Maize Mill Project Final Design Review

ME 430

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Executive Summary

Engineers Without Borders (EWB) has worked on several projects to help developing communities around the world build the infrastructure necessary for modern life. One of their projects is the creation of an inexpensive and easily manufactured maize mill that communities in Africa (mainly Malawi) can use to grind corn and make their main food source, Nsima. Geoffery Wheeler, an accomplished engineer and former mentor to EWB's Malawi team, wants an inexpensive, easily manufacturable and effective maize mill that can be fabricated and sustained in Africa.

This report describes the process in which the Maize Mill Senior Project team created the Maize Mill design and prototype. This report is written in a way that the reader will see the steps taken to complete the senior project. Included are the background research done on different types of mills, the ideation sessions, design selection, analysis techniques, design calculations, drawings, prototype manufacturing and testing.

Ultimately the testing of the finished prototype indicated that the design must be altered in order for the Maize Mill to operate under the desired specifications. This design iteration will hopefully be carried out by Cal Poly's Engineers Without Borders organization or future senior project groups.

Chapter 1

Introduction

The people of Malawi go through many struggles just to create maize flour for their famous nsima. The scope of the Maize Mill senior project is to provide an alternative to the current mill, which is hours away, and provide Malawi with a sustainable replacement. Our project will work with the Power Transmission senior project team, whose main objective is to transmit bicycle input power to shaft output power. Together, both of the project teams will provide Malawi with an alternative milling method.

Geoffery Wheeler, an experienced Mechanical Engineer, and an Engineers Without Borders (EWB) team have been attempting to develop a solution for the past few years. With guidance from their experiences, the Maize Mill project team will provide Malawi with a sustainable, reliable, sanitary and easy-to-use mill that can be operated and powered by one person.

Chapter 2

Background

I. Engineering Without Borders

Malawi is a developing country located in South East Africa with a population size of roughly 18 million people. Currently, malnutrition is the 10th leading cause of death there. To help address this issue, Engineers Without Borders (EWB) has traveled to villages in Malawi to observe their lives and learn about their needs so they can improve their way of life as much as possible. Through observation, the EWB team learned that one of their primary sources of food is a maize flour pancake called "nsima" [1]. However, the process of making the maize flour itself is currently a very time-consuming process. Villagers carry roughly 20 kg of maize kernels on a three-hour walk to an electric-powered maize mill. Additionally, the electricity for the mill comes from a hydroelectric power plant. Due to the drought and the present state of the economy in Malawi, electricity cannot be relied upon to consistently power the mill.

To address this issue, EWB has tried to develop a human-powered maize mill that they can put into the village, so that the villagers would not have to travel as far or worry about electricity. EWB has currently tried two designs: a plate mill that feeds the maize between two spinning grinding plates and a multi-stage roller mill that feeds the maize between two metal rolling cylinders that would crush the maize. Both designs did not grind the maize into flour that is fine enough or meet the yield expectations of a maize mill.

II. Benchmarking

There are many mill designs in which human power input is optimized to produce relatively fast wheat grain grinding speeds. Since wheat grain is not the main food source of Malawi, the time differences between grinding wheat grain and grinding maize kernels must be taken into account. The current method used in Malawi is passing soaked maize kernels through an electric hammer mill. Since our project has a power input much smaller than the electric mill, different methods of preparing the maize are being considered: dried maize and water-soaked maize. These different methods would potentially reduce the power needed to crush the maize into flour, but they could also cause new problems: jamming, variable consistencies, and producing only pressed flour. All three of the methods of preparing maize (dried, undried, and water soaked) will be taken into account when testing our prototype.

Grinding maize is nothing new, many different methods have been tested and used throughout the world. Each method has its own take on creating crushed maize either for cornmeal or flour. Some methods commonly used are the Metate y Mano, the hammer mill, and the Chard #140 burr plate.

The Metate y Mano is old technology involving a stone roller and stone plate. Figure 1 shows the typical setup for this method. This design is highly efficient but labor intensive method of crushing maize. Crushing is from the constant pressure of the roller stone atop of the stone plate [2]. A more current adaptation of this design is the roller mills used by the EWB team in Malawi shown in Figure 2. The EWB Malawi team has worked on the roller mill design creating a multi-stage milling process which

crushes maize into flour using rollers ranging from smooth to rough textures. The use of small input power is the main reason EWB decided to create a multi-stage system with interchangeable rollers [1]. The pros of using a roller mill design will be simplicity of design and easily found materials. The cons with this design would be high tolerances, lower rotation speeds, and high amounts of torque.

Figure 1. The Metate y Mano from Gourmetsleuth [2].

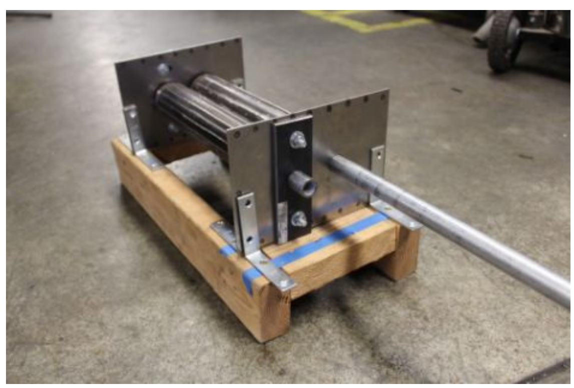


Figure 2. EWB roller mill design [1].

The hammer mill is a large scale mill with a large power input. The mill can achieve high grinding rates at high power inputs. This milling process is the current method of grinding maize used in Malawi. The crushing method behind the hammer mill is multiple breaker bars attached to a rotor above a mesh screen as seen in Figure 3. The design also uses a fan in order to keep flour particles flying in the housing reducing the chances of clogging the mesh screen. Figure 3 shows a typical design of a hammer mill. The specific mill used in Malawi runs off of a 20 horse power (hp) motor powered by a hydro-electric generator. The pros of this design would be high grinding rate and the abundant amount of benchmarking backing the design. The cons of the design is the large amount of power needed to effectively run the machine and also the high amounts of manufacturing required.

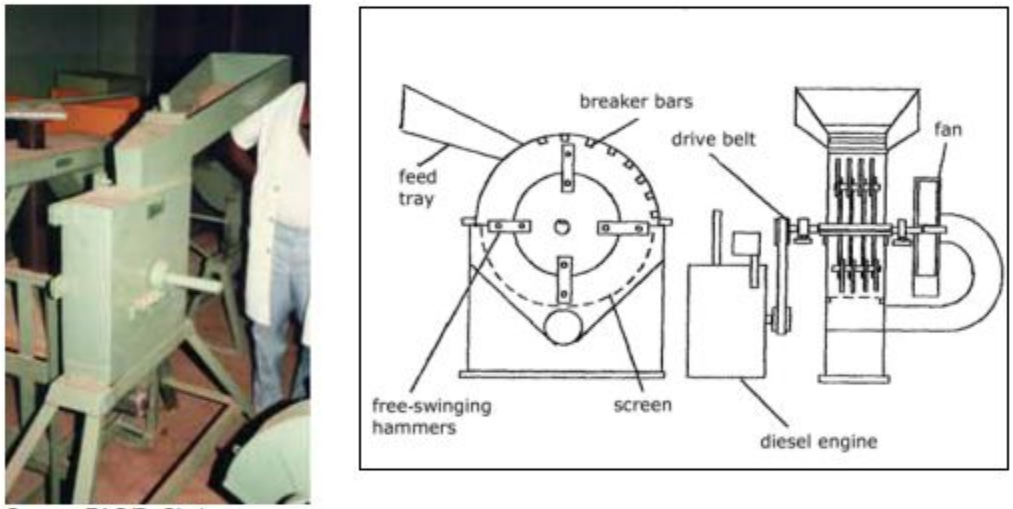


Figure 3. Hammer mill design presented by Agricultural and Food Engineering Working Document [3].

The final example is the simple Chard #150 Table Clamp Grain Mill [4], seen below in Figure 4, or the Grain Maker [14] which both basically consist of a casted frame, steel hopper, casted burr plates and worm gear, and a casted hand crank. This hand operated maize grinder is a cheap and easy way to grind maize into either flour or cornmeal, the differences between the Chard and Grain Marker hand mills are the appearance and materials used when building them. The cast iron frame and parts as well as the use of stainless steel combine for a durable design. The grinding mechanism in this design is the burr plate seen in Figure 5. Burr plates are circular disks with radial burrs machined into them at an angle with the mating burr plate having the burrs machined at an opposite angle. This method also uses a worm gear (auger) to initially crack the maize and transfer it to the burr plates [5]. The pros of the design would be the simplicity of manufacturing, and the lower power needed to run it. The cons would be analysis on the burr plate and the adaptation to different forms of operation (bicycle, hand power, etc.).

Figure 4. The Chard #150 off-the-shelf product [4].

Figure 5. Commonly used burr plates [13].

These grinding methods were chosen in order to showcase the various ways to grind maize into flour. The hammer mill, which is already used in Malawi for the purpose of grinding maize, requires a power input much higher than can be provided using any forms of human power. From the article Small Mills in Africa, by the Agricultural and Food Engineering Work Document [3] it is seen that the power input for a typical hammer mill ranges between 2 and 50 kiloWatts. This needed power is much greater than the max power available: 150 Watts. Designs as the burr and roller seem to be the best suited for our project, due to their lower power needed for effective operation. The only downsides to these designs are the complex and precise machining it takes to make them fully-functioning mills.

III. Objectives

The main source of food for a village in Malawi, Africa is a maize flour pancake called nsima. Currently, maize is ground into flour using a distant, unreliable, electric powered maize mill. The goal of our project is to create a reliable, sanitary, and easy to manufacture maize mill that can be operated with the power output capable of an adult individual.

We have established several objectives and specifications from our understanding of the problem presented to us. These specifications will work as goals throughout our project and will guide the design of our maize mill. The mapping and importance ranking of theses specifications can be found in the Quality Function Deployment, QFD, (Appendix A) and the Specification Table below (Table 1). The Quality Function Deployment table is a method of indicating the manners in which our different specifications influence one another, as well as their relative importance. The QFD also provides information on how competitor solutions align with our project's requirements and specifications. Our QFD takes the customer requirements gained from either the sponsor or the problem statement and checks their connection towards any technical specifications we add to the final product. The QFD also accounts for technical specifications that supplement or contradict each other, an example is seen with achieving a small grain size and the total cost. Trying to achieve a high grinding rate may entail larger burrs and auger causing the total cost to increase. Multiple products are also compared with our customer requirements and technical specifications in order to rank how each benchmarked product fits into our project. The

Specification Table, Table 1, lists each of the specifications and demonstrates their risk (capability to make or break the project) as well as how we intend to test for their qualification. Table 1 below shows the numerical values associated with each technical specification as well as a tolerance, risk, and compliance. Tolerance is given as either max or min meaning that either the specified value is a minimum or maximum requirement, as power is expected to reach a maximum of 150 Watts. Risk is ranked as either High, Medium, or Low entailing how important each specification is to completing the project. An example is if the product can not run off the specified power then the project has a High probability of failing. The compliance is used show how each specification will be checked later in the project, either with Testing (T), Analysis (A), or Similarity (S).

Table 1. Engineering Specifications for the Malawi Maize Mill.

Spec. #	Parameter Description	Requirement or Target (units)	Tolerance	Risk	Compliance
1	Power	150 (Watts)	Max	M	A,T
2	Grinding Rate	15 kg/ hr	Min	H	T
3	Production Cost	$300	Max	H	A
4	Sanitation	0 kg of metal bits	Max	M	T
5	Fineness	#50 mesh	Max	L	T
6	Yield	80% fine flour by mass	Min	H	T

i. Power

This specification comes from the power output capability of both adult men and women of Malawi. With collaboration with the Malawi Power Transmissions project group it was decided that 150 Watts would be the maximum expected power produced by one person. It is important to note that the power input to our mill is ultimately decided by the Power Transmission team and that they specified 150 W as their minimum operating power. This power specification is validated by several online articles, including a blog on mapawatt.com [5] that claims “the best human efforts at producing power over the course of an hour on a bicycle are around 300-400 Watts.” Additionally, the Wikipedia page for “Bicycle Performance” [6] indicates that “maximum power levels during a one hour range from about 250 W (‘healthy men’) to 500 W (‘exceptionally athletic men’).” A minimum operating power of 150 W seems appropriate due to the requirement for the mill to be operable by both men and women.

ii. Grinding Rate

The community members of Kumpanda currently travel several kilometers each way to an electric maize mill while carrying approximately 20 kg of maize kernels in order to make their flour. We would like for our maize mill to be a more time-efficient solution to making flour. This means that our grinding rate should be high enough to completely grind 20 kg of maize within the time period that it would take to alternatively bike to and from the electric maize mill. Assuming the current method has a travel time of at least 1.5 hours of travel and 30 minutes of grinding, our maize mill should comparably be

able to grind 20 kg in two hours or less. This is appropriate since operating the maize mill for longer than two hours would be fairly exhausting for the operator. The International Labor Organization [12] describes hand-operated grinders, claiming that “Available equipment allows production rates ranging from 7 kg to 30 kg per hour.” Assuming that this claim is true, we should easily be able to exceed 20 kg in two hours. A conflicting paper, Small Mills in Africa by the Agriculture and Food Engineering Organization of the United Nations, claims that “As a rule of thumb, about one kW can mill 25–30 kg of produce per hour.” Proportionally, our 150 W could mill approximately 4.5 kg/hr. We have specified our grinding rate as at least 15 kg/hr as a result of these two conflicting authorities.

iii. Cost

As defined by our sponsor, our maize mill should not cost more than $300 for parts and manufacturing. Note that this is not a project budget but rather a target price for the end product. Popular human-powered grain and maize mills can range anywhere from $21 (Chard GM-150) [4] to $675 (Grain Maker Model No. 99) [14]. $300 is a good target when taking into account that we are not producing our mill on a large scale. This will be treated as a maximum cost; however, our final design may be less expensive.

iv. Sanitation

All flour must be edible after milling. This mostly concerns metal bits that may shear off into the flour during grinding but also encompasses any other possible health hazards or inherent toxins. Previous iterations used in milling maize have produced small bits of metal in the maize flour from the continuous shearing needed.

v. Fineness

The flour mass produced through the milling process should pass through a number 50 mesh. This designates a maximum discharged particle size of 0.297 mm in diameter to be considered fine flour. This specification was obtained through testing of a current on-the-market hand crank mill and research into maize flour particle size. Progressivedairy.com [10] recommends a mean particle size of “1,500 microns for high-moisture maize compared to 800 microns for dry maize.” This is consistent with the maize flour that we obtained by using an Estrella Crank maize Grain Grinder.

vi. Yield

At least 80% (by mass) of the maize input should pass as fine flour after the milling process. This was dictated to us as a desired goal by our sponsor and would be an improvement on past iterations of this project.

vii. Manufacturing

Our goal is for the maize mill to be built completely in Malawi. All chosen parts and materials should be available in Malawi and any necessary manufacturing and machining should be able to be performed in Malawi. Currently our prototype will be made outside of Malawi, but all chosen parts and processes should follow this standard.

viii. Assembly

We will create a manual that will include instructions for the assembly and use of the maize mill. Without any engineering or machining experience, Malawian villagers should be able to assemble (after manufacturing) and maintain the mill.

ix. Durability

The finalized project must endure harsh conditions and be able to deal with any foreign objects that may be included with the maize. In the harvesting procedure objects such as rocks and nails may pass through visual inspection. The Maize Mill project will need to have a “fail safe” in order to account for any of these objects being present in the grinding process. Creating a maize mill that is able to encounter a foreign object and then stop is the purpose of this specification.

In Figure 4 seen below, the sketch for the entire Malawi senior project is shown. The boundary, indicated by the dashed square, is the scope of our project. All other parts of the sketch outside of that boundary would be in the scope of the second Malawi senior project team, the Power Transmission team. Our project will be to take the output shaft power and convert that into crushing power to produce acceptable maize flour.

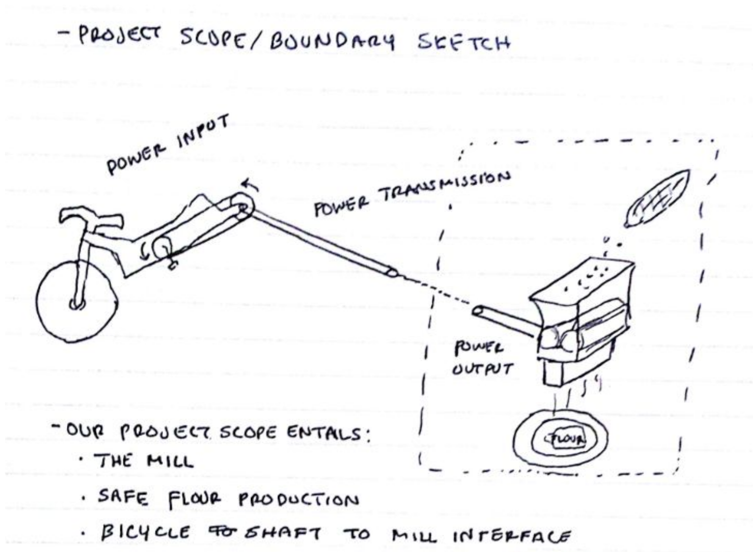


Figure 6. Maize Mill project boundary sketch.

Chapter 3

Design Development

I. Concept Generation

After clearly defining the problem and identifying what is needed from our final product, our team conducted several ideation sessions to come up with different solutions to the problem. The ideation sessions were meant to focus on a single function needed from the product and create multiple solutions. With each function each team member independently brainstormed as many solutions as possible, once done each member's designs were compiled to have a large amount of solutions. These solutions were quickly analyzed on feasibility then modified to make them a bit more applicable, and ideas that were still too abstract were removed. With those solutions we chose the best one and put it through S.C.A.M.P.E.R: substitute, combine, adapt, modify, purpose, eliminate, and rearrange. The S.C.A.M.P.E.R. technique allows for updating and reworking the initial design to improve it. In our maize mill we defined 2 different functions: grinding and safety. Through the ideation and S.C.A.M.P.E.R. sessions we defined five different methods that could be used to grind the maize into flour, also we defined five methods to increase safety. The methods were analyzed using Pugh Matrices shown in Table 2 and Table 3. The Pugh Matrix is a process where each method is evaluated with respect to the technical specifications of the problem. The grinding ideas are described below along with the Grinding Method Pugh Matrix, Table 2.

II. Concept Selection

Below are descriptions of each of the designs used in the Method Pugh Matrix and later in the Decision Matrix. Each method is presented with a short description of how they work as well as a sketch of the method. Each description also includes a discussion on the pros and cons of each method and why those are important to our project. The sketches have also been compiled together in Appendix B.

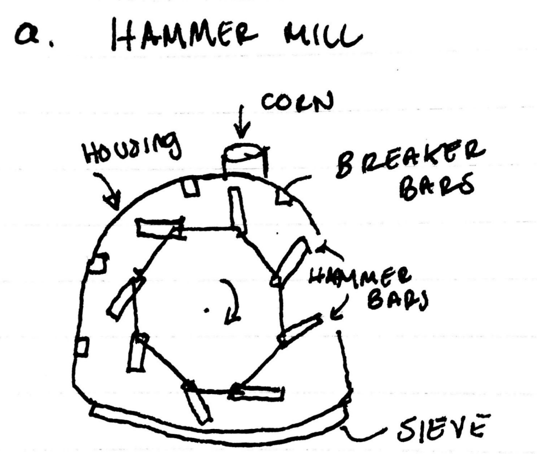


Figure 7. Hammer mill sketch

i. Hammer Mill

This mill is one of the most commonly used mills in the large scale flour production, a typical set-up sketch can be seen above in Figure7. The high flour production usually correlates to a large required power input. From the article Small Scale Mills in Africa, Clarke and Rottger explain that an average hammer mill requires a minimum 2 kiloWatts of power to operate correctly and efficiently [3]. The construction of the hammer mill includes an outer housing, large rotor, and various free swinging bars or “hammers.” The free swinging bars are attached to the outer radius of the rotor and create the large amount of braking force as they contact fixed breaker bars attached to the outer housing. A large fan is usually used to keep crushed maize particles circulating within the housing and also help the sieving process. Some of the pros of having a hammer mill would be the large amount of benchmarking behind it and having the current model in Malawi as a reference. The cons of this mill is the large amount of power required to be effective, the size of the total assembly, and also complications with trying to add a fan into the project. The large amount of information on the hammer mill is intriguing, but trying to make it perform effectively off of the small amount of available power can be very difficult.

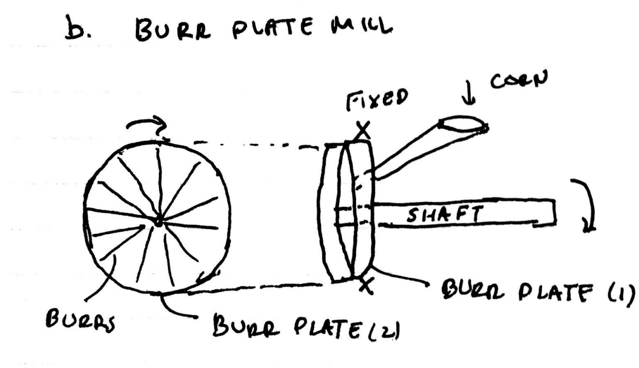


Figure 8. Burr plate mill sketch

ii. Burr Plate Mill

The burr plate mill is one of the most common off the shelf personal mills, a typical burr plate sketch can be seen in Figure 8. The burr design is usually easier to manufacture and requires lower amounts of power to effectively operate it. Clarke and Rottger explain that a typical burr plate mill requires a minimum of 0.5 kiloWatts of power [3]. This is a much lower power requirement compared to the hammer mill. Although it is still greater than the power available many other products have been able to operate a burr plate mill using only human power. The typical burr plate mill construction includes two burr plates, a feeding mechanism to the middle of the burr, and a frame to hold everything together. The burr plate construction is a disk shaped piece of metal with “burrs” cut into one face. The large burrs are responsible for the crushing of the maize while continuous shearing from the smaller burrs take the maize from a large kernel to fine flour. The burr plate also has a lot of benchmarking behind it especially with being operated with only one human's power input. Some other pros are that it can be easily built using cast iron models. Some of the cons are that without casting making the burr plates can be troublesome also most burr plate designs include an auger with adds complexity to the design.

