Final Design Report for the Cookie Dough Portioning Tool

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1 Introduction

Brown Butter Cookie Company is a small business located in Cayucos, California. They are known for making small, delicious cookies, and are a common stop for any visitors traveling the California Central Coast. Their cookies are unique in that they contain no eggs, and are made entirely by hand. One particularly strenuous step is the balling process, in which larger batches of dough are portioned into cookie-sized pieces. This is the rate limiting step in their cookie making process, and has prevented Traci and Christa, sisters and co-owners of Brown Butter Cookie Company, from expanding their operation to meet demand from other retailers. Eliminating this bottleneck would allow them to sell more cookies and increase their profits.

After trying a few existing mechanical solutions, Traci approached California Polytechnic State University in San Luis Obispo looking for a solution to improve the balling step of the cookie making process. Our team, Cookie Dough Engineering (CDE), consists of Alex Haughton, Courtney Shipp, and Grant Wittenberg, senior mechanical engineering students at California Polytechnic University, working on our senior project. We visited the Brown Butter Cookie Company and talked with Traci, one of the owners, and Bethany, the kitchen manager, about their desires for the project. Our goal is to develop a solution to quickly portion cookie dough pieces of equal size, weighing three-quarters of an ounce, with little operator effort.

To this end, we have generated detailed designs, analysis, and manufacture plans for the Shiny Dough Master 3000, our solution to portioning cookie dough. This report details the design of a fully functioning prototype, as well as cost and sourcing for this machine. This report also details the testing procedure used to measure behavior of the dough, and manufacturing of the system used to perform this testing.

2 Background

We decided to begin our project by thoroughly investigating the cookie dough balling process. First, we visited the facility to understand the entire current process of making these cookies. We also investigated devices previously tried by the Brown Butter Cookie Company, as well as other potential existing solutions. We spoke with professors to gain a better understanding of the property of the dough and what sort of physical tests may be necessary to predict its behavior. Finally, we researched the legal requirements and limitations applying to worker and food safety.

2.1 Cookie making process

The floor of the Brown Butter Cookie Company smells delicious, and feels like a home kitchen, just a little bigger and a little more crowded. Butter is first browned and set aside to cool. Once cooled to just warmer than room temperature, the browned butter is mixed with the dry ingredients in a large power mixer. The dough is removed from this mixer and placed in a medium-sized silver bowl. At this time, the dough has a consistency similar to wet sand. It is not as viscous as it will be after it cools, but it also lacks the cohesion of the hand mixed dough. The dough sits to one side for up to an hour after it leaves the power mixers. It then goes to the balling station where it is worked by hand. This improves the consistency of the dough, and the customer also refers to this step as mixing. This hand mixing takes the dough from a very crumbly, very chunky and solid texture to a feel much more like oily Play-Doh.

At the balling station, one tablespoon scoops are used to hand-portion out balls of cookie dough. The workers, called ballers, then weigh the balls on scales such that four balls weigh three ounces. The four balls are transferred to a large bowl and the process is repeated. After the ballers have finished a batch, the bowl is set aside for the next set of workers. These workers, called rollers, roll the balls of dough into the correct shape and ensure cohesiveness. Finally, the cookies are sent off to the ovens.

The balling station serves to bridge two crucial states of the dough, portioning one batch of dough into approximately 115 individual pieces. They also inspect the dough for brown sugar crystals. They crush these crystals or pick them out as appropriate. If not removed, these crystals can cause surface imperfections in the final cookies. Batches where the sugar crystals cannot be removed often are used as floor samples, because they cannot be sold.

2.2 Previous solutions

The Brown Butter Cookie Company tried several solutions before coming to us. They put considerable effort into investigating a Champion-brand machine. This machine works to roll the cookie dough into sheets. However, it did not work for the cookie dough of the Brown Butter Cookie Company. No matter what temperature or texture the dough had before it was fed into the machine, it did not maintain cohesion. The dough crumbled as it entered the rolling section. This not only meant an inconsistent cookie piece, it also meant that the gears of the Champion machine were gummed by the dough, and the machine ceased to function.

In more general terms, the owners have also mentioned difficulties with both mold-type portioning tools and portioning tools that include wire cutters. In the case of the mold-based designs, their frustration comes from the way which the dough will stick in the mold. In order to remove it, the ball of dough inevitably falls apart or leaves behind an unacceptable amount of dough. In the case of the wire cutters, the dough simply falls apart under the pressure of the blade. In both cases, there is a root problem at work: the consistency of the dough. To solve the tough cookie dough problem in the most time-efficient manner possible, the team has put together a design with robust safety factors built into all the dough manipulating elements of the device. There may need to be some tinkering to get the details right on the final design, but the device should defeat the dough consistency issue easily.

2.3 Potential Competing Solutions

Besides looking at the products that haven't worked for the company, we also did some research on other existing processes to portion various materials. One example we found was the Reiser Vemag Cookie Dough Depositor, shown in Figure 1 (Reiser, Canada, 2014). In this machine, cookie dough is extruded at a constant rate through a tube, and at regular intervals a large blade slices off a portion of the cookie dough, which then lands on a conveyor belt. While the extrude-and-slice method may well inspire our design, a large industrial machine of this size and a conveyor belt would be impractical for the Brown Butter Cookie Company.


Figure 1: Still shot of the Vemag Reiser cookie dough extruding machine

On the smaller scale of things, the team researched smaller hand tools such as a spritz cookie press. In a spritz cookie press, such as the Wilton Cookie Pro™ Ultra II Cookie Press (Wilton Industries, 2014) shown in Figure 2, dough is placed in a tube and is then pushed out through a smaller opening at the other end by a hand operated plunger. Specially designed disks allow the dough to be molded into creative shapes. These tools are cheap, small, and simple, but there is concern that such a tool would not be fast enough or reduce operator effort enough to meet our goals.


Figure 2: Still shot of the Wilton Cookie Pro™ Ultra II Cookie Press for making spritz cookies

Other methods researched include sand portioning methods, as the cookie dough has been described as having a sand-like texture. These were found to be impractical, as sand portioning tools are meant to spread sand evenly over a piece of land, and spray sand out from an exit of the machine. They do not divide the sand into clumps.

Figure 3: Picture of sand spreader used in domestic gardening (Kindersley, 2012)

Finally, because one of the complication encountered by the Brown Butter Cookie Company was the tendency of their dough to gum up any wire or knife used to cut it, we also looked into alternative cutting methods. While most food processing devices do use blades and wires (often heavier and faster than a human hand), one method outside the food industry found to be potentially applicable was that of water jets. Water jet cutters have been around for a while and started cutting soft materials such as paper at pressures much lower than they are used for today (Synergetix, 2014).

Figure 4: Water jet cutting on a sheet of metal

While this method has proven to be too complex and expensive to be practical for simply portioning cookie dough, it does solve the problem of cookie dough sticking to the cutting device.

2.4 Fluid proprieties, measurements, and tests

In the course of our background research, we began to wonder about the properties of the cookie dough. We theorized that the cookie dough could be modeled as a very high viscosity fluid which would allow us to estimate the loads before production of prototype. However, we weren't sure how to go about measuring the relevant fluid properties. We spoke with several professors on campus (see Appendix A, Contacts and Appreciation) to address the problem.

After discussion, it was decided that the benefits of knowing these fluid properties was outweighed by the difficulty of measuring these very large values. As the project continued further, we moved from believing the cookie dough acted as a shear-thinning non-Newtonian fluid to the point where we believe it is impossible to model the dough as a fluid at all. We have observed that there is a finite limit to the motion of the dough. When using perpendicular force to spread the dough, there comes a point where the dough will simply lock and cease moving. This locking was not overcome with the force currently available to us at that time. We consulted a materials engineer, who was unable to explain this phenomenon. Even though we cannot explain the cause of this property of the dough, we will nevertheless need to engineer our solution with it in mind.

Instead of trying to work with existing fluid models, the team decided it was better to use models of design subsystems to determine dough behavior. We performed scaled tests to demonstrate feasibility of the design, and to determine the forces and pressures needed to manipulate the dough in the intended fashion. This modeling suggested that the dough's extrusion was largely driven by pressure, and to meet specifications we would need a pressure of 115 psi. Full details are discussed in Appendix B, however, these test later proved to be insufficient and therefore a second phase of testing was performed as detailed in Section 9: The Doughbreaker. Surprisingly, this extensive testing yielded very similar results.

We did visit the Brown Butter Cookie Company facilities on multiple occasions to measure a few basic dough properties. We measured the mass of individual balls on an electric mass balance. We also measured the volume of those same balls by dropping the balls into a graduated cylinder containing enough water to cover the dough balls and observing the amount of water displaced by the ball. We measured the individual volume and mass of 30 different balls. We found the average volume and mass were 20.1 mL and 21.70 g respectively. Due to the measurement devices used, the mass was the more precise measurement. The mass of these 30 balls varied by 2.24%. The Brown Butter Cookie Company attempts to produce balls weighing 0.75 ounces. We calculated their average ball weight to be 0.765 ounces, which is 2% higher than this goal. Therefore, we will ensure that our average ball size is between 0.75 ounces and 0.765 ounces and that the balls do not vary from this average by more than 2% in order to match their current accuracy.

The Brown Butter Cookie Company has two main types of cookies. They have their brown butter cookies, for which they are famous, and their much larger, traditional cookies. Later in the project it was decided the portioning tool would ideally be able to portion both types of cookies, so we went back to get additional volume and variation information on their traditional cookies as well. The most important data point gained from these additional measurements is that the larger cookies have an average volume of 4.2 cubic inches. A complete table of the relevant results is available in Appendix C.

While at the Brown Butter Cookie Company facility, we also took temperature measurements at different points along the production line. The dough had a temperature of 74.3 °F (23.5 °C) after the mixer and an average temperature of 73.9 °F (23.3 °C) after the ballers hand worked the dough. From these measurements we can conclude that adding a heating element to our device would not help us as the temperature drop between the ballers and the mixer is minimal. This also confirmed that working the dough increased malleability. Later, during more extensive testing we realized that small temperature differences can have a large impact on dough malleability: while that is not what happens during mixing, it can be a factor.

We thought it might be beneficial to find an artificial manner by which we could work the dough and possibly eliminate or supplement the hand mixing stage of the process. We approached the casting professor on campus (see Appendix A) who helped us set up and run some tests involving a vibrator, which can impart shear forces to the dough.

First, we tried pushing the dough through a tube and funnel with a plunger. As per usual, the dough was uncooperative and did not budge. The dough was then placed in a metal bowl and put on the vibrator. During vibration we held the bowl down to help transfer the vibrations to the dough from the table, as shown in Figure 5.

Figure 5: A bowl of cookie dough on the vibrator.

The results from this first test were unpromising, as the dough, once vibrated, still did not move through the tube and funnel combination. For the next test, the dough was hand mixed. After the dough was hand mixed it could be pushed through the tube and funnel with some difficulty. That said, we tried vibrating the dough again to see if there was any change in the consistency. The mixed and vibrated dough moved through the tube and funnel with less force than before, and the dough flowed a little smoother than before the second round of vibrating.

From this set of tests we concluded that vibrating the dough did help improve the consistency of the dough. However, hand mixing was obviously a more effective means of improving dough consistency. Because of the complications involved with adding another machine (a vibrator) to our design and the minimal benefit to the overall process (hand mixing could not be eliminated), it was decided the adding a vibrator to the design would be detrimental rather than beneficial.

2.5 Legal requirements

The team has researched the legal guidelines necessary to build a safe device. This has helped us create a safe cookie portioning tool that will prevent risks to the customers and the employees. The current design has already undergone initial electrical and mechanical safety reviews and had been approved to move forward with construction. Our device conforms to Food and Drug Administration (FDA) regulations, The Public Health Code, The California Food Code, and Occupational Safety and Health Administration (OSHA) guidelines.

The following are lists of codes and regulations from various agencies that are relevant to our project and will be accounted for to guarantee safety. Full text of these regulations are available upon request. Note: the subsequently listed regulations are only relevant to design and construction, not for installation and daily operation.

Food and Drug Administration (FDA, 2013)

- Section 4-101: Food contact and noncontact surface materials
- Section 4-204: Moving part lubricant specification

Occupational Safety and Health Administration (OSHA, 2007)

- Section 1910.95b: Sustained sound limitation for safe operation
- Section 1910.212: Safeguard necessity and specification. Anchoring machinery with moving parts. Rotating machinery safety regulations and safeguards. Pinch point safety
- Section 1926.302: Electric power option and grounding for safety.

American Society for Testing and Material (ASTM, 1999)

- Section C105: Heated system surface conditions that produce contact burn injuries. Sets surface temperature limits for instant and sustained contact

National Science Foundation (NSF, 1998)

- Section: “Food Equipment Material Standards” Specifies the proper materials and material grades for food contact surfaces within a food processor. Material choices in regards to sanitary needs, corrosion, and surface pitting

National Institute for Occupational Safety and Health (Waters, 1994)

- "NIOSH Lifting Equation": This formula is widely recognized and will provide a guideline for repetitive load limits

3 Objectives

Our overall goal for this project is to create a cookie dough portioning tool that will maintain or improve the current rate of production. This tool will need minimal maintenance, be relatively easy to clean, simple and safe to operate. In order to ensure complete compliance with the requirements of the Brown Butter Cookie Company, Cookie Dough Engineering chose to utilize a version of a tool known as the House of Quality.

The House of Quality is designed to ensure that the engineering specifications chosen by the engineers match the requirements expressed by the customers. First, a list of customer requirements is developed. Then, a list of engineering specifications is derived from these requirements. The House of Quality then gives criteria by which to rank the engineering specifications, demonstrating which specifications are most important to the success of the product. Finally, the House of Quality can be used to evaluate potential solutions. This is crucial in two ways. First, it is important to judge other solutions which may already be on the market. Second, it offers effective tools by which to evaluate ideas before proceeding to the design phase. More information on the House of Quality and the House of Quality itself are located in Appendix D.

The other tool used to evaluate our engineering specifications is the compliance matrix. The compliance matrix is simply a list of the engineering specifications, the level of risk associated with each specification, and the manner in which each specification can be tested.

3.1 Customer Requirements

Customer requirements are those needs or constraints on the problem of a project expressed by the customer, either directly or indirectly. These requirements are then used to create the engineering specifications. The ten customer requirements of the Brown Butter Cookie Company are described below.

Ball Size

This customer requirement is a leading concern for our project: the cookie dough balls must be of the proper size or the product is useless. Thus, the device will need to be quite accurate in its ability to portion cookie dough. This is being addressed by the engineering specifications of ball volume and ball weight. Both of these quantitative tests will be conducted and prove the cookie dough portioning tool can produce cookies of the desired size within a reasonable statistical uncertainty.

Physical Safety

Safety is another primary concern, and is covered by a range of various engineering specifications. These specifications include: eliminating pinch points, reducing surface temperature, rotating equipment/blade protection, no sharp edges, operating lifting weight, pulling weight, repetitive motions, decibels produced, and food safe/cleanable materials. Many of these engineering specifications are design dependent and may not be relevant. However, we wanted to cover all design options and have a comprehensive list of verifiable safety criteria.

Production Rate

The customer wants to replace their current, labor and training intensive process, with an easier, mechanized one. While they do not require that the new process can portion cookies faster than the old one, they could not afford a drop in rate either. This means that the rate of cookie production will need to be a minimum of 25 cookies per minute. A maximum of three devices can be used to meet this requirement in the case of multiple hand held devices.

Repetitive Stress Injury (RSI) Reduction

One advantage of designing a new tool is the reduction of injuries caused by repetitive motion. The best way to address this is to completely mechanize the process. If this cannot be done, we will try to optimize the design to protect the workers who are using it daily. Operating lift weight, pulling weight, and repetitive motion are all relevant in the case of any solution which is a manual device. These specifications are dependent upon specific loads and paths of a design, which can be checked through the NIOSH Lifting Equation (see background or references for further details).

Easy to Clean

Cleanliness is very important in the kitchen, and significant time can be lost in simple cleaning if the solution is not carefully designed. Additionally, the customers have requested the ability to change cookie dough flavors several times a day as necessary, which will require cleaning between batches. In order to facilitate easy cleaning, we will carefully choose our materials to be friendly to frequent use and cleaning. We will also minimize the time required to clean the device to be less than two total man hours every day.

Easy to Operate

Under current operating conditions, employees must be trained for three months before they can match the expected production rates. This one of the driving reasons for this project; our design should be intuitive enough to pick up and use with very little prior knowledge. Thus, we have set the maximum training time for basic operation to be one day.

Durable

The Brown Butter Cookie Company is looking for a reliable machine to permanently solve their problem, not one that breaks and must be replaced frequently. This must be a sturdy, reliable device of quality make. We aim to develop a product that will have a minimum life of two years peak use and will require only one hour of maintenance for every 80 hours of use.

Cheap

The budget goal for our product is dependent on type of solution chosen. The Brown Butter Cookie Company is willing to adjust budget based on the type of solution generated by our team. That being said, we had set a personal goal to have the prototype cost less than $3000 dollars.

This was determined by the price of comparable commercial kitchen appliances. The original hard budget given to us by the Brown Butter Cookie Company was $10,000.

Single Batch Size

The Brown Butter Cookie Company is a small company, which values the hand-made quality of every cookie. Dough is produced in single batches, and therefore the portioning tool should reflect this. The device must be able to handle small portions of cookie dough, equal to a single batch size.

Not Too Big

Our customer has a limited amount of space where this device will be operating and it has been deemed necessary that our product fit within a 3' by 3' by 5' space in order to not interfere with the table space of the Brown Butter Cookie Company.

3.2 Other Requests

In addition to these requirements our customers have mentioned other qualities which would improve the use of the device. One customer requirement that changed was the ability to process multiple types of cookie dough. They have three basic consistencies of cookie dough, and at this point our goal is to be able to process all three through the same device. For details on the variation between dough types, see Appendix C.

Additionally, the presence of brown sugar crystals in the cookie dough is undesirable and they are currently removed from the dough by hand during the balling process. As we will be replacing this process it would be ideal for our device to do that same. However, this is not a requirement of our product.

3.3 Compliance Matrix

The compliance matrix lists the engineering specifications which we will meet in order to satisfy the customer requirements listed above. These specifications were developed through the House of Quality in Appendix D. Each specification is given a specific target and tolerance which must be met in order to satisfy the needs of this project. Each specification has also been evaluated as a low, medium, or high risk according to the likelihood of satisfying that specification. High risk specifications are discussed immediately after the compliance matrix. Finally, each specification is given a compliance code. "T" means the specification will be tested in order to determine if it has been met. "I" signifies the product will be inspected for compliance. "A" means we will perform engineering analysis to determine if the specification can be met.

Table 1: Compliance Matrix

Spec	Description	Target	Tolerance	Risk	Compliance
1	Ball Volume	20 cm^3	±1 cm^3	H	T
2	Ball Weight	21.5 grams	±1 gram	M	T
3	Pinch Points	None	None	L	I
4	Rotating Parts / Blades	All Protected	None	L	I
5	Sharp Edges	None	None	L	I
6	Food Safe Material	Fits Legal Standards	None	L	I
7	Surface Temperature	< 104 F	Max	L	A, T
8	Cookie Rate	≥ 25 cookies/min	Min	H	A, T
9	dB Produced	< 90 dB	Max	M	A, T, I
10	Operating Lift Weight	< 2 lbs	Max	M	A, T, I
11	Pulling Weight	< 10 lbs	Max	M	A, T, I
12	Repetitive Motion	Meets CDC Matrix	Green Rating	L	A, I
13	Cleanable Material	Non-stick surfaces	None	L	I
14	Cleaning Time	120 Minutes A Day	Max	M	T
15	Training Time	1 Day	Max	L	T
16	Life Cycle	2 Years	Min	L	A
17	Maintenance Required	80 In Use Hours Per 1 Maintenance Hour	Min	M	A
18	Cost	$3000	Max	H	A, T
19	Small Batch	One Batch of Original	None	M	A, I
20	Total Weight	< 75 lbs	Max	M	A, T, I
21	Length, Width, Height	5 ft x 3ft x 3ft	Max	L	A, I

3.4 Most Important and High Risk Engineering Specifications

Ball Volume – Consistent and accurate size of cookie dough pieces is very important to our customer, but may be very difficult to achieve. It is due to the failure of other products to meet this need that the project has come to our attention. Thus, we anticipate that filling this specification will require the most time and effort from us, and our chosen design was chosen because it had the best potential in this specification.

Ball Weight – This combined with ball volume are the specifications that measure the ball size requirement. Currently they measure their ball size by weight, so this specification ended up getting more weight on the House of Quality and is one of our top four most important specifications.

Cookie Rate – The Brown Butter Cookie Company currently averages about a cookie every 2 seconds. This rate may be difficult to match with only one device, and ideally this rate would be doubled in order to remove the bottleneck from the process. If this bottleneck is removed, the customer will be able to expand their business significantly. This requirement is considered high risk because their current speed of a cookie every two seconds is already pretty fast, and it is considered an important specification because failure to maintain cookie rate will drastically reduce the usefulness of the final device.

Cost - This specification is highly dependent on the type of solution which is chosen, and may be difficult to meet depending on the final design considerations. Our sponsor has indicated that they would be willing to pay to up to $10,000 depending on the quality of the final product. After meeting with the project sponsor, and with the Brown Butter Cookie Company on January 28th, we decided to build the Shiny Dough Master 3000 using a linear actuator costing $7,310. This jeopardizes our ability to meet our budget limit, but was necessary in order to meet the cookie rate and minimize cleaning time.

Cleaning Time – Cleaning time needs to be held to a minimum or the cookie rate of the device will be useless. The Brown Butter Cookie Company has a lot of different types of cookie dough; they need to be able to switch types of cookie dough relatively rapidly. This specification was a major concern to the customer and is considered a top four specification in importance.

Training Time – One of the main points of emphasis from our sponsors was that current training time for ballers is three months. With our device we want someone who has never used it before to become an expert in one day, thereby eliminating much of the hassle of training employees. This is one of the most important specifications.

4 Ideation

Ideation, also known as idea generation or brainstorming, is a very important part of the engineering process. In fact, there has been significant research in various areas dedicated to discovering how to generate the best and most useful ideas, and how to identify which ideas those are. We chose to have three idea generation sessions, each with a different focus. These sessions, and their results, are discussed below.

4.1 Idea Generation Sessions

CDE chose to perform idea generation in three sessions. First, we used simple list-function brainstorming to generate a large number of ways in which each part of the problem might be solved. For example, one list we generated identified methods for parting the pieces of dough. This list included items such as knives, wires, molds, water jets, lasers, teeth, and gravity. The realism of the ideas was not important, as unrealistic ideas could inspire creative solutions. We generated lists for many potential subsystems of the solution: heating the dough, mixing or working the dough, powering the machine, moving the dough, parting or portioning the dough, and so on.

Once we had a large number of possible solutions, we met for a second time in Kennedy Library. This time, we brought a bowl of dough with us to allow hands-on demonstration of concepts. Taking our previously brainstormed lists, we rolled dice to randomly identify traits on each list, and then forced each other to draw potential solutions combining the individual traits into a single solution. After we had a number of these drawings, we passed them around randomly and attempted to describe in words what was drawn on the page. Then we passed these descriptions on, and the next person was required to draw what was described without looking at the original drawing. We continued this Telephone Pictionary for six rounds, and then discussed results. To finish this session, we each sketched a few of our top ideas, choosing whichever traits we liked.

Finally, we met again to begin evaluating the existing ideas and to continue to brainstorm new ideas. This meeting was unstructured. We simply began making very simple concept models and testing the viability of the ideas which had been generated and allowed conversation to lead us into new ideas. It was in this session that the final top ideas began to take form and solidify.

4.2 Ideas Generated

The advantage of unhindered idea generation is a wide span of ideas and increased creativity. However, the disadvantage of never saying no to any idea, at least in the generation stages, is that many, many impractical ideas are generated. We have included a complete list of our generated ideas in Appendix E.

As the ideas were evaluated for their usefulness and feasibility, four general concepts eventually rose to the top. These ideas were a mold and freezer combination (the ice tray), a hand-powered rolling blade (the water wheel), a wire grid and sheet combination (the cookie press), and a motorized extruder (The Shiny Dough Master 3000).

4.3 The Ice Tray

This idea came about from the simple question – how do you get the cookie dough out of a mold? The hand balling currently used by the Brown Butter Cookie Company is, in a manner of speaking, a mold based operation, and cannot be automated because the dough has to be packed into the spoons by hand, and removed the same way. However, we theorized that if the dough was frozen in a mold, it would come out easily. We tested this theory during our third idea session with some success, as shown in Figure 6.

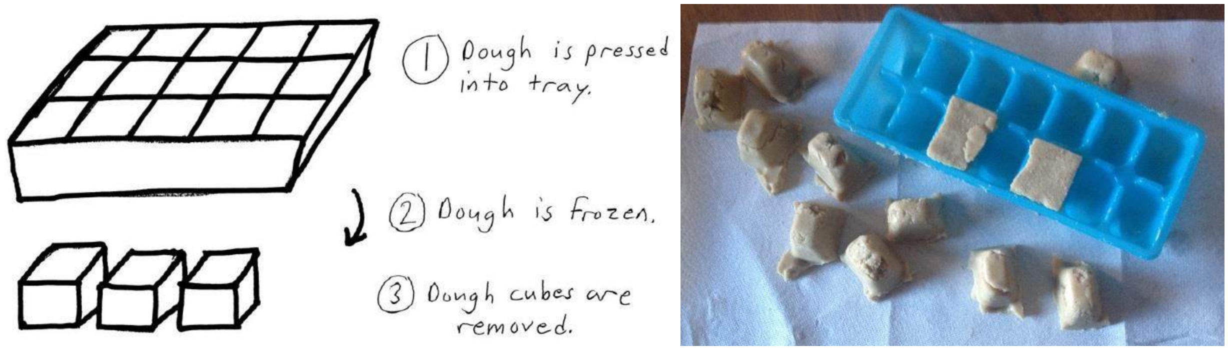

Figure 6: Concept sketch and concept modeling of ice tray design

An advantage of this method is it rapidly and consistently portions the pieces. During our test they easily slid out of the ice tray. The main disadvantages of the ice tray are twofold. First, to meet the rate specification, it requires the dough to be rapidly frozen and then thawed, which may change the texture of the dough or of the final cookie. Second, it requires the cookie dough to fill the mold properly to fit the ball size requirement, and we discovered filling a mold is quite difficult with this cookie dough.

4.4 The Water Wheel

This idea actually came about as the result of a miscommunication. While describing a completely separate concept, one teammate used a comparison to a waterwheel and was misunderstood by the rest of the team. After much sketching, inquiry, and confusion, the two ideas were separated and this mishap became one of the top ideas. For clarity, an early concept drawing of this device is shown in Figure 7.

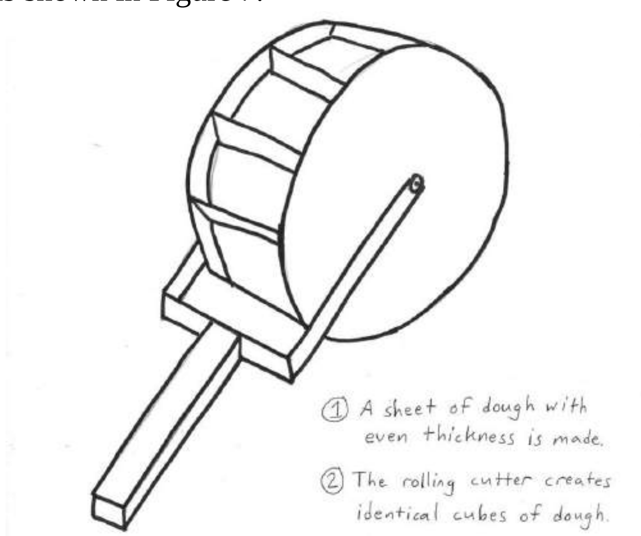

Figure 7: Concept sketch of water wheel device

The water wheel is a hand-held device, meant to function like a fancy pizza cutter. The wheel contains a grid of blades, carefully sized to cut the dough into the proper size portions when the wheel is rolled over a sheet of dough of the correct thickness. This design has several disadvantages, namely that it is still a hand-held device and it requires a sheet of dough to be rolled across.

4.5 The Cookie Press

This idea is named after the printing press, which inspired it. The device operates by pressing a sheet of cookie dough onto a grid of wires (or, in other iterations, pressing wires into a sheet of cookie dough). The cookie press takes slightly longer to set up and load than the other ideas, but can theoretically portion an entire batch in one lever pull, for an overall improved rate of production. An early concept drawing of this device is shown in Figure 8.

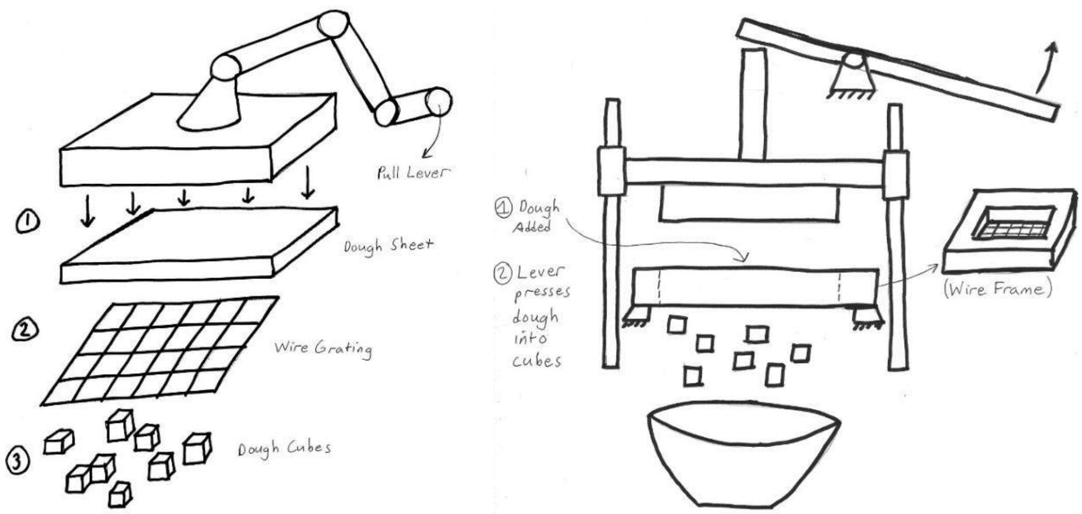

Figure 8: Cookie press early conception sketch and more developed drawing

The cookie press was identified as a top design based on the simplicity of the design when it comes to moving parts and maintenance. Wires would be easy to replace if necessary, and no motor actuation would be necessary to portion a batch of dough quickly. The size of cookie pieces was in question, however, because consistency required a well-formed sheet of dough to press against the wires.

Significant concept model testing was spent on this idea, because it was one of the most viable designs. We built a number of models and found that the wires cut the dough cleanly. Even the first tests which we performed with a foam frame, shown in Figure 9, made very clean pieces of dough.

Figure 9: Foam board concept model of cookie press

However, pressing the dough into an even sheet was less successful than we hoped. We built a wooden press to allow us to exert more force on the dough. However, the dough did not compact evenly or spread cleanly in the press, which caused the cuts to also be less even. This test equipment and result is shown in Figure 10.

Figure 10: Wooden concept model of cookie press

4.6 The Shiny Dough Master 3000

This idea actually started as something of a joke, because it seemed almost too obvious. It is the simplest idea to come up with, and yet one of the hardest to actually produce. It is very similar to products already on the market, both for cookie dough and for other food products. The Shiny Dough Master 3000 extrudes the cookie dough from a funnel and tube at a constant rate and cuts the dough with a spinning blade. The proper ball size portioning is controlled by the rate of extrusion and the rate of the cuts. An early concept drawing of this device is shown in Figure 11.

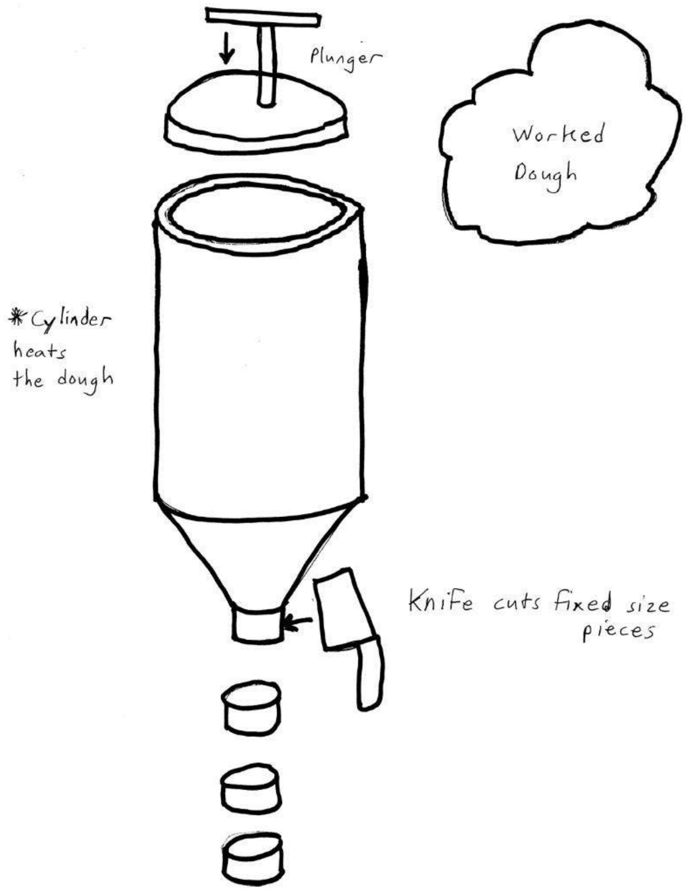

Figure 11: Early Concept Drawing of the Shiny Dough Master 3000

The Shiny Dough Master 3000 was identified early on as the ideal solution (the shiny answer to the problem) if certain feasibly hurtles could be overcome. The size of the cookies is simple to control by synchronizing the rate of extrusion and the rate of cut. The rate of cookie production is limited only by the speed of the motor or linear actuator pushing the dough. Cleaning is simple, since the dough only contacts a straight tube, a blade, a funnel, and a plunger.

4.7 Detail Design Ideas

As much as we would prefer if it were otherwise, idea generation and problem solving do not stop with the general design decisions. Since the Preliminary Design Report the Shiny Dough Master 3000 has undergone a number of changes and revisions. Most of these decisions occurred very organically, but there were two exceptions that should be mentioned. First, the cutting mechanism changed dramatically. We considered using wires, blades, and other methods before finally deciding on the paddle. Secondly, we had significant difficulty in determining the best base for the machine.

The paddle was chosen to increase the safety of the machine. In place of a blade, which would need to be covered, we now have a blunt object. It is lightweight, easy to power, and shouldn't gunk up the way a wire would. Additionally, if someone blocks it with their hand, their hand will remain unharmed, so we eliminated the need to have the safety cage cover the entire device.

The initial design considerations for the base were that it was aesthetically pleasing, lightweight, and food safe. Eventually, however, every one of these specifications had to be abandoned in order to choose a base which could withstand the forces exerted upon it. In order to build a base structure capable of withstanding the applied moment we returned to a previous brainstorming method. We listed every shape we could think of with a high moment of inertia, and then mixed and matched until we found a combination that worked for our designs.

Although these idea generations did not require a formal decision matrix to determine the outcome, they were an important part of our iterative design process.

5 Decision Matrices

In order to properly evaluate the usefulness of the ideas generated by our brainstorming sessions, we utilized a tool known as a Pugh Matrix. In a Pugh Matrix, designs are compared to a datum and judged to be better, the same, or worse performers in each category of the customer requirements. The number of better, same, and worse judgments are then each totaled. The purpose is not to produce a single score which automatically determines the best design, but to carefully compare areas of strength and weakness to identify designs which are clearly superior or inferior. We chose to add one more row of calculations to each Pugh Matrix which we called weighted score. This accounted for the varying weight of the customer requirements to produce a single score which we then took into account during our final deliberation. After producing four Pugh Matrices, we chose the Shiny Dough Master 3000 as the best design to solve the problem facing the Brown Butter Cookie Company.

5.1 Pugh Matrices

Our first Pugh Matrix used the hand balling method currently employed by the Brown Butter Cookie Company as the datum against which the other designs were compared. However, the designs were too similar. For example, all four top concepts rated as less safe because they were all more dangerous than a simple tablespoon. All four concepts rated as better RSI reduction because no mechanized process could be more intensive than hand balling every single portion of dough. The full Pugh Matrix is shown in Table 2.

Table 2: Full Pugh Matrix with hand balling datum

Customer Requirement	**Average Weight**	**Hand Balling**	**Shiny Dough Master**	**Cookie Press**	**Ice Tray**	**Water Wheel**
Ball Size	10	**DATUM**	0	0	-1	0
Physical Safety	9		-1	-1	-1	-1
Production Rate	7		1	1	0	1
RSI Reduction	6.5		1	1	1	1
Easy to Clean	6.5		-1	-1	0	-1
Easy to Operate	6		1	1	1	1
Durable	4		-1	-1	0	0
Cheap	2.5		1	1	1	1
Single Batch Size	2		0	0	0	0
Not Too Big	1.5		-1	-1	-1	0
weighted score			1	1	-5.5	6.5
count of better			4	4	3	4
count of worse			4	4	3	2
count of same			2	2	4	4

After examining this Pugh Matrix, we decided that the hand balling was not a good choice of datum. We generated a second Pugh Matrix using the Shiny Dough Master 3000 as the datum to try to better separate the designs, as shown in Table 3. This matrix was much more useful. It clearly separated the designs from one another, and supported our first instincts that the Shiny Dough Master 3000 and the cookie press were our best ideas.

Table 3: Full Pugh Matrix with Shiny Dough Master 3000 datum

Customer Requirement	Average Weight	Hand Balling	Shiny Dough Master	Cookie Press	Ice Tray	Water Wheel
Ball Size	10	0		-1	-1	-1
Physical Safety	9	1		1	-1	1
Production Rate	7	-1		-1	-1	-1
RSI Reduction	6.5	-1		-1	-1	-1
Easy to Clean	6.5	1	DATUM	0	1	-1
Easy to Operate	6	-1		-1	-1	-1
Durable	4	1		0	0	0
Cheap	2.5	-1		1	-1	1
Single Batch Size	2	0		0	0	0
Not Too Big	1.5	1		0	0	1
weighted score		-1	0	-18	-34.5	-23
count of better		4	0	2	1	3
count of worse		4	0	4	6	5
count of same		2	0	4	3	2

After we had narrowed our ideas down to just two options, we examined the individual designs more closely. The cookie press had lost on three important categories (production rate, RSI reduction, and easy to operate) due to our belief that the dough would be difficult to form into a good, useable sheet. Thus, we made a Pugh Matrix to examine the different options we had brainstormed for making a sheet of dough, in case one of these ideas could improve the overall cookie press design.

The cookie press design used a lever press with a mold to create its sheet, such that the press applies pressure to the cookie dough and forces it to conform to a mold of the sheet, which is then removed. We used this design as the datum for the matrix. We compared it with four other ideas. The first was to require the sheets of dough to be made by hand, perhaps with a removable mold or other tools to help as necessary. We also considered extruding the sheet of dough by forcing the dough to flow through a slot. The third idea was to extrude the dough between two rollers. Finally, we considered using a machine, rather than a hand-powered lever, to press the dough into a mold. The resulting Pugh Matrix is shown in Table 4.

Table 4: Pugh Matrix for making a sheet of dough

(Make a Sheet) Requirement	Average Weight	Hand Press Sheet	Extrude a Sheet - slot	Extrude a sheet - rollers	Lever Press with mold	Machine press into a mold
Sheet Thickness	10	-1	1	1		0
Sheet edges	10	1	-1	-1		0
Feasibility	10	1	-1	-1		-1
Safety	9	1	1	-1		0
Effort	8	-1	1	1	DATUM	1
Clean-ability	7	1	-1	-1		0
Durable	5	1	-1	-1		-1
Cheap	3	1	-1	-1		-1
Time / Rate	8	-1	1	1		0
Footprint / Size	1	1	0	0		0
weighted score		19	0	-18	0	-10
count of better		7	4	3	0	1
count of worse		3	5	6	0	3
count of same		0	1	1	0	6

Notice that this Pugh Matrix used a different set of criteria to compare the ideas. Because this matrix was focused on a sub-function of the design, we chose criteria specific to the making of a sheet of dough and created our own weight for each criteria. This matrix showed that the best method by far was to have the dough be formed by hand into sheets. This was more hand processing than we wished to include in our final design, and so we chose to pursue the Shiny Dough Master 3000 as our final idea.

In so doing, however, we found there were still a few details about the Shiny Dough Master 3000 which had not yet been refined. For example, we had not closely considered how the dough was to be cut as it emerged from the funnel of the device. We developed one more Pugh Matrix to evaluate a variety of options which had previously been suggested.

We considered using a taunt wire as the first option, and then added more extreme options such as using a water jet or allowing the weight of the dough to break each piece off. We included a blade moving linearly, as well as spinning blade. Since these two options were the same except for the motion of the blade, the comparison of these two options allowed us to compare linear and rotary motion in general. Finally, we considered extruding into a mold for the sake of completeness. As in the previous sub-function Pugh Matrix, this matrix required a new list of requirements and weights for those requirements. The complete matrix is shown in Table 5.

Table 5: Pugh Matrix for cutting dough

(Cutting Dough) Requirement	Average Weight	Wire	Water Jet	Gravity / Fall	Linear Blade	Rotary Blade	Extrude into mold
Clean cut	9	0	1	-1	DATUM	0	-1
Clean-ability	7	1	1	1		0	-1
Safety	9	1	-1	1		-1	1
Size added to footprint	5	0	-1	1		-1	-1
Size Consistency	10	0	1	-1		0	-1
Time / Rate	8	0	-1	-1		0	-1
Durable / Maintenance	4	-1	-1	1		0	1
Timing Mechanism	7	0	1	1		1	-1
Cost	3	0	-1	1		0	1
Feasibility	10	0	-1	-1		1	-1
weighted score		12	-6	-2	0	3	-40
count of better		2	4	6	0	2	3
count of worse		1	6	4	0	2	7
count of same		7	0	0	0	6	0

From this matrix we concluded two things. First, we judged that using a wire was better than using a blade. We also decided that rotary motion was slightly better than linear motion. However, neither of these distinctions was so drastic that we could not use the other option if it became necessary based on later design considerations such as synchronization, space, or cost. Therefore, we will wait to make the final decision on the method for cutting dough until later in the design process.

5.2 Final Decision

As we discussed the Shiny Dough Master 3000, it continued to be changed and revised. Discussing the design in the terms required for the Pugh Matrices greatly improved the overall concept of the device and our agreement on its features. The entire device was turned on its side to improve stability, and a linear actuator was tentatively chosen to provide the force necessary to extrude the dough through the cylinder and funnel.

We choose to model the device with a set of three spinning blades, shown for visibility without any guard or protection. At the time, we were more inclined to choose a wheel with three wires for cutting, and to completely enclose the cutting portion of the device for safety purposes. However, the isometric computer model shown in Figure 12 gave an excellent sample of our original vision for the Shiny Dough Master 3000 in the loading position.

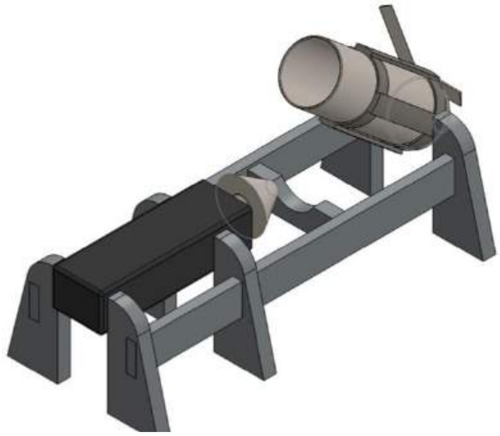

Figure 12: Shiny Dough Master 3000 computer concept model in loading position

6 Detailed Design and Technical Content

Each component of the Shiny Dough Master 3000 was designed to interact with the entire machine. This section will explore each subsystem and part in detail, providing justification for design decisions and safety considerations. Purchasing, manufacturing, and assembly information will be included as relevant for each part or subsystem. Also included will be a summary of any modeling, calculations, tests, or other technical content used to develop the parts and ensure success of the prototype. Full calculation details, including free body diagrams, section cut diagrams, and computer code, can be found in Appendix F. Parts will be referenced by common name and part number in parenthesis, for example: funnel (202). These part numbers can be used to locate an item on the Bill of Materials, found in Appendix G. Specific drawings and spec sheets for each part match the part numbers. All drawings and specification sheets can be found in Appendix G, organized by drawing number.

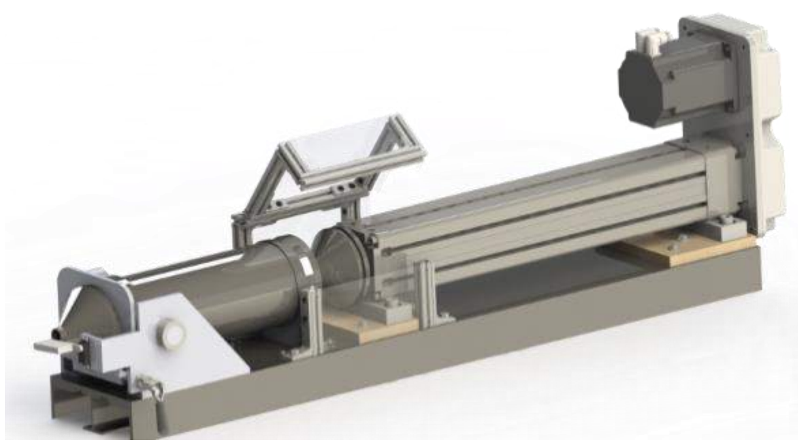

Figure 13: Isometric rendering of the Shiny Dough Master 3000 to demonstate orientation convention

Before getting into details, it is important to establish an orientation by which to address various parts of the Shiny Dough Master 3000. By convention we have decided that the linear actuator sits at the back of the device, and that the cutting motor is located at the front. The right and left side of the machine are determined by looking down the device, with the front closest to the viewer, so that in general isometric views the right side is the side closest to the viewer, as it is in Figure 13. By this convention, the cutting motor is mounted on the right side and the hinges of the safety cage are on the left side of the device.

6.1 Linear Actuator

The linear actuator (101) is the main moving mechanical system in the Shiny Dough Master 3000 and provides the force needed to push the cookie dough through the cylinder and funnel system. This pushing force was the design parameter that drove the size of almost all of the other components in the system. Thus, calculating the necessary size of this force was the step on which the rest of the detail design was waiting.

To calculate the necessary force the team measured the pressure present in the sausage press and then calculated the force necessary to produce the same pressure in a six inch diameter cylinder. The result was an estimate of 3,250 pounds force. For more details on this calculation, see Appendix B. Once we looked at the options for linear actuators on the market we decided to go with a slightly bigger device to allow a factor of safety and uncertainty. The linear actuator chosen is the Thomson ECT13-B63R03PB4010-0600FU21S1, shown below in Figure 14.

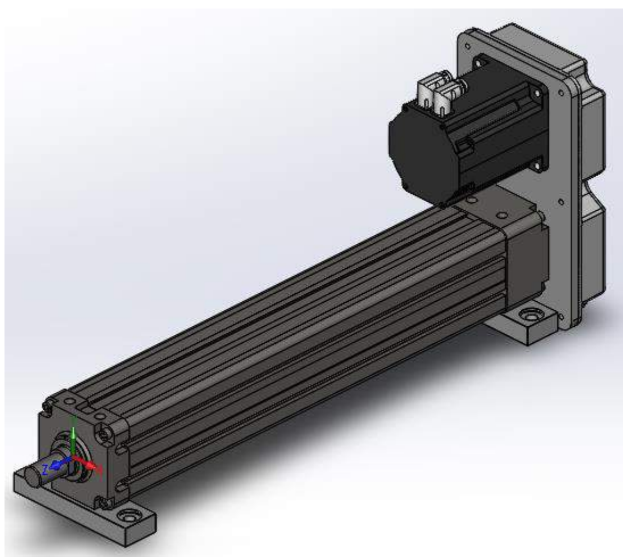

Figure 14: A Solidworks model of the Thomson ECT13 Linear Actuator (101), (Thomson Linear, 2015)

This linear actuator has a stroke length of 600 millimeters (enough to push the dough through the tube and leave a gap to remove the tube between cycles) and is rated to handle axial loads of up to 4,800 pounds. The entire device is wash down rated (a form of protection); it should be able to handle the conditions of the Brown Butter Cookie Company kitchen with ease. It is also capable of running at a 100% duty cycle, which means that there is no need for any cool down time between runs.

The advantage of this model is that it is capable of such large forces that we are confident in its ability to extrude the cookie dough. It does have some disadvantages, however. For starters, the amount of space occupied by the linear actuator is large (it is a total of 978 millimeters long, or 3.2 feet). We chose a parallel motor mount to help reduce the length, but ultimately this was driven by the batch size requirement and was a necessary (and sponsor approved) sacrifice. Another, related, effect is that the linear actuator weighs around 45 pounds, putting the entire weight of the device at around 250 pounds. This is not in line with the engineering specifications, but we have designed handles into the base to help with this problem, and once it is in place in the kitchen it should remained stationary.

The linear actuator has a two-year warranty included from Thomson and should not need any maintenance. If it has issues, the Brown Butter Cookie Company can contact Thomson. This contact information would be included in a user manual of the Shiny Dough Master 3000.

When in use, the user will interact with the controls system to activate the linear actuator. The linear actuator will push the plunger through the cylinder to the end of the funnel, pushing any dough ahead of it. The speed at which the linear actuator moves is 0.056 inches per second. This, along with the six to one contraction of the funnel, will produce cookie dough pieces much faster than their current rate.

This part is delivered fully assembled, so no manufacturing is required besides adapting structural parts to its specifications. With that in mind, the adapter on the actuator (where the plunger attaches) comes threaded with M33x2 external threads. The actuator also comes with mounting feet with 17 mm holes; it will be bolted to the base plate with 16 mm bolts. The actuator comes with a motor from Thomson, and power will be supplied by the controller, which will be discussed later in the report.

