Final Design Report

Team Poly Cup

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April 22, 2014

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Section I: Introduction

This project involves the use of mechanical engineering expertise to develop, design, and create a functioning prototype of a collapsible coffee cup. The prototype is to be designed to the specifications given by Jason Blum, the project sponsor. Allowances may be given for design freedom as specified by Jason Blum. The goal of this project is to create a product which may replace the both the disposable coffee cups distributed at coffee shops as well as to create a product which may replace the traditional travel mug due to its increased portability.

Team Poly Cup has worked throughout the year to design and test numerous locking mechanisms, water-tight seals, grips, and lids and have performed many calculations and created many prototypes to ensure the best design. We have expanded and finalized the design, completed a detailed cost analysis, finalized design verification, developed a manufacturing plan, and compiled a list of unique features that can be patented. In this report, we conclude the project, leaving Jason Blum with a completed prototype of the cup, as well as all documents needed for him to proceed with patenting and manufacturing of the cup.

Section II: Background

A) Existing Products

Figure 1. Sea to Summit X-Mug

Due to the provisionally patented nature of this product, nothing like this design has been patented; however, there are a few similar functioning products out on the market. The largest competitor is a collapsible cup sold by REI. The Sea to Summit X-Mug is a collapsible travel cup made of flexible, food-grade silicone that sells for $10 online. This cup boasts a collapsible height of only .5 inches, and maintains a collapsed diameter of 4.25 inches. The expanded cup can hold up to 16 oz of liquid, and has volume markers on the internal wall siding for easy fluid measurement. The X-mug is very durable and lightweight, while also maintaining a sleek design with top notch functionality. The disadvantages to this cup are few and far between, but it does have its defects. First and foremost, the X-mug fails at maintaining liquid temperature for a high range of temperatures. The food-grade silicon is watertight; however it does not do a great job at retaining heat. Another big disadvantage in the coffee market is the lack of a lid. While this product does not meet the requirement of our design, the Sea to Summit X-mug excels in both functionality and design, and is a great product to measure against.

Figure 2: IDS Stainless Steel Hip Flask

The telescoping IDS Stainless Steel Hip Flask SIX-Folding Collapsible Cup is another product currently on the market that is sold for $6 online. This cup collapses to a storage size of 1.75'' x 2.25'', and holds 12 fluid oz. when expanded. It has a key ring attached to it for ease of use while backpacking or traveling. However, this cup has a fatal flaw in the context of our design problem: it collapses when a hot liquid is poured in it. The metal rings have no locking mechanism, and when the metal expands due to the heat of the liquid, it collapses.

Figure 3: Flatterware collaspible cup

The next competitor product on the market is a plastic cup made by Flatterware. This $6 cup holds 12 oz. of liquid and claims to be pocket-sized. This design has a lid that screws in place, and boasts a unique “spring-loaded” design. The cup twists and extends when the top is taken off, and collapses similarly. This cup claims to be leak-proof as well as claiming to hot/cold insulation capabilities. At this point in our research, this is the only competitor product we have not used or seen in person. In order to properly assess its functionality and design, we will need to test the product ourselves at a later date.

The final competitor most closely resembles our proposed design from our sponsor. The Mille Mug is a spinning, threaded collapsing design with vertical walls and a drinking lid. The body of the mug is made of recyclable post-consumer polypropylene with silicone O-rings to ensure a watertight seal. The Mille Mug has a good functional design, but it requires the consumer to pull the rings tight to lock it in place. This cup was also one of the 10 winners of the Starbucks Sustainable Cup Design Competition in 2010. This cup also comes with a Starbucks rewards program and is sold for $18.

Figure 4: Mille Mug

Team Poly Cup kept the competitor’s products in mind while designing our potential collapsible cup. Our goal is to either improve upon one of the existing designs, or to use features of each existing design to help formulate the final design. We decided to explore other design options outside of the provisional patent, as long as the new design remains patentable. This will allow us to explore more options and develop the best design for this product.

B. Design Specifications

The goal of Team Poly Cup is to design, develop, and manufacture a collapsible travel coffee cup capable of holding and insulating both hot and cold beverages. The cup should be made out of stainless steel or similar material and follow the provisional patent that Jason has previously obtained.

In order to derive our engineering specifications from the sponsor requirements that Jason supplied our team, a process called the Quality Function Deployment (QFD) was used. A copy of the Poly Cup QFD is attached in Appendix A. The QFD process starts by identifying the customers, or “the who”. In this situation, the customer is both Jason, the project sponsor, and the future customers who will purchase the cup once it is on the market. It is important to design a cup that fits both customers’ requirements. The next step identifies the requirements the customers have from the cup, or “the what”. For this, features were selected based on conversations with Jason, along with what we anticipated the customers would expect to see in a product. Each feature is then ranked by importance to the different customers, which becomes “the who vs. the what”.

The next step is to benchmark the competition. It is necessary to acknowledge the strengths and weaknesses of similar products so that a superior product can be designed. This step will acknowledge what the competition does well, and highlight areas for product improvement. A few similar products were found to our cup, as previously discussed. These products were compared to our requirements and ranked in terms of how well they met the requirement.

Following benchmarking, comes filling in the engineering requirements or specifications. This is “the how”. Each customer requirement needs to have at least one engineering specification. An engineering specification is a measurable, testable requirement. For example, “holds a normal amount of liquid” would be a customer requirement while “holds at least 12 oz.” would be an engineering specification. Thus, “the how” needs to correspond with a “how much”. Next, the engineering requirements need to be related to the customer requirements; “the how vs. the what”. The diagonal of the chart is filled in with the correlation between the customer requirements and the engineering specifications. Some requirements will have no correlation with some specifications, but each requirement should have at least one specification with a strong correlation and vice versa.

The final step in QFD is analyzing the results. If there are specifications without a correlating requirement, then they are unnecessary. Addressing the competition can be a way to check that the right problem is being solved. Our final QFD model is attached, and was very helpful in defining the requirements of the design project. Since the QFD table can be hard to understand to the untrained reader, it has been narrowed down into the following specification table, Table 1, below.

The table is organized so that each specification in the QFD is described by a parameter, or “the how”. The “how much” is in the requirements column, followed by the tolerance which just further describes the target. The risk column asses the importance of each parameter, and the compliance column determines how the parameter’s completion will be checked at the end of the project.

Table 1. Poly Cup Specification Requirements Table

Spec #	Parameter Description	Requirement or Targets	Tolerance	Risk	Compliance
1	Insulation	80 ^{o}F/hr	Maximum	Med	T, A
2	Leakage	0 ft3/s	Maximum	High	T, I
3	Volume	12 fluid oz	Minimum	Med	T, I
4	Collapsibility	4”□ x 2”	Maximum	High	T, I
5	Material Choice	Metallic Silver	N/A	Low	I
6	Design to Patent	Yes	N/A	Med	I
10	External Temperature Regulation	100^{o}F	Maximum	High	T, A

T stands for testing, A for analysis, and I for inspection. For example, to determine if the cup leaks, we will test it by putting liquid inside it and then inspect to see if any liquid leaks out.

Our QFD model helped us to gain insight on our parameters. As seen in the table, we determined that our cup should be able to insulate better than a paper or plastic Starbucks cup. We feel that if the cup does not insulate better than these free versions, nobody will pay for it. We will determine our success in this area at the end of the project through testing and analysis of the design. It is obvious that a travel mug must not leak or it will be rendered useless. From this we determined that absolutely no liquid is allowable to leak through the cup. Completion will be determined through testing and inspection.

Since the minimum size drink offered at many coffee shops is 12 oz, we determined that our cup should hold at least 12 fl oz. of liquid. Any less and the user would not be able to order a typical drink. In order to be convenient to carry around, the cup should collapse down to be no larger than a 4” diameter with 2” height. We feel this is the maximum size that the average customer will be willing to carry around. The success of both these features will be determined through testing and inspection.

It is important to Jason that the cup be stainless steel or a comparable alternative. We recognize the importance of a sleek design and will design with this in mind.We also recognize the it is the utmost importance to chose a material that is not harmful to the user to ingest. Being engineers, we create all our designs to a code of ethics which states that we will never create a design that is harmful to its users.

Whichever material is selected for the final product will be guaranteed safe to its users. It is also important to design with the provisional patent that Jason has obtained in mind. We have done our research on existing patents and will create a design that is patentable in April. These features’ success will be determined through inspection.

Since the cup will be carried around by users, it is extremely important to keep their safety at a high priority. 105^{o}F is the threshold of pain for humans, so we must keep the external temperature of the cup beneath 100^{o}F. This requirement will be determined through testing as well as with the use of analysis.

No specifications have been updated in this version our project. We still aim to be within the previously approved parameters.

Section III: Design Development

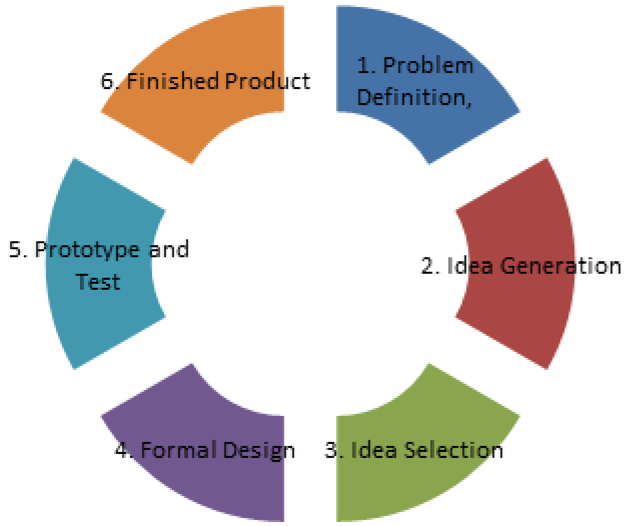


Figure 5: Design development cycle

The design process follows a basic procedure as displayed above. First, the problem is defined. Then comes idea generation, idea selection, design, and then test and finalization. Often, a group must go back and forth through the cycle. For example, a group might select an idea that they believe will work well, but once they get to the prototype stage, they realize that the design is not feasible. The group must return to the idea selection, or even idea generation stages and start over until they have a working prototype and then a finished product.

The schedule that Team Poly Cup has set is attached in Appendix A. We hope to have the conceptual design (Idea Selection) by December 5th and the critical design (Formal Design) by January 14. We plan on beginning prototyping February 4, and presenting Jason with the final cup on April 14.

Since Jason has supplied our team with the basic idea of the design, we will begin by generating ideas for how the mechanical element will work, then selecting which idea we believe will best suit the cup. Stainless steel is our material goal, however we plan to run numerous tests before we select the material to confirm that stainless steel is truly the best option. We believe that a other metallic options may be cheaper and easier to work with, however we will discover what the best options are in the design process.

We plan to spend the majority of our time in the prototype phase because we believe that the collapsible cup design will be best developed in the tangible form. This may mean that we need to be able to rapid prototype a few different possible designs to feel how the tolerances and design work. This may use a portion of our budget, however we feel that it is necessary and will be extremely helpful to the design process.

Team Poly Cup has taken an approach which leads us through each successive design decision. We began looking first at the mechanism for collapsibility as the first and most important design feature. So far, we have looked into the design of other dependent design features such as sealing the cup, implementing a locking mechanism, varying cup geometries, and developing a lid for our cup. Details on all of these follow.

A. Locking Mechanism

After defining the problem, our team immediately began brainstorming ideas for how to collapse our coffee cup. All sorts of designs were considered in the process. Ideas for collapsible mechanisms included springs, threads, friction-locking, motors, gears, rollers, pins, slots, deformation, and magnets. No ideas were initially tossed out and in fact many were expanded on during the process.

After a week of processing each design, subtle changes were made before we began the idea selection phase. We considered the feasibility of the ideas which were generated. Of the six ideas had strong potential, four ideas were ultimately selected to continue through to the conceptual design phase. The six feasible ideas (shown below) included magnets (I), springs (II), threads (III), pins (IV), and friction (V and VI) as the potential locking mechanisms.

From there, it was determined that the top four designs should be modeled in Solidworks. The chosen designs (shown below) were the magnet (I), spring (II), thread (III), and L-lock (IV) design.

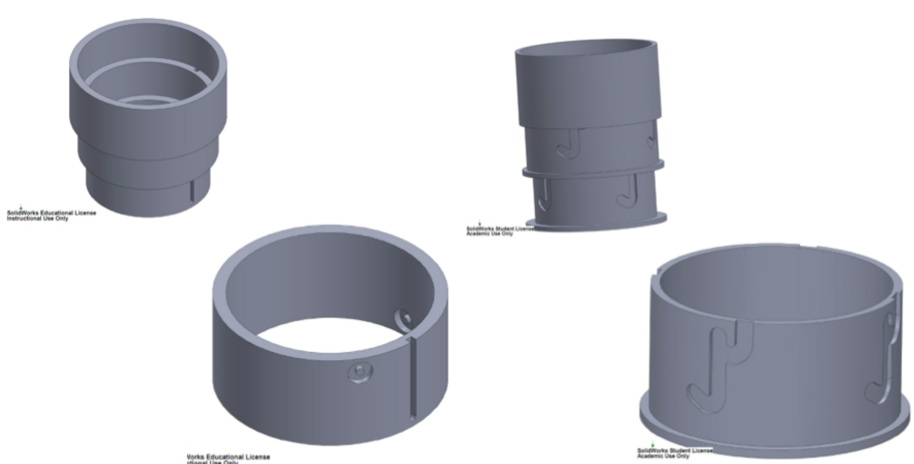


Figure 6: Magnetic (left) and Spring design (right)

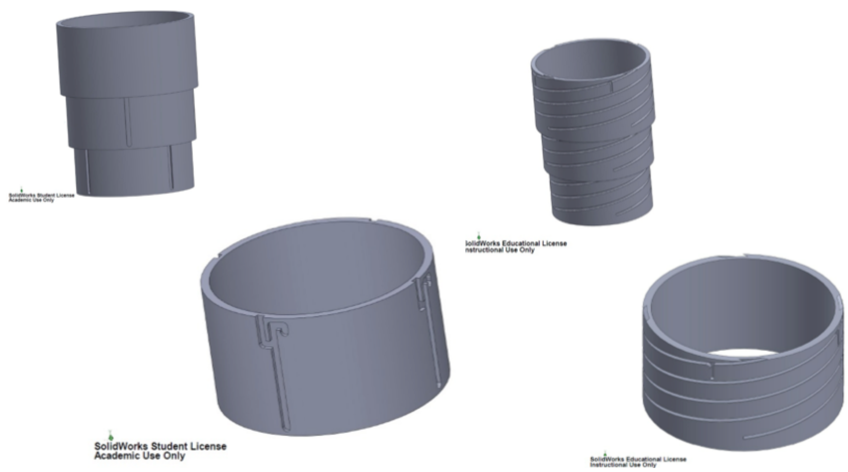


Figure 7: L-Lock (left) and Threaded design (right)

The **L-lock** design was ranked the weakest of the 4 prototypes we modeled. It is a simplistic design, which is why it received a low score on a decision matrix where innovative design and intuitive feel are ranked as the most important requirements. The L-lock is a relatively safe design, and parts of the L-locking mechanism may be adapted to our final design. While the L-lock is a useful prototype to learn from, we would like to pursue more complex designs.

The **spring** design was also one of the weaker designs we prototyped due to the physical size of the springs needed for the motion mechanism. The springs are bulky and take up valuable space in the collapsed position, while also limiting the total fluid volume in the expanded state. The spring concept was deemed the "safe design" because of its fail-safe design. If the locks were to disengage, and the potential energy of the spring was to be released, the cup would fail to the expanded state. In the other concepts, if the locking mechanism were to fail in the expanded state, the cup would collapse and spill coffee. In this design, the potential energy of the spring ensures that the cup will not spill coffee if it fails. However, due to the bulky nature of the spring design, we feel that other designs fulfill the project specifications and requirements better.

The **threaded** design was the initial design presented to us, and was the first design we prototyped. Upon first analysis of this design, the user notices the difficulty and strain it takes to collapse the 3 rings together. Part of this problem is due to the nature of the rapid prototyping, creating a rough stepped groove for the pin to slide in. A few other design flaws were encountered that should be fixed if the threaded concept were to overtake the magnetic concept for the final design. The first of these is the number of threads. The current prototype uses 4 pins and 4 threads to complete the spiraling motion in each ring. In a future model of the threaded design we would reduce the number of pins/threads to 1-2 per ring. Another issue encountered was the locking depth of the pin slot. The slot dropped too deep and created difficulties getting each pin to engage smoothly back in the track after being held in the locked position. The threaded concept did excel in both storage size, as well as fluid volume contained.

As far as feel and function go, it is clear that the **magnetic** cup is ahead of the other concepts at this point in time. The magnetic design is much more intuitive to collapse and seems to be more novel to the average user. It has the feel that would make it a successful consumer product. This is our hardest design obstacle.

Many of our designs rely on the look and feel of the cup rather than other measurable elements. Though our team is utilizing SolidWorks to view the look of the cup, it seems that rapid prototyping will be the easiest way to access the feel of each design. The drawbacks are the time and cost which is involved to rapid prototype these designs.