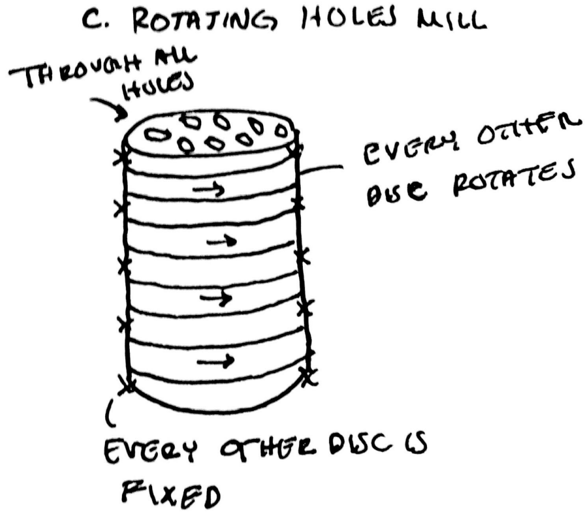


Figure 9. Rotating holes mill sketch

iii. Rotating Holes Mill

The rotating holes mill is the only idea that has not been previously used to make maize flour, a sketch of the set-up is seen in Figure 9. Our rotating holes method did not appear when researching different types of maize milling. The design consists of multiple plates of various thicknesses with holes drilled through them stacked atop of each other. The main grinding force is the interface between the plates which act as shearing points for any maize that passes through them. The varying thicknesses will account for the particle size reduction as maize progresses through the mill. Without any records of previous models used in the working world, or even the internet, no comparison of required power can be made. Some of the pros of this design are that machining is not too difficult and the overall design is simple, while some of the cons are that tolerances may need to be very high in order to keep ground maize out from in between the discs and also because there are no forms of benchmarking to help guide our decisions.

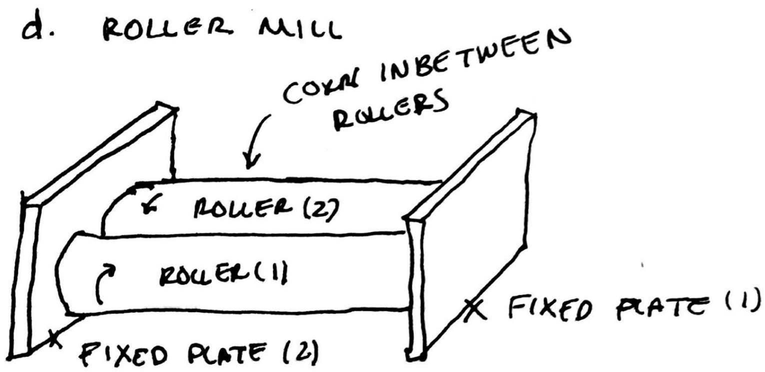


Figure 10. Roller mill sketch

iv. Roller Mill

The roller mill is the primary design that the Cal Poly Engineering Without Borders Malawi team has utilized. A preliminary sketch is seen above in Figure 10. The roller mill has been able to achieve full functionality with the specified human bicycle power input. The typical design of the roller mill includes a strong rigid frame and two large rollers. The rollers are run at lower speeds in order to produce enough force, which is used crush the maize directly from large kernels to flour. High pressure between the two rollers is the main force used in crushing the maize. The pros of this design is that maize can be ground up will low RPM and high torque and that design does not need extensive machining. Extensive pressure exerted from the maize can, over time, warp the shape of the rollers. This con is related to the lifetime of the design.

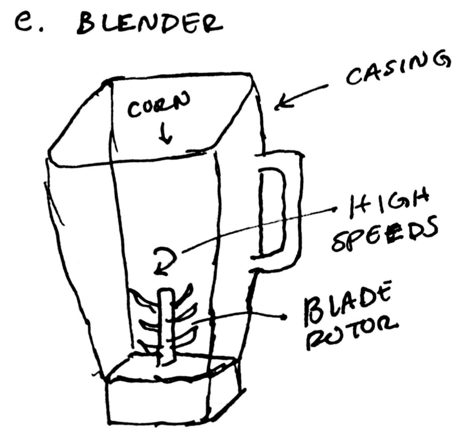


Figure 11. Blending mill sketch

v. Blender

Common in most homes Blenders have been, at times, used as maize grinders. Although grinding maize is not the first thing the inventors of the blender had in mind, many online do-it-yourselfers have been utilizing the high speed cutting power to produce maize flour. The main crushing force behind a blender is the high impact force when the rotating blades come into contact with the maize kernels. The average blender power requirement is 300 Watts which is twice as much as our specified 150 Watts, but with varying gear ratios the same rotation speed can be achieved using the 150 Watts.

Table 2 below depicts the Pugh Matrix associated with the grinding methods. Five different grinding methods resulted from our ideation process and are shown in the top row of the matrix. The criteria on the left-most column is the technical specifications derived in the Objectives section. Each method is given a “+,” “-,” or “S” referring to whether the design is better, worse, or similar to the datum grinding method. The Pugh Matrix gives a good starting point when deciding which methods should be chosen depending on their agreements to the criteria and datum, but fails to account for the importance of each criteria to the entire project. Some of the things noticed are that all methods, with respect to the datum, have a slower grinding speed and also most require less power to operate.

Table 2. Grinding methods Pugh matrix

Criteria	**Plate Mill**	**Hammer**	**Holes**	**Blender**	**Roller**	**Gear**
Sanitation	-		S	+	+	+
Manufacturability	S	D	+	S	-	-
Grind Speed	-		-	-	-	-
Variable Grain Size	+	A	S	-	S	S
Operable	+		S	+	+	+
Affordable	+	T	+	+	S	S
Lower Power	+		+	-	+	+
Positive Sum	4	U	3	3	3	3
Negative Sum	2	M	1	3	2	1
Total	2		2	0	1	1

The results from the Pugh Matrix above shows that there are two methods of grinding that are expected to be the best. Those two methods are the burr plate and the rotating holes, although they scored very differently they both amounted to the max total of two. Later in the report a more advanced method of choosing a grinding method will be used, that will take into account the importance of each specification.

A different feature that needs to be addressed, especially in the final product is sanitation methods. This is an important feature because of the possibilities of foreign contaminants entering the ground flour used for nsima. The five methods we chose were sieving, magnets, pre-prep, tolerance, and fillets. Sieving consists of having the user sieve through the ground flour removing any contaminants found. Magnets will be useful for catching sheared material from the mill (in the case of using ferrous material) , but will have no effect for non-metallic contaminants (i.e. rocks, dirt, etc.). Pre-prep is a visual method that is already in place with the current setup, but it is not as extensive as it should be. Tolerance is way of reducing the amount of contacting surfaces in the mill in order to reduce the probability of shearing off metal. Fillets will work by eliminating any sharp edges that could cause any shearing in the milling process.

Below in Table 3 is the Pugh Matrix used to analyze sanitation methods. In the matrix we decided no sanitation method was the best Datum since that is what is currently implemented. No sanitation means that no mechanism is included within the mill. The community members sift through the ground maize flour after the milling process in order to remove any foreign contaminants. The methods shown in the

matrix below include using a sieve, adding magnets, pre-preparation of the maize, high tolerances, and fillets both for reduced friction. The final product may need to have a combination of multiple of these sanitation methods.

Table 3. Pugh Matrix for maize mill sanitation methods.

Criteria	**Sieve**	**None**	**Magnets**	**Pre-prep**	**Tolerance**	**Fillets**
Sanitation	+	DATUM	+	+	+	+
Manufacturability	-		-	S	-	-
Grind Speed	S		S	S	S	S
Variable Grain Size	S		S	S	S	S
Operable	S		S	S	S	S
Affordable	-		-	-	-	-
Lower Power	-		S	-	S	S
Positive Sum	1		1	1	1	1
Negative Sum	3		2	2	2	2
Total	-2		-1	-1	-1	-1

The matrix above shows that most designs came in below the datum which is expected. Adding a new method to a systems usually creates more work and increases the cost. Although the Pugh Matrix was used, a single sanitation method has not been chosen. We have decided that a sanitation method will depend on the chosen design and which type of foreign contaminants will be seen after testing.

A decision matrix will be used to attain a more accurate representation of which grinding method fits the most important specifications. The decision matrix is provided below in Table 2. A decision matrix is used like the Pugh Matrix but includes weights to each specification. This is useful as the final decision is made on how well a design fits into the important specifications rather on how many specifications they fit into. The decision matrix below only includes the grinding concepts, this was decided above since the sanitation methods depend on each design and can be implemented after the design is completed.

Table 4. Decision matrix of top concepts and top specifications.

Grinding Concepts		Specifications								
		Grinding Rate	Power	Cost	Grain Size	Assembly	Manufacturability	Efficiency	Sanitation	Total
	Weight	17.2%	15.4%	13.5%	19.3%	5.8%	7.7%	11.5%	9.6%	100.0%
Hammer	Rating	10	1	1	8	2	2	8	9	--
	Wgt Rtg	1.72	0.15	0.14	1.54	0.12	0.15	0.92	0.86	5.61
Burr Plate	Rating	5	7	8	7	9	7	8	9	--
	Wgt Rtg	0.86	1.08	1.08	1.35	0.52	0.54	0.92	0.86	7.21
Roller	Rating	3	7	5	8	9	6	5	8	--
	Wgt Rtg	0.52	1.08	0.68	1.54	0.52	0.46	0.58	0.77	6.14
Blender	Rating	3	4	8	2	2	9	3	10	--
	Wgt Rtg	0.52	0.62	1.08	0.39	0.12	0.69	0.35	0.96	4.71

The decision matrix above shows the technical specifications used when deciding the top concept. Benchmarking is one of the main methods that was used in finding the correct weights seen in the matrix. Preliminary testing was done for the burr plate and blender design concepts which helped in part narrow down the ratings for several of the specifications. For results from the preliminary tests performed on both the blender and burr plate see Appendix D. The rotating disks concept has been omitted due to no previous benchmarking on the design as well as no simple way of testing the designs effectiveness. The highest weighted rating was used to choose the best overall concept for grinding maize.

Chapter 4

Top Concept

I. Qualifications

We arrived at the decision to use the burr plate design through the decision matrix, testing (Appendix D), benchmarking and some basic analysis (Appendix F). Ultimately, we established the burr plate mechanism as our preferred design due to its capacity to satisfy all of our design specifications. A SolidWorks model of a typical burr plate assembly is shown in Appendix G or in Figure 5 below and includes an auger in case we choose to implement one. The manners in which it satisfies those specifications are as follows:

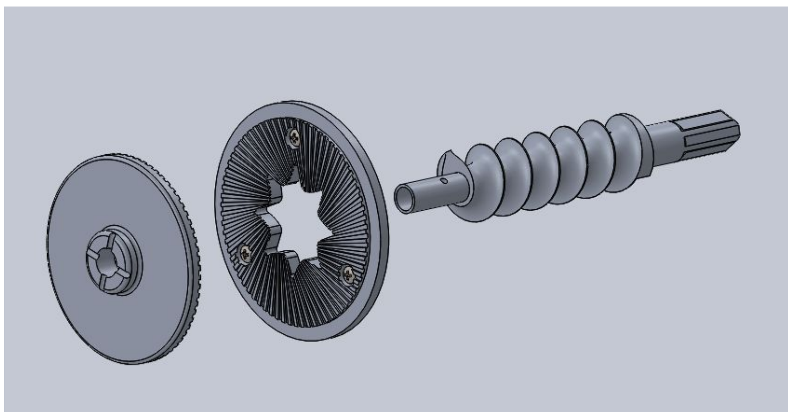


Figure 5. Chosen grinding method solid model.

i. Power

Burr plate mills are the most commonly used hand crank mill and can be easily operated below 150 watts. The low required rotational speed of about 50-100 RPM is also easily attainable with a bicycle input and will not require us to sacrifice much torque.

ii. Grinding Rate

We tested a standard hand-powered burr plate mill and found the grinding rate to be approximately 5.6 kg/hr. Given this benchmark, it is conceivable that we can meet our specified grinding rate of 15 kg/hr with the application of bicycle power and increased size.

iii. Production Cost

The low tolerance requirements of the burr plate design allow for cheaper manufacturing processes. A burr plate mill could be manufactured using basic machining or sand casting and could easily cost under $300.

iv. Sanitation

While sanitation is a major concern due to the potential for high shearing forces in the grinding of burr plates, we are confident that a mechanism with the proper design and material properties will result in zero metal fragments being ground into the flour.

v. Fineness

We have confirmed through testing and knowledge of past EWB design iterations [1] that the burr plate mill produces the finest flour of any of our top design considerations. Our benchmark testing, shown in Appendix D, confirms the burr plates superiority in making fine flour when compared to other small scale milling methods.

vi. Yield

The yield of the burr plate mechanism is the most unclear of our parameters since we first must obtain the sieve specified in our fineness requirement in order to do any testing. The flour ground during our benchmark testing (Appendix D) appeared to have a high proportion of fine flour.

vii. Manufacturing

The low tolerance requirements of a burr plate mechanism make it the ideal choice for Malawi's manufacturing infrastructure. Most hand crank burr plate mills are made of primarily sand cast components. A contact of ours near Kumpanda has confirmed that they are capable of sand casting if provided the necessary patterns.

viii. Durability

The burr plate design is a highly durable design that has easily replaceable components. A static load jamming scenario is considered in Appendix F in which the burr plate mill shaft is subjected to the torque produced by a 250 lb operator putting their full body weight onto a single pedal of the operator's bicycle.

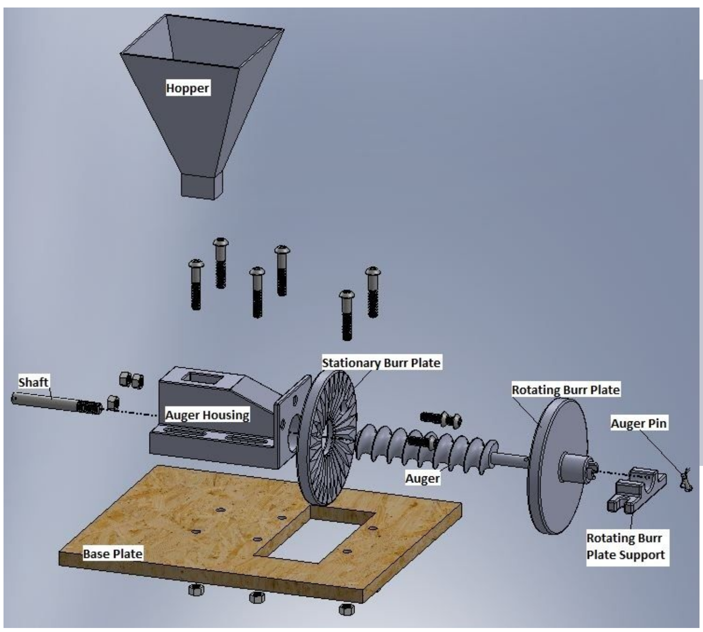
In the design of our top concept, the burr plate, our team will try and take all of the advantages of the burr plates in America today and make it able to be manufactured in Malawi. In order to make a successful burr plate design we will optimize things like burr depth and plate diameter to best meet our customer requirements shown in Appendix C.

Chapter 5

Description of Final Design

I. Functional Description

There are five main functional components of our mill design: the stationary burr plate, rotating burr plate, auger, hopper and shaft. The grinding mechanism is driven by the rotation of the shaft and powered by the bicycle transmission. The unground maize is first placed into the hopper. Gravity then feeds the maize into the auger. The auger is driven by the shaft and is shaped in such a way that it feeds the maize forward into the burr plates with the rotation of the shaft. The initial cracking of the maize is accomplished by the auger compressing the kernels against the center of the rotating burr plate. The crushed maize begins at the center of the interface of the two burr plates and is then pushed outwards, being ground across the burr plates. This is when the maize is ground into a fine flour. The flour is then discharged at the edges of the burr plates. An exploded view and full assembly view can be seen below in Figure 13. Full drawings of all custom parts and assemblies can be found in Appendix P.



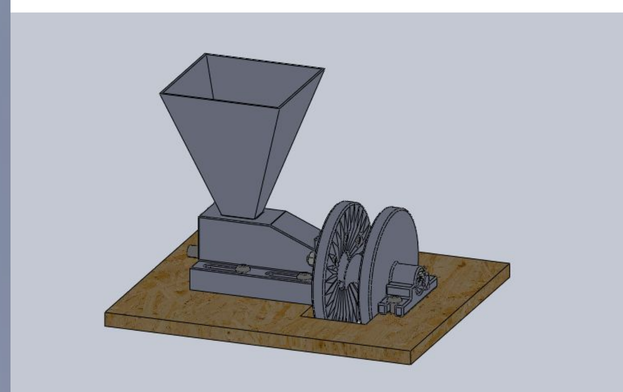


Figure 13. Labeled exploded view of the Maize Mill assembly (Left), and full assembly (Right).

Other components of the design include the auger housing, rotating burr plate support, collar and base plate. The auger housing makes up the main body of the mechanism and encases the auger and much of the shaft. The stationary burr plate is also fixed to the auger housing. The rotating burr plate support holds the rotating burr plate and supports the free end of the auger. The collar is used to couple our shaft to the shaft of the Bicycle Transmission Team.

The shaft is a ½ inch round bar with a D-Slot machined on one end for connection with the Transmission Team. The shaft will also be threaded on the opposite end in order to connect into the auger. The thickness of the shaft and the D-Slot connection were both established by the Transmission Team.

The auger has a spiral shape in order to turn the rotational motion of the shaft into translational motion of the maize moving forward into the burr plates. The auger was designed so that the negative space between its teeth would transfer the proper amount of maize required to achieve our grinding rate of 15 kg/hr. The end of the auger has a small protrusion with a hole so that it may be fixed to the rotating burr plate with a pin.

The auger housing has a cavity in its center and holes at both ends for containing the maize, auger and shaft. The housing also has a rectangular hole in the top for the feed of maize from the hopper. The mounts of the auger housing are slotted so that the housing may be moved back and forth in order to change the proximity of the burr plates.

The burr plates have angled burrs for grinding the crushed maize into fine flour. The proximity of the burrs decreases towards the outside of the plates so that the flour becomes more finely ground as it moves towards the outside of the plates. The stationary plate has a large hole at its center so that the auger may pass through it. The stationary plate also has three screw holes so that it may be fixed to the auger housing. The rotating burr plate has a small hole at its center so that the protrusion at the end of the auger may pass through it. Notches on the backside of the rotating burr plate allow it to be fixed to the auger protrusion using a clevis pin.

The hopper has a square top that tapers down into a rectangular base. At its base there is a 1 inch long straight section for interfacing with the auger housing. The straight section is dimensioned so that it fits tightly into the rectangular hole at the top of the auger housing.

II. Analysis Results

The majority of the specification validation for our design was completed through the testing of and comparison of an Estrella hand crank burr plate mill. The designed diameter of our burr plates was chosen by measuring the grinding rate of the Estrella mill (5.56 kg/hr) and computing the factor by which that grinding rate would need to be increased in order to meet our specification of 15 kg/hr. We computed the burr plate surface area of our design by calculating the surface area of the Estrella mill and scaling up that surface area by the previously mentioned grinding rate factor. The burr plate surface area was assumed to be proportional to the grinding rate. The designed burr plate diameter was calculated to be 5.75 inches in order to achieve the 15 kg/hr grinding rate. This calculation is shown in Appendix I.

The torque required by our mill was similarly validated through testing. We measured the torque required to operate the Estrella mill using a torque wrench and found it to be about 10-17.5 ft lb (13.5-23.7 Nm). We then made the assumption that the torque required by the mill would be proportional to the burr plate surface area. We computed the required torque for our design by multiplying the measured operating torque of the Estrella mill by the proportion of our design's burr plate surface area over the surface area of the Estrella mill's burr plates. This is proportion is the same as the grinding rate factor. The operating torque for our design was calculated to be 27-47.24 ft lb (36.6-64 Nm). Dividing the available power (150 W) by our design's operating torque yielded our design's operating RPM. This

RPM was very comparable to the operating RPM of the Estrella mill. This calculation can be seen in Appendix J.

The torque able to be supplied by the user was validated against the torque required by the mill. We were able to make this validation by assuming that our mill should operate at an RPM similar to the RPM of the Estrella mill. We measured the RPM of the Estrella mill with a range of burr plate tightness settings (changing torque and therefore changing RPM) and found the range to be approximately 20-30 RPM. We computed the range of torques capable of being supplied with 150 W at these RPMs to be 47.75-71.62 Nm. This is exceeds the calculated range of torque required by our mill design (36.6-64 Nm). The supplied torque calculation can be seen in Appendix K.