The cost of the actuator is $7310, including shipping and estimated taxes and fees. This part is custom made and has a lead time of seven weeks. Because the cost of this part is so high, we sought specific approval from our sponsor to proceed with this purchase. After discussing other alternatives, including a smaller prototype, Traci and Christa decided to expand the project budget and proceed with the full, expensive model. Later, after the model was completed, construction was further delayed for other reasons not known at the time of that decision. Therefore, all manufacturing discussed in the remainder of this section assumed the manufacturing team would have access to the Cal Poly shops and resources.

6.2 Cutting Motor and Paddle

The cutting motor (104) rotates the paddle (105) at a constant, controllable speed. As the dough comes out of the funnel at a constant rate, the paddle hits the dough, causing it to shear on the edge of the funnel and fall, presumably into a bowl placed below the exit of the device by the operator (Figure 15).

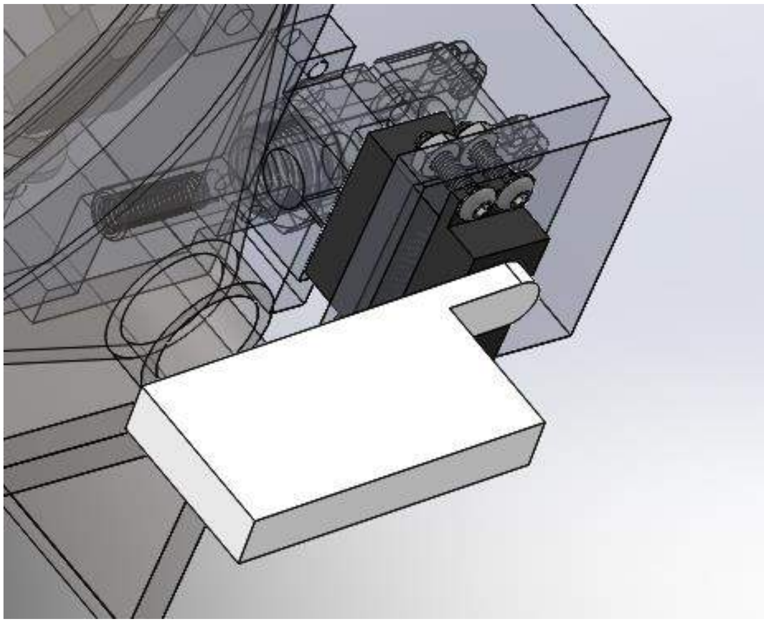

Figure 15: Motor (104) and paddle (105) assembled on the front of the machine

To reach a goal rate of 40 cookies per minute, and factoring in time for cleaning, we need to be producing about 1.326 cookies per second at the standard size cookie. From measuring dough balls at the Brown Butter Cookie Company, we know that each dough ball has a volume of 1.227 cubic inches. Combining these two data points gives us a desired volumetric flowrate of 1.627 cubic inches of dough per second.

On the front end of the device, each rotation of the paddle will produce one ball of cookie dough. Thus the motor needs to turn at 1.326 rotations per second, or 79.56 rotations per minute. Our device has been asked to handle the classic style cookies as well, and these are much bigger. These we will produce at a slower rate (still improving the rate at which they make them) of one cookie per second, which translates to 60 rotations per minute. Thus, the main specification for our motor is that can run at different speeds in the range of 60 rpm to 80 rpm.

The other specification for the motor output, of course, is torque. The torque the motor needs to be able to apply is minimal. Firstly, it needs to be able to rotate the full weight of the paddle, which is made of high density polyethylene (HDPE). HDPE has a density of about 0.56 ounces per cubic inch (United States Plastic Corp., 2015). The paddle, as designed, has a volume of 2.51 cubic inches, and therefore a weight of 1.406 ounces. Instead of finding the exact center of mass for the paddle, we used an estimate of two and half inches out from the shaft of the motor, which is further out than the center of mass actually is. Multiplying these values gives a necessary torque of 3.515 ounce-inches to move the paddle.

The main function of the paddle, however, is to strike the cookie dough with enough force to cause it to shear and fall. Back when we were measuring the force required for the linear actuator, we noticed the original dough always fell off after extruding somewhere between two and three inches from the opening, with the force of the weight of the dough providing enough shear. The opening of the sausage press was also one inch in diameter, or an area of 0.785 square inches. Being conservative, at three inches out the dough would have a volume of 2.355 cubic inches. The density of the dough is 0.624 ounces per cubic inch, so the weight of the dough at this point is 1.470 ounces. If the motor must apply this force at the edge of the paddle (4.0 inches out), the torque required to shear the dough is 5.878 ounce-inches. Add this to the torque needed to move the paddle and the required torque is 9.393 ounce-inches.

We decided that because we needed a motor to rotate at various speeds, we would buy a servomotor, which allows for position control and can easily be adapted to speed control (the much more powerful motor in the linear actuator is also a servomotor). On the other hand, because our speed and torque requirements were minimal, we could afford to get a very small motor. The motor we decided on is the BMS-661DMG+HS Digital Servo from Blue Bird, sold by Hobby King, as shown in Figure 16.

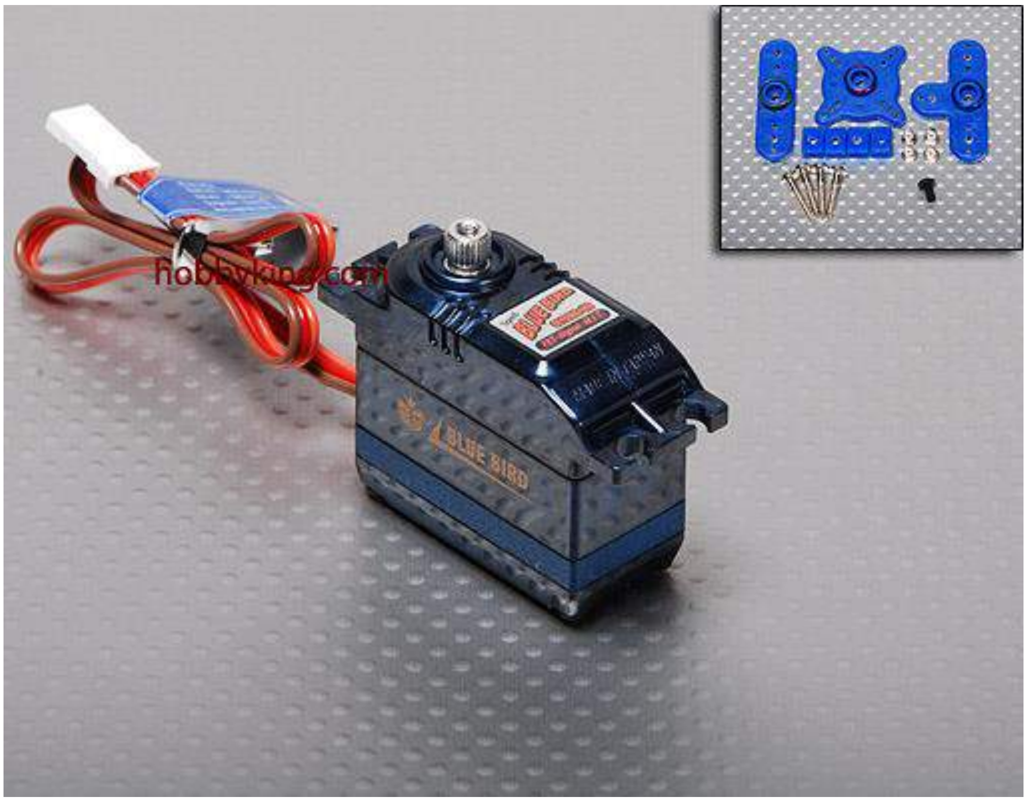

Figure 16: The BMS-661DMG+HS Digital Servo Motor (104)

This motor comes in a sealed waterproof case (good for the kitchen environment) and is small enough to easily attach to the front of our machine (about 1.7 inches long by 1.6 inches high by 0.8 inches wide). It provides 89 ounce-inches of torque, well over a needed 9.4 ounce-inches, and can rotate at speeds of up to 125 rotations per minute. Our required speed was up to 80 rotations per minute. It comes with its own plastic attachments: we cannot quite find the exact specifications of these, but the plan is to drill holes into our paddle and attach it to the plastic pieces provided, thus linking the motor and the paddle. The motor costs $27 after shipping and tax and has a lead time of six to eight days. The specification sheet for the motor (104) can be found in Appendix G.

The paddle, as mentioned, is four inches long and is machined from a half inch sheet of HDPE. We've talked with the Cal Poly Shops and they assure us plastic is the easiest thing to machine besides wood. The plan is to cut the general shape of the paddle from a 12 inch by 12 inch sheet, then align the motor attachments and drill small holes into the handle of the paddle. We will then screw the paddle onto the attachment, which will easily attach to the motor. The material for the paddle is to be bought off of Amazon for $14 including shipping and tax. There is a drawing for the paddle (105) in Appendix G, but it does not include the holes to be made for the attachment of the paddle to the motor, as those are as of yet unknown (105).

There is a stress concentration in the thin part of the paddle where it attaches to the motor. We calculated the expected force needed to make the paddle break at this point. With the 9.4 ounces of force used for the motor calculations on the end of the paddle (a worst case scenario), this area of the paddle is secure, with a factor of safety of about nine. You can see the hand calculations and EES code for this in Appendix F.

The motor and paddle combination are exposed to the operator of the device, and although there is dough constantly coming out of the funnel during operation, it is possible for a deliberately masochistic operator to stick their finger into said dough as the paddle comes around and whacks it. The maximum torque of the motor, as stated, is 89 ounce-inches, so it would apply a force of 22.25 ounces at the end of the paddle, or about a pound and a half. Looking through various human factors literature, minimal estimates for human single finger grip strength is around 7.87 pounds (Astin, 1999), so a person could easily break the motor before any damage or even pain was felt on their finger. While there are large forces in this machine, the cutting motor does not require or use any sort of dangerous amount of force.

6.3 Controls and Electronics

This is the portion of the design that has not been completely finished. There is, however, a strong start and a solid plan for moving forward from here. There are certain end requirements of the controls system, and these are well defined. The controls must supply power to the cutting motor and the linear actuator, as well as controlling the speeds of these devices. The linear actuator comes with a feedback port, and thus the controller should take that feedback into account and have programming to adapt to what the linear actuator is reporting.

The controller must have the capacity to output three settings for each of these devices, one for the brown butter dough, one for traditional cookie dough which is portioned in larger bigger cookies, and one for retracting the actuator. There must be an easy to use human-machine interface so that the Brown Butter Cookie Company can easily distinguish between these settings.

There are also safety requirements the controller must handle. The first precaution is a large red emergency stop switch in the middle of the device, easily within reach of either end. This stop switch must safely shutoff the device without breaking it. Additionally, we are going to put a magnetic switch on the safety cage of the device. If the safety cage is open, the controller must not allow power to access either motor. When the safety cage is down, the operator can then select the desired cookie type from the human-machine interface.

Finally, we need to be able to safely supply the controller with power from a 120 volt alternating current wall socket, such as can be found in just about any room in America. We talked with Ben Johnson, the campus electrician, and he gave us a small diagram of the parts we would need and what the basic wiring might look like. An adaptation of this diagram is shown in Figure 17.

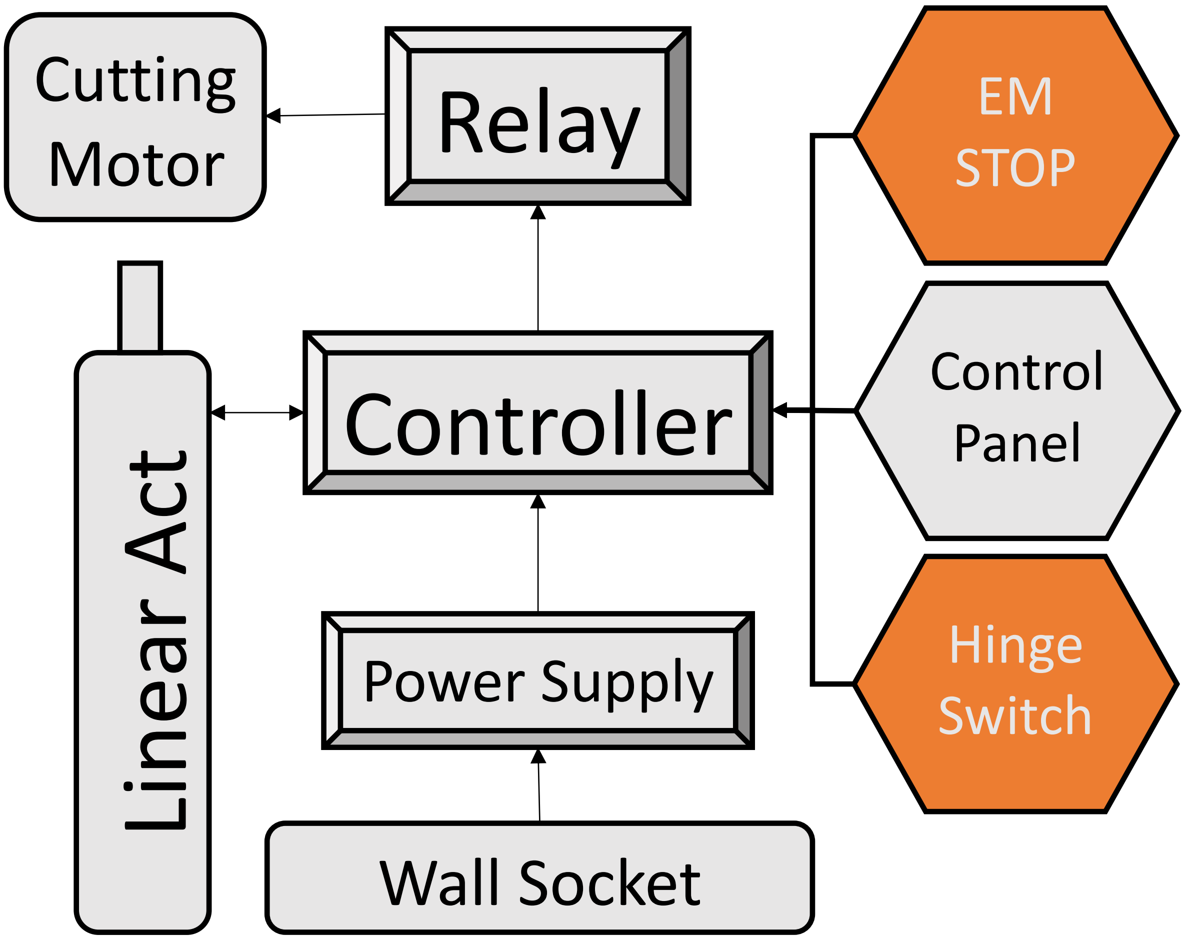

Figure 17: Block diagram of electrical control system

The linear actuator and cutting motor of Figure 17 have been covered earlier in this report. The central item here, both in the diagram and the end requirements, is the controller (102). The controller demands a large amount of functionality, the largest of which is communicating with the linear actuator. We talked to the company that makes the motor for the linear actuator, and they design controllers for their motors as well. Their distributor, Motion Solutions, suggested a controller that has enough inputs and outputs to control all of our devices and comes with an interface to easily program the controller (Figure 18).

Figure 18: Kollmorgen AKM63K-ANCR-00 Drive and Controller (102)

The Kollmorgen AKM63K-ANCR-00 drive and controller is specifically designed to interact easily with the AKM63K motor used in our linear actuator. The quote we got from the distributor included the cables to connect to the motor. This controller is 8.86 inches tall, 3.09 inches wide, and 8.46 inches long. It takes a supply of 120 or 240 volts alternating current in either one or three phase. It has an analog input and analog output, seven digital inputs, and two digital outputs, all programmable.

The analog input and output will probably connect to the linear actuator. The emergency stop will be a single digital input, as will the magnetic switch on the safety box. The control panel will occupy one input, and possibly an output if we can find useful feedback to give the operator. Finally, there will be one digital input and output to a relay supplying the servomotor with power and velocity information. Kollmorgen did not supply a concise specification sheet, but there are a few pages from the installation manual of the controller (102) with relevant specifications in Appendix G.

The next step is to talk to Ben Johnson again to correctly choose the emergency stop, magnetic switch, relay, and power supply for our controller. He has given us very loose ballpark estimates for how much these might cost, and these have been included in our budget. In all, the Kollmorgen Controller has been quoted to us at $1,367, and we have estimates for the magnetic switch ($30), the relay ($200), the emergency stop switch ($50), the fuses necessary to safely run the device ($200), the human machine interface ($200), and the power supply ($250).

In terms of manufacturing, none of the items here will be manufactured by CDE, but they will certainly need to be set up safely and wired correctly to run all of our systems. Once again, Ben Johnson has kindly agreed to run us through how to do this. We already anticipate an out-of-pocket expense to buy Ben dinner if he wishes, or at the very least a very large thank-you note. His help has been indispensable.

Also involved in this subsystem is programming. The Kollmorgen controller uses BASIC as a program language and includes the software needed to communicate with and program the controller by a computer hookup. They also provide a detailed user manual (1,300 pages) on how to program the controller, but from a brief skim it appears to be a fairly standard PID affair. While we may not know much about wiring, our controls class has given us confidence we will be able to test our actuator and controller and discover their response, and then accurately program the controller.

The control system was never developed beyond this point due to other considerations, discussed later in this report.

6.4 Funnel, Cylinder, and Plunger (200 Series Parts)

The funnel (202), cylinder (201), and plunger (203), shown in Figure 19, make up the main subsystem of the Shiny Dough Master 3000. These three pieces are the only food contact surfaces, and have been the core of this idea since the concept generation phase.

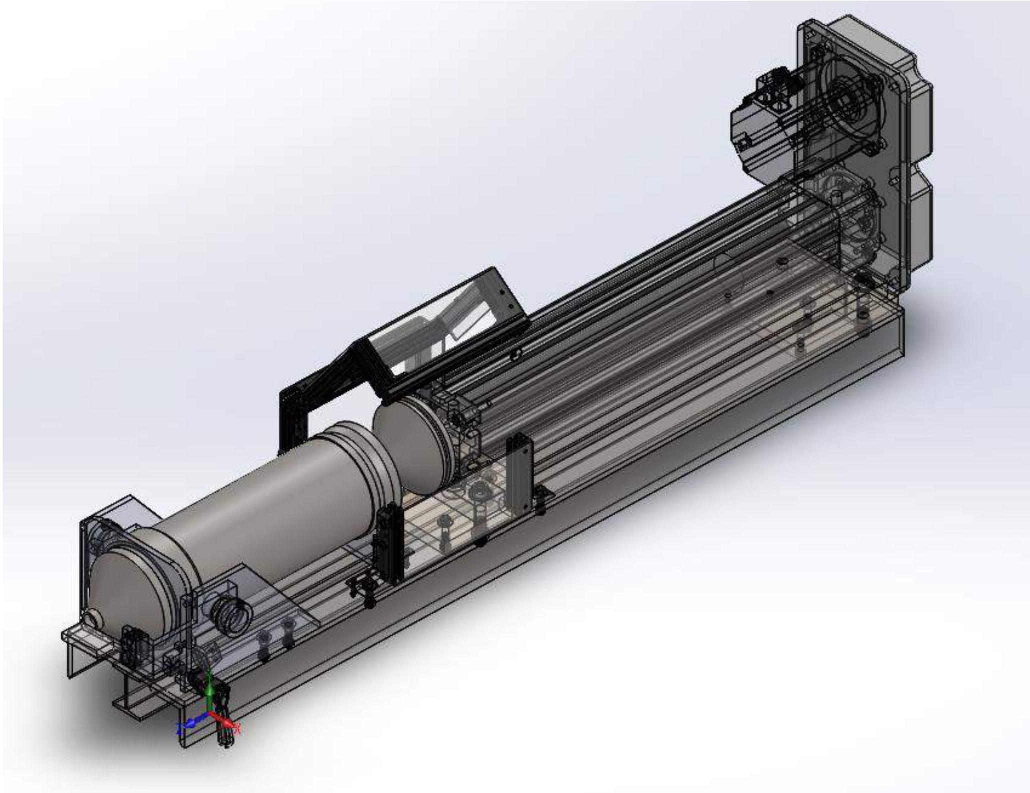

Figure 19: Funnel (202), cylinder (201), and plunger (203) in semi-transparent full assembly

After discussion with welding, casting, and machining professors here at Cal Poly, we decided to machine these pieces out of stainless steel 304 stock parts. The funnel and plunger will be machined out of a single foot-long, seven-inch diameter plug of stainless steel 304. We chose stainless steel 304 because it is food-safe, strong, but still cheaper than other types of stainless steel and aluminum. The funnel will be machined out of a single, 24 inch piece of schedule 40 stainless steel 304 pipe. Both of these pieces of stainless steel will be purchased from B&B Surplus, located in Bakersfield CA. The combined price of these parts, including the cost of outsourcing the machining, is $1,536. For exact price breakdown, see the complete budget included in Section 8.1 of this report.

The funnel (202) is tapered at 45 degrees from a large diameter of 6.093 inches down to an extrusion diameter of one inch, as shown in Figure 20.

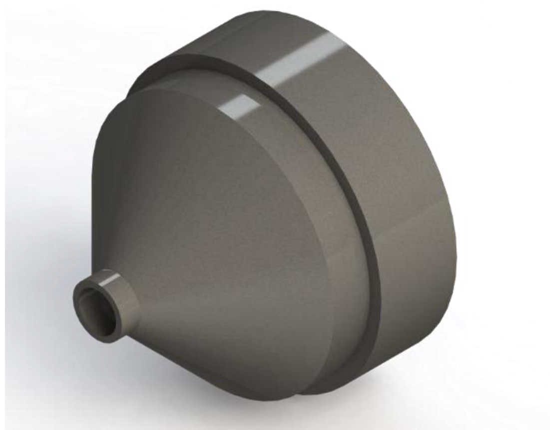

Figure 20: Computer rendering of the funnel (202)

We are confident that we can force the dough to reduce by this amount because it is approximately the same reduction ratio which we achieved during the sausage press demonstrations (for details, see Appendix B).

Both the funnel (202) and the cylinder (201) are subjected to stresses similar to those found in pressurized vessels. In order to analyze the strain caused by this loading, we referred to Roark's Formulas of Stress and Strain which gives the resultant strain and deformation for many types of bodies undergoing many different types of strain. Using these formulas, we determined that as long as the minimum thickness of the material was always equal to or greater than one tenth of an inch, there would be no danger of either part breaking from the pressure.

The cylinder and funnel are held together by standard 6" ANSI threads. These threads see very little loading other than the internal pressure already discussed, and both parts have been engineered to ensure that the threading does not cause a minimum thickness less than the previous mentioned tenth of an inch. These threads will need to be strayed down every time the cylinder and funnel are disassembled for washing in order to ensure no particulates remain in the threads and cause difficulty in re-attaching.

The cylinder (201), shown in Figure 21, is 18 inches long in order to allow the Shiny Dough Master 3000 to handle up to three batches simultaneously. This specification change was requested by the sponsor after they witnessed the sausage press demonstrations. This request was also a large part of the reason to increase the cylinder diameter to six inches, for easier loading and to decrease the total device length.

Figure 21: Isometric rendering of the cylinder (201) showing threads and back lip

As shown in Figure 21, the thread has a lip on the back inch and half of the cylinder. This is to allow the cylinder to sit securely on the back support and to ensure the cylinder is properly located at all times during normal operation.

The plunger (203), shown in Figure 22, was designed to match the taper of the funnel, and to maximize the use of our choice of seal (204), which ensures proper pressure in the cylinder and funnel and prevents dough from being wasted as the plunger extrudes the dough.

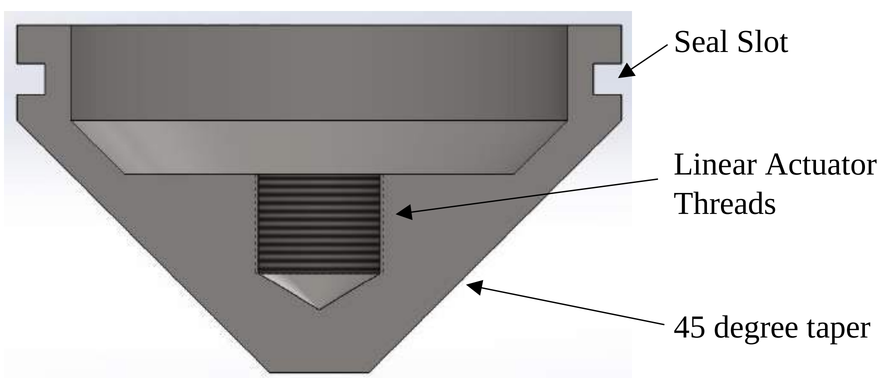

Figure 22: Computer simulatin of a section cut of the plunger (203) showing the slot for the seal, the linear actuator threads, and the 45 degree taper to match the funnel reduction

The slot for the seal, as well as both the diameter of the slot and the outer diameter of the plunger were chosen to maximize the life and use of the seal. The choice of seal also drove the specification for the finish on the inside diameter of the cylinder. We chose to use this particular seal due to the availability of this data from the distributer, Parker. Despite these measures, the seal is only designed to last for ___ months. We are therefore including 3 extra seals, to be used as replacements when necessary. The seal will need to be cleaned as frequently as the cylinder and funnel are cleaned, and can be removed from the plunger to do so.

The plunger (203) attaches to the linear actuator (101) by threads specified by Thompson, the company building the linear actuator. It is not, however, intended to be regularly removed. It can be cleaned with a hot, soapy rag while still attached to the linear actuator, once the seal is removed and cleaned separately.

6.5 Base (300 Series Parts)

The base of the structure consists of two angle irons (303) and an I beam (302) attached to the base plate (301), as well as the wooden mounting blocks for the linear actuator (304, 305). The full assembly of these parts in shown below in Figure 23.

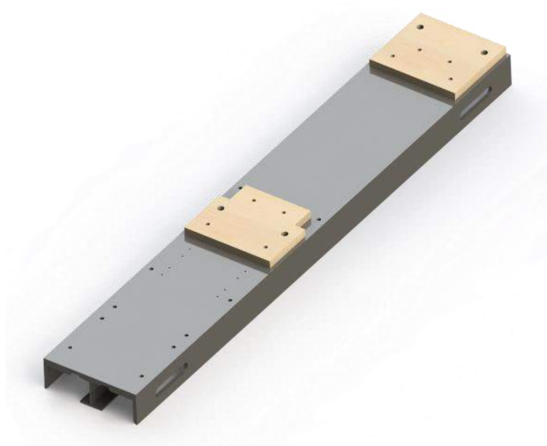

Figure 23: Fully assembled base subsystem (300)

Everything in the base, except the mounting blocks, are made from A36 steel. This material was chosen for its strength and cost. Additionally, these areas are non-food-contact areas and thus are not subjected to the same restrictions as other portions of this machine.

The plate will be cut from a quarter sheet of 3/8th inch steel and welded together to make a single five foot plate, as shown specified in Section 8.2, Manufacturing Plan. Next, the I-beam will be welded to the necessary sections to reinforce the plate and prevent bending. The hand holds will be cut into the angle iron. This angle iron and the mounting blocks will be then attached to the rest of the base with bolts.

The base was carefully design with two types of stress in mind. First, the base had to be able to withstand the stress caused by the moment of the linear actuator, which is positioned approximately 5 inches above the top of the base plate. This moment causes stress in the material, as well as deflection. Large deflection, greater than on hundredth of an inch, has the potential to harm or even break the linear actuator as well as the funnel and cylinder. Thus, the

I-beam was added to increase the resistance the base had to deflecting due to this moment. Figure 24 shows a cross section of the profile of the base, which resists the moment.

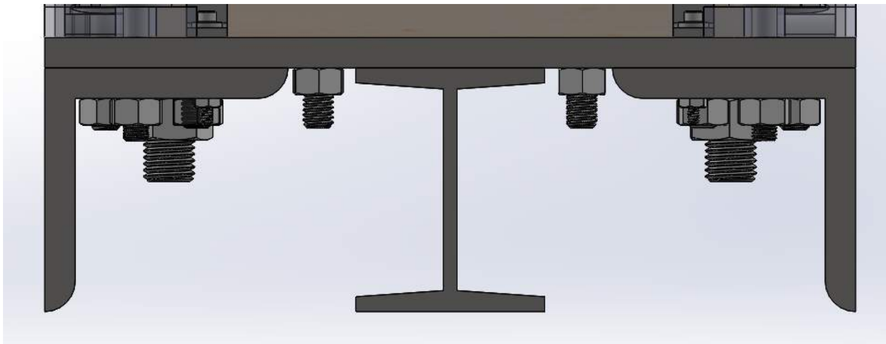

Figure 24: Perpendicular view of fully assembled base (300)

Second, the base had to be sufficiently thick to prevent bolts from twisting or deforming the structural material. The details of these calculations can be found in Appendix F. In both types of stress, the design factor for the base if very close to one. However, we felt that this was an acceptable compromise between increasing cost and small safety concerns if a failure were to occur failure. We felt that it would be safest for the base to fail first, where it would be easy to spot and repair before danger occurred.

6.6 Structural Steel (400 Series Parts)
The structural steel subsystem consists of the two trapezoidal funnel supports (404, 405) as well as the collar (402) they support and attached smaller parts. These parts are shown in Figure 25.

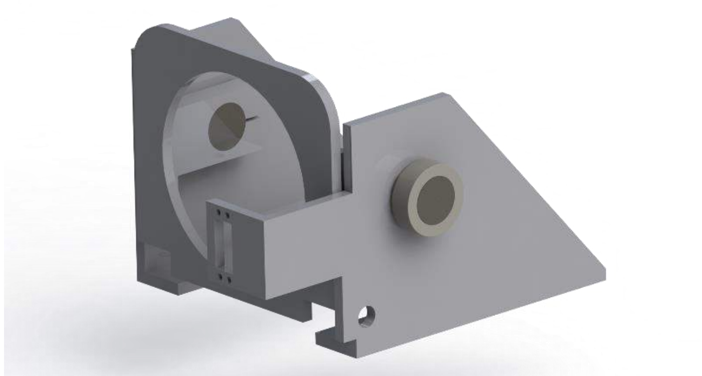

Figure 25: Structural steel subsystem (400)

The semi-rectangular collar and both funnel supports are made of out A36 Steel. This material was chosen for its strength, its price, and because it can be machined at the Cal Poly shops. This is not a food-safe material, however, these surfaces are classified as non-food-contact surfaces and therefore FDA code allows a lower rated material. We are still looking into the possibility of later powder coating these surfaces to make them food safe if budget allows. These three parts (as well as others) will be cut out of a single quarter sheet of 3/8th inch steel plate, as shown in Section 8.1, Manufacturing Plan. The smaller leg of the funnel supports will then be welded onto the taller portions.

Attached to the collar plate are two T-shaft mounts (409). These can be purchased from Misumi and will attach to two one and half inch shafts (406). These shafts will be mounted into bronze bushings (407), which will be press-fit into the funnel supports. These bushings are made to be self-lubricating but still food safe and should allow for smooth operation. Together, this arrangement will allow the collar to rotate for easy loading of the cylinder and funnel during regular operation. Attached to the front funnel support will be a clamp (410), allowing the operator to force the collar to remain in the tilted position.

Each funnel support will be bolted to the base by three 3/8th inch bolts (###). In addition, the right funnel support will be welded with an extended arm to mount the cutting motor.

Stress and strain analysis was performed on critical cross sections of all of these pieces in order to ensure that there would be no structural failure, even under the strongest load from the linear actuator. Additionally, all failure modes were measured against a conservative fatigue failure criteria of 4 years and von misses stress and in all cases, the design safety factor was 1.5 or greater.

This subsystem will require no maintenance other than a daily wipe-down to eliminate stray food particles. In total, it will cost $350 and it will be assembled entirely by CDE in the Cal Poly shops. The collar and attachments will be assembled first. Then, the bushings will be loaded into the welded funnel supports. Next, the shafts will be inserted into the bushings. Finally, the funnel supports will be bolted to the base and the rod collars (408) will be attached.

6.7 Safety Cage (500 Series Parts)

The safety cage (500) is in place solely to prevent fingers or other items getting pinched between the plunger and cylinder when the Shiny Dough Master 3000 is operating, as demonstrated in Figure 26 .

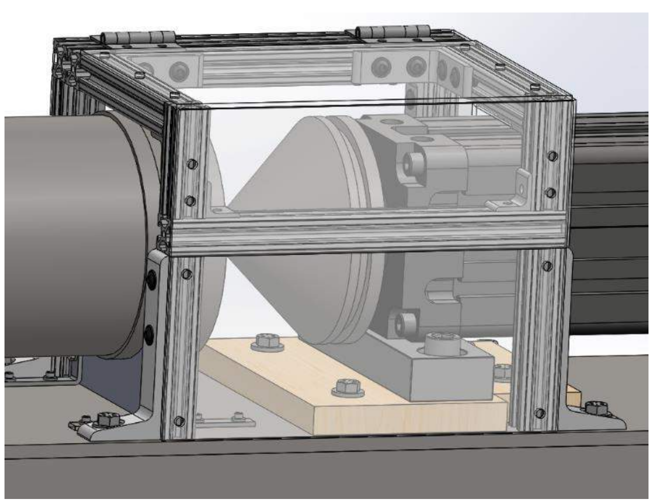

Figure 26: Safety cage in the closed position, protecting the plunger as it enters the cylinder

The safety cage is not meant to protect from impact or projectile forces, nor does it need to. For this reason, we chose to build the cage out of aluminum T-slot (501-506) and acrylic (507-511), as shown in assembly drawing 500. Aluminum T-slot is very easy to work with and comes in many sizes with many cheap attachments and parts. The acrylic allows the users to see the device while still providing a barrier, and is easy for CDE to cut in the Cal Poly shops. Together, this subsystem costs less than $200. It will be assembled separately and then attached to the base assembly. The acrylic will need to be cut to the correct shape and holes will be drilled to accommodate attaching screws.

Also present in this subsystem, but not shown in Figure 26, is a magnetic switch which will attach to the seam of the cage lid. Thus when the case is open, as shown in Figure 27, the switch will be tripped.

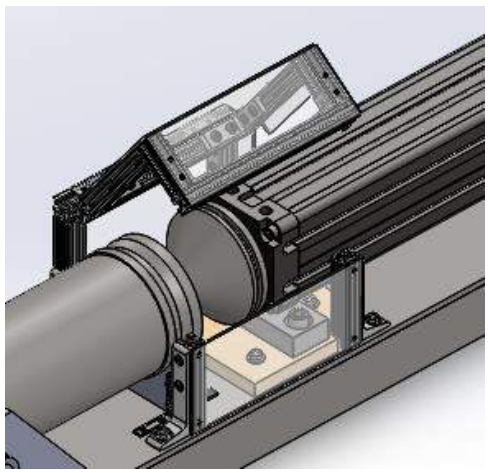

Figure 27: Safety cage in open position, system prevented from moving by magnetic switch (not shown)

Once the switch is tripped, it will trigger an automatic emergency stop sequence in the controls system and force a system reset. This prevents fingers from being pinched once the device is in motion. Additionally, the system will not start unless this switch reads as closed. This safety system will need no maintenance from the Brown Butter Cookie Company.

7 Safety

The safety of our customers is our first priority. In order to ensure that our device is as safe as it can be, we have followed a number of guidelines. Some of these are set down by the framework of senior project. Others we have adapted to fit our specific machine.

7.1 Safety Hazard Awareness Table and Checklist

The first step we took in safety awareness was to make a basic table of hazards. This table was inspired and informed by the senior project safety checklist and identified four hazards which we would need to eliminate during the design process. This table can be found in Appendix H. Every hazard on this table has been eliminated or greatly reduced.

7.2 Failure Mode and Effects Analysis

Next, we used a more detailed safety tool known as a Failure Mode and Effects Analysis (FMEA). This table lists every system or subsystem, its possible failure mode or modes, and the potential effects of those failures. CDE then classified these failures according to the severity of the failure, with a 10 representing certain death and a 1 representing a very minor inconvenience. Failures are also given an occurrence rating based on how likely they were to occur, with a 10 representing a failure which would occur every time and a 1 representing a failure which we are absolutely certain will never occur. These two scores are then multiplied to give a criticality rating. For our FMEA, any criticality rating over 20 required mitigation to decrease either the severity or, more likely, the occurrence. The original FMEA we produced had a dozen different possible failure modes, but now after detailed design we have one possible failure mode left is greater than this threshold, and it will be reduced after testing and programing adjustments. The full FMEA can be located in Appendix H.

7.3 Safety Checks

In addition to this documentation, the Shiny Dough Master 3000 will be subjected to several safety inspections before start up. We have already presented our mechanical design for inspection and been approved to build the prototype. Once the electrical system is finalized, it will also be inspected before it is built. After construction, the prototype will be inspected again to ensure there are still no concerns. Only then will the device be operated.

8 Management Plan

In order to ensure that this prototype could have been completed on time, CDE developed a management plan. This detailed the expected costs of the project, the manufacturing and design verification plan, and a projected schedule for future progress.

8.1 Budget

In the last report, the hard budget was set at $10,000 with a goal to meet a budget of $3,000. The amount of force required to push the dough, and the subsequent selection of the linear actuator and necessary thickness of the supports pushed the price up towards the hard budget. The go-ahead on the linear actuator was approved at a late January meeting with our sponsor. Since then, the price of the full system has increased again, largely due to two factors. The first factor is that the controls for the device cost much more than originally anticipated. This is again due to the large size of the linear actuator. The second factor is that the team decided to outsource the precise manufacturing of the stainless steel items as we were not confident in our ability to meet the tolerance for these items, and as the device was growing so much more valuable, we wanted to decrease the likelihood of any sort of complication.

Table 6 features an itemized budget for every part. The first is that we are officially well over budget, with the price of the Shiny Dough Master 3000 costing $13,042.46. At this point the team cannot build this device for under $10,000 without sacrificing the safety or the functionality of the device, or stepping back and completely redesigning the actuator system. A redesign of the actuator is not currently feasible within the scope of this project, although it could possibly initiate a future project to take the Shiny Dough Master and build it cheaper.

That said, it is feasible that the final cost of the Shiny Dough Master 3000 will clock in at less than $13,000. There are a few budget items that have yet to be sourced, and these are marked with an asterisk (*) in the source column. The biggest one is the manufacturing of the stainless steel parts, which is currently estimated at $2,010. Our initial estimate of the cost of this process was $1,000 dollars, which we doubled because we usually have been optimistic on the costs of items. Also not yet sourced are many of the controls parts that were waiting on the controller. Some of these are very likely to cost near the amount listed, including the fuses, emergency stop switch, and human machine interface. The relay and the power source, however, may be cheaper than originally estimated, as the controller runs on 120V AC as opposed to an originally guessed 240V AC. That said, the electrics series 100 items are where much of our cost estimates have gone haywire throughout the project, so we left these costs in the budget to be safe.

Overall, the budget is both much higher than desired and much more uncertain than desired, but the table given below is the most accurate representation of where we stand to date.

Table 6: The full line item budget and Bill of Materials for the Shiny Dough Master 3000

Part Number	Part Name	Subsystem	Unit Price	Supplier	Quantity	Total Price
101	Linear Actuator	Electrics	$ 7,310.00	Thomson/Kaman	1	$ 7,310.00
102	Controller	Electrics	$ 1,400.00	Kollmorgen/Motion Solutions	1	$ 1,400.00
103	Power Supply	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
104	Motor	Electrics	$ 30.00	Hobby King	1	$ 30.00
105	Paddle	Electrics	$ 15.00	Amazon	1	$ 15.00
106	Relay	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
107	Emergency Stop Switch	Electrics	$ 50.00	Automation Direct*	1	$ 50.00
108	Fuses	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
109	Human Machine Interface	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
201	Cylinder	Food Contact	$ 96.00	B & B Supply	1	$ 96.00
202	Funnel	Food Contact	$ 180.00	B & B Supply	1	$ 180.00
203	Plunger	Food Contact	$ 180.00	B & B Supply	1	$ 180.00
204	Seal	Food Contact	$ 30.00	Parker Hannafin	4	$ 120.00
301	Base Plate	Base	$ 40.00	B & B Supply	1	$ 40.00
302	I Beam	Base	$ 46.00	Metals Depot	1	$ 46.00
303	Angle Iron	Base	$ 40.00	Metals Depot	2	$ 80.00
304	Front Wood Mounting Block	Base	$ 5.00	Home Depot	1	$ 5.00
305	Rear Wood Mounting Block	Base	$ 5.00	Home Depot	1	$ 5.00
401	Funnel Collar Plate	Structure	$ 10.00	B & B Supply	1	$ 10.00
402	Cylinder Support Plate	Structure	$ 5.00	B & B Supply	1	$ 5.00
403	CSP Brackets	Structure	$ 35.00	McMastercarr	1	$ 35.00
404	Right Funnel Support Bracket	Structure	$ 10.00	B & B Supply	1	$ 10.00
405	Left Funnel Support Bracket	Structure	$ 10.00	B & B Supply	1	$ 10.00
406	Rod	Structure	$ 7.00	Misumi	1	$ 7.00
407	Bushing	Structure	$ 60.00	McMastercarr	1	$ 60.00
408	Rod Collars	Structure	$ 17.00	McMastercarr	1	$ 17.00
409	T-shaft Mount	Structure	$ 130.00	Misumi	1	$ 130.00
410	Toggle Clamp	Structure	$ 25.00	McMastercarr	1	$ 25.00
411	T Support Set Screw	Structure	$ 2.00	Accuscrews	2	$ 4.00
412	Collar Set Screw	Structure	$ 20.00	Accuscrews	4	$ 80.00
501	Long Vertical Frame	Safety Cage	$ 20.00	Futura Industries	1	$ 20.00
502	Long Horizontal Frame	Safety Cage	$ 20.00	Futura Industries	1	$ 20.00
503	Medium Vertical Frame	Safety Cage	$ 15.00	Futura Industries	1	$ 15.00
504	Short Horizontal Frame	Safety Cage	$ 10.00	Futura Industries	1	$ 10.00
505	Short Vertical Frame	Safety Cage	$ 10.00	Futura Industries	1	$ 10.00
506	Acrylic Sheet	Safety Cage	$ 5.00	Tap Plastics	1	$ 5.00
507	Acrylic Sheet	Safety Cage	$ 2.00	Tap Plastics	1	$ 2.00
508	Acrylic Sheet	Safety Cage	$ 2.00	Tap Plastics	1	$ 2.00
509	Acrylic Sheet	Safety Cage	$ 4.00	Tap Plastics	1	$ 4.00
510	Acrylic Sheet	Safety Cage	$ 1.00	Tap Plastics	1	$ 1.00
511	Acrylic Sheet	Safety Cage	$ 8.00	Tap Plastics	1	$ 8.00
512	Floor Mount	Safety Cage	$ 8.79	Futura Industries	2	$ 17.58
513	4 Hole Corner Bracket	Safety Cage	$ 4.43	Futura Industries	2	$ 8.86
514	2 Hole Corner Bracket	Safety Cage	$ 2.95	Futura Industries	4	$ 11.80
515	T-Slot Hinges	Safety Cage	$ 13.27	Futura Industries	1	$ 13.27
516	Fasteners	Safety Cage	$ 33.95	Futura Industries	1	$ 33.95
600	Bolts	Structure	$ 100.00	Bolts Depot	1	$ 100.00
	Manufacturing of 201, 202, 203	Food Contact	$ 2,010.00	Santa Maria Tool*	1	$ 2,010.00
				TOTAL COST		**$13,042.46**

8.2 Manufacturing and Assembly Plan

Much of the planned manufacturing for this design is discussed in the detailed design and technical content section, but it is gathered and expanded upon in this section. Additionally, there is an explanation of how the whole part will be put together once the parts and pieces are assembled. Again, we reiterate that his manufacturing plan was designed for three college students using the college shops available to us and may no longer be feasible for this design.

For starters, it should be noted that many of the parts do not need to be manufactured, but are just bought as is. These include all the bolts and fasteners throughout the device, many of the electrical devices including the linear actuator, controller, and cutting motor, and most all of the set screws, clamps, and support brackets near the collar of the device. Many more of the parts are not off the shelf parts but will be cut to our specifications by the supplier. This includes the base plate, angle irons, and I-beam, as well as the T-slot used in the safety cage.

With all that in mind, there is some manufacturing that must be done to many of the support parts. The most complicated machining involves the 200 series of parts: the tube, funnel, and plunger. Santa Maria Tool and Next Intent are local shops that have both claimed the capability to machine our parts, but they have not gotten back to us with set quotes yet. That said, the manufacturing plan for these parts is to buy the raw material from B & B Supply and then outsource the manufacturing to one of these shops. The drawings for these and any other part can be found in Appendix G.

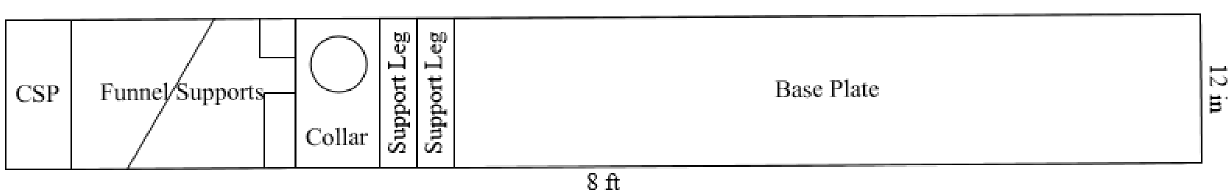

Figure 28: Layout sketch of the cutout for parts made of 3/8th inch sheet metal

Most of the support parts that are not stock parts are going to be cut from 3/8th inch A36 steel plate. B & B Supply in Bakersfield has agreed to cut us a sheet one foot by eight feet long, out of which we can machine all of our supports. As seen in Figure 28, all of our relevant support material can be machined out of this giant plate of metal. The cuts will be made with a band saw, and the collar hole will be milled, all here at the Cal Poly shops. These cuts are estimated to take three hours of machine time, and the collar hole an additional hour, and should be done within half a week of receiving the metal from B & B Supply.

Once the pieces are cut, the next step is to drill the bolt holes in all the supports (including the wooden ones for the linear actuator) and in the base plate. The various bolt holes needed can be seen in the drawings for the respective parts, but we'll use the base plate (301) as an example here because it's the most complex. There are 30 bolt holes in the base plate: 6 3/8 x 1.75 in, 8 6-32 x 1.25 in, 4 M16 x 90 mm (for the linear actuator mount, Thomson uses metric), 4 3/8 x 2.5

in, and 8 3/8 by 2 in. The locations of these can be seen on drawing 301. It is expected to take ten hours to drill all the holes specified in the design, and this is to be done within two weeks of receiving the metal sheet.

After the relevant holes in the pieces are cut, there are a few pieces that will need to be welded together. The funnel supports (404 and 405) have each require a fillet weld to create the 90 degree bend in the part so it can be bolted through the base plate. A36 Steel is some of the easiest to weld, and the recommended method is stick welding with a basic E6011 stick. This has less tensile strength than an E7024 stick, for example, but has a tensile strength of 60,000 pounds per square inch, which is plenty for our application. We plan on laying a quarter inch thick fillet weld along the entire ten inch base of the support to create the strongest joint possible. Theoretically, this weld should only see around 3000 psi of pressure at most, as most of the load is in shear, so we have a safety factor of 20 on a well-crafted weld. Of course, our welds might not be the best crafted, but that's where the safety factor comes in.

These support welds are the most complex (fillet welds) and see the most load. The other welds needed are to make the extend one funnel support for the cutting motor (this weld is seeing almost no load), and to attach the I-beam (302) to the base plate, which will be another long weld, but this weld will not actually see much load, as the I-beam is mostly preventing the base plate from bending and doesn't carry much of the axial load generated by the linear actuator. Total welding time is actually pretty minimal, and shouldn't take more than five hours of shop time at most. All cutting, drilling, milling, and welding should be done before spring break, minimizing our need for the shops in spring quarter.

Once the I-beam and funnel supports are welded, the base, supports, and various brackets can all be bolted together to form the structure of the device. Once the funnel, plunger, and cylinder are returned from the shop (we don't have a quote for this, but we expect it will take two weeks for our series 200 parts to be machined), they too will be ready to be added to the structure, the seal (204) can be pulled onto the plunger, and the 200 and 300 series of parts will be ready for action.

The last little bits of machining to be done are the cutting of the various plastics involved in the project. The paddle (105) will be machined from the ½ inch sheet of HDPE, and then drilled properly to attach it to the motor attachments. The acrylic sheets (506-511) will also be cut to the correct size. Both HDPE and acrylic can be cut with most saw blades. All this cutting is estimated to take five hours of shop time.

Once this machining is done, the rest of the work is in the assembly of the device. The paddle can be attached to the motor pieces, which themselves screw into the cutting motor (104). The motor will bolt into place (10-32 x 0.75 in) with the paddle in the front of the funnel. The safety cage can be assembled by sliding the cut acrylic into the T-slot in the correct fashion as seen in the safety cage assembly drawing number 500, and then tightening the fasteners (516). Two pieces of T-slot will be attached with T-slot hinges (515). After the shape of the cage is assembled it, too, is bolted into place with the floor mount and corner brackets (512, 513, 514). The motor should take at most an hour to assemble, and the safety cage up to two hours.

At this point everything mechanical is attached with the exception of the linear actuator (101), which will be the last part to arrive due to the large lead time. The goal is to get the structure machined and presentable for the manufacturing review at the end of winter quarter. In the first few weeks of spring quarter, while waiting for the actuator to arrive, the team will practice setting up the controls system. This stage of the process, as like everything with the controls architecture, is still somewhat uncertain at this point, but we do have a general plan.

The first step is to make sure the controller (102) is grounded, for safety. Then the fuse (108) will be set up between the power supply (103) and the controller to make sure any excess current cuts the circuit. The power supply and the controller can then hook up and plug into the wall. Even if the linear actuator hasn't arrived at this point, the controller will still have the capability of powering and controlling the cutting motor, so this will act as the guinea pig device to learn programming of the controller until the linear actuator arrives. Once it is demonstrated that the controller can power the cutting motor (likely through the relay (106)), and control the speed of the motor with different programs, we can also plug in and program the emergency stop switch and the magnetic switch (107) from the safety box. We may even be able to get the human machine interface (109) working. This will be the time to thoroughly learn and understand the capabilities of the controller and get the BASIC programming down pat.

