indoor Enclosure, 30 Amps	1	$ 37.07	$ 37.07
		Total	$289.94

Final Product Labor Cost

The final product labor cost was calculated by conservatively assuming three fabrication technicians each being payed $20/hour would be able to fully fabricate and test the winnower in two, 40-hour work weeks.

Table 8: Spreadsheet for Final Design Labor Costs

Labour		
Hourly Wage	Employees Assighned to the Project	Fab. Hours
$ 20.00	3	80
Total Labor Cost	$ 4,800.00	

The labor cost is 59% of the total estimated cost of the final budget. This number could be reduced depending on the actual wage of the technicians, the total number of employees assigned to the project, and the amount of hours needed to fabricate it. Actual man hours needed to complete the final design were not able to be determined due to the outsourcing used to fabricate the winnower prototype. All values used to calculate labor are extremely conservative and will probably be reduced when manufacturing the winnower.

Final Product Cost

The estimated product cost of the final winnower is $8,129.87, with the table below showing the where the cost was divided into three main sections below. The percentages show what each component costs in relation to the entire project.

Table 9: Final Cost Percentage Breakdown

	Cost	%
Materials	$3,039.93	37%
Cracking	$1,584.92	19%
Sorting	$ 845.10	10%
Separating	$ 609.91	8%
Controls	$ 289.94	4%
Labor	$4,800.00	59%
Total	$8,129.87	

In order to reduce the cost of the overall project specific areas need to be focused on. The suggested areas are in materials, specifically with the cracker component.

The overall housing for the cracker is made of steel with a thickness of 0.5 in. The housing thickness could be reduced without compromising the housing. Doing this would reduce the cost of the cracker because less material would be needed. It would also make the cracker lighter and thus easier and cheaper to transport.

The rollers used in the cracker can also be reduced. It is currently designed to have two, 7-in diameter steel rollers that are both 12-in long. The rollers could be reduced to a length of 6-in long without negatively affecting the winnower. This would mean less materials would be needed to fabricate the rollers as well as less time would be spent to cut the groves into them, freeing up more time for technicians and reducing the labor cost. Shortening the rollers would also reduce the torque requirement needed for the rollers, meaning a smaller and cheaper motor could be selected to power the rollers.

Final Testing and Troubleshooting

The first thing tested on the prototype was the rollers. After running five samples of 2000 ml of cocoa beans through the cracker it was determined that a frequency setting of 30 hertz on the VFD was optimal for bean cracking. Frequencies lower than 30 hertz caused jamming issues with the rollers. If too many beans accumulated in the rollers at low frequencies, the motor couldn't supply enough torque to the rollers to keep them from jamming. It was also noticed that the spring tension on the adjustment feature of the cracker was insufficient to keep the rollers in place. The force of the beans on the rollers as they were being crushed was able to displace the rollers causing some whole beans to not get crushed.

The next thing tested was the separation component. First the component was calibrated by adjusting the two discriminator valves on the component. Samples of cocoa beans were first weighed and then ran through the winnower. From there the amount of chaff that was still in the nib, or product stream, was sorted out and weighed to determine the chaff content in the product stream. The waste was also checked and any usable nib was sorted out and the contents separately weighed. Once the amount of nib that made it into the waste was determined, the efficiency for that calibration was verified. The calibration continued until an optimal calibration was selected. The efficiency and chaff content in the product stream is heavily influenced by the feed rate. Therefore, the sorting component will need to be calibrated to the specific feed rate.

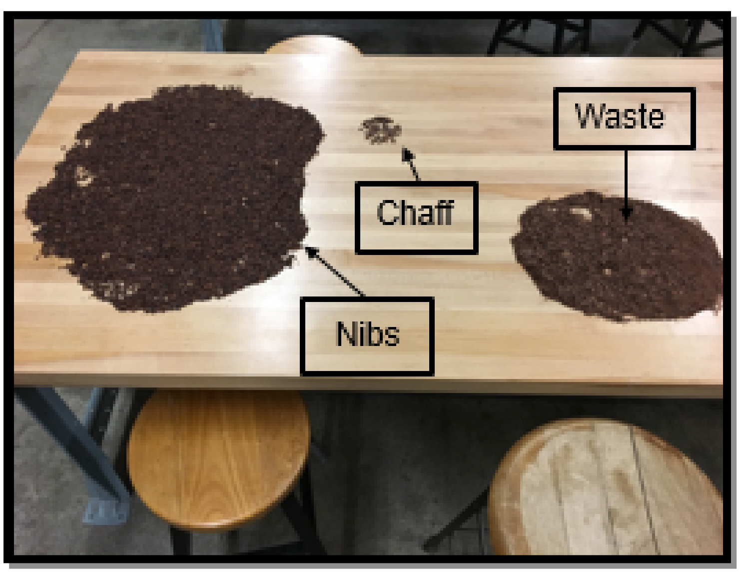

Figure 7: Winnowed Cocoa Beans

If the feed rate is too high, the separation component will not be able to properly sort the chaff from the nib. For the prototype manual feeding was needed to ensure that the crackers did not jam and that the separation component was not bogged down. This should not be as big of a concern on the final product, as the trommel will slow the rate of product entering the separation component.

The sample size that was used to determine the efficiency and the percent of chaff in the product stream was 1.6 lb., or 1650 ml, of cocoa beans. This sample size was chosen because if the winnower could run 1.6 lb. of cocoa beans per minute for an hour, the winnower would process 100 lb. of cocoa beans.

Table 10: Final Testing Results

Winnow Rate	1.6 lb/min
Winnowing Efficiency	98%
Chaff in Product Stream	1%-1.7%

Failure Modes Effects Analysis (FMEA)

The purpose of the Failure Modes Effect Analysis is to provide a structured system that is used to identify how the product might fail, both in development and in the field. A tool was developed to identify where and how often problems may develop within the life of the product and also implement measures used to prevent or reduce the severity and occurrences of the failures. This was done in two stages. First, a Cause & Effect Matrix was developed to determine what inputs into the winnower would affect the client's desired outcomes as shown in Figure 8. Each component was given a rating and the rank of inputs that are most critical to the project were identified. This information was then used in the FMEA to determine the potential causes of failures and their solutions, as shown in Figure 9.

TRIAD ENTERPRISES Cause & Effect Matrix

#	KPIV	Winnow at an efficiency >95%	Process at 100 lb/hour	Retail price near $3000	Be easy to clean	Minimal Noise	Minimize moving parts	Be aesthetically pleasing	Total	% Rank
	Rating of Importance to Customer	10	9	6	8	7	4	8		
1	Size of Cocoa Bean	2	2	1	1	1	1	1	71	3%
2	Distance b/w rollers	10	9	5	6	7	6	1	340	16%
3	Sanitation Fequency	6	6	5	10	3	10	7	341	16%
4	Suction Pressure	10	10	7	6	8	4	2	368	18%
5	Roller Speed	10	10	7	5	9	4	2	367	18%
6	Roller Torque	10	10	8	5	9	4	2	373	18%
7	Operacion Fequency	3	2	2	10	3	5	5	221	11%
8									0	0%
9									0	0%
10									0	0%
11									0	0%
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17									0	0%
18									0	0%
19									0	0%
20									0	0%
Total		51	49	35	43	40	34	20		100%

Figure 8: Cause & Effect Matrix Tool

Failure Modes Effects Analysis

Process or Product Name: Cocoa Bean Winnower								Prepared by: Triad Enterprises			Page: 1	of	1	
Process Owner: Triad Enterprises								FMEA Date (Orig): 2/27/2017			Rev:	4/20/2017		
Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN
Hopper	Hopper Getting Clogged	Beans Won't be Processed	10	The Inlet of the Cracker is too Small	3	The Inlet Is Large Enough to Prevent Clogging	3	Design a Feeding System to Feed Into the Hopper	Future Desgin Engineer (FDE)	N/A	10	3	3	90
Cocoa Bean Cracking	Cracker Rollers Getting Stuck	Beans Won't be Cracked	10	The Motor of the Cracker Roller is not Powerful Enough	2	The Motor Selected Have More HP Than is Regired To Run the Rollers	2	Decrease the Size of the Rollers	FDE	N/A	10	2	2	40
	Cracker Roller Motor Failure	The Beans Don't Get Cracked	10	The Motor of the Cracker Roller is not Maintained Properly	3	The Motor Selected Have More HP Than is Required To Run the Rollers	2	Develop a Maintenance Schedule for the Motor	FDE	N/A	10	3	2	60
	Cracker Roller Movment	Beans Don't Crack Properly	7	Operator Error	4	The Rollers are Manually Adjusted & Held in place by a Spring	6	Add a Mechanism that Prevents the Rollers from Moving While Cracking	FDE	N/A	7	4	6	168
Sorting Cracked Cocoa Beans	Sifting Screens Getting Clogged	Inadequate Sorting Of Cocoa Nibs	6	Infrequent Cleaning of the Screens	7	The Operators Implement a Consistent Cleaning Regiment	3	Develop an Automatic Cleaning System for the Screens	FDE	N/A	6	7	3	126
	Sorter Motor Failure	The Beans Won't be Cracked	10	The Motor is not Maintained Properly	3	The Motor Selected Has More HP Than is Required	2	Develop a Maintenance Schedule for the Motor	FDE	N/A	10	3	2	60
	Sorter Belt Drive Failure	The Sorting Can Not Occur	10	Belt Breaks	4	Regulary Replace Belt	3	Develop a Maintenance Schedule for the Belt	FDE	N/A	10	4	3	120
Winnowing	Winnower Air Velocity Tuning	Nibs Won't be Winnowed Properly	10	The Winnower Sytem is misadjusted	8	Adjust the Air Intake Valves	1	Develop an Automatic Adjustment System	FDE	N/A	10	8	1	80
	Vacuum Failure	Nibs Won't be Winnowed Properly	10	The Vacuum Filter Gets Clogged	3	A Cyclone Air Filture System Has Been Installed	2	Add More Fail safes to Prevent the Vacuum from being Worn Down	FDE	N/A	10	3	2	60
Safty	Winnower Falling Over	Something Colliding With It	9	Damage to the Winnower & People Near It	1	The Winnower Will be Bolted Down	2	Develop a More Stable Base	FDE	N/A	9	1	2	18
	Operator Injuries	Harm to Operators	10	Operator Negligence	5	Safety Labeling/Component Housing	4	Put in more Safty Controles	FDE	N/A	10	5	4	200
Sanitation	Food Contamination	Ruined Product	9	Improper Sanitation	6	GMP Guidelines	3	Develop Components that are Easier to Disassemble	FDE	N/A	9	6	3	162

Figure 9: Failure Modes Effect Analysis Tool

Due to the time constraints of this project, many of the items identified in the FMEA were not able to be addressed in this design cycle, but this matrix can be easily used to improve the current design in further iterations.

Good Manufacturing Practices

Good Manufacturing Practices (GMP) must be implemented in order to ensure compliance with regulatory rules and to ensure a food safe product. This section will address the need for the owner of the winnowing system to develop their own GMP to properly fit their needs and facility. The scope of this section will focus only on the development for the GMP of the winnower system. All other processes outside of the winnower system are not covered in these GMP guidelines. There are five key components of the winnower that the GMP will cover. The components are: initial storage of the cocoa beans, the cracking component, the sorting component, the winnowing component, and the storage of the product (winnowed cocoa nibs) and waste.

General Housekeeping

In general the following steps should be taken to ensure a clean and safe working environment. These housekeeping guides are taken directly from the Food Technology Fact Sheet: Process and Facility Sanitation.

- Neat grounds surrounding the facility, free from rodent harborage, insect-breeding materials, debris, dust, weeds, and odor producing conditions
- Floors, aisles, ceilings, structural beams, piping light fixtures, and other overhead areas should be cleaned regularly
- Restrooms, toilets, urinals and hand washing stations should be cleaned and functioning properly
- Lockers and personal property storage areas should be clean and orderly
- Drinking fountains and cooler must be clean

Cleaning Materials Suggested to Maintain the GMP

The materials suggested to help maintain the GMP that the client will develop were selected based on the cost and how they will impact the winnower system. First, the use of water should be avoided when sanitizing the winnower system. This is due to the high biological risk that water poses when introduced to systems. Wet surfaces provide microorganisms with ideal conditions to reproduce and spread. It can also increase the risk that particles will stick and collect on the surfaces and attract microorganisms and other pests. When sanitizing the winnower system, it is suggested to uses materials such as:

- food grade brushes
- blowers
- vacuums
- alcohol wipes

Brushes and blowers can be used to dislodge particles that may have collected in certain areas of the winnower system while vacuums can collect the dislodged particles. Since air is used by the blowers and vacuums there is little risk involved in contaminating the system and are relatively cheap when compared to industrial cleaners or solvents. The bushes will also pose little risk to contaminating the system as long as they are routinely cleaned, sanitized, and replaced. Alcohol wipes are suggested to sanitize the system. They can help clean fat residue that may be left by the cocoa beans and it quickly dries and disinfects the surfaces that it is used on.

Initial Storage of the Roasted Uncracked Cocoa Beans

If the cocoa beans are not directly feed into the winnowing system after being roasted, the client should keep the cocoa beans in a clean, dry, sealed, food grade container that is stored in a clean and dry storage space. When the cocoa beans are transferred to the hopper of the winnowing system the client should keep the cocoa beans safely covered to prevent foreign objects from falling into processing stream. Note that the covering should also not be at risk of falling into the processing stream or contaminating the product in any way. Should the hopper require cleaning, the client must first turn off the winnowing system and remove the winnower from its power source. Never attempt to clean or maneuver around or in the hopper when the winnowing system is connected to a power source. It is suggested to use blowers and vacuums to dislodge and particles that have collected in the hopper and then use alcohol wipes to clean any fat residue.

Cracking Component

The cracking component, or the rollers and roller housing, should be routinely cleaned. This is because during the cracking process fats and oils from the cocoa beans could be released and collect on the rollers. This could cause a microbial and pest risk in the winnowing system and possibly contaminate the product stream. Turn off and disconnect the winnower from its power source before attempting to clean the cracking component of the winnower system. Once the winnower is removed from its power source, the blowers and brushes should be used to dislodge particles that may have accumulated on the rollers or in the housing. Vacuums can also be used to collect and remove these loose particles. It is also suggested to clean off the rollers with alcohol wipes to remove excess oil and to sanitize the rollers.

Sorting Component

The sorting component should be routinely cleaned, especially due to the nature of the screens utilized to separate the cracked cocoa beans based on particle size. It is likely that particles will accumulate in the screens. This accumulation can not only contaminate the product stream but also reduce the efficiency of the sorting trommel. The separation trommel must be turned off and disconnected from its power source before it is cleaned. Use air blowers, vacuums, and food grade brushes to dislodge the particles that have accumulated in the trommel screens. If necessary, remove the trommel from its housing and take it to a proper rinsing area away from the main winnowing system and wash the screens with water and food safe cleaners. Allow the trommel screens to fully dry before returning it to its housing. Note that the use of water for cleaning or sanitation is highly discouraged due to its heightened microbial risk.

Winnowing Component

The winnowing component should be routinely inspected for any buildup of particles or residues. It is suggested to disassemble the components to clean any hard to reach places within the winnowing component. If necessary use alcohol wipes to clean off any fats or oils left by the cocoa nibs or chaff.

Storage of Product and Waste

The storage area for the product should be kept clean and the product storage bin should be kept off the floor at all times. After every use the storage bin should be cleaned using alcohol wipes. If nibs are left in the storage bin for an extended period of time the bin should be sealed and stored off the floor in a clean and dry space. All waste that is generated from the winnowing system should be properly stored and/or disposed of. This will reduce the risk of attracting pests, promoting microbial growth, and generating unpleasant odors.

Recommendations

Based on our research and current prototype design flaws, both foreseen and unforeseen, we have the following recommendations for further design iterations:

- Hopper design
    - Add a slide in order to stop/meter the flow of beans
    - Increase hopper holding capacity
    - Construct from a food-grade material
- Funnel design
    - Close the space between roller housing and funnel
    - Design the funnel to flow into the entrance of trommel
- Spring design/roller separation method
    - Increase spring tension/install axle locks
    - Add spring guide to ensure linear compression
- Trommel design
    - Ensure screens are appropriately sized for output of rollers
    - Motor sized appropriately
    - Method of rotation
        - Driving belt
        - Wheels that move up or down to increase slope of trommel
    - Catch bucket at the end of the trommel for any whole beans
    - Trommel boxed in on frame to hide it from sight

        - Make hinged door or clear window for viewing purposes
- Decrease total weight/height of winnower
    - Decrease wall thickness
    - Decrease roller length/diameter
- Operator safety
    - Add chain guards/guards around moving parts in general
    - Add emergency shutoff controls when moving parts are accessed
    - Add warning labels
    - Round exposed edges
- Food contamination
    - Upgrade all materials to food grade materials, i.e. Stainless steel, UHMW, etc.
    - Make components easier to disassemble in order to ease cleaning
        - No narrow openings, long tubes, sharp bends, etc.
- Offer various models
    - Stacked rollers
    - More screens on trommel
    - Size up for faster winnowing rate
    - Add more aesthetically pleasing models for customers who give tours of their facilities
- Operation
    - Add PLC with screen to ease operation
        - Start all aspects of machine from one location
        - Change roller speed
        - Automatic shutoff when hopper is empty
    - Decrease noise
    - Decrease floor space
- Decrease size of vacuum
    - Need same air flow, but smaller box
    - Doesn’t necessarily require shop-vac, just need something to provide suction

Project Schedule

ID		Task Mode	Task Name	Duration	Start	Finish	July B
1	✓		Develop Team Organization & Structure	20 days	Mon 8/22/16	Fri 9/16/16	
2	✓		Meet Client: U.S. Roaster Corperation	0 days	Fri 9/16/16	Fri 9/16/16	
3	✓		Technical Literature Review & Analysis	42 days	Mon 9/19/16	Tue 11/15/16	
4	✓		Market Research Trip: Izzard Chocolate	0 days	Thu 10/13/16	Thu 10/13/16	
5	✓		Develop Project Proposal	55 days	Mon 8/22/16	Fri 11/4/16	
6	✓		Develop Preliminary Design Concepts	16 days	Mon 10/17/16	Mon 11/7/16	
7	✓		Present Preliminary Design Concepts	0 days	Fri 11/11/16	Fri 11/11/16	
8	✓		Fall Semester Design Review Presentation	0 days	Fri 11/18/16	Fri 11/18/16	
9	✓		Fall Semester Design Final Report	0 days	Fri 12/2/16	Fri 12/2/16	
10			Testing on Conceptual Cocoa Bean Cracking Methods	57 days	Thu 11/3/16	Fri 1/20/17	
11			Testing on Conceptual Cocoa Nib Sorting Methods	42 days	Thu 12/1/16	Fri 1/27/17	
12			Control Systems Design	47 days	Thu 12/1/16	Fri 2/3/17	
13			Determine Power/Utility Requirements for the Winnower Design	9 days	Fri 1/27/17	Wed 2/8/17	
14			Determine Expected Prototype Cost Analysis	13 days	Wed 2/1/17	Fri 2/17/17	
15			Finalize Winnower Design and Receive client approval	0 days	Wed 2/22/17	Wed 2/22/17	
16			Finalize Drafting all Necessary Parts Diagrams	16 days	Fri 2/10/17	Fri 3/3/17	
17			Order All Necessary Material and Components for Prototype	0 days	Wed 3/8/17	Wed 3/8/17	
18			Fabrication/Assembly of Prototype	13 days	Mon 3/20/17	Wed 4/5/17	
19			Prototype Troubleshooting	31 days	Sun 3/5/17	Fri 4/14/17	
20			Spring Final Report Draft	37 days	Fri 3/3/17	Mon 4/24/17	
21			Final Presentation Preperation	11 days	Sat 4/15/17	Fri 4/28/17	
22			Final Spring Design Report	0 days	Thu 4/20/17	Thu 4/20/17	
23			Final Senior Design Presentation	0 days	Fri 5/5/17	Fri 5/5/17	

Figure 10: Project Milestones

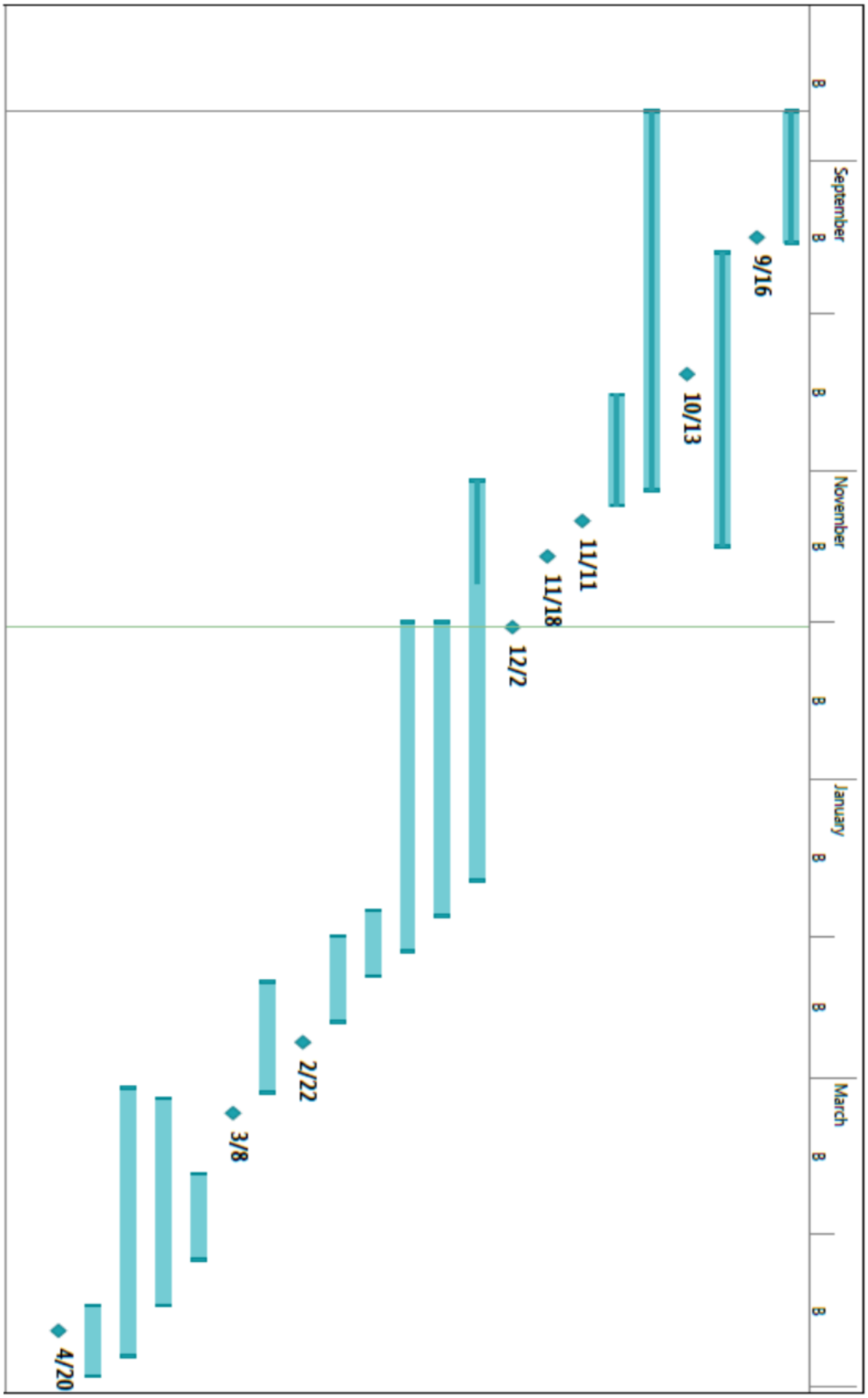

Figure 11: Project Plan Gannt Chart

Environmental, Societal & Global Impacts

The areas of sustainability that this project will impact include the economic, environmental, and socioeconomic impact to the gourmet chocolate industry. US Roaster Corp prides itself on the high quality of their equipment that rarely needs to be serviced. Building a machine that will withstand the rigors of constant usage is essential to this project. Cocoa products are growing in demand each year, especially products for small bean-to-bar producers. Therefore, from an economic standpoint the winnower will be a good investment for US Roaster Corp. Bean-to-bar chocolate producers care where their chocolate is sourced from, often choosing organic and fair-trade cocoa beans. Consciously sourcing cocoa beans not only looks good for their brand, it is better for the environment and for the many cocoa bean growers around the world, many of which are in third-world countries. By enabling small bean-to-bar chocolate producers to more efficiently make chocolate, our product should have a positive impact on the environment and socioeconomic status of many cocoa bean farmers around the world.

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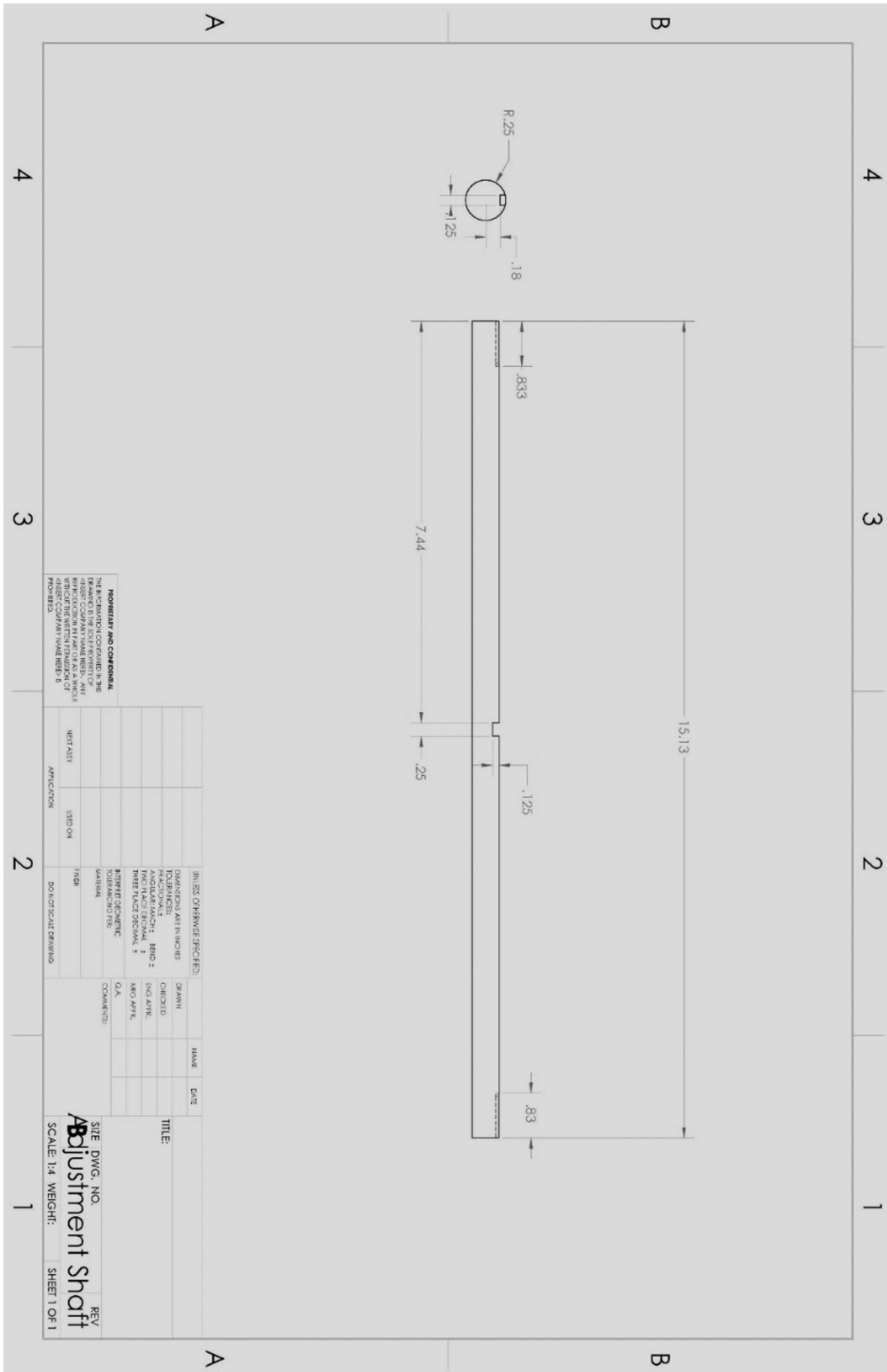
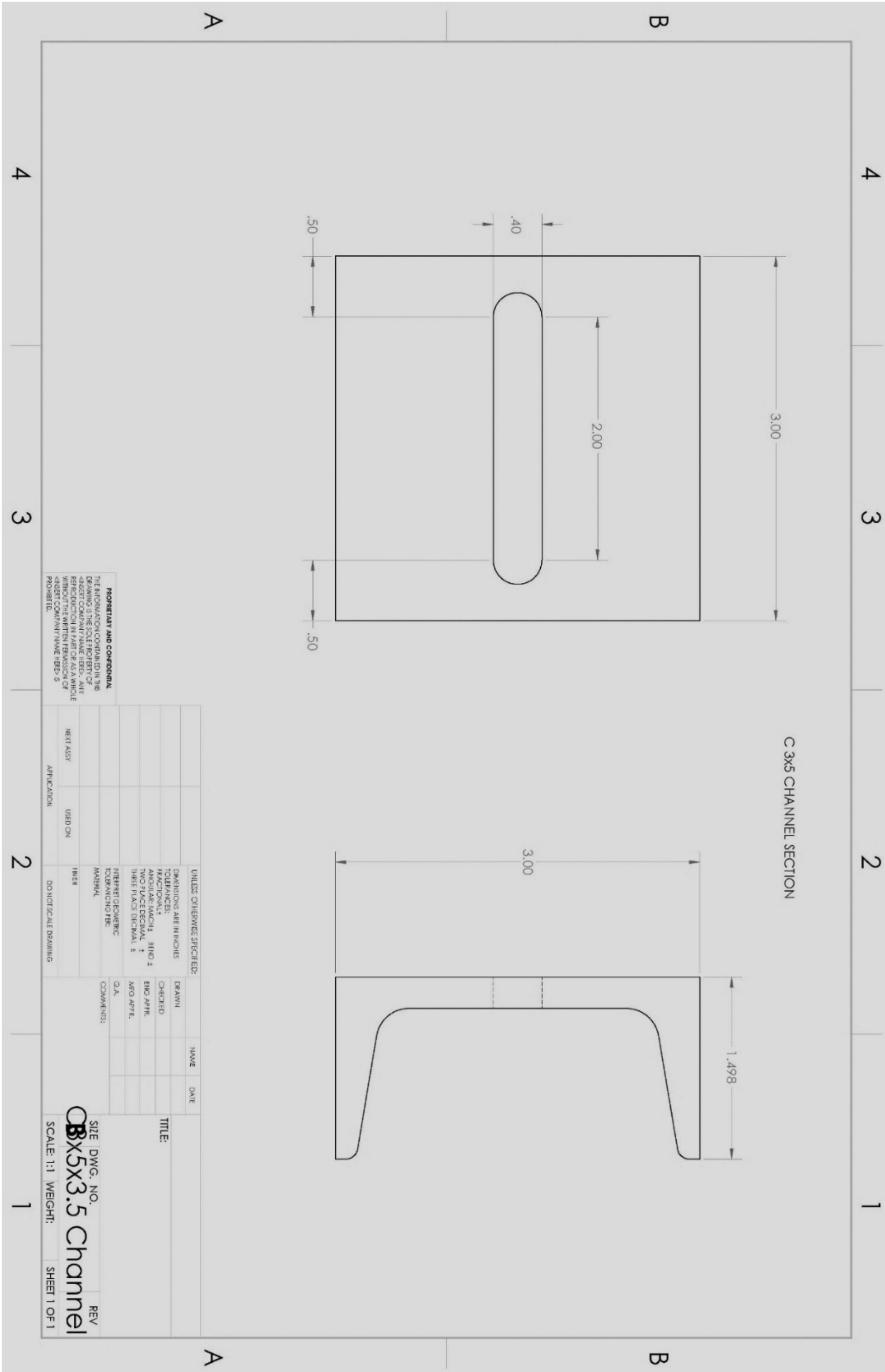
Appendix

SolidWorks Drawings

Below are SolidWorks drawings, with dimensions, of each part of the winnower.