We were also concerned about the required shaft diameter. The weakest point on the driving shaft and auger is the aluminum protrusion at the end of the auger. A calculation was conducted for a maximum possible torque condition on the shaft. This condition is considered to be a 68 kg (about 200lb) person applying their complete body weight to a single pedal of the bicycle while the mill is jammed. A minimum protrusion diameter was calculated to be 0.35 in. A universal shaft diameter of 0.5 in has been chosen; giving a yield factor of safety of 1.43. This calculation can be seen in Appendix O. The auger was also sized to meet the 15 kg/hr grinding rate requirement. The amount of dead space around the auger and the rotation speed were assumed to be the only influencing factors in the augers feed rate. The model off of GrabCad resulted in a feed rate of approximately 12.5 kg/hr which was lower than the specified rate. The larger sized auger was calculated to have a feed rate of over 16 kg/hr. Calculations for the auger feed rate can be found in Appendix R.

III. Safety Considerations

Addressing Potential Hazards:

- Putting hand in the auger: We will make the slot that feeds maize to the auger small enough to make it difficult for children place their hands near the spinning auger.
- Rock caught in mill: If a rock were to be fed into the mill along with the maize there could be catastrophic effects. The rock could break the burr plates of the mill or be ground into the flour, making it inedible. We will remedy this by instructing the users, in the operator's manual, to sift through their maize in search for foreign objects prior to milling.
- Metal bits shearing off: It is conceivable that metal fragments could shear off of the burr plates since there is such close proximity and high torque between the burr plates. We intend to prevent this by making the burr plates out of a high-strength material that is unlikely to shear under the given torque. We also intend to make a calibration gauge/spacer for the assembly of the mill. This gauge would be placed between the burr plates during assembly in order to set the correct distance between the two plates. This would guarantee that there is no interference between the burrs.
- Harmful material in mill: It is possible that someone may misuse the mill and introduce a material into the mechanism that should not be ingested. An example of this would be the use of a poisonous lubricant. In order to prevent this we will specify in our operator's manual the exact guidelines for what materials may be used in the mill and emphasize the dangers of introducing foreign substances.

A hazards checklist can be found in Appendix H. All potential failure modes of the mill can be found in the Failure Modes & Effects Analysis (Appendix L).

IV. Material

When selecting the material for the mill, we had to find one with these properties:

1. The material must have sufficient hardness to withstand the constant crushing of maize.
2. The material must be safe to contact food.
3. The material must be able to survive Malawi's environment.
4. The material must accessible in Malawi (for manufacturing purposes).
5. The material must not require advanced handling.

When taking into account all these material parameters we narrowed down the selection to three "usable" materials: aluminum, cast iron, and steel. With their high strength and accessibility these materials are the frontrunners for our mill. Although the materials pass through the described parameters each one has it's own downside.

Although aluminum is a bit softer (up to 40 HB) than steel (up to 60 HB, 88 HB for stainless) and cast iron (up to 86 HB), it may provide enough hardness to withstand the continuous crushing of maize [15]. For the complex geometry present in the design of our mill, machining blocks of aluminum would result in high costs and lots of wasted material. The only method that seems to reduce the amount of wasted material is casting. This is also the same manufacturing method to be used for stainless steel and cast iron.

Aluminum seems to be the frontrunner of the three materials. With the lower melting temperature compared to the others, a wider range of kilns could be used for the casting process. Although it comes in with about half the hardness as compared to the other two metals, we expect this material to withstand the continuous crushing of maize. Aluminum also tops the other two materials because of its non-corrosive quality. In case of aluminum failure the total project will then be cast out of iron substantially increasing the hardness and strength.

V. Manufacturing and Fabrication Plans

Ultimately we intend for our design to be manufactured in Malawi. We have made many design considerations with this in mind and have anticipated the fabrication methods of Malawi. We have fairly limited knowledge of the stock parts that are available in Malawi and have chosen to have a majority of our components fabricated (rather than procured) as a result. While CNC machining is non-existent in Malawi, other methods of manufacturing are available. We have chosen to sand cast a majority of our components with minimal post-processing. This will allow for the production of complex components without the need for CNC. We will produce the patterns and necessary tooling here at Cal Poly and will send them to the city of Blantyre where the components will be fabricated.

Nearly all fabricated components of prototypes as well as the final product are to be sand casted. Casted components include both burr plates, the rotating burr plate support, auger housing and auger. Procured components are the shaft, screws, clevis pin and collar. The only fabricated component that will not be sand casted will be the hopper. The hopper will be made out of sheet metal that will be cut using a

plasma cutter or metal shears. The sheet metal will then be properly bent and welded using a spot welder. Prototype patterns, necessary for sand casting, are to be made out of ABS plastic using the 3D printers available here on campus. We will sand cast our prototypes out of aluminum in the on-campus Net Shape laboratory. The final design patterns will be standard flat plate cope and drag patterns (example shown below in Figure 14 and will be CNC cut out of wood. These patterns will be sent to Malawi for their own manufacturing purposes. 3D printed patterns will be used as final design patterns in the case that complex geometries, such as the burr plates, cannot be CNC cut.

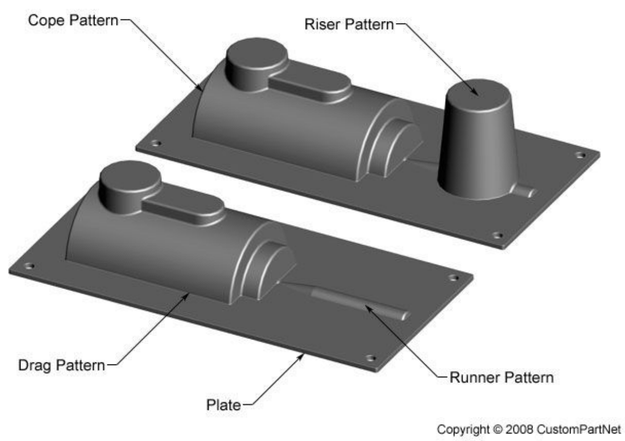


Figure 14. Example of cope and drag plate patterns for sand casting.

VI. Maintenance and Repair

Maintenance and repair should be easy for our users since we are providing them with all of the necessary tooling to manufacture their own replacement parts. We will also provide a operator's manual and manufacturing instructions to facilitate the fabrication and proper use of the mill. The main concerns for repair would be the feasibility of manufacturing a new component in Malawi and the potential for the loss of our patterns or tooling. The 3D printed sand patterns will allow the people of Malawi to recreate any component that breaks.

VII. Cost Analysis

The objective of this Maize Mill senior project is to provide Malawi and other communities in Africa an efficient and effective substitute for their hydro-electric mills. Our project was given a specification that after all material, machining, and assembling costs our mill will be available for under 300 U.S. dollars. This design will work as a sustainable product for those communities as all parts have been designed and built to reflect the available processes in that area. Replacement parts will be easily manufactured and accessible.

Our prototype bill of materials, found in Appendix N, shows that our prototype will come in at \$302.98 with material costs. Specification and cost sheets for the hardware used in the maize assembly can be found in Appendix Q. This cost is quite high due to the 3D printing of the molds used in our

casting processes which amounts to $251.02. The 3D printing of molds will be a one time cost as the mold will be reusable for multiple mill productions. Our prototype will be manufactured and built on Cal Poly's machine shops and IME labs. A majority of the parts will be casted in the IME labs under the supervision of Professor Martin Koch. Material for the castings will be purchased through Cal Poly at an estimated 60 cents per pound of Aluminum. After our prototype manufacturing and testing we will be able to provide an estimate on the works hours needed for casting, machining, and assembling the entire mill. A total cost of production will be included in the FDR, due June 2nd, as well as an off the shelf price estimate.

Chapter 6

Design Verification Plan

The main test that will be conducted on each prototype iteration will be a timed milling of maize. The prefered power source for the mill during this test is a human riding a bicycle. In the case that a bicycle transmission prototype is not ready, we will use an electric motor. The motor will be powered with 150W and we will use a step-up gear ratio in order to produce the 20-30 operating RPM. A container of maize of a known mass will be completely milled. The milling will be timed in order to calculate the grinding rate and compare to the 15 kg/hr specification. The flour will then be weighed before conducting a sieve test. In the sieve test the flour will be passed through a #50 sieve that will be obtained through Professor Nephi Debridge of the Civil Engineering department. During the sieving the flour will be inspected for any metal bits in order to guarantee the sanitation of our design. The flour that has passed through the sieve will then be weighed. The weight of the flour after being sieved divided by the weight of the flour prior to sieving will give us our experimental yield. This yield will be compared to the 80% yield specification. A summary testing table can be seen below in Table 5, while a full table of test descriptions and acceptance criteria can be found in the Design Verification Plan (Appendix T).

Table 5. Top concept specification fulfillment.

Specification	**Validation Method**
Power (150 W)	Attach mill to 150 W power source to check operation
Grinding Rate (15 kg/hr)	Timed milling of 20 kg of maize
Production Cost ($300)	Tabulation of material and labor costs in Malawi
Sanitation (0 kg of metal)	Inspect discharged flour and sieve to check contaminants
Fineness (#50 Sieve)	Check mass of flour that goes through #50 sieve
Yield (80%)	Weigh flour before grinding and after passing through sieve

Chapter 7
Product Realization

I. Manufacturing

The maize mill was designed in order to reduce the need of high performance manufacturing to accommodate the shops found in Africa. The initial designs were also made to reduce the amount of different processes needed to make the maize mill. The main process for our mill was casting, which would be able to create everything other than the base plate, shaft, auger, and small hardware. The process of creating our mill included modeling our parts in CAD, printing molds for each casted part, casting each part, buying the needed hardware, and using simple machining processes to fine-tune dimensions and fits.

When creating the 3D models on SolidWorks we used design for manufacturing in order to satisfy everything needed for a successful cast. Parts drawings were created of each part to have correct dimensions of each part after final post processing. The 3D solid models were using in a stl format to create 3D prints for all the molds. Using the assistance of Innovation Sandbox and the IME Casting Facilities we were able to create molds for each casted part. Below in Figure 15 are pictures of the molds used to create the patterns for the burr plates and the auger. The auger housing was not cast due to complications with creating cores for the internal cavities.

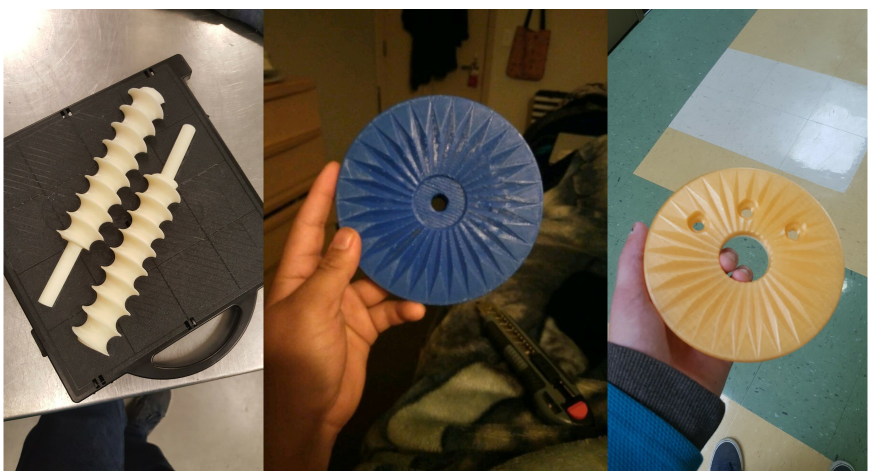


Figure 15. 3D printed molds of the auger (left), rotating burr plate (center), and the stationary burr plate (right).

When creating the patterns for each part we followed the procedure taught in the IME 141 Net Shape class. First each 3D print was sanded down to remove layering left over from the printer as well as tapered to a 2 degree angle for pulling out the mold once the pattern had set. Each mold was placed in a certain flask fitted to its dimensions and then covered with baby powder to ensure that the setter in the sand would not attach to the mold. For the auger 3D prints a match plate was created in order to create two half patterns and the burr plates were placed in molds face down both are seen in Figure 16 below. The burr plates were cast face down to ensure that the mating faces and burrs were all cast correctly. The

auger would have been cast vertically for the same reason, but due to its size complications in cooling time as the pattern fills also the high flow due to gravity could cause the augers teeth to shear off.

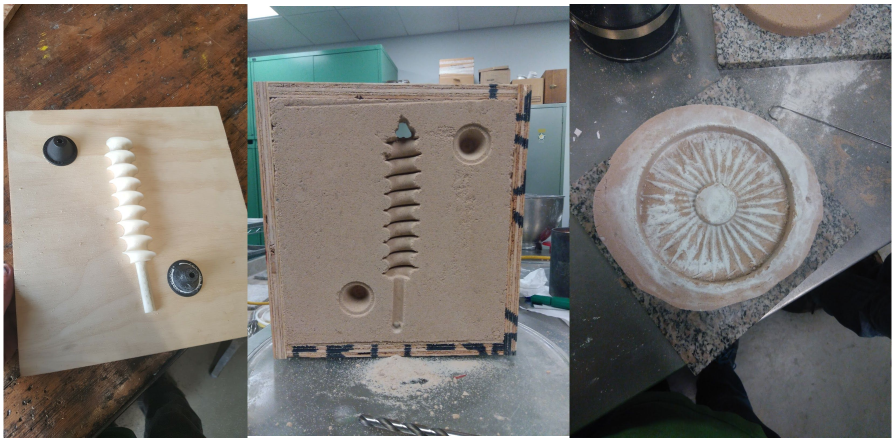


Figure 16. The auger match plate showing the drag side, also showing alignment features with the black inserts on the corners (left), sand pattern of the auger mold (center), sand pattern of the stationary burr plate (right).

The casting process was difficult and never really repeatable. Our first cast part was the stationary burr plate which was deformed by blowout on one side. The blowout occurred because of the steel funnelling blocks were placed off center inflicting a moment and ultimately allowing one side to fill more than the other. Below in Figure 17 you can see the placement of the steel funnelling blocks as well as the blowout on one side of the stationary burr plate. After this issue we corrected the future casting setups to ensure this blow out does not occur again, below in Figure 18 you can see the casted parts.

Figure 17. Casting setup with the off-center funneling blocks (left) and casted stationary burr plate blowout (right).

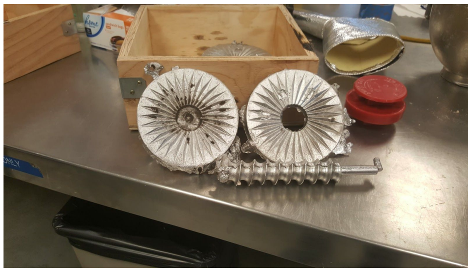



Figure 18. Casted parts before post processing (left) and corrected funnelling block placement for the remaining casts (right).

The casting process, especially with sand casting, is not very precise or accurate. Post-processing was done on all the casted parts to ensure that they would be able to fit into the bearings and housing, All the casted parts involved circular profiles and were mainly worked on a lathe to ensure concentricity and with a belt sander to sand down the flare out from castin. Flare out can be seen on the edges of the casts above in Figure 18. On the lathe each part was held from the most concentric area while the others were turned until concentric, center drilling also happened at this stage to locate the centers for boring. Other machines were also used to complete post processing of the casted parts as a drill press and tapping the threads into the auger. Below in Figure 19 are some pictures of the machining processes that took place.

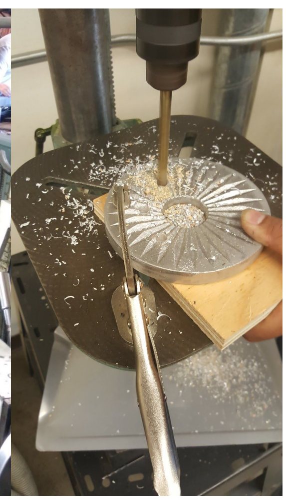



Figure 19. Rotating burr plate being turned on a lathe (right) and mounting holes being drilled into the stationary burr plate (left).

The remained of the manufacturing mainly involved creating the auger housing. The final auger housing was made from half of a 4”x4”x12” solid block of aluminum. After countless hours using the mill and machining all the necessary features, we created a functional auger housing able to connect all the pieces of our maize mill. Figure 20 below shows some pictures of the machining processes that went into creating the auger housing as well as a photo of the completed auger housing.

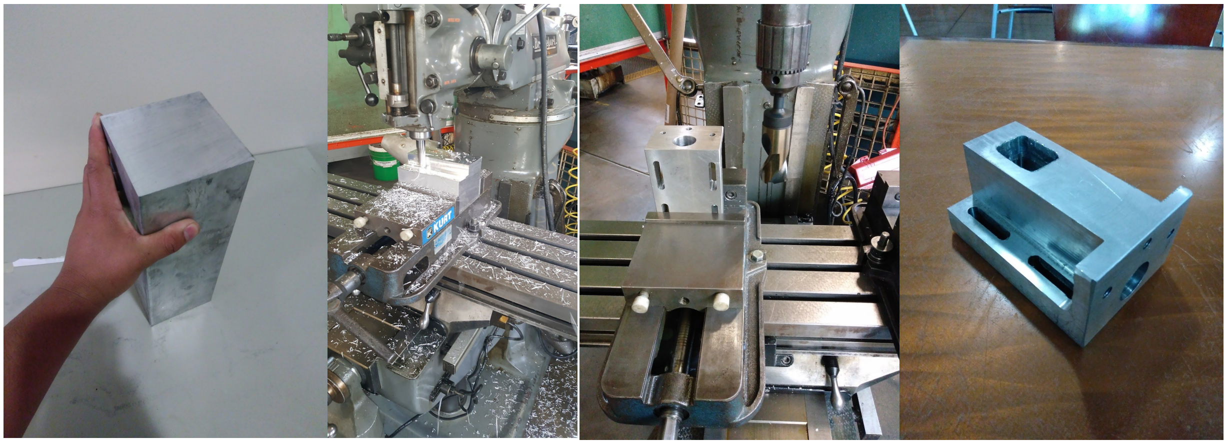


Figure 20. Solid stock used to create the housing (left), end milling the block to size (middle left), boring the 1.5in auger hole (middle right), and the finished auger housing (right).

With the casted parts post processed and auger housing completely machine all that was left to manufacture was the hopper and the base plate as well as buying all the hardware and assembling the mill. The hopper was made out of steel sheet metal and ead cut using corner shears and then MIG welded together. The base plate was created out of ¾ inch plywood and mainly consisted of using a drill press, table saw, and jigsaw. Below in Figure 21 are photos of the process of creating the hopper and base plate. Figure 22 shows the complete maize mill assemble without the bike team.

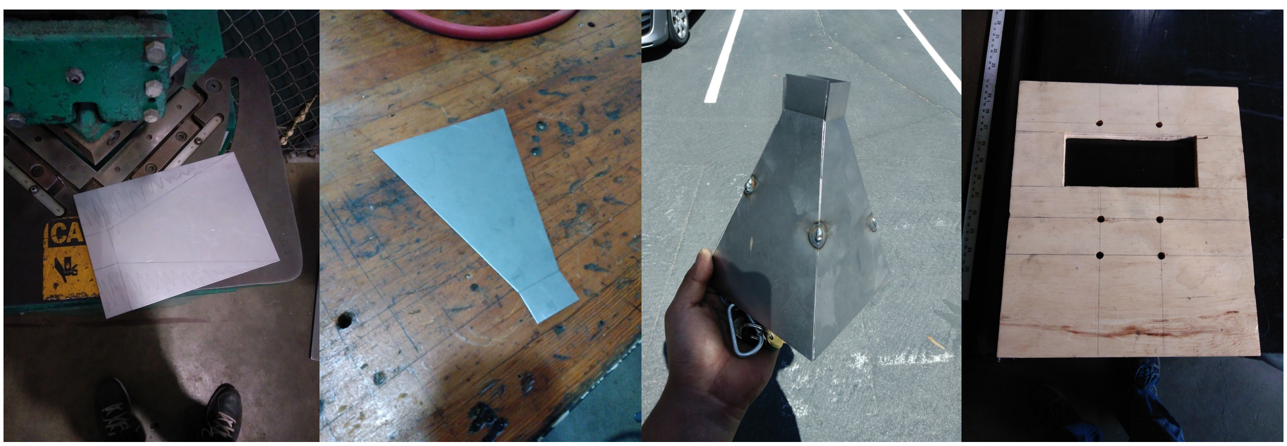


Figure 21. Hopper edge drawn on sheet metal (left), hopper edge cut to size (middle left), welded hopper (middle right), base plate (right).

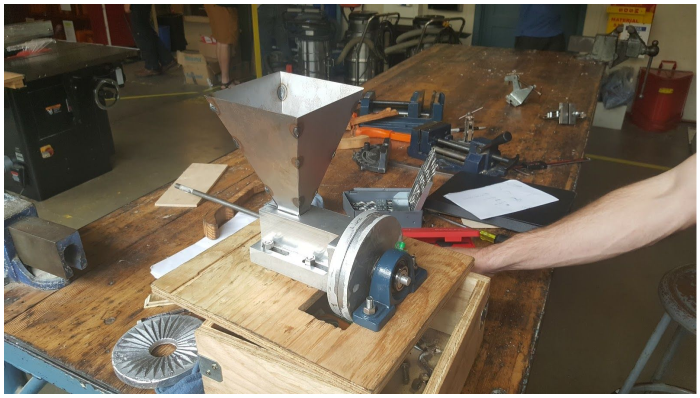


Figure 22. The complete maize mill assembly.