Of the 4 main concepts, the first round of prototyping has our team to believe that the **magnetic design will be the superior design** because it excels in both functionality and aesthetic/ergonomic appeal. Our team used a weighted decision matrix to determine which of the four designed excelled. The decision matrix is included in the appendix A.2. As a baseline for the ranking, we used the Mille Mug since it is the best collapsible cup currently on the market. The factors each design was ranked on, in order of importance, was the “feel” of the motion, how intuitive the motion is, if the design is fail-safe, the collapsed size, the liquid volume capacity, and how aesthetically pleasing the cup is. The “feel” of the cup was ranked much higher than the other factors, because we feel that no consumer will purchase this cup, even if it is mechanically sound, if it does not have a great feel.

The magnetic concept overtook the threaded concept after the prototyping stage primarily because the design excels in the functionality of the collapsing mechanism. The prototype for the magnetic design exceeded our expectations, and most importantly it excelled in the categories that we found to be of most importance to the consumer. While not only being the superior design in regards to collapsibility, it had the best “feel” in regards to ergonomic design. It is important to our sponsor, and the market that the cup will eventually be sold in, that the cup has an aesthetic and innovative appeal to the design while remaining fully functional.

A few downsides to the magnetic design in its current state are mostly due to the size of the magnets. These magnets were low quality magnets bought at Home Depot and can be replaced by smaller magnets to be discussed later. The magnets require the expanded cup to have overlapping layers, thus decreasing the volume of fluid the cup will be able to hold given equal collapsed size constraints.

Other parameters were independently tested in each model, in an attempt to conserve materials. We found that the 0.2” wall on the magnetic design was too thick, while the 0.1” wall was at the very lowest end of acceptable thickness. In our final design, we will likely have a wall thickness in the range of 0.1-0.15” thick.

In the next round of prototypes, the magnets chosen were 1/16” x 1/4” x 1/4” Neodymium magnets from Magnets4Less.com They cost $0.18 /each and have an approximate pull force of 2.7lbs. The magnets will be used not only as a locking mechanism, but they will double over as backup static support for the pins. We tested 2 magnets during our 2.0 prototype. We found that the larger magnets (1/16” x 1/4” x 1/2”) were too large to fit the curved wall. In addition, we felt that the smaller magnets provided plenty of magnetic force to do the job they were intended to do.

Initially, we had three layouts for our pin tracks. Images of the three designs are shown below. The first design was an inverted “L” locking track, the second design was a “C” locking track, and the third possibility was an “S” lock. Each track shared one unique aspect: They all maintained a locking position at the top which utilized a flat “landing zone” for the pin to sit on. This prevented the cup from collapsing if the user overcame the force of the magnets. Instead, the user would have to shear the pins to create failure when the cup was in its expanded state. It was determined that we would test two of these pin designs in our second generation prototype due to space limitations. Based on our engineering intuition, we were able to rule out the “C” lock design because it required the user to twist in one direction to unlock the cup, perform the expanding or collapsing motion, and then twist back to the original position. This dual directional motion is counterintuitive to most users. Also, the “C” lock does not allow the user an easy way to get the cup into the collapsed position.

After rapid prototyping the “L” Lock and “S” Lock in our second generation, we were able to see that twisting the cup is much more intuitive than twisting slightly to unlock and pulling. It is also important to note that the twisting design allowed the user to utilize the bottom of the cup to twist, whereas the pulling action would require an additional mechanism to deliver the pulling force to the bottom of the cup. Thus, we decided to proceed with the “S” lock for our final design.

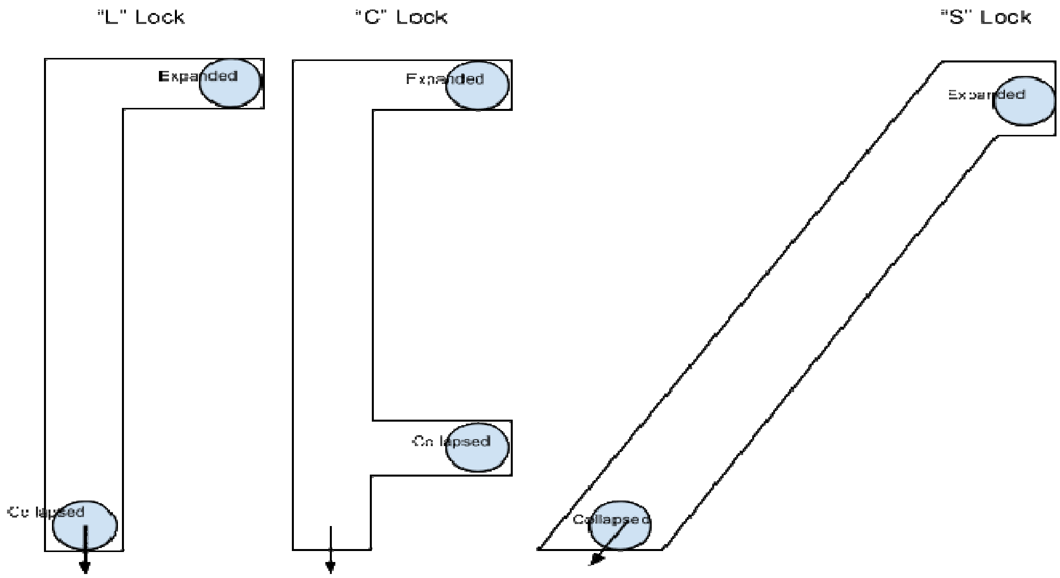


Figure 8: Different pin and track configurations considered in Gen 03 Prototype

B. Water-tight Dynamic Seal

The most problematic design feature we encountered during the version 2.0 prototype was the O-rings. In order to provide a watertight seal for the cup, we proposed using a recessed groove at the top of every ring that would hold an O-ring that would effectively seal the cup. Our first design to implement the O-ring was the version 2.0 prototype, which was an utter disaster.

The first problem we encountered with the O-ring design was that the O-rings we ordered did not fit the cup. This happened for a few reasons. First off, the O-rings stretch to a much larger OD than the nominal size listed online. The second problem we encountered was our error in designing the slot. We researched O-ring design after we encountered the failure to see where we had gone wrong. We also consulted a few store clerks, and the manager of Central Coast Bearings for advice in O-ring design. We obtained the Hercules 2013 Seal Catalog design manual for O-rings from Central Coast Bearings in order to correct the problem for the version 3.0 prototype. The final problem we noticed was that our Version 2.0 prototype's rings could not easily slide past each other and collapse/expand while the O-rings were in place. We concluded that the root of all 3 problems was in our slot design. The O-rings didn't fit because the O-rings were being elongated by a slot that was too narrow. That in turn caused the O-rings to extrude outward and cause interference with the next ring and making it difficult to move the cup.

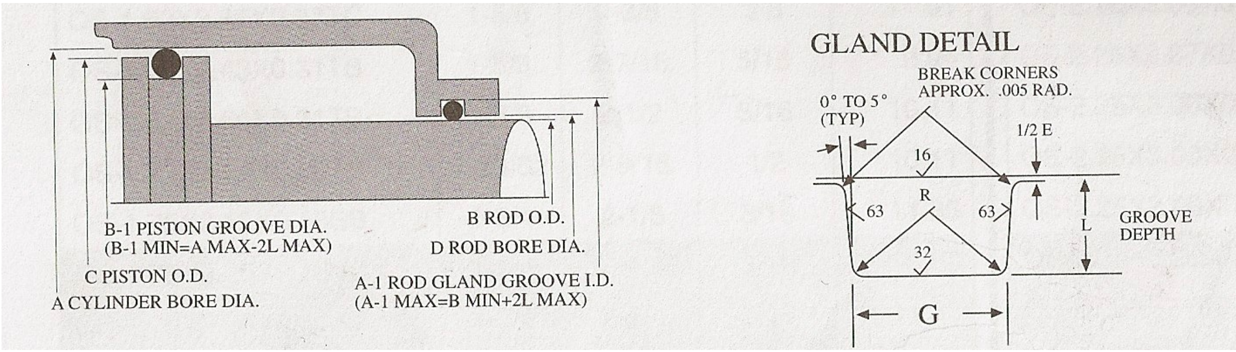


Figure 9: Design schematic of the reciprocating seal.

Our research led us to discover that we needed to use a reciprocating seal design. The reciprocating design schematic is shown in the figure above. Our cup uses O-rings with a cross section (W) of 1/16”, corresponding to the 0.070” diameter line in the figure shown below. Following the design table for 0.070” cross section the important slot parameters are as follows: Groove Depth (L) = 0.055-0.057”, Diametrical Clearance (E) = 0.004”, Groove Width (G) [no backup ring] = 0.095 ± 0.005”. These are the dimensions of each slot in Version 3.0.

W O-RING CROSS SECTION	L GROOVE DEPTH	SQUEEZE		E DIAMETRICAL CLEARANCE MAX.	G GROOVE WIDTH ± .005		
		INCHES	%		NO BACKUP RING	ONE BACKUP RING	TWO BACKUP RINGS
.070	.055-.057	.010-.018	15-25	.004	.095	.140	.207
.103	.088-.090	.010-.018	10-17	.005	.142	.173	.240
.139	.121-.123	.012-.022	9-16	.006	.189	.210	.277
.210	.185-.188	.017-.030	8-14	.006	.283	.313	.413
.275	.237-.240	.029-.044	11-16	.007	.377	.410	.540

Figure 10: Hercules Seal Handbook design table for reciprocating seals.

Following the design table for reciprocating seals, we were able to design a test using concentric aluminum piping, in an attempt to verify the slot design shown in the manual would work for a metal application. We were fortunate enough to find two concentric aluminum pipes from the scrap metal pile that we used to test the slot design. The test was designed as a cost efficient approach to test O-ring slot design (without rapid prototyping) that would also allow us to test the rings on a metal application. The larger pipe had an ID = 2.250” while the smaller pipe was machined to within the desired diametrical clearance of 0.004”. Two slots were cut into the piping: one slot for O-ring cross sections of 1/16” (0.070”) and another slot to test 3/32” (0.103”). At first the tests were done using a wide variety of mismatched O-rings from the local Miner’s Hardware. We found that the slot fit the O-rings much better due to the widened Groove Width (G) that allows the O-ring to compress inward radially, allowing the pipes to slide past each other smoothly. We used O-rings of nominal OD ranging from 1.75” up to 2.25” in both sizes to test our theory behind the design manual. The results of our test are shown in the table below.

Table 2. Results of the Aluminum Pipe Test

Nominal OD (in)	1.75	1.875	2	2.125	2.25
1/16" cross section	-	Medium Leakage	Minor Leakage	No Leakage	No Leakage
3/32" cross section	Heavy Leakage	Medium Leakage	Minor Leakage	-	-
Mobility (1-10)	8	7	6	6	3

*Rating of 10 is easy to move, 1 is impossible to move

Our testing has led us to believe that it is best to use O-rings approximately OD = 1/8” smaller than that of the cup’s OD. O-rings at nominal size, and sometimes up to 1/4” smaller than the needed OD will all provide enough interference to pass the leak proof testing. However, the O-ring 1/8” smaller provided the best compromise between leak proof design and mobility, ranking best in mobility for the sizes that passed the water-tight test. Continued O-ring design and analysis is recommended moving forward. A test to find the optimal Groove Depth for minimum interference, as well as testing in the correct diameter range (3.0-3.5”) is recommended.

C. Cup “Bottom Grip”

One design flaw encountered with Version 1.0 and Version 2.0 of the magnetic prototype design is that there is no easy way to grip the bottom of the cup when you want to expand it. We held a brainstorming session to determine the best way to create a “grip” for the bottom of the cup. A summary of the ideas we developed and their key strengths/weaknesses is shown in the figure below.

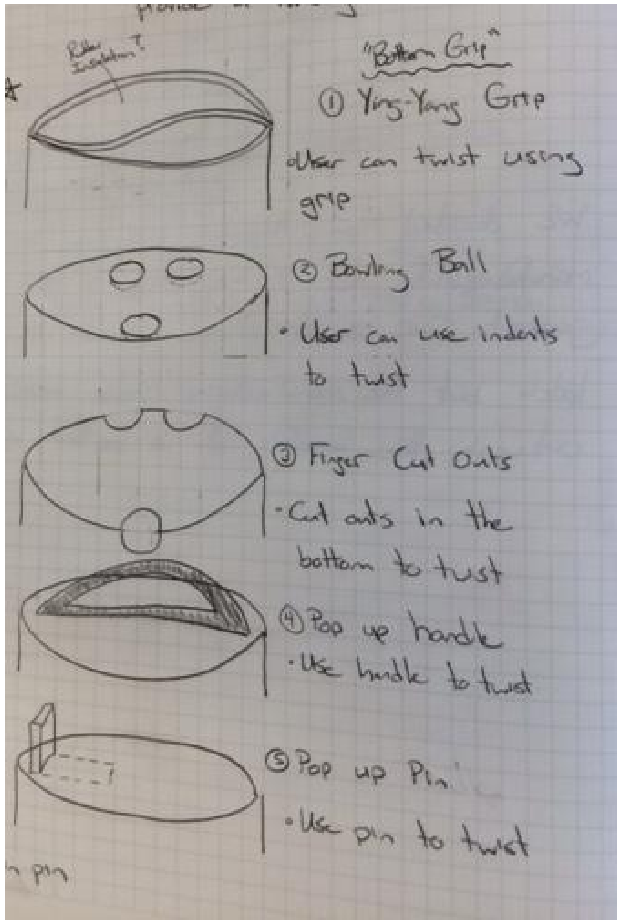


Figure 11. 1) Yin-Yang Grip 2) Bowling Grip 3) Finger Cut-outs 4) Pop-up Handle 5) Pop-up Pin

The constraints on this feature are that we want the grip to sit flat in a cup holder, effectively allow the user to grip the bottom, while also minimizing the volume lost in the bottom ring of the cup. The “Bowling Grip” and “Finger Cut-outs” both excel in axial pull ability, but they decrease too much volume due to the depth of the finger holes. On the other hand the “Pop-up Handle” and the “Pop-up Pin” both excel in axial pull, but they take up a large amount of volume and won’t sit as flat as the other designs. Our initial analysis has led us to believe that the “Yin-Yang Grip” is the best option to test in the Version 3.0 prototype. This design is loosely based on the finger wheel of the paper towel dispensers you see around campus. We believe the Yin-Yang Grip is the superior option because it is the best compromise that fulfills our design constraints. A decision matrix of our 5 bottom grip designs is shown below.

Table 3. A decision matrix of the 5 proposed bottom grip designs.

Grip Design	Yin Yang Grip	Bowling Grip	Finger Cut-outs	Pop-up Handle	Pop-up Pin
Axial Pull	7	7	7	10	9
Volume	9	6	6	7	7
Sits flat	10	10	10	8	8

**Rating of 10 is good, 1 is poor*

D. Lid

One of the most important design features to Jason is the lid for the top of the cup. The first requirement of the lid was that it was able to stay attached when the lid was both attached and collapsed. While our goal was to have a lid that was watertight, realistically for this round of prototypes, the requirement was that it would prevent the whole contents of the cup from spilling if the cup was knocked over, but it did not have to be watertight. The goal was to prevent spillage as well as a Starbucks plastic lid. The lid was broken up into two main components: the mouthpiece and the lid to cup interface. We held a brainstorming session and developed a few design ideas for both.

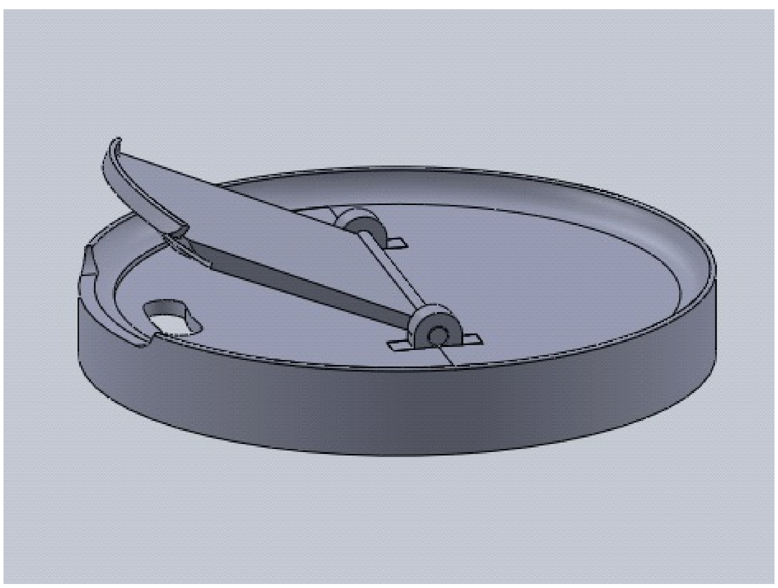


Figure 12. 3D Model of Cup Lid

For the mouthpiece, five design ideas were derived. They were a sliding top, a hinge and press, a rotating slider, a one way valve, and a squirt top. Based on our design abilities, the designs were paired down to the sliding top and the hinge and press top. From these two, a decision matrix was created. It is below:

Table 4. Decision Matrix for Lid Design

	Sliding Top	Hinge and Press Top
Potential for Leakage	-	+
Feel	-	+
Ease of Manufacturing	+	-

Note: + means that the lid functions better than its opponent.