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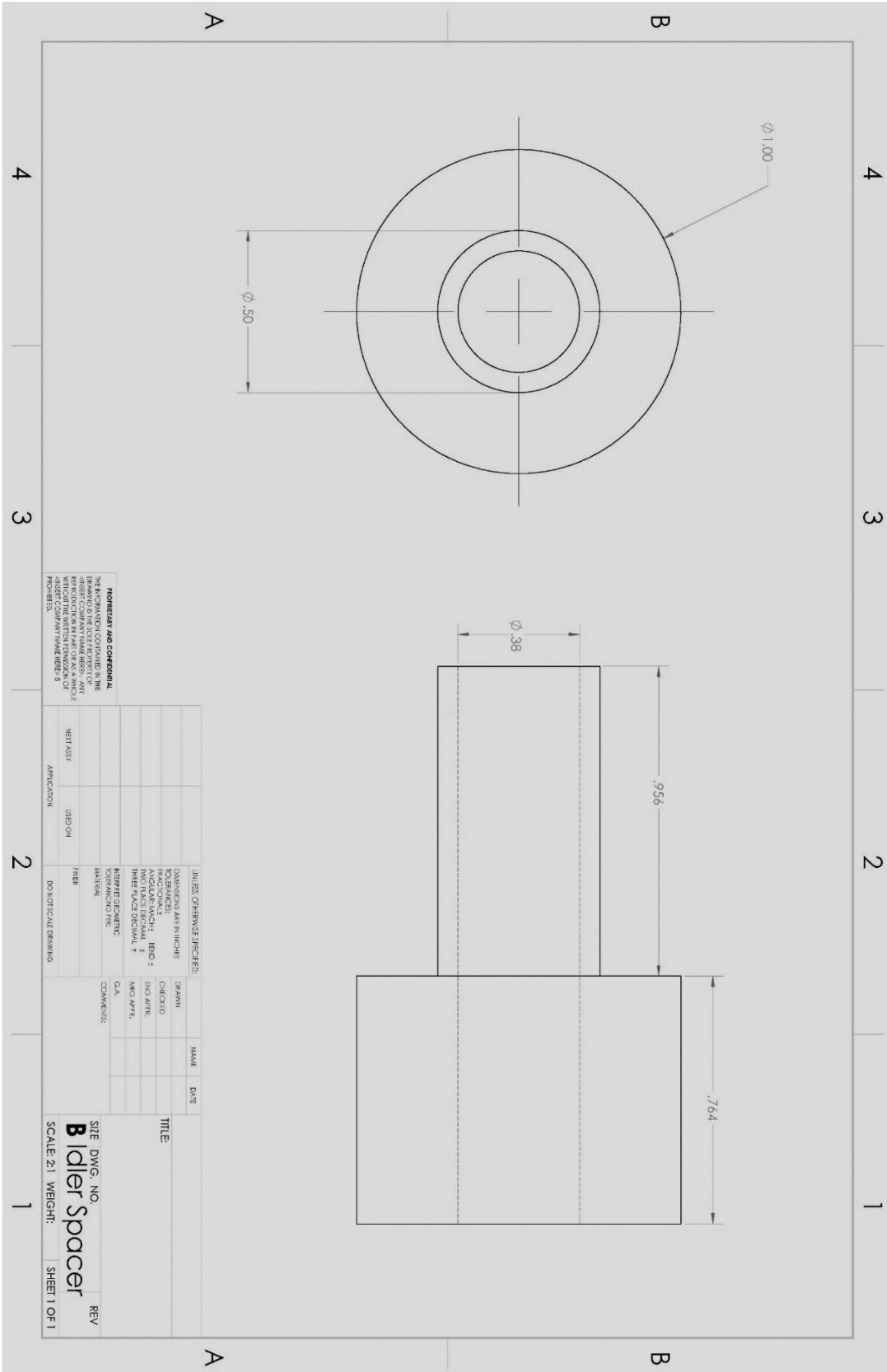
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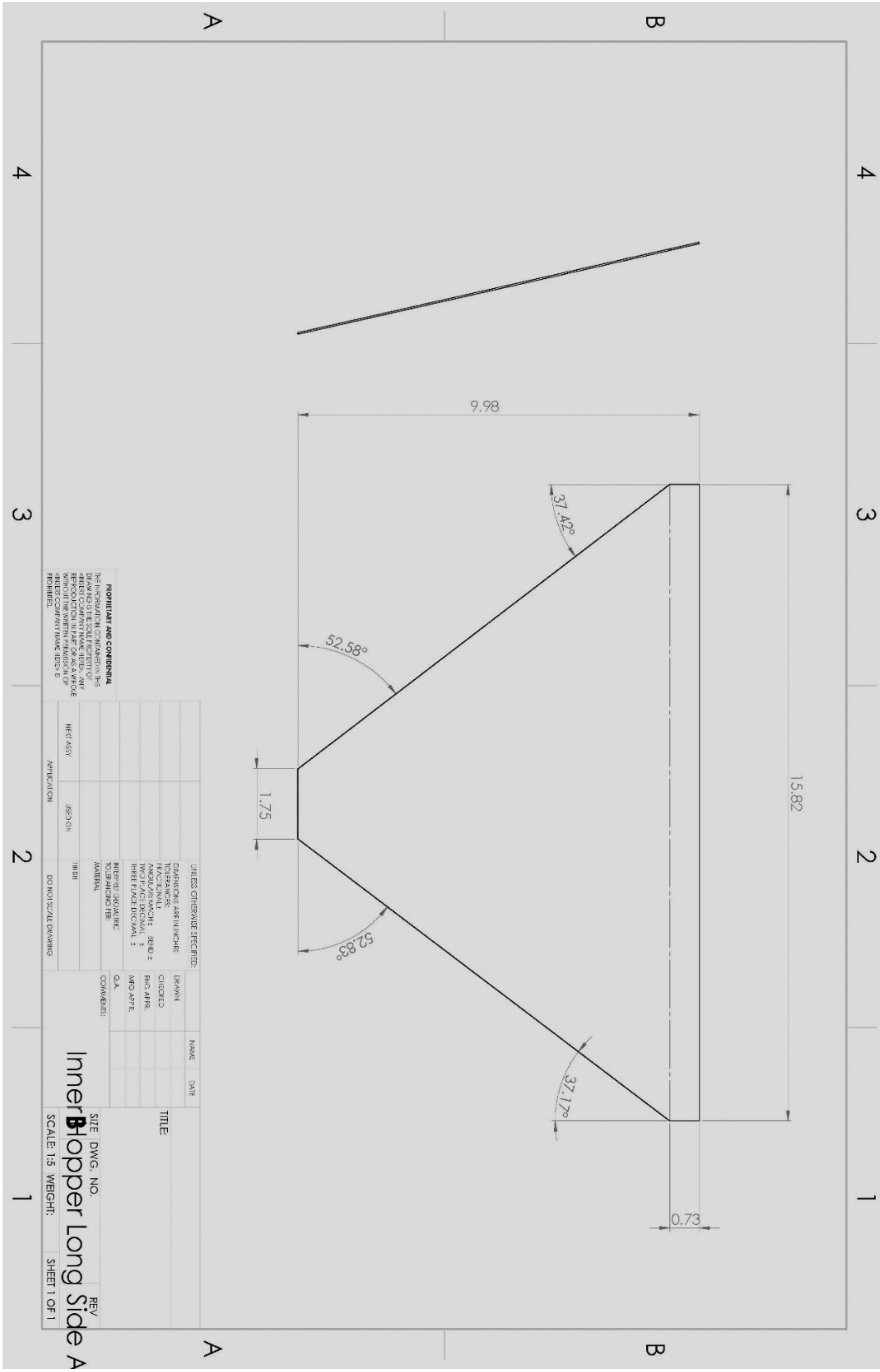
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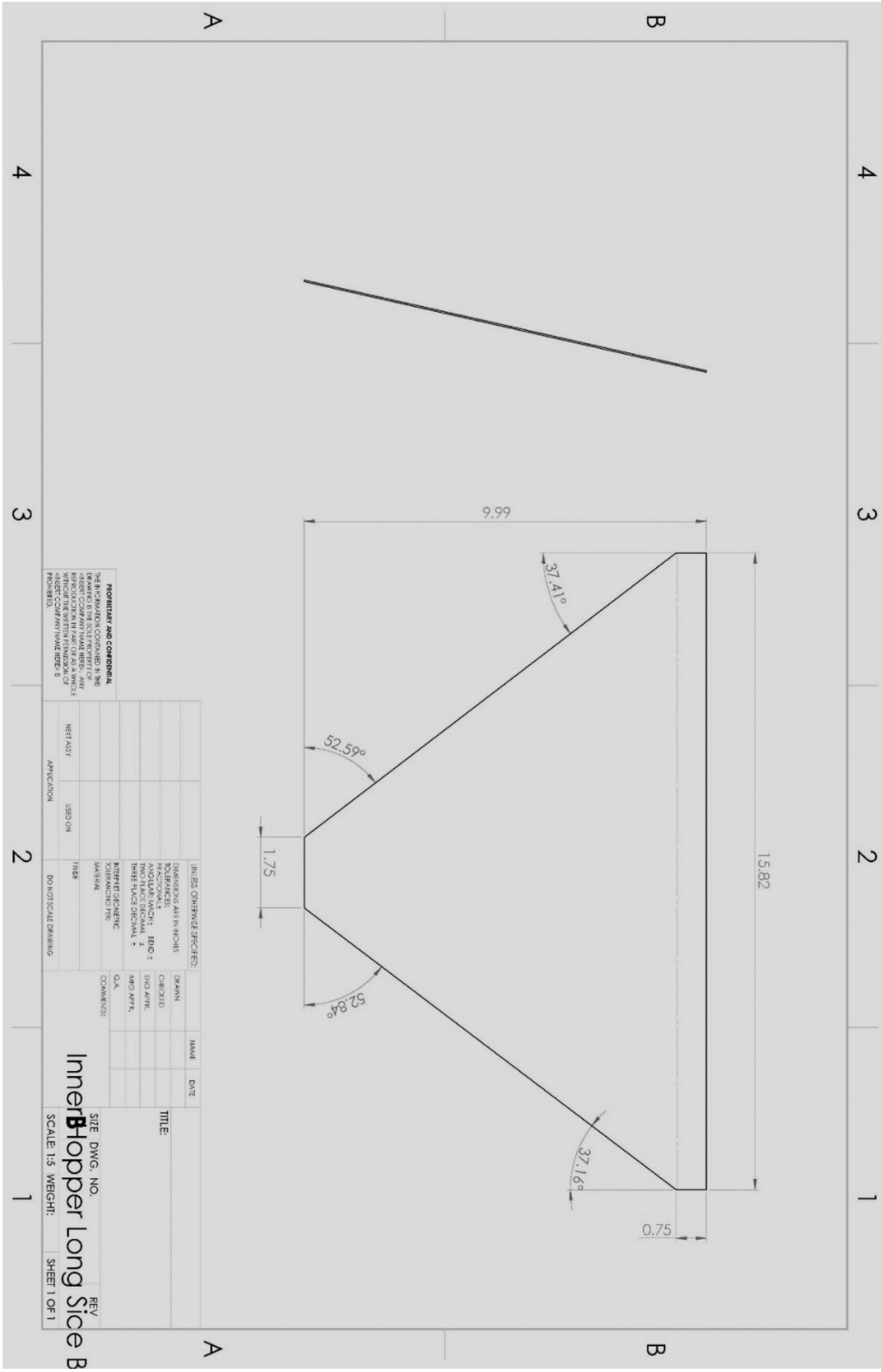
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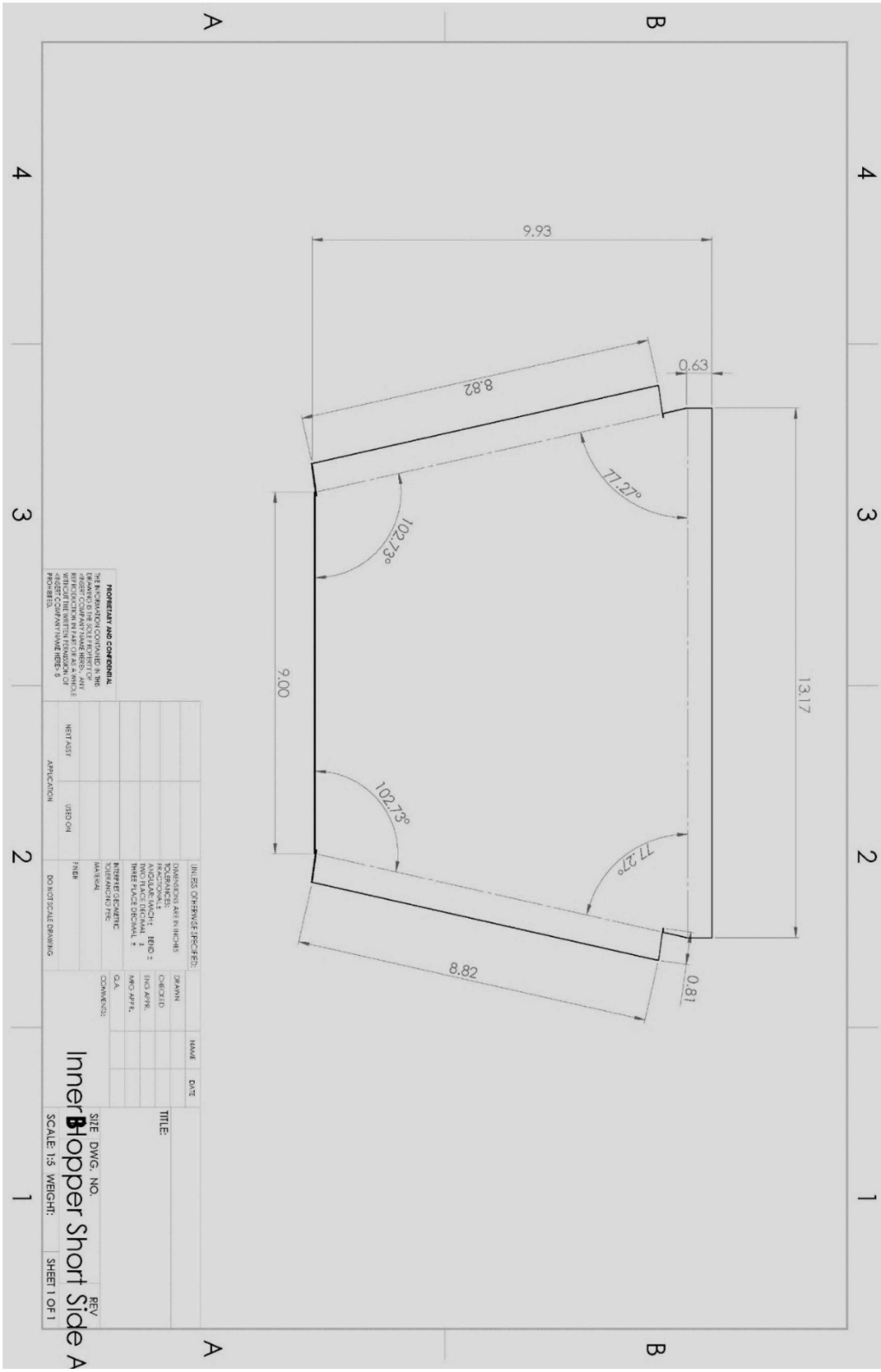
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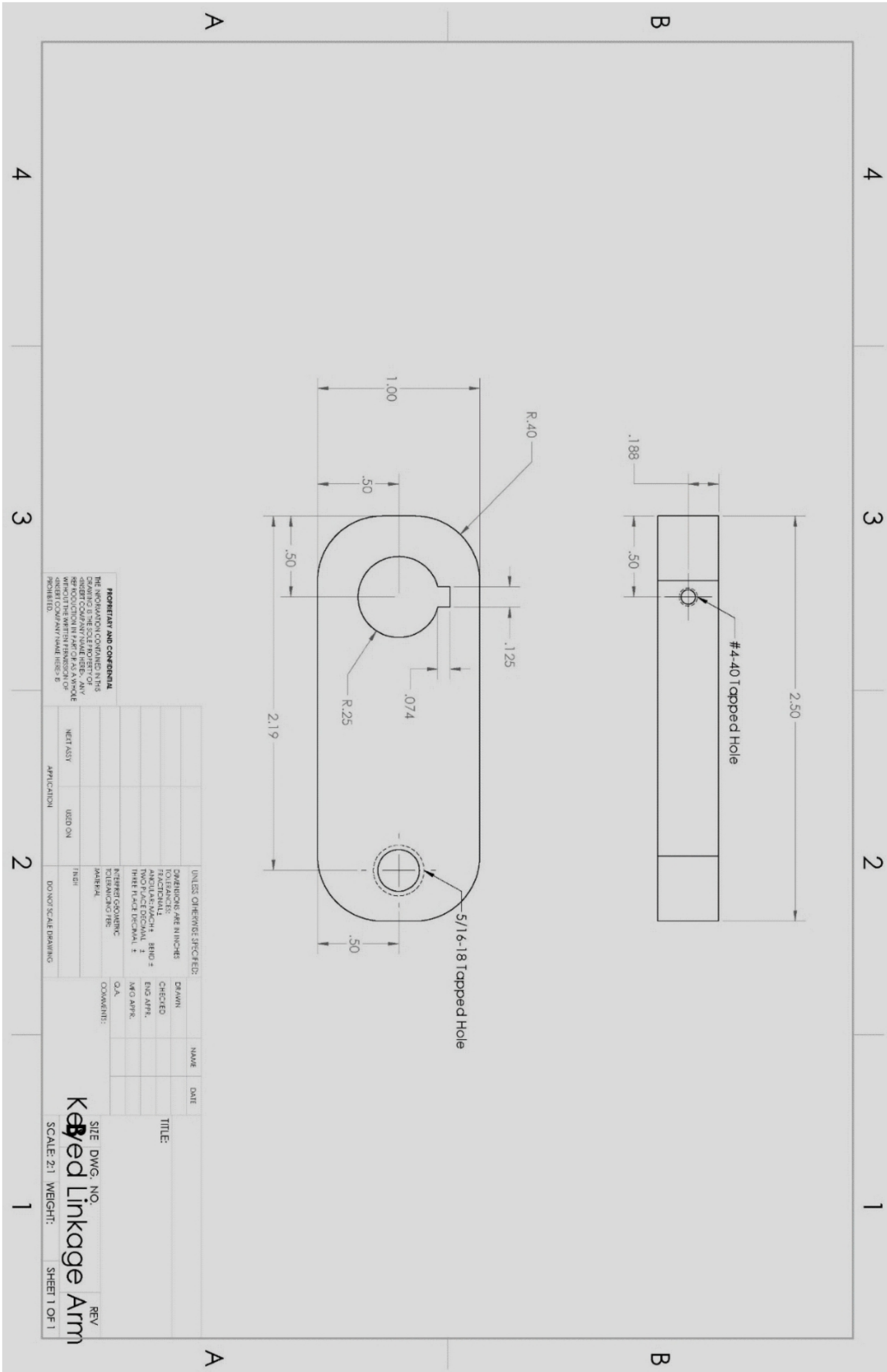
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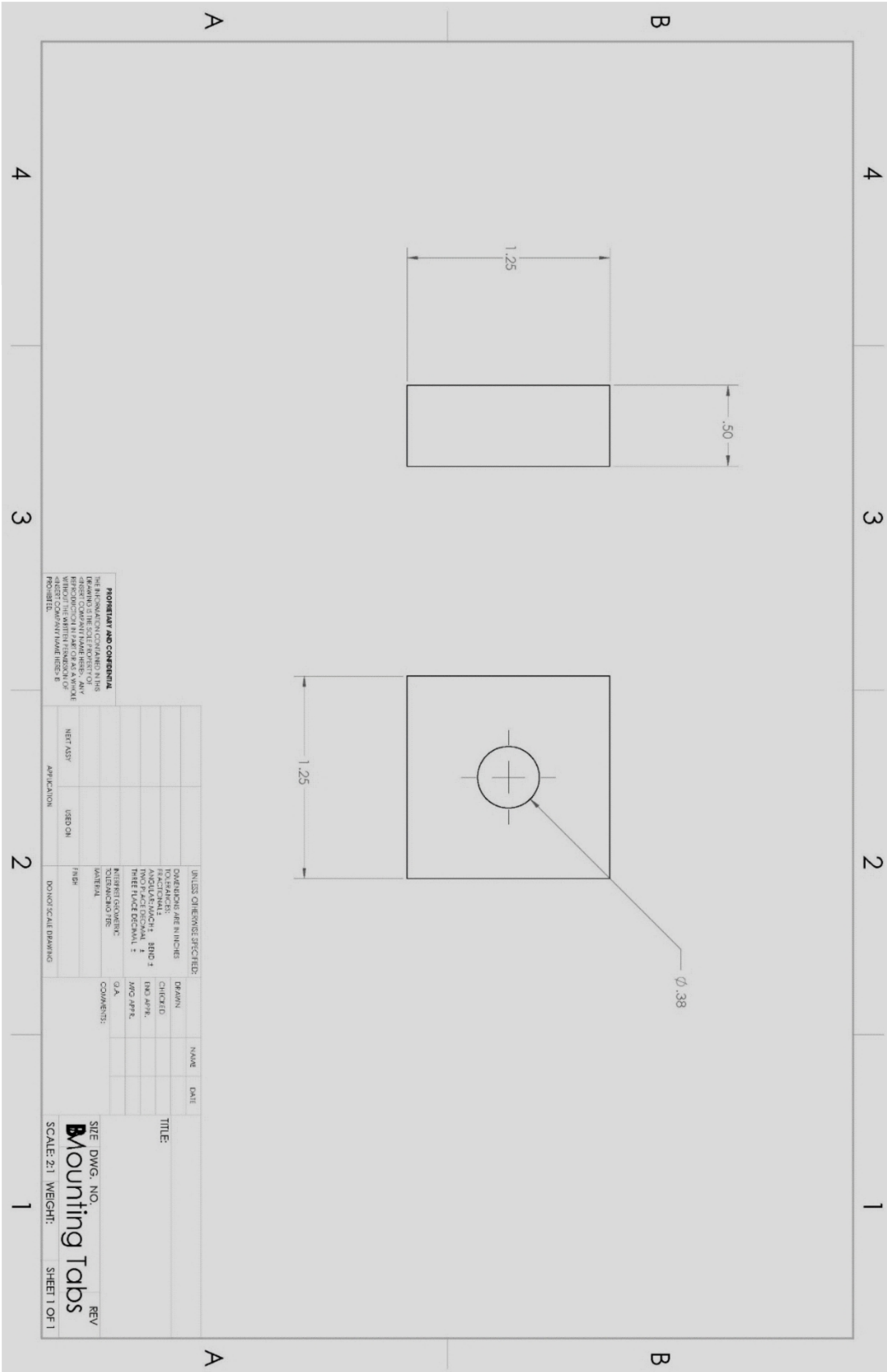

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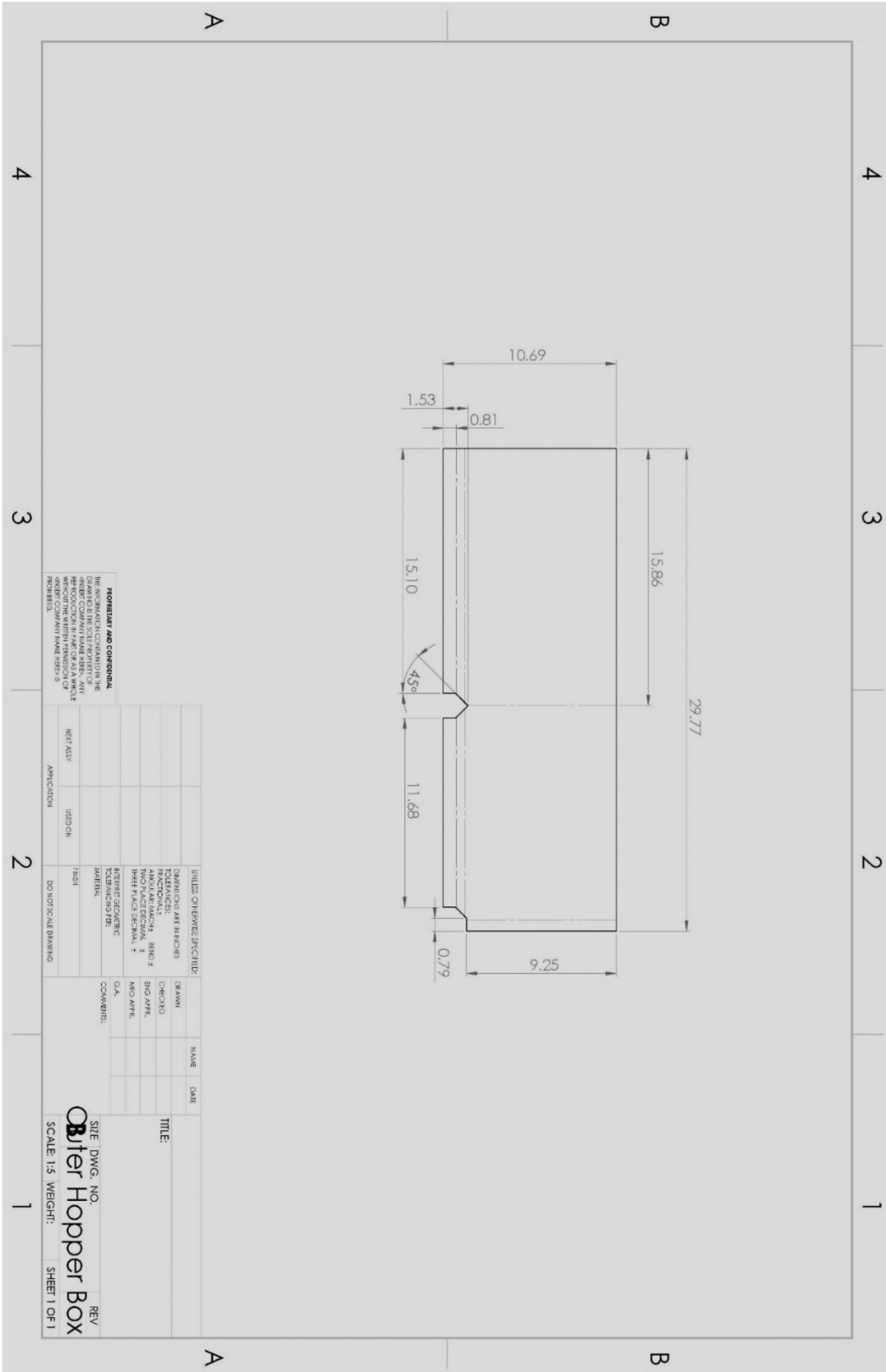
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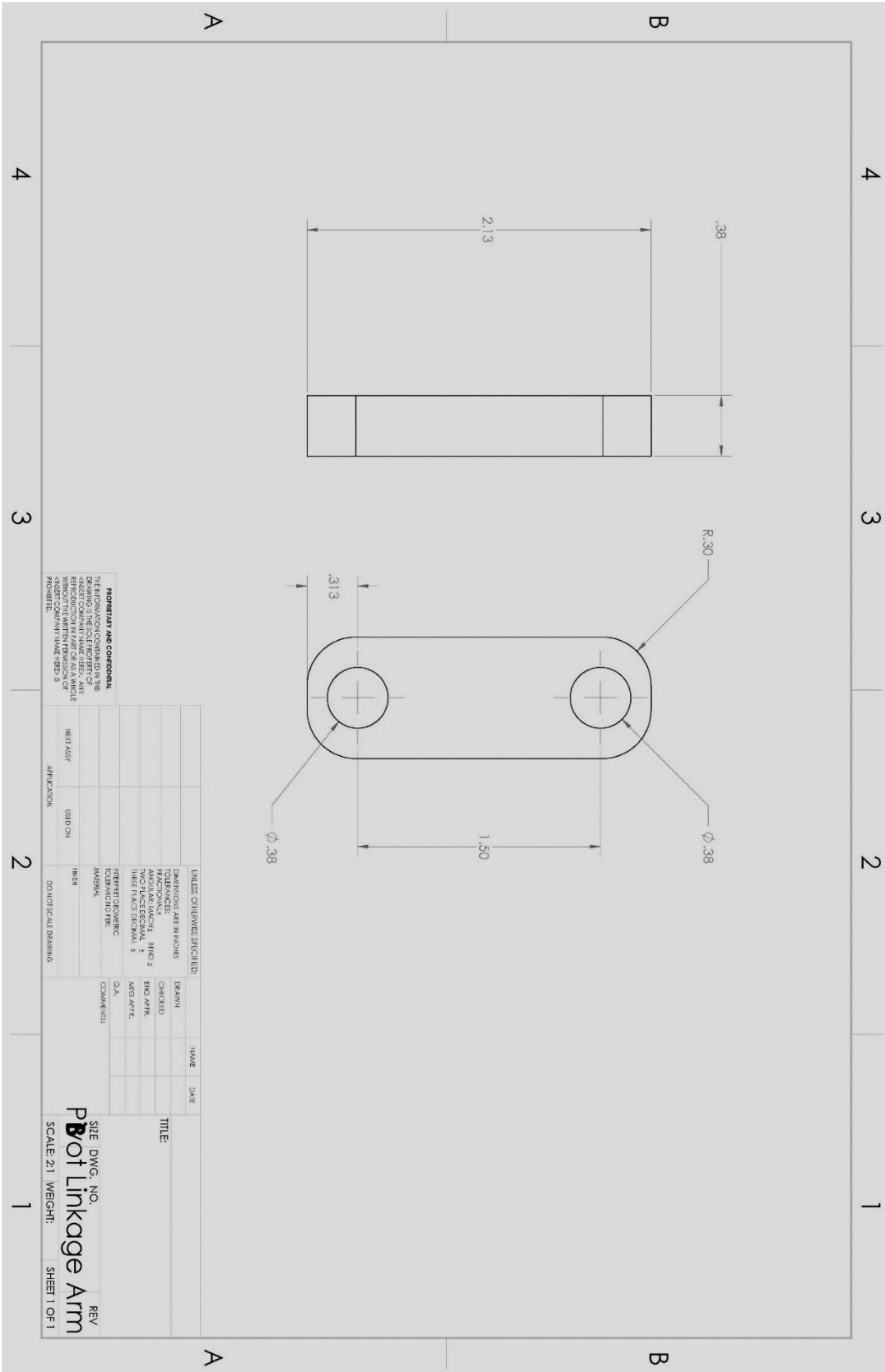

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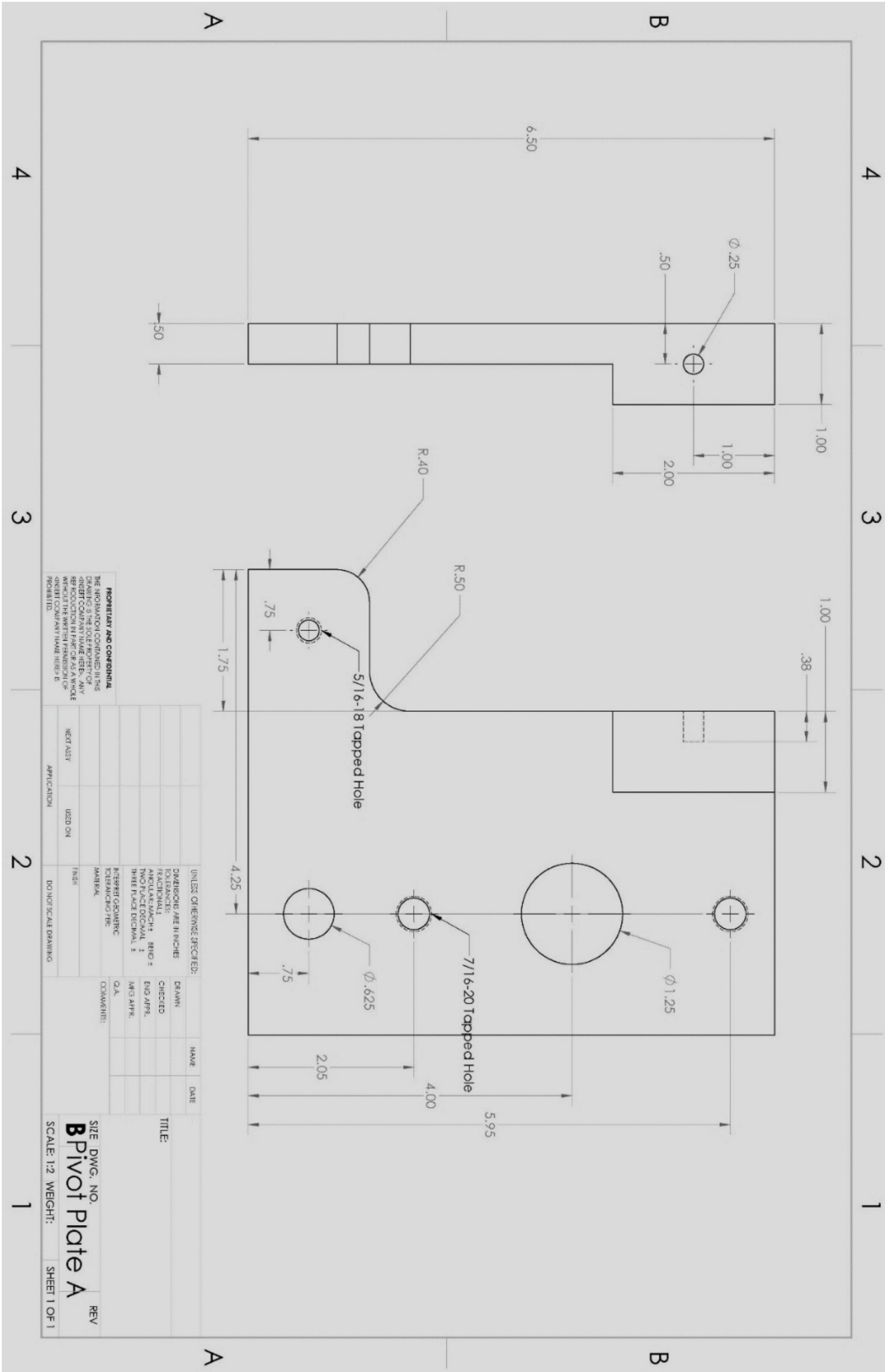
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DIMENSIONS ARE IN INCHES
TOLERANCES:
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ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
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COMMENTS:
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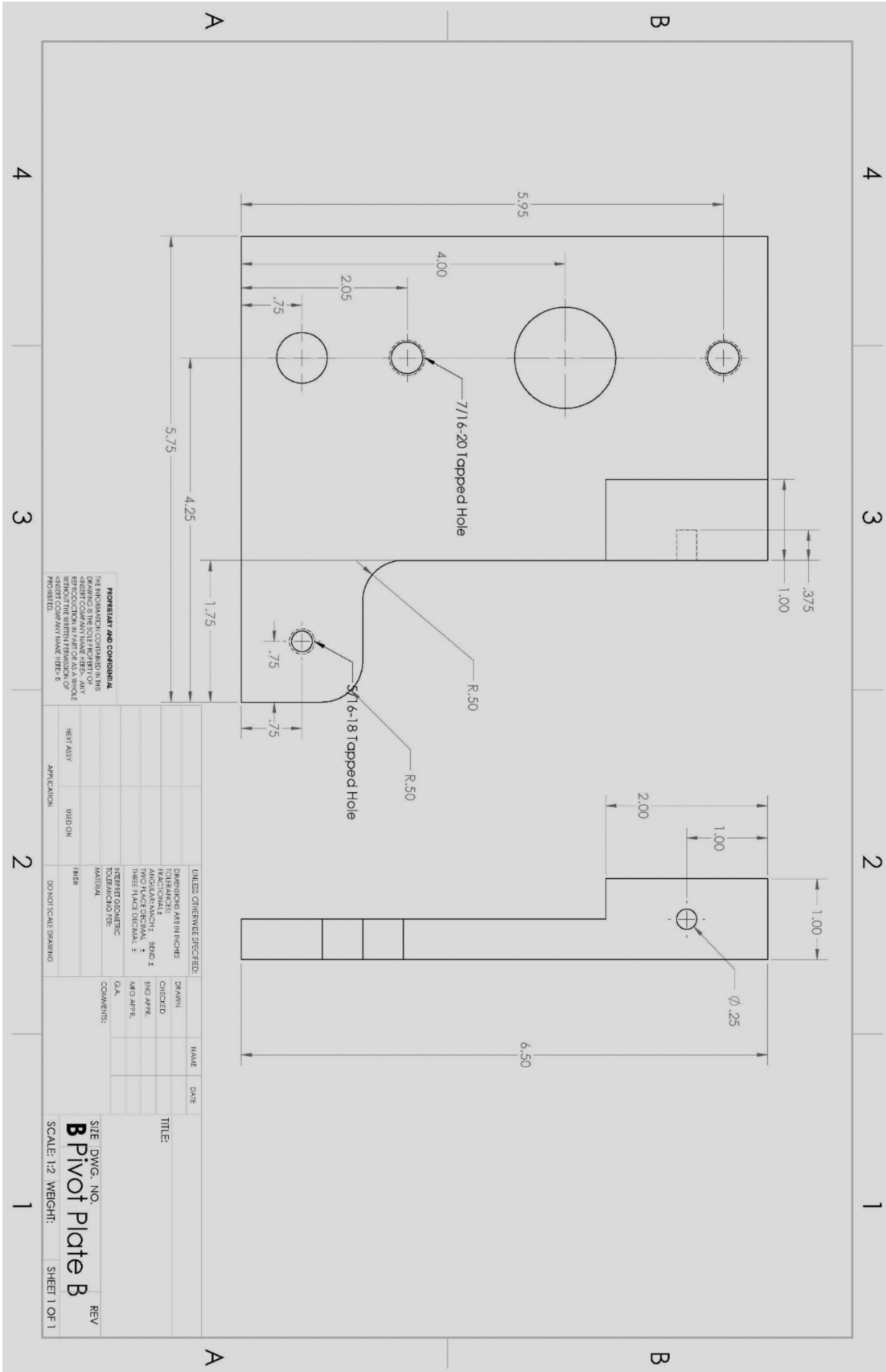
TITLE:
SIZE DWG. NO. REV
B Pivot Plate A
SCALE: 1:2 WEIGHT: SHEET 1 OF 1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5/16-18 Tapped Hole
R.50
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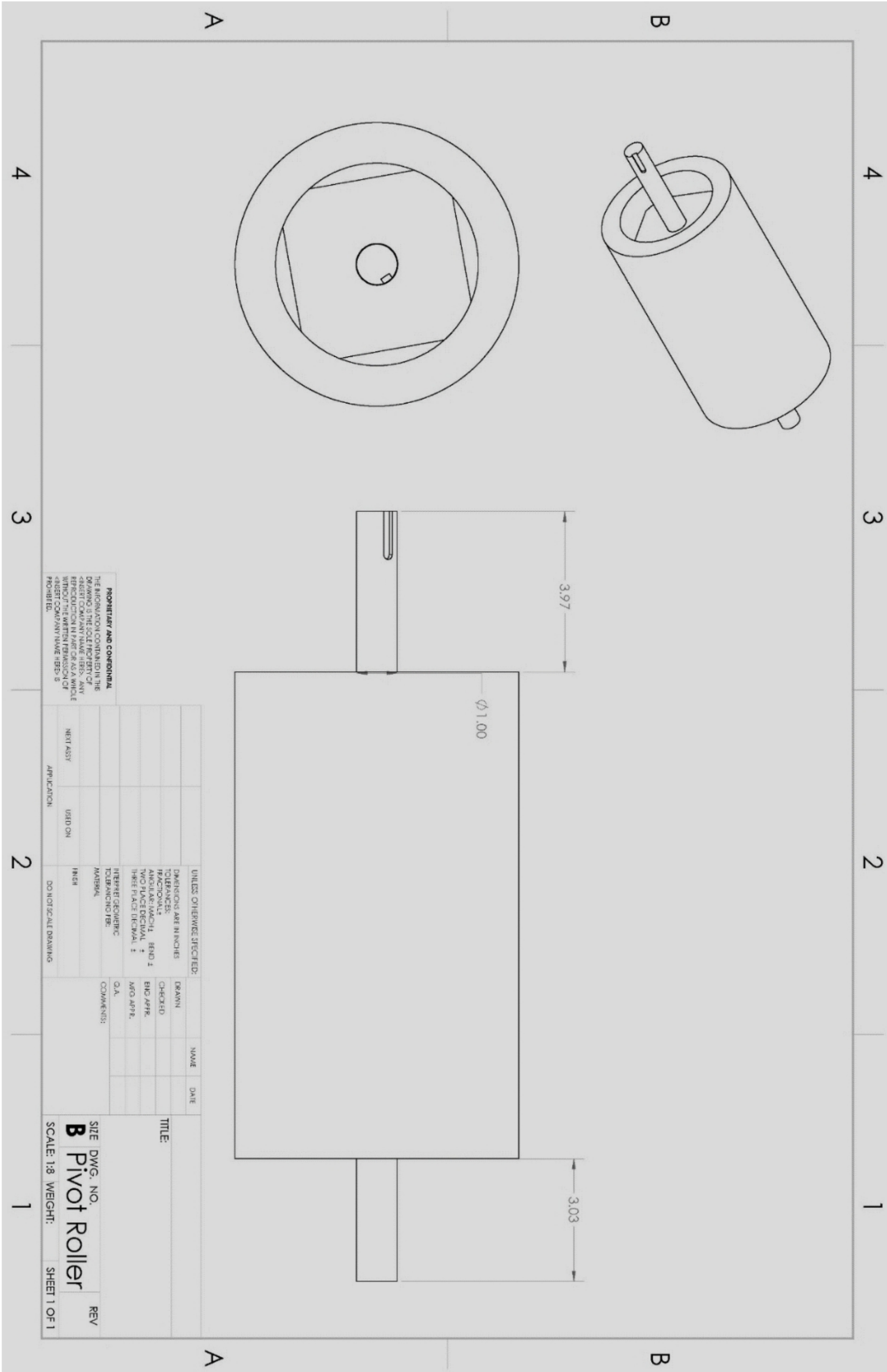