II. Prototype and Model Differences

During the manufacturing process there were some parts that had been modified from their part drawings to accommodate the manufacturing flow. One of the big things that was changed was the auger housing which was machined out of a solid block rather than cast. Also the auger had some problems during manufacturing and testing that called for a redesign. Appendix P contains the updated part designs that have been modified to make manufacturing easier.

The auger housing proved to be the most difficult part to cast because of the amount of internal cavities present. In order to cast this part a series of cores are needed to create all the internal cavities. Cores are not reusable with sand casting molds and patterns for each core would also have to be made. The process of creating the cores and the auger housing mold proved to be a much more extensive process when compared to just machining the part from a solid block of aluminum per recommendation of various professors. Ultimately our project modified the auger housing drawing to reflect machining processes rather than casting.

The auger proved to be the most difficult part to machine during post processing. Due to the complex geometry of the auger and the imprecision of sand casting, creating concentricity between all the parts was extremely difficult. During manufacturing the non-concentricity of the auger between the rest of the parts forced us to modify the shaft with its own non-concentricity to counteract that of the auger. Another issue that arose with the first auger design was that the auger was not producing an adequate mass-flow rate of maize at the designed speed and torque. To fix both the issues of non concentricity and of the flow rate a new auger with larger volumetric-flow rate around the threads and to concentric shafts was designed. The larger volumetric displacement is easily visible when comparing the old auger to the new one as in Figure 23 below. The two concentric shafts were meant to help align the auger during post processing, but due to some impurities in the cast and the low strength of aluminum, the shaft connecting to the rotating burr plate bent off while turning it on a lathe. Manufacturing processes, like turning, had not been accounted for when doing design stress calculations. With the shaft sheared off we connected the input shaft the same way as in the first auger design by threading it into the auger. This auger modification also proved difficult as the internal threads of the auger were broken several times during

testing due to the high shaft torque and the low material strength of the cast aluminum auger. This was ultimately resolved by adhering the shaft to the auger using high strength epoxy.

Figure 23. New auger with rotating burr plate (left) and old auger (right).

Although the redesign of the auger did help solve one of the problems another redesign could help create a better functioning part. The future design should incorporate larger shafts to hold torque, concentric shafts for alignment, and gradual thickness changes to reduce the risk of shearing.

III. Manufacturing Recommendations

The manufacturing of you maize mill went smoothly other than some design issues with the auger. For future manufacturing we recommend that the auger be designed adequately for the machine processes that are to be used. A lathe worked well in getting the parts concentric with each other and should be used for all processes involving circular profiles (other than the auger housing bore which should be bored with a drill bit). All the manufacturing involved with the maize mill was pretty straightforward and can be accomplished in many shops. When working with the auger it is recommended that it aligned in the lathe chuck and held with a center bit on the other side to reduce the amount of bending force applied to the section in the chuck. The auger housing was the only part that required a mill and it was very simple. It is recommended that all the milling processes be done in a single setup to reduce the amount of imprecision added when recentering the part. Using the auto-feed functions of the mills helps reduce the time milling a CNC file could also be made in the future if needed.

Chapter 8

Final Design Verification

Unfortunately we were unable to conduct several of our specification verification tests since our prototype was only fully functional very briefly before the end of the allotted project timeline. Our mill has only been run for a total of approximately 5-6 minutes as a result of shaft failures. Despite this we were able to conduct rough tests for all of our design specifications.

I. Power

Figure 24. Mill operation while coupled with the bicycle transmission system.

The power specification was verified by virtue of the mill being operated by the bicycle transmission system. The mill was extremely easy to operate. It is probable that we underestimated the power output of a human or overestimated the torque required to crack maize kernels. It could also be a result of our auger not transferring kernels to the burr plates effectively. Either way, the lack of power utilization is made clear by the ease with which we were able to peddle the bicycle during operation. We were able to peddle the bicycle as fast as possible while staying below approximately 20% of our maximum physical output torque. This means that the gearing of the bicycle transmission system could be altered for less output torque and greater burr plate rpm. Our design can be considered to pass the specification of the mill running on the limit of human power, however, the design could certainly be improved to better utilize the available power.

II. Grinding Rate

Figure 25. Collection of discharged flour for grinding rate verification.

The grinding rate was measured by operating the mill for 2 minutes and weighing the flour output. The timer for the test was not started until the maize had passed completely across the auger and reached the intersection of the burr plates. After grinding, the flour was weighed using a high precision scale. The output was 12 grams. Considering the 2 minute run time, this equates to and grinding rate of 0.36 kg/hr. This is only 2.4% of our specified design grinding rate. Our design does not pass the desired specification of 15 kg/hr. This outcome is likely because our auger does not effectively transfer kernels.This grinding rate could also be increased by increasing the burr plate rotational speed and better utilizing the available power.

III. Sanitation

Figure 26. Image showing the adapted sanitation test.

An improvised sanitation test for finding if metal was ground into the flour was conducted rather than the original visual inspection test. Instead, a permanent marker was used to mark all of the surfaces that could be subject to friction between metals. The marker would rub off if there was any major friction between the surfaces. This newly developed test is reflected in the Design Verification Plan (appendix T). Both the edges of the auger and the outsides of the burr plates were found to rub slightly. The rubbing

edges of the auger were easily removed using a file. The outside edges of the burr plates should rub less with use. Overall, however, the mill cannot be considered sanitary in its current condition.

VI. Fineness and Yield

Figure 27. Visual comparison of flour. Flour of our mill is shown on the left. Flour of the Estrella mill is shown on the right.

A standard sieve test for analyzing the fineness and yield of our discharged flour could not be conducted. A rough visual estimate can be made by comparison with the flour ground by the Estrella mill. We can tell that both the overall fineness and the yield of our discharged flour are less than that of the Estrella mill. Because of this we can assume that our mill does not meet the design specifications of 80% yield through a #50 sieve.

Overall, our design only passes one of the six design criteria that was set. While unfortunate, hopefully Engineers Without Borders can learn from our design's pros and cons and use that knowledge to create an adequate solution that can be built in country.

Chapter 9

Conclusions and Recommendations

Throughout the design, planning, and manufacturing of this project our team has come to many realizations and learned much. Every stage of this project made us face new challenges. Right from the beginning, because we were given a project that had already been worked on by Engineers without Borders, we had to question and identify issues with past designs that we had not worked on. Then, during the design process, we had to take into account the manufacturability challenges that an African village presents. Finally, we went through the manufacturing stage. Through parts breaking and countless unexpected obstacles, our team learned to the full extent how a design doesn't always translate easily into reality. Next time going through this process our team would have made a few changes to how we handled different scenarios. One major thing we would have changed is to not be overly reliant on industry experts for help, instead we would have started off our testing earlier and learned from our mistakes instead of just waiting on their opinions.

Our first recommendation for how to progress this design would be to utilize a higher burr plate rotational speed. This would allow more corn to be ground. We originally used a lower rpm because we used an overly conservative power estimate for how much a human could pedal on a bike. We would also recommend that the cast components be made using a higher strength material, such as cast iron. This should resolve problems with auger strength and increase the sanitation of the flour by reducing the metal that is sheared off of the burr plates during grinding. The overall design of the auger could also be improved due to its ineffective transfer of maize to the burr plates. We would recommend experimentation with auger designs that utilize different thread angles, depths and spacing. Our last design change would be to the burr plates. We recommend an increased the number of burrs on the outside diameter of the burr plate that are spaced at smaller intervals. This small change should improve the overall fineness and yield of the flour by increasing the number of burrs that the maize passes through before being discharged. This change could also potentially increase the grinding rate of the mill by reducing the amount of larger particles that get stuck in the burr plates and cause blockages.

References

[1] Malawi Maize Mill Team, “Pre-Implementation Final,” Engineers Without Borders, 2015-2016.

[2] Bowman, Barbara, “How To Make Masa Nixtamal,” Gourmet Sleuth (Web Site: http://www.gourmetsleuth.com/articles/detail/make-masa-nixtamal), 2000-2016.

[3] Clarke, Brian and Rottger, Alexander, “Small mills in Africa,” Agricultural and Food Organization of the United Nations, PDF, 2006.

[4] “Chard #150 Table Clamp Grain Mill,” Item # HN-CHRD012, Hayneedle (Web Site: http://www.hayneedle.com/product/chard150tableclampgrainmill.cfm?ltype=child&tid=CHRD012-1), 2002-2016.

[5] “Bicycle Power - How many Watts can you produce?” mapawatt (Web Site: http://mapawatt.com/2009/07/19/bicycle-power-how-many-watts-can-you-produce), 2009.

[6] “Bicycle Performance,” Wikipedia (Web Site: https://en.wikipedia.org/wiki/Bicycle_performance), 2016.

[7] “Mesh (scale),” Wikipedia (Web Site: https://en.wikipedia.org/wiki/Mesh_(scale)), 2016.

[8] Smith, Amy, “New Mill Design Grinds More Grain for Less Money,” African Technology Forum (Web Site: http://web.mit.edu/africantech/www/articles/Hammermill.htm), Massachucetts Institute of Technology, 1998.

[9] World Health Organization, “Health Profile: Malawi,” World Health Rankings (Web Site: http://www.worldlifeexpectancy.com/country-health-profile/malawi), 2014.

[10] Seglar, Bill, “Use of grain sieves for evaluation of processed maize grain,” Progressive Dairyman (Web Site: http://www.progressivedairy.com/topics/feed-nutrition/use-of-grain-sieves-for-evaluation -of-processed-maize-grain), 2014.

[11] ME 428/429/430 Senior Project Design Reference Book and Success Guide, Mechanical Engineering Department, California Polytechnic State University - San Luis Obispo, September 2016.

[12] “Small-scale maize milling,” International Labour Organisation (Web Site: http://staging.ilo.org /public/libdoc/ilo/1984/84B09_313_engl.pdf), Geneva 1984.

[13] Digital image. https://www.paulasbread.com/replacement-burr-plates-for-country-living-mill.html. N.p., n.d. Web.

[14] "GrainMaker® Grain Mill Model No.99." *GrainMaker*. GrainMaker, n.d. Web.

[15] “Zahner® Resources > Metal Hardness.” Zahner® Resources. Web. Accessed 2/5/2017. (Web Site: http://www.azahner.com/resources_metal_hardness.cfm)/

Appendices

Appendix A - Quality Function Diagram
Appendix B - Top concept sketches
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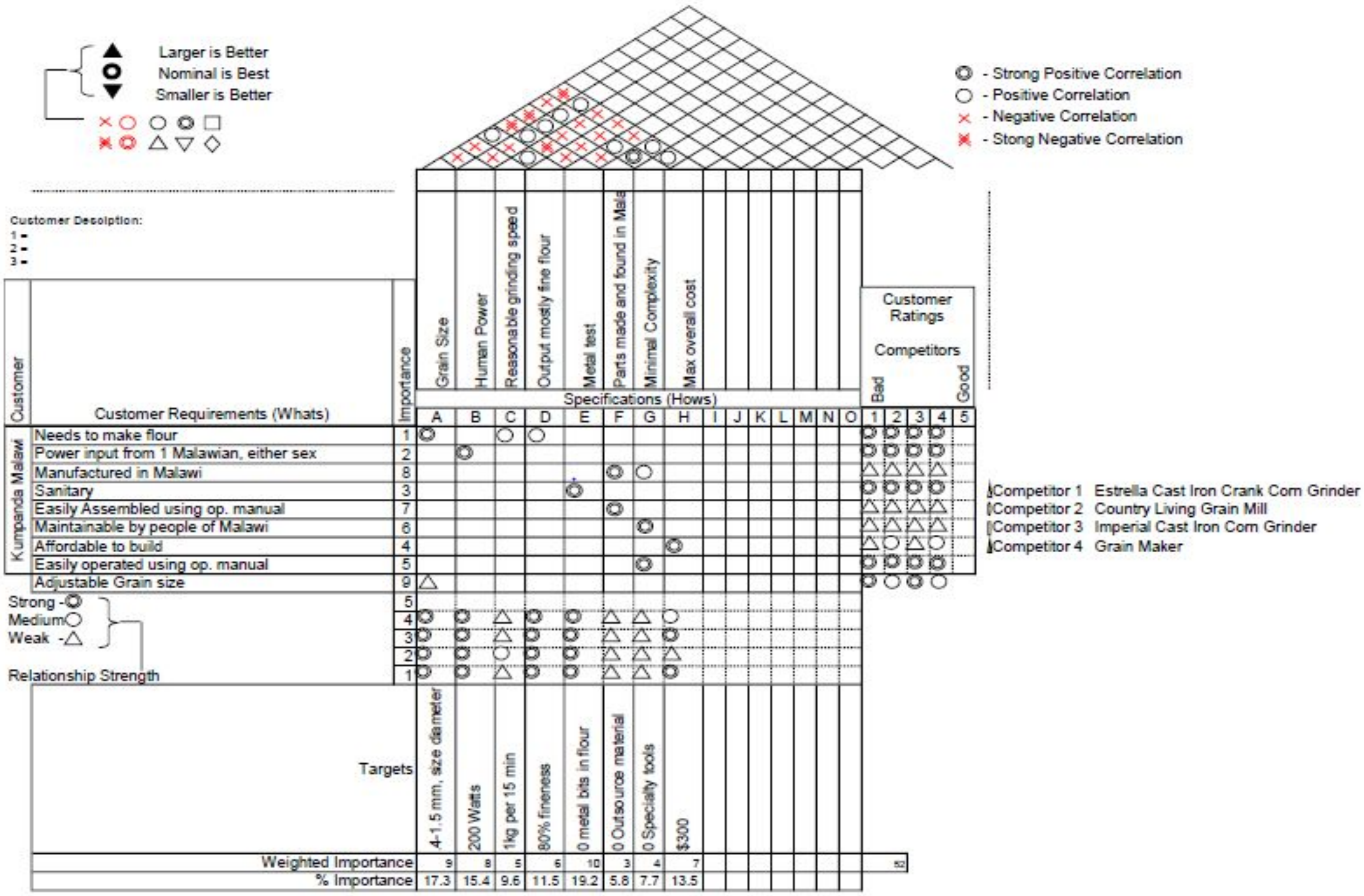
Appendix A.

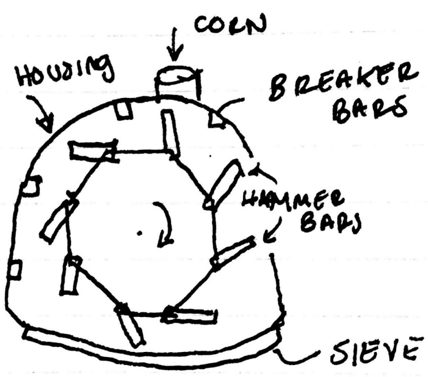
Quality Function Diagram.



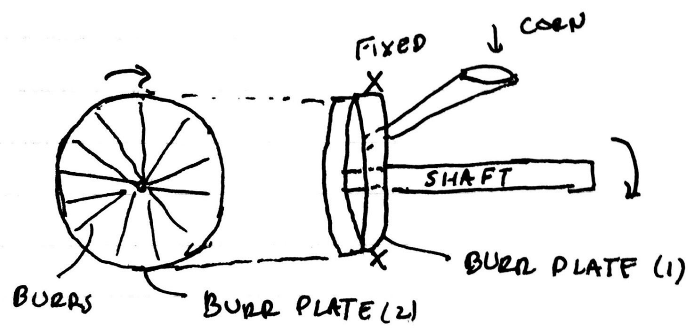
The Quality Function Deployment (QFD) is a method of taking customer/sponsor requirements and all the projects technical specifications and evaluating them on importance versus each other. The house of quality is one way of displaying the results from the QFD and is shown above. The advantages of the house of quality is the ability to compare the specifications to each other as well as being able to compare competitors solutions to both the requirements and specifications. The right side shows how competitors meet our projects requirements while the bottom section, above the targets, compares them to the technical specifications. The left column shows the customer requirements, the top row is the specifications, and the bottom row is the specification targets. The top triangular section shows whether specifications positively build off each other or negatively. The bottom two rows show the weighted importance of the specifications.

Appendix B.
Top concept sketches.

a. HAMMER MILL



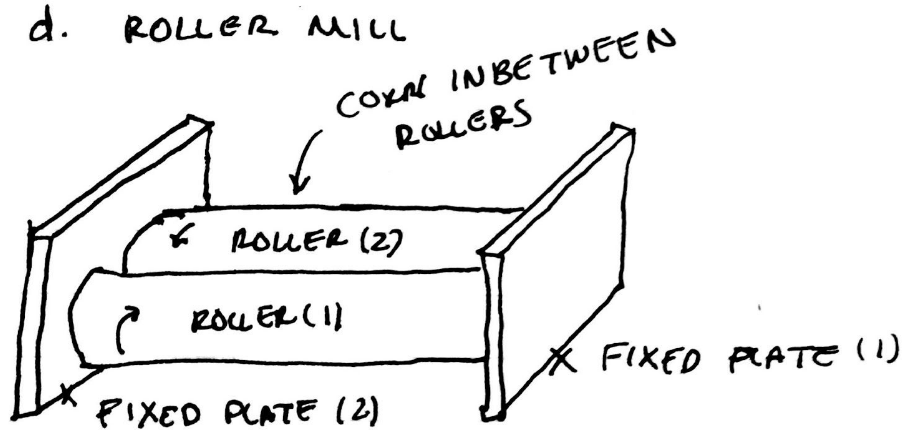
b. BURR PLATE MILL



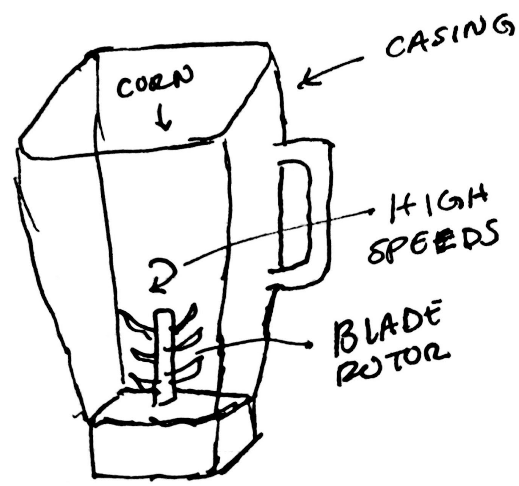
C. ROTATING HOLES MILL

Appendix B. (continued)

d. ROLLER MILL



e. BLENDER



Appendix C.

Optimization Table for Burr Plate Design

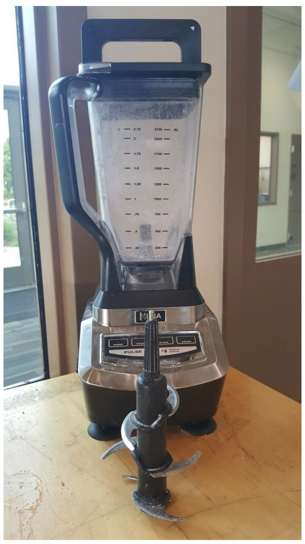
Topic	Variable	Optimization
Geometry	Plate Diameter	Optimized in unison with RPM to get the most flour yield from the power of one individual.
	Plate Thickness	Will be optimized to use as little material as possible, but designed to have an infinite fatigue lifetime.
	Hopper Size	Hopper size will be based on how much maize an individual normally carries to the mill.
	Auger	The auger diameter will depend on the plate diameter. The threading will depend on the RPM, and how much flour the mill produces.
Material	Burr Plate: Cast Iron, Steel, Aluminum	The burr plate material will be chosen to not ever ship from shear while being as cost effective as possible.
	Auger: Cast Iron, Steel, Aluminum	The auger material will be chosen to be as cost effective as possible.
	Frame: Aluminum, Cast Iron, Steel, Wood	The material of the frame will will be chosen to be as cost effective as possible.
Manufacturing Processes	Sand Casting	Based on flour yield, surface finish, sustainability, and cost a manufacturing cost will be chosen.
	Die Casting	
Other Design Considerations	RPM	Optimized in unison with plate diameter to get the most flour yield from the power of one individual.

Appendix D.

Grinding Benchmark Testing

In this experiment we compared the milling potential of two main design concepts: burr plates and rotating blades. 6 ounce portions of maize kernels were ground in three different machines: an Estrella hand powered burr plate mill, a Ninja industrial blender and a Magic Bullet miniature blender. In each case we recorded the milling time and made observations on the flour produced. We used primarily used dry maize in our trials although we also used soaked maize and maize with water in some tests as noted.