From the decision matrix, we decided that the hinge and press fit top would be the best design. From similar lids that we have had experience with, the sliding tops are much easier to leak than the hinge and press fit lids. Leakage is especially important to this feature because it would be detrimental to the cup if it were to leak while collapsed in the user's pocket. An image of the final lid design is shown below:

E. Manufacturing and Materials

It is imperative to Jason that cup is made of stainless steel or a similar material. In order to determine if stainless steel was a feasible material for our design, heat transfer calculations were performed. Using the EES software to solve the equations, we calculated that the outside wall temperature of a single walled cup based on the assumption that the coffee was at a constant temperature of 180 ^{o}F which makes sense for the worst case scenario. In reality, the coffee would become cooler than 180 ^{o}F over time, making the assumption worse than reality. The result was that the outside temperature of the cup would be 170 ^{o}F for a plastic material, polypropylene, and 179.9 ^{o}F for stainless steel. The threshold for pain to humans is around 120 ^{o}F, making both of these cups too hot to be safe for the consumer.

Based on these results, we decided to calculate again using the same assumptions, but for a cup with two walls with an air gap between them. The results were 99 ^{o}F for the stainless steel cup and 97 ^{o}F for the plastic cup. This proved that for either single wall cup, the material would get too warm, but adding an air gap made both stainless steel and plastic safe to the consumer. Thus, stainless steel was still a viable design option.

Next, we researched manufacturing methods. We sent some basic files to a few metal prototyping companies for pricing and feasibility. The results are summarized in the table below:

Table 5. Manufacturing Costs

Method	Material	Cost for 5 Ring Cup
Selective Laser Sintering	Steel	$2700
Investment Casting	Stainless Steel	$2800
Stereolithography	Plastic	$2900
Direct Metal Laser Sintering	Stainless Steel	$7500
Metal Plated	Nickel Dipped Plastic	$2500

As can be seen in the table, none of the methods of manufacturing are inexpensive, and none fit in our budget of $1000. Selective laser sintering is basically rapid prototyping in different metal materials, but stainless steel is not an option. Investment casting is a method where a mold of the part is made, and then used as a mold for future parts. Molten metal is poured into the mold, and used to cast mass amounts of a product. The cost of the mold is high, but it is a fixed cost, and when making thousands of parts, it tends to be a cost effective manufacturing method. Stereolithography is another form of plastic rapid prototyping, but it has a smoother finish than the rapid prototyping method available on campus. Direct metal laser sintering is very similar to selective laser sintering, but stainless steel is an option. From the difference in price, it is obvious that stainless steel is much more expensive for comparable technology. Finally, metal plated plastic is a plastic prototype that is dipped in a metal. We chose a nickel alloy. For the final prototype which Jason will manufacture and sell, we suggest investment casting as the most efficient manufacturing method. None of these methods are cost efficient enough to buy for the prototype stage.

F. Cup Geometry

One of the most challenging problems for designing an aesthetic and efficiently designed collapsible cup is the wall thickness of each ring. The cup walls serve multiple purposes in our design. Firstly, they make up the cup's structure. Secondly, they serve to insulate the user's hand from the hot coffee inside it. This is done with an air gap. Thirdly, they hold the O-Rings in place. Lastly, the walls also house the magnets as well as function as the tracks for the pin.

Because of the multiple functions of the walls, the wall thickness is critical. It needs to incorporate the O-ring recess, track recess, air gap, and magnets within it’s design. Additionally, most of these components need to be in series with some material in between them for structural support. All of this together makes the wall thickness a critical component of the cup geometry.

With the help of EES, we have been able to create a code which will output a height and diameter of each ring as a function of the cup outer wall thickness, air gap distance, and inner wall thickness. The EES code produces this for a number of cup rings ranging from 2 to 10 rings. The Figure 12 shows how the number of rings affects the collapsed height and collapsed diameter. From this, we determined that four rings is the maximum height that we want to use. We ultimately want to aim for the highest maximum height to keep the cup looking more like a cup and less like a bowl. Figure 13 shows where the vertices will be of each ring will be located. From this, we can see what the approximate shape of the expanded cup will look like.

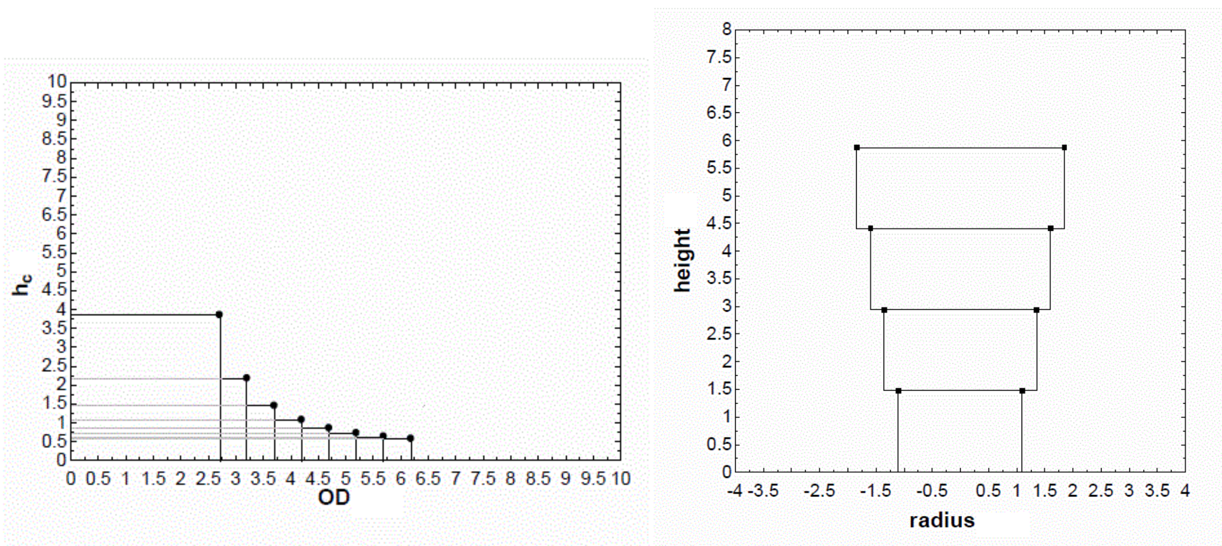
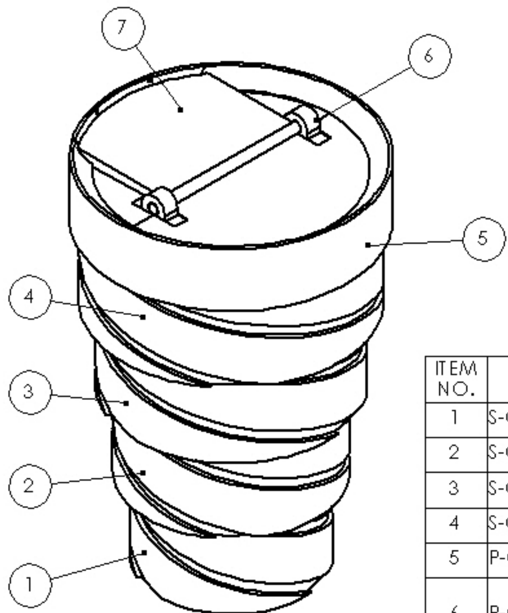


Figure 13. Collapsed profile view of cup based on number of rings(left) and expanded profile view of cup with four rings(right).

Section IV: Description of the Final Design



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S-Gen04-Ring01	Innermost ring+bottom grip	1
2	S-Gen04-Ring02	2nd Ring	1
3	S-Gen04-Ring03	3rd Ring	1
4	S-Gen04-Ring04	4th Ring	1
5	P-Gen04-Lid-Flipping	Lid w/ flipping mechanism	1
6	P-Gen04-Lid-FlippingMechClips	Permanent press fit clips for the lid	2
7	P-Gen04-Lid-FlippingMech	Drinking spout for lid	1

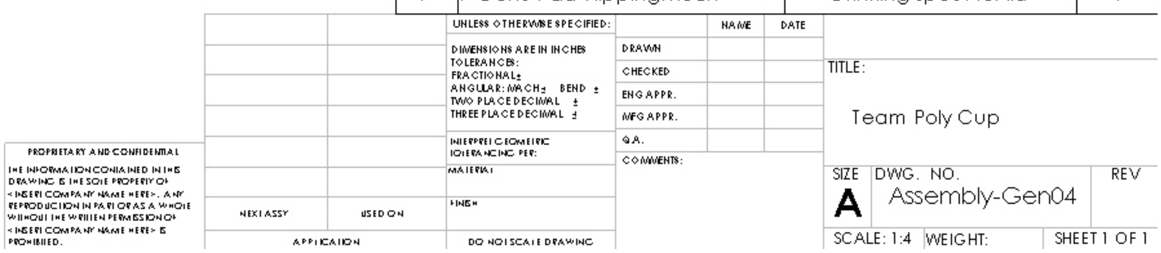


Figure 14: Isometric view of final design, with Bill of Materials.

The final design of the collapsible cup contains a locking mechanism with magnets and pins and slots. The pin and slot joints provide a fail-safe mechanism so that if a strong force was to be applied to the top of the cup, it would not immediately collapse. The magnets are intended to lock the cup in the expanded and collapsed position and are located inside the walls of the air gap. The air gap insulates the cup to keep coffee hot and prevent the user from being burned and is sealed with caps to each ring that also create a slot for O-rings. The O-rings are the feature that seals the cup and prevents it from leaking. The cup contains a grip on the bottom to start and stop the motion. Finally, the design contains a lid that prevents excessive leakage but is not water tight. Each feature is expanded on in the following sections.

A. Locking Mechanism

The magnetic locking cup has been the superior design throughout this project and was developed to have six magnets per ring as well as three pin slot joints per ring. The “S” track slot was also kept the same in this version of the prototype as it was determined to be the most user-friendly. It is shown below in Figure 14. In order for the cup to be disassembled to allow for ease while washing, the tracks extend through the bottom of the cup. With Generation 04, the motion that collapses the cup could cause it to disassemble if the shear force of the magnet was to be overcome. For Generation 05, to fix this problem, the track exits at a vertical angle at the bottom to prevent it from unlocking the rings. This requires the user to consciously, rather than accidentally, remove the rings for washing. It is also shown below in Figure 15.

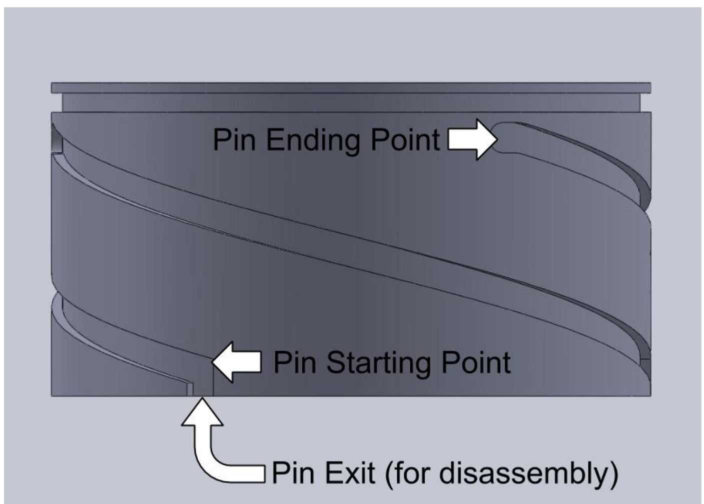


Figure 15. “S” Track locking mechanism with Vertical Track Exit

For the final design of the cup, we added an air gap in between the inner and outer walls of each ring of the cup to help insulate the cup. This allowed us to embed the top magnets in the air gap to protect them from falling out of place on the outside of the cup. The bottom magnets are press fit into the bottom of the cup. This embedded design was tested in Generation 03 and we determined that more than just one magnet was necessary to create the same amount of force with the larger distance between them. To be efficient in both cost of the magnets and force necessary, three magnets at each top and bottom were decided upon for each ring. The embedded slots for each magnet are shown below in Figure 16. To minimize the necessary wall thickness in Generation 04 and 05, the air gap sits in between each pin track. In order to close the air gap, a ring was added to the top of each portion of cup, sealed with a press fit. The press fit works substantially well, as it was not removable once fixed on.

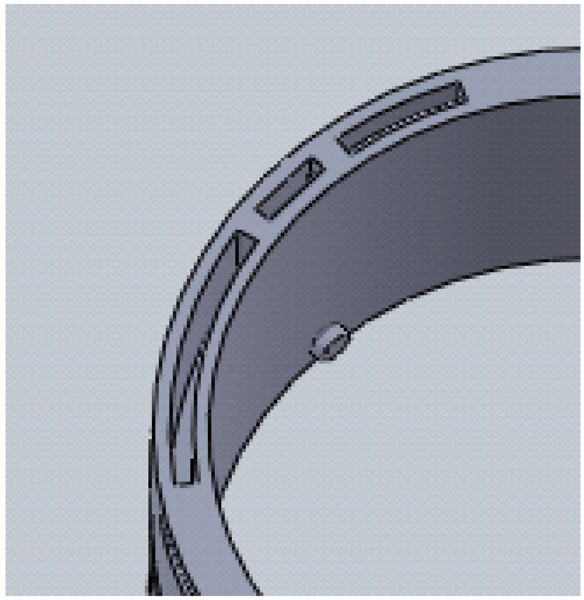


Figure 16. (from bottom to top) Air gap to provide insulation, magnet slot, and female ring press fit slot

*Since the magnets used in Generation 01, 02, and 03 were the smallest magnets we could find, they were kept for Generation 04 and 05. These magnets are **1/4" x 1/4" x 1/16"** Rare Earth Magnets in a Neodymium block. They have a pull force of 2.7 lbs., which is extremely strong for their small size. Overall, the cup has 21 magnets.*

B. Water-tight Dynamic Seal

Water-proofing the cup is extremely important because it will be a failure if it leaks at all. This was the main focus and biggest challenge of much of our design. For Generation 03, a successful O-ring design was mastered. In the final design of the cup, the same O-rings and design are used. This design was tested, as previously stated, with machined aluminum rings, and successfully did not leak. To design the slot, we used the Hercules 2013 Seal Catalog. Red 70-durometer, silicone AS568 O-rings were selected, and sizes -033, -035, -038 and -041 were selected for the smallest through largest rings, respectively.

C. Cup Grip Handle

In order to start the motion of the cup when it is collapsed without touching the inside, a tab was necessary at the bottom of the cup. A yin-yang design was implemented in Generation 03. Upon testing, it was very user friendly and intuitive. The only fault was that the design was a little unsturdy. For Generation 04 and 05, the tab was thickened from 0.05” across to 0.25” across to provide for greater durability. This thickening made the grip substantially more sturdy and easy to use. Figure 17 shows the design.

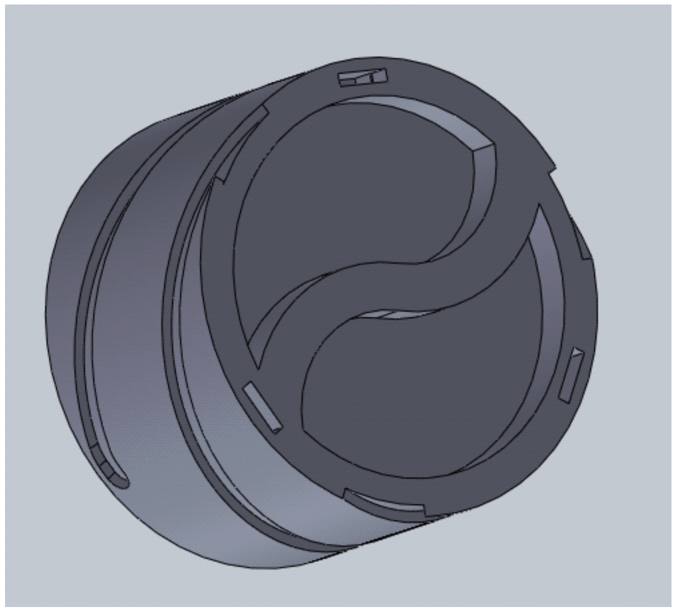


Figure 17. “Yin-Yang” bottom grip model.

D. Lid

The lid was an exceptionally important design feature to Jason. It was required to stay attached to the cup while expanded and collapsed. The lid did not necessarily need to be water-proof; however it had to prevent spillage as well as a Starbucks plastic lid. The lid was broken up into two main components: a mouthpiece and a lid to cup interface. Figure 18 shows the components of the lid and a final assembly.