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REV
B
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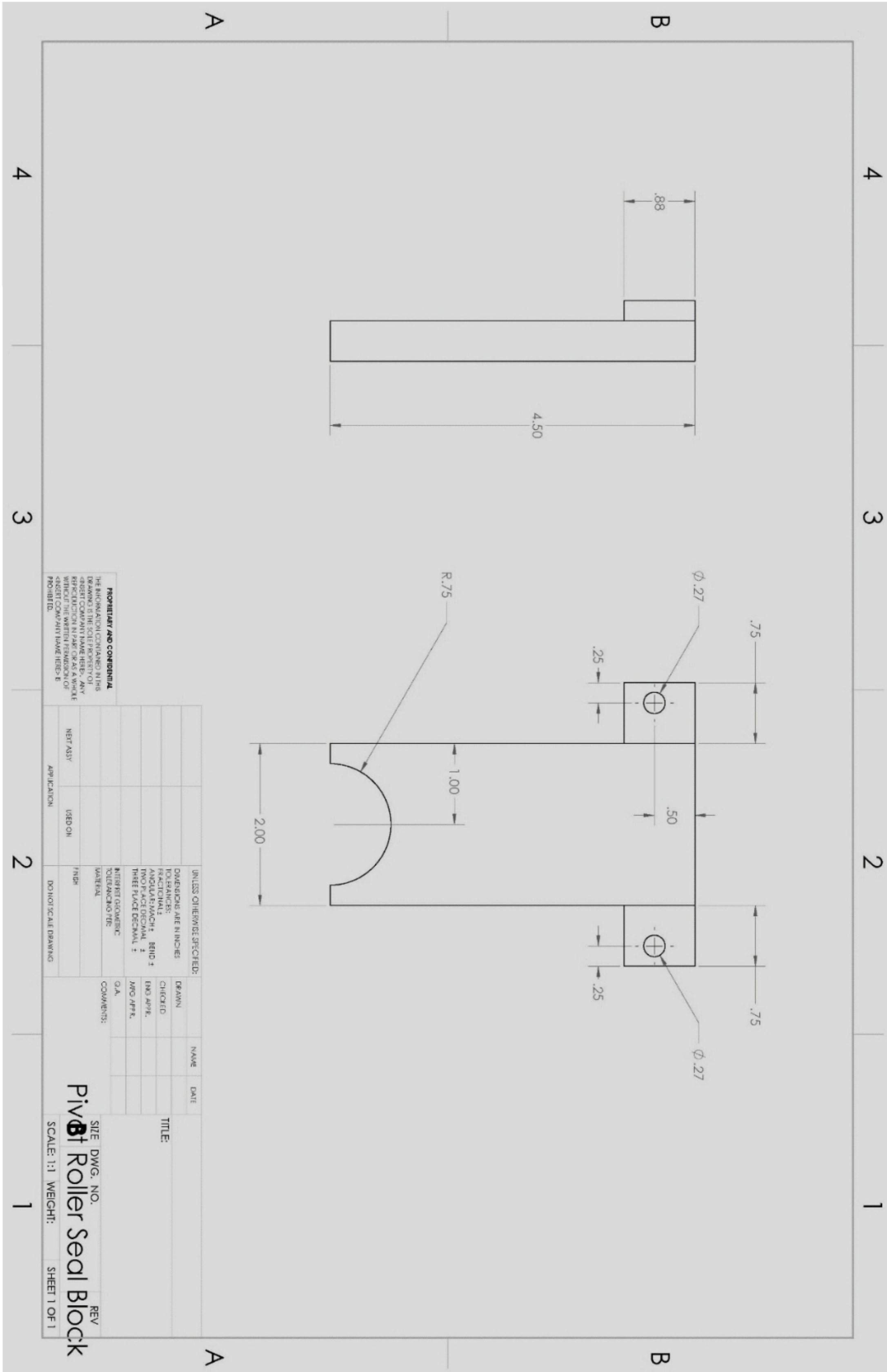
WEIGHT:
SHEET 1 OF 1



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COMMENTS:
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REV
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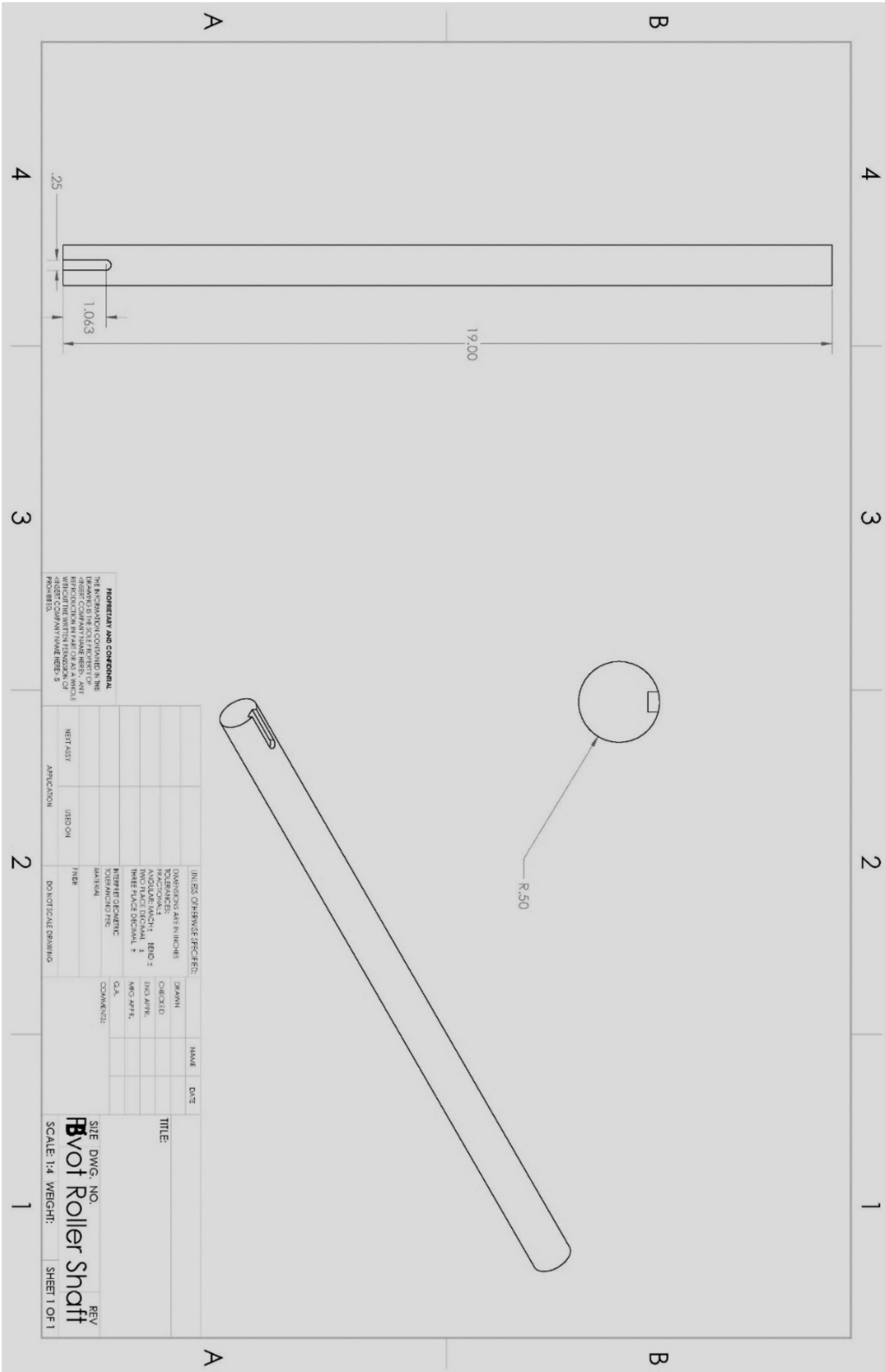
WEIGHT:
SHEET 1 OF 1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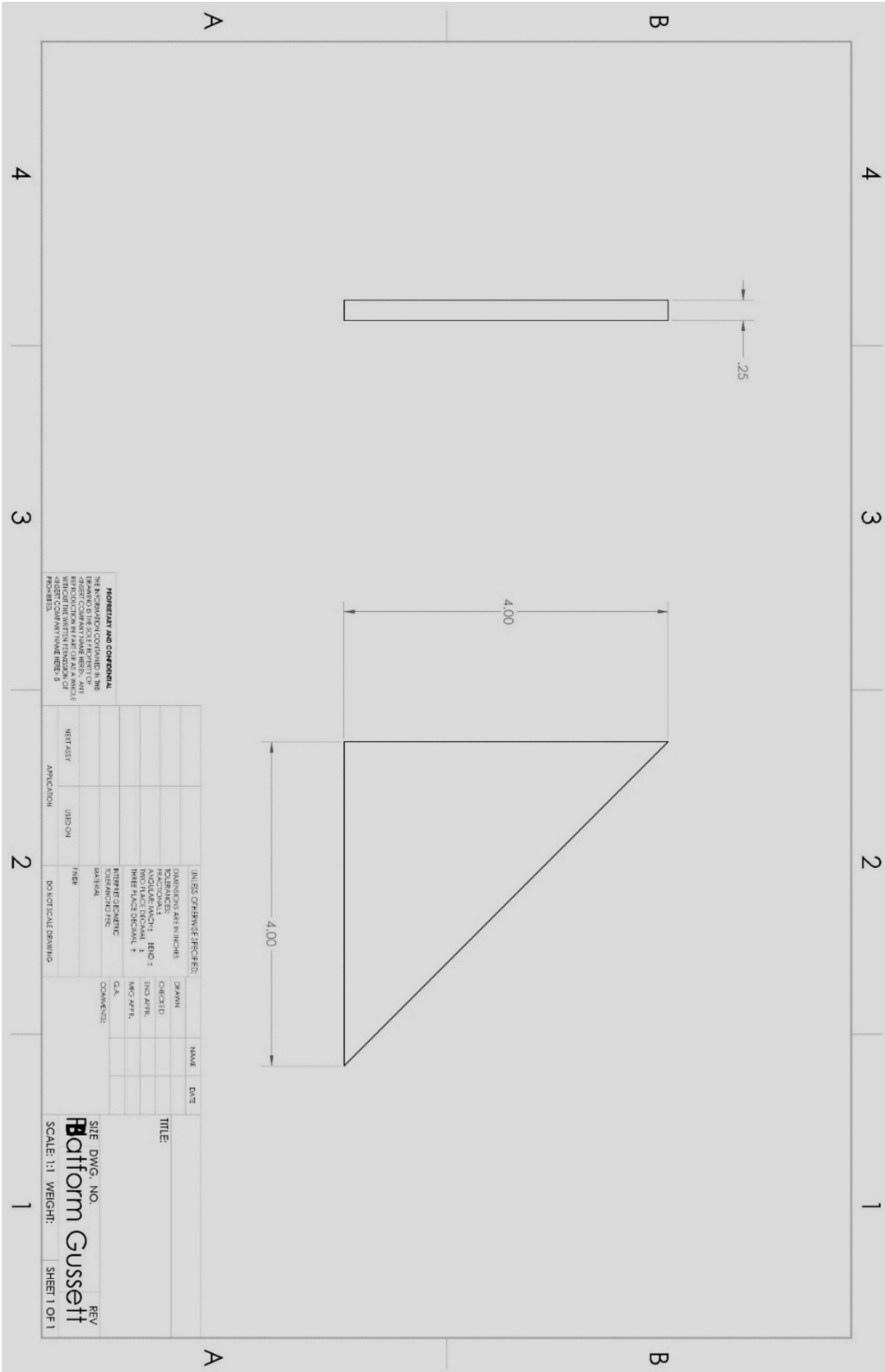
SHEET 1 OF 1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TITLE:
SIZE DWG. NO.
REV
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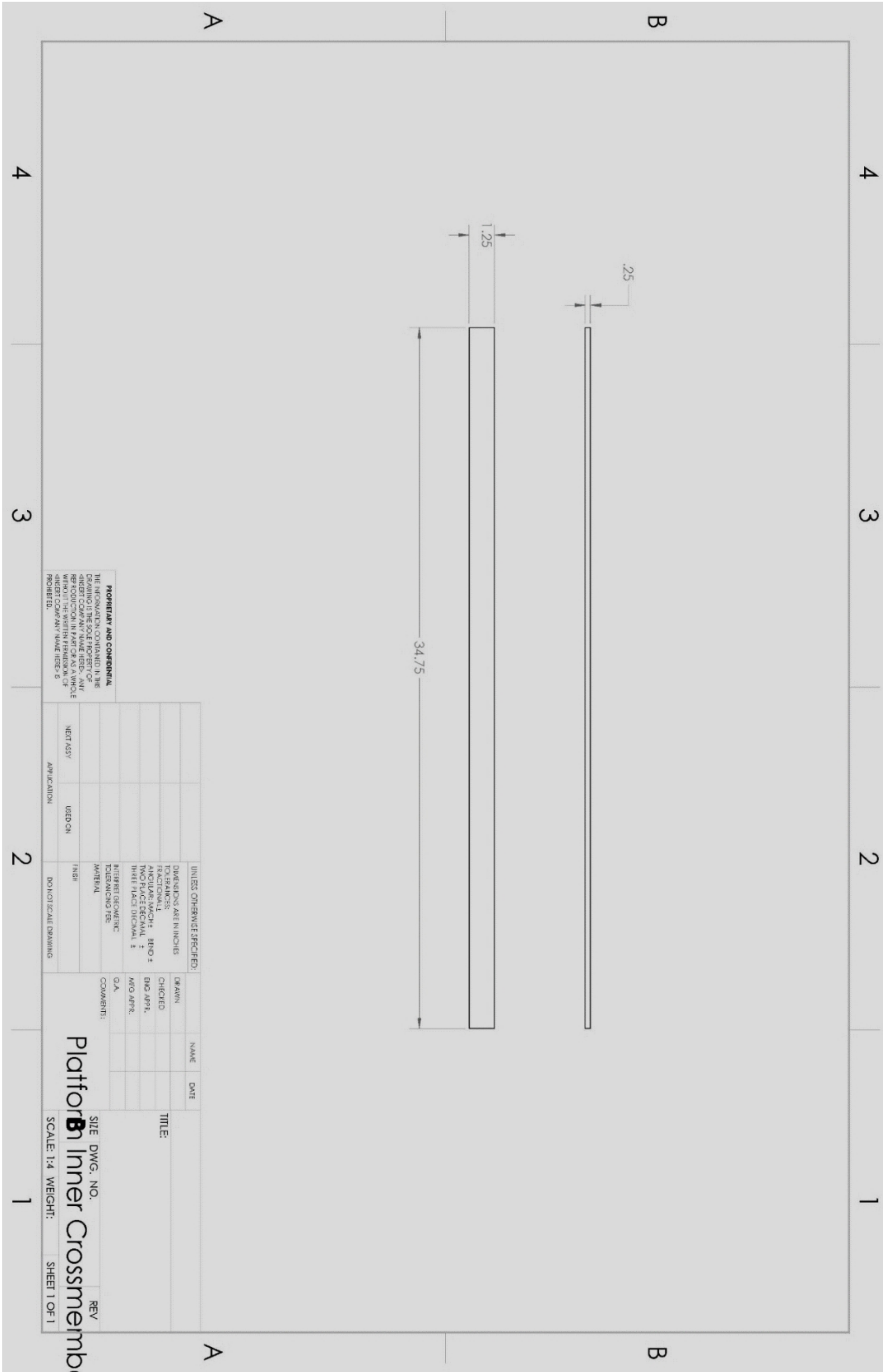

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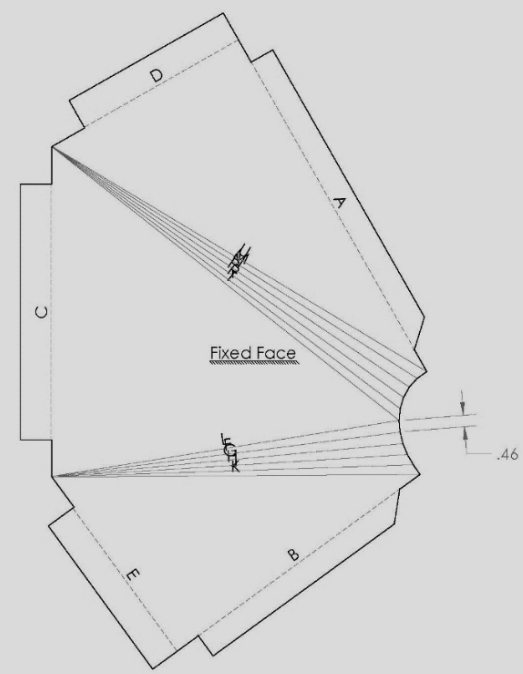
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Platform Inner Crossmember
SIZE B
DWG. NO.
REV
SCALE: 1:4 WEIGHT:
SHEET 1 OF 1

Tag	Direction	Angle	Inner Radius
A	DOWN	0.5°	0.06
B	DOWN	0.5°	0.06
C	DOWN	59.3°	0.06
D	DOWN	47.54°	0.06
E	DOWN	90°	0.06
F	UP	15.37°	0.06
G	UP	16.12°	0.06
H	UP	17.89°	0.06
J	UP	20.23°	0.06
K	UP	10.93°	0.06
L	UP	7.75°	0.06
M	UP	13.51°	0.06
N	UP	12.54°	0.06
P	UP	13.14°	0.06
R	UP	15.45°	0.06
T	UP	9.26°	0.06
U	UP	7.69°	0.06



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TOLERANCES:
FRACTIONAL ±
ANGULAR: MACH ± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
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DO NOT SCALE DRAWING

NAME | DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:

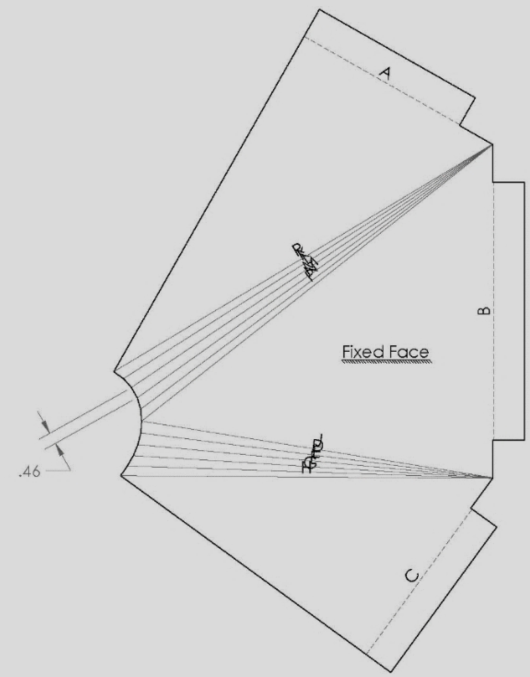
TITLE:

SIZE B DWG. NO. REV

Reverse Hopper Side A

SCALE: 1:8 WEIGHT: SHEET 1 OF 1

Tag	Direction	Angle	Inner Radius
A	DOWN	47.54°	0.06
B	DOWN	59.3°	0.06
C	DOWN	90°	0.06
D	UP	15.37°	0.06
E	UP	16.12°	0.06
F	UP	17.89°	0.06
G	UP	20.23°	0.06
H	UP	10.93°	0.06
J	UP	7.75°	0.06
K	UP	13.51°	0.06
L	UP	12.54°	0.06
M	UP	13.14°	0.06
N	UP	15.45°	0.06
P	UP	9.26°	0.06
R	UP	7.69°	0.06



PROPRIETARY AND CONFIDENTIAL
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NEXT ASSY | USED ON
APPLICATION

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

	NAME	DATE
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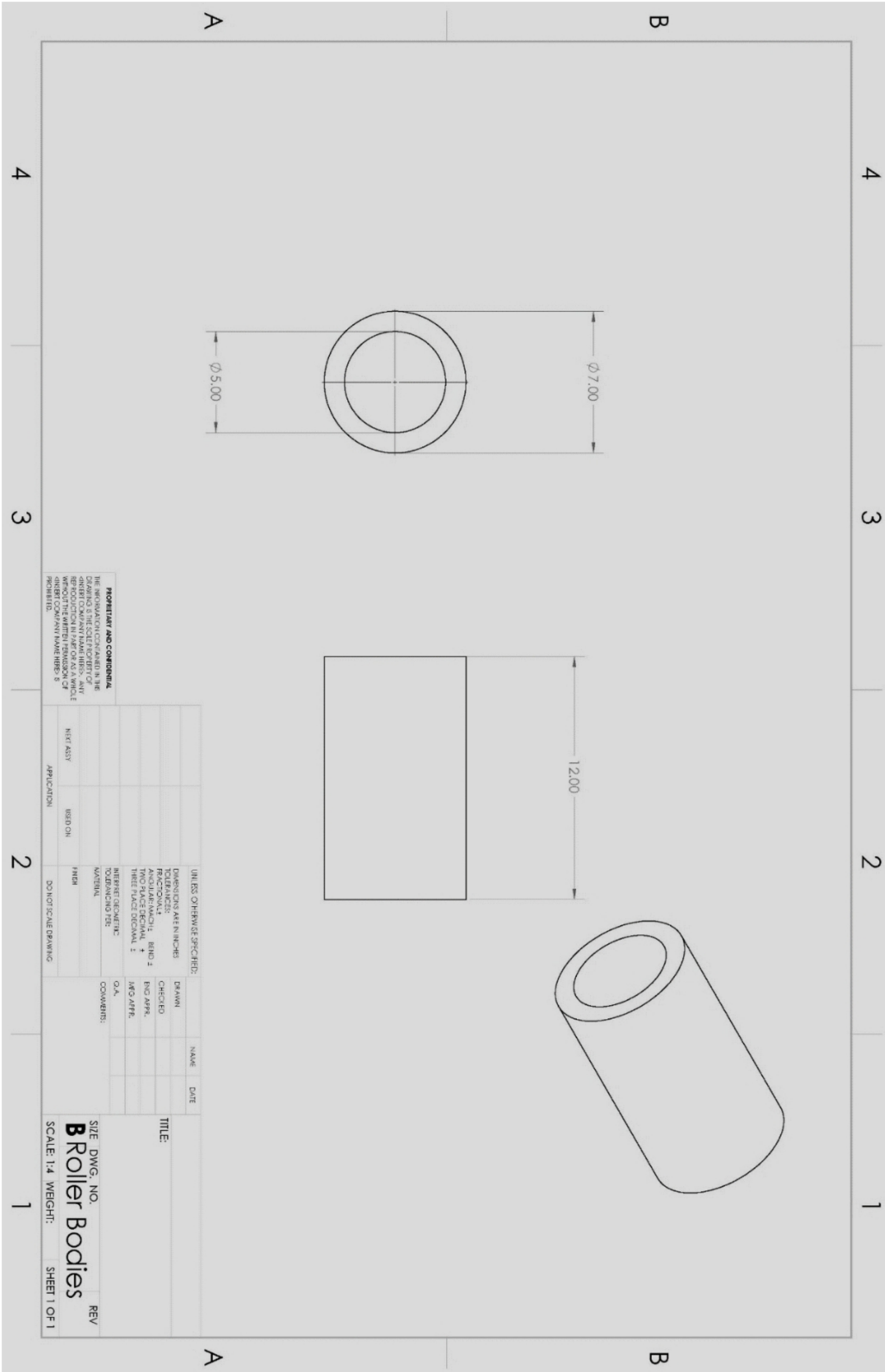
COMMENTS:

TITLE:

SIZE B DWG. NO. Reverse Hopper Side B REV

SCALE: 1:8 WEIGHT: SHEET 1 OF 1



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MATERIAL
FINISH
NEXT ASSY
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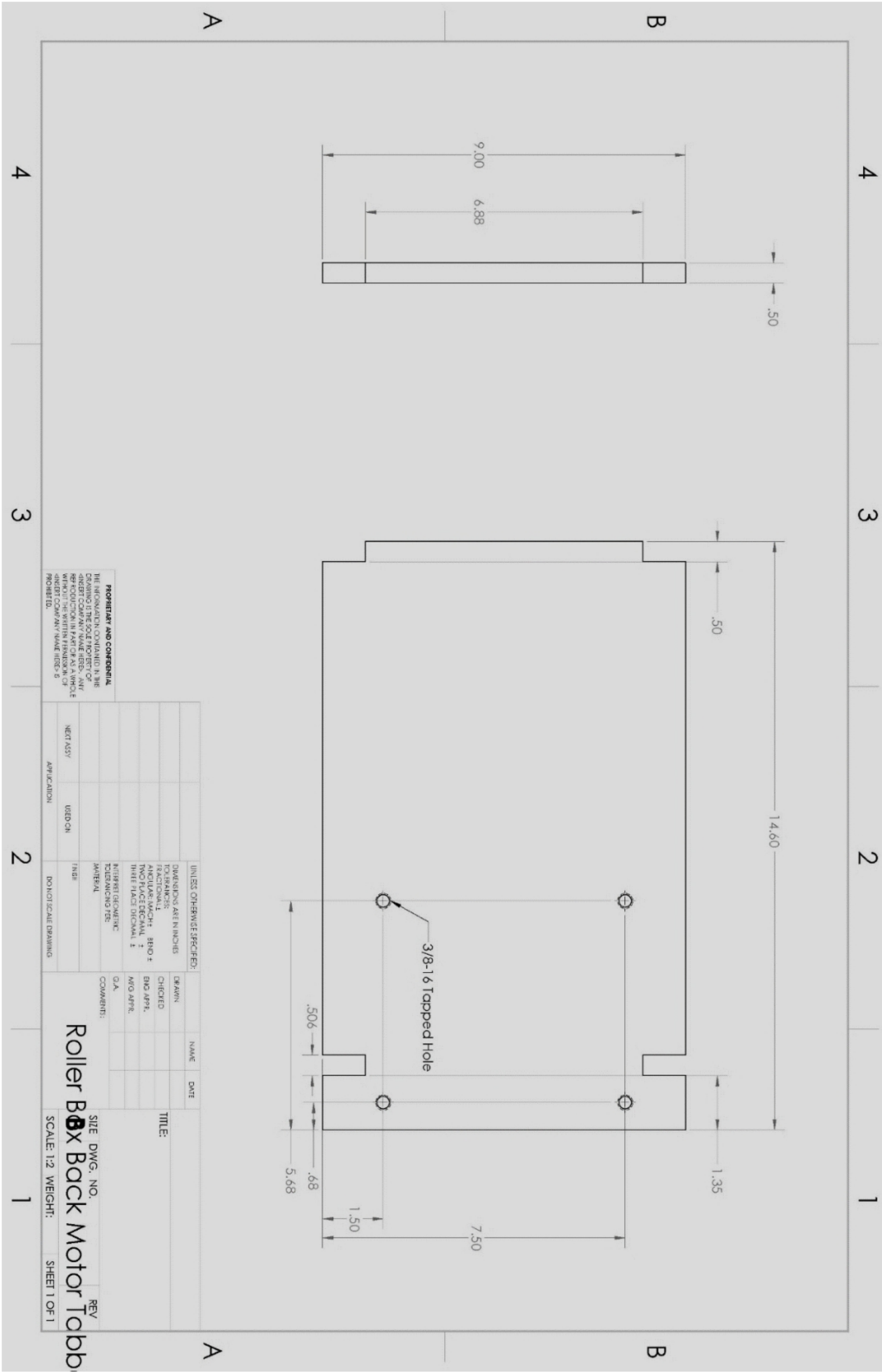
TITLE:
SIZE DWG. NO.
B Roller Bodies
REV
SCALE: 1:4 WEIGHT:
SHEET 1 OF 1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3/8-16 Tapped Hole
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.68
5.68
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7.50
TITLE:
SIZE DWG. NO.
REV
SCALE: 1:2 WEIGHT:
SHEET 1 OF 1
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
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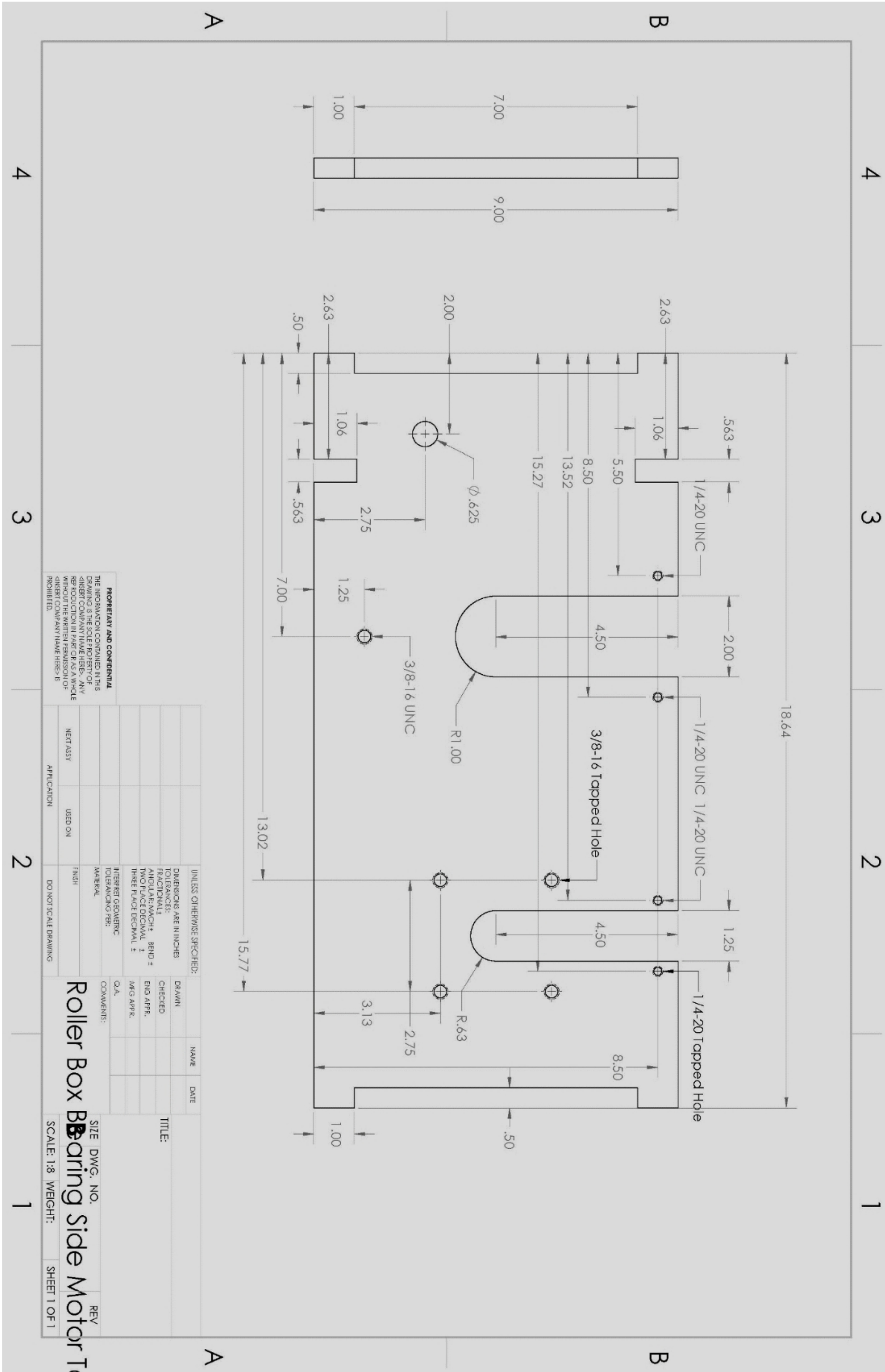
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3/8-16 Tapped Hole
1/4-20 UNC 1/4-20 UNC
13.02
15.77
3.13
R.63
1/4-20 Tapped Hole
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DO NOT SCALE DRAWING
NEXT ASSY
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
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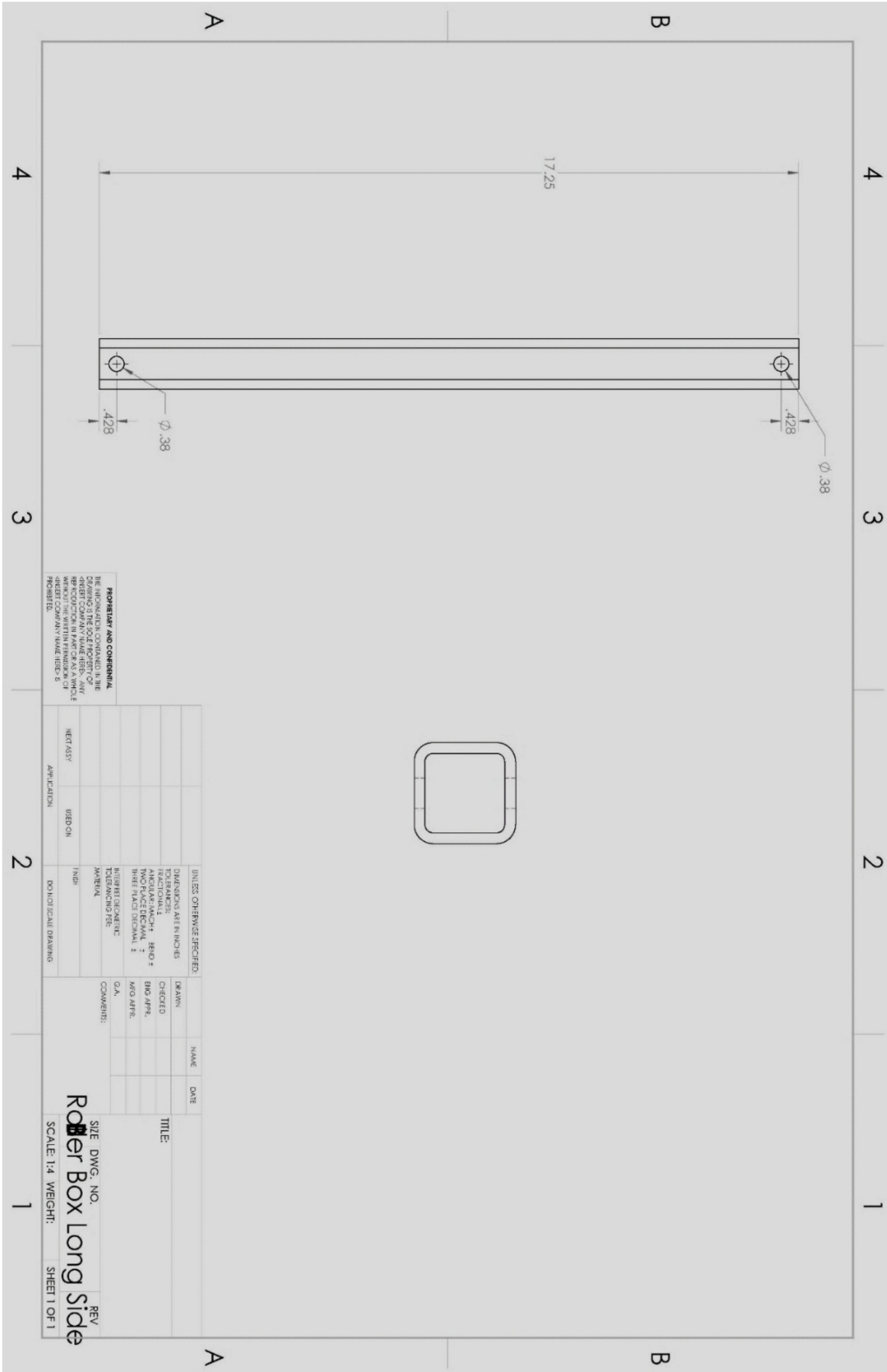
SIZE DWG. NO.
B
REV
SCALE: 1:8 WEIGHT:
SHEET 1 OF 1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.428
.428
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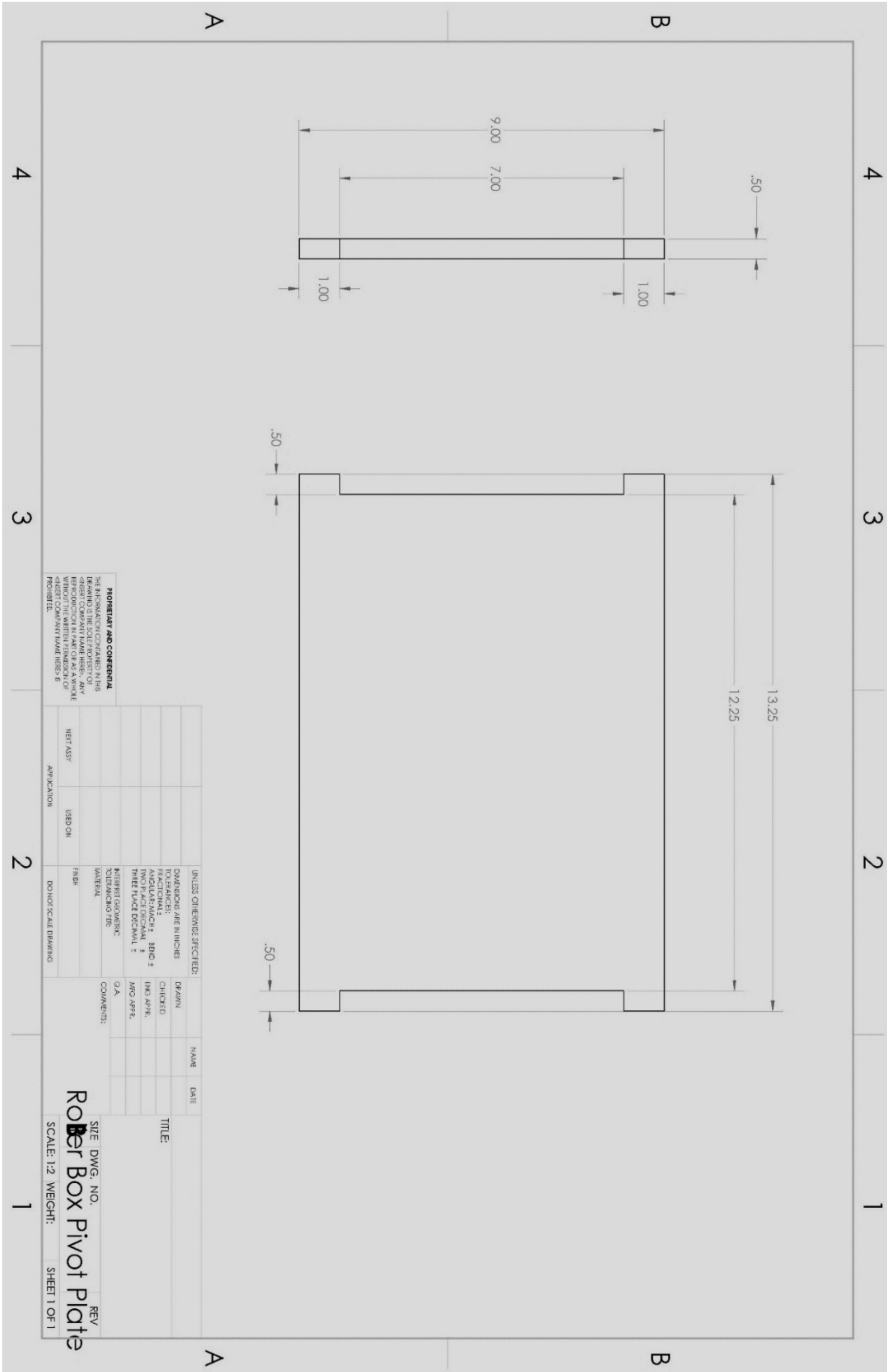
SIZE DWG. NO.
REV
Ro[redacted]er Box Long Side
SCALE: 1:4 WEIGHT:
SHEET 1 OF 1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UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
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ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
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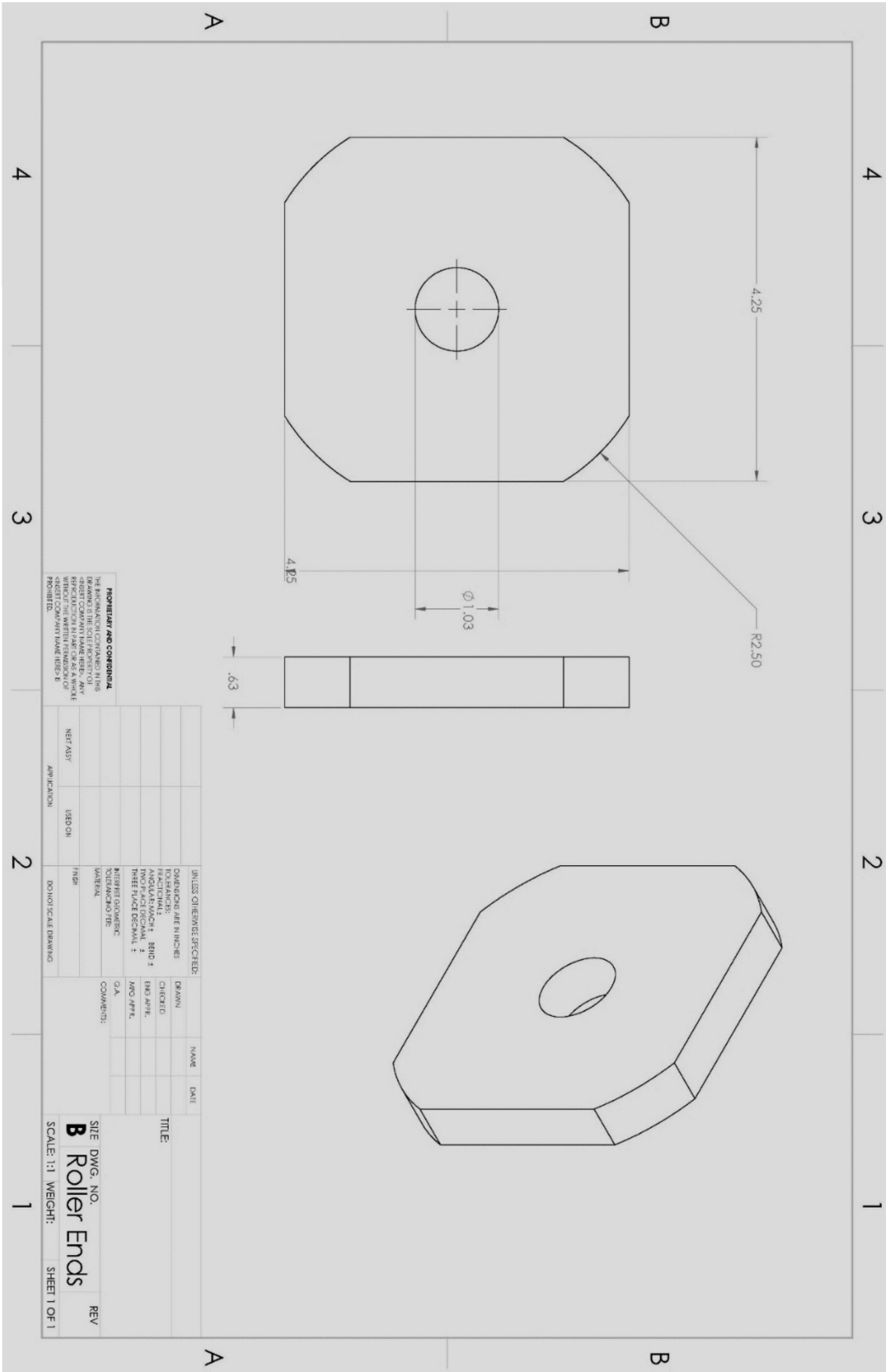
SIZE
DWG. NO.
REV
SCALE: 1:2
WEIGHT:
SHEET 1 OF 1