1. Ninja Industrial Blender
   - Large volume blender
   - Rotor has three sets of blades
   - Extremely high RPM
   - Several speed settings



Dry maize test:

- 6 ounces in 2.02 min (5.05 kg/hr)
- Flour contains large chunks
- Blender appeared to be too high in volume and had too large of blade spacing to adequately mill kernels.
- Largest particles appear to be approximately 2-3mm

Appendix D. (continued)

2. Magic Bullet
   - Single rotating blade at base of blender
   - Contained in small volume container
   - Relatively high RPM although visibly less than the Ninja

Dry maize Test:

- 6 ounces in 50s (12.24 kg/hr)
- Fastest grinding rate of all tests conducted
- Fairly fine flour
- Largest particles appear to be approximately 1mm

Appendix D. (continued)

Soaked maize Test:

- 6 ounces in 45s
- Milling was impossible since kernels were not sifting to the bottom towards the blade
- Largest particles were whole kernels, approximately 5-6 mm
- Very little fine flour

Maize With Water Test:

- We added water to the soaked maize in this test in the hope that it would help to sift the kernels towards the bottom of the blender
- 6 ounces in 2 minutes (5.1 kg/hr)
- The added water did help slightly but the kernels sifted very slowly and only with some intervention.
- Lots of large particles, approximately 3mm

Appendix D. (continued)

3. Burr Plate Hand Mill

- Ultimately chosen as top concept
- Hand crank turns both feed auger and exterior burr plate
- Interior burr plate is stationary
- Burr plates approximately 3.5 inches in diameter

Dry maize Test:

- 6 ounces in 1min 50 s (5.56 kg/hr)
- Finest flour of any test
- Largest particle size of approximately .5 mm
- Milling took a fair amount of torque

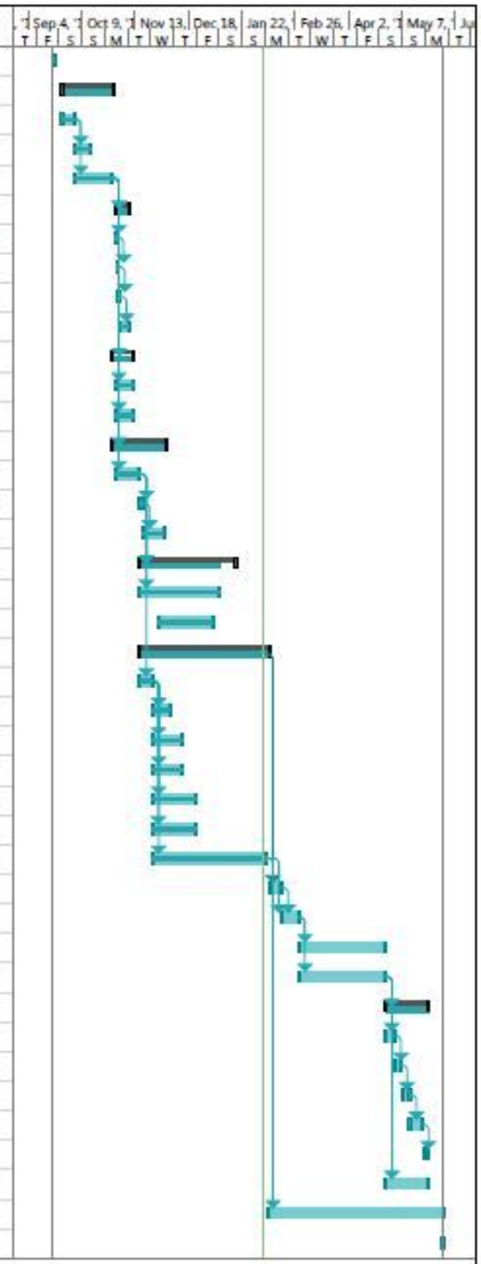
Appendix D. (continued)

Soaked maize Test:

- 6 ounces in 1min 15s (8.16 kg/hr)
- Required less torque to operate
- Flour appears to be comprised of flakes
- Particles appear to have been squished rather than ground, resulting in flakes
- Largest particle size approximately 1-2 mm
- Flour has different texture and color

Appendix E.

ID	Task Mode	Task Name	Duration	Start	Finish
1	✓	Choose Project	1 day	Tue 9/20/16	Tue 9/20/16
2	✓	**Define Project**	**26 days**	**Mon 9/26/16**	**Sat 10/29/16**
3	✓	Sponsor Meeting	6 days	Mon 9/26/16	Mon 10/3/16
4	✓	Problem Statement	9 days	Tue 10/4/16	Fri 10/14/16
5	✓	Project Proposal	19 days	Tue 10/4/16	Fri 10/28/16
6	✓	**Conceptualize Solutions**	**7 days**	**Mon 10/31/16**	**Tue 11/8/16**
7	✓	Ideation Session(1)	1 day	Mon 10/31/16	Mon 10/31/16
8	✓	Ideation Session(2)	1 day	Tue 11/1/16	Tue 11/1/16
9	✓	Ideation Session(3)	1 day	Wed 11/2/16	Wed 11/2/16
10	✓	Concept Design	4 days	Thu 11/3/16	Tue 11/8/16
11	✓	**Pick a Solution**	**11 days**	**Sat 10/29/16**	**Fri 11/11/16**
12	✓	Pugh Matrices	10 days	Mon 10/31/16	Fri 11/11/16
13	✓	Decision Matrix	10 days	Mon 10/31/16	Fri 11/11/16
14	✓	**Prepare Design Review**	**26 days**	**Sat 10/29/16**	**Fri 12/2/16**
15	✓	PDR Report	12 days	Mon 10/31/16	Tue 11/15/16
16	✓	Presentaion	2 days	Wed 11/16/16	Thu 11/17/16
17	✓	Sponsor Meeting	10 days	Fri 11/18/16	Thu 12/1/16
18	✓	**Detail Design**	**46 days**	**Tue 11/15/16**	**Tue 1/17/17**
19	✓	SolidWorks	38 days	Wed 11/16/16	Fri 1/6/17
20	✓	Analysis	26 days	Mon 11/28/16	Mon 1/2/17
21	✓	**Prepare CDR**	**61 days**	**Wed 11/16/16**	**Wed 2/8/17**
22	✓	Fix PDR Issues	6 days	Wed 11/16/16	Wed 11/23/16
23	✓	Maintenance/Repair	8 days	Thu 11/24/16	Mon 12/5/16
24	✓	Cost Analysis	14 days	Thu 11/24/16	Tue 12/13/16
25	✓	Functional Description	14 days	Thu 11/24/16	Tue 12/13/16
26	✓	Analysis	21 days	Thu 11/24/16	Thu 12/22/16
27	✓	Fabrication/Assembly	21 days	Thu 11/24/16	Thu 12/22/16
28	✓	Report	53 days	Thu 11/24/16	Mon 2/6/17
29		Sponsor Design Approval	6 days	Thu 2/9/17	Thu 2/16/17
30		Order Supplies	7 days	Fri 2/17/17	Mon 2/27/17
31		Manufacturing	41 days	Tue 2/28/17	Tue 4/25/17
32		Assembly	41 days	Tue 2/28/17	Tue 4/25/17
33		**Test**	**20 days**	**Wed 4/26/17**	**Tue 5/23/17**
34		Power Test	4 days	Wed 4/26/17	Mon 5/1/17
35		Grinding Rate Test	4 days	Tue 5/2/17	Fri 5/5/17
36		"Metal" Test	4 days	Mon 5/8/17	Thu 5/11/17
37		Effectiveness Test	6 days	Fri 5/12/17	Fri 5/19/17
38		Reliability Test	2 days	Mon 5/22/17	Tue 5/23/17
39		Saftey Test	20 days	Wed 4/26/17	Tue 5/23/17
40		Prepare FDR	83 days	Wed 2/8/17	Fri 6/2/17
41		Design Expo	1 day	Fri 6/2/17	Fri 6/2/17



Project: GanttChart Ed3
Date: Sun 2/5/17

Task		Inactive Summary		External Tasks	
Split		Manual Task		External Milestone	
Milestone		Duration-only		Deadline	
Summary		Manual Summary Rollup		Progress	
Project Summary		Manual Summary		Manual Progress	
Inactive Task		Start-only			
Inactive Milestone		Finish-only			

Page 1

Appendix F.

Appendix F: Static Load Shaft Stress Calculation

CALCULATION OF STRESSES INHERENT IN A STATIC LOADING SITUATION

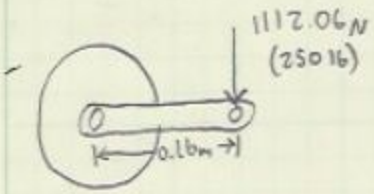
KNOWN: A PERSON WEIGHING 250 lb SHOULD BE ABLE TO APPLY THEIR COMPLETE WEIGHT TO ONE OF THE OPERATING PEDALS AND THE GRINDING MECHANISM SHOULD NOT BREAK. THE GRINDER OPERATES AT APPROXIMATELY 60 RPM.

FIND: a) GRINDING SHAFT TORQUE

b) REQUIRED GRINDING SHAFT DIAMETER FOR IRON

ASSUMPTIONS: MINIMUM RIDER HEIGHT OF 5'5", MAX OPERATOR WEIGHT OF 250 lb, CYCLING CADENCE OF 70 RPM

a) ASSUMING RIDER HEIGHT OF AT LEAST 5'5", THE BIKE CRANK ARM SHOULD BE 0.16 m



$$T_C = 1112.06_N \cdot 0.16_m$$

$$T_C = 117.93_{Nm}$$

FIND THE APPLIED (CRANK) TORQUE

$$T_G = T_C \cdot \frac{W_C}{W_G}$$

$$= 117.93_{Nm} \cdot \frac{70_{rpm}}{60_{rpm}}$$

$$\boxed{T_G = 137.59_{Nm}}$$

FIND THE TORQUE APPLIED TO THE GRINDING SHAFT

Appendix F. (continued)

6) $\tau_y = \frac{Tr}{J}$ EQUATION FOR YIELD STRESS

$130 \cdot 10^6 \, Pa = \frac{137.59 \, Nm \cdot r}{\frac{\pi (2r)^4}{32}}$ USE YIELD STRESS FOR CAST IRON.

(CAST IRON)

$130 \cdot 10^6 \, Pa = \frac{87.58}{r^3}$

$r = 0.00877 m$

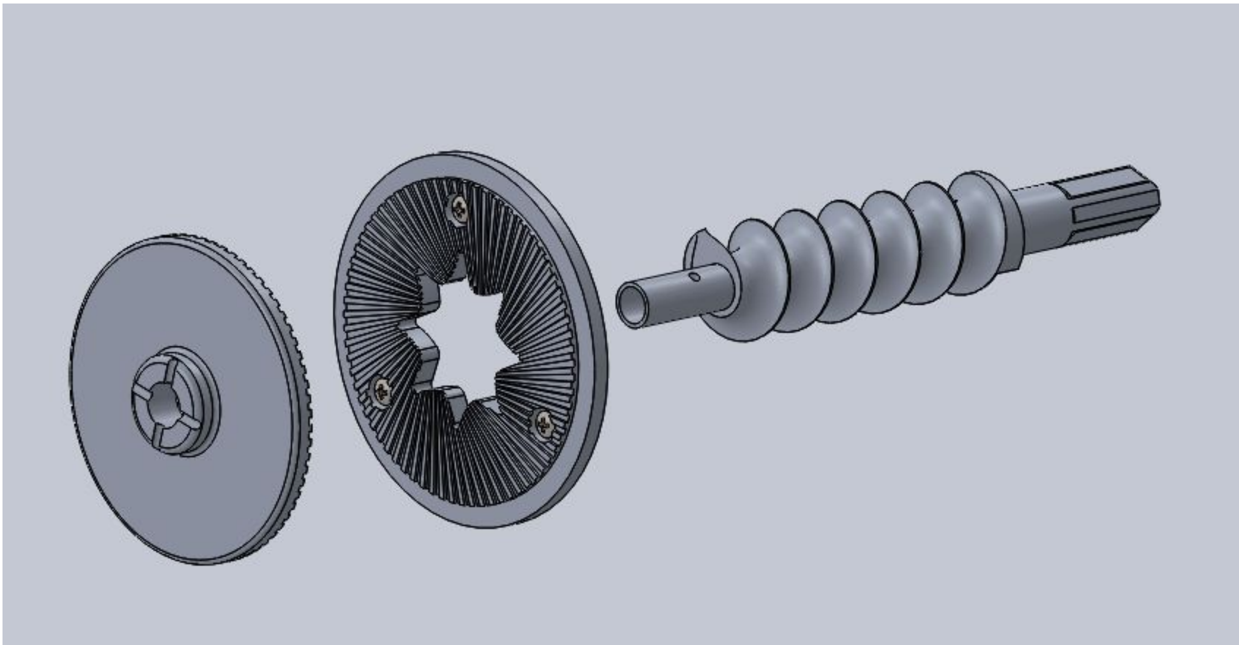
$r = 8.77 mm$

$D = 2r$

$\boxed{D = 17.54 mm}$

THIS IS A VERY REASONABLE DIAMETER FOR THE GRINDER DRIVING SHAT

Appendix G.
Burr plate SolidWorks assembly.



Solidworks was modified from a free Solidworks burr plate mill download, from grabcad.com.

Appendix H.

DESIGN HAZARD CHECKLIST

Team: Maize Mill   Advisor: Professor Rossman

Y	N	
■	□	1. Will any part of the design create hazardous revolving, reciprocating, running, shearing, punching, pressing, squeezing, drawing, cutting, rolling, mixing or similar action, including pinch points and sheer points?
■	□	2. Can any part of the design undergo high accelerations/decelerations?
□	■	3. Will the system have any large moving masses or large forces?
□	■	4. Will the system produce a projectile?
□	■	5. Would it be possible for the system to fall under gravity creating injury?
□	■	6. Will a user be exposed to overhanging weights as part of the design?
■	□	7. Will the system have any sharp edges?
□	■	8. Will any part of the electrical systems not be grounded?
□	■	9. Will there be any large batteries or electrical voltage in the system above 40 V?
■	□	10. Will there be any stored energy in the system such as batteries, flywheels, hanging weights or pressurized fluids?
□	■	11. Will there be any explosive or flammable liquids, gases, or dust fuel as part of the system?
■	□	12. Will the user of the design be required to exert any abnormal effort or physical posture during the use of the design?
■	□	13. Will there be any materials known to be hazardous to humans involved in either the design or the manufacturing of the design?
■	□	14. Can the system generate high levels of noise?
■	□	15. Will the device/system be exposed to extreme environmental conditions such as fog, humidity, cold, high temperatures, etc?
□	■	16. Is it possible for the system to be used in an unsafe manner?
□	■	17. Will there be any other potential hazards not listed above? If yes, please explain on reverse.

For any "Y" responses, add (1) a complete description, (2) a list of corrective actions to be taken, and (3) date to be completed on the reverse side.

Appendix H - Continued

Description of Hazard	Planned Corrective Action	Planned Date	Actual Date
Spinning burr plate	Add a cover as well as hazard stickers	3/1	
Foreign objects being caught in mill	Put sieve in hopper	3/1	
Sharp burrs on burr plate	Add a cover as well as hazard stickers	3/1	
May have a flywheel store inertia	Consult with Shaft on potential cover methods and hazrd signs	3/1	
Requires user to exert themselves physically in order to operate mill	Put recommended maximum time of use in user manual	3/1	
Manufacturing incorparates dangerous processes such as machining and casting	Only have experienced people build our design	3/1	
System can produce large amounts of noise	Recommend use of earplugs in user manual	3/1	
System will be exposed to extreme environmental conditions (high heat and humidity)	use only materials that will not deform easily in high heat	3/1	

Appendix I.

BURR PLATE DIAMETER CALCULATION

KNOWN: • ASTRELLA BURR PLATE MILL GRIND RATE: 5.56 Kg/hr
• ASTRELLA BURR PLATE DIAMETER: 3.5 in

FIND: BURR PLATE DIAMETER NECESSARY TO ACHIEVE 15 Kg/hr GRIND RATE

ASSUME: GRIND RATE PROPORTIONAL TO BURR PLATE SURFACE AREA

$$A_u = \pi\left(\frac{D_u}{2}\right)^2$$

$$= \pi\left(\frac{3.5\,in}{2}\right)^2$$

$$A_u = 9.62\,in$$

$$\frac{\dot{m}_u}{A_u} = \frac{\dot{m}_n}{A_n}$$

$$\frac{5.56\,kg/hr}{9.62\,in^2} = \frac{15\,kg/hr}{\pi\left(\frac{D_n}{2}\right)^2}$$

$$25.95\,in^2 = \pi\left(\frac{D_2}{2}\right)^2$$

$$\boxed{D_2 = 5.75\,in}$$

Burr plates should be at least this diameter since this is our target MINIMUM grinding rate.

CDR

Analysis: BURR PLATE SIZE

Appendix J.

TORQUE DEMANDED BY MILL

from testing (3.5 in Plate): • 10 - 17.5 ft lb operating torque
• 22.5 ft lb max torque seen

Scale up as proportion of surface area:

new plate diameter: 5.75in (see pg. 28)

$$A_0 = \pi\left(\frac{3.5in}{2}\right)^2$$

$A_0 = 9.62$

$$A_2 = \pi\left(\frac{5.75}{2}\right)^2$$

$A_2 = 25.97 in^2$

$$\frac{22.5 ft lb}{9.62 in^2} = \frac{\tau_{2max}}{25.97 in^2}$$

$\tau_{2max} = 60.74$ ft lb (82.35 Nm)

$$\frac{17.5 ft lb}{9.62 in^2} = \frac{\tau_{op}}{25.97 in^2}$$

$\tau_{op} = 47.24$ ft lb (64.05 Nm)

$$\frac{10 ft lb}{9.62 in^2} = \frac{\tau_{op_0}}{25.97 in^2}$$

$\tau_{op_0} = 27$ ft lb (36.61 Nm)

operating torque:	27 - 47.24 ft lb (36.61 - 64.05 Nm)
Max torque:	60.74 ft lb (82.35 Nm)

$$\frac{150w}{64.05Nm} = 2.342 \text{ rad/s} = 22.36 \text{ rpm}$$

$$\frac{150w}{36.6Nm} = 4.098 \text{ rad/s} = 39.14 \text{ rpm}$$

CDR

Design Analysis: Torque (demanded)

Appendix K.

RPM TESTING:

TRIAL 1: 11 in 32s (TIGHT) ← CONSISTENCY OF THIS RUN WAS MUCH BETTER

TRIAL 2: 15 in 32s

$$\frac{11}{32} = \frac{w}{60}$$

$$\boxed{w = 20.63 \text{ rpm}}$$

$$\frac{15}{32} = \frac{w_2}{60}$$

$$\boxed{w_2 = 28.13 \text{ rpm}}$$

Torque output of 150w bike:

$$\frac{20 \text{ rpm} \cdot 2\pi \text{ rad/r}}{60 \text{ s/m}} = 2.09 \text{ rad/s}$$

$$\frac{150\text{w}}{2.04 \text{ rad/s}} = \boxed{71.62 \text{ Nm}}$$

$$\frac{30 \text{ rpm} \cdot 2\pi \text{ rad/r}}{60 \text{sm}} = 3.14 \text{ rad/s}$$

$$\frac{150\text{w}}{3.14 \text{ rad/s}} = \boxed{47.75 \text{ Nm}}$$

$$\boxed{\text{Supplied torque } (20\text{-}30 \text{ rpm})\text{: } 47.75 \text{Nm} - 71.62 \text{Nm}}$$

RPM BASED ON OPERATIONAL DEMANDED TORQUE.

$$\frac{150\text{w}}{64 \text{Nm}} = 2.3 \text{ rad/s}$$

$$\frac{2.3 \text{ rad/s} \cdot 60 \text{ s/m}}{2\pi} = 22 \text{ rpm}$$

CDR

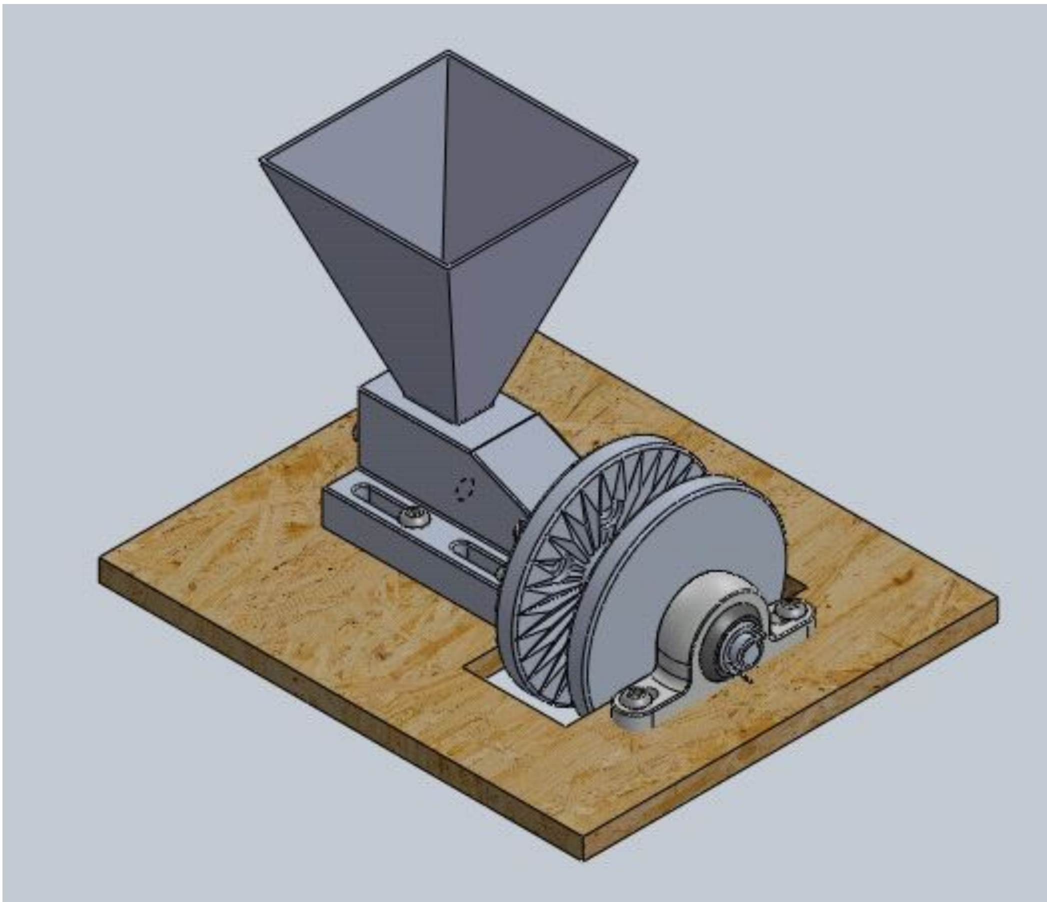
Design Analysis: Torque Supplied (w/ testing)

Appendix L.

Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurrence	Criticality	Recommended Action(s)	Responsibility & Target Completion Date
Grinding	Grinding Rate too Slow	longer time needed for operation	2	Low RPM	5	15		
		user fatigue	3	Too much friction	3	9		
	Binding	unable to operate	6	Plates contacting	3	21	Design gap between plates	Maize Mill Team, 3/1/16
		wares down grinding plate	4	High density of maize	4	28	Design hopper to allow limited feed rate	Maize Mill Team, 3/1/16
		could break connecting shaft	7	Foreign object in mill	1	7		
	Flour not fine enough	inadequate for making nsima	5	Dull burrs	2	10		
				Maize not being ground for long enough	7	35	Design corn flowrate adjuster	Maize Mill Team, 3/1/16
				Plates too far apart	6	30	Design gap between plates	Maize Mill Team, 3/1/16
	Low effectiveness (%flour)	Requires repetition	2	Maize falling out prematurely	5	15		
		wasted user effort	3	flat/flakey discharged particles	4	12		
		potential for wasted maize	3			0		
Maize Feed	Clogged	Unable to operate	4	Corn locks into a specific pattern	3	12		
	Does not feed fast enough	Low grinding rate	2	Designed opening is too small	10	20	Design adjustable hopper entrance	Maize Mill Team, 3/1/16
	Feeds too fast	Binding of grinding mechanism	4	Designed opening is too big	10	40	Design adjustable hopper entrance	Maize Mill Team, 3/1/16
	Spilling	Wasted maize	4	Hopper walls not high enough	10	40	Design adjustable hopper	Maize Mill Team, 3/1/16
		Requires user clean up	2	Hopper not wide enough	10	40	Design adjustable hopper	Maize Mill Team, 3/1/16
				Damaged hopper	1	4		
Power Coupling	Connection Breaks	Mill does not grind	7	Excessive Torque	2	14		
		User experiences jerk	6	Sudden Binding	7	49	Put sieve in hopper to keep out foreign abjects	Maize Mill Team, 3/1/16
		Wasted power	3	Weak Connection	10	70	Connection rated for max impact torque	Maize Mill Team, 3/1/16
		No food until fixed	4			0		
	Connection does not fit	Mill does not grind	5	Miscommunication with Shaft team	3	15		
		Inoperable	5	Faulty connections	10	50	Make or buy high quality parts	Maize Mill Team, 3/1/16
		No food until fixed	4			0		
Sanitation	Metal Shears Off Plates	Inedible nsima	8	Burr plates are too close together	4	32		
				Material is not hard enough	10	80	Buy materials rate for max applied forces	Maize Mill Team, 3/1/16
	Not made of a safe material	Inedible nsima	8	Low quality material used	10	80	Make sure material is non-toxic	Maize Mill Team, 3/1/16
				Toxic chemicals on material while manufacturing	10	80	Design Properly	Maize Mill Team, 3/1/16

Appendix M.

MAIZE MILL OPERATION MANUAL



Designers: Wes Curtis, Jose Delgado, Chad Steese

WARNINGS!!

Unsafe use of this product could result in damage to the product, personal injury, or DEATH.

Dangers:

- Product is rigid and heavy which could cause harm or death if used as a weapon.
- Product has rotating auger which could cause severe injury or death if in contact with any body part.
- Incorrect installation may cause metal bits to contaminate flour and cause severe harm or death.
- Product may require one to exert themselves for use which may cause severe injury or death.
- Product has small parts that if ingested will cause severe injury or death.
- Do not apply lubricants to the mill. Most lubricants are poisonous and will result in inedible flour

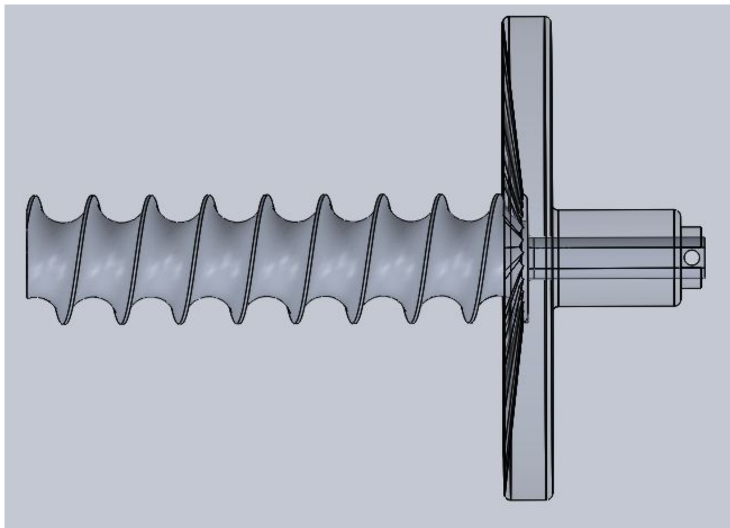
---

Cautions:

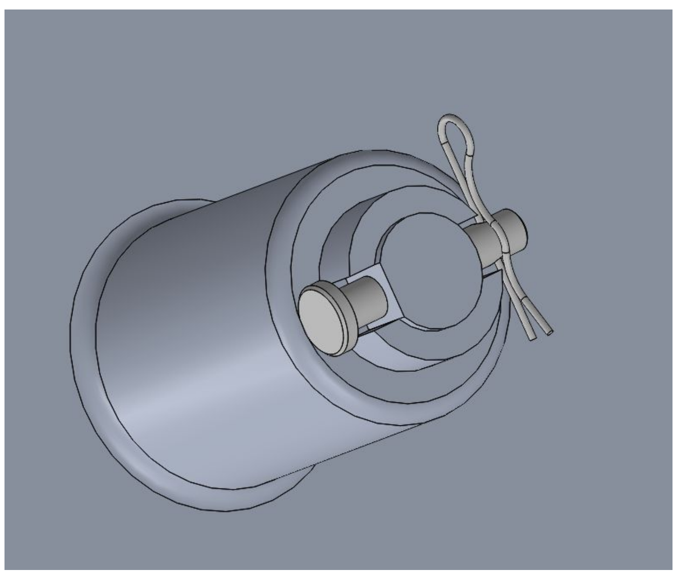
- Product may have sharp edges which could cause minor injuries.
- Product has rotating parts which may latch onto long hair, jewelry, or loose clothing.
- Product is heavy and may cause minor injury if dropped.
- Product has multiple pinching points that may cause minor harm.

Assembly

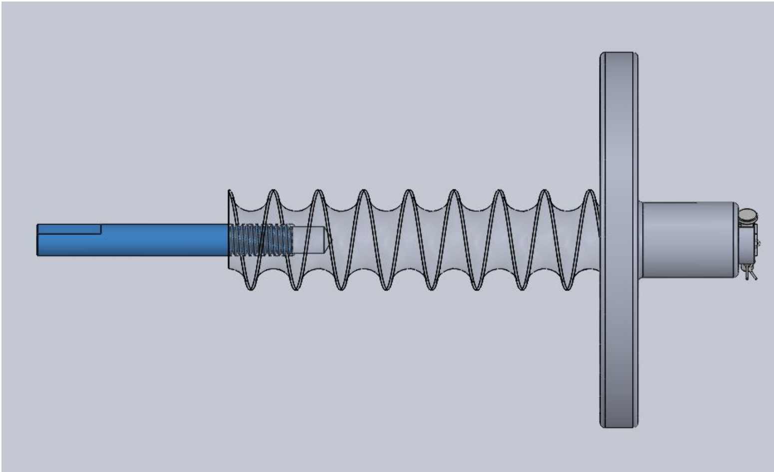
1. Insert the auger into the moving burr plate.
2. Remove the key from the pin.
3. Align the small hole on the auger with the slot of the moving burr plate. Push the pin through the hole.



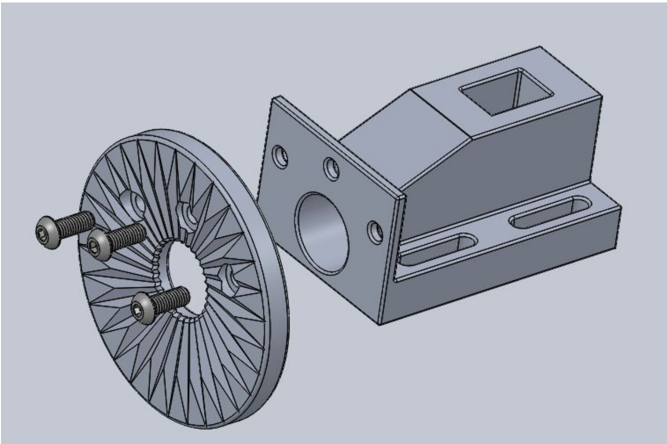
4. Lock the pin in place by inserting the key through the pin.



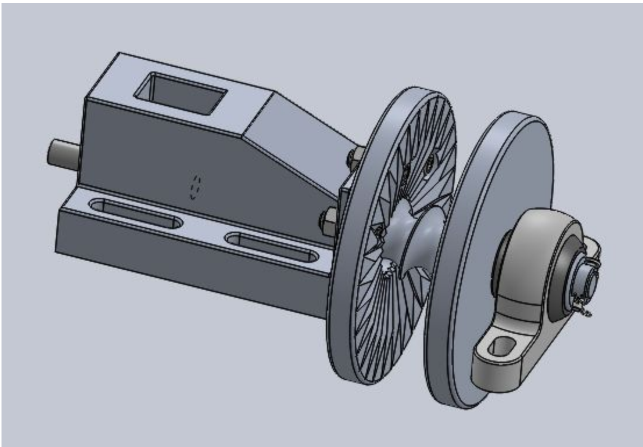
5. Screw the shaft into the large hole in the auger.



6. Put the small diameter of the moving burr plate into the pillow block and secure with the set screw.
7. Screw on the stationary burr plate into the auger housing using 3 nuts and 3 of the short bolts.

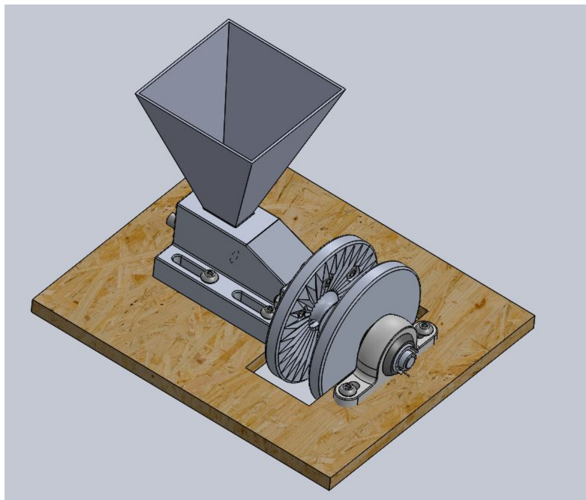


8. Insert the shaft and auger into the auger housing and make sure it can rotate freely.



9. Put the flat surfaces of the auger housing and the pillow block on top of the base plate. The assembly should lay flat against the surface with the burr plates resting in the rectangular cut out on the base plate.

    Note: The rectangular slot on the auger housing should be facing up.
10. Secure the auger housing to the base plate using four nuts and long bolts.
11. Secure the pillow block to the base plate with the remaining two nuts and bolts.
12. Insert the hopper into the auger housing.



13. Couple shafts.

Operation

1. Inspect corn and remove foreign objects and debris.
2. Pour corn into auger. Do not overflow.
3. Make sure there is a bucket under the burr plates to catch the flour.
4. Sit on the bike and start pedaling until all the corn has passed through the mill.

    Warning: If the bike jams. STOP PEDALING and inspect mill.
5. Use a sieve on the discharged flour to obtain proper flour fineness.
6. Enjoy your flour for Nsima!!!

Cleaning Mill and Unclogging Foreign Debris

1. Uncouple the shafts.
2. Unscrew the auger housing and pillow blocks from the base plate.
3. Remove excess corn and foreign debris.
4. Wipe down mill with a damp cloth.
5. Thoroughly dry, then reassemble starting from Step 8 of the assembly section.

Maintenance and Repair

- Prior to each use, inspect the mill for chips and other damage.
- If any part is cracked, or pieces have broken off STOP USING THE PART and replace it.
- If any part needs to be repaired or replaced see your local machine shop. All parts can be remade with the drawings attached.

Appendix N.

Indented Bill of Materials

Maize Mill Indented Bill of Materials (BOM)

Team 35

Assembly Number	Part Number	Levels (Level 0 / Level 1 / Level 2)	Vendor	Qty	Material	Mass(lb)	Cost($/lb)	Total Cost
0	1000	Final Assembly	-	-	-	-	-	-
1	1001	Auger Housing	Cal Poly Shop	1	Aluminum	1.30	$ 0.60	$ 0.78
1	1002	Stationary Burr Plate	Cal Poly Shop	1	Aluminum	1.29	$ 0.60	$ 0.77
1	1003	Rotating Burr Plate Support	Cal Poly Shop	1	Aluminum	0.28	$ 0.60	$ 0.17
1	1004	Hopper	Cal Poly Shop	1	Steel	-	$ 25.00	$ 25.00
1	1005	Base Plate	Cal Poly Shop	1	Wood	-	$ 10.00	$ 10.00
1	1006	Housing/Suppot Bolts	McMASTER	6	-	-	$ 0.76	$ 4.56
1	1007	Stationary Burr Plate Bolts	McMASTER	3	-	-	$ 0.48	$ 1.44
1	1008	Bolt Nuts	McMASTER	9	-	-	$ 0.16	$ 1.44
1	1100	Auger Assembly	-	-	-	-	-	-
2	1101	Rotating Burr Plate	Cal Poly Shop	1	Aluminum	1.48	$ 0.60	$ 0.89
2	1102	Auger	Cal Poly Shop	1	Aluminum	0.57	$ 0.60	$ 0.34
2	1103	Shaft	Cal Poly Shop	1	-	-	$ 5.00	$ 5.00
2	1104	Pin	McMASTER	1	-	-	$ 0.37	$ 0.37
-	-	Left over material from casting	Cal Poly Shop	-	Aluminum	2.00	$ 0.60	$ 1.20
				27		4.92		$ 51.96

Total Prototype Cost $ 302.98

3-D Printing	
Cost($/in^3)	5.00
Al Density(lb/in^3)	0.10
Al Mass(lb)	4.92
Al Volume(in^3)	50.20
Model Cost($)	251.02

Appendix O

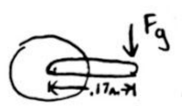
CALCULATION OF MINIMUM SHAFT DIAMETER

GIVEN: Aluminum, $m = 68\,kg$ (MAX RIDER MASS), $\tau_y = 240\ MPa$ (6061)

FIND: shaft diameter

ASSUMPTIONS: CRANK LENGTH OF 0.17m, RIDER CADENCE OF 70 rpm

ANALYSIS:



$$F_g = 68\,kg \cdot 9.8\,m/s^2$$
$$= 666.4\,N$$

$$T_c = 666.4\,N \cdot 0.17\,m$$
$$= 113.29\,Nm$$

$$T_G = T_c \cdot \frac{\omega_c}{\omega_G}$$

$$= 113.29\,Nm \cdot \frac{70\,rpm}{30\,rpm}$$

$$T_G = 264.34\,Nm$$

$$\tau_y = \frac{Tr}{J}$$

$$240 \cdot 10^6\,Pa = \frac{264.34\,Nm \cdot r}{\frac{\pi (2r)^4}{32}}$$

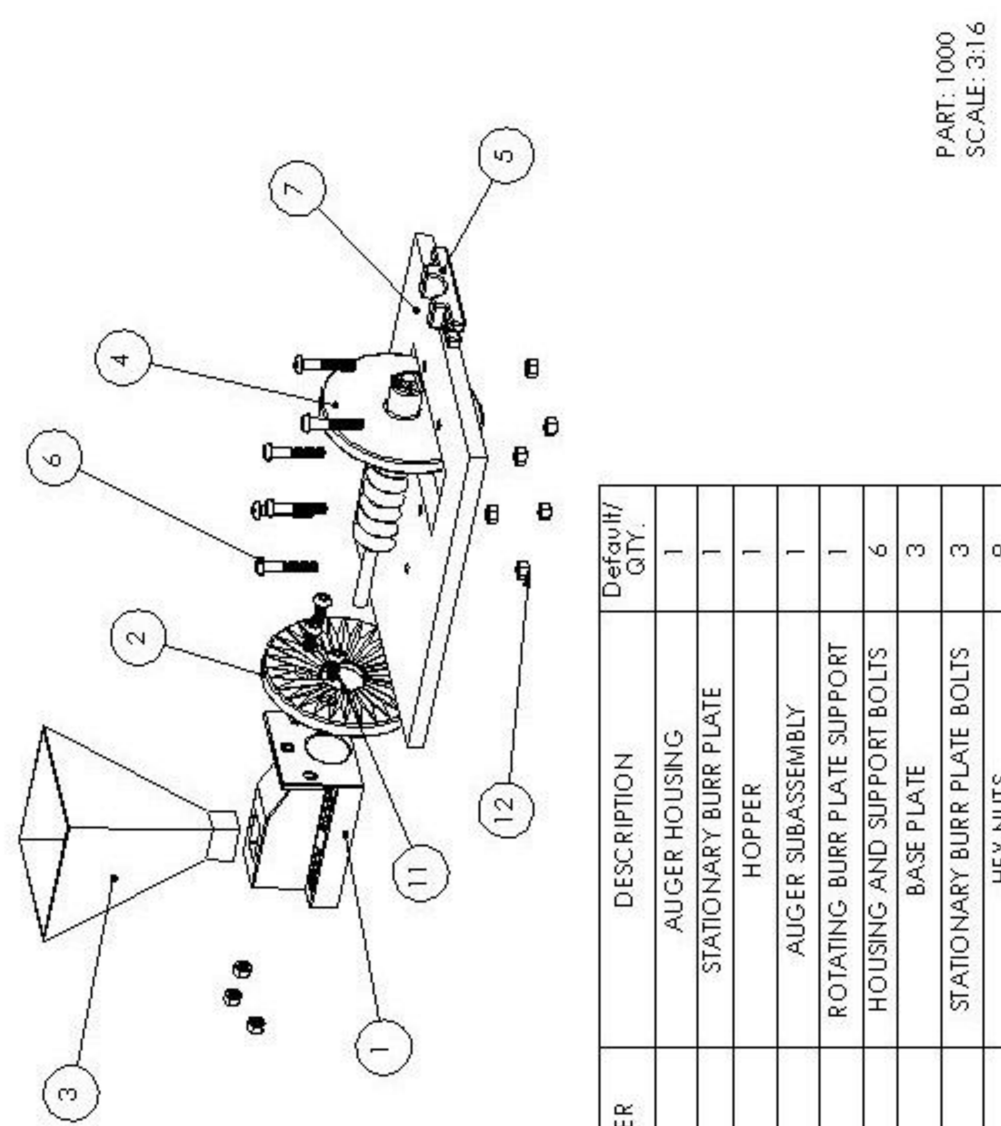
$$240 \cdot 10^6\,Pa = \frac{168.28}{r^3}$$

$$r = 0.0088\,m$$
$$= 8.88\,mm$$
$$= 0.35\,in$$

THIS GIVES A 1.43 FACTOR OF SAFETY WITH A .5 INCH SHAFT

Appendix P.