Finally, the linear actuator will arrive. It may be tempting to bolt it straight into the rest of the machine and run the thing, but getting proper alignment with the cylinder is critical. To align the linear actuator and the cylinder, we have the linear actuator bolted through wooden blocks (304 and 305) that can be adjusted if necessary.

To do this properly, we would actually plug the linear actuator into the controller first and fully extend the linear actuator. Then, the plunger (203) can be screwed onto the linear actuator, as they have matching threads. Next, we would place the fully extended linear actuator into the rest of the device, with the plunger going through the cylinder and filling the funnel as designed. Any adjustments to the wooden blocks will be made at this time until the actuator is properly aligned, and then we will bolt it down through the wooden blocks.

The next step is to hook the linear actuator up to the controller, check to make sure the gains exhibited from the controller to the linear actuator behave as predicted, and make sure our emergency and safety box switches stop the actuator as planned. At this point the machine is built and we can move to the design verification plan.

8.3 Design Verification Plan for the Shiny Dough Master 3000

Our design verification will consist of two types of tests. First will be the inspection tests. We will weigh the total device, for example, in order to inspect the weight of the Shiny Dough Master 3000 and verify that it matches the specification established at the beginning of the design process.

Once the inspection tests are complete, we will perform a complete system functioning test. We will obtain dough from Brown Butter Cookie Company and portion it using the Shiny Dough Master 3000. This will allow us to measure the ball size and weight as well as the cookie rate.

To test the cleaning specification, we will travel to the Brown Butter Cookie Company and wash the cylinder, funnel, and plunger in their sink and dishwasher to ensure that it will meet their needs. We have had several volunteers who are willing to help us test our training specification by being instructed in the operation of the Shiny Dough Master 3000.

The full DVP for this project is shown in Appendix I. This table details each individual engineering specification and the testing method to verify the specification.

Some engineering specifications have already been verified as passing. We have already determined that there will be no unprotected pinch points and that there is no danger from rotating parts while the Shiny Dough Master 3000 is running. We have also verified that FDA requirements are met for all construction materials. Fatigue and stress analysis of all parts assumed a four year operation, which is twice the requirement of two years. Only the seal will have a life shorter than the two year threshold, so we will buy multiple seals to supply to the Brown Butter Cookie Company. We have also been able to verify that the device will fit within the three by three by five foot box required by our engineering specifications.

8.4 Iterative Design-Build-Test (DBT)

We are dedicated to delivering the best possible product through the use of iterative design-built-test engineering. Despite our best efforts, we were not able to deliver a working prototype in a single cycle. Therefore, we returned to designing and prototyping a subsystem. The exact reasons for this decisions are discussed below. The remainder of this report will address this second iteration of designing, building, and testing, as illustrated in Figure 29.

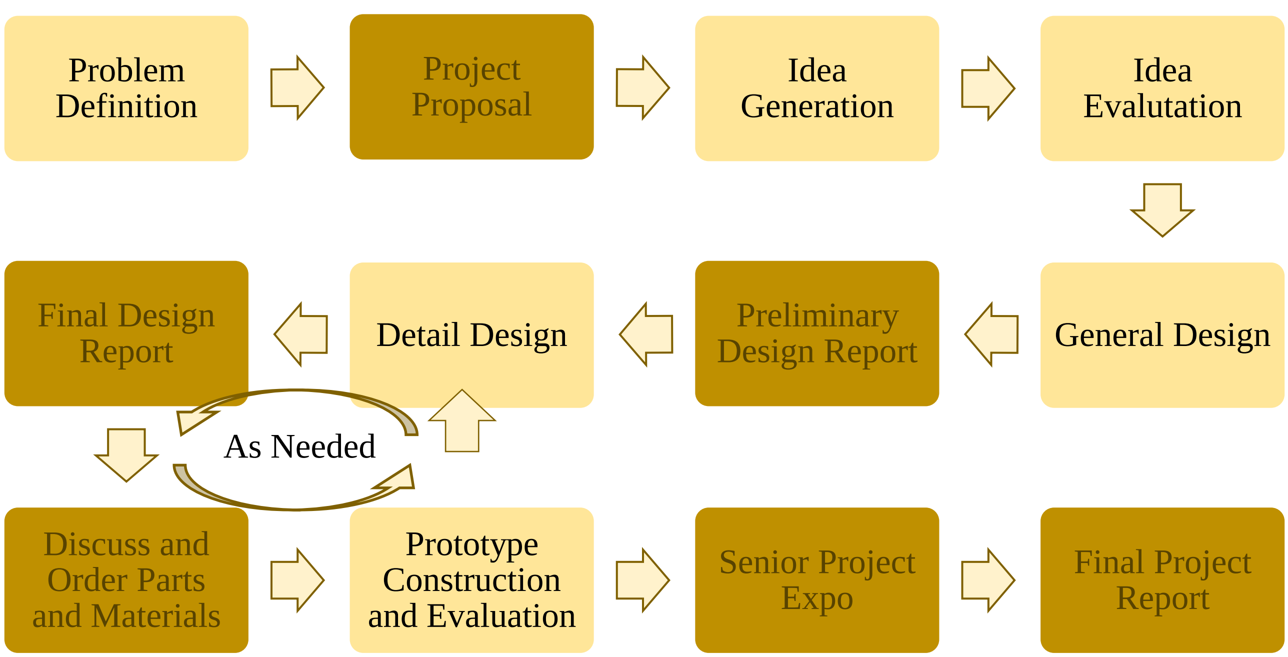

Figure 29: A flowchart of the timeline for our project and the Design-Build-Test process

Once the Shiny Dough Master 3000 (or its equivalent) is built, we anticipate some need for iteration in the programing and synchronization of the motor and linear actuator. In this way, the solution will constantly improve until the original problem is completely solved.

8.5 Schedule

Cookie Dough Engineering is beholden to certain deadlines throughout the academic year. Some of these are strictly part of Senior Project, others are more important to the design process and also involve the Brown Butter Cookie Company. The first deadline was the Project Proposal in October 2014. The Project Proposal included information on the people involved in the project (both students and sponsors), background information on the current solution to the problem as well as other existing solutions, and a detailed set of customer requirements and engineering specifications for the end design. In November, Cookie Dough Engineering delivered the Preliminary Design Report, which included a list of the top concepts considered and the initial design chosen based on how it was predicted to meet specifications. Also included was an explanation of the testing process used to choose the preliminary design.

This document is the Final Design Report. It contains full models and drawings of the final design, a complete plan and budget for acquiring parts and building a device, and a timeline for building and testing the final prototype.

Also, due to the decision of this team and our sponsors, it includes the results of an iterative testing device which we constructed rather than the Shiny Dough Master 3000. The schedule of this project thus far is shown in Table 7.

Table 7: Project Timeline and Important Dates

Date	**Item Due**
October 21st	Project Proposal
November 14th	Preliminary Design Report
February 10th	Final Design Report
February	Discuss Design and Begin Prototype Construction
March - April	Prototype Construction
Early May	Product Testing
May 29th	Senior Project Expo
June 5th	Final Project Report

In order to provide additional scheduling detail, we have developed a Gantt Chart schedule, which is available in Appendix J.

9 Dough Property Testing

Before building the Shiny Dough Master 3000, the team spoke with the Brown Butter Cookie Company and decided to perform preliminary testing to confirm the likely behavior of the dough. Due to the inconsistent properties exhibited by the dough at various times, we felt it was necessary to develop a mathematical model for the behavior of the dough. Doing so had several advantages, including the possibility of making the Shiny Dough Master lighter and cheaper. As previously discussed, the need for more than 3,000 lbs of force was a driving factor for both the weight of the structural portions of the device and the cost of the linear actuator. If this force was known more exactly, it would allow for more exact engineering, including the possibility of a smaller linear actuator and cheaper, lighter structure.

9.1 The Doughbreaker

In order to improve the model of the Shiny Dough Master 3000 we isolated four variables that seemed to be inter-dependent on each other. These were the diameter of the cylinder where the dough was loaded, (D_{Cyl}), the diameter of the extrusion opening for the dough (D_{Ext}), the force exerted on the dough (F) and the mass flow rate of the dough (q). (Testing showed the density of the dough was constant within 4%, so this is approximately proportional to the volumetric flow rate.)

Ideally, we wished to build a device which would allow us to control the diameters and flow rate while measuring the required force. However, this would have required an expensive motor and testing equipment to measure power input and internal system losses. After some discussion, we decided to instead apply a known, constant force and measure the resulting flow rate.

We next turned our attention to the best way to generate this constant force. A simple hand-crank sausage press had proven to be very useful in early modeling and had been a leading factor in proving the feasibility of extruding the dough, so we purchased a sausage press specifically for use in the testing device, which was named the Doughbreaker. PVC inserts allowed the diameter of the cylinder to be varied, and prefabricated extrusion diameters came with the sausage press. After another round of brain storming and simple modeling, we settled on the remaining details of the testing equipment.

We replaced the hand-crank of the sausage press with a wheel measuring 11.5 inches in diameter. Fishing line was wrapped around the wheel so that every pound applied to the fishing line applied 83.3 lbs to dough in the cylinder of the press. The press and wheel were mounted on a table to allow easier transportation. Additional, because every turn of the wheel moved the plunger only 0.43 inches, the testing was done on top of a parking garage, allowing approximately 60 feet of fishing line to be wrapped around the wheel and a greater volume of dough to be extruded. PVC inserts allowed the diameter of the cylinder to be varied, and prefabricated extrusion diameters came with the sausage press.

9.2 Manufacturing the Doughbreaker

The design of the Doughbreaker was driven by cost and how effectively it would be able to model the needed information for the Shiny Dough Master 3000. In order to develop the design of the Doughbreaker a concept model was produced in SolidWorks, which is shown in Figure 30. The following section details the construction of the dough breaker in a part by part basis as labeled in Figure 30. Note: This section describes design decisions made within the construction process, but not any alterations that were made to the Doughbreaker throughout the testing period.

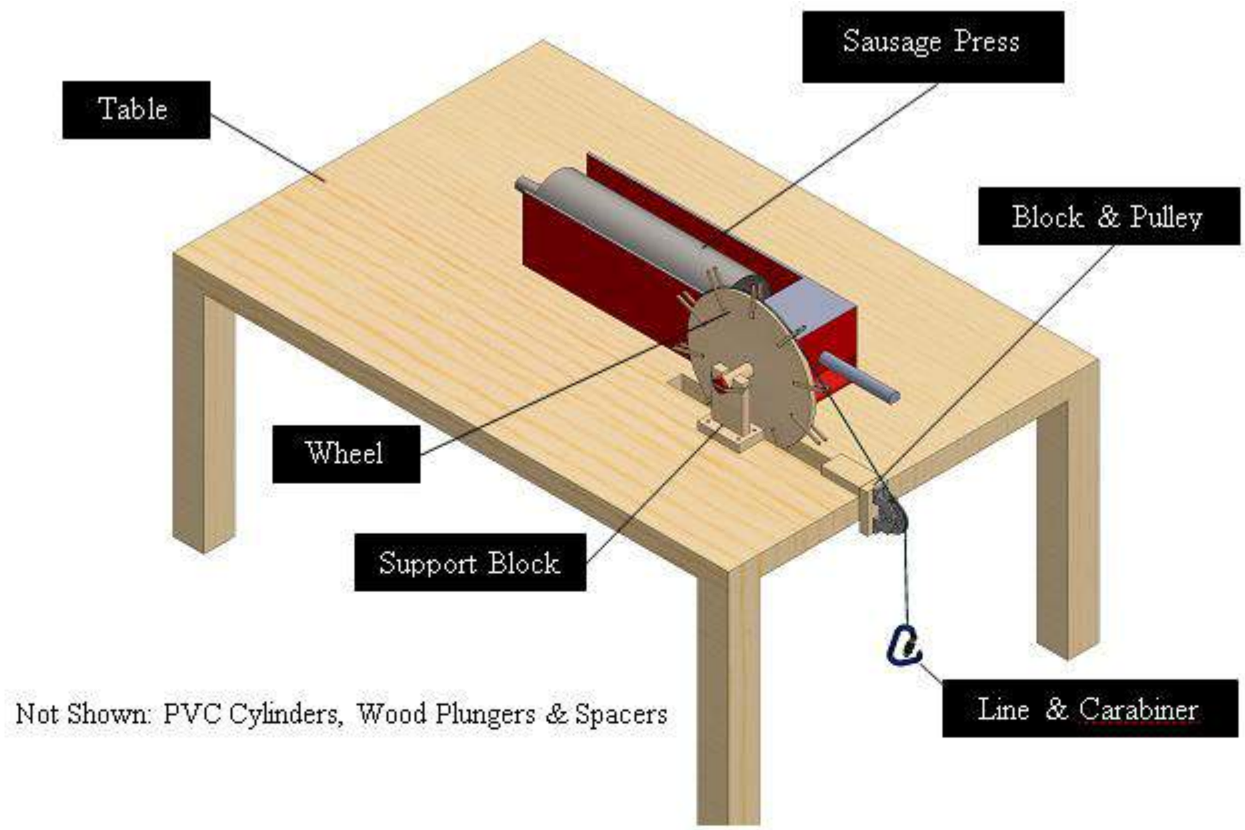

Figure 30: The Doughbreaker

Table

A table with removable legs was ultimately chosen as it could be easily disassembled and transferred the test site. The table consisted of four cylindrical steel legs that could be removed by threads and a table top that had a cardboard baffle core. Firstly, in order to make the table optimal for transport, it table was shortened in length. The legs were removed before the table was cut with a jig-saw and afterwards reattached with a hand drill. Secondly, a slot was placed in the table's surface with a jig-saw in order to provide space for the wheel to rotate.

Sausage Press

The sausage press was purchased from an online vendor and was largely unmodified. However, the plunger of the sausage press was replaced throughout testing process. The plunger used for each test was sized correctly for the PVC cylinder in operation. Furthermore, an appropriately sized socket was used to interface the wheel with the handle connection of the sausage press. After the sausage press was place next the slot on the table in its proper position, wooden blocks of 2x4 wood were fastened to the table with screws surrounding the sausage press. These wooden blocks provided a reference location for when the dough breaker was set-up for each test and prevented misalignment of the wheel and sausage press. During testing, for additional safety concerns, straps were placed around the sausage press and table to prevent any vertical movement of the press. The wooden blocks and straps can be seen in Figure 31.

Figure 31: Side view of sausage press mounted on the table.

PVC Cylinders

PVC pipe was mounted within the sausage press tube to provide a greater variation in contraction ratio. This PVC pipe was sized at 2, 3, and 4 inches in diameter and cut to lengths of 18 inches with a ban saw. After cutting the PVC, the ends were sanded with a belt sander in order to provide a more uniform surface and eliminate any sharp edges.

Wood Plungers

The wood plungers were cut from ¾" thick oak planks with a fly-cutter. The fly-cutter allowed us to produce highly accurate circular pieces with a center hole. The fly-cutter was adjusted to create plungers for each of the PVC cylinders and the sausage press. After the circles were cut, a drill press was used to resize the center holes created by the fly-cutter to 3/8" in diameter, which could then be directly attached to the sausage press' rod with a bolt. A jig for the belt sander was created to more accurately resize the plungers for the PVC cylinders. This jig allowed the wooden plungers to rotate perpendicularly to the belt sander at a fixed distance, which created a more accurate circle.

Wood Spacers

The wood spacers, which centered the PVC diameters within the sausage were cut from ¾" thick pine planks with a fly-cutter. Initially, the outer diameter was cut at 5.5 inches, the internal size of the sausage press tube, on all of the spacers. Secondly, the center whole was used for alignment as a second cut was made for the inside diameter of each spacer, which was sized to match the PVC pieces. Lastly, the spacers were sanded with the belt sander to eliminate all sharp edges and splinters.

Support Block

The support block was constructed with four 6" 2x4 wood pieces that were stacked on top of each other and screw together. A hole was bored within one side of the support block, which provided a mounting location for the wheel's axle to rotate. The support block's hole was then placed directly across from the handle location on the sausage press and the support block was attached to the surface of the table with screws.

Wheel

The wheel was cut with a ban saw from ¾" thick plank of oak wood. After the initial ban saw cut, a jig was used (similar to the one described for wood plungers) with on the belt sander in order to removed rough edges. A transition fit hole was cut through the center of the wheel that was sized to accommodate a piece of 1" PVC piping. The 1" PVC was approximately 6" in length and was used as the axle for the wheel. The socket that interfaces with the sausage press was placed within the PVC tubing on one end. Both the wheel and socket were set in place permanently with epoxy. Popsicle sticks were attached to the exterior of the wheel with wood glue in order to create a channel for the fishing line. After the wood glue and epoxy dried, a test fit was conducted by placing the wheel in the support block and the gear of the sausage press.

Block and Pulley

While the concept model is shown with a pulley, during construction it was determined that a simple screw with a key hole on the end could still provide a minimal friction surface and would be significantly less expensive. Additionally, we noticed the need to extend the descending position of the weight away from the edge of the building in order to reduce its chance of the weight hitting the walls during operation. To accomplish this a 4 foot length piece of 2x4 wood was used as the block. The screw with the key hole was attached a one end and hole for mounting the 2x4 to the table were bored in the other end. Washers were used on the table side of the bolt because of the tables less ridged cardboard surface on the bottom. This modified block and pulley design can be seen at the testing location in Figure 32.


Figure 32: Dough Breaker side view at testing location.

Line and Carabineer
100 lb. fishing line was used on the Doughbreaker and was attached to the wheel by a screw. A mountain climbing carabineer was attached to the fishing line in order for weights to be changed easily between experiments. In Figure 32 you can see the fishing line extend from the wheel to the end of the extension block. Note: The screw with the key hole is on the opposite side and cannot be seen.

9.3 Budget the Doughbreaker
We were given a $500 dollar modeling budget for this portion of the project, which we spent as shown in Table 8.

Table 8: Budget and Expeditures for the Doughbreaker

Description	Subsystem	Budget	Spent
Wood Plank	Plunger	$20.00	$18.14
Bolts	Plunger	$5.00	$3.04
Pop sickle Sticks	Plunger	$10.00	$3.99
Wood	Torque	$20.00	$19.35
Socket	Torque	$5.00	$36.31
Wood Block	Torque	$10.00	$2.79
Epoxy	Torque	$15.00	$16.65
Screws	Torque	$5.00	$16.16
Table	Torque	$25.00	$20.00
Gorilla glue	Torque	$10.00	$13.54
Fishing Line	Torque	$20.00	$12.50
PVC Shaft	Torque	$15.00	$12.33
Pulley	Torque	$20.00	$1.48
Sausage Press	Press	$300.00	$223.28
4" PVC	Press	$5.00	$7.77
3" PVC	Press	$5.00	$5.37
2" PVC	Press	$5.00	$2.67
9V Battery	Testing		$8.09
Sum:		$495.00	$423.46

9.4 Design Verification Plan for the Doughbreaker

A design verification plan was developed for the Doughbreaker for safety reasons and can be found in Appendix I with the DVP for The Shiny Dough Master 3000.

9.5 Dough Testing Procedure

Set up of the Doughbreaker and dough testing can take place at any suitable location with a high enough vertical drop, but our testing all took place on the roof of the Poly Canyon Village back parking structure on the Cal Poly campus. The parking structure is six stories high, and therefore has more than fifty feet of drop, as required. Caution tape was used to block off the fall and landing zone of the weights.

To set up the Doughbreaker, the legs are screwed onto the table, and the arm is then attached to the table such that when the table is upright the arm extends over the edge of the parking structure. The sausage press is then slotted into its place on the Doughbreaker and was strapped down with climbing webbing. Next, 50 feet of 100-lb test fishing line were tied to the wheel and wrapped with a loop at the exposed end. Loops in the fishing line were tied with a figure-eight knot, which reduces the strength of a rope to 80% of its rated strength. The figure-eight was chosen because it is simple to tie and one of the strongest knots known. Additionally, testing was done to verify that the fishing line could withstand the maximum test weight using this knot.

Figure 33: The rock climbing carabiner used for dough testing

The wheel is then slotted onto the slow turning gear of the sausage press. This creates an 83:1 force ratio from the sausage press to the fishing line. At this point, a contraction ratio must be chosen: we started with the smallest ratio, using our 2” diameter tube and the 1.512” diameter extruder. The extruder is screwed onto the outside of the sausage press, and the tube slides into the sausage press with the corresponding rings constructed to center it in the sausage press.

The weights are then prepared: double loops of fishing line are used to secure the weight to a rock climbing carabineer, seen in Figure 33. Carabineeers are lightweight loops (ours weighed 1.3 ounces) with spring-loaded gates frequently used for rock climbing applications. The carabineer used was rated to 24 kilonewtons, or about 5,400 pounds force, in the long direction. Loops easily clip into the gate, and the fishing line holding the weights are clipped into the carabineer. Our starting weight was one pound.

The next step is to prepare the cookie dough for testing. It is recommended that a hand wash station and several bowls be available to make this process cleaner. This is a very important step of the process, as the main cause of variation in the data is variation in the properties of the dough. Several things can cause this variation: a change in the ambient air temperature, an increase or decrease of local wind speed, or inconsistent or over mixing between sets of data. One team member mixes the dough by hand: this member should get a good feel for the dough and make sure all the dough being put into the Doughbreaker feels about the same.

Usually, unmixed dough is a dark brown color, crumbly, and hard to the touch. After mixing, dough should become a lighter brown, become slightly greasy and begin to stick to itself much better, and is soft and easily molded. This is the dough needed for testing. Overmixing will result in the butter beginning to melt out of the dough in warm temperature conditions.

Figure 34: The Doughbreaker during testing. Alex is on the left; Grant is on the right.

Once the dough is prepared, a team member lifts up the sausage press and loads the dough into the large tube, attempting to pack the dough down as much as possible, as this will help eliminate air bubbles (air bubbles cause bad data points). While one team member loads the dough, another can screw the proper size plunger onto the sausage press (plunger size corresponds with tube size).

To achieve as consistent results as possible, the dough should be pushed through the sausage press by hand turning the wheel and reloaded; the dough properties changes slightly when it gets run through the sausage press, and an initial run during set up helps eliminate some inconsistencies. Another contingency taken by the group was to tie a “brake rope” to the carabineer and anchor it at the top of the drop zone. The brake rope would run out of length before the weight hit the ground and before the fishing line ran out of length, thus saving the system a shock of suddenly stopping a large weight falling at speed. This also makes it easier to pull the weight back up after a test run. Alex can be seen holding the brake rope in Figure 34.

At this point, testing can begin. A team member turns the wheel by hand until dough starts coming out of the sausage press, and then loop the fishing line out through the eye on the arm and clip the carabineer with weight onto the fishing line. During our testing, the team member clipping the carabineer onto the fishing line wore a climbing harness anchored to a car due to leaning out over a six story drop. The team member collecting dough removes any dough extruded, and then on a count of three, the weight should be applied to the line and the timer should be started.

Figure 35: Dough extruded from the sausage press is collected in a bag of known weight

The dough extruded from the sausage press while the weight drops is collected in a pre-weighed bag, as seen in Figure 35. After the weight drops to the bottom of the run, the timer is stopped, and the bag and dough are weighed, as seen in Figure 36.

Figure 36: Extruded dough being weighed during testing

During testing, the dough should flow steadily from the extruder. It may flow at an extremely slow rate, but that rate should be relatively consistent. The wheel may not spin smoothly, but dough may still extrude. These data points are still good data points. There are also data points of zero flow, where the weight used is not sufficient to move the dough through the sausage press. In this case, the data point is still recorded, but the dough is remixed and it is necessary to verify that the flow rate is truly zero for this setup. As mentioned, speeds will vary largely due to changes in the properties of the dough. Sometimes an air bubble is seen in the dough, or a sudden spurt of dough bursts out and then the machine gets stuck; these data points are no good and are not recorded.

Once the data point has been taken, the weight can be pulled back up with the brake rope, the fishing line can be rewound around the wheel, and the plunger can be pulled back to reload the tube with cookie dough. While the plunger is pulled back, make sure the tube stays firmly wedged against the front of the sausage press. Also note how much dough has leaked around the plunger: for our tests, this was less than 1% of the dough extruded, and caused negligible variation in comparison to the dough properties. The dough is remixed by hand before reloading to test for dough consistency.

For our testing, we tried to get three data points for each combination of weight and contraction ratio, at least three weights for each contraction ratio (we usually managed four), and tried to test nine different contraction ratios (we managed eight). We had several problems that we had to fix during testing. The first was the epoxy on the wheel was not strong enough to hold the torque that was required. To fix this problem we drilled through the PVC, epoxy, and socket with a cobalt drill bit, and then set screws into the holes created to handle the load. Another issue was with the 4” tube: the dough kept leaking out around the end, making it impossible to get good data points. This could be fixed with epoxy on the wooden spacers combined with clamps at the end, but we felt that we were pressed for time and had enough data at that point and did not take any tests with a 4” tube. Finally, the large plunger sheared in half from the force exerted by the cookie dough on the plunger on the 5.5” tube diameter. Luckily, we had a spare, and just switched them out.

Finally, in an attempt to control for the properties of the cookie dough, occasional density measurements of the dough were taken. However, while the flow properties of the dough changed, the density did not change appreciably throughout testing.

9.6 Data and Modeling Analysis

In total, 81 good data points were collected. The goal of this data was to be able to predict the force needed in the Shiny Dough Master 3000, which has a tube diameter of 6”, an extrusion diameter of 1” and a desired flowrate of 24 grams per second. Therefore, we needed a relationship linking tube diameter, extrusion diameter, flowrate, and force in the tube.

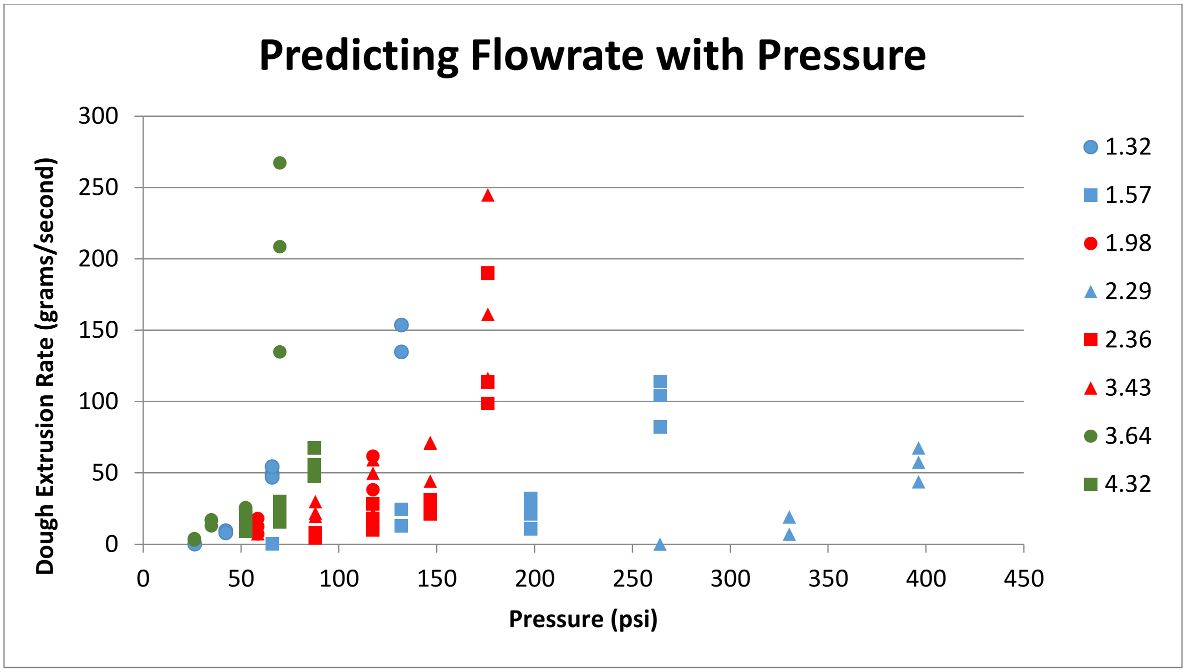

Figure 37: Trying to predict flowrate with pressure (contraction ratio at right)

Figure 37 is a little chaotic. The contraction ratios are listed at right (contraction ratio is defined as tube diameter over extrusion diameter). Obviously, by the lay of the data, there is no direct correlation between pressure in the tube and flowrate when the contraction ratio is allowed to vary. That said, if the contraction ratio is held constant, any given set of data makes a parabolic curve (look at just the red triangles, or just the blue squares). However, whereas one would predict that the required pressure to achieve a flowrate would go up with a higher contraction ratio, we can see that is not the case here. The contraction ratio requiring the highest pressure is the blue triangles, at the far right. This is one of the smaller contraction ratios. The green circles, which are one of the highest contraction ratios at 3.64, pushed the dough through with very little pressure.

Initially we thought this might be due to a change in the tube diameter. Larger tubes could extrude dough faster, regardless of the pressure. Therefore, the colors represent different tubes. Blue is the 2" tube, red is the 3" tube, and green is the 5.5" tube. While this does bring some sense to the data (within a tube diameter, shrinking the extrusion diameter brings a higher pressure requirement), in the end the change from tube to tube was unpredictable. Therefore, we concluded we could not predict the dough flowrate simply from pressure and contraction ratio.

We took a look at the actual, physical test, and decided we needed one metric that represented the three independent variables we could control. These were extrusion diameter, tube diameter, and force in the tube. Therefore, we decided to combine all of these variables together into one metric we titled the Tyler Number in honor of our fictional fourth group member. The advantages of this is that it would allow us to treat and weight all the data points equally, would separate out extrusion and tube diameter from the other variables (contraction ratio combined the two, but there was evidence they should be separate), and allow us to see the variation in the flowrate independent of these properties. Any variation outside of these variables is due to changes in the properties of the dough during testing.

The results from the pressure graph showed that these variables did not affect the flowrate equally. Therefore to develop the Tyler Number, we decided to raise each variable to a power, such that the Tyler Number equation looked like this:

$$Ty = D_{ext}^{\ A} \times D_{tube}^{\ B} \times F^{C} \qquad \text{Equation 1}$$

Setting up an Excel document, we then varied A, B, and C to determine the best correlation between Tyler Number and flowrate. This development method, then, is completely empirical and non-theoretical, based solely on real-world results. The advantage of this is it gives us good predictions for the very specific case we are working with here. The disadvantage is it cannot be applied to any other situation. In the end, we got the best results with A = 2.6, B = -1.2, and C = 1.4. This means that the extrusion diameter, with an exponent of 2.6, is the most important factor affecting flowrate, which explains why the data points with the smallest extrusion diameter required the highest pressure.

Now we were able to plot all the data on one, relatively coherent graph, seen below in Figure 38.

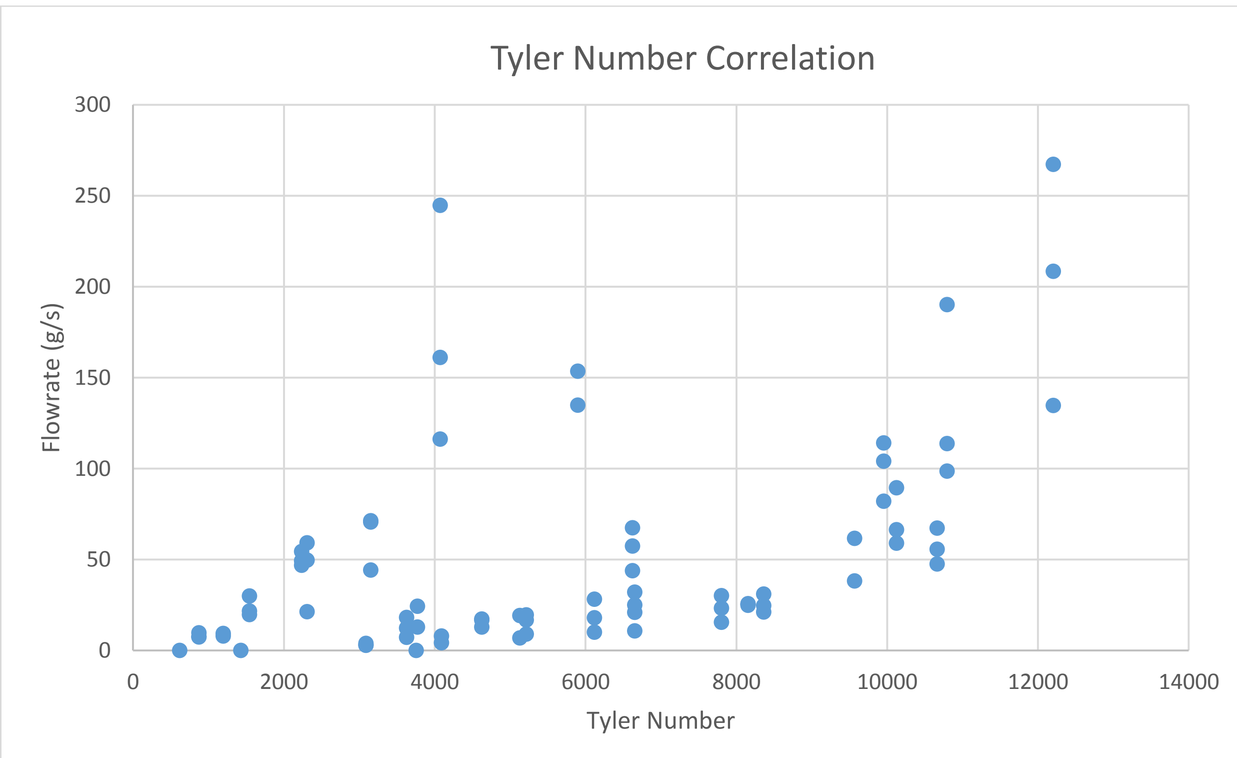

Figure 38: Using Tyler Number to predict flowrate

We can see here, as we could with the pressure graph, that flowrate becomes exponentially faster as the force is increased and extrusion diameter is decreased. Better yet, most of the points seem to fall into a much nicer pattern, with a few outliers in the 4000 to 6000 Tyler Number range. These represent flowrates that were exceptionally fast for the situation. We suspect these points correlate with a very hot day of testing when the butter began to melt out of the dough. We hadn't quite refined our testing procedures at the time, and we didn't throw that data out. Rather than throw that out here, however, we thought it was indicative of the varying behavior of the dough due to temperature and mixing effects.

That all said, we wanted to come up with an equation that would predict the force needed in the linear actuator, and we didn't want the Shiny Dough Master 3000 to fail. Looking at the best-fit line given by Excel, we realized that any point falling below this line would represent a failure of the machine. Therefore, a solution for making a conservative engineering design decision was simple: use the slowest flowrates and get a predictive equation from that data. We put both of those best-fit lines on a nice graph for Senior Project Expo, and that graph is shown in Figure 39.

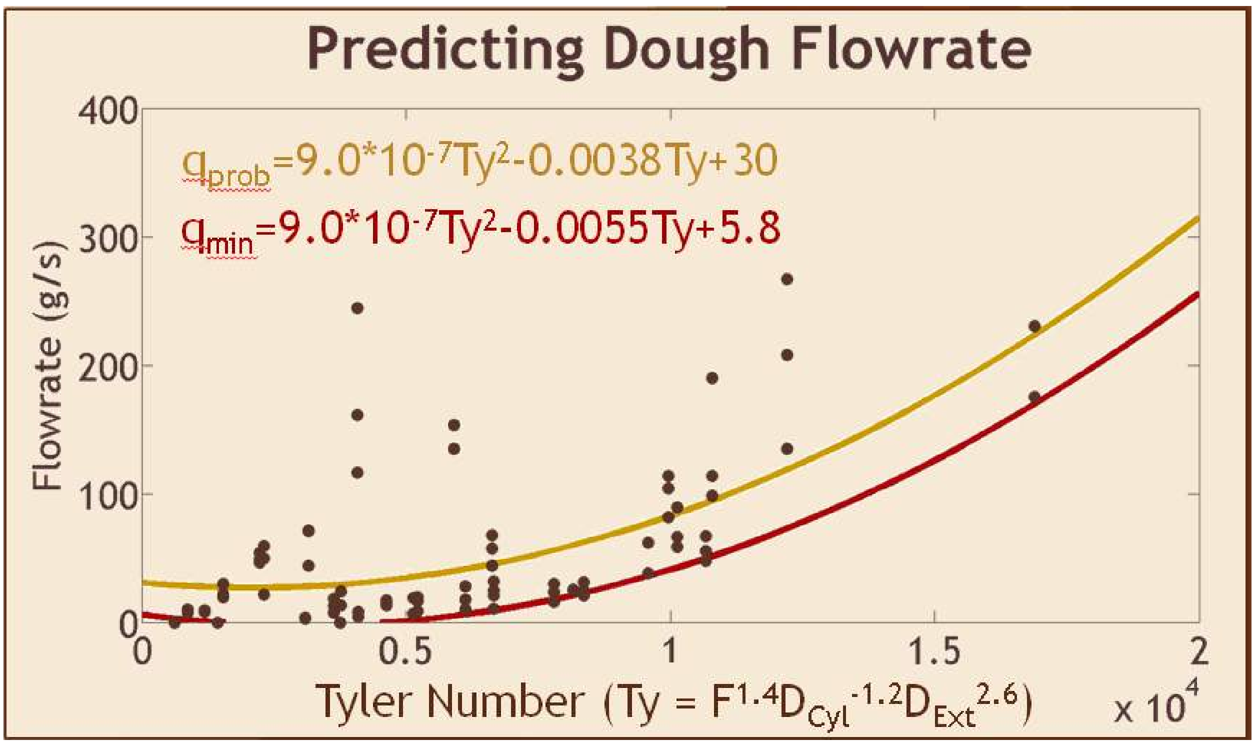

Figure 39: Final spread used to predict dough flowrate

The gold line can be used to estimate probable flowrate, representative of an average of all the data points. The red line is used to predict minimum flowrate: basically, if the red line is used to pick a force for the linear actuator, the linear actuator will never fail regardless of the dough properties at the time. The raw data used to make these charts can be found in Appendix K.

9.7 Relevance to the Shiny Dough Master 3000

To use the Tyler Number for design, one must specify the desired flowrate, tube or cylinder diameter, and extrusion diameter, and then they can use the minimum flow equation to solve for the necessary force. Using the red line correlation and values of 6 inches for the tube diameter, 1 inch for the extrusion diameter, and 24 grams per second of flow, the modeling indicates that the Shiny Dough Master 3000 would have required a maximum of 2,975 lbs of force to extrude the dough, which was within the allowable range of the chosen linear actuator. Thus, although not optimal, the Shiny Dough Master 3000 is a viable design solution to the problem presented by the Brown Butter Cookie Company.

10 Recommendations Moving Forward

As mentioned previously, we have been able to verify the viability of our final design and we have reasonable confidence in its success if it is built. That said, there are a couple of design modifications we have thought of since our design phase that could help deal with the main problems of this design, namely, the heavy weight of the machine. Additionally, the device still needs to be manufactured and built. Either way, for the Brown Butter Cookie Company, they will need to pass off this design to a new team of engineers.

We recommend finding a small local firm specializing in prototyping and product development to handle the process moving forward. While we have little experience working with local firms, we have heard good things about Scott Industries and Progressiv Engineering Inc. Scott Industries can be contacted via phone at (916) 812-7217 or email at paul@scott-industries.com. Progressiv Engineering Inc. can be contacted via phone at (805) 541-0511 or email at sganaja@pro-gressiv.com. They may or may not be able to take the lead on the design themselves, but hopefully they should be able to recommend a firm in the area that can.

For the team taking this design forward, we have some ideas as well. When we brought this paper design to the Brown Butter Cookie Company, as far as we could tell it was the weight of the device that led to it not being built at the time. Most of this weight comes from the base plate with the angle iron and I beam. The reason these are so big is not to hold the tension caused by the linear actuator, but because the bending moment created causes too much deflection over the length of the cylinder.

We have two suggestions on this front. The first is that, if weight is really the only problem and cost isn't an option, the base could be made from carbon-fiber composites, which are incredibly stiff and incredibly light, but also quite expensive (they also have their own manufacturing issues). The second is that this deflection could be eliminated by replacing the base plate with two plates along the sides, thus splitting the moment with symmetry. This would require a redesign of all the supports, but should help reduce the weight of the machine significantly.

In manufacturing, Santa Maria Tool and Next Intent both seemed capable and willing to manufacture the funnel, plunger, and cylinder. Next Intent even gave us some feedback on manufacturing of the cylinder: our tolerances are too tight (especially cylindricity), so taking a second look at what is required of the seal will be necessary. They may need to be used for more than just these parts, as all the manufacturing that was to take place in the Cal Poly shops will now take place elsewhere. Water Jet Central in Paso Robles might be useful for cutting all the supports and materials out of the plate steel.

The weight and cost of the machine may be able to be brought down by varying the cylinder and extrusion diameters. The data suggests that increasing the extrusion diameter to 1.25 inches would require less than 2,000 pounds of force from the linear actuator, allowing a much smaller linear actuator, which brings down both cost and weight.

Finally, whichever team takes this forward will have major design left to do on the controls for the linear actuator, and the installation and programming of those controls, as this was the part of the design left unfinished.

11 Conclusion

This document represents all the research, ideation, calculations, designs, and testing done by Cookie Dough Engineering for the Brown Butter Cookie Company. CDE designed a prototype to portion cookie dough as required by the Brown Butter Cookie Company. CDE then built a representative system to verify the viability of that paper design and confirmed that the final design, nicknamed the Shiny Dough Master 3000, would work as specified. There is no user manual for the Shiny Dough Master 3000 or the Doughbreaker because neither product was delivered to the Brown Butter Cookie Company. This document was presented to the Brown Butter Cookie Company on June 5th, 2015.

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Appendix A: Contacts and Appreciation

We would like to thank the following people for their help in making the project possible. These contacts are listed in the order in which we requested their help for the project.

Professor Russell Westphal (Mechanical Engineering, Cal Poly SLO).

> Thank you for offering your advice on measuring the fluid properties of the cookie dough. Also, thank you for speaking to your wife on our behalf and offering us her expert opinion.
> Contact: rvwestph@calpoly.edu. 805-756-1336

Professor Kim Shollenberger (Mechanical Engineering, Cal Poly SLO).

> Thank you for offering your advice on measuring the fluid properties of the cookie dough.
> Contact: kshollen@calpoly.edu. 805-756-1379

Professor Grace Neff (Head of Chemistry Department, Cal Poly SLO).

> Thank you for lending lab equipment to us, allowing us to perform destructive tests on the cookie dough, measuring mass and volume of portioned balls.
> Contact: gneff@calpoly.edu. 805-756-1687

Professor Martin Koch (Industrial and Manufacturing Engineering, Cal Poly SLO).

> Thank you for opening the casting lab to us and letting us use the vibration tables and equipment.
> Contact: mkoch@calpoly.edu 805-756-1114

Professor Trevor Harding (Materials Engineering, Cal Poly SLO)

> Thank you for analyzing the cookie dough and offering materials advice.
> Contact: tharding@calpoly.edu 805-756-7163

Electrician Ben Johnson (Electrician, Cal Poly SLO)

> Thank you for your advice and expertise on the controls and electrical systems of this machine.
> Contact: brjohnso@calpoly.edu. 805-756-2321

Technical Support Eric Pulse (Shop Tech, Cal Poly SLO)

> Thank you for your advice on how to manufacture the cylinder, funnel, and plunger parts of this design.
> Contact: epulse@calpoly.edu 805-756-5634

Appendix B: Force Required to Move the Dough

From the very first days of this project, it was clear that the most difficult part of the problem would be how to make the dough into a smooth, cohesive mass which could be evenly proportioned. Due to early success we chose to use a contraction to mold the dough into a consistent density and texture. However, even very early modelling made it clear that this path would require extreme amounts of force. Determining just how much force was the driving factor behind which linear actuator to purchase and how to size the funnel and cylinder.

The very first attempts to push cookie dough through a funnel were failures due to the tricky material properties of the cookie dough. After some initial setbacks, we succeeded with those most hallowed of modeling materials: duct tape and PVC pipe.

Figure 40: The first successful contraction and extrusion test

Figure 40 shows one of the first successes. The PVC pipe being used for the cylinder is 1 ¼" Schedule 40 PVC pipe, with an inside diameter of 1.380 inches. The inner PVC pipe used as a plunger is 1" Schedule 40 pipe, which has an outside diameter of 1.315 inches (The Engineering Toolbox, 2011). Thus the difference between the two is 0.065 inches. Assuming the plunger was perfectly centered in the tube, the radial clearance is half of that, or 0.0325 inches. To block the cookie dough from entering the plunger, a piece of duct tape was stuck over the end of the smaller pipe.

Duct tape is about 0.3 inches thick, which is certainly greater than the clearance between the pipes. When the plunger was first pushed through the tube, a bunch of duct tape caught and scraped off on the rim of the pipe. The duct tape created an excellent movable seal between the two pipe walls.

Next, a funnel was made out of duct tape and attached to the end of the tube. At this point, dough was loaded into the tube, and then pushed through the funnel successfully. As seen in Figure 40, the dough emerged in a relatively smooth manner, with just a few minor cracks along the edges of the dough tube. After a certain amount of dough got pushed out, the weight of the dough would cause it to break off and fall to the table. The pieces that fell off ranged from two to three inches long. The diameter of these cookie dough pieces was about one inch.

The volume of the dough pieces currently made by the Brown Butter Cookie Company is about 1.23 cubic inches (converted from the original metric data taken during process measuring at Brown Butter Cookie Company). If the pieces are made in cylinder form, as they are here, and are pushed out of a funnel with a final diameter of one inch, we can solve for the length the cookie dough pieces would need to be. The formula for volume of a cylinder is given below.

$$V = \pi r^2 l \qquad \text{Equation 2}$$

This is easily rearranged to solve for the length of the tube of cookie dough.

$$l = \frac{V}{\pi r^2} \qquad \text{Equation 3}$$

Using this equation with radius equal to 0.5 inches and volume as 1.23 cubic inches, the length of each cookie dough cylinder will be 1.56 inches long. This was ideal because it was less than the two inches where the dough might break off due to its own weight.

Once that we were certain the dough could be pushed through a contraction, we needed to prove that we could mechanize the process and add enough force to a plunger to let the dough emerge at the correct speed. We also wanted to make sure the dough could flow through a smaller contraction than the initial test. Since our plunger and tube size was set, we made the funnel smaller, with a final opening of half an inch on the small end of the funnel, which allowed this test to mimic on a smaller scale our final design. The second test device can be seen in Figure 41. It worked grandly; the rate at which the dough came out was close to desirable, about an inch and a half per second.

Figure 41: The second tube and funnel test showing a smaller contraction

Grant was the team member pushing the dough through the tube, and he was putting a lot of his weight on it. For these calculations we want to assume the worst case scenario, so we're going to say the force on the plunger was Grant's full weight, which is 170 lbs. Therefore the pressure exerted on the dough by the plunger was Grant's weight divided by the area of the tube (πr^2 = 1.5 square inches).

$$p = \frac{F}{A} \qquad \text{Equation 4}$$

Running the numbers the pressure on the dough was, at most, 114 psig. Since the pressure at the outlet of the funnel is atmospheric, the pressure drop across the contraction was 114 psi.

Once we had established that the dough could be extruded, we were curious to know how the forces and pressure involved would scale up as we increased the diameter of our design. We were also concerned with the effect of changing the reduction radio. To gather more data, we borrowed a sausage press similar to the one show in Figure 42 from Grant's family and used it to model the movement which we hoped to achieve.

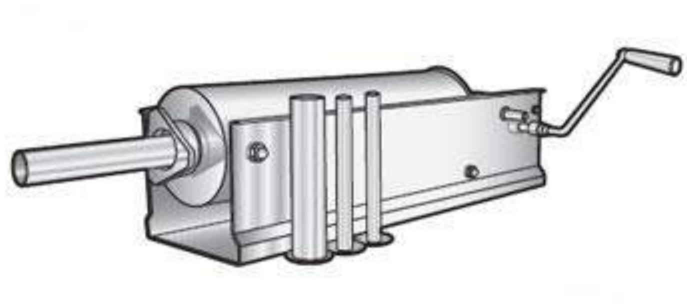


Figure 42: Rendering of sausage press used for proof-of-concept and dough property tests

This sausage press had a main diameter of five and half inches and various smaller extrusion diameters, from three quarters of an inch up to one and a half inches, and was operated by a hand crank. Using this sausage press, we were able to extrude the dough at approximately the correct speeds. Thus, we had an excellent model for how our final device might look. To measure the mechanical advantage of the device, we noted the distance the plunger inside the sausage press moved for each revolution of the lever arm. With this data, we would be able to calculate the force applied to the dough and the pressure in the cylinder if we knew the torque needed to move the dough.

We loaded the sausage press with cookie dough and cranked the lever to the point where the crank arm was parallel with the ground. Then, we hung a cloth shopping bag on the lever arm and put weights into the bag until it turned and moved the dough. By multiplying the weight in the bag by the length of the lever arm we could calculate the torque produced by the lever arm and the subsequent pressures and forces in the sausage press. We were able to verify that the press exerted between 80 and 100 psi to begin to move the dough, which is consistent with the 114 psi estimate from the PVC tests. All relevant test data is summarized in Table 9. Thus, we decided to use 115 psi as our target pressure. We theorize, based on the tests we were able to conduct, that the dough has a very high coefficient of static friction. However, once the dough begins to extrude, it does so smoothly and simply.

In order to produce 115 psi in a 6in diameter cylinder, we needed to find a linear actuator capable of 3,250 lbs.

Table 9: Simplification and summary of extrusion test data

Test No	Device	Pressure	Speed
1	PVC	40 psi	Very slow
2	Sausage press	60 psi	Very slow
3	Sausage press	90 psi	0.5 in/s
4	Sausage press	100 psi	1 in/s
5	PVC	114 psi	1 to 2 in/s

Appendix C: Dough Properties

In order to match the size and variation in the dough balls produced by the Shiny Dough Master 3000 to the current average size and variation, we visited the Brown Butter Cookie Company and measured 30 dough balls each of 7 different flavors. We measured individual masses of the dough balls to the nearest .01 g using a mass balance borrowed from the chemistry department (see Appendix A for acknowledgement and appreciation). We also measured the total volume the dough displaced in graduated cylinders partially filled with water. The results are summarized below.