4.25
R2.50
4.25
Ø1.03
.63
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NAME
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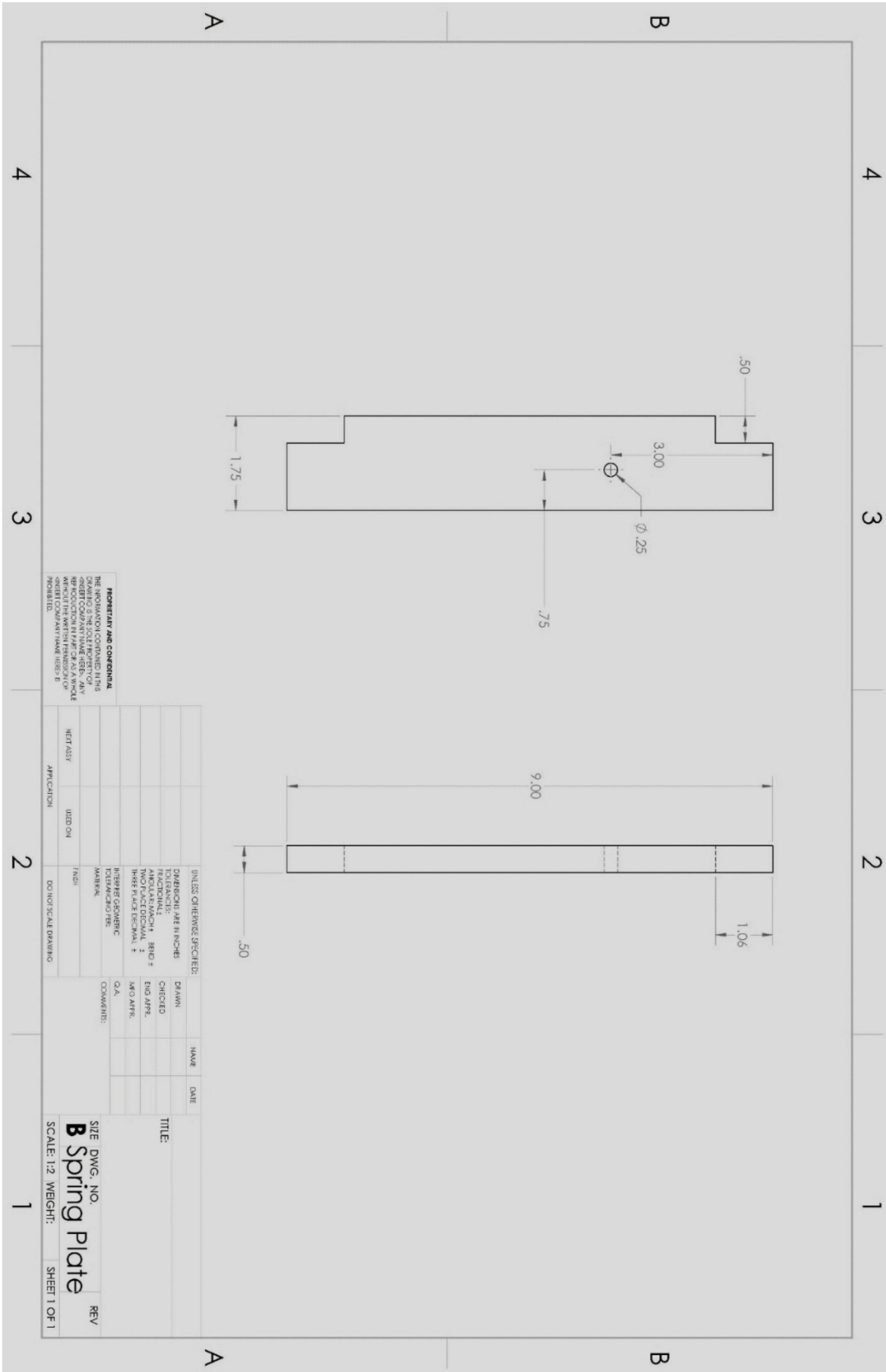
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
TITLE:
SIZE
DWG. NO.
REV
B
Roller Ends
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1



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COMMENTS:
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DWG. NO.
B
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REV
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WEIGHT:
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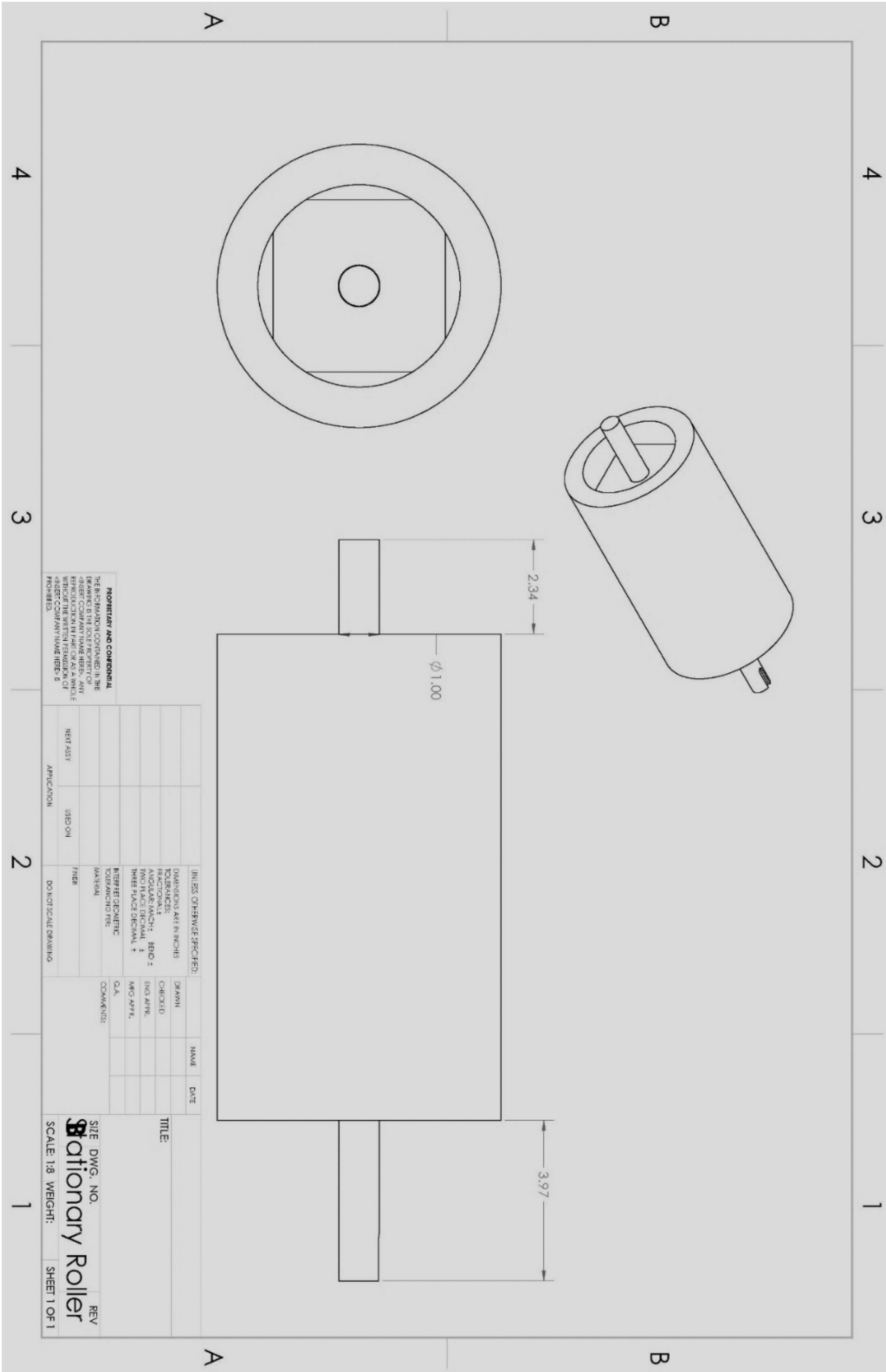
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COMMENTS:
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REV
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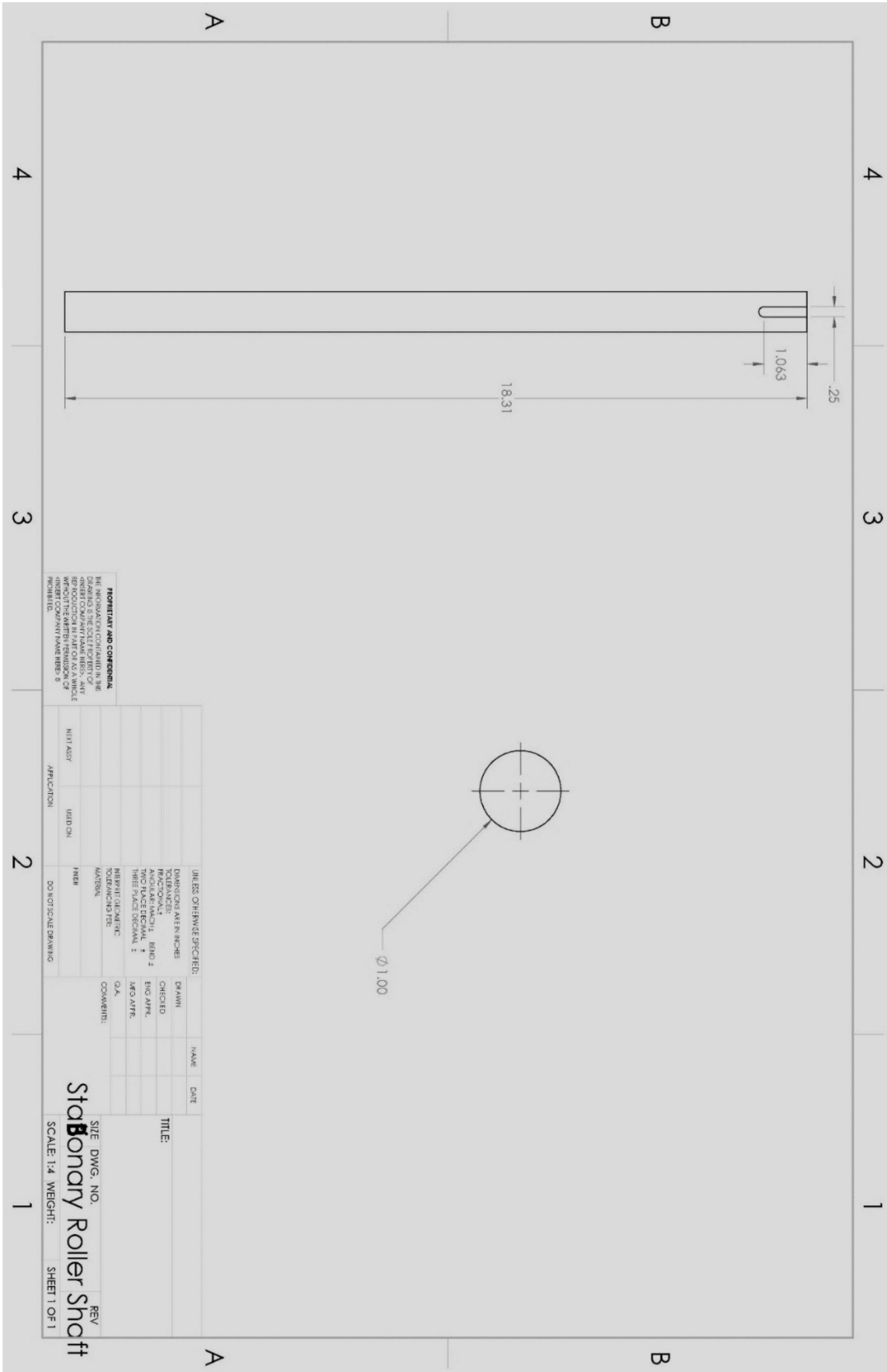
SCALE: 1:8
WEIGHT:
SHEET 1 OF 1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REV
SCALE: 1:4
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SHEET 1 OF 1
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UNLESS OTHERWISE SPECIFIED:
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Q.A.
COMMENTS:
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APPLICATION
MATERIAL
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Highlights of Fall Report

Fall 2016

1) Start initial test on conceptual cocoa bean cracking methods-(Thursday Nov. 3rd)
2) Complete Project Proposal-(Friday Nov. 4th)
3) Submit Preliminary Design Concepts-(Monday Nov. 7th)
4) Present Preliminary Design Concepts-(Friday Nov. 11th)
5) Finalize Technical Literature Review and Research-(Tuesday Nov. 15th)
6) Finalize Fall Semester Design Review Presentation-(Friday Nov. 18th)
7) Finish Analyzing Faculty and Client Feedback-(Wednesday Nov. 23rd)
8) Complete Fall Design Report Draft-(Friday Nov. 25th)
9) Finalize Fall Semester Design Report Draft-(Wednesday Nov. 30th)
10) Initiate Tests on Conceptual Cocoa Nib Sorting Methods-(Thursday Dec. 1st)

Spring 2017

1.) Complete Testing on Conceptual Cocoa Bean Cracking Methods-(Friday Jan. 20th)
2.) Complete Testing on Conceptual Cocoa Nib Sorting Methods-(Friday Jan. 27th)
3.) Complete Control Systems Design-(Friday February 3rd)
4.) Complete Power/Utility Requirements for the Winnower Design-(Wednesday February 8th)
5.) Complete Expected Prototype Cost Analysis-(Friday February 17th)
6.) Finalize Winnower Design and Receive client approval-(Wednesday February 22nd)
7.) Finalize Drafting all Necessary Parts Diagrams-(Friday March 3rd)
8.) Order All Necessary Material and Components for Prototype-(Wednesday March 8th)
9.) Begin Fabrication/Assembly of Prototype-(Monday March 20th)
10.) Complete Prototype Assembly-(Wednesday April 5th)
11.) Complete Prototype Troubleshooting-(Friday April 14th)
12.) Complete Spring Final Report Draft-(Friday April 21st)
13.) Complete Final Presentation-(Friday April 28th)
14.) Complete Final Spring Design Report-(Friday April 28th)
15.) Final Senior Design Presentation-(Thursday May 4th)

Technical Analysis

Patents

Patents that deal with the winnowing process of cocoa bean manufacturing are not greatly available. Several patents were found that are related to the winnowing process.

Method for Producing Fat and/or Solids from Cocoa Beans (2000) Patent #6015913

This patent goes farther into the cocoa bean manufacturing process than the scope of our project requires our team to go. The patent discusses a method of processing cocoa beans for producing solids from fat-containing products. They go into the cocoa bean process as a whole, and include some of the winnowing process.

Method and Apparatus for Separating Lighter and Heavier Portions of Threshold Tobacco (1977)
Patent #4045334

This patent gives the method and an apparatus that separates lighter and heavier parts of threshold tobacco by creating two adjacent vortices which circulate in opposing directions. The turbulence of the vortices causes the separation by combining to form a rising column of high-velocity air which carries off the lighter material while the heavier portions drop down. A similar approach could be used to separate the hulls from the nibs.

Technical Literature Review

Semi-Theoretical Analyses on Mechanical Performance of Flexible-Belt Shearing Extrusion Walnut Shell Crushing. (Lui, 2016)

The article analyzes a specific walnut cracking process and the theoretical calculation for it. Aspects of this process could be modified to better suit cocoa winnowing. The flexible belt process is as follows; “First, the walnut is broken to a certain extent by extrusion and shearing between the upper extrusion roller and the supporting plate. Then, rubbing, extrusion, and shearing of the walnuts with two working belts--the upper working belt at a higher speed and lower working belt at a lower speed-- simultaneously ensures effective breakage and protects the walnut meat. The height of the upper and lower extrusion rollers is adjustable. In this way, the space between the two working belts in the rubbing area and the wedge-shaped angle can be adjusted effectively to fit all sizes of walnuts.” A critical difference in the cracking process between walnuts and cocoa beans is that walnuts have much thicker and harder shells. Cocoa beans will not need as strenuous process to crack/separate the shaft from the nib.

Chocolate Alchemy Winnowing Forums

Several forums are available for people researching on how to process and produce chocolate products. There are specifically 39 different forums related to the cracking and winnowing process for cocoa beans. Topics range from issues in trying to manufacture small scale DIY winnowers to troubleshooting winnower systems.

Design Concepts towards Cocoa Winnowing Mechanization for Nibs Production in Manufacturing Industries (Akinnuili, 2015)

This article gives detailed design descriptions as well as theoretical mathematical models for many of the components of the cocoa bean winnowing process. The best description of their bean crushing utilizes gravity to crack the beans onto a vibratory tray and a blower to recycle the beans back into a “crushing chamber”. The design details include the actual designs for some mechanical components such as the frame, the hopper, and auger lifting system. The estimated cost of the materials for the components, the required system assembly, and the final cost of the possible designs are also included.

Market Research

<u>Aether Winnower</u>:
A vacuum winnower that also cracks the bean. The cracking utilizes a juicer with the juice screen removed, but the blades and housing is recognized as a wear item. The vacuum is a shop vacuum and is not contained within the unit itself. Costs $1800 without champion juicer or 6.5hp vacuum.

Figure 1*: photo of the Aether Winnower equipped with champion juicer*

<u>Bear BWI</u>:

Table 1.1 Specifications of Bear BWI winnowers

Specifications	BWI 500	BWI 1.500	BWI 3.000
Capacity [kg/h]:	ca. 500	ca 1.500	ca. 3.000
Electrical power[kW]:	7	10	26
Air consumption [m3/h]:	2900	3600	4900
Dimensions [m]:	2.6x2.7x4	6.8x2.7x5.6	5.8x3x6.5
Loss nibs	.15-.25%		
shell content in nibs	<1.75%		

This system cracks and winnows the beans using both screens and vacuum. The machine is large enough that an elevator is required to lift the beans up and into the hopper. The scale of this machine is much larger than what would be appropriate for the scale of this project.

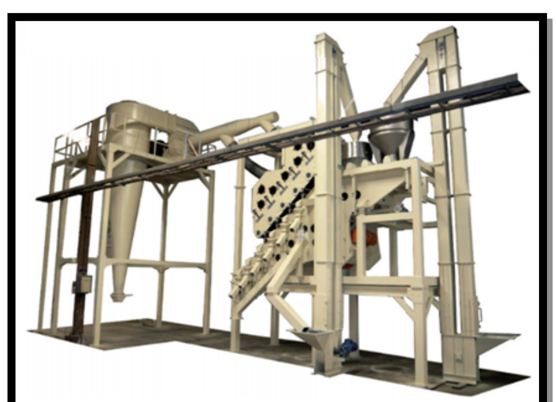

Figure 2*: A photo of the industrial size Bear BWI Winnower*

Vortex Winnower:

Table 1.2 Specifications of Vortex winnower

Specifications	single	double
Footprint [in]:	49x16	49x16
Winnowing speed (Variable) [kg/h]:	20	40
Cracker Feeder/vacuum [V]:	110/110	110/110
Cracker Feeder/vacuum [amps]:	4/9	4/18
Nib loss	0.25%	0.25%
Shell Content in Nibs	0.20%	0.20%

***Figure 3**: A photo of the Vortex Winnower*

This machine simply winnows the chaff from the nibs using a cyclone vacuum system. The machine has a pending patent for their process and does not appear to be as robust as other designs. Again, the vacuum is a separate unit and is not included in the machine itself.

Winn-150:

Table 1.3 Specifications of Winn-150 winnower

Specifications	
Capacity [lbs/hr]:	330
Footprint [ft]:	5x12
Materials	Stainless Steel

This winnower is all inclusive, both cracking and winnowing. It is a very through process utilizing a screen rake, vacuum, and vibration. The machine also sucks the beans up and into their cracking system. The machine layout is very spacious and takes up a good deal of floor space.

Delani CAC-101-WIN:

http://delanitrading.com/producto_detalle.php?categoria=9&grupo=151&producto=98213
*Awaiting response from manufacturer for more information

Sunrise DX-400:

Table 1.4 Specifications of DX-400 winnower

Specifications	
Capacity[kg/h]:	100-400
Power [kW]:	2.2
Fan Power[kW]:	0.75
Dimensions [m]:	1.05x0.9x1.55
weight [kg]:	140
Material	304 SS

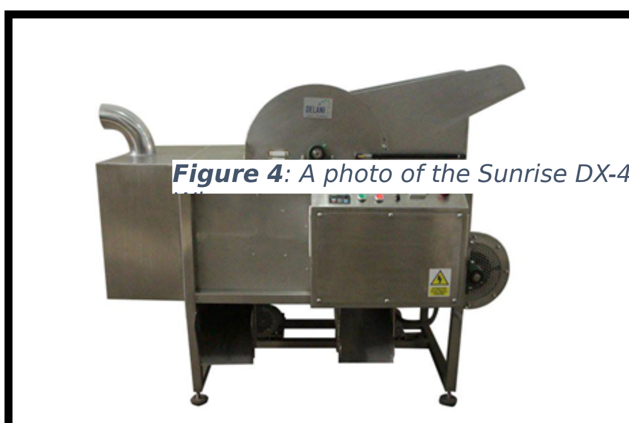

***Figure 4**: A photo of the Sunrise DX-400*

This winnower both cracks the beans and separates them using only air velocity. It is all inclusive and has a wide range of capacity.
It costs between $10,000 and $100,000 depending on order size and if you purchase other equipment as well.

Fall 2016 Testing

Temperature Testing

An apparatus was made to test the effectiveness of impact on cocoa beans under various conditions. The apparatus was constructed using 2x4 piece of wood 24 inches long with a weight of approximately 1lb per 12 inches and hinged on one end. This devise allowed us a consistent and repeatable crushing of the cocoa beans to simulate a crushing force. This was used to test four variations of cocoa beans: dry cocoa beans, wet cocoa beans, dry cocoa beans frozen in liquid nitrogen, and wet cocoa beans frozen in liquid nitrogen. After beans were impacted, they were then sieved through a screen whose voids measured 3.5mm diagonally and the small and large particles were weighed separately. It was hoped that freezing would take advantage of the differences in physical properties between the cocoa nib and hull. It was determined that freezing made little effect on final particle size after impacting. It was also determined that cocoa beans become soaked rapidly, negating the need for an increased soaking period.

Impact Testing

Another devise has been constructed utilizing a squirrel cage fan as the basis. The blade were removed and impact paddles have been added. The Motor turns at a speed of 1600 rpm and the diameter of the rotating assembly is 5in. Without varying the motor’s speed, an impact speed of 34.88 ft/sec was achieved. Initial testing has shown that there is insufficient spacing between the impacting paddles to allow the beans to fall low enough past the top edge of the paddle to get an honest impact. To solve this problem, the number of paddles will either decrease and/or the motor’s speed will need to be reduced. If these strategies prove to not be successful, it may be necessary to increase the diameter of the rotating assembly. Once a large enough gap between impacting paddles has been developed, velocities that yield good separation will further be tested by varying the impacting speed and possibly the inclination of the impacting paddles with respect to the rotating axis.

General Design Concepts

Hopper

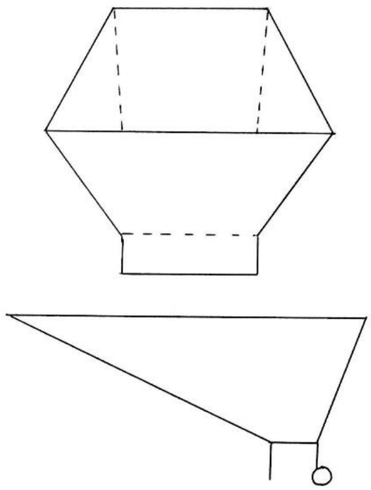

Figure 5: A sketch of the shape of the hopper concept

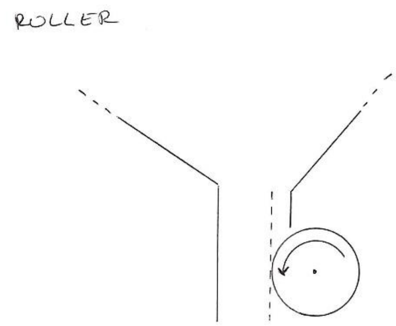

Figure 6: A sketch of an agitating roller at the outlet of the hopper concept

Clogging was anticipated at the base of the hopper, and was observed at Izzard Chocolate during a site visit, so a simple roller to agitate the clogged area was conceived.

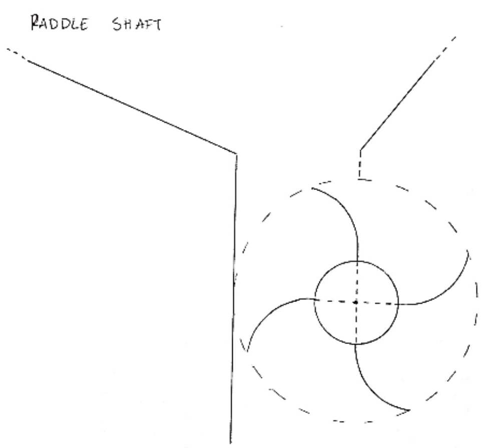

Figure 7: A side view sketch of another agitator concept with paddles

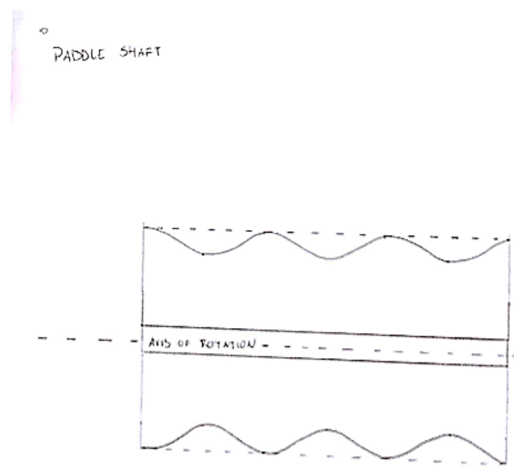

Figure 8: A sketch highlighting the curved edges to prevent binding of the paddles with beans

The tendency of the beans to slide on the simple roller required a redesign of the base of the hopper. A paddled wheel was conceived that would no only prevent clogging of the beans, but also allow adjustable and predictable delivery rate of the beans from the hopper.

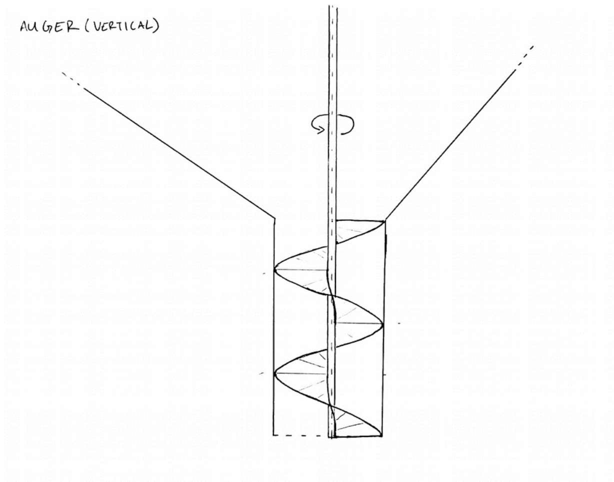

Figure 9: A sketch of our initial auger iteration design in a vertical position

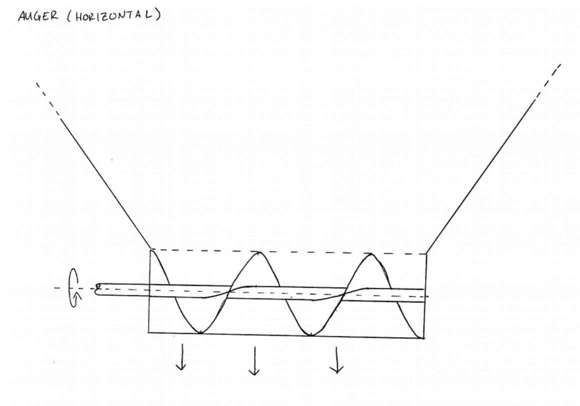

Figure 10: A sketch of our second auger iteration in a more viable horizontal position

A more common and possibly cheaper method to feed beans out of the hopper is an auger, typically vertical in orientation. A horizontal orientation would not only be easier to drive, but help keep overall height to a minimum.

Cracking Method

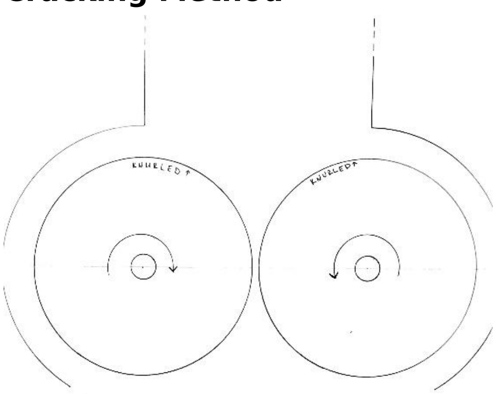

Figure 11: An initial sketch of simple rollers

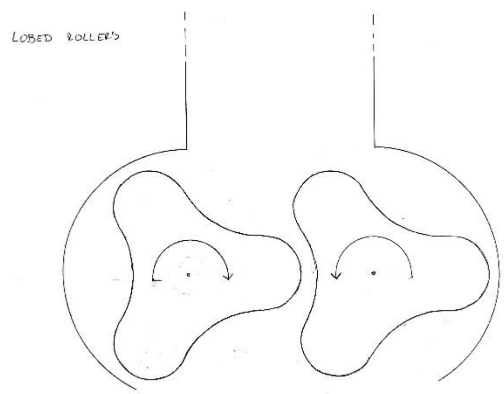

Figure 12: A sketch of lobed rollers that would encourage the passage of the beans

Much like US Roaster Corp's current roller grinders, cracking the cocoa beans with a roller grinder would be a simple and achievable design. To mitigate the beans from not passing through the round rollers, lobed rollers were thought of as an alternative to smooth roller grinders.

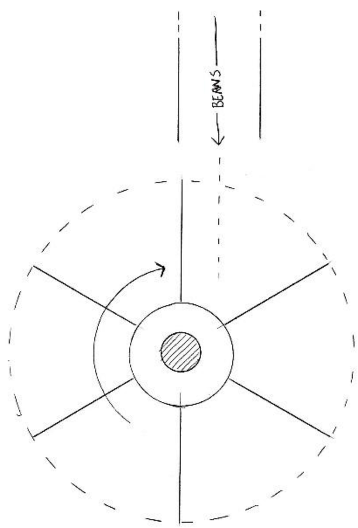

Figure 13: Initial design of an impact wheel rotating horizontally

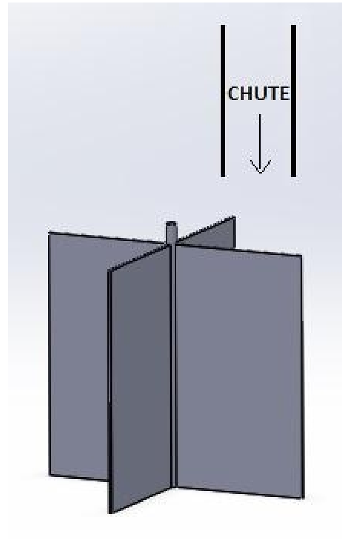

Figure 14: Second design of a vertical impact wheel

Upon observation, quick impact was seen as an effective way of cracking the beans. A paddle wheel that rotates and impacts the beans would also be independent of individual bean size. The axis of rotation of the wheel in the first draft was horizontal, which is perpendicular to the flow of beans. To ensure consistent contact impact velocity, it was thought to feed the beans down in parallel with the rotating axis.