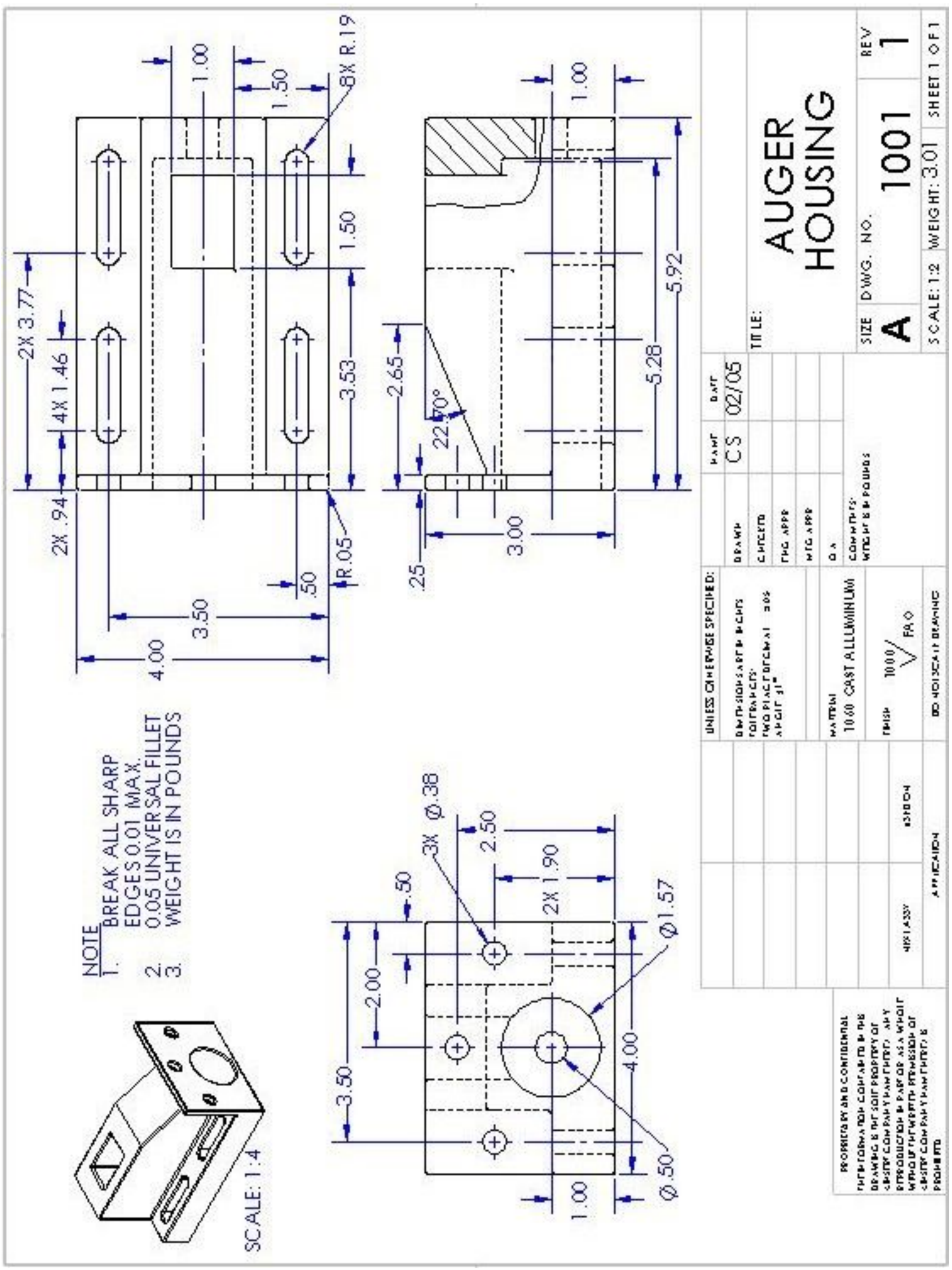
Part Drawings: 1000



ITEM NO.	PART NUMBER	DESCRIPTION	Default/ QTY.
1	1001	AUGER HOUSING	1
2	1002	STATIONARY BURR PLATE	1
3	1004	HOPPER	1
4	1100	AUGER SUBASSEMBLY	1
5	1003	ROTATING BURR PLATE SUPPORT	1
6	1006	HOUSING AND SUPPORT BOLTS	6
7	1005	BASE PLATE	3
11	1007	STATIONARY BURR PLATE BOLTS	3
12	1008	HEX NUTS	9

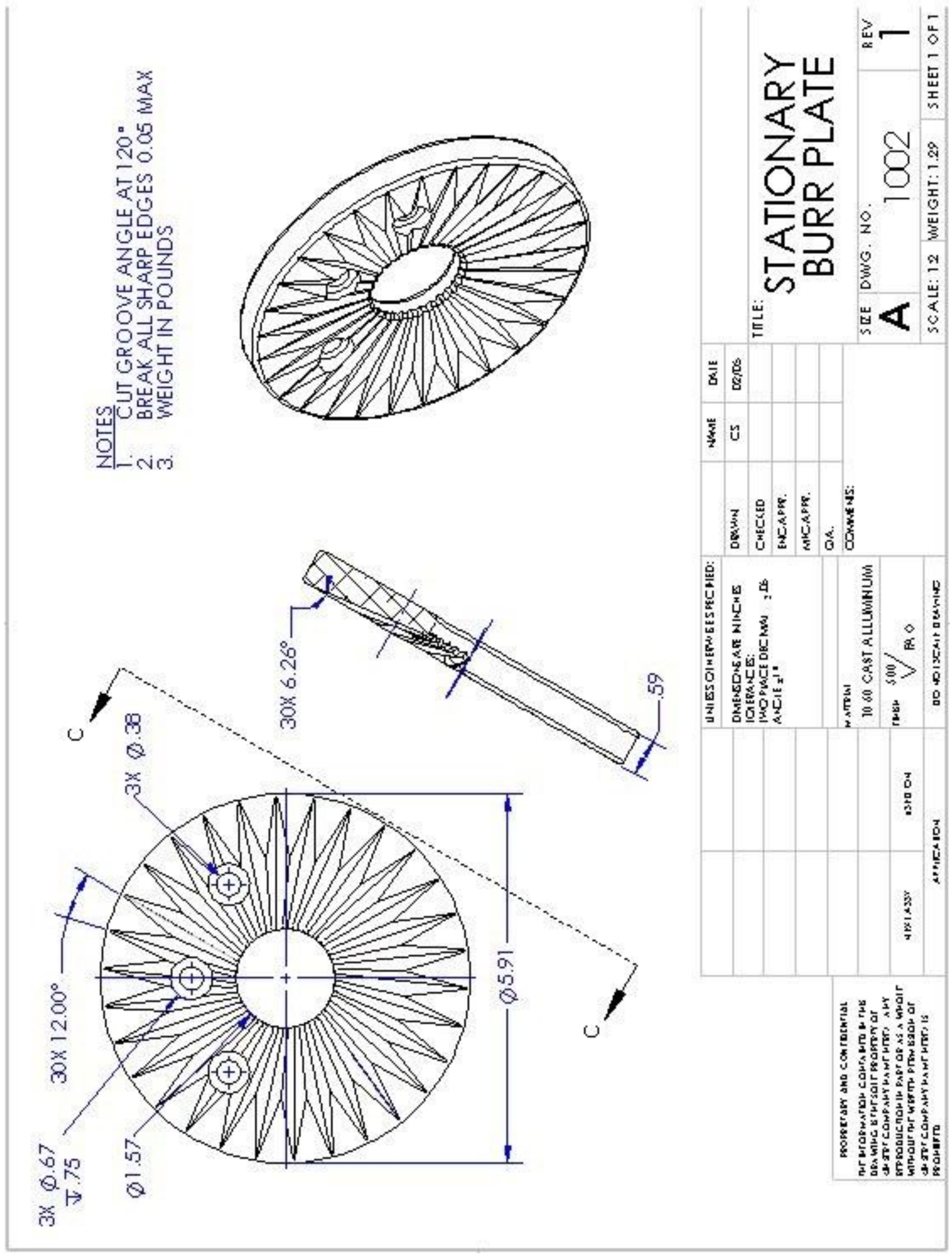
Appendix P. continued

Part Drawings: 1001



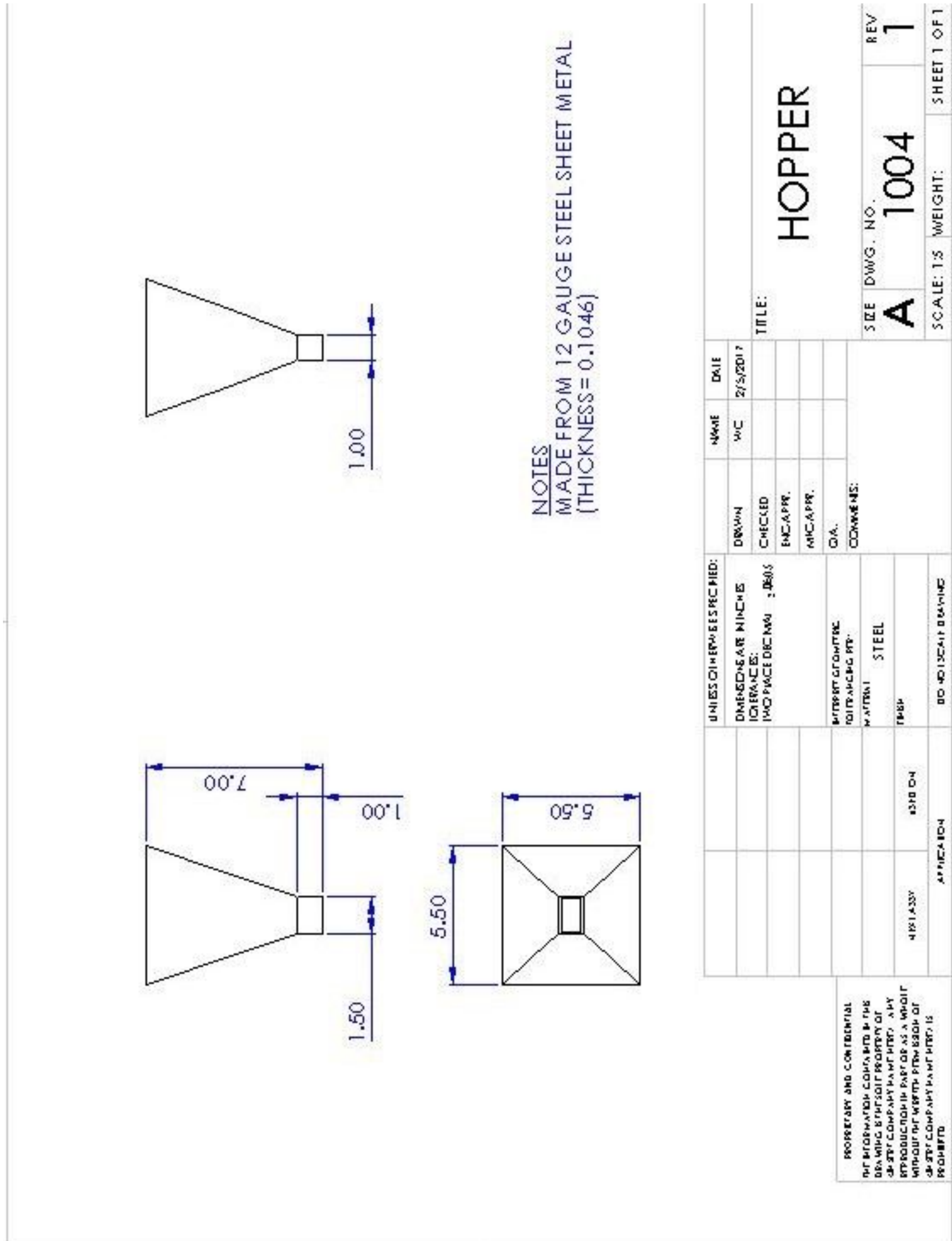
Appendix P. continued

Part Drawings: 1002



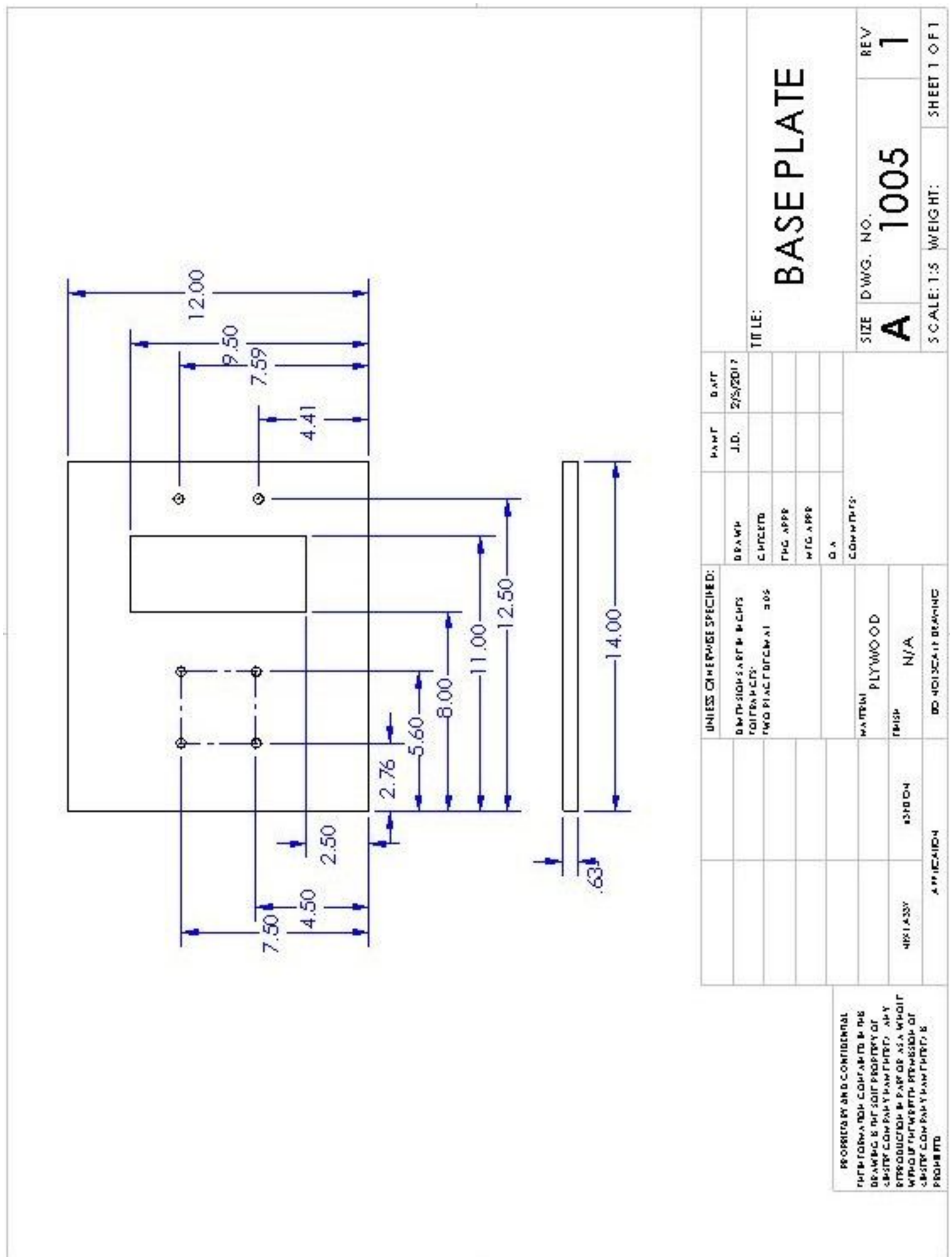
Appendix P. continued

Part Drawings: 1004



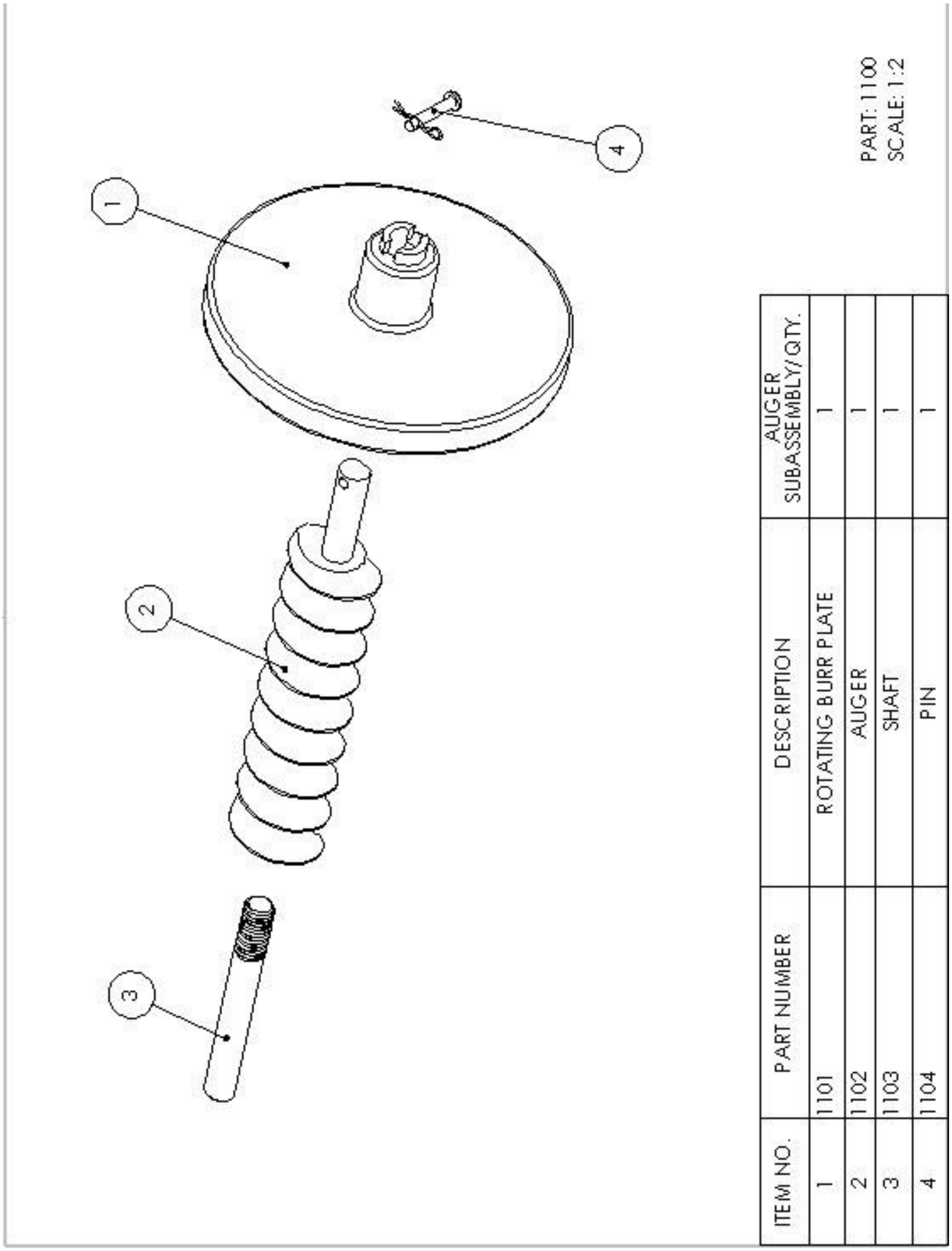
Appendix P. continued

Part Drawings: 1005



Appendix P. continued

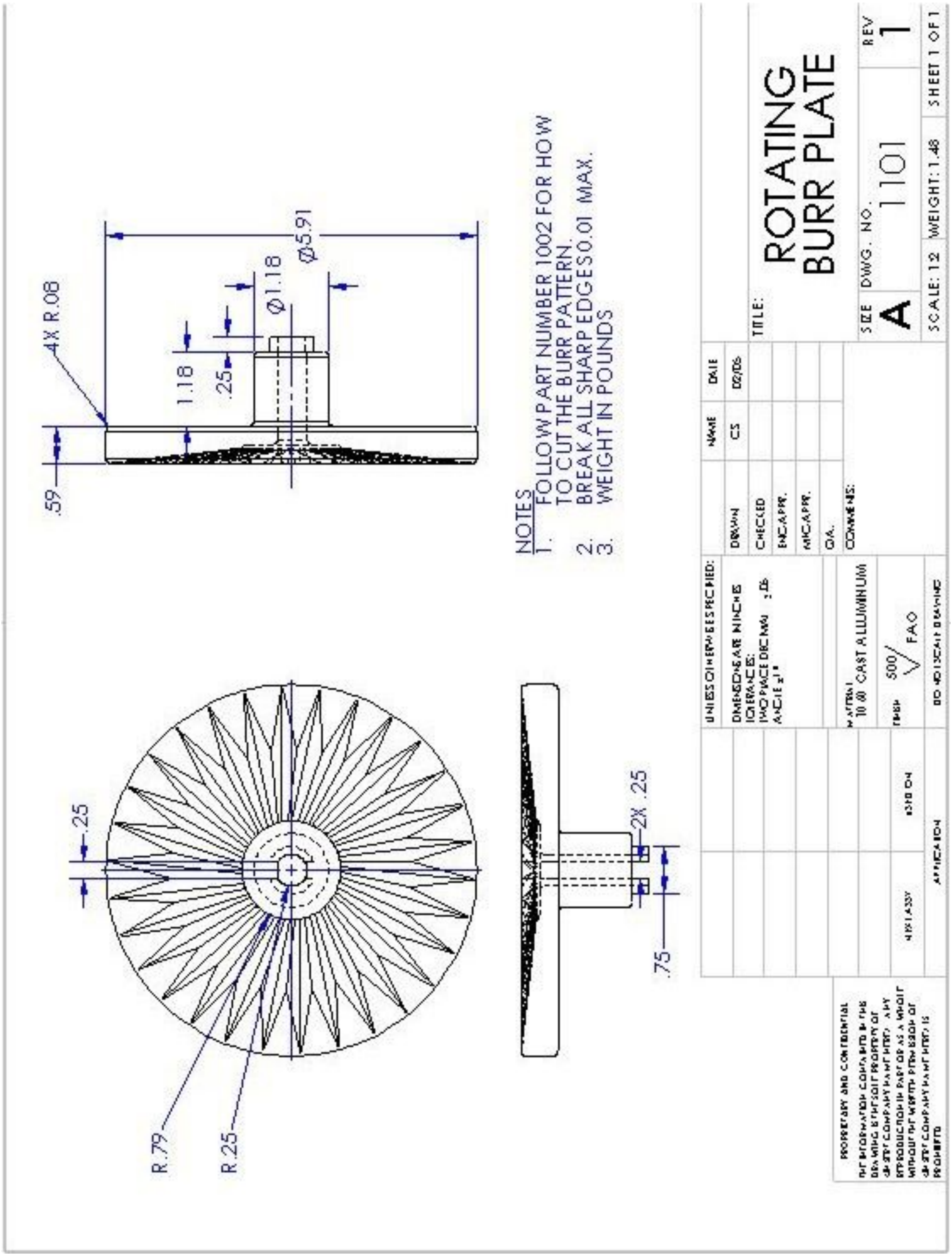
Part Drawings: 1100



ITEM NO.	PART NUMBER	DESCRIPTION	AUGER SUBASSEMBLY/ QTY.
1	1101	ROTATING BURR PLATE	1
2	1102	AUGER	1
3	1103	SHAFT	1
4	1104	PIN	1