Table 10: Basic properties of various dough flavors, both brown butter and traditional

Dough Flavor	Type	Average Mass (g)	Average Volume (in^3)	Standard Deviation
Original	Brown Butter	21.70	1.227	2.2%
Citris	Brown Butter	21.67	1.200	3.7%
Almond	Brown Butter	21.45	1.220	2.5%
Coco	Brown Butter	22.31	1.200	2.8%
Lemon Sugar	Traditional	79.40	4.150	1.1%
Chocolate Chip	Traditional	79.63	4.170	2.2%
Oatmeal	Traditional	81.82	4.495	1.2%

Achieving the correct cookie size will require careful synchronization of the speed of the linear actuator and the speed of the rotation of the cutting motor. The specifications of the project require the average dough volume to match the original batch dimensions. However, final determination of which average volume to use as a datum will be done in the programming stage after discussion with the Brown Butter Cookie Company.

Appendix D: Technical Specifications

The House of Quality is used to match customer requirements to engineering specifications, and then evaluate both specifications and possible solutions. After the list of requirements was generated, it was necessary to weight the requirements to reflect their respective value. This weight was determined by estimating the customer preference for both the owners and the other users (mostly the ballers) and then taking a weighted average, with the owners carrying twice as much weight as the other users, as they are the primary customers. For simplicity, this average was rounded to the nearest half-number. Requirements and their weights are along the left hand side of the House of Quality.

Next, engineering specifications on how to test the possible requirements for different designs were brainstormed and are listed across the top of the House of Quality. At this point, each specification was matched with the customer requirement based on relevance: nine being highly correlated, three, a medium correlation, and one, little correlation. Specifications with no relevance to a requirement are left blank.

The numbers are then calculated (each specification gets the summation of the multiplied correlative values and requirement weights) to assign each specification an importance. For example, ball weight has a high correlation corresponding with ball size, so it gets a score of nine for the correlation times ten for the importance of ball size for a total importance of 90. The most important specifications, as determined by the house of quality, are ball weight, cookie rate, training time, and cleaning time.

Finally, the House of Quality was used to rank existing solutions to the cookie dough portioning problem. Each competitor was given a pass/fail score of either one or zero for each engineering specification. Total scores can then be directly compared. Based on the standards established by our House of Quality, the best existing solution is the hand balling method currently in use. This is logical, since it is the method currently being utilized. Our solutions must therefore score at least 508 points or better to be considered improvements from the status quo.

CDE

Customer Requirement	Average Weight	1 Ball Volume	2 Ball Weight	3 Pinch Point	4 Blade / Rot Protection	5 Sharp Edges	6 Food Safe Material	7 Surface Temperature	8 Cookie Rate	9 Sound (dB)	10 Operating Lift Weight	11 Pulling Weight	12 OSHA RSI Standard	13 Cleanable Material	14 Cleaning Time	15 Training Time	16 Batchs in Life Cycle	17 Usage : Maintenance	18 Cost	19 Single Batch	20 Total Moving Weight	21 Length, Width, Height Limitations
Ball Size	10	3	9																			
Physical Safety	9			3	3	3	3	3														
Production Rate	7								9						3							
RSI Reduction	6.5									3	3	3	3									
"Easy to Clean"	6.5													3	9							
Easy to Operate	6															9						
Durable	4																3	9				
Cheap	2.5																1		9			
Single Batch Size	2																			9		
"Not Too Big"	1.5																				3	9
Spec Importance		**30**	**90**	**27**	**27**	**27**	**27**	**27**	**63**	**20**	**20**	**20**	**20**	**20**	**80**	**54**	**15**	**36**	**23**	**18**	**5**	**14**
Weight Percent		5%	14%	4%	4%	4%	4%	4%	10%	3%	3%	3%	3%	3%	12%	8%	2%	5%	3%	3%	1%	2%
Rank		5	1	7	7	7	7	7	3	12	12	12	12	12	2	4	19	5	12	12	21	19
Threshold (Tolerance) or Test Method		1 T (5%)	.75 oz (1/16 oz)	Inspection	Inspection	Inspection	Inspection	< 104 F	25 cookies/min	90 dB	2 lbs	10 lbs	Inspection	Inspection	120 min/day	1 day	2 years	80:1 ratio	$3,000	Inspection	75 lbs	3ft x 3ft x 5ft
Risk		H	M	L	L	L	L	L	H	M	M	M	L	L	M	L	L	M	H	M	M	L
Competitor	Score																					
Hand balling	508	1	1	1	1	1	1	1	0	1	1	1	0	1	1	0	1	1	1	1	1	0
Reiser Vemag	483	1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	0	0	1	0	0
Spritz	342	0	0	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	1	1	1

Appendix E: List of Generated Ideas

In the first idea generation session, we generated lists of ways to design various predicted sub-components of our final product. These lists, shown in Table 11, allow for nearly four million unique combinations. We explored approximately 20-30 of them in various degrees of depth.

Table 11: Categorized idea generation lists

Heating	Compacting	Cleaning	Movement	Portioning / Parting	
induction	pressure	steel	pressure	lasers	cutting
convection	plungers	stainless	plungers	knives	scoops
fire	air bursts	rubber	pistons	swords	karate
heat from a nuke	motor driven press	removable lining	conveyor	blades in general	stamp
conduction	gravity	hose	vacuum	flame	casting
heated device	funnels	UV sterilization	gravity	plasma	wheel / conveyor
steam	sit on it	flush system	roll it	light saber	wire
coal	wires	fluid chemical	slope	force pull	hammer
radiation	pressure	glass	water pressure	air jet	brittle
friction	expansion	multiple devices	pull it	water jet	ice cube tray
wires	air injection	lubricant	spread it	grating	rolling cutter
coiled wires	vacuum	heat	rollers	molding	fabric knife
liquid nitrogen	step on it	disposable device	throw it / drop it	gravity	sell the dough
sun	levers	fire	motorized	mesh	paper cut
spare oven heat	cycles	dishwasher safe	nano-bots	cookie cutters	make-your-own system
geothermal	wheel	fabric	wheels	dollop	spray spread
hair dryer	bicycle-rollers		magnets	auger	
clothes dryer	rollers		gears		
hot air			rail gun		
electrocution					
insulate					
body heat					
dry ice					

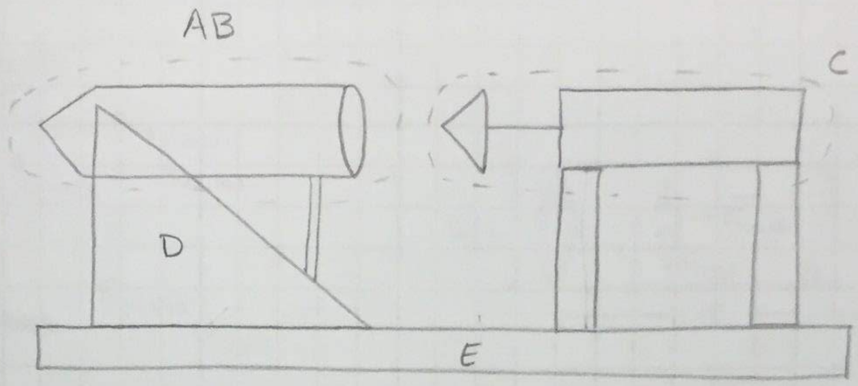
Appendix F: Stress Calculations

The stress calculations performed for this project are based on a few simplifying assumptions. First, each type of stress is assumed to be caused by the maximum possible force from the linear actuator (4,900 lbf). Second, each type of stress is evaluated at its maximum value and combined with other stresses only if the corresponding maximum value occurs in the same location. Often, these two assumptions allowed the problems to be simplified to 2D or even 1D planes of forces and reactions. All combined stresses were analyzed using Von Misses stress theories. Three texts were used for reference throughout this process. The most basic is the text from Mechanics of Materials. This text is referred to as MechM or simply M in the hand notes which follow. (Hibbeler, 2005) Second was Shigley's Mechanical Engineering Design, which is referenced as Shigley's or S. This text contains more sophisticated stress analysis models, including guidelines for fatigue analysis, and also provided some basic bolt equations (Budynas, 2008). Finally, I used Roark's Formulas of Stress And Strain (Roark's or R) to analyze complex sections such as the funnel and the cross section of the bearing and funnel support (Young, 2012). This text had many, many useful tables and equations which I used throughout the analysis.

In the free body and cut diagrams, M represents a moment, V a shear force, F a directly applied force or perpendicular force, and T a torque. In the coding, all stresses are calculated to be positive, even compressive forces. This allowed a single sign convention for the design factors, which was helpful. Where necessary, shading indicates the portion of the cut through a material which is absorbing the stress and shear in question for that section.

Each line of the EES code has been annotated for ease of understanding. Subscripts refer to those established in free body and cut diagrams.

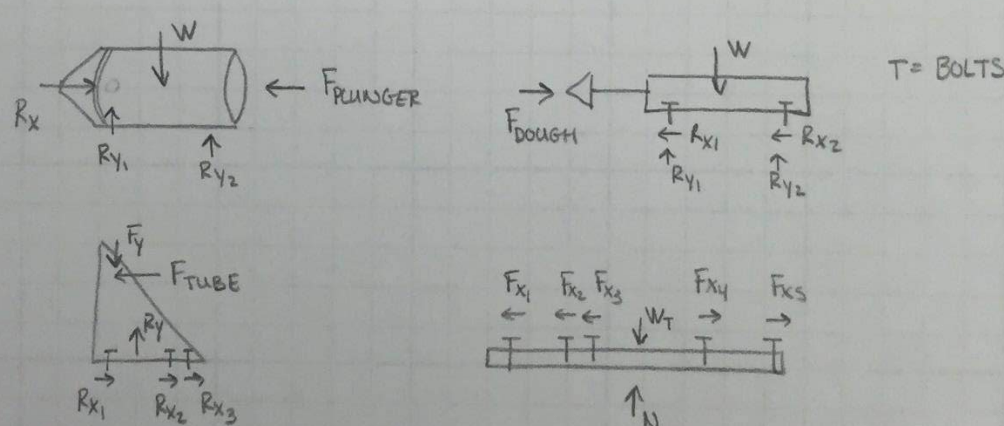
HAND CALCULATIONS



SIMPLIFIED SYSTEM DIAGRAM
NOT TO SCALE

A - TUBE
B - FUNNEL
C - PLUNGER + ACTUATOR (LA)
D - STRUCTURAL SUPPORT STEEL (SSS)
E - BASE

FBDs

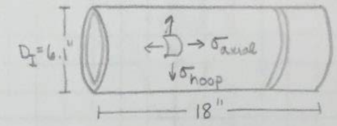


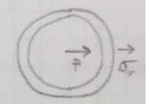
TUBE "THIN WALL PRESSURE VESSEL"

ASSUME

$P_{int,max} \leq P_{PLUNGER}$

$F_{PLUNGER} \leq 4900$ lbs





$P_{PLUNGER} = F_{PLUNGER} / A_{INT}$

$A_{INT} = \pi (6.1'')^2 / 4$

$$\sigma_{hoop} = \frac{P_{INT} \cdot D_I}{2 \cdot t}$$

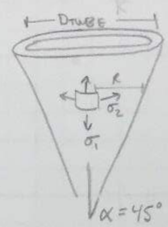
$$\sigma_{axial} = \frac{P_{INT} \cdot D_I}{4 \cdot t}$$

$$\sigma_{rad} = -P_{INT}/2$$

$$\sigma_{YS} = n_d \cdot \sqrt{0.5\left[(\sigma_{hoop} - \sigma_{axial})^2 + (\sigma_{axial} - \sigma_r)^2 + (\sigma_r - \sigma_{hoop})^2\right]}$$ (pg 51)

FUNNEL (ROARK'S FORMULAS FOR STRESS + STRAIN)

$\frac{R}{t} > 10$ UNIFORM INTERNAL PRESSURE



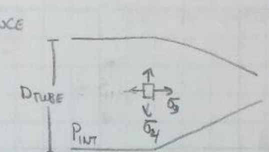
(p 610, T. 13-1)

$$\sigma_{1MAX} = \frac{P D_{TUBE}}{4 t \cos(\alpha)}$$

$$\sigma_{2MAX} = \frac{P D_{TUBE}}{2 t \cos(\alpha)}$$

$$\sigma_3 = \frac{N}{t} = \frac{F/C}{t}$$ C = CIRCUMFRANCE

$$\sigma_4 = \frac{P_{INT}(D_{TUBE})}{2t}(1.13)$$



(p 657 T13.4)

$$\sigma_{YS} = n_d \sqrt{.5\left[(\sigma_{1max} + \sigma_3 - \sigma_{2MAX} - \sigma_4)^2 + (\sigma_{2MAX} + \sigma_4)^2 + (-\sigma_{1MAX} - \sigma_3)^2\right]}$$

EES

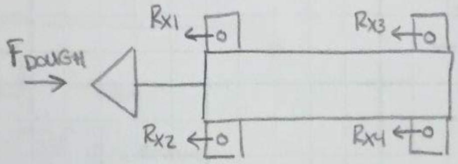
$\sigma_{1MAX} = \sigma_{funnel,1}$

$\sigma_{2MAX} = \sigma_{funnel,2}$

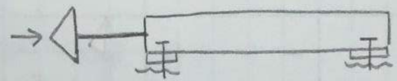
$\sigma_3 = \sigma_{funnel,3}$

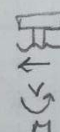
$\sigma_4 = \sigma_{funnel,4}$

LINEAR ACTUATOR BOLT SELECTION



- CUT THROUGH BOLTS
- STATICALLY INDETERMINANT
- ASSUME LOAD = $\frac{1}{2}F$ (CONSERVATIVE)





@ CUT

$V = \frac{1}{2} F$

$M = \frac{1}{2} Fd$

$d = \perp$ axis of LA TO BASE

EES

$F = F_{ext}$

$d = t\_base,LA$

$A = A_{BOLT,LA}$

$y = t_{base,LA}$

$r = D_{BOLT,LA}/2$

$d_{bolt} = D_{bolt,LA}$

$$\tau_{xy} = \frac{VQ}{It}$$

$$\tau_{max} = \frac{4V}{3A}$$ (@ center of bolt)

$$\sigma = \frac{My}{I}$$

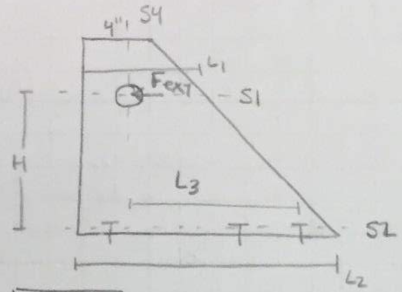
$$\sigma_{max} = \frac{Fd}{2}\left(\frac{r}{I}\right)$$ (@ edge of bolt)

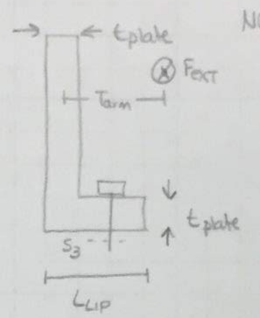
$$A = \pi (d_{bolt})^2/4$$

$$I = \pi/4 \cdot r^4$$

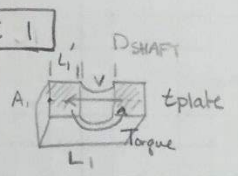
STRUCTURE SUPPORT STEEL (SSS)

NOT TO SCALE





$\boxed{\text{SEC 1}}$



ROARK TABLE 10.2 + 10.3

$$\tau_{A_1} = -t_{plate}(L_1 t_{plate}) E\theta''' - L_1' G\theta'$$

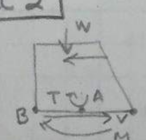
$$\theta''' = 0 \qquad \theta' = \frac{-Torque}{KG}$$

$$K = \frac{L_1'^3}{3} 2 t_{plate}$$

$$\sigma_{TORQUE} = \frac{t_{plate}}{2}\left(L_1/2\right) E\theta''$$

$$\theta'' = 0$$

$\boxed{\text{SEC 2}}$



$\tau_{SHEAR} = \frac{3V}{2A}$ max @ A ∅ @B

ROARK T10.1

$$\tau_{TORQUE} = \frac{3T}{8ab^2}\left[1 + .6\frac{b}{a} + .8\left(\frac{b}{a}\right)^2 - 1.8\left(b/a\right)^3 + .9\left(\frac{b}{a}\right)^4\right] \text{ @A}$$

$a = L_2/2$

$b = t_{plate}/2$

$$\sigma_{AP}^3 + \sigma_{AP}\left(-\tau_{SHEAR}^2 - \tau_{TORQUE}^2\right) = 2\tau_{SHEAR}\tau_{TORQUE}$$

$\sigma_{max} = \frac{-W}{A} + \frac{-My}{I}$ @ B

$\sigma_{BP} = \sigma_{max}$

$M = F_{ext} H \qquad A = L_2 t_{plate}$

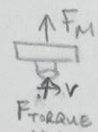
$y = \frac{1}{2} L_2$

$I = \frac{L_{LIP} \cdot t_{plate}^3}{12}$

$\boxed{\text{SEC 3}}$

BOLTS IN LA

FARTHEST BOLT HAS GREATEST STR



$$\tau_{max} = \frac{4V}{3A}$$

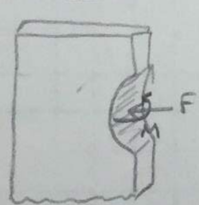
$$\sigma = \frac{F_M}{A}$$

F_M = FORCE TO RESIST MOMENT

$$F_M = \frac{F_{ext} \cdot H}{L_3}$$

$$\tau_{max\ F_{TORQUE}} = \frac{4F \cdot T_{arm}}{3AL_1}$$

$\boxed{\text{SECTION 4}}$



$$\sigma = \frac{F}{2A} + \frac{M\bar{y}}{I}$$

$$M = F\,T_{arm}$$

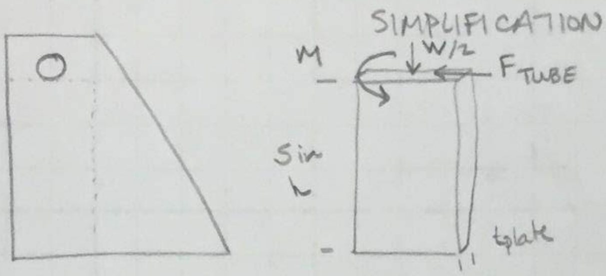
$$A = D_{SHAFT}\, t_{plate}$$

$$I \approx t_{plate} \cdot D^3/12$$

STRUCTURAL STEEL SUPPORT

COLUMN ANALYSIS

$M = F_{TUBE} \cdot 7 [in]$



FROM ROARK (ch12, p 551)

$$\lambda = \frac{KL}{r\pi}\left(\frac{\sigma}{E}\right)^{1/2} \qquad K \leq 2$$

$$r = \frac{t_{plate}}{2\sqrt{3}}$$

$$\sigma = S_y = 31.2 \text{ Ksi}$$

$$E = 28000 \text{ Ksi}$$

$$\lambda = \frac{2(5)2\sqrt{3}}{t_{plate}\ \pi}\left(\frac{31.2}{28000}\right)^{1/2}$$

$$\lambda = 2.9$$

use rankine formula

$$\frac{\sigma_{compression\ failure}}{\sigma_y} = \frac{1}{1+\lambda^2}$$

BUCKLING (F_{TUBE} NOT CONTRIBUTE)

CRITICAL T, P (W/2)

$$\frac{T^2}{4(EI)^2} + \frac{P}{EI} = \frac{\pi^2}{h^2}$$

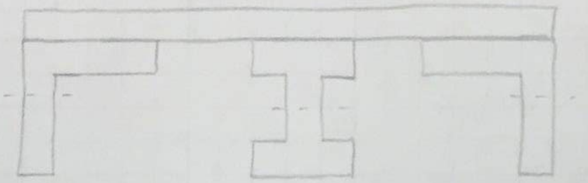
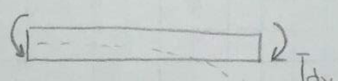


	PLATE	IBAR	ANGLE
A	$w \cdot t$	2.21	2.11 in^2
I_{xx}	$w \cdot t^3/12$	2.93	1.76 in^4
Y	$3+t/2$	1.5 in	.88 in

$$\bar{y} = \frac{\Sigma A y}{A} = \frac{2.11(3-.88)2 + 2.21(1.5) + w(t)(t/2+3)}{2.11(2) + 2.21 + w(t)}$$

$$I = \Sigma I_{xx} + 2.11(2)(\bar{y} - (3-.88))^{\wedge 2} + 2.21(\bar{y}-1.5)^2 + wt(3+t/2-r_n)^2$$

SIMPLE BEAM DEFLECTION



DEFLECTION OCCURS BETWEEN STRUCTURAL STEEL SUPPORTS + LA

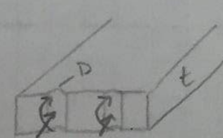
$L = 14$ in

$$\frac{d^2y}{dx} = \frac{M}{EI}$$

$$\frac{dy}{dx} = \frac{M(x)}{EI}$$

$$dy = \frac{Mx^2}{2EI} \Rightarrow \frac{ML^2}{2EI}$$

CONCENTRATION @ BOLTS



$\frac{F}{2}$ compression @ neutral axis

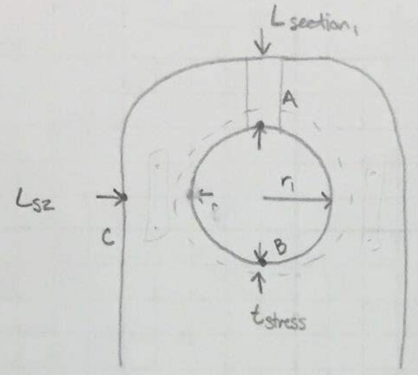
M couple from Force transformation $= \frac{F}{2} r_n$

$$\sigma_{max} = \frac{F}{2A_B} + \frac{M r_n}{I_B}$$

$A_B = D \cdot t$
$I_B = B \cdot t^3/12$

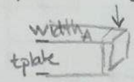
At Linear Actuator use $K = \frac{E_{wood}}{E_{iron}}$ to account for composite members

TUBE COLLAR



ASSUME $Load = F_{ext} / 2\pi r_1 t_{stress}$

A:



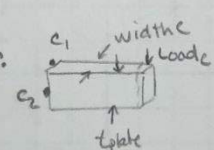
$$Load_A = \frac{F_{ext} \cdot width_A \cdot t_{stress}}{2\pi r_1 \, t_{stress}}$$

$$\tau_{max} = \frac{3V}{2A} = \frac{3 \, Load_A}{2 \cdot t_{plate} \cdot width_A}$$

$$\sigma_A = Load$$

B: same as A + $\frac{W_{total}}{t_{plate} \cdot \pi r_1}$

C:

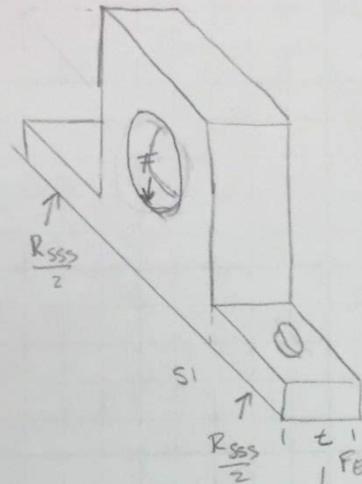


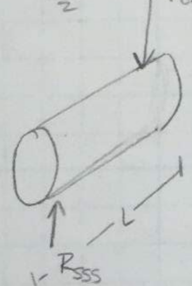
$$Load_c = \frac{F_{ext} \cdot width_c}{2\pi r_1}$$

$$\sigma_{c_1} = \frac{Load_c \cdot L_{s2} \cdot t_{plate}/2}{width_c \cdot t_{plate}^3/12}$$

$$\tau_{c_2} = \frac{3V}{2A} = \frac{3 \, Load_c}{2 \, t_p \, w_c}$$

$$\text{sigma} = \frac{F}{A} + \frac{My}{I}$$

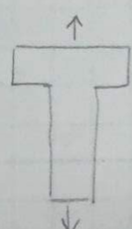




$$t_{max} = \frac{4V}{3A} = \frac{4F_{EXT}}{3A_{SHAFT}}$$

$$\sigma_{max} = \frac{F_{ext} \cdot L \cdot r/2}{I}$$

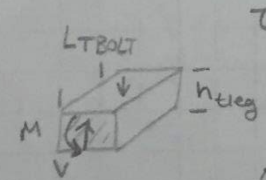
$$L = T_{bearing} + T_{tsupport}$$



$$\sigma_{bolt} = \frac{F}{4A}$$

$$A = \frac{D^2}{4}\pi$$

SECT 1



$$\tau_{max} = \frac{3V}{2A} \quad A = t_{tsupport} h_{tleg}$$

$$\sigma_{max} = \frac{My}{I} = \frac{F/4 \, L_{TBOLT} \, h_{tleg}/2}{t_{tsupport} \, h_{tleg}^3/12}$$

FATIGUE

$N_{CYCLE} = 30{,}500$

$\frac{6000 \text{ cookies/day}}{1} \times \frac{1 \text{ batch}}{115 \text{ cookies}} \times \frac{1 \text{ cycle}}{2.5 \text{ batch}} \times \frac{365 \text{ days}}{1 \text{ yr}} \times \frac{4 \text{ yr}}{1} = 30{,}500 \text{ cycles}$

$S_e' = 0.5\, S_{ut}$ (SHIGLEY 6.8)

$\sigma_F' = S_{ut} + 50{,}000 \text{ psi}$ (S. 6.11)

$b = -\frac{\log(\sigma'_F / S_e)}{\log(2 \cdot 10^6)}$ (S. 6.12)

$S_f' = \sigma_F' (2 \cdot N)^b$ (S. 6.9)

$S_f = K_a K_b K_c K_d K_e K_f S_f'$

K_a - surface condition

$K_a = a\, S_{ut}^b$ (Kpsi)

$a = 2.7$ for machined
$b = -.265$ cold-drawn

K_b - 1 for axial
~ .8 for torsion + bending

K_c - loading

$K_c = .59$ (torsion)
$= .85$ (axial)
$= 1$ (bending)

$K_d = 1$ (temp)

K_e = reliability $1 - .08 z_a$
99%

$K_e = 0.814$

$K_f = 1$ no other factors

$S_f \geq S_{yield}$

TO FIND MAX STRESS IN 3-D STRESS APPLICATIONS:

$$\sigma_p^3 - (\sigma_x+\sigma_y+\sigma_z)\sigma_p^2 + (\sigma_x\sigma_y + \sigma_y\sigma_z + \sigma_z\sigma_x - \tau_{xy}^2 - \tau_{xz}^2 - \tau_{yz}^2)\sigma_p =$$
$$\sigma_x\sigma_y\sigma_z + 2\tau_{xy}\tau_{yz}\tau_{zx} - \sigma_x\tau_{yz}^2 - \sigma_y\tau_{xz}^2 - \sigma_z\tau_{xy}^2$$

IN 2D

$$\sigma_p = \frac{1}{2}\left[\sigma_x + \sigma_y \pm \sqrt{(\sigma_x-\sigma_y)^2 + 4\tau_{xy}^2}\right]$$

VON MISES FAIL CRITERIA σ_{ys} = yield strength

$$\sigma_{ys} = n_d\sqrt{\left[(\sigma_1-\sigma_2)^2+(\sigma_2-\sigma_3)^2+(\sigma_3-\sigma_1)^2\right].5}$$

if $\sigma_3 = 0$...

$$\sigma_{ys} = n_d\sqrt{\left[(\sigma_1-\sigma_2)^2+\sigma_2^2+\sigma_1^2\right].5}$$

if $\sigma_2 = 0$...

$$\sigma_{ys} = n_d\sigma_1$$

Determine Givens

$F_{ext} = 4900$ [lbf] *maximum capable by the Linear Actuator (LA)*

$D_{tube} = 6.1$ [in] *Inner diameter of tube*

$D_{tube,outer} = 6.435$ [in] *Average outer diameter of tube*

$t_{vessel} = 0.095$ [in] *minimum thickness of tube and funnel, including tolerance*

$t_{plate} = 0.375$ [in] *nominal thickness of A36 steel plate use for structural steel applications*

$t_{plate,collar} = 0.375$ [in] *nominal thickness of A36 steel used in the funnel collar*

$L_{bushing} = 0.8$ [in] *Length of the bushing set into the structrual steel support*

$T_{arm} = 1.374$ [in] *Length of offset causing torque at structural steel supports*

$L_{bend,base} = 14$ [in] *Length between linear actuator and structural steel supports where bending becomes a danger*

$width_{base} = 10$ [in] *total width of the base of the device*

See Basic Variable Code

$L_{tube} = 18$ [in] *Total Length of the tube including threads*

$W_{dough,total} = 17.06$ [lbf] *Total weight of 3 batches of dough*

$W_{tube} = 17.3$ [lbf] *Total Weight of the tube, empty*

$A_{tube} = \pi \cdot \frac{D_{tube}^2}{4}$ *cross-sectional area of the dough in the tube*

$Vol_{tube} = A_{tube} \cdot L_{tube}$ *Total volume of the tube*

$H = 4.625$ [in] *Distance from center of F_{ext} to base of dough master; causes moments*

$W_{total} = W_{tube} + W_{dough,total}$ *Total weight applied to structural supports due to gravity*

Properties of Materials

$P_{dough} = \frac{F_{ext}}{A_{tube}}$ *Pressure in dough, also equal to max pressure inside tube and funnel*

$S_{ut,316} = 84100$ [psi] *Utlimate strength of 316 steel*

$S_{y,316} = 42100$ [psi] *Yield strength of 316 steel*

$S_{ut,304} = 73200$ [psi] $\cdot$ 0.814 $\cdot$ 0.8 *Utlimate strength of 304 stainless steel, including fatigue calculations*

$S_{y,304} = 31200$ [psi] *Yield strength of 304 stainless steel*

$S_{ut,AL} = 45000$ [psi] $\cdot$ 0.814 $\cdot$ 0.8 *Utlimate strength of 6061 Aluminmum, including reductions for repeated loading*

$S_{y,AL} = 40000$ [psi] *Yield strength of 6061 Aluminmum steel*

$E_{304} = 2.8 \times 10^7$ [psi] *Young's modulus of elasticity for 304 stainless steel*

$E_{AL} = 10$ [psi] $\cdot 10^6$ *Young's modulus of elasticity for Aluminum*

$E_{A36} = 2.9 \times 10^7$ [psi] *Young's modulus of elasticity for A36 steel*

$S_{y,A36} = 36000$ [psi] *Yield strength of 316 steel*

$S_{ut,A36} = 58000$ [psi] $\cdot 0.814 \cdot 0.8$ *Utlimate strength of A36 steel, including fatigue calculations*

$S_{y,wood} = 6500$ [kPa] $\cdot \left| 0.145 \cdot \frac{psi}{kPa} \right|$ *best guess for yield strength of wood, given quick research*

$E_{wood} = 9000$ [MPa] $\cdot \left| 145 \cdot \frac{psi}{MPa} \right|$ *estimate for young's modulus for wood, based on internet research*

Brass Bushing

$\sigma_{bushing,inner} = \frac{F_{ext}}{2 \cdot D_{shaft} \cdot L_{bushing}}$ *Compression stress caused by force perpendicular to the bushing*

2000 [psi] $= \sigma_{bushing} \cdot n_{d,bushing}$ *maximum stress allowed on bushing based on manufacturer specs*

$\sigma_{bushing,outer} = \frac{F_{ext}}{2 \cdot D_{bearing} \cdot t_{plate}}$ *compression stress on the outside of the bushing due to perpendicular loading*

$\sigma_{bushing} = \mathbf{Max}\left[\sigma_{bushing,inner}, \sigma_{bushing,outer}\right]$ *choose maximum compressive stress*

Shaft and T Support

$D_{shaft} = 1.5$ [in] *diameter of shaft connecting collar to structural steel support*

$\tau_{shaft} = 4 \cdot \frac{F_{ext}}{3 \cdot A_{shaft}}$ *shear stress in shaft due to perpendicular loading*

$A_{shaft} = \frac{D_{shaft}^2}{4} \cdot \pi$ *cross sectional area of shaft*

$I_{shaft} = \frac{\pi}{4} \cdot \left[\frac{D_{shaft}}{2}\right]^4$ *moment of inertia of shaft in direction of cut and moment*

$\sigma_{shaft} = F_{ext} \cdot T_{arm} \cdot \frac{D_{shaft}}{4 \cdot I_{shaft}}$ *stress in shaft due to moment, caused by force offset. This moment is transmitted to SSS as a torque*

$S_{y,A36} = \mathbf{Max}\left[\tau_{shaft}, \sigma_{shaft}\right] \cdot n_{d,shaft}$ *shear stress and moment stress act at different portions of cross sections. choose largest for safety equation.*

$t_{tsupport} = 0.75$ [in] *thickness of T support for shaft*

$L_{shaft} = L_{bushing} + t_{tsupport}$ *minimum length of shaft required*

$\sigma_{tsupport} = \frac{F_{ext}}{A_{support}}$ *stress in t support from perpendicular loading*

$\sigma_{tsupport,moment} = F_{ext} \cdot [T_{arm} - L_{bushing}] \cdot \frac{t_{tsupport}}{2 \cdot I_{support}}$ *stress in t support from moment / torque, very small because t_{arm} is too small at this location*

$A_{support} = D_{shaft} \cdot t_{tsupport}$ *area of tsupport perpendicular to load from linear actuator*

$I_{support} = D_{shat} \cdot \frac{t_{tsupport}^3}{12}$ *moment of inertia of t support at shaft mounting*

$S_{y,A36} = n_{d,tsupport} \cdot \sigma_{tsupport}$ *design factor for t support*

$D_{bolt,tsupport} = 0.344$ [in] *diameter of bolt in tsupport*

$L_{tobolt,tsupport} = \frac{0.625 \text{ [in]}}{2}$ *length from cross section to bolt*

$H_{tleg} = 0.5$ [in] *height of cross section*

$A_{bolt,tsupport} = \frac{D_{bolt,tsupport}^2}{4} \cdot \pi$ *area absorbing direct loading*

$\sigma_{bolt,tsupport} = \frac{F_{ext}}{4 \cdot A_{bolt,tsupport}}$ *stress distributed between four bolts*

$\tau_{tsupport,leg} = 3 \cdot \frac{\frac{F_{ext}}{4}}{2 \cdot A_{tsupport,leg}}$ *shear stress distributed between four bolts*

$A_{tsupport,leg} = t_{tsupport} \cdot H_{tleg}$ *area resisting shear stress*

$\sigma_{tsupport,leg} = \frac{F_{ext}}{4} \cdot L_{tobolt,tsupport} \cdot \frac{\frac{H_{tleg}}{2}}{t_{tsupport} \cdot \frac{H_{tleg}^3}{12}}$ *stress from moment*

$S_{y,A36} = n_{d,tsupport,leg} \cdot \mathbf{Max}[\sigma_{tsupport,leg}, \tau_{tsupport,leg}]$ *determine design factor, because stresses operate at different points in material*

$S_{y,A36} = n_{d,bolt,tsupport} \cdot \sigma_{bolt,tsupport}$ *determine design factor*

Thin Walled Vessel

$\sigma_{hoop} = P_{dough} \cdot \frac{D_{tube}}{2 \cdot t_{vessel}}$ *calc hoop stress based on pressure in vessel.*

$\sigma_{axial} = P_{dough} \cdot \frac{D_{tube}}{4 \cdot t_{vessel}}$ *calc axial stress based on pressure in vessel.*

$\sigma_z = \frac{-P_{dough}}{2}$ *calc radial stress, very small but not negligable.*

$\sigma_{hoop,total}^2 = 0.5 \cdot [(\sigma_{hoop} - \sigma_{axial})^2 + (\sigma_{axial} - \sigma_z)^2 + (\sigma_z - \sigma_{axial})^2]$ *find 3-d stress, von misses*

$S_{y,304} = \sigma_{hoop,total} \cdot n_{d,tube}$ *find safety factor for vessel.*

Funnel Calcs, See Roark for full equations

$$\sigma_{funnel,1} = P_{dough} \cdot \frac{D_{tube}}{4 \cdot \mathbf{cos}\left[45 \ [deg]\right] \cdot t_{vessel}}$$

$$\sigma_{funnel,2} = P_{dough} \cdot \frac{D_{tube}}{2 \cdot \mathbf{cos}\left[45 \ [deg]\right] \cdot t_{vessel}}$$

$$\sigma_{funnel,3} = \frac{F_{ext}}{\pi \cdot D_{tube} \cdot t_{vessel}}$$

$$\sigma_{funnel,4} = P_{dough} \cdot \frac{D_{tube}}{2} \cdot \frac{1.13}{t_{vessel}}$$

$$\sigma_{funnel,axial} = \sigma_{funnel,1} + \sigma_{funnel,3} + \tau_{funnel,front} \cdot \mathbf{sin}\left[45 \ [deg]\right]$$

$$\sigma_{funnel,hoop} = \sigma_{funnel,2} + \sigma_{funnel,4}$$

$$\sigma_{funnel,radial} = \tau_{funnel,front} \cdot \mathbf{cos}\left[45 \ [deg]\right]$$

$$\sigma_{funnel,total}^2 = 0.5 \cdot \left[\left(\sigma_{funnel,hoop} - \sigma_{funnel,axial}\right)^2 + \left(\sigma_{funnel,axial} - \sigma_{funnel,radial}\right)^2 + \left(\sigma_{funnel,radial} - \sigma_{funnel,axial}\right)^2\right]$$

find 3-d stress, von misses

$S_{y,304} = n_{d,funnel} \cdot \sigma_{funnel,total}$

$$\tau_{funnel,front} = 4 \cdot \frac{F_{ext}}{3 \cdot D_{tube} \cdot t_{vessel} \cdot \pi}$$

Bolts in Linear Actuator

$N_{bolt,LA} = 4$ *Assumes loads equally distributed among all four bolts.*

$$\tau_{bolts,LA} = 4 \cdot \frac{F_{ext}}{3 \cdot A_{bolt,LA} \cdot N_{bolt,LA}}$$ *shear stress in all bolts*

$$A_{bolt,LA} = \frac{D_{bolt,LA}^2}{4} \cdot \pi$$ *cross sectional area of bolts*

$D_{bolt,LA} = 0.66 \ [in]$ *diameter of bolts required by linear actuator*

$$\sigma_{LA,Bolts} = F_{ext} \cdot \frac{t_{base,LA}}{2} \cdot \frac{\frac{D_{bolt,LA}}{2}}{\frac{\pi}{4} \cdot \left[\frac{D_{bolt,LA}}{2}\right]^4 \cdot N_{bolt,LA}}$$ *stress in bolts from moment*

$\sigma_{LA,Bolts,1} = \mathbf{Max}\left[\sigma_{LA,Bolts}, \tau_{bolts,LA}\right]$ *stresses act at different places in section cut, do not combine*

$S_{y,A36} = n_{d,bolts,LA} \cdot \sigma_{LA,Bolts,1}$

Structural Steel Support Section 1

$T_{sss} = F_{ext} \cdot T_{arm}$ *Torque applied to Structural Steel Support (SSS)*

$L_{sss1} = 4$ [in] *conservative cross sectional length*

$D_{bearing} = 1.75$ [in] *outer diameter of bushing/bearing in SSS*

$A_{sss1} = t_{plate} \cdot \left[\frac{L_{sss1} - D_{bearing}}{2} \right]$ *cross sectional area of section 1*

$r_{n,sss1} = \frac{L_{sss1}}{2}$ *location neutral axis of section 1*

$\tau_{sss1,V} = F_{ext} \cdot A_{sss1} \cdot \frac{r_{n,sss1}}{t_{plate} \cdot I_{sss1}}$ *shear stress in section 1, max at edges*

$I_{sss1} = \left[\frac{L_{sss1}}{2} - \frac{D_{bearing}}{2} \right]^3 \cdot \frac{t_{plate}}{12} + A_{sss1} \cdot \left[r_{n,sss1} - \left(\frac{L_{sss1}}{4} - \frac{D_{bearing}}{4} \right) \right]^2$ *moment of inertia of cross section 1 at neutral axis.*

$$\tau_{sss1,T} = \left[\frac{T_{sss}}{\frac{\left(\frac{L_{sss1}}{2} - \frac{D_{bearing}}{2} \right)^3}{3} \cdot 2 \cdot t_{plate} \cdot G_{304}} \cdot \left(\frac{L_{sss1}}{2} - \frac{D_{bearing}}{2} \right) \right] \cdot G_{304}$$

stress in cross section 1 from torque max at center of edges

$G_{304} = \frac{E_{304}}{2 \cdot 1.29}$ *modulus of rigidity, where posuon's ratio is 0.29*

$\sigma_{sss1,1} = \mathbf{Max}\left[\tau_{sss1,V} , \tau_{sss1,T} \right]$ *stresses act at different places in section cut, do not combine*

$S_{y,A36} = n_{d,sss1} \cdot \frac{\sigma_{sss1,1}}{2}$ *assumes equal distribution between both sides of device*

Structural Steel Support Section 2

$\sigma_{sss2} = 0.5 \cdot \frac{W_{total}}{A_{sss2}} + F_{ext} \cdot H \cdot \frac{L_{sss2}}{2 \cdot I_{sss2}}$ *stress in section 2 from weight and moment due to H*

$A_{sss2} = L_{sss2} \cdot t_{plate}$ *cross sectional area of section 2*

$L_{sss2} = 10$ [in] *length of section 2*

$I_{sss2} = t_{plate} \cdot \frac{L_{sss2}^{\ 3}}{12}$ *moment of inertia of section 2*

$\tau_{sss2,V} = 3 \cdot \frac{F_{ext}}{2 \cdot A_{sss2}}$ *shear stress in section 2*

$$\tau_{sss2,T} = 3 \cdot \frac{T_{sss}}{8 \cdot \frac{L_{sss2}}{2} \cdot \left[\frac{t_{plate}}{2} \right]^2} \cdot \left[1 + 0.6 \cdot \frac{t_{plate}}{L_{sss2}} + 0.88 \cdot \left(\frac{t_{plate}}{L_{sss2}} \right)^2 - 1.8 \cdot \left(\frac{t_{plate}}{L_{sss2}} \right)^3 + 0.9 \cdot \left(\frac{t_{plate}}{L_{sss2}} \right)^4 \right]$$

Shear stress in section 2 caused by torque. See Roark's for details

$\sigma_{sss2,eq}{}^2 = \tau_{sss2,V}{}^2 + \tau_{sss2,T}{}^2$ *neglect effect of weight stress in finding equivalent stress*

$S_{y,A36} = n_{d,sss2} \cdot \sigma_{sss2}$ *find design factor for stress*

$S_{y,A36} = n_{d,sss2,tau} \cdot \left[0.5 \cdot \sigma_{sss2,eq}{}^2\right]^{0.5}$ *find design factor for shear stresses acting in 2nd location*

Structural Steel Support Section 3b

$N_{bolt,SSS} = 6$ *assume equal distribution among N bolts in 2 SSS*

$D_{bolt,sss} = \dfrac{3 \ [in]}{8}$ *diameter of bolts to be used*

$\tau_{sss3,V} = 4 \cdot \dfrac{F_{ext}}{3 \cdot A_{bolt,sss} \cdot N_{bolt,SSS}}$ *distributed among N bolts*

$A_{bolt,sss} = \dfrac{D_{bolt,sss}{}^2}{4} \cdot \pi$ *cross sectional area of one bolt*

$L_{sss3} = 5.7 \ [in]$ *distance to furthest bolt*

$\sigma_{sss3,pull} = \dfrac{\dfrac{F_{ext}}{2} \cdot \dfrac{H}{L_{sss3}}}{A_{bolt,sss}}$ *distributed among 2 side supports*

$\tau_{sss3,FT} = 4 \cdot \dfrac{F_{ext}}{2} \cdot \dfrac{T_{arm}}{L_{sss3} \cdot 3 \cdot A_{bolt,sss}}$ *distributed among 2 side supports*

$\sigma_{sss3,1}{}^2 - \sigma_{sss3,pull} \cdot \sigma_{sss3,1} + - \tau_{sss3,V}{}^2 - \tau_{sss3,FT}{}^2 = 0$ *determine principal stresses*

$S_{y,A36} = n_{d,bolts,sss} \cdot \sigma_{sss3,1}$

Structural Steel Support Section 4

$\sigma_{sss4} = \dfrac{F_{ext}}{A_{sss4}} + F_{ext} \cdot T_{arm} \cdot \dfrac{t_{plate}}{2 \cdot I_{sss4}}$ *combined stress from direct loading and moment*

$I_{sss4} = t_{plate} \cdot \dfrac{D_{bearing}{}^3}{12}$ *moment of inertia of section 4*

$A_{sss4} = t_{plate} \cdot D_{bearing}$ *cross sectional area of section*

$S_{y,A36} = n_{d,sss4} \cdot \sigma_{sss4}$

Column Analysis of SSS

$lamda = K_{column} \cdot \dfrac{H}{r_{equ,column} \cdot \pi} \cdot \left[\dfrac{S_{y,A36}}{E_{A36}}\right]^{0.5}$ *see Roarks for details*

$K_{column} = 2$ *largest imperical value, Roark's*

$r_{equ,column} = t_{plate} \cdot 2 \cdot 3^{0.5}$ *determine equivalent length of column*

$$\frac{\sigma_{column,allowable}}{S_{y,A36}} = \frac{1}{1 + lamda^2}$$ *calcuate allowable compressive stress in column*

$$\sigma_{comp} = \frac{W_{total}}{2 \cdot A_{column}}$$ *compressive stress from weight*

$$A_{column} = L_{sss1} \cdot t_{plate}$$ *cross sectional area of section*

$$\sigma_{comp} \cdot n_{d,column} = \sigma_{column,allowable}$$ *determine if SSS will fail in column fashion.*

Buckling in Column

$$\frac{\left[\frac{\pi}{H}\right]^2}{n_{d,buckling}} = \frac{\left[F_{ext} \cdot T_{arm}\right]^2}{4 \cdot \left[E_{A36} \cdot I_{sss,buckling}\right]^2} + \frac{\frac{W_{total}}{2}}{E_{A36} \cdot I_{sss,buckling}}$$ *check buckling of SSS*

$$I_{sss,buckling} = L_{sss1} \cdot \frac{t_{plate}^{\ 3}}{12}$$ *moment of inertia of section*

Base at Bolts LA

$$t_{spacer} = 0.7864 \quad [in]$$

$$K_{wood} = \frac{E_{wood}}{E_{iron}}$$ *transform wood into iron*

$$\sigma_{base,LA,compression} = \frac{\frac{F_{ext}}{2}}{D_{bolt,LA} \cdot \left[t_{ang} + t_{plate,base}\right]}$$ *discount wood spacers*

$$\sigma_{base,LA,moment} = \frac{F_{ext}}{2} \cdot \frac{r_{n,base,LA}^{\ 2}}{I_{base,LA}}$$ *stress caused by moment in base at bolts*

$$r_{n,base,LA} = \frac{\frac{t_{base}^{\ 2}}{2} + K_{wood} \cdot t_{spacer} \cdot \left[\frac{t_{spacer}}{2} + t_{base}\right]}{t_{base} + K_{wood} \cdot t_{spacer}}$$ *calculate neutral axis, including wood spacers*

$$I_{base,LA} = I_{base} + A_{base} \cdot \left[r_{n,base,LA} - \frac{t_{base}}{2}\right]^2 + width_{base} \cdot K_{wood} \cdot \frac{t_{spacer}^{\ 3}}{12} + K_{wood} \cdot width_{base} \cdot t_{spacer} \cdot \left[t_{base} + \frac{t_{spacer}}{2} - r_{n,base,LA}\right]^2$$

moment of inertia of section at neutral axis

$$t_{base,LA} = t_{base} + t_{spacer}$$ *find thickness of base including wood spacers*

$$\sigma_{base,LA} = \sigma_{base,LA,moment} + \sigma_{base,LA,compression}$$ *find stress in iron under spacers*

$$\sigma_{spacer} = \sigma_{base,LA} \cdot K_{wood}$$ *find stress in spacers at bolts*

$$S_{y,wood} = \sigma_{spacer} \cdot n_{d,spacer}$$ *determine factor of safety*

$$S_{y,A36} = \sigma_{base,LA} \cdot n_{d,base,LA}$$ *determine factor of safety*

Base at Bolts SSS

$I_{base} = \dfrac{t_{base}^{3}}{12} \cdot width_{base}$ *moment of inertia of section*

$I_{base,sss} = \dfrac{t_{base,sss}^{3}}{12} \cdot width_{base}$ *moment of inertia of section*

$A_{base} = t_{base} \cdot width_{base}$ *cross sectional area of section*

$A_{base,sss} = t_{base,sss} \cdot D_{bolt,sss}$ *cross sectional area of bolts*

$\sigma_{base,sss} = \dfrac{F_{ext}}{2} \cdot \dfrac{\left[\dfrac{t_{base,sss}}{2}\right]^2}{I_{base,sss}} + \dfrac{F_{ext}}{2 \cdot A_{base,sss}}$ *stress in base at SSS bolts, ensure no tearing*

$t_{base} = t_{ang} + t_{plate,base}$ *thickness of base*

$t_{base,sss} = t_{base} + t_{plate}$ *thickness of base including SSS leg*

$S_{y,A36} = \sigma_{base,sss} \cdot n_{d,base,sss}$ *stress in base at SSS bolts with design factor*

Tube Collar A

$r_{collar} = \dfrac{6.524 \text{ [in]}}{2}$ *radius of cut in collar*

$t_{stress} = 0.15 \text{ [in]}$ *thickness of stress applied to collar*

$L_{collar,c} = 1.5 \text{ [in]}$ *thickness of collar where shaft is mounted.*

$\tau_{collar,a} = 3 \cdot \dfrac{\dfrac{F_{ext}}{2 \cdot \pi \cdot r_{collar}}}{2 \cdot t_{plate,collar}}$ *shear stress in collar, see FBD for location*

$\sigma_{collar,a} = \dfrac{F_{ext}}{2 \cdot \pi \cdot r_{collar} \cdot t_{stress}} + \dfrac{W_{total}}{t_{plate,collar} \cdot \pi \cdot r_{collar}}$ *stress in collar, see FBD for location*