High Risk Design

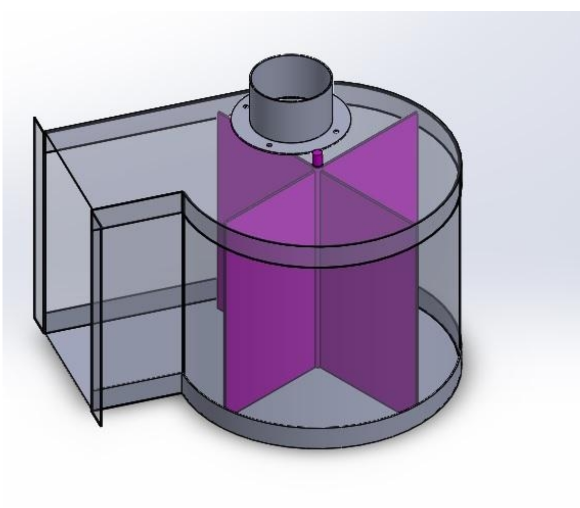

Figure 15: A modeled representation of the vertical impact wheel

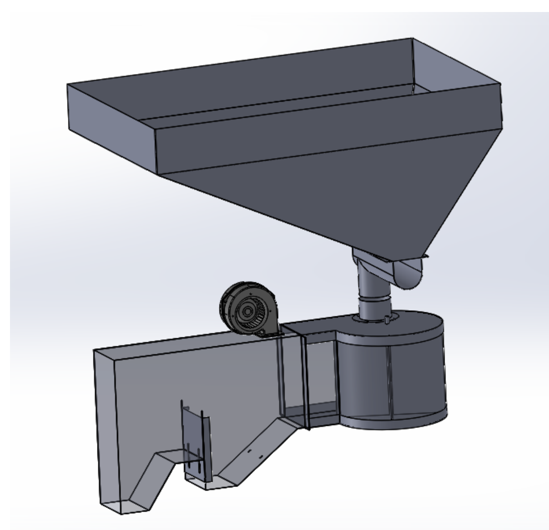

Figure 16: The preliminary model of the impact wheel with hopper and chute

This design is appropriately named because it is high risk. No other winnower on the market uses this approach and it has yet to be thoroughly tested. The main cracking method is impact with the paddles on a wheel traveling with high angular velocity. Some pros of this design include: the cracker is indiscriminant of bean size, the velocity adjustable to vary impact force and a simple design and construction. Some cons of this design include: unproven and untested design, loss of contact with bean and requires metered feed out of hopper.

Low Risk Design

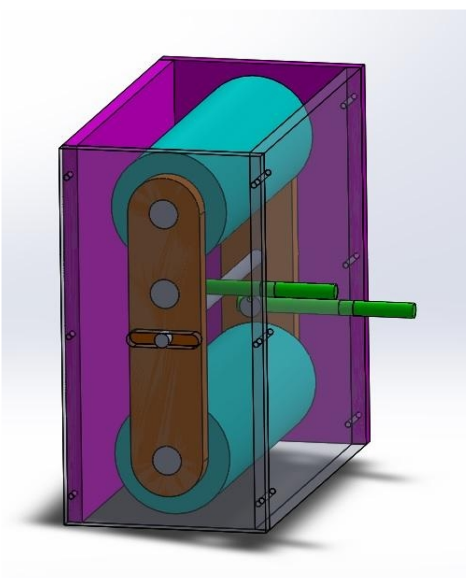

Figure 17: A modeled representation of the concept rollers

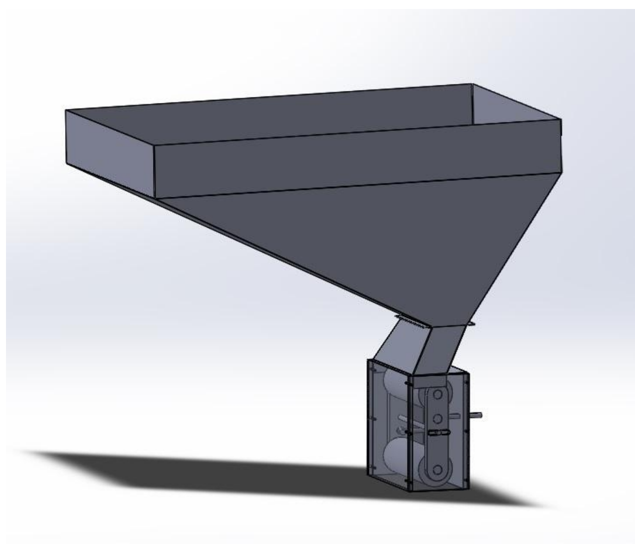

Figure 18: Modeled concept rollers with hopper and connecting chute

This is the low risk design. It is a conceptually common design utilizing a two stage roller-cracker design which homogenizes the crushed bean size. The cocoa beans would be crushed between the roller and the wall of the housing. A lobed roller from the conceptual designs could be utilized. The roller-cracker is similar to US Roaster Corp's current coffee roller-grinders, so fabrication would not be difficult. Some pros of this design include: robust and adjustable, guarantees beans that have passed through will be cracked/crushed and self-metering flow of beans out of the hopper. Some cons of this design include: tolerance and part intensive, potentially less differentiable qualities between nib and hull and finer particles will require a more thorough separation process.

Freshman Teams

Two freshmen teams were assigned to work in conjunction on this project, with each group having five members. Tasks were delegated to the freshman groups that would assist in the development of the project and allow them to be introduced to the engineering design process. The freshmen were required to complete the given task, write a report over the task, and prepare and present a poster.

Team 1

Team 1's task was to determine a viable air velocity range to separate the hull and the nib of the cocoa beans. To complete this task, the freshmen utilized the air velocity separator in the BAE lab. They determined that the best sort was achieved at around 5 m/s, shown in Figure 2.1.

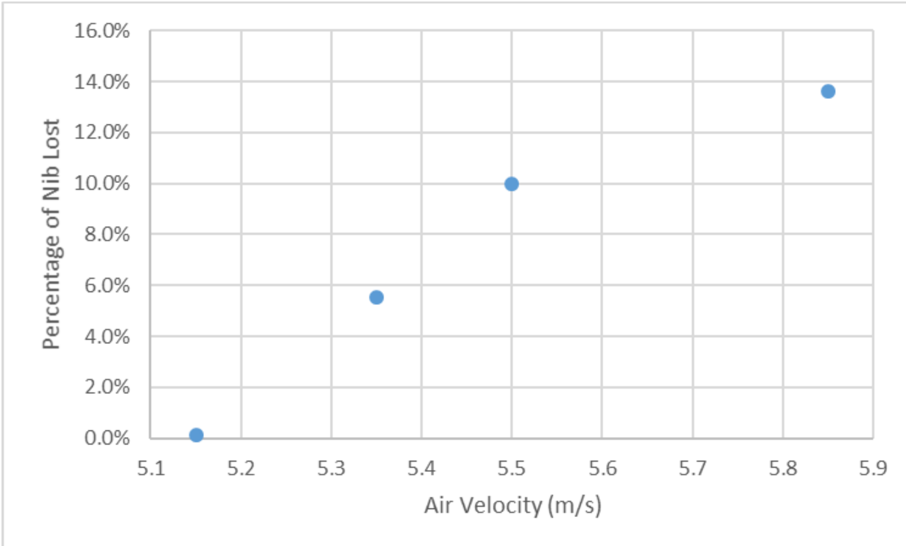

Figure 2.1 Plot of percentage of Nib loss with various air velocities

Team 2

Team 2's task was to design a hopper that meets the given specifications: the hopper must hold 100 lbs of roasted cocoa beans, determine appropriate food grade material, not exceed a loading height of 5 ft, and must minimize the surface area while maintaining the proper volume. The freshmen must also make a model of hopper utilizing CAD software, seen in Figure 2.2. The final task for team 2 was to contact material suppliers and estimate a price of the hopper.

Table 2.1 Cone hopper dimensions

Cone			
Radius (ft)	Height (ft)	Volume (ft^3)	Surface Area (ft^2)
1.20	2.40	3.01	14.63
1.10	2.60	2.99	13.55
1.00	2.90	3.04	12.77
0.90	3.10	2.92	11.67

Table 2.2 Rectangular hopper dimensions

Rectangle				
Height (ft)	Width (ft)	Length (ft)	Volume (ft^3)	Surface Area (ft^2)
1.02	1.70	1.80	3.12	13.26
1.01	1.90	1.60	3.08	13.17
0.98	1.40	2.10	2.88	12.74
1.03	2.20	1.40	3.16	13.55

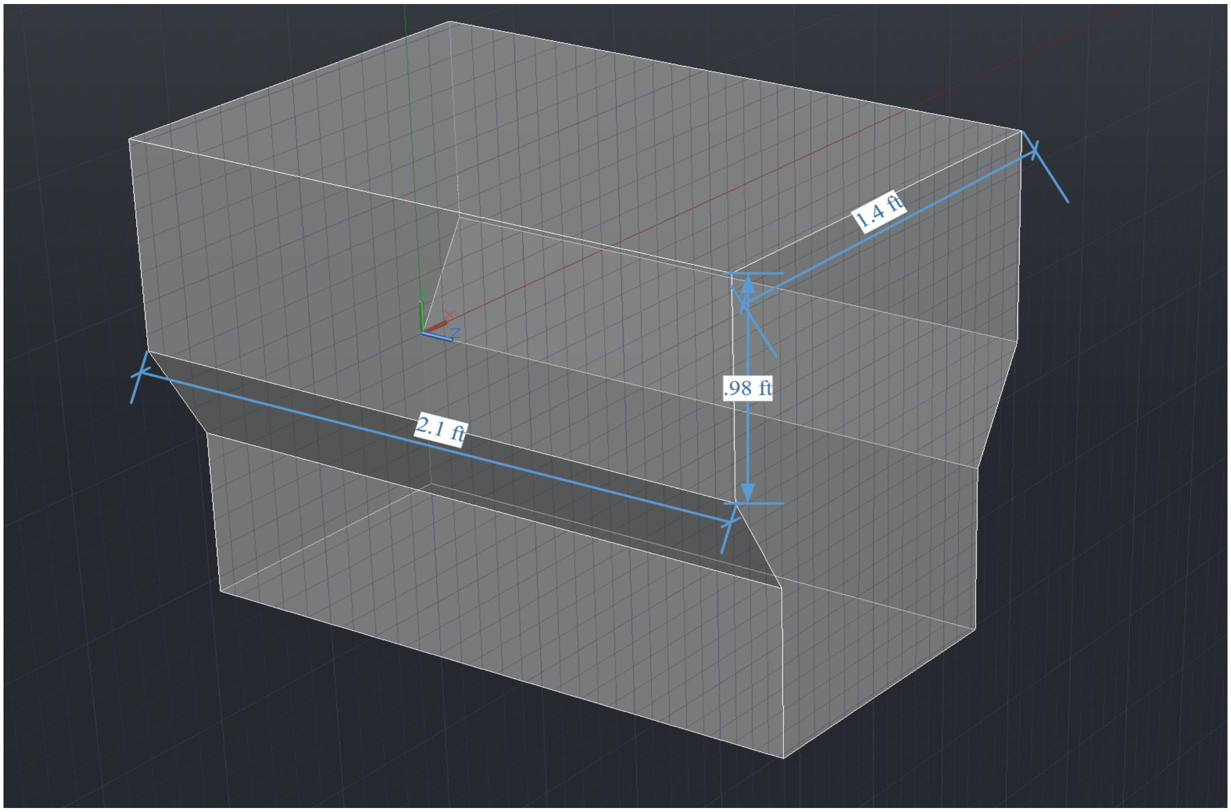

Figure 2.2 Proposed hopper design

Senior Design Fall 2016 Report

Cocoa Bean Winnowing Project

Joseph Barnes, Benjamin Jenkins, Montana Wells

Table of Contents

Introduction

The client for the Cocoa Bean Winnower Project is U. S. Roaster Corporation. U.S. Roaster Corp. is located in downtown Oklahoma City, OK and they specialize in the repair, manufacturing and design of coffee bean roasters for coffee producers. Their roasters range in capacity from 3 oz to 300 kg. While the roasters are designed to roast coffee, they are easily adapted to roast cocoa beans. Recently, several small scale gourmet chocolate producers have started using US Roaster Corp. roasters in the production of their product. The chocolate making process begins with roasting the cocoa beans. Once the beans are roasted they must be de-hulled, or winnowed. Winnowing separates the cocoa nib (the edible and sought after portion) from the outer hull. The cocoa nibs are then processed into chocolate or other cocoa products. The winnowing process in particular is important because if there is a high percentage of the husk present with the cocoa nibs, then the quality of the chocolate will be poor.

Currently in the industry there is not a small scale winnower that is both efficient and affordable for a small scale chocolate producers. US Roaster Corp. is interested in expanding their range of products to meet the needs of the gourmet chocolate industry.

Problem Statement

Triad Enterprises will research, design, and produce a winnower system that will be marketable to small scale chocolate producers.

Statement of Work

Scope of Work

The winnower must incorporate features and a price range that will make it marketable to small scale chocolate producers. US Roaster Corp. must be able to fabricate the majority of all the components of the winnowing system at their facilities with their current equipment. Aspects that are out of the scope of this project will be other components of chocolate production such as roasting, grinding, and tempering.

Deliverables

Triad Enterprises will deliver the following:

- A functioning cocoa bean winnowing system
- Marketable to small scale chocolate producers
- Primarily manufactured with stainless steel
- Provide easy access for cleaning of critical components
- Designed to be an unmanned operation
- Designed to be self-contained
- Produce minimal noise

Be powered by a standard wall outlet

Work Breakdown Structure

WBS 1.0 Hopper Design

- 1.1 Dimensions
- 1.2 Shape
- 1.3 Materials
  - 1.3.1 Lifespan
  - 1.3.2 Manufacturing requirements

1.4 Control System

1.4.1 Low capacity alarm

1.4.2 Automatic shutoff system

WBS 2.0 Initial Chaff Separating System

2.1* Choose Separating Option

2.1.1 Roots Blower/ PD Pump style rollers

2.1.2 Reciprocating Crusher Plate

2.1.2 Conveyor Mesh Crushing Screen

2.1.3 Rotary Impact

2.1.4 Rubber Belt Shearing

WBS 3.0 Chaff and Nib Sorting System

3.1 Pneumatic Separation

3.1.1 Method of separation

3.1.1.1 Cyclone

3.1.1.2 Air blast

3.1.1.3 Constant flow

3.1.2 Required air velocity

3.1.2.1 Determine Terminal Velocity Thresholds

3.1.3 Fan/vacuum specification

3.1.4 Materials

3.1.4.1 Lifespan

3.1.4.2 Manufacturing requirements

3.1.5 Control Systems

3.1.5.1 Shutoff mechanism

3.2 Vibratory sifting

3.2.1 Sifter

3.2.1.1 Sifter mesh size

3.2.2 Vibration mechanism

3.2.2.1 Vibration rate/displacement

3.2.2.2 Durability of material/components being vibrated

3.2.3 Stages of sifting

3.2.3.1 Number of necessary screens

3.2.3.2 Desired/attainable sieve size necessary

3.2.4 Materials

3.2.4.1 Lifespan

3.2.4.2 Manufacturing requirements

3.3 Integration of sorting systems

3.3.1 Determine to what extent each method of sort will be used

3.3.2 Determine integration parameters

WBS 4.0 Conveyance Methods

4.1 Conveyors

4.1.1 Type of conveyors

4.1.2 Material of the conveyors

4.1.3 Power system for the conveyors

WBS 5.0 Systems Integration

5.1 Integrate all sensors of the components together

5.2 Ensure all convenience systems are compatible

5.3 Install integrated controls interface

WBS 6.0 Physical Properties

6.1 Range of variability of cocoa beans

6.1.1 Weight

6.1.2 Density

6.1.3 Size

6.1.4 Shape

6.1.5 Volume

6.2 Properties of cocoa bean chaff

6.2.1 What affects how it clings to the cocoa nib?

6.2.2 What affects how the chaff fractures?

WBS 7.0 Documentation

7.1 Specifications

7.1.1 List design specifications and drawings for each component

7.1.2 List of materials needed

7.2 Research

7.2.1 Physical properties of cocoa beans

7.2.2 How roasting affects the physical properties of cocoa beans

7.2.3 Existing methods of how to winnow cocoa beans

7.2.4 Existing cocoa bean winnowers in the market

7.2.5 Existing patents relevant to cocoa bean winnowing

7.2.6 Food safety requirements for the winnowing system

7.3 Budget

7.3.1 Cost of travel

7.3.2 Cost of prototype

7.3.2.1 Material cost

7.3.2.2 Design cost

7.3.3 Cost of testing samples

7.3.4 Cost of testing experiments

7.4 Planning

7.4.1 Milestones for design process

7.4.2 Gantt chart

7.4.3 Task list

7.4.4 Work Breakdown Structure

7.4.5 Dates for field trips

7.4.6 Dates for testing

7.5 Presentation and Report material

7.5.1 Fall presentation material

7.5.2 Fall final report draft

7.5.3 Fall final report

WBS 8.0 Engineering Review and Approval

8.1 Review and approve engineering

8.1.1 Evaluation meeting

8.1.2 Troubleshooting
8.1.3 Design review

8.2 Verify design meets client's parameters and expectation

8.3 Approve Final Design

8.3.1 Finalization Review Meeting

Task List

Fall 2016

1) Start initial test on conceptual cocoa bean cracking methods-(Thursday Nov. 3)
2) Complete Project Proposal-(Friday Nov. 4 by 5:30pm)
3) Submit Preliminary Design Concepts-(Monday Nov. 7)
4) Present Preliminary Design Concepts-(Friday Nov. 11)
5) Finalize Technical Literature Review and Research-(Tuesday Nov. 15)
6) Finalize Fall Semester Design Review Presentation-(Friday Nov. 18)
7) Finish Analyzing Faculty and Client Feedback-(Wednesday Nov. 23)
8) Complete Fall Design Report Draft-(Friday Nov. 25)
9) Finalize Fall Semester Design Report Draft-(Wednesday Nov.30)
10) Initiate Tests on Conceptual Cocoa Nib Sorting Methods-(Thursday Dec. 1)

Spring 2017

1.) Complete Testing on Conceptual Cocoa Bean Cracking Methods-(Friday Jan. 20th)
2.) Complete Testing on Conceptual Cocoa Nib Sorting Methods-(Friday Jan. 27th)
3.) Complete Control Systems Design-(Friday February 3rd)
4.) Complete Power/Utility Requirements for the Winnower Design-(Wednesday February 8th)
5.) Complete Expected Prototype Cost Analysis-(Friday February 17th)
6.) Finalize Winnower Design and Receive client approval-(Wednesday February 22nd)
7.) Finalize Drafting all Necessary Parts Diagrams-(Friday March 3rd)
8.) Order All Necessary Material and Components for Prototype-(Wednesday March 8th)
9.) Begin Fabrication/Assembly of Prototype-(Monday March 20th)
10.) Complete Prototype Assembly-(Wednesday April 5th)
11.) Complete Prototype Troubleshooting-(Friday April 14th)
12.) Complete Spring Final Report Draft-(Friday April 21st)
13.) Complete Final Presentation-(Friday April 28th)
14.) Complete Final Spring Design Report-(Friday April 28th)
15.) Final Senior Design Presentation-(Friday May 5th)

Technical Analysis

Patents

Patents that deal with the winnowing process of cocoa bean manufacturing are not greatly available. Several patents were found that are related to the winnowing process.

Method for Producing Fat and/or Solids from Cocoa Beans (2000) Patent #6015913

This patent goes farther into the cocoa bean manufacturing process than the scope of our project requires our team to go. The patent discusses a method of processing cocoa beans for producing solids from fat-containing products. They go into the cocoa bean process as a whole, and include some of the winnowing process.

Method and Apparatus for Separating Lighter and Heavier Portions of Threshold Tobacco (1977)
Patent #4045334

This patent gives the method and an apparatus that separates lighter and heavier parts of threshold tobacco by creating two adjacent vortices which circulate in opposing directions. The turbulence of the vortices causes the separation by combining to form a rising column of high-velocity air which carries off the lighter material while the heavier portions drop down. A similar approach could be used to separate the hulls from the nibs.

Technical Literature Review

Semi-Theoretical Analyses on Mechanical Performance of Flexible-Belt Shearing Extrusion Walnut Shell Crushing. (Lui, 2016)

The article analyzes a specific walnut cracking process and the theoretical calculation for it. Aspects of this process could be modified to better suit cocoa winnowing. The flexible belt process is as follows; “First, the walnut is broken to a certain extent by extrusion and shearing between the upper extrusion roller and the supporting plate. Then, rubbing, extrusion, and shearing of the walnuts with two working belts--the upper working belt at a higher speed and lower working belt at a lower speed-- simultaneously ensures effective breakage and protects the walnut meat. The height of the upper and lower extrusion rollers is adjustable. In this way, the space between the two working belts in the rubbing area and the wedge-shaped angle can be adjusted effectively to fit all sizes of walnuts.” A critical difference in the cracking process between walnuts and cocoa beans is that walnuts have much thicker and harder shells. Cocoa beans will not need as strenuous process to crack/separate the shaft from the nib.

Chocolate Alchemy Winnowing Forums

Several forums are available for people researching on how to process and produce chocolate products. There are specifically 39 different forums related to the cracking and winnowing process for cocoa beans. Topics range from issues in trying to manufacture small scale DIY winnowers to troubleshooting winnower systems.

Design Concepts towards Cocoa Winnowing Mechanization for Nibs Production in Manufacturing Industries (Akinnuili, 2015)

This article gives detailed design descriptions as well as theoretical mathematical models for many of the components of the cocoa bean winnowing process. The best description of their bean crushing utilizes gravity to crack the beans onto a vibratory tray and a blower to recycle the beans back into a “crushing chamber”. The design details include the actual designs for some mechanical components such as the frame, the hopper, and auger lifting system. The estimated cost of the materials for the components, the required system assembly, and the final cost of the possible designs are also included.

Market Research

<u>Aether Winnower</u>:
A vacuum winnower that also cracks the bean. The cracking utilizes a juicer with the juice screen removed, but the blades and housing is recognized as a wear item. The vacuum is a shop vacuum and is not contained within the unit itself. Costs $1800 without champion juicer or 6.5hp vacuum.

Figure 1.1 A photo of the Aether Winnower equipped with champion juicer

Bear BWI:

Table 1.1 Specifications of Bear BWI winnowers

Specifications	BWI 500	BWI 1.500	BWI 3.000
Capacity [kg/h]:	ca. 500	ca 1.500	ca. 3.000
Electrical power[kW]:	7	10	26
Air consumption [m3/h]:	2900	3600	4900
Dimensions [m]:	2.6x2.7x4	6.8x2.7x5.6	5.8x3x6.5
Loss nibs	.15-.25%		
shell content in nibs	<1.75%		

This system cracks and winnows the beans using both screens and vacuum. The machine is large enough that an elevator is required to lift the beans up and into the hopper. The scale of this machine is much larger than what would be appropriate for the scale of this project.

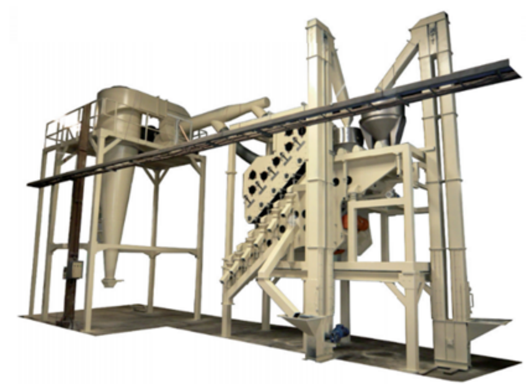

Figure 1.2 A photo of the industrial size Bear BWI Winnower

Vortex Winnower:

Table 1.2 Specifications of Vortex winnower

Specifications	single	double
Footprint [in]:	49x16	49x16
Winnowing speed (Variable) [kg/h]:	20	40
Cracker Feeder/vacuum [V]:	110/110	110/110
Cracker Feeder/vacuum [amps]:	4/9	4/18
Nib loss	0.25%	0.25%
Shell Content in Nibs	0.20%	0.20%

This machine simply winnows the chaff from the nibs using a cyclone vacuum system. The machine has a pending patent for their process and does not appear to be as robust as other designs. Again, the vacuum is a separate unit and is not included in the machine itself.

Figure 1.3 A photo of the Vortex Winnower

Winn-150:

Table 1.3 Specifications of Winn-150 winnower

Specifications	
Capacity [lbs/hr]:	330
Footprint [ft]:	5x12
Materials	Stainless Steel

This winnower is all inclusive, both cracking and winnowing. It is a very through process utilizing a screen rake, vacuum, and vibration. The machine also sucks the beans up and into their cracking system. The machine layout is very spacious and takes up a good deal of floor space.

Delani CAC-101-WIN:
http://delanitrading.com/producto_detalle.php?

categoria=9&grupo=151&producto=98213
*Awaiting response from manufacturer for more information

Figure 1.4 A photo of the industrial Delani CAC-101-WIN

Sunrise DX-400:

Table 1.4 Specifications of DX-400 winnower

Specifications	
Capacity[kg/h]:	100-400
Power [kW]:	2.2
Fan Power[kW]:	0.75
Dimensions [m]:	1.05x0.9x1.55
weight [kg]:	140
Material	304 SS

This winnower both cracks the beans and separates them using only air velocity. It is all inclusive and has a wide range of capacity. It costs between $10,000 and $100,000 depending on order size and if you purchase other equipment as well.

Testing

Temperature Testing
An apparatus was made to test the effectiveness of impact on cocoa beans under various conditions. The apparatus was constructed using 2x4 piece of wood 24 inches long with a weight of approximately 1lb per 12 inches and hinged on one end. This devise allowed us a consistent and repeatable crushing of the cocoa beans to simulate a crushing force. This was used to test four variations of cocoa beans: dry cocoa beans, wet cocoa beans, dry cocoa beans frozen in liquid nitrogen, and wet cocoa beans frozen in liquid nitrogen. After beans were impacted, they were then sieved through a screen whose voids measured 3.5mm diagonally and the small and large particles were weighed separately. It was hoped that freezing would take advantage of the differences in physical properties between the cocoa nib and hull. It was determined that freezing made little effect on final particle size after impacting. It was also determined that cocoa beans become soaked rapidly, negating the need for an increased soaking period.

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impacting speed and possibly the inclination of the impacting paddles with respect to the rotating axis.

Environmental, Societal & Global Impacts

The areas of sustainability that this project will impact include the economic, environmental, and socioeconomic impact to the gourmet chocolate industry. US Roaster Corp prides itself on the high quality of their equipment that rarely needs to be serviced. Building a machine that will withstand the rigors of constant usage is essential to this project. Cocoa products are growing in demand each year, especially products from small bean-to-bar producers. Therefore, from an economic standpoint the winnower will be a good investment for US Roaster Corp. Bean-to-bar chocolate producers care where their chocolate is sourced from, often choosing organic and fair-trade cocoa beans. Consciously sourcing cocoa beans not only looks good for their brand, it is better for the environment and for the many cocoa bean growers around the world, many of which are in third-world countries. By enabling small bean-to-bar chocolate producers to more efficiently make chocolate, our product should have a positive impact on the environment and socioeconomic status of many cocoa bean farmers around the world.

Engineering Specifications

- Winnow at a rate of 100 lbs/hr
- Winnow at an efficiency >95%
- Not allow greater than 2% shell in the final nib output
- Retail price near $3000
- Be powered by either 120V or 240V AC
- Not exceed 90 dB of sound
- Minimize moving parts
- Be aesthetically pleasing
- Be easy to clean

Freshman Teams

Two freshmen teams were assigned to work in conjunction on this project, with each group having five members. Tasks were delegated to the freshman groups that would assist in the development of the project and allow them to be introduced to the engineering design process. The freshmen were required to complete the given task, write a report over the task, and prepare and present a poster.

Team 1

Team 1's task was to determine a viable air velocity range to separate the hull and the nib of the cocoa beans. To complete this task, the freshmen utilized the air velocity separator in the BAE lab. They determined that the best sort was achieved at around 5 m/s, shown in Figure 2.1.

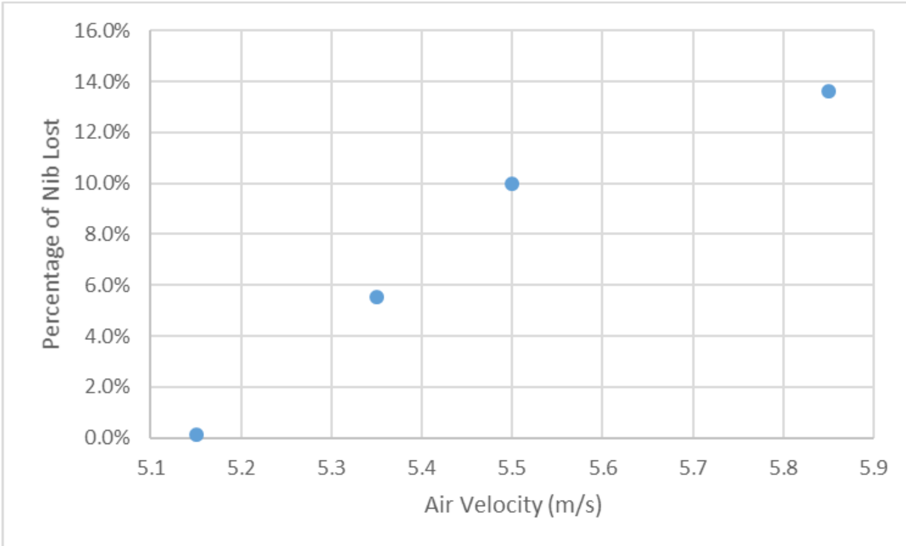


Figure 2.1 Plot of percentage of Nib loss with various air velocities

Team 2

Team 2's task was to design a hopper that meets the given specifications: the hopper must hold 100 lbs of roasted cocoa beans, determine appropriate food grade material, not exceed a loading height of 5 ft, and must minimize the surface area while maintaining the proper volume. The freshmen must also make a model of hopper utilizing CAD software, seen in Figure 2.2. The final task for team 2 was to contact material suppliers and estimate a price of the hopper.

Table 2.1 Cone hopper dimensions dimensions

Cone			
Radius (ft)	Height (ft)	Volume (ft^3)	Surface Area (ft^2)
1.20	2.40	3.01	14.63
1.10	2.60	2.99	13.55
1.00	2.90	3.04	12.77
0.90	3.10	2.92	11.67

Table 2.2 Rectangular hopper

Rectangle				
Height (ft)	Width (ft)	Length (ft)	Volume (ft^3)	Surface Area (ft^2)
1.02	1.70	1.80	3.12	13.26
1.01	1.90	1.60	3.08	13.17
0.98	1.40	2.10	2.88	12.74
1.03	2.20	1.40	3.16	13.55

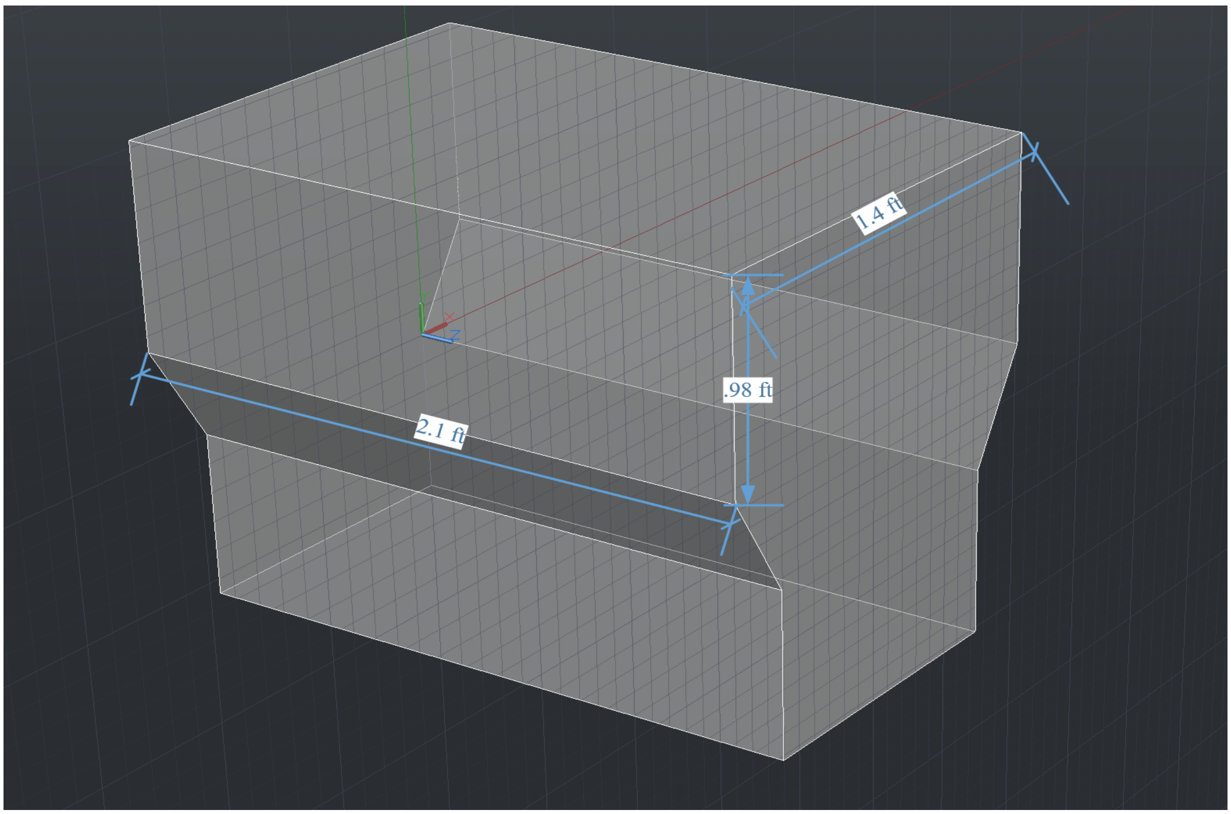
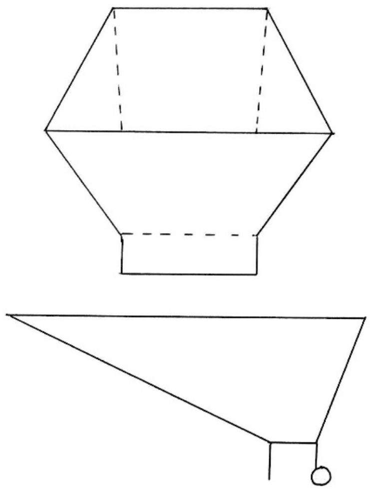


Figure 2.2 Proposed hopper design

General Design Concepts

Hopper



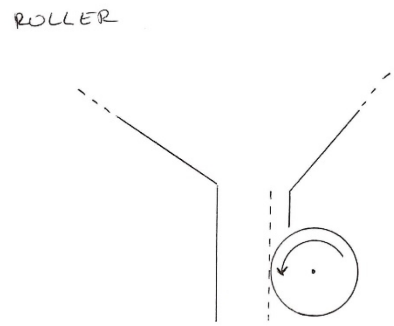
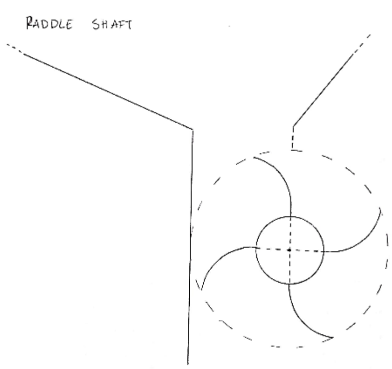


Figure 3.1 A sketch of the shape the hopper concept

Figure 3.2 A sketch of an agitating of roller at the outlet of the hopper concept

Clogging was anticipated at the base of the hopper, and was observed at Izzard Chocolate during a site visit, so a simple roller to agitate the clogged area was conceived.



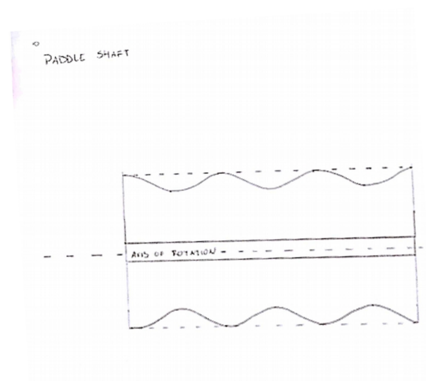


Figure 3.3 A side view sketch of another agitator concept with paddles

Fi ... the curved edges to prevent binding of the paddles with beans

Tendency of the beans to slide on the simple roller required a redesign of the base of the hopper. A paddled wheel was conceived that would no only prevent clogging of the beans, but also allow adjustable and predictable delivery rate of the beans from the hopper.