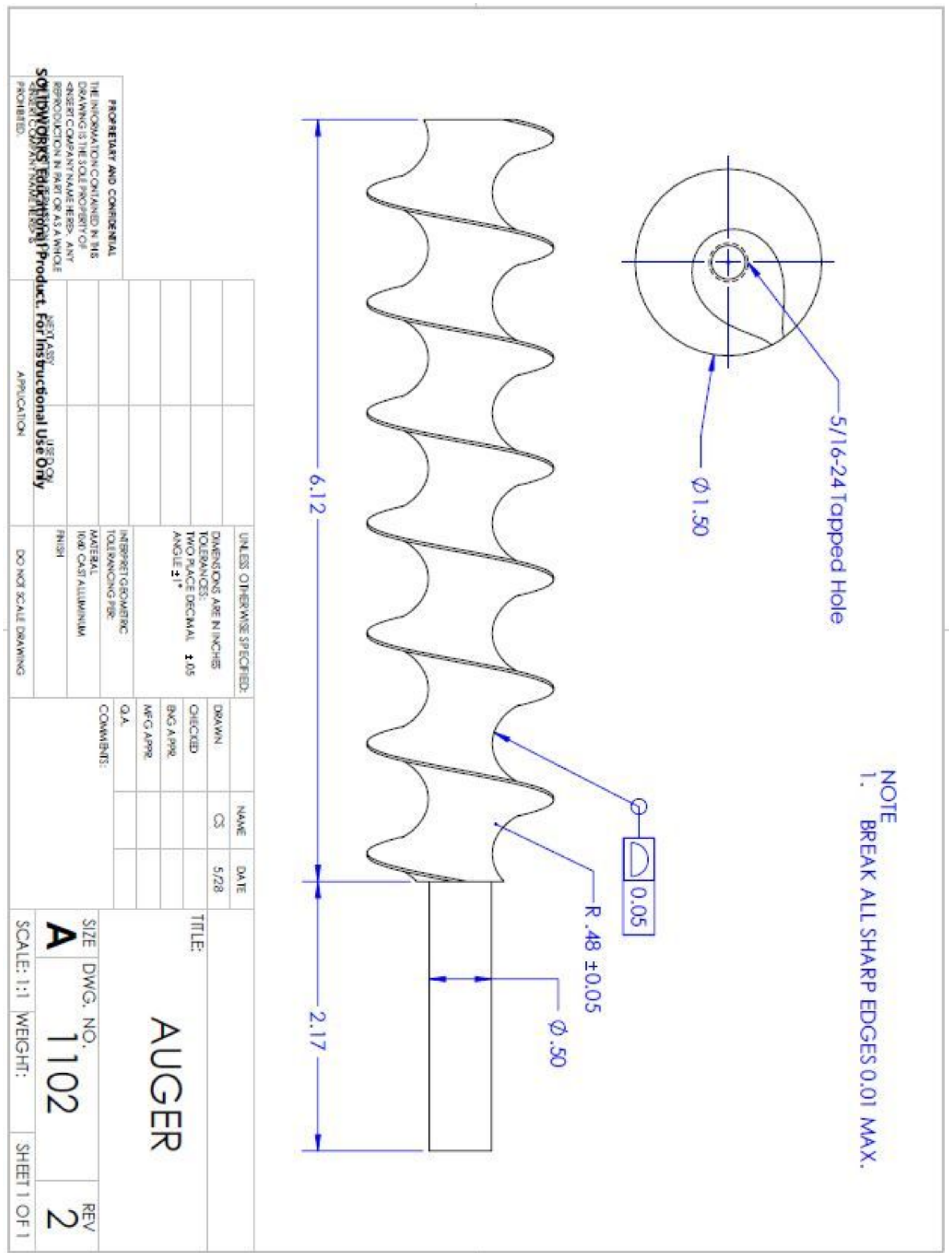
Appendix P. continued

Part Drawings: 1101



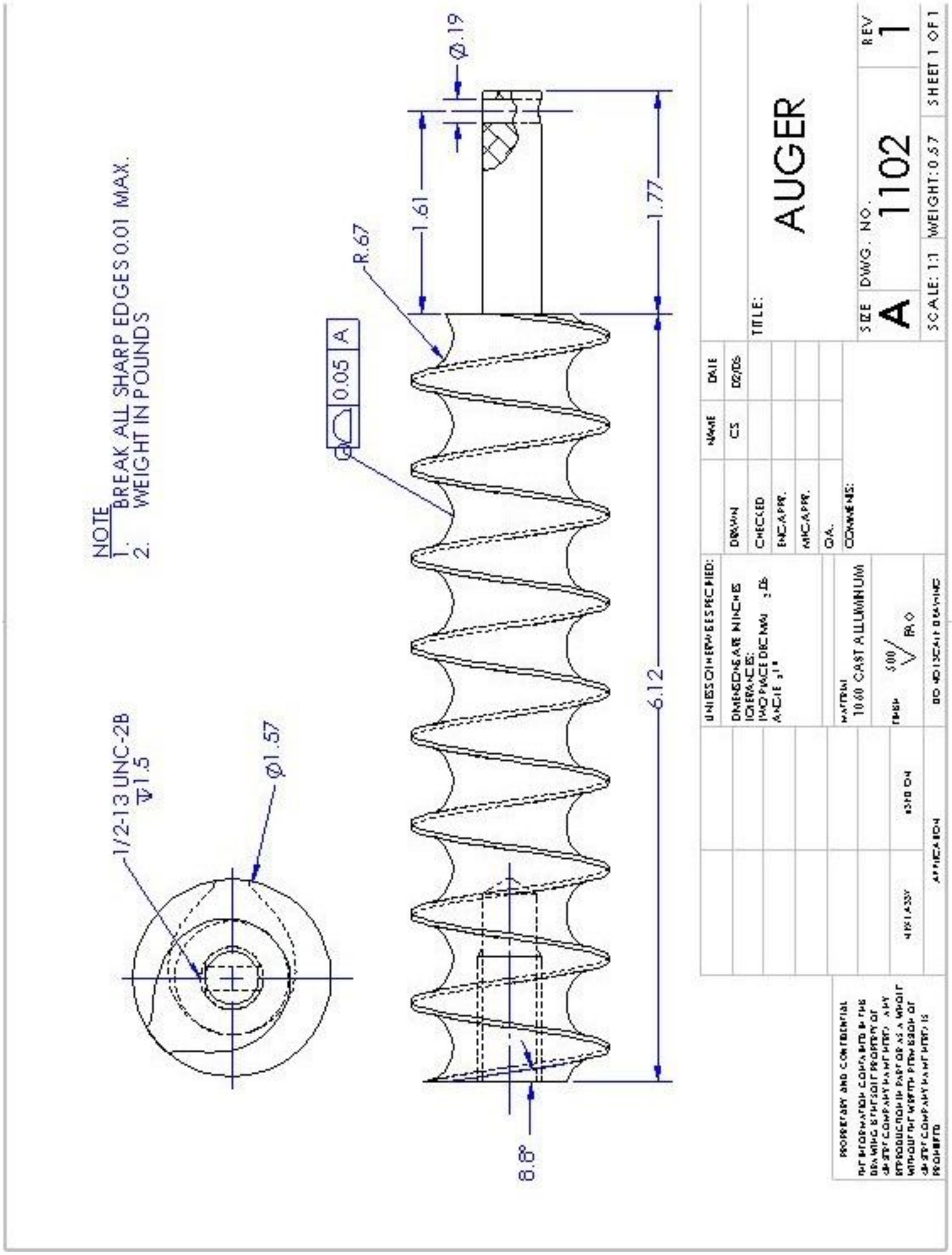
Appendix P. continued

Part Drawings: 1102 (New Revision)



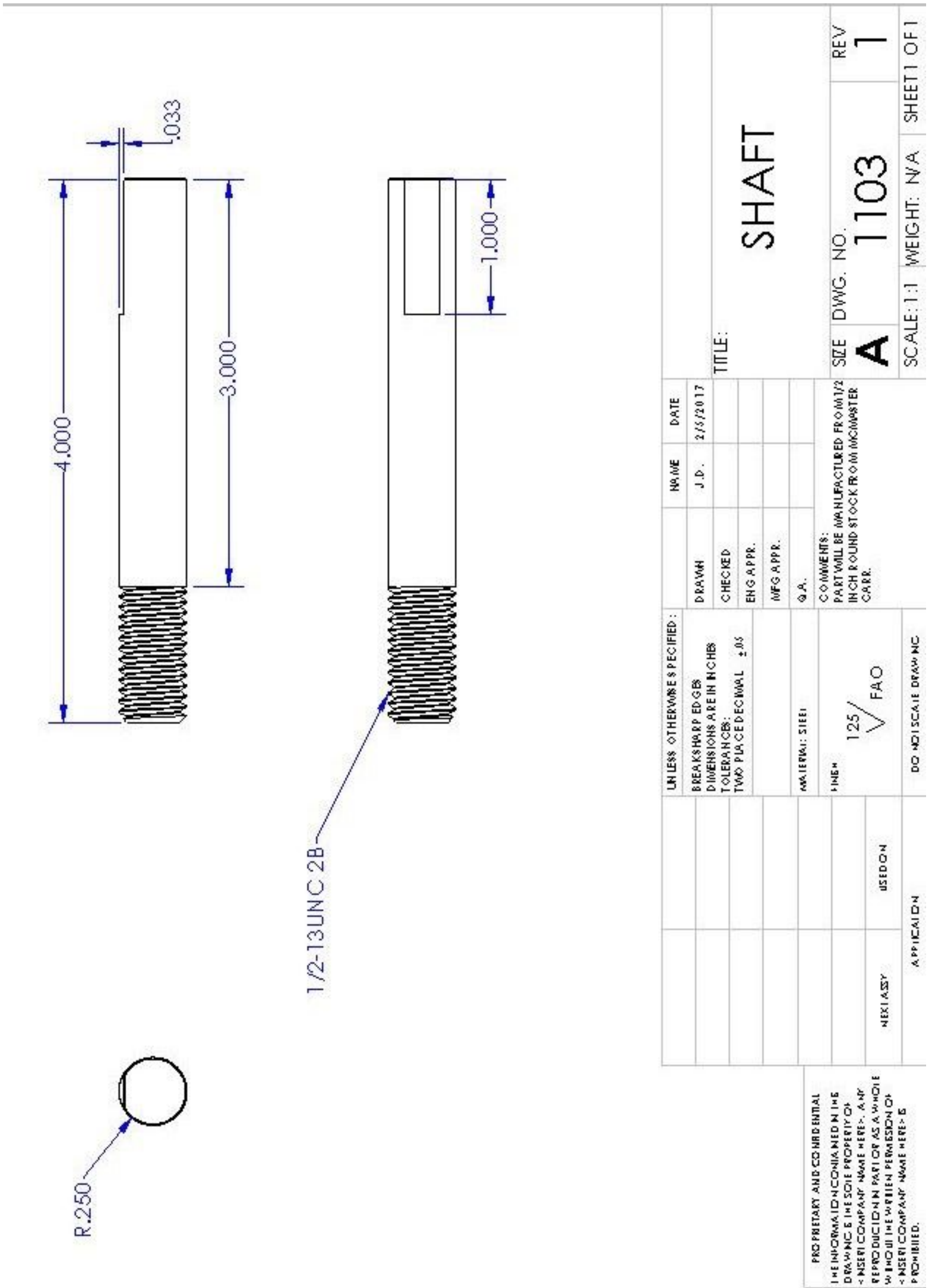
Appendix P. continued

Part Drawings: 1102 (Old Drawing)



Appendix P. continued

Part Drawings: 1103



Appendix Q.

Long Screw

McMASTER-CARR

Find

18-8 Stainless Steel Hex Drive Rounded Head Screw

3/8"-16 Thread Size, 2" Long

Packs of 10

ADD TO ORDER

In stock
$7.55 per pack of 10
92949A632

Thread Size	3/8"-16
Length	2"
Threading	Partially Threaded
Minimum Thread Length	1 1/4"
Head Diameter	0.656"
Head Height	0.199"
Drive Size	7/32"
Material	18-8 Stainless Steel
Hardness	Rockwell B55
Tensile Strength	70,000 psi
Screw Size Decimal Equivalent	0.375"
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 3A

Appendix Q. continued

Short Screw

MCMASTER-CARR

Find

18-8 Stainless Steel Hex Drive Rounded Head Screw

3/8"-16 Thread Size, 1" Long

Packs of 10

ADD TO ORDER

In stock
$4.71 per pack of 10
92949A624

Thread Size	3/8"-16
Length	1"
Threading	Fully Threaded
Head Diameter	0.656"
Head Height	0.199"
Drive Size	7/32"
Material	18-8 Stainless Steel
Hardness	Rockwell B55
Tensile Strength	70,000 psi
Screw Size Decimal Equivalent	0.375"
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 3A
Thread Direction	Right Hand

Appendix Q. continued

Hex Nut

MCMASTER-CARR

Find

Super-Corrosion-Resistant 316 Stainless Steel Hex Nut

3/8"-16 Thread Size, ASTM F594

Packs of 25

ADD TO ORDER

In stock
$3.96 per pack of 25
94819A049

Material	316 Stainless Steel
Thread Size	3/8"-16
Thread Type	UNC
Thread Spacing	Coarse
Thread Fit	Class 2B
Thread Direction	Right Hand
Width	9/16"
Height	21/64"
Specifications Met	ASTM F594
Drive Style	External Hex
Nut Type	Hex
Hex Nut Profile	Standard
System of Measurement	Inch
RoHS	Compliant

Appendix Q. continued

Clevis Pin

MCMASTER-CARR.

Find

Zinc-Plated Steel Clevis Pin

with Cotter Pin, 3/16" Diameter, 1" Long, 13/16" Usable Length

Packs of 10

ADD TO ORDER

In stock
$3.68 per pack of 10
97245A607

Length	1"
Usable Length	13/16"
Additional Specifications	Zinc-Plated Steel 3/16" Dia.
RoHS	Compliant

An alternative to bolts and rivets, these pins have a head on one end, a through-hole for locking on the other, and a hairpin cotter pin for quick installation and removal.

Zinc-plated steel pins are more rust resistant than steel pins. Minimum Rockwell hardness is B80.

Appendix R.

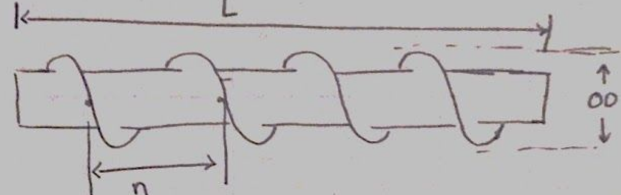
CALCULATION OF AUGER FEED RATE

GIVEN: 49.57 cm^3 OF NEGATIVE SPACE FOR CARRYING CORN/MAIZE. RUNS AT 30 RPM. $\gamma_{CORN} \approx 44.8$ lbs/ft^3

FIND: NEEDED AUGER DIAMETER FOR 15 kg/hr CORN DELIVERY

ASSUMPTION: SPEED (RPM) & AUGER NEGATIVE SPACE ARE THE ONLY FACTORS INFLUENCING DELIVERY RATE

ANALYSIS:



DEAD SPACE → 49.57 cm^3

PITCH → 5 REVOLUTIONS PER AUGER

$$\left(\frac{5\text{ rev}}{\text{worm}}\right)\left(\frac{\text{min}}{30\text{ rev}}\right)\left(\frac{\text{ft}^3}{44.8\text{ lbs}}\right)\left(\frac{2.205\text{ lbs}}{\text{kg}}\right)\left(\frac{.028\text{ m}^3}{\text{ft}^3}\right)\left(\frac{1{,}000{,}000\text{ cm}^3}{\text{m}^3}\right)\left(\frac{\text{worm}}{49.57\text{ cm}^3}\right)$$

$$= \frac{4.63\text{ min}}{\text{kg}}$$

$$\Rightarrow \frac{0.216\text{ kg}}{\text{min}} \Rightarrow x\left(\frac{60\text{ min}}{\text{hr}}\right) \Rightarrow 12.95\frac{\text{kg}}{\text{hr}}$$

$$\frac{12.95\text{ kg}}{\text{hr}} < \frac{15\text{ kg}}{\text{hr}}$$ (SPECIFICATION)

$$\left(\frac{15\text{ kg}}{\text{hr}}\right)\left(\frac{\text{hr}}{60\text{ min}}\right)\left(\frac{\text{min}}{30\text{ rev}}\right)\left(\frac{5\text{ rev}}{\text{worm}}\right)\left(\frac{2.205\text{ lbs}}{\text{kg}}\right)\left(\frac{1{,}000{,}000\text{ cm}^3}{\text{m}^3}\right)\left(\frac{\text{ft}^3}{44.8\text{ lbs}}\right)\left(\frac{.028\text{ m}^3}{\text{ft}^3}\right)$$

$$= \frac{57.42\text{ cm}^3}{\text{worm}}$$

TARGET WORM NEGATIVE SPACE

⇒ NEW SOLIDWORKS WORM DEAD SPACE: 63.4 cm^3

$$\left(\frac{63.4\text{ cm}^3}{\text{worm}}\right)^{-1}\left(\frac{5\text{ rev}}{\text{worm}}\right)\left(\frac{\text{min}}{30\text{ rev}}\right)\left(\frac{\text{hr}}{60\text{ min}}\right)\left(\frac{\text{ft}^3}{44.8\text{ lbs}}\right)\left(\frac{2.205\text{ lbs}}{\text{kg}}\right)\left(\frac{.028\text{ m}^3}{\text{ft}^3}\right)\left(\frac{1{,}000{,}000\text{ cm}^3}{\text{m}^3}\right)$$

$$= \frac{0.0604\text{ hr}}{\text{kg}}$$

$$\Rightarrow \frac{16.56\text{ kg}}{\text{hr}} > \frac{15\text{ kg}}{\text{hr}}$$ ✓

Appendix S.

Final Bill of Materials		
Store	**Location**	**Price**
Metal Depot	Aluminum Block	$140.39
Fastenal	1.5" Drill Bit	$131.95
McMaster Carr	0.5" Shaft Coupling	$41.57
Home Depot	100	$31.00
Miners	Nuts and bolts	$29.60
Fastenal	Bearing	$20.36
Home Depot	180	$15.00
Home Depot	Sheet Metal	$11.29
Home Depot	2500	$5.12
Home Depot	Liquid nails Glue	$3.00
Cal Poly	Cardboard Poster	$1.45
	Total	**$430.73**

Appendix T. Design Verification Plan and Review

ME428 DVP&R Format													
Report Date	12/5/2016		Sponsor	Geoffery Wheeler				Component/Assembly		Maize Mill	REPORTING ENGINEER:		Maize Mill Team
TEST PLAN										TEST REPORT			
						SAMPLES TESTED		TIMING		TEST RESULTS			
Item No	Specification or Clause Reference	Test Description	Acceptance Criteria	Test Responsibility	Test Stage	Quantity	Type	Start date	Finish date	Test Result	Quantity Pass	Quantity Fail	NOTES
1	150 Watt input power	Mill operates correctly using the specified torque. Use electric motor to act as power source	The mill can run properly when only 150 W of power is provided. The mill can withstand the maximum amount of force a human could apply without breaking.	Maize Mill (Mill) Team	Mill Prototype	1	n/a	5/31	5/31	Mill ran with e	1	0	Mill took minimal power to run
2	15 kg/hr grinding rate	Pass sets of corn through mill and record grind time and flour mass	The mill is able to pass 15 kg in an hour that still meets our fineness specification.	Maize Mill (Mill) Team	Mill Prototype	1	n/a	5/31	5/31	12 g milled in 2 min. 0.036 kg/hr grinding rate. does not pass spec	0	1	increased rot speed could increase grinding rate
3	0 kg of metal in discharged flour	Mark all edges that can make metal to metal contact with a permanent marker. If the marker is rubbed off then there is too much friction	No marker rubbed off	Maize Mill (Mill) Team	Mill Prototype	2	n/a	5/31	5/31	edges of burr plate continue to contact. does not pass spec	0	2	2 tests conducted. initial test both auger and burr plate failed. Only burr plate failed in 2nd trial after auger augmentation.
4	80% of the discharged flour mass should pass though a #50 sieve	Weigh flour before and after passing it through a #50 sieve.	80% of the maize passed through the mill comes out as flour that can fit through a #50 sieve.	Maize Mill (Mill) Team	Mill Prototype	1	n/a	5/31	5/31	flour does not pass when visually compared to Estrella flour	0	1	Rough visual inspection test was done rather than offical sieve test. Flour clearly did not meet spec under visual inspection
5	Reliablilty	Run the mill continously for 8 hours	There is no noticible ware and the machine runs as expected the entire time	Maize Mill (Mill) Team	Mill Prototype	2	n/a	5/30	5/32	auger shaft broke under torque under both tests. does not meet spec	0	2	1 st run lasted 3 min before shaft breaking. Second test lasted approximately 6 minutes before shaft breaking.