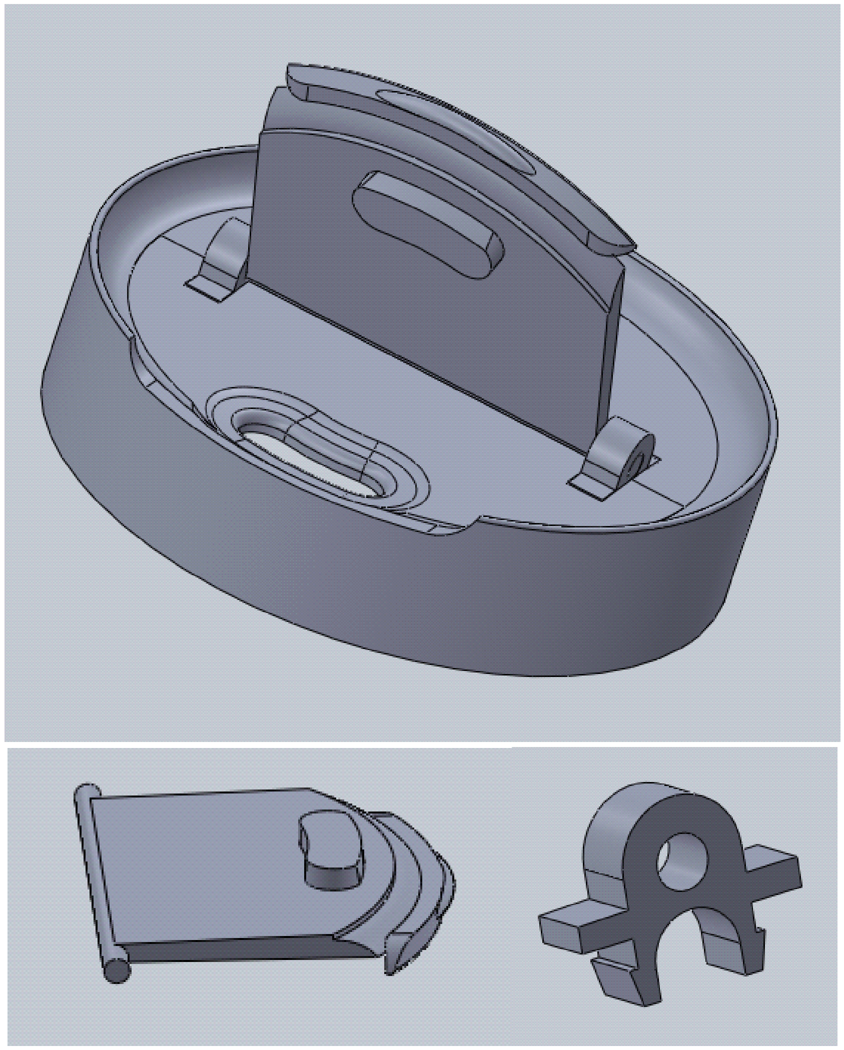


Figure 18. Lid assembly (above), flipping mechanism (left), and flipping mechanism clips (right)

In Generation 03, we tested our first lid design and overall it was successful. It contains a pop-top spout that hinges to the lid, and a threaded interface with the cup. The pop-top was very successful in the first round, and the only thing changed was a small quick release tab to more easily open the top once it has been closed. The threads were also changed to have a variable diameter so that it is easier to start the motion. Finally, instead of having a single thread that wrapped fully around the cup, Generation 04 contains two shorter threads that quicken the motion.

E. Materials Selection

The final prototype which we are presenting to Jason is made out of rapid prototyped ABS plastic. Once he has made it to the manufacturing stage of the project, Jason can manufacture the cup out of stainless steel. He prefers this material for its sleek look and cleanliness. We suggest Type 304 Stainless Steel with an 18/10 grade. This, along with 18/8 grade are the two most common types of stainless steel used for food preparation and dining. They can also successfully be cast, which is the manufacturing process we suggest for the cup. The numbers 18 and 8/10 refer to the amount of chromium and nickel present, respectively, in the alloy. The chromium helps prevent rusting in the material. The higher a nickel content in a stainless steel, the more resistant it is to corrosion. There is negligible difference in weight from type 8 to type 10, but the additional nickel in 18/10 makes it sturdier and gives a shinier surface. This is why we have selected 18/10 over 18/8. Type 304 is comprised of no more than 0.8% carbon and at least 50% iron.

F. Cup Geometry

Based on the output of the EES code and the required thickness of the walls with the magnets, air gap, and pin tracks, the finalized dimensions of the collapsed cup is 3.4” in diameter and 1.8” tall with the lid. This easily fits into our allowed dimensions of 4” diameter and 2” tall. The collapsed cup easily fits into pockets and purses. We all agree it is a cup that we would carry around. Expanded, the cup looks much more like an actual coffee cup rather than the previous cups which tended to be more short and squat.

Section V: Cost Analysis

At the start of the project, Jason authorized us a $1000 dollar budget. We used this budget throughout the project, and it was spent on the prototyping for different generations of the cup, as well as for materials used to test different designs. We anticipated prototyping four generations of the cup, and with this we ended up under budget by $140. However, upon completion of the prototype, we noticed a few cosmetic defects. In order to present Jason with an immaculate cup, he authorized an additional $70 in order to manufacture Generation 05. This brought our total budget to **$1066**.24 Table 6 below shows a total breakdown of the money we spent, and what Jason still owes us on the project.

Table 6. $1000 Budget Summary

TOTAL BUDGET: $1,000

Item	Date of Purchase	Prototype Generation	Retailer	Estimated Cost	Actual Cost	Paid	Purchaser
Gen01	15-Nov	1	Cal Poly ME Department	$200	$0.00	Y	ME Dept.
Rare Earth Magnets (Donuts)	16-Nov	1	Home Depot	$20	$17.19	N	Scott
Spings (3)	18-Nov	1	Century Spring Corporation	$50	$77.58	N	Scott
Super Magnets (Rectangles/Squares) (50/20)	15-Jan	2	Applied Magnets	$30	$34.27	Y	Jason
O-Rings	16-Jan	2	Apple Rubber	$20	$21.31	Y	Jason
Gen02	23-Jan	2	Cal Poly ME Department	$100	$137.00	N	Jason
O-Rings - Metal Prototype Leak Testing	19-Feb	3	O-Ring Warehouse	$15	$15.00	Y	Jason
Gen03	12-Mar	3	Cal Poly ME Department	$200	$305.43	N	Jason
O-Rings (Gen 04 and 05)	9-Apr	4	O-Ring Warehouse	$25	$26.96	Y	Jason
Magnets (Gen 04 and 05)	10-Apr	4	Applied Magnets	$25	$24.67	Y	Jason
Gen04	14-Apr	4	Cal Poly ME Department	$200	$204.15	N	Jason
Gen05	17-Apr	5	Cal Poly ME Department	$200	$202.68	N	Jason

Subtotal	**$1,085**	**$1,066.24**
Remaining	**($85)**	**($66.24)**

To simplify Table 6, our expenses have been grouped by Generation below in Table 7. These totals include cost of prototype and accessories including magnets, springs, O-rings, etc.

Table 7. Summary of Expenses Broken Down by Prototype Generation

Gen.	Cost	Predicted Total Budget Spent
01	$95	$95
02	$193	$287
03	$320	$607
04	$255	$862
05	$205	$1,067

Since Jason is planning on manufacturing and selling this cup, the overall cost of production of the cup is important. If he plans on selling the final cup for around $20, it is rule of thumb that he must manufacture the cup for less than $10 in order to account for overhead, advertising, and startup costs. Table 8 below shows the cost breakdown we anticipate for the materials per cup.

Table 8. Materials Summary Broken Down by Price per Cup

Materials	**Total Per Cup**	**Cost**	**Total Cost Per Cup**
Magnets	21	$ 0.10	$ 2.10
O-Rings Ring 1	1	$ 0.14	$ 0.14
O-Rings Ring 2	1	$ 0.17	$ 0.17
O-Rings Ring 3	1	$ 0.19	$ 0.19
O-Rings Ring 4	1	$ 0.22	$ 0.22
Stainless Steel	0.00125	$ 2,400.00	$ 3.00

TOTAL COST OF MATERIALS $ 5.82

Based on this estimate, Jason will spend approximately $6.00 on materials, which will leave him $4.00 per cup to afford manufacturing costs. This price of stainless steel was found based on pricing in North America, since Jason expressed interest in manufacturing locally. Based on costs in China, stainless steel would cost $1.25 per cup, leaving $6 to manufacture. Depending on the cost of manufacturing, this may be necessary to meet the budget, or it could lead to extra profits.

Section VI: Design Verification

The testing plan that Team Poly Cup has been summarized in the table below:

Table 9. Testing Plan Summary

Parameter Description	Requirement or Targets	Test Plan	Results
Leakage	Water Tight	Aluminum Rings	**No Leakage**
External Temperature Regulation	Less than 100 ^{o}F	Calculations	**98 ^{o}F**
Feel of Cup	N/A	Testing Prototype	**Intuitive, Easy**
Durability	Dents less than .0075" Pins will not shear under normal circumstances	Calculations	**Dents less than .0075" with 130 Kip Force** **Pins Shear with 820 lbf force**

Leakage Test

The most important parameter of the cup is that the cup will not leak at all. We tested this using our aluminum rings and O-rings. Water was placed in the rings and the rings were twisted and opened while being observed. **No water leaked out of the cup. The test was a success.**

External Temperature Test

The next parameter is external temperature regulation. The outside temperature of the cup needs to be less than 100 ^{o}F. We cannot test this with a stainless steel prototype, so we are relying upon the heat transfer calculations to determine whether this design decision is successful. **Based on the calculation, the cup will be less than 98 ^{o}F which meets the specifications.**

Feel Test

Since this is a consumer product, the feel of the cup is extremely important. There are no specifications set in stone, since feel is not a feature that can be put on paper. The feel will be tested by playing and using each round of prototypes. **After playing with the final design, we feel that it most definitely meets the feel criteria. It is a product that each of us has agreed we would purchase.**

Cup Durability Test

Finally, the durability of the cup is important. If it is dropped and dents more than the tolerance between the rings, it will not function because the rings will interfere with one another. If the pins are too weak and shear when a moderate force is applied, the cup will fail and not meet consumer durability. Once again, since we will never have a stainless steel prototype, this must be determined through calculations. **Calculations for the deflection of the cup determined that a force of 130 kips was necessary to cause interference with the two outermost rings. This force will not realistically be found in day to day cup use. For the pin shearing, the calculations showed that a load of over 800 pounds was necessary to shear the pins. Once again, this force will realistically not be seen in day to day use of the cup and are acceptable for expected durability of the cup.**

Section VIII: Conclusion

A. Patentability

At the beginning of the project, Jason presented us with his provisional patent obtained for the cup. Unfortunately it was not plausible, and the design was completely overhauled, but the goal has consistently been to obtain a patent. Patentable features of the cup include:

1. Collapsibility Function
2. Magnetic Locking Mechanism
3. Double-Walls
4. Overall Cup Geometry
5. Pin Locations and Track Design
6. O-Ring Slot Design with Press Fit

The first patentable element is that the cup has a mechanical feature used to collapse the cup when not in use. During patent research during the start of the project, we were able to find many existing products that contained collapsible features, however none were patented, and none were intended for hot beverages. Many were simple plastic cups to use for camping purposes.

Next, the fact that the mechanical locking mechanism uses magnetic forces is not only the reason that the cup locks so well, it is also a feature unique to this cup. The magnetic design is patentable.

Another component that is patentable is the double walls. These are used to insulate the hot coffee and both keep it warm for longer as well as protecting the user's hands. The air gap is also unique because it wraps around the cup between the pin rings. It is uniquely sealed with a cap at the top of the ring.

The overall cup geometry is patentable because it has been designed to keep manufacturing cost and time low while reducing the collapsed size as much as possible. The pin and track design is unique to this cup and also patentable both for the number of pins and tracks, but also for the way that it turns vertical near the end to prevent the user from unlocking it thoughtlessly.

B. Manufacturing Plan

Due to the complex nature of the design, the only perceivable manufacturing method is casting. The 304 18/10 grade stainless steel that we have suggested using is a castable stainless steel. Overall, there will be 12 individual parts using 11 different molds, since there are two identical flipping mechanism clips. Initial cost for casting is high, however over the life of the production of the cup, it is significantly cheaper than other manufacturing methods.

For the manufacturing process, each ring and cap will be separately cast, each magnet will be inserted into the top of the cup, and then the cap will be press fit to seal the gap. Each magnet and O-ring will be assembled by hand. The total cup will also need to be assembled by hand. In the future, if sales are going well, the process could potentially be automated, but for now, the cost outweighs the benefits.

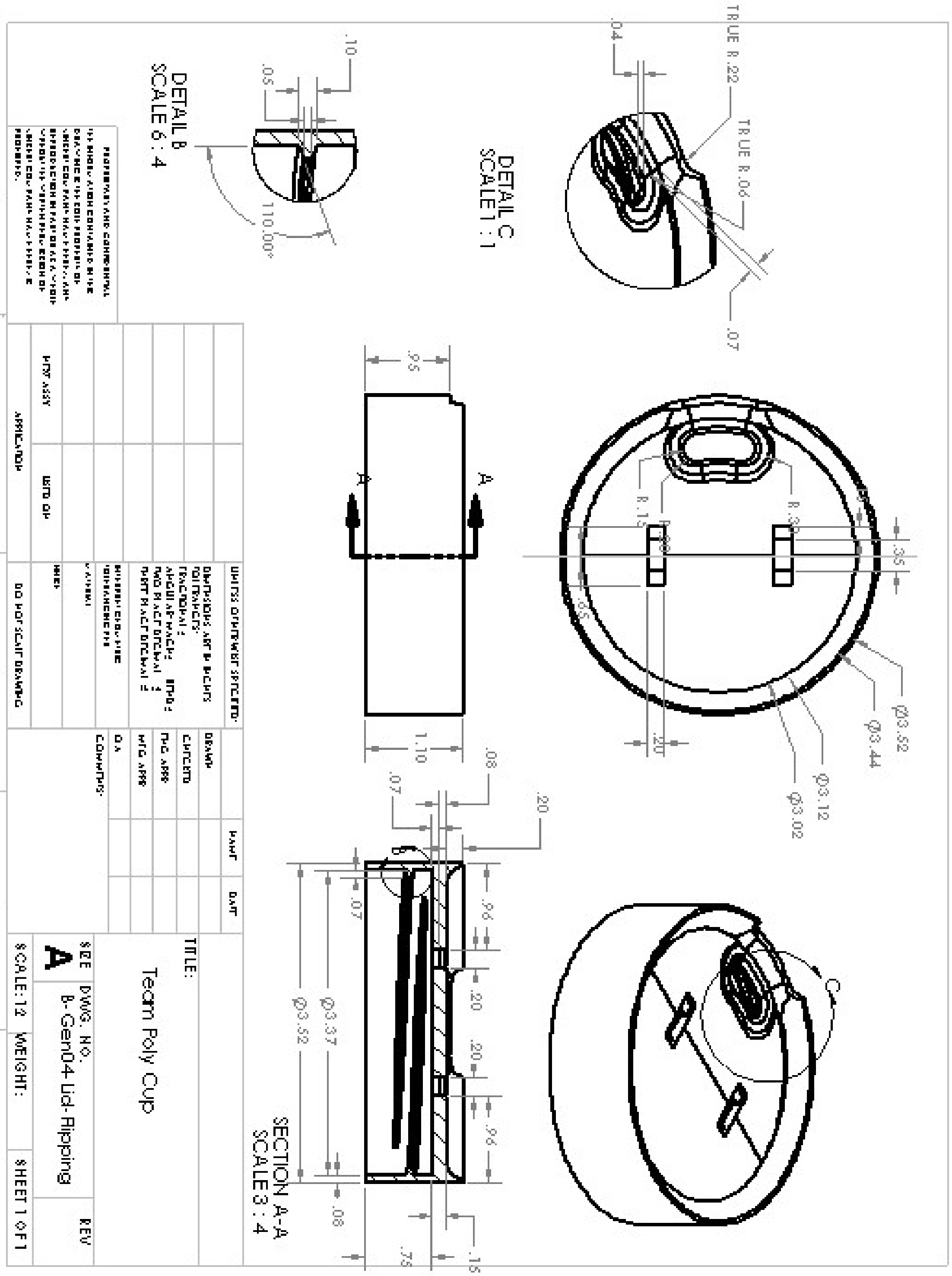
C. Recommendations

Overall, we believe that this has been an incredibly successful project. We have accomplished all the goals set out at the beginning of the year. As a team, we have learned a significant amount about design, product development, teamwork, professionalism, pleasing a customer and much more. In order for the collapsible cup to make it to the market, Jason will need to obtain a patent, start manufacturing, packaging, and work on sales development. This cup has a great chance for success; however we assume that Jason will need to invest a high amount of capital before the cup starts being profitable.