$\sigma_{collar,a,1} = 0.5 \cdot \left[\sigma_{collar,a} + \sqrt{\sigma_{collar,a}^{2} + 4 \cdot \tau_{collar,a}^{2}}\right]$ *stress in collar, combine with von misses*

$S_{y,A36} = \sigma_{collar,a,1} \cdot n_{d,collar,a}$ *stress in collar, see FBD for location*

$\sigma_{collar,c} = \dfrac{F_{ext}}{2 \cdot \pi \cdot r_{collar}} \cdot L_{collar,c} \cdot \dfrac{\dfrac{t_{plate,collar}}{2}}{\dfrac{t_{plate,collar}^{3}}{12}}$ *stress in collar, see FBD for location*

$\tau_{collar,c} = 3 \cdot \dfrac{\dfrac{F_{ext}}{2 \cdot \pi \cdot r_{collar}}}{2 \cdot t_{plate,collar}}$ *shear stress in collar, see FBD for location*

$\sigma_{collar,c,1} = \mathbf{Max}\left[\sigma_{collar,c}, \tau_{collar,c}\right]$ *maximum stress in collar, see FBD for location, do not combine stresses*

$S_{y,A36} = \sigma_{collar,c,1} \cdot n_{d,collar,c}$ *design factor in collar at C.*

Structure Calcs for Pin

$0.4 \cdot F_{shear} = \frac{17}{2} \cdot W_{total}$ *shear absorbed by supporting pin*

$S_{y,A36} = n_{d,pin} \cdot 2 \cdot \frac{F_{shear}}{\pi \cdot \left[\frac{D_{pin}^2}{4} - 0.16 \ [in^2] \right]}$ *design factor of pin*

$D_{pin} = 0.43 \ [in]$ *diameter of pin*

Angle Iron

$\sigma_{iron} = \frac{F_{ext}}{2} \cdot H \cdot \frac{r_{n,iron}}{I_{iron}}$ *stress in base from LA*

$$r_{n,iron} = \frac{2 \cdot A_{ang} \cdot [3 - 0.88] \cdot 1 \ [in] + A_{ibeam} \cdot 1.5 \ [in] + A_{base,plate} \cdot \left[\frac{t_{plate,base}}{2} + 3 \ [in] \right]}{A_{ibeam} + A_{ang} \cdot 2 + A_{base,plate}}$$

$$I_{iron} = width_{base} \cdot \frac{t_{plate,base}^3}{12} + 2.52 \ [in^4] + 1.76 \ [in^4] + A_{ibeam} \cdot [r_{n,iron} - 1.5 \ [in]]^2 + 2 \cdot A_{ang} \cdot [r_{n,iron} - 3 \ [in] + 0.88 \ [in]]^2 + width_{base} \cdot t_{plate,base} \cdot \left[3 \ [in] + \frac{t_{plate,base}}{2} - r_{n,iron} \right]^2$$

moment of inertia of section about neutral axis

$A_{ibeam} = 1.67 \ [in^2]$ *cross sectional area of section*

$A_{ang} = 2.11 \ [in^2]$ *cross sectional area of section*

$A_{base,plate} = t_{plate,base} \cdot width_{base}$ *cross sectional area of section*

$t_{ang} = 0.375 \ [in]$ *nominal thickness of angle iron*

$t_{plate,base} = 0.375 \ [in]$ *nominal thickness of base plate*

$E_{iron} = E_{A36}$ *type of iron used in iron base*

$S_{y,A36} = n_{d,iron} \cdot \sigma_{iron}$ *determine design factor of base*

$\delta_{iron} = F_{ext} \cdot H \cdot \frac{L_{bend,base}^2}{2 \cdot E_{iron} \cdot I_{iron}}$ *determine deflection in base between LA and SSS*

SOLUTION

Unit Settings: SI C kPa kJ mass deg

$A_{ang} = 2.11 \ [in^2]$
$A_{base,plate} = 3.75 \ [in^2]$
$A_{bolt,LA} = 0.3421 \ [in^2]$
$A_{bolt,tsupport} = 0.09294 \ [in^2]$
$A_{base} = 7.5 \ [in^2]$
$A_{base,sss} = 0.4219 \ [in^2]$
$A_{bolt,sss} = 0.1104 \ [in^2]$
$A_{column} = 1.5 \ [in^2]$

A_{beam} = 1.67 [in^2]
A_{sss1} = 0.4219 [in^2]
A_{sss4} = 0.6563 [in^2]
$A_{tsupport,leg}$ = 0.375 [in^2]
δ_{iron} = 0.009199 [in]
$D_{bolt,LA}$ = 0.66 [in]
$D_{bolt,tsupport}$ = 0.344 [in]
D_{shaft} = 1.5 [in]
$D_{tube,outer}$ = 6.435 [in]
E_{A36} = 2.900E+07 [psi]
E_{iron} = 2.900E+07 [psi]
F_{ext} = 4900 [lbf]
G_{304} = 1.085E+07 [psi]
H_{tleg} = 0.5 [in]
$I_{base,LA}$ = 0.5693 [in^4]
I_{iron} = 8.326 [in^4]
I_{sss1} = 0.9163 [in^4]
I_{sss4} = 0.1675 [in^4]
$I_{support}$ = 0.05273 [in^4]
K_{wood} = 0.04501
$L_{bend,base}$ = 14 [in]
$L_{collar,c}$ = 1.5 [in]
L_{sss1} = 4 [in]
L_{sss3} = 5.7 [in]
L_{tube} = 18 [in]
$N_{bolt,SSS}$ = 6
$n_{d,base,sss}$ = 5.572
$n_{d,bolts,sss}$ = 1.492
$n_{d,buckling}$ = 5968
$n_{d,collar,a}$ = 17.57
$n_{d,column}$ = 3123
$n_{d,iron}$ = 10.89
$n_{d,shaft}$ = 3.543
$n_{d,sss1}$ = 3.384
$n_{d,sss2,\tau}$ = 3.432
$n_{d,tsupport}$ = 8.265
$n_{d,tube}$ = 9.271
r_{collar} = 3.262 [in]
$r_{n,base,LA}$ = 0.4096 [in]
$r_{n,sss1}$ = 2 [in]
$\sigma_{base,LA}$ = 5672 [psi]
$\sigma_{base,LA,moment}$ = 722.1 [psi]
$\sigma_{bolt,tsupport}$ = 13180 [psi]
$\sigma_{bushing,inner}$ = 2042 [psi]
$\sigma_{collar,a}$ = 1603 [psi]
$\sigma_{collar,c}$ = 15301 [psi]
$\sigma_{column,allowable}$ = 35772 [psi]
$\sigma_{funnel,1}$ = 3806 [psi]
$\sigma_{funnel,3}$ = 2691 [psi]
$\sigma_{funnel,axial}$ = 9035 [psi]
$\sigma_{funnel,radial}$ = 2538 [psi]
σ_{hoop} = 5383 [psi]
σ_{iron} = 3304 [psi]
$\sigma_{LA,Bolts,1}$ = 33341 [psi]
σ_{spacer} = 255.3 [psi]
σ_{sss2} = 3631 [psi]

A_{shaft} = 1.767 [in^2]
A_{sss2} = 3.75 [in^2]
$A_{support}$ = 1.125 [in^2]
A_{tube} = 29.22 [in^2]
$D_{bearing}$ = 1.75 [in]
$D_{bolt,sss}$ = 0.375 [in]
D_{pin} = 0.43 [in]
D_{tube} = 6.1 [in]
E_{304} = 2.800E+07 [psi]
E_{AL} = 1.000E+07 [psi]
E_{wood} = 1.305E+06 [psi]
F_{shear} = 730.1 [lbf]
H = 4.625 [in]
I_{base} = 0.3516 [in^4]
$I_{base,sss}$ = 1.187 [in^4]
I_{shaft} = 0.2485 [in^4]
I_{sss2} = 31.25 [in^4]
$I_{sss,buckling}$ = 0.01758 [in^4]
K_{column} = 2
lamda = 0.07986
$L_{bushing}$ = 0.8 [in]
L_{shaft} = 1.55 [in]
L_{sss2} = 10 [in]
$L_{tobolt,tsupport}$ = 0.3125 [in]
$N_{bolt,LA}$ = 4
$n_{d,base,LA}$ = 6.347
$n_{d,bolts,LA}$ = 1.08
$n_{d,bolt,tsupport}$ = 2.731
$n_{d,bushing}$ = 0.5357
$n_{d,collar,c}$ = 2.353
$n_{d,funnel}$ = 4.282
$n_{d,pin}$ = 1.597
$n_{d,spacer}$ = 3.693
$n_{d,sss2}$ = 9.916
$n_{d,sss4}$ = 2.399
$n_{d,tsupport,leg}$ = 2.939
P_{dough} = 167.7 [psi]
$r_{equ,column}$ = 1.299 [in]
$r_{n,iron}$ = 2.428 [in]
σ_{axial} = 2691 [psi]
$\sigma_{base,LA,compression}$ = 4949 [psi]
$\sigma_{base,sss}$ = 6461 [psi]
$\sigma_{bushing}$ = 3733 [psi]
$\sigma_{bushing,outer}$ = 3733 [psi]
$\sigma_{collar,a,1}$ = 2049 [psi]
$\sigma_{collar,c,1}$ = 15301 [psi]
σ_{comp} = 11.45 [psi]
$\sigma_{funnel,2}$ = 7613 [psi]
$\sigma_{funnel,4}$ = 6083 [psi]
$\sigma_{funnel,hoop}$ = 13695 [psi]
$\sigma_{funnel,total}$ = 7286 [psi]
$\sigma_{hoop,total}$ = 3365 [psi]
$\sigma_{LA,Bolts}$ = 33341 [psi]
σ_{shaft} = 10160 [psi]
$\sigma_{sss1,1}$ = 21278 [psi]
$\sigma_{sss2,eq}$ = 14833 [psi]

$\sigma_{sss3,1}$ = 24133 [psi]
σ_{sss4} = 15004 [psi]
$\sigma_{tsupport,leg}$ = 12250 [psi]
σ_z = -83.83 [psi]
$S_{ut,316}$ = 84100 [psi]
$S_{ut,AL}$ = 29304 [psi]
$S_{y,316}$ = 42100 [psi]
$S_{y,AL}$ = 40000 [psi]
$\tau_{bolts,LA}$ = 4774 [psi]
$\tau_{collar,c}$ = 956.3 [psi]
τ_{shaft} = 3697 [psi]
$\tau_{sss1,V}$ = 12033 [psi]
$\tau_{sss2,V}$ = 1960 [psi]
$\tau_{sss3,V}$ = 9859 [psi]
t_{ang} = 0.375 [in]
t_{base} = 0.75 [in]
$t_{base,sss}$ = 1.125 [in]
$t_{plate,base}$ = 0.375 [in]
t_{spacer} = 0.7864 [in]
t_{stress} = 0.15 [in]
t_{vessel} = 0.095 [in]
$width_{base}$ = 10 [in]
W_{total} = 34.36 [lbf]

$\sigma_{sss3,pull}$ = 17999 [psi]
$\sigma_{tsupport}$ = 4356 [psi]
$\sigma_{tsupport,moment}$ = 20001 [psi]
$S_{ut,304}$ = 47668 [psi]
$S_{ut,A36}$ = 37770 [psi]
$S_{y,304}$ = 31200 [psi]
$S_{y,A36}$ = 36000 [psi]
$S_{y,wood}$ = 942.7 [psi]
$\tau_{collar,a}$ = 956.3 [psi]
$\tau_{funnel,front}$ = 3589 [psi]
$\tau_{sss1,T}$ = 21278 [psi]
$\tau_{sss2,T}$ = 14702 [psi]
$\tau_{sss3,FT}$ = 7130 [psi]
$\tau_{support,leg}$ = 4900 [psi]
T_{arm} = 1.374 [in]
$t_{base,LA}$ = 1.536 [in]
t_{plate} = 0.375 [in]
$t_{plate,collar}$ = 0.375 [in]
T_{sss} = 6733 [lbf-in]
$t_{tsupport}$ = 0.75 [in]
Vol_{tube} = 526 [in^3]
$W_{dough,total}$ = 17.06 [lbf]
W_{tube} = 17.3 [lbf]

No unit problems were detected.

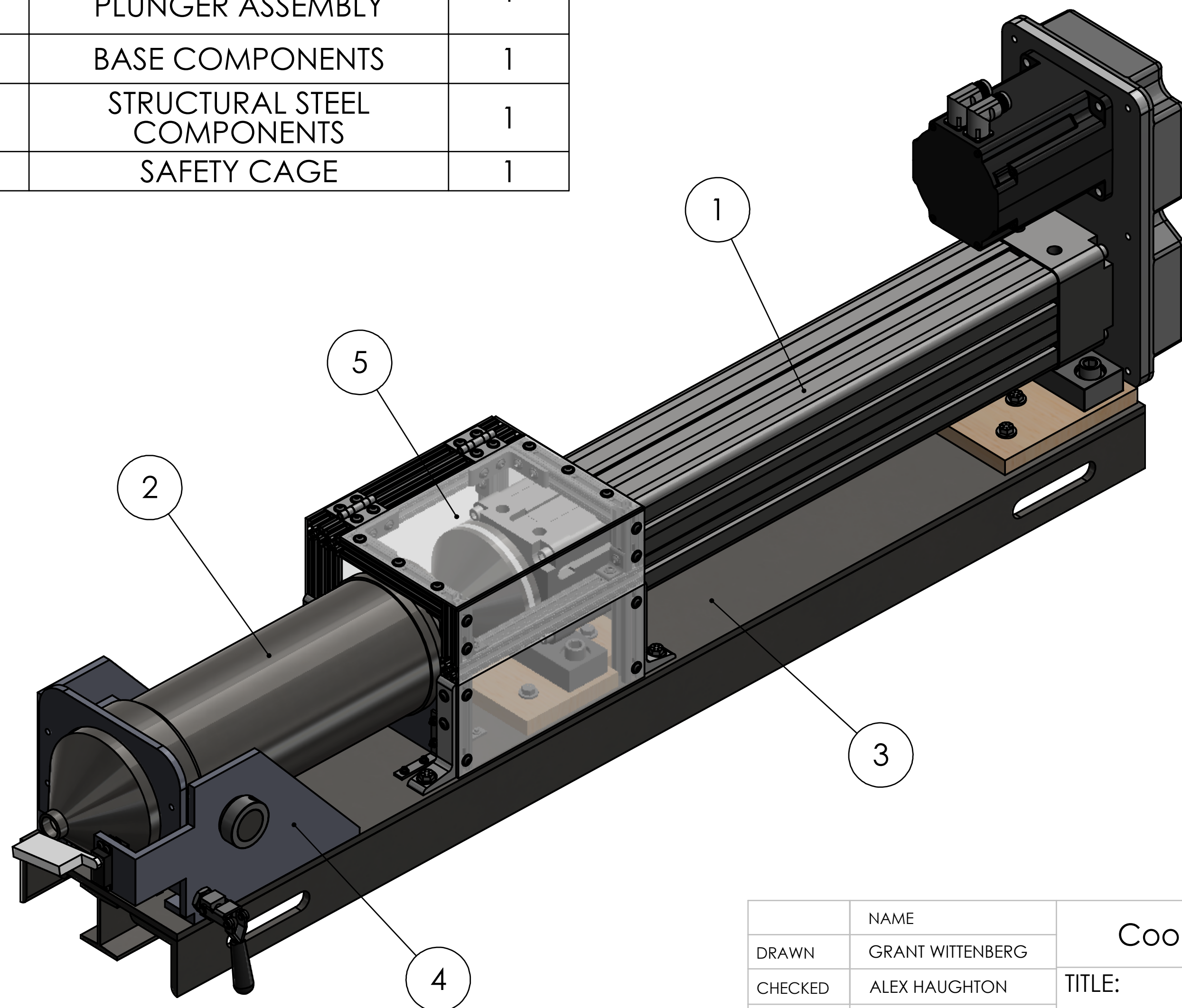
KEY VARIABLES
$n_{d,funnel}$ = 4.282
$n_{d,pin}$ = 1.597
$n_{d,sss1}$ = 3.384
$n_{d,tube}$ = 9.271
$n_{d,bolts,LA}$ = 1.08
$n_{d,column}$ = 3123
$n_{d,buckling}$ = 5968
$n_{d,sss2}$ = 9.916
$n_{d,bolts,sss}$ = 1.492
$n_{d,sss4}$ = 2.399
$n_{d,collar,c}$ = 2.353
$n_{d,collar,a}$ = 17.57
$n_{d,shaft}$ = 3.543
$n_{d,tsupport}$ = 8.265
$n_{d,iron}$ = 10.89
$n_{d,spacer}$ = 3.693
δ_{iron} = 0.009199 [in]
$n_{d,bolt,tsupport}$ = 2.731
$n_{d,sss2,\tau}$ = 3.432
$n_{d,tsupport,leg}$ = 2.939
$n_{d,bushing}$ = 0.5357
$n_{d,base,sss}$ = 5.572
$n_{d,base,LA}$ = 6.347

Appendix G: Drawings, Specifications and Bill of Materials

Table 12: Bill of Materials Including Prices

Part Number	Part Name	Subsystem	Unit Price	Supplier	Quantity	Total Price
101	Linear Actuator	Electrics	$ 7,310.00	Thomson/Kaman	1	$ 7,310.00
102	Controller	Electrics	$ 1,400.00	Kollmorgen/Motion Solutions	1	$ 1,400.00
103	Power Supply	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
104	Motor	Electrics	$ 30.00	Hobby King	1	$ 30.00
105	Paddle	Electrics	$ 15.00	Amazon	1	$ 15.00
106	Relay	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
107	Emergency Stop Switch	Electrics	$ 50.00	Automation Direct*	1	$ 50.00
108	Fuses	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
109	Human Machine Interface	Electrics	$ 200.00	Automation Direct*	1	$ 200.00
201	Cylinder	Food Contact	$ 96.00	B & B Supply	1	$ 96.00
202	Funnel	Food Contact	$ 180.00	B & B Supply	1	$ 180.00
203	Plunger	Food Contact	$ 180.00	B & B Supply	1	$ 180.00
204	Seal	Food Contact	$ 30.00	Parker Hannafin	4	$ 120.00
301	Base Plate	Base	$ 40.00	B & B Supply	1	$ 40.00
302	I Beam	Base	$ 46.00	Metals Depot	1	$ 46.00
303	Angle Iron	Base	$ 40.00	Metals Depot	2	$ 80.00
304	Front Wood Mounting Block	Base	$ 5.00	Home Depot	1	$ 5.00
305	Rear Wood Mounting Block	Base	$ 5.00	Home Depot	1	$ 5.00
401	Funnel Collar Plate	Structure	$ 10.00	B & B Supply	1	$ 10.00
402	Cylinder Support Plate	Structure	$ 5.00	B & B Supply	1	$ 5.00
403	CSP Brackets	Structure	$ 35.00	McMastercarr	1	$ 35.00
404	Right Funnel Support Bracket	Structure	$ 10.00	B & B Supply	1	$ 10.00
405	Left Funnel Support Bracket	Structure	$ 10.00	B & B Supply	1	$ 10.00
406	Rod	Structure	$ 7.00	Misumi	1	$ 7.00
407	Bushing	Structure	$ 60.00	McMastercarr	1	$ 60.00
408	Rod Collars	Structure	$ 17.00	McMastercarr	1	$ 17.00
409	T-shaft Mount	Structure	$ 130.00	Misumi	1	$ 130.00
410	Toggle Clamp	Structure	$ 25.00	McMastercarr	1	$ 25.00
411	T Support Set Screw	Structure	$ 2.00	Accuscrews	2	$ 4.00
412	Collar Set Screw	Structure	$ 20.00	Accuscrews	4	$ 80.00
501	Long Vertical Frame	Safety Cage	$ 20.00	Futura Industries	1	$ 20.00
502	Long Horizontal Frame	Safety Cage	$ 20.00	Futura Industries	1	$ 20.00
503	Medium Vertical Frame	Safety Cage	$ 15.00	Futura Industries	1	$ 15.00
504	Short Horizontal Frame	Safety Cage	$ 10.00	Futura Industries	1	$ 10.00
505	Short Vertical Frame	Safety Cage	$ 10.00	Futura Industries	1	$ 10.00
506	Acrylic Sheet	Safety Cage	$ 5.00	Tap Plastics	1	$ 5.00
507	Acrylic Sheet	Safety Cage	$ 2.00	Tap Plastics	1	$ 2.00
508	Acrylic Sheet	Safety Cage	$ 2.00	Tap Plastics	1	$ 2.00
509	Acrylic Sheet	Safety Cage	$ 4.00	Tap Plastics	1	$ 4.00
510	Acrylic Sheet	Safety Cage	$ 1.00	Tap Plastics	1	$ 1.00
511	Acrylic Sheet	Safety Cage	$ 8.00	Tap Plastics	1	$ 8.00
512	Floor Mount	Safety Cage	$ 8.79	Futura Industries	2	$ 17.58
513	4 Hole Corner Bracket	Safety Cage	$ 4.43	Futura Industries	2	$ 8.86
514	2 Hole Corner Bracket	Safety Cage	$ 2.95	Futura Industries	4	$ 11.80
515	T-Slot Hinges	Safety Cage	$ 13.27	Futura Industries	1	$ 13.27
516	Fasteners	Safety Cage	$ 33.95	Futura Industries	1	$ 33.95
600	Bolts	Structure	$ 100.00	Bolts Depot	1	$ 100.00

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	101	LINEAR ACTUATOR	1
2	200	CYLINDER, FUNNEL, PLUNGER ASSEMBLY	1
3	300	BASE COMPONENTS	1
4	400	STRUCTURAL STEEL COMPONENTS	1
5	500	SAFETY CAGE	1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL: VARIOUS

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:

Cookie Dough Engineering

TITLE:

Full Assembly

DWG. NO. 000

REV A

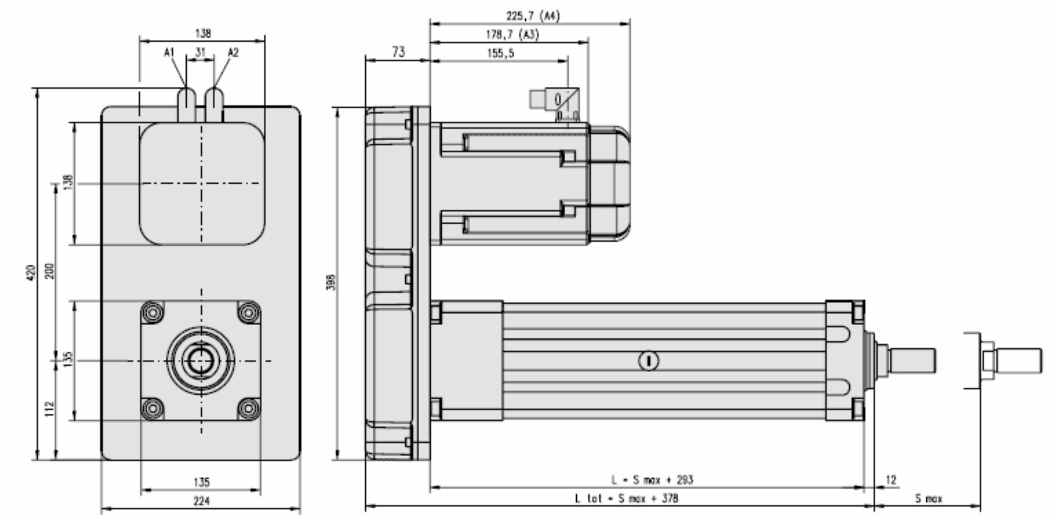
SCALE: 1:24

DATE: 02/10/2015

5 4 3 2 1

ECT130 Parallel B63 AC Servo Motor

• Robust and reliable
• Brushless AC servo motor
• Belt gear
• Ball screw
• Hard chromed steel extension tube
• IP65 as standard
• Stroke up to 2000 mm
• Load up to 21500 N
• Speed up to 440 mm/s



Order No.

ECT13-B63R03PB4010-0600FU12S1

Type

ECT130 Parallel B63 AC servo motor

Type	B63R03PB-4010
Stroke (mm)	600
Mounting options	Mounting feet
Adapter options	Outside thread M33x2
Number of magnetic sensors N.C	1
Number of magnetic sensors N.O	2
Protection	Wash down protection

Created: 2015-02-12 04:02:17

Address: Tollo Linear
Box 9053
291 09 Kristianstad
Sweden

Phone: 044 - 24 67 00
Web: www.tollo.com

6.1 The AKD Family of Digital Drives

Available AKD versions

Variant (short)	Description	Current	Housing	Connectivity
AKD-B***	Base drive is controlled by analog torque & velocity commands (electronic gearing).	3 to 24 A	Standard	Analog, SynqNet
AKD-P**	Position Indexer drive adds the ability to command multiple motions, process I/O, make decisions, add time delays, modify drive process variables to the base drive.	3 to 48 A	Standard	Analog, CANopen, EtherCAT, PROFINET RT, Ethernet/IP, sercos® III
AKD-M***	Motion Controller PDMM/EtherCAT master drive. Includes all five IEC 61131 languages, PLC Open and Pipes Network. This drive is called AKD PDMM.	3 to 24 A	Extended width	EtherCAT
AKD-T***	Simple BASIC programmability added to theBase drive. This drive is called AKD BASIC.	3 to 24 A	Standard	Analog
AKD-T***-IC	AKD BASIC with I/O expansion.	3 to 24 A	Extended width	Analog, I/O expansion

Standard features

- Supply voltage range 120 V to 480 V ±10%
- Several housing dimensions, depending on current and hardware options.
- Motion bus onboard, TCP/IP service channel onboard.
- SFD, Hiperface DSL, Tamagawa Smart Abs, Resolver, Comcoder, 1Vp-p Sin-Cos encoders, incremental encoders support onboard.
- Support for ENDAT 2.1 & 2.2, BiSS or HIPERFACE protocols onboard.
- Encoder emulation onboard and support for second feedback
- Safe Torque Off (STO) according to IEC 61508 SIL 2 onboard.
- Use with Synchronous servomotors, linear motors, and induction machines can be used.

Power section

- One or three phase supply, voltage range 120 to 480 V ±10%, 50 to 400 Hz ±5% or DC. Connection to higher voltage mains only via isolating transformer, ➜ p. 98. Single phase supply possible with output power derating.
- B6 bridge rectifier, integral soft-start circuit.
- Fusing to be provided by the user.
- DC bus link voltage range 170 to 680 VDC, can be connected in parallel.
- Output stage IGBT module with floating current measurement.
- Regen circuit with dynamic distribution of the generated power between several drives on the same DC bus link circuit.
- Internal regen resistor for all AKD models (except AKD-x00306, AKD-x00606 and AKD-x04807), external regen resistors if required.

Integrated safety

- Appropriate insulation/creepage distances and electrical isolation for safe electrical separation, per IEC 61800-5-1, between the power input/motor connections and the signal electronics.
- Soft-start, overvoltage detection, short-circuit protection, phase-failure monitoring.
- Temperature monitoring of the drive and motor.
- Motor overload protection: foldback mechanism
- SIL 2 safe torque off in accordance with IEC 61508, ➜ p. 52.

Auxiliary supply voltage 24V DC

- From an external, safety approved 24 V ±10% power supply.

Operation and parameter setting

- Using the setup software WorkBench for setup via TCP/IP or KAS IDE for AKD PDMM setup.

Full digital control

- Digital current controller (670 ns)
- Adjustable digital velocity controller (62.5 µs)
- Software option position controller (250 µs)

Inputs/Outputs

- 1 programmable analog input ➜ p. 142
- 1 programmable analog output ➜ p. 143
- 7 programmable digital inputs ➜ p. 144
- 2 programmable digital outputs ➜ p. 151
- 1 Enable input ➜ p. 144
- 1 STO input ➜ p. 52
- additional digital inputs and outputs depending on variants (for example AKD PDMM)

Option Cards

Integrated option cards affect the device width.

- IC: additional digital inputs and outputs.
- MC/M1: Motion Controller card with additional digital inputs and outputs. Extends the AKD to AKD PDMM type (part number scheme: AKD-M), a master drive for multiaxis, synchronized drive systems.

Connectivity

- Inputs/Outputs (➜ p. 138)
- Encoder feedback output (➜ p. 136)
- Service Interface (➜ p. 162)
- CANopen (➜ p. 166), optional
- Motion Bus interface (➜ p. 171)
  - SynqNet (➜ p. 173), optional
  - EtherCAT (➜ p. 172), optional
  - PROFINET RT (➜ p. 173), optional
  - Ethernet/IP (➜ p. 173), optional
  - sercos® III (➜ p. 174), optional

6.2 Ambient Conditions, Ventilation, and Mounting Position

Storage	➜ p. 19
Transport	➜ p. 19
Ambient temperature in operation	0 to +40 °C under rated conditions +40 to +55 °C with continuous current derating 4 % per Kelvin
Humidity in operation	Relative humidity 5 to 85%, no condensation, class 3K3
Site altitude	Up to 1000 meters above mean sea level without restriction 1,000 to 2,500 meters above mean sea level with power derating 1.5%/100 m
Pollution level	Pollution level 2 as per IEC 60664-1
Vibrations	Class 3M1 according to IEC 60721-3-3
Enclosure protection	IP 20 according to IEC 60529
Mounting position	Vertical, ➜ p. 65
Ventilation	Built-in fan (except AKD-x00306 type)
NOTICE	The drive shuts down (fault F234, ➜ p. 193, motor has no torque) in case of excessively high temperature in the control cabinet. Make sure sufficient forced ventilation is supplied within the control cabinet.

6.3 Mechanical Data

Mechanical data	Units	AKD-x00306	AKD-x00606	AKD-x01206	AKD-x02406
Weight (standard width)	kg	1.1		2	3.7
Weight (extended width)	kg	1.3		2.2	4
Height, without connectors	mm	168		196	248
Height, with connector	mm	200		225	280
Standard Width front/back	mm	54/59		72/78.4	96/100
Extended Width front/back	mm	84/89		91/96	96/100
Depth, without connectors	mm	156		187	228
Depth, with connectors	mm	185		< 215	<265

Mechanical data	Units	AKD-x00307	AKD-x00607	AKD-x01207	AKD-x02407	AKD-x04807
Weight (standard width)	kg	2.7			5.3	11.5
Weight (extended width)	kg	2.9			5.5	11.7
Height, without connectors	mm	256			306	385
Height, with connector	mm	290			340	526
Standard Width front/back	mm	65/70			99/105	185/185
Extended Width front/back	mm	95/100			99/105	-
Depth, without connectors	mm	185			228	225
Depth, with connectors	mm	<225			<265	<265

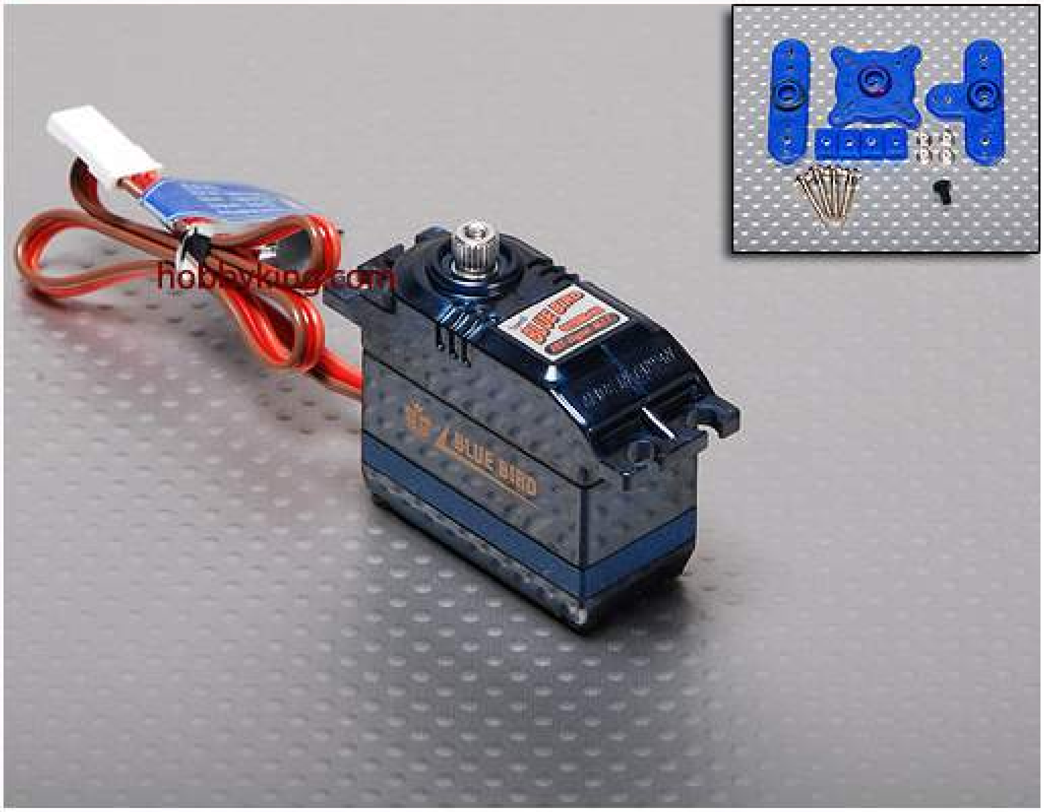
6.4 Inputs/Outputs

Interface	Electrical Data
Analog inputs	• ±12 VDC • Common Mode Rejection Ratio: > 30 dB at 60 Hz • resolution 16 bit and full monotonic • nonlinearity < 0.1% of full scale • offset drift max. 250µV/°C • input impedance > 13 kOhms
Analog outputs	• ±10 VDC • max 20mA • resolution 16 bit and full monotonic • nonlinearity < 0.1% of full scale • offset drift max. 250µV/°C • short circuit protected to AGND • output impedance 110 Ohms
Digital inputs	• ON: 3.5 VDC to 30 VDC, 2 mA to 15 mA • OFF: -2 VDC to 2 VDC, max.15 mA • galvanic isolation for 250 VDC
Digital outputs	• max. 30 VDC, 100 mA • short circuit proof • galvanic isolation for 250 VDC
Relay outputs	• max. 30 VDC, 1A • max. 42 VAC, 1 A • time open/close 10ms • isolation 400 VDC contact/coil

6.5 Electrical Data AKD-xzzz06

Electrical Data	Units	AKD-x00306	AKD-x00606	AKD-x01206	AKD-x02406
Rated supply voltage	V	3 x 120 V to 240 V ±10% 1 x 120 V to 240 V ±10%			3x240 V ±10%
Rated supply input frequency	Hz	50 Hz to 400 Hz ±5% or DC			
Rated input power for S1 operation	kVA	1.2	2.38	3.82	7.6
Rated input current					
at 1x120 V	A	5.0	9.9	12	N/A
at 1x240 V	A	5.0	9.9	12	N/A
at 3x120 V	A	2.3	4.6	9.2	N/A
at 3x240 V	A	2.3	4.6	9.2	18.3
Permitted switch on/off frequency	1/h	30			
Max. inrush current	A	10	10	10	20
Rated DC bus link voltage (Bus Turn on Delay 3ph 1 sec)	V	170 to 340			
Continuous output current (± 3%)					
at 120 V	Arms	3	6	12	N/A
at 240 V	Arms	3	6	12	24
Peak output current (for 5 s, ± 3%)	Arms	9	18	30	48
Continuous output power @ rated input current					
at 1x120 V	VA	312.5	625	1250	N/A
at 1x240 V	VA	625	1250	2500	N/A
at 3x120 V	VA	312.5	625	1250	N/A
at 3x240 V	VA	625	1250	2500	5000
Peak output power (for 1 s)					
at 1x120 V	kVA	0.937	1.875	3.125	N/A
at 1x240 V	kVA	1.875	3.750	6.250	N/A
at 3x120 V	kVA	0.937	1.875	3.125	N/A
at 3x240 V	kVA	1.875	3.750	6.250	10
Technical data for regen circuit	—	➜ p. 40			
Motor inductance min.					
at 120 V	mH	1.3	0.6	0.5	0.3
at 240 V	mH	2.5	1.3	1	0.6
Motor inductance max.	mH	250	125	100	60
Thermal dissipation, output stage disable	W	max. 20	max. 20	max. 20	max. 25
Thermal dissipation at rated current	W	31	57	137	175
Noise emission (low speed/high speed fan)	dB (A)	N/A	33/39	37/43	41/56
Aux. voltage supply	V	24 V (±10%, check voltage drop)			
-current B, P, T types without/with motor brake	A	0.5 / 1.7	0.6 / 1.8	0.7 / 1.9	1.0 / 2.5
-current M type without/with motor brake	A	0.8 / 2.0	0.9 / 2.1	1.0 / 2.2	1.3 / 2.8

BMS-661DMGplusHS Super Fast Digital Servo (MG) 6.4kg / .08sec / 46.5g (US Warehouse)



BMS-661DMG+HS Super Fast Digital Servo (Metal Gear) 6.4kg / .08sec / 46.5g

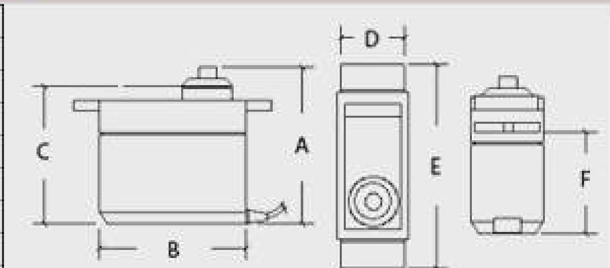
Double ball bearing (Si-oil)
CE Certified Strong 3 Pole Motor
Heavy duty sealed water proof case
Alloy heatsink
Digital signal design with 100% fitting square PWS
Automatic measures central ms
ALU 6061 alloy and C95 gear material
Digital IC (SOP package with 12bits transfer data)
MOS-FET driver (spirited driver able to push over 7A power)

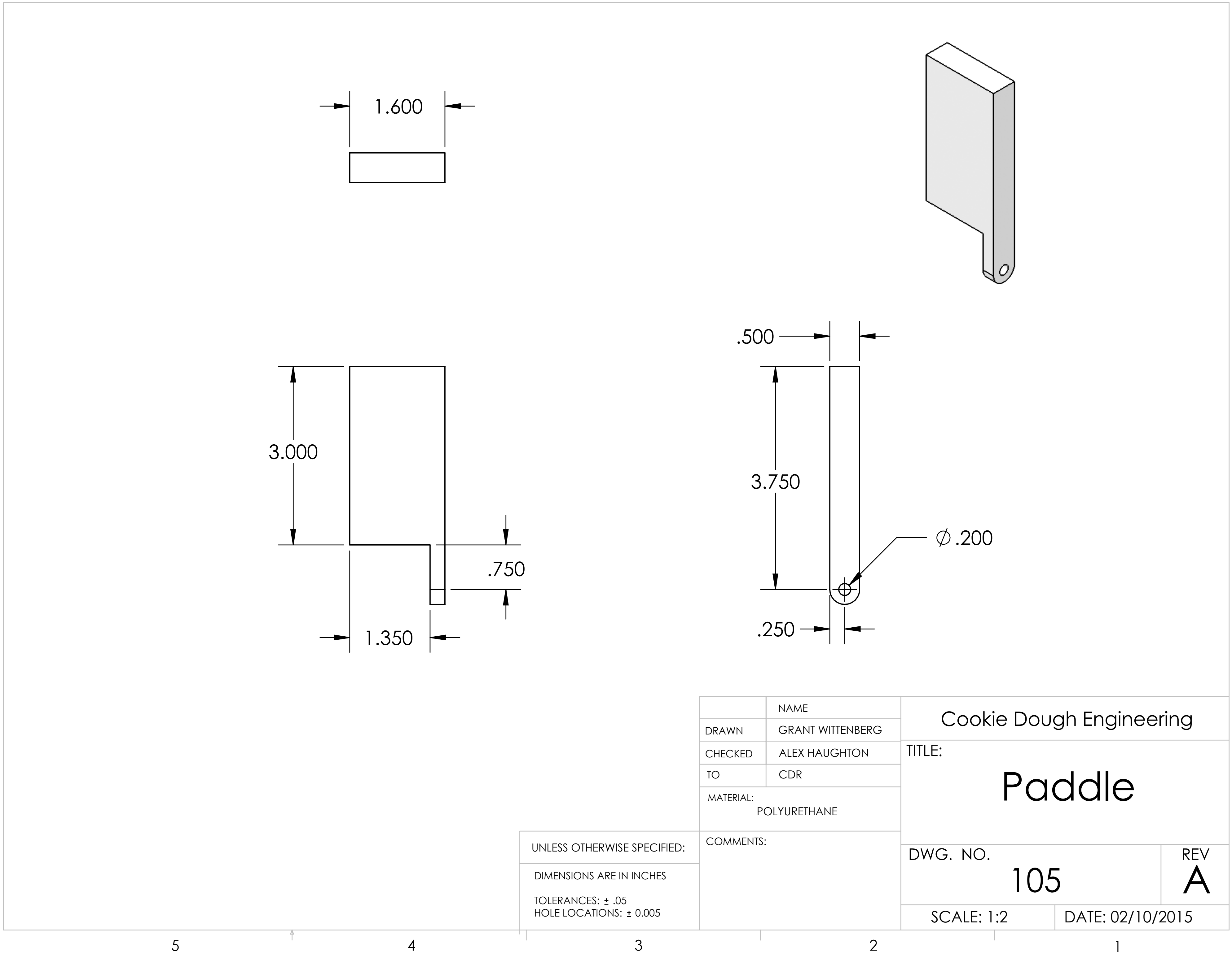
Weight: 46.5g / 1.66oz
Dimensions: 40.5 x 20 x 38mm / 1.60" x 0.78" x 1.54"
Torque At 6.0V: 6.4kg/cm , 89 oz/in
Speed At 6.0V: 0.08 sec / 60° at no load
Operating voltage: 4.8 - 6.0V

PRODUCT ID: 661DMG-HS

Product Config Table

Weight (g)	46.5
Torque (kg)	6.4
Speed(Sec/60deg)	0.08
A(mm)	42
B(mm)	41
C(mm)	38
D(mm)	20
E(mm)	55
F(mm)	26





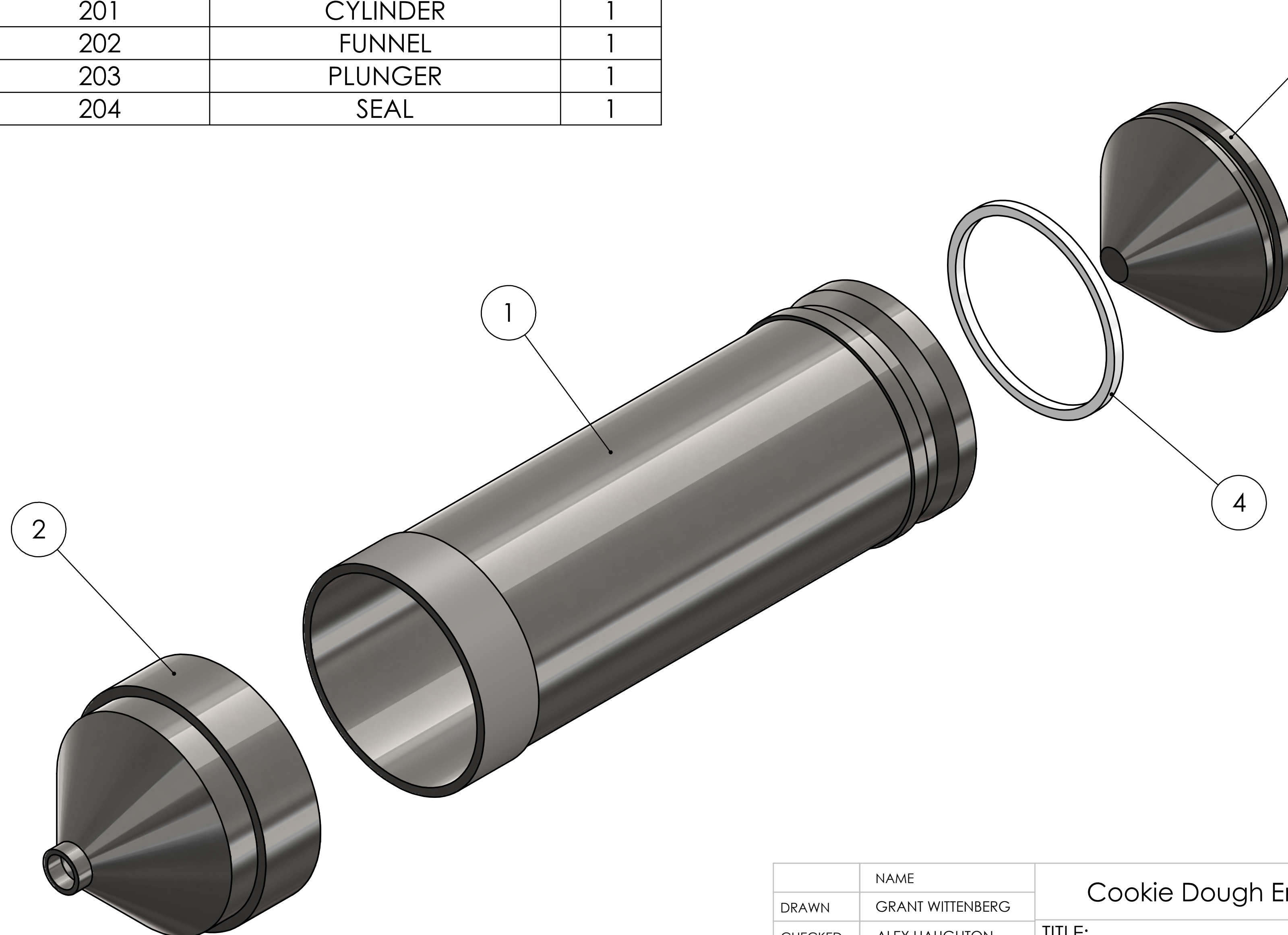
	NAME	Cookie Dough Engineering	
DRAWN	GRANT WITTENBERG	TITLE:	
CHECKED	ALEX HAUGHTON	Paddle	
TO	CDR		
MATERIAL: POLYURETHANE			
COMMENTS:		DWG. NO. 105	REV A
		SCALE: 1:2	DATE: 02/10/2015

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	201	CYLINDER	1
2	202	FUNNEL	1
3	203	PLUNGER	1
4	204	SEAL	1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL: VARIOUS