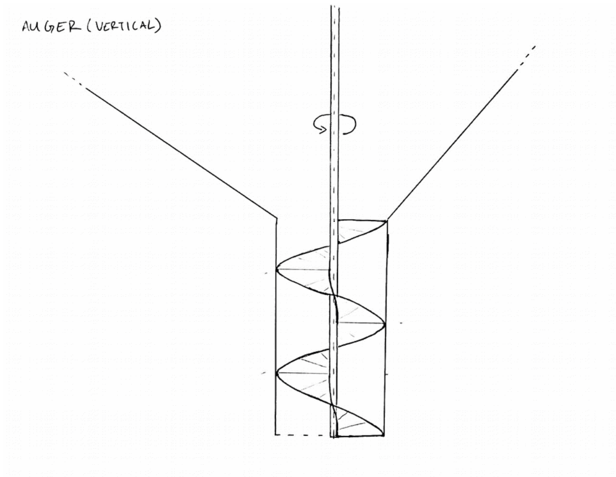


Figure 3.5 A sketch of our initial auger design in a vertical position

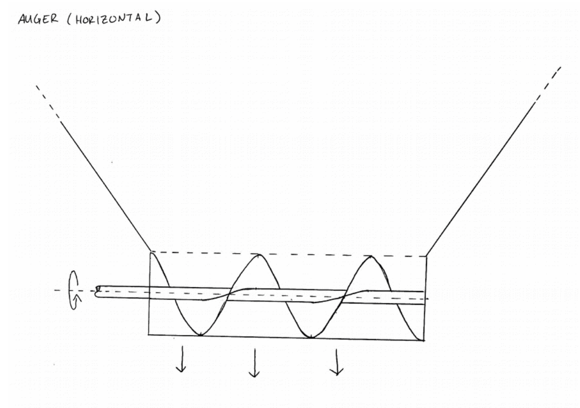


Figure 3.6 A sketch of our second iteration of an auger in a more viable horizontal position

A more common and possibly cheaper method to feed beans out of the hopper is an auger, typically vertical in orientation. A horizontal orientation would not only be easier to drive, but help keep overall height to a minimum.

Cracking Method

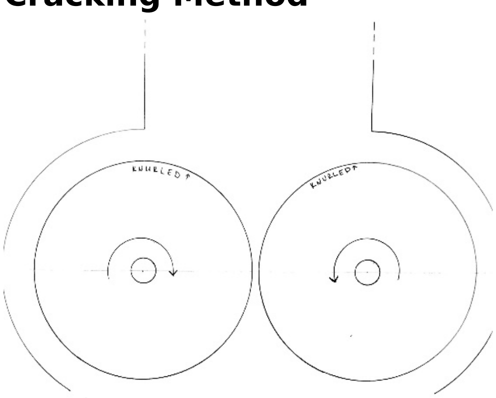


Figure 4.1 An initial sketch of simple rollers

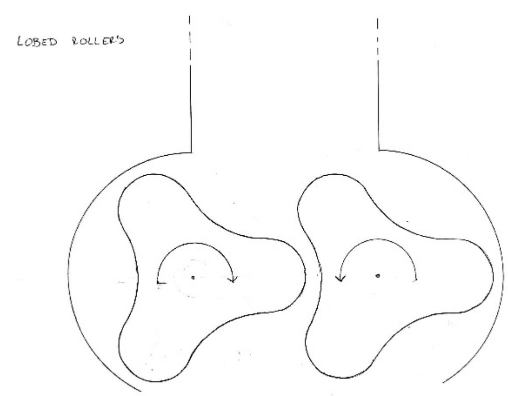


Figure 4.2 A sketch of lobed rollers that would encourage the passage of the beans

Much like US Roaster Corp's current roller grinders, cracking the cocoa beans with a roller grinder would be a simple and achievable design. To mitigate the beans from not passing through the round rollers, lobed rollers were thought of as an alternative to smooth roller grinders.

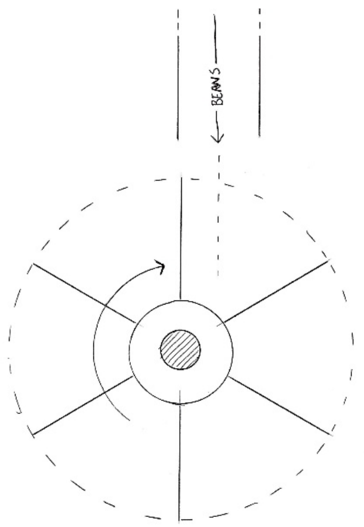


Figure 4.3 Initial design of an impact wheel rotating horizontally

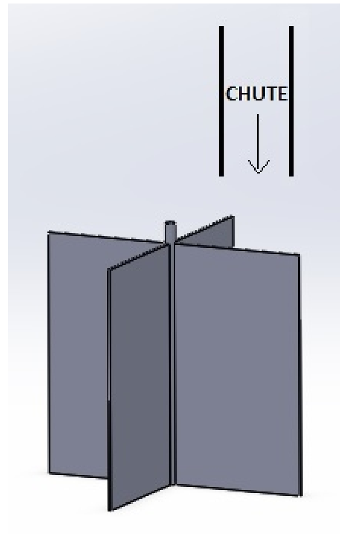
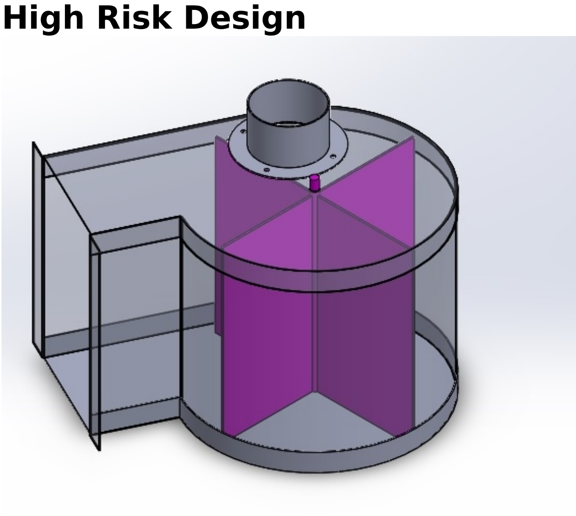


Figure 4.4 Second design of a vertical impact wheel

Upon observation, quick impact was seen as an effective way of cracking the beans. A paddle wheel that rotates and impacts the beans would also be independent of individual bean size. The axis of rotatation of the wheel in the first draft was horizontal, which is perpendicular to the flow of beans. To ensure consistent contact impact velocity, it was thought to feed the beans down in parallel with the rotating axis.

High Risk Design



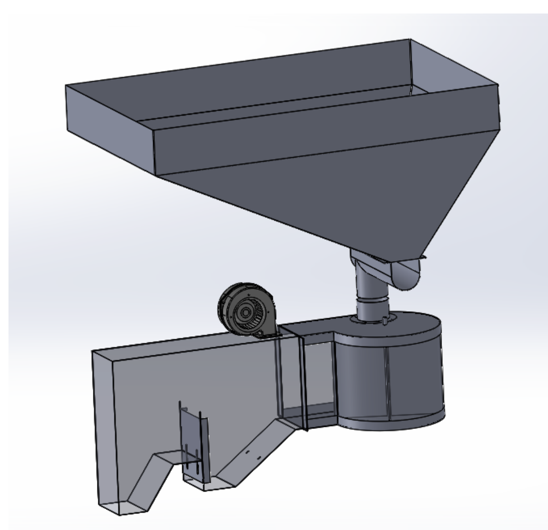


Figure 5.1 A modeled representation of the vertical impact wheel

Figure 5.2 The preliminary model of the impact wheel with hopper and chute

This design is appropriatly named because it is high risk. No other winnower on the market uses this approach and it has yet to be thoroughly tested. The main cracking method is impact with the paddles on a wheel traveling with high angular velocity. Some pros of this design include: the cracker is indiscriminant of bean size, the velocity adjustable to vary impact force and a simple design and construction. Some cons of this design include: unproven and untested design, loss of contact with bean and requires metered feed out of hopper.

Low Risk Design

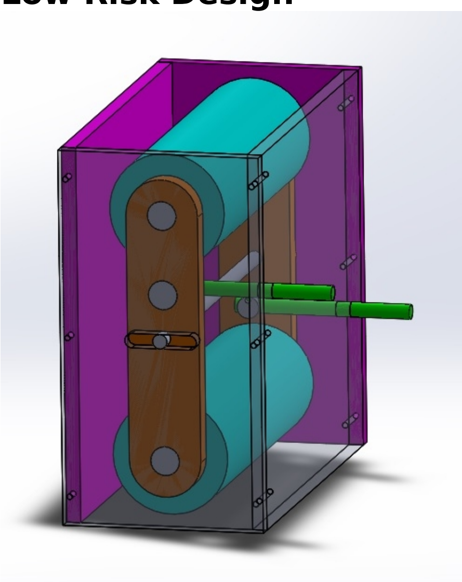


Figure 5.3 A modeled representation of the concept rollers

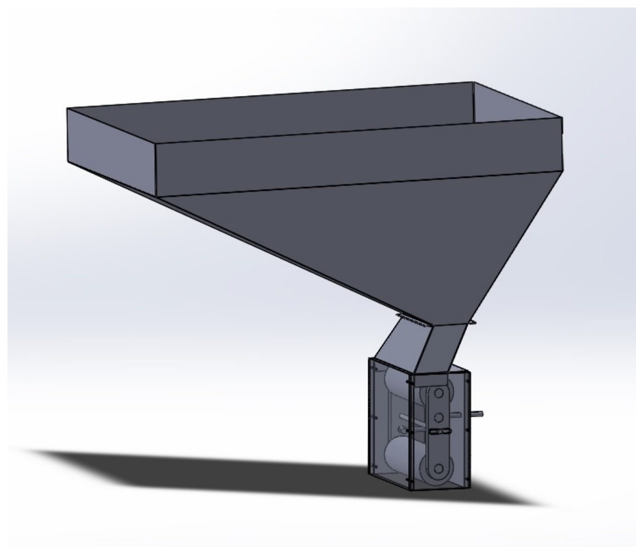


Figure 5.4 Modeled concept rollers with hopper and connecting chute

This is the low risk design. It is a conceptually common design utilizing a two stage roller-cracker design which homogenizes the crushed bean size. The cocoa beans would be crushed between the roller and the wall of the housing. A lobed roller from the conceptual designs could be utilized. The roller-cracker is similar to US Roaster Corp’s current coffee roller-grinders, so fabrication would not be difficult. Some pros of this design include: robust and adjustable, guarantees beans that have passed through will be cracked/crushed and self-metering flow of beans out of the hopper. Some cons of this design include: tolerance and part intensive, potentially less differentiable qualities between nib and hull and finer particles will require a more thorough separation process.

Project Schedule

ID	Indicators	Task Mode	Task Name	Duration	Start	Finish	July B
1	✓		Develop Team Organization & Structure	20 days	Mon 8/22/16	Fri 9/16/16	
2	✓		Meet Client: U.S. Roaster Corperation	0 days	Fri 9/16/16	Fri 9/16/16	
3	✓		Technical Literature Review & Analysis	42 days	Mon 9/19/16	Tue 11/15/16	
4	✓		Market Research Trip: Izzard Chocolate	0 days	Thu 10/13/16	Thu 10/13/16	
5	✓		Develop Project Proposal	55 days	Mon 8/22/16	Fri 11/4/16	
6	✓		Develop Preliminary Design Concepts	16 days	Mon 10/17/16	Mon 11/7/16	
7	✓		Present Preliminary Design Concepts	0 days	Fri 11/11/16	Fri 11/11/16	
8	✓		Fall Semester Design Review Presentation	0 days	Fri 11/18/16	Fri 11/18/16	
9	✓		Fall Semester Design Final Report	0 days	Fri 12/2/16	Fri 12/2/16	
10			Testing on Conceptual Cocoa Bean Cracking Methods	57 days	Thu 11/3/16	Fri 1/20/17	
11			Testing on Conceptual Cocoa Nib Sorting Methods	42 days	Thu 12/1/16	Fri 1/27/17	
12			Control Systems Design	47 days	Thu 12/1/16	Fri 2/3/17	
13			Determine Power/Utility Requirements for the Winnower Design	9 days	Fri 1/27/17	Wed 2/8/17	
14			Determine Expected Prototype Cost Analysis	13 days	Wed 2/1/17	Fri 2/17/17	
15			Finalize Winnower Design and Receive client approval	0 days	Wed 2/22/17	Wed 2/22/17	
16			Finalize Drafting all Necessary Parts Diagrams	16 days	Fri 2/10/17	Fri 3/3/17	
17			Order All Necessary Material and Components for Prototype	0 days	Wed 3/8/17	Wed 3/8/17	
18			Fabrication/Assembly of Prototype	13 days	Mon 3/20/17	Wed 4/5/17	
19			Prototype Troubleshooting	31 days	Sun 3/5/17	Fri 4/14/17	
20			Spring Final Report Draft	37 days	Fri 3/3/17	Mon 4/24/17	
21			Final Presentation Preperation	11 days	Sat 4/15/17	Fri 4/28/17	
22			Final Spring Design Report	0 days	Thu 4/20/17	Thu 4/20/17	
23			Final Senior Design Presentation	0 days	Fri 5/5/17	Fri 5/5/17	

Figure 6.1 Gantt Chart Tasks

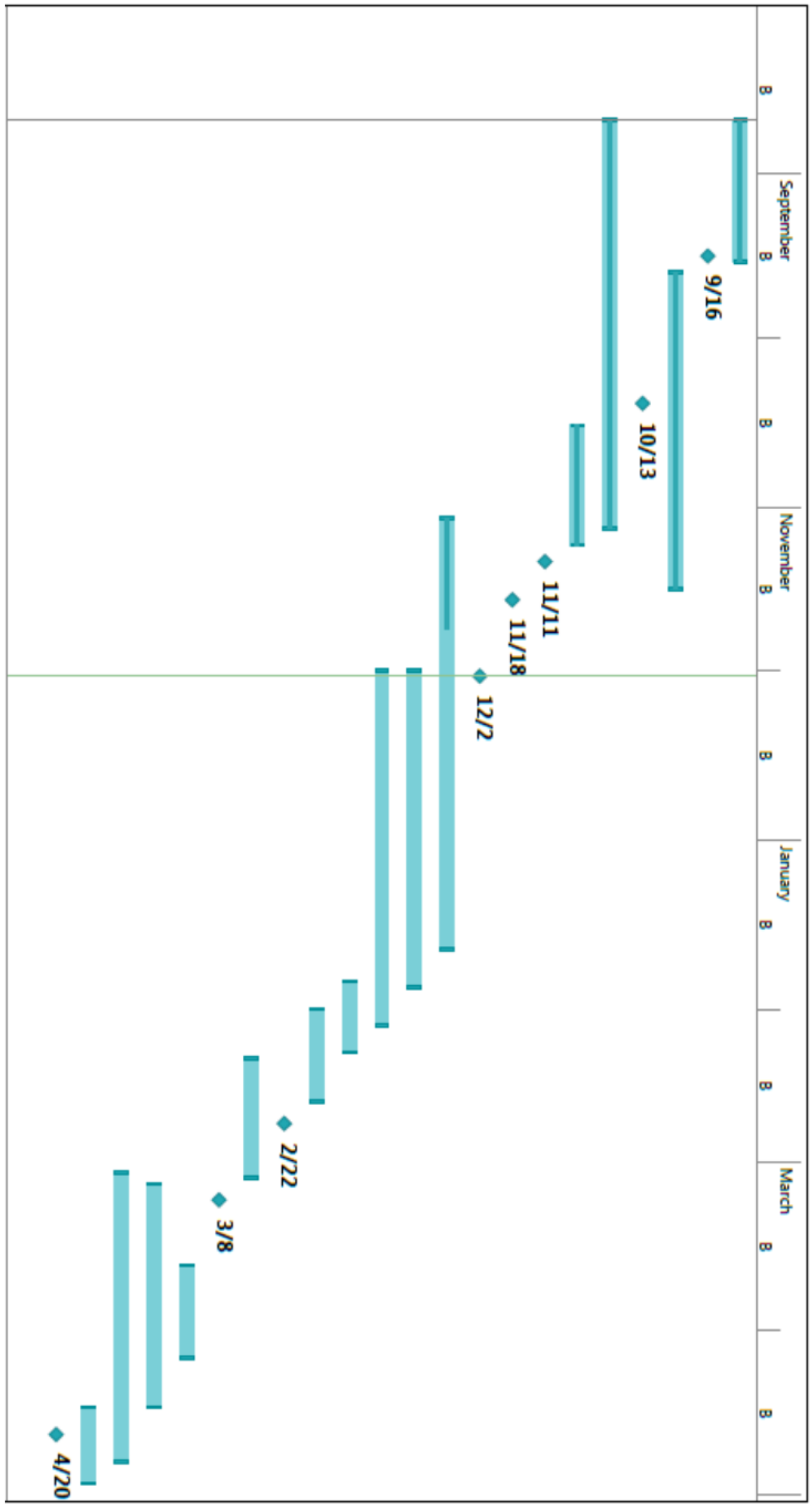


Figure 6.2 Gantt Chart

Proposed Budget

After consulting with the client, Dan Jolliff, about his expected costs for this endeavor, he voiced his wishes to keep our testing and concept construction near his expected retail price. His aim is to market these winnowers to the small volume chocolatiers with a price tag in the range of $3000 - $4500. What is needed in the construction is roughly estimated in the table below. After concluding the testing and determining the plan of action with regards to the high-risk or low-risk design, a much more detailed and accurate description of our budget will be developed.

Table 6.1 An estimated budget breakdown

Item	Percent Budget
Electric motor(s)	12
Frame material	15
Stainless sheet	17
Drive belts	5
Bearings	2
Electrical cords	2
Electrical controllers	8
Fans	5
Vaccuums	13
Wire mesh	6
Fabrication	5
Testing	10
	100

List of Tables

List of Figures

References

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US Roaster Corp

TRIAD ENTERPRISES

Joseph Barnes, Ben Jenkins, Montana Wells

TRIAD ENTERPRISES

Who we are

Triad Enterprises is a small local firm supplying various services including, but not limited to, engineering consultation and small scale manufacturing.

Mission Statement

“Partnering with others to help them reach their goal”

Background

- Located in Oklahoma City, OK
- Founded by Dan Jolliff
- Has served the roasting industry for over 33 years
- Specializes in new roaster fabrication and rebuilding older roasters
- Provides wide range of roasters, from 3 oz to 300 kg

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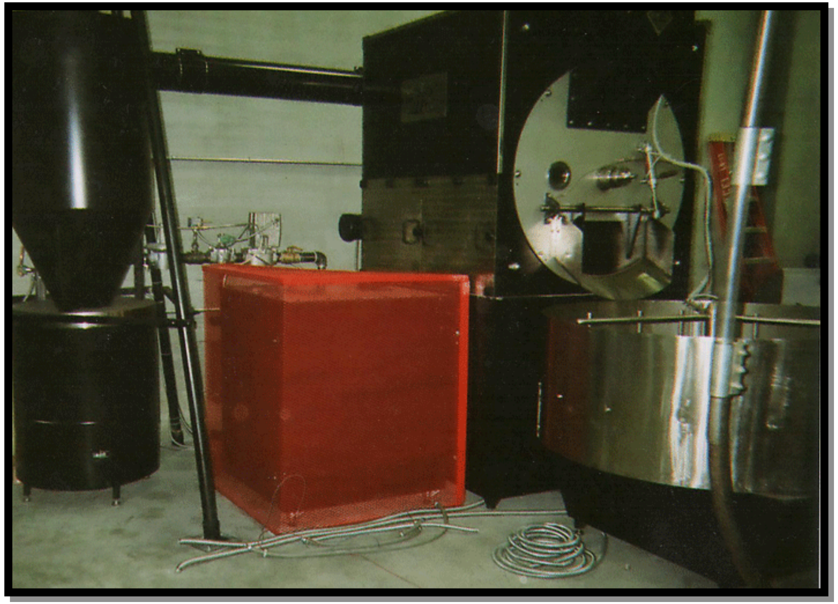
A few examples of US Roaster Corp coffee roasters



Problem Statement

Triad Enterprises is to design, build and test a cocoa bean winnower that meets the following specifications:

- Affordable for bean-to-bar chocolate producers
- Able to fabricate at US Roaster Corp facilities
- Incorporates competitive features:
  - Unsupervised operation
  - Easily adjustable
  - Quiet and fast

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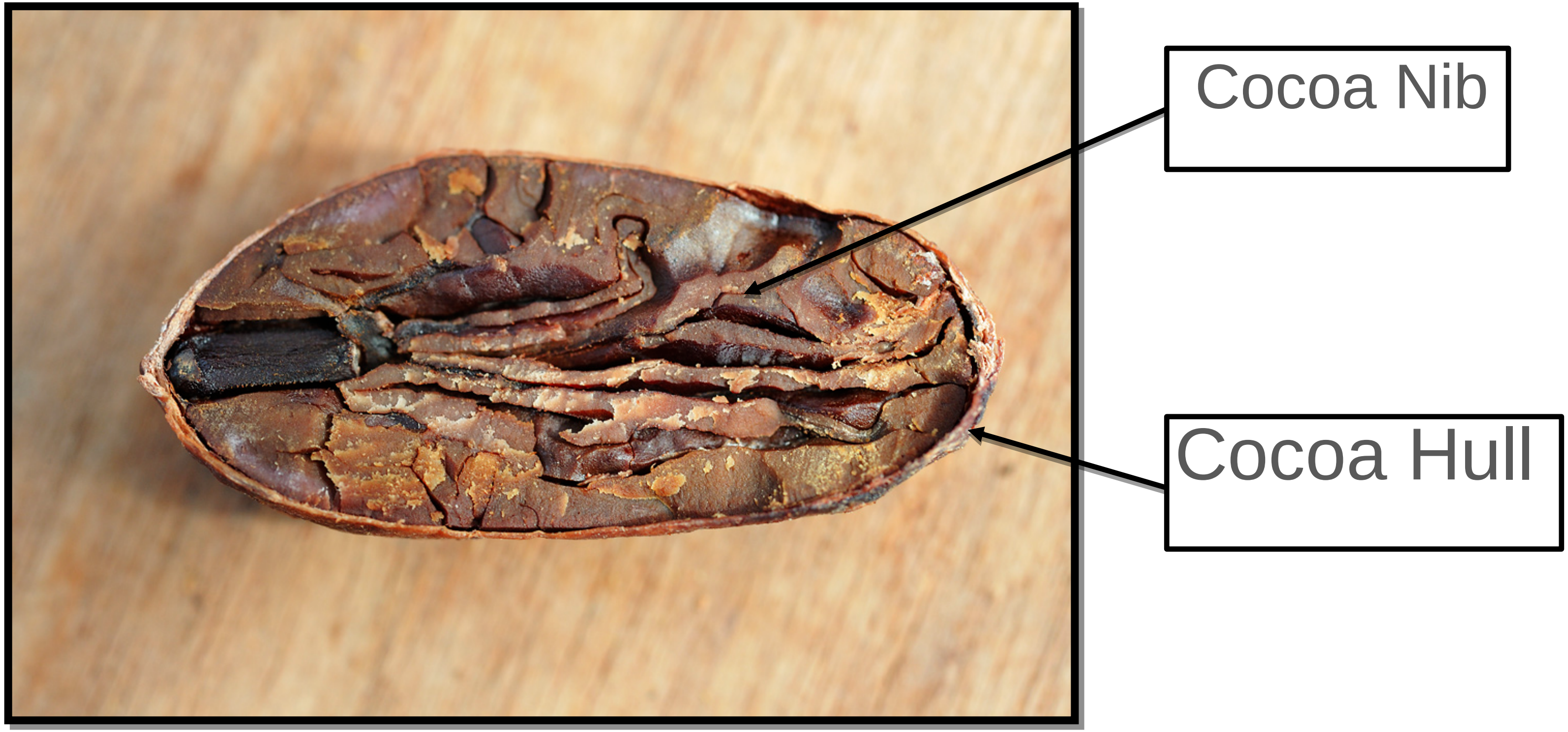

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What is a winnower?

- A winnower is an apparatus that separates out the undesired portion from the desired portion of a material

Cocoa beans

Crushed cocoa beans

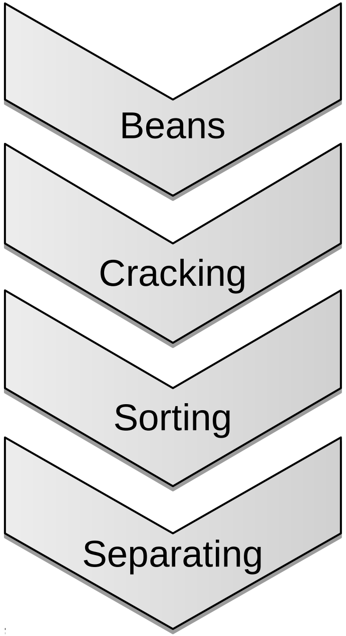
Cocoa nibs

Cocoa hulls

Engineering Specifications Goals

- Winnow at a rate of 100 lbs/hr
- Winnow at an efficiency >95%
- Not allow greater than 2% chaff in the final nib output
- Retail price between $4,000-$6,000
- Minimize moving parts
- Be easily cleaned

General Overview of Project



Researched the physical properties of cocoa beans

Designed cracking methods based on physical properties of cocoa beans

Designed sorting methods based on output of cracker

Designed separation methods for nibs and chaff

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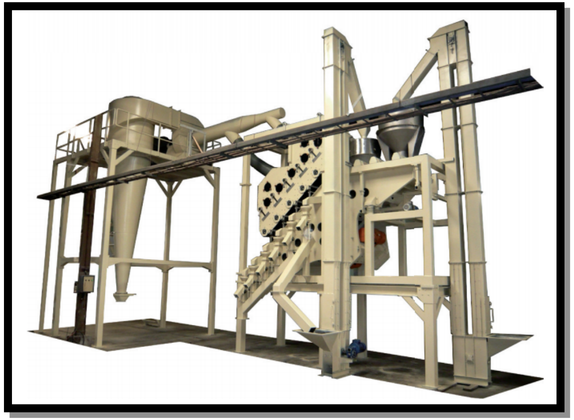
Winnowers in Industry



Bear Winnower Type BWI

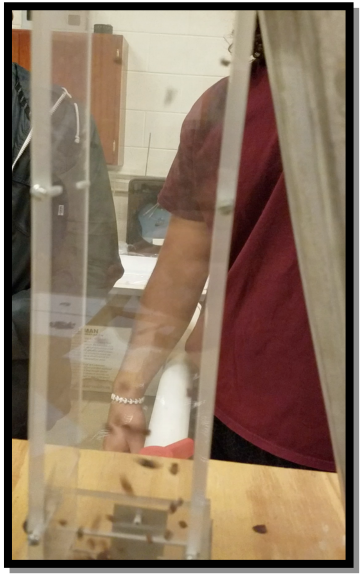
- 1100-6600 lbs/hr
- Nib content in chaff = 0.25%
- Chaff content in nibs = 1.75%

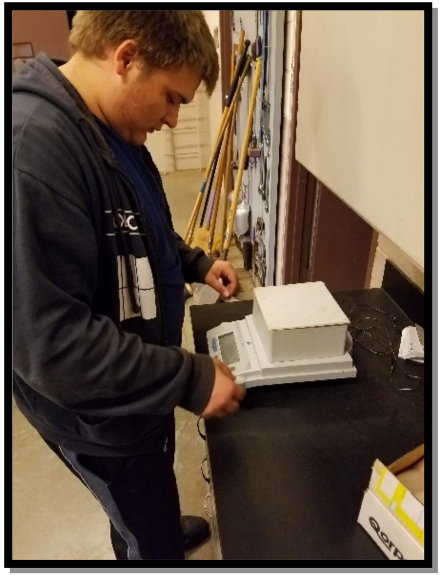
Vortex Winnower by Brooklyn Cocoa

- 88 lbs/hr
- Nib content in chaff = 0.25%
- Chaff content in nibs = 0.20%
- $34,000

Freshman Group 1

- Tasked with determining viable air velocity range to separate chaff from nib
- Utilized air velocity separator in BAE lab to determine range





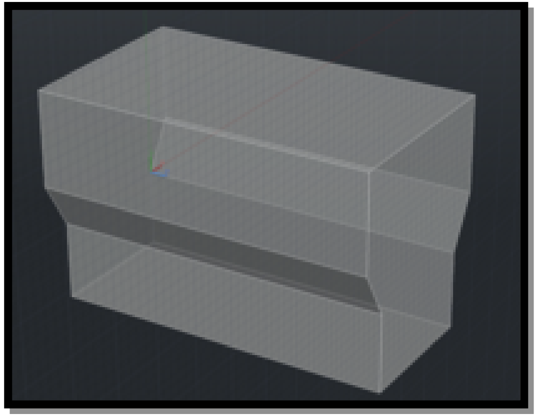
$$v_{terminal} = \sqrt{\frac{2 * m * g}{C_d * \rho_{air} * A}}$$

Determined air velocity of 5.15 m/s was best for separating nib from chaff. Viable range was from 5-6 m/s for this apparatus.

Determined air velocity of 5.15 m/s was best for separating nib from chaff. Viable range was from 5-6 m/s for this apparatus.

Freshman Group 2

- Tasked with designing hopper that meets specifications:
  - Must hold 100 lbs of roasted cocoa beans
  - Must determine appropriate foodgrade material
  - Must not exceed loading height of 5 ft
- Make a model of hopper utilizing CAD software
- Contact material suppliers and estimate a price for the hopper



Visit to Izard Chocolate

- Bean-to-bar chocolate company in Little Rock, AR
- Founded in 2014
- Introduced us to chocolate process and issues related to current winnower

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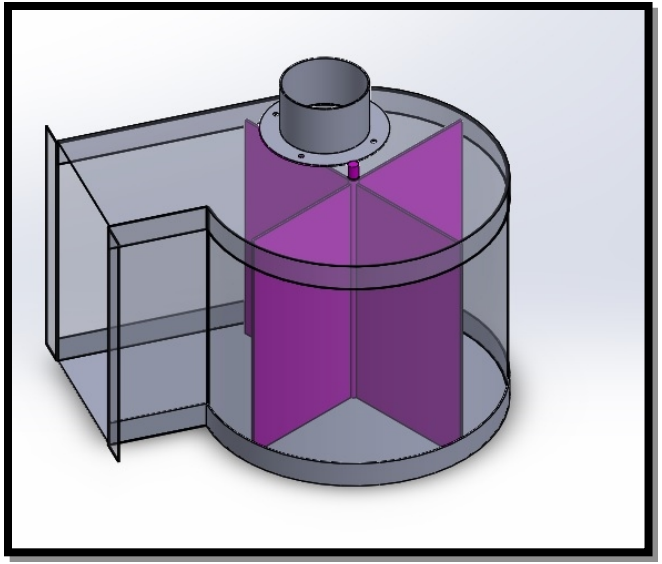
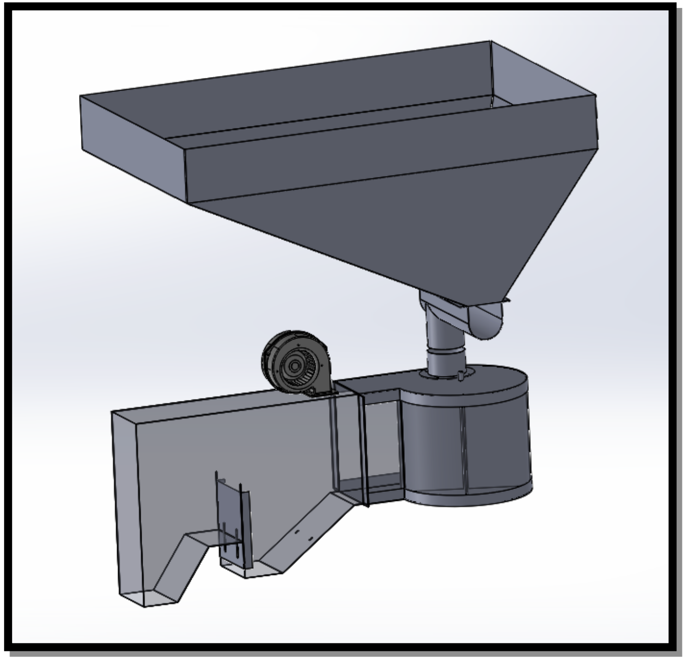
Fall - Testing

Physical Properties of Cocoa Beans	
Sample Size	122
Average Weight (g)	1.19
Max Weight (g)	2
Min. Weight (g)	0.5
Average Sphericity	0.61
Max Diameter (mm)	28.97
Min Diameter (mm)	5.01

Fall - High Risk Suggested Design

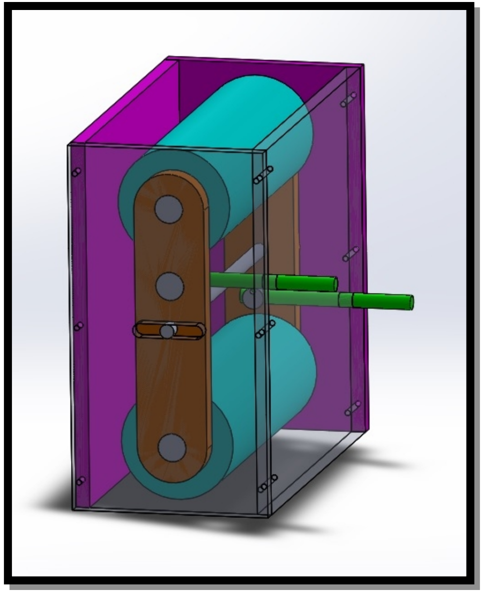
- The main cracking method is impact with the paddles on a wheel traveling with high angular velocity

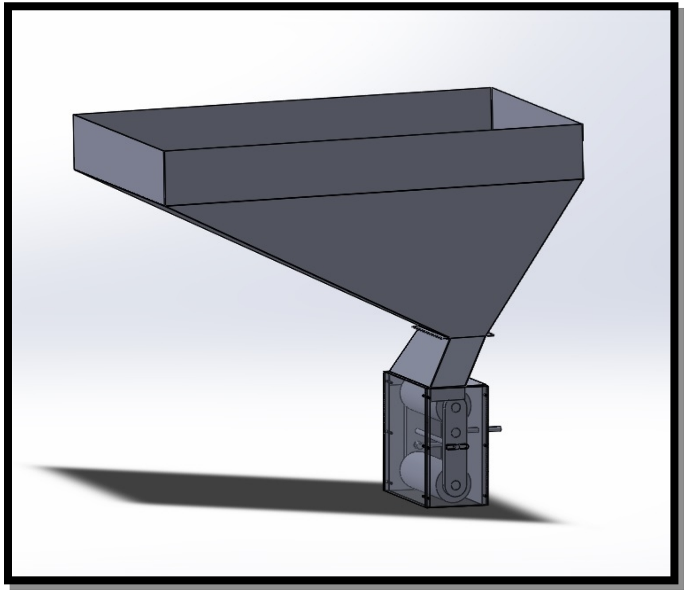




Fall - Low Risk Suggested Design

- Conceptually common design utilizing a two stage roller-cracker design which standardizes the crushed bean size





Spring Testing

- Varied gap distance between the rollers to study crushing effect
- Able to increase/decrease speed with VFD