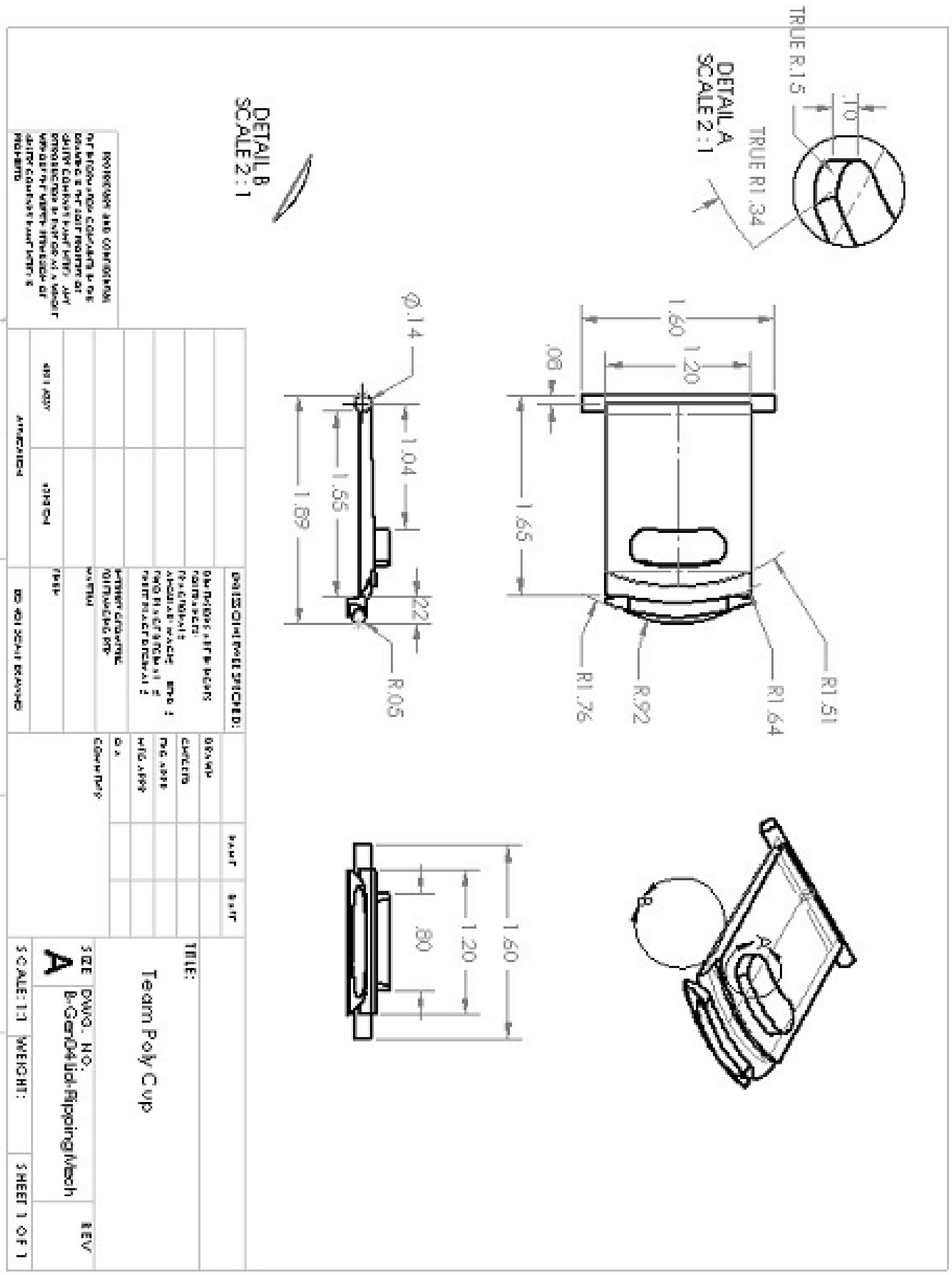
Section VIII: Appendices

Appendix A - Final Drawings and Parts List

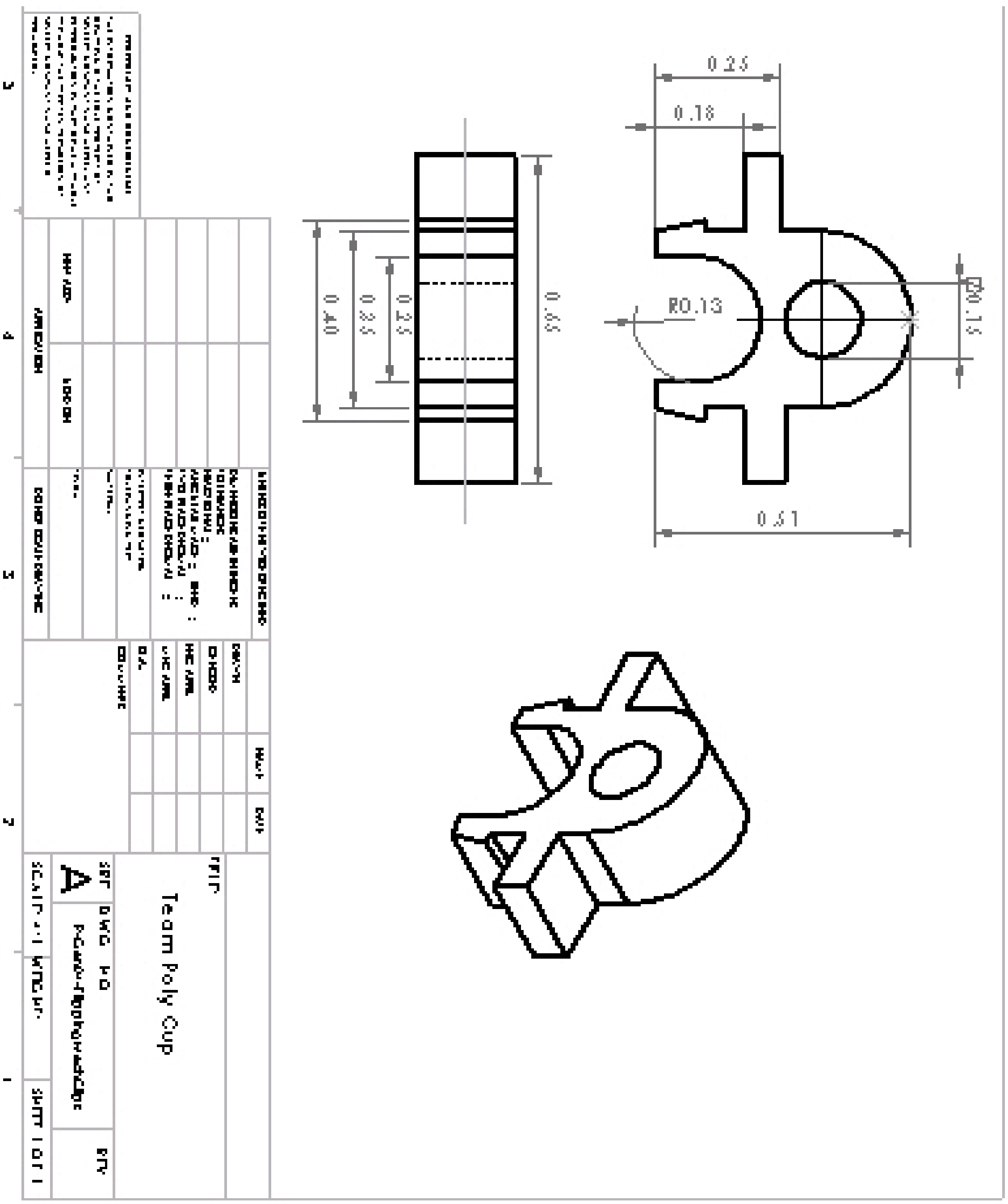
A-1: Lid



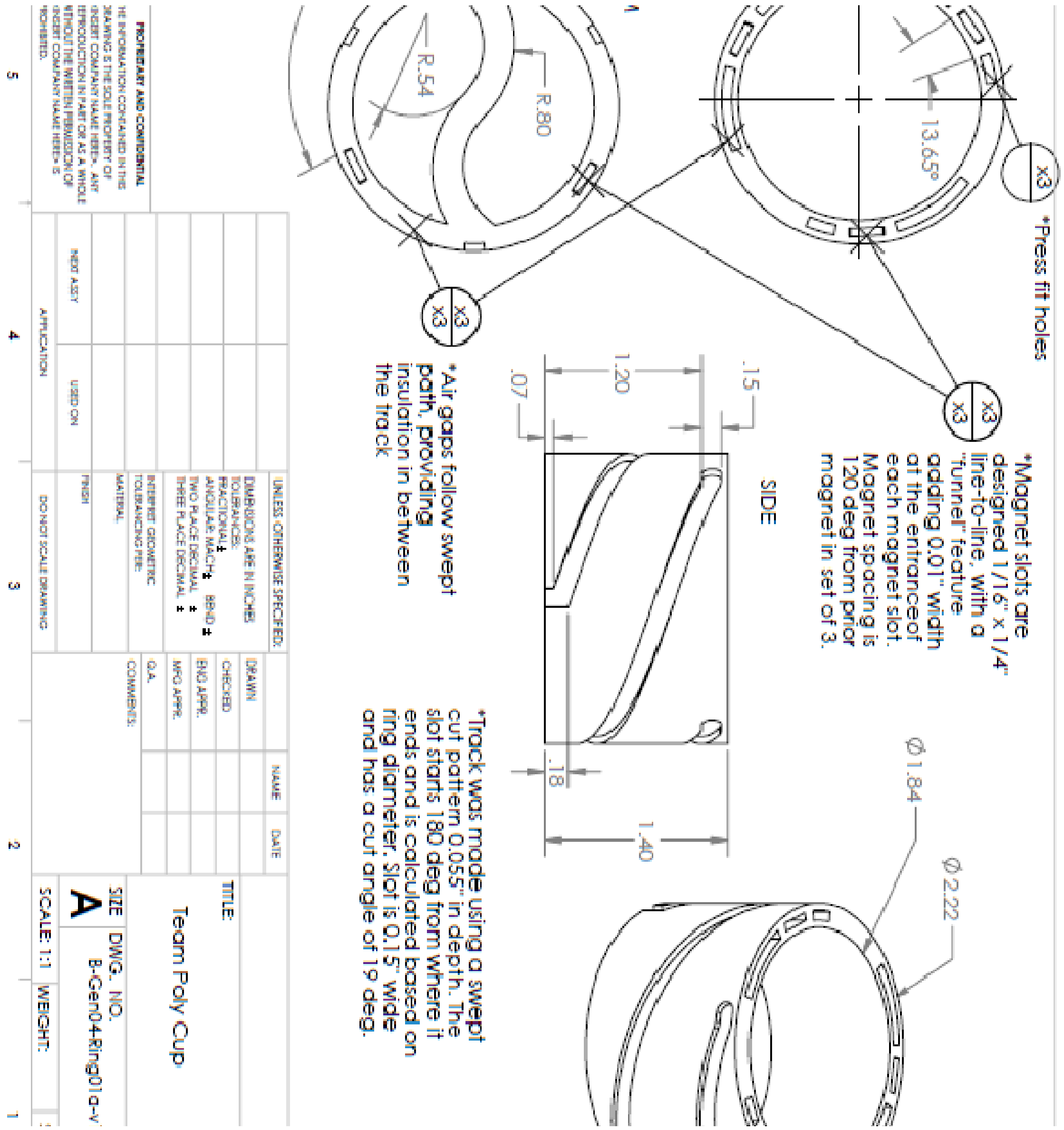
A-2: Flipping Mechanism



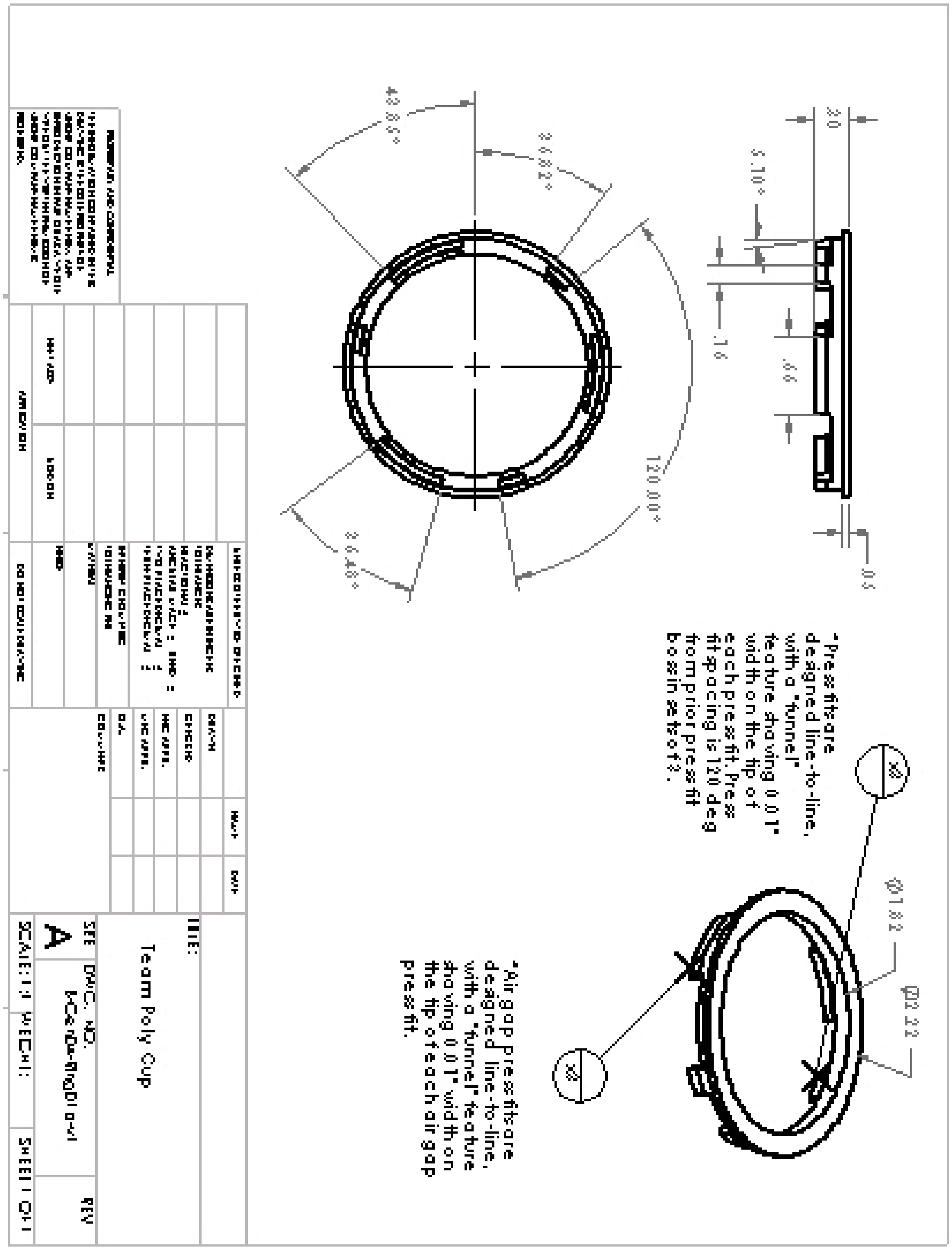
A-3: Flipping Mechanism Clips



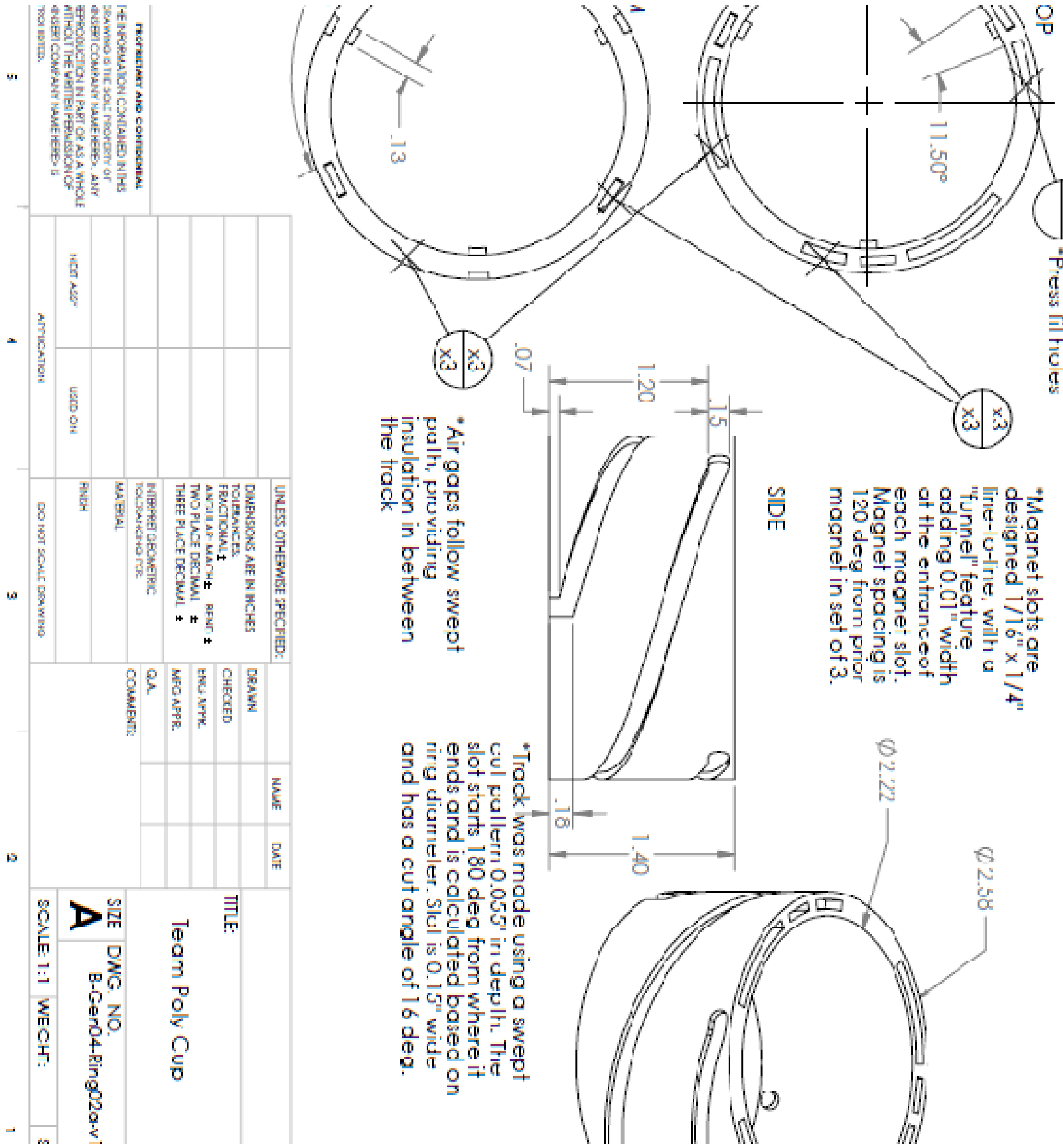
A-4: Ring 1a



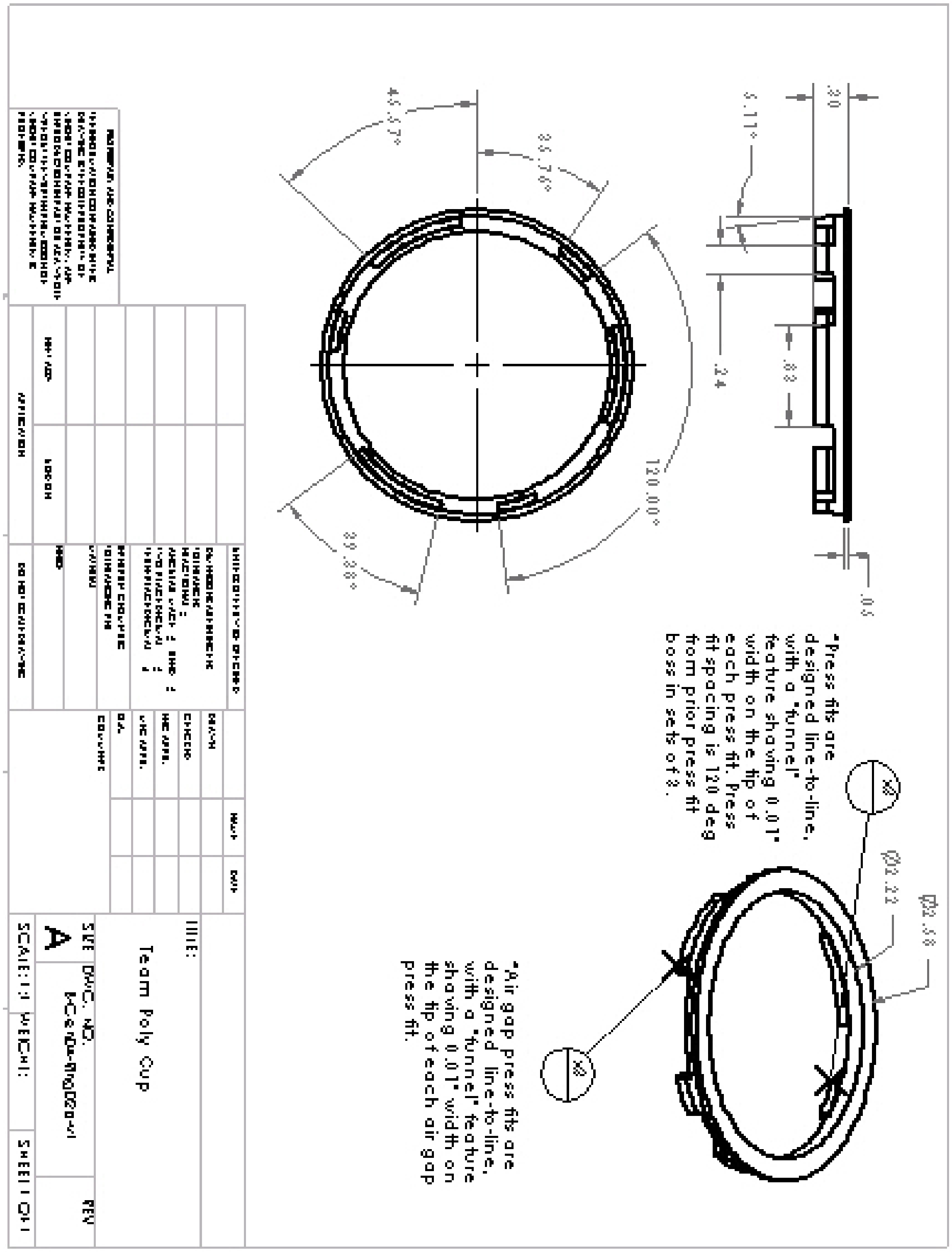
A-5: Ring 1b



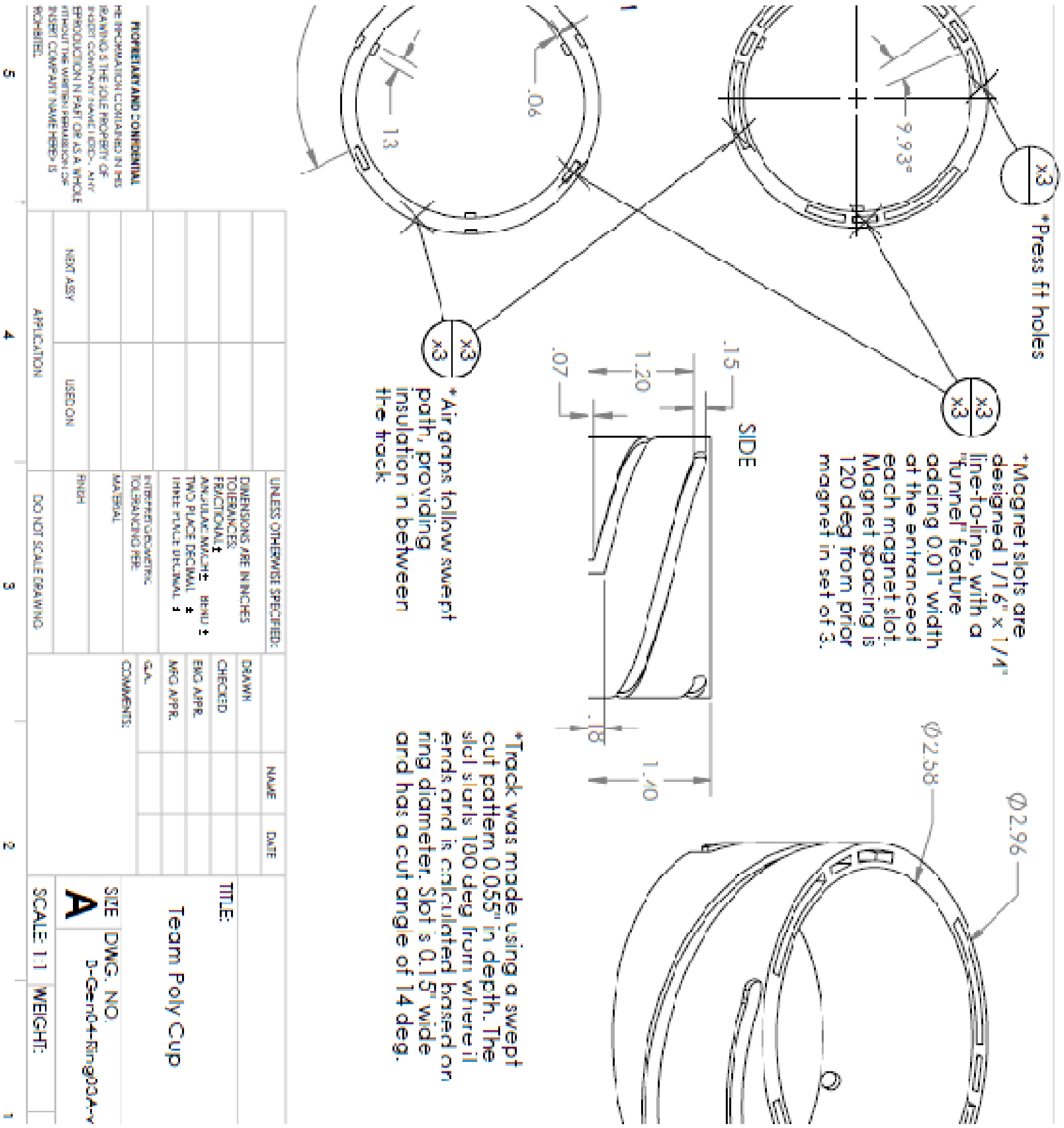
A-6: Ring 2a


*Press fill holes
*Magnet slots are designed 1/16" x 1/4" line-a-line, with a "funnel" feature adding 0.01" width at the entrance of each magnet slot. Magnet spacing is 120 deg from prior magnet in set of 3.
SIDE
*Air gaps follow swept path, providing insulation in between the track
*Track was made using a swept cut pattern 0.055" in depth. The slot starts 180 deg from where it ends and is calculated based on ring diameter. Slot is 0.15" wide and has a cut angle of 16 deg.
11.50°
.13
.07
1.20
.15
.18
1.40
Ø 2.22
Ø 2.58
x3
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
TITLE:
Team Poly Cup
SIZE
A
DWG. NO.
SCALE: 1:1
WEIGHT:
APPLICATION
DO NOT SCALE DRAWING

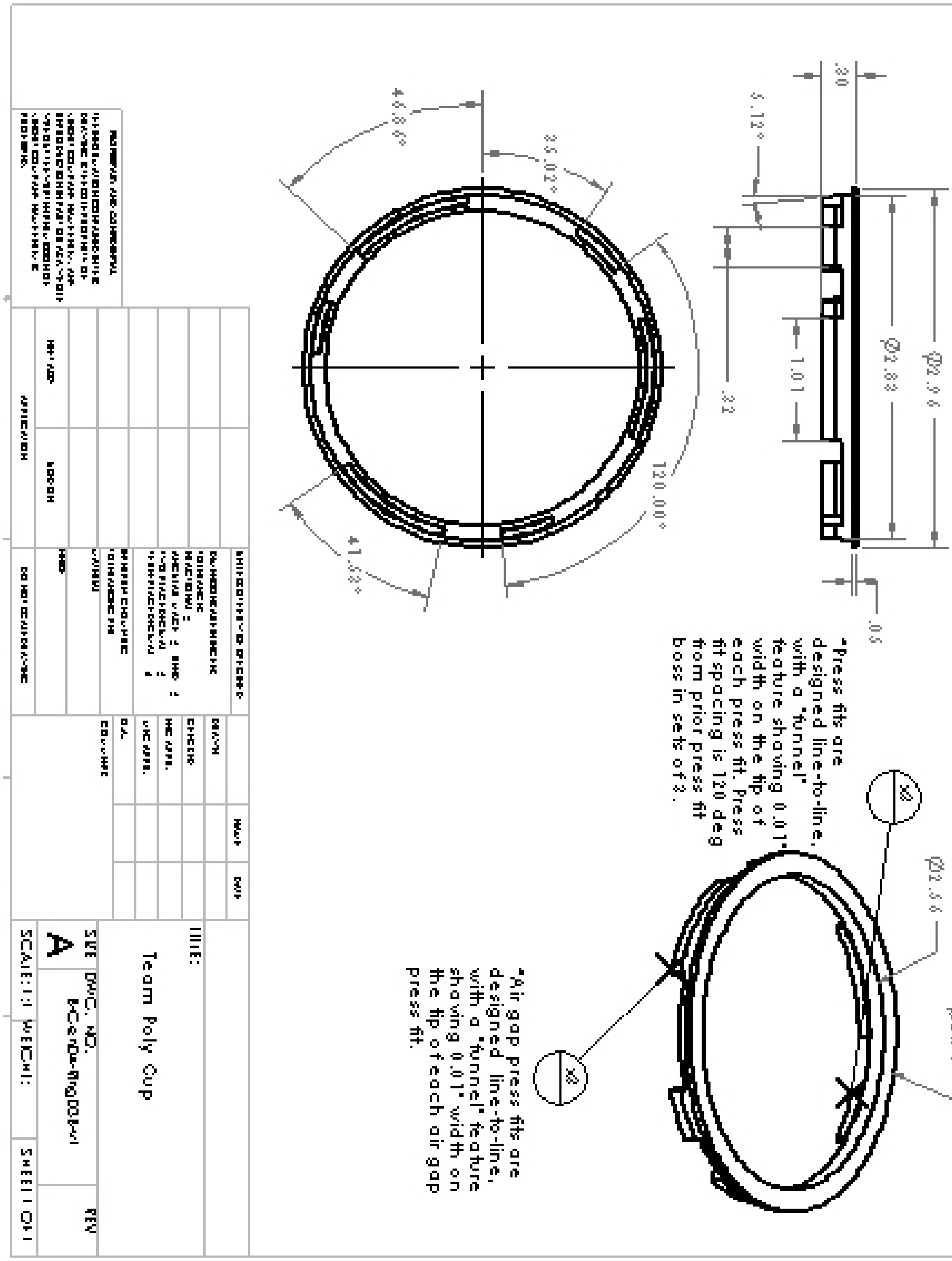
A-7: Ring 2b