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

Cookie Dough Engineering

TITLE:
Cylinder, Funnel, & Plunger Assembly

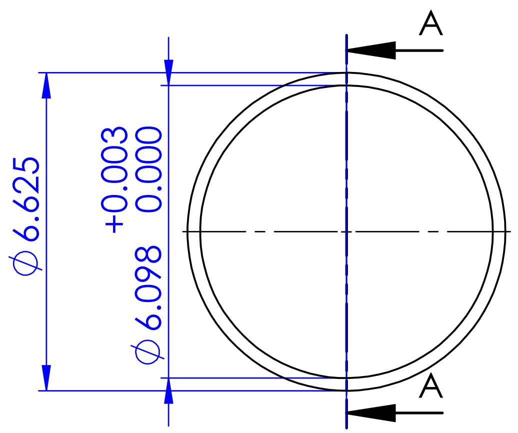
DWG. NO. 200

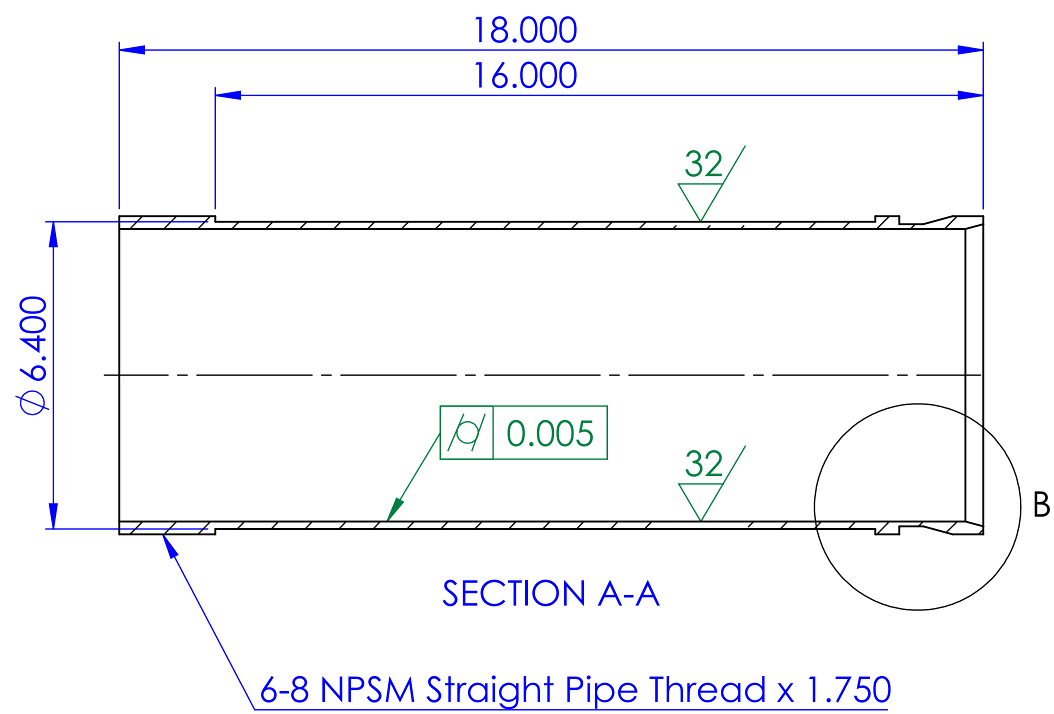
REV A

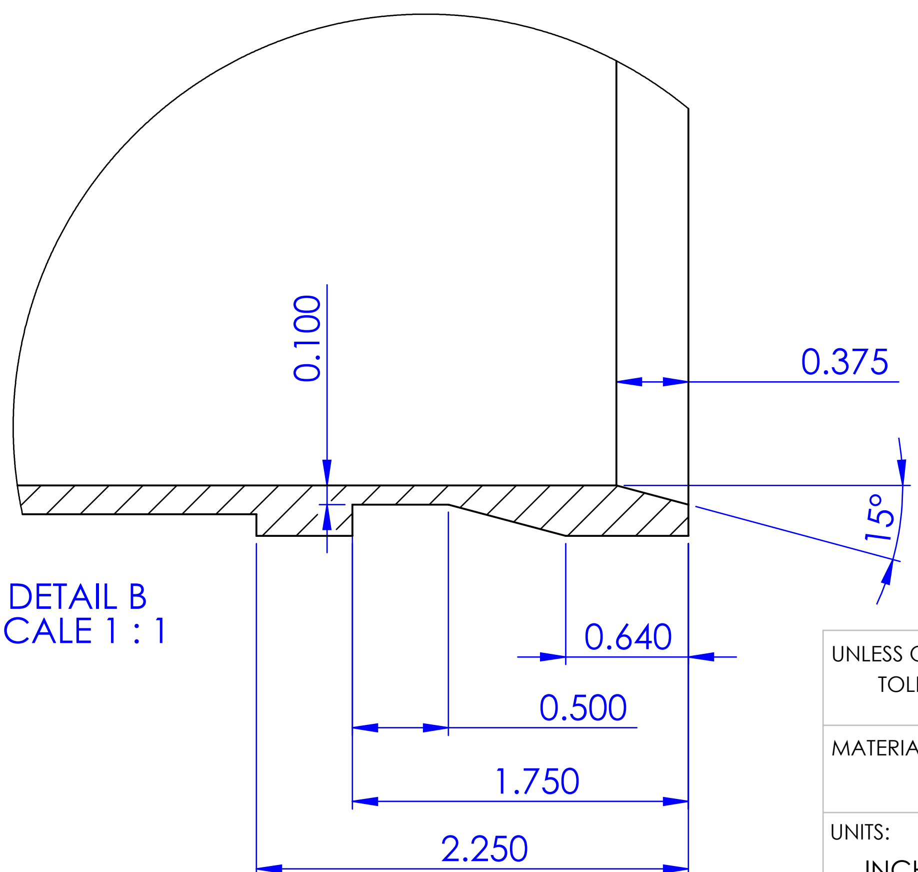
SCALE: 1:12

DATE: 02/10/2015

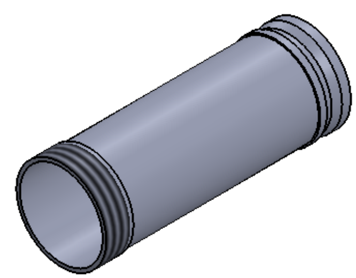
5 4 3 2 1



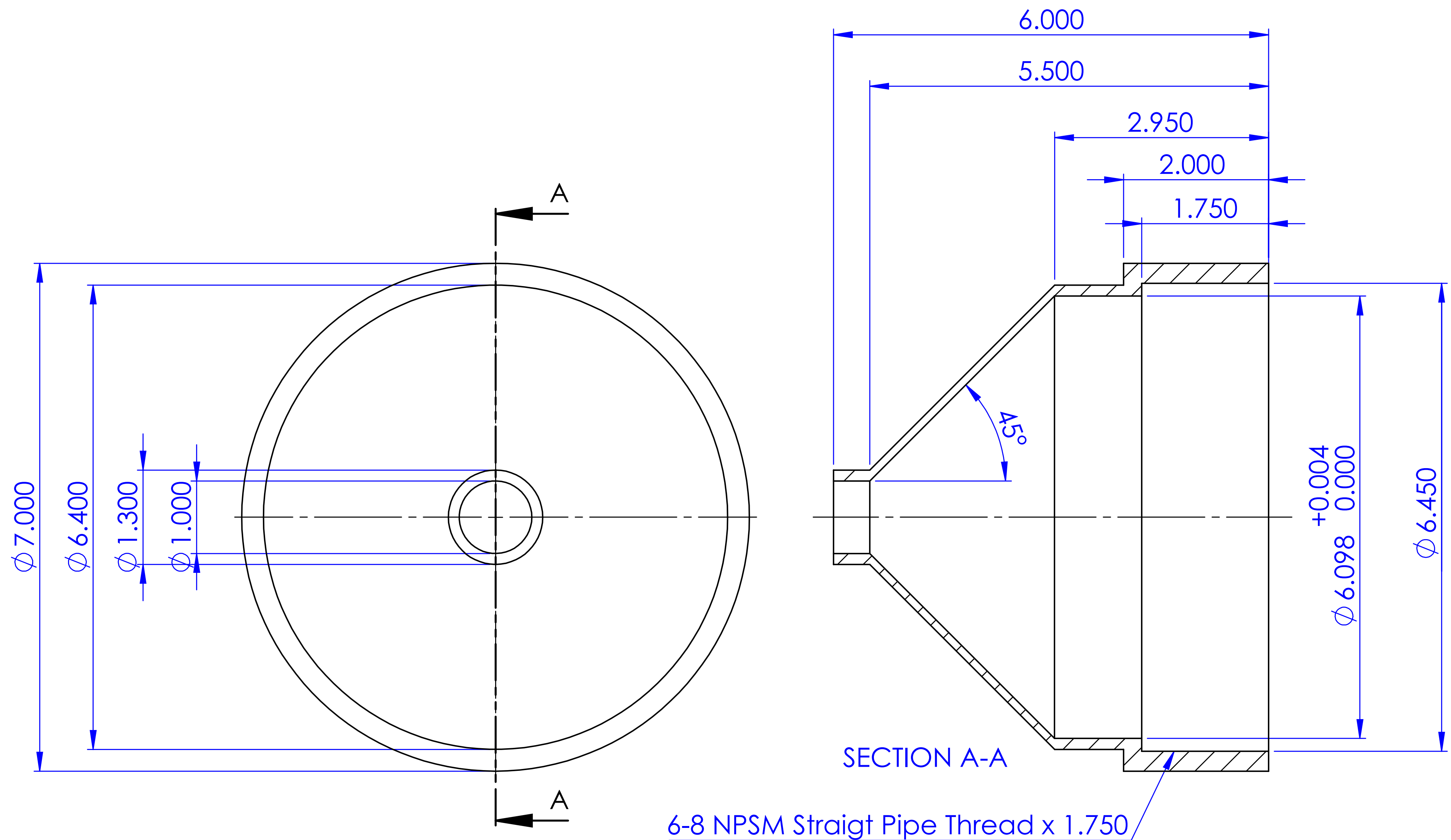


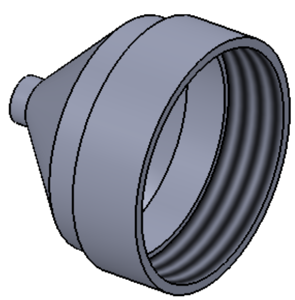


DETAIL B
SCALE 1 : 1



		FOR: NEXT INTENT	Cookie Dough Engineering	
UNLESS OTHERWISE SPECIFIED: TOLERANCES: ±0.005		COMMENTS: + RFQ ONLY + TO BE FABRICATED FROM 6 IN SS 304 SCH. 40 PIPE	TITLE: CYLINDER	
MATERIAL: SS 304		DRAWN BY: GRANT WITTENBERG	PART NO. 201	
UNITS: INCHES	SCALE: 1:4	CHECKED BY: ALEX HAUGHTON	REV. NO. 3	REV. DATE 2/8/15





FOR: NEXT INTENT

Cookie Dough Engineering

COMMENTS:
+ RFQ ONLY
+ TO BE FABRICATED FROM
6 IN LONG SS 304
7 IN DIA. PLUG

TITLE: FUNNEL

UNLESS OTHERWISE SPECIFIED:
TOLERANCES: ±0.005

MATERIAL: SS 304

DRAWN BY: GRANT WITTENBERG

PART NO. 202

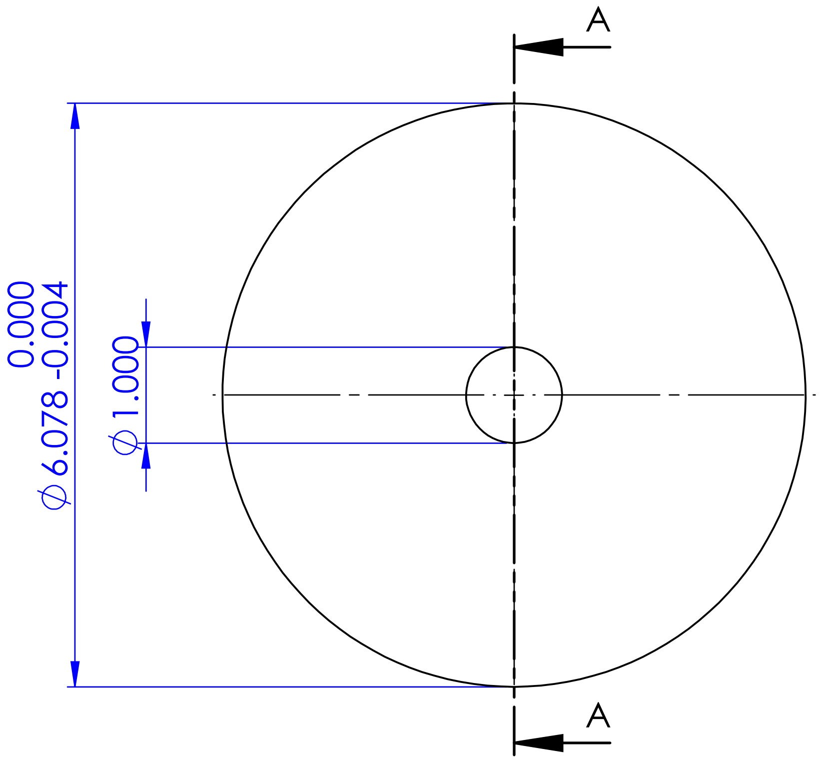
UNITS: INCHES

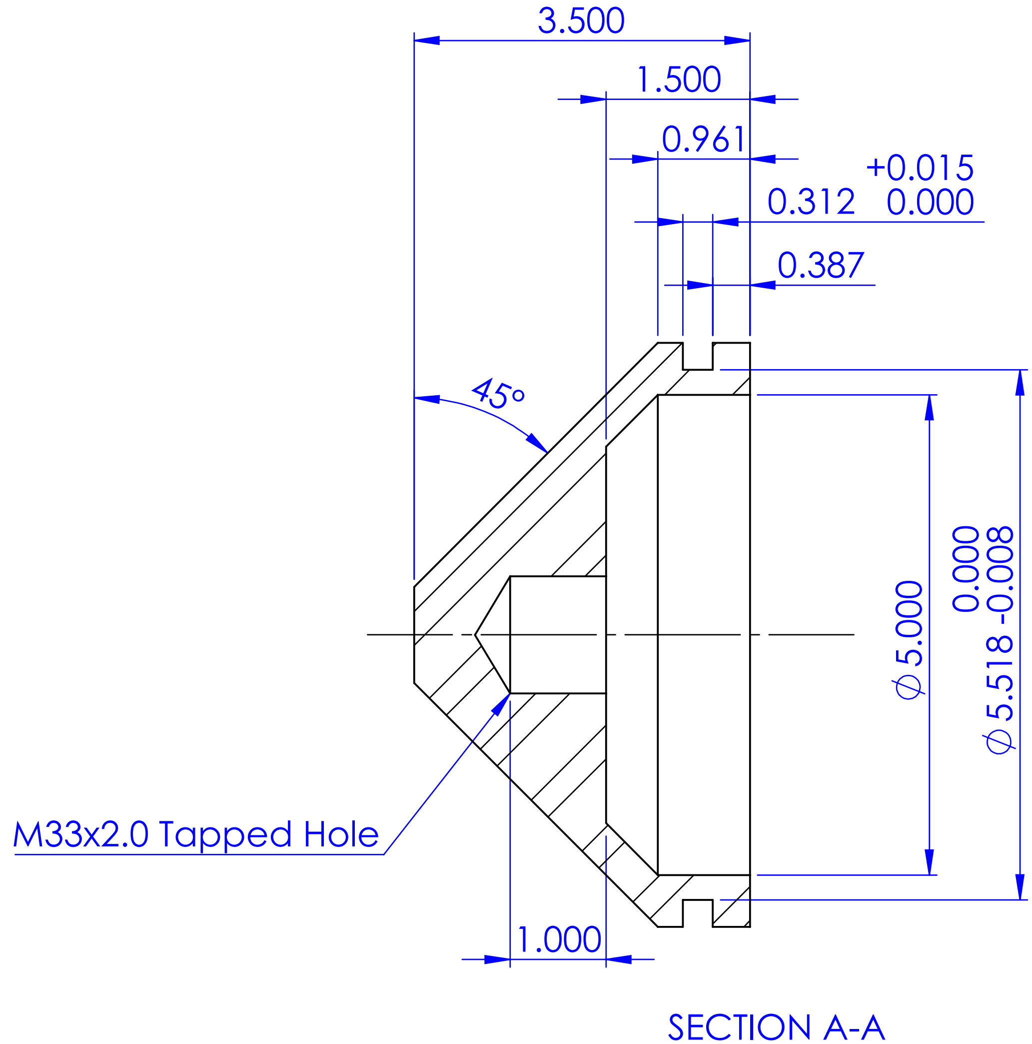
SCALE: 1:2

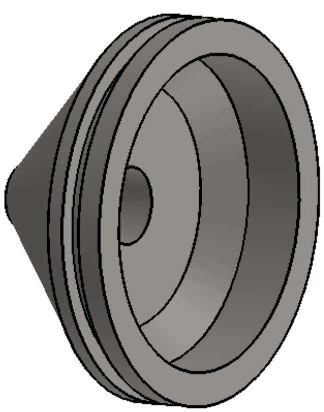
CHECKED BY: ALEX HAUGHTON

REV. NO. 2

REV. DATE 2/8/15







	FOR: NEXT INTENT	Cookie Dough Engineering	
UNLESS OTHERWISE SPECIFIED: TOLERANCES: ±0.005	COMMENTS: + RFQ ONLY + TO BE FABRICATED FROM 3.5 IN LONG SS 304 7 IN DIA. PLUG	TITLE: PLUNGER	
MATERIAL: SS 304	DRAWN BY: GRANT WITTENBERG	PART NO. 203	
UNITS: INCHES / SCALE: 1:2	CHECKED BY: ALEX HAUGHTON	REV. NO. 2	REV. DATE 2/8/15

E4 Profile, Premium Rounded Lip U-cup Piston Seal

Parker's E4 profile is a non-symmetrical piston seal designed to seal both lubricated and non-lubricated air. To ensure that critical surfaces retain lubrication, the radius edge of the lip is designed to hydroplane over pre-lubricated surfaces. The standard compound for the E4 profile is Parker proprietary Nitroxile ELF compound N4274A85. This compound is formulated with proprietary internal lubricants to provide "Extreme Low Friction" and excellent wear resistance. This compound provides extended cycle life over standard nitrile and carboxylated nitrile compounds.

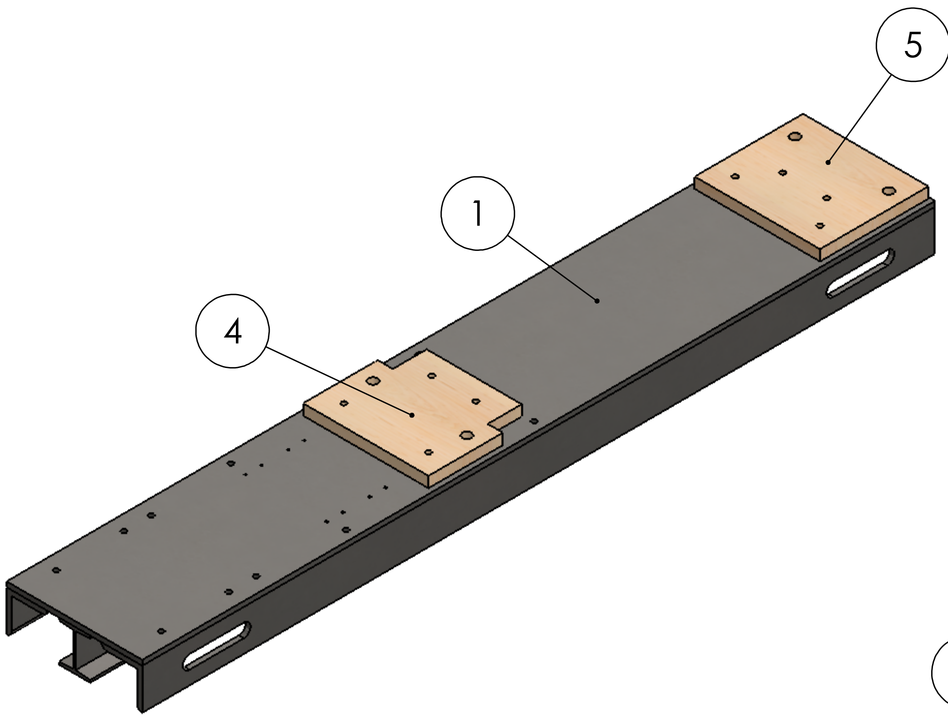
E4 Cross-Section

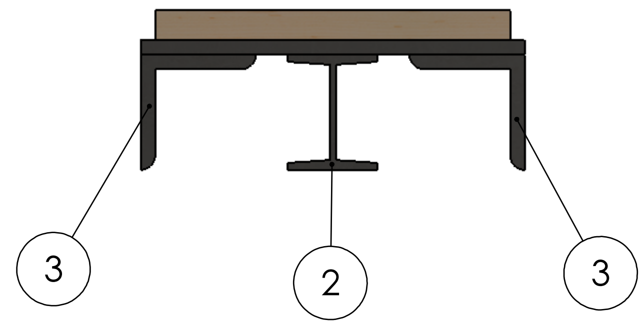
Technical Data

Standard Materials*	Temperature Range	Pressure Range†	Surface Speed
N4274A85	-10°F to 250°F (-23°C to 121°C)	250 psi (17 bar)	< 3 ft/s (1 m/s)
N4180A80	-40°F to 250°F (-40°C to 121°C)	250 psi (17 bar)	< 3 ft/s (1 m/s)
V4208A90	-5°F to 400°F (-21°C to 204°C)	250 psi (17 bar)	< 3 ft/s (1 m/s)
P5065A88	-70°F to 200°F (-57°C to 93°C)	250 psi (17 bar)	< 3 ft/s (1 m/s)

***Alternate Materials:** For applications that may require an alternate material, please contact Industrial seal Inc.

†Pressure Range without wear rings





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	301	3/8 Steel Plate	1
2	302	I Beam S3 x 5.7	1
3	303	Angle Iron 3 x 3 x 3/8	2
4	304	Front Wood Block	1
5	305	Back Wood Block	1

	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL: VARIOUS

COMMENTS:

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

Cookie Dough Engineering

TITLE:

Base Assembly

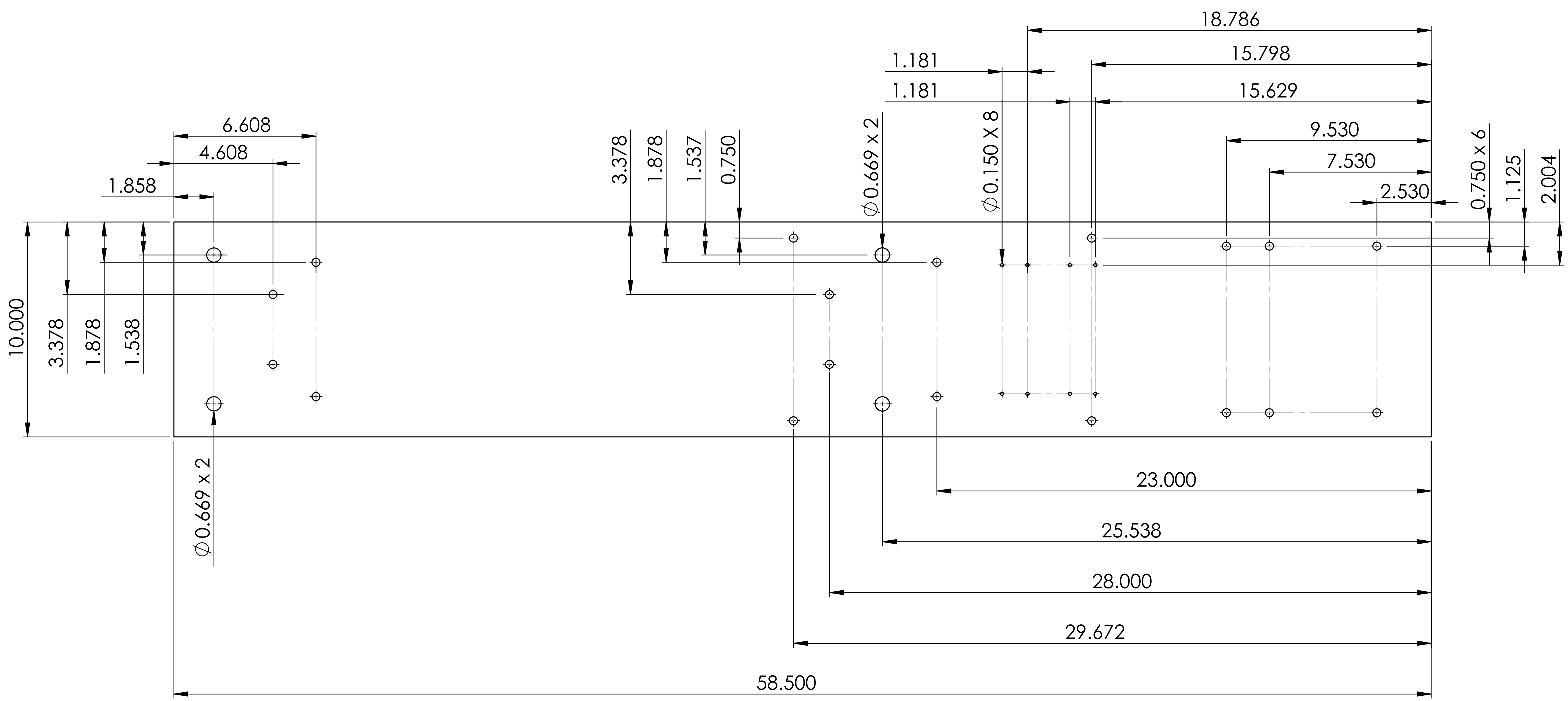
DWG. NO. 300

REV A

SCALE: 1:20

DATE: 02/10/2015

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR
MATERIAL:	A36 STEEL

Cookie Dough Engineering

TITLE:

Base Plate

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

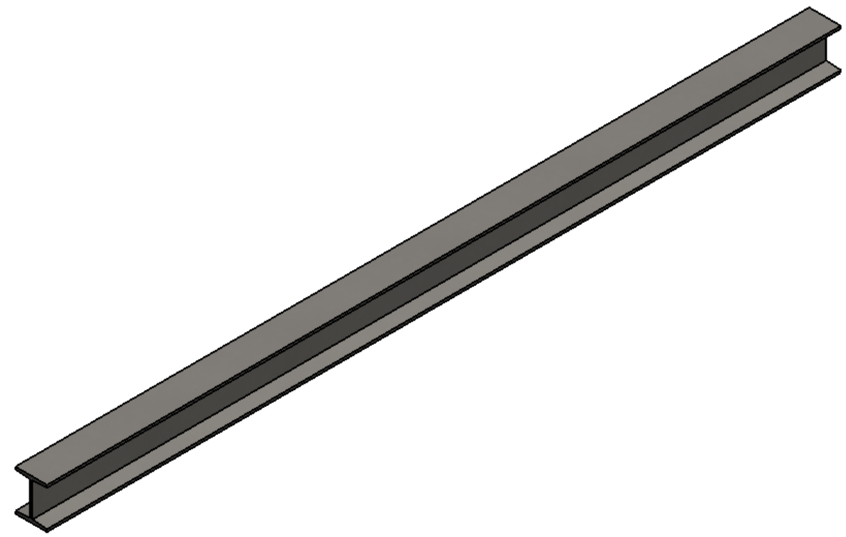
COMMENTS:
1)FEATURES ARE SYMETRIC FROM TOP TO BOTTOM ON THIS PART
2)PLATE IS 3/8 INCHES THICK
3)HOLES ARE 3/8 INCH UNLESS OTHERWISE SPECIFIED

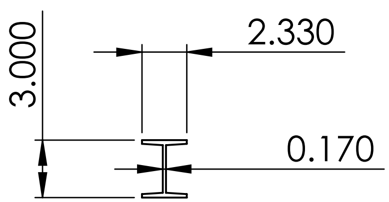
DWG. NO. 301

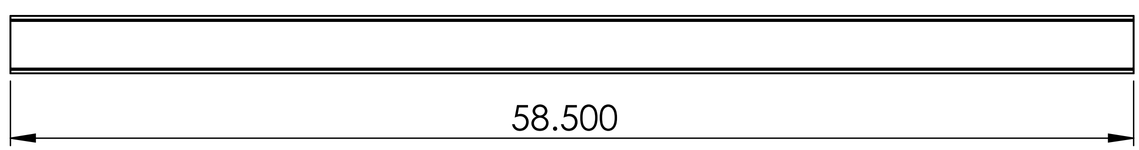
REV A

SCALE: 1:10

DATE: 02/10/2015







	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
A36 STEEL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1)THIS I-BEAM IS A U.S. STANDARD S3-5.7
2)THERE ARE NO FEATURES, CUT TO LENGTH.

Cookie Dough Engineering

TITLE:

I-BEAM

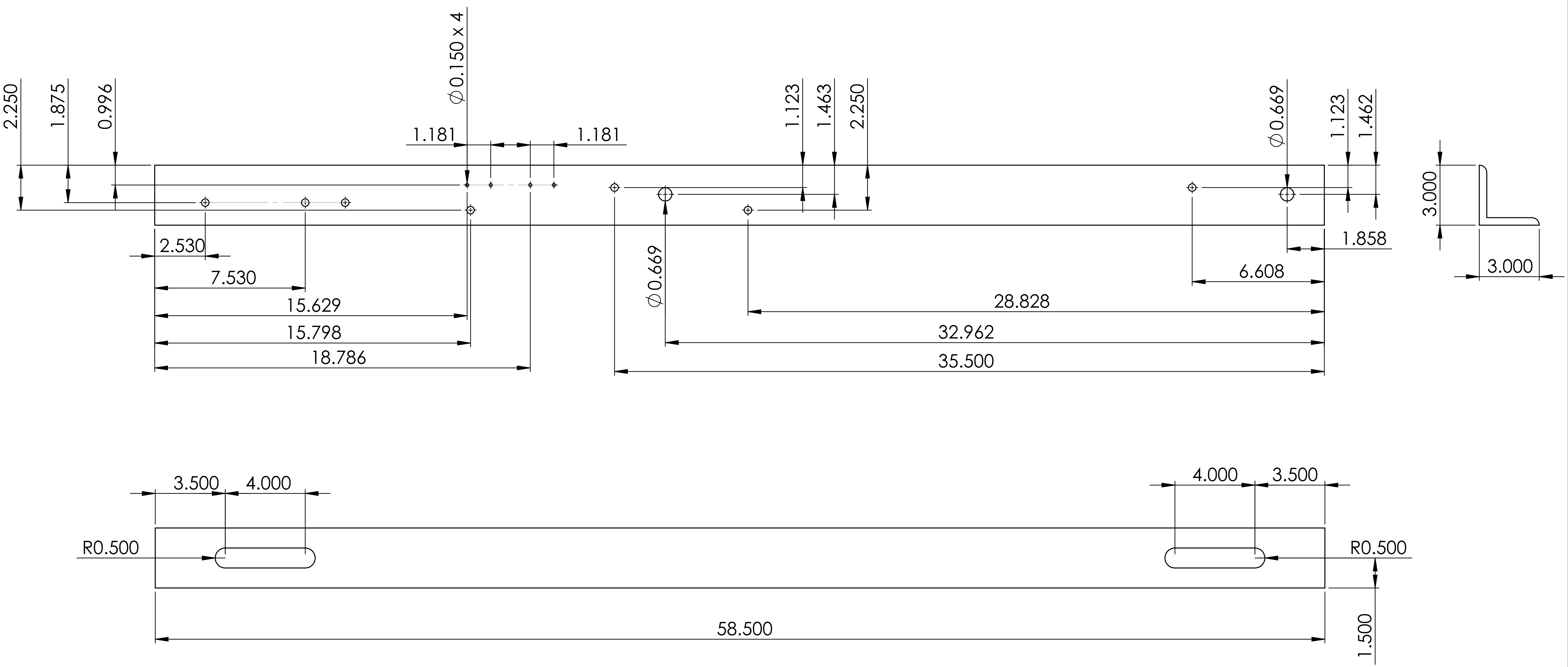
DWG. NO. 302

REV A

SCALE: 1:20

DATE: 02/10/2015

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL: A36 STEEL

Cookie Dough Engineering

TITLE: Angle Iron

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

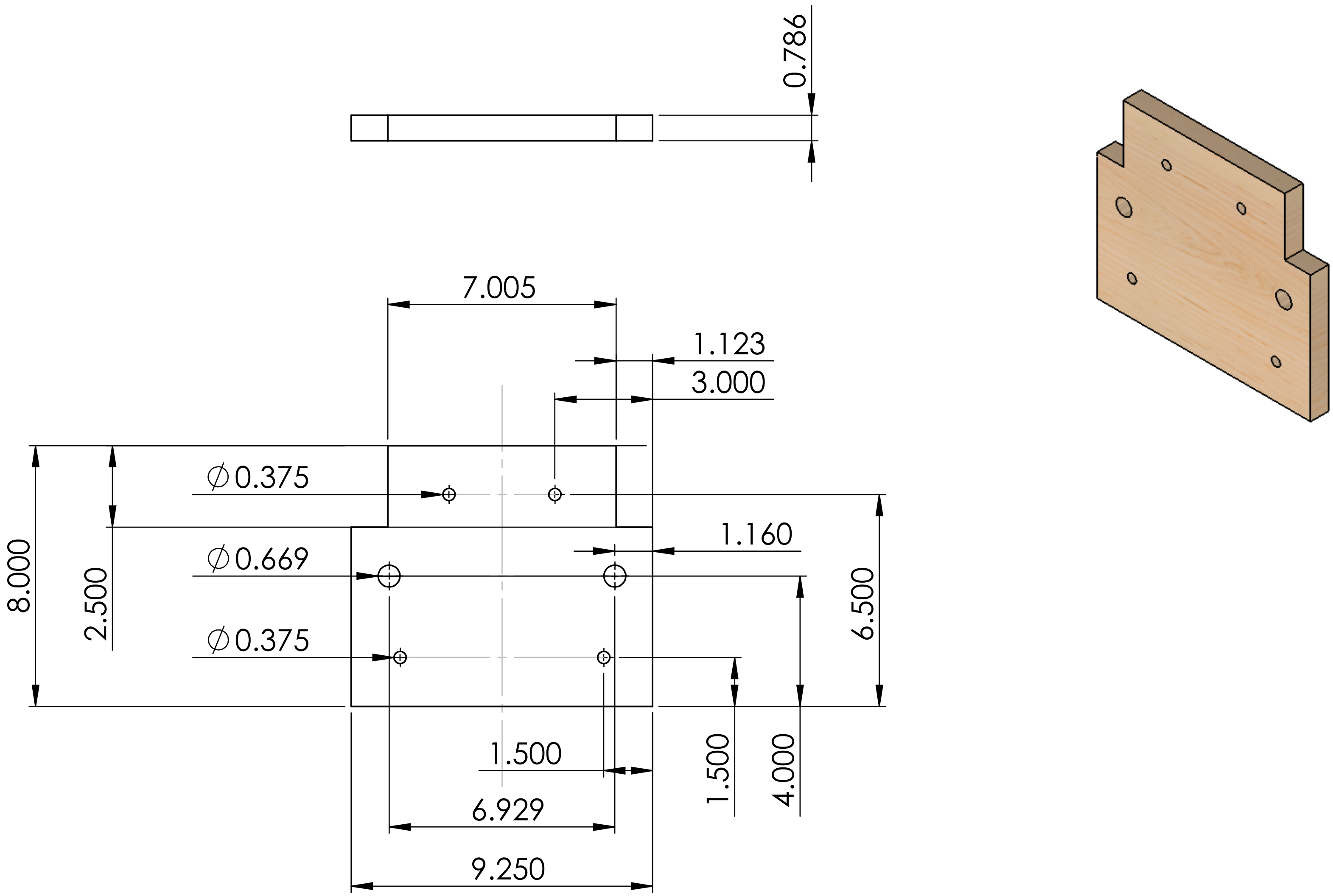
COMMENTS:
1)BOTH ANGLE IRON'S FEATURES AND DIMENSIONS ARE MIRRORED, ONLY ONE IS SHOWN ABOVE
2)HOLES ARE 3/8 INCH UNLESS OTHERWISE SPECIFIED

DWG. NO. 303

REV A

SCALE: 1:10

DATE: 02/10/2015



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR
MATERIAL:	WOOD

Cookie Dough Engineering

TITLE:

Front Wood Block

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
DIMENSIONS AND FEATURES ARE SYMETRIC FROM RIGHT TO LEFT ON THIS PART

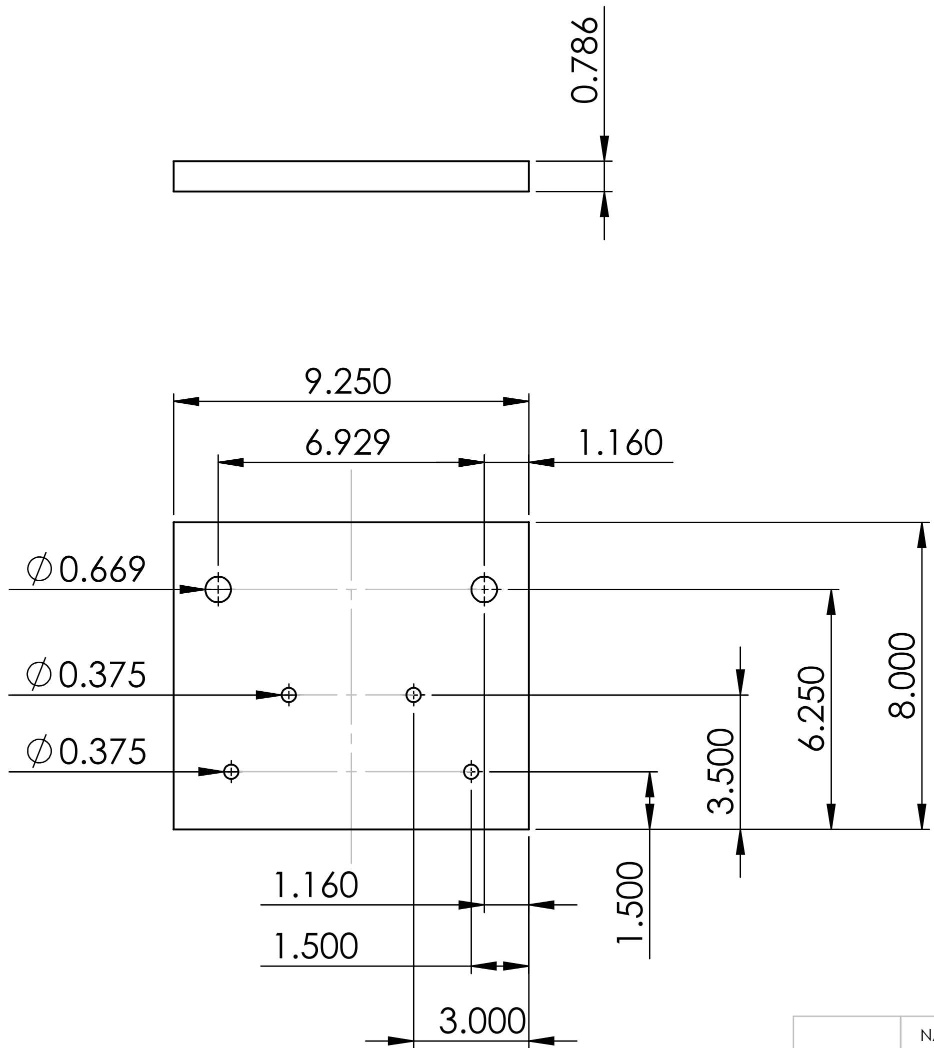
DWG. NO. 304

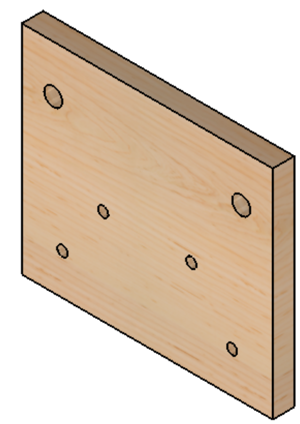
REV A

SCALE: 1:5

DATE: 02/10/2015

5 4 3 2 1

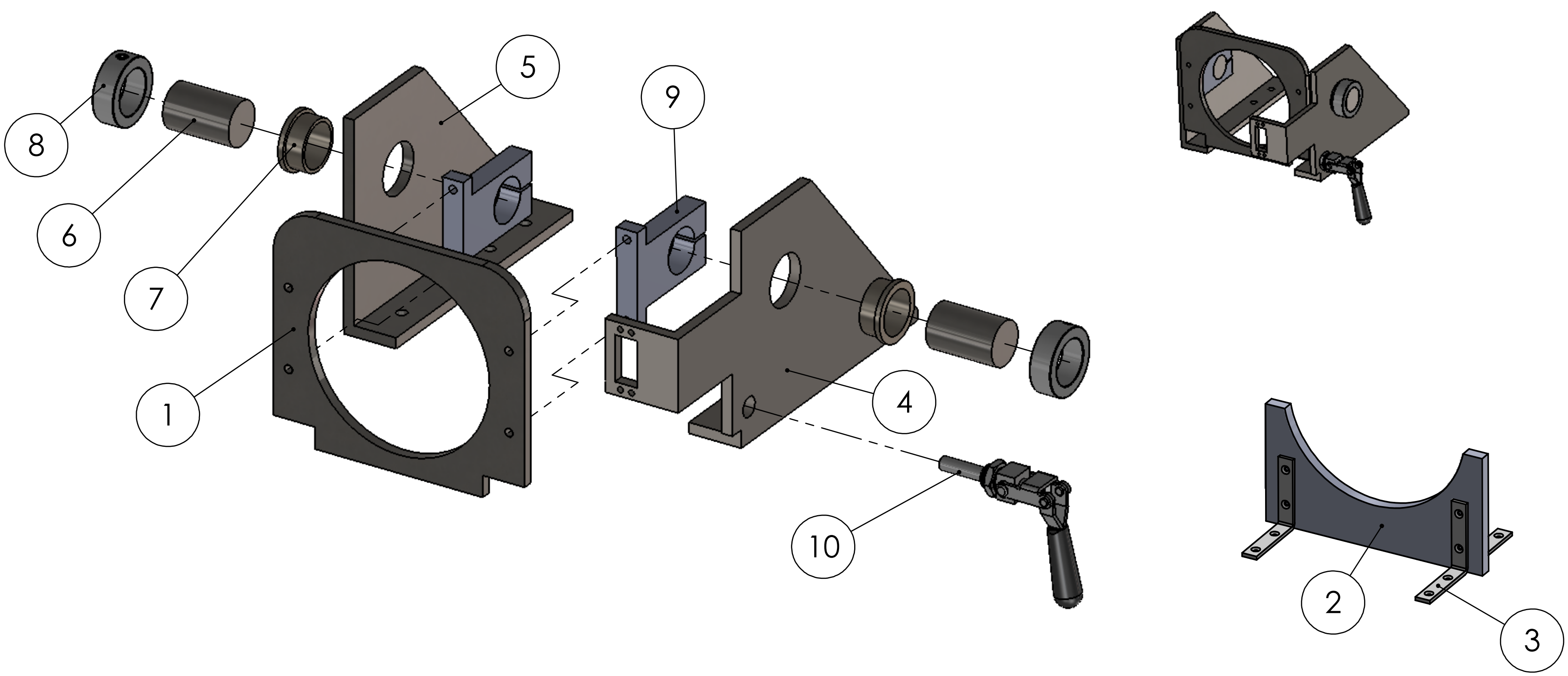




	NAME	Cookie Dough Engineering
DRAWN	GRANT WITTENBERG	TITLE:
CHECKED	ALEX HAUGHTON	Rear Wood Block
TO	CDR	
MATERIAL: WOOD		

UNLESS OTHERWISE SPECIFIED:	COMMENTS: DIMENSIONS AND FEATURES ARE SYMETRIC FROM RIGHT TO LEFT ON THIS PART	DWG. NO. 305 — REV A
DIMENSIONS ARE IN INCHES		SCALE: 1:5 — DATE: 02/10/2015
TOLERANCES: ± .05 HOLE LOCATIONS: ± 0.005		

5 4 3 2 1



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	401	FUNNEL COLLAR PLATE	1
2	402	CYLINDER SUPPORT PLATE	1
3	403	C.S.P. BRACKET	4
4	404	RIGHT FUNNEL SUPPORT BRACKET	1
5	405	LEFT FUNNEL SUPPORT BRACKET	1
6	406	ROD	2
7	407	BUSHING	2
8	408	ROD COLLAR	2
9	409	T-SHAFT MOUNT	2
10	410	TOGGLE CLAMP	1

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL: VARIOUS

COMMENTS:

Cookie Dough Engineering

TITLE:

Structural Steel

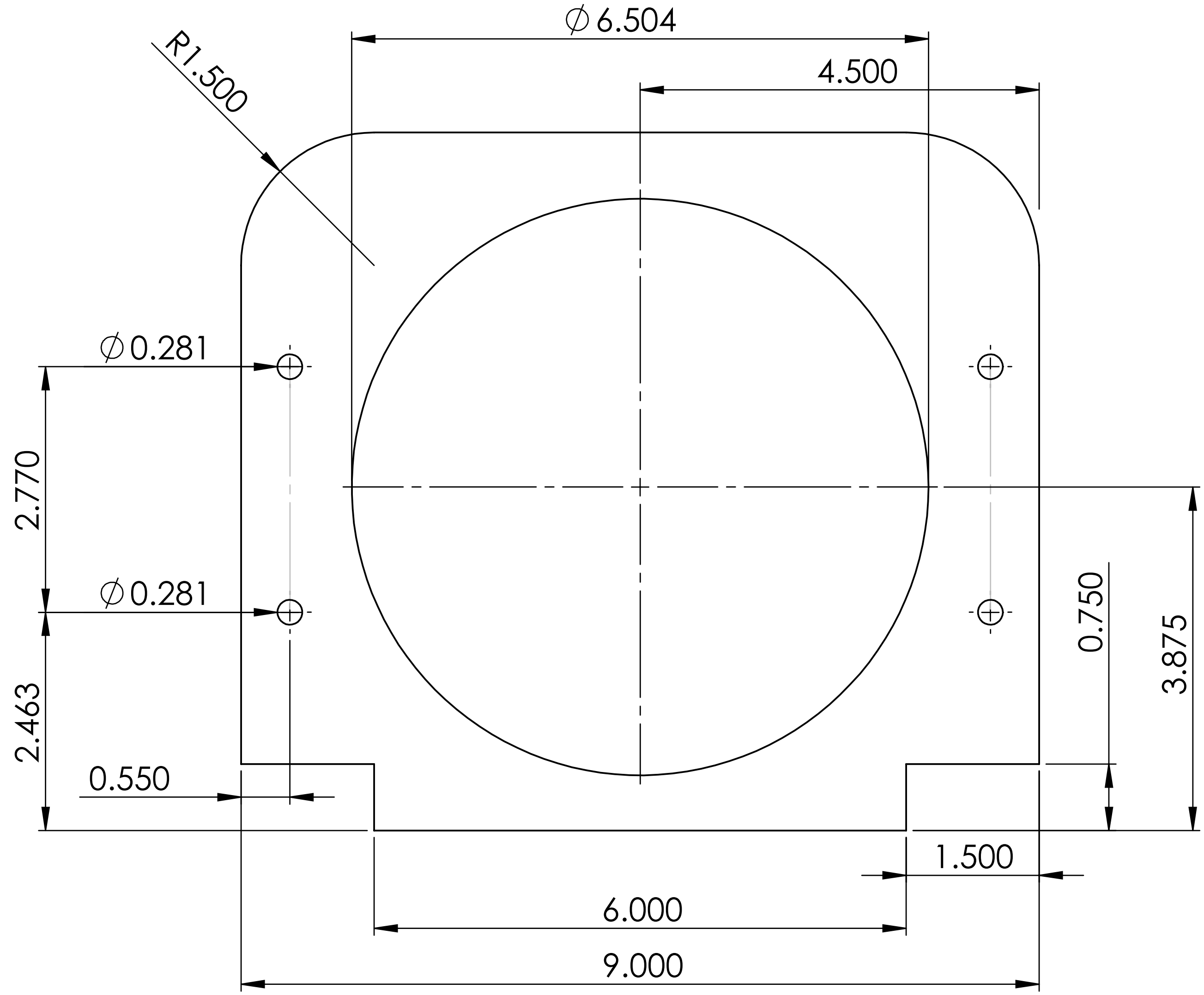
DWG. NO. 400

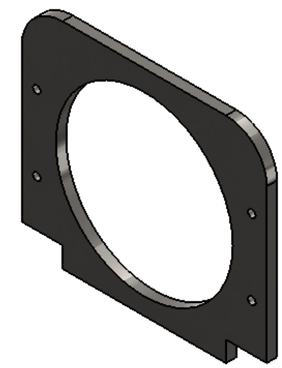
REV A

SCALE: 1:10

DATE: 02/10/2015

5 4 3 2 1





	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL: A36 STEEL

Cookie Dough Engineering

TITLE:

Funnel Collar Plate

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1)PLATE STEEL IS 3/8 IN THICKNESS
2)FEATURES ARE SYMETRIC FROM LEFT TO RIGHT ON THIS PART

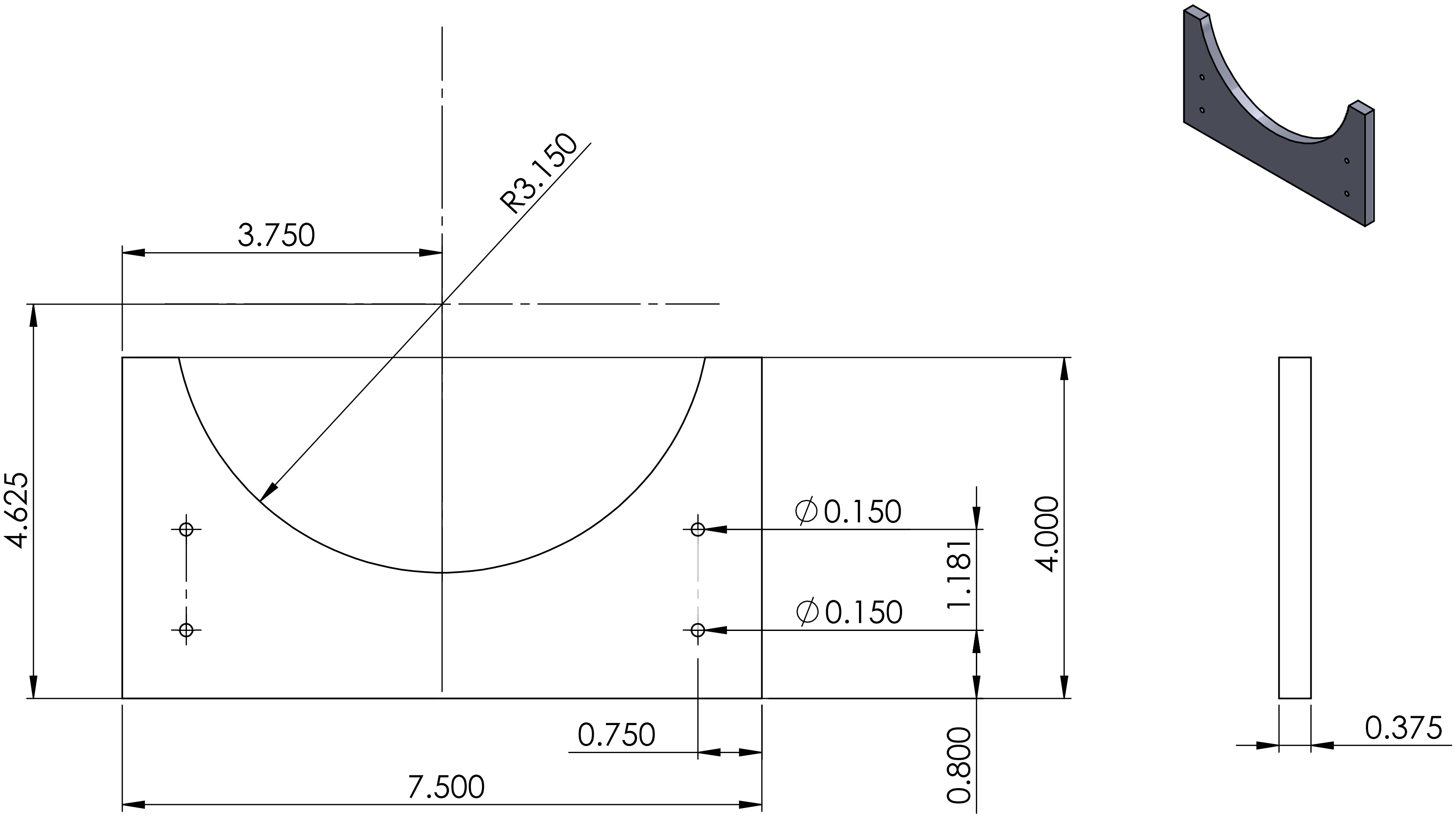
DWG. NO. 401

REV A

SCALE: 1:2

DATE: 02/10/2015

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
A36 STEEL

Cookie Dough Engineering

TITLE:

Cylinder Support Plate

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1)PLATE STEEL IS 3/8 INCHES THICK
2)FEATURES ARE SYMETRIC FROM LEFT TO RIGHT ON THIS PART

DWG. NO. 402

REV A

SCALE: 1:2

DATE: 02/10/2015

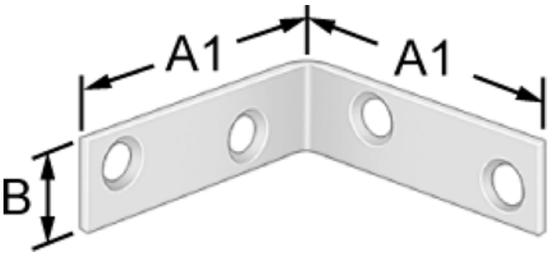
5 4 3 2 1

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Bracket

Polished Stainless Steel, 2-3/8" Length of Sides

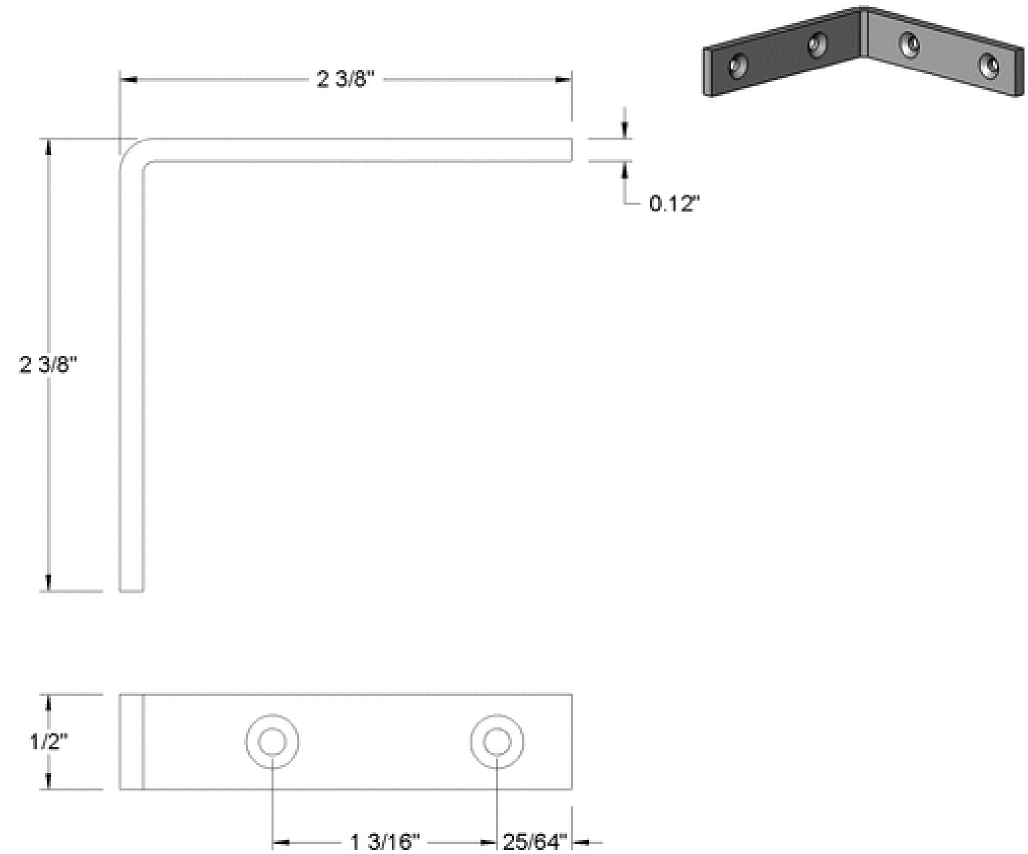
In stock
1-49 Each $8.10
50 or more $6.14
19155A38



Material	Polished Type 304 Stainless Steel—NSF Certified
Length (A1), (A2)	2 3/8"
Width (B)	1/2"
Thickness	0.12"
Screw/Nail Size	No. 6
Number of Holes	4

Also known as angle brackets, corner brackets, and mending plates, these brackets support corners and joints. They do not include mounting fasteners, except Style 2 stainless steel brackets.