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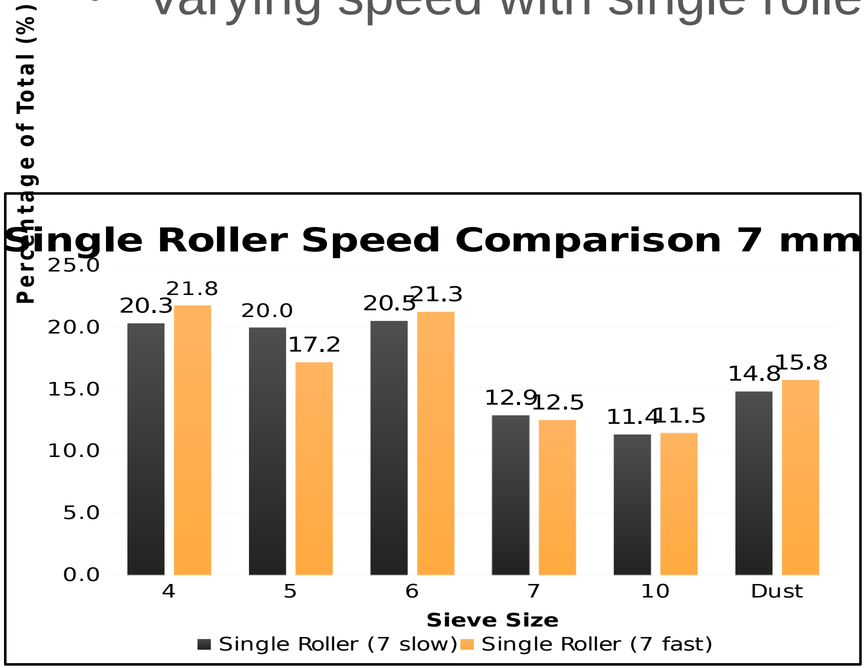
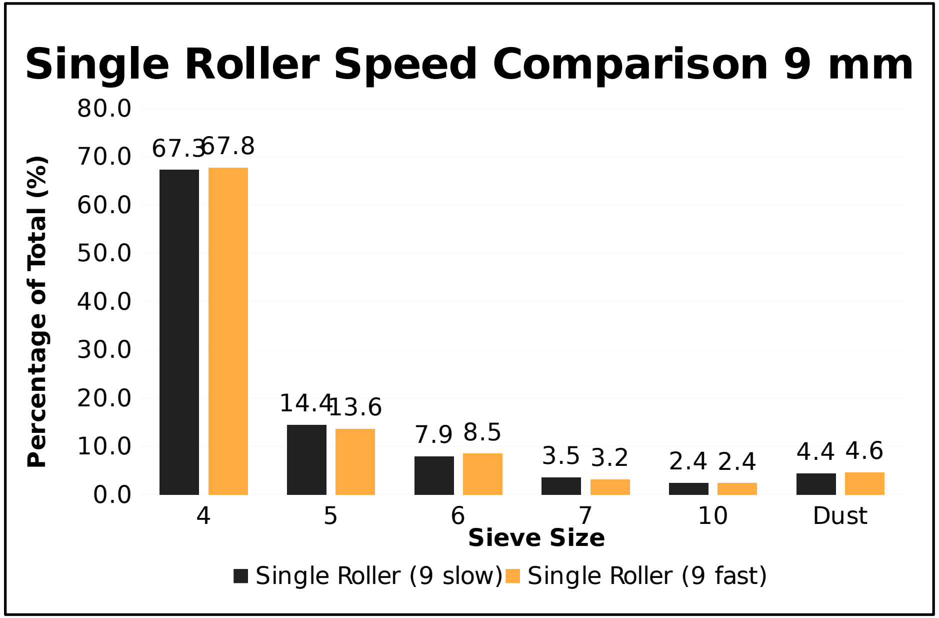
Spring Testing

- Used Ro-Tap machine to sieve the nibs and chaff into quantifiable catagories
- Utilized data to assist in designing the separation aspect of the winnower

Spring Testing

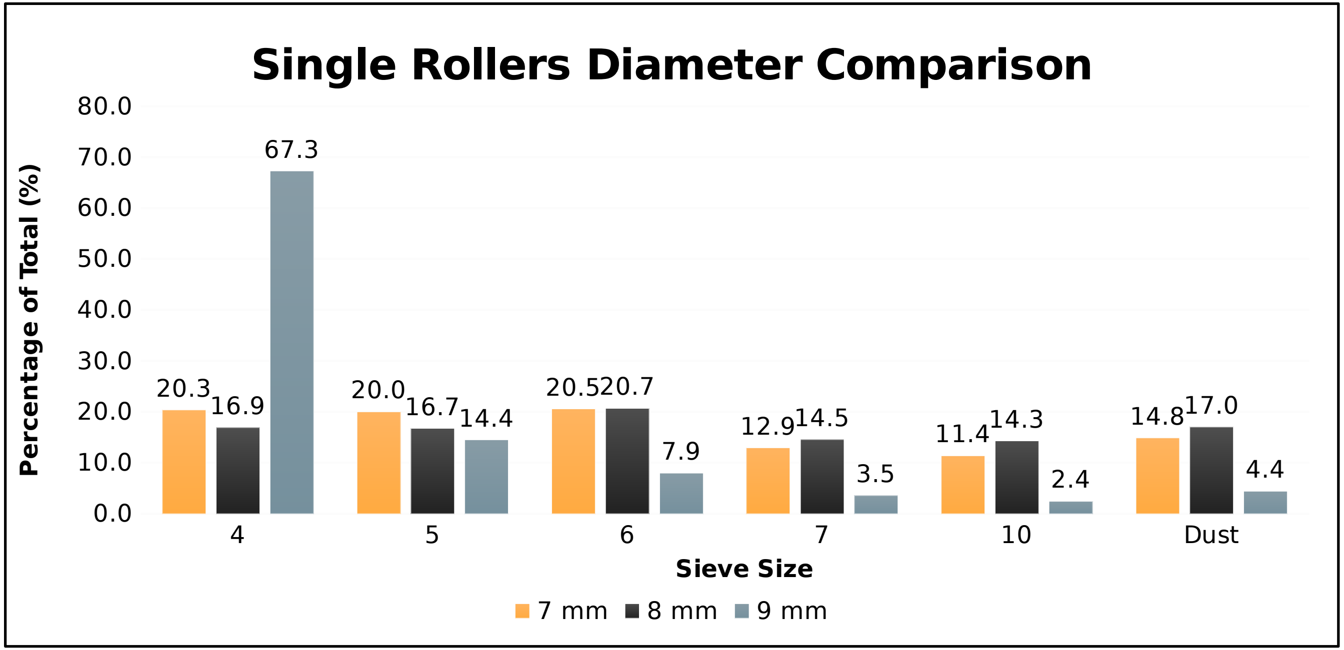
- Varying speed with single roller





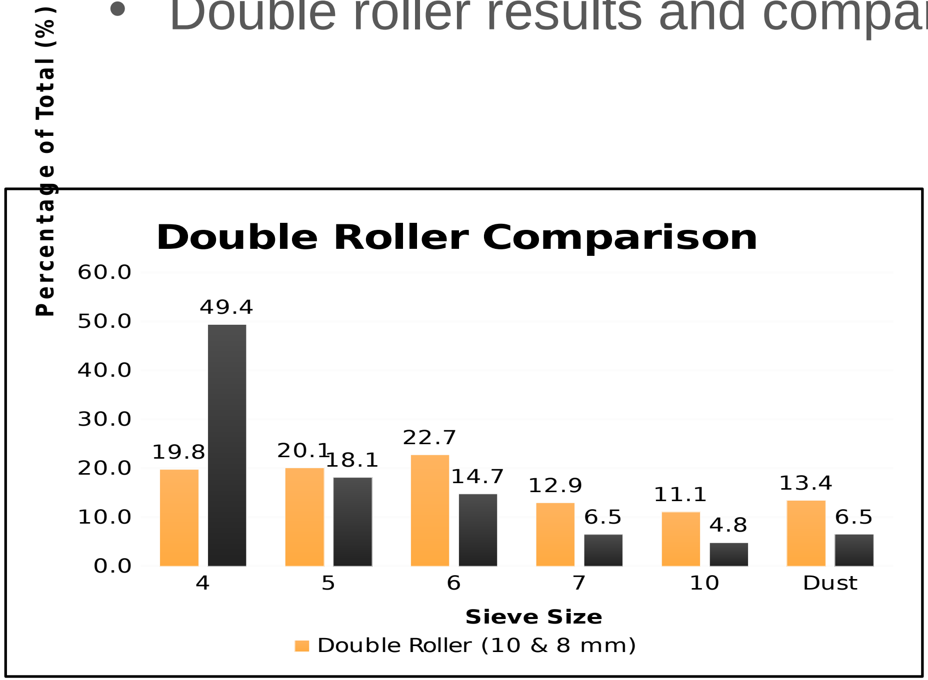
Spring Testing

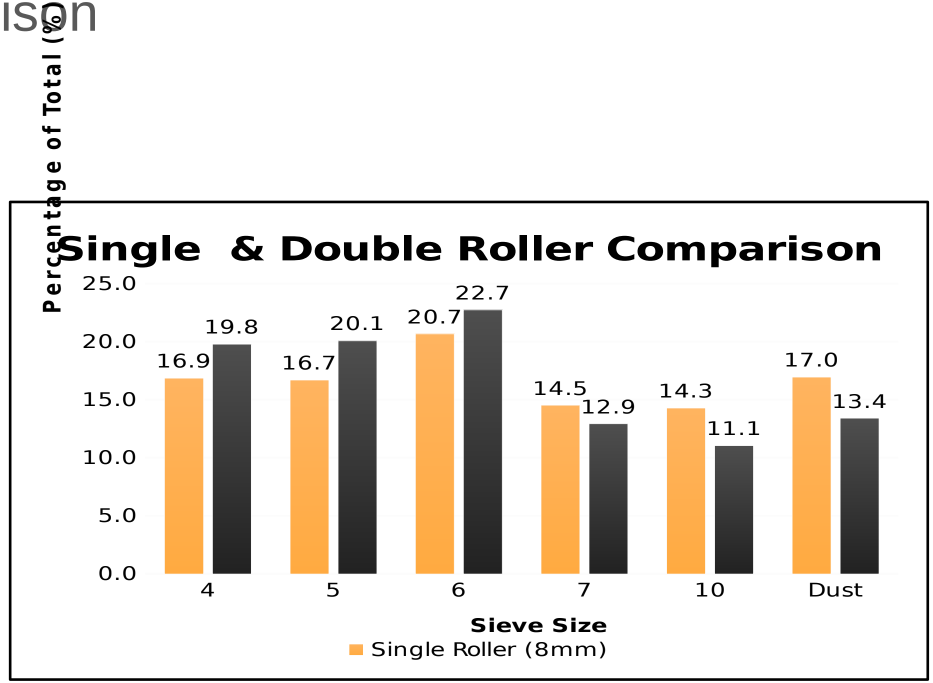
- Single roller comparison



Spring Testing

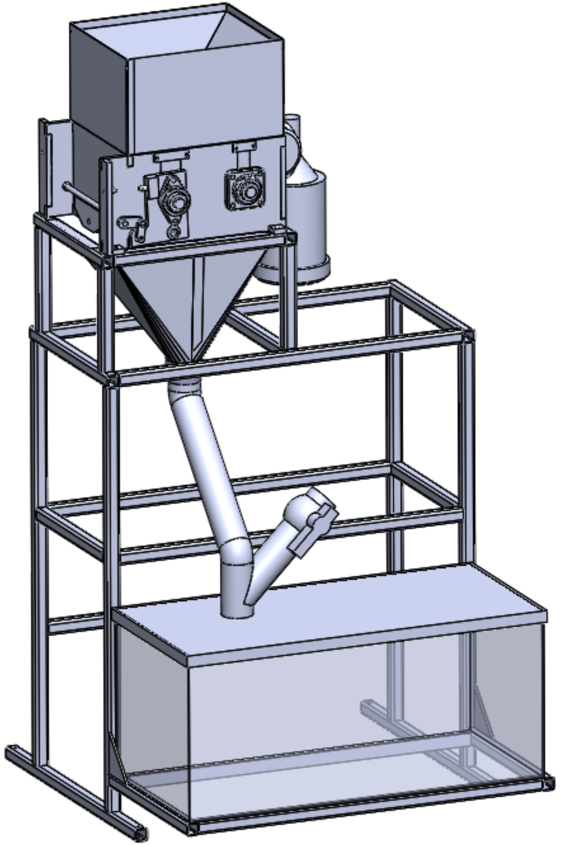
- Double roller results and comparison





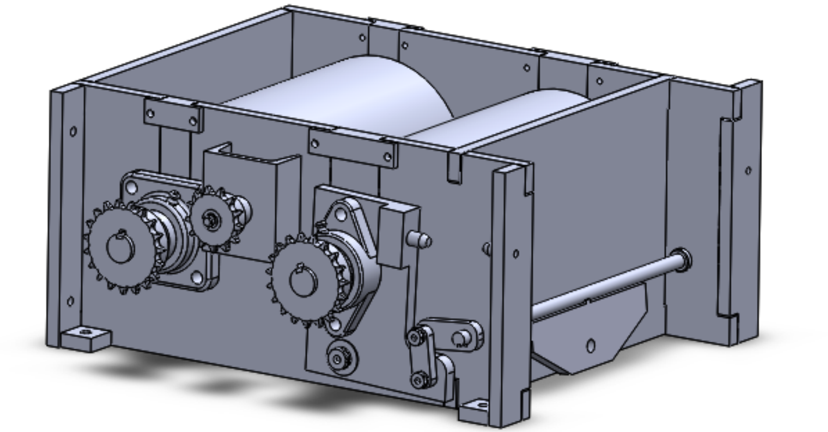
Model – Complete Model

- Robust roller design
- High process rate
- Simple and easy to fabricate frame design
- Easy operation
- Managable floor footprint
- Easy access to rollers for cleaning



Model – Rollers and Housing

- 0.5" Steel plate housing
- 12"x7" diameter rollers with grooved surface
- Food grade flange mounted bearings
- Schedule 40 chain drive sprockets
- Infinite linkage roller gap adjustment



Model – Motor and VFD

Where
Θ = 90º
F= 75 lbs
R= 5”

$$T = F \cdot R \cdot Sin(\theta)$$

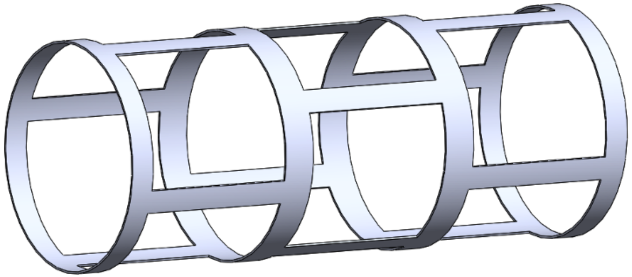
This was divided by the test roller length, to get a torque requirement per in. of roller length.

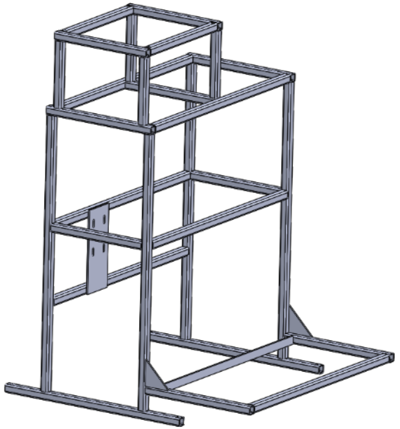
$$HP = \frac{RPM \cdot T}{5252}$$

This equation was used to verify the motor that was specified would be suitable

- 0.37 to 11 kW/0.5 to 15 hp 200V
- 0.37 to 22kW/0.5 to 30 hp 400V
- IP20 enclosure
- Embedded Modbus EIA-485 interface

Model – Trommel and Frame





- Simple, low maintenance design
- Would utilize three screen sizes
  - 0.187”, 0.111”, and 0.073”
- Sort cracked beans to allow more specific air velocities for better separation

1 1/4" x 1 1/4" Square Steel Tubing	
Length (in)	Count
10	4
15.5	3
15.75	2
17.25	2
18	4
30	2
34.75	6
41	4

* Specified but not fabricated

Model – Seperation

Piping

- 2” Diameter PVC input
- 3” Diameter PVC plenum chamber/outlet
- Two discriminator valves for seperation velocity adjustment

Vaccum

- 170 CFM of airflow
- 6.5 Peak HP

Cyclone

- 14” Cyclone
- 10 Gallon waste storage

Prototype - Assembly

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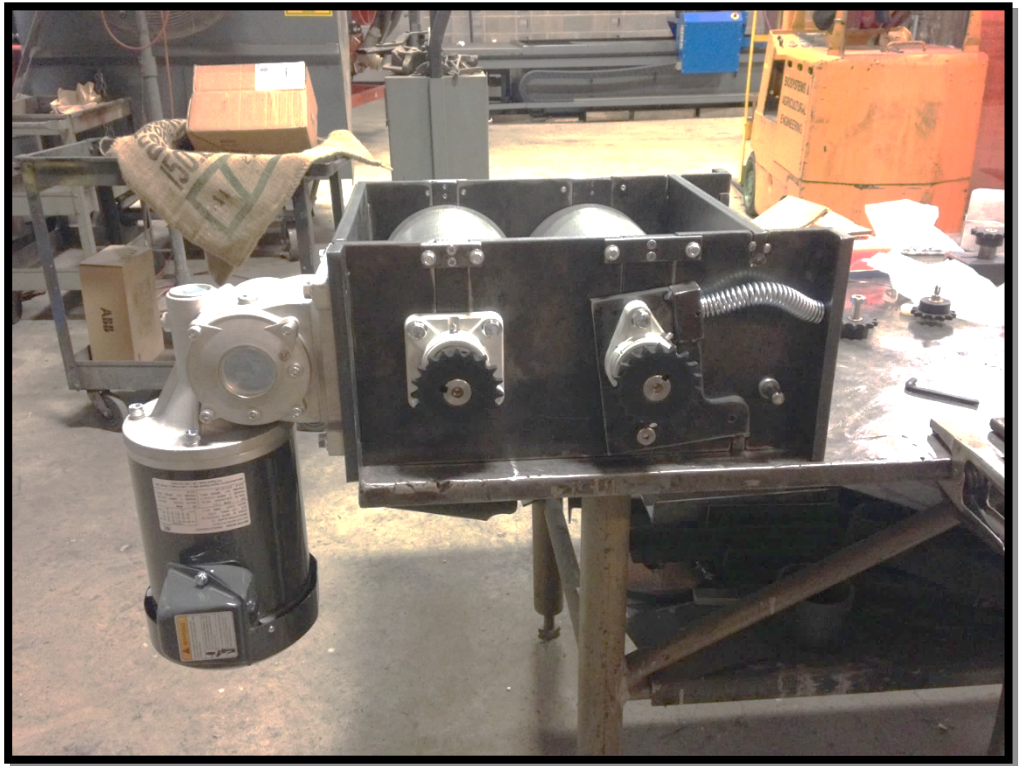
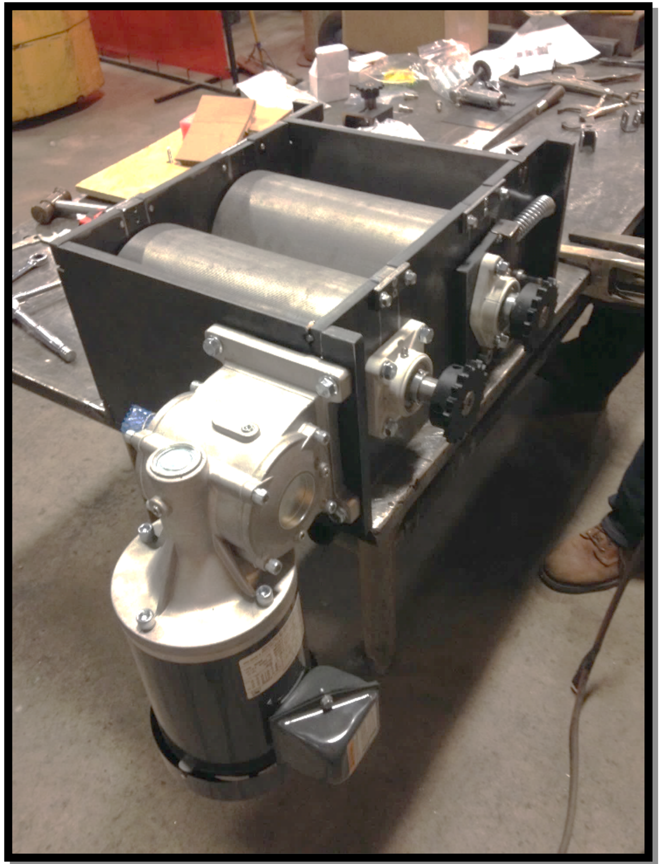
Prototype – Rollers and Housing





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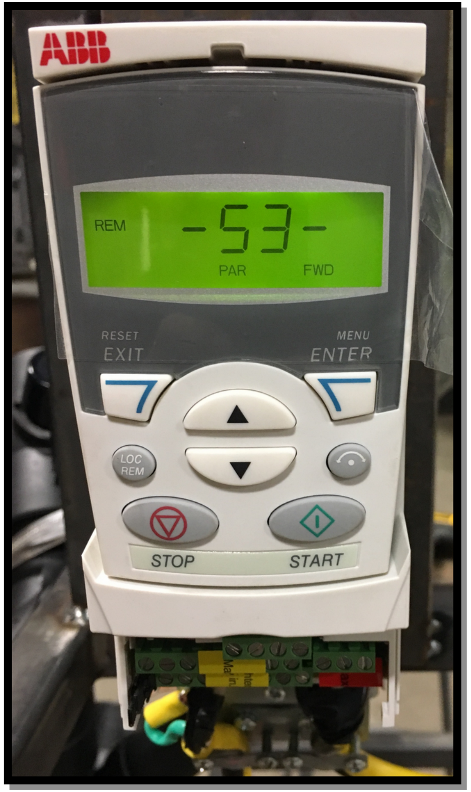
Finalized Prototype

Testing-Rollers

Bean Cracking

- At VFD setting f=30 hz nearly all beans were cracked
- Consistent cracking at this frequency
- Lower than 30 hz caused jamming issues
- If overloaded the rollers would jam
- Spring tension on the adjustment feature was insufficient to keep the rollers in place



Testing - Winnower

- Max measured inlet air velocity was capapble of picking up whole beans
- Large volumes of cocoa beans at once reduced winnowing efficiency
- Trommel would help address this issue
- Manual slow feeding was required to achieve proper sort

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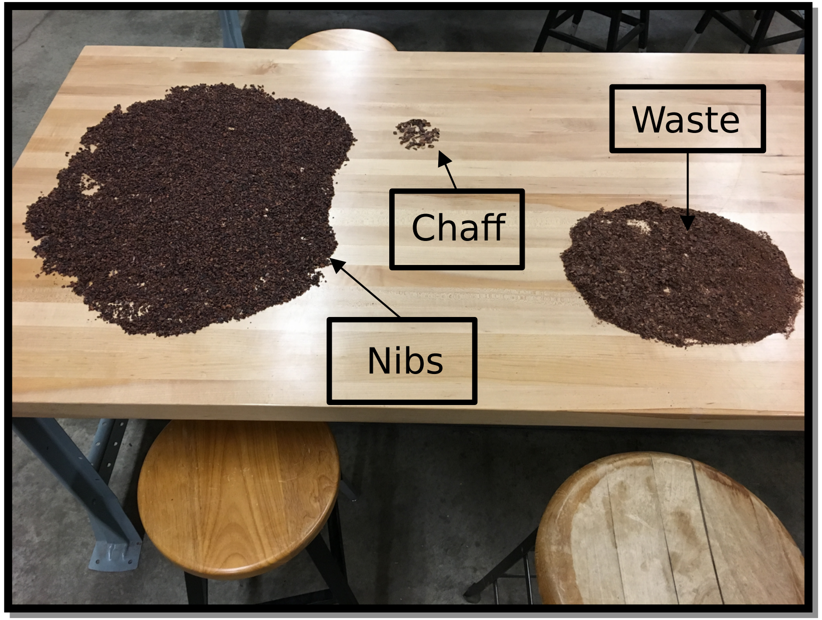
Testing - Video

Testing - results

- Winnowing rate with manual feed was 1.6 lb/min
- Winnowing efficiency was around 98%
- 1%-1.7% chaff in the winnowed cocoa nib



Prototype Financial Breakdown-What We Built

- Overall budget of $3,000
- Material cost of the project is $1,741.82
- Cost of the control system is $289.94
- Labor was not included
- Direct donation of material to the project from McElroy Mfg. valued at $348
- **Total Cost of Prototype $2,031.78**

Final Design Financial Breakdown

- Target production cost is $3,000-$4,000
- Materials cost $3,485
- Control cost $579
- Labor $4,800
- Estimated production cost of the winnower is $8,285.

- Operator Safety
- Roller Movement During Cracking
- Food Contamination

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Failure Modes Effects Analysis

Process or Product Name: Cocoa Bean Winnower								Prepared by: Triad Enterprises			Page: 1		of 1		
Process Owner: Triad Enterprises								FMEA Date (Orig): 2/27/2017			Rev: 4/20/2017				
Key Process Step or Input	Potential Failure Mode	Potential Failure Effects	SEV	Potential Causes	OCC	Current Controls	DET	Actions Recommended	Resp.	Actions Taken	SEV	OCC	DET	RPN	
Hopper	Hopper Getting Clogged	Beans Won't be Processed	10	The Inlet of the Cracker is too Small	3	The Inlet Is Large Enough to Prevent Clogging	3	Design a Feeding System to Feed Into the Hopper	Future Desgin Engineer (FDE)	N/A	10	3	3	90	
Cocoa Bean Cracking	Cracker Rollers Getting Stuck	Beans Won't be Cracked	10	The Motor of the Cracker Roller is not Powerful Enough	2	The Motor Selected Have More HP Than is Regired To Run the Rollers	2	Decrease the Size of the Rollers	FDE	N/A	10	2	2	40	
	Cracker Roller Motor Failure	The Beans Don't Get Cracked	10	The Motor of the Cracker Roller is not Maintained Properly	3	The Motor Selected Have More HP Than is Required To Run the Rollers	2	Develop a Maintenance Schedule for the Motor	FDE	N/A	10	3	2	60	
	Cracker Roller Movment	Beans Don't Crack Properly	7	Operator Error	4	The Rollers are Manually Adjusted & Held in place by a Spring	6	Add a Mechanism that Prevents the Rollers from Moving While Cracking	FDE	N/A	7	4	6	168	
Sorting Cracked Cocoa Beans	Sifting Screens Getting Clogged	Inadequate Sorting Of Cocoa Nibs	6	Infrequent Cleaning of the Screens	7	The Operators Implement a Consistent Cleaning Regiment	3	Develop an Automatic Cleaning System for the Screens	FDE	N/A	6	7	3	126	
	Sorter Motor Failure	The Beans Won't be Cracked	10	The Motor is not Maintained Properly	3	The Motor Selected Has More HP Than is Required	2	Develop a Maintenance Schedule for the Motor	FDE	N/A	10	3	2	60	
	Sorter Belt Drive Failure	The Sorting Can Not Occur	10	Belt Breaks	4	Regulary Replace Belt	3	Develop a Maintenance Schedule for the Belt	FDE	N/A	10	4	3	120	
Winnowing	Winnower Air Velocity Tuning	Nibs Won't be Winnowed Properly	10	The Winnower Sytem is misadjusted	8	Adjust the Air Intake Valves	1	Develop an Automatic Adjustment System	FDE	N/A	10	8	1	80	
	Vacuum Failure	Nibs Won't be Winnowed Properly	10	The Vacuum Filter Gets Clogged	3	A Cyclone Air Filture System Has Been Installed	2	Add More Fail safes to Prevent the Vacuum from being Worn Down	FDE	N/A	10	3	2	60	
Safty	Winnower Falling Over	Something Colliding With It	9	Damage to the Winnower & People Near It	1	The Winnower Will be Bolted Down	2	Develop a More Stable Base	FDE	N/A	9	1	2	18	
	Operator Injuries	Harm to Operators	10	Operator Negligence	5	Safety Labeling/Component Housing	4	Put in more Safty Controles	FDE	N/A	10	5	4	200	
Sanitation	Food Contamination	Ruined Product	9	Improper Sanitation	6	GMP Guidelines	3	Develop Components that are Easier to Disassemble	FDE	N/A	9	6	3	162	

Recommendations

Operator Safety

- Add chain guards
- Add emergency shutoff controls when moving parts are accessed
- On subsequent iterations, make winnower shorter to ease loading of beans and make maintenance easier
- Reduce weight of machine and add warning labels

Roller Movement

- Increase spring tension and add spring guide to decrease or eliminate roller movement

Food Contamination

- Upgrade all materials to food grade materials, such as stainless steel or UHMW
- Make all components easier to disassemble to assist in cleaning

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Compare results to goals/specifications

Objective

- Winnowing rate of 100 lb/hr
- Efficiency of 95%
- No more than 2% chaff in the product stream
- Production cost of $3,000-$4,000
- Easy to clean
- Minimal moving parts

Obtained

- Winnowing rate of at least 100 lb/hr
- Efficiency of 95%-98%
- 1%-1.7% chaff in the product stream
- Production cost estimate of $8,285
- Ease of cleaning needs improvement
- Only moving parts are in the cracker

Lessons Learned

- Organization
- Communication
- Prioritization

Questions?

Acknowledgments

Dan Jolliff - US Roaster Corp

Mr. Wayne Kiner

McElroy Mfg.

Dr. Paul Weckler

Dr. Tim Bowser

Dr. Carol Jones

Dr. Niels Maness

Joseph Barnes, Ben Jenkins, Montana Wells

TRIAD
ENTERPRISES

Mission Statement

"Partnering with others to help them reach their goal"

Who we are

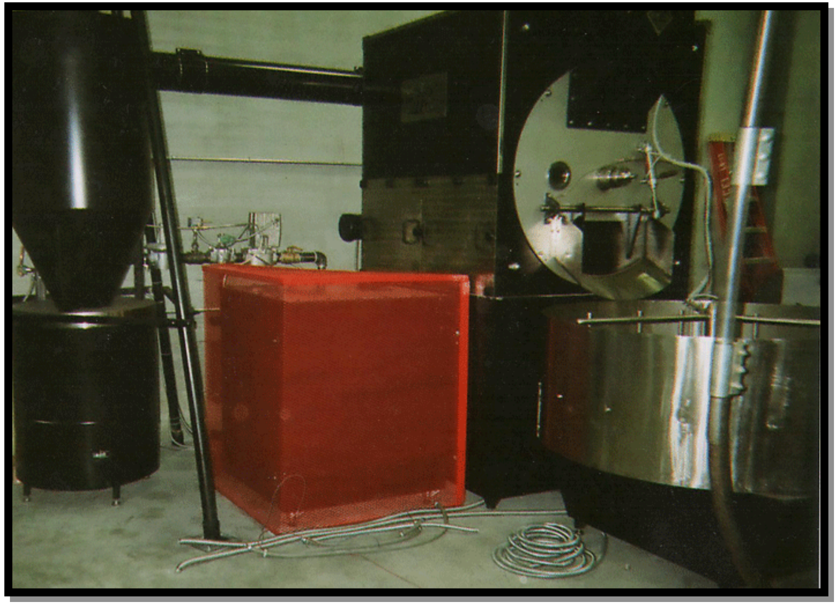
Triad Enterprises is small local firm supplying various services including, but not limited to, engineering consultation and small scale manufacturing.

Background

- Located in Oklahoma City, OK
- Founded by Dan Jolliff
- Has served the roasting industry for over 33 years
- Specializes in new roaster fabrication and rebuilding older roasters
- Provides wide range of roasters, from 3 oz to 300 kg

US Roaster Corp

A few examples of US Roaster Corp coffee roasters

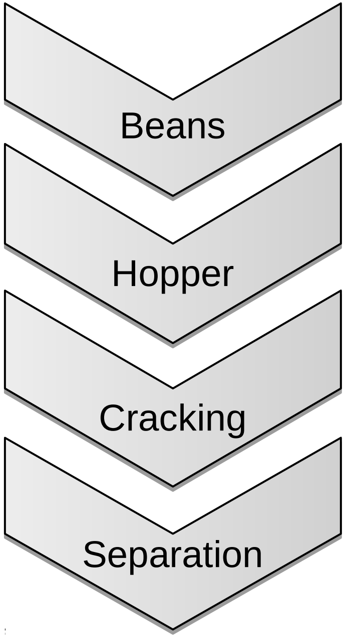


Problem Statement

Triad Enterprises will be designing, building and testing a cocoa bean winnower that meets the following specifications:

- Affordable for bean-to-bar chocolate producers
- Able to fabricate winnower at US Roaster Corp facilities
- Incorporates competitive features
  - Unsupervised operation
  - Easily adjustable
  - PLC interface*

General Overview of Project



Researched the physical properties of cocoa beans

Design of hoppers based on physical properties of cocoa beans

Design of cracking methods based on physical properties of cocoa beans

Design of separation methods for nibs and hulls

What is a winnower?

- A winnower is any apparatus that separates out the undesired portion from the desired portion of a material

Cocoa beans

Crushed cocoa beans

Cocoa nibs

Cocoa hulls

Why is winnowing important?

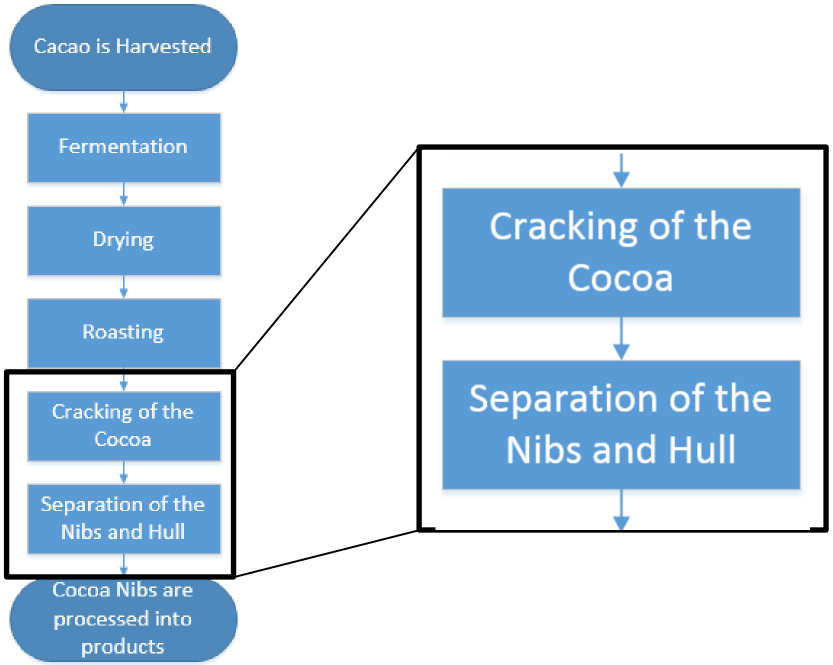
- A cocoa bean winnower is essential to:
  - Separate hull from inner portion, called the nib, before processing
  - Hull is bitter and too much will ruin final product
    - Industry standard is <2% hull left in nibs
  - Hull contains heavy metals, pesticides, and mycotoxins (1)(2)

(1) http://www.sciencedirect.com/science/article/pii/S0168160508002225
(2) https://www.sciencenews.org/blog/food-thought/leaden-chocolates

Engineering Specifications

- Winnow at a rate of 100 lbs/hr
- Winnow at an efficiency >95%
- Not allow greater than 2% shell in the final nib output
- Retail price near $3000
- Be powered by either 120V or 240V AC
- Not exceed 90 dB of sound
- *minimize moving parts (simplify), cleanibility, aesthetics, stainless steel frame, division of work

Overview of Cocoa Bean Process up to Winnowing



There are two key steps to winnowing

- The cracking of the bean
- The separation of the hull and nib

The variability of cocoa beans depends on previous processes

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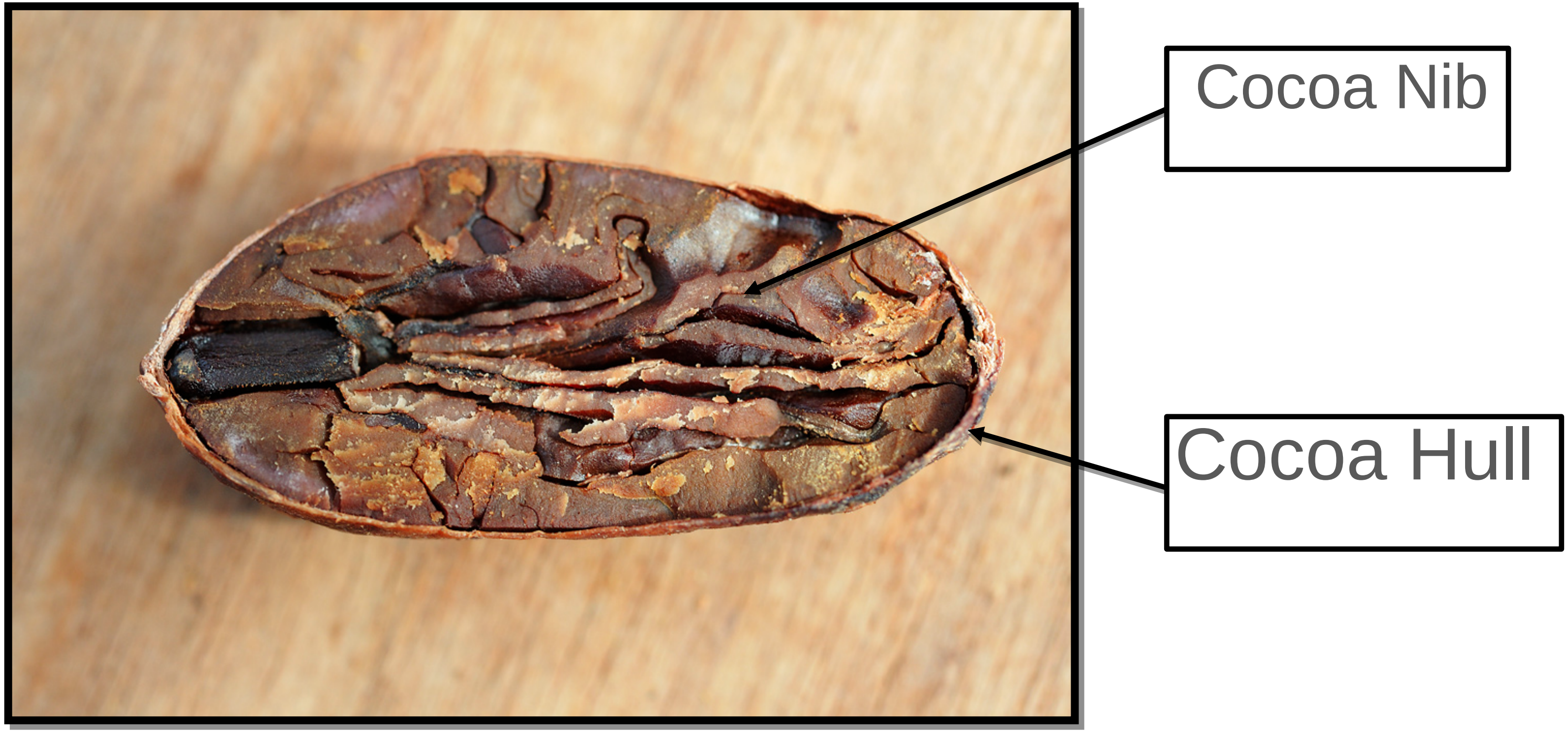