*Press fits are designed line-to-line, with a "funnel" feature shaving 0.01" width on the tip of each press fit. Press fit spacing is 120 deg from prior press fit boss in sets of 3.
*Air gap press fits are designed line-to-line, with a "funnel" feature shaving 0.01" width on the tip of each air gap press fit.
120.00°
TITLE:
Team Poly Cup
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

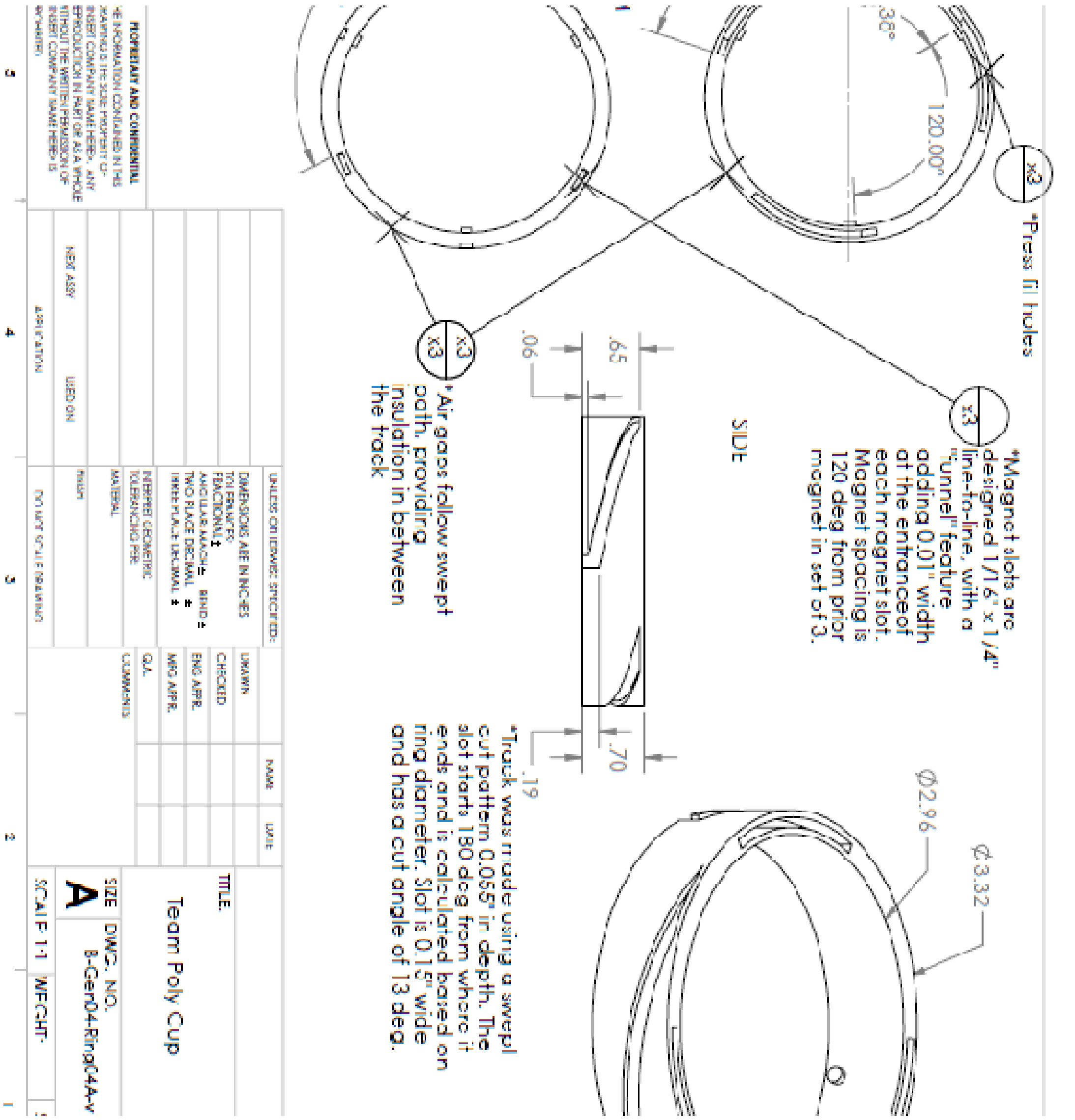
A-8: Ring 3a


x3
*Press fit holes
9.93°
.06
.13
x3
x3
*Magnet slots are designed 1/16" x 1/4" line-to-line, with a "funnel" feature adding 0.01" width at the entrance of each magnet slot. Magnet spacing is 120 deg from prior magnet in set of 3.
SIDE
.15
1.20
.07
.18
1.40
Ø2.58
Ø2.96
*Air gaps follow swept path, providing insulation in between the track.
*Track was made using a swept cut pattern 0.055" in depth. The slot starts 100 deg from where it ends and is calculated based on ring diameter. Slot s 0.15" wide and has a cut angle of 14 deg.
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NAME
DATE
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
MATERIAL
FINISH
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
PROPRIETARY AND CONFIDENTIAL
TITLE:
Team Poly Cup
SIZE
A
DWG. NO.
D-Gen04-Ring03A-v
SCALE: 1:1
WEIGHT:

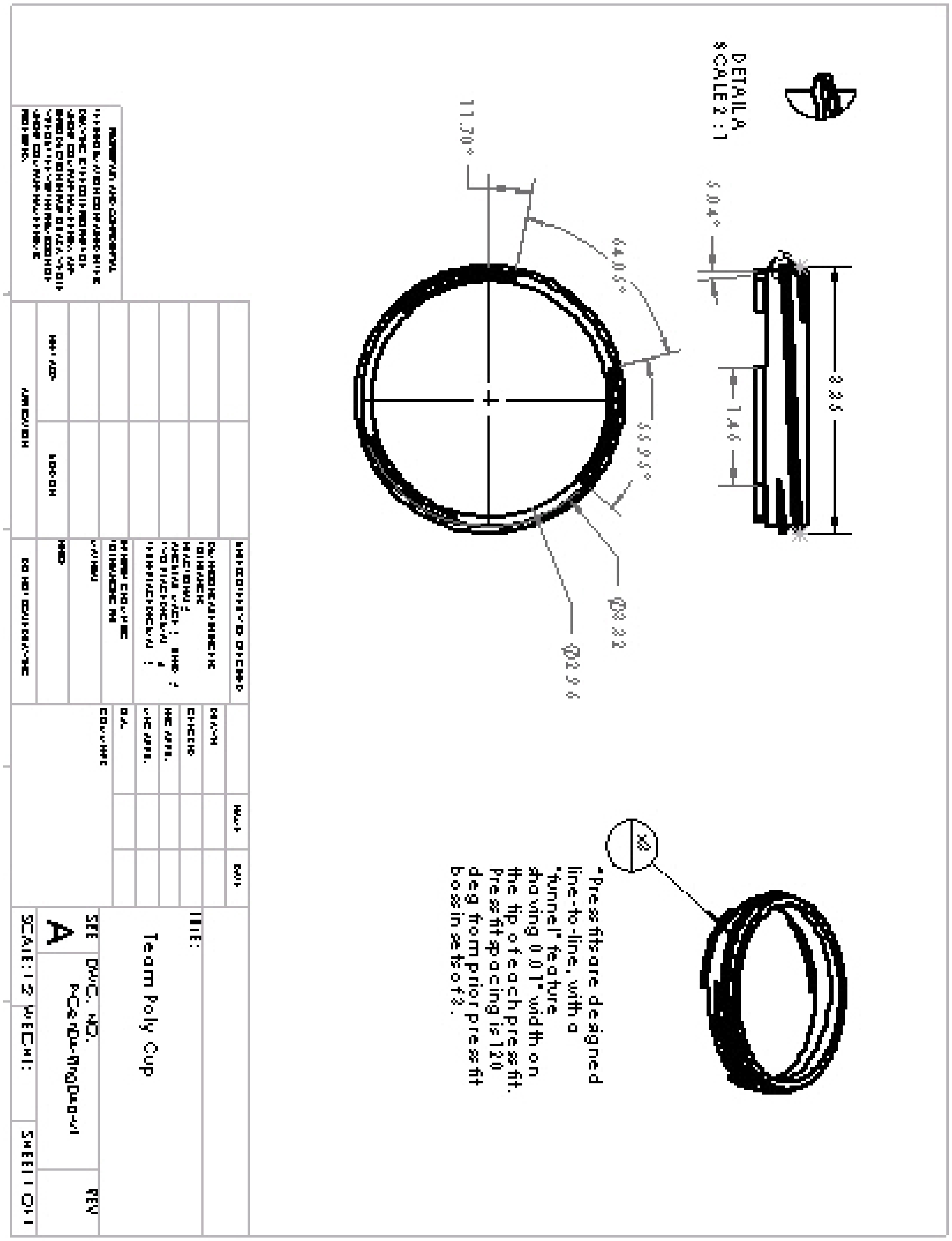
A-9: Ring 3b


.30
5.12°
Ø2.96
Ø2.83
1.01
.32
.05
46.86°
35.02°
120.00°
41.53°
*Press fits are designed line-to-line, with a "funnel" feature shaving 0.01" width on the tip of each press fit. Press fit spacing is 120 deg from prior press fit boss in sets of 3.
Ø2.56
Ø2.96
*Air gap press fits are designed line-to-line, with a "funnel" feature, shaving 0.01" width on the tip of each air gap press fit.
TITLE:
Team Poly Cup
SIZE
A
DWG. NO.
REV
SCALE: 1:1
WEIGHT:
SHEET 1 OF 1

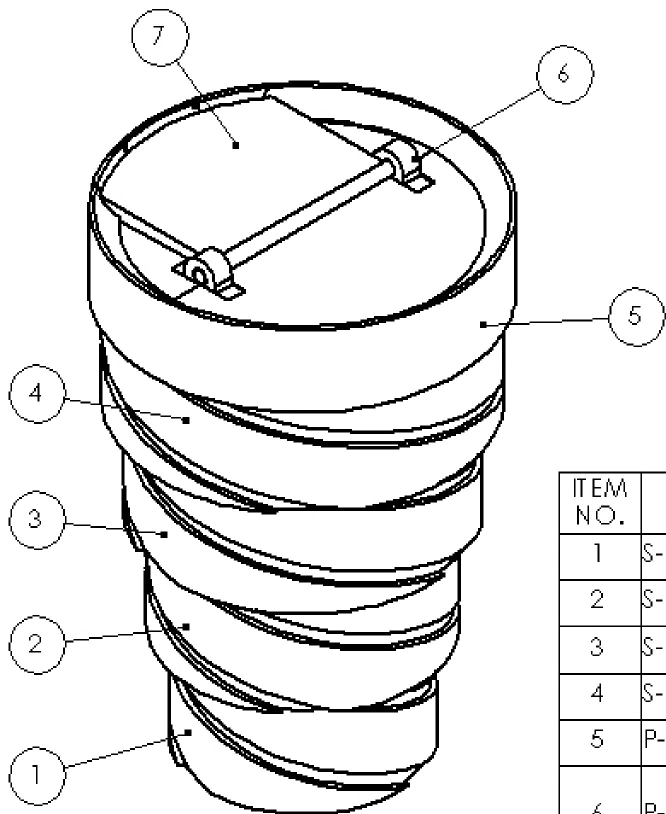
A-10: Ring 4a


x3
*Press fit holes
*Magnet slots are designed 1/16" x 1/4" line-to-line, with a "funnel" feature adding 0.01" width at the entrance of each magnet slot. Magnet spacing is 120 deg from prior magnet in set of 3.
120.00°
SIDE
.65
.06
.70
.19
Ø2.96
Ø3.32
*Air gaps follow swept path, providing insulation in between the track
*Track was made using a swept cut pattern 0.055" in depth. The slot starts 180 deg from where it ends and is calculated based on ring diameter. Slot is 0.15" wide and has a cut angle of 13 deg.
PROPRIETARY AND CONFIDENTIAL
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING
DRAWN
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
NAME
DATE
TITLE:
Team Poly Cup
SIZE
A
DWG. NO.
B-Gen04-Ring04A-v
SCALE 1:1
WEIGHT:

A-11: Ring 4b



A-12: Final design isometric view, and Bill of Materials



ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	S-Gen04-Ring01	Innermost ring+bottom grip	1
2	S-Gen04-Ring02	2nd Ring	1
3	S-Gen04-Ring03	3rd Ring	1
4	S-Gen04-Ring04	4th Ring	1
5	P-Gen04-Lid-Flipping	Lid w/ flipping mechanism	1
6	P-Gen04-Lid-FlippingMechClips	Permanent press fit clips for the lid	2
7	P-Gen04-Lid-FlippingMech	Drinking spout for lid	1

PROPRIETARY AND CONFIDENTIAL

THE INFORMATION CONTAINED IN THIS DRAWING IS THE SOLE PROPERTY OF <INSERT COMPANY NAME HERE>. ANY REPRODUCTION IN PART OR AS A WHOLE WITHOUT THE WRITTEN PERMISSION OF <INSERT COMPANY NAME HERE> IS PROHIBITED.

		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL± ANGULAR: MACH± BEND ± TWO PLACE DECIMAL ± THREE PLACE DECIMAL ±	DRAWN			TITLE: Team Poly Cup
			CHECKED			
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A DWG. NO. Assembly-Gen04 REV
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:4 WEIGHT: SHEET 1 OF 1

Appendix B - Component Specifications

B-1: O-Ring Product Details Table

-010	1/4	3/8	1/16	.239±.005	.070±.003	-108	1/4	7/16	3/32	.237±.005	.103±.003
-011	5/16	7/16	1/16	.301±.005	.070±.003	-109	5/16	1/2	3/32	.299±.005	.103±.003
-012	3/8	1/2	1/16	.364±.005	.070±.003	-110	3/8	9/16	3/32	.362±.005	.103±.003
-013	7/16	9/16	1/16	.426±.005	.070±.003	-111	7/16	5/8	3/32	.424±.005	.103±.003
-014	1/2	5/8	1/16	.489±.005	.070±.003	-112	1/2	11/16	3/32	.487±.005	.103±.003
-015	9/16	11/16	1/16	.551±.007	.070±.003	-113	9/16	3/4	3/32	.549±.005	.103±.003
-016	5/8	3/4	1/16	.614±.009	.070±.003	-114	5/8	13/16	3/32	.612±.009	.103±.003
-017	11/16	13/16	1/16	.676±.009	.070±.003	-115	11/16	7/8	3/32	.674±.009	.103±.003
-018	3/4	7/8	1/16	.739±.009	.070±.003	-116	3/4	15/16	3/32	.737±.009	.103±.003
-019	13/16	15/16	1/16	.801±.009	.070±.003	-117	13/16	1	3/32	.799±.010	.103±.003
-020	7/8	1	1/16	.864±.009	.070±.003	-118	7/8	1 1/16	3/32	.862±.010	.103±.003
-021	15/16	1 1/16	1/16	.926±.009	.070±.003	-119	15/16	1 1/8	3/32	.924±.010	.103±.003
-022	1	1 1/8	1/16	.989±.010	.070±.003	-120	1	1 3/16	3/32	.987±.010	.103±.003
-023	1 1/16	1 3/16	1/16	1.051±.010	.070±.003	-121	1 1/16	1 1/4	3/32	1.049±.010	.103±.003
-024	1 1/8	1 1/4	1/16	1.114±.010	.070±.003	-122	1 1/8	1 5/16	3/32	1.112±.010	.103±.003
-025	1 3/16	1 5/16	1/16	1.176±.011	.070±.003	-123	1 3/16	1 3/8	3/32	1.174±.012	.103±.003
-026	1 1/4	1 3/8	1/16	1.239±.011	.070±.003	-124	1 1/4	1 7/16	3/32	1.237±.012	.103±.003
-027	1 5/16	1 7/16	1/16	1.301±.011	.070±.003	-125	1 5/16	1 1/2	3/32	1.299±.012	.103±.003
-028	1 3/8	1 1/2	1/16	1.364±.013	.070±.003	-126	1 3/8	1 9/16	3/32	1.362±.012	.103±.003
-029	1 1/2	1 5/8	1/16	1.489±.013	.070±.003	-127	1 7/16	1 5/8	3/32	1.424±.012	.103±.003
-030	1 5/8	1 3/4	1/16	1.614±.013	.070±.003	-128	1 1/2	1 11/16	3/32	1.487±.012	.103±.003
-031	1 3/4	1 7/8	1/16	1.739±.015	.070±.003	-129	1 9/16	1 3/4	3/32	1.549±.015	.103±.003
-032	1 7/8	2	1/16	1.864±.015	.070±.003	-130	1 5/8	1 13/16	3/32	1.612±.015	.103±.003
-033	2	2 1/8	1/16	1.989±.018	.070±.003	-131	1 11/16	1 7/8	3/32	1.674±.015	.103±.003
-034	2 1/8	2 1/4	1/16	2.114±.018	.070±.003	-132	1 3/4	1 15/16	3/32	1.737±.015	.103±.003
-035	2 1/4	2 3/8	1/16	2.239±.018	.070±.003	-133	1 13/16	2	3/32	1.799±.015	.103±.003
-036	2 3/8	2 1/2	1/16	2.364±.018	.070±.003	-134	1 7/8	2 1/16	3/32	1.862±.015	.103±.003
-037	2 1/2	2 5/8	1/16	2.489±.018	.070±.003	-135	1 15/16	2 1/8	3/32	1.925±.017	.103±.003
-038	2 5/8	2 3/4	1/16	2.614±.020	.070±.003	-136	2	2 3/16	3/32	1.987±.017	.103±.003
-039	2 3/4	2 7/8	1/16	2.739±.020	.070±.003	-137	2 1/16	2 1/4	3/32	2.050±.017	.103±.003
-040	2 7/8	3	1/16	2.864±.020	.070±.003	-138	2 1/8	2 5/16	3/32	2.112±.017	.103±.003
-041	3	3 1/8	1/16	2.989±.024	.070±.003	-139	2 3/16	2 3/8	3/32	2.175±.017	.103±.003
-042	3 1/4	3 3/8	1/16	3.239±.024	.070±.003	-140	2 1/4	2 7/16	3/32	2.237±.017	.103±.003
-043	3 1/2	3 5/8	1/16	3.489±.024	.070±.003	-141	2 5/16	2 1/2	3/32	2.300±.020	.103±.003
-044	3 3/4	3 7/8	1/16	3.739±.027	.070±.003	-142	2 3/8	2 9/16	3/32	2.362±.020	.103±.003
-045	4	4 1/8	1/16	3.989±.027	.070±.003	-143	2 7/16	2 5/8	3/32	2.425±.020	.103±.003
-046	4 1/4	4 3/8	1/16	4.239±.030	.070±.003	-144	2 1/2	2 11/16	3/32	2.487±.020	.103±.003

B-2: Magnet Product Details

Product Details

Rare earth magnets neodymium ndfeb are the world's strongest magnets. All magnets are not created equal! Applied Magnets offers the highest quality rare earth magnets with consistent performance at lowest price. Our strong rare earth magnets are designed & manufactured to meet stringent quality standards using the latest technology. Neodymium magnets (also known as Neo, NdFeB, NIB or super magnet) , a type of rare earth magnets, are the permanent magnets made from neodymium, iron, boron and other rare earth elements.

Strong Rare Earth Magnets Neodymium N42 are stronger than N40, N38 and N35.

Grade N42 Br Max is 13200 gauss.

Nickel-Copper-Nickel triple layer coated for maximum rare earth magnets durability and protection again corrosion.

Neodymium rare earth magnets made by Applied Magnets are composed of top quality Neodymium, Iron, Boron raw materials, they have excellent magnetic property and extremely strong for its size. Neodymium rare earth magnets are the strongest types of permanent magnets. They have highest maximum energy product among all permanent magnets. All of our rare earth magnets are ISO Certified, top notch quality guaranteed.