Note: Prices are approximately 25% lower when you buy 50 or more of the same bracket.



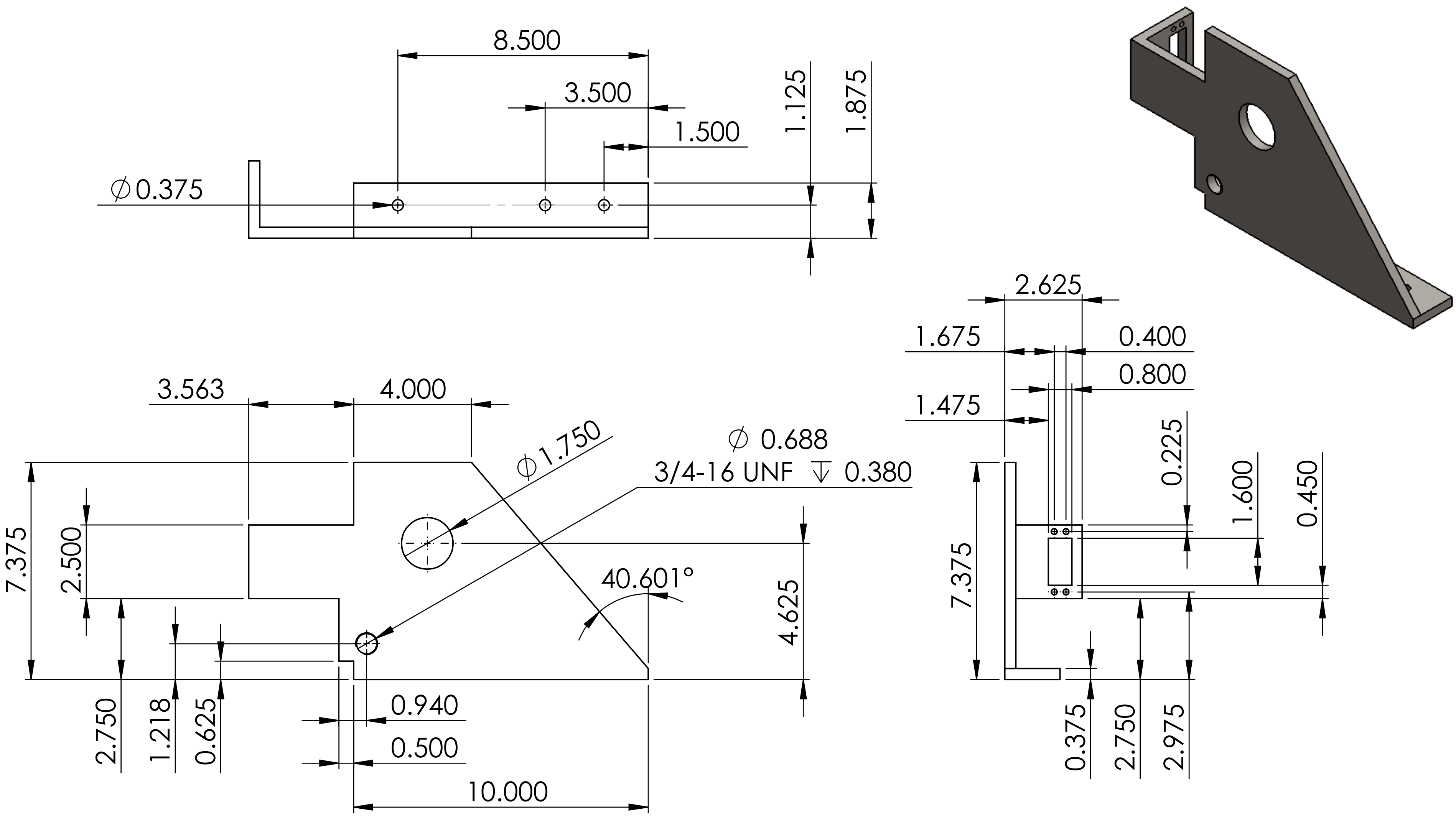
Bracket has 4 holes.
Bracket uses No. 6 screws.

McMASTER-CARR® CAD

http://www.mcmaster.com

PART NUMBER 19155A38

Bracket



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
A36 STEEL

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1) PLATE STEEL IS 3/8 INCHES THICK

Cookie Dough Engineering

TITLE:

Right Funnel
Support Bracket

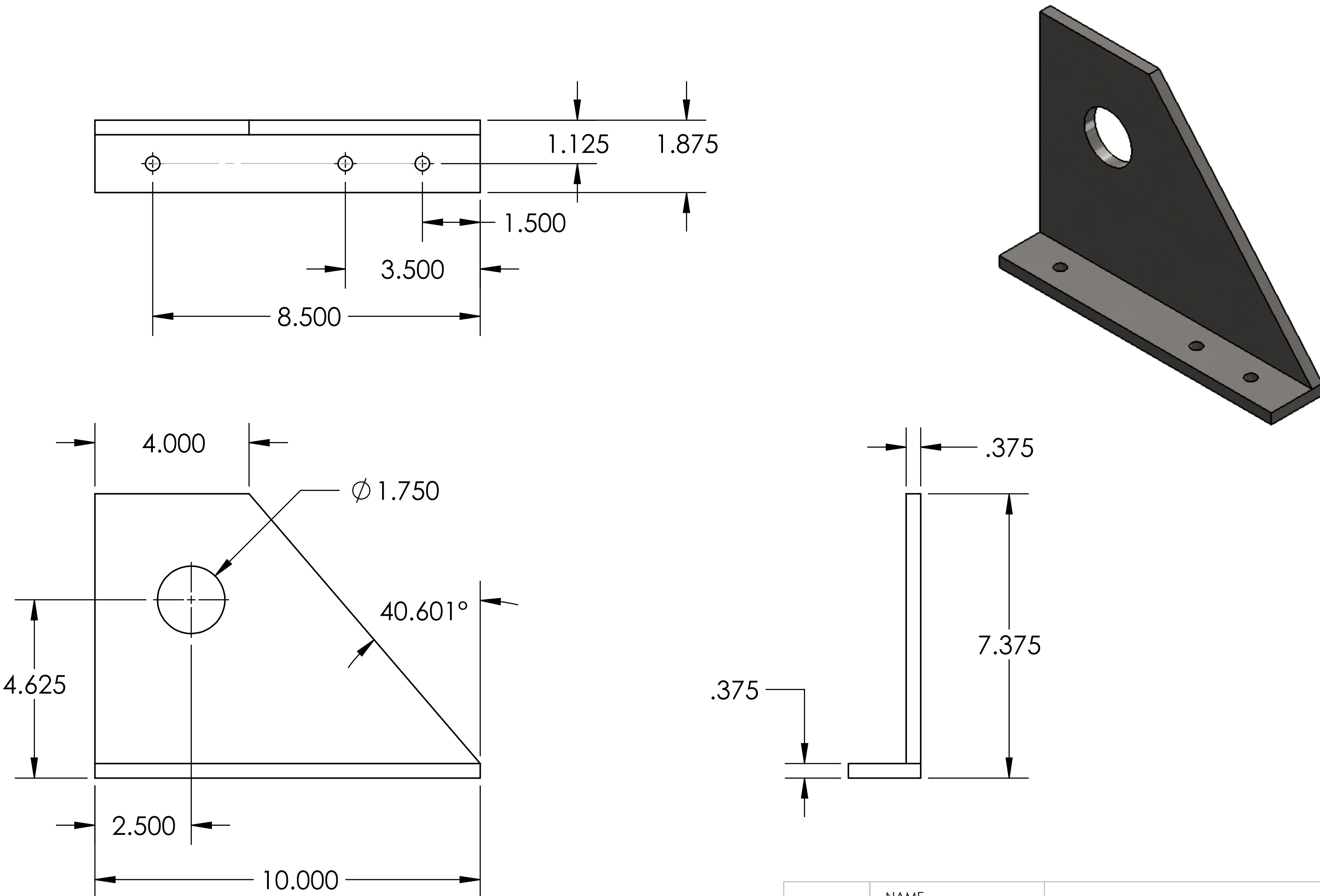
DWG. NO. 404

REV A

SCALE: 1:5

DATE: 02/10/2015

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
A36 STEEL

Cookie Dough Engineering

TITLE:
Left Funnel Support Bracket

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

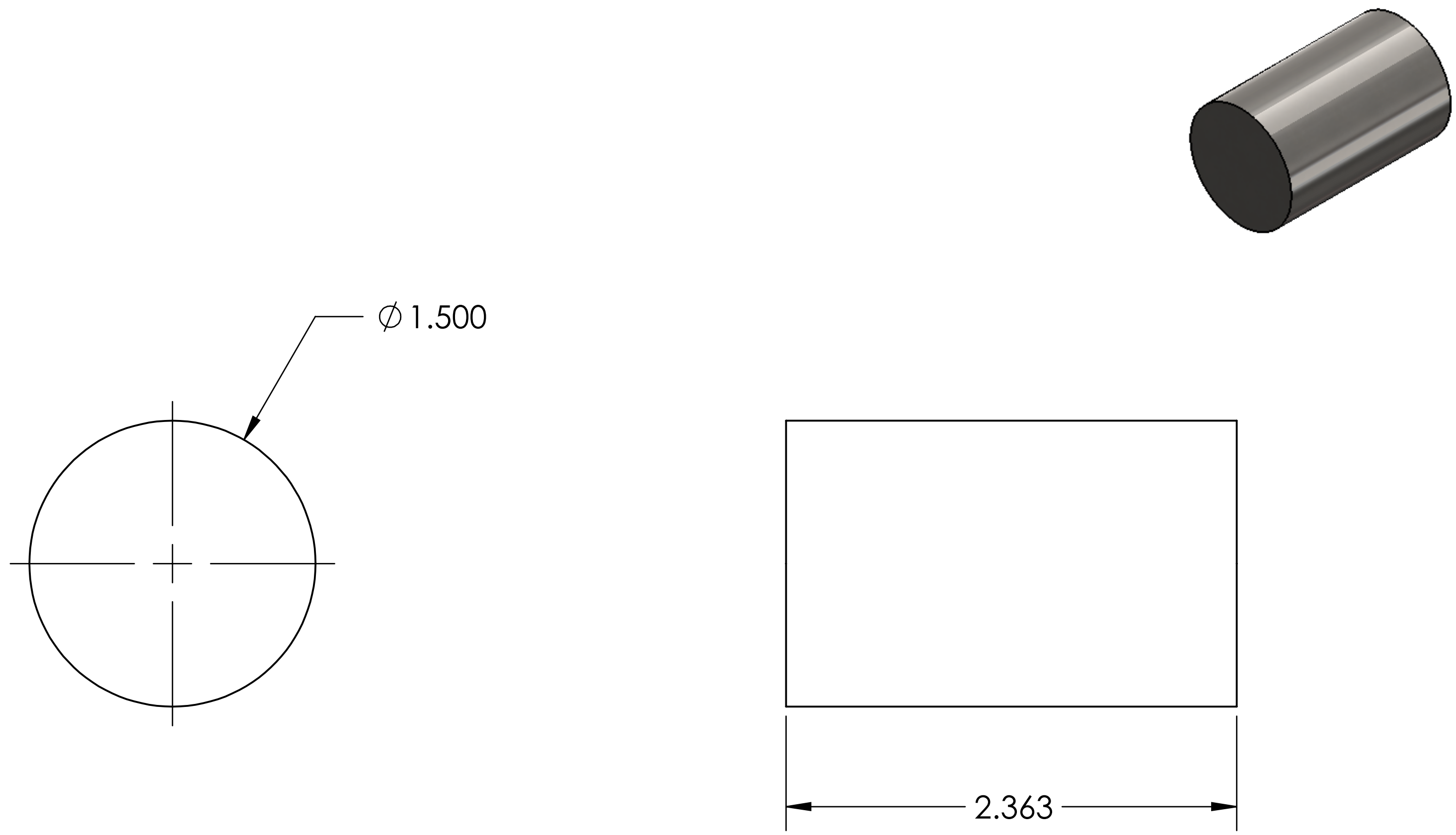
TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1) PLATE STEEL IN 3/8 IN THICKNESS

DWG. NO.	REV
405	A

SCALE: 1:1 | DATE: 02/10/2015

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR
MATERIAL:	A36 STEEL
COMMENTS:	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

Cookie Dough Engineering

TITLE:

Rod

DWG. NO.	REV
406	A
SCALE: 1:1	DATE: 02/10/2015

(562) 692-5911
(562) 695-2323 (fax)
la.sales@mcmaster.com
Text 75930

Food Grade SAE 863 Bronze Flanged Sleeve Bearing

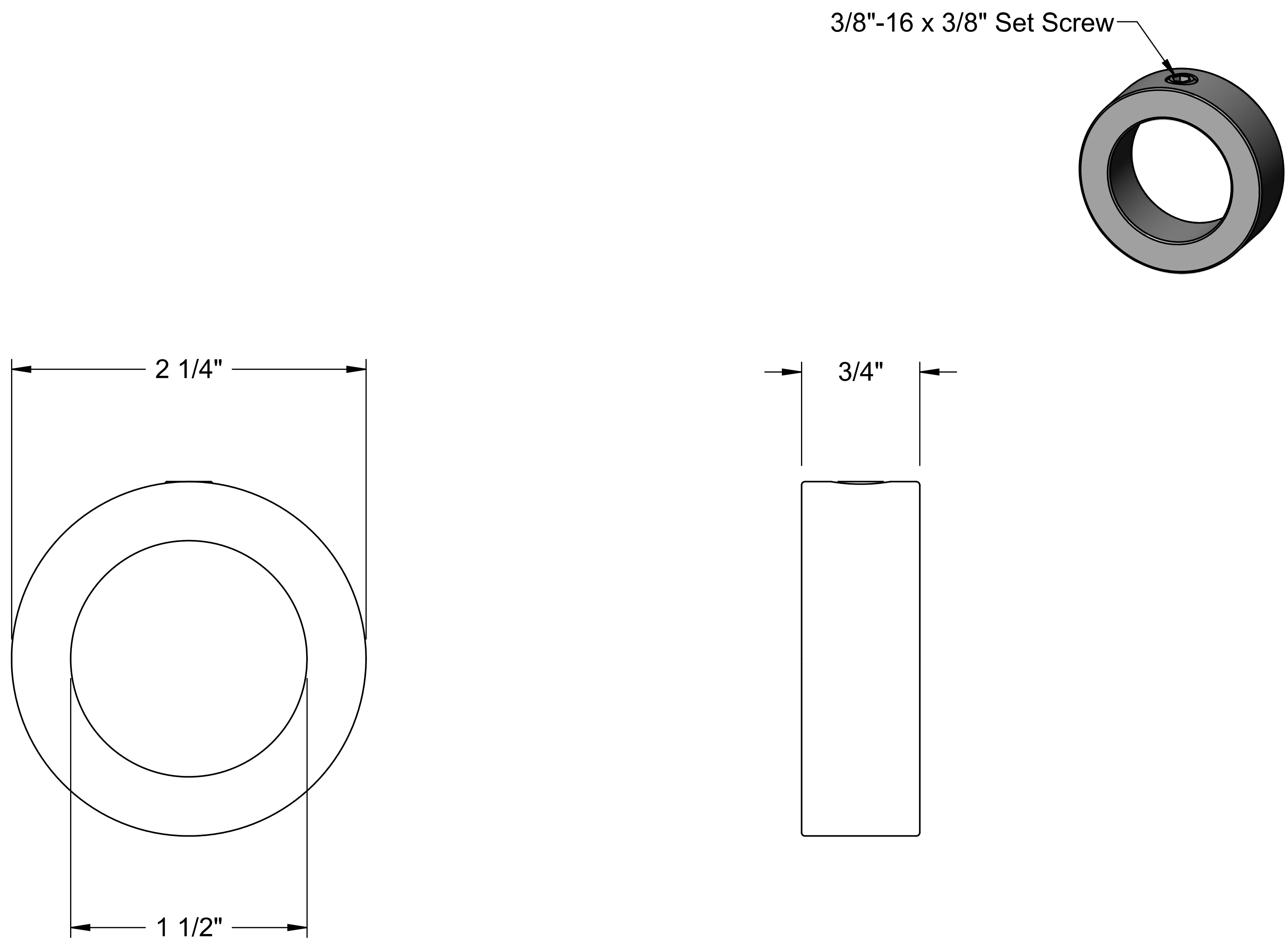
for 1-1/2" Shaft Diameter, 1-3/4" OD, 1-1/2" Length

In stock
$20.38 Each
3083K35

For Shaft Diameter	1 1/2"
OD	1 3/4"
Length	1 1/2"
Flange	
OD	2"
Thickness	3/16"
Material	SAE 863 Bronze
Temperature Range	-30° to 350° F
P Maximum	4,000
V Maximum	225
PV Maximum	35,000
For Shaft Diameter Tolerance	+0.002" to +0.004"
OD Tolerance	+0.003" to +0.005"
Length Tolerance	-0.0100" to +0.0100"
RoHS	Compliant

Impregnated with oil that meets USDA H-1, these self-lubricating bearings are perfect for applications with incidental food contact.

SAE 863—Also called Super Oilite® Non-Tox®, this material is similar to SAE 841 but contains more iron for greater strength. Note: Color is silver because of the iron.



McMASTER-CARR® CAD	PART NUMBER	9946K33
http://www.mcmaster.com	Set Screw Shaft Collar	

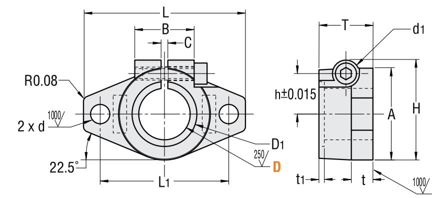
Shaft Supports –Cast–

The precision Cast Shaft Supports are made from steel, stainless steel or aluminum, and are post-process machined on the bores to provide high precision tolerances.

■ Flange Mount

Material	Surface Treatment	Included Hardware & Material	Type
1045 Steel	Black Oxide	Steel S.H.C.S. (1 Piece)	U-SHFT
Aluminum Casting Alloy 514.0	Clear Anodizing	Stainless Steel S.H.C.S. (1 Piece)	U-SHF
304 Stainless Steel	-		U-SHFSS

Material Characteristics P.628, 629



General Tolerance
Unless otherwise specified use the table below.

From	To	Tolerance
0.000	5.000	±0.01
5.001	16.000	±0.02
16.001	60.000	±0.05

Thread or hole location tolerance: ±0.005" non-cumulative.

Surface Roughness: Unless otherwise specified 1000

Type	Part No. D Callout	Nominal	Tolerance		$ Unit Price (Qty. 1~9) U-SHFT	U-SHF	U-SHFSS
U-SHFT U-SHF U-SHFSS	0.38	3/8	0.3756	0.3750	11.00	11.10	16.50
	0.50	1/2	0.5007	0.5000	11.00	11.10	16.50
	0.63	5/8	0.6257	0.6250	11.20	11.50	17.00
	0.75	3/4	0.7508	0.7500	12.00	12.50	18.50
	1.00	1"	1.0008	1.0000	14.10	14.40	21.50
	1.50	1-1/2	1.5010	1.5000	-	21.40	-

Order Example

Part No.	
Type	D
U-SHFT	0.38

Technical Information

D	L	T	t	H	A	L1	d Dia.	d Compatible Bolt	d1	D1	t1	B	C	h	Included Bolt Size
0.38	1.69	0.39	0.20	0.94	0.79	1.250	0.180	#8	0.35	0.47	0.06	0.71	0.08	0.374	#8-32
0.50	1.85	0.51	0.28	1.10	0.98	1.438	0.206	#10	0.35	0.63	0.06	0.71	0.10	0.433	#8-32
0.63	1.97	0.63	0.31	1.22	1.10	1.563	0.206	#10	0.35	0.79	0.08	0.71	0.10	0.492	#8-32
0.75	2.36	0.79	0.31	1.46	1.34	1.875	0.281	1/4	0.39	0.94	0.08	0.87	0.10	0.591	#10-32
1.00	2.76	0.98	0.39	1.65	1.57	2.188	0.281	1/4	0.39	1.18	0.08	0.87	0.10	0.669	#10-32
1.50	4.02	1.57	0.63	2.64	2.20	3.125	0.406	3/8	0.71	1.77	0.12	0.87	0.10	1.181	3/8-16

Days to Ship: 1 Day

Price

■ Quantity Discount Rate

Quantity	1~9	10~19	20~49	50~
Rate	—	2%	3%	5%

For larger quantity orders "Days to Ship" may differ from published catalog term. P.29

Shaft Supports –Base Mount–

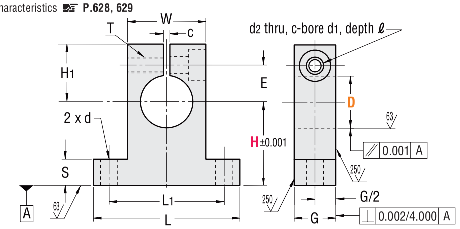
The Base Mount Shaft Supports are suitable for applications requiring free-standing linear shaft installations. Various mounting options are available to choose from.

■ Slit

Material	Surface Treatment	Included Hardware & Material	Type
1045 Steel	Electroless Nickel Plating	Stainless Steel S.H.C.S. (1 Piece)	U-SHSTM
304 Stainless Steel	-		U-SHSTS
6061-T6 Aluminum	Clear Anodizing		U-SHSTA

Material Characteristics P.628, 629

The slit is manufactured after the hole D is bored at indicated tolerance. The tolerance may vary slightly depending on the machining condition.



General Tolerance
Unless otherwise specified use the table below.

From	To	Tolerance
0.000	5.000	±0.01
5.001	16.000	±0.02
16.001	60.000	±0.05

Thread or hole location tolerance: ±0.005" non-cumulative.

Surface Roughness: Unless otherwise specified 1000

Type	Part No. D Callout	Nominal	Tolerance		H Selection (Callout) 1/2	3/4	1"	1-1/4	1-1/2	1-3/4	2"	2-1/2	$ Unit Price (Qty. 1~4) U-SHSTM	U-SHSTS	U-SHSTA
U-SHSTM U-SHSTS U-SHSTA	0.25	1/4	0.2506	0.2500	0.50	0.75							12.60	26.00	12.20
	0.38	3/8	0.3756	0.3750		0.75	1.00						13.50	35.80	13.50
	0.50	1/2	0.5007	0.5000		0.75	1.00						14.00	39.50	14.40
	0.63	5/8	0.6257	0.6250			1.00	1.25					16.20	43.00	16.20
	0.75	3/4	0.7508	0.7500				1.25	1.50				22.50	58.00	19.80
	1.00	1"	1.0008	1.0000					1.50	1.75			24.30	59.50	22.50
	1.50	1-1/2	1.5010	1.5000							2.00	2.50	43.60	92.70	41.40

Order Example

Part No.		—	H
Type	D		

U-SHSTM 0.25 — H 0.75

Technical Information

H Callout	Nominal	Actual
0.50	1/2	0.500
0.75	3/4	0.750
1.00	1"	1.000
1.25	1-1/4	1.250
1.50	1-1/2	1.500
1.75	1-3/4	1.750
2.00	2"	2.000
2.50	2-1/2	2.500

D	L	H1	G	S	W	L1	d Dia.	d Compatible Bolt	E	T (Thread) Size	T (Thread) Major Dia.	d2	d1	ℓ	C
0.25	1.00	0.391	0.250	0.16	0.41	0.688	0.141	#5	0.250	#4-40	0.112	0.125	0.219	0.125	0.059
0.38	1.25	0.516	0.375	0.25	0.56	0.938	0.180	#8	0.344	#6-32	0.138	0.154	0.281	0.154	0.079
0.50	1.44	0.594	0.500	0.25	0.75	1.125	0.180	#8	0.391	#8-32	0.164	0.180	0.313	0.180	0.079
0.63	1.75	0.688	0.500	0.31	0.94	1.375	0.206	#10	0.438	#10-32	0.190	0.206	0.375	0.206	0.079
0.75	2.00	0.750	0.625	0.31	1.13	1.563	0.206	#10	0.531	#10-32	0.190	0.206	0.375	0.206	0.079
1.00	2.50	1.000	0.625	0.38	1.50	2.000	0.281	1/4	0.719	1/4-20	0.250	0.281	0.438	0.281	0.079
1.50	3.38	1.375	0.750	0.50	2.13	2.750	0.344	5/16	1.063	5/16-18	0.313	0.344	0.531	0.344	0.118

Days to Ship: 1 Day

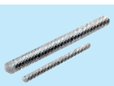
Price

■ Quantity Discount Rate

Quantity	1~4	5~19	20~49	50~
Rate	—	2%	3%	5%

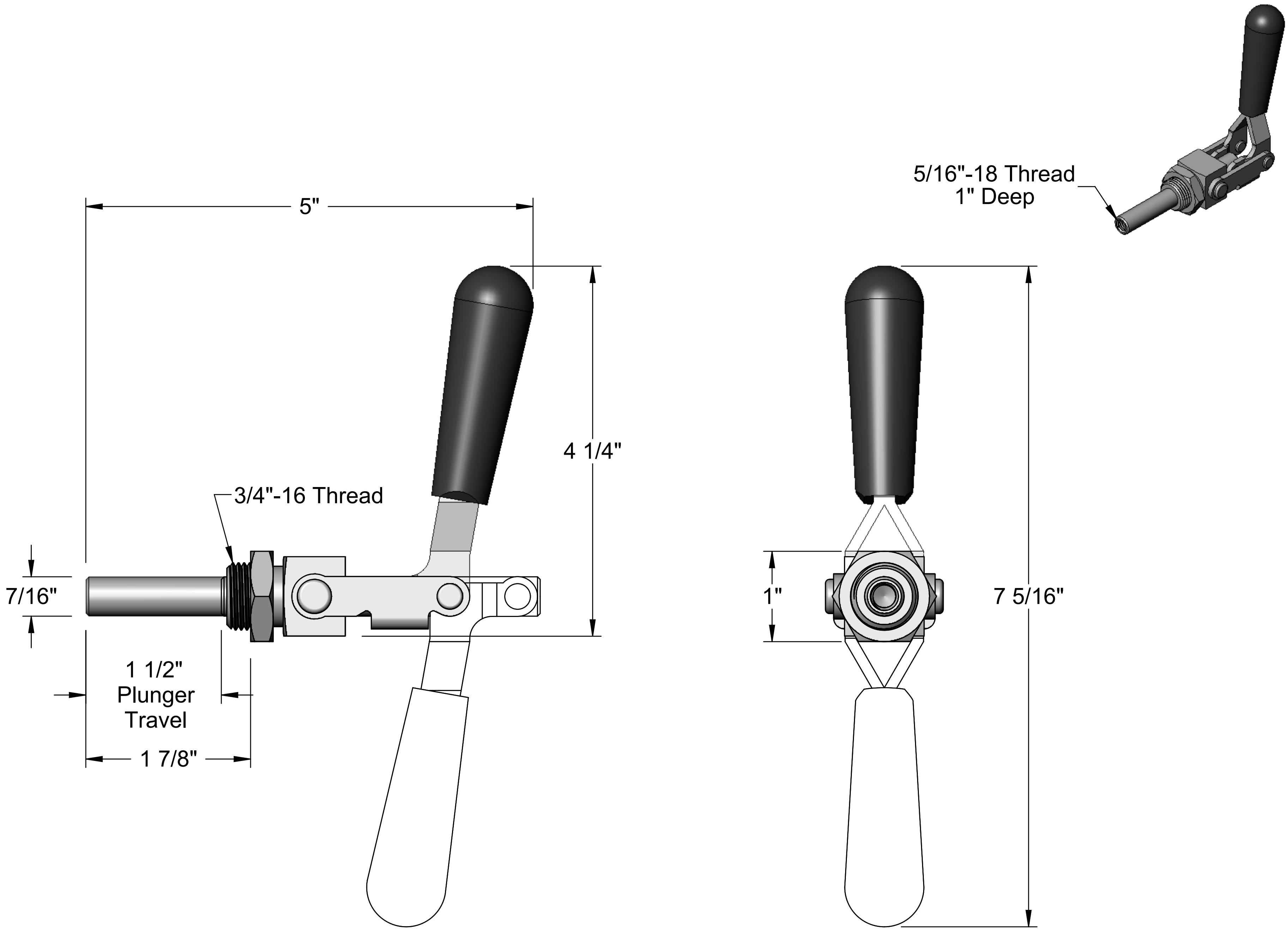
For larger quantity orders "Days to Ship" may differ from published catalog term. P.29

Related Components

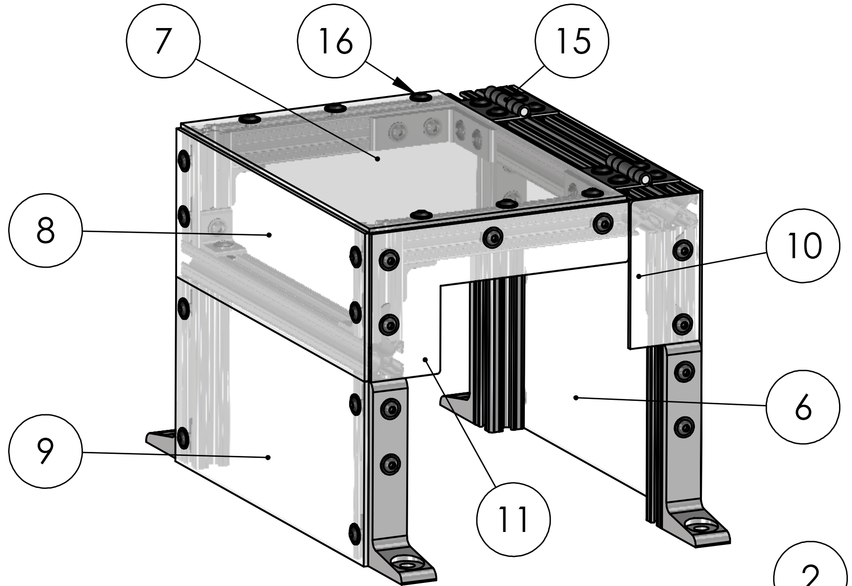


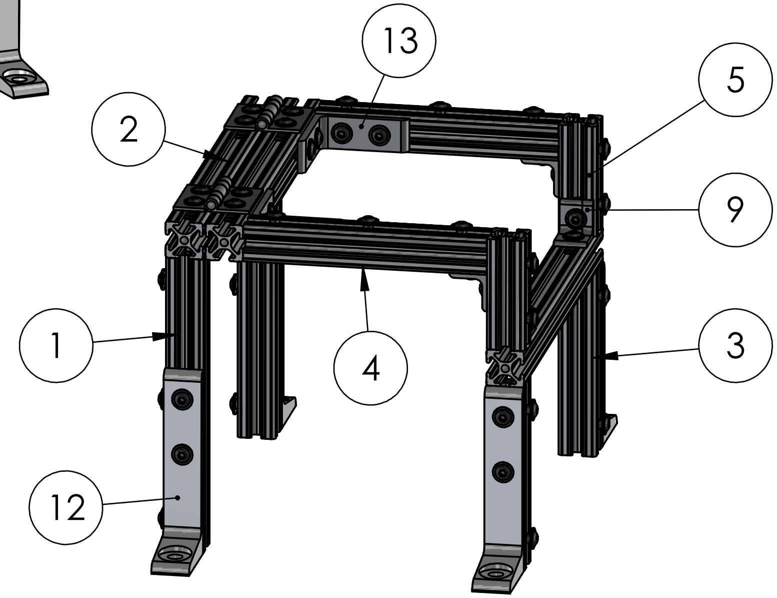
Linear Shafts
P.39

Linear Bushings
P.77



McMASTER-CARR® CAD	PART NUMBER	5093A63
http://www.mcmaster.com © 2013 McMaster-Carr Supply Company Information in this drawing is provided for reference only.	Push/Pull-Action Toggle Clamp	





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	501	T-Slot Extrusion	2
2	502	T-Slot Extrusion	3
3	503	T-Slot Extrusion	2
4	504	T-Slot Extrusion	2
5	505	T-Slot Extrusion	2
6	506	Acrylic Sheet	1
7	507	Acrylic Sheet	1
8	508	Acrylic Sheet	1
9	509	Acrylic Sheet	1
10	510	Acrylic Sheet	1
11	511	Acrylic Sheet	1
12	512	Floor Mount	4
13	513	4-Hole Corner Bracket	2
14	514	2-Hole Corner Bracket	4
15	515	T-Slot Hinges	2
15	516	Fasteners	34

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
VARIOUS

COMMENTS:
ALL T-SLOT COMPONENTS (NON-ACRYLIC) ARE TO BE PURCHASED FROM FUTURA INDUSTRIES

Cookie Dough Engineering

TITLE:

Safety Cage Assembly

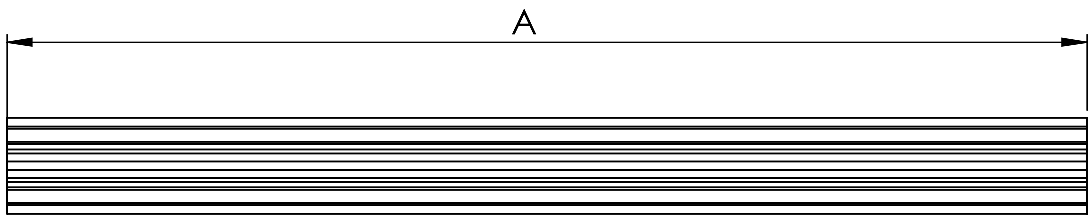
DWG. NO. 500

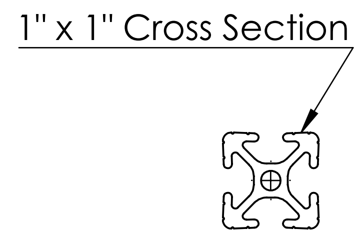
REV A

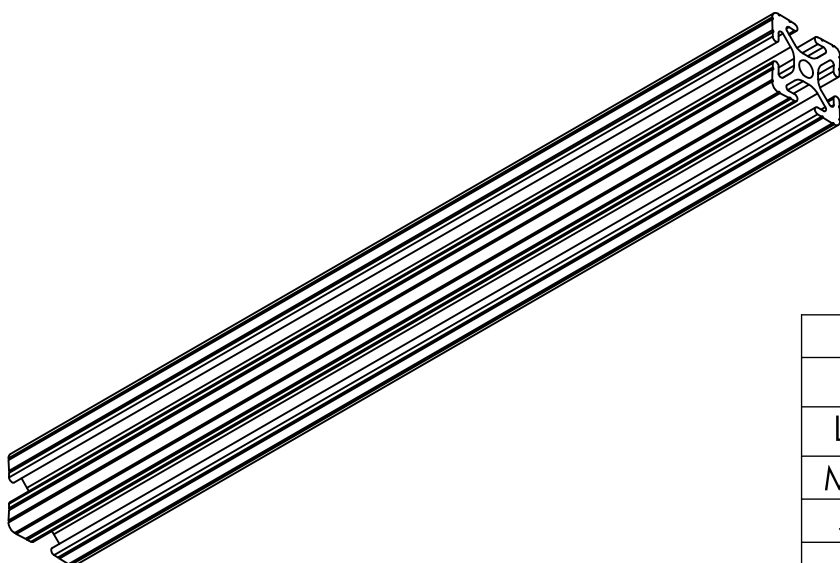
SCALE: 1:10

DATE: 02/10/2015

5 4 3 2 1







PART NAME	PART NUMBER	DIM 'A'	QTY.
Long Vertical Frame	501	8	2
Long Horizontal Frame	502	11.25	3
Medium Vertical Frame	503	5	2
Short Hoizontal Frame	504	6.45	2
Short Vertical Frame	505	3	2

	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
T-Slot Aluminum

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:

Cookie Dough Engineering

TITLE:

T-Slot Extrusions

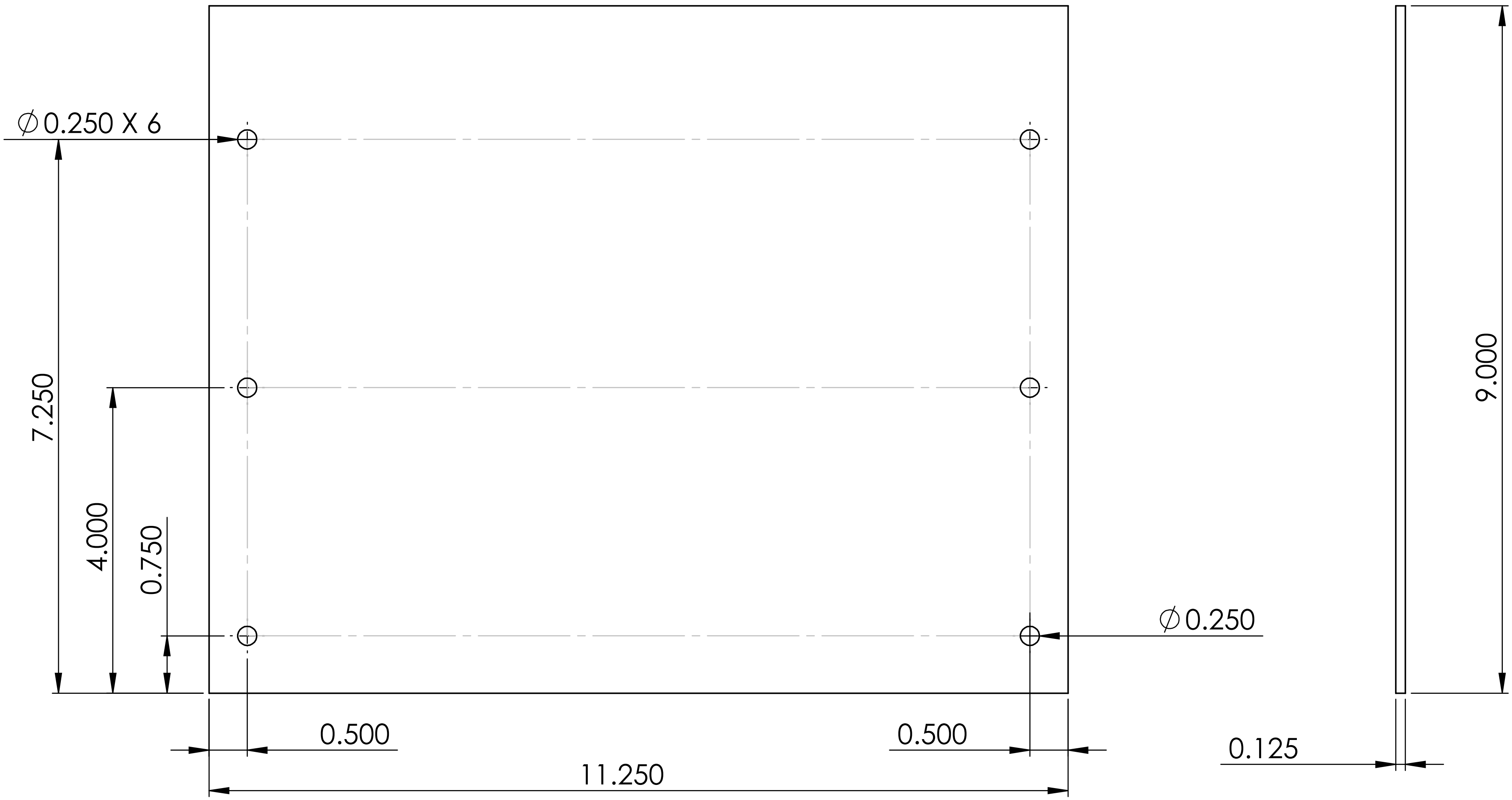
DWG. NO. Various

REV A

SCALE: 1:5

DATE: 02/10/2015

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
ACRYLIC

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1) ALL HOLES ARE 1/4 INCH

Cookie Dough Engineering

TITLE:
Acrylic Sheet

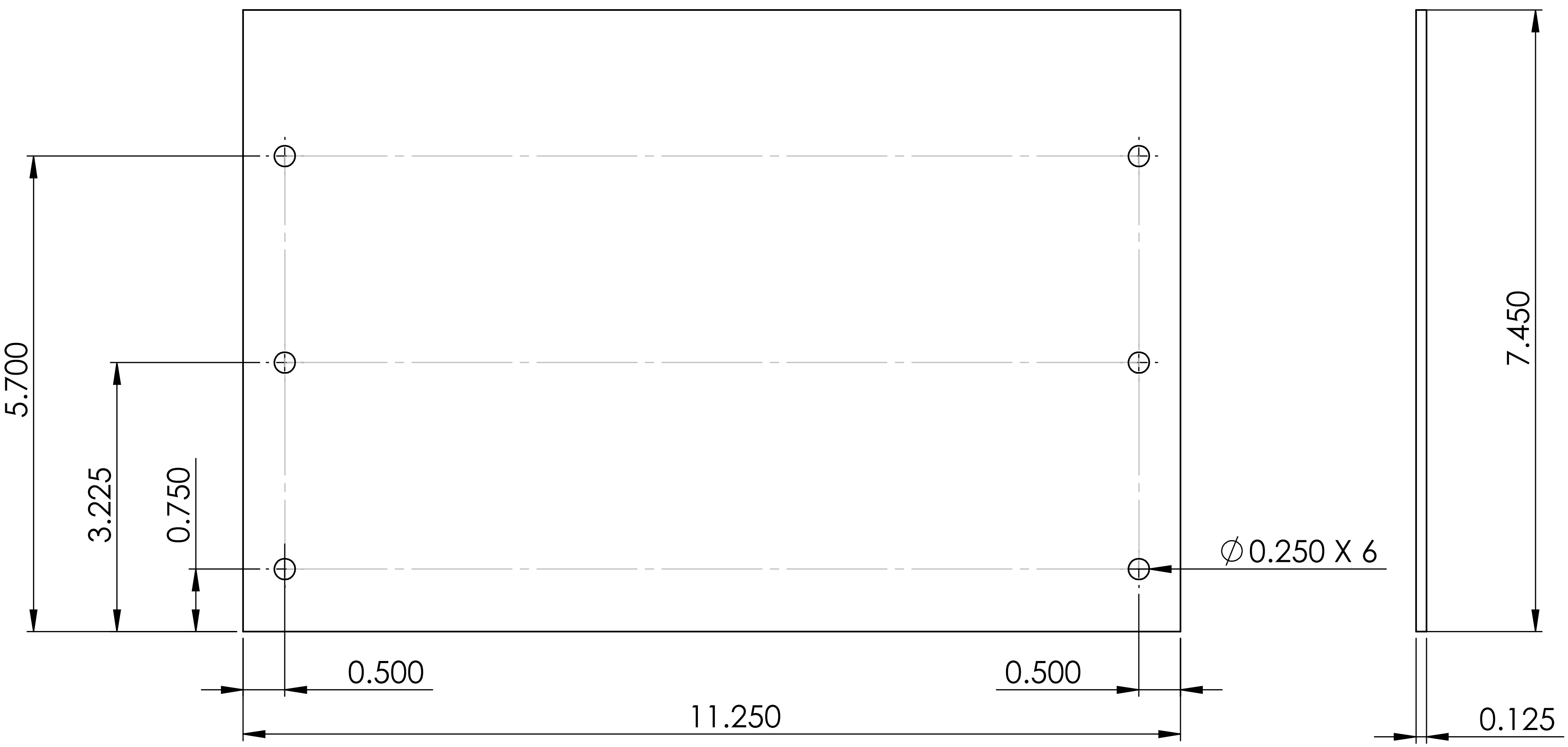
DWG. NO. 506

REV A

SCALE: 1:5

DATE: 02/10/2015

5 4 3 2 1



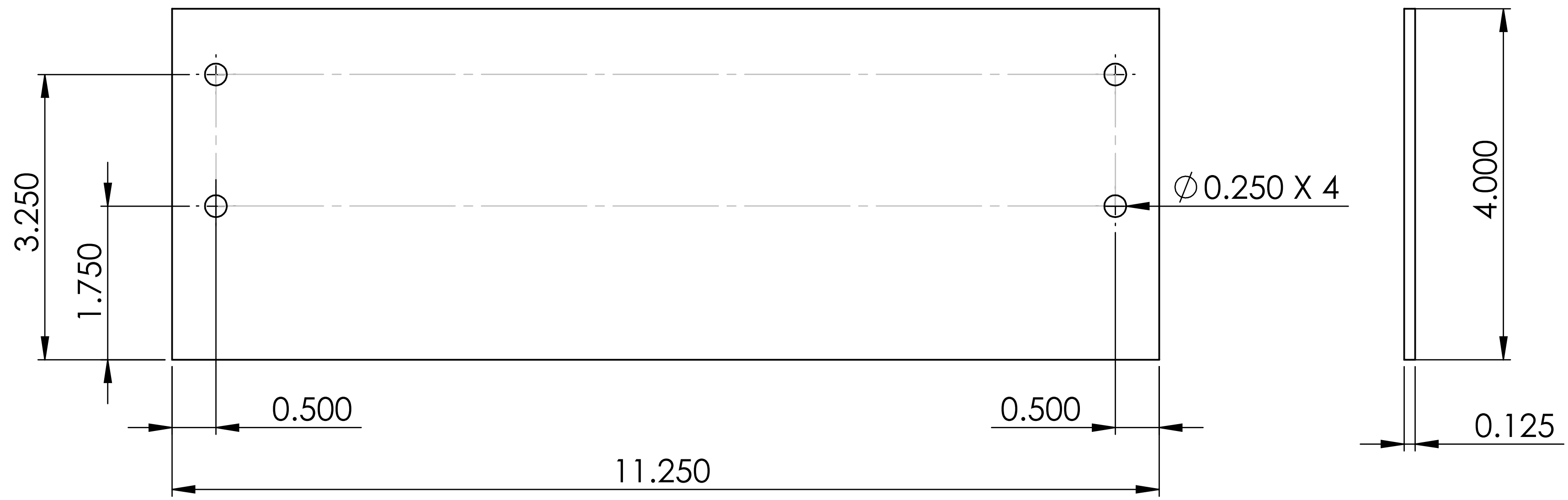
	NAME	Cookie Dough Engineering
DRAWN	GRANT WITTENBERG	
CHECKED	ALEX HAUGHTON	TITLE:
TO	CDR	Acrylic Sheet
MATERIAL: ACRYLIC		
COMMENTS: 1) ALL HOLES ARE 1/4 INCH		DWG. NO. 507 — REV A
		SCALE: 1:5 — DATE: 02/10/2015

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
ACRYLIC

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1) ALL HOLES ARE 1/4 INCH

Cookie Dough Engineering

TITLE:

Acrylic Sheet

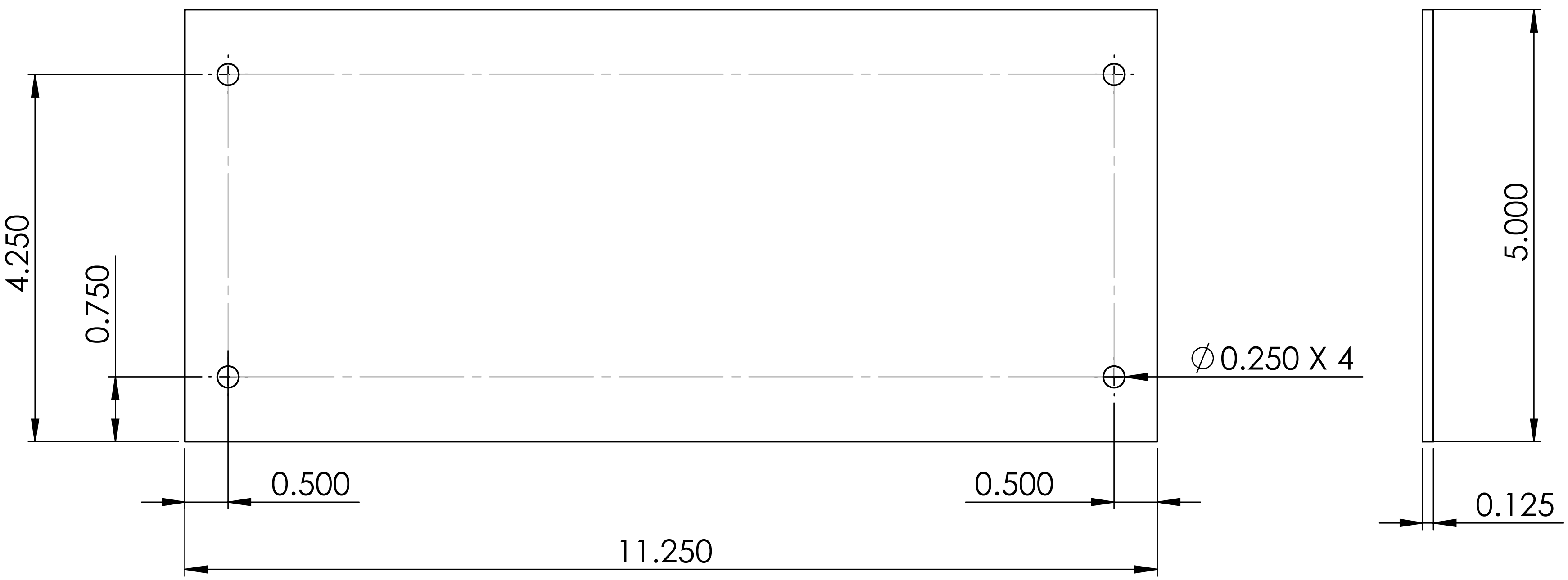
DWG. NO. 508

REV A

SCALE: 1:5

DATE: 02/10/2015

5 4 3 2 1



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR
MATERIAL:	ACRYLIC

Cookie Dough Engineering

TITLE:

Acrylic Sheet

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1) ALL HOLES ARE 1/4 INCH

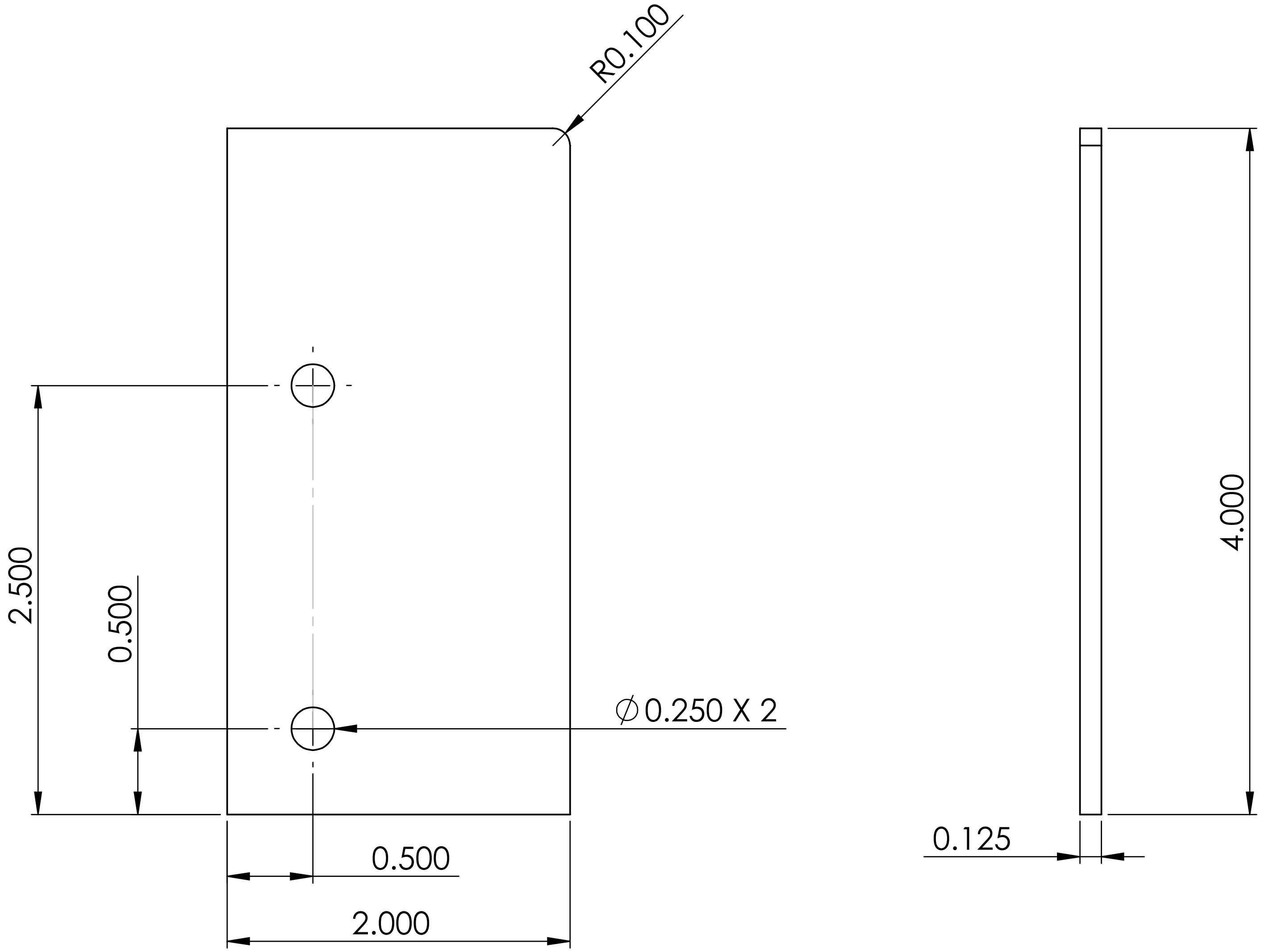
DWG. NO. 509

REV A

SCALE: 1:5

DATE: 02/10/2015

5 4 3 2 1



Cookie Dough Engineering

	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR

MATERIAL:
ACRYLIC

TITLE:

Acrylic Sheet

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

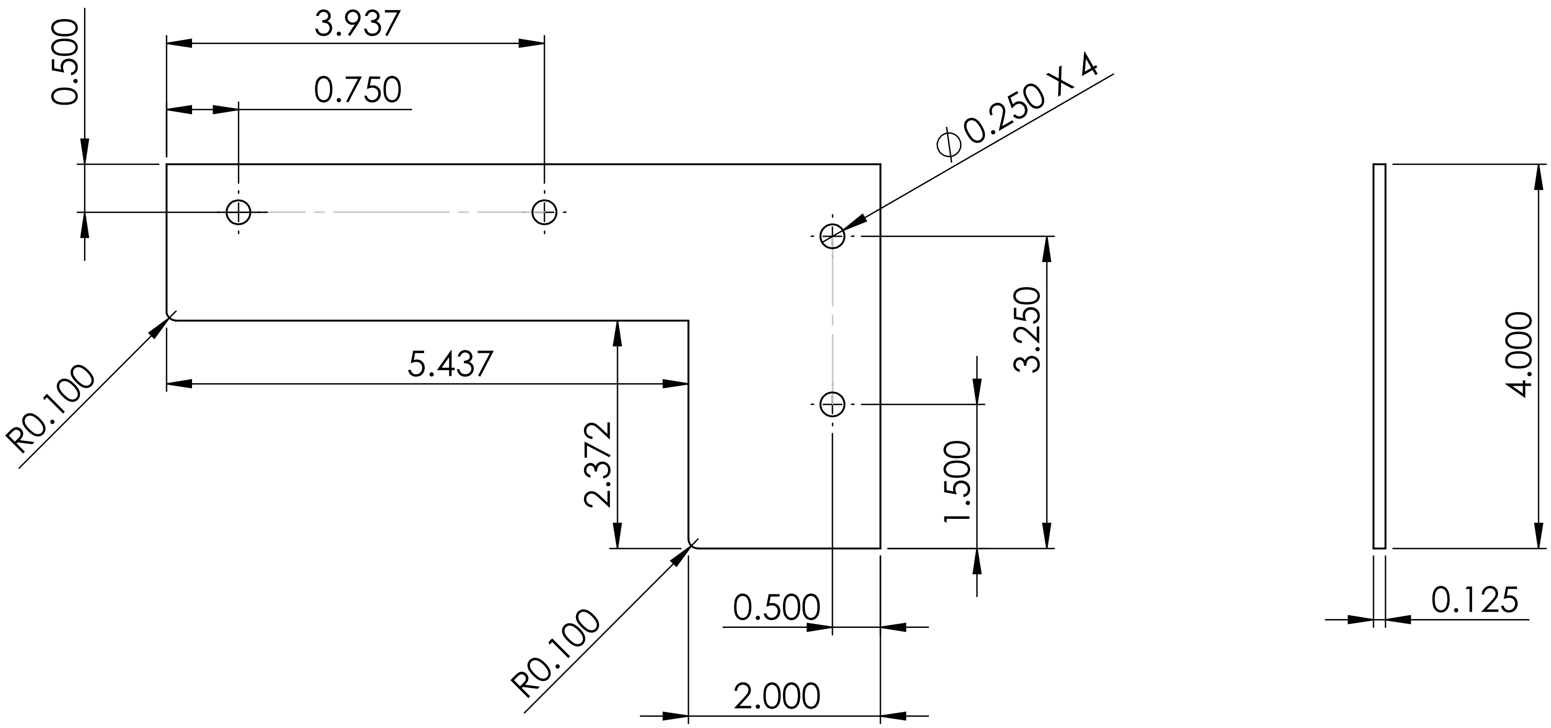
COMMENTS:
ALL HOLES ARE 1/4 INCH

DWG. NO. 510

REV A

SCALE: 1:1

DATE: 02/10/2015



	NAME
DRAWN	GRANT WITTENBERG
CHECKED	ALEX HAUGHTON
TO	CDR
MATERIAL:	ACRYLIC

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES

TOLERANCES: ± .05
HOLE LOCATIONS: ± 0.005

COMMENTS:
1) ALL HOLES ARE 1/4 INCH

Cookie Dough Engineering

TITLE:

Acrylic Sheet

DWG. NO. 511

REV A

SCALE: 1:2

DATE: 02/10/2015

5 4 3 2 1

BASE PLATES - FLOOR MOUNT 10 SERIES ECONOMY 10S 25S


655275

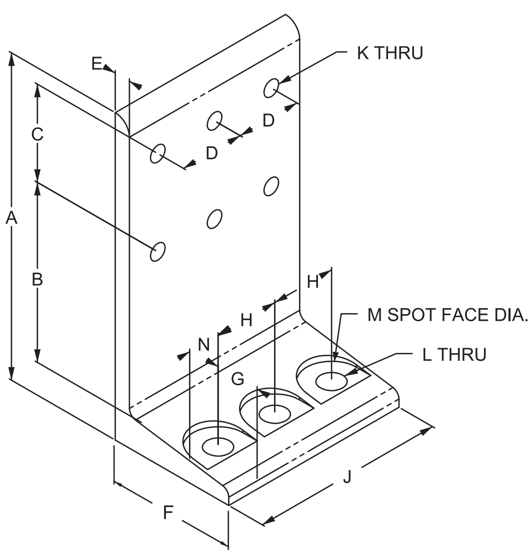

655277


655272

ITEM #	DESCRIPTION	BOLT KIT TO MOUNT TO TSLOT
655275	10 S 1" Economy Floor Mount Base Plate	(2) 651130
655277	10 S 2" Economy Floor Mount Base Plate	(4) 651130
655272	10 S 3" Economy Floor Mount Base Plate	(6) 651130

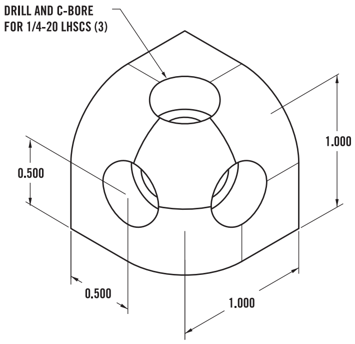
- *Strong economy base plates*
- *Bolts directly in the T-Slot*
- *Allows vertical adjustments*
- *More economical than standard Floor Mount Base Plate*

ITEM #	655275	655277	655272
A	5.00	5.00	5.00
B	2.75	2.75	2.75
C	1.50	1.50	1.50
D	N/A	1.00	1.00
E	.250	.250	.250
F	2.00	2.00	2.00
G	.688	.688	.688
H	N/A	1.00	1.00
J	1.00	2.00	3.00
K	.257	.257	.257
L	.390	.390	.390
M	.875	.875	.875
N	.500	.500	.500
LBS	.175	.350	.525



10 SERIES - Rounded Tri Corner

Item Number: **653034**



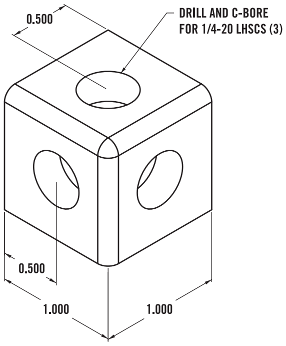
RECOMMENDED FASTENERS

QTY	DESCRIPTION	PART#
3	1/4 - 20 x 1" LHSCS	651003

» Tap service required. See page 11:06.

10 SERIES - Square Tri Corner

Item Number: **653035**



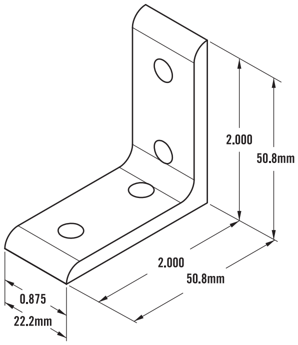
RECOMMENDED FASTENERS

QTY	DESCRIPTION	PART#
3	1/4 - 20 x 1" LHSCS	651003

» Tap service required. See page 11:06.

10 SERIES / 25 SERIES - 4 Hole Inside Corner Bracket

Item Number: **653052**



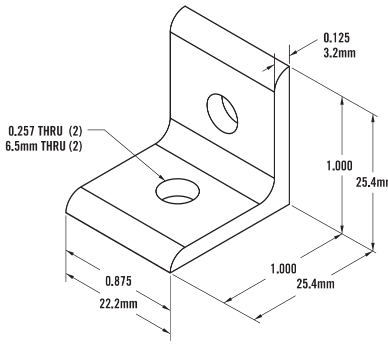
RECOMMENDED FASTENERS

QTY	DESCRIPTION	PART#
4	1/4 - 20 x 1/2" BHSCS & Economy T-Nut	651171
or 2	1/4 - 20 x 1/2" BHSCS & Double Economy T-Nut	651490
4	M6 x 12mm BHSCS & Economy T-Nut	651503
or 2	M6 x 12mm BHSCS & Double Economy T-Nut	651519

TSLOTS Brackets

10 SERIES / 25 SERIES - 1/8" 2 Hole Inside Corner Bracket

Item Number: **653047**

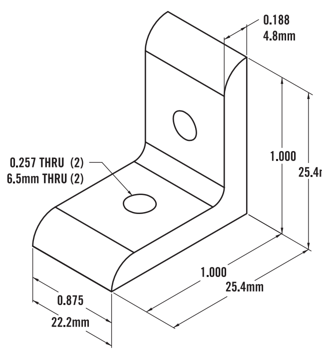


RECOMMENDED FASTENERS

QTY	DESCRIPTION	PART#
2	1/4 - 20 x 3/8" FBHSCS & Economy T-Nut	651166
2	M6 x 12mm BHSCS & Economy T-Nut	651503

10 SERIES / 25 SERIES - 3/16" 2 Hole Inside Corner Bracket

Item Number: **653056**

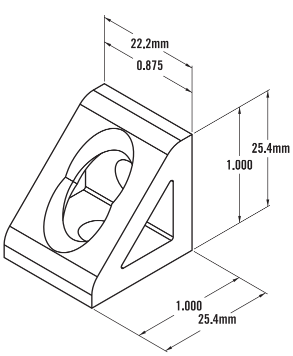


RECOMMENDED FASTENERS

QTY	DESCRIPTION	PART#
2	1/4 - 20 x 1/2" BHSCS & Economy T-Nut	651171
2	M6 x 12mm BHSCS & Economy T-Nut	651503

10 SERIES / 25 SERIES - 2 Hole Inside Corner Gusset

Item Number: **653069**

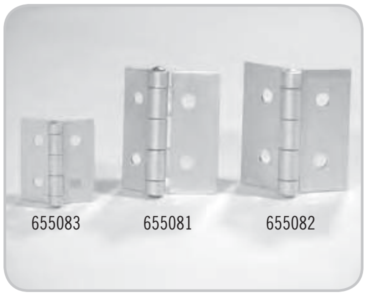


RECOMMENDED FASTENERS

QTY	DESCRIPTION	PART#
2	1/4 - 20 x 1/2" BHSCS & Economy T-Nut	651171
2	M6 x 12mm BHSCS & Economy T-Nut	651503

Extrusion Profiles available in stocked lengths. See Section 10 - Extrusion Profiles.

ALUMINUM HINGE

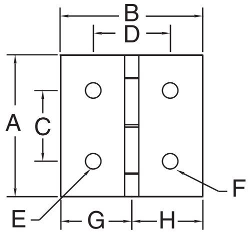


ITEM #	DESCRIPTION
655083	10 S Aluminum Hinge 10S 25S
655081	10 To 15 S Aluminum Transition Hinge
655082	15 S Aluminum Hinge 15S 40S

RECOMMENDED BOLT ASSEMBLY

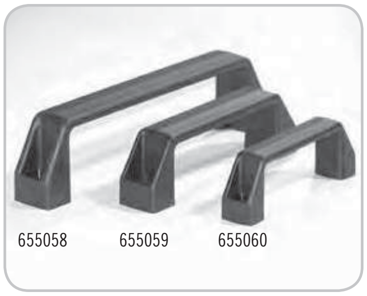
QTY	ITEM #
4	(4) 651166 (For #655083)
4	(2) 651166 & (2) 651128 (For #655081)
4	(4) 651128 (For #655082)

- *Mount heavier doors*
  - *10 Series – 40 lb. capacity*
  - *15 Series – 75 lb. capacity*
- *Hinges TSLOTS extrusions together*
- *Low profile mounts to T-Slot*
- *Clear anodize finish matches TSLOTS finish*



ITEM #	CAPACITY	A	B	C	D	E	F	G	H
655083	40 lbs	2.00	2.00	1.00	1.063	.257(4)	N/A	1.00	1.00
655081	75 lbs	3.00	2.50	1.50	1.375	.328(2)	.257(2)	1.50	1.00
655082	75 lbs	3.00	3.00	1.50	1.625	.328(4)	N/A	1.50	1.50

DOOR HANDLES

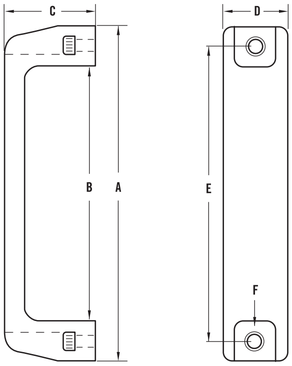


ITEM #	DESCRIPTION
655058	15 S Large Plastic Door Handle-Black 15S 40S
655059	15 S Medium Plastic Door Handle-Black 15S 40S
655060	10 S Small Plastic Door Handle-Black 10S 25S

RECOMMENDED BOLT ASSEMBLY

QTY	ITEM #
2	651234 (For Handle Item #655060)
2	651202 (For Handle Item #655059)
2	651202 (For Handle Item #655058)

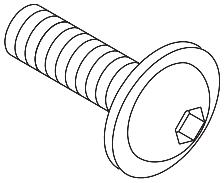
- *Mounts directly in T-Slot or machined panel*
- *Made of black nylon*
- *10 and 15 Series sizes*



ITEM #	SERIES	A	B	C	D	E	F
655060	10 S	4.30	2.90	1.40	.82	3.60	1/4" SHCS (2)
655059	15 S	5.37	3.73	1.62	1.03	4.50	5/16" SHCS (2)
655058	15 S	7.81	5.93	2.00	1.18	6.97	5/16" SHCS (2)

10S *10 Series Compatible* 15S *15 Series Compatible* 25S *25 Series Compatible* 40S *40 Series Compatible*

FLANGED BUTTON HEAD SOCKET CAP SCREWS & ASSEMBLIES



ITEM #	DESCRIPTION
651169	1/4-20 x 3/8" Flanged BHSCS
651136	1/4-20 x 1/2" Flanged BHSCS
651026	1/4-20 x 3/4" Flanged BHSCS
651134	5/16-18 x 11/16" Flanged BHSCS
651135	5/16-18 x 1/2" Flanged BHSCS
651634	5/16-18 x 11/16" Flanged BHSCS w/Loctite

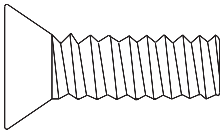
10 SERIES ASSEMBLIES

ITEM #	DESCRIPTION
651002	1/4-20 x 3/8" FBHSCS w/ Washer & Hex Nut
651166	1/4-20 x 3/8" FBHSCS & Economy T-Nut
651130	1/4-20 x 1/2" FBHSCS & Economy T-Nut
651224	1/4-20 x 1/2" FBHSCS & Drop In T-Nut
651164	1/4-20 x 3/4" FBHSCS & Economy T-Nut
651228	1/4-20 x 3/4" FBHSCS & Drop In T-Nut
651142	1/4- 20 x 1/2" FBHSCS & Double Economy T-Nut
651144	1/4-20 x 1/2" FBHSCS & Triple Economy T-Nut

15 SERIES ASSEMBLIES

ITEM #	DESCRIPTION
651127	5/16-18 x 1/2" FBHSCS & Drop In T-Nut
651128	5/16-18 x 1/2" FBHSCS & Economy T-Nut
651129	5/16-18 x 11/16" FBHSCS & Economy T-Nut
651132	5/16-18 x 5/8" FBHSCS & Drop In T-Nut
651210	5/16-18 x 5/8" FBHSCS w/ Washer & Hex Nut
651141	5/16-18 x 11/16" FBHSCS & Double Econ. T-Nut
651143	5/16-18 x 11/16" FBHSCS & Triple Economy T-Nut

FLATHEAD SOCKET CAP SCREW & ASSEMBLIES



ITEM #	DESCRIPTION
651188	6-32 x 3/8" FHSCS - Black Zinc
651005	10-32 x 1/2" FHSCS
651179	10-32 x 1/2" FHSCS - Black Zinc
651178	1/4-20 x 1/2" FHSCS - Black Zinc
651180	1/4-20 x 5/8" FHSCS - Black Zinc
651181	5/16-18 x 5/8" FHSCS - Black Zinc
651182	5/16-18 x 3/4" FHSCS - Black Zinc
651187	3/8-16 x 3/4" FHSCS - Black Zinc
651515	M6 x 12 mm FHSCS
651516	M6 x 16 mm FHSCS
651549	M6 X 20 mm FHSCS
651517	M8 x 16 mm FHSCS
651518	M8 x 20 mm FHSCS

ASSEMBLIES

ITEM #	DESCRIPTION
651185	1/4-20 x 1/2" FHSCS & Economy T-Nut - 10 S
651183	5/16-18 x 5/8" FHSCS & Economy T-Nut
651545	1/4-20 x 5/8" FHSCS & Economy T-nut - 15 S

Appendix H: Safety Documentation

Table 13: Safety Hazard Awareness Chart detailing eliminated hazards

Description of Hazard	Corrective Actions to be Taken	Planned Completion Date	Actual Completion Date
Hands being caught between the plunger and the cylinder.	Design considerations will be taken to eliminate this hazard before construction.	January 30, 2015	February 12, 2015
Harm from rotary wire or blade.	Design considerations will be taken to eliminate this hazard before construction.	January 30, 2015	February 12, 2015
Electrocution from exposed wires.	Design considerations will be taken to eliminate this hazard before construction.	January 30, 2015	February 12, 2015
Explosion due to structural failure under high pressure.	Design considerations will be taken to eliminate this hazard before construction.	January 30, 2015	February 12, 2015
High speed dough projectile.	Design considerations will be taken to eliminate this hazard before construction.	January 30, 2015	February 12, 2015

Table 14: Most Current Failure Mode and Effect Analysis

Potential

Failure Mode and Effect Analysis

System Level FMEA		**The Shiny Dough Master 3000**		**FMEA Number:**	**2**
	Design Responsibility:	**Cookie Dough Engineering**		**Page 1 of 1**	
Model Year:	**2015**	**Key Date:**	**February 9th, 2014**	**Prepared By:**	**Alex Haughton**
Core Team:	**Alex Haughton, Courtney Shipp, Grant Wittenberg**			**FMEA Date (Orig.)**	**December 3rd, 2014**

									Action Results			
Item / Function	Potential Failure Mode	Potential Effect(s) of Failure	Severity	Potential Cause(s) / Mechanism(s) of Failure	Occurance	Criticality	Recommended Action(s)	Team Member and Date	Actions Taken	Severity	Occurance	Criticality
Tube, Funnel, and Plunger	Material Strength of	Tube Cracks and Leaks	7	Calculations of Tube Strength Incorrect	1	7				7	1	7
	Funnel and Tube Connection	Funnel Pops Off Tube; Dough Leaks	8	Funnel Connection Impropoerly Designed	1	8				8	1	8
	Plunger Does Not Seal Tube	Dough Leaks Back Through Tube, Jams	6	Seal Does Not Mate Properly With Tube Wall	3	18				6	3	18
Dough is Pushed By A Linear Motion	Dough Does Not Flow Through	No Dough Balls Are Formed; Could Cause	9	Not Enough Power in Linear Actuator	1	9				9	1	9
	Actuator and Plunger Fail To Mate Properly	Actuator Doesn't Push Plunger At All	8	Lack Of Inter System Design Between Plunger and Actuator	2	16				8	2	16
Cut Dough	Timing On Cutting Device Not	Dough Pieces Wrong Size	7	Actual Cutting Rate Fails to Match Calculated Rate	3	21	Once prototype built, measure ball size and adjust motor accordingly	Alex Haughton, 4/22/14	Adjust device as necessary to reduce or eliminate occurance	7	2	14
	Cutting Device Sticks, Or Is Unreliable On	Dough Pieces Are Different Sizes	7	Timing of Device Is Inconsistent	2	14				7	2	14
	Dough Cuts Unevenly or Crumbles	Dough Does Not Form Proper Balls	6	Device Doesn't Make A Clean Cut; Dough Is Too Tough	2	12				6	2	12
	Linear Actuator Breaks Frame	Actuator Pushes Itself Backwards	8	Frame Metal Not Thick Enough	1	8				8	1	8
Overall Structure	Loose Sleave Caught Between	Customer Pulled Into Device, Breaks	10	Open System	1	10				10	1	10
	Large Amount of Leftover Dough In	Loss of Cookie Potential, Extra Cleaning Time	5	Plunger Doesn't Fit Funnel Properly	3	15				3	5	15

Appendix I: Design Verification Plan

This table details how CDE will determine if each engineering specification has been met. The tests have been designated as PC or DC. This refers to whether the test will be conducted "post construction" or if it represents a specification where the device has been "designed for compliance".

Report Date: 2-12-2014			Sponsor: Brown Butter Cookie Company				Engineer Responsibility: Courtney Shipp		
TEST PLAN								TEST REPORT	
Item	Specification	Test	Criteria	Engineer	Type	Samples	Finished	Results	NOTES
1	Ball Volume	Volume displacement test in graduated cylinder.	Ball volume is 1.227 ± 0.025 in^3	CS	PC	30			
2	Ball Weight	Weight taken on a scales with a minimum tolerance of ±0.1 grams.	Ball volume is 21.5 ± 1 gram	CS	PC	30			
3	Pinch Points	Visual Inspection	Moving parts do not created any unguarded pinch points.	AH	DC	1	2/12/2014	Pass	Pinch point protected by safety cage
4	Rotating Parts/Blades	Visual Inspection	Rotating parts and blades have protection guards as required for operation.	AH	DC	1	2/12/2014	Pass	Rotation of cutting motor has been deemed not a safety hazard.
5	Sharp Edges	Visual Inspection	There are no exposed sharp edges	CS	PC	1			
6	Food Safe Material	Verify FDA requirements for construction materials	All materials meet FDA standards.	CS	DC	1	2/12/2014	Pass	All food-contact surfaces are stainless steel 304

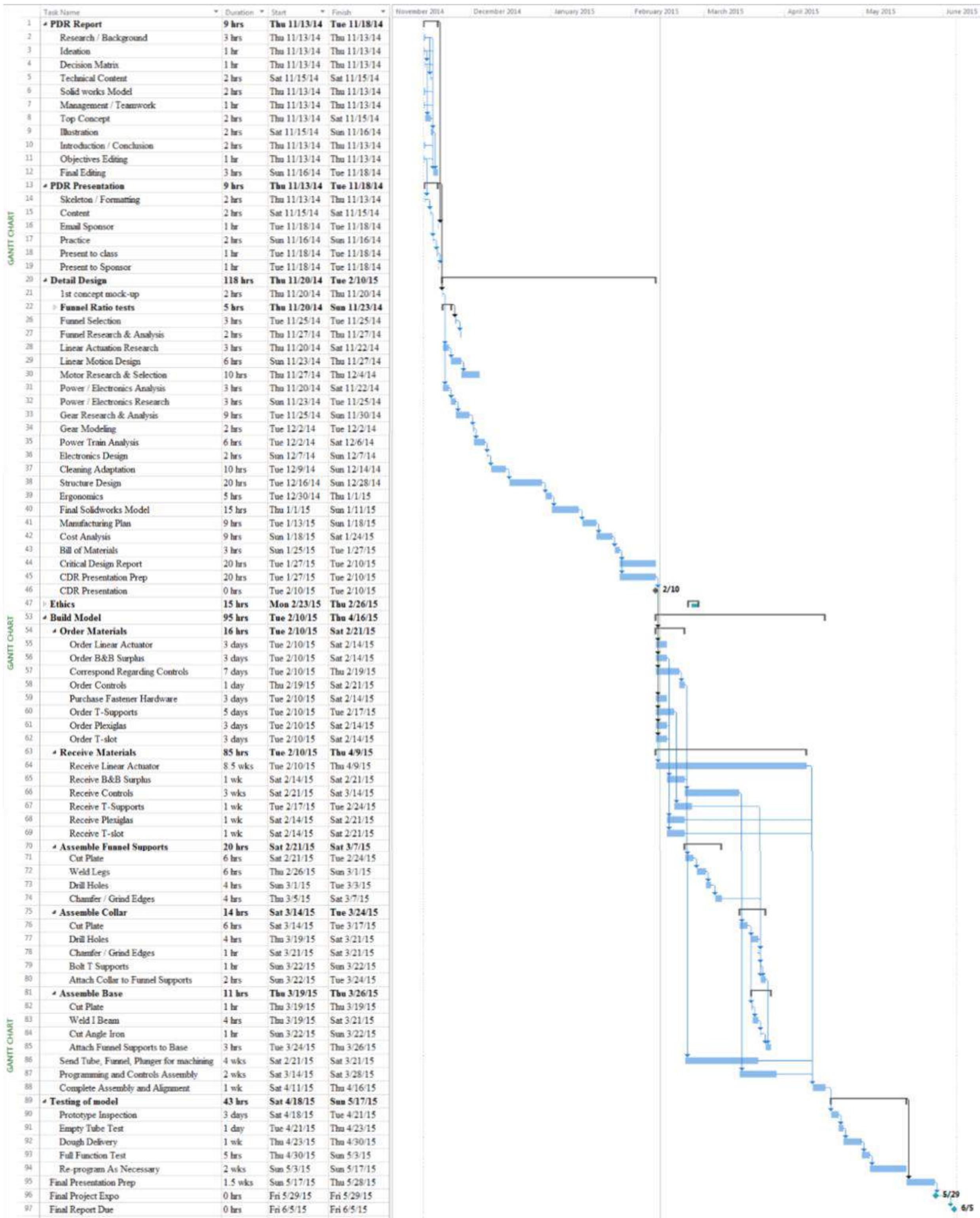
7	Surface Temperature	Temperature on all heated surfaces is measured with a thermocouple.	Surface temperatures are to be less than 104 degrees F.	GW	PC	1			
8	Cookie Rate	Machine is operated an normal speed and cookie rate is measured.	Cookie rate is equal to or exceeds 25 cookies per minute.	CS	PC	1			
9	dB Produced	A decibel meter is used to measure to peak and average decibel level during normal operation.	Decibels produced is less than 90.	GW	PC	1			
10	Operating Lift Weight	Force gauge is used to measure routine operating lift weight.	Operating lift weight is less 2 lbs.	AH	PC	1			
11	Pulling Weight	Force gauge is used to measure routine pulling weight.	Pulling weight is less than 20 lbs.	AH	PC	1			
12	Repetitive Motion	Verify with CDC and OSHA requirements.	Repetitive Motion loads do not exceed CDC and OSHA requirements.	GW	PC	1			
15	Cleanable Material	On-site testing of necessary cleaning time using the BBCC's cleaning facilities.	Surfaces are cleanable with the BBCC's dish washing machine.	GW	PC	1			
16	Cleaning Time	On-site testing of necessary cleaning time using the BBCC's cleaning facilities.	Full cleaning time is less than 120 minutes a day.	GW	PC	1			

17	Training Time	At BBCC one of our team members trains an employee to use the machine.	Total training time takes less than 1 day.	CS	PC	1			
18	Life Cycle	Design analysis calculations.	All parts should have a minimum of a 2 year life expectancy before needing to be replaced.	CS	DC	1	2/12/2014	Pass	Fatigue calculations assumed a 4 year life cycle.
19	Maintenance Required	Numerous batches of dough will be put through the machine.	Maintenance required should be less than 1 hour per every 80 hours of use.	AH	PC	1			
20	Cost	Budget analysis	Total expenses are less than $3000.	CS	PC	1			
21	Small Batch	A single batch of dough is put through the machine.	A single batch of dough can be successfully put through the machine.	CS	PC	1			
22	Total Weight	Use of a large scale to measure the total weight of the machine.	The total weight is less than 75 pounds.	AH	PC	1			
23	Length, Weight, Height	Take linear measurements of the length, height, and width.	Length, height, and width are less than 3' x 3' x 5', respectfully.	GW	DC	1	2/12/2014	Pass	Final dimensions in model are less than those specified.

Report Date: 06-05-2015			Sponsor: Brown Butter Cookie Company				Engineer Responsibility: Courtney Shipp		
TEST PLAN								**TEST REPORT**	
Item	Specification	Test	Criteria	Engineer	Type	Samples	Finished	Results	NOTES
1	Variable Extrusion Ratio	Verify # of workable extrusion ratio combinations.	# of Extrusion Ratios should be equal to or exceed 8.	CS	DC	1	4/25/2015	Pass	There are 12 possible extrusion ratio combinations.
2	Set-up Time	Time set-up time during initial testing.	Set-up time should be less than 30 minutes.	CS	PC	1	4/25/2015	Pass	Set-time takes about 20 minutes.
3	Adjustable Load	Time load changing period.	Load changing period should not exceed 2 minutes.	AH	PC	1	4/25/2015	Pass	Load changing time takes about 20 seconds.
4	Rotating Parts/Blades	Visual Inspection	Rotating parts and blades have protection guards as required for operation.	AH	DC	1	4/25/2015	Pass	Wheel is labeled as a rotary hazard and contact can be easily avoided.
5	Sharp Edges	Visual Inspection	There are no exposed sharp edges	CS	PC	1	4/25/2015	Pass	Sharp edges have been eliminated.
6	Flowrate can be accurately measured.	Dough measured on a scale for a measured amount of time.	Scale resolution is less than 2 grams.	CS	PC	1	4/25/2015	Pass	Scale used exceeds the required criteria.
7	Cleaning time	Cleaning time is measured.	Cleaning time should not exceed 1 hour.	GW	PC	1	5/7/2015	Pass	Cleaning time is about 45 minutes.
8	Time before cleaning is required.	Time how long device can operate effectively before cleaning is necessary.	Cleaning should not be necessary in less than 4 hours of data collection.	GW	PC	1	5/7/2015	Pass	Cleaning is required about every 8 hours of data collection.
9	Mobility	Load device components on one vehicle.	Device can be loaded on an average vehicle.	AH	DC	1	4/25/2015	Pass	All components easily fit in the bed of one truck.

10	Pulling Weight	Routine pulling weight is measured.	Pulling weight is less than 20 lbs.	AH	DC	1	4/25/2015	Pass	Weights can be retrieved from the ground level.
11	Life Cycle	Determine during testing if device become inoperable.	Device should remain operable and effective through all data collection	CS	PC	1	5/23/2015	Pass	Needed repairs, but remained operable.
12	Maintenance Required	Testing will be conducted for an extended amount of time.	10 data points can be collected before maintenance is required.	CS	PC	1	4/25/2015	Fail	Repair/modification was required after about every 5 data points.
13	Cost	Budget analysis	Total expenses are less than $500.	GW	PC	1	6/5/2015	Pass	Budget met.

Appendix J: Project Gantt Chart



	Task Name	Duration	Start	Finish
1	**PDR Report**	**9 hrs**	**Thu 11/13/14**	**Tue 11/18/14**
2	Research / Background	3 hrs	Thu 11/13/14	Thu 11/13/14
3	Ideation	1 hr	Thu 11/13/14	Thu 11/13/14
4	Decision Matrix	1 hr	Thu 11/13/14	Thu 11/13/14
5	Technical Content	2 hrs	Sat 11/15/14	Sat 11/15/14
6	Solid works Model	2 hrs	Thu 11/13/14	Thu 11/13/14
7	Management / Teamwork	1 hr	Thu 11/13/14	Thu 11/13/14
8	Top Concept	2 hrs	Thu 11/13/14	Sat 11/15/14
9	Illustration	2 hrs	Sat 11/15/14	Sun 11/16/14
10	Introduction / Conclusion	2 hrs	Thu 11/13/14	Thu 11/13/14
11	Objectives Editing	1 hr	Thu 11/13/14	Thu 11/13/14
12	Final Editing	3 hrs	Sun 11/16/14	Tue 11/18/14
13	**PDR Presentation**	**9 hrs**	**Thu 11/13/14**	**Tue 11/18/14**
14	Skeleton / Formatting	2 hrs	Thu 11/13/14	Thu 11/13/14
15	Content	2 hrs	Sat 11/15/14	Sat 11/15/14
16	Email Sponsor	1 hr	Tue 11/18/14	Tue 11/18/14
17	Practice	2 hrs	Sun 11/16/14	Sun 11/16/14
18	Present to class	1 hr	Tue 11/18/14	Tue 11/18/14
19	Present to Sponsor	1 hr	Tue 11/18/14	Tue 11/18/14
20	**Detail Design**	**118 hrs**	**Thu 11/20/14**	**Tue 2/10/15**
21	1st concept mock-up	2 hrs	Thu 11/20/14	Thu 11/20/14
22	**Funnel Ratio tests**	**5 hrs**	**Thu 11/20/14**	**Sun 11/23/14**
26	Funnel Selection	3 hrs	Tue 11/25/14	Tue 11/25/14
27	Funnel Research & Analysis	2 hrs	Thu 11/27/14	Thu 11/27/14
28	Linear Actuation Research	3 hrs	Thu 11/20/14	Sat 11/22/14
29	Linear Motion Design	6 hrs	Sun 11/23/14	Thu 11/27/14
30	Motor Research & Selection	10 hrs	Thu 11/27/14	Thu 12/4/14
31	Power / Electronics Analysis	3 hrs	Thu 11/20/14	Sat 11/22/14
32	Power / Electronics Research	3 hrs	Sun 11/23/14	Tue 11/25/14
33	Gear Research & Analysis	9 hrs	Tue 11/25/14	Sun 11/30/14
34	Gear Modeling	2 hrs	Tue 12/2/14	Tue 12/2/14
35	Power Train Analysis	6 hrs	Tue 12/2/14	Sat 12/6/14
36	Electronics Design	2 hrs	Sun 12/7/14	Sun 12/7/14
37	Cleaning Adaptation	10 hrs	Tue 12/9/14	Sun 12/14/14
38	Structure Design	20 hrs	Tue 12/16/14	Sun 12/28/14
39	Ergonomics	5 hrs	Tue 12/30/14	Thu 1/1/15
40	Final Solidworks Model	15 hrs	Thu 1/1/15	Sun 1/11/15
41	Manufacturing Plan	9 hrs	Tue 1/13/15	Sun 1/18/15
42	Cost Analysis	9 hrs	Sun 1/18/15	Sat 1/24/15
43	Bill of Materials	3 hrs	Sun 1/25/15	Tue 1/27/15
44	Critical Design Report	20 hrs	Tue 1/27/15	Tue 2/10/15
45	CDR Presentation Prep	20 hrs	Tue 1/27/15	Tue 2/10/15
46	CDR Presentation	0 hrs	Tue 2/10/15	Tue 2/10/15
47	**Ethics**	**15 hrs**	**Mon 2/23/15**	**Thu 2/26/15**
53	**Build Model**	**95 hrs**	**Tue 2/10/15**	**Thu 4/16/15**
54	**Order Materials**	**16 hrs**	**Tue 2/10/15**	**Sat 2/21/15**
55	Order Linear Actuator	3 days	Tue 2/10/15	Sat 2/14/15
56	Order B&B Surplus	3 days	Tue 2/10/15	Sat 2/14/15
57	Correspond Regarding Controls	7 days	Tue 2/10/15	Thu 2/19/15
58	Order Controls	1 day	Thu 2/19/15	Sat 2/21/15
59	Purchase Fastener Hardware	3 days	Tue 2/10/15	Sat 2/14/15
60	Order T-Supports	5 days	Tue 2/10/15	Tue 2/17/15
61	Order Plexiglas	3 days	Tue 2/10/15	Sat 2/14/15
62	Order T-slot	3 days	Tue 2/10/15	Sat 2/14/15
63	**Receive Materials**	**85 hrs**	**Tue 2/10/15**	**Thu 4/9/15**
64	Receive Linear Actuator	8.5 wks	Tue 2/10/15	Thu 4/9/15
65	Receive B&B Surplus	1 wk	Sat 2/14/15	Sat 2/21/15
66	Receive Controls	3 wks	Sat 2/21/15	Sat 3/14/15
67	Receive T-Supports	1 wk	Tue 2/17/15	Tue 2/24/15
68	Receive Plexiglas	1 wk	Sat 2/14/15	Sat 2/21/15
69	Receive T-slot	1 wk	Sat 2/14/15	Sat 2/21/15
70	**Assemble Funnel Supports**	**20 hrs**	**Sat 2/21/15**	**Sat 3/7/15**
71	Cut Plate	6 hrs	Sat 2/21/15	Tue 2/24/15
72	Weld Legs	6 hrs	Thu 2/26/15	Sun 3/1/15
73	Drill Holes	4 hrs	Sun 3/1/15	Tue 3/3/15
74	Chamfer / Grind Edges	4 hrs	Thu 3/5/15	Sat 3/7/15
75	**Assemble Collar**	**14 hrs**	**Sat 3/14/15**	**Tue 3/24/15**
76	Cut Plate	6 hrs	Sat 3/14/15	Tue 3/17/15
77	Drill Holes	4 hrs	Thu 3/19/15	Sat 3/21/15
78	Chamfer / Grind Edges	1 hr	Sat 3/21/15	Sat 3/21/15
79	Bolt T Supports	1 hr	Sun 3/22/15	Sun 3/22/15
80	Attach Collar to Funnel Supports	2 hrs	Sun 3/22/15	Tue 3/24/15
81	**Assemble Base**	**11 hrs**	**Thu 3/19/15**	**Thu 3/26/15**
82	Cut Plate	1 hr	Thu 3/19/15	Thu 3/19/15
83	Weld I Beam	4 hrs	Thu 3/19/15	Sat 3/21/15
84	Cut Angle Iron	1 hr	Sun 3/22/15	Sun 3/22/15
85	Attach Funnel Supports to Base	3 hrs	Tue 3/24/15	Thu 3/26/15
86	Send Tube, Funnel, Plunger for machining	4 wks	Sat 2/21/15	Sat 3/21/15
87	Programming and Controls Assembly	2 wks	Sat 3/14/15	Sat 3/28/15
88	Complete Assembly and Alignment	1 wk	Sat 4/11/15	Thu 4/16/15
89	**Testing of model**	**43 hrs**	**Sat 4/18/15**	**Sun 5/17/15**
90	Prototype Inspection	3 days	Sat 4/18/15	Tue 4/21/15
91	Empty Tube Test	1 day	Tue 4/21/15	Thu 4/23/15
92	Dough Delivery	1 wk	Thu 4/23/15	Thu 4/30/15
93	Full Function Test	5 hrs	Thu 4/30/15	Sun 5/3/15
94	Re-program As Necessary	2 wks	Sun 5/3/15	Sun 5/17/15
95	Final Presentation Prep	1.5 wks	Sun 5/17/15	Thu 5/28/15
96	Final Project Expo	0 hrs	Fri 5/29/15	Fri 5/29/15
97	Final Report Due	0 hrs	Fri 6/5/15	Fri 6/5/15

Appendix K: Raw Dough Data

Minor D (in)	Weight (lb)	Mass Extruded (g)	Time (s)	Flowrate (g/s)	Force in tube (lb)	Tyler Number	Pressure (psi)
1.512	2.5	204.31	4	49	207.5	2236	66
1.512	2.5	163.73	4	47	207.5	2236	66
1.512	2.5	218.83	4	54	207.5	2236	66
1.512	5.0	416.38	3	135	415	5900	132
1.512	5.0	422.2	3	154	415	5900	132
1.512	1.0	0	14.42	0	83	620	26
1.512	1.6	164.06	17.49	9	132.8	1197	42
1.512	1.6	150.17	19.02	8	132.8	1197	42
1.273	2.5	0	10	0	207.5	1429	66
1.273	5.0	162	13	13	415	3772	132
1.273	5.0	146	6	24	415	3772	132
1.273	7.5	82	4	21	622.5	6654	198
1.273	7.5	54	5	11	622.5	6654	198
1.273	7.5	382	12	32	622.5	6654	198
1.273	7.5	88	4	25	622.5	6654	198
1.273	10.0	427	5	82	830	9955	264
1.273	10.0	414	4	114	830	9955	264
1.273	10.0	385	4	104	830	9955	264
0.875	10.0	0	17	0	830	3756	264
0.875	12.5	359	52	7	1037.5	5133	330
0.875	12.5	441	23	19	1037.5	5133	330
0.875	15.0	332	6	57	1245	6626	396
0.875	15.0	398	9	44	1245	6626	396
0.875	15.0	409	6	67	1245	6626	396
1.512	10.0	858	23	38	830	9572	117
1.512	10.0	603	10	62	830	9572	117
1.512	5.0	140	11	12	415	3627	59
1.512	5.0	410	57	7	415	3627	59
1.512	5.0	770	43	18	415	3627	59
1.273	10.0	672	38	18	830	6120	117
1.273	10.0	600	21	28	830	6120	117
1.273	10.0	452	46	10	830	6120	117
1.273	7.5	173	41	4	622.5	4091	88
1.273	7.5	330	42	8	622.5	4091	88
1.273	12.5	350	11	31	1037.5	8364	147

1.273	12.5	211	10	21	1037.5	8364	147
1.273	12.5	848	34	25	1037.5	8364	147
1.273	15.0	884	5	190	1245	10796	176
1.273	15.0	915	9	99	1245	10796	176
1.273	15.0	865	8	114	1245	10796	176
0.875	10.0	795	16	50	830	2309	117
0.875	10.0	414	19	21	830	2309	117
0.875	10.0	465	8	59	830	2309	117
0.875	7.5	396	13	30	622.5	1543	88
0.875	7.5	296	15	20	622.5	1543	88
0.875	7.5	402	19	22	622.5	1543	88
0.875	5.0	238	32	8	415	875	59
0.875	5.0	236	24	10	415	875	59
0.875	5.0	287	39	7	415	875	59
0.875	12.5	494	7	71	1037.5	3155	147
0.875	12.5	618	14	44	1037.5	3155	147
0.875	12.5	713	10	71	1037.5	3155	147
0.875	15.0	641	4	161	1245	4073	176
0.875	15.0	612	3	245	1245	4073	176
0.875	15.0	714	6	116	1245	4073	176
1.512	10.0	441	34	13	830	4625	35
1.512	10.0	440	26	17	830	4625	35
1.512	10.0	514	30	17	830	4625	35
1.512	7.5	197	52	4	622.5	3092	26
1.512	7.5	175	61	3	622.5	3092	26
1.512	7.5	171	59	3	622.5	3092	26
1.512	15.0	421	17	25	1245	8159	52
1.512	15.0	381	15	25	1245	8159	52
1.512	15.0	511	20	26	1245	8159	52
1.512	20.0	1215	9	135	1660	12205	70
1.512	20.0	1344	6	208	1660	12205	70
1.512	20.0	831	3	267	1660	12205	70
1.273	25.0	597.22	12.57	48	2075	10665	87
1.273	25.0	659.81	11.87	56	2075	10665	87
1.273	25.0	603	8.97	67	2075	10665	87
1.273	15.0	215.7	24.34	9	1245	5216	52
1.273	15.0	258.42	15.56	17	1245	5216	52
1.273	15.0	253.32	13.02	19	1245	5216	52
1.273	20.0	382.76	12.75	30	1660	7803	70

1.273	20.0	508.87	21.99	23	1660	7803	70
1.273	20.0	275.1	17.72	16	1660	7803	70
1.512	17.5	470.03	7.08	66	1452.5	10124	61
1.512	17.5	854.52	14.5	59	1452.5	10124	61
1.512	17.5	629.97	7.05	89	1452.5	10124	61