Physical Properties of Cocoa Beans

Three Main Varieties of Cacao:

Criollo

- Considered to be high quality & only used in luxury chocolates
- Consists of around 3% of the global consumption of cocoa

Forastero

- Used in most bulk chocolate operations
- Consists of around 85% of the global consumption of cocoa

Trinitario

- Is a hybrid of Criollo & Forastero beans
- Consists of around 12% of the global consumption of cocoa

Physical Properties of Cocoa Beans

The Fermentation & Drying Process

Fermentation

- Critical for the development of the flavors of cocoa
- The fermentation process depends on the bean type

Drying

- Necessary to prevent microbial spoilage
- Bulk of the moisture of the bean is removed

Physical Properties of Cocoa Beans

Moisture Content Before Roasting

- 18-22%
- Varies depending on fermentation and drying processes

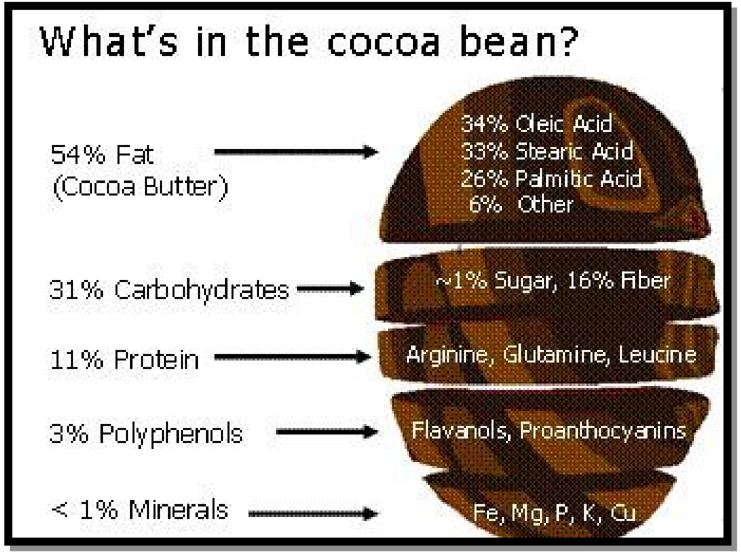
Moisture Content After Roasting

- 6-8%

Physical Properties of Cocoa Beans

Physical Properties of Cocoa Beans	
Sample Size	122
Average Weight (g)	1.19
Max Weight (g)	2
Min. Weight (g)	0.5
Average Sphericity	0.61
Max Diameter (mm)	28.97
Min Diameter (mm)	5.01

Physical Properties of Cocoa Beans



Fat content could affect the process:

- Crushing could press fats out of the nib
- Fat residues may accumlate on the machinery
- Increases biological hazard

Physical Properties of Cocoa Beans

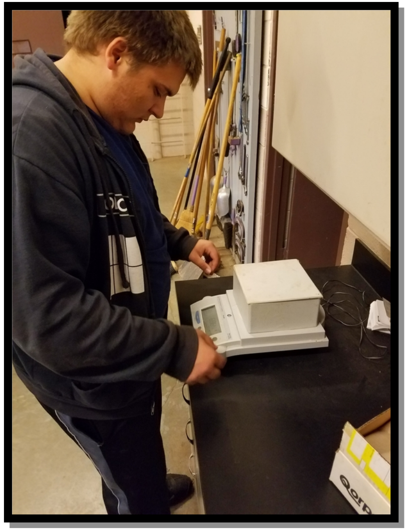
Comparison of roasted coffee and cocoa

Coffee	**Cocoa**
Fat Content: 10%	Fat Content: 54%
Hull Type*: Similar to parchment	Hull Type: Thin & brittle

Freshman Group 1

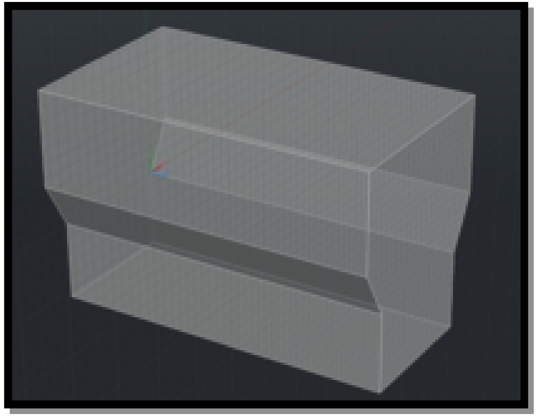
- Tasked with determining viable air velocity range to separate hull from nib
- Utilized air velocity separator in BAE lab to determine range





Freshman Group 2

- Tasked with designing hopper that meets specifications:
  - Must hold 100 lbs of roasted cocoa beans
  - Must determine appropriate foodgrade material
  - Must not exceed loading height of 5 ft
- Make a model of hopper utilizing CAD software
- Contact material suppliers and determine price of the hopper



Freshman Group 2

- Group determined that rectangular hopper would have the least surface area
- The two materials that they looked at for the design are stainless steel & aluminum
- Stainless steel was $118.40 for a sheet, and aluminum is $40.96 per sheet.

Rectangle				
Height	Width	Length	Volume	Surface Area
1.02	1.70	1.80	3.12	13.26
1.01	1.90	1.60	3.08	13.17
0.98	1.40	2.10	2.88	12.74
1.03	2.20	1.40	3.16	13.55

Cone			
Radius	Height	Volume	Surface Area
1.20	2.40	3.01	14.63
1.10	2.60	2.99	13.55
1.00	2.90	3.04	12.77
0.90	3.10	2.92	11.67

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Technical Analysis-Winnowers in the Industry

Vortex Winnower by Brooklyn Cocoa

- 88 lbs/hr
- Nib loss = 0.25%
- Shell content in nibs = 0.20%
- $34,000

Aether Winnower

- 70-80 lbs/hr
- Nib loss = 0.5%
- Shell content in nibs = 0.5%
- $1,800*

*Price does not include Champion Juicer or Shop Vac. Also, blades and housing must be replaced regularly at a cost of ~$1800/yr

Technical Analysis-Winnowers in the Industry

Pros: Vortex Winnower

- Aesthetically pleasing
- Sorts hulls and nibs well

Cons: Vortex Winnower

- High upfront cost
- Requires external vacuum
- Requires cocoa beans to be pre-cracked

Technical Analysis-Winnowers in the Industry

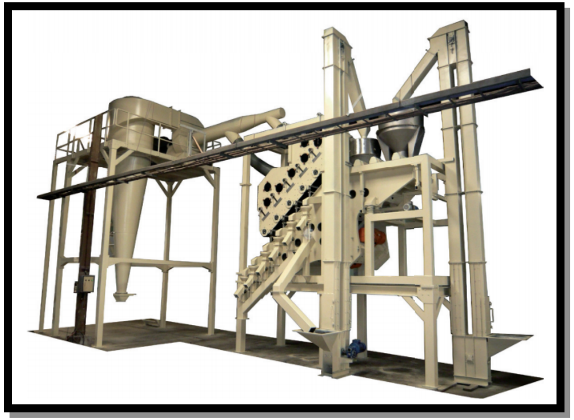
Pros: Aether Winnower

- Lower upfront cost
- Compact

Cons: Aether Winnower

- Continual costs from blade and housing ($1800/year)
- Requires external vacuum

Technical Analysis-Winnowers in the Industry



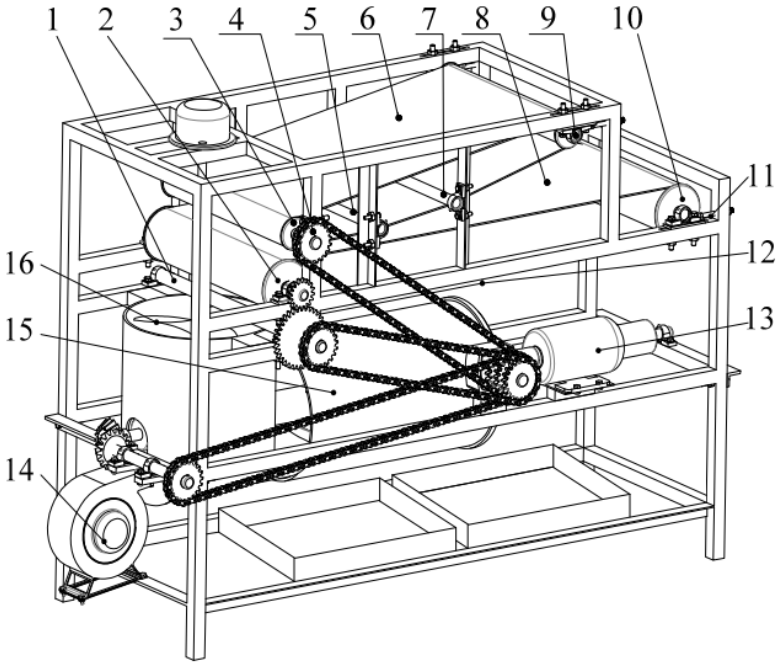
Bear Winnower Type BWI

- 1100-6600 lbs/hr
- Nib content in shells = 0.25%
- Shell content in nibs = 1.75%

Delani CAC-101-WIN

- 441 lbs/hr
- Weight = 231.5 lbs
- Shell content in nibs = 1%

Technical Analysis-Technical Literature

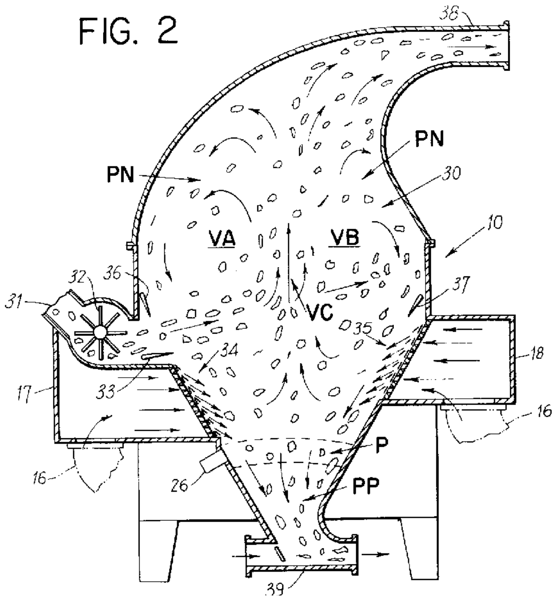


Semi-Theoretical Analyses on Mechanical Performance of Flexible-Belt Shearing Extrusion Walnut Shell Crushing

- Paper analyzes specific walnut cracking process
- Uses belts and rollers to shear the walnuts enough to crack the shell but protect the walnut meat
- Process could be modified to better suit cocoa bean winnowing

Technical Analysis-Applicable Patents

FIG. 2

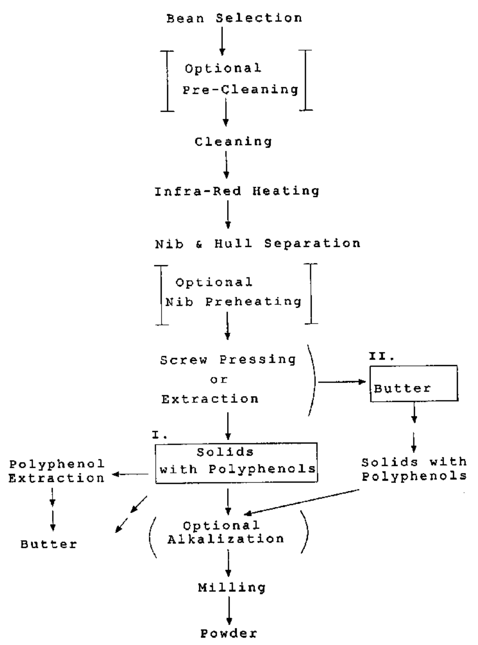


Method and apparatus for separating lighter and heavier portions of threshed tobacco

- Separates by creating two adjacent vortices that circulate in opposing directions
- Turbulence causes separation by combining to form a rising column of high-velocity air
- Lighter portions rise while heavier portions drop down
- Could use a similar approach to separate lighter hulls from heavier nibs

Technical Analysis-Applicable Patents

U.S. Patent Jan. 18, 2000 Sheet 2 of 5 6,015,913



Method for producing fat and/or solids from cocoa beans

- Goes deeper into the cocoa manufacturing process than project requires
- Discusses a method of processing cocoa beans for producing solids from fat-containing products
- Discusses cocoa bean process as a whole, helpful to keep whole process in mind
- Includes parts of winnowing process

Technical Analysis-Technical Literature

Chocolate Alchemy Winnowing Forums

- Online database of everything related to the chocolate making process
- 39 different forums related to cracking and winnowing process
- Knowledge and experience will be of assistance throughout the project

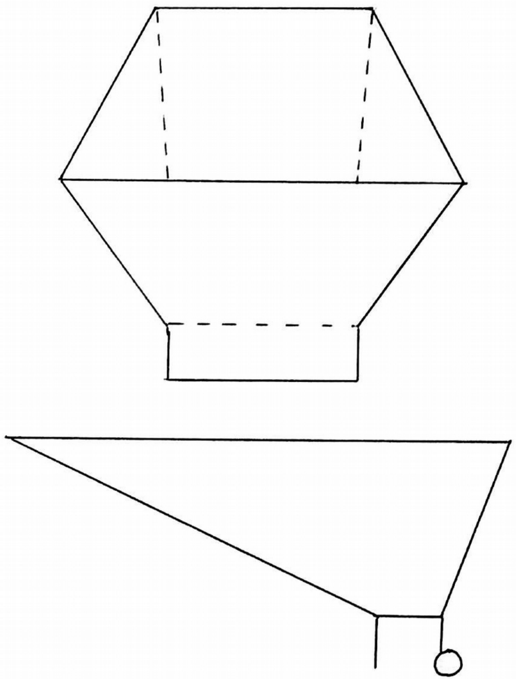
Visit to Izard Chocolate

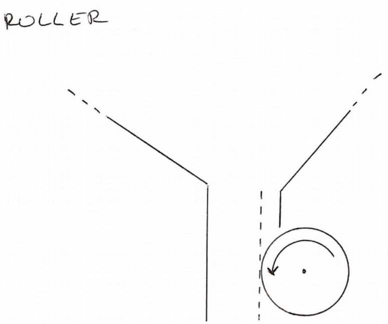
- Bean-to-bar chocolate company in Little Rock, AR
- Founded in 2014
- Introduced us to chocolate process and issues related to current winnower

Completed Testing

- Impact testing
  - Made an apparatus to test effectiveness of impact on cocoa beans under various conditions
  - Used dry cocoa beans, wet cocoa beans, dry cocoa beans frozen in liquid nitrogen, and wet cocoa beans frozen in liquid nitrogen
  - Determined that freezing made little effect on final particle size after impacting
  - Determined that cocoa beans become soaked rapidly, no matter how long they are left in water

Conceptual Designs-Hopper Feed





- We anticipate clogging at the base of the hopper, as observed during our visit to Izzard Chocolate, so a simple roller to agitate the clogged area was conceived

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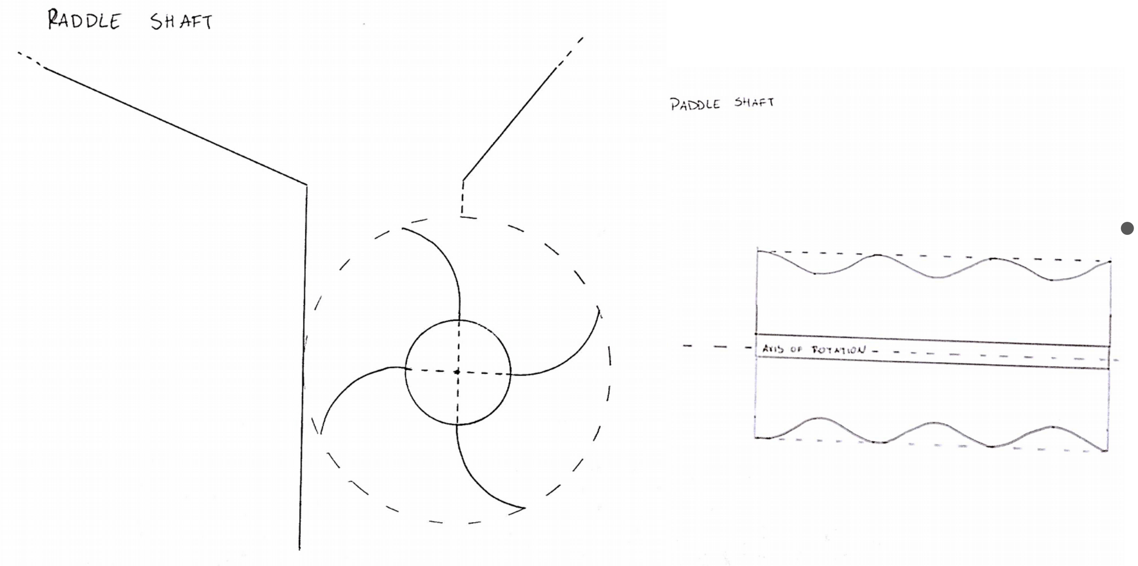
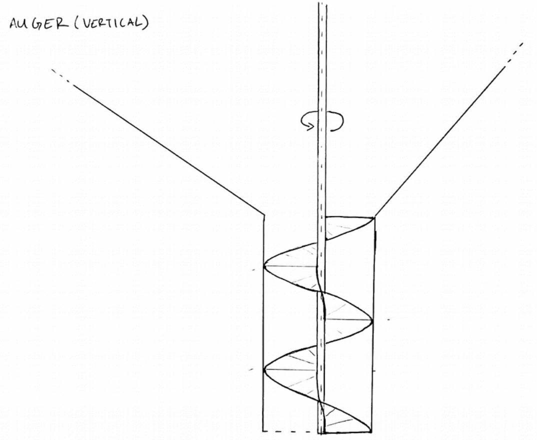
Conceptual Designs-Hopper Feed

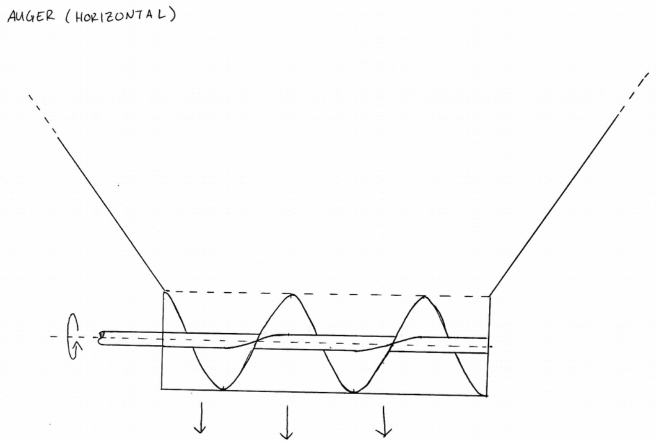


- Concern of the bean’s tendency to slide on the simple roller led us to rethink the base of the hopper
- A paddled wheel was conceived that would no only prevent clogging of the beans, but also allow adjustable and predictable delivery rate of the beans from the hopper

Conceptual Designs-Hopper Feed

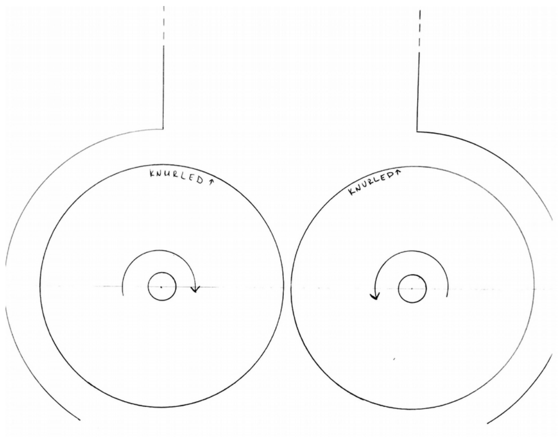
- A more common and possibly cheaper method is an auger, typically vertical in orientation
- A horizontal orientation would not only be easier to drive, but help keep overall height to a minimum

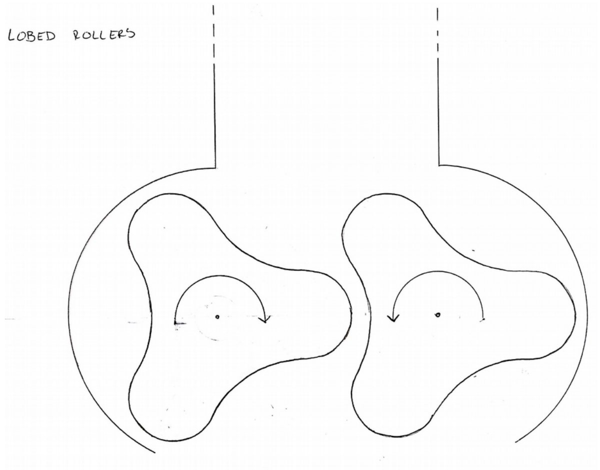




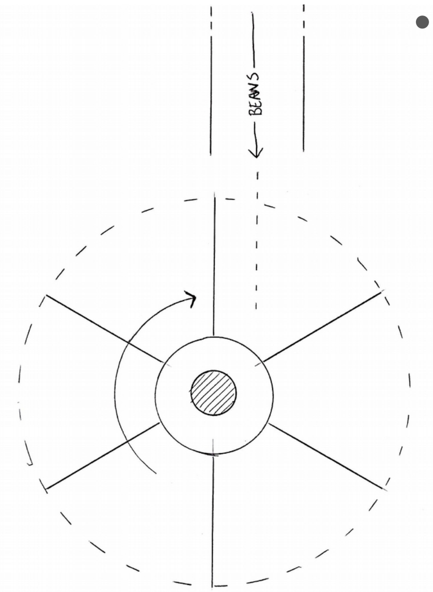
Conceptual Design-Cracking

- Much like US Roaster Corp's roller grinders, this would be a simple and achievable design
- To mitigate the beans from not passing through the round rollers, lobed rollers were thought of as an alternative

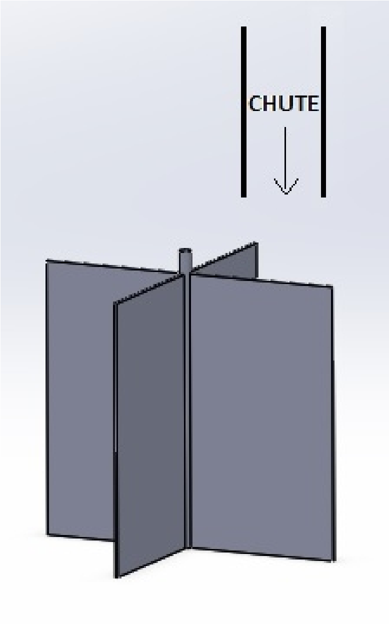




Conceptual Design-Cracking



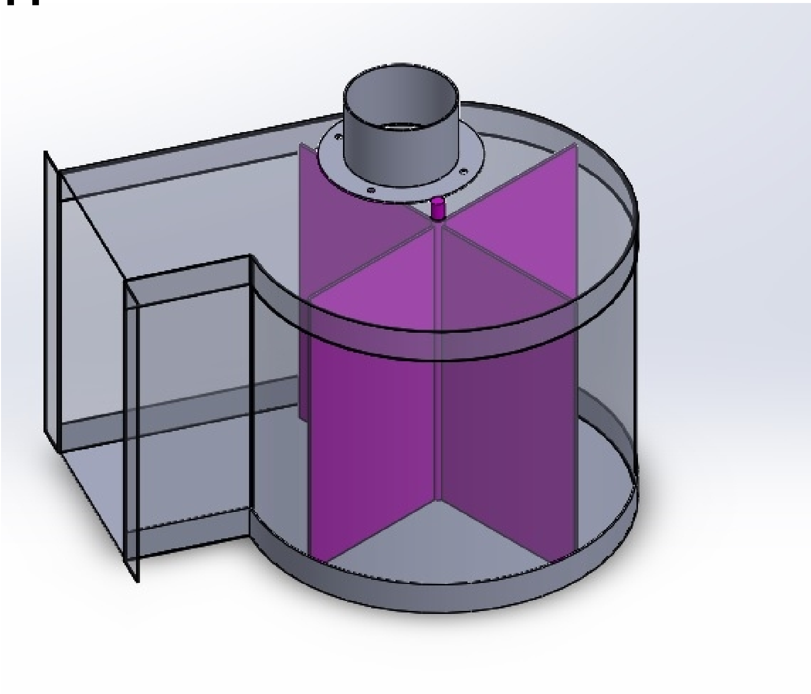
- Upon observation, quick impact was seen as an effective way of cracking the beans, which would also be independent of individual bean size



- To ensure consistent contact velocity, it was thought to feed the beans down in parallel with the rotating axis

High Risk Suggested Design

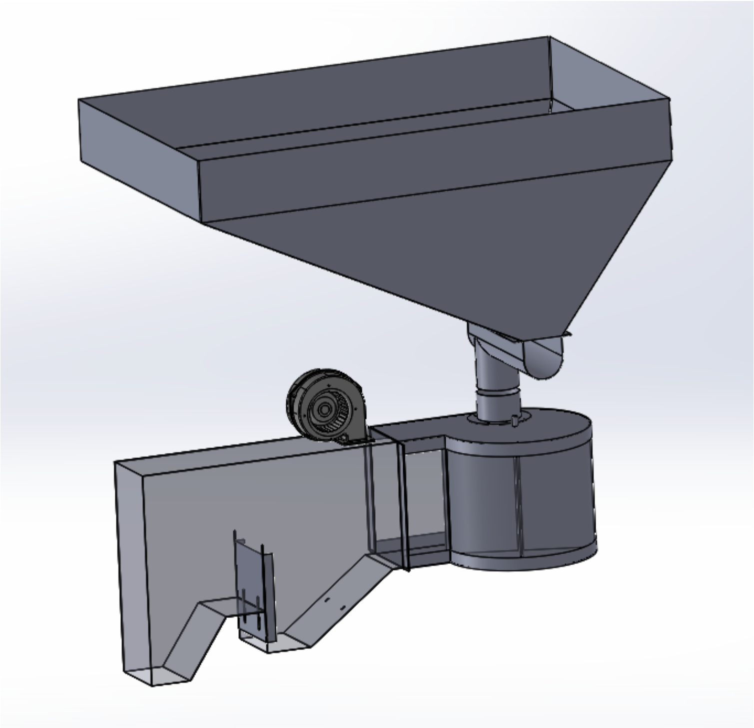
- The main cracking method is impact with the paddles on a wheel traveling with high angular velocity



High Risk Suggested Design

Pros

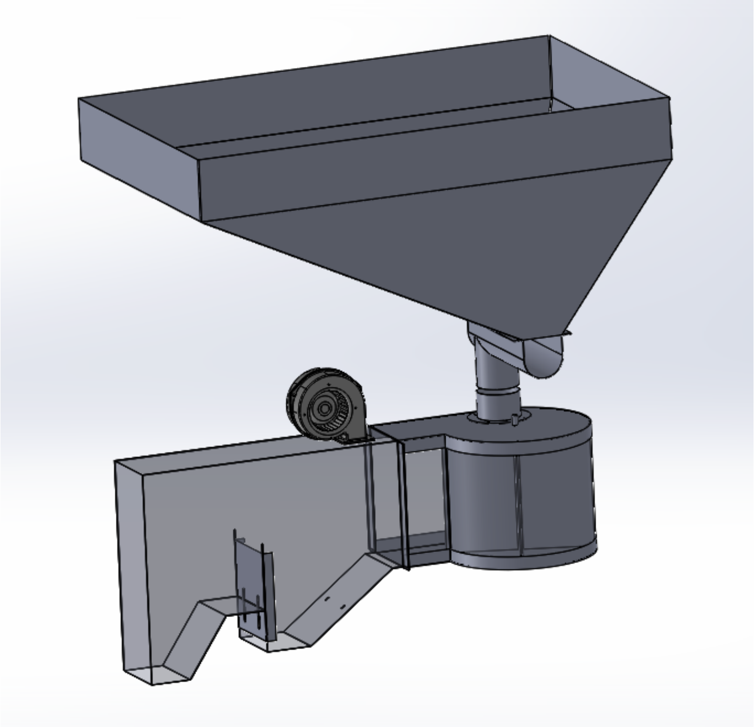
- Indiscriminant of bean size
- Velocity adjustable to vary impact force
- Simple design and construction



High Risk Suggested Design

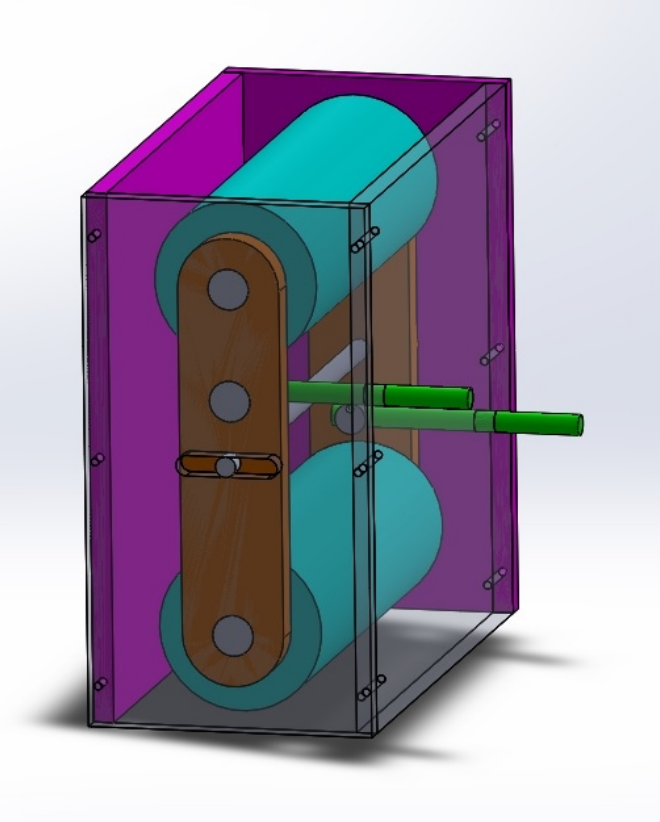
Cons

- Un-proven design
- Loss of contact with bean
- Requires metered feed



Low Risk Suggested Design

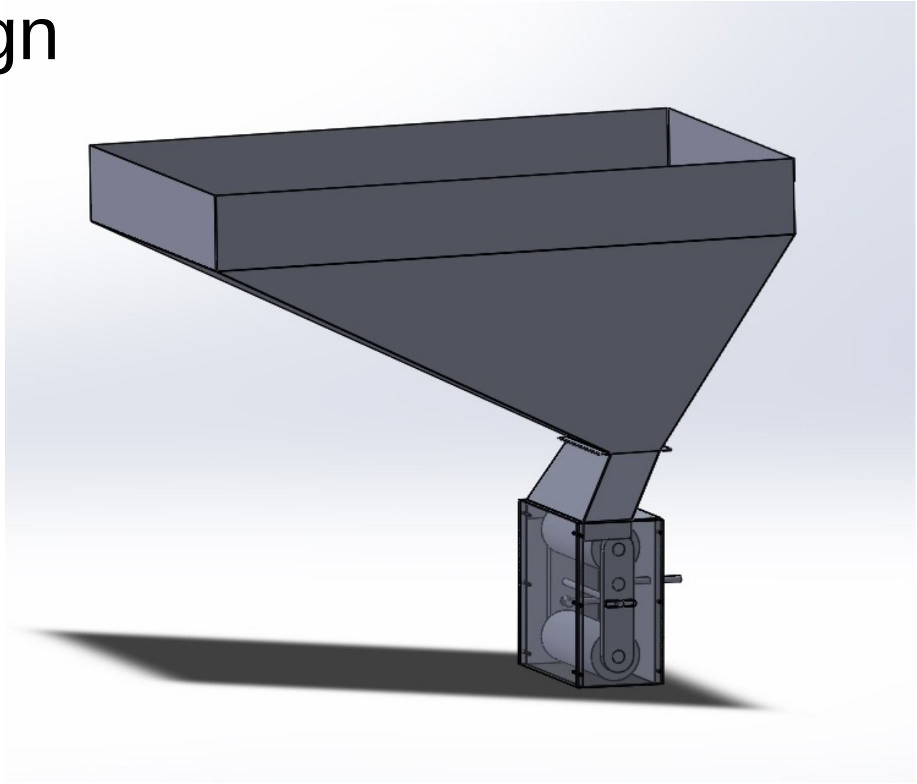
- Conceptually common design utilizing a two stage roller-cracker design which standardizes the crushed bean size



Low Risk Suggested Design

Pros

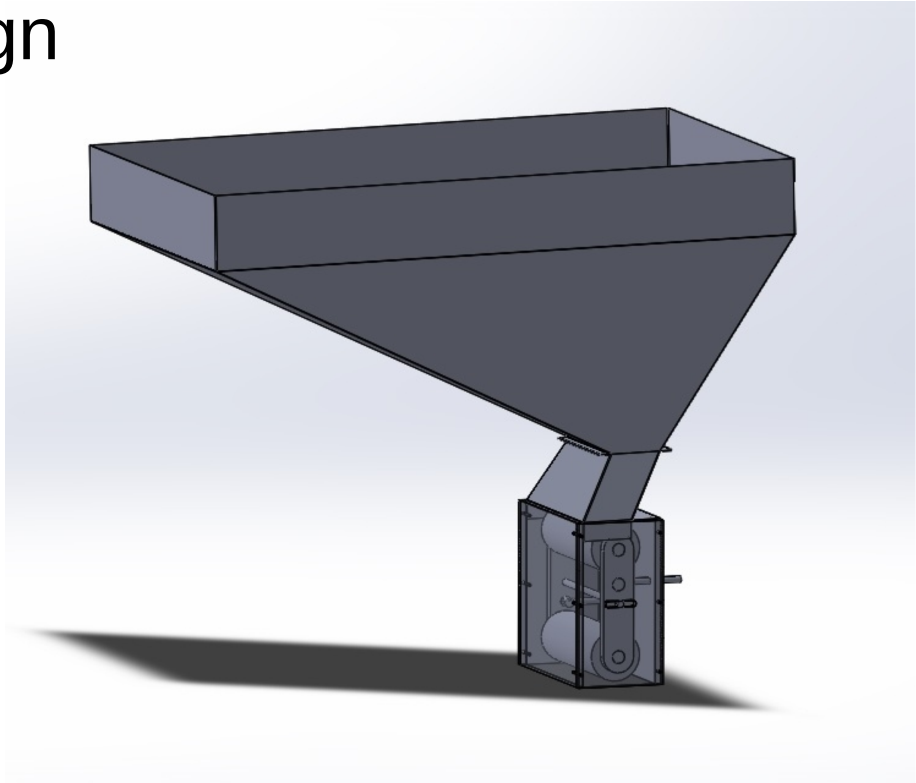
- Robust and adjustable
- Guarantees beans that have passed will be cracked/crushed
- Self-metering flow of beans



Low Risk Suggested Design

Cons

- Tolerance and part intensive
- Potentially less differentiable qualities between nib and hull
- Finer particles will require a more thorough separation process



Materials for Suggested Design

Part	Material
Hopper	Stainless Steel
Impact Wheel	Stainless Steel
Rollers	Hardened Steel
	Delrin
	Knurled Stainless
Support Frame	Mild Steel
Sieves	Stainless Steel
Drive belt(s)	Urethane
Separation Chutes	Stainless Steel

Spring Semester Testing

- Test velocity range and efficiency of impact cracking
- Effectiveness and speed of hopper auger
- Air sort implementation and design
- Sieving sizes and effectiveness/need

Spring Semester Plan of Action

1. Complete Testing for Conceptual Designs
2. Finalize Cracking Design
3. Finalize Separation Design
4. Fabricate a Prototype
5. Troubleshoot Prototype

Spring Semester

- January 27th – Complete testing on conceptual cocoa bean cracking methods
- February 3rd – Complete testing on conceptual nib sorting methods
- February 10th – Complete control systems design
- February 17th – Complete power/utility requirements for winnower design

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Spring Semester

- February 22nd – Complete expected prototype cost analysis
- *March 1st – Finalize winnower design and receive client approval
- *March 8th – Draft all necessary parts diagrams
- *March 10th – Order all necessary materials and components for prototype

*a month too late

Spring Semester

- March 13th-17th – Spring Break
- March 20th – Begin fabrication/assembly of prototype
- March 31st – Complete prototype assembly
- April 12th – Complete prototype troubleshooting

Spring Semester

- April 19th – Complete spring final report draft
- May 3rd – Complete final presentation
- May 1st – Complete final spring design report
- May 5th – Final Senior design presentation

Questions?