Rare earth magnets are powerful and fragile, they can be stuck together easily and pinch your fingers, they can get chipped or broken in a collision. please read rare earth magnets safety information on our website before usage.

0.25" x 0.25"x 0.0625" Thick Neodymium NdFeB Block Magnet

Magnetized through the Thickness

Approximate pull force: 2.7 lbs

Contact us for rare earth magnets wholesale discount.

Note : Pull force is estimate only, please test it for your application

Product was added to our catalog on Tuesday May 15, 2007.

Appendix C - Supporting Calculations

C-1: Pin Shear

Pin Shear Calculations
Team Poly Cup 13

Diameter of Pin

$D = 0.135$ *in*

Length of Pin

$L = 0.055$ *in*

Yeild Strength of Stainless Steel

$S_{UT} = 31200$ *psi*

Finding Distributed Force Necesary to Shear One Pin

$$F = \frac{3.14159 \cdot D^3 \cdot S_{UT}}{16 \cdot L^2} \quad lbf/in$$

Finding the Force On the Top of the Cup Necessary to Shear All Pins

$F_T = 3 \cdot F \cdot 0.055$ *lbf*

SOLUTION

Unit Settings: Eng F psia mass deg

$D = 0.135$	$F = 4983$
$F_T = 822.1$	$L = 0.055$
$S_{UT} = 31200$	

No unit problems were detected.

C-2: Deflection

Deflection Calculations
Team Poly Cup 13

Outer radius of the largest ring

$$r_2 = \frac{3.313}{2} \quad in$$

Inner radius of the largest ring

$$r_1 = \frac{3.203}{2} \quad in$$

Young's Modulus for Stainless Steel

$$E = 28500 \cdot 1000 \quad psi$$

Area Moment of Inertia for a Ring

$$I = \frac{3.14159}{4} \cdot \left[r_2^{\ 4} - r_1^{\ 4} \right] \quad in^4$$

Allowable Deflection

$$\delta = 0.0075 \quad in$$

Finding the force necessary to deflect the largest ring enough to interfere with the next ring

$$F = \frac{2 \cdot 3.14159 \cdot E \cdot I \cdot \delta}{r_1^{\ 3} \cdot \left[3.14159^2 - 8 \right]} \quad lbf$$

$$F_T = \frac{F}{1000} \quad ksi$$

SOLUTION
Unit Settings: Eng F psia mass deg

δ = 0.0075	E = 2.850E+07
F = 130665	F_T = 130.7
I = 0.7471	r_1 = 1.602
r_2 = 1.657	

No unit problems were detected.

C-3: Heat Transfer with Solid Wall

Heat Transfer Calculations with Single Walled Cup

Team Poly Cup 13

K1 is plastic and K2 is stainless steel

Temperature of the Outside Air and Coffee

$T_{coffee} = 180$ *oF*

$T_{air} = 70$ *oF*

Coefficient of Heat Transfer of Air

$h_{air} = 1.4$ *BTU/ft2 hr oF*

Inner and Outer Radius of the Wall, Height of the Cup

$r_o = \frac{1.4}{12}$ *ft*

$r_i = \frac{1.3}{12}$ *ft*

$L = \frac{0.8}{12}$ *ft*

Area of Heat Tranfer

$A_o = 2 \cdot 3.14 \cdot r_o \cdot L$ *ft2*

Thermal Resistance of the Cup Wall

$$R_c = \frac{\ln\left[\frac{r_o}{r_i}\right]}{2 \cdot 3.14 \cdot K \cdot L}$$ *hr oF/BTU*

Resistance Network for Heat Transfer

$$\frac{T_c - T_{air}}{\frac{1}{h_{air} \cdot A_o}} = \frac{T_{coffee} - T_c}{R_c}$$

Parametric Table: Table 1

	K	**T_c**
Run 1	*0.121*	170
Run 2	*9.42*	179.9

C-4: Heat Transfer with Air Gap

Heat Transfer Calculations for Cup with Air Gap

Team Poly Cup 13

K1 is Plastic and K2 is Stainless Steel

Resistance Network for Heat Transfer

$$\frac{T_{cup} - T_{air}}{A} = \frac{T_{coffee} - T_{cup}}{O + G + I}$$

Temperature of the Air and Coffee

$T_{air} = 70$ *oF*

$T_{coffee} = 180$ *oF*

Coefficient of Heat Transfer For Outside Air (a) and Air Gap (g)

$h_a = 1.4$ *BTU/ft2 hr oF*

$h_g = \frac{1.6 - 0.6}{2}$ *BTU/ft2 hr oF*

Thickness of the Cup Walls

$t = \frac{0.178}{12}$ *ft*

Inner Radius

$r_1 = \frac{2.957}{2 \cdot 12}$ *ft*

Inner (2) and Outer (3) Radius of the Outer Ring

$r_2 = \frac{3.203}{2 \cdot 12}$ *ft*

$r_3 = \frac{3.313}{2 \cdot 12}$ *ft*

Height of the Ring

$L = \frac{1.543}{12}$ *ft*

Resistance of the Air

$$A = \frac{1}{h_a \cdot 2 \cdot 3.14 \cdot r_3 \cdot L} \quad \textit{hr oF/BTU}$$

Resistance of the Outer Ring

$$O = \frac{\ln\left[\frac{r_2}{r_1 + t}\right]}{2 \cdot 3.14 \cdot K \cdot L} \quad \textit{hr oF/BTU}$$

Resistance of the Air Gap

$$G = \frac{1}{h_g \cdot 2 \cdot 3.14 \cdot r_2 \cdot L} \quad \textit{hr oF/BTU}$$

Resistance of the Inner Ring

$$I = \frac{\ln\left[\frac{r_1 + t}{r_1}\right]}{2 \cdot 3.14 \cdot K \cdot L} \quad \textit{hr oF/BTU}$$

Parametric Table: Table 1

	K	T_{cup}
Run 1	*0.127*	97.38
Run 2	*9.42*	98.22

C-5: Geometric Study

```
"Step 1: Set Parameters"

"Clearance, c"
c = 0.0075
"Base Thickness, b"
b = 0.3
"Height of O-Ring Slot"
h_slot = 0.095
"Heigth Overlap, o"
o = m + h_slot + h_magnet
"Minimum Material Thickness, m"
m = 0.05
"Magnet Dimensions"
w_magnet = 0.25
h_magnet = w_magnet
t_magnet = 0.0625
w_magnetslot = w_magnet + (2*c_magnet)
"Clearance of Magnet"
c_magnet = 0.0075

"Step 2: Set Bottom Ring OD"

"Outside Diameter, Ring 1, Target Value"
OD[1] = 2.2
"Ring Study: Set Number of Rings"
n = 4

"Wall Thicknesses: Outer Wall, Air Gap, Inner Wall"
t_o = 0.055
t_i = m
t_w = t_o + t_AirGap+ t_i

"Outside Diameter, Ring 1, Actual Value"
OD[1] = 2*t_w + ID1
OD[1] = OW[1] + (2*t_o)
OD[1] = IW[1] + (2*t_o) + (2*t_AirGap)
OD[1] = ID[1] + (2*t_i) + (2*t_o) + (2*t_AirGap)

"Step 3: Determine Other Rings OD's"

n[2] = 2
"Nominal Slot Sizes >> Ring Outside Diameters"
Duplicate i = 2,9
OD[i] = (ID1 + 2*t_w) + 2*(n[i]-1)*(t_w + c)
Y[i] = (ID1+ 2*(n[i]-1)*(t_w + c))^2
sigma[i] = sum(Y[2..i])
V[i] = ((h_c[i] - b)*pi/4*ID1^2) + (h_c[i] - o)*pi/4*sigma[i]
V[i] = 21.656
n[i+1] = n[i] + 1
OD[i] = OW[i] + (2*t_o)
OD[i] = IW[i] + (2*t_o) + (2*t_AirGap)
OD[i] = ID[i] + (2*t_i) + (2*t_o) + (2*t_AirGap)

end
```

```
"Collapsed Dimension Results"

h_total = h_c[n]
D_collapsed = OD[n]

h_a = h_total - h_b
h_b = m + h_slot

"Circular Air Gap - Squared Magnets >> Minimum Air Gap Thickness"
"For uniformity, use smallest OD (it will need the largest gap)"

g = - sqrt((OD[1]/2)^2 - (w_magnetslot/2)^2) + (OD[1]/2)

t_w  = g + (2*m) + t_magnet + c_magnet

"Plot Geometry"

v = n-1
k[1] = 1

Duplicate j = 1,v
radius_right[j] = OD[j]/2
radius_right[j] = -radius_left[j]
h_ring[j] = (k[j]*h_c[n]) - (k[j]*o)
k[j+1] = k[j] + 1

end

radius_right[n] = OD[n]/2
radius_right[n] = -radius_left[n]
h_ring[n] = h_c[n] + h_ring[v]
```

Arrays Table: Main

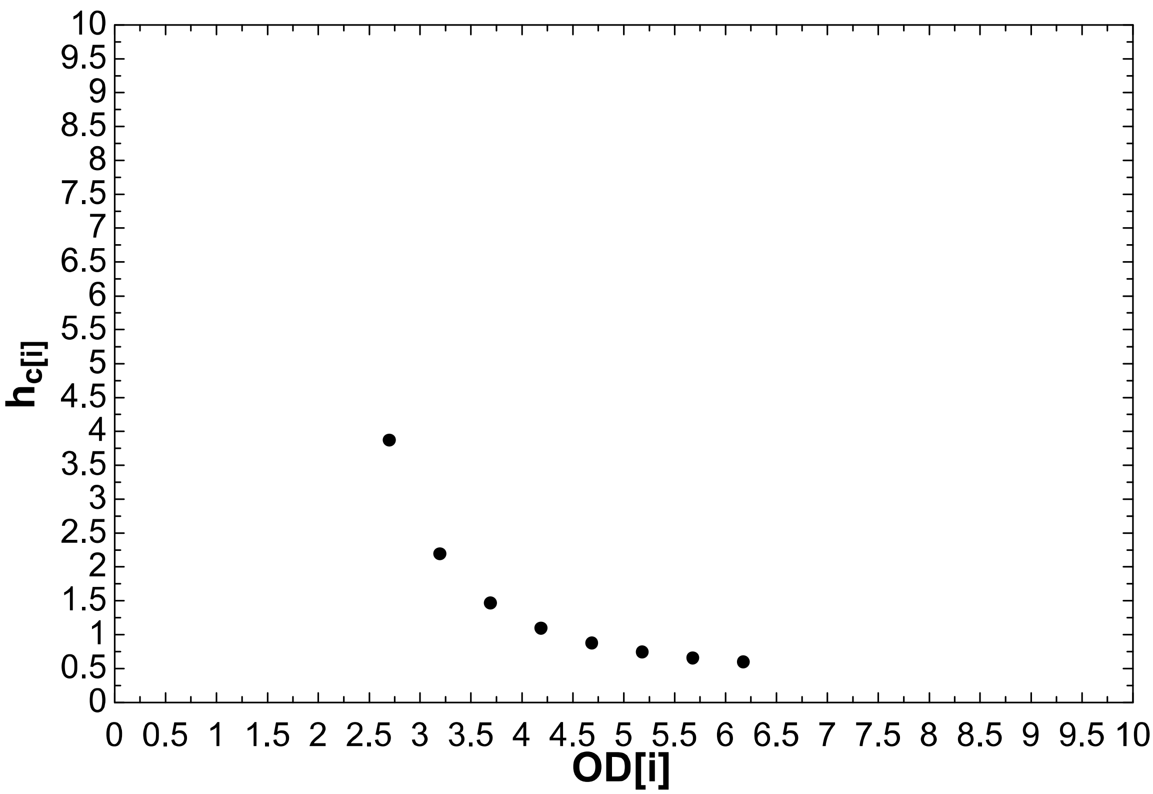
	$h_{c,i}$	n_i	V_i	Y_i	σ_i	OD_i	ID_i	IW_i	OW_i	$h_{ring,i}$	k_i
1						2.2	1.844	1.944	2.09	1.148	1
2	3.676	2	21.656	4.906	4.906	2.571	2.215	2.315	2.461	2.296	2
3	2.212	3	21.656	6.687	11.59	2.942	2.586	2.686	2.832	3.444	3
4	1.543	4	21.656	8.744	20.34	3.313	2.957	3.057	3.203	4.987	4

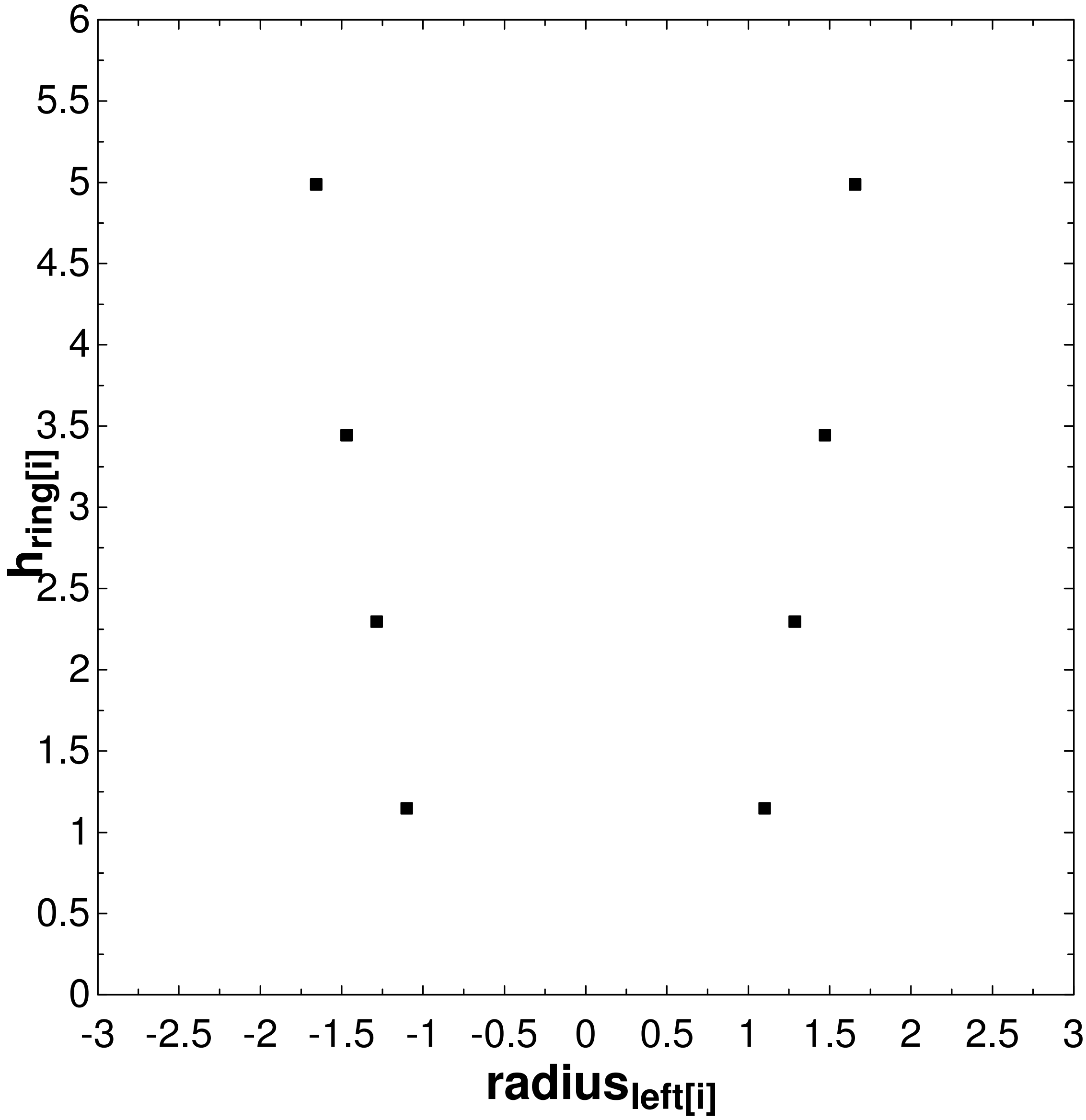
Arrays Table: Main

	$h_{c,i}$	n_i	V_i	Y_i	σ_i	OD_i	ID_i	IW_i	OW_i	$h_{ring,i}$	k_i
5	1.178	5	21.656	11.076	31.41	3.684	3.328	3.428	3.574		
6	0.9569	6	21.656	13.683	45.1	4.055	3.699	3.799	3.945		
7	0.8138	7	21.656	16.566	61.66	4.426	4.07	4.17	4.316		
8	0.7164	8	21.656	19.723	81.39	4.797	4.441	4.541	4.687		
9	0.6475	9	21.656	23.157	104.5	5.168	4.812	4.912	5.058		
10		10									

Arrays Table: Main

	$radius_{left,i}$	$radius_{right,i}$
1	-1.1	1.1
2	-1.286	1.286
3	-1.471	1.471
4	-1.657	1.657
5		
6		
7		
8		
9		
10		




6
5.5
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
$h_{ring[i]}$
$radius_{left[i]}$

Appendix D – Management